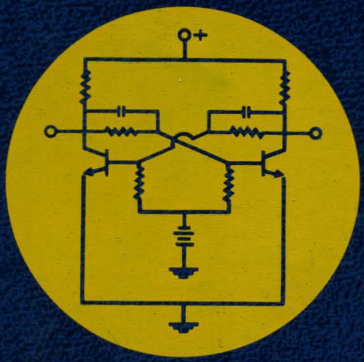
TELEPHONE COMMUNICATION SYSTEMS

VOLUME V

TRANSMISSION SYSTEMS AND
CENTRAL OFFICE FACILITIES



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PREFACE

Connecting any two phones among the millions of subscribers is accomplished by telephone switching systems. The process, although not simple, is normally taken for granted in our everyday use of telephone services. This is indeed a compliment to the Bell System people who have developed, engineered, and maintained the many types of telephone systems. The switching equipment in the Central office is considered by many to be the heart of the telephone highway, for without it the telephone never would have progressed to the highly developed and integrated entity it is today.

Although the switching equipments may be considered the "heart," the other parts of the telephone network are equally important. For without the connecting wires and cables, the subscribers' equipment and the power plant, there could be no universal telephone network and no Direct Distance Dialing.

Switching is a highly dynamic field. From the first crude switching arrangements developed by the Holmes Electric Company in Boston in 1877 to the highly sophisticated No. 1 ESS system developed by the Bell System Laboratories in the early 1960's, the telephone switching system has indeed come a long way. What the future holds can only be speculated upon: on the horizon, we now see new developments, such as the use of satellites, lasers, and holography in communications.

Each subject covered in this text could be developed much more extensively; however, our objective is not to print a comprehensive treatise on telephony, but rather to treat each subject briefly presenting a general technical explanation of its operation and function.

This text has been prepared for Graduate Engineering Education courses presented at the Western Electric Corporate Education Center. Its contents are the result of over 12 years of development, starting from a group of handouts given to students and leading to the book we have today. Although much of the material and ideas were taken from various Bell System sources, a great deal of the book can be attributed to the members of the Graduate Engineering Education staff. Acting as writers, instructors, and editors, each diligently worked in assembling a well organized telephone communications text. Their collective efforts are sincerely appreciated, and are hereby gratefully acknowledged.

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TABLE OF CONTENTS

VOLUME V

CHAPTER 15

OUTSIDE PLANT FACILITIES

15.1 INTRODUCTION

The outside plant of a telephone company provides the physical paths over which communication signals are propagated. These paths are divided into two distinct but related categories of outside plant. The path that connects the customer's telephone to the local central office is designated as the customer loop plant. The path that connects the local central office to other central offices or to a switching network is the trunk and toll plant. These physical paths should be provided in such a way as to satisfy the requirements of:

(a) Safety to the public, the customers, and the company property.
(b) Satisfaction from the standpoint of the customers.
(c) Reliability under all conditions.
(d) Flexibility to meet the changing demands of the population growth and distribution.
(e) Arrangements that meet all the preceding requirements in an optimum manner and at a minimum cost.

To gain an appreciation of the magnitude of the outside plant, it should be noted that the total investment in this area amounts to approximately one-third of the total worth of the Bell System. There are currently over 235 million conductor miles of cable in service, and the annual addition to the outside plant throughout the Bell System amounts to roughly one billion dollars.

A. OUTSIDE PLANT COMPONENTS

The physical paths provided by outside plant are made up of the wires and cables that conduct signals together with the structures, such as underground conduit, poles, or the earth (buried systems), that support these cables and wires.

Although distinct in design and purpose, the customer loop plant and the trunk and toll plant systems share many specific items of outside plant. Many of the standard cables and wires are used equally as well in either system. The various types of structures can be exclusive to one system or may be shared jointly. For example, underground conduit systems or pole lines may support cables of the customer loop plant and trunk or toll cables simultaneously.

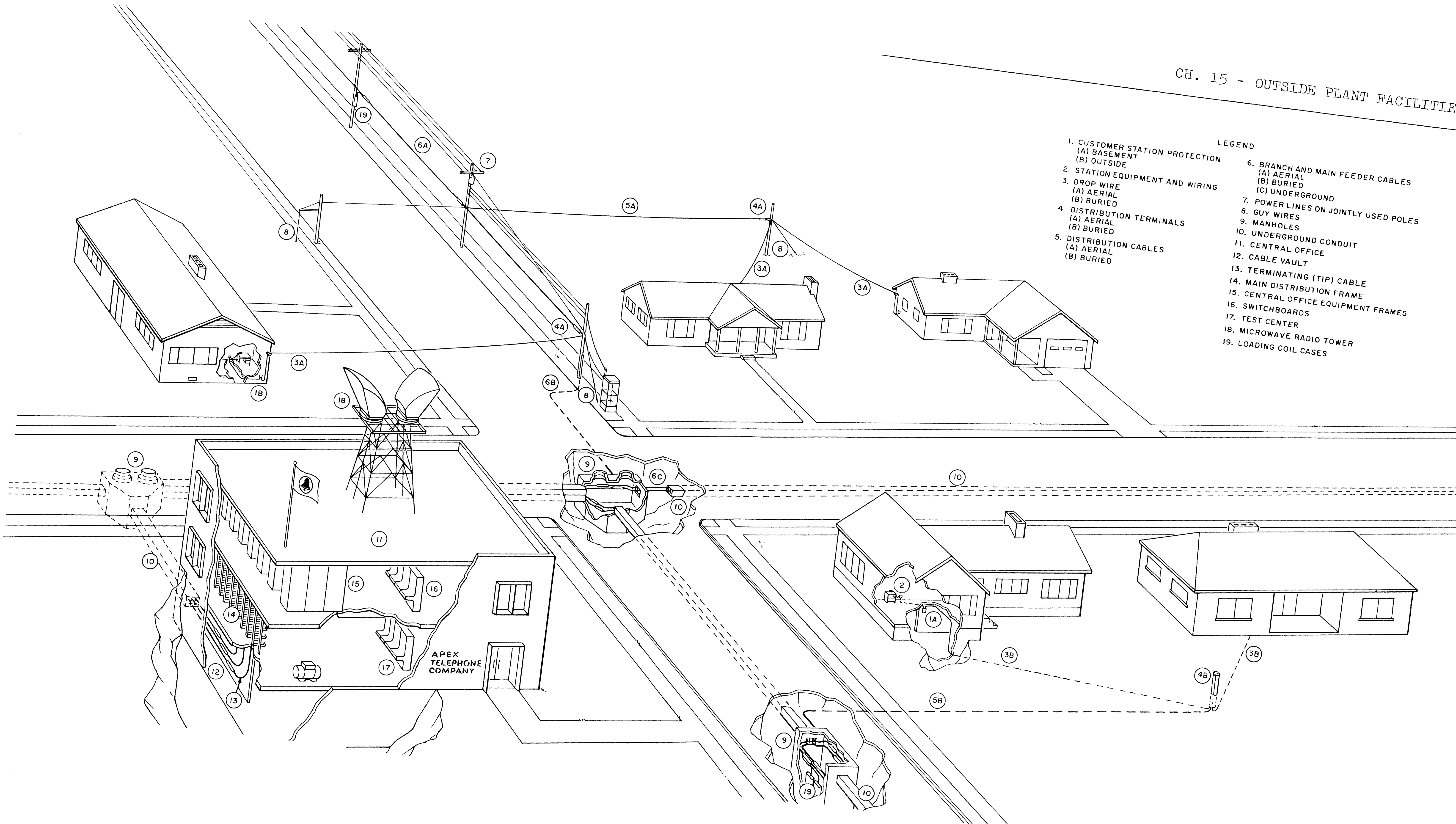
1. Customer Loop Plant

The customer loop facilities include the greater part of the total telephone plant because of the size and complexity of the area to be served. The items of plant that make up the customer loop facilities are shown in Figure 15-1. The items are numbered to show their interrelation in connecting customer telephones 1 to the main distributing frame at the central office 14.

The outside plant portion of customer loop systems may be thought of as beginning with the station protector at the customer's home. The wiring inside the house and the instruments are classified as station equipment. Service is provided to the house by drop wires, either buried or placed aerially from a pole line to the house. Cable pairs are made available for connection to drop wires in buried or aerial distribution terminals. Distribution cables that provide telephone service for groups of houses may be buried or aerial. The distribution cables are consolidated to form branch and main feeder cables. The feeder cables may be buried directly in the ground, supported aerially by poles, or placed in underground conduit. Poles are often used in conjunction with power companies and frequently require guying of some type. Underground conduit systems are a series of manholes joined by conduits that vary in type and formation. Main feeder cables usually enter the central office through a cable vault, and special cables splay the cable pairs for termination on the main distributing frame. The outside plant portion of the customer's loop is completed at the main frame. The central office houses the equipment necessary to connect the customer station to every other station in the Bell System. When the customer loop plant supplies telephone facilities to a building where there is considerable demand for service, such as an office building or an apartment, the cable, wiring, and housings within the building are considered part of the outside plant.

2. Trunk and Toll Plant Facilities

The trunk and toll portion of the outside plant connects a local customer with any other customer. Figure 15-2 is a simplified schematic drawing of the trunk and toll networks. Connections through these networks range from the simple requiring only direct trunks between local central offices to the more complex involving switching between toll centers. The tandem office provides switching between local offices. Variations to the straight connections depicted in Figure 15-2 provide the multitude of connections demanded of the trunk and toll network.



LEGEND

1. CUSTOMER STATION PROTECTION
   (A) BASEMENT
   (B) OUTSIDE
2. STATION EQUIPMENT AND WIRING
3. DROP WIRE
   (A) AERIAL
   (B) BURIED
4. DISTRIBUTION TERMINALS
   (A) AERIAL
   (B) BURIED
5. DISTRIBUTION CABLES
   (A) AERIAL
   (B) BURIED
6. BRANCH AND MAIN FEEDER CABLES
   (A) AERIAL
   (B) BURIED
   (C) UNDERGROUND
7. POWER LINES ON JOINTLY USED POLES
8. GUY WIRES
9. MANHOLES
10. UNDERGROUND CONDUIT
11. CENTRAL OFFICE
12. CABLE VAULT
13. TERMINATING (TIP) CABLE
14. MAIN DISTRIBUTION FRAME
15. CENTRAL OFFICE EQUIPMENT FRAMES
16. SWITCHBOARDS
17. TEST CENTER
18. MICROWAVE RADIO TOWER
19. LOADING COIL CASES

Fig. 15-1 — Representation of Outside Plant

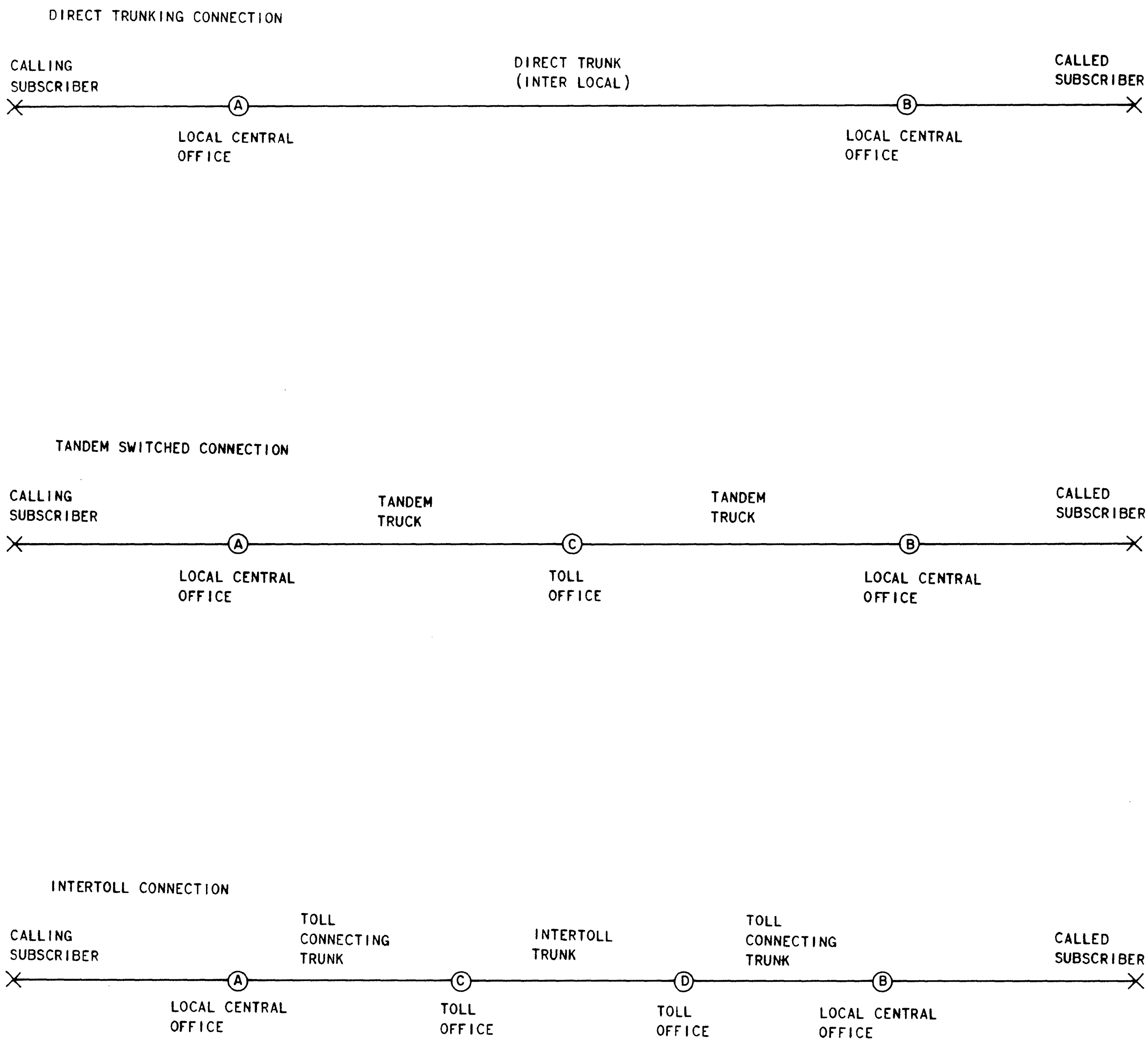


Fig. 15-2 — Toll and Trunk Network

Calls that involve connections to the trunk and toll network necessarily have a connection to the customer loop plant. Transmission on the entire connection is maintained at a satisfactory level most economically by putting the more costly facilities into the trunk and toll plant. This is judicious because individual circuits in the trunk and toll plant, in contrast to individual circuits in the customer loop plant, are:

(a) Available to more customers.
(b) Usually more direct (between offices).
(c) Of a discrete length.
(d) More uniform in design.

The quality of the circuits, the service reliability, and the number of facilities provided in the trunk and toll network are in direct proportion to the number of calls accommodated by the facilities.

The development of the telephone art has involved the use of many types of facilities in the past. Changes will continue to be made as new methods come into use. At any given time the working plant will consist of facilities ranging from types on the verge of obsolescence to newly developed types barely out of the development stage.

15.2 TRANSMISSION MEDIA

One of the areas of outside plant that to a great extent is shared between customer loop plant and the toll and trunk plant is the transmission media, the cables and wires that conduct the communication signal.

A. OPEN WIRE

One of the first facilities to be used for the transmission of telephone signals was open wire pairs. Ten wires generally spaced 10 to 12 inches apart were attached to crossarms mounted on poles. A variety of materials, each with specific design characteristics, was ultimately developed. Steel wire permitted long spans between poles. Copper wire presented better transmission characteristics but required shorter sections and consequently more poles. Combinations of copper and steel presented an economic selection between span lengths and transmission requirements. Open wire had several economic advantages in addition to a relatively simple manufacturing process. Additional circuits of open wire could be added as they were required by demand, and wires were available for service anywhere along the length of the wire route. The latter feature was a distinct advantage in the early multiparty lines.

Open wire systems grew as service increased and several objectionable features became apparent. It was unsightly as evidenced by the New York scene of Broadway in 1890 presented in Figure 15-3.

Fig. 15-3 — Broadway, New York City, in 1890

Additionally, open wire proved costly to maintain and was extremely vulnerable to storms and accidents. With the rapid growth of telephony, it became increasingly difficult to add new circuits to already congested pole lines. It soon became apparent that it was necessary to group wires closer together than was possible with individual bare wires. The advent and development of cable for aerial, underground, and buried use have eliminated open wire as a new facility except in some isolated and remote rural areas. By way of contrast, Figure 15-4 presents a view of lower Broadway, New York, after underground facilities were installed.

Fig. 15-4 — Lower Broadway, New York, After Underground Facilities Were Installed

B. CABLE FACILITIES

The design of currently available cables represents the resolution of physical and electrical problems occasioned by improvements in the communication art. The physical problems in cable development were twofold. The individual conductors had to be insulated from each other and protected from moisture and physical damage.

1. Conductor Insulation

Individual conductors were insulated with cotton string, jute, and other materials in initial cable designs, and the finished core was impregnated with resin compound, oil, or paraffin. Strip paper-insulated conductor cables were manufactured until 1963. In 1930, Western Electric introduced for field use a conductor insulation that consisted of wood pulp. The dyed or natural wood pulp is applied directly on the conductor. Polyethylene-insulated conductor (PIC) cable was introduced in 1950. Polyethylene, applied over the individual conductor by an extrusion process, has excellent insulating and dielectric properties.

2. Cable Sheaths

The second physical problem, that of protecting cable pairs from moisture and physical damage, is still a subject of research as witnessed by the variety of cable sheaths currently available. When cable was first produced, the core of wires was pulled into sections of iron or lead pipe by hand. As extruding processes improved, lead was used to cover the core of paper-insulated conductors. Lead was originally used for cable sheaths because of its ease of extrusion, its ductility, its high resistance to corrosion, and because it could be readily sealed by soldering. Lead-sheathed cables were used in underground and aerial plant. At present lead is used where conditions do not permit the use of the more economical plastic sheaths, for instance in oil storage areas where polyethylene is vulnerable to damage. Lead sheath is also used on loading coil cases and other apparatus cases, as well as for terminal stubs. A typical lead-sheathed cable is shown in Figure 15-5.

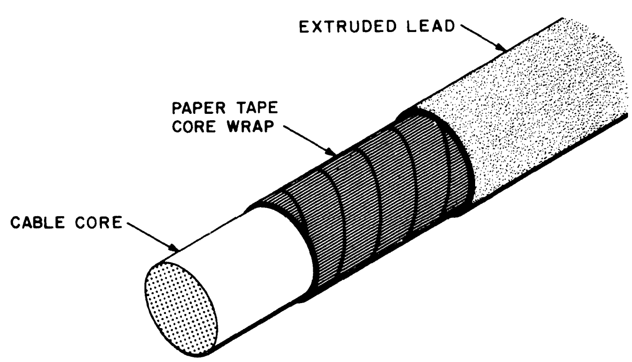


Fig. 15-5 — Lead Sheath

The advent of plastic sheaths in 1947 led to the development of a variety of combinations of polyethylene and polyvinyl chloride jackets, with aluminum and steel shields. These elements have been combined in various ways to satisfy the specific requirements for protection against moisture, lightning, induction, corrosion, and damage by rodents or rocks.

Alpeth (aluminum-polyethylene) sheath is now provided only on PIC cables. It is intended for aerial use, for building distribution, and for buried urban distribution where there is minimum lightning exposure. This sheath was formerly used on pulp-insulated conductors, but was discontinued with the introduction of stalpeth sheath. The detail construction of the alpeth sheath is shown in Figure 15-6.

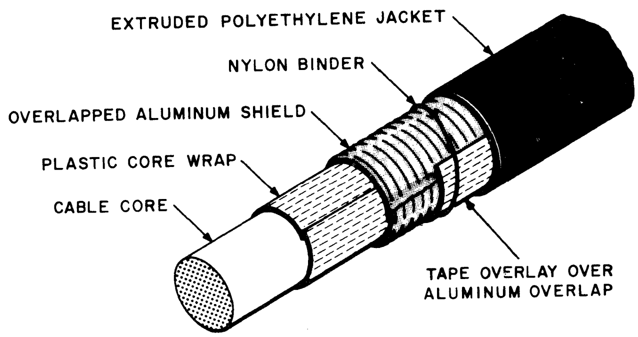


Fig. 15-6 — Alpeth Sheath

Stalpeth (steel-aluminum-polyethylene) sheath (Figure 15-7) is used on pulp-insulated cables and was used on some paper-insulated cables. It is intended for use in conduit and in aerial plant in cities and urban areas. The dielectric strength is generally adequate for urban trunk and feeder plant where lightning exposure is not usually severe. Stalpeth sheath is not intended for buried use.

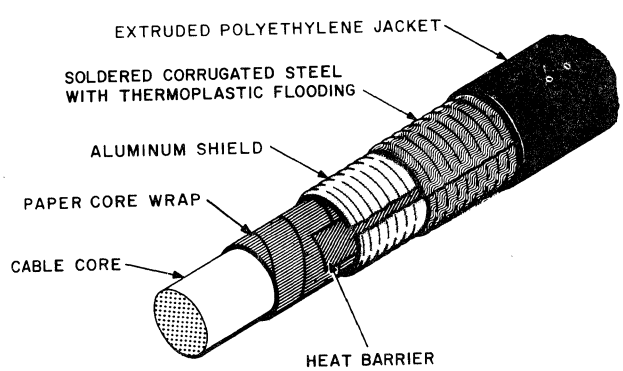


Fig. 15-7 — Stalpeth Sheath

PAP (polyethylene-aluminum-polyethylene) sheath (Figure 15-8) is used only on PIC cables since the overlapping aluminum does not completely protect the core against vapor diffusion. PAP sheath must not be used as an air feed to paper- or pulp-insulated cable. This sheath is intended primarily for buried use in lightning areas. In the event that lightning or some accidental mechanical puncture of the outer jacket occurs, the inner jacket will prevent entrance of water into the core.

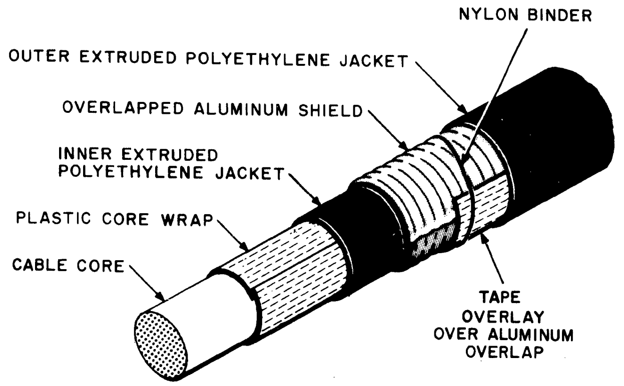


Fig. 15-8 — PAP Sheath

PASP (polyethylene-aluminum-steel-polyethylene) sheath (Figure 15-9) is used on both pulp- and polyethylene-insulated cables. The soldered steel shield reduces the vapor diffusion rate. This sheath is recommended primarily for buried use. It can be used without additional protection in most areas, including those where there is gopher activity. PASP sheath should be used in conduit and buried plant where the cable will serve as a pressure feed to paper- or pulp-insulated cables. It may also be used in aerial plant that is subject to insect or rodent damage, or where local conditions justify the added cost. PASP sheath should be used on pulp-insulated aerial cable where it is likely that the cable will later be lowered and buried or placed in split duct in lightning areas.

A complete list of the available sheaths and their principal uses is found in Table A.

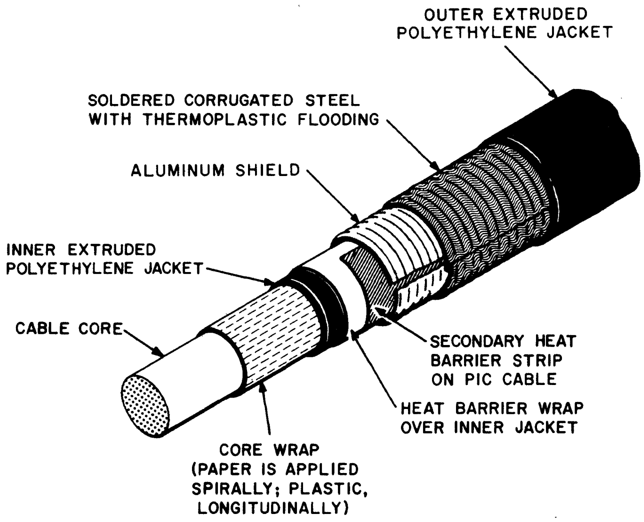


Fig. 15-9 — PASP Sheath

3. Sheath Outer Protection

Various types of outer protections are available for use over the basic lead or plastic sheath of buried, underground, and aerial cables. These outer protections are used where field conditions indicate that the protection limits of the standard sheath would be exceeded. They provide the cable with additional corrosion resistance, mechanical protection, low-frequency shielding, or a combination thereof. Several combinations of steel tape, paper tape (either impregnated with an asphalt compound or plain), jute, and polyethylene provide protection for buried cables against damage by gophers or rocks, and aerial cables from low-frequency induction. Cables intended for underwater installation across reservoirs or shallow, quiet bodies of water where navigation is limited to shallow draft boats, such as canoes, rowboats, or motorboats, are protected with coverings of jute and steel wires. Cables used for crossing rivers or deep bodies of water are protected by two layers of jute and a layer of neoprene-jacketed steel wires. Additional layers of steel wires and jute are added as the probability of severe abrasive action or high tensile strain is increased. Table B includes a list of the available outer protections and their code designations.

4. Cable Identification Code

A four-letter cable identification code has been standardized for use on outside plant records and construction work prints. Table A contains an explanation of the code and its application to currently used materials.

TABLE A

CABLE CODE DESIGNATIONS

FIRST LETTER	SECOND LETTER	THIRD LETTER		
SEQUENCE OF STANDARDIZATION	TYPE OF CONDUCTOR INSULATION	GAUGE AND MATERIAL OF CONDUCTOR		
		GA	COPPER	ALUMINUM
Alphabetical progression from A	B Solid Plastic Insulation: Polyethylene or Polyethylene-Polyvinyl Chloride	13	J	-
		16	H	-
		17	-	C
		19	B	-
		20	-	D
		22	A	F
		24	M	K
		26	T	-
	C Expanded Polypropylene (Propylex)	28	W	-
	D Pulp			
	H Polyethylene [1]			
	K Polyethylene [2]			
	Superseded 2nd Letter (Dielectric Strength)			
	S 350 Volts rms			
	N 500 Volts rms			

FOURTH LETTER	
TYPE OF SHEATH	PRINCIPAL USE
A Alpeth (Fig. 15-6)	Aerial and building distribution cables and buried in urban areas.
C Stalpeth (Fig. 15-7)	In conduit and aerial in urban areas. Not to be buried.
D Lepeth	Buried intercity coaxial cables in severe lightning areas.
E Polyethylene-Jacketed Lead	In conduit and buried in areas of minimum lightning exposure.
F Polyethylene-Jacketed Lepeth	Buried intercity coaxial cables in severe lightning or corrosion areas.

TABLE A (Cont)

CABLE CODE DESIGNATIONS

FOURTH LETTER		
	TYPE OF SHEATH	PRINCIPAL USE
G	PAP (Fig. 15-8)	General buried use in lightning areas.
H	PASP (Fig. 15-9)	General buried use. Aerial in rodent-infested areas.
J	Tolpeth: Aluminum- or Copper-Steel-Polyethylene	Toll-type cables. In conduit or aerial in minimum lightning areas.
K	Tolpeth: Polyethylene-Copper-Steel-Polyethylene	Buried toll-type cables. In conduit and aerial in severe lightning areas.
L	Lead (Fig. 15-5)	Underground and aerial use where conditions preclude plastic sheaths.
M	Alvyn: Aluminum-Polyvinyl Chloride	Terminating cables. Building riser shafts.
N	Stalvyn: Aluminum-Steel-Polyvinyl Chloride	Pulp-insulated conductor cables. Building riser shafts.
S	Self-Supporting Alpeth	Aerial.
T	ARPAP	Buried intercity toll or trunk where PAP sheath can be used.
U	ARPASP	Aerial intercity toll or trunk where PASP sheath can be used.

Note 1: Dielectric strength between conductors:

19-Gauge - 10,000 volts dc.
22-Gauge - 8000 volts dc.

Note 2: Dielectric strength between conductors:

24-Gauge - 5000 volts dc.
26-Gauge - 3000 volts dc.

TABLE B

OUTER PROTECTION CODE DESIGNATIONS

TYPE OF PROTECTION	CODE
Aerial tape armor	AT
Buried tape armor	BT
Gopher tape armor	GT
Gopher tape armor[1]	MP
Modified gopher tape armor	MG
Modified tape armor	MT
Light wire armor	LA
Submarine single armor	SA
Submarine double armor	DA

Note 1: MP-type gopher tape armor is used only on plastic sheath. Introduced in 1965.

5. Cable Electrical Development

Two electrical problems are continuous in the development of cable: (1) telephone circuits must be efficient in transmitting electric energy without distortion and without too great a loss, and (2) the circuits must be protected against induced voltage caused by adjacent telephone circuits.

(a) Crosstalk: Induced voltages can cause crosstalk, the imposition on one circuit of intelligible or nearly intelligible conversations from another circuit. Crosstalk can be caused by the direct leakage of current from a disturbing to a disturbed circuit; however, this condition is negligible in properly maintained lines with sufficiently good insulation. The crosstalk coupling which presents the real problem in practice is due to electric and magnetic fields set up by the currents in the disturbing circuit.

Magnetic induction is the effect of the magnetic field of one circuit on a second paralleling circuit. Similarly, electric or electrostatic induction is the effect on the second current of the electric field of the first circuit. How magnetic and electric induction causes crosstalk can be seen in Figures 15-10, 15-11, and 15-12. In Figure 15-10 in any given segment, S, of paralleling circuits, the fluctuating magnetic lines, e, produced by the alternating current, I_a, flowing in circuit A induce a current, i, in circuit B.

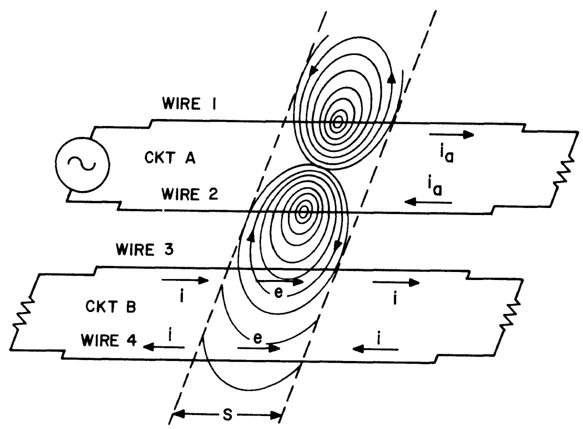


Fig. 15-10 — Magnetic Induction

In a similar circuit in Figure 15-11, the difference in capacitance between the four wires during the current flow in circuit A will tend to cause small currents to flow through the distributed capacitance as represented by capacitors c, c', and c" to the wires of circuit B.

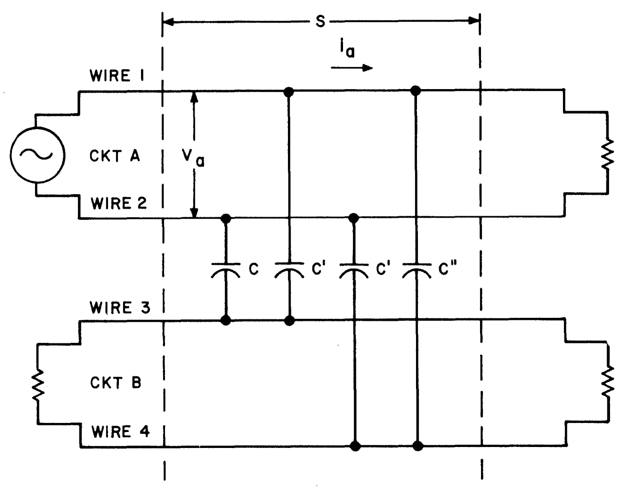


Fig. 15-11 — Electric Induction

The crosstalk currents induced in parallel circuits by the combined electric and magnetic induction are shown in Figure 15-12.

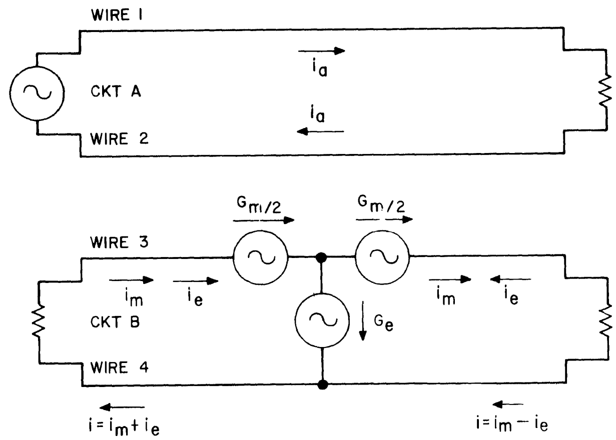


Fig. 15-12 — Combined Electric and Magnetic Induction

The crosstalk due to electric induction may be thought of as being caused by a small generator, G_e, connected across the disturbed pair, while the crosstalk due to magnetic induction may be thought of as being caused by a generator, G_m, connected in series with the disturbed pair. Under these conditions it will be noted that the currents, i_m and i_e, established by the two generators flow in the same direction in the left portion of the line but in opposite directions in the right portion. In other words, the crosstalk effects of magnetic and electric induction are additive in the case of near-end crosstalk but opposed to each other in the case of far-end crosstalk.

The magnitude of the crosstalk increases with the length of the parallel circuits, the strength (energy level) of the transmitted signal, and the frequency of the transmitted current.

(b) Crosstalk Reduction: There are three principal methods of reducing crosstalk induction.

(1) Parallel wires could be so arranged that the effect of the fields of one pair will be the same on both wires of the other pair.

(2) The distance between conductors could be decreased and the spacing between pairs increased so that the induction fields set up by the two wires would tend to neutralize each other. Similarly, if the two wires of the disturbed pair are close together, the effect of any field set up by the disturbing pair will be practically the same on both wires of the disturbed pair,

so that there will be no resultant unbalance voltage to produce crosstalk.

(3) Use could be made of transpositions. If the four wires in Figure 15-10 were rearranged as in Figure 15-13, it is evident that when equal and opposite currents are flowing in the two wires of circuit A, the voltages induced in wires 3 and 4 will flow in opposite directions on the two sides of the point where circuit A is transposed.

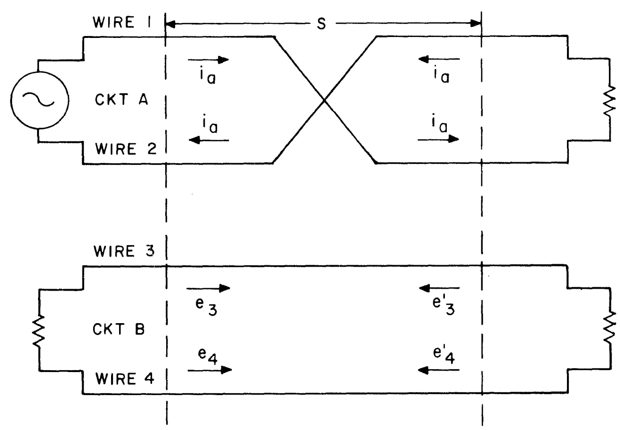


Fig. 15-13 — Crosstalk Reduction by Transpositions

In the case of open wire lines, crosstalk reduction depended upon wire configuration on the poles, transpositions, and resistance balances. Resistance balances were primarily a question of maintenance and ordinarily presented little difficulty. Configuration consisted of spacing the individual conductors of a pair closer together but spacing the entire pair farther apart from other pairs. The use of high-frequency carrier systems with their much greater crosstalk probabilities led to the development of configurations in open wire lines. Transpositions consisted of transposing the two sides of a pair of an open wire circuit at specific intervals such as every fifth pole.

In the development of cable, crosstalk reduction is a guiding factor in the arrangement of individual wires with respect to their mates in a pair and in the association of each pair with other pairs in the cable. Early paper-insulated conductors were twisted together spirally to form a pair in such a manner that a 360-degree twist was completed every

3 inches. Cable cores were built up by applying successive layers of pairs over a center consisting of one, two, or three pairs. These layer-type exchange cables were originally made with all pairs having the same length of pair twist and with adjacent layers spiraled around the core in opposite directions (reversed lay). In this arrangement, the crosstalk coupling between adjacent pairs within a reel length was relatively high, but the mixing which occured in random splicing of adjacent lengths provided reasonable results. With the establishment of long trunk circuits and the introduction of loading, it was necessary to change the core design in order to reduce the crosstalk level to tolerable limits. The condition was improved by using pairs having two different lengths of pair twists within each layer (staggered twist design). In addition, adjacent layers were spiraled in opposite directions, or two layers were applied in the same direction with different lengths of lay to avoid parallelism of pairs in such adjacent layers. Layer-type cable has been superseded by multiple-unit type cables. The different pair twist lengths in a layer-type cable are identified by intermittent bands of colored stain on one conductor of the pairs. Figure 15-14 is an example of layer-type cable.

More recent cable designs have employed a multiple-unit type of core makeup to further disassociate individual pairs. A unit is an assembly of pairs held together by a binder. Units in currently manufactured cables consist of 25, 50, or 100 pairs. Each unit of the cable contains a combination of pairs having nine different lengths of twist. The use of the nine lengths of pair twist in each unit results in a substantial reduction in rms capacitance unbalance as compared to units having fewer lengths of pair twists.

Pair and unit identification in pulp-insulated conductor cable is maintained by a standard color code. The tip side of each pair is of natural pulp color (referred to as white) while the ring side may be stained a solid color (green, red, blue) or have 3/8-inch wide bands of color stain at the rate of 15 per foot. A band of color stain on only the tip conductor identifies the length of pair twist.

In multiple-unit type cable, units are placed in layers. Each layer contains one and only one green-white unit regardless of the number of pairs in the cable. In each layer the green-white unit is

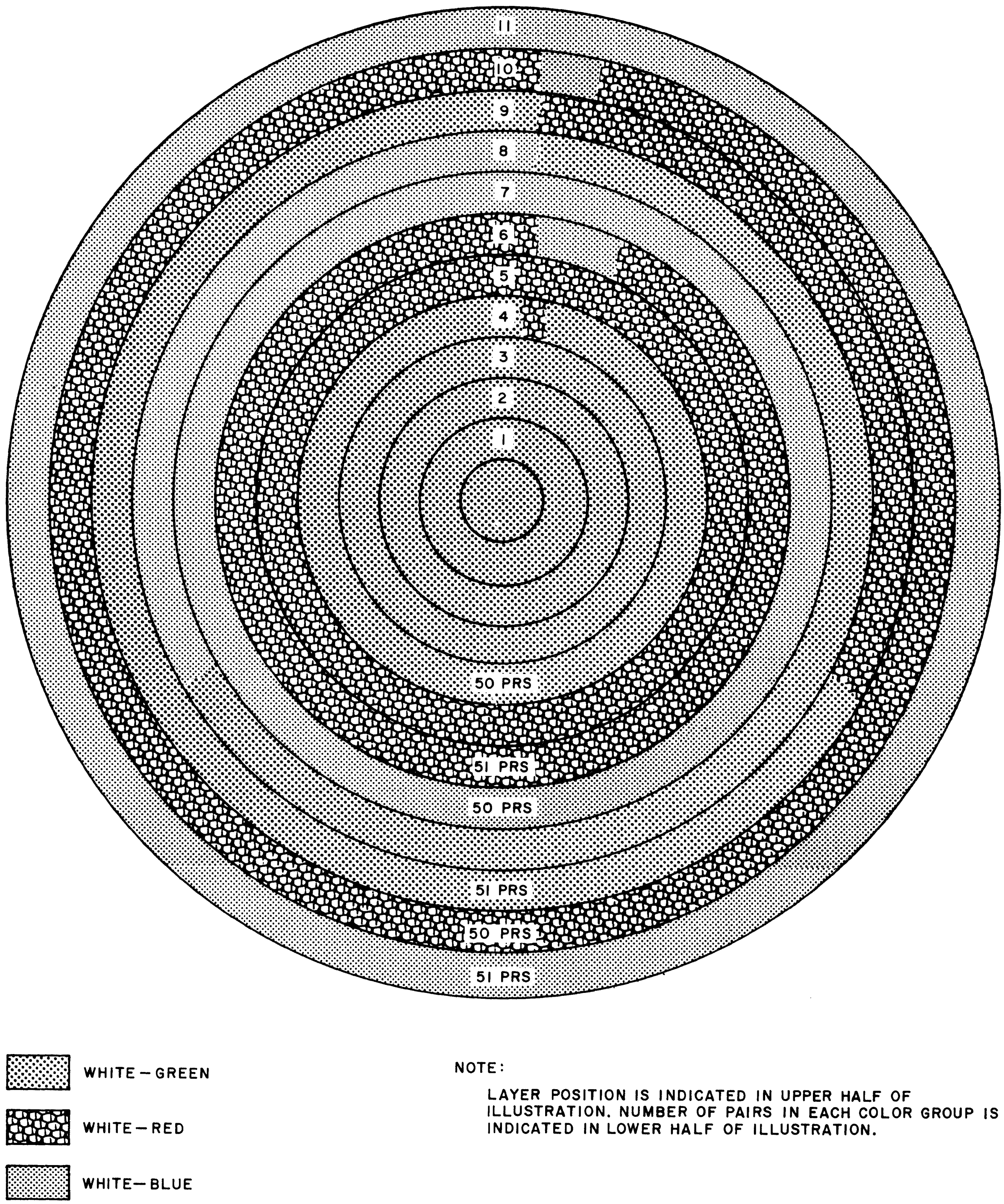
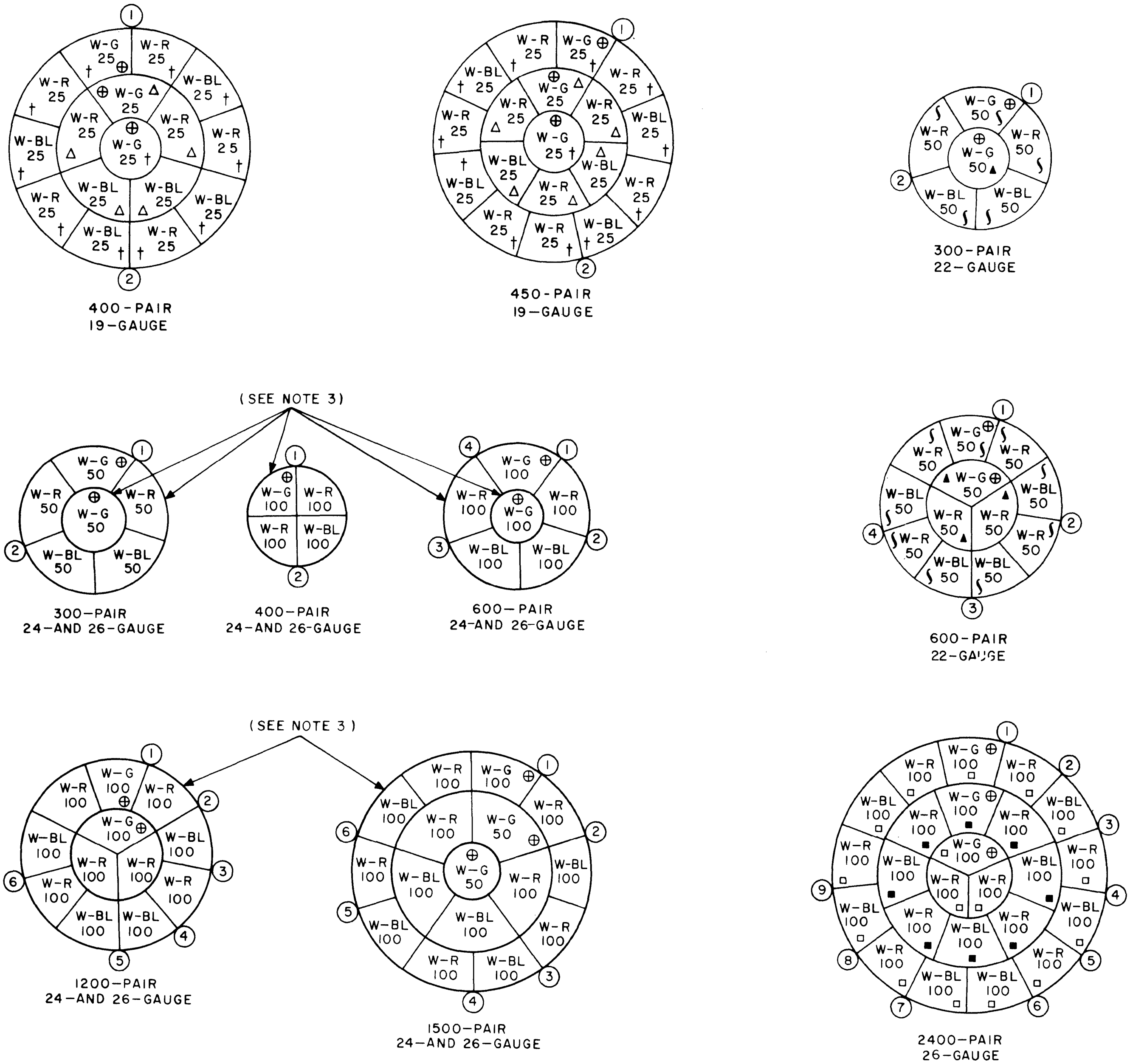


Fig. 15-14 – 303-Pair, 19-Gauge DNB Cable Makeup flanked by a red-white unit, and then blue-white and red-white units alternate until the layer is completed. The colors of insulation, arrangement of units, colors of unit binder strings, and other details for various sizes of cable currently in use are shown in Figure 15-15.

The versatility of polyethylene as a conductor insulation has permitted a standardization of pair identification and unit composition. The insulating properties of polyethylene have increased the dielectric strength between conductors and between the conductors and the sheath, and have minimized the importance of maintaining rigid pair twist requirements. The variety of colors available in polyethylene has made possible the physical identification of each pair in the cable. Ten colors of insulation are provided, five used exclusively for ring conductors and five for tip conductors. Cable sizes from 6 through 25 pairs consist of a single unit. The basic subdivision in the other sizes is a binder group which has 25 distinctly colored pairs. A binder group may consist of a single 25-pair unit or a combination of 12- and 13-pair units having the same colored binders. The pairs in each binder group and the binder tapes are colored in such a way as to permit selection of any pair in the cable by color code. Table C shows the individual pair color code for cables of 6 through 25 pairs and for units comprising the 25-pair binder groups used in the remaining sizes. The binder group color code follows the same sequence as the pair color code, i.e., white-blue, white-orange, white-green, etc., but for clarity the binder group color code designations are reversed. Figure 15-16 shows the makeup of various polyethylene-insulated conductor cables.

(c) Conductor Gauge: Early in the development of cable, economic factors encouraged the use of cables of different attenuations for various conditions in the plant. For example, if a subscriber was located quite close to the central office, adequate service could be provided with a cable pair with much higher attenuation than would be possible if the subscriber were located at a considerable distance from the central office. In order that different cable lengths match each other as well as their associated equipment, it was necessary that the capacitance be standardized in the design of cables. Two values of capacitance were chosen: one for high-grade transmission such as trunk and toll and another for local or customer loop transmission. These values are fixed at approximately 0.062 and 0.083 microfarad



NOTES:

1. THE COLORS OF INSULATION INDICATED ARE THOSE OF THE PAIRS IN THE OUTER LAYER OF THE UNIT.
2. GREEN-RED TRACER PROVIDED ONLY IN SOLID-COLOR PULP CABLE; REPLACED BY A WHITE-GREEN PAIR IN MULTISTAIN PULP CABLE.
3. THE BINDERS ON THESE CABLES ARE RED OR GREEN-RED FOR 24-GAUGE; ORANGE OR GREEN-ORANGE FOR 26 GAUGE. THE LAYER POSITION OF THE UNITS IS IDENTIFIED BY BINDERS OF SOLID OR DUAL-COLOR. STARTING WITH THE OUTSIDE LAYER OF UNITS THE BINDER COLORS WILL ALTERNATE SOLID, DUAL-COLOR, SOLID.

⊕ = TRACER PAIR IN SOLID-COLOR PULP ONLY. (NOTE 2).
□ = ORANGE-BINDER STRINGS
■ = GREEN-ORANGE BINDER STRINGS
† = BLUE BINDER STRINGS
Δ = GREEN-BLUE BINDER STRINGS
ʃ = WHITE BINDER STRINGS
▲ = GREEN-WHITE BINDER STRINGS
W-G = WHITE-GREEN
W-R = WHITE-RED
W-BL = WHITE-BLUE

○ = EXTRA PAIR

NO.	EXTRA PAIR COLOR
1	RED-BLUE
2	GREEN-WHITE
3	RED-WHITE
4	BLUE-WHITE
5	GREEN-WHITE/BLACK STAIN
6	RED-WHITE/BLACK STAIN
7	BLUE-WHITE/BLACK STAIN
8	GREEN-WHITE/ORANGE STAIN
9	RED-WHITE/ORANGE STAIN
10	BLUE-WHITE ORANGE STAIN

Fig. 15-15 — Unit Cable Makeup

TABLE C — COLOR CODE FOR PIC CABLE

25-PAIR COLOR CODE			BINDER GROUPS		
			STANDARD		SUPERSEDED[1]
PAIR NUMBER SEQUENCE	COLOR CODE		12-13 PAIR UNITS	25 PAIR UNIT	8-8-9 PAIR UNITS
	TIP	RING			
1	W	BL	12	25	8
2	W	O			
3	W	G			
4	W	BR			
5	W	S			
6	R	BL			
7	R	O			
8	R	G			
9	R	BR			8
10	R	S			
11	BK	BL			
12	BK	O			
13	BK	G	13		
14	BK	BR			
15	BK	S			
16	Y	BL			
17	Y	O			9
18	Y	G			
19	Y	BR			
20	Y	S			
21	V	BL			
22	V	O			
23	V	G			
24	V	BR			
25	V	S			

ABBREVIATIONS

BL	Blue	W	White
O	Orange	R	Red
G	Green	BK	Black
BR	Brown	Y	Yellow
S	Slate	V	Violet

Note 1: The 8-8-9 pair units were manufactured prior to 1964.

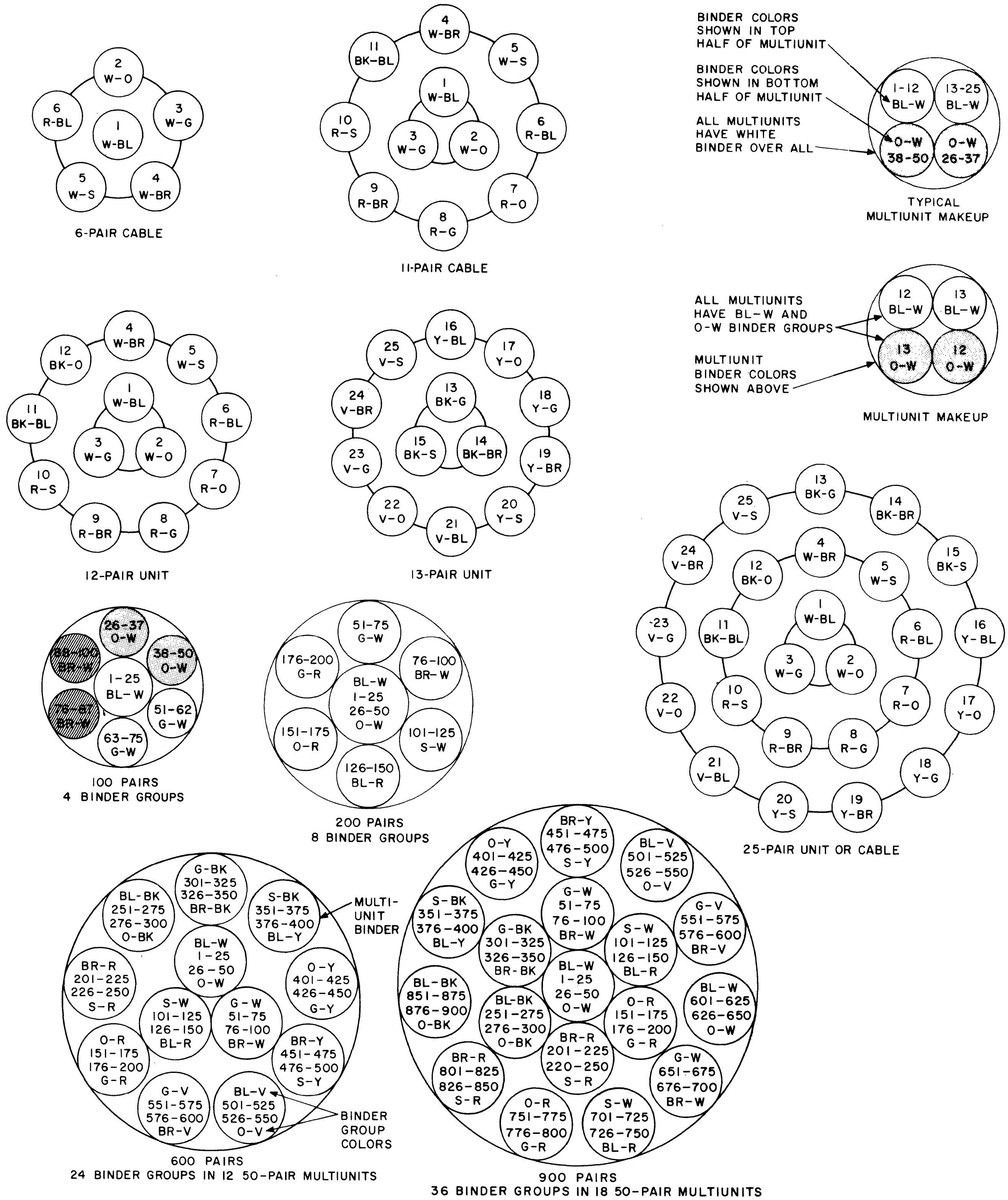


Fig. 15-16 — PIC Cable Makeup

per mile, respectively. The primary electrical characteristics of cable transmission lines, i.e., inductance and capacitance, are a function of the design of the cable. The remaining parameter affecting the attenuation is resistance. Unit resistance of conductors is directly proportional to the conductivity of the material and inversely proportional to the square of the diameter of the conductor. In outside plant four main sizes of copper conductors, i.e., 19, 22, 24, and 26 gauges, are used. These gauges provide adequate increments of attenuation for most field conditions. Recently a 17-gauge alumunium, high-capacitance (0.083 microfarad per mile), solid polyethylene-insulated conductor cable has been introduced for use on projects which ordinarily would require 19-gauge copper conductors. Aluminum conductor cables of finer gauges are currently under development. The sizes of standard cables currently being manufactured are shown in Table D.

TABLE D

CURRENTLY AVAILABLE CABLE SIZES

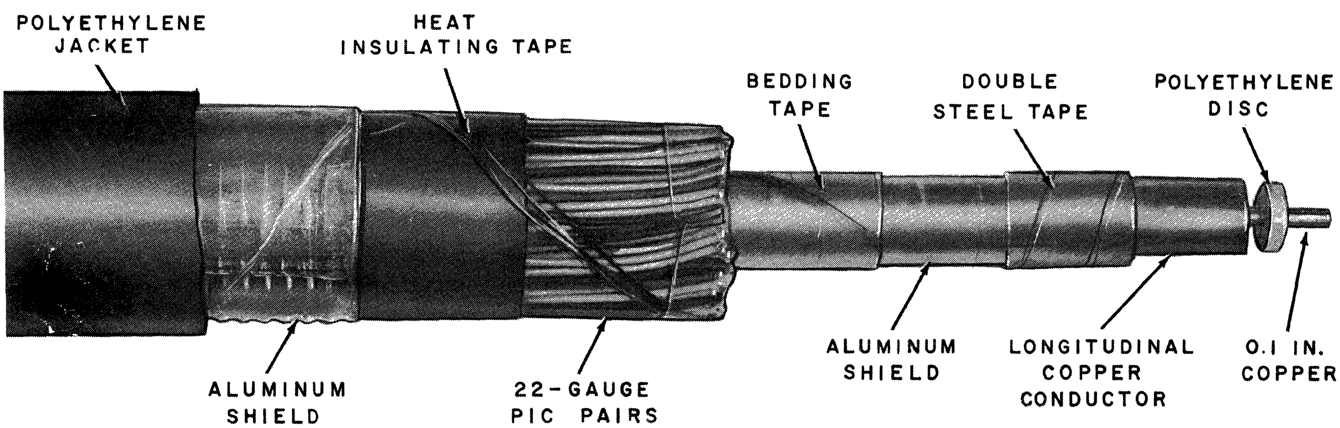
	19-GAUGE	22-GAUGE	24-GAUGE	26-GAUGE
AD series pulp-insulated conductors	ADB 300, 400, 450	ADA 300, 400, 600, 900, 1100	ADM 300, 400, 600, 900, 1200, 1500, 1800	ADT 300, 400, 600, 900, 1200, 1500, 1800, 2100, 2400, 2700, 3000 [1]
BK and BH polyethylene-insulated conductors	BHB 6, 11, 16, 25, 50, 75, 100, 150, 200, 300	BHA 11, 16, 25, 50, 75, 100, 150, 200, 300, 400, 600	BKM 11, 16, 25, 50, 75, 100, 150, 200, 300, 400, 600, 900	BKT 11, 16, 25, 50, 75, 100, 150, 200, 300, 400, 600, 900

Note 1: In Bell of Canada only.

6. SPECIAL CABLES

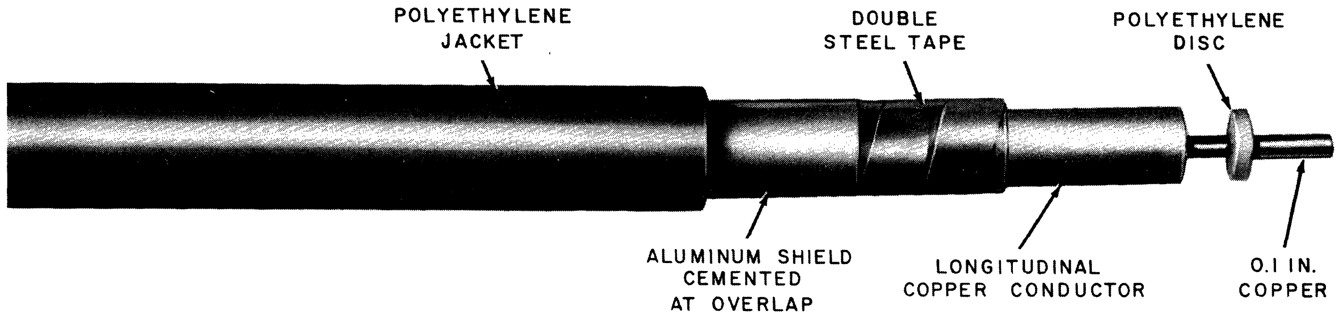
A group of cables has been developed to provide transmission characteristics demanded by a variety of special circuits. Quadded cables were developed for early long-haul carrier systems. A quad consisted of four individually insulated conductors arranged in twisted pairs with the two pairs twisted together. The improvement of carrier systems and the advent of coaxial cables have almost eliminated quadded cable except for replacement reasons.

Coaxial cables are provided for carrier system, wide-band data, and television transmission. Such cables may be disc insulated, expanded polyethylene insulated, or solid polyethylene insulated. These cables may consist of single coaxials, up to 20 coaxials and a number of service pairs, or a combination of coaxials and other standard types of quads or pairs. A disc-insulated coaxial consists of an inner conductor of semihard drawn copper wire positioned in the center of an outer conductor by polyethylene discs placed at intervals along the inner conductor. The outer conductor consists of a longitudinally seamed copper tube. Two steel tapes are spiraled over the copper tube to provide mechanical support and shielding. Disc-insulated coaxial cables are used primarily as main and branch feeder cables in community antenna and closed circuit television systems, CATV and CCTV, respectively. Table E is a description of the currently available disc-insulated cables, and Figures 15-17 and 15-18 are examples of the physical makeup of these cables.

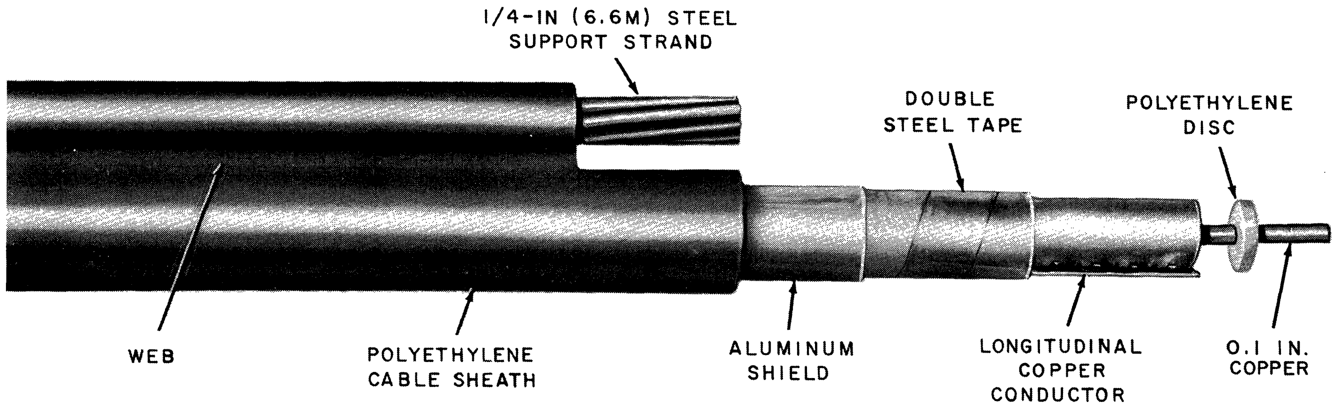


CA-3070-A-SINGLE COAXIAL WITH 22-GAUGE PIC PAIRS

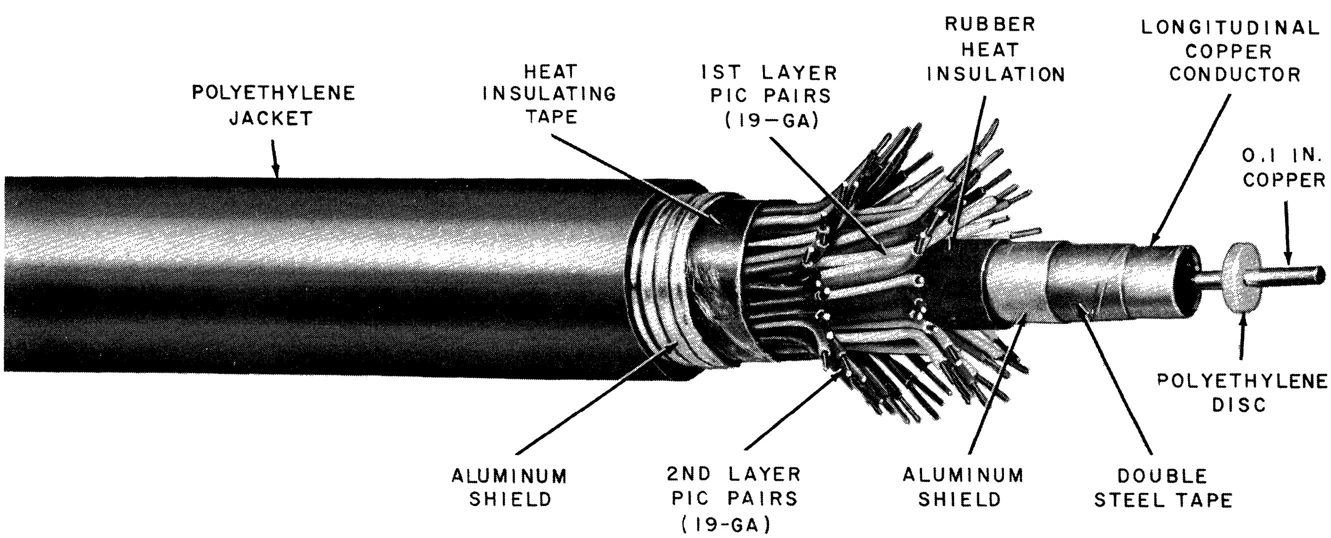
Fig. 15-17 — Disc-Insulated Coaxial Cable



CA-3185— SINGLE COAXIAL



CA-3178— SINGLE COAXIAL SELF SUPPORTING TYPE



CA-3016-A— SINGLE COAXIAL WITH 19-GAUGE PIC PAIRS

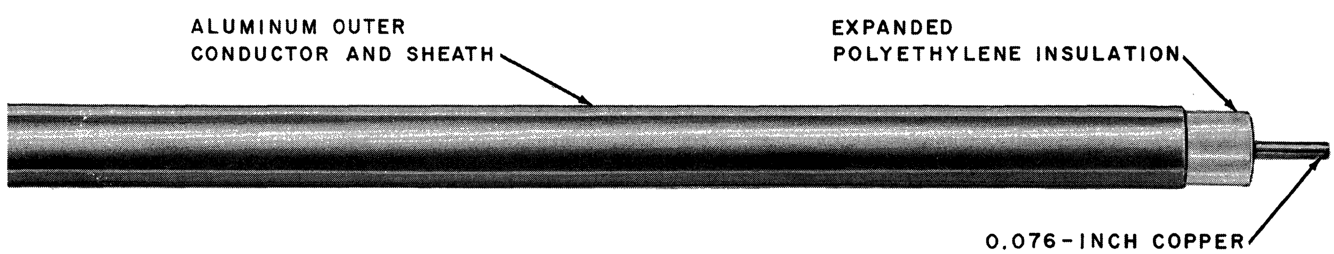
Fig. 15-18 — Disc-Insulated Coaxial Cables

TABLE E

DISC-INSULATED FEEDER COAXIAL CABLES

CA-3185	Single coaxial with sheath similar to alpeth except that the aluminum shield is cemented together at the overlap.
CA-3178	Single coaxial self-supporting type with sheath similar to alpeth. Self-supporting member of the structure consists of continuous built-in 1/4-inch (6.6M) extra high strength steel support strand.
CA-3198	Single coaxial with PASP sheath that has under the inner jacket an additional moisture barrier consisting of a longitudinal aluminum shield which is cemented together at the overlap.
CA-3015-H CA-3016-A CA-3070-A CA-3070-H CA-3070-K	Single coaxials with 19- or 22-gauge PIC pair options with alpeth, PASP, and tolpeth K sheath.
CA-3140-H-LA	Single coaxial PASP sheath with light wire armor.

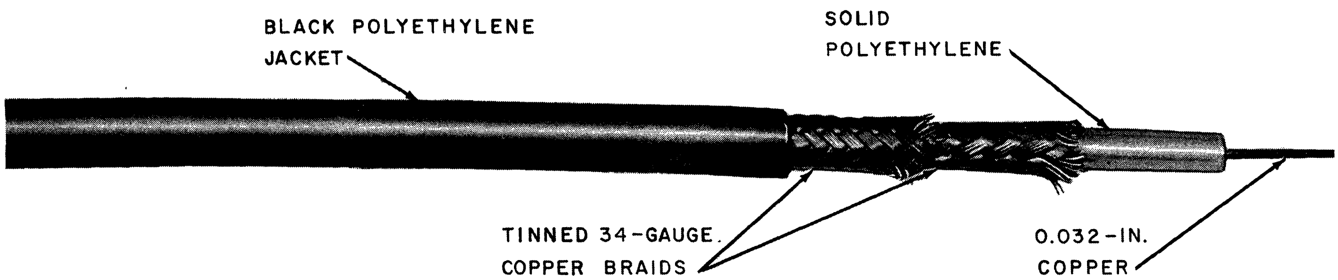
Expanded polyethylene-insulated coaxial cables are single coaxial cables that are used as distribution cables in CATV and CCTV systems. The current standard expanded polyethylene-insulated coaxial cable (AT-8386) consists of a single center wire surrounded by an aluminum outer conductor. In the AT-8386B cable shown in Figure 15-19 the outer conductor functions as the sheath. In other designs a layer of polyethylene is placed over the aluminum.



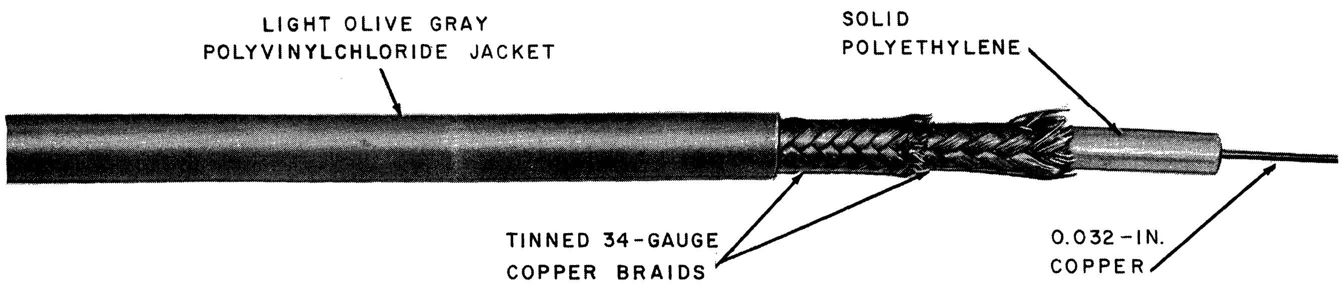
AT-8386B-SINGLE COAXIAL WITH ALUMINUM OUTER CONDUCTOR AND SHEATH

Fig. 15-19 — Expanded Polyethylene-Insulated Coaxial Cable

In CCTV and CATV systems, service between the distribution cables and the customer's premises is generally provided by solid polyethylene-insulated wires, cables, or drops. Description and illustration of the currently available wire, cable, and drops are found in Figures 15-20, 15-21, and Table F.



CA-3049-FOR OUTDOOR WIRING

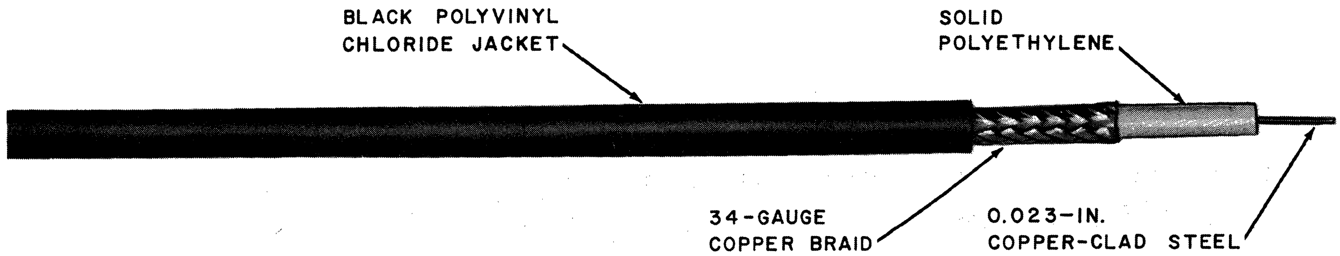


CA-3050-FOR INDOOR WIRING

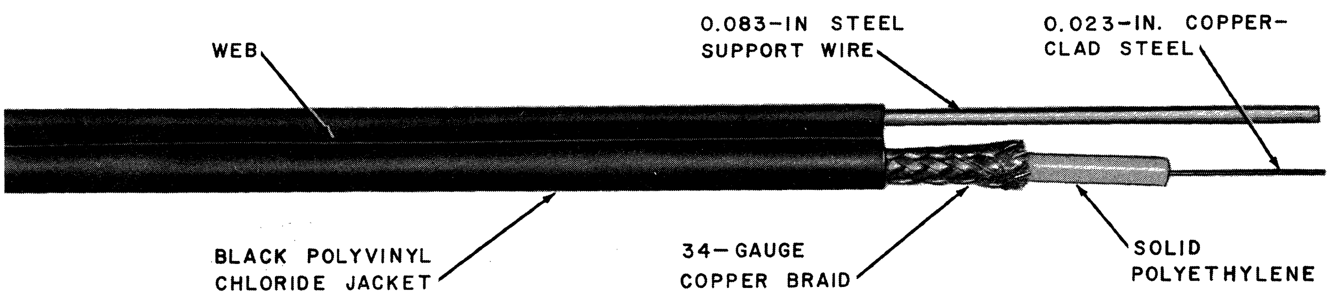
Fig. 15-20 — Solid Polyethylene-Insulated Coaxial Wires

When conductors designed primarily for television transmission between studios or between other points in the television network in the exchange areas are required, they are usually included in cables with other standard types of quads or pairs. The construction of a standard video pair is shown in Figure 15-22.

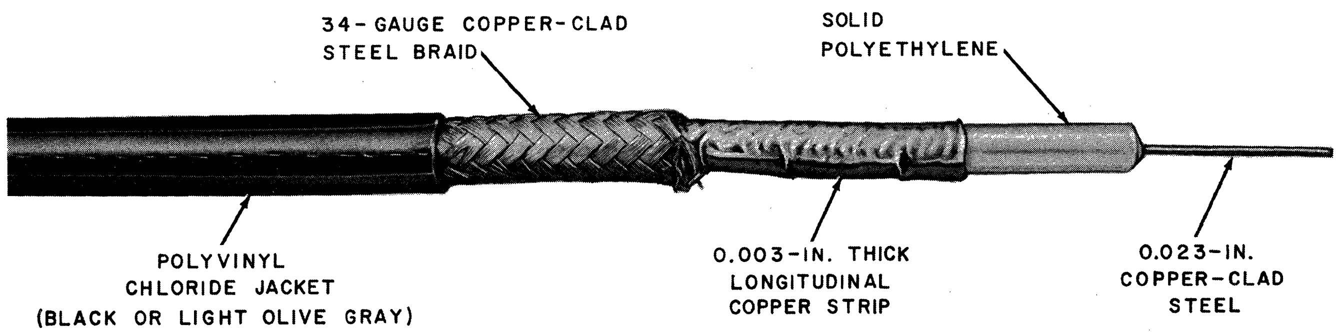
Specially manufactured cables containing groups of pairs of different gauges are also available in outside plant. These cables are used mostly where service is required in areas both near and remote from the central office and economies can be gained by using a single sheath. Any economic advantage gained by the use of composite cables must be carefully examined so that hidden manufacturing costs are fully evaluated. Pair combinations of composite cables are limited to the physical size of the largest straight gauge cable.



E COAXIAL WIRE (AT-8288E)—FOR AERIAL OR BURIED DROPS AND WIRING



F COAXIAL WIRE (AT-8288F)—FOR LONG AERIAL DROPS



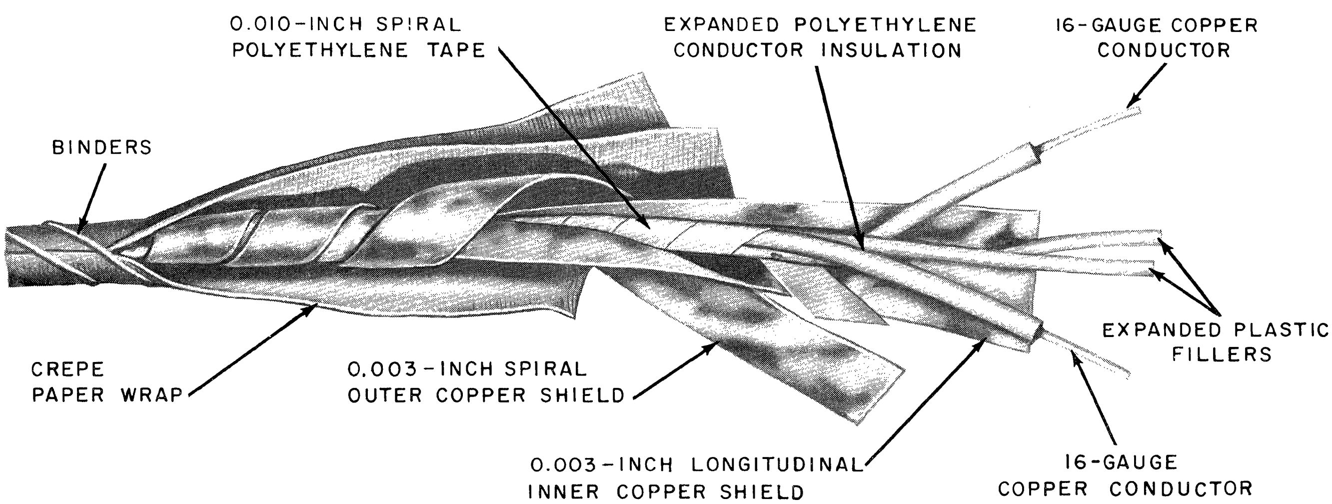
G COAXIAL WIRE (AT-8522)—SHIELDED COAXIAL WIRE

Fig. 15-21 — Solid Polyethylene-Insulated Coaxial Wires

TABLE F

SOLID POLYETHYLENE-INSULATED WIRES, CABLES, AND DROPS

E coaxial wire	Single flexible coaxial wire with high strength copper-clad steel center conductor, single copper braid outer conductor, and a black PVC jacket.
F coaxial wire	Single flexible coaxial wire with high strength copper-clad steel center conductor, single copper braid outer conductor, a 0.083-inch high strength steel support wire, and a black PVC jacket.
G coaxial wire	Single flexible coaxial wire with high strength copper-clad steel center conductor, an outer conductor of a copper strip in parallel with a single braid of copper-clad steel conductors, and either a black or light olive gray PVC jacket.
CA-3049	Coaxial cable with a single coaxial with a copper center conductor, two layers of tinned copper braid outer conductor, and a black polyethylene jacket.
CA-3050	Single coaxial with a copper center conductor, two layers of tinned copper braid outer conductor, and a gray PVC jacket.



LONGITUDINAL SHIELD TYPE (16 PEV-L)

Fig. 15-22 — Standard Video Pair

15.3 STRUCTURES

The structures that support cables and wires are an intrinsic part of the outside plant system. These structures include pole lines in the case of aerial plant, the earth for buried systems, and manholes and conduits for underground cables. In the representation of outside plant shown in Figure 15-1, it is obvious that there is a commonness of structures in that they can be shared by customer loop facilities and trunk and toll plant. Underground conduit systems can easily accommodate trunk, toll, and customer loop cables simultaneously. Similarly, pole lines may support all three types of cable. Individual poles may support different types of facilities such as toll open wire and customer loop distribution cables. Two major factors must be considered in the design of structures: (1) the service life of structures is generally longer than the plant supported, so the structure must be designed to accommodate all the plant that will be supported by that structure throughout its service life, and (2) the strength and safety levels incorporated in the design of a structure must be compatible with the relative service value of the plant supported. For example, a pole line supporting trunk and toll cables may be as much as 50 percent stronger than a pole line supporting only customer loop plant. Similarly, in buried cable systems cables of a high service value should be buried deeper than cables of less service value.

A. POLE LINES

The design of pole lines embraces consideration of the following factors:

(1) Right-of-Way: Pole lines along public streets or roads frequently require general permission by ordinance and specific approval of individual poles by the municipal body in charge of utilities. Pole lines on private property require firm commitments regarding access, egress, and length of occupation.

(2) Storm Loading: Heavy, medium, and light storm loading areas are recognized in the United States. These zones were established by a study of the frequency and severity of storms over a period of years. An important factor in the design of individual poles is the force of the wind acting upon the area presented by the plant when covered with ice.

(3) Load to be Supported: Basically a pole is a cantilever beam, fixed at one end (the ground) and with a load at the other. Circumferences at the ground line and at the top of the pole are computed using standard beam formulae to support any load that may be imposed on the pole during its service life. Storm loading for the specific area is considered.

(4) Timber and Treatments: The fiber strength of the various types of timber is a factor in determining pole sizes. The service life of poles is influenced by the ability of standard timber preservative treatments to resist decay. The type of timber used naturally depends upon the availability of supply. For example, its availability makes southern pine with a pentachlorophenol treatment the standard pole for most of the southeastern states.

(5) Joint Use with Power Companies: Where aerial construction is necessary, joint use of poles by power and telephone companies is desirable. There is less adverse public reaction to a single pole line than to duplicate pole lines. Standard clearances between electric and telephone wires established by the National Electrical Safety Code are more easily obtained on jointly used poles. Economies are accrued by both companies in that the shared cost of joint poles is frequently less than the cost of individual pole lines. Typical joint pole usage is shown in Figure 15-23.

(6) Guying: Unequal forces acting upon the pole must be balanced by some form of guying. The most functionally efficient guying is an anchor guy. The anchor, which is buried in the ground, may be one of a number of the standard patent anchors or may be constructed with materials on hand. The size and type of anchor depend upon the load to be balanced, the distance of the anchor from the pole (lead), and the soil conditions. Guys into trees or guys to other immovable structures such as building steel or bridges, etc., may be satisfactory. In the absence of suitable guying, sufficient strength must be added to the pole to compensate for the unbalanced force.

B. BURIED SYSTEMS

The need for service reliability and a more critical concern over the Bell System's responsibility for the improvement of communities have prompted the development of tools, materials, and techniques to make burying the first choice in placing new outside plant. The average telephone customer generally displays his interest in the operation of a telephone company in three broad areas: the cost of telephone service, the reliability of the service, and the poles and wires he can see. The Bell System policy on out-of-sight plant has been succinctly stated by Mr. K. G. McKay, Vice President of the American Telephone and Telegraph Company, in his letter to operating company presidents on March 3, 1969.

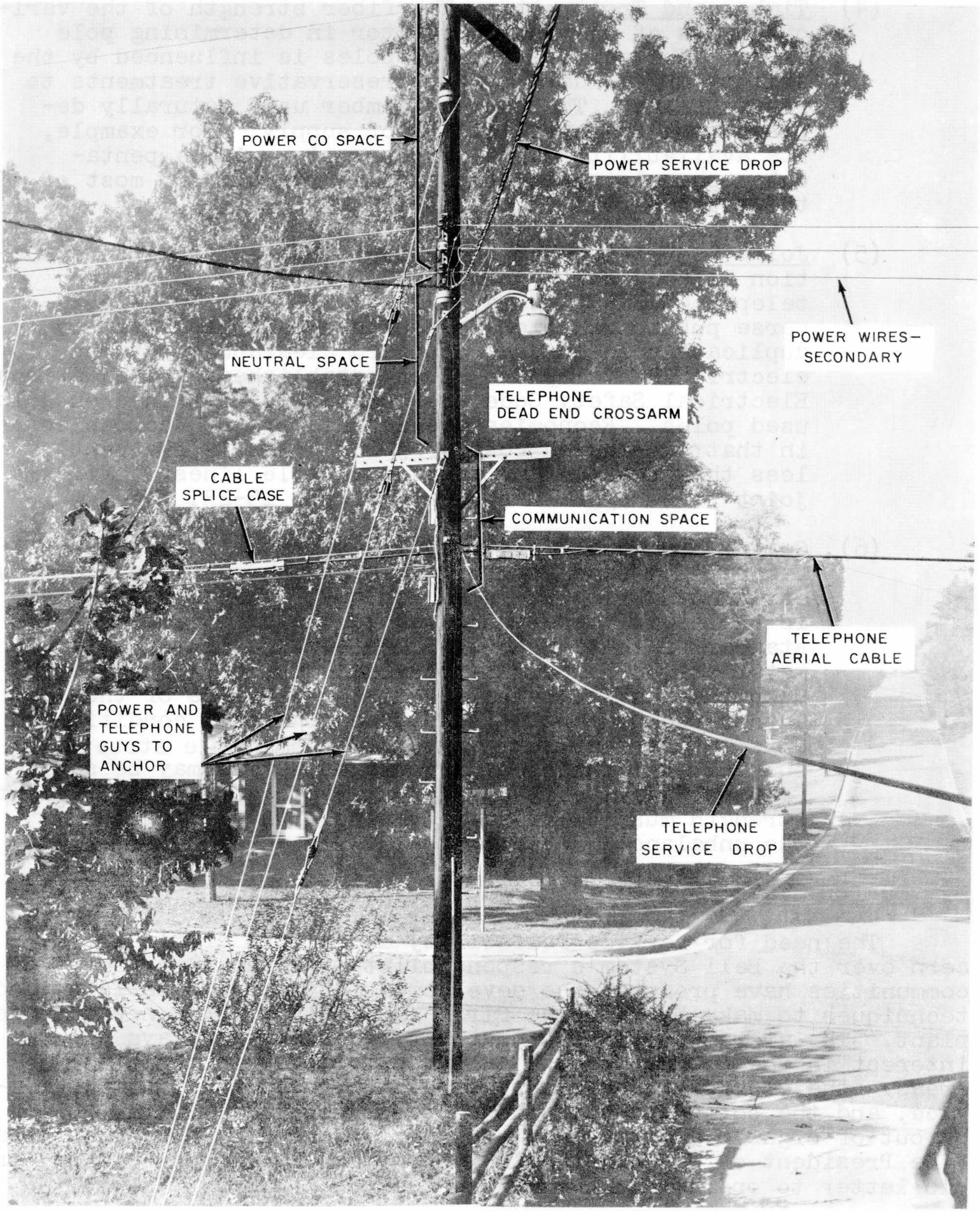


Fig. 15-23 — Typical Joint Pole Usage

"Public interest in preserving and enhancing our national environment has been growing in recent years. Telephone companies can anticipate renewed and sustained interest in beautification on the part of government agencies and community leaders. This development warrants the responsive attention of these companies on the grounds of business prudence and responsible citizenship.

"There is no intent that this general view should override sound engineering judgment which takes all factors into consideration. Rather, its purpose is to create the kind of forceful policy so often required to motivate a change from old established methods, and reflect the current concern for the nation's environment, new technology, and methods."

In line with this policy, outside plant cables are being buried directly in the ground or placed in underground conduit in ever-increasing numbers. New cable laying machines and techniques have substantially reduced the cost per foot of buried plant. The choice of buried plant over aerial is rapidly becoming the economic choice.

Service reliability is improved through the use of buried plant. The public is justified in expecting fewer service interruptions, particularly those due to adverse weather conditions. The vulnerability of aerial plant to storm damage is exemplified in Figure 15-24. The favorable public reaction to out-of-sight utilities could be the most important advantage of the program. How the absence of poles can enhance the appearance of a residential area is demonstrated in Figure 15-25.

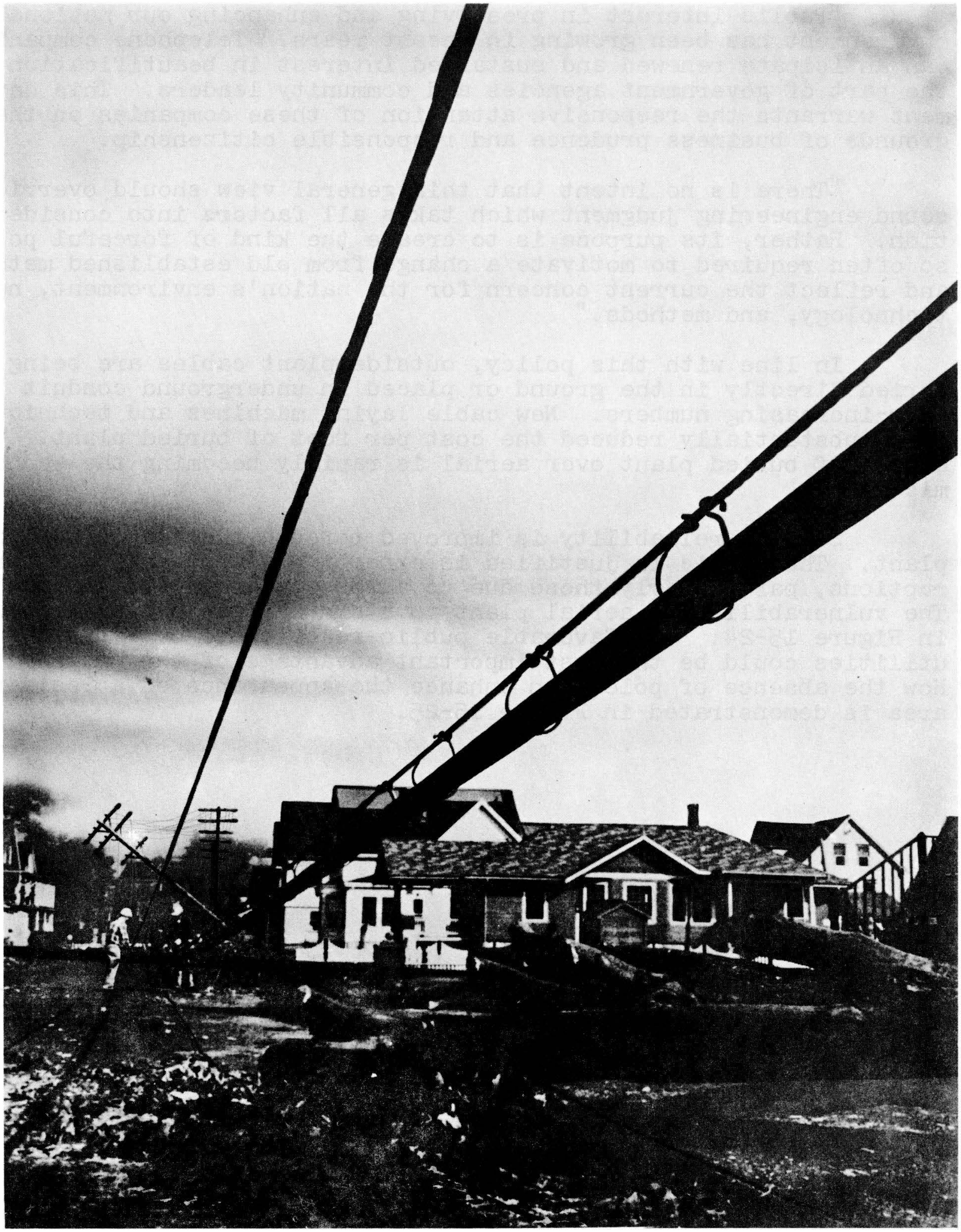


Fig. 15-24 - Wind Damage

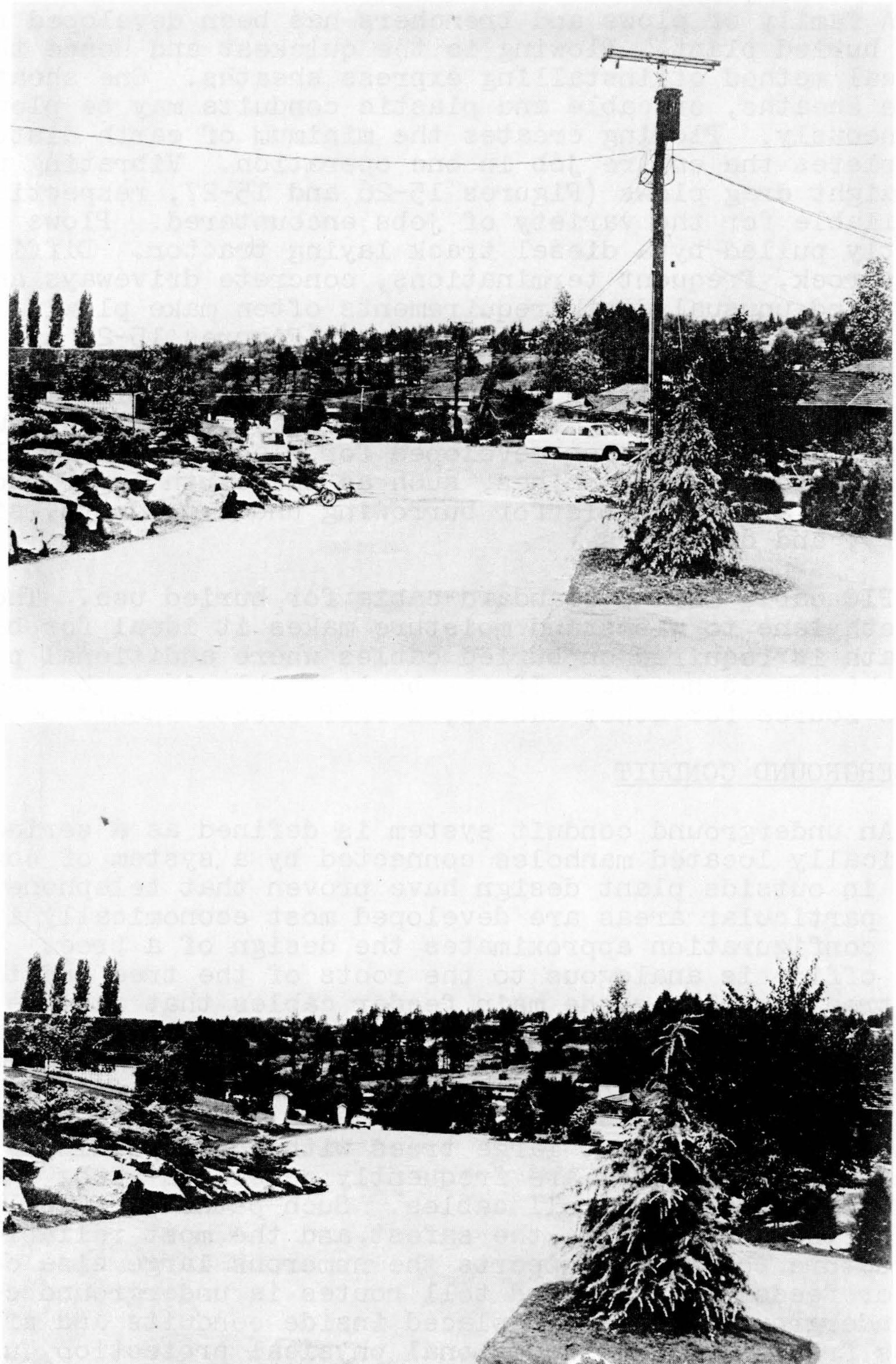


Fig. 15-25 — Comparison of Aerial and Buried Utilities

A family of plows and trenchers has been developed for placing buried plant. Plowing is the quickest and hence the most economical method of installing express sheaths. One sheath, multiple sheaths, or cable and plastic conduits may be plowed simultaneously. Plowing creates the minimum of earth disturbance and completes the entire job in one operation. Vibrating plows and straight drag plows (Figures 15-26 and 15-27, respectively) are available for the variety of jobs encountered. Plows are most frequently pulled by a diesel track laying tractor. Difficult terrain, rock, frequent terminations, concrete driveways and streets, and unusual depth requirements often make plowing uneconomical. A variety of trenching machines (Figures 15-28 and 15-29) has been developed to maneuver over many types of terrain. Trenching requires a disposition of the spoil during digging and backfilling after the digging is complete. Small, special plows with vibrating shears have been developed for placing individual service wires to residences. Machines, such as the earth auger shown in Figure 15-30, are available for burrowing under roadways, sidewalks, shrubbery, and driveways.

PIC cable is the standard cable for buried use. The ability of polyethylene to withstand moisture makes it ideal for burying. PAP sheath is required on buried cables where additional protection from lightning is needed. If the buried cable is to be used as a pressure source for other cables, a PASP sheath should be specified.

C. UNDERGROUND CONDUIT

An underground conduit system is defined as a series of strategically located manholes connected by a system of conduits. Studies in outside plant design have proven that telephone facilities to particular areas are developed most economically if their general configuration approximates the design of a tree. The central office is analogous to the roots of the tree and the trunk of the tree symbolizes the main feeder cables that radiate from the central office. The large branches of the tree are comparable to the branch feeder cable routes, and the small tree branches characterize the distribution cable systems. This analogy is logical with respect to size in that the cable routes feeding densely populated areas represent large trees with correspondingly large branches. Feeder routes are frequently developed along the path established by trunk or toll cables. Such paths are usually established on the most direct, the safest, and the most reliable routes. The structure that best supports the numerous large size cables in the major feeder or trunk and toll routes is underground conduit. Since underground cables are placed inside conduits and since the conduits frequently have additional physical protection, underground cables are less susceptible to accidental damage than either aerial or buried cables. Underground cable systems are more flexible in design and utilization than buried cable systems because of the accessibility of cables at manholes. This availability of

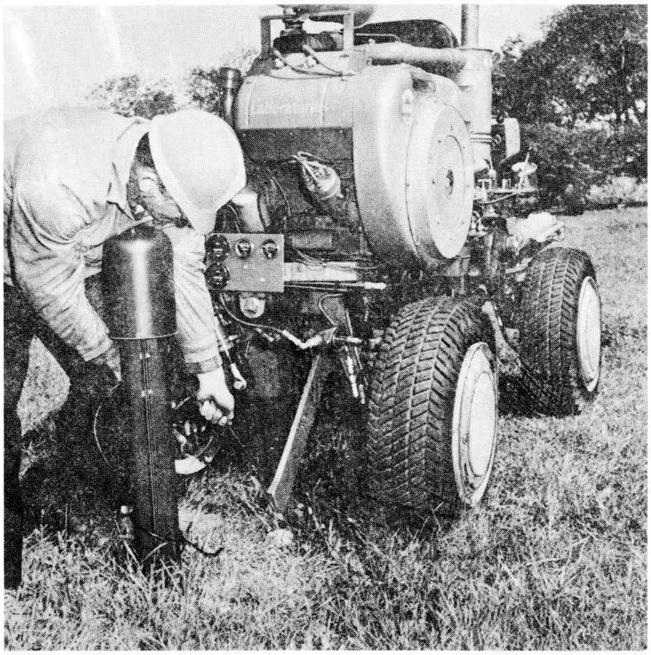
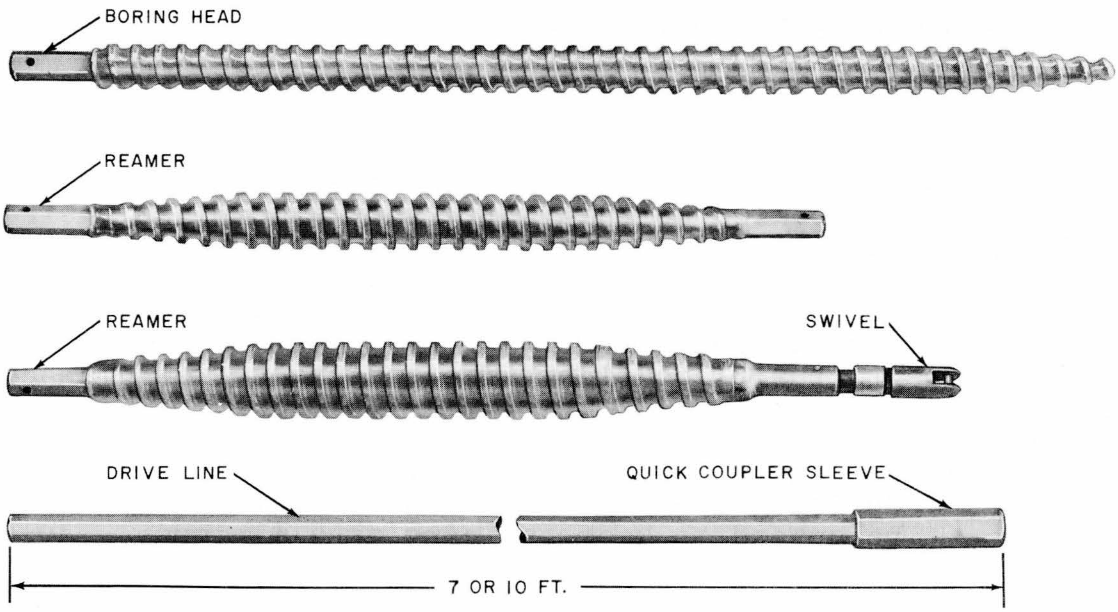


Fig. 15-26 — Vibrating Lawn Plow

Fig. 15-27 — Straight Drag Cable Plow

Fig. 15-28 — Trenching Machine

Fig. 15-29 — Trenching Machine



APPARATUS USED WITH AUGER

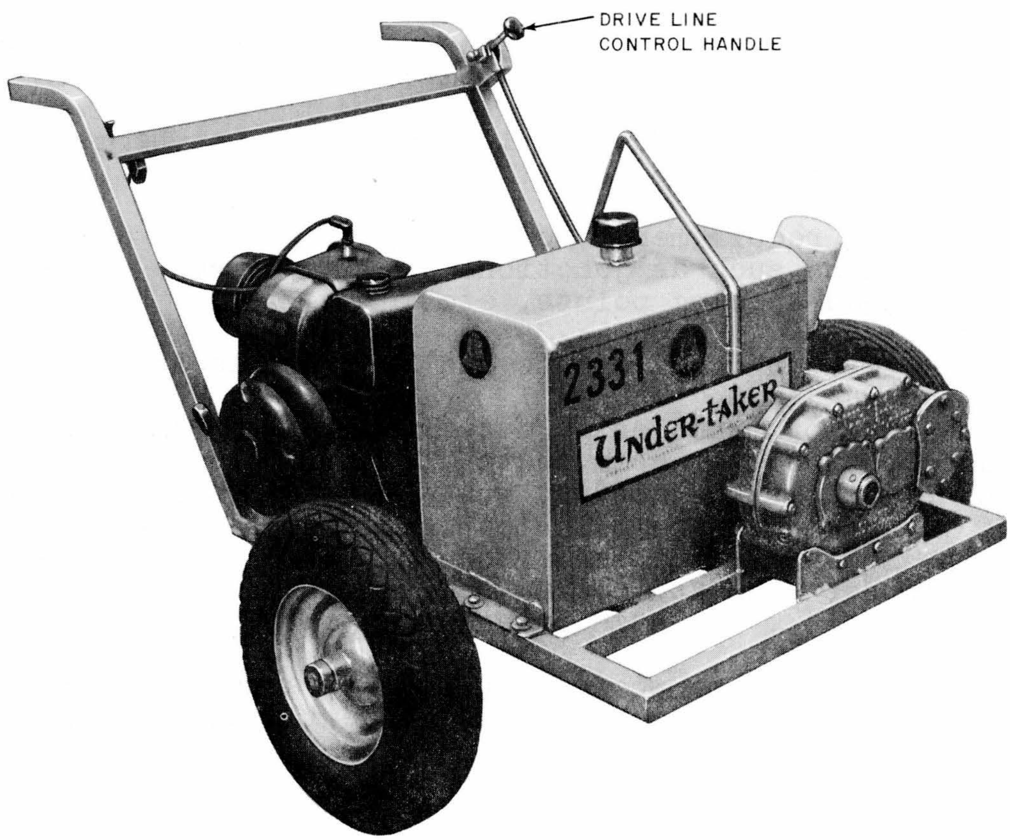


Fig. 15-30 — Earth Auger

cables permits rearrangements and additions without expensive locating and digging operations.

The physical placement of individual manholes and the spacing between manholes frequently determine the design of conduit systems. The factors to be considered in the physical locations of manholes are equally applicable to other items of outside plant. They should be located so that: (1) they accomplish their primary purpose efficiently and according to well formulated plans, (2) they can be placed, used, and maintained in the most economical manner, (3) they can be placed, used, and maintained with safety to workmen and the general public, and (4) they will not cause adverse public reaction due to their location. The spacing between manholes is determined by several factors:

(1) The number of splices to be made in underground cables. Splicing large size cables is costly, and manholes must be spaced to keep splicing at a minimum.

(2) The physical properties of the conduits that limit the length of cable that can be pulled at one time. For example, plastic duct has a lower coefficient of friction than concrete duct.

(3) The amount of cable that can be placed on a cable reel that can be handled with standard equipment.

(4) The number of cable lengths that must be maintained for emergency use.

(5) The requirements for having manholes in specific locations such as junctions of conduit runs, repeater or load spacing points, etc.

(6) Service requirements and specific location details.

The size of manholes is determined by the amount of wall or rack space required to accommodate all the cables that can potentially be placed in the conduit run. The headroom, length, and width of the manholes are computed using the space needed to splice or rack the individual cables. When manholes are required for special purposes such as loading, carrier repeaters, junctions of conduit runs, etc., the size is adjusted accordingly.

In early designs wooden conduits arranged in banks were placed between manholes. Materials currently being used for conduits include the following:

(1) Vitreous tile, either as single ducts or in multiple sections containing up to nine ducts. Multiple tile ducts (MTD) are manufactured in 4- and 5-foot sections. In the construction of a conduit run, the sections are aligned by steel pins and the joints are sealed by a tape consisting of woven glass fabric impregnated with bitumen and synthetic resin. Multiple tile conduits and placing techniques are shown in Figure 15-31.

Fig. 15-31 — Placing 9-Duct Multiple Tile Conduit

(2) Multiple concrete duct (MCD) sections containing up to nine ducts (Figure 15-32). MCD is manufactured in straight sections that are butted together and joined by a plastic sleeve. It is also manufactured in sections having a bell on one end and a spigot on the other and, when assembled, the spigot end is inserted into the bell and a rubber gasket is compressed to seal the joint.

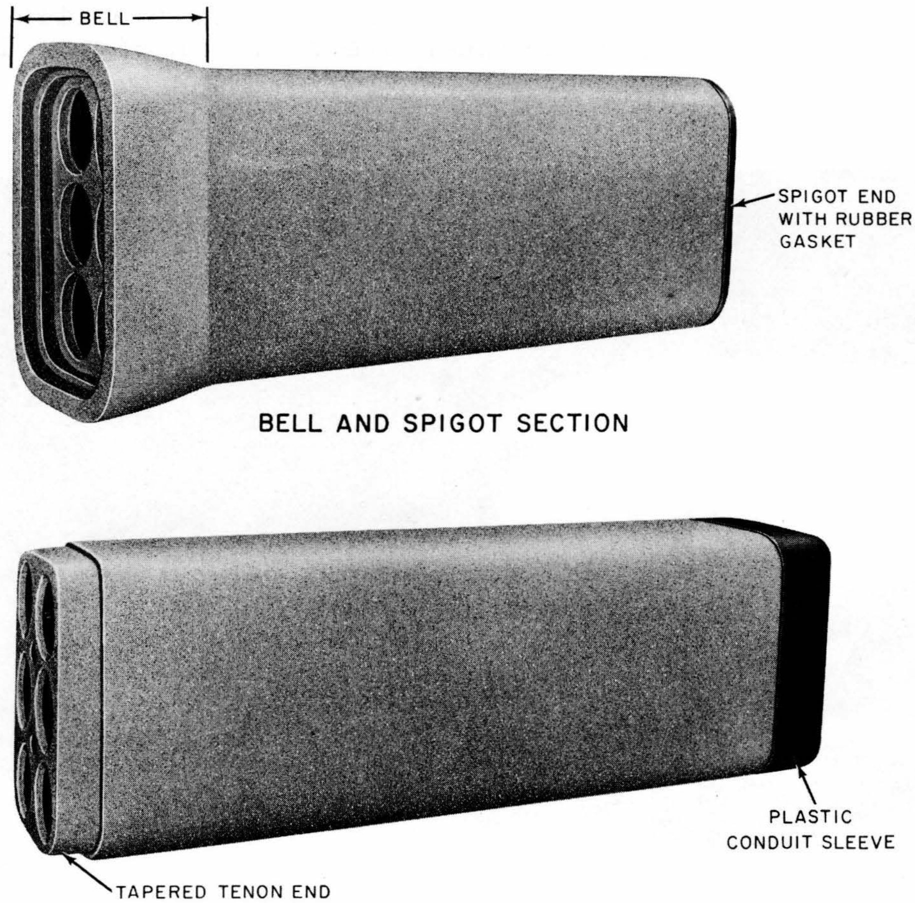


Fig. 15-32 — Multiple Concrete Conduits

(3) Individual conduits of asbestos concrete (transite), impregnated fiber, or plastic. Multiple duct systems are formed by using individual conduits in banks of the desired number of ducts. Figure 15-33 shows individual fiber conduits formed to make up a multiple duct run. Separators are placed between conduits to facilitate encasing the structure with concrete.

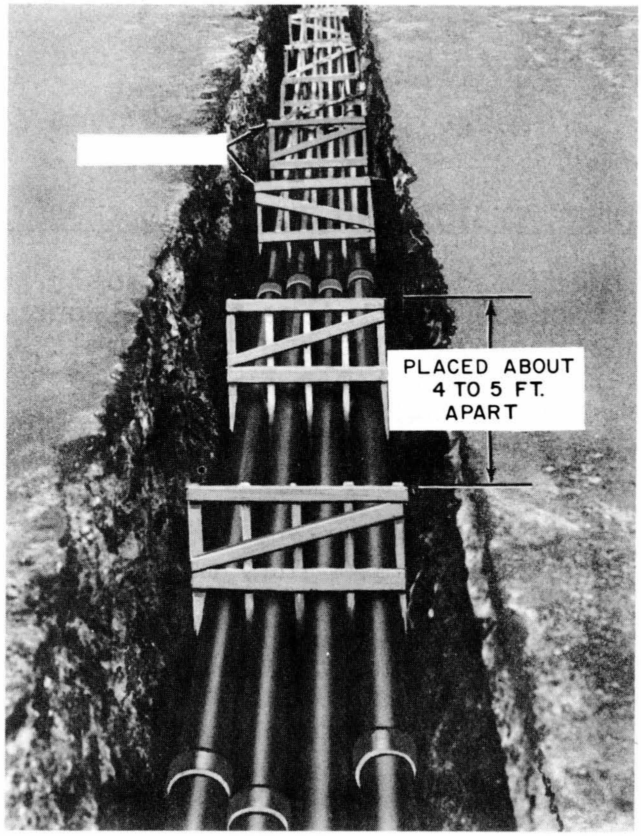


Fig. 15-33 — Single Conduits Forming Multiple Duct Structure

As with pole lines, the availability of material frequently influences the type of conduits to be used. Each type has advantages and disadvantages. The multiple duct sections are heavy and in the case of concrete special equipment is needed to handle the larger sections. The taped joint allows silt and water to enter the duct, but the short sections permit smaller lengths of trench to be opened and closed quickly. The latter is most desirable when streets can only be closed to traffic for short periods. Individual conduits are easily handled, form watertight connections, are more flexible in the formations that can be used, and permit longer sections between manholes, but usually require some form of mechanical protection such as concrete encasement.

The number of ducts to be placed initially in an underground conduit system is a function of the number of cable sheaths to be placed in the system during its service life. The number of sheaths to be placed is based upon the forecast pair requirements in each gauge for customer loop plant use, the number of sheaths required for trunk or any special facilities, and municipal requirements. Computerized programs which can recommend the number of ducts to be placed in any area are available. Using the estimated number of sheaths per year, the computer compares the annual charges of various numbers of ducts and recommends the number of ducts to be placed. The inside dimension of individual ducts has for many years been 3-1/2 inches, but with the advent of the larger size cables (2700-pair, 26-gauge), the standard duct size is now 4 inches.

D. SPECIAL STRUCTURE DESIGN AND SUBMARINE CROSSINGS

Special structure designs are frequently required to cope with unusual conditions. Provisions for telephone facilities are often included in structural designs of tunnels and bridges. Pipe chases, open cable racks, and cable troughs are used to support cables in tunnels. For bridges, conduits may be placed on racks suspended under the bridges, laid in sidewalk areas, or exposed cables may be suspended from the bridge.

Submarine cables may at times represent an economic choice over other types of structures. They may in certain situations be the only choice. To be economical, initial and subsequent submarine cables must be compatible with the overall outside plant plan. Some of the factors that must be considered in establishing a submarine crossing are the security and accessibility of the landing site and the width, depth, and rate of flow of the water.

15.4 CUSTOMER LOOP PLANT

The service policy of the Bell System as applied to the outside plant is that facilities should be available whenever and wherever a customer requests them. These outside plant facilities must give satisfactory service and they must be placed, administerd, and maintained in the most economical manner. The customer loop portion of outside plant can be divided easily into three components that differ in purpose, design, and utilization. These components are the beginning at the central office, the feeder cable system, and the distribution portion. The design, utilization, and maintenance of these components are examined in subsequent paragraphs.

A. CENTRAL OFFICE

Large size (e.g., 1500, 1800, 2700 pairs, etc.), pulp-insulated conductor cables enter most central offices via underground conduit into a vault. The typical vault is usually a basement room that serves as a splicing chamber. The method of bringing the outside plant cables into the office, the size of the cables, and the arrangement of the vault may vary considerably with the size of the office. The conductors of the cables are splayed and terminated on a protection device at the main distributing frame. This provides the terminating point for all cables entering the office, and the interface between the central office equipment and outside plant facilities is accomplished here. Individual circuits are completed by running a jumper (cross-connection) wire from the cable termination to the central office equipment terminations. Traditionally, the outside plant side of the main frame is designated as the vertical side because of the position of the protector mountings, and the central office side is known as the horizontal side.

Pulp and paper insulations absorb moisture quickly and deteriorate rapidly when wet. To permit the splaying of cable conductors without deterioration of the insulation, terminating (tip) cables are used between the vault and the main frame. Terminating cables used with older types of protector mountings (C50 and C52) are ordered by size and length and are splayed in the field. On newer installations the mountings (300 type) are equipped at the factory with the required cable. Polyvinyl chloride pair insulation is used with terminating cables because of its ability to withstand heat from soldering operations and moisture.

B. FEEDER CABLE

The distribution portion of the customer loop plant is the area where conductors are available for service. A feeder cable is one that connects distribution cables to the central office. Feeder cables are subdivided into main feeder and branch feeder, depending upon the size and ultimate configuration of the cable route. Main feeders are direct backbone routes through major concentrations of service (the trunk of the tree referred to earlier). Branch feeders are minor cables and routes branching from the main feeder routes (the branches of the tree). The large underground feeder cables generally serve densely populated routes in urban areas. At places where service requirements diminish, the underground cables may be spliced to buried or aerial cables. These buried or aerial cables divide and subdivide to serve streets and areas that intersect the main cable run. Hence, the number of pairs in the system diminishes with the distance from the central office. Ultimately, a point may be reached where customers may be served most economically with some form of wire other than cable.

1. Utilization

One objective of the outside plant is that it must meet changing demands of the population growth and distribution. The anticipation of facilities to meet these demands is complicated in the outside plant by the requirement to have these facilities in specific locations. The investment represented in outside plant does not permit an indiscriminate reservation of idle facilities. Consequently, the administration of plant entails the economic utilization of existing facilities in addition to the planning for new facilities. The economic utilization of existing facilities requires a system of records portraying the type and location of these facilities. The facilities must be monitored so that areas of congestion can be anticipated, and an orderly plan for their use, rearrangement, extension, and reinforcement must be kept current at all times. The records system of the outside plant includes a location record, a cable pair record, and a test board record in which the details of every circuit are maintained.

(a) Multiple Design: It is difficult to keep the policy of having facilities available whenever a customer may demand service in perspective with the obligation to administer the existing facilities economically. General demand for service can be anticipated for large areas, and facilities can be provided in appropriate quantities. However, providing for demand for service in specific feeder and branch feeder routes is more difficult. A partial solution to this problem is multipling or bridging of cable facilities. Multipling is a term used in cable plant design to indicate that the same cable pairs are available for use in several locations. The principle of multipling is applicable in feeder route design by using the same cable complements in several branch feeder routes. This provides facilities for service in several areas simultaneously and promotes high pair usage in large feeder cable cross sections. These advantages are valid only when balanced by the following limitations. (1) Multipling is uneconomical in the bridged branches. Bridged pairs can only be used in one branch (party lines excepted) and once used cannot be used in any other (bridged) branch without some rearrangements. This is more important in the feeder plant because of the size of the cables and the length of branch feeders involved. (2) The portion of a multipled circuit not in the direct path of the circuit reduces transmission efficiency. This is a bridged tap and is a particularly important factor in loaded circuits. The amount of multipling in the feeder plant must be a balance of these advantages and limitations. The feeder plant must be well planned and flexible enough to adjust to changes in demands for service.

(b) Justification of New Facilities: The need for new facilities is naturally based upon the current condition of existing facilities. In addition, the justification of new facilities must contain:

(1) A forecast of demand beyond the capabilities of the existing structure involved. A detailed forecast of growth by specific plant areas is prepared annually by the marketing and development forces. Additional forecasts are prepared when requested. The forecast of growth includes an actual count of immediate growth, an estimate of the growth by lines for subsequent years, and an assessment of the economic climate of the community as it will affect new buildings, new service to existing buildings, changes in class of service, etc.

(2) An economic comparison of the various alternative plans available. The costs that are considered in analyzing comparable plans are the first cost, the net salvage, annual costs that include taxes and maintenance, and any nonrecurring expenses.

(3) A plan for the ultimate use of the new facilities. The practical aspect of the economical job must be examined critically. Pair utilization within the discipline of economics and transmission criteria must be planned.

(4) Documentation of a long-term plan for subsequent projects. The average economic study extends beyond 20 years so succeeding plans should be maintained on cable location records.

(c) Feeder Route Analysis: A computer program, the Exchange Feeder Route Analysis Program (EFRAP), is available to assist in the design of outside plant feeder cable systems. Using standard present worth of annual costs (PWAC) study methods, this computer program can study each feeder route problem and identify the timing, cost, and amount of required cable and structure relief. A separate analysis for any plan may be obtained to explore the effect of modified rates of growth, different construction costs, or alternate types of structure. Each problem is analyzed by the computer to determine its economic optimum solution for up to a 30-year maximum study period. The plant is divided into sections for computer study and a section schematic prepared as shown in Figure 15-34.

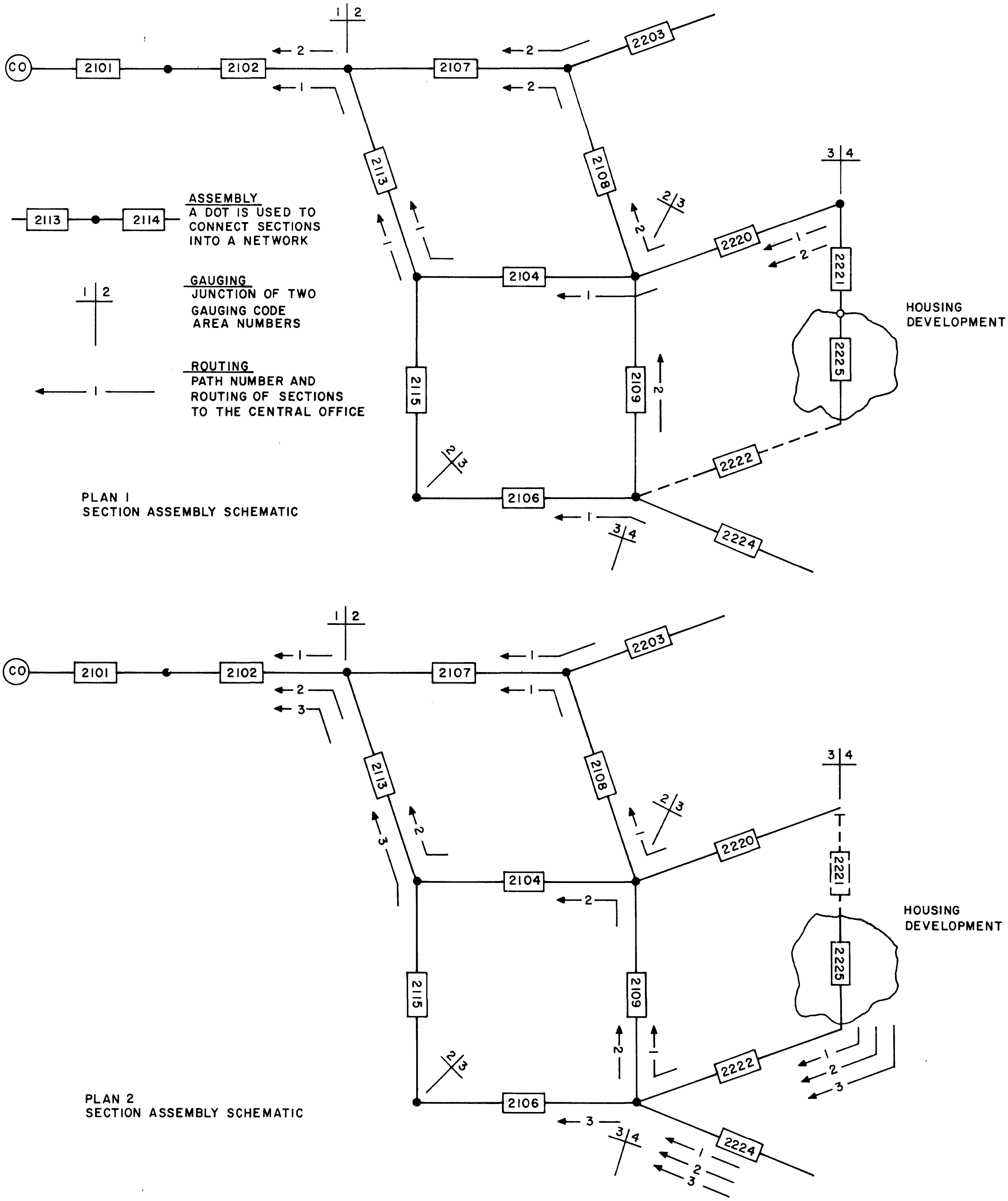


Fig. 15-34 — EFRAP Section Schematic

The input data is divided into three categories: (1) the semipermanent data that is pertinent to all problems within an operating area, (2) transitory data that is unique to the problem at hand, and (3) the instructions to the computer. The semipermanent data consist of costs of placing, removing, and rearranging various items of plant as well as annual cost percentages, maintenance costs, available sizes and gauges of cables, and time-value factors. The transitory data consist of the details of the section, its length, the number of pairs of each gauge available, the number and size of cables, the type of existing structure, and the number of working pairs in the section. The instructions to the computer are specific instructions pertaining to particular sections of plant and general instructions involving the entire study. The instructions in relation to a specific section include the structure proposed for that section, the percentage of cable pairs in use at which the computer should design relief, and the estimated growth in lines for the study period. The instructions of a general nature involve assembling the various sections into paths that constitute the feeder route. The computer checks each section to determine if sufficient pairs are available in the correct gauge or in a coarser gauge to meet the demand. Whenever a shortage is found, one or more studies are automatically made to recommend relief measures. The computer determines an optimum solution and signifies this on the output. It recommends a specific month when the new facilities should be placed and, assuming they are placed, calculates annual charges from that date. A summary of all the decisions reached by the computer, the costs involved with those decisions, and the cumulative total of all the costs is printed at the end of each study.

(d) Multiplexers: In telephone systems, the customer's telephone instrument has always been connected to the central switching point over individual paths (except in the case of party lines). Since 1908 and probably earlier, development engineers have been trying to devise a method of utilizing the accepted principle of concentration and expansion to reduce the number of paths required between the switching point and the customer without affecting service. The principle of concentration and expansion, i.e., multiplexing, forms the basis of all switching systems. Not until recently (1960) has the state of the art advanced to the point where such multiplexing could be designed to be practical and economically attractive as compared with individual metallic conductors between the customer's premises and the central office.

A multiplexing device or multiplexer refers to any device which provides for a number of telephones to share a smaller number of cable pairs between it and the central office. A multiplexer system consists of a concentration unit remote from the central office and expander unit located at the central office. Multiplexers include not only the family of line concentrators currently in use but also the customer loop carrier systems under development.

Temporary use of multiplexers in the outside plant is economical in areas where deferment of cable reinforcement is desirable or necessary because of slow, unpredictable, or unstable growth, because of seasonable fluctuation in the demand for service, or where large capital expenditures can be deferred. The length of time that cable reinforcement can be deferred depends on the relative annual charge rates of cable and whatever multiplexer arrangements are substituted, as well as the length of time before cable reinforcement becomes absolutely necessary. The recent trend toward higher investment per line for outside plant than for central office equipment tends to make multiplexer installations more attractive than they would have been several years ago.

Multiplexers can also be used economically on a permanent basis where the distance from the central office is such that annual charges for cable facilities are greater than annual charges for facilities developed through the application of multiplexers.

In areas where customers are located beyond the normal operating range of the central office, it is customary to use long line circuits. It is obvious that whenever there is a concentration of such customers sufficient to load a multiplexer, savings in long line equipment could be realized if it could be connected into the multiplexer trunks instead of being provided on a per-line basis.

C. DISTRIBUTION FACILITIES

The distribution portion of the customer loop plant is the area where facilities are available for connecting service. In the analogy of the tree, distribution facilities are the small branches. Distribution facilities may be individual cables or cable pairs within feeder cables. Facilities used for distribution generally have the following characteristics:

(1) They are designed to serve a small, well defined geographical area. This area may be a single street, a city block, a portion of a street, or a building.

(2) They are designed to provide adequate facilities within each area for an indefinite period.

(3) They are relatively small (under 200 pairs) and permanent.

(4) They are generally of fine gauge. Distribution cables less than 1500 feet in length will be 26-gauge.

1. Aerial Distribution - Urban and Nonurban

The design of aerial distribution cables in urban areas is simplified by the fact that the saturation of the area to be served by the cable is reached within the capability of the cable. Therefore, cable sizes can be based upon the number of living units that will ultimately be within the area. In urban areas the regularity of lot sizes and the homogeneity of areas permit a more accurate estimate of the ultimate number of housing units. Generally, one and one-half cable pairs are provided in aerial cables for every living unit to be served. This provides a satisfactory margin of facilities for additional service. The area to be served by specific distribution facilities can be easily regulated to conform to the standard cable units of 50 or 100 pairs.

The design of aerial distribution facilities in slow growing, sparsely populated nonurban areas is more difficult. The saturation of nonurban areas generally extends beyond the capability of a single cable. Therefore, a series of cables must be planned for the ultimate service to the area, and the size of the cables must be an economic selection based upon the anticipated rate of growth. The degree of difficulty in placing subsequent cables and the rearrangement costs must be considered in the economic selection. The area to be served by distribution facilities in nonurban areas will change as the area approaches saturation, and because of bridged tap and loading limitations, the facilities will frequently be in units as small as five and ten pairs.

Before the introduction of PIC cables, distribution cables had pulp or paper conductor insulation, and hermetically sealed terminals to make cable pairs available for use at a customer's location were required. Early terminals consisted of binding posts embedded in a ceramic faceplate and connected to a paper- or pulp-insulated, lead-sheathed cable stub. These terminals are known as fixed count terminals in that wires of the terminal stub are spliced directly to pairs in the distribution cable and the splice enclosed in a sealed sleeve. Installation, removal of terminals, or rearrangement of cable pairs within the terminal required a splicing operation. Installation of customer service required connecting a drop wire between the binding post of the terminal and the customer's premises.

The introduction of PIC cables eliminated the need for hermetically sealed terminals, and the color coding available with the plastic insulation permitted quick physical identification of all cable pairs. Terminals with PIC cables are known as ready-access terminals in that the cable sheath is removed and the opening covered with a rubber boot so that all cable pairs are accessible to craftsmen. Installation of a customer service is made by the craftsman, who identifies his assigned cable pair by color and connects the drop wire to that pair by using a small connecting block. The installation or rearrangement of cable pairs within a ready-access terminal does not require electrical identification of the cable pairs and consequently may be accomplished by most craftsmen.

The principles of multipling as explained under feeder cable design are applicable in distribution facility design. High party-line development, the low percentage of living units with service, the relative inflexibility of pulp-type cable, and the difficulty of correctly forecasting line demand led originally to a highly multipled form of distribution plant. The smaller sizes, the shorter lengths of distribution cables, and the comparative ease of making rearrangements in aerial cables tended to mitigate the penalties of too many multiples.

In recent years these factors have undergone radical changes. Demand for party-line service has been decreasing steadily. As a result of this trend, bridging of party-line customers in the field is becoming more difficult and the need for a cable pair per main station in the present plant is rapidly approaching. The percentage of households with service has been rising steadily. In most new developments one hundred percent usage is frequently forecast. Color-coded PIC distribution cable and ready-access terminals are now being used in lieu of pulp cable and hermetically sealed terminals. All pairs within a distribution cable are therefore available for use at every terminal location. Terminal multipling is no longer necessary, and the flexibility of the distribution portion of the network is greatly increased. Outside plant forecasts of lines should improve as a result of the decrease in party-line demand and the increase in the number of households with service.

2. Buried Distribution Cables

The basic design principles of distribution cable systems as discussed previously are applicable to buried distribution cable systems. Compared with aerial distribution cables, buried cables are inaccessible and are difficult and expensive to relieve. For these reasons additional margins are provided initially in the design of buried cables to reduce these difficulties. The design of buried distribution cables closely parallels the design of aerial distribution cables except that two pairs for each living unit are provided in buried cables, and the service design period of these cables is increased to a minimum of 20 years. The trenching and plowing techniques and machinery described for buried feeder cables are used for buried distribution cables.

Buried distribution cables in urban areas are usually installed coincidentally with the extension of other utilities into newly developed areas. The cables are generally placed within utility easements along rear property lines or within the public right-of-way. The placing of buried distribution facilities in nonurban areas is simplified by the lack of paving and the absence of other subsurface utilities. Maximum use of plowing techniques can be made because of the distances between service locations. However, municipal control of road shoulders and drainage ditches frequently forces the use of more inaccessible portions of the right-of-way.

Distribution terminals for a buried cable system consist mainly of physical devices to support a vertical loop in the distribution cable. These terminals are either a ready-access type with a pedestal above the ground (Figure 15-35), a ready-access type with a flush-with-the-ground closure (Figure 15-36), or an encapsulated type where house service wires are connected directly to the cable pair and the entire splice is hermetically sealed (Figure 15-37). Continuous research has reduced the size and silhouette of buried cable terminals. Special pedestals to house protectors, load coils, branch splices, and access and control points have been developed.

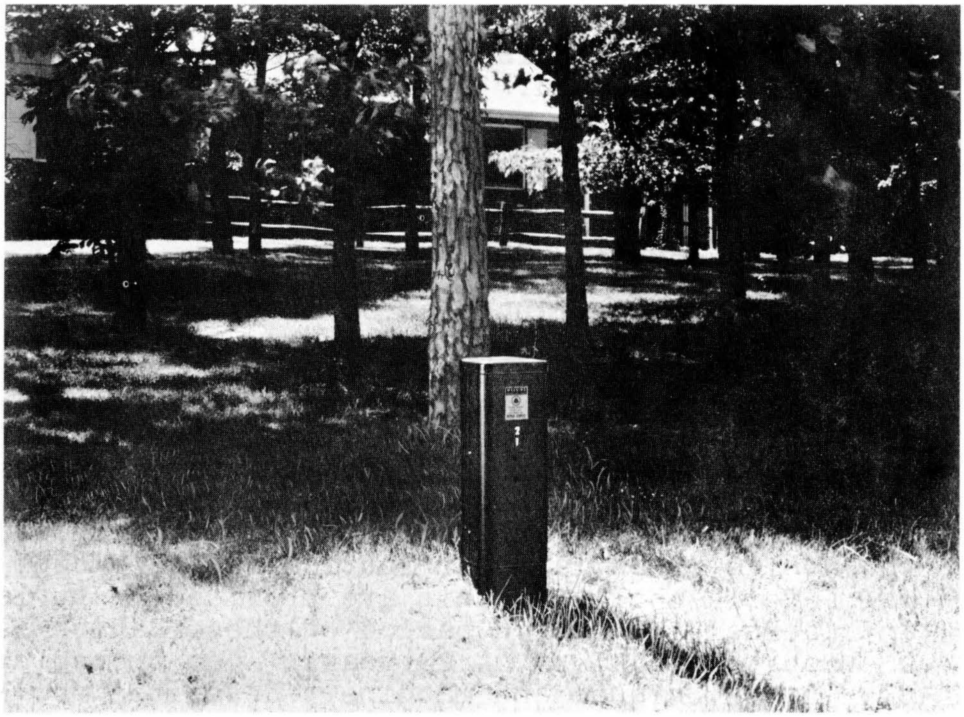


Fig. 15-35 — Aboveground Buried Cable Closure

An important adjunct to the design of distribution cables is that the additional pairs provided for anticipated second-line growth cannot economically be extended into the feeder cable system. Some form of interface between the additional pairs and the feeder system must be provided. This interface can be accomplished in a cross-connecting terminal or in dedicated plant areas by the use of control or access points.

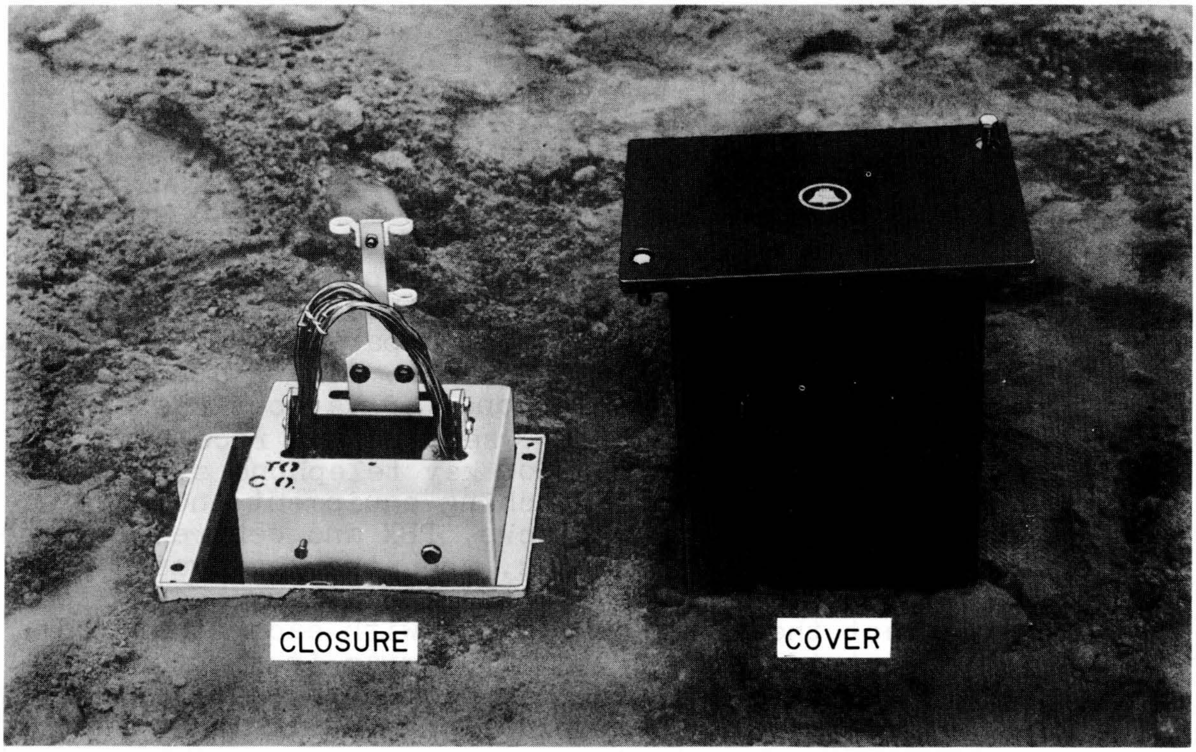


Fig. 15-36 — Flush-with-the-Ground Buried Cable Closure

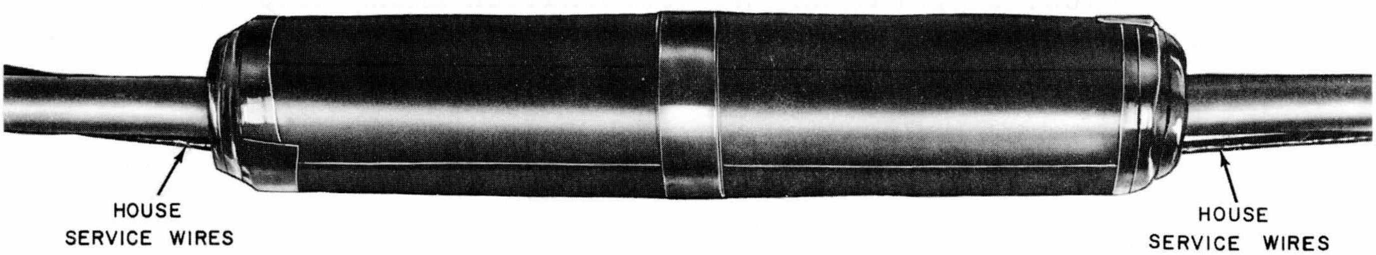


Fig. 15-37 — Encapsulated-Type Buried Cable Closure

3. Distribution Within Buildings

An important part of the distribution portion of outside plant is the telephone facilities within private buildings. The changeable nature of commercial buildings, the high concentration of service, and the frequency of special service equipment and lines make the design of building cable unique. Although cable systems in different types of buildings may vary in extent and in many details of design, there are three basic components of any system, i.e., the station apparatus, the switching equipment, and the cables and wires. The station apparatus broadly includes telephones of various kinds, teletypewriters, DATA-PHONE® senders and receivers, the relay circuitry needed for key telephone systems, and other devices. The switching equipment includes power plants, connecting blocks, PBX and centrex switches, switchboards, centrex consoles, and other hardware. The cables and wires include all the facilities needed to interconnect the other components with each other and with the outside network. The diagram in Figure 15-38 portrays the interrelationship of the three basic elements of in-building communications facilities. The concept is for a typical key telephone system. The way the components shown in Figure 15-38 may be defined in terms of an actual building is shown in Figure 15-39. The insets to the right are common examples of the utilization of available area for the installation of behind-the-scenes equipment and the provision for its interconnection with station equipment. The design of efficient, economical in-building facilities requires close cooperation and coordination among telephone personnel, the architect, and the owner of the building.

D. DEDICATED OUTSIDE PLANT

Dedicated outside plant is a method of designing and administering the local customer cable network. The Dedicated Plant Plan provides for the permanent assignment of a cable pair from the central office main frame to a residential or business location without key telephones, regardless of the class of service. Once a cable pair is dedicated, it will remain permanently assigned to the same address whether the service is working or not.

1. Definitions

A glossary of new terms has been introduced with dedicated plant. Some of the more important terms are defined and explained as follows:

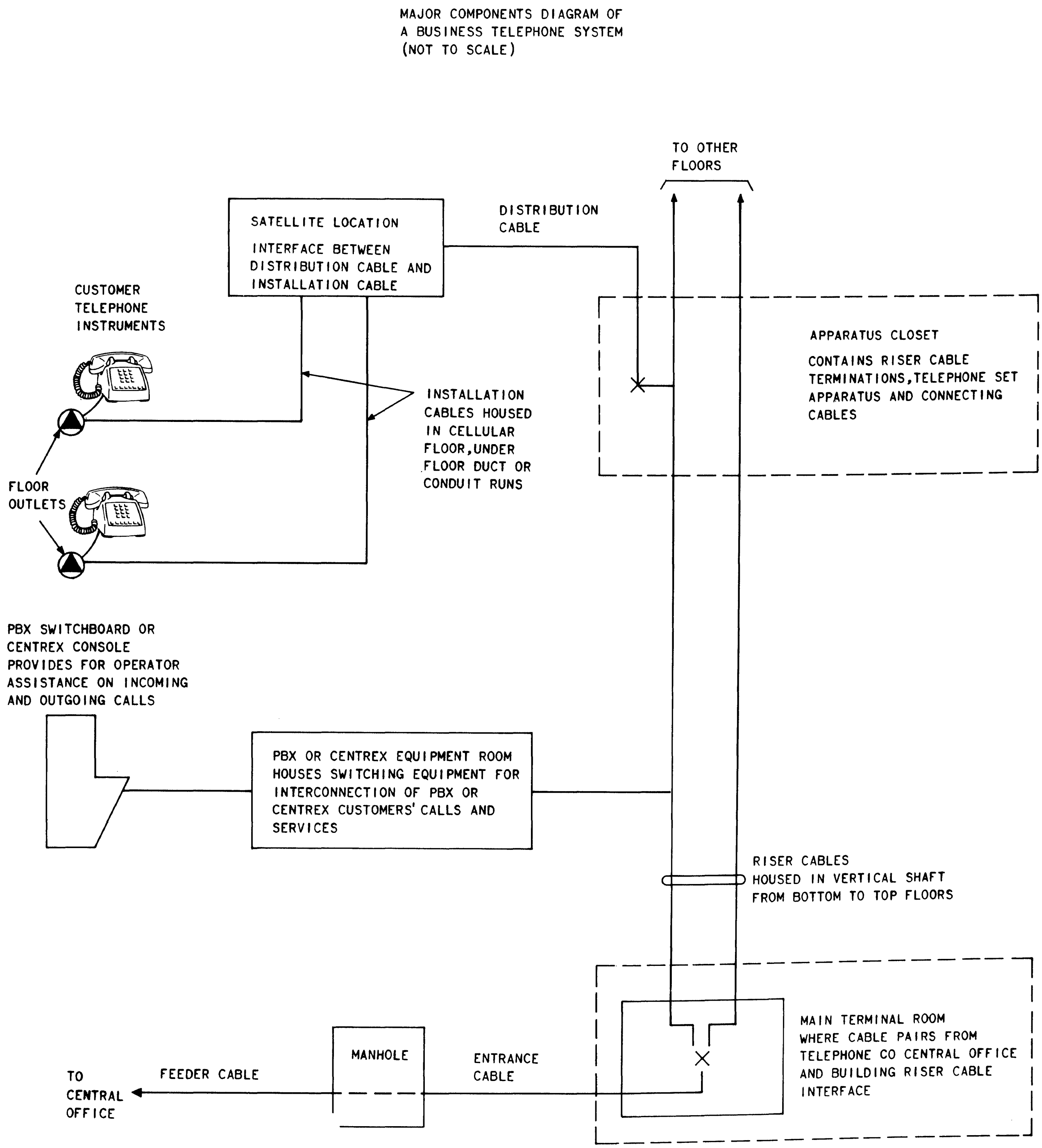
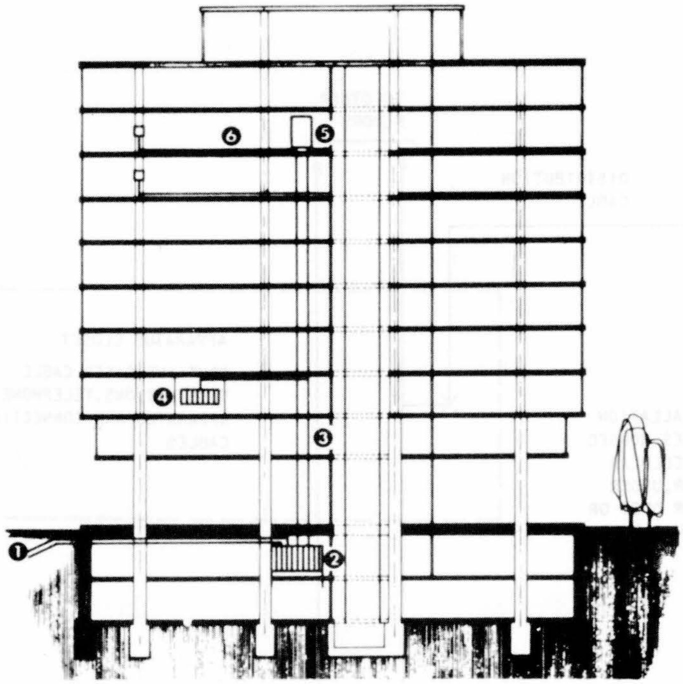


Fig. 15-38 – Interrelationship of Basic Elements of
In-Building Communications Facilities



① *SERVICE ENTRANCE. This is the point where telephone lines or cables cross the property line and enter the building.*

② *MAIN TERMINAL ROOM. The interface of incoming cables and the in-building cables is located in space defined as the main terminal room.*

③ *CABLE RISER SYSTEM. This space is used for vertical distribution of in-building cables from the main terminal room to the floors above. In some buildings, where large horizontal areas with few floors exist, this major cable artery is primarily distributed laterally.*

④ *EQUIPMENT ROOM. Many buildings, particularly those equipped with PBX or centrex service, require special space for its switching equipment.*

⑤ *APPARATUS AND SATELLITE LOCATIONS. These locations are found in closets, wall-mounted cabinets or both, strategically placed on each floor of the building. They contain terminals for cross-connection of riser cables and those distributed throughout floors for ultimate termination to station apparatus. Apparatus closet locations also contain relay circuitry and power equipment to operate station apparatus*

⑥ *UNDERFLOOR DISTRIBUTION FACILITIES. These facilities distribute cables laterally from apparatus and satellite locations to station apparatus located on each floor. Included in this space consideration are the service fittings where cables emerge from the floor at specific station apparatus locations.*

Fig. 15-39 — Utilization of Building Space

(a) Control Point: A point in the outside plant network where administrative control of spare facilities is exercised to achieve the most efficient and economical utilization of these facilities. At a control point spare facilities are administered (1) according to a preconceived plan, (2) as directed by forecast growth, and (3) to satisfy transmission requirements. Most frequently, control points are instituted at the junction of main and branch feeder cables and/or at junctions of branch feeder cables. They may be introduced into either new or existing cable plant. Physically, a control point is a closure (the exact type depends upon the number and size of cables involved) where all pairs are identified by color-coded PIC cables. A record of the pairs available in the control point is maintained in engineering records, and all pair connections are made under engineering work orders.

(b) Access Point: A point in the distribution cable network where spare facilities in the feeder cables are connected to distribution cable pairs. Access points may be introduced into either new or existing cable plant. As new service in distribution cables is required, pair connections through the access point are made by the craftsman installing the service. After the access point has been placed, it is under the administrative control of the plant service center, and a record of pairs available and pairs connected is maintained on the Exchange Customer Cable Record.

(c) "In" Cable or Terminating Cable: A cable entering a control or access point from the direction of the central office. Pairs in such cables are referred to as "in" or "terminating" pairs.

(d) "Out" Cable or Originating Cable: A cable leaving a central office, control point, or access point. Pairs in such cables are referred to as "out" or "originating" pairs and assume a new identity at each originating location (see Figure 15-39, 110B Birch control point).

(e) Cable PIC Sheath Count: The sheath count of the PIC cable is the pair count of all pairs in the cable starting with pair one in the center.

(f) Continuous PIC Sheath Count: The continuous PIC sheath count is a pair count assigned to all of the "in" and "out" cable pairs appearing in a control (or access) point closure and in the associated splice. A consecutive pair count starting with pair one will be assigned to all of the "in" cable pairs regardless of the number of cable sheaths involved. The "out" cable pairs will be treated in an identical manner starting with pair one. The binder groups of the cables will also be continuous to correspond to these pair counts. By this technique each control (or access) point will appear to have only one "in" cable and one "out" cable, thus facilitating pair identification. Continuous PIC sheath count is illustrated in Figure 15-40.

(g) Dedicated Pair: A cable pair which has been permanently assigned to a living unit or nonkey telephone business location.

(h) Nondedicated Pair: A working pair not permanently assigned to a living unit or nonkey telephone business location. Nondedicated pairs rendered idle through disconnection are available for reassignment of all classes of service.

(i) Idle Assigned Pair: A dedicated cable pair that is temporarily not working due to disconnection of service at a dedicated location. Idle assigned pairs are not available for reassignment.

(j) Allocation Area: A geographic area containing the maximum number of branch feeder and direct distribution legs consistent with bridged tap limitations and loading considerations so as to make common spare pairs available to the greatest practical number of cable legs.

(k) Allocated Pair: A spare cable pair that is reserved for a specific allocation area.

(l) Committed Pair: An allocated spare pair that has been spliced through a control point for use in a specific branch feeder cable.

2. Dedicated Plant Plan

Generally, distribution cables are sized to contain a minimum of one pair for each existing or anticipated living unit plus additional pairs for second lines. Under the Dedicated Plant Plan all pairs currently in service will remain permanently connected (dedicated)

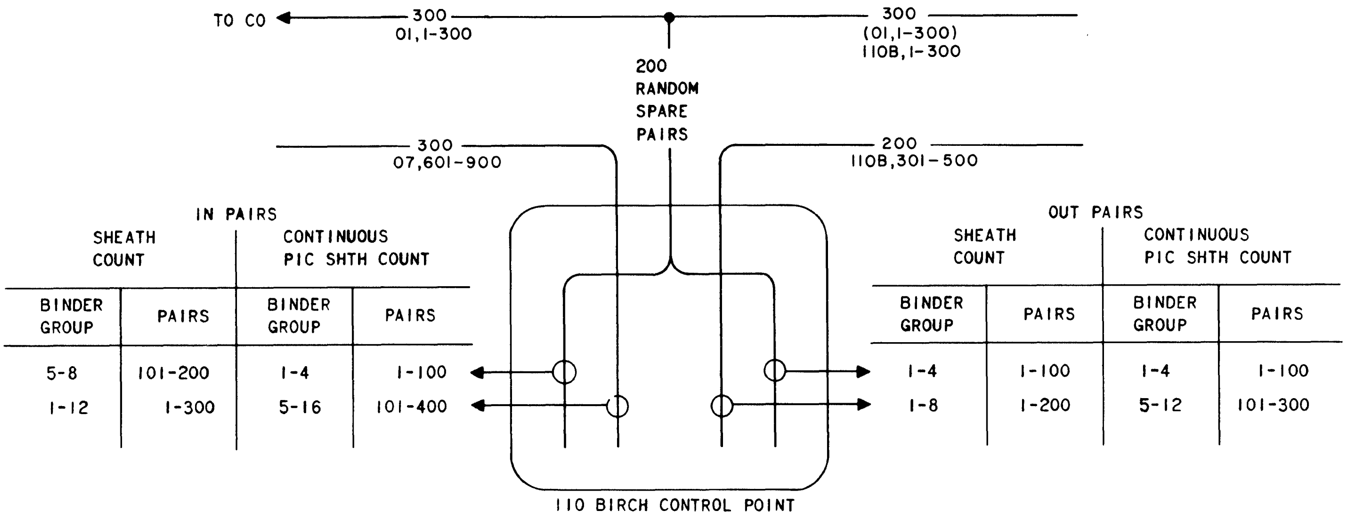


Fig. 15-40 — Continuous PIC Sheath Count

between the main frame and the address where the service is working. As service is required in vacant or "nonuser" living units, the pairs providing that service will be connected and dedicated. Thus, within a period of time every living unit will have its specific individual pair.

One concept of the Dedicated Plant Plan is that the pairs provided in distribution cables for anticipated service should be available for use where needed without rearrangement of working pairs. Parallel to this, the spare pair concept of the plan states that feeder facilities should also be available for use where needed without rearrangement of working pairs. The former concept is accomplished by the use of control and access points that provide terminating points for pairs provided for growth.

Under the the spare pair concept, the spare pairs in a cable route are apportioned to allocation areas predicated upon the ratio of growth in a specific area to the forecasted total growth in the route. When feeder cable complements are allocated and committed to a branch feeder, they are cut dead in the main cable beyond the point at which they are used. Pairs provided for future use in laterals or branch feeder "in" cables are left unspliced at the junction of the main feeders until required by service demand. Figure 15-41 is a schematic representation of the main concepts of the Dedicated Plant Plan.

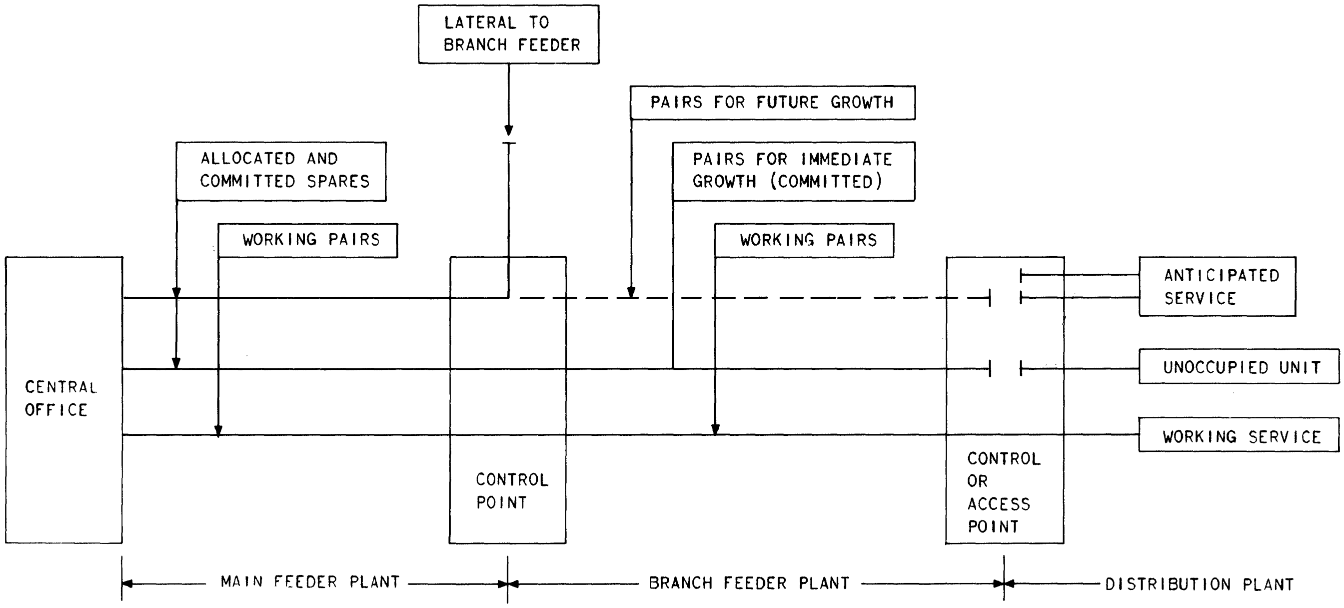


Fig. 15-41 — Dedicated Plant Plan Schematic

E. TRANSMISSION

As previously stated, outside plant provides the physical paths over which communication signals are propagated. How well these signals are propagated is covered in the overall heading of transmission. The transmission objective of the Bell System is that every customer should have good transmission regardless of the extent of a call. To achieve this objective, each segment of the connection, i.e., the customer loop, the central office and switching equipment, and the trunk and toll plant, is assigned transmission tolerances that cannot be exceeded. The transmission tolerances and the design of toll and trunk plant are covered in Section 15.5. Currently, there are three basic designs that meet the transmission objectives assigned to the customer loop plant. These are: resistance design, Unigauge design, and long route design.

1. Resistance Design

The design of the customer loop, i.e., the wire path from the central office to the customer's instrument, must conform to the prescribed transmission tolerances. A simplified method of designing customer loops is based upon establishing a resistance limit for each central office and applying a few simple rules to control the transmission losses. Consistent application of the resistance design method will yield a distribution of loop losses that will result in satisfactory transmission for all customers. Four variable factors control the total transmission characteristics of the customer loop.

(a) Gauge of Conductors: The gauge of the customer loop is determined by selecting the gauge or combination of gauges so that the resistance to the ultimate cable termination will not exceed the office design limit. For economic reasons, maximum use should be made of the finest gauges and these fine gauges, hence the largest cables, should normally be placed adjacent to the office. Figure 15-42 is a schematic representation of the

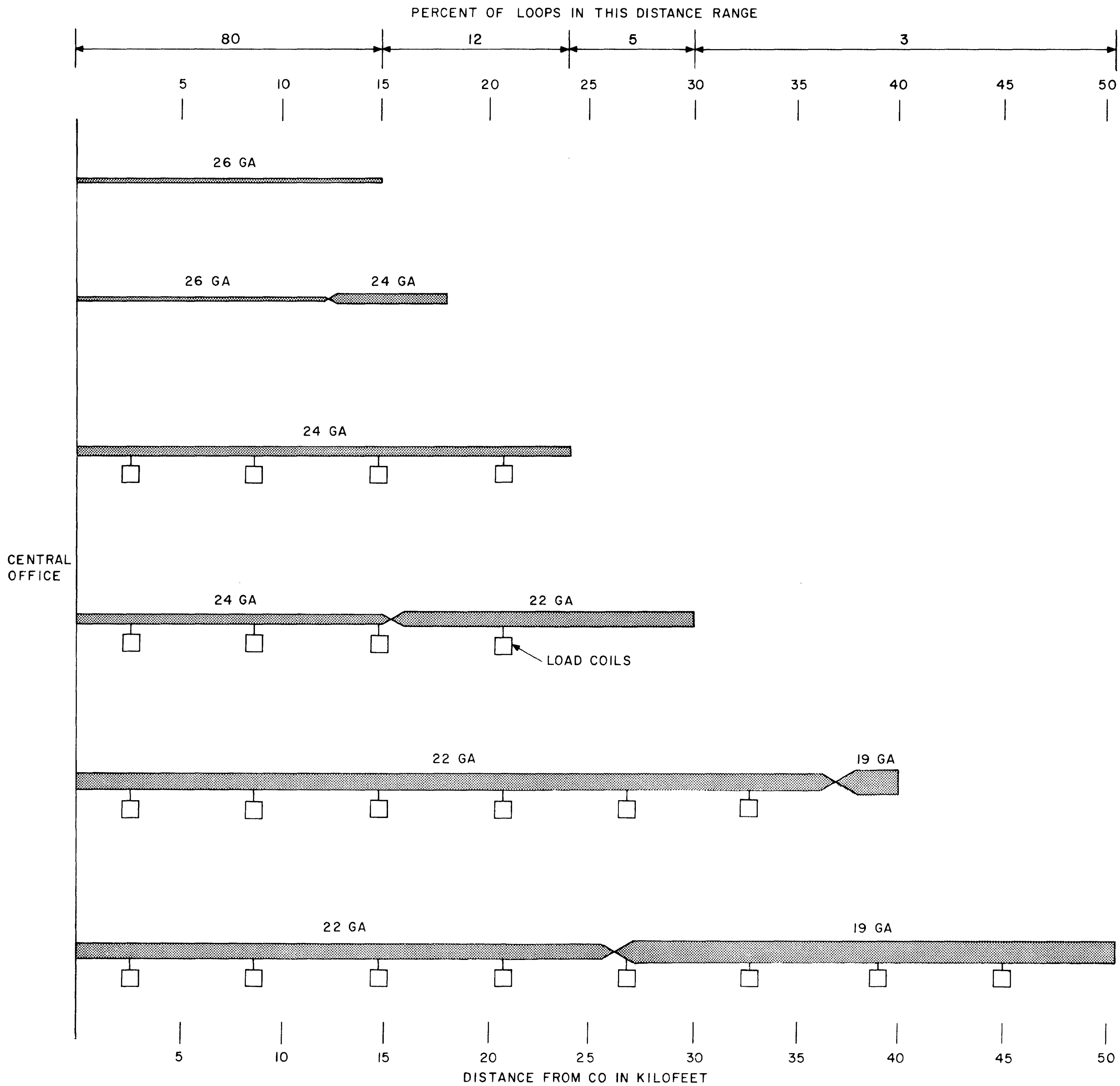


Fig. 15-42 — Cable Plant Gauge Composition Resistance Design resistance design method of controlling transmission losses. The weight of a line is synonymous with the copper content of the conductors used.

(b) Bridged Tap: A bridged tap is any portion of the cable pair that is not in the direct current path between the central office and the customer's telephone. It results from multiple appearances of the cable pair due to branches or from its extension beyond the point where the customer is connected. Bridged taps add capacitance to the line, causing greater attenuation of the voice signal, particularly at the higher voice frequencies.

(c) Loading: The transmission loss characteristic of cable increases as the square root of the frequency, and on longer lengths of cable, this higher attenuation in the upper range of the voice-frequency band seriously impairs the quality of voice transmission. This rising loss characteristic with frequency is primarily due to the distributed capacitance of the cable pair. Loading (inductance added at regular intervals) will equalize this and produce a relatively constant loss over the entire voiceband. The major benefit of loading is in the higher voice frequencies; however, there will be some decrease in loss in almost all of the frequencies of the voiceband. The standard loading plan for voice-frequency pairs used in the Bell System is H88. This consists of 88-millihenry load coils placed at intervals of 6000 feet along the cable pair. The first load coil from the central office is the most critical as far as spacing is concerned. This distance (cable end section) should be such that when the allowance for office wiring is added, the combination will be equivalent to 3000 feet of cable. Multiple branches of cable pairs are sometimes necessary, and the bridged tap resulting from these branches has relatively the same effect on transmission as a longer end section. A combination of these two is used in setting the limits at the customer's end of a loaded cable. The recommended minimum distance between the last load coil and any station is a combination of end section and bridged tap totaling at least 3000 feet. Less than 3000 feet of cable or equivalent may cause abnormally high sidetone.

(d) Stations (Telephone Sets): The provision of the proper telephone set is a vital part of resistance design. Transmission zones are established to designate where the 500-type set can be used and where other sets are permissible.

2. Unigauge Design

The Unigauge design system is available under specific conditions as an alternative to resistance design. The Unigauge system employs electronic equipment to maintain standard transmission while reducing the amount of copper required in the subscriber loop. This design system employs the use of a unique range extender with No. 5 crossbar switching machines to permit the use of all 26-gauge cable facilities in outside plant loops that are less than 30 kilofeet from the central office. This system extends the maximum loop resistance range of the central office from 1300 ohms permitted with resistance design to 2500 ohms. The additional transmission and signaling range is obtained through the use of range extension equipment which includes a Unigauge repeater at the central office. The Unigauge range extender provides increased tripping, pulsing, and talking voltage (72 volts) and about 6-dB gain at midband voice frequency. Unigauge loop design is intended to be applied to customer loops within 30 kilofeet of their serving office and to use all 26-gauge facilities. The customer loops can be divided into four main groups (Figure 15-43).

(a) The loops within 15 kilofeet of their central office are designed with all 26-gauge nonloaded cable and are associated with the standard 48-volt central office battery. This design is identical to resistance design. Loops in this area are designated as short loops.

(b) Loops between 15 and 24 kilofeet from the central office are part of the Unigauge loops and are also designed with all 26-gauge nonloaded facilities. These loops have a resistance in excess of 1300 ohms, and their transmission and signaling losses are greater than those permitted with resistance design. These loops require the addition of a Unigauge range extender at the central office.

(c) Loops between 24 and 30 kilofeet from the central office are also part of the Unigauge loop category and are designed with all 26-gauge facilities; however, these loops require more transmission gain than can be provided by the range extender circuit at the central office. Consequently, these loops are loaded with H88 loading, with the first load point located 15 kilofeet from the central office.

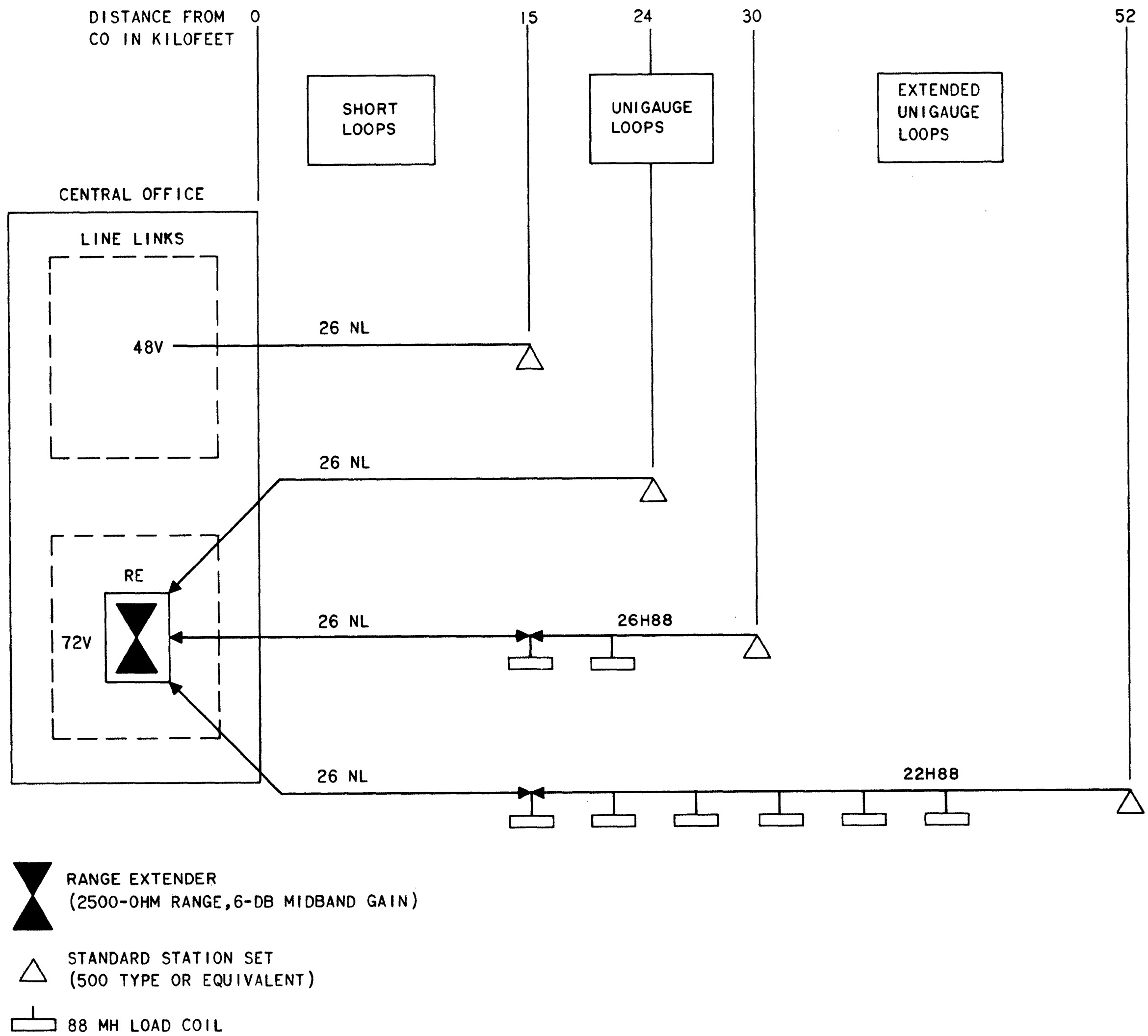


Fig. 15-43 — Unigauge Loop Plant Layout

(d) Thirty kilofeet is the limit of strictly Unigauge loop plant, i.e., plant constructed with only 26-gauge cable. Many of the Unigauge features may be applied to most loops that are more than 30 kilofeet from the central office. These extended Unigauge loops are treated with standard Unigauge equipment. They are designed with the 15 kilofeet adjacent to the office as 26-gauge nonloaded cable, and the remaining loop as 22-gauge cable with H88 loading. The first load point for all loaded Unigauge design loops is 15 kilofeet from the office.

All customer loops that require a range extender circuit in the central office have 15 kilofeet of 26-gauge nonloaded cable adjacent to the central office. The impedance provided by the 26-gauge permits a single nonadjustable repeater to be used in all repeatered loops. This also permits the range extender circuits to be placed within the switching equipment and switched in as required, thus allowing concentration of range extension devices. The range extender is inserted between the primary and the secondary stages of the line link frame. Customer lines that require range extenders are concentrated on horizontal groups that are equipped for Unigauge operation.

3. <u>Long Route Design</u>

The second alternative to resistance design, i.e., long route design, has a more specific application than Unigauge design. Long route design techniques are applied to slowly growing areas where considerable amounts of coarse gauge cables would be required to meet standard transmission criteria. Long routes are not defined with specific boundaries but are characterized by the economic feasibility of providing standard transmission through the use of electronic equipment rather than coarse gauge cable. Currently, a limit of 3600 ohms is imposed, and electronics used in conjunction with all 19-gauge cable facilities could provide for loops up to 203 kilofeet (38 miles) from the central office. The electronic equipment used includes 1A range extenders, 96-volt dial long line equipment, E6 repeaters in the central office, and E6 repeaters located remotely from the central office. The type of equipment, the combinations of equipment, and the combinations of equipment and cable gauge to be used are matters of economic selection from the various design possibilities.

4. Special Circuit Design

Special service circuits, such as data transmission lines, tielines between PBX's, off-premises extensions that may be switched to other facilities, broadcast lines, etc., frequently require outside plant designs that exceed the normal design parameters. Many of these circuits demand total resistance limits that are less than standard customer loop limits and bridged tap and loading restrictions that are more exact than those permitted on standard loops. Frequently, these circuits demand some form of amplification either in the form of repeaters on the line or as equipment at either or both ends of the loop.

F. PROTECTION

The currents and voltages used in the operation of the telephone system are not generally considered to be dangerous to persons, property, or apparatus. The dielectric strength and current-carrying capacity of the equipment and plant are more than adequate for handling the operating currents and voltages. When necessary, current-limiting resistors or fuses are provided for holding the current within safe limits or for interrupting abnormal current in the event of faults. When high voltage is used, as in coaxial cable operation, special protective measures are employed.

The major portion of the outside plant may be exposed to lightning, abnormal induction from power circuits, and accidental contact with power wires. Therefore it is necessary to provide protective devices whenever exposed conductors enter a customer's station or a central office building. Protective devices are designed to provide the highest practical degree of protection to persons, equipment, and property. The devices employed in telephone plant have two major purposes: to limit the impressed voltage and to limit the duration of high current flow. The general applications of protective devices are shown in Figure 15-44.

1. Customer Protection

The principal protective device used in telephone plant is a carbon block protector, which consists basically of two carbon block electrodes separated by an air gap. The air gap is varied according to the voltage of the power circuits involved and/or the frequency of lightning occurrence. The carbon block protector is installed at the customer's premises whenever the customer's line is exposed. When the line is exposed to voltages exceeding 2900 volts to ground, additional fuses or protector blocks capable of discharging higher voltages and currents must be used. Customer buildings that contain multiple living units or commercial offices can be

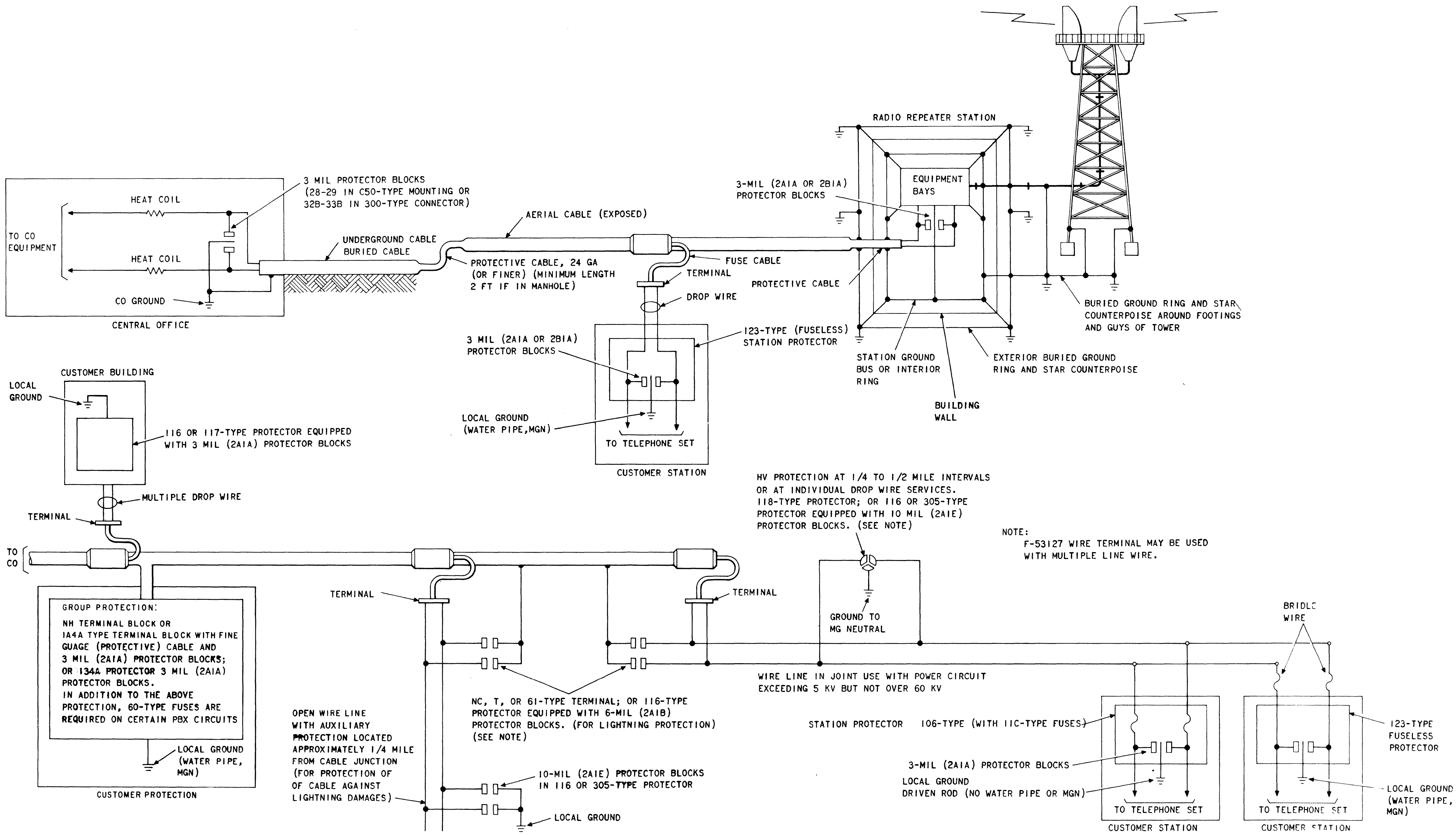


Fig. 15-44 — General Applications of Protective Devices protected by cable or wire terminals that contain group protectors. The basic 3-mil carbon block protector is used in these terminals.

2. Equipment Protection

Protection for central office and large PBX equipment from the voltages of lightning and power crosses is provided by a 3-mil carbon block protector similar to customer station protectors. Frequently, foreign voltages not high enough to operate protection blocks appear on the telephone plant, and the central office or PBX equipment may provide the only path to ground. If these small currents are allowed to continue, they may overheat the equipment or associated wiring and create a fire hazard. Two devices, a heat coil and a 60-type fuse, are used for protection against these currents. In the heat coil the heat produced by the current softens a solder plug and a pin moves to ground the circuit. The grounding feature also provides a permanent line signal to indicate trouble. The 60-type fuse, when operated, opens the circuit. Additional protection for central office and large PBX equipment is provided by a section of fine gauge cable (24-gauge or finer) placed in series with the entrance cable. The individual protector mountings on the main frame can safely carry currents up to the fusing point of 24-gauge cable. If the foreign current exceeds this value, the fine gauge (protective) cable will fuse, thus distributing the current through all conductors of the cable.

3. Protection of Outside Plant

General protection is required in outside plant to protect the plant itself from damage by foreign voltages and from moisture.

(a) Electrical Protection: The objective to be achieved in protecting the outside plant from foreign voltages involves limiting the extent of the current flow and providing suitable paths to ground to dissipate the current. The best defense against accidental contact between power and telephone wires is sound structural practice. This involves coordinated planning and adherence to accepted grades of construction and standard clearance requirements. Foreign voltages impressed on aerial cables are usually dissipated through the extent of the network and the numerous paths to ground present in aerial plant. Although not directly exposed to foreign voltages, the fine gauge underground cables must be protected from voltages impressed on the connecting aerial plant. A fine gauge (24-gauge or finer) protective cable is installed in series at the junction of aerial and underground or buried plant. This protective cable performs the same function as protective cables at central office or PBX entrances.

Great care is exercised in outside plant to maintain all telephone plant at ground potential and to ensure that there is no difference in potential between telephone and power grounds. Aerial and underground cable sheaths, strand, and uninsulated guy wires are bonded together and in aerial plant are frequently bonded to power multigrounded neutrals. Whenever possible, station and equipment protectors use a common ground with power.

Open wire creates special protection problems because of its excellent transmission characteristics and because the areas in which open wire is placed frequently have a high incidence of lightning. Six-mil carbon protector blocks are installed at the junction of open wire and aerial or buried cables. Other protective devices are placed at intervals along the line to limit the hazard of induced voltages or lightning.

(b) <u>Moisture Protection</u>: Early in the development of cable, the effect of moisture on paper-insulated conductor cable was recognized as a major maintenance problem. Moisture enters cables through openings in the sheath. In many instances no conductor trouble is experienced when an opening develops nor will any be experienced unless moisture enters through the opening and penetrates to the conductors. The idea of making the cables gastight and maintaining them under continuous internal pressure was conceived, and a plan was generated to provide some form of mechanical device which could be connected permanently to the cable and so arranged that a decrease of pressure would operate an electrical alarm. Three pressure testing systems were initially developed for maintenance purposes and, because of the concentration of circuits, initial systems were installed on trunk and toll plant.

Flash Testing: Flash testing is the application on a periodic basis of a soap test to make a quick check of the gastightness of accessible portions of cable plant that are most likely to leak. It requires very little preparatory work since gas is admitted merely to build up pressure temporarily and locally for testing purposes.

Continuous Pressure Without Alarms: Continuous pressure systems require considerable preparation. Gas plugs are installed at the end of the main cable as well as in all branches, and valves for testing purposes are installed about every 3000 feet. Gas sections are preferably at least 35,000 feet in length, particularly where cable of low pneumatic resistance is involved. A typical continuous pressure layout is shown in Figure 15-45. A reservoir consisting of one or more cylinders of gas is connected to the cable, preferably in the cable vault of an attended office where it is convenient for inspection. As the system is charged and leaks located and corrected, satisfactory cable pressure is attained at the distant end of the cable.

Continuous Pressure with Alarm: Continuous pressure systems are more effective when means are provided to give automatic indication of dangerous decreases in cable pressure. This is accomplished by equipping the cable with one or more pressure contactors connected to an alarm circuit in an office by means of a pair of conductors, usually in the cable involved. When the pressure at the contactor point falls below the operating value to which the contactor is adjusted, the latter short circuits the pair and operates visual and audible alarms in the maintenance or alarm center. Leak location in a continuous pressure system consists of taking pressure readings at the series of valves and plotting the pressure gradient until the point of least pressure is determined.

The introduction of the air compressor-dehydrators produced a source of continuous dry air under controlled pressure and expanded the capabilities of continuous air pressure systems. The maintenance advantages of air pressure were extended to customer loop plant. The amount of work to prepare this complex network of cables for air pressure was considerable. Pressure contactors used to monitor the gas pressure consist essentially of an electrical

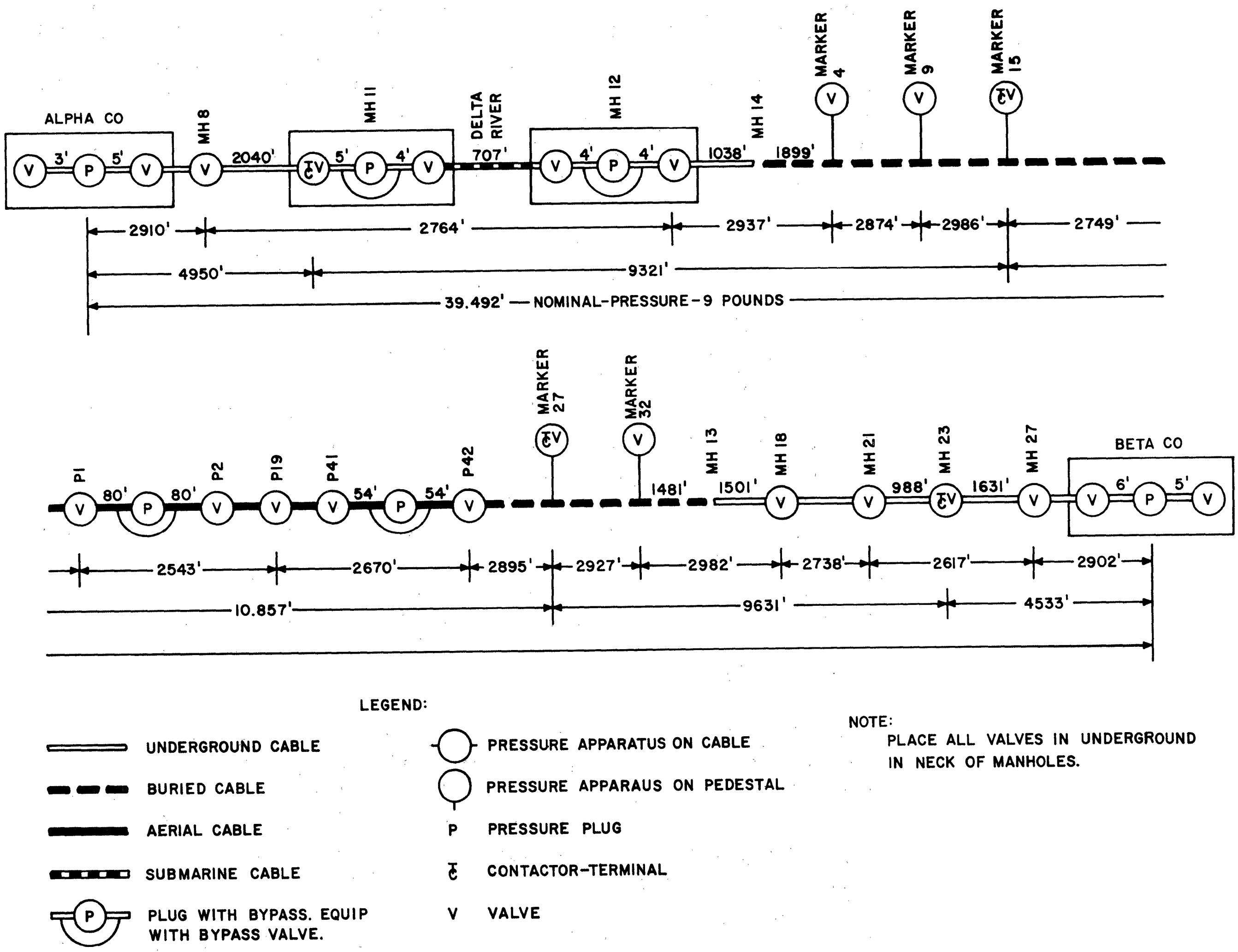


Fig. 15-45 — Continuous Gas Pressure Layout

switch which is operated by gas pressure through the expansion and contraction of a bellows arrangement, and a high-resistance network connected to the switch contacts. When the contactor is not operated, a resistance is bridged across a subscriber's line. The test center line card of the subscriber's circuit to which the contactor is connected is so noted. The presence of the contactor on the subscriber's line has no effect upon the line. Automatic line insulation test frames at the central office are adjusted to read contactors, and operated contactors are identified by the customer's line to which they are connected.

Currently, the monitoring of air pressures on toll cables is provided by a pressure transducer system. The D pressure transducer contains a bellows-operated variable resistor (pressure sensor) which converts the cable pressure to electrical resistance. The resistance presented to the central control circuit is directly related to the cable pressure at the transducer location. The central control unit consists of bay-mounted equipment which will read the resistance of the transducers, convert the readings to pressure, furnish a printed record of the gas pressure at all transducer locations, and activate alarms when cable pressures drop below predetermined levels. A sample central control printout is shown in Figure 15-46.

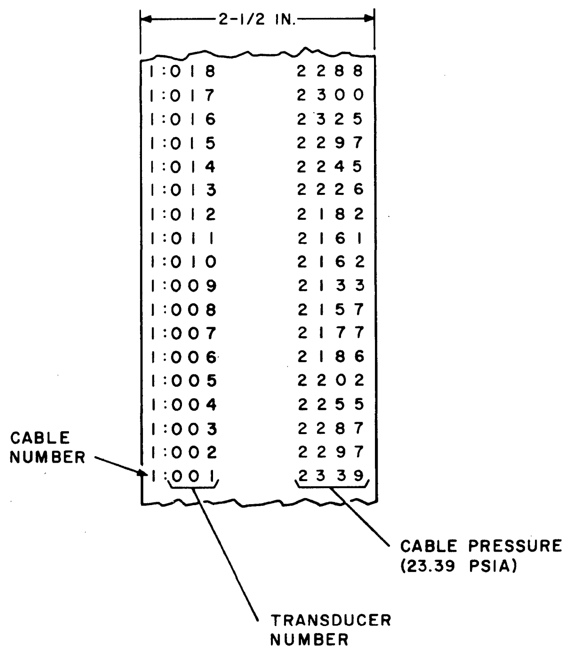


Fig. 15-46 — Example of Printout Tape from Central Control Unit

The most recent innovation to continuous feed gas pressure systems is the introduction of two new methods of providing auxiliary air sources. The plastic pipe method requires the installation of an aluminum-lined plastic pipe from a pipe alarm meter panel in the central office through each major underground conduit route. The pipe connects to a dry air source in the central office. Those cables that are to be pressurized by the pipe system are manifolded to the pipe at each auxiliary source location. The second method utilizes small pole-mounted air dryers located at remote locations on aerial cable routes.

Two computer programs, Air Pressurization Analysis Program (AIRPAP) and Air Monitor Analysis Program, have been prepared to assist in the design of outside plant cable pressurization systems.

15.5 TOLL AND TRUNK PLANT

Toll and trunk plant consists of the network of cables and cable complements which join operating or switching centers. It provides the communication paths that connect one customer loop with any other customer loop outside the immediate central office. Some of the factors that must be considered in the design of this network are: the offices that are connected, the amount of traffic carried by a specific segment of plant, and the flexibility of the network. Specific design parameters of individual cables or cable complements include the length and gauge of the physical pairs and the transmitting facility.

The offices that are connecting points for the toll and trunk network are defined as follows:

(a) A central office is a switching unit in a telephone system that provides service to the general public and has the necessary equipment for terminating and interconnecting customer lines and trunks.

(b) A local central office or end office is a central office serving primarily as a place of termination for customer lines and providing telephone service to these customers.

(c) A tandem office is a central office used primarily as an intermediate switching point between other central offices.

(d) A toll office is a central office used primarily for completing and supervising interexchange calls.

The facilities that join these various offices comprise the outside plant portion of the trunk and toll network. These facilities are usually defined in terms of their principal function such as:

(a) Local or end office direct trunks connect any two local or end offices without an intermediate switching point.

(b) Tandem trunks interconnect a local office and a local tandem office.

(c) Intertandem trunks interconnect two tandem offices for completion of local connections.

(d) Toll connecting trunks interconnect a local office and a toll center.

(e) Intertoll trunks interconnect toll centers.

(f) Secondary intertoll trunks are used to interconnect a toll switching machine and its associated switchboard.

In addition to these interoffice trunks, a group of trunks not directly concerned with customer transmission is used for administration purposes. These trunks include directory assistance, repair service, and verification trunks.

Trunk networks vary from those consisting of a few complements to extremely complex systems in the larger metropolitan areas. Generally, the trunk network pattern follows some combination of either a series of operating centers along approximately parallel routes with cross routes forming a grid, or several series of centers along radial routes from a common center with cross routes at various locations. Trunks used to connect operating centers usually are associated in groups having the same transmission characteristics. Trunk networks are more conveniently studied by complement spans or route and route sections. The diagram in Figure 15-47 represents the actual geographical routes between five centers. A complement span contains all the facilities between two offices regardless of the route of these facilities.

In many cases there may be more than one complement route for a given complement span such as AC, AD, or AE in Figure 15-47. The route section diagram shown in Figure 15-48 shows the geographic routes but does not distinguish between parallel complement routes along sections where they are identical. The routes naturally divide themselves into sections between junction points and operating centers. Route section numbers are used for convenient reference. These complement spans and route section diagrams are used extensively in the study and analysis of trunk plant. In addition to the diagrams, lists of the number of pairs in each section, the number of pairs in each grade of facility in each complement span (Figure 15-49), and the total number of facilities (both physical and carrier) between centers assist in the analysis of trunk pair requirements.

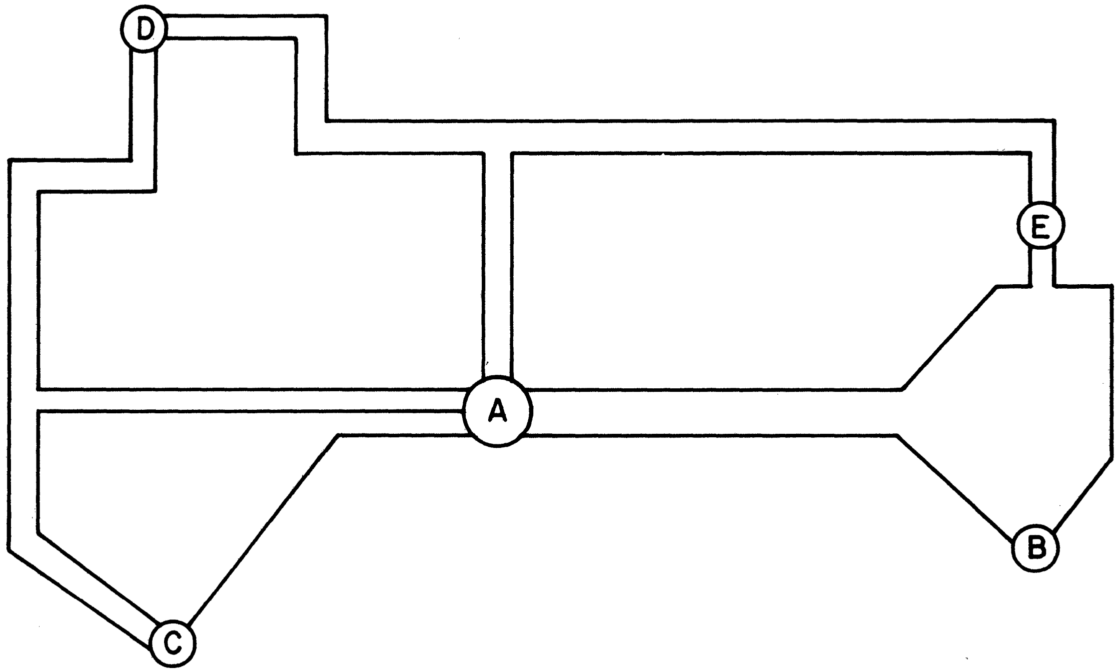


Fig. 15-47 — Complement Route Diagram

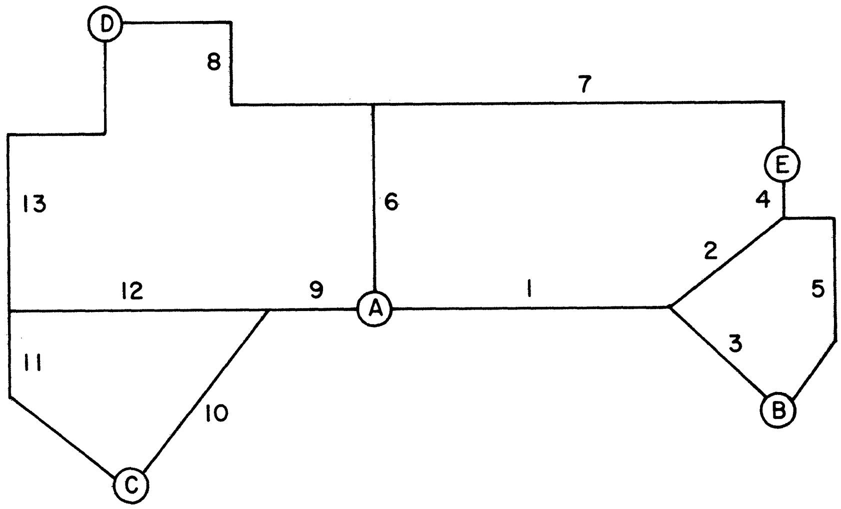


Fig. 15-48 — Route Section Diagram

A traffic trunk estimate is prepared annually to show the expected trunk requirements. Preparatory to making this estimate, the number of trunks presently required in each existing trunk group is determined, usually from the readings on the trunk registers. The comparison of the available facilities in a particular complement route or route section with the requirement for that section yields a definite indication of the cable fill. A high fill, indicating approaching trunk congestion in a particular route or route

Number of Pairs in Each Grade of Facility

Complement Span	22 H88	24 H88	22NL	24NL	Total
A-B	—	51	—	858	909
A-C	—	51	505	151	707
A-D	152	—	555	—	707
A-E	152	—	151	404	707
C-D	—	—	202	—	202
D-E	—	—	303	—	303
B-E	—	—	—	202	202

Fig. 15-49 — Complement Spans and Grade of Facility

section, does not necessarily mean that new plant is required. It may mean that relief routes will soon be required or that transfers to other existing routes should be considered.

A computer program currently in use is capable of administering trunk and toll systems. Details of complements between switching points are established as permanent data. These details include the total number of facilities available, the design, and the overall transmission loss of the complement. By recording the inward and outward movement of trunk circuits, the computer program provides a continuing monitoring of the facilities and can make routing assignments to satisfy prescribed transmission losses and maintain uniform complement fills.

The facilities that comprise the trunk and toll network vary from the two-wire direct trunks between local offices to the microwave radio systems connecting regional toll centers. The distances involved and the transmission limits imposed upon the trunk and toll plant have made the use of multiplex systems the economic choice over physical facilities. The use of carrier systems in the trunk and toll network is shown in Figure 15-50. The distances shown represent nominal distances over which the system is most economical. Full details of operation and application of the various carrier systems are found in Chapter 16.

Structures that are shared by both customer loop plant and trunk or toll plant must be compatible with both types of plant. However, the transmission design limits assigned to various sections of the trunk and toll plant must be strictly enforced, and deviations from designed spacings of loads and repeaters must be kept to a minimum. Therefore, preference to the trunk and toll plant must be allowed in locating manholes, poles, etc.

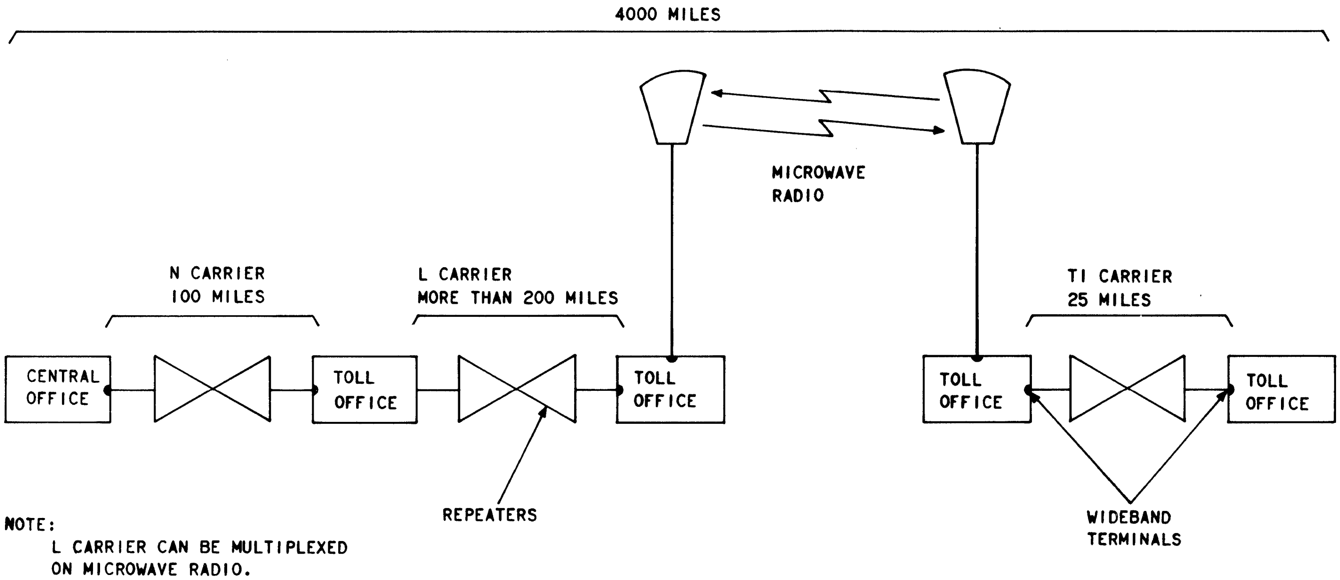


Fig. 15-50 — Use of Carrier Systems in Trunk and Toll Network

Transmission objectives are assigned to all central offices and trunks. Transmission losses in the toll and trunk plant and traffic routings that ensure proper transmission routing patterns are controlled by ensuring that these losses and routings conform to the assigned transmission objectives. The transmission objective is the expected measured loss (EML) which has been established throughout the Bell System for each particular class of trunk, e.g., local trunk, intertandem trunk, etc. Cable, carrier, microwave, and trunk terminating equipment must be planned to attain these transmission objectives.

15.6 TELEVISION TRANSMISSION SYSTEMS

Transmission of television signals includes theatre or entertainment systems, educational systems, and community antenna television distribution systems. The special nature of the service and facilities involved in transmitting television signals generally dictates that the basic responsibility is one of transmission design. When the basic transmission design has been established, however, issuance of plans for the outside plant facilities follows the normal routines for all other outside plant.

A. CLOSED CIRCUIT TELEVISION (CCTV)

Figure 15-51 provides a typical layout of part of a closed circuit television system. A brief explanation, omitting facility and equipment details, follows.

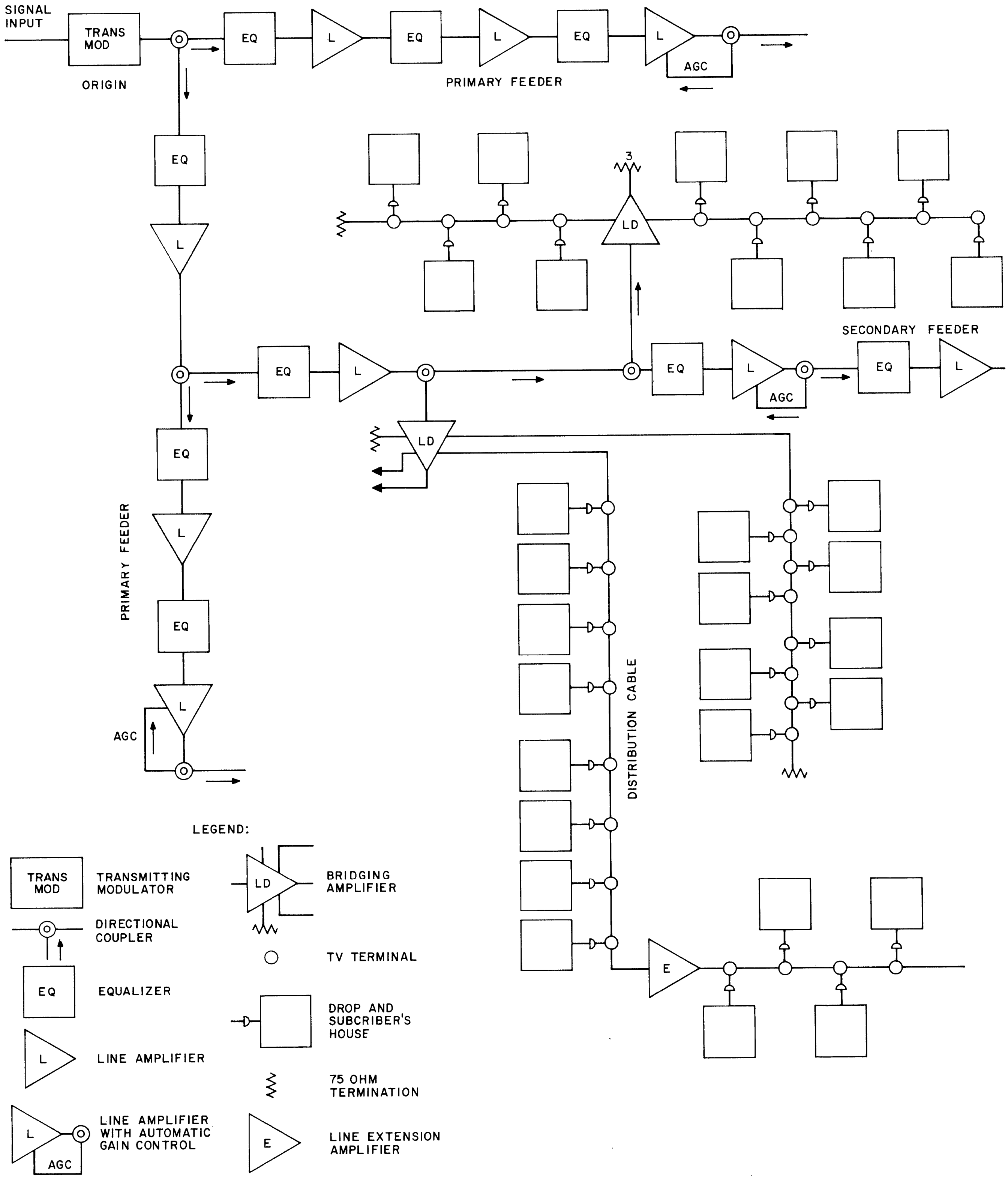


Fig. 15-51 — Typical Layout - Closed Circuit TV Systems

At the origin, video and sound baseband signals are accepted from the customer by a transmitting modulator in which appropriate video and sound intermediate frequency carriers are modulated for transmission to the subscribers' sets. The modulated signals are transmitted from the origin over feeder cables. Primary feeder cables differ from secondary feeder cables only in that the latter provide connections for distributing the signals to subscribers. It is possible, in some routes or systems, that secondary feeders only will be provided. Other systems such as educational TV systems will be comprised almost entirely of primary feeders.

The cables used for primary and secondary feeders are disc-insulated coaxial cables, either as single coaxials or in conjunction with other service pairs. The currently available disc-insulated cables are shown in Figures 15-17 and 15-18.

A line amplifier is used at intervals along the feeder cables to compensate for attenuation of the signals. An equalizer is required in each amplifier section to assist in compensating for transmission differences in the signal frequencies as temperatures vary. Automatic level control is applied at every third line amplifier to assure maintenance of signals at their proper strength. A bridging amplifier, connected to the secondary feeder cable by a passive divider, provides a means for connecting distribution cable to the feeder cable. Several (up to four) distribution cables may be connected at a bridging amplifier. Maximum length of a distribution cable should vary from about 1000 feet to 1500 feet, depending upon frequencies transmitted. The cables used for distribution cables are expanded polyethylene-insulated single coaxial cables. The currently available expanded polyethylene-insulated cables are shown in Figure 15-19.

A TV terminal is required at each service drop connection at the distribution cable. A line extension amplifier may be used to permit the use of longer distribution cables. Only one such amplifier may be used in each distribution cable, however, as a greater number results in considerable signal distortion. Maximum length of distribution cable, with a line extension amplifier located near the center of the cable, is about 2000 feet to 3000 feet, depending upon frequencies transmitted. The drop wires and cables that connect the customer's premises to the cable system are solid polyethylene insulated. The currently available solid polyethylene-insulated wires are shown in Figures 15-20 and 15-21.
The foregoing description, being very general, applies equally whether the system is aerial or underground.

B. COMMUNITY ANTENNA TELEVISION (CATV)

A CATV transmission system consists of three major subsystems which are (1) the head end, (2) the feeder system, and (3) the distribution system. In CATV systems, it is not contemplated that the telephone company would own or operate the antennas or associated towers, but would provide channels from the head end of the system to the premises of the user. The head-end equipment itself may be provided by either the telephone company or the CATV system operator. Therefore, the Bell System interface with the customer can either be at the input to the head-end equipment or at the input to the line facilities.

The feeder system is that portion of the CATV system which is used for the transmission of the signal from the head end to the areas in which it is to be distributed. It consists of coaxial cable which provides the transmission medium, and line amplifiers with proper equalization which compensate for the cable attenuation. The distribution system is that portion of the CATV system which is used to transmit the signal from the feeder system to the individual user within a distribution area. The primary objectives of the design of a distribution cable system may be briefly stated as follows: (1) to deliver a signal to the user's station within the level range required and under all cable temperature conditions, (2) to deliver a signal to the user which meets the slope requirement, i.e., that each channel signal shall be within ± 1 dB of the adjacent channel signals, (3) to provide distribution systems as free from echo effects as possible, and (4) to provide as much isolation as possible between adjacent subscribers' television sets to guard against the interferences which may originate in a particular television set and be fed back into the distribution cable.

CHAPTER 16

CARRIER SYSTEMS

16.1 INTRODUCTION

In the early history of the telephone system one of the major transmission problems was the struggle for distance. As telephone lines became longer and longer a serious technical limitation became more and more apparent. This was the progressive weakening of the speech currents as the distance increased. The principle of inductive loading helped extend distance but there still remained definite limits of practical telephony. These limits were overcome with the dawn of the electronic era, in which the vacuum tube made it possible to stretch the range of telephony to unlimited distances by wire and radio. The application of the vacuum tube to telephone repeaters made it possible to compensate for loss of signal strength by amplifier gain.

When vacuum tubes made amplification available for application to telephone lines, research was aimed at utilizing these lines more efficiently. The outcome of this research was a powerful new transmission method - the application of the carrier principle to wire lines. The method is to convert the audible frequencies of a communication channel to a corresponding band of frequencies centered about, or otherwise related to a particular frequency beyond the audible range, known as a carrier frequency. By suitably spacing such carrier frequencies over a comparatively wide range, several communication channels may be combined to transmit signals or voice over a single pair of wires, without interference from one channel to another.

The next two chapters will be devoted to the systems which were developed from these transmission improvements - namely the carrier system and the repeater. The discussion on repeaters will be limited to voice frequency repeaters. Carrier systems also make use of repeaters but these will be considered as an integral part of each system.

Before beginning this discussion, however, it is advisable to define several common transmission terms.

<u>Voice Frequency Systems</u> - Systems which transmit intelligence over lines at frequencies which fall within the useful portion of the audible spectrum; in general, the frequencies are between 200 and 4000 Hz.

<u>Carrier Systems</u> - Systems which employ some form of modulation at each end of the circuit, so that the signal is transmitted at frequencies above the principle audible range.

<u>Two-Wire Operation</u> - By its basic nature a telephone conversation requires transmissions in both directions between the customers at opposite ends of a transmission system. In the early days of telephony, most transmissions were made over paired conductors (or wires) and the transmissions in opposite directions used the same electrical path between the customers. At switching points the two transmission path terminals of one circuit were connected through cord circuits or switching mechanisms to the two transmission path terminals of a similar circuit. This method of transmission and switching was therefore designated as two-wire operation.

Thus by definition, transmission and switching operations are "two-wire" when oppositely directed portions of a single conversation occur over the same electrical transmission path or channel.

<u>Four-Wire Operation</u> - When carrier system operation was introduced into the open wire plant and circuits of increasingly greater length were routed in cable plant, echo and singing considerations made it necessary to separate the electrical paths used for oppositely directed transmissions between the customers involved in a single conversation. This separation is accomplished by either or both of two methods, as follows:

a. Separate pairs in outside plant and office cabling

b. Separate carrier frequency bands.

In the larger intertoll switching mechanisms used today such separation is also maintained through the switches.

Because two separate pairs (or 4 wires) were used for the oppositely directed transmission paths of many of the longer voice-frequency circuits in cable, circuits operated in this manner were designated as <u>Four-Wire</u> circuits.

Thus, by definition, transmission and switching operations are <u>Four-Wire</u> when the oppositely directed portions of a single conversation are routed over separate electrical transmission paths or channels.

A distinction is sometimes made between the two methods of four-wire operation. Systems using the same frequency band in two separate paths for the two directions are said to give "real four-wire operation"; those using two frequency bands over a single path are said to provide "equivalent four-wire operation."

16.2 GENERAL

In the early days of telephone communication, speech was transmitted over the wirelines only at its natural voice frequencies. It was soon realized, however, that this was a very inefficient use of the costly wire plant, since the lines are capable of transmitting a much wider frequency band than the 3KHz or so required by speech. The incentive was strong for developing systems which could utilize some of the wasted frequency band above 3 KHz to provide additional telephone channels. The advent of the electron tube provided the needed tool for such a development, and the first carrier system made its appearance during World War I. This system, designated type "A", is now obsolete, and has been followed by a succession of carrier systems designated by the letters of the alphabet, which are briefly described in this chapter.

All of the carrier systems, except the type "L" which requires coaxial cables or microwave radio systems, were designed to be applicable to one or more of the already existing types of line facilities. The application of a carrier system to a line requires the addition of carrier terminals and repeaters, and frequently also, special treatment of the line itself such as the carrier transposing of open-wire lines or the balancing of cables. The cost of this equipment and line treatment therefore represents the cost of the telephone channels furnished by the carrier system.

A carrier system would not be used unless it proved in economically. For a carrier system to prove in, the cost of obtaining additional telephone channels by means of the carrier system must be less than the cost of obtaining the same number of channels on that route by other means, such as stringing new wires or cables and equipping them with voice frequency systems. An important part of the cost of carrier systems is the cost of the terminals. This is a fixed cost per system regardless of its length, for a particular type of system. When expressed in terms of cost per mile, it looms up as a much larger part of the total cost on short than on long systems. It follows that for each type of carrier system, there is some minimum length of system below which the carrier costs per telephone channel mile are so great that the system does not prove in, and it is more economical to obtain the telephone channels by other means. The fact that carrier systems have tended to prove in more naturally and by larger margins on long than on short circuits, has had a large effect on the engineering of the telephone plant. This effect has been to drive voice-frequency systems out of the long toll circuit field and to relegate them more and more to the shorter circuits which feed the main toll routes. Today, practically all circuits over 50 miles long and many shorter ones, are carrier circuits. The trend toward the use of carrier for long circuits receives added impetus from the fact that better transmission performance can be obtained from long carrier systems than from long voice-frequency systems.

The carrier systems are classified as "long haul" and "short haul" systems. The long haul systems are designed to meet all the transmission requirements of a toll link, for the longest systems which would be encountered in the United States, 2000 to 4000 miles. The minimum length for which most of the long haul systems prove in is usually of the order of 75 to 100 miles. The short haul systems have the specific purpose of extending the carrier applications to shorter distances, some of them proving in at as short a length as 10 to 15 miles. This result is attained by reducing the cost of the terminal and line equipment, which is made possible by lightening the transmission requirements in view of the shorter distances to be spanned. Consequently, for the short-haul systems there is not only a minimum length at which the system proves in but also a maximum length beyond which the transmission requirements of toll links will not be met.

It is evident that the carrier systems increase the efficiency of use of the wire lines by the principle of superimposition. That is, they add additional speech channels to the line, each utilizing an otherwise unused part of the frequency band. For example, when a type "C" carrier system is added to an open-wire pair, three additional 2-way telephone channels are superimposed above the regular voice-frequency channel, using frequencies up to about 30 KHz. To the same pair can be further added a type "J" carrier system furnishing twelve more channels in the frequencies between about 36 and 143 KHz. When both systems are used, the open-wire pair furnishes sixteen two-way toll telephone circuits. The stacking of channels one above the other with different carrier frequencies is known as frequency division multiplex.

Following World War II, a new concept of telephone multiplex was introduced. This culmunated in the development of the T1 carrier system for wire lines. In this system, the telephone signals are transmitted by means of a series of pulses of energy. The conversion of the telephone signal into energy pulses from which it can be reproduced at the receiving end is known as pulse modulation. It makes possible the transmission of a number of separate signals over a wire line or by a single radio carrier by means of time division multiplex. This is, the intervals between the successive pulses of a given signal can be employed to transmit comparable pulses of other signals.

16.3 FUNDAMENTALS OF CARRIER TELEPHONE SYSTEMS

In ordinary telephone transmission a pair of wires between telephone subscribers ordinarily carries one conversation and is required to transmit intelligence or voice frequency energy in both directions. In other words, we speak and hear over the same pair. This is called a two-wire system and is possible because of the circuit arrangement of the subscribers instrument, see Figure 16-1.

If we attempt to use one pair for more than one conversation at one time, we succeed only in making a four person conference out of it in which each person can hear everything everyone else says. Adding more instruments only adds more confusion, see Figure 16-2.

Changing to a four-wire system has definite advantages in carrier telephony. Since we are developing a simple carrier system, we will convert our circuit to "four-wire." This simply means that when A talks to B, one pair is used. When B talks to A, a different pair is used. Even with our simple telephone circuit the confusion has been reduced somewhat since now only two receivers can be actuated by any one transmitter, see Figure 16-3.

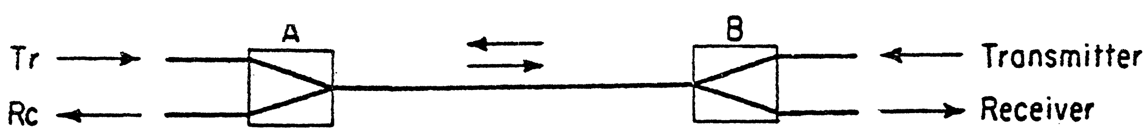


Figure 16-1 Two Wire System (One Conversation)

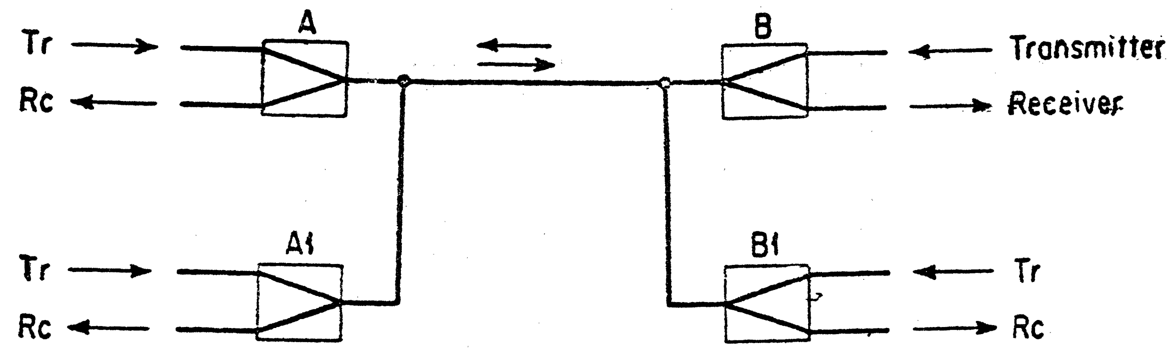


Figure 16-2 Two Wire System (Two Conversations)

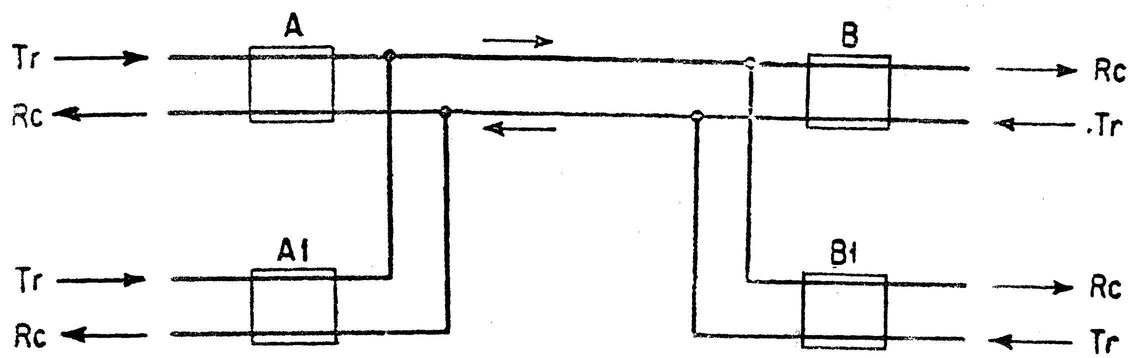


Figure 16-3 4 Wire System

Speech transmitted over telephone lines, generally speaking, is in the range of 200 to 3500 Hz. If we can change the frequency range of the speech of customers A1 and B1 from the 200 to 3500 Hz range to a range of, say 4200 to 7500 Hz and, further, arrange to separate the A-B from the A1-B1 conversations at the receiving ends of the circuit, we can use two pairs of wires for two separate conversations or even more with a saving in plant investment. This is the beginning of a carrier system, see Figure 16-4.

Carrier telephony consists of superimposing voice frequencies on a carrier frequency and then transmitting this information to a point where the reverse will occur. The full range of voice frequencies is 50 to 8000 Hz or higher. For telephone use a range of 200 to 3500 Hz is

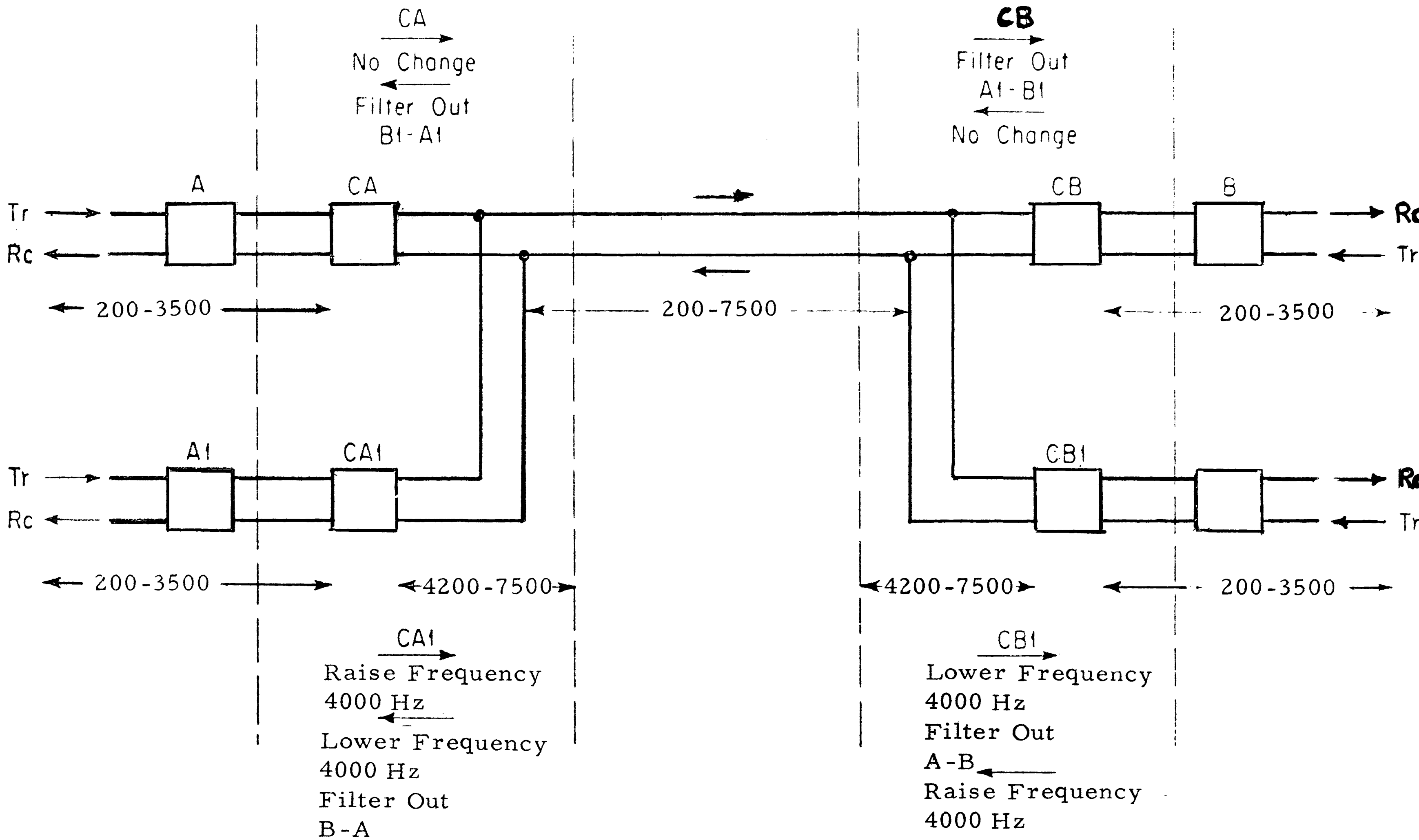


Figure 16-4 Simplified Carrier System

sufficient. This range will allow one subscriber to identify any other subscriber. The carrier frequencies are steady frequencies other than voice frequencies, usually higher than the voice range. Superimposing is accomplished by modulation.

16.4 AMPLITUDE MODULATION

The type of modulation employed in the majority of the systems is that known as amplitude modulation (AM). As shown later, when the amplitude of a carrier wave is modulated by a signal, the result is a wave composed of the carrier frequency plus an upper and a lower sideband which differ from the carrier by the frequency of the signal. It is evident that the two sidebands are redundant, since they both contain all of the intelligence of the signal, and that the carrier is superfluous, carrying no intelligence at all. Therefore in most of the multichannel systems, maximum efficiency is attained by removing the carrier and one sideband by means of filters, and transmitting only the other sideband. However, in certain of the systems where economy is a main object, both of the sidebands and also the carrier are transmitted.

When single-sideband transmission is employed, it is evident that the carrier signal in a given channel has the same bandwidth as the original voice-frequency channel. The single sidebands corresponding to the different telephone channels handled by the system are usually placed in adjacent positions in the carrier frequency band, one every 4 KHz. With modern filters this permits a useful band for each channel which is somewhat wider than 3 KHz.

When the voice frequency is superimposed or impressed on the carrier frequency by amplitude modulation there is obtained, among other things, the sum and the difference of the two frequencies. For example if we let:

V = voice frequency
C = carrier frequency

Then the results of modulation may be expressed in the basic formula:

$$C \pm V = \text{frequency output.}$$

Using the voice frequency band 200 to 3500 Hz and assuming a carrier frequency of 7000 Hz:

$$C + V = 7000 + (200 \text{ to } 3500) = 7200 \text{ to } 10{,}500$$
$$C - V = 7000 - (200 \text{ to } 3500) = 3500 \text{ to } 6{,}800$$

The band of C + V is called the upper sideband and the band of C - V is called the lower sideband. A reverse process is necessary to regain the original voice frequency band. This is known as demodulation.

16.5 FREQUENCY MODULATION

The use of frequency modulation (FM) is confined entirely to radio systems operating in the very high frequency band or above, where it has certain definite advantages over amplitude modulation in minimizing interference from "static" and extraneous signals. It depends upon varying the frequency of a carrier wave of fixed amplitude above and below a central or normal frequency in accordance with the amplitude variations of an applied signal voltage. The process is roughly illustrated by the wave diagrams of Figure 16-5. The amount of frequency change that is produced by the signal is called the frequency deviation and, ideally, this should be as high as possible in order to obtain the maximum signal to noise ratio. However, since it is obvious that the total bandwidth of the modulated wave to be transmitted will increase with increases in the maximum frequency deviations on both sides of the unmodulated carrier frequency, it is necessary as a practical matter to arbitrarily limit the maximum permissible deviations to values that will keep the total bandwidth that must be assigned in the radio spectrum to each FM channel as narrow as feasible. The maximum permissible deviation has been specified by the Federal Communications Commission at 75 KHz for FM broadcasting, and at 15 KHz for such applications as mobile radio service.

As in amplitude modulation, frequency modulation results in a modulated wave containing the carrier frequency and other frequencies above and below the carrier frequency.

In addition to the carrier frequency itself, the modulated wave includes an infinite series of side frequencies having values equal to the carrier frequency plus and minus the signal frequency and all of its integral multiples.

The following **three** statements can be listed as specifications of FM:

a. The amplitude of the carrier remains constant as the carrier frequency is varied by modulation.

b. Deviation (i.e., frequency swing) is proportional to the amplitude of the modulation. Maximum deviations occurs at peaks of audio signal.

c. The rate of frequency change is proportional to the frequency of the modulation.

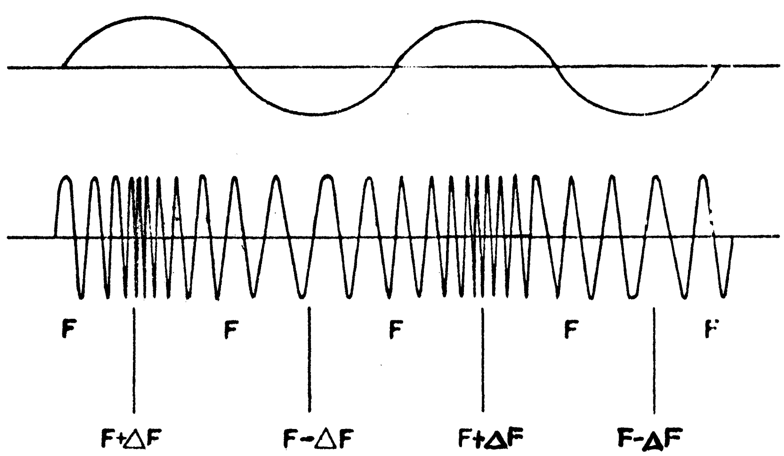


Figure 16-5 Frequency Modulation of Carrier Wave

16.6 PULSE CODE MODULATION

In amplitude or frequency modulation, the amplitude or frequency of a sinusoidal carrier is continuously varied in accordance with the modulating function. In contrast with this, pulse code modulation uses a series of pulses instead of a sinusoidal carrier to carry the information contained in the modulating function.

In the operation of this new type of modulation the voice signal applied to each channel is in effect, transmitted sample by sample. Instantaneous samples of the signal voltage are taken at intervals sufficiently close together to permit a receiver to produce a faithful reproduction of the original signal. Sampling takes place at a rate which is slightly higher than twice the highest frequency component of the signal.

These samples must be coded into a series of on or off pulses. The amplitude of the basic signal being sampled, however, may vary continuously over a wide range and may thus have an infinite number of values. The specific samples approximate the actual voltage of the signal. To keep the total number of codes within reasonable limits, it is necessary to divide the total amplitude range of the signal into a number of finite steps or quanta. Each sample is quantized, that is, it is assigned a specific voltage value between specific limits. The sample is in effect scaled off against some known yardstick and given a definite value. It has been found that when as many as 128 quantum steps are employed, speech signals can be reproduced with a high degree of fidelity. The amount of error between the actual amplitude of the sample and its assigned quanta level gives rise to the term quantizing noise.

These specific voltages are then coded into a binary pulse code. In a binary or off-or-on system 128 separate codes require the use of seven positions or "bits" per code.

At the receiving end each 7-element code signal is translated into the single amplitude pulse which the code represents. The successive amplitude pulses are then applied to a low pass filter (cutting off at 4000 Hz in the case of a voice wave) the output of which will be an exact copy of the original wave sent. Figure 16.6 is a simplified sketch of the pulse code modulation principle.

There is an optimum rate for the transmission of short pulses through a band-limited medium. For a low pass characteristic which transmits up to some frequency f_1 Hz, $2f_1$ pulses per second can be sent. Thus a 750 KHz channel could carry 1.5 million pulses per second. Consider the transmission of 4 KHz telephone messages by 8 digit* binary PCM over a channel which has a bandwidth of 750 KHz.

It was previously seen that our sampling rate should be 8,000 times per second or one sample per 125 microseconds. Each sample will result in one code character consisting of eight code elements (1's or 0's). If we can send 1.5 million pulses per second, eight pulses can be sent in 5.33 microseconds. If only the information pertaining to one message is sent, the pulse pattern vs time would consist of an

*Actually it is assumed that seven digits represents the message sample, and the eighth pulse is for supervisory and signalling purposes.

8-pulse character, taking 5.33 microseconds, then idle time for about 120 microseconds, followed by another 5.33 microseconds of use, and so on. Obviously, the channel is not used very efficiently. On the other hand, if code characters from other channels are sent during the idle time, not one, but about 24 telephone messages could be transmitted over our 750 KHz channel. Interleaving signals on a time basis in this way is called time division multiplex.

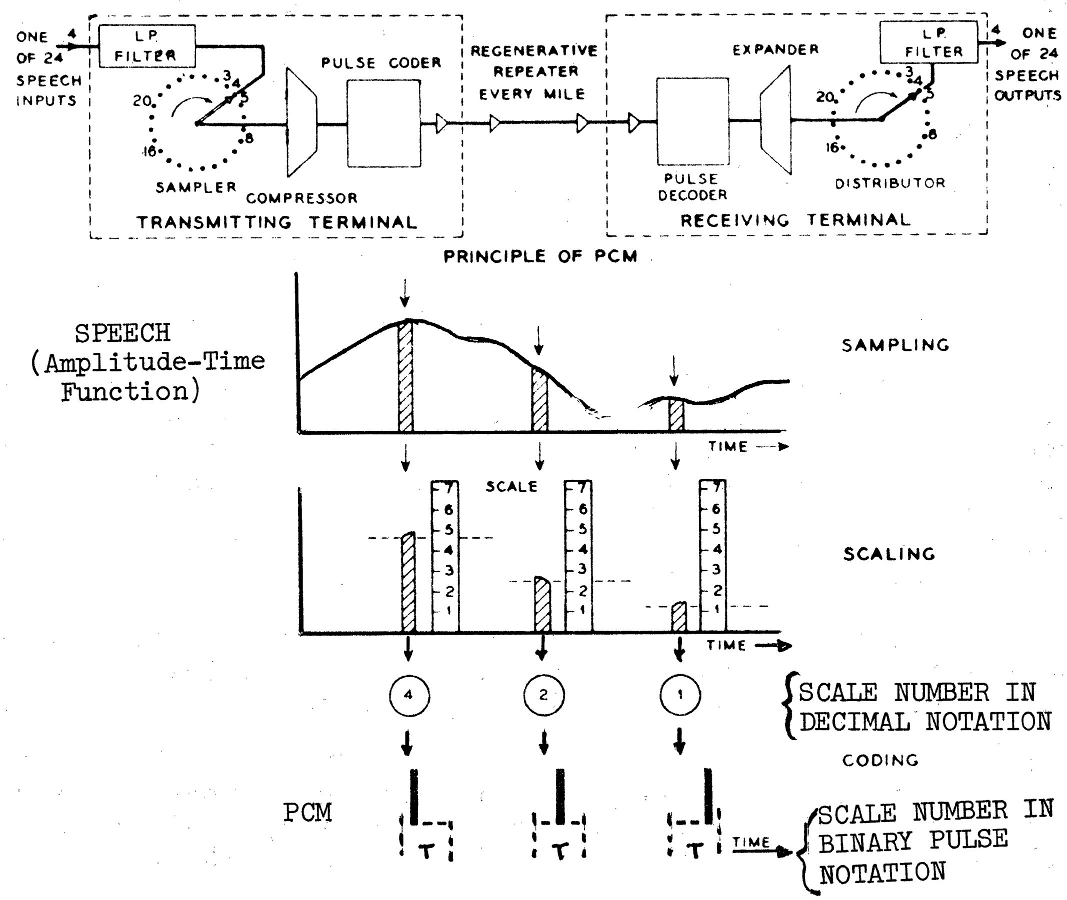


Figure 16-6 Pulse Code Modulation

16.7 A TYPICAL CARRIER SYSTEM TERMINAL

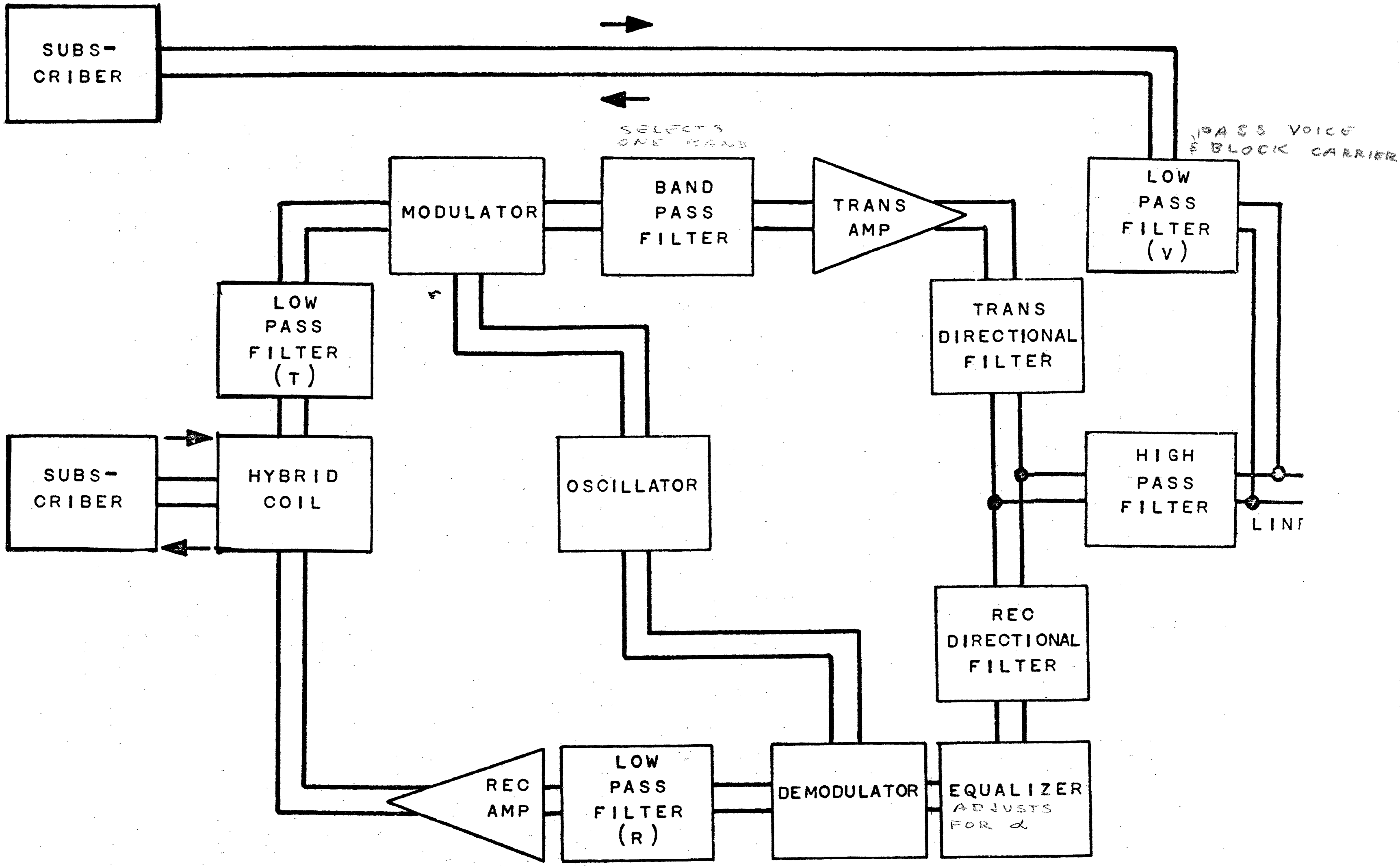
As was stated before, the majority of the Bell System carrier systems make use of amplitude modulation. In developing a typical terminal, therefore, discussion shall be limited to this type of system. In Figure 16-4 additional equipment designated C was added to devise an arrangement by which subscribers A and B may talk to each other without interfering with or being interfered with by two other subscribers A1 and B1. They are the carrier components. The blocks designated C are the filters, modulators and demodulators required in a carrier system.

A carrier terminal Figure 16-7 may be divided into three portions, the voice frequency, transmitting and receiving portion.

In the voice frequency portion the low pass filter (V) allows the voice frequency channel to pass through but blocks the carrier frequencies. The high pass filter lets carrier frequencies into carrier equipment while it blocks out the voice frequencies. This path is established for one message circuit, receiving and transmitting.

In the transmitting portion of Figure 16-7 the voice frequencies from the subscriber are directed into the transmitting portion of the carrier channel by the hybrid coil. The low pass filter (T) eliminates any undesirable frequencies outside of the voice frequency band 200 to 3500 Hz. The oscillator produces the carrier frequency. Each terminal has its own oscillator. The modulator impresses the voice frequency band on the carrier frequency and produces the upper and lower sidebands. In most carrier systems only one sideband is transmitted and this is called Single Side Band transmission. The band pass filter removes all frequencies except one of the sidebands. The transmitting amplifier steps up the sideband being transmitted to the desired power level for transmission. The function of the transmitting directional filter is to keep the frequencies being received from coming into the plate circuit of the transmitting amplifier. This establishes the transmitting circuit.

In the receiving portion of the carrier terminal, the receiving directional filter blocks out the frequencies of the sideband being transmitted but allows the sideband being received to enter the receiving circuit. As the transmitted sideband is conducted to the receiver via the transmission



TYPICAL SINGLE CHANNEL CARRIER TERMINAL

Figure 16-7

lines the higher frequencies are attenuated more than the lower frequencies. The equalizer adds loss for the lower frequencies so that all frequencies will pass into the demodulator at the same level. The demodulator combines the carrier frequency with the received sideband and one of the resultant products is the voice frequency. The low pass filter (R) removes all the products of demodulation except the voice frequency. The receiving amplifier steps up the power level of the voice frequencies to that required for transmission to the subscriber. The receiving frequencies are then directed to the subscriber through the hybrid coil, thus establishing the receiving circuit.

In the system just described we had two message paths over one pair of wires. It would be possible to add more message paths using this same pair of wires by adding more carrier terminals using different carrier frequencies.

From this typical terminal it can be seen that an important feature of every carrier system consists of the modulators and demodulators which shift the frequencies of the telephone signals. Another feature of all carrier systems is the need of filters needed to select the desired signals from the modulators for transmission to the line, and to separate the line channels from each other for application to their respective demodulators, at the receiving end of the line. Filters are also used to separate groups of channels from each other.

The signals are usually transmitted over the lines between the terminals in two groups, one consisting of the E-W (east-to-west) one-way channels of all the telephone circuits handled by the system and the other consisting of the W-E (west-to-east) one-way channels of the same telephone circuits. As noted earlier, the two groups may be transmitted over different pairs, or over the same pair in different frequency ranges. The channels constituting a group are amplified by one common carrier line amplifier (or repeater) at each repeater point.

The lines, of course, have considerably greater attenuation at the higher frequencies needed for carrier transmission than at voice frequencies. Therefore carrier line amplifiers must be spaced at much shorter intervals along the line than most voice-frequency repeaters. The length of the repeater sections on any system is a function of the line attenuation, the standards for allowable noise at the end of the system on each telephone channel, the maximum length of system, the noise on the line sections and the amplifiers, and, in the case of multichannel systems, of the amount of modulation in the line amplifiers. Since the line attenuation is greatest for the highest frequency channel transmitted by the system, the repeater spacing is usually determined by the rules as applied to that channel.

Because the line attenuation is great at the carrier frequencies, the variation in attenuation with temperature (and with weather in the case of open-wire lines) is also large. Furthermore, both because of the large attenuation and also because of the wide frequency band required for most carrier systems, the difference in attenuation between the highest and lowest transmitted frequency is large. These considerations impose severe transmission problems on the carrier systems which are solved in different ways on the various systems.

The variations of the lines with frequency and temperature are compensated for by equipment associated with the line amplifiers. It will be noted that though the total effects to be compensated may have very great magnitudes, the distribution of the compensation among many line amplifiers reduces the problem at each amplifier to manageable proportions. The equipment which does the compensating falls into two categories, namely, basic <u>equalizers</u> which compensate for the attenuation-versus-frequency distortion of the lines under mean ambient conditions, and <u>regulating networks</u> which adjust for the variations in the attenuation and in the attenuation-versus-frequency characteristics of the line due to changes in temperature (and other causes). The regulating networks are automatically operated, usually under control of one or more pilot frequencies wedged in between the telephone channels. In some cases, the flat gain variations may be controlled by a d-c pilot channel similar to that used in the pilot-wire regulations of voice-frequency systems, or by the energy in the carrier channel themselves. The specific application of the techniques to the various carrier systems is described in later sections.

The pilot frequencies, when used, are of course supplied by the system terminals. Another feature of carrier terminals, therefore, consists of the means for generating the pilot frequencies, and also the carrier frequencies required by the various modulators and demodulators. In most systems, these frequencies must be very exact in order that the signal and pilot frequencies will accurately match the pass bands of the filters through which they must be transmitted, and that they will fall properly into their allotted frequency positions on the lines. It may be noted that in those systems in which the carrier is not transmitted, which is the case with many of the systems, the carriers supplied to the modulators and demodulators at the two ends of the system must be generated by physically separated oscillators. Any actual difference between the carrier frequencies at the two ends, which ideally should be identical, results in a corresponding displacement of the same number of cycles in all the frequencies in the telephone signals emerging from the system. The tolerance for such frequency displacements is at most a few cycles, which in terms of per cent error in the carrier frequencies necessitates considerable accuracy.

16.8 SUMMARY AND DESCRIPTION OF THE CARRIER SYSTEMS

Some of the important information on Bell System carrier systems is tabulated on Table 16-1. It will be noted that for all the systems there is given the minimum length below which it is not normally economical to use the system. For the short haul systems, a maximum length is given beyond which the transmission would be likely to fail to meet standards, due to noise, crosstalk, equalization, regulation, or for other reasons.

16.9 HISTORY AND GENERAL DESCRIPTIONS OF THE CARRIER SYSTEMS

Type

A The first carrier system introduced in 1917 was known as the "A" system and provided four 2-way channels above the voice channel on open wire pairs in the frequency range between 5 and 25 KHz. The system used single sideband transmission, and each channel used the same frequency for both directions of transmission; directional discrimination was secured by hybrid coil balance at terminals and repeater stations as with 2-wire repeaters. Later systems used separate pairs for each direction of transmission. A total of seven type "A" systems were installed in the United States, but all have long since been removed. The last one in service was between Merced and Yosemite Valley, California.

TABLE 16-1A MAJOR BELL SYSTEM CARRIER SYSTEMS

SHORT HAUL

	N1	N2	O	ON1	ON2	T1	N3
Line Facility	Cable	Cable	O.W.	Cable	Cable	Cable	Cable
Channels	12	12	16	20	24	24	24
Modulation	A.M.	A.M.	A.M.	A.M.	A.M.	P.C.M.	A.M.
Sidebands	2	2	1	1	1		1
Transmitted Carrier	Yes	Yes	Reduced	Reduced	Reduced		Yes
Method of Operation	(2)	(2)	(1)	(2)	(2)	(2)	(2)
Frequency Allocations (KHz)							
Lowest Trans. Freq.	36	36	2	40	36	(3)	36
Highest Trans. Freq.	268	268	156	264	268	(3)	268
System Length (Miles)							
Minimum	15	15	15	15	15	10	35
Maximum	200	200	150	200	200	50	200
Approx. Repeater Spacing (Miles)	5	5	50	5	5	6000 Ft.	5
Frogging	Each Rept.	Each Rept.	Each Rept.	Each Rept.	Each Rept.	No	Each Rept.
Compandors	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pilots	No	No	No	No	No	No	No

NOTES:

(1) Equivalent Four Wire
(2) Real Four Wire
(3) Line Signal Consists of Bipolar Pulses at rate of 1.544×10^{-6} P.P.S.

TABLE 16-1B MAJOR BELL SYSTEM CARRIER SYSTEMS

LONG HAUL

	C5	J2	K2	L1	L3	L4
Line Facility	O.W.	O.W.	Cable	Coax.	Coax	Coax.
Channels	3	12	12	600(4)	1860(5)	3600
Modulation	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.
Sidebands	1	1	1	1	1	1
Transmitted Carrier	No	No	No	No	No	No
Method of Operation	(1)	(1)	(2)	(2)	(2)	(2)
Frequency Allocations (KHz)						
Lowest Trans. Freq.	5	36	12	60	308	280
Highest Trans. Freq.	30	143	60	3096	8320	20,448
System Length (Miles)						
Minimum	60	125	75	75	75	75
Maximum	1000	4000	4000	4000	4000	4000
Approx. Repeater Spacing (Miles)	150	30	17	8	4	2
Frogging	No	No	No	No	800 Mi.	800 Mi.
Compandors	No	No (3)	No	No	No	No
Pilots	Yes	Yes	Yes	Yes	Yes	Yes

NOTES:

(1) Equivalent Four Wire
(2) Real Four Wire
(3) Compandors are sometimes added for Crosstalk and Noise Control, but are not part of the System Terminals
(4) Or two one-way TV channels
(5) Or 660 Telephone Channels and two one-way TV channels

Type

B The "B" system was introduced in 1920 and provided three channels above the voice channel on one open wire pair. Different frequencies were used for transmission in opposite directions, making it possible to rely upon filter selectivity instead of impedance balance to separate the directions of transmission. This system transmitted a single sideband and the carrier frequency, using the lower sidebands of carrier frequencies at 6, 9 and 12 KHz, in the East and West direction, and the upper sidebands of carrier frequencies at 15, 18 and 21 KHz in the West to East direction. A score of type "B" systems were installed. The last one in operation was between Spokane and Lewiston, Washington.

C The type "C" system made its appearance in the 1920's. It was the first really successful carrier system and is still a member of the family of carrier systems. The last and current standard model, the C5, is a fairly complete redesign to incorporate the advantages of the modern techniques of varistor modulators, filters with molybdenum permalloy coils, new types of vacuum tubes, and feedback amplifiers. It operates on open wire facilities and provides three telephone circuits in addition to the normal voice-frequency circuit, on a single open wire pair.

The frequency allocations used in the type "C" systems lie between 6.3 and 16 KHz for transmission from East to West and between 17.7 and 30.2 KHz for transmission from West to East. The upper and lower halves of this range are used for the opposite directions of transmission. The channels are single-sideband with suppressed carriers. To reduce crosstalk, there are several "staggered" frequency allocations, some using upper and others using lower sidebands. The C5 system is available in four allocations, the CA, CB, CS and CU. These allocations are shown in Figure 16-8.

It will be noted that the "allocations" differ from each other not only in the frequencies the channels occupy but also in whether the channels are upper or lower sidebands.

Type

C Unlike the more complicated systems the type "C" systems translate each telephone channel to its assigned frequency position on the line in a single stage of modulation. The required carriers are not multiples of any base frequency but are generated by individual oscillators, one for each modulator and demodulator. One pilot is transmitted in each direction on all of the type "C" systems. The pilot frequency is located 50 cycles from the frequency of the suppressed carrier of the middle channel, between the carrier and the transmitted sideband. In the longer systems, the pilots are used for the automatic regulation of the systems. In the systems which are so short as to have no repeaters, the regulation may be manual.

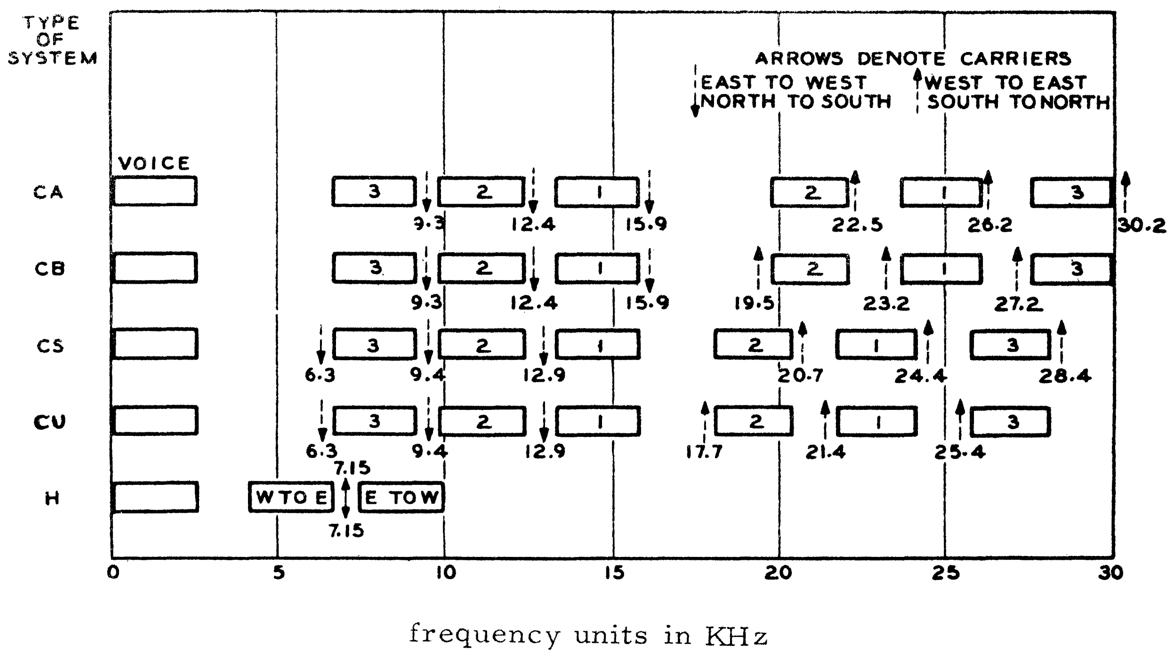


Figure 16-8 Frequency Allocations of Type C and H Carrier Systems

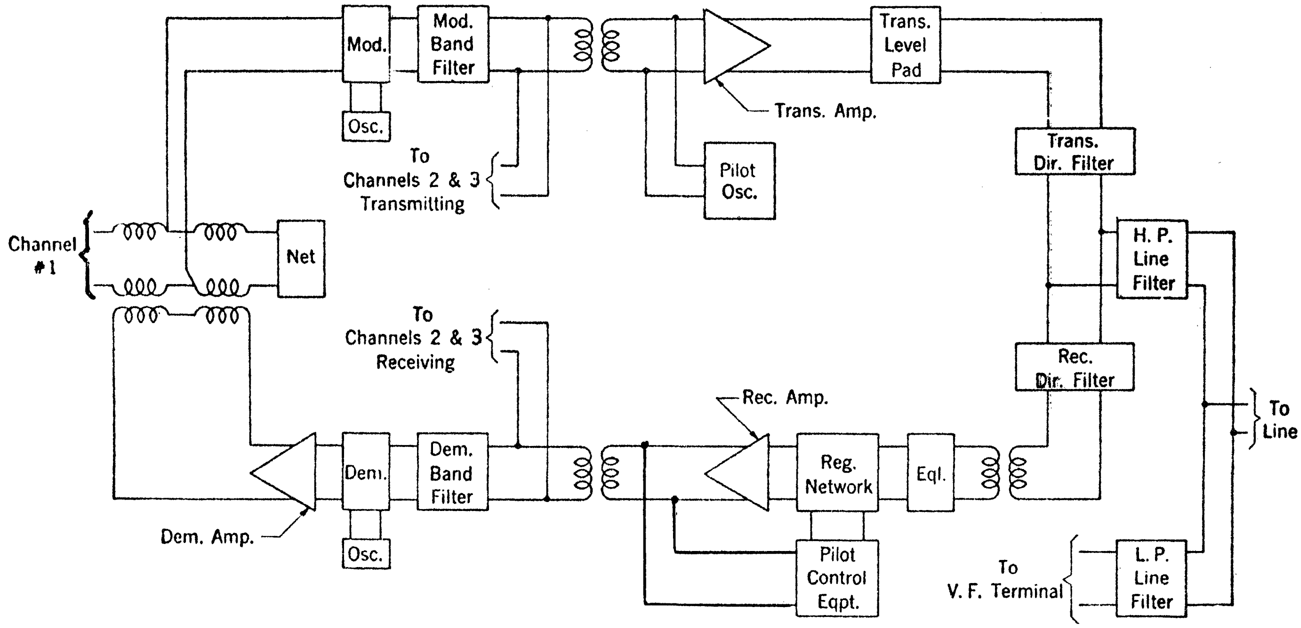


Figure 16-9 Type C Carrier Telephone Terminal

Type

C The type "C" systems are designed so that the repeater spacings are the same as for the voice-frequency systems (about 150 miles) and therefore the repeaters are located in the same stations as the voice repeaters. Spacing will vary with cable conditions.

Figure 16-9 is a simplified schematic of one channel of a Type "C" carrier system. The basic arrangements of the components, such as modulators, bandpass filters, directional filters, line filters, etc., are typical of those used in most carrier systems. Hence, circuit schematics will not be discussed for other carrier systems to be covered hereafter.

D The "D" system was designed for use on short circuits in areas of slow growth on open wire lines (1927). It provided one 2-way telephone circuit on a pair in addition to the voice frequency circuit. Like the "C" it employed single sideband transmission with the carrier suppressed, and used different frequencies

Type

D for opposite directions employing the lower sidebands at 10.3 and 6.87 KHz. The DA system employed a transmitting amplifier which extended the length of circuit to which the system could be applied to about 200 miles. About 550 type "D" systems have been installed.

E The "E" (1926) is a single channel system for power lines. It transmits a single sideband with the carrier suppressed. With the aid of V.F. switching the same frequency band is used for both directions of transmission. The carrier band may be placed anywhere between 50 and 150 KHz. Eleven "E" terminals grouped into three systems were placed in service.

F "F" was assigned to a single channel system using "C" equipment in 1927. Designed for foreign use. No. U.S. installation.

G-1 "G1" (1935) is a system designed for use on open wire lines for short distances not exceeding 30 miles and provides a single channel in addition to the voice channel. A novel feature is that the carrier is generated only at one terminal. The carrier and both sidebands are transmitted and the same frequencies are used for both directions. A frequency band between 6500 and 14,000 Hz is required on the line.

H The "H" system (1936) employs the same frequency allocation as the "D" system but the same frequency of 7.5 KHz is used for both directions of transmission. The carrier is suppressed and the lower sideband is used in the West of East direction and the upper in E to W. May be operated on either AC or DC. Panel mounted for relay rack or cabinet. Has a repeater as well as terminals and may be used for long circuits where only a single channel is required.

J This system provides twelve 2-way long-haul telephone channels on one open-wire pair, and has frequency allocations such that a type "C" carrier system and a voice-frequency system can also be operated on the same pair. Thus, with the advent of the type "J" system, one open-wire pair became capable of furnishing a total of sixteen 2-way telephone channels.

Type

J The development of the type "J" system began at about the same time as that of the type "K" and type "L" systems, and reached the stage of a field trial on a 250-mile line between Wichita, Kansas and Lamar, Colorado in 1937 and 1938.

In the type "J" systems, the west-to-east channels are transmitted in the lower part of the frequency range between about 36 and 84 KHz, and the east-to-west channels are transmitted in the upper part of the frequency range between about 92 and 143 KHz. The two oppositely directed groups of channels are sent on the same pair and are separated from each other by directional filters at each repeater point.

In order to reduce crosstalk between systems operating on the same pole line, the type "J" systems have been provided with four slightly different frequency allocations in the above general ranges. These are designated the JNA, JSA, JNB, and JSB systems, as shown in Figure 16-10. The frequency allocations for the west-to-east direction are the same for all four type "J" systems except that in two of them the channels are inverted. In the east-to-west direction the allocations are staggered in increments of one KHz, two of them being also inverted.

In the terminals of a type "J" system, the twelve telephone channels handled by the system are modulated and combined to form a basic group of channels lying between 60 and 108 KHz, by the channel bank which is also used in the type "K" and type "L" systems. It will be noted that 12 voice-frequency channels are individually modulated by carriers spaced at 4 KHz intervals from 64 KHz to 108 KHz inclusive. The lower side bands are selected for each channel by filters with the result that the 12 channels occupy the frequency range from 60 to 108 KHz. This is the band occupied after the first step of modulation for transmission in each direction and is likewise the band occupied before the last step of demodulation for transmission in each direction. The basic group is translated to the desired frequency allocation

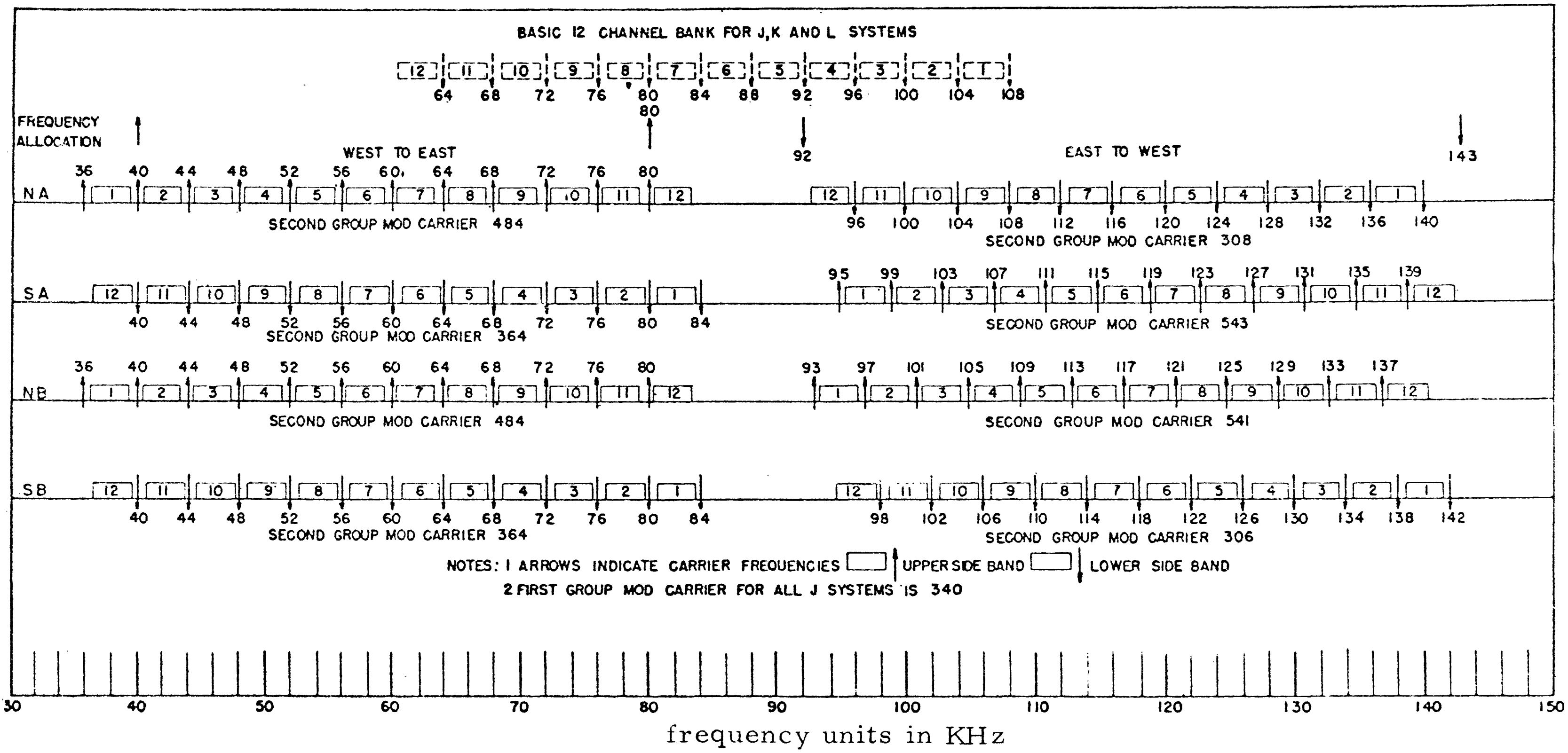


Figure 16-10 Frequency Assignments of the Type J2 Carrier Telephone System

Type

J on the line by group modulators, requiring two stages of modulation in the sending end and two stages of demodulation in the receiving end of the system.

The terminal equipment also supplies the line pilots. The frequencies of the pilots on the lines are the same for all four of the type "J" allocations, and are 40 and 80 KHz in the west-to-east direction, and 92 and 143 KHz in the east-to-west direction. The 80- and 92-KHz pilots are used for flatgain regulation, while the 40- and 143-KHz pilots are used for slope regulation. The pilots are actually injected at the input to the first group modulator at such frequencies as to reach the line at the above frequencies after passing through the two group modulators.

K This system was the first of the all cable carrier systems developed for use in this country. Most of the installations were made just prior to and during the World War II period.

The type "K" system provides twelve 2-way telephone channels on two 19-gauge nonloaded pairs in aerial or underground toll cables. These pairs cannot at the same time be used for voice-frequency systems. The type "K" system operates on a 4-wire basis using one pair for each direction of transmission. The two pairs are ordinarily in different cables, although in special cases a single cable may be used which has a shield between layers to separate the pairs into two groups. Because of the higher attenuation of the 19-gauge pairs at the carrier frequencies, the line amplifiers must be spaced at about one-third the interval required for voice-frequency systems, or about every 17 miles. On a route which also has voice-frequency systems, therefore, the carrier system requires two "auxiliary" repeaters between each pair of main stations where the voice-frequency repeaters are located. On new routes not already equipped with voice-frequency systems, the main, attended stations may be as far apart as 100 to 200 miles. The auxiliary stations are arranged to be unattended, with suitable alarm indications of troubles, to the nearest main station.

Type

K The twelve telephone channels are transmitted on the cable pairs as the upper sidebands of carriers located every 4 KHz from 12 to 56 KHz, inclusive. The total frequency band transmitted on the line therefore extends approximately from 12 to 60 KHz. The original voice-frequency telephone bands are translated to the line frequencies, and vice versa, by a double modula tion process. The first step takes place in the channel modulators forming part of a "12-channel bank" which translate the twelve voice bands to a group of lower sidebands, lying between 60 and 108 KHz. This is done in order to realize the performance obtainable with quartz filters, which type of filter would not be suitable at the lower frequencies that would be involved in a single modulation process translating the voice bands directly to the 12- to 60 KHz range. The second stage of modulation in the type "K" system takes place in a group modulator which translates the 60- to 108-KHz band as a whole, to the line frequencies between 12 and 60 KHz. The frequency allocations for the two stages of modulation are shown in Figure 16 11.

All carriers used in the modulation processes are sup pressed, but pilot frequencies of 12, 28, 56 and 60 KHz are transmitted from the K2 terminals along with the carrier speech bands. These serve automatically to regulate the gain and the frequency characteristics of the system, the 60-KHz pilot acting to regulate the flat gain of all of the line amplifiers, and the other three pilots serving to control the gain and the fre quency characteristic of "twist" amplifiers placed in the line at occasional intervals. The 60 KHz pilot, not used in the earlier K-1 system, provides a novel method of regulation. By keeping the sum of the transmitted pilot and all other frequencies at a constant power level, variations at the input of the line amplifiers is due only to the line and can be corrected by negative feedback.

Crosstalk is controlled for type "K" carrier operation by three measures, two of which are evident by inspec- tion of Figure 15-12. This figure shows the manner in which the carrier system is applied to the cables. The first crosstalk reducing measure is the use of pairs in two different cables for the two opposite directions of transmission. This effectively elimi- nates all near-end crosstalk between different type "K" systems using the same cables. The second cross- talk reducing measure is the frogging of the oppositely directed one-way carrier channels between the two cables at each carrier repeater point. As shown in Figure 16-12 the two directions of transmission are alternated between the two cables in successive

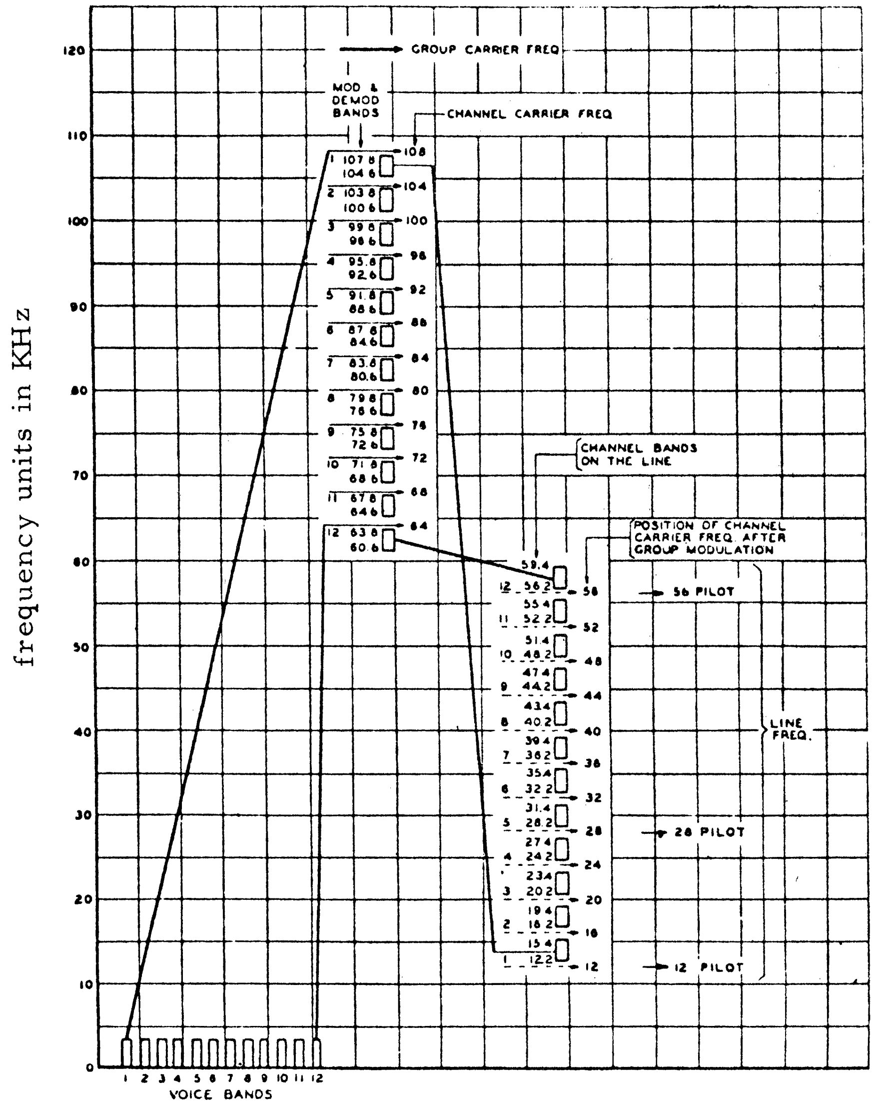


Figure 16-11 Frequency Allocations, Type K Carrier System

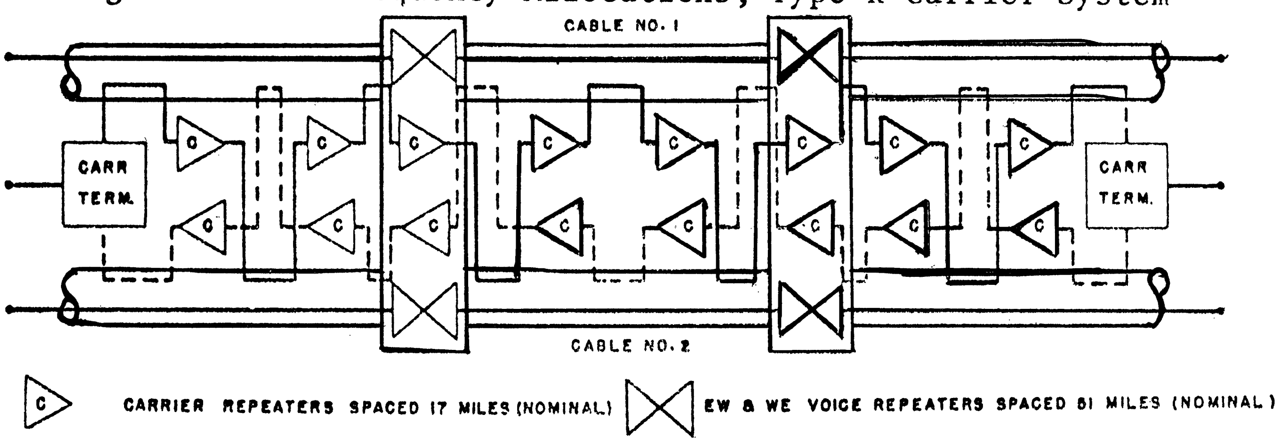


Figure 16-12 Block Schematic, Type K Carrier System

Type

K repeater sections. If the carrier circuits were not frogged, the high level signals at the output of a carrier repeater on one system could crosstalk into the paralleling voice-frequency pairs in the cable and could then be propagated back a short distance on the voice-frequency pairs to a point ahead of the carrier repeaters, where they could again crosstalk into another carrier system at the low level input to its carrier repeater. When the systems are frogged as shown, the second crosstalk coupling in the interaction crosstalk path just described terminates in the disturbed carrier system at a high level point at the output of a repeater, and therefore is less serious by the gain of a carrier repeater.

Crosstalk between systems transmitting in the same direction is reduced by the use of special balancing coils interconnecting the various "K" system cable pairs at certain repeater stations.

L The Type L-1 Carrier System was developed just prior to World War II but most of the installations were made after the war ended. The "L-3" Carrier System was introduced about 1953. Type "L" carrier telephone systems are designed for application to coaxial conductors. The telephone terminal equipment may also be used on microwave radio systems or other mediums capable of handling an extremely wide range of frequencies. The coaxial cable structure is inherently self-shielding against crosstalk from paralleling tubes.

Separate coaxial tubes are used for opposite directions of transmission, using the same frequency spectrum for both directions. It is, therefore, a true four-wire system. One coaxial tube transmits in one direction, and another tube transmits in the opposite direction.

The type "L-1" Carrier System has a capacity of handling either 600 telephone message channels or two one-way 2.7 KHz black and white television channels on one pair of coaxial tubes. Special terminals permit transmission of color television with slight picture degradation.

Type

L The type "L-3" Carrier System is capable of handling 1,860 telephone message channels or 660 message channels and one 4 MHz television channel simultaneously on one coaxial tube. Therefore, each pair of tubes will transmit 1,860 telephone conversations or 600 conversations together with 2 oppositely directed black and white or color television programs.

In the "L-1" system the first modulation step places 12 voice channels in the 60 to 108 KHz range to form a channel bank identical with the channel banks used in the "J" and "K" systems, as previously discussed. In a second step of modulation, five channel banks are translated to the frequency band between 312 and 552 KHz. This constitutes a basic supergroup of 60 voice channels. The final modulation step translates the supergroups to appropriate line frequency positions as shown in Figure 16-13, which also indicates the carrier frequencies used in the group and supergroup modulators.

The "L-3' Carrier System was designed to operate over a broader frequency band than the "L-1" system. This design provides for a maximum of as many as 1860 two-way telephone channels in the frequency range between 312 and 8284 KHz. As shown in Figure 16-14, ten 60 channel supergroups are modulated with appropriate carriers to form a master group of 600 voice channels in the frequency range between 564 and 3084 KHz. The first master group is transmitted on the line at these frequencies, while further modulation steps are used to place the second between 3164 and 5684 KHz, and the third between 5764 and 8284 KHz. In addition, a single supergroup may be transmitted below master group No. 1 in the basic supergroup range of 312 to 552 KHz.

Through the use of submaster and master group equipment in a manner similar to the "L-3" master group 1 arrangement, 720 channels can be realized on existing "L-1" lines. Figure 16-15 shows this 12 supergroup arrangement.

In both systems sixty-Hz A.C. power for the operation of repeaters is fed from terminal and main repeater points over a series loop made up of the two center conductors of the pair of coaxials used

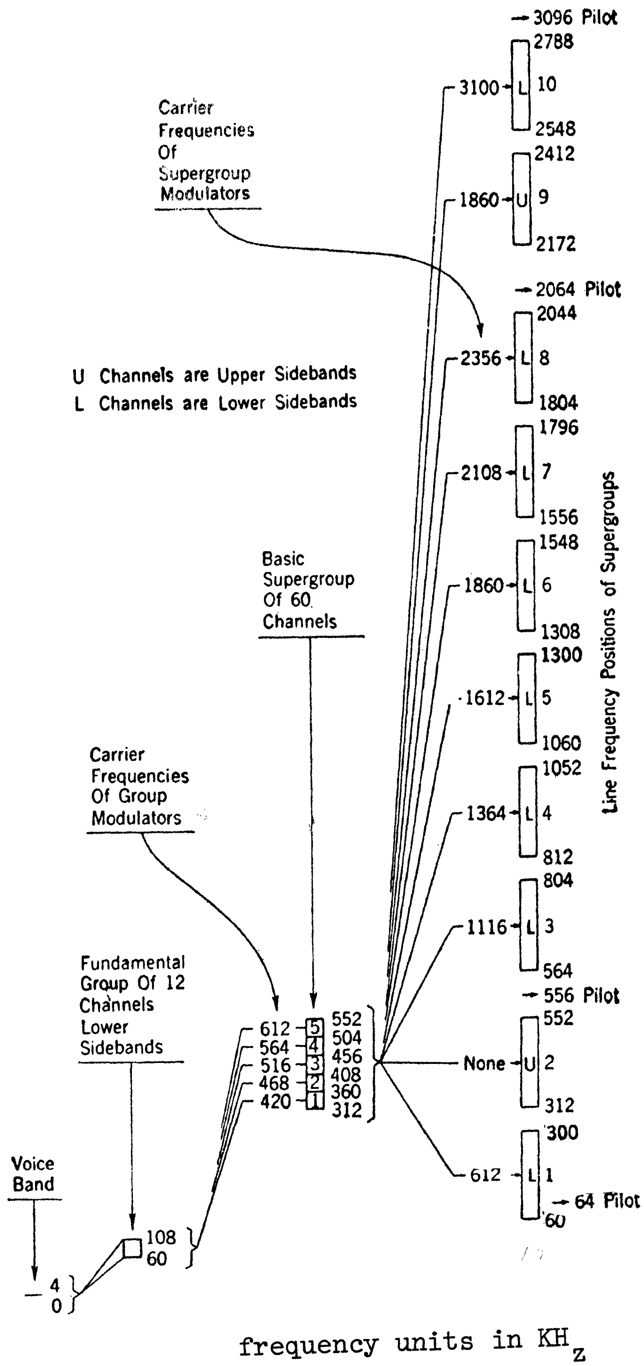


Figure 16-13 L1 Coaxial System Frequency Allocations

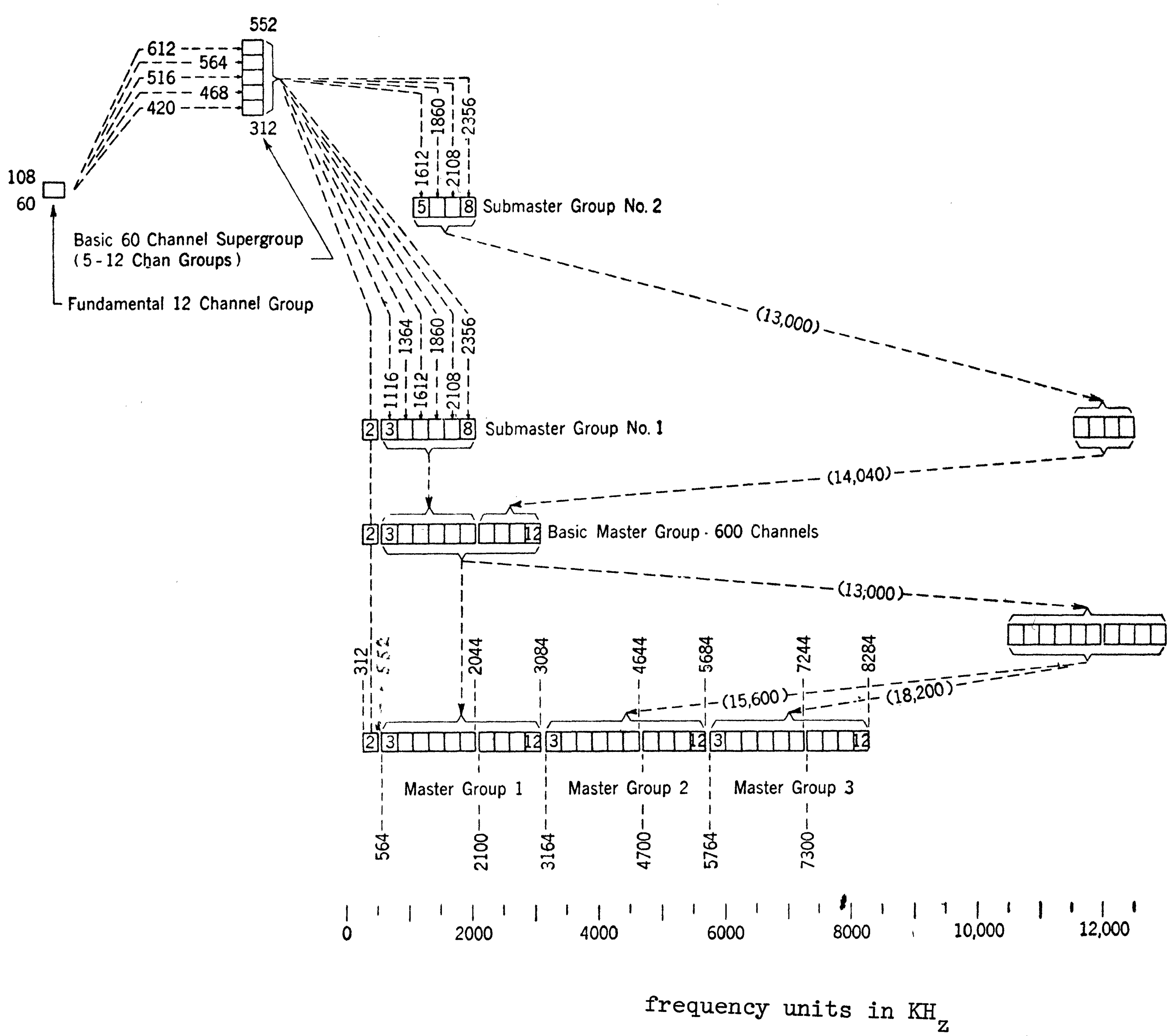


Figure 16-14 Frequency Translations of L3 System

Type

L for the two directions of transmission. The 60-Hz currents are separated from the high frequency transmission currents by means of power separation filters.

Regulation in the "L-1" system is accomplished with the use of four pilot frequencies of 64,556, 2064 and 3096 KHz. The 2064 KHz pilot is used to vary gains of amplifiers to compensate for line attenuation caused by temperature variations. The other three pilots control adjustable equalizers.

Regulation in "L-3" systems employees six pilot frequencies at 308, 566, 2064, 3096, 7266 and 8320 KHz. The 7266 KHz pilot controls amplifier gains compensating for line attenuation changes due to temperature variations. The other five pilots control adjustable equalizers.

The L-1860 multiplex plan differs from the earlier L-3 plan shown in Fig. 16-14 by eliminating the submastergroup stages of modulation. Additional carrier frequencies are used instead to modulate the supergroups directly to their basic master group allocation. The final frequency spectrum remains the same.

The L-4 system is the latest in the family of heavy duty coaxial cable transmission systems. It is capable of handling 3600 two-way message circuits (conversations) one each pair of coaxials. Although the nominal repeater spacing is reduced to 2 miles, the relative cost per channel mile is much lower than the L-3 system.

There are a five types of repeaters used in the L-4 system: basic, regulating and equalizing line repeaters, transmitting and receiving main station repeaters.

The basic repeater has a fixed gain that is about equal to the loss of 2 miles of 3/8 inch coaxial cable. At intervals of no more than five basic repeaters, regulating repeaters are used. These repeaters have a variable gain to compensate for changes in cable loss due to temperature. The equalizing repeater has all of the functions of the regulating repeater plus the circuitry for effecting remote control of six variable

Type

L equalizers under command from a main station control center. The main station repeaters are capable of all of the functions of an equalizing line repeater as well as providing 10 additional adjustable equalizer networks. The receiving main station repeater also provides post-regulation of the lower edge of the transmission band.

Just as in the L-3 system, a final multiplexing step is required to stack the 600 channel message blocks into one broadband array for L-4. The MMX-2 has been developed to translate six basic 600 channel message groups, LMX-2, into a 0.564 to 17.548 MHz broadband signal. The L-3 carrier terminal has been redesignated as MMX-1.

Automatic protection of transmission equipment is provided on a one spare for three regular basis, with individual mastergroups being transferred rather than a complete bank of six. Each MMX-2 bay accommodates three transmit and three receive L4 coaxial tubes with a maximum capacity of 10,800 voice channels. Although the MMX-2 terminal handles a frequency band twice as wide as MMX-1, the new system occupies less space, is easier to install, is less expensive, and produces a cleaner signal.

Development of a new L-carrier with even more capacity has begun. The L5 coaxial system is planned to use a pair of 0.375 inch coaxial tubes for 9,000 circuits consisting of 15 master groups in a bandwidth of 48 MHz. Route capacity is anticipated at 90,000 circuits at an even lower cost per channel mile than L4. Service is aimed at the early 1970's.

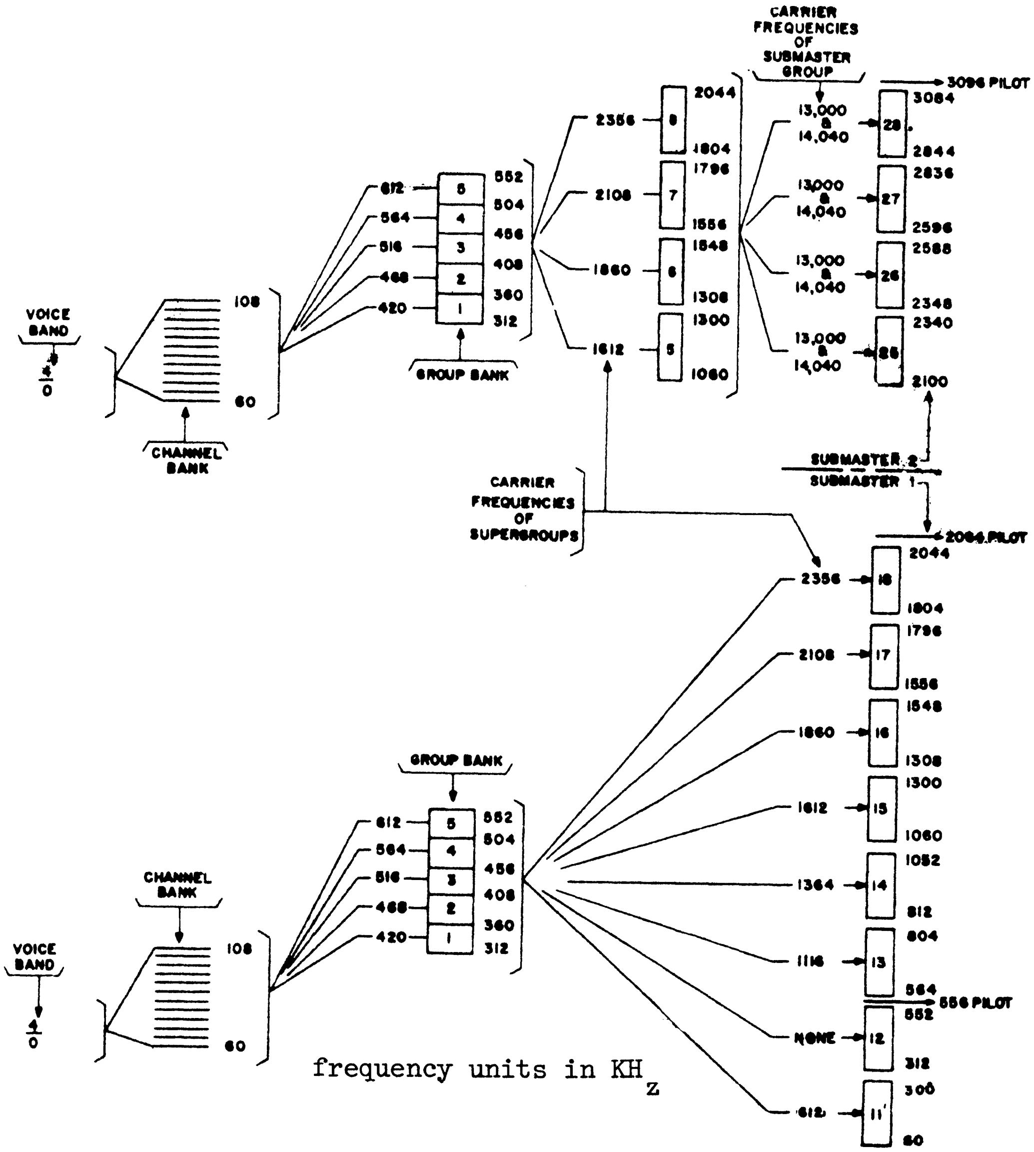


Figure 16-15 Frequency Allocations - 12 Supergroup Arrangement

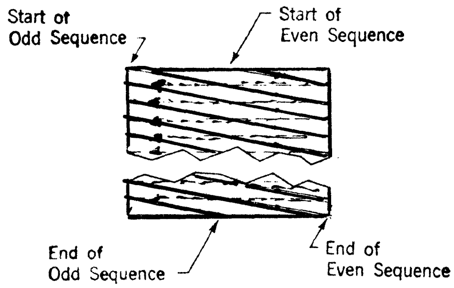


Figure 16-16 TV Scanning Sequence

Type "L" carrier system facilities are used for the transmission of television signals as well as for multiple channel voice transmission. Transmission of a television signal necessarily requires the employment of a very wide band of frequencies. This results from the fact that, television depends upon the repetitive detail scanning of a scene at extremely rapid intervals. Standard practice in the United States for black and white television calls for 525 horizontal lines for each complete scanning of the scene and for 30 complete scans per second, with the reproduced image having a width to height ratio of 4 to 3. In practice, a single complete scan or "frame" is accomplished in two steps. In the first step, the scene is scanned over the odd-numbered 262-1/2 lines to form one "field"; and the second step, it is again scanned over the even 262-1/2 lines. This procedure, known as interlaced scanning, affects the eye of the viewer of the image as if the total scene were being reproduced 60 times per second instead of 30, and thus minimizes "flicker."

The scanning sequence is shown in Figure 16-16. For each line, the electron beam in the television camera and in the cathode-ray receiving tube moves horizontally across the image. At the same time it moves vertically downward a distance corresponding

Type

L to two lines, under the control of the sweep circuit voltages applied to the deflecting plates or coils of the tubes. The scanning beam is blanked out at the completion of each horizontal line and returned quickly to the starting point of the next line, as indicated by the dotted lines in the figure. The process is repeated until the bottom of the image is reached. The beam is then blanked out for a longer interval while it is returned to the top of the image for the start of the next scanning sequence. The duration of each scanning line is 54 microseconds and 9.5 microseconds are allowed for the horizontal retrace of the beam. The image is scanned at the rate of 15,750 lines per second.

To maintain the exact synchronization between the camera and the receiver that is obviously necessary, synchronizing pulses generated at the image pickup point are applied to the camera tube and transmitted to the receiver along with the image signals. The synchronizing pulses are superimposed on the signal blanking pulses in such a way that they can be "clipped" from the image signal and applied to the saw-tooth generators which control the deflections of the scanning beam. As previously noted, the horizontal synchronizing pulses must recur at the rate of 15,750 per second and the vertical pulses, which return the beam from the bottom to the top of the image, must recur at the rate of 60 times per second.

Figure 16-17(A) indicates graphically the form of the TV signal at the receiver for two scanning lines covering a total time of 127.0 microseconds. The image signal, which is applied to the control electrode (grid) of the picture tube, may vary between zero amplitude for "white" and an amplitude which effectively blocks the electron beam to produce "black" in the image. The synchronizing signals, it may be noted, rise above the black level to a region sometimes called "blacker than black." Figure 16-17(B) illustrates the form of the longer vertical synchronizing pulse, which extends over a period of 190.5 microseconds. Vertical and horizontal synchronizing pulses are separated for application to their proper respective deflecting coils by means of a simple RC timing circuit which recognizes the

Type

L large difference in their time duration. The vertical pulse is "serrated" as shown so that the horizontal pulses will continue during the vertical deflection period to avoid the possibility of their falling out of step. A series of "equalizing" pulses is included before and after the vertical synchronizing pulse to take care of the time factors introduced by the fact that the first scanning field is completed in the middle of a line, and the second at the end of a line.

Considering the transmission of the total television signal, it is evident that the indispensable synchronizing pulses alone make the signal rather complex. The part of the signal carrying the image must be much more complex if satisfactory image detail (resolution) is to be obtained. Thus if a scene is to be analyzed as the horizontal beam crosses it in the same detail as is provided by the 525 line dissection of the image vertically, the signal might take 4/3 x 525 or 700 different values for each horizontal trace. This would correspond to a variation at the rate of 350 Hz per line which would mean 350 x 525 x 30 or approximately 5-1/2 MHz. Furthermore, if the scene being televised was one in which there were many transitions between black and white, such as a black and white checkerboard pattern, the image signal would tend to take the form of a square wave. Accurate transmission in such a case would theoretically involve frequencies extending toward infinity. Actually, practical experience indicates that entirely satisfactory resolution for black and white images is obtained from a video signal including frequencies up to a maximum of about 3 million cycles, although the standard broadcast TV signal is normally considered as 4.2 million cycles in width. In any event, it is to be noted that the lower frequencies are indispensable. Included here are the vital synchronizing pulses as well as the major values in the image structure. The higher frequencies become increasingly less important as they approach values which tend to enhance the detailed accuracy of the picture beyond the practical limit of perception of the normal eye. As might be expected also, the major energy content of the signal tends to be concentrated in the lower frequencies.

Type

L For transmission over the Type "L-1" carrier system, the frequency range on the line between about 200 and 3100 KHz is employed. The lower frequency is limited by equalization difficulties and the upper by the characteristics of the line repeaters. Since the standard video signal begins at about 30 Hz and may be considered as extending upward, in this case, to about 2800 KHz, it is necessary to translate it by modulation procedures to place it in the proper position for transmission over the line. This is accomplished by two stages of modulation, as indicated in Figure 16-18. The carrier frequency of the first modulation stage is 7944.72 KHz. A bandpass filter permits the passage of the lower sideband, extending from about 5100 KHz up to the carrier frequency plus a small part of the upper sideband, extending from the carrier frequency up to about 8100 KHz. This latter is known as a "vestigial sideband" and is included in the passed band to insure first that there is no clipping of the lower sideband and second to reinforce the lower frequencies of the signal which are of vital importance. The second modulation stage employs a carrier of 8256 KHz to translate the foregoing main and vestigal sidebands to the range between about 200 and 3100 KHz, with the carrier frequency now appearing at 311.27 KHz.

The color television currently standard in the United States employs a video signal extending from a few cycles to about 4.2 MHz. This is necessary because the color or chrominace information of the signal is modulated on a subcarrier whose frequency is 3.579545 MHz.

Such a frequency band is too broad for transmission over ordinary "L-1" facilities. Color transmission in this case requires the use of an additional modulation step which effectively shifts the color subcarrier down to a value of 2.612 MHz. This results in some degradation of the "luminace" or black-and-white part of the signal which, however, has little visible effect in a color picture. When a purely black-and-white signal is sent over the same line, an automatic switch changes the filters so as to permit the signal to occupy the full frequency band.

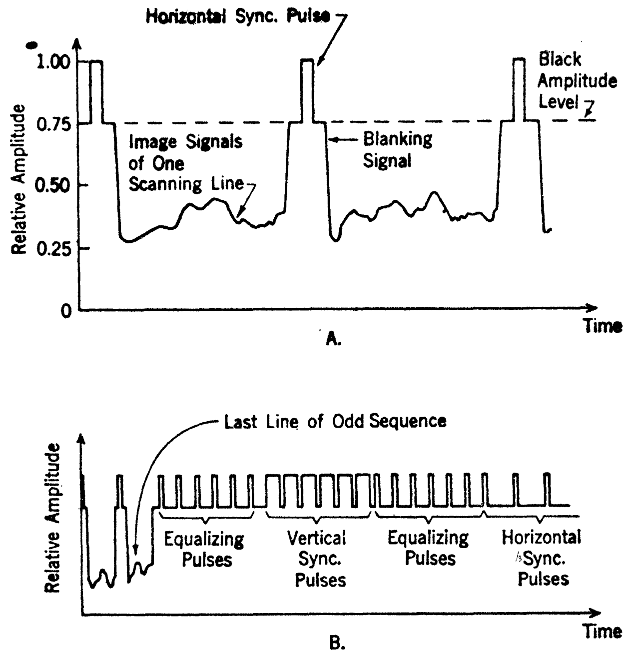


Figure 16-17 TV Signal Form

Type

L Transmission of an unmodified color signal is well within the capacity of "L-3" systems. Here, the 0-4.2 MHz color signal is modulated with a 4139 KHz carrier so that it appears on the "L-3" line as an upper sideband extending between the carrier frequency and about 8340 KHz. A vestigial lower sideband extending downward to approximately 3640 KHz is also transmitted. This still leaves room for 660 telephone circuits in the 512 KHz to 3084 KHz band. At the receiving end the video signal is restored to its original 0-4200 KHz band by modulation with the same carrier frequency of 4139 KHz. The demodulating carrier is generated locally but is controlled by synchronizing pulses transmitted along with the video signal.

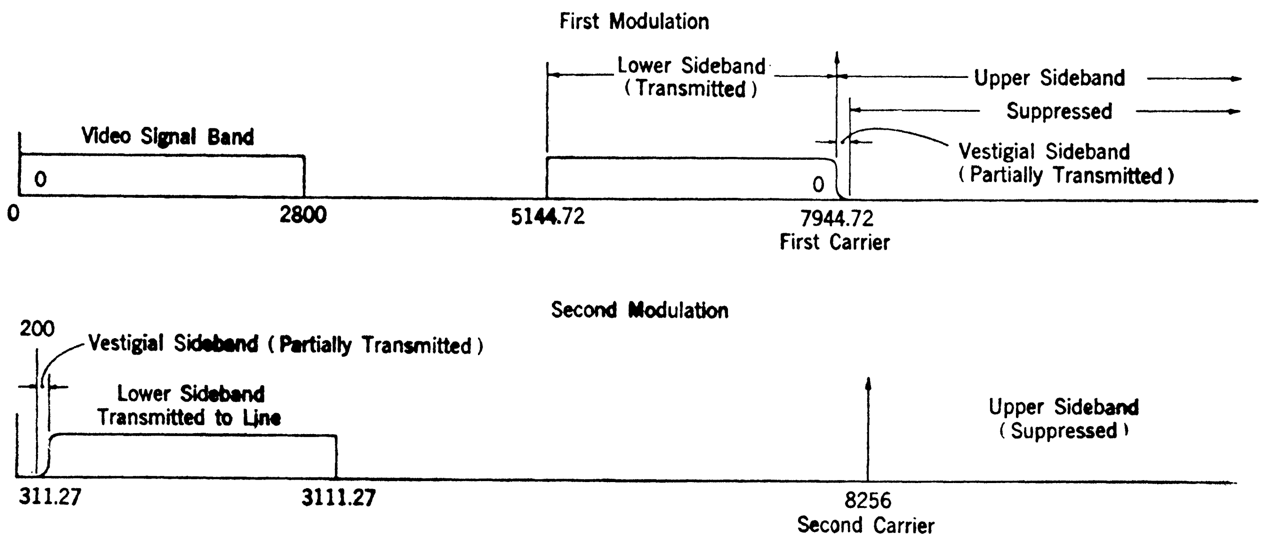


Figure 16-18 Video Signal Frequency Translations

Type

M The "M1" carrier system was developed primarily to provide rural telephone service by means of carrier transmission over power distribution lines, open wire telephone lines, or a combination of the two. Unlike other systems, carrier equipment is installed on the subscribers premises. The "M1" system uses amplitude modulation with double sideband and carrier transmitted. A maximum of five frequency divided channels are provided. Transmission from the common (central office) terminal is within a frequency band of approximately 152 KHz to 233 KHz. From the subscribers' terminals the transmitted frequencies are in a band from approximately 287 KHz to 413 KHz; on a reverting call connection the carrier frequency of the calling subscribers transmitter is automatically raised by 10 KHz.

Ringing, dial and switch-hook signals are accomplished by the interruption of the carrier; a 30 Hz rate is used for ringing. Power is derived from the 60 Hz power line.

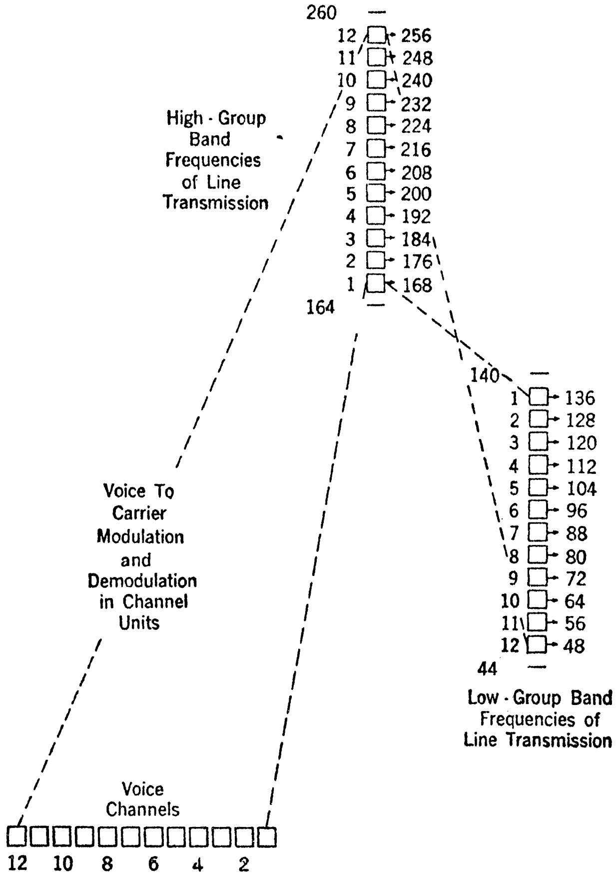
Type

M The length of lines is limited to about 15 to 20 miles for power lines or to about 40 miles for open wire telephone lines.

N The "N1" carrier system was designed specifically for short haul circuits up to 200 miles in cable. The system provides 12 two-way telephone circuits on two nonloaded pairs or a quad in a single cable. The system is designed to operate on a "4-wire" basis using separate pairs and different frequency bands for each direction of transmission. Double sideband modulation with transmitted carriers spaced 8 KHz apart is utilized, considerably simplifying carrier supply arrangements compared to single sideband carrier systems.

The frequency allocation of the Type "N" system is given in Figure 16-19 and 16-20. The frequencies on the line are nominally 164 to 260 KHz in one direction of transmission with channel 1 carrier at 168 KHz and channel 12 carrier at 256 kc. In the other direction the frequency band nominally is 44 to 140 KHz with channel 1 carrier at 136 KHz channel 12 carrier at 48 KHz. Group modulation from one frequency band to the other is accomplished by modulating the group with the 304 KHz group carrier and selecting the lower sideband. An additional channel numbered 13 and occupying the frequencies 40 and 264 KHz is available to replace channel 1 in case signaling difficulties are encountered in long systems, or to replace any other channel which may be inoperative due to interference from extraneous sources. The frequency space below 36 KHz is unused except for the transmission of d-c power over the simplex to repeaters. Operation on a channel 2-13 basis is now preferred over channels 1-12 due to superior frequency response and noise performance.

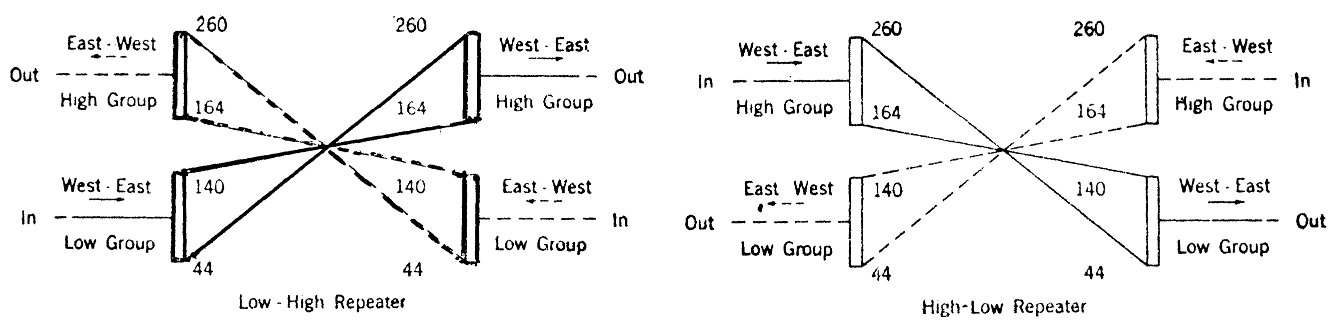
Devices known as "compandors" are used to compress the range of speech volume as transmitted to the line and to expand it to its original range at the receiving end of the line. This process improves the signal to noise and crosstalk ratio for the system and eliminates the need for special crosstalk balancing and noise treatment for the cable pairs.



frequency units in KHz

Figure 16-19 Type N Carrier Frequency Translations

Channels 1-12



frequency units in MHz

Channels 1-12

Figure 16-20 Type N Carrier Repeater Frequency Translations

Type

N Frequency frogging is used at each repeater whereby the frequency groups are interchanged for each direction of transmission, and the frequency sequence of the individual channels is inverted. This is done by modulating both groups with a single 304 KHz carrier. The frequency frogging minimizes the possibility of interaction crosstalk around the repeaters through paralling V.F. cable pairs. It also permits the same repeater spacing to be used for both directions of transmission.

Regulation of line transmission is accomplished in each repeater and in the receiving group unit in each terminal by thermistors in the feedback circuits of the respective amplifiers using the energy of the transmitted frequencies (primarily the channel carriers) as pilots.

Another feature of the Type "N1" carrier systems, not provided on previous types, is a built-in signalling system using a single frequency above the voice range (3700 Hz) in each direction of transmission. These signaling systems are suitable for intertoll dialing and supervision.

The "N2" carrier terminal is a transistorized version of this system designed to meet the transmission performance requirements of intertoll trunks handling direct distance dialing and message channel traffic.

The transmission plan is the same as for the earlier "N1" terminals. Since carrier line frequencies, levels, type of modulation, and the use of compandors is the same, the "N2" terminals may connect to the same cables and the same repeated line circuits that are suitable for "N1" use.

Type

N The "N2" terminals are designed to work with separate, type E, single-frequency signaling equipment or multi-frequency key pulsing. No provision will be made for the 3700 Hz out-of-band signaling provided optionally for "N1" terminals.

"N3" carrier is a 24 channel, completely transistorized four-wire short haul cable system. "N3" operates on the same frequencies as "N1" and "N2" over "N" repeated lines.

"N3" carrier uses the building block of a twelve channel group. The voice signals are compressed, modulated, filtered and combined in the transmitting channel equipment. The reverse process takes place in the receiving channel equipment. The channels are filtered, demodulated and expanded in order to retrieve the voice frequency. Transmitted carriers are used to demodulate the even numbered channels. Nontransmitted carriers are obtained from a common supply to demodulate the odd numbered channels. Two twelve channel groups are combined into a broadband 24 channel signal.

"N3" carrier group equipment is similar to that used in "N2". High-group and low-group transmit and receive units are available for application to any established N carrier line frequency plan.

The "N3" carrier system uses a common carrier supply rather than a locally generated one. The supply is derived from an 8 KHz oscillator operating into a binary divider for stability. A 4 KHz tap of a "J", "K" or "L" primary supply can be used when available.

O The Type "O" carrier system is designed to provide relatively short-haul carrier channels over open wire conductors on an economic basis. It makes use of miniaturized equipment and many of the other features of the Type-N system including compandors, frequency-frogging and built-in 3700 Hz signaling.

Type

O The "O" carrier system operates on a two wire basis over an open wire pair suitably transposed for such carrier transmission.

"O" carrier provides a maximum of 16 voice channels "stacked" from 4 subsystems designated OA, OB, OC and OD. Each subsystem provides 4 channels in frequency ranges as follows:

	Low Groups		High Groups
OA System	2 to 18 KHz	and	20 to 36 KHz
OB System	40 to 56 KHz	and	60 to 76 KHz
OC System	80 to 96 KHz	and	100 to 116 KHz
OD System	120 to 136 KHz	and	140 to 156 KHz

If all 4 channels of the OA system are used, the V.F. channel on the pair must be discontinued, but some carrier telegraph channels may be added in the spectrum space below 2 KHz. If the OA system is operated as a 3 channel system, it may be used as a supplement to a V.F. circuit on the same pair in exactly the same manner as a Type C system. The OB, OC, and OD systems use frequency frogging at the repeaters in the same manner as the Type "N" cable systems. OB, OC, and OD systems may be used on the same pair as Type "C" or Type OA systems (but not both) to obtain 12 additional carrier channels. Two types of repeaters are provided for the "O" carrier systems. One type is for the Type OA system which does not provide frequency frogging. The other is for the OB, OC, and OD systems which do provide such frogging.

Unlike the "N" system, twin sideband transmission is used, with the upper and lower sidebands of a single carrier providing two channels transmitting in the same direction. Thus only two carriers, spaced 8 KHz apart, are required to obtain the 4 voice channels. Figure 16-21 indicates the frequency translations employed in the O system. The two carriers are transmitted over the line, and their combined power is used for regulation of the amplifiers at repeater and group receiving terminals to correct for line attenuation variations.

Type

ON The Type "ON1" cable carrier system is a composite system using Type "O" carrier terminal equipment and Type "N1" repeater equipment. Since the Type "O" terminal equipment provides for single sideband channel operation, it is possible to obtain 5 basic 4 channel groups (20 channels total) within a line frequency group band width equivalent to that used for the 12 double sideband channels of the Type "N1" system. Figure 16-22 indicates the modulation and demodulation steps of the Type "ON1" system and the frequency spectrums used. Note that the basic 4 channel group frequency band is the same as for the "O" system and the high and low group line frequency spectrums are approximately the same as for the Type "N1" system.

(Low group 4KC lower at both ends and)
(High group 4KC higher at both ends)

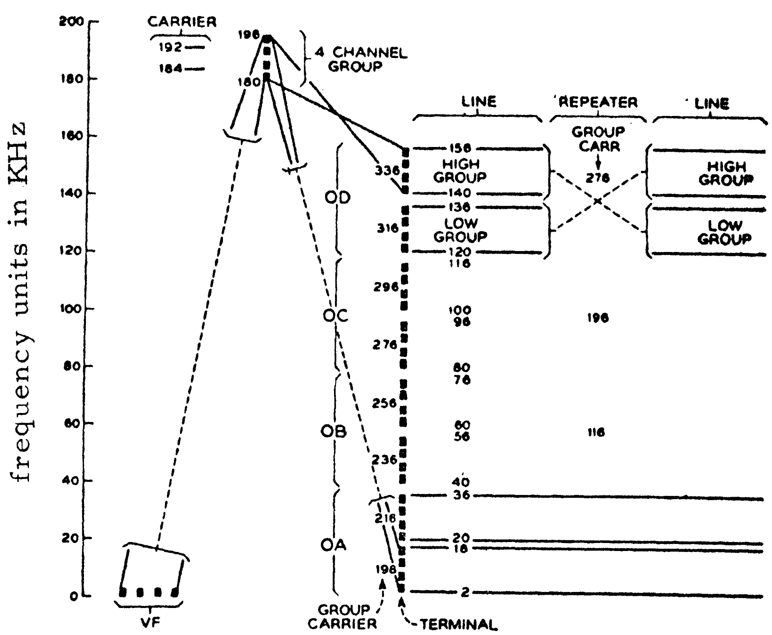


Figure 16-21 Type O Modulation Plan

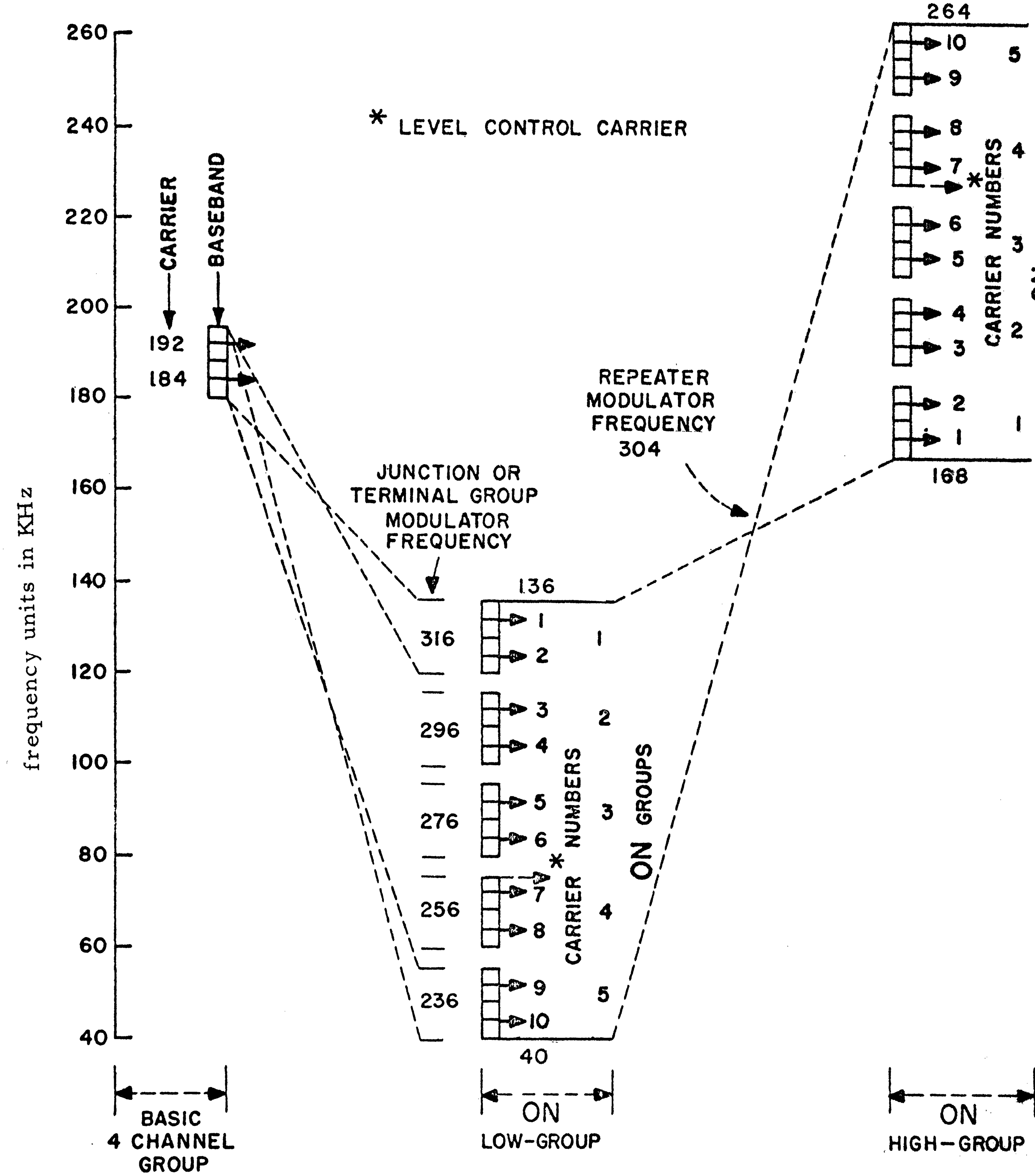


Figure 16-22 ON1 Carrier System Modulation Plan

Type

ON Because of the ease of transition between cable and open wire, and because this transition can be made at any point, the "ON1" system is adapted to open-wire, cable and radio-link combinations. For example:

(1) Any number of type "O" channels up to 20 can be installed at one end of the cable, transmitted over two pairs in the cable to a junction with one or more open-wire lines, and then distributed to the open-wire facilities in any way desired. The 20 channels might be divided among five OB systems on five separate open-wire pairs or connected to a family of OA, OB, OC and OD Systems on one pair, and a fifth system of any type on a second pair.

(2) The cable can be located between two open-wire lines. It is not necessary that the cable terminate at a central office at either end. Alternately, open-wire can occur between two cables.

(3) The "ON1" arrangement can be applied readily to radio systems either directly or through intervening cable or open wire.

(4) Type "ON1" channel terminals can be installed at each end of the cable to obtain a maximum of 20 all-cable circuits per quad in "N" cables.

A terminal is made up of standard "O1" channel units and group-transmitting units, and slightly modified "O1" group-receiving, twin-channel, and group-oscillator units.

The "ON1" repeaters located between the junction or the terminal and the type "N" carrier line are similar to "N1" repeaters.

In order to more fully utilize the frequency carrying capabilities of the "N" type high frequency line and of some microwave radio systems the "ON2" carrier system was developed. The "ON2" system provides 24 voice-frequency channels as compared to the 20 obtainable with "ON1". The "ON2" carrier can be used for systems to be operated over all cable, all radio, and cable-radio combinations.

<u>Type</u>

ON Standard arrangements are available for stacking four of these systems so that up to 96 voice frequency channels can be multiplexed on a single radio path.

The 24 channels of the "ON2" system are arranged at the terminal in the frequency band from 36 to 132 KHz (see Figure 16-23). For transmission on the line 36 to 132 KHz is used as the low band and is modulated with a 304 KHz oscillator to produce 172 to 268 KHz which is the high band. The resultant carriers are the same as those of channels 2 to 13 of the "N1" carrier system.

Like the "ON1", the "ON2" is basically an arrangement of stacked "O" carrier terminals which are combined for transmission over an "N1" carrier line. The "ON2" uses a stack of 6 of these 4 channel terminals in order to obtain a total of 24 channels. As indicated in Figure 16-23 the only differences in the 4 channel terminals used for "ON2" as compared to "ON1" are in the group oscillator and the group receiver.

P Unlike other types of carrier systems, the "P" was designed to operate between a telephone office and small groups of rural customers instead of between two telephone offices. This system provides up to four two-way channels for simulataneous operation on a single pair of wires above a voice-frequency circuit. Each channel uses a transmitted carrier and double-sideband transmission for each direction. The carriers are spaced at 12-KHz intervals and are arranged in the frequency band between 12 and 96 KHz.

Each channel, capable of serving eight telephones on a party line, requires one terminal at the central office and another mounted on a pole near the customers' premises. To make this system economically feasible, it was necessary to reduce the cost of terminal equipment to a minimum. This was accomplished by using the latest devices and techniques, including transistors, silicon aluminum varistors, ferrite inductors, printed wiring, etc.

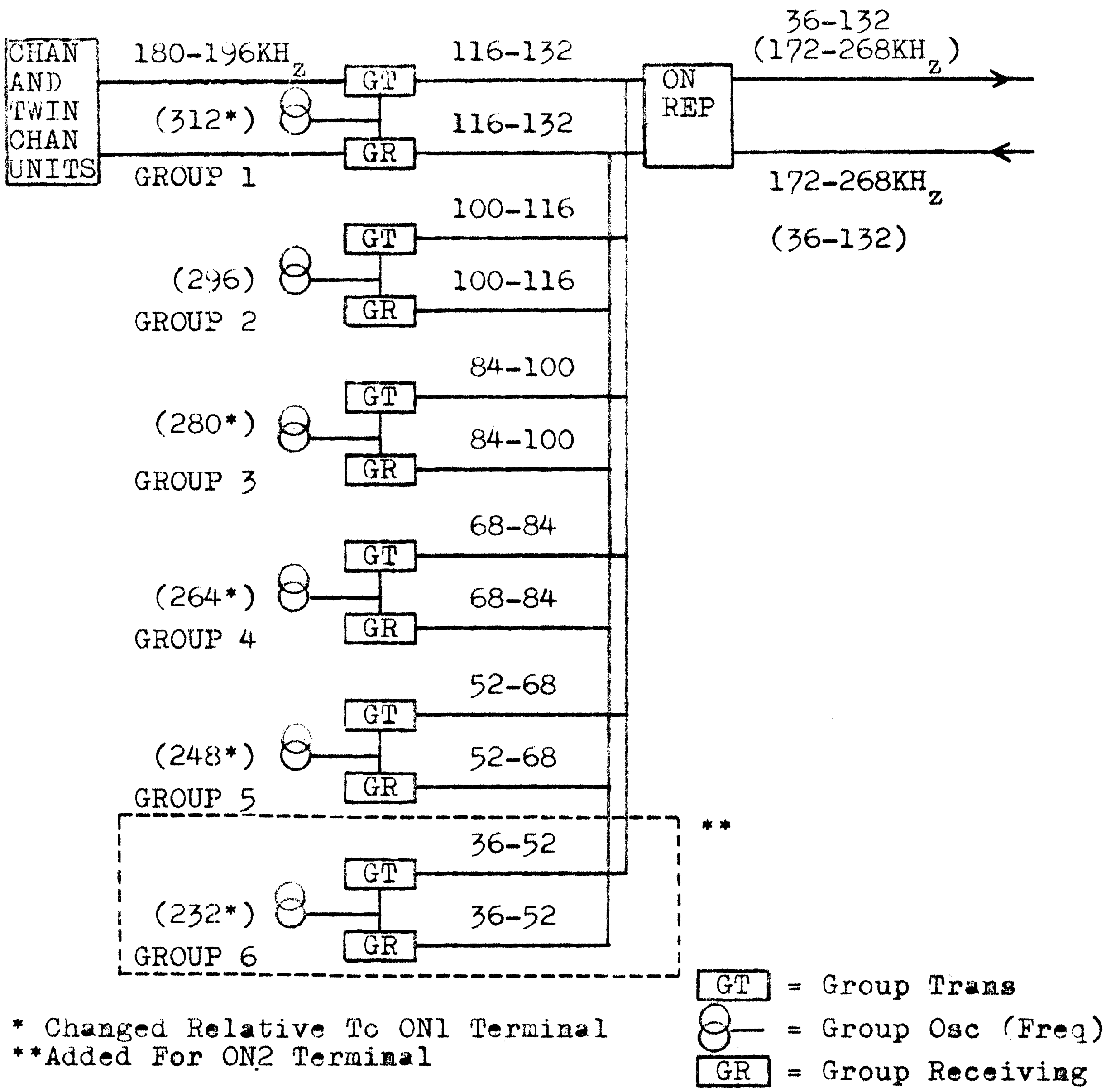


Figure 16-23 Block Diagram of 24 Channel ON2 Terminal

Type

T The "T1" Carrier System, a completely transistorized 24-channel PCM system, is designed to provide an economical facility for short haul trunks primarily in the large metropolitan areas.

In the type "T1" Carrier System, 24 voice channels are combined into a single pulse amplitude modulated (PAM) wave by time division multiplexing. The sampling rate for each channel is 8000 samples per second. The PAM signal is compressed and encoded into a pulse code modulation (PCM) signal for transmission over the line. A 7-digit code is used to represent each PAM sample. At the distant terminal, the received pulse train is decoded, expanded, amplified, and distributed to 24 low-pass filters. The low-pass filters extract the envelope of the received PAM pulses, which is a very close approximation to the original signal.

An additional digit is added to the 7-digit code representing the PAM sample to carry the signaling information. This increases the number of digits per channel to eight and provides a 2-state signaling channel which is adequate for dial pulse and E & M lead signaling. For revertive pulse signaling a 3-state signaling channel is required. The additional state is obtained by using the least significant digit (seventh digit in the code representing the PAM sample) for signaling information while pulsing is in progress.

In a time division system, synchronization of the terminals at the two ends is essential. Synchronization includes both timing and framing. Timing is marking the individual pulse positions or times when a decision must be made as to whether or not a pulse is present. Framing is the process of uniquely marking a particular pulse position so that the individual channel pulse positions are identifiable. The transmitting section of the terminal obtains its timing information from a 1.544-MHz crystal oscillator. The repeaters and the receiving section of the terminal derive their timing from the incoming pulse train.

Type

T Framing is accomplished by inserting a framing pulse position after each group of 24 coded samples. A pulse is inserted in the framing pulse position on every other frame; on the alternate frames the pulse position is left blank. This gives the framing pulse a unique pattern that is seldom duplicated by any other pulse position for more than a few frame intervals at a time.

The signal to be transmitted over the repeatered line consists of a train of pulses. The pulse position repetition rate is 1.544×10^6 positions per second. This is made up of 24 eight-digit codes in each frame (7 for the PAM sample and 1 for signalling for each of the 24 channels) plus 1 framing digit or 193 pulse positions per frame. Since the sampling rate is 8000 times a second, there are 8000 frames transmitted each second. The information in the signal is contained in whether or not a pulse is present in a particular pulse position.

Figure 16-24 is a simplified "T1" system. A system terminal consists of 24 channel units and 29 common equipment units. The channel units contain the signaling converters and connect to two-wire or four-wire trunk circuits. The four-wire type units also contain individual channel amplifiers.

The common equipment includes the compressor, encoder, decoder, expandor, common amplifier, and the digital control circuits. The sampling and demultiplex gates with their associated filters are also considered part of the common equipment, because it is desirable to concentrate these circuits into a few packages located physically close to the remainder of the common equipment in order to reduce lead length. Therefore, the common equipment alone provides 24 complete 4-wire voice channels. The channel units serve only as the matching units between these channels and the external trunk circuitry.

The "T1" carrier system is designed to work on existing types of 19- and 22-gauge paper - or pulp-insulated staggered twist, paired exchange cables. Short sections of 24- and 26-gauge cables may be used if the

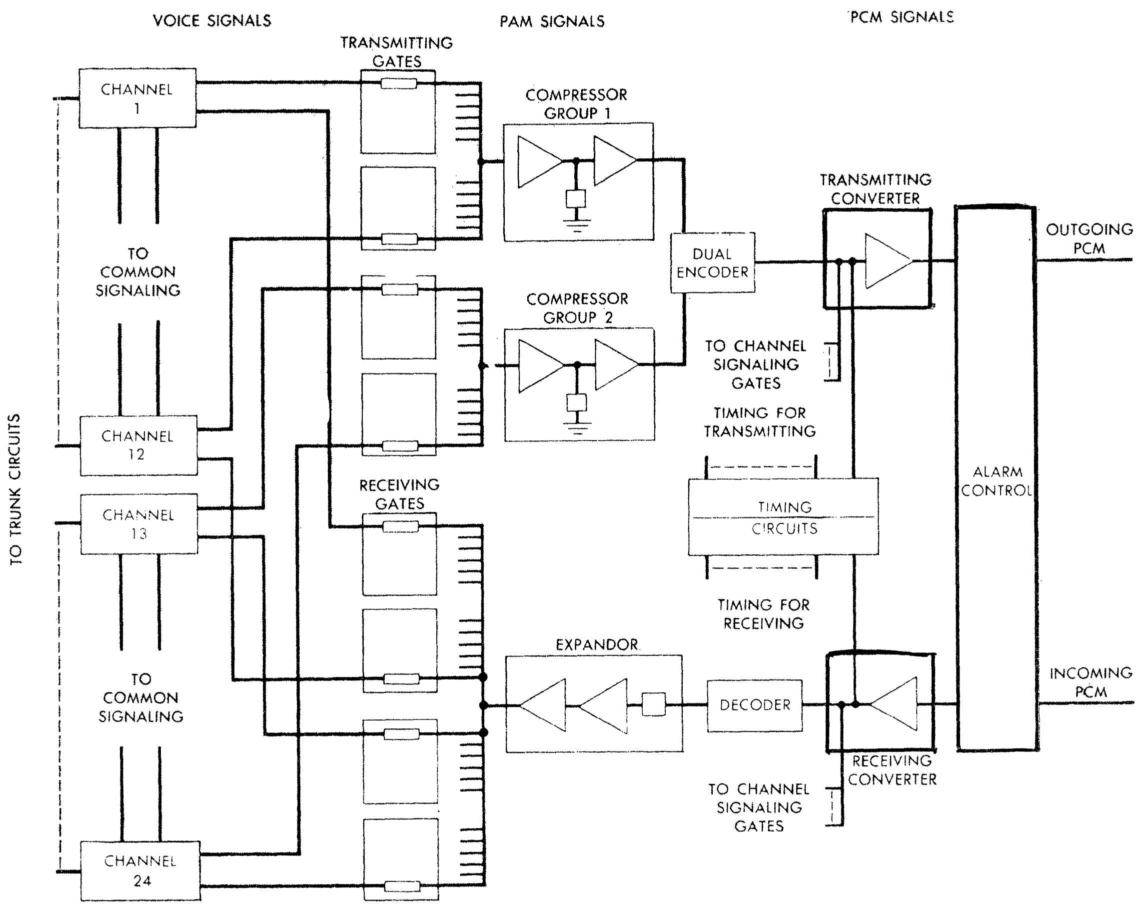


Figure 16-24 T1 Carrier Terminal

<u>Type</u>

T repeater spacing is reduced appropriately. The system will operate over these types of facilities for distances up to at least 50 miles. Two cable pairs are required, one for each direction of transmission.

To reduce the effect of intersystem crosstalk, the particular pulse train selected for the "T1" system uses bipolar pulses. The signal to be transmitted over the repeated line consists of a train of pulses. The information in the signal is contained in whether or not a pulse is present in a particular

Type

T pulse position. Successive pulses, regardless of the number of intervening spaces, are made to be of opposite polarity. However, the significance of a pulse in any particular pulse position is independent of its polarity. Therefore, it is possible to convert from a unipolar pulse train (all pulses of the same polarity) to a bipolar pulse train (successive pulses of opposite polarity) by inverting every other pulse and to return to a unipolar pulse train by full wave rectification.

Attenuation and distortion of the pulse train results from transmission over cables. Since the information is contained in the presence or absence of a pulse in a particular pulse position, the signal is capable of regeneration. Regeneration consists of deciding whether or not a pulse is being received in a particular pulse position and, if one is, of sending out a completely new pulse. Deciding whether or not a pulse is being received entails two things: knowing when to make the decision, i.e., timing, and determining whether or not the received voltage exceeds a predetermined threshold. All of the repeaters in the "T1" system are of the regenerative type.

Timing is accomplished by rectifying the incoming bipolar pulse train to obtain a unipolar pulse train with 1.544×10^6 pulse positions per second. This unipolar pulse train has a strong single-frequency component at 1.544 MHz, which is at exactly the same frequency as the crystal oscillator in the transmitting terminal. This sine wave is used to mark the individual pulse positions.

The pulses are regenerated by blocking oscillators (separate blocking oscillators for the positive and negative pulses of the bipolar pulse train). A threshold bias circuit sets the decision level to regenerate a particular pulse. Both a received pulse above the threshold and a timing pulse from the timing circuit are required to trigger the blocking oscillator.

Type

U The U1 Carrier System, is a new carrier telephone service for customer loops. Using frequency modulation techniques, the system provides an additional two-way, single-party telephone circuit over an existing customer's loop.

A single system for one customer loop consists of only two relatively small transmitter/receiver units. One unit is located in the central office and transmits at 30 KHz; the other unit, called the "subscriber set," transmits at 18 KHz and is located on the customer's premises. A conventional telephone is connected to the subscriber set.

The system has a transmission range of 15,000 feet over nonloaded, 26-gauge, copper conductor pairs (or greater length on coarser gauges equivalent to 40 db loss at 30 KHz), and can transmit either dial pulse or Multifrequency signals and the necessary supervisory signals. A system can provide "second line" service to a single customer, or it can be used to provide the only service to another customer located near an existing customer loop.

The carrier system (added channel) is connected to the existing loop (original channel) through high-pass filters. The original channel remains undisturbed except for the insertion of two low-pass filters. One low-pass filter is included in the subscriber set of the carrier system; the other filter is installed in the central office. When the carrier system serves a separate customer over a working loop (not as second line service to the same customer), an option is available which assures privacy for each customer. When the system is used in this manner, the low-pass filter and two capacitors in the subscriber set are not used, and identical elements are installed outside the customer's premises (on a pole for example). Thus, signals from the original channel are not within reach of the added channel customer. The option protects both customers equally.

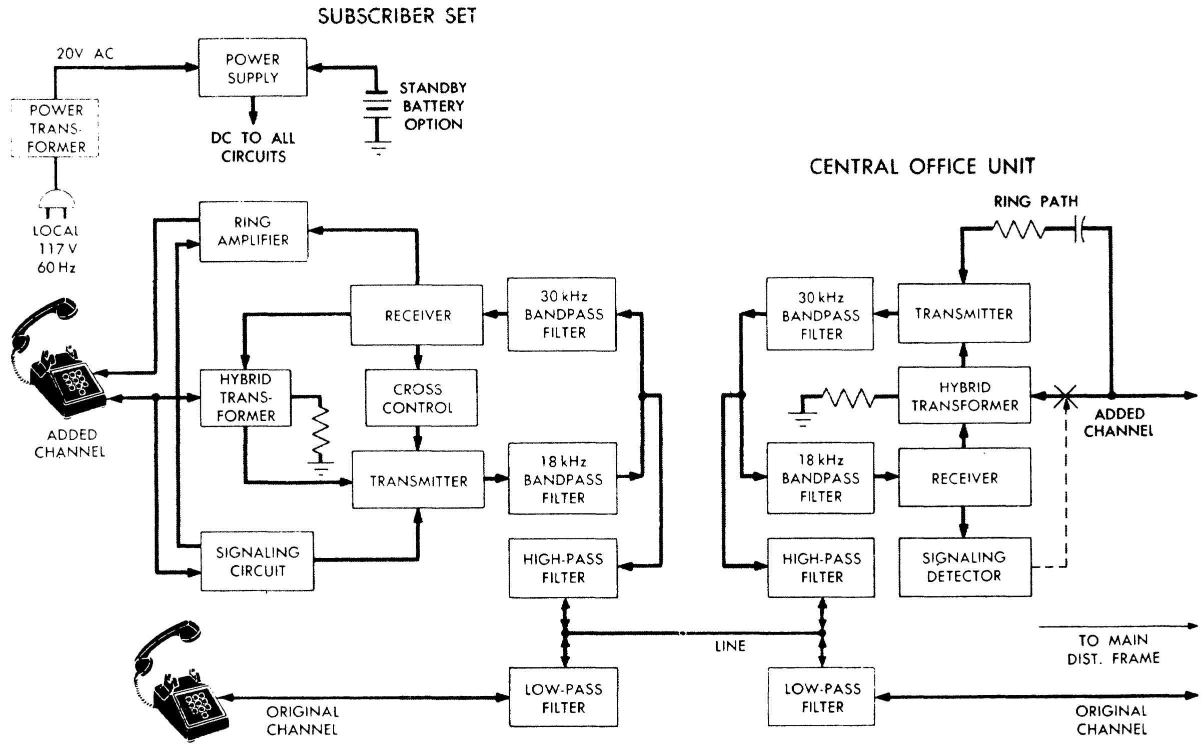


Figure 16-25 U1 Carrier System

Type

U In each unit of the carrier system (see Figure 16.25), the transmitter and receiver are coupled by a hybrid transformer at voice frequencies and by parallel band-pass filters at carrier frequencies. The units are basically similar except for special circuits required for ringing and supervision. The subscriber set also contains a power supply circuit, which obtains its power from the commercial source in the customer's home.

The transmitter in the central office unit consists of a buffer input stage, a 30 KHz carrier oscillator, and a buffer output amplifier. The carrier oscillator

Type

U is modulated by voice frequencies through a bias voltage supplied by the buffer input stage. The dc bias voltage is adjustable so that the carrier frequency can be set to 30 KHz when the unit is manufactured. The buffer amplifier following the carrier oscillator derives the modulated carrier signal through the 30 KHz bandpass filter to the customer loop.

The central office receiver consists of a two-stage preamplifier, an 18 KHz demodulator, a low-pass filter, and an audio output amplifier. When the voice frequency signal is recovered by the demodulator, the low-pass filter passes the signal to the two-stage output amplifier and rejects carrier frequencies.

Dial pulses (transmitted from the subscriber set by interruptions of the 18 KHz carrier at the dial-pulse rate) are recovered by the signaling detector circuit, which responds to the presence or absence of the dc voltage at the output of the low-pass filter. This signal determines the state of a carrier detector transistor, which in turn drives a relay. Contacts of this relay are in the two-wire voice frequency line from the central office. Switching equipment in the central office responds to these relay contacts as the customer goes off-hook or when he dials on the telephone set.

Supervision in the opposite direction is accomplished by modulating the 30 KHz carrier with a portion of the ringing signal. When the telephone set is on-hook, however, the relay contacts in the voice frequency line are open, and there is no continuity from the central office switching equipment to the input of the hybrid transformer. Therefore, to sound the bell of the customer's telephone, a separate, high-loss path is provided from the two-wire line directly to the central-office transmitter. An 85-volt ring signal causes the 30 KHz carrier oscillator to deviate almost 2 KHz.

The subscriber set for the carrier system consists of a transmitter and receiver, similar to those of the central office unit, a cross control circuit, a ring amplifier, a signaling circuit, and a power supply.

Type

U The transmitter has an adjustable dc bias circuit, specifically designed to minimize drifting of the carrier frequency during dial pulsing. The receiver does not require a carrier detector circuit since the carrier signal from the central office is continuously transmitted.

The automatic cross control circuit reduces the probability of "far end" crosstalk between systems when several systems are superimposed on pairs in the same cable and the systems are located at various distances from the central office. The automatic cross control is a clamping circuit between the carrier oscillator and the output buffer stage which adjusts the level of the transmitted signal depending on the level of the received signal. The circuit can reduce the transmitter output to a level 15 db below maximum when the cable loss is zero.

The ring amplifier circuit in the subscriber set is driven from the audio output stage of the receiver. When the telephone set is off-hook, the ring amplifier circuit is disabled. The amplifier in one subscriber set can supply power to sound the bell in as many as three telephones.

A two-transistor network in the subscriber signaling circuit is energized when the telephone set goes off-hook. The circuit supplies power to the transmitter and disables the ring amplifier.

16.10 MICROWAVE RADIO SYSTEMS

The essential elements of any radio system are (1) a transmitter for modulating a high-frequency carrier wave with the signal, (2) a transmitting antenna that will radiate the energy of the modulated carrier wave, (3) a receiving antenna that will intercept the radiated energy after its transmission through space, and (4) a receiver to select the carrier wave and detect or separate the signal from the carrier. Although the basic principles are the same in all cases, there are many different designs of radio systems. These differences depend upon the types of signal to be transmitted, the distances involved, and various other factors, including particularly the part of the frequency spectrum in which transmission is to be effected.

Figure 16-26 is a chart of the radio spectrum indicating at the left the commonly accepted classification of radio frequency ranges; and showing at the right the more important frequency ranges of special interest in current telephone practice. It will be noted that telephone practice makes use of some part of nearly all of the major frequency ranges. It must accordingly employ a corresponding variety of types of radio facility. It is not practicable or desirable to attempt to describe all of these in this book, and what follows will therefore be limited to a brief general discussion of the radio relay systems in the superhigh frequency range.

16.11 TD-2 AND TD-3 MICROWAVE RADIO RELAY

A. TD-2 MICROWAVE

Type TD-2 radio is a multichannel, multihop relay system designed to provide facilities for the transmission of television, multiplex telephony, or other wide band communication signals over distances up to 4000 miles. The system operates in the common carrier super high frequency, or microwave band, between 3700 and 4200 MHz and originally was designed to provide a maximum of six wide band channels in each direction of transmission. It is composed of a chain of radio stations or repeaters spaced 20 to 40 miles apart. Provision is made for dropping and picking up radio channels at repeater stations and terminals to make the system adaptable to a nationwide radio network with interconnections to wire lines as required. The six radio channels in each direction are spaced 80 MHz apart, as shown in Figure 16-27, with a 40 MHz difference between the receiving and transmitting channels. Each channel is 20 MHz wide and is suitable for one standard television circuit, or one multiplex telephone band providing several hundred message circuits in one direction of transmission. The audio portion of a television program is not transmitted on the radio channel with the picture signal. Regular program wire facilities are used for this part of the program. The original TD-2 system channel capacity of 600 has been increased by such technological improvements as the Schottky-Barrier diode and Solid-State 3A-FM transmitters so that today 1200 message circuits can be transmitted on a single channel.

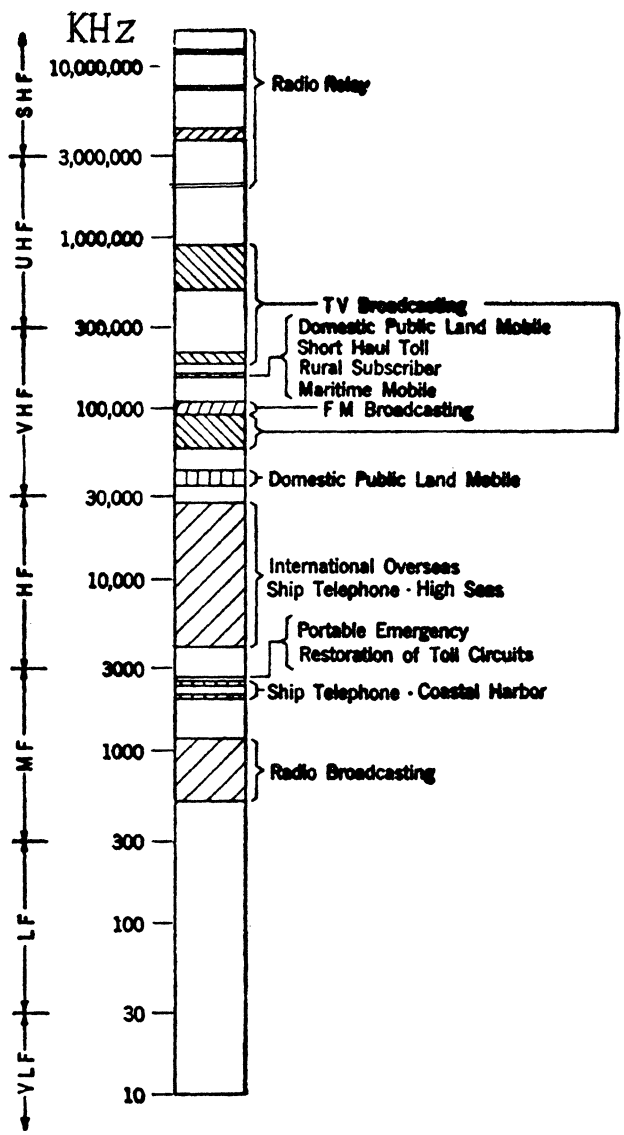


Figure 16-26 Radio Frequency Spectrum

The 20 MHz channels carrier frequencies are allocated as indicated below:

Channel No.		Frequencies (MHz)
	Regular	
1		3730 and 3770
2		3810 and 3850
3		3890 and 3930
4		3970 and 4010
5		4050 and 4090
6		4130 and 4170
	Alternate	
7		3710 and 3750
8		3790 and 3830
9		3870 and 3910
10		3950 and 3990
11		4030 and 4070
12		4110 and 4150

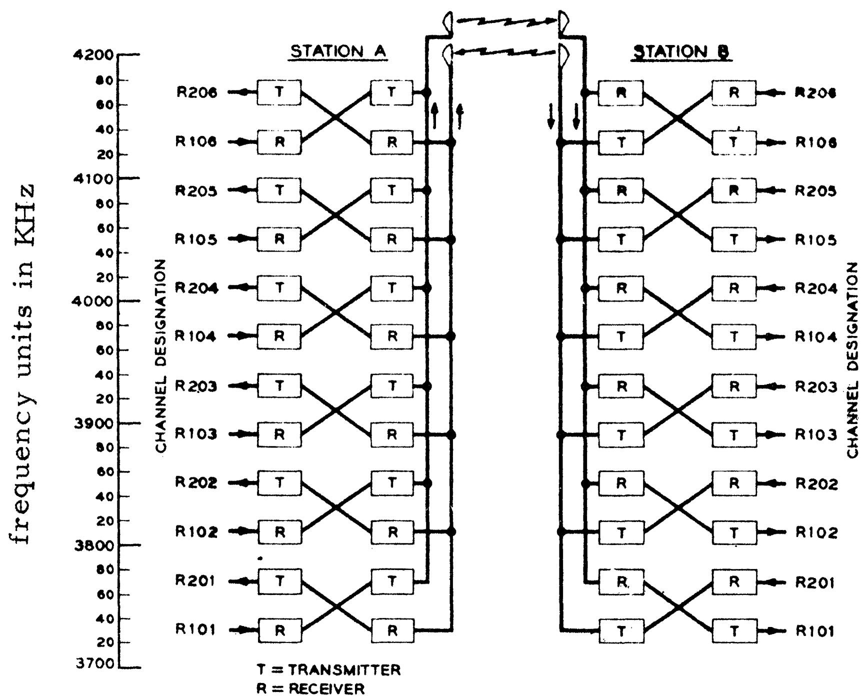


Figure 16-27 Frequency Plan for Six Channels

In the six channel systems the channel carrier frequencies are assigned so that the space between the carrier of a transmitter and the carrier of its nearest receiver operating in the same direction is 40 MHz. This leaves six interstitial bands of 20 MHz each which are essentially empty. In the frequency allocation alternate or "slot" frequencies were established for spur or other routes which intersected existing routes at angles of 90 degrees.

The capacity of the TD-2 system was expanded to twelve two-way channels by making use of different polarizations for the regular and slot frequencies and by means of an I.F. filter which allowed the spacing between carriers to be only 20 MHz. Figure 16-28 shows this 12 channel frequency plan.

One antenna for receiving and one for transmitting is required for each direction of transmission. Thus, for a two-way system at a repeater station without branching or spur facilities, four antennas are required.

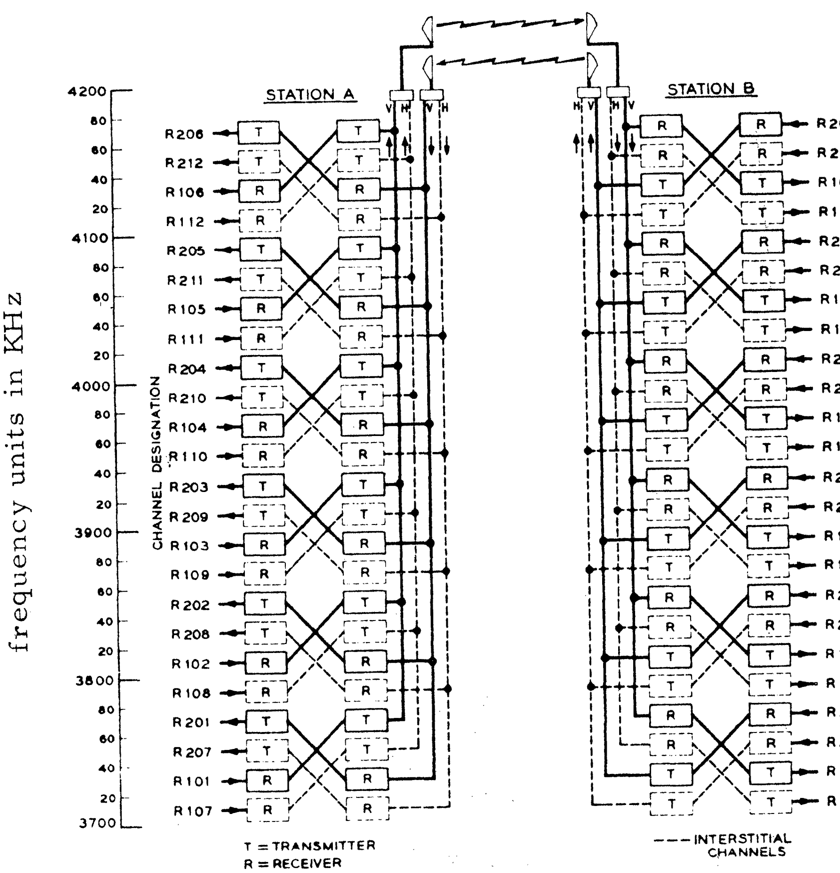


Figure 16-28 Frequency Plan for 12 Channels

On major routes the delay lens antenna, shown in Figure 16-29, was used until about 1954. It was replaced by the horn-reflector antenna shown in Figure 16-30.

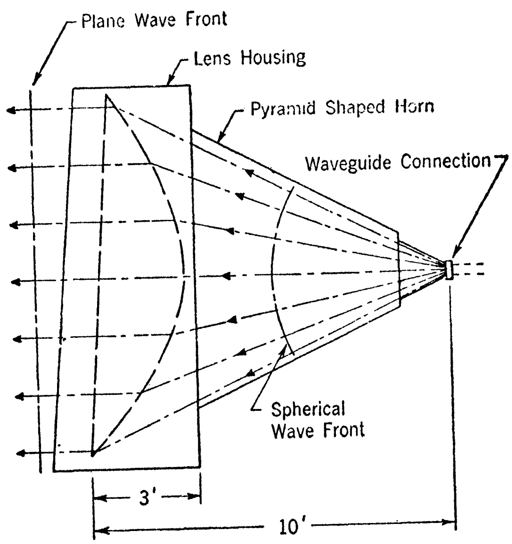


Figure 16-29 Delay Lens Antenna

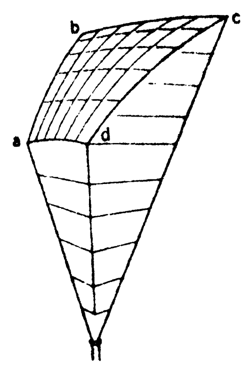


Figure 16-30 Horn-Reflector Antenna

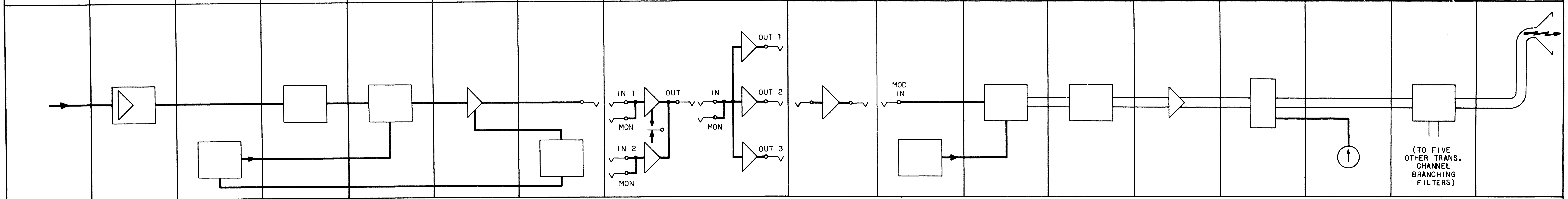
The delay lens antenna is a rectangular cross-section horn approximately 10 feet square and 10 feet deep. The mount of the horn contains a microwave delay lens to converge the radiated energy into a narrow beam. It is designed for the propagation of vertically polarized radio waves only and therefore cannot be used for interstitial channels. It is fed by means of rectangular waveguide at the apex of the horn.

The horn-reflector antenna consists of an electromagnetic horn that illuminates a sector (ABCD) of a large paraboloidal reflector some forty feet in diameter whose focal point is at the apex or feed point of the horn. The antenna will transmit signals of either vertical or horizontal polarization in the 3700-4200 MHz band, as well as in the 5925-6425 MHz and 10,700-11,700 MHz common carrier bands. The antenna measures about 20.5 feet vertically from the apex to the outer edge of the reflector. It is fed by means of a 2.812 inches inside diameter round waveguide at the apex.

FM TRANSMITTING TERMINAL EQUIPMENT — IF MONITORING AND SWITCHING BAY — MICROWAVE TRANSMITTING EQUIPMENT

FM BAY (FM MODULATOR) — TRANSMITTER-RECEIVER BAY

INPUT SIGNAL	VIDEO AMPLIFIER AND CLAMPER	BEAT OSCILLATOR (FM MODULATOR)	DEVIATION OSCILLATOR MODULATOR (FM MODULATOR)	CONVERTER (FM MODULATOR)	TRANSMITTING AMPLIFIER AND LIMITER	AUTOMATIC FREQUENCY CONTROL CIRCUIT	SWITCHING CIRCUIT	IF BUFFER AMPLIFIER	TRANSMITTER LOCAL MICROWAVE GENERATOR	TRANSMITTER MODULATOR	TRANSMITTER FILTER	TRANSMITTER AMPLIFIER	DIRECTIONAL COUPLER	POWER OUTPUT MONITOR	TRANSMITTER CHANNEL BRANCHING FILTER	TRANSMITTING ANTENNA
FUNCTIONS																
INPUT SIGNAL, 0.2 VOLTS PEAK-PEAK TO 2.5 VOLTS PEAK-PEAK (MAY BE EITHER TELEPHONE "L" CARRIER OR TELEVISION SIGNAL)	AMPLIFIES VIDEO SIGNAL. ADDS D-C COMPONENT WHEN TERMINAL IS BEING USED FOR TELEVISION	OSCILLATOR PRODUCES BEAT FREQUENCY	OSCILLATOR FREQUENCY IS VARIED BY THE VIDEO SIGNAL BEING APPLIED TO REFLEX TYPE KLYSTRON TUBE	COMBINES FREQUENCY MODULATED DEVIATION OSCILLATOR SIGNAL WITH BEAT OSCILLATOR FREQUENCY TO PRODUCE THE FREQUENCY MODULATED 70 MC IF SIGNAL	AMPLIFIES IF SIGNAL. LIMITER REMOVES ANY AMPLITUDE MODULATION. OUTPUT LEVEL IS 13 DBM	MEASURES FREQUENCY OUTPUT OF IF AMPLIFIER CAUSING CORRECTION OF THE BEAT OSCILLATOR AS REQUIRED	PROVIDES FOR MANUAL SWITCHING, PATCHING TO A SPARE CHANNEL, PATCHING TO A BRANCH ROUTE, PATCHING TO A THROUGH ROUTE, AND MONITORING BY OSCILLOSCOPE OR VIDEO TEST SETS (2)	COMPENSATES FOR SLOPE FROM SWITCHING EQUIPMENT. PROVIDES CONTROL OF INPUT TO TRANSMITTER	QUARTZ CRYSTAL CONTROLLED HARMONIC GENERATOR PRODUCES LOCAL MICROWAVE FREQUENCY 70 MC REMOVED FROM DESIRED TRANSMITTER FREQUENCY	VACUUM TUBE MODULATOR COMBINES 70 MC IF FM SIGNAL WITH LOCAL MICROWAVE FREQUENCY TO PRODUCE MICROWAVE TRANSMITTING SIGNAL	PASSES ONLY DESIRED FM MICROWAVE SIDEBAND	THREE CAVITY TYPE VACUUM TUBE AMPLIFIERS. AMPLIFY TRANSMITTED SIGNAL 16 DB.	WAVEGUIDE COUPLING OBTAINS SAMPLING OF OUTPUT POWER AND CONVERTS IT TO DC BY MEANS OF A VARISTOR CRYSTAL PROBE	VISUALLY INDICATES AMOUNT OF OUTPUT POWER AND ALSO INITIATES ALARM IF POWER DROPS 10 DB OR MORE	PASSES THIS MICROWAVE SIGNAL TOWARDS ANTENNA AND COMBINES THE SIGNAL WITH SIGNALS FROM OTHER CHANNELS TO BE TRANSMITTED	TRANSMITS TOTAL MICROWAVE BAND FROM 3700 TO 4200 MC. ANTENNA IS DESIGNED TO GIVE GAIN AND DIRECTIVITY
TRANSMITS																
FREQUENCY RANGE D-C TO 4 MC	VIDEO SIGNAL	4210 MC BEAT FREQUENCY (1)	FM SIGNAL CENTERING AT 4280 MC (1)	FM SIGNAL, FROM 66 TO 74 MC; ALSO CALLED "70 MC IF SIGNAL"					LOCAL MICROWAVE FREQUENCY	MICROWAVE CARRIER AND TWO FM MICROWAVE SIDEBANDS	ONE FM MICROWAVE SIDEBAND, BAND-PASS IS 20 MC WIDE. THIS IS ONE CHANNEL				SEE FUNCTION	



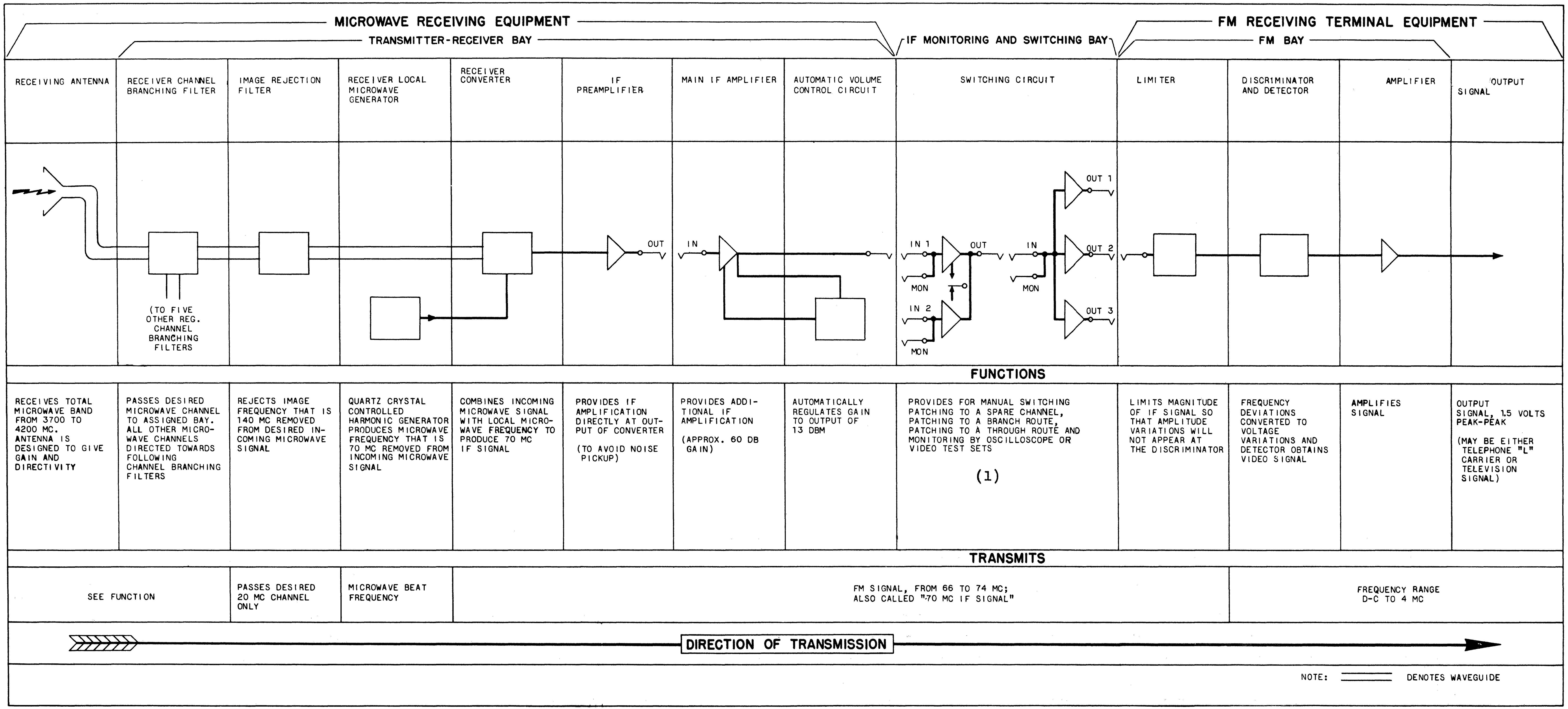
DIRECTION OF TRANSMISSION

NOTE: ═══ DENOTES WAVEGUIDE

NOTES: (1) These are klystron frequencies for vacuum tube FM terminals
(2) 100A Automatic switching, operating at IF frequencies. Permits continuity of service by automatically switching to a standby protection channel in case of failure.

Figure 16-31

TD-2 TRANSMITTING TERMINAL FOR ONE MICROWAVE CHANNEL



NOTES: (1) 100A Automatic Protection Switching, operating at IF frequencies permits continuity of service by automatically switching to a standby protection channel in case of failure.

Figure 16-32

TD-2 RECEIVING TERMINAL FOR ONE MICROWAVE CHANNEL

Figures 16-31 and 16-32 are block schematics of the TD-2 transmitting and receiving terminals. Since the other microwave systems are similar in basic operation, circuit arrangements will not be shown for any of these systems.

The high reliability demanded of microwave systems requires that protection be provided against fading or equipment failures. The TD-2 Automatic Protection System uses up to two protection channels for up to ten regular channels. Switching is done at IF frequencies in at most a few milliseconds, a time short enough to prevent false operations in the telephone switching plant. A logic system of switch requests and information is maintained between the receiving and transmitting ends over a separate wire or radio facility.

B. TD-3 MICROWAVE

The TD-3 Radio System is designed to carry 1200 telephone circuit loads (or one television channel load) on each of the ten working and two protection two-way channels provided by the 4 GHz frequency plan, with 41 dbrnc0 noise performance on 4000 mile systems. It has an RF channel width of 20 MHz and spaced 20 MHz center to center, with alternate channels cross-polarized. Ordinarily one protection channel will be used on systems equipped with up to 5 working channels, and a second protection channel added when 6 to 10 working channels are installed. The microwave equipment is constructed with solid state components, except for a traveling wave tube in the transmitter amplifier. Power for all of the equipment is obtained from a 24 volt battery power plant.

The TD-3 is designed primarily for long-haul applications, and is compatible in most respects to the TD-2 system. However, there are certain advantages over that of the TD-2 system, such as better noise performance, improved fade margin, and better stability and equipment reliability. The output power will be between 5 and 10 watts, with 5 watts the lower maintenance limit.

The alarm circuit arrangements for TD-3 are similar to those used for TD-2 except that the TD-3 transmitter-receiver bay includes an alarm panel containing relays which provide an interface between the bay and external alarm circuits; the TD-3 is also arranged for use with an aisle pilot visual alarm system.

16.12 TE MICROWAVE RADIO RELAY

The TE microwave radio relay system was designed for short haul transmission of television service. The TE system operates in a 3700 to 4200 MHz band. A maximum of six one-way channels or three two-way channels may be obtained. Channel bandwidth is 20 MHz and frequency modulation is used. A portable arrangement of the TE system is used for video pickup at a temporary location, or path testing. Limited to 35 miles and +24.8 dbm RF output power, the system sees little use today.

16.13 TH RADIO SYSTEM

TH-1 radio is a microwave system designed to provide long-haul facilities suitable for handling television, multiplex telephone or any other wide-band communication signals. The system operates in a common carrier band between 5925 and 6425 MHz.

The system is set up to provide a maximum of eight broadband radio communication channels and two narrow-band auxiliary channels in each direction of transmission. At a normal repeater point, this will mean a 2-way system with a maximum of eight broadband channels in each direction, six of which are available for regular use, and two reserved for protection.

Each broadband channel accommodates a baseband signal of approximately 10 MHz which may comprise up to 1,800 message channels. Although the system bandwidth is large enough, TH-1 radio is not usually used for television transmission because of economic considerations.

The TH system also uses the horn-reflector antenna and circular wave-guide. Therefore, a TH system may be added to an existing TD-2 route if all the stations on this route are equipped with horn-reflector antennas.

An automatic protection switching system was developed for use in conjunction with the TH system to assure that transmission performance will be maintained at the desired level despite fading and equipment troubles.

The TH system differs from the TD-2 system in having an auxiliary channel for automatic switching and radio order, alarm and control purposes as an integral part of the system.

On each TH broadband channel frequency modulation is employed. The narrow band auxiliary radio order channel uses amplitude modulation. Higher power on the broadband channels is obtained through the use of traveling wave tubes.

Figure 16-33 illustrates the frequency plan for the TH system. This plan provides for a maximum of eight broadband and two narrow band auxiliary channels in each direction. Channels 11 to 18 and 21 to 28, inclusive, are the broadband FM channels for TV, telephone or telegraph services. Channels 10, 19, 20 and 29 are the narrow band AM auxiliary channels for order, alarm and short haul toll circuits.

Note that all transmitting frequencies are located at one end of the 5925-6425 MHz band and the receiving frequencies placed at the other end. The auxiliary channels are situated in the guard band between the broadband transmitting and receiving frequencies as well as in the guard bands between the TH system and other services in adjacent bands. Note also that adjacent broadband channels are alternately polarized to minimize crosstalk. Cross polarization permits overlapping channels slightly so that the effective frequency use is 514 MHz in a band only 500 MHz wide.

The TH system uses a single carrier supply which will furnish ten transmitting and receiving beat frequencies for 16 broadband receivers, 16 broadband transmitters, 4 narrow band auxiliary transmitters and 4 narrow band auxiliary receivers. All frequencies are derived from a 14.83 MHz crystal by suitable multiplications and additions.

By making each component of the carrier supply serve as many channels as possible, a minimum amount of equipment will be needed.

While the TH-1 system was designed around a large amount of common equipment, with transmitters and receivers in separate bays, the TH-3 system has transmitter-receiver bays which are completely self-contained and will not require additional common equipment other than the antenna system. The TH-3 system has been designed to satisfy the requirements of both long and medium haul applications.

The TH-3 system is also provided with all solid-state electronic components except for a 10-watt traveling wave tube at the transmitter output. At the receiver modulator input stage a low noise Schottky Diode Down-Converter is furnished. The IF main amplifier and AGC circuitry, of the TH-3, is the same as the solid state components used in the TD-3. Other portions of the TH-3 are also very similar to those of the TD-3. Benefits of the solid state components include decreased noise, increased reliability and a reduction in the power consumption, which eliminates the need for a forced-air cooling system. The TH-3 system was designed for a performance objective of 41 dbrnc0 total noise over a 4000 mile range.

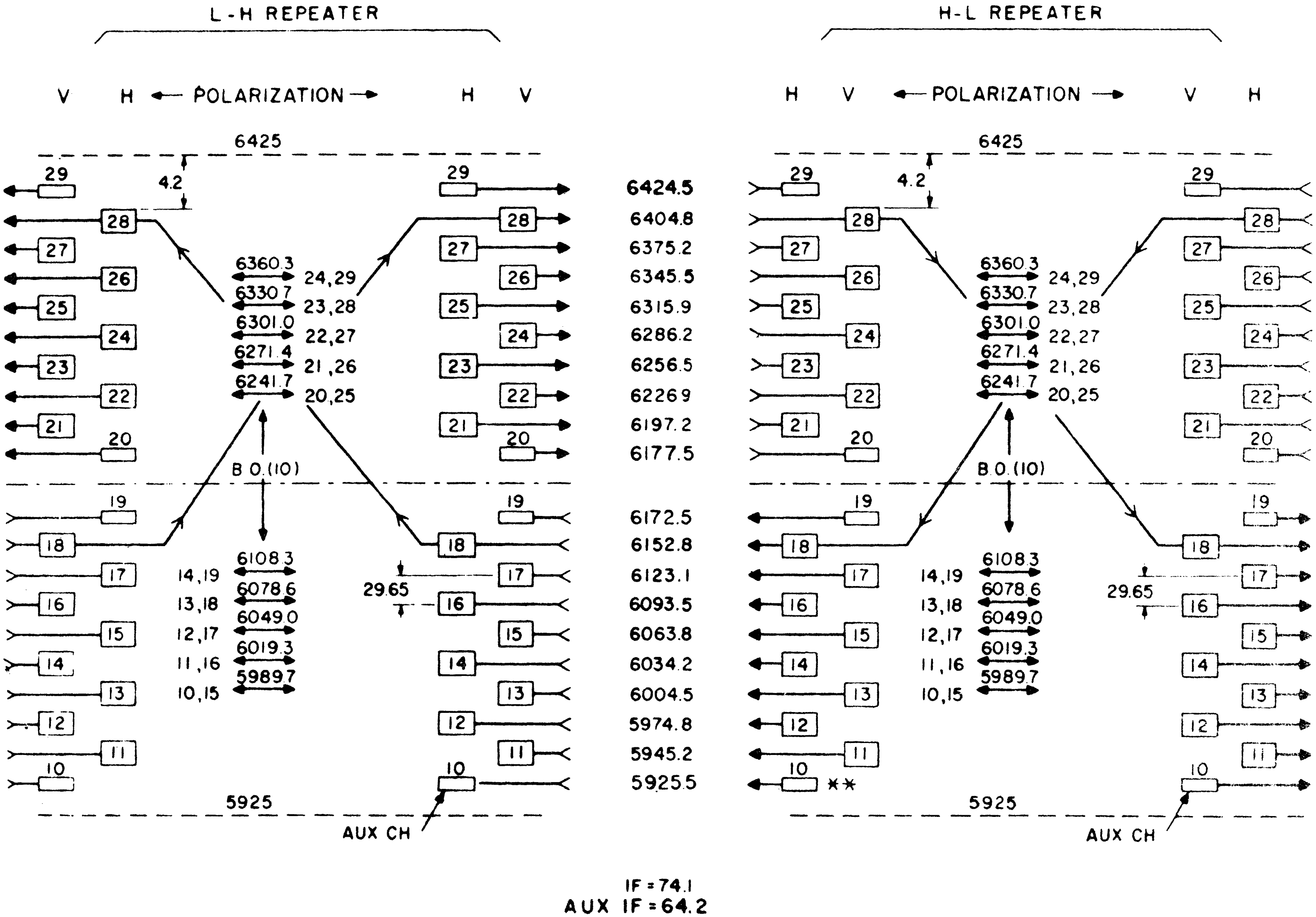
The basic features of the TH-1 and TH-3 systems are outlined below:

Feature	TH-1	TH-3
(1) Frequency Plan	High-Low Bands, in Transmitter and Receiver	Same
(2) Antenna System	Horn Reflector	Same
(3) Repeater	10-Watt (Electron Tube)	10-Watt (Solid State, except Traveling Wave Tube)
(4) Protection	TH(1) Switching System Initiated by Monitoring Carrier at each Repeater	Similar to 100A System
(5) FM Terminals	New Solid State Terminals have superseded the original klystrons and electron tubes	3A FM Terminal Transmitter and 3A or 4A FM Terminal Receiver (All Solid State - same as TD-3)
(6) Auxiliary Channel Facility	Special Radio Channel Designed as part of the system	Standard Voice Frequency Facilities

Feature	TH-1	TH-3
(7) Wire Line Entrance Links	TH Message Connecting Link	3A Solid State Wire Line Entrance Link - Same as TD-3
(8) Power	230V AC Inverter Plant	24V DC (Same as TD-3)
(9) Air Conditioning	Required to Maintain 75° ± 10°F	Required to Maintain 75° + 20°F. No Humidity Control. Dry Air to be Blown into Waveguide Filters and Networks
(10) Microwave Networks	Conventional Channel Dropping Networks and Filters	New Directional Filter Approach
(11) Receiver Modulator	Conventional Point Contact Diode	Low Noise Schottky Barrier Diode
(12) IF Circuitry	Electron Tube at 74.1 MHz	TD-3 Solid State Circuits at 70 MHz
(13) RF Amplifier	10-Watt Traveling Wave Tube with Large Magnetic Structure and Forced Air Cooling	10-Watt Traveling Wave Tube with Small Magnetic Structure and No Forced Air Cooling
(14) Microwave Carrier Supply	Electron Tube Multiplier Stages and Traveling Wave Tube for +39 DBM Output	Transistor Amplifier-Multiplier Stages and Varactor-Multiplier for +21 DBM Output (Same as TD-3 up to 1,000 MHz Stage

16.14 TJ RADIO SYSTEM

The TJ Microwave system provides short haul line-of-sight facilities for frequency modulated microwave transmission of monochrome or color television signals, multiplex telephony, or other broadband communication signals. The



frequency units in MHz

Figure 16-33 TH Radio System, Frequency Allocation and Polarization Plan system operates in the common-carrier frequency band between 10,700 and 11,700 MHz and provides as many as six broadband 2-way communication channels. The number of message circuits obtainable in a single broadband channel of TJ radio is a function of many variables. The length of the system, its signal-to-noise ratio, fading margin, intermodulation products, the delay equalization, and the permissible degradation of transmission are some of the more important factors.

In TJ radio, each 2-way broadband channel is designed to transmit 96 ON2 type message circuits, or 600 L carrier message circuits over 10 hops. Suitable outside supplier message carrier equipment may also be used. In television service each radio channel is designed to transmit one standard monochrome or NTSC color television signal over six hops for a distance of about 100 miles. The repeater spacings for either message or television application will average between 15 and 25 miles, depending upon the terrain, over-all system economics, fading, the expected rate of rainfall, and other microwave considerations.

For maximum reliability and protection against multi-path fading and equipment failure the TJ radio system can be operated as a one-for-one frequency diversity system. In this system channels are used in pairs and a diversity switch and transmission unit provides facilities for comparing the signals from both channels and through a logic or control circuit determines which channel should be used. When operated in this manner, as it is for general Bell System use, a fully loaded system provides three working and three protection channels in each direction of transmission.

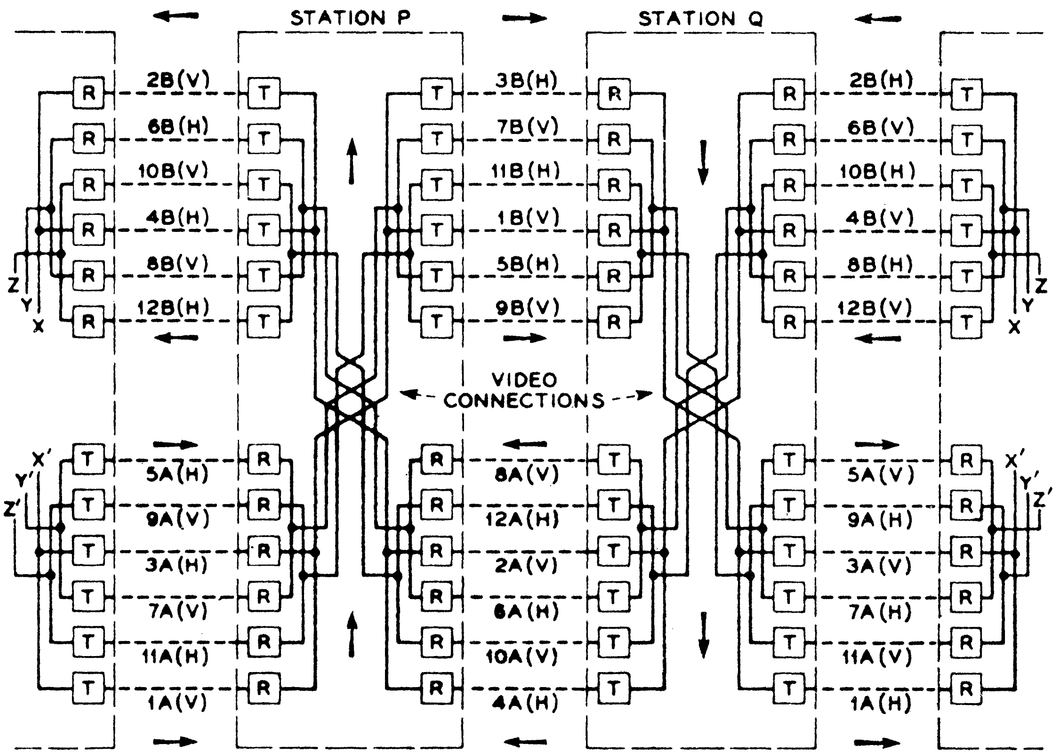
The basic element of the TJ system is the transmitter-receiver bay which includes a transmitter, receiver, and associated power supply operating from 117 volts AC.

The Western Electric type 445A Reflex Klystron oscillator is the heart of the TJ transmitter. This klystron has a normal operating frequency range of 10.7 to 11.7 GHz with a nominal power output of 1/2 watt. The klystron is air cooled by a blower. The 445A is essentially a single cavity klystron which produces an F.M. signal by application of an amplified baseband signal to its repeller.

The repeaters consist of a transmitter and receiver for each channel. The receiver reduces the incoming signals to 70 MHz IF, and again to baseband or video frequencies. The baseband frequencies in turn, modulate the transmitter for transmission to the next station. By reducing the signals down to baseband frequencies instead of just the 70 MHz IF frequencies as in the TD-2 system, message circuits may easily be dropped or inserted at each repeater.

The radio signals are transmitted to a dual polarized antenna by RF channelizing and duplexing arrangements. Many systems use a "periscope" type of antenna arrangement to minimize the loss associated with long waveguide runs. Such a system uses a paraboloidal antenna at the base of the tower directed at a plane or a "dished" reflector at the top of the tower. In addition, an 11,000 MHz systems-combining network is available so that the TJ system may utilize the horn-reflector antennas installed on TD-2 and TH backbone routes.

One of the TJ frequency plans is shown in Figure 16-34. Because of the use of the "periscope" antenna system, the plan is based on the use of four frequencies for each two-way radio channel. The 10,700- to 11,700-MHz common carrier band is divided into 24 channels, each about 20 MHz wide. In a given repeater section, only 12 of these are used, resulting in 80-MHz spacing between midchannel frequencies. These channels are divided into two groups of six for transmission in each direction. The polarization of the channels alternates between vertical and horizontal to provide 160-MHz separation between signals having the same polarization, thereby substantially easing requirements on the channel-separation networks. The remaining 12 channel assignments are used in adjacent repeater sections. These frequencies are repeated in alternate hops. Potential "overreach" interference is reduced by reversing the polarization of the third section with respect to the first section. Co-channel interference from adjacent repeater stations, a necessary consideration in the TD-2 and TH systems because of their use of the two-frequency plan, is eliminated in this system by the use of the four-frequency plan. At a given repeater, adequate frequency separation between transmitters and receivers is achieved by using the upper half of the band for transmitting and the lower half for receiving. This arrangement is naturally inverted at alternate stations.



Channel Number	Transmitter Frequency,	Beat Oscillator Frequency,	Channel Number	Transmitter Frequency,	Beat Oscillator Frequency,
4A	10.715	10.785	9B	11.245	11.315
1A	10.755	10.825	12B	11.285	11.355
10A	10.795	10.865	5B	11.325	11.395
11A	10.835	10.905	8B	11.365	11.435
6A	10.875	10.945	1B	11.405	11.475
7A	10.915	10.985	4B	11.445	11.515
2A	10.955	10.885	11B	11.485	11.415
3A	10.995	10.925	10B	11.525	11.455
12A	11.035	10.965	7B	11.565	11.495
9A	11.075	11.005	6B	11.605	11.535
8A	11.115	10.045	3B	11.645	11.575
5A	11.155	11.085	2B	11.685	11.615
	GHz	GHz		GHz	GHz

Figure 16-34 TJ Frequency Assignment Plan

The channels in the lower half of the total frequency band are designated Group A. The channels are numbered 1A to 12A. The channels in the upper half of the band are designated B and are numbered 1B to 12B. All channels transmitting North or East have odd numbers. All channels transmitting South or West have even numbers. All channels transmitting in one direction on a specific hop are designated A, in the opposite direction B and on adjacent hops this is reversed. Another frequency plan uses frequencies midway between those shown in Fig. 34, and is known as the "staggered" plan.

16.15 TL RADIO SYSTEM

With the advent of high frequency solid-state devices, a new, lower cost, short haul system in the 11 GHz range was introduced. With the exception of transmitter and receiver klystrons, the TL-1 system used solid-state circuitry throughout and required considerably less power than the tube type TJ system.

The TL-1 system was introduced as a low cost, reliable system capable of handling 240 message circuits for 250 miles over 10 hops. Even as this new system was beginning its service to the Bell System, more circuit capacity was required. The short haul radio field, originally conceived as lightly loaded routes, faced a rapidly growing demand in data, commercial and educational TV, and message circuit transmission.

The TL-2 system was developed as a 600 message circuit system. It was followed shortly by a companion system in the 6 GHz range called TM-1.

16.16 TL-2/TM-1 DIVERSITY SYSTEM

Both the TL-2 system, operating in the 11 GHz range, and the TM-1 system, operating in the 6 GHz range, are capable of handling 600 message circuits for 250 miles over 10 hops. A crossband diversity arrangement provides improved reliability. In this arrangement a pair of channels, one at 6 GHz and one at 11 GHz, are used together for the same transmission. A diversity switch is used at the receiver to select either channel.

A bistable diversity switch can be used to select the best channel where performance of the two channels is comparable. A revertive diversity switch can be used to favor a preferred channel in the event one of the channel pair has superior performance.

The advantages of crossband diversity using 6 GHz and 11 GHz channels over in-band diversity using two channels in either the 6 GHz or 11 GHz range lie in the greater freedom from rain fades in the 6 GHz range and in the greater freedom from congestion in the 11 GHz range. Although the nominal repeater spacing is about 25 miles, a TM-A1 traveling wave tube power amplifier can be used to increase the power output of the TM 1 system from +20 dbm to +33 dbm where conditions warrant.

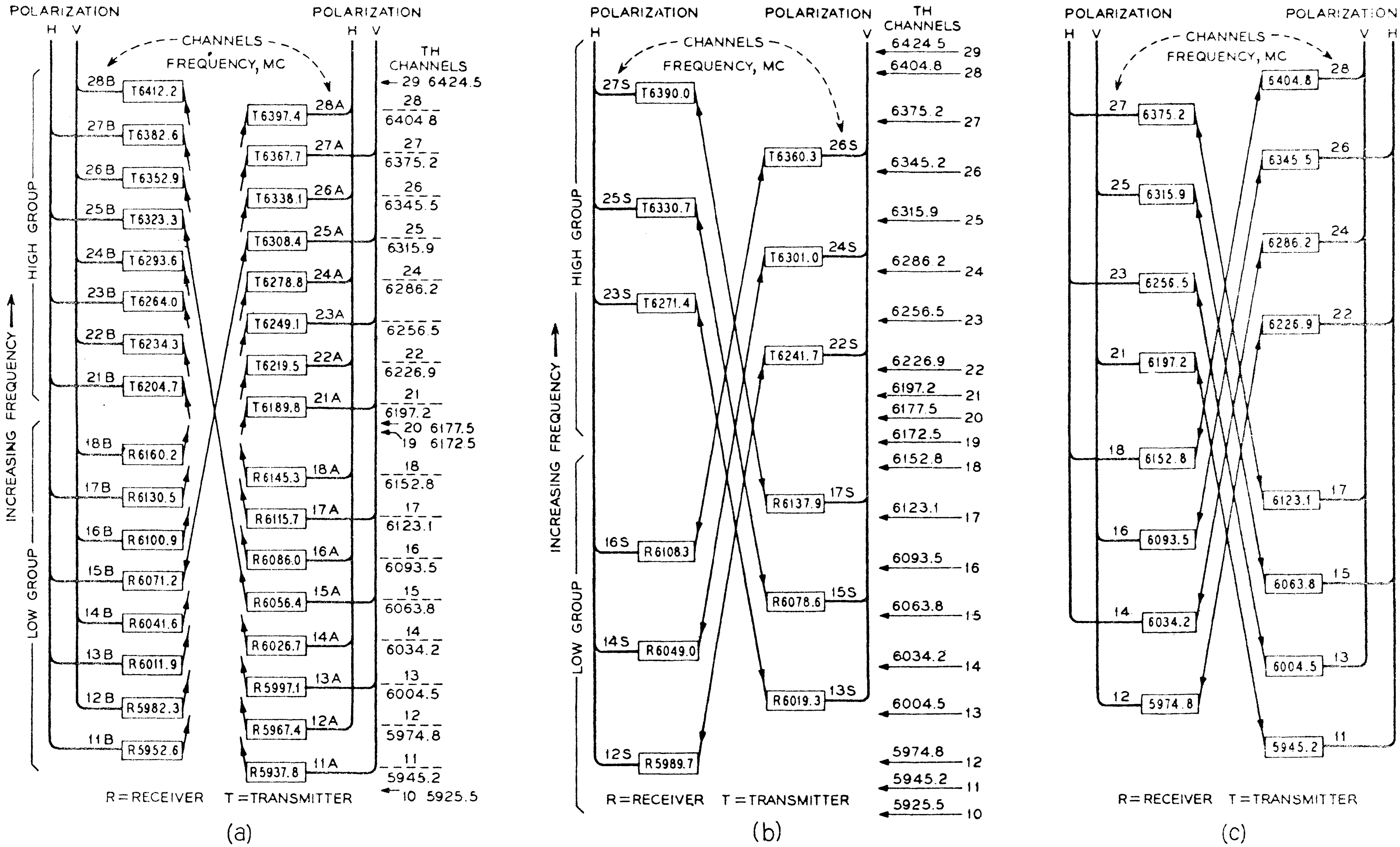
The number of two-way diversity channels which may be provided depends upon several factors. When dual-frequency parabolic antennas are used only one polarization at 6 GHz is possible, limiting the crossband channel pairs to four two-way pairs. When the horn-reflector antenna is used, both polarizations are available in both the 6 GHz and 11 GHz range, making six two-way crossband diversity channels possible.

Basically, the normal TL-2 frequencies are the same as TJ, and the normal or split channel TM-1 plan provides two TM-1 channels in the frequency space allotted to each TH channel. There are also staggered plans for both TL-2 and TM-1. The staggered plan provides less TM-1 channels but locates them midway between TH channel assignments to minimize interference in the case of crossing routes. A co-channel plan is also used where TH and TM share the same route.

One of the interesting innovations of the TL and TM systems is vapor phase cooling. To meet the frequency accuracy requirements of the system ($\pm$ 0.02 percent for TM-1), the temperature sensitive klystrons must be kept in a range of $\pm 3^{\circ}$F, during an ambient temperature change of 100°F. (Over a nominal 3-month maintenance interval the ambient temperature is not likely to exceed a 100°F variation.)

To meet these stability requirements, a pair of klystrons are clamped to the sides of a copper boiler. The boiler is filled with a heat transfer fluid that absorbs the heat from the klystrons by boiling. Vapor from the boiling liquid is led off, condensed and returned to the boiler. The condenser is connected to a heat sink and a bladder whose expansion and contraction reduces pressure changes in the system.

The TM-1 vapor phase cooler is a refined version of the earlier TL-2 design. Laboratory tests show this system is capable of holding the klystrons to a range of $\pm$ 1^{O}F for an ambient temperature range of 100 F. A $\pm$ 3^{O}F klystron range may be expected over a 3 month maintenance interval due to both ambient temperature and ambient pressure changes.



— Frequency plans—TM-1 microwave high-group transmitting repeater; (a) normal channel frequency plan, (b) staggered channel frequency plan, (c) co-channel frequency plan.

Figure 16-35

CHAPTER 17

VOICE FREQUENCY REPEATERS

17.1 INTRODUCTION

A modern voice frequency repeater is an arrangement of electron tube or solid state amplifiers and associated apparatus capable of receiving a voice frequency current and from either side and retransmitting it, without appreciable distortion, at a greater magnitude. The energy required to produce the output currents is obtained from local sources at the repeater and is released under the control of the received currents. A repeater, then, is a two-way amplifier with some associated circuitry.

Telephone repeaters are an essential factor in our present system of long distance telephone communication. They are used:

1. To extend the range of transmission.
2. To provide a more economical means of transmission by employing inexpensive lines with repeaters instead of expensive lines without repeaters.
3. To improve the standards of volume and quality over long distance telephone lines.

For satisfactory telephone communication, there must be sufficient energy transmitted over the line to provide adequate sound volume at the receiving end. If we attempted to transmit energy over a 1,000 mile 19H44 cable circuit of approximately 480 db loss without any means of boosting the transmitted power along the line, an input power of one milliwatt at the sending end would be attenuated to 10^{-51} watt at the receiving end. If we were to attempt to increase the power received to a value equal to that of the power sent (one milliwatt) by means of a single amplifier or repeater inserted anywhere in the circuit, we would have to use a device capable of amplifying power by 10^{48}. Such an amplifier is, of course, a practical absurdity. However, by placing repeaters on cable circuits at intervals of about 50 miles, the power may be restored by each one in steps of practicable size.

The first successful telephone repeater was invented by a Bell System engineer, H. E. Shreeve, and was tried out successfully on a circuit between Amesbury, Mass.

and Boston in 1904. An improved form of this mechanical repeater, consisting of an amplifier made up of mechanically coupled receivers and transmitters, was commercially operated in the latter part of the same year on a circuit between New York and Chicago. Since the invention of the vacuum tube the use of repeaters has steadily increased, resulting in the economical extension of telephone service over distances which previsously could not be connected satisfactorily at all.

17.2 TYPES OF TELEPHONE REPEATERS

Repeaters can be divided into three types: (a) through line repeaters; (b) switched-in line repeaters; and (c) cord circuit repeaters. Through line repeaters are permanently associated with a particular toll line; switched-in repeaters are automatically associated with a particular toll line as the result of special operations; cord circuit repeaters, before becoming obsolete, could be associated with any connection for which they were specified by the toll board operator by means of switchboard cords.

In general, telephone repeaters use two one-way amplifiers to provide transmission gain and are equipped with regulating devices for adjusting gain to meet operating requirements. Hybrid coils are used for adapting one-way amplifiers to two-way transmission. A balancing network is employed to approximate closely the impedances of each line of the circuit and its transmitted associated frequency band, thereby maintaining the degree of balance required for the proper functioning of the hybrid coil. That is, energy (at voice frequencies) from the output of one amplifier of a repeater must be prevented from reaching the input of the other. This would impair the quality of the transmission, or even cause "singing." Filters are used to filter out unwanted frequencies. Other miscellaneous apparatus and circuit features are used to adapt the repeater circuit to standard operating practices and become more or less a part of the repeater.

The function of such equipment is to: match impedance; connect 2-wire to 4-wire lines; compensate for unequal attenuation at different frequencies; adjust for variations in attenuation due to varying conditions; by-pass low-frequency or d-c signaling; and device phantom channels separately. The selection of this apparatus is sometimes determined more by the line to which it is assigned than by the amplifier with which it is used. For example, the repeater is designed to have a nominal impedance (e.g. 600 ohms), so the repeat coils (for matching impedance of repeaters and lines) have different ratios because of different line impedances. Also, low-frequency ringing does not pass through the amplifier at all, so that means of deriving the signaling circuits are controlled by the line not by the amplifier.

The maximum overall gain of repeaters is limited by the amplifiers used, but adjustments, for example, by means of the slide-wire potentiometer and resistance pads, can bring this overall gain to any lower value. It is well to remember, however, that one-half of the energy is lost each time it must pass through a hybrid coil circuit. This means that the actual gain of each amplifying element must be at least 6 db greater than the overall gain required. This is recognized in the calibration of the repeater potentiometers.

The various types of through line repeaters used by the Bell System are as follows:

1. Reading - high impedance repeater for heavy loaded H245-155 facilities; initially used at Reading, Pa.; mostly floor type, but some of later ones were relay rack type. Obsolete

2. 21 - one-amplifier repeater for 2 directional use at exact mid-point of a two-wire circuits; used for service observing boards. Also obsolete.

3. 22A1 - two-amplifier repeaters for use on two-wire circuits. Superseded by V3.

4. 22A2 - two-amplifier repeater for use on high cut-off two-wire facilities, especially B88-50 facilities; modified 22A1. Superseded by V3.

5. 24A1 - two-amplifier repeater for use on 2-wire to 4-wire circuits. Superseded by V3.

6. 44A1 - four-amplifier repeater for use on four-wire circuits. Superseded by V3.

7. V1 - two one-way amplifiers with repeating coil hybrids for use as a 2-wire repeater, 4-wire repeater, or as a 2-wire to 4-wire repeater. Superseded by V3.

8. V2 - similar to V1, except for use with 48 volt filament and plate supply at small installations in offices having no 130-volt power plant.

9. V3 - two small compact, plug-in type amplifiers designed to replace the V1.

10. V4 - two transistorized plug-in amplifiers with associated plug-in terminating sets and equalizers designed to replace the V3.

11. E1 - miniature single amplifier, two-way negative impedance repeater for use primarily on exchange area trunks and special services.

12. E2 - an equipment redesign of the E1 employing plug-in type units as series elements.

13. E3 - a plug-in unit similar to the E2 but used as a shunt element between the midpoints of the E2 coils or across the line at either side of the line winding of the series element.

14. E6 - a transistorized plug-in type, designed to replace the E23.

15. E7 - is a transistorized shunt type repeater intended for operation on 2-wire nonloaded lines for certain types of service.

17.3 22-TYPE REPEATER

Figure 17-1 is a schematic of a telephone repeater known as the 22-type. As will be observed, the amplifier units in this arrangement are triodes connected with transformers in both input and output circuits. The drawing also shows the connections of the hybrid coil output transformers with their balancing networks; and the potentiometers in the input circuits for controlling the amplifier gains. Equalizing networks are inserted at the midpoints of the low-impedance sides of the input transformers; and low-pass filters are included in the output circuits to prevent the passage of high frequencies not essential for voice transmission. The maximum overall gain of this repeater is approximately 19.5 db when the potentiometers are on top step, but the gain of the amplifying units themselves must be higher than this to overcome the losses in the hybrid coils and other circuit elements. The gain is essentially flat over the frequency range from about 200 to 3,000 Hertz.

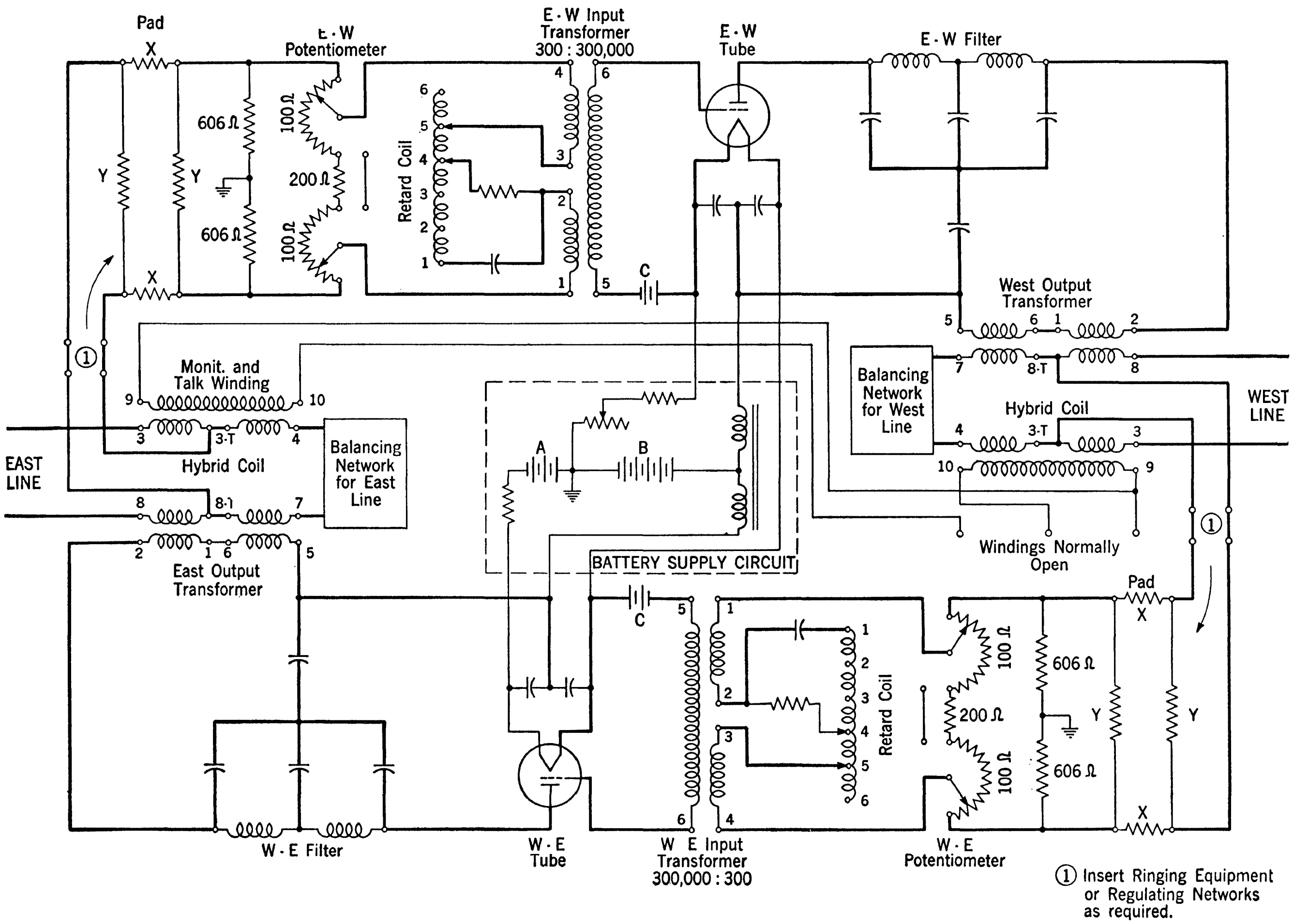


Figure 17.1 22-Type Telephone Repeater Circuit

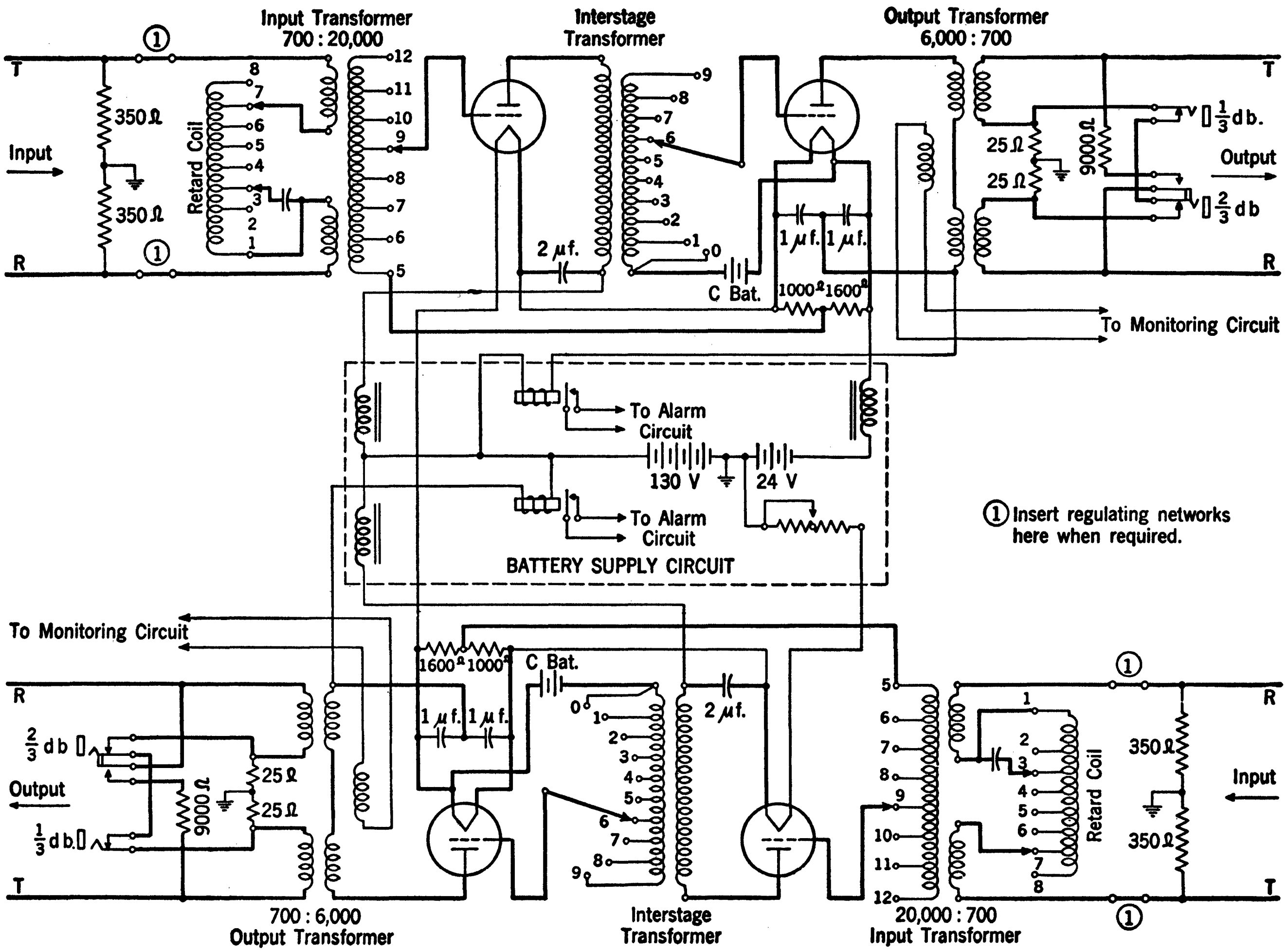


Figure 17.2 44-Type Telephone Repeater Circuit

17.4 44-TYPE REPEATER

For 4-wire circuits, the repeater corresponding to the 22-type repeater is known as the 44-type. In this case, the circuit itself is double-tracked so that there is no necessity for using hybrid coils except at the circuit terminals where the 4-wire circuit is converted to a 2-wire for connection to the switchboard. There is therefore no need for line balancing networks at repeater points, and little possibility of a "singing" path around the individual repeater. For this reason, 4-wire repeaters may generally be operated at higher gains than 2-wire repeaters.

The circuit arrangements of the 44-type repeater are illustrated schematically by Figure 17-2. It will be noted that each amplifier has two triode stages, the first tube acting as a voltage amplifier and the second as a power amplifier. Transformers are used for interstage coupling, as well as in the input and output circuits. The gain is controlled by adjustable steps on the secondary windings of both the input and interstage transformers. The shape of the gain-frequency characteristic is controlled by an equalizing network connected in series at the midpoint of the primary of the input transformer. The maximum overall gain of this repeater is 42.7 db and is flat to frequencies well above 3,000 Hertz.

Where extremely stable amplifier operation is required, as for example in the repeaters of telephotograph circuits, the 44-type repeater may be modified for operation with negative feedback. This reduces the maximum overall gain to about 38 db. Feedback is from an output unit made up of capacitors and resistors inserted between the second-stage tube and the output transformer, to a similar input unit inserted between the input transformer and the first-stage tube.

17.5 V-TYPE REPEATER - GENERAL

Another and more recent design of the voice-frequency telephone repeater is known as the V-type. It differs from the 22- and 44-types considerably, both with respect to the amplifiers themselves and the associated equipment arrangements. Figure 17-3 shows a comparison of the 22A1 and the V1 repeater arrangements in block form. Hybrid coils, equalizers, filters and regulating networks are associated with the line equipment instead of with the amplifiers, so that the repeater proper consists only of the amplifiers themselves. All repeaters are thus essentially identical and this makes it possible to transfer them freely from one circuit to another, as may be required for maintenance purposes. It also makes possible the use of the same repeaters for either 2-wire or 4-wire operation.

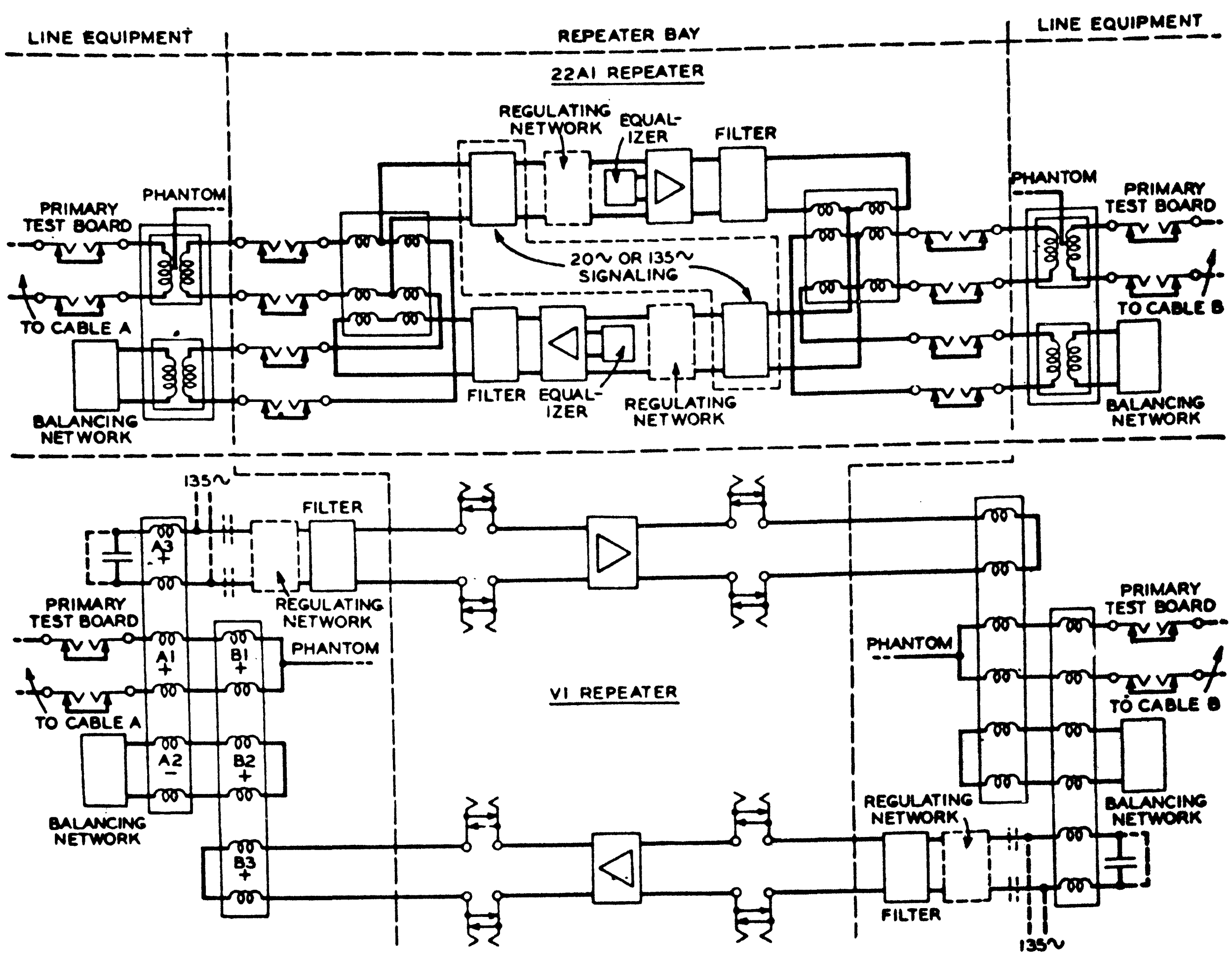


Figure 17-3 (above) - Block Schematic of an Intermediate 22A1 Repeater;
(below) - Block Schematic of a V1 Repeater.

The V-type repeater consists fundamentally of two one-way amplifiers, including talking and monitoring features. A schematic of one amplifier of a V-type repeater is shown in Figure 17-4.

A. V1 Repeater

It will be noted that the amplifying element is a pentode rather than a triode. This permits a maximum net gain of about 35 db, even though the feedback circuit causes a reduction of approximately 10 db.

The amplifier employs negative feedback which reduces gain fluctuations with changes in potentials applied to the vacuum tube. As a result, the variations in gain, due to battery fluctuations, are only one-third of those in the 22A1 repeater. The gain frequency characteristic of the amplifier varies less than 1 db over a range of about 250 to 4,000 Hertz. Feedback is derived from an extra winding on the output transformer and resistances in the cathode circuit. These latter parts include a potentiometer, which, together with taps on the secondary winding of the input transformer, serves to control the gain. The amount of effective feedback changes with the setting of the potentiometer.

The gain change resulting from a movement of the potentiometer contact arm is due to the combined effects of a change in feedback voltage and a change in the amplification of the vacuum tube due to the change in grid bias. This method permits a continuous control of gain over a range of about 5 db. For both direction of transmission, two amplifiers are required of the type shown in Figure 17-4, as this figure only provides amplification in one direction.

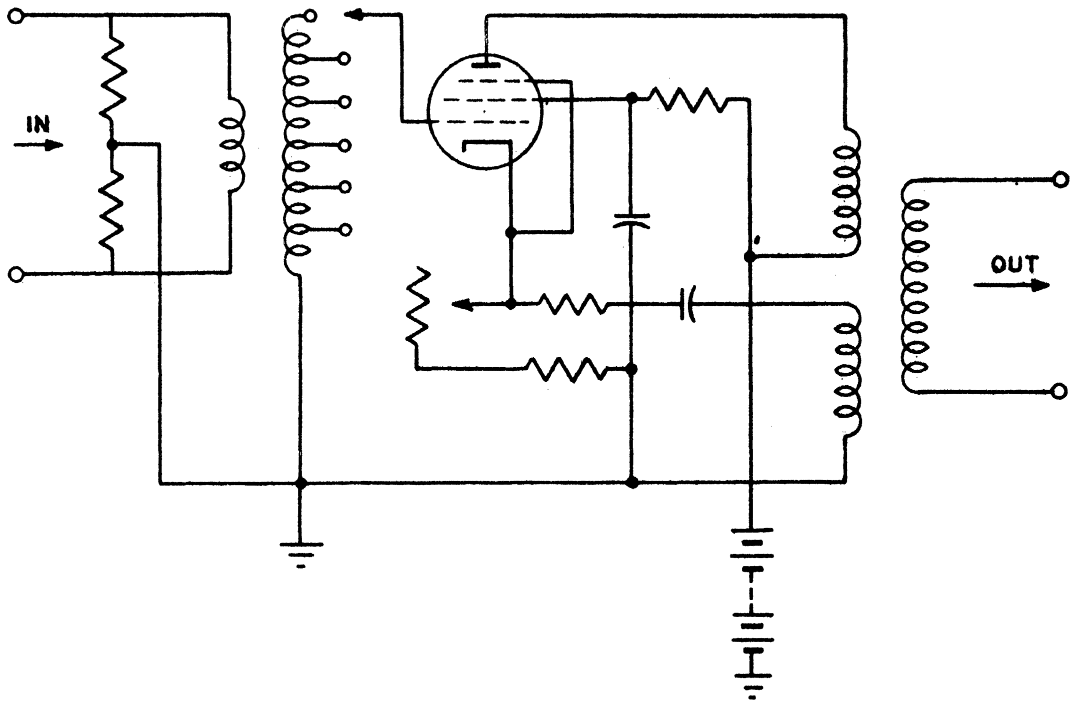


Figure 17-4 One Half Of V Type Repeater

B. V3 Repeater

The V3 repeater consists of two amplifiers and supersedes the V1 telephone repeater. The amplifiers composing the V3 are of the miniature type arranged on an 11-pin plug-in base. The overall size of the V3 repeater is 1/6 that of the V1. This has been accomplished principally by the use of a small combined input-output transformer in a single can, a small carbon composition potentiometer for gain adjustment, a small 1 uf capacitor, and a small vacuum tube.

The "miniature" technique is used primarily for space saving purposes, and the overall characteristics of the amplifier are approximately the same as for the V1 repeater. The vacuum tube used has about twice the transconductance and substantially the same output power as the tube employed in the earlier V-type amplifier. The entire amplifier unit is of the plug-in type which provides for quick replacement of defective units and facilitates testing and maintenance.

The gain may be varied continuously from a maximum of about 36 db to a small loss by a logarithmically tapered potentiometer having approximately 40 db range connected across the secondary of the input transformer. Feedback is obtained by coupling from the output to the input through a cathode resistance and a feedback winding on the output transformer. The total amount of feedback over the voice frequency band from the output to the input is about 14 db and is independent of gain adjustment. This is about 6 db more than the V1 and stabilizes the gain better against tube and battery variations.

C. V4 Repeater

The V4 telephone repeater consists of two 227 type transistorized voice frequency amplifiers and their associated equipment. The repeaters have been designed primarily for use between 600- or 900-ohm central office equipment and H88 loaded exchange cable, 600-ohm equipment, or nonloaded cable, by utilizing miniature repeating coils. The associated equipment consists of 1-type terminating sets, 359-type equalizers, and 849-type networks. These various equipments have been designed as plug-in units to facilitate field maintenance, line-up and monitor procedures, and unit replacement as the demand for a particular circuit arrangement changes. Balanced center tap input and output coils built into the amplifier units provide simplex signaling legs without the use of additional repeating coils. If no provision for simplex signaling is needed, these center taps can be used to match the 150- or 300-ohm impedance of nonloaded cable sections or to provide over the line power to intermediate repeater stations.

The V4 operates from either a 48- or 24-volt source. Power consumption is reduced because of solid-state design. For example, each amplifier uses no more than one watt. The V4 will perform substantially longer without maintenance than repeaters previously available. Since all the equipment for a single telephone circuit is contained in one shelf, repeaters may be placed economically and without complex wiring on a customer's premises. In many cases, the V4 offers an approximate 4 to 1 size reduction over V3. Contributing to this efficient use of central office space are the built-in line coils which save additional space on the relay rack and distributing frame.

D. 24V4 Repeater

The 24V4 repeater is used to terminate a four wire circuit at a Central Office as an exchange area trunk or to extend a four-wire circuit in a two wire line to a distant office or PBX. Figure 17-5 is a typical circuit configuration and equipment arrangement of this repeater. The repeater consists of a mounting shelf which holds a terminating set, two amplifiers or networks, an equalizer, and includes a jack field and power supply arrangements. This repeater, therefore, furnishes equalization, amplification and transition from two-wire to four-wire using V4 repeaters. These repeaters are also used in Traffic Service Position Systems using one repeater for every local position at the base unit.

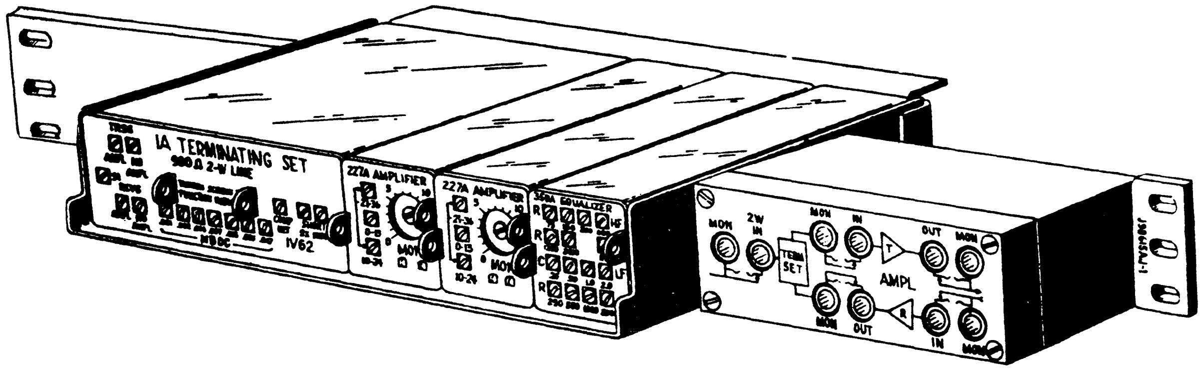
17.6 AMPLIFIER UNITS

The 227-type amplifiers are of the miniature type employing transistors. A 227-type amplifier is available for use in telephone circuits served by underground cable where lightning protection is normally not required. Another 227-type amplifier has essentially the same transmission characteristics but has built-in protection against lightning surges. The input and output transformers of both types are designed primarily to provide either 600- or 1,200-ohm line impedances with a highly balanced center-tap connection for simplex signaling. These amplifiers may be connected directly to the line without the use of repeating coils. By using a center tap for connection to one side of the line, additional input and output impedances of 150 and 300 ohms can be obtained for special applications. The simplex must be sacrificed in order to do this.

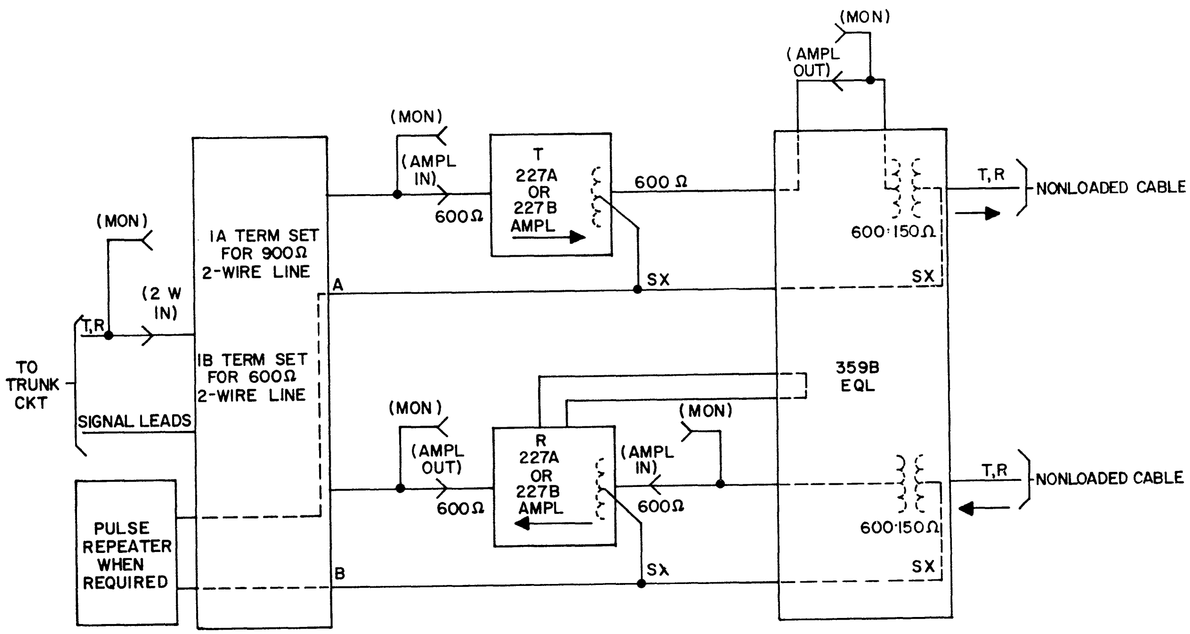
Figure 17-6 is a schematic of a 227-type amplifier, which employs two transistors, an input and output transformer capable of working directly into the line, gain controls, and feedback. For descriptive purposes, the circuit can be divided into three parts:

(a) Input Circuit
(b) Output Circuit
(c) Feedback Loop

The input circuit comprises a terminated transformer, a continuous gain control potentiometer of approximately 15 db range, and an 11 db pad that can be inserted, when required, to reduce the gain. The line winding of the input transformer is center-tapped for

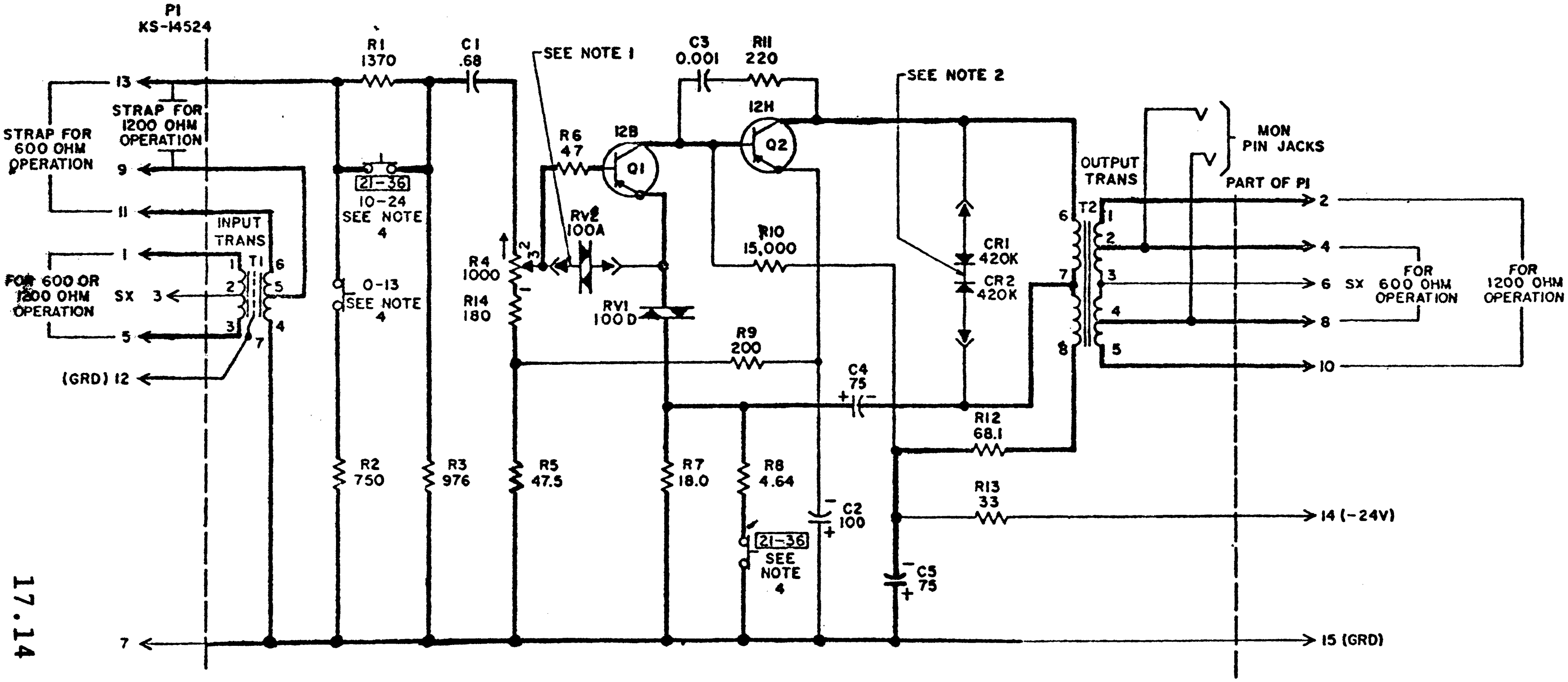


(A) 24V4 Equipment Arrangement



(B) 24V4 Repeater Arranged for Non-Loaded Cable Requiring Gain and Loop Signaling

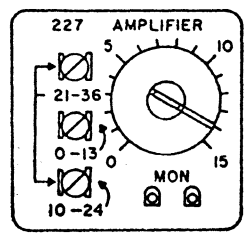
Figure 17-5



NOTES:

1. OMIT VARISTOR, RV2, FOR 227A.
2. OMIT DIODES, CR1 AND CR2, FOR 227A.
3. UNLESS OTHERWISE SPECIFIED ALL RESISTANCE VALUES ARE IN OHMS AND ALL CAPACITANCE VALUES ARE IN MICROFARADS.
4.

RANGE DB	SCREW POSITIONS		
	21-36	0-13	21-36, 10-24
21 → 36	CLOSED	OPEN	CLOSED
10 → 24	OPEN	OPEN	CLOSED
0 → 13	OPEN	CLOSED	OPFN



227 AMPLIFIER FACE PLATE

Figure 17-6 Schematic 227-Type Amplifiers balanced-to-ground operation, and an electrostatic shield is provided. The secondary winding is tapped to provide either 600- or 1,200-ohm termination for the line. The secondary side of the input coil is brought out to terminals, so that a network can be inserted to equalize for loaded cable.

The output circuit comprises a multiple winding transformer used in an unbalanced hybrid connection for feedback, a line-balancing network, and a feedback network. The line winding is center-tapped for balanced operation and taps are provided for connection to either 600- or 1,200-ohm lines. The primary winding is tapped for 10:1 impedance division to minimize power loss to the line. The output impedance is generated by feedback action, thus avoiding power loss in a terminating resistance.

The feedback system comprises two essential loops, one being effective for voice-frequency currents, and the other being effective for bias currents, which are essentially direct currents serving to stabilize the operating point for the transistor. In one loop, voice-frequency current from the hybrid transformer is fed back through a resistor in series with the input circuit. By shunting this resistor with one of lower value, the feedback may be changed to increase the gain by approximately 11 db. The collector current for the output transistor is stabilized by a common emitter resistance. A fraction of the current is diverted to the base circuit of the first transistor to stabilize the collector voltage of the input transistor.

The amplifier may be operated from a 24-volt battery or from a 48-volt battery with a series dropping resistor of 1,400 ohms. The gain of the amplifier is 0 to 36 ± 1 db in three overlapping ranges of about 15 db each. Range is selected by making screw-down contacts at the front of the amplifier. Gain within any range is smoothly adjustable by potentiometer. Gain is down about 0.5 db at 300 and 12,000 Hertz.

17.7 ASSOCIATED PLUG-IN APPARATUS UNITS

The one-type terminating set used with the 24V4 repeater provides the transition between four-wire lines and two-wire lines or drops. Each set is made up of a two coil hybrid transformer, series blocking capacitors, compromise network, building-out capacitors and two optional impedance improving networks for each direction of transmission.

The 359-type equalizers serve to compensate for the transmission-frequency characteristics of the line facilities with which they are used.

Where gain is not needed in the repeaters, the 849-type network is used in lieu of the amplifiers. In special cases, both amplifiers are replaced by these networks. Electrically, each network is the equivalent of a 1C pad, plus a transformer when needed, for matching the pad to line facilities. The pad part is adjusted by means of 89-type plug-in resistors.

17.8 44V4 REPEATER

The 44V4 repeater is a four-wire voice frequency repeater usually inserted at an intermediate point in a long trunk to provide gain and equalization for low loss circuits on loaded or nonloaded lines. It consists of two amplifiers, two equalizers and a jack field. Figure 17-7 shows a typical circuit configuration of this repeater.

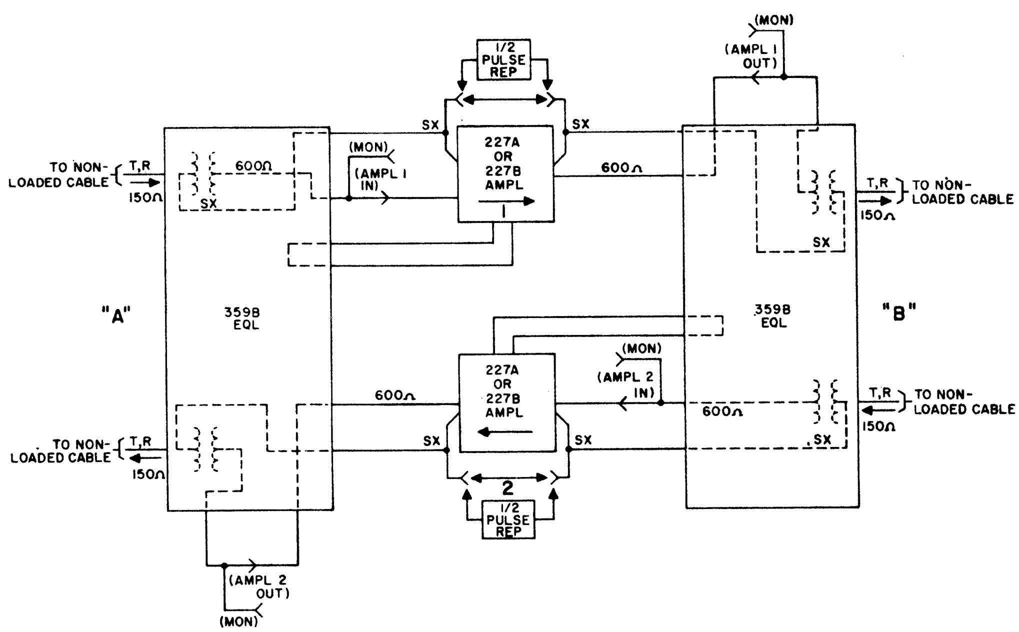


Figure 17-7 44V Repeater Plug-In Units Arranged For Non-Loaded Cable Requiring Gain, Equalization, and Simplex Signaling

17.9 E-TYPE REPEATERS

A. E1 Repeater

An interesting and rather remarkable design of voice-frequency repeater circuit is illustrated in Figure 17-8. This device is sometimes known as a negative-impedance repeater or converter, but is coded in the Bell System as an E-type telephone repeater. Instead of being inserted in the line as in the case of other types of telephone repeaters, the amplifier is coupled to the line through a transformer without breaking the line continuity This transformer may be viewed as both an input and output transformer. As indicated in the drawing, the amplifier circuit employs a dual-triode connected in a push-pull arrangement. The grounded grid connection of the tubes results in a very large feedback because the input and output are in a common circuit. The secondary windings of the transformer are included in the output (plate to cathode) circuit as well as in the input circuit, and plate to cathode current thus flows through both the output and input circuits. Plate to cathode current changes accordingly tend to set up induced voltages in the primary side of the transformer.

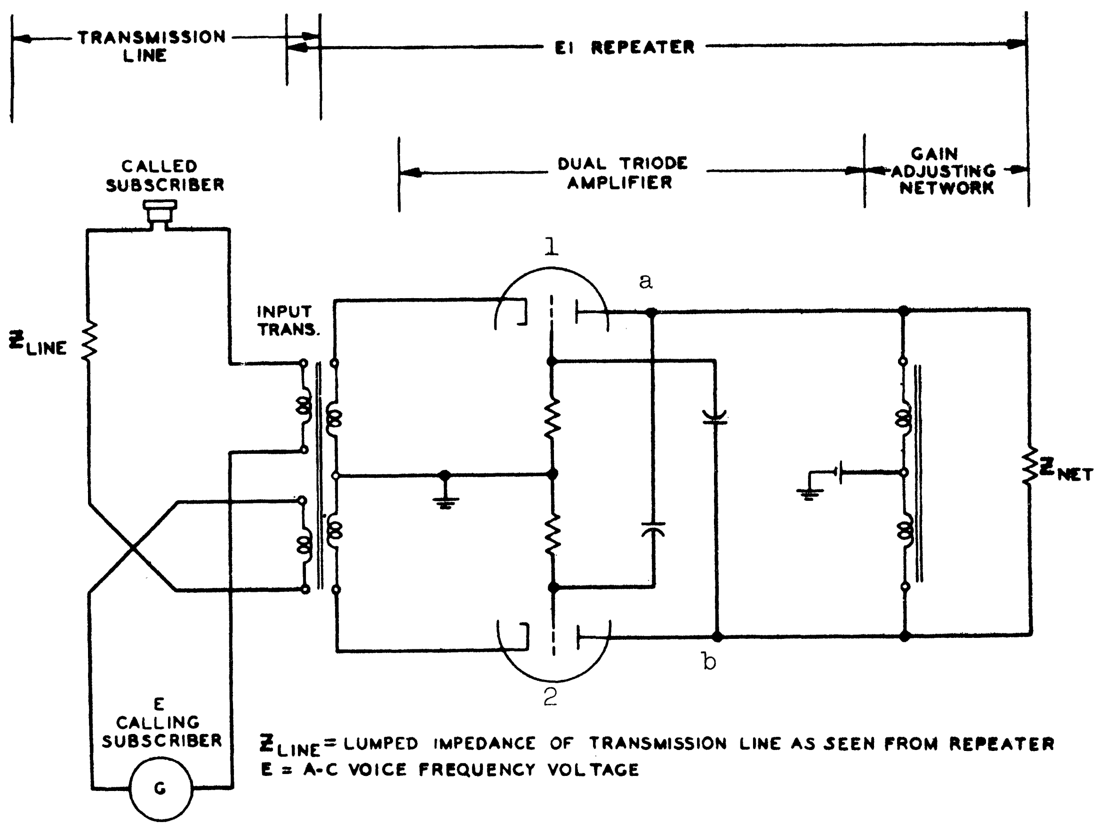


Figure 17-8 Simplfied Schematic of E1 Repeater

At first glance it might appear that this circuit arrangement would have practically no effect on the transmission line because current flowing in the line would induce voltages in the transformer secondary, which would be applied across the cathode-grid circuit of the tubes to cause corresponding currents in the plate-cathode circuits that would flow through the transformer secondaries and set up voltages that would counteract the original applied voltages. This would be true if it were not for the capacitors which couple the plate of each tube to the grid of the other tube. The potential at the grid of Tube 2 is thus determined not alone by the input voltage, but also by the potential at point a. This potential depends on the amount of current flowing in the circuit of Tube 1 and the resultant voltage drops across the retardation coil and the elements of the gain adjusting network. Similarly, the grid potential of Tube 1 is controlled by the potential at point b.

A careful analysis of the voltages throughout the circuit when an a-c input signal is applied, will show that amplified voltages are set up in the secondary windings, and that these voltages are of such phase as to induce voltages in the primary windings that add to the line signal voltages so as to increase the current in the line in either direction. The net amount of amplification secured is controlled by the gain adjusting network by virtue of its control over the potentials at points a and b. In practice, the gain adjusting networks are designed so that the connections of their elements can be adjusted in various specified ways depending upon the characteristics of the line facilities in which the repeater is used. The network connections thus determine not only the overall gain of the repeater, but provide equalization to match the loss-frequency characteristics of the line.

Transmission-wise, it is convenient to consider the E repeater as an impedance converter, which makes the positive impedance of the gain adjusting network appear as a negative impedance coupled in series with the line by the transformer. For this reason, it is frequently called a "negative impedance repeater." When current passes through a positive impedance, a voltage difference IZ, is developed across the impedance. The voltage will be directly proportional to the current, as long as the impedance is not changed. A negative impedance also produces a voltage across its terminals which is proportional to the current which it carries.

However, this voltage will have a polarity that aids the flow of current. So a negative impedance will tend to cancel the "opposition" to current flow offered by a positive impedance in series with it. It is in this way that the E repeater overcomes a portion of the attenuation of the transmission line to which it is connected.

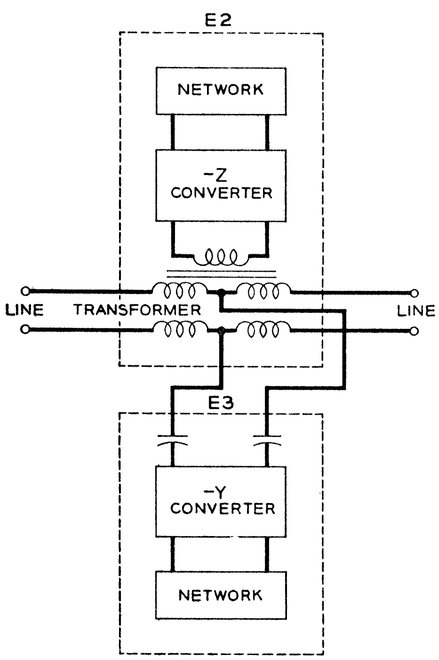
Repeaters of this type provide gains up to 8 or 10 db over the voice-frequency range of approximately 300 to 3,500 Hertz. The application of E repeaters is generally to Exchange telephone plant, where they may be used effectively to improve transmission on long trunks or subscriber lines. They can be applied either at terminals or intermediate points of such lines or trunks.

B. E23 Repeater

Since the equivalent circuit of any transmission line is a T-network, a connected device that is not to be a source of reflections must have an equivalent circuit with both a series and a shunt component. The E repeater is in effect only a negative impedance in series with the line, and it is inherently a source of echo.

This unfortunate characteristic has generally restricted the E1's use to interlocal trunks where the echo problem is usually less critical. This limitation brought about the introduction of two new negative impedance repeaters, the E2 and E3. The E2 is electrically the same as its predecessor, the E1, differing only in equipment arrangements. However, center taps are provided on the line windings of the E2 transformer to permit connection of a shunt element. The circuit of the E3 is materially different from that of the E2, but it performs the same function. It makes the positive impedance of its network appear as a negative impedance between the line terminals of the repeater. However, this negative impedance is designed to be bridged across the line. Normally this connection is made between the center taps on the line windings of an E2. Such a combination is termed an E23 repeater and can be seen in Figure 17-9. The E23 can be viewed as an artificial transmission line having an impedance which matches that of the real circuits with which it is associated, but having a negative attenuation constant so that it which replaces some of the energy lost in the real line.

Since the E23 can provide appreciable gain without introducing objectionable echo, it is finding increasing application in toll connecting trunks as well as inter-local trunks and special service lines.



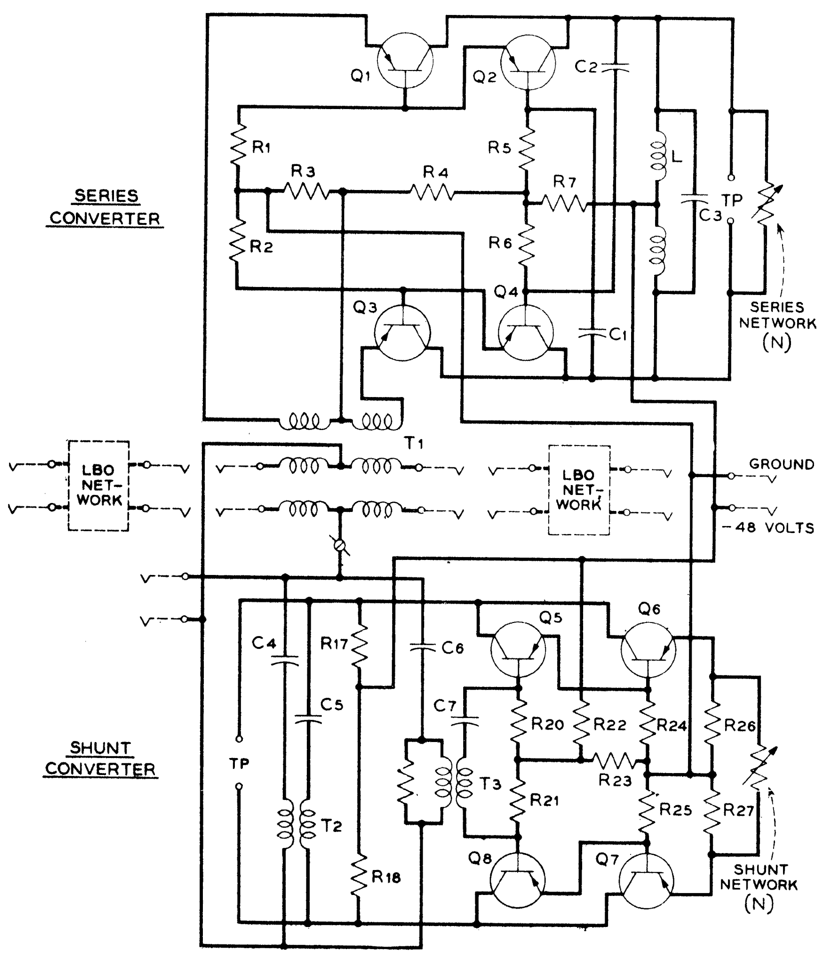


Figure 17-9 Block Diagram E23 Repeater

Figure 17-10 Complete Schematic of E6 Repeater

C. E6 Repeater

. The E6 is a transistorized two-wire, voice-frequency repeater of the plug-in type. The repeater consists of an 831A network and two line-building-out (LBO) networks. Figure 17-10 shows the schematic of an E6 repeater.

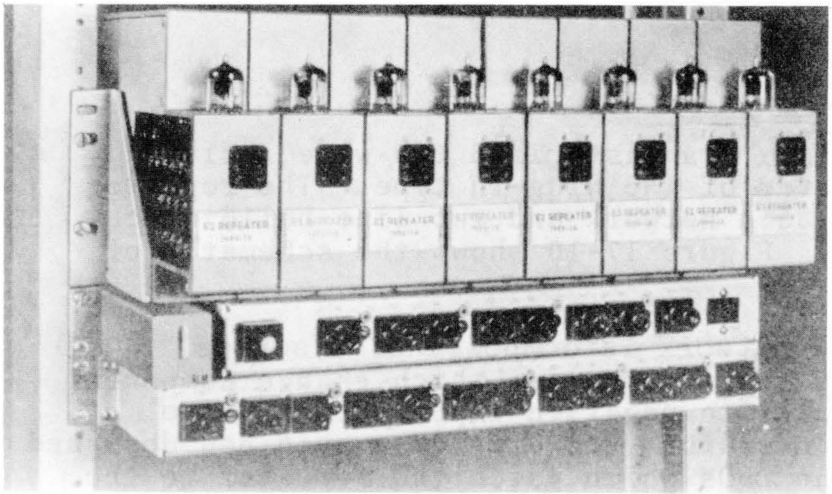
The 831A network is composed of a series converter and a shunt converter which change component resistive networks to negative impedances. These negative impedances form the arms of a gain pad designed to work with the LBOs which match the repeater to the line. The LBO contains elements to build out the line with regard to length, gauge, loading, capacitance, and whether the repeater is to be used at a terminal or intermediate location. Adjustments of the LBO and of repeater gain are made by screwdriver-operated screws which short out or connect in the various components as required.

Repeater gains up to approximately 12 db are possible in favorable cases. In a specific circuit, (12V, 6db) more gain can be realized from a repeater at or near the midpoint than from one at a terminal.

On certain types of circuits, more repeater gain is required than is normally obtainable without resultant singing during idle- or switching-circuit conditions. The greater gains are operable only with idle-circuit terminations or with repeater disablers of the loop-current-operated type. In many cases, the idle-circuit terminations cannot be used without adverse effect on signaling features, and in these cases, repeater disablers are required. The disablers must be located in the same bay with the associated repeaters in order to minimize the effect of capacitance of office cabling upon frequency characteristic of equipped facilities and to prevent interchannel crosstalk.

The E6 repeaters may be operated in tandem on the same circuit, provided the rules for maximum permissible gain are observed.

Combination of the series and shunt units, reduction in size of the line transformer, transistorization, and simplification of repeater networks result in space saving of about 50% over the E23 repeater, as seen in Figure 17-11. Combination of the two units also saves



Four E23 Repeater With Mounting Shelf

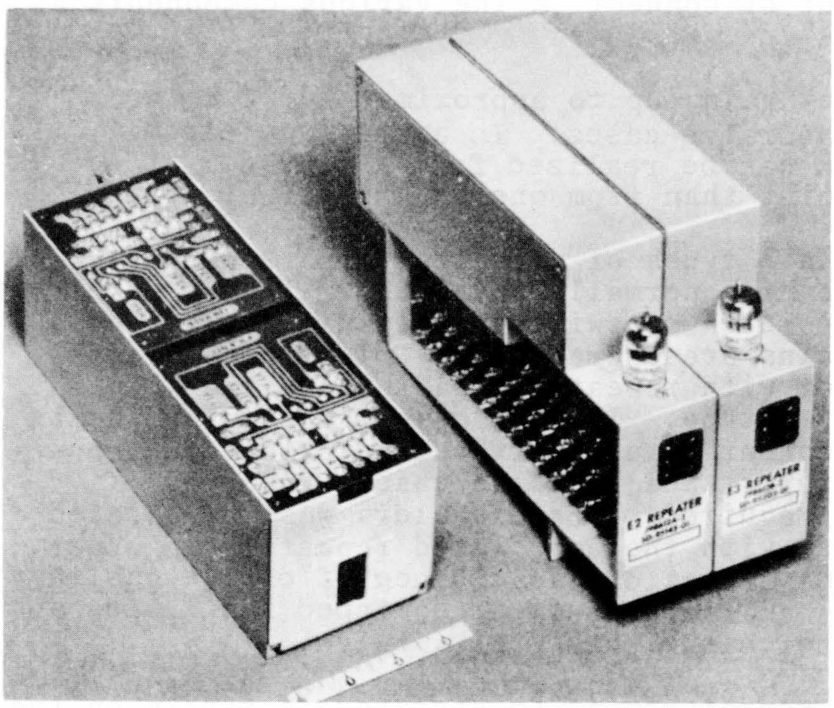


Figure 17-11 E23 and E6 Repeater

handling the time during installation and maintenance, and reduces the number of plug-in contacts.

The use of transistors in place of vacuum tubes frees the E6 repeater from the need for 130 volt battery. This permits easy application in outlying offices that have only 48-volt supply. It also reduces power consumption and the problem of heat dissipation. In the vacuum-tube repeater, filament-current adjustments were required; the use of transistors does away with filament currents.

D. E7 Repeater

The E7 repeater is a transistorized, two-wire, voice-frequency telephone repeater of the plug-in type. It is designed to be inserted between the central office and the subscribers nonloaded loop and used for TWX and Dataphone services, in the manner indicated in Figure 17-12. The repeater improves the loop return loss by modifying the impedance seen from the central office end, provides moderate gains at higher voice - frequencies to permit meeting return-loss and insertion-loss requirements, respectively, and inserts moderate losses at frequencies below 850 Hz as part of its equalization function.

The E7 repeater, although it uses the same mounting shelf arrangements and housing as the E6, has no counterpart among the other E type negative-impedance repeaters. The E7 repeater consists of three major parts:

(1) The Coupling Transformer
(2) The Negative-impedance Converter (NIC)
(3) The Adjustable Network

This repeater acts basically as a shunt repeater at high voice frequencies and a series repeater at low frequencies. As the E7 repeaters must improve the impedance matches between nonloaded loops, which can vary over a considerable range, and nominal office impedance of 900 ohms and 2 microfarads in series, they are necessarily unsymmetrical devices. To couple the office to the loop, a transformer with taps on the loop windings is employed. The converter is coupled to both the office and the loop by means of a fixed third winding.

The E7 repeater improves the transmission by decreasing the loop loss at the high-frequency end of the voice band and increasing it at the low-frequency end. The amount of the high-frequency gain introduced by the repeater is primarily determined by the coupling-transformer turns ratio and may be as high as 8 db. As the E7 is not designed to present a smooth-termination at the central office end of the loop it may reduce the return loss at the station end of the loop. Therefore, this repeater is restricted to terminal subscriber loops that do not switch the station end circuit.

The E7 repeater's negative-impedance converter is a shunt-type (short-circuit stable) negative-impedance converter which presents to the coupling transformer approximately the negative of the impedance of its adjustable network. The shunt converter employs compount-connected transistors in a balanced amplifier and keeps the gain essentially constant, regardless of normal variations of the transistors and of the power-supply voltage.

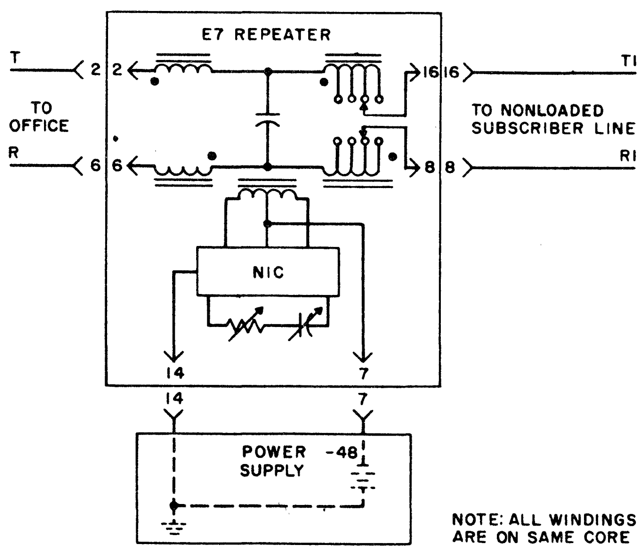


Figure 17-12 Simplified Schematic of E7 Repeater

CHAPTER 18

TELEPHONE POWER PLANTS

18.1 INTRODUCTION

The term power plant, or power equipment, when applied to telephone work, refers to that part of the central office which is devoted to furnishing current required to operate the telephone apparatus. The purpose of the telephone power plant is to furnish energy of the required character in the proper amount and be available 100 percent of the time. An elaborate telephone system is rendered useless if the supply of power fails. Such a failure could cause the "memory" circuits used in today's larger telephone exchanges to lose their stored information to say nothing of cutting off thousands of established telephone conversations and preventing new calls from being made. In addition, a power failure could interrupt the orderly flow of data transmission, halt TV programs and other connected services. In an emergency such a failure could be disastrous. In a way, the power plant might be termed the heart of the telephone system since every line and connection depends on the supply of power.

To meet the vital need of every-ready power, it is necessary to furnish a primary source of power which is reliable. This is usually available through the commercial power services of the local electric and power company. Wherever possible, two services connected to different generating stations or systems are brought into the telephone building. Storage batteries of sufficient capacity to carry the load of the office during failure of the sources of power supply are also used. Common practice and experience have resulted in batteries being provided to carry the load for certain specified intervals.

Carrier power plant ac requirements are such that a continuous supply of power is necessary for the proper functioning of repeater units. This is accomplished by motor alternator sets which are ac driven from commercial power under normal conditions and battery driven during the period of commercial power failure.

To provide reserve power to clocks and other ac operated apparatus during momentary interruptions of commercial power or where the commercial voltage drops below approximately 85% of normal, ac generating units driven from the central office battery are automatically switched-in.

Reserve power supplied by an engine driven alternator on the premises is usually provided under present day practices to supply the essential ac power requirements of the telephone office until the commercial power service is restored.

The central office equipment requires direct current (dc), usually at 24 and 48 volts, for voice transmission and also for operating switching mechanism, relays and other apparatus. In addition many other forms of current are required such as 20-cycle, or 1000-cycle alternating current (ac) for ringing and signaling subscribers or operators in other central offices. 130 volt (dc) supply, both positive and negative is required for telegraph and teletypewriter operation and for plate battery on electron tubes. Since central office equipment and apparatus is engineered to function within specified voltage limits, all battery voltages are closely regulated.

Since continuous power must be provided by the telephone power plant, storage batteries are usually provided. Motor generator units and rectifier units are used to keep them charged so that they can take over the load temporarily when the commercial power supply fails. There are several arrangements of generators and batteries that have been used in the past to develop central office power. The practice at present is to supply the load current continuously from several charging units operated in parallel with each other and with a single storage battery line-up. In this arrangement, the storage battery is "floated," or connected continuously across the main bus bars. Being always connected to the load, the storage batteries, in addition to being immediately available in case of a power failure, have an important filtering effect in reducing noise caused by the charging units. Noiseless direct current (free from ripples or fluctuations) must be furnished for the talking circuits as the telephone receiver is sensitive to noises as well as voice currents. Noise filters, therefore, are provided in the battery feeders for this purpose.

The nominal voltage of each charging unit used is maintained at a value sufficiently high to take care of the load requirements of the office and to supply a small "trickle" charge to the battery, thus keeping it fully charged. The present practice is to provide automatic voltage regulation to insure that the load on the plant is absorbed by the output of the charging units and to insure that the required number of charging units to absorb the load may be cut-in or cut-out as required. In some power plants all charging rectifiers operate continuously to share the load between them.

A. PRINCIPAL UNITS

Telephone power plants vary in magnitude and detail depending upon the size and kind of central office they are used with. Broadly, the principal units of power plants for medium and large sized central offices are:

(a) Commercial power supply fusing and protective equipment for safeguarding the supply as it enters the power plant.

(b) The charging equipment consisting of the motor generator charging machines or rectifiers and their associated equipment, used to convert the commercial power supply to direct current at voltages suitable for central office operation.

(c) The power board containing the control and distribution equipment which includes switches, meters, safety devices and other equipment, necessary for the operation of the plant.

(d) The storage batteries for providing a source of emergency power in case of failure of the power source, and to aid in maintaining a uniform voltage for the current supply.

(e) The ringing and signaling equipment including the ringing machines and ringing power boards for supply and control of the ringing current, tone supply, interrupted current, coin control current and other forms of current supplied for signaling purposes.

(f) The reserve power supply consisting of an engine-alternator set with its associated controls and equipment is used to furnish ac power when the commercial power service fails.

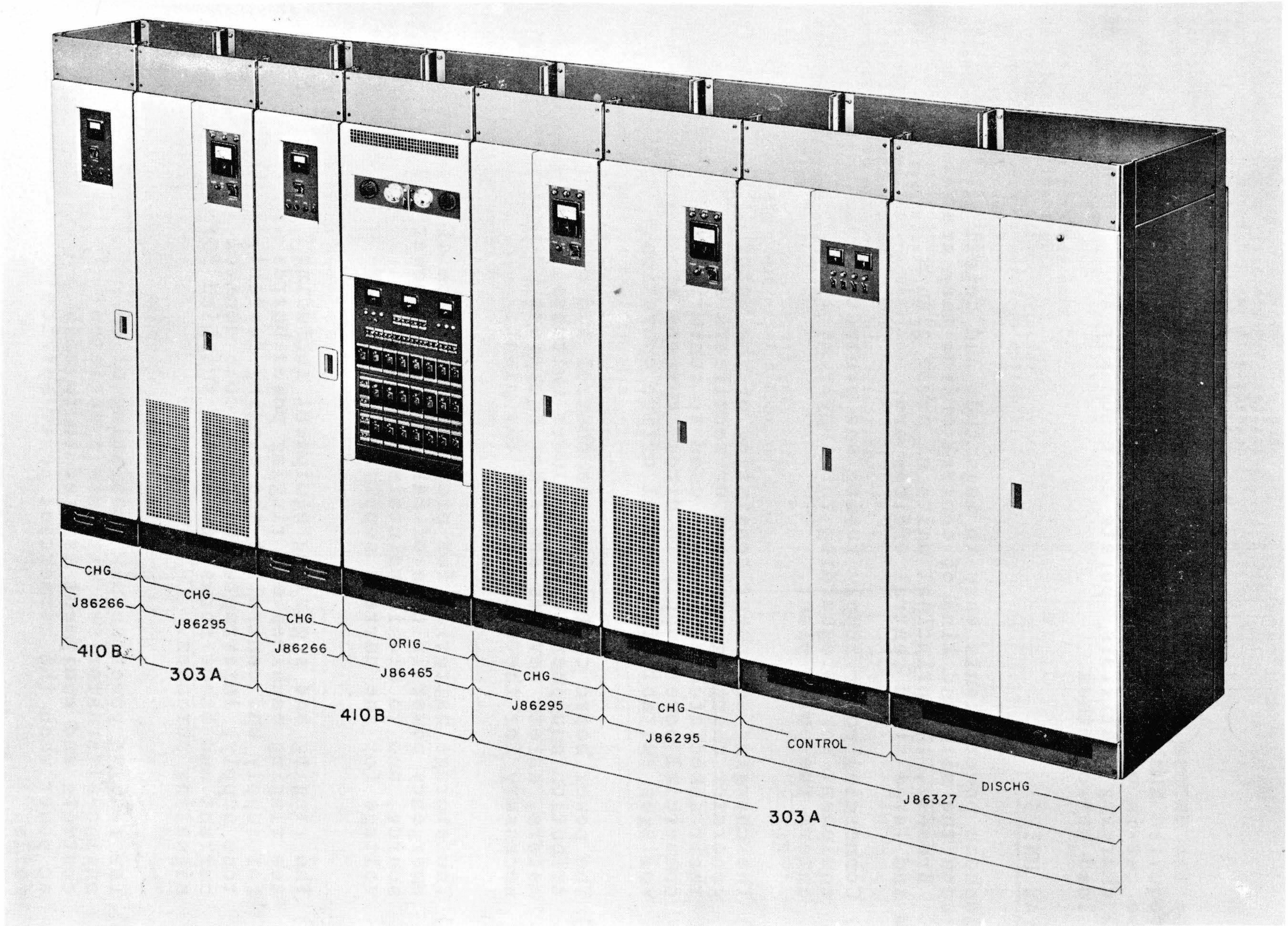


Figure 18-1 Combined 303A And 410B Power Plants

B. POWER PLANT SCHEMATIC

Figure 18.2 is a schematic of an automatic power plant showing both a motor generator and a rectifier as a source of supply and having load requirements of 100 to 4000 amperes. The battery in this plant is continuously floated and the charging unit voltage, therefore, maintained at a constant value. As indicated in Figure 18.2 this is accomplished automatically by means of a motor driven field rheostat associated with a shunt wound generator and by an electronic regulating and control circuit associated with the rectifier.

A voltage relay designated GEN, REG. Voltage Relay in the drawing, is bridged across the main battery. As long as the battery voltage remains as its proper value, this relay is not operated. If the battery voltage becomes too high or too low, one or the other of the two relay contacts is closed. This causes either relay L or relay R to operate and the operation of either of these relays causes the motor driven field rheostat to move in the direction which will restore the generator voltage to its normal value; or in the case of a rectifier, cause the electronic control circuit to raise or lower the rectifier as required.

To avoid overloading the charging unit, an ammeter relay is inserted in series with the line. When the unit is fully loaded, a contact on this relay closes causing the A relay to operate and open the regulating voltage relay circuit. This prevents any further attempt by the relay to increase the charging unit output.

The circuit shown includes two emergency cells which are connected to switches in such a way that one or both may be connected in series with the main battery. These cells are provided to take care of emergency conditions where the outside power supply fails and the charging units are not operating. In such cases the load must be carried by the batteries alone and if the failure continues for an appreciable time, the battery voltage will decrease below the specified minimum value. The emergency cells are then automatically cut into the circuit by a voltage relay bridged across the line as shown.

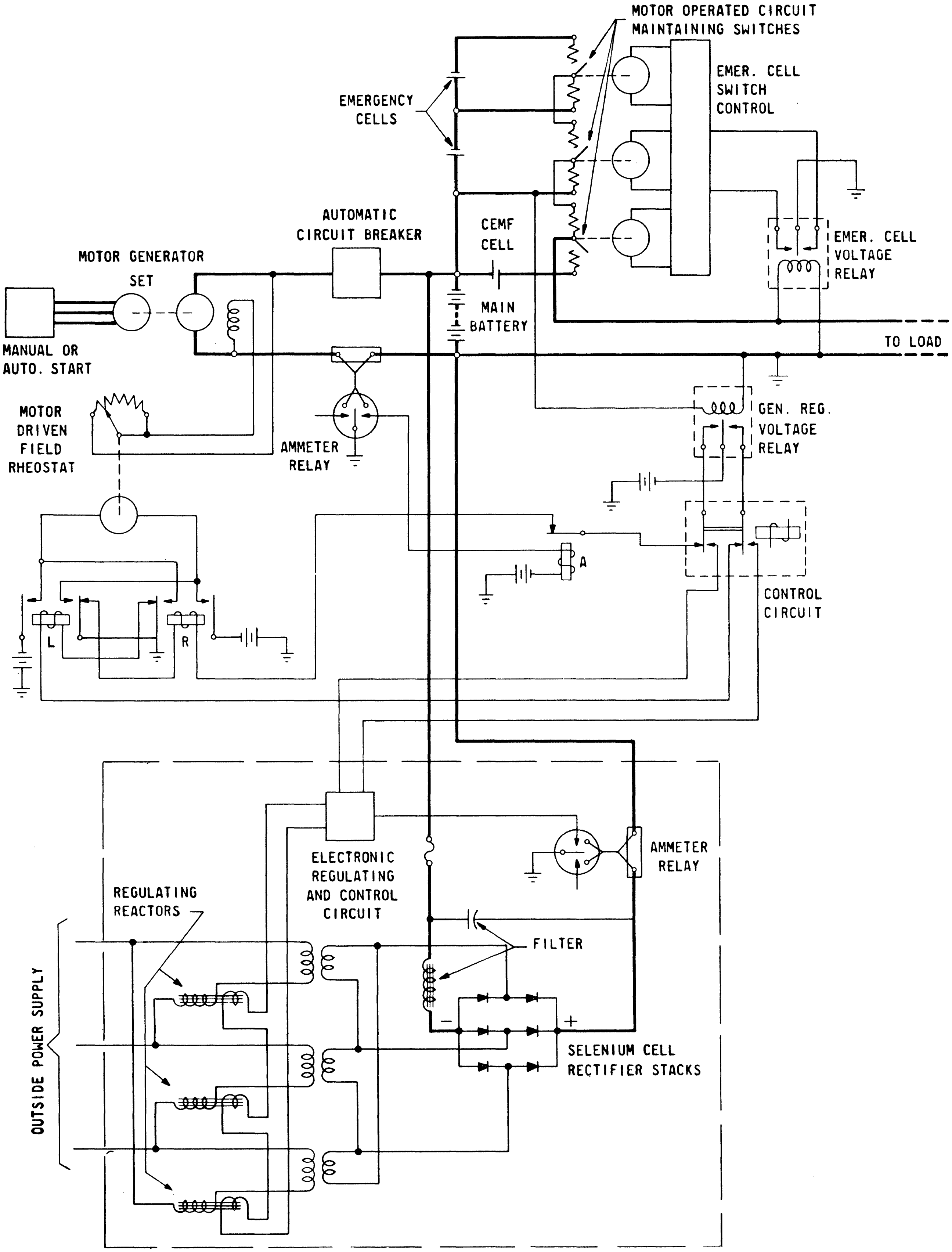


Figure 18-2 Simplified Schematic Of An Automatic Power Plant

Switches are provided for charging the emergency cells from the charging units in series with the main battery. However, since the emergency cells are not always in use they are continuously supplied with a small trickle charge furnished by a rectifier which maintains them in a fully charged condition. These switches and the emergency cell charging rectifier are not shown in the circuit of Figure 18-2.

The main battery is, or course, kept in a charged condition as long as the plant is operating normally. When failure of the outside supply requires the battery to carry the load for an appreciable time, however, the battery will become more or less discharged and will therefore require special charging. To provide charging current in such a case, it is necessary to increase the output voltage of the charging unit above its normal value. However, since the charging unit is connected directly to the load, an increase in its output voltage would also increase the load voltage.

To avoid increasing the load voltage, the circuit also includes a <u>counter-emf</u> (C.E.M.F.) cell which is automatically <u>inserted in series</u> with the load circuit when the output voltage of the charging unit is increased above its specified value. The C.E.M.F. cells, when current flows through it, sets up a voltage opposing the voltage which is driving the current. The countercell voltage is approximately 2 volts per cell and is substantially constant under wide variations of current. Physically, the C.E.M.F. cell consists of two plates of pure nickel immersed in a caustic soda solution. The size of the plates is determined by the amount of current which the cell is required to handle. The cells are usually mounted along with the storage battery cells.

Figure 18-2 shows one generator and one rectifier. However, additional units may be included to carry the maximum office load. With a light load the motor generator set is running and the battery voltage is held to close limits by the motor driven field rheostat under control of the voltage relay.

With a <u>rising office load</u>, when the first charging unit reaches <u>full load</u>, the ammeter relay makes its "high" contact and causes the voltage relay to be disconnected from control of the first unit thus preventing an overload and at the same time connecting it to the second unit. A further increase in the office load again decreases the battery voltage causing the voltage relay to make its "low" contact. This causes relays in the control circuit to function and start up the second unit under control of the voltage relay. Any further increase in the load will be handled in the same way and as soon as the second unit reaches its rated full load, the next unit will be started and connected.

With a falling office load, the battery voltage increases and the output of the charging unit is decreased when the voltage relay makes its low contact. When the output is decreased to no load the unit is shut down and control including the voltage relay is transferred to the next lower numbered charging unit. This process continues until the output of the charging unit or units is sufficient to float the load.

C. ALARM SIGNALS

Visual and audible signals are provided to indicate abnormal conditions such as high or low charging or floating voltages. Alarms are also provided to indicate not only trouble conditions, such as blown fuses and equipment failures, but also to serve as a warning to the attendant when a charging unit is out of service.

18.2 POWER SERVICE SUPPLY AND DISTRIBUTION

The source of primary power for telephone power plants must be dependable. Commercial ac power obtainable from the local power companies is as reliable as can be expected. If the power company can furnish power from two generating plants independently or if there is available some other source of suitable power, the most dependable and adoptable source is selected as the regular supply and facilities for switching to the alternative source are provided. However, interruptions in the transmission of the power supply to telephone central offices do occur on occasions and because of this possibility provision must be made to furnish reserve power. By this means the telephone power plant may continue functioning in the normal manner irrespective of the duration of the commercial power failure.

Reserve power is supplied by Engine Alternator sets which are manually controlled in the larger offices. These units are usually large enough to provide all the ac power required to properly operate the power plant in the regular manner including radio and television channels, automatic message accounting equipment, emergency lights and certain elevator services.

In the smaller central offices, particularly those that are unattended, the engine alternator sets are automatically controlled and are cut-in as soon as the ac voltage drops below a certain value for a predetermined period of time. In some remote localities such as microwave towers, engine alternator sets furnish the power exclusively. In these instances, two sets are provided and each one automatically carries the load 1/2 of the time.

A. POWER SERVICE PANELS

A power service panel including the necessary switches, wattmeters and protective equipment are provided by the power company for terminating the power supply within the central office building. This main power supply panel is used to furnish all the power required for lighting and operating the various electrical equipments within the building, as well as for operating the central office power plant. Additional smaller Power Distributing Service Cabinets fed from the main service panel are located throughout the central office building as required.

B. PROTECTIVE DEVICES

All electrical circuits are protected against abnormal current flow, short circuits or grounds, which might damage the equipment or create a fire hazard, by means of fuses or other protective devices. Protection for power circuits includes fuses, saftofuses, fusetrons and circuit breakers.

Fuses of the cartridge type (N.E.C. or National Electrical Code Standard) are most commonly used for power circuits.

Saftofuse is the trade name of a safety fuse unit (called dead front) consisting of fuse clips (for holding a cartridge fuse) attached to an insulating holder which may be connected to the current carrying parts of the circuit by inserting the holder into an insulating body which carries the bus-bar and lead connections.

Saftofuse Cabinets are sheet metal housings for enclosing the saftofuse units. The larger saftofuse cabinets are provided with covered wiring gutters which are opened only during installation or maintenance work. In a central office power plant the power service leads are run from the power service panel to the saftofuse cabinet (also called "power distributing service cabinet") where the circuits which lead to the charging machines, rectifiers and other electrical equipment requiring primary power voltages are protected.

Fusetrons (and Fustats) are the trade names of a protective device which is a combination of a fuse and a thermal element. They are commonly used for the protection of small motors. The motor starting current, for a short period while the motor is accelerating to normal speed, may be several times the full load ampere rating. A standard fuse large enough to carry the starting current would not, therefore, adequately protect the motor against a continuous overload which in time would heat it up sufficiently to damage it. The fusible link of the fusetron provides the same protection against momentary abnormal currents as an ordinary fuse, while the thermal element heats up and opens the circuit on a continuous current flow only slightly greater than its rated capacity. A fusetron of approximately the same ampere rating as the nameplate rating of the motor is usually used. A fusetron will open in about 1 or 3 minutes at 50 percent above its rating and in a somewhat longer period at 25 percent above its rating. It would carry 6 or 7 times its rated capacity for only one to two seconds.

C. POWER SERVICE DISTRIBUTION

The block schematic shown in Figure 18-3 illustrates a typical method of distributing power service to power equipment on various floors of a telephone building. The notes in Table 18-1 explain the symbols that are used in Figure 18-3.

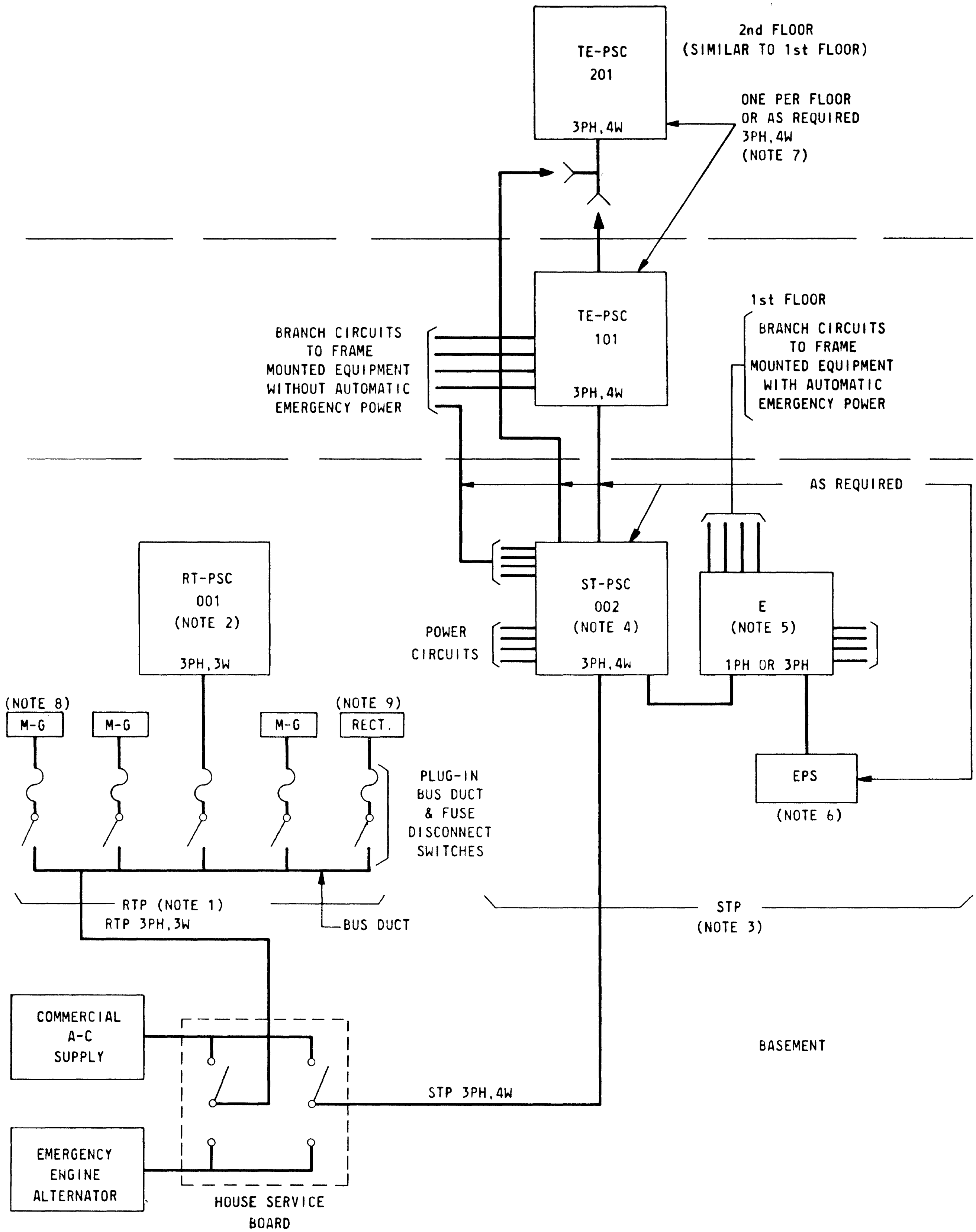


Figure 18-3 Power Service Distribution Schematic

TABLE 18-1

LEGEND AND NOTES ASSOCIATED WITH FIGURE 18-3

1. RTP or Regular Telephone Power Loads. Consists of battery charging equipment and miscellaneous equipment loads with engine alternator reserve.
2. RT-PSC or Regular Telephone - Power Service Cabinet. Supplies all single-phase ungrounded or small three-phase telephone power equipment loads when bus duct is used. It also supplies the MG sets of rectifiers when bus duct is not used.
3. STP or Special Telephone Loads. Consists of all AC operated equipment loads which should not be transferred to a manual or automatic start engine alternator during regular engine load test.
4. ST-PSC or Special Telephone - Power Service Cabinet. Its branch circuits feed power service cabinets on various floors and power outlets mounted on frames or walls. It also feeds the Emergency Power Distributing Cabinet or Panel.
5. E-Emergency Power Distributing Cabinet or Panel for Automatic Emergency Supplies. Supplies all AC operated equipment loads which require an automatically started emergency power supply similar to 500-type power plants.
6. EPS-Emergency Power Supply with Converter. For power service feeds to power outlets when commercial service fails.
7. TE-PSC-101 And 102 Telephone Equipment - Power Service Cabinet. For power distribution on each floor as required.
8. M-G, Motor-Generator. Used for charging the battery and floating the load.
9. RECT-Large Rectifier. Used for charging the battery and floating the load.
10. 277/480-Volts Service. When 277/480-volts service is used instead of 120/208-volts, the RTP 3-phase, 3-wire feeder would furnish 277/480-volts from the house switchboard only to equipment that is wired to accept this service. The STP 3-phase 4-wire feeder would be reduced to 120/208-volts by the use of step down transformers for all equipment that cannot operate on 277/480-volts supply.

18.3 CHARGING EQUIPMENT

The term "charging equipment" applies to rectifiers and motor generator sets and their associated controls, used to convert commercial power service supplies into direct current at the proper potential required for the operation of central office equipment and for charging central office batteries. Rectifiers make this conversion directly as compared with motor generator sets that convert electrical energy to mechanical energy and then to a different type of electrical energy. The output of the charging equipment is controlled to float the central office load in addition to a small conditioning charge that flows through the battery to keep the cells fully charged. When the commercial power service fails, and the charging units are stopped, the battery voltage is lowered in proportion to the amount of load and the length of time it takes to restore commercial power service to normal. Following a commercial power service failure, it is necessary to immediately charge the battery so that it can be ready for the next emergency. To expedite this recovery, a higher charging rate is used which is called the "charge voltage" as compared with the "float voltage" normally used to float the load.

Rectifiers and motor generator units are usually arranged for manual and automatic operation. The manual control is used to facilitate maintenance, adjustment and testing.

A. RECTIFIERS

A charging rectifier is commonly defined as a device for converting alternating current to direct current. All rectifying elements operate on the principle of permitting electric current to flow freely in one direction only. Basically two types of rectifiers are now used in the telephone power plant, Electron Tube and Semiconductor type rectifiers.

The electron tube type rectifiers are primarily used for battery charging or supplying plate circuits. They vary in size from a few watts to 1200 watts and are furnished for manual or automatic regulation. Electron tube rectifiers operate on the principle that a small change in voltage on the grid of an electron tube causes a comparatively large change in its output. The grid controls the flow of space current between the plate and the filament. Since the space current flows in only one direction, this rectifies the alternating current.

Semiconductor type rectifiers are used for battery charging, supplying current to batteryless power plants and various other types of central office loads. They are equipped for manual or automatic regulation. Their size varies from approximately one watt to 20 kilowatts and larger.

Magnetic amplifiers, saturable reactors and SCR's are used under control of transistorized printed circuit package units in modern rectifiers. The package unit consists of a voltage reference standard, an error detector and an amplifier which closely regulates the rectifier output as required. Figure 18-4 shows a 200 ampere 48-volt rectifier of this type. Modern rectifiers use silicon elements unlike previous metallic rectifiers that used germanium, selenium, or copper oxide elements for rectification of ac currents.

A new class of semiconductor being used in control circuits of charging rectifiers is the PN PN device, commonly called as silicon controlled rectifier (SCR). A rectifier, using this device, usually consists of transformers connected to a full wave bridge. The rectified voltage is blocked by SCR's in either the positive or negative output lead. The SCR is fired by a pulse over the gate lead of the SCR, from a blocking oscillator, which in turn is controlled by a transistorized error detector circuit. The conversion of electron tube rectifiers (thyratron) to semiconductor type rectifiers is now possible by using SCR devices in place of thyratron tubes.

B. MOTOR GENERATORS

The motor generator charging sets consist of a direct current generator directly coupled to a 200/230 or 440 volt 3-phase, 60-cycle alternating current induction motor. Alternating current service is practically universal at the present time. However, in a few older offices, in some larger cities, direct current commercial power is still furnished thus requiring the use of direct current motors.

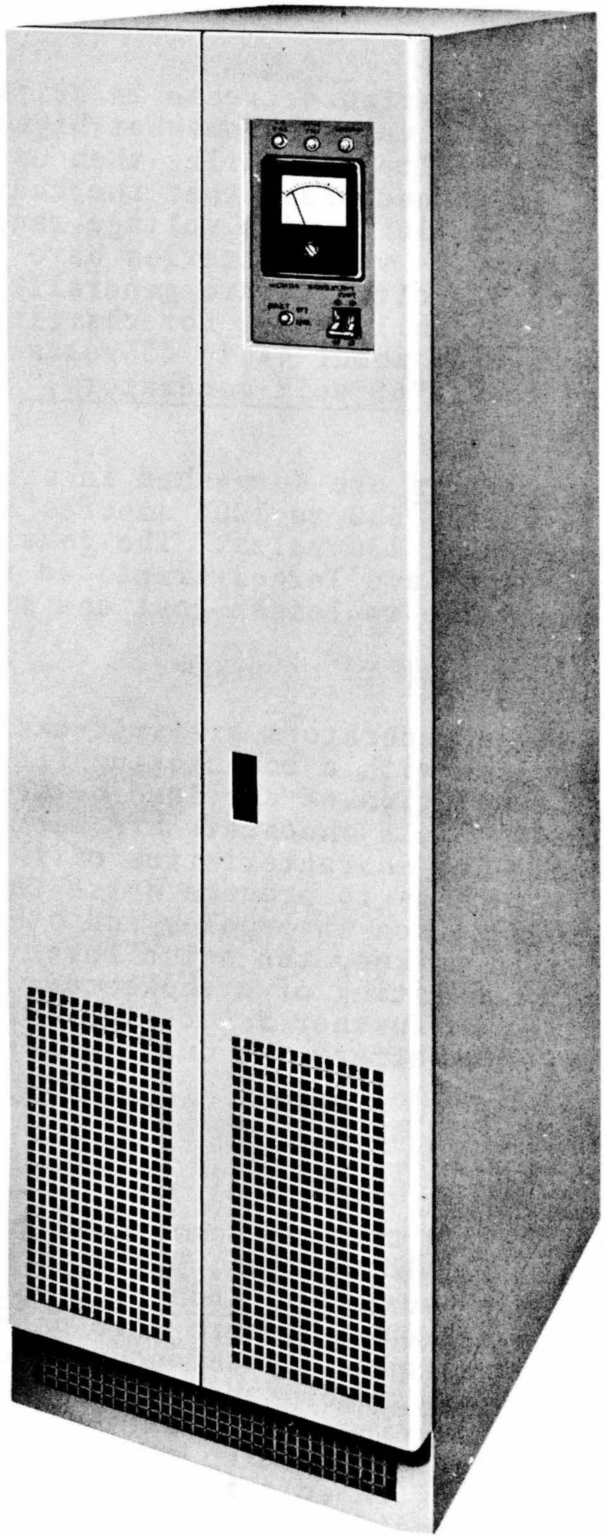


Figure 18-4 200 Ampere 48 Volt Semiconductor Type Rectifier

Since storage batteries decrease in voltage when discharging and require a voltage somewhat higher than the "normal" or "floating" voltage to bring them up to a fully charged condition, it is necessary that the charging generators have a controllable wide voltage range. The generators for charging 24 volt batteries have a voltage range of about 22 to 33 volts and are generally referred to as "33 volt generators" while those for charging 48 volt batteries have a range of about 44 to 65 volts and are generally referred to as "65 volt generators."

Charging generators are furnished in sizes of 600 to 1500 amperes at 24 volts, 500 to 1200 amperes at 48 volts and 100 to 300 amperes at 130 volts. The generators are of the commercial type and have largely replaced the "M" and "Diverter Pole" types due to lesser cost and standardized features.

Commercial type generators are self-excited (shunt wound) and are provided with a commutating field winding for satisfactory commutation at any load between no load and rated full load. Field rheostats are used to control the output voltage. The characteristics of the armature and commutator are such as to produce noise in the generated current and for this reason interpoles and other design features are utilized to keep the noise level at a minimum. However, a filter, consisting of a choke coil and condensers, is required to further reduce the noise to the point where it will not affect the quality of transmission.

C. AC INDUCTION MOTORS

Since alternating current commercial power is available in practically all localities, the motors for driving the dc generators are usually ac induction motors. However, in the past a few synchronous motors were used because of power factor considerations. Synchronous motors are more expensive than induction motors and require a more costly starting mechanism. In view of the higher initial costs and because power factor correction can be more economically accomplished by means of capacitors, synchronous motors are in general not being specified for motor generator use in telephone power plants.

The ac induction motors generally used are of the squirrel-cage type and are capable of continuously driving the dc generator at the specified maximum voltage and rated load under any condition of commercial power service within the limits of 190 to 253 volts or 400 to 500 volts depending on the list number and 58.8 and 61.2 cycles per second. They are also capable of carrying without injury to the equipment a 50 percent momentary current overload on the generator.

D. POWER FACTOR

This term is used to indicate a relationship between the ac current wave and voltage wave. If these waves are in phase with each other, this condition is known as "unity power factor." If the current wave lags behind the voltage wave, due to the reaction of inductive loads (such as motors, etc.) this is termed a "lagging power factor," and when the current wave leads the voltage wave it is termed a "leading power factor." Since the technical explanation of power factors is quite complicated it will, therefore, merely be pointed out here that a low power factor results in "wattless" current or current which does no useful work, but heats up the conductors and increases the voltage drop. This condition is observable with a power factor meter, a phase angle meter or a varmeter, which may be mounted on the power board. Some commercial power companies have a form of contract for power service which includes a penalty for power consumed by electrical equipment which operates at a low power factor. One means of power factor correction is by the use of capacitors which in general are associated with the motor starter circuit. They consist of metallic enclosures containing pyranol condensers.

E. MOTOR STARTERS

The various types and sizes of motors used in power plants require different types of starters. For small motors, the starter may consist simply of a tumbler switch associated with thermal cut-outs, or fusetrons, to protect the motor against overloads or abnormal currents. From this simple starter, the types progress to apparatus of a complex nature, such as the automatic starting compensators for polyphase ac motors. Some of those most commonly used in medium and large sized power plants are briefly described.

1. Across-the-Line Type

These starters are usually employed with motors from 1.5 to 15 HP where the starting current is sufficiently low to permit the motors to be started by connecting them directly across the line. They are furnished in either manually operated or automatic types. Both types include a magnetic contactor (electrically operated switch) for closing the circuit to the motor and a temperature overload relay which opens the circuit to the operating coil of the contactor in case of an overload. The contactor and overload relay are mounted on an insulating base and enclosed in a sheet metal housing. A reset button is provided in the cover for manually resetting the temperature overload relay after it has been operated due to an overload.

The manually operated type employs "start" and "stop" buttons, which may be located on the power board or other location, for controlling the operation of the magnetic contactor.

The automatic type is equipped with a 24 volt dc relay, (with a resistance for use on 48 volts) for controlling the operation of the magnetic contactor. This relay is operated by the control circuit in an automatic power plant.

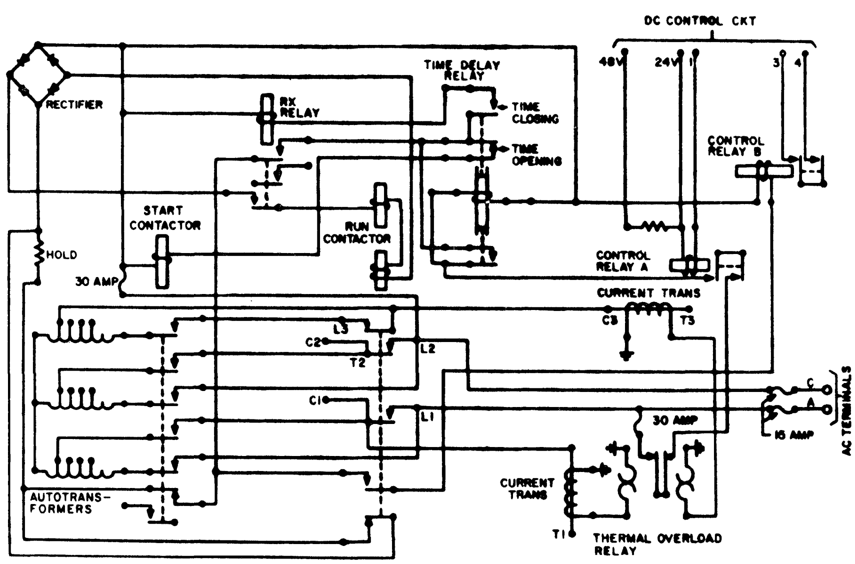


Figure 18-5 Motor Starter Schematic

2. Autotransformer Type AC Starter

The primary purpose of this type starting compensator is to limit the starting current of the larger ac motors (15 HP up) and to provide automatic starting. Each ac starter consists of a polyphase autotransformer with taps, a multipole starting contactor for connecting the autotransformer to the line and the motor to the autotransformer low-voltage taps, a running contactor for connecting the motor directly to the line, a definite time delay which, after a predetermined time, causes the starting contactor to open and the running contactor to close, and overload relays which open the running contactor in case of overload. As the motor rotates, it drives the adjustment dial until a projection on the dial actuates a switchette, thereby operating contacts to control the opening and closing of the start and run contactors. A control relay is mounted in the starter case and connected for operating the starter. The control relay is for use on 20 to 28 volts direct current. A series resistor is furnished for connecting in series with the relay coil for operation on 42 to 52 volts direct current. The complete equipment is mounted with a sheet metal case. A schematic and picture of a 3-phase automatic ac starter are shown in Figures 18-5 and 18-6 respectively.

Where manual start control features are required, manual starters may be used instead of automatic starters. Motor Generator Sets with manual starters are generally used as supplementary units to aid those under automatic control that normally carry the office load. Manual starters for the larger motors (larger than 15 HP) may be identified by the operating handle on the outside of the case with three different positions marked as "OFF," "START" and "RUN."

F. RHEOSTATS

Field rheostats are used to control the current output of generators by regulating the generator field current. There are two kinds: hand operated and motor driven, both are used in series in automatic plants. The hand operated rheostat is preset at the charge voltage for the regular and emergency batteries.

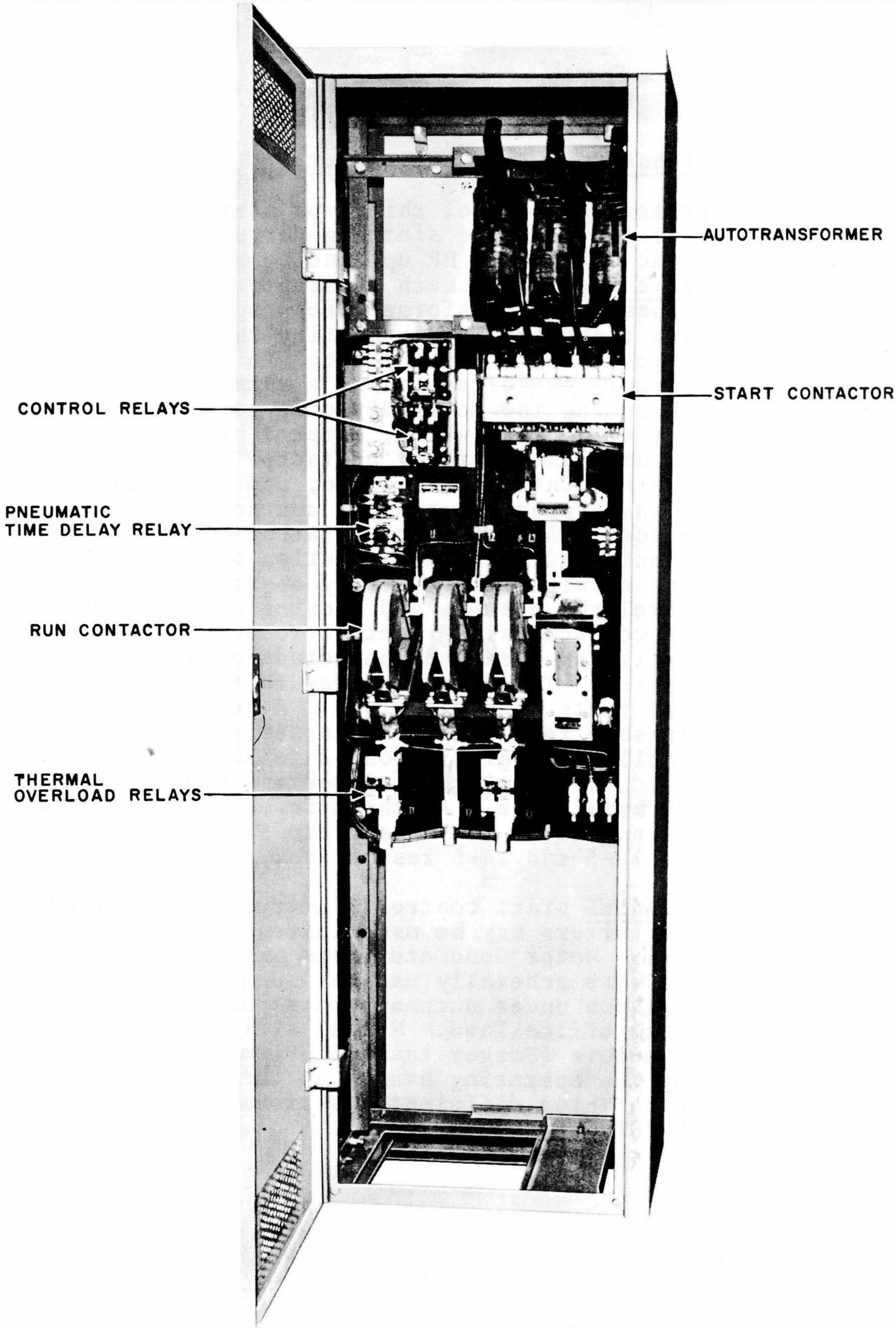


Figure 18-6 Typical Motor Starter

Each rheostat is made up of one or more circular plates on which are mounted contact buttons for terminating the resistance elements. Movable arms, with contact shoes, are provided for varying the amount of resistance in the circuit. To permit the dissipation of heat generated, the apparatus is not enclosed.

Hand operated field rheostats (Figure 18-7) are mounted on the rear of the generator control panels associated with the motor generator units. Handwheels on the front of the board are connected to the movable arms for varying the resistance. Interpolating rheostats have two sections: a main section consisting of coarse resistance steps covering the entire operating range of the associated machine and an interpolating section, consisting of fine resistance steps, which has a total resistance approximately equal to the highest resistance step of the Main Section. Dual handwheels are used, one fastened to a hollow shaft and the other fastened to a solid shaft which passes through the hollow shaft. The smallest handwheel fastened to the inner shaft controls the interpolating section.

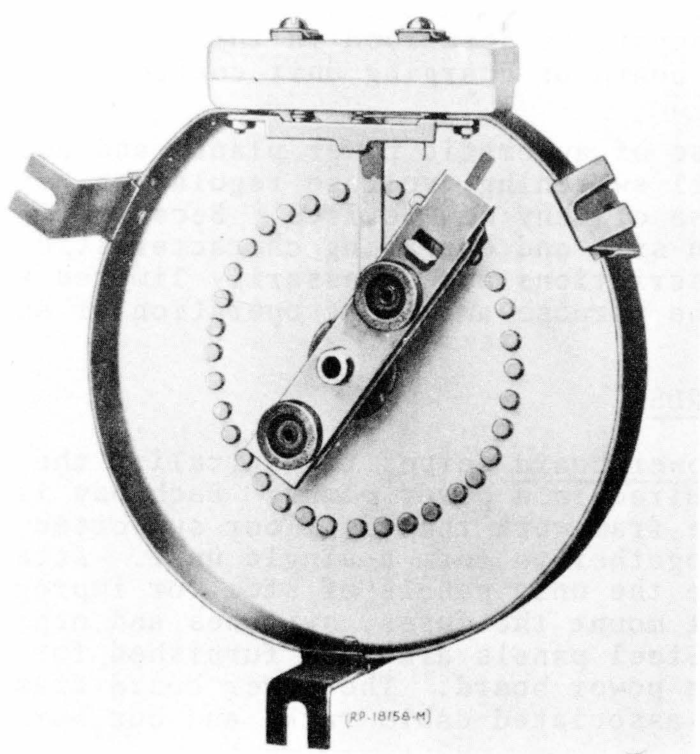


Figure 18-7 Generator Field Rheostat

The motor driven field rheostat used in automatically regulated power plants consists of a circular resistance plate and contact arm operated by a small motor driven through a speed reducing mechanism. This contact arm may be operated in either direction, shunting all or a portion of the total resistance of the plate. Limit switches, which open the motor circuit, are provided to prevent the operation of the contact arm beyond the end contacts. Control circuits actuate the motor drive through relays designated RAISE and LOWER to increase or decrease the output of the charging unit. Arrangements are also available for actuating these relays by means of manually operated keys. The motor driven rheostat is usually mounted near the bottom of the generator control bay.

18.4 CONTROL AND DISTRIBUTION

This section describes the principal items of equipment and apparatus employed to control the operation of the power plant and for controlling the power plant output. Some apparatus that might be considered in this category has been previously described in paragraph 18.3 because of its close association with the operation of charging units. Most of the apparatus described in this section is mounted on the power board or charging unit control panel.

The use of automatic power plants and automatic emergency cell switching, voltage regulation, etc., have led to the use of many new devices. Because of the wide variations in size and operating characteristics, the following descriptions are necessarily limited to a brief outline of the purpose and basic operation of each type.

A. POWER BOARDS

The power board serves to centralize the various controls required in a power plant. Each bay is assembled on a box type framework that is floor supported, the bays are bolted together to form a single unit. Attached to the framework are the unit panels of steel or impregnated asbestos that mount the fuses, switches and other control equipment. Steel panels are also furnished for closing in the ends of a power board. The power board framework also supports the associated cable racks and bus bars.

The main control bay of a large power board mounts the various voltage control and alarm relays together with the fuses, lamps and keys associated with these circuits. Emergency cell trickle charging rectifiers are usually mounted on this bay except when a separate rectifier bay is necessary.

The battery control board portion of a power board, is used as a switching center and distributing point for power to the telephone central office. Two or more bays mount the emergency cell switches, the main charge fuses, a discharge ammeter and voltmeter, voltage relay and the various sizes of discharge fuses required for central office loads. The emergency cell switches in most power plants operate automatically to connect or disconnect emergency cells as required. A battery control board is shown in Figure 18-8.

Small power plants usually consist of a control unit, charging equipment and discharge fusing mounted on one or more bays.

B. SWITCHES

Broadly, the term "switch" applies to any device used for opening and closing a circuit or for transferring the continuity of a circuit from one path to another. In the past, most switches were of the manually operated knife blade type, either single throw or double throw and equipped with one or more poles (current carrying blades). As power circuits became more complicated and many operating features were automatically controlled, switches likewise became more complex in character. Additional features were added to the knife switches, and electrically operated switches known as "contactors," "multipole electrically operated switches," "motor-driven emergency cell switches," "emergency lighting relay switches," "control relays" and others were introduced. In a modern power plant, most of the switches are of an electrically operated type, except for the knife switches associated with the discharge fuse and switch units and the charge switches on generator panels. Figure 18-9 shows various type switches.

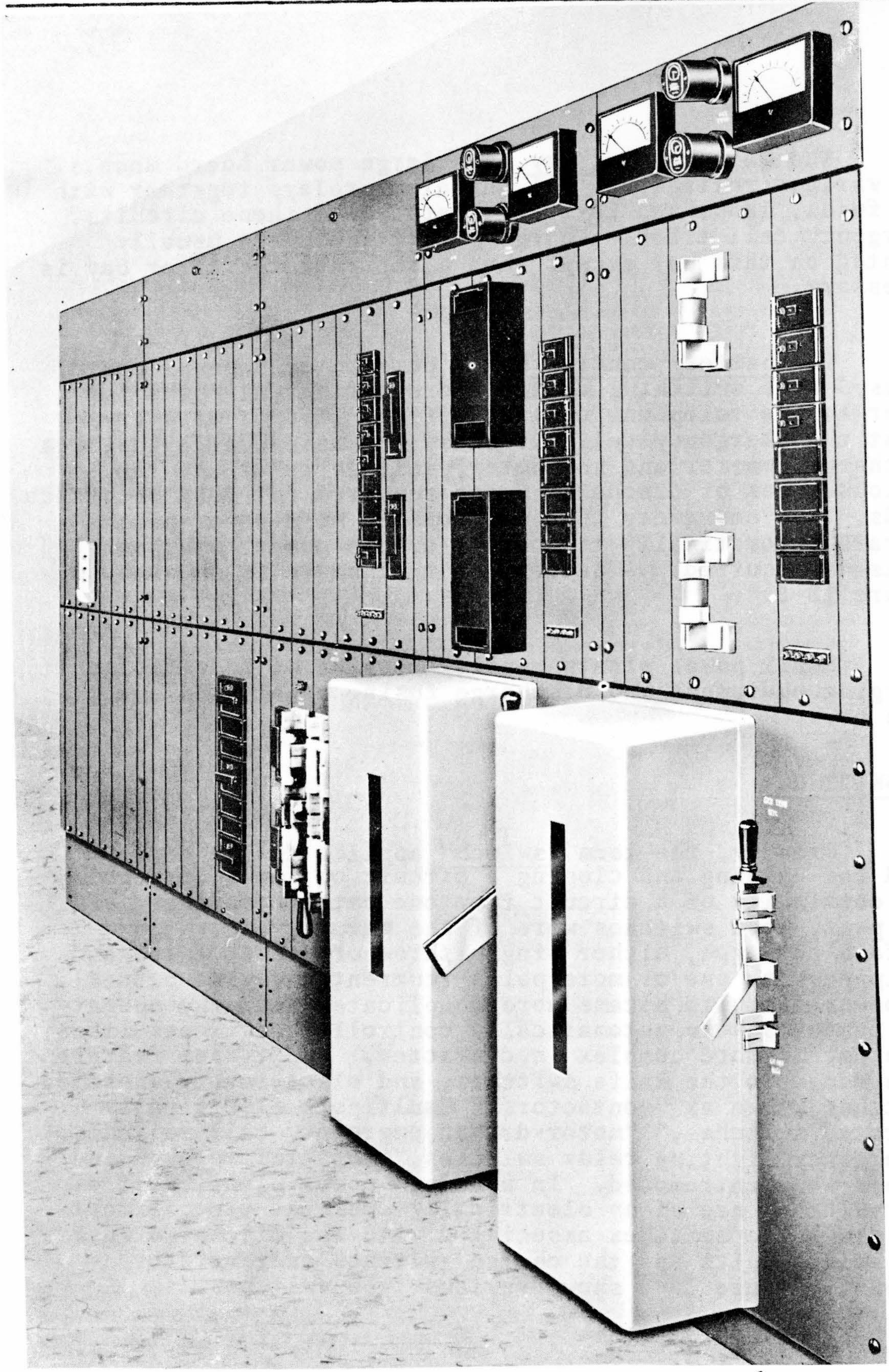
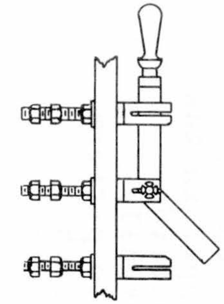
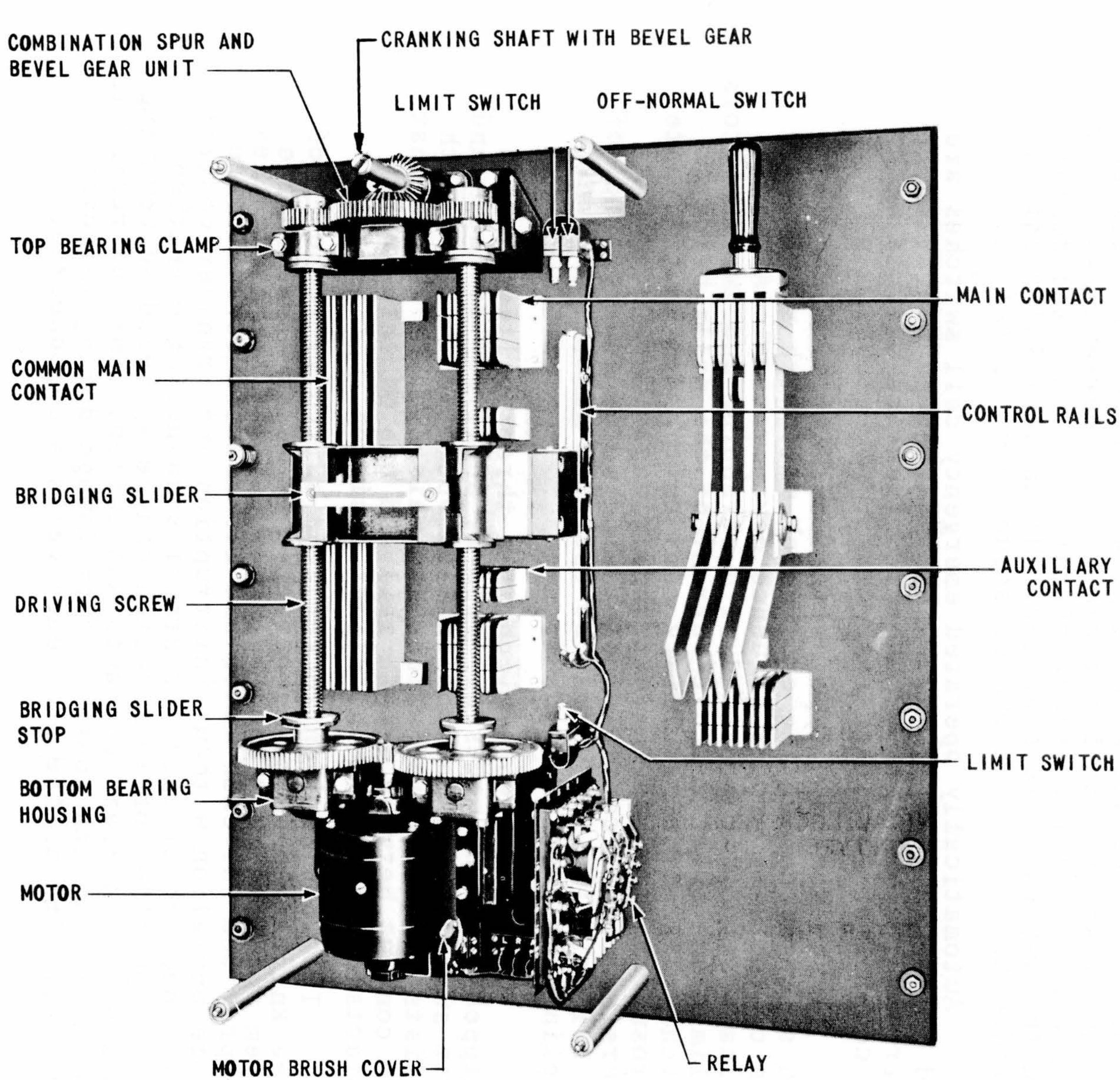


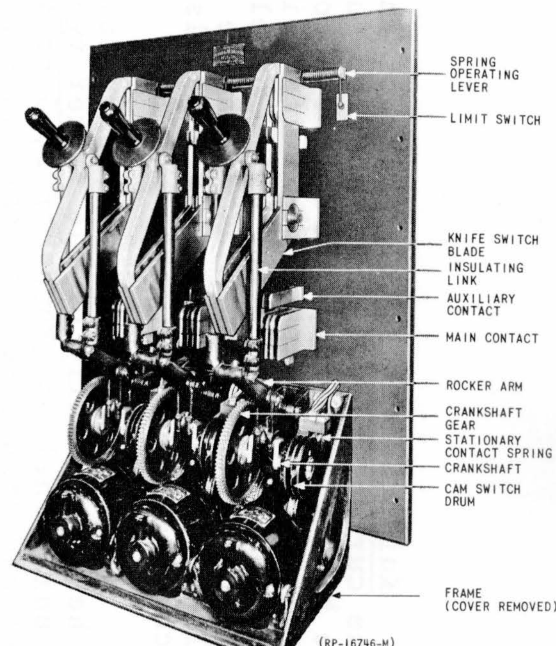
Figure 18-8 Battery Control Board



Rocker Type Knife Switch
Manually Operated



Motor-Driven Slider Type Switch



Motor-Driven Knife Blade Type Switch

Figure 18-9 Emergency Cell Switches Mounted On Battery Control Board

Knife Switches: The size of the switch is controlled by the current flow. There must be sufficient copper in the knife blades and jaws, and suitable contacts to provide adequate carrying capacity. Knife switches are usually mounted on unit type power board panels arranged to perform specific functions; such as discharge fuse and switch panels, battery transfer switch panels, emergency cell switch panels and the like.

Manually operated emergency cell and C.E.M.F. cell switches are usually of the rocker type. They are mounted on a unit panel in groups of 2, 3 or 4 depending on the number and arrangement of the cells to be switched. The switches are equipped with auxiliary contacts and current limiting resistors to limit the flow of current as the cells are momentarily short circuited through the resistors when the switches are operated. Mechanical interlocks are provided to insure the proper sequence of operation.

Automatically operated emergency cell switches are used in modern power plants where unattended operation is desired. The switches are motor driven and operate under the control of a voltage relay.

The rotary cam type switch consists of a camshaft with a set of conducting cams which mate with stationary main contacts in proper sequence of operation. A set of laminated studs is provided with strapping and two resistors to limit the short circuit current of the cells being switched. A set of auxiliary cams on the camshaft actuate microswitches to provide external signals and through a reversing relay, control the driving motor and rotation of the switch. The switch may be operated manually by uncoupling the gear train.

The slider type switch is a three position switch equipped with the necessary relays, auxiliary contacts and limit switches for controlling its operation. The switch consists of a bridging slider and main contact blades that make contact between a main rail and one of three main contacts depending on the slider position.

The motor driven rocker type switch is composed of three knife type switches operated by means of a linkage system and motor for each switch. Cam and limit switches are provided for each motor and its associated switch to insure operation without interruption and transfer control to the next motor unit for proper sequence of operation. Manual operation of each switch can be achieved by removing the link. Auxiliary contacts and current limiting resistors protect the switch contacts from damage during temporary short circuits as the emergency cells are connected.

A discharge fuse and switch unit consist of a double-throw knife switch associated with two fuses. The two fuses are connected in series with the discharge lead but the knife switch short circuits one of them. Should the other fuse operate, the switch can be thrown, thereby short circuiting the operated fuse and placing the good fuse in the circuit. After the operated fuse is replaced, the switch blade may be returned to its normal position.

Safety type switches consist essentially of knife type switches mounted on an insulating panel and enclosed in a metal cabinet. A handle on the outside of the cabinet operates the switch. They are furnished in single-throw and double-throw type having fuse clips of the proper capacity mounted on the panel. They range in capacity of 30 to 1200 amperes and are used principally for controlling circuits carrying primary commercial power supply voltages.

Saftofuse units serve as switches in many applications. The insulated saftofuse unit which carries the fuse may be removed from its holder, thereby opening the circuit. This unit may then be placed in the holder reversed, exposing the fuse to view as an indication that the circuit is open.

Emergency lighting relay switches function to automatically connect emergency lighting circuits in case the regular service voltage fails or decreases below a predetermined value and to disconnect the lamps from the emergency service upon restoration of the regular service voltage. The emergency lighting switch for use on single-phase power service is essentially a magnet switch of the mechanically-latched type with a self-contained closing coil and an undervoltage tripping device. Emergency lighting switches for use on polyphase services are similar to the single-phase switches except that additional undervoltage relays are included. A terminal block is provided for connecting the grounded side of the emergency lighting system. A test switch or switches are provided on the panel for simulating a power failure for testing purposes. Emergency lighting switches are double-pole single-throw, are available in capacities of 30, 60 and 100 amperes per pole and are suitable for use on 115 and 230 volt single phase and 200 volt three phase, 60 cycle regular lighting services and on 24 and 48 volt dc emergency lighting services. They are available in either flush mounted or surface mounted cabinets or on panels without cabinets.

Multipole Electrically Operated Transfer Switches are used on ringing power boards to transfer ringing, tone and signaling leads from the regular ringing machine to a reserve machine in case of a primary commercial power failure or other emergency affecting the output of the regular machine. It is operated by electromagnets, and transfers 12 circuits from one set of 12 contacts to another set of 12 contacts. The switch is held closed on one throw when the operating coils of the magnets are energized, and held closed on the opposite throw by springs, when the coils are de-energized.

C. CONTACTORS

The term "contactor" is used to designate a type of relay that can safely conduct higher currents through its contacts than can be conducted over the contacts of its associated control relay. The main contacts (1 or 2) are operated by an electromagnet, which in turn is controlled by power circuit control apparatus such as control relays. They are arranged for front or rear-of-board connection, that is, the terminals may be on the front or brought through to the rear of the power panel. The operating parts are on the front. The larger sizes are usually provided with magnetic blowout coils connected in series with the main contacts and arc shields which form a chute into which the arc is blown by the magnetic blowout. The contactors in some cases are equipped with one or more sets of auxiliary contacts for performing associated circuit functions. They are furnished in various types such as single-pole, double-pole, normally-open or normally-closed types; and they range in size up to 1500 amperes capacity for the normally-open types and 300 amperes for the normally-closed type.

Normally-open contactors are those on which the main contacts remain open when the electromagnet is not energized. Normally-closed contactors have the main contacts held closed under spring pressure and are open only while the electromagnet is energized.

D. CONTROL RELAYS

Many types of electrically operated power apparatus (such as contactors, motor operated emergency cell switches, etc.) require more current to operate them than the originating control device such as a key, telephone relay or voltage relay will carry. It is therefore, necessary to have the originating control device operate a "control relay" which in turn operates the larger apparatus. Control relays are furnished in many types and sizes to meet various operating conditions. They may be furnished with one to four contacts and with front contacts, back contacts, or combinations of both. Some types operate on direct current and some on alternating current. The smaller sizes have contacts intended to carry one or two amperes and some of the larger sizes may carry up to 30 amperes under certain conditions. The control relays, arranged for back of board connections and mounted on power board panels, are usually fitted with glass or sheet metal covers. Those arranged for front connections may not have covers, although some are enclosed in sheet metal housings, when they are not located on power board panels.

E. VOLTAGE RELAYS

Voltage relays are used to operate alarm circuits and control emergency cell switching circuits and charging rates for battery charging units when the voltage reaches a predetermined high or low value. Each voltage relay is furnished for a specified voltage range. The relay is so designed and adjusted that the "low" contact will make at its rated low voltage limit and the "high" contact will make at the rated "high" voltage limit. The contacts are also adjustable to a limited extent, within the range of the particular relays, the method of adjustment depending on the type of voltage relay used. Broadly, voltage relays fall into two general types, the moving coil type and the solenoid type. The current carrying capacity of the contacts of both types is limited, so they are arranged in the circuit to operate telephone type relays which in turn operate alarm circuits, control relays or other equipment.

The moving coil type voltage relay is similar to a standard voltmeter in general construction except that the moving arm is provided with contacts. The cases may be designed for either flush or surface mounting depending on the type used. Shielded type voltage relays are provided for applications where the accuracy of operation might be affected by the field created by the presence of current carrying leads.

The solenoid type voltage relay employs a solenoid with a floating core linked to a pivoted contact arm. Holding coils are provided, one connected in series with each contact. These coils, when the contacts close, tend to hold them tighter. The holding effect of the coil is adjustable, and the contacts are adjustable. This type voltage relay is in general used to regulate the discharge voltage of power plants by controlling the automatic switching of EM cells and CEMF cells.

F. AMMETER RELAYS

In automatic power plants, ammeter relays are connected in the output circuit of the charging machines as part of the control circuit equipment for the starting and stopping of individual charging units as the office load varies. The ammeter relay resembles a conventional ammeter in appearance but the moving pointer is equipped with contacts which make on "high" or "low" stationary contacts.

Each ammeter relay consists of a millivoltmeter of the D' Arsonval type for use with an external shunt. Suitable shunts, connected in series with the charging unit output, are available in capacities of from 25 to 1500 amperes inclusive. The moving pointer is provided with a set of insulated contacts which move with the pointer and make contact with corresponding contacts on two stationary pointers (high and low). The ammeter scale is calibrated to correspond to the output of the associated charging unit; such as 0-400 amperes for a 400 ampere unit. Each meter is enclosed in a pressed steel, circular, dust-tight, moisture-proof case with a removable cover.

The high and low contacts are adjustable and are equally adjusted at the factory. The high contacts are adjustable by means of an adjusting screw outside of the case. The low contacts are adjustable by means of an adjusting screw located under the case.

In an automatic power plant, the low contacts are set at a point which will cause the charging unit to be shut off through the control circuit. The high contacts when operated cause the motor driven field rheostat to stop so that the charging unit will not be overloaded and at the same time, when furnished, starts up the next charging unit, connects it to the battery and increases its output as required to carry the office load.

The contacts of ammeter relays are limited in their current carrying capacity and, therefore, they are arranged in the circuit to operate telephone type relays which in turn operate control relays or other apparatus required for controlling the output of the charging units.

G. AUTOMATIC VOLTAGE REGULATORS

In general, the purpose of an automatic voltage regulator is to control the output of a charging unit to float the office load and maintain the battery voltage within specified float or charge voltage limits.

Since the output of a generator depends upon the generator field strength, it is necessary to change the field strength as the load and voltage tend to vary. An automatic voltage regulator which responds to changes in voltage is, therefore, used to control the field strength of the generator to accomplish this purpose. Several types of automatic voltage regulators are used depending on the size and characteristics of the generators involved.

Voltage regulators are also used to control ac line voltages where power service line voltage variations exceed the allowable voltage variation of the equipment. They may be either the magnetic type with no adjustments to control the degree of regulation or a motor operated variable transformer type which controls the voltage applied to an auxiliary transformer to correct for changes in line voltage and load.

1. Voltage Controller

The voltage controller shown in Figure 18-10 is mounted on the battery control board of the power plant involved and consists of a solenoid coil and plunger operating a contact lever which controls two sets of contacts, a main set and an auxiliary set. These contacts operate in conjunction with a cam which is driven by a synchronous type single phase motor. The main contacts make and break with the toothed part of the cam and the auxiliary contacts make and break with the solid disc part.

The rotating cam and disc permit the "high" or "low" contacts to make every 10 seconds if the movement of the contact arm places them in a position to make. This allows time for the motor driven rheostat, located on the charging unit control panel and operated through control relays, to function and the regulated voltage to stabilize between the contact intervals.

2. Motor Driven Centrifugal Type Automatic Voltage Regulator

These regulators are usually mounted on the power board. When used for ac ringing generators, the ac voltage to be regulated is fed to the regulating motor through an autotransformer and a copper oxide rectifier, both of which are part of the regulating unit.

This type consists of a permanent magnet excited dc motor which is connected to a centrifugal type regulator enclosed in the same housing. The regulator includes contacts which in normal operation open and close rapidly, in turn opening and closing a shunt circuit across part of the resistance which is in series with the generator field, thereby varying the field excitations of the ringing generator. The dc motor, which is connected to the output circuit of the ringing generator being regulated, increases or decreases in speed as the voltage varies.

As the ringing generator voltage drops and the regulator speed slows down, the contacts close the short circuiting part of the ringing generator field resistance thus strengthening the field and increasing the voltage. The increase in voltage causes the regulator motor to speed up. The centrifugal action on the weights causes the contacts to open and again insert the field resistance in the circuit, thus weakening the field and descreasing the ringing generator voltage. Rapid cutting in and out of the resistance in the field circuit provides an effective excitation which gives the desired voltage. An adjusting knob and dial is provided on the end of the frame to increase or decrease the regulated generator voltage.

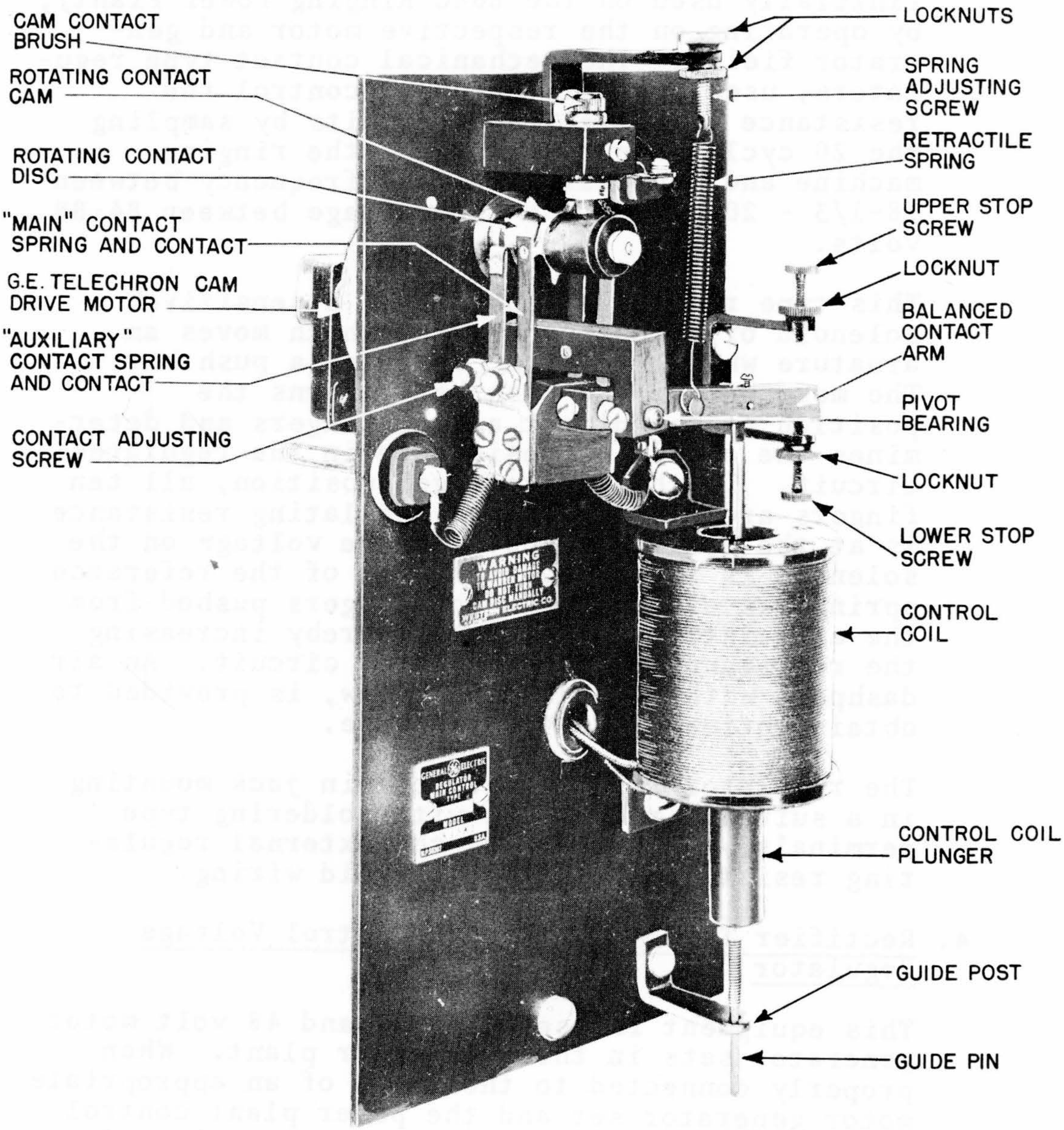


Figure 18-10 Voltage Controller

3. Contact Type Speed Voltage Regulators

They are designed to control the speed (frequency) and voltage of battery driven ringing machine (initially used on the 804C Ringing Power Plant), by operating on the respective motor and generator fields. The mechanical contact type regulators, used for this purpose, control the resistance of these field circuits by sampling the 20 cycle output voltage of the ringing machine and thus maintains the frequency between 18-1/3 - 20 cycles and the voltage between 84-88 volts.

This type regulator consists of a sensitive solenoid or actuating element which moves an armature which, in turn, operates a push bar. The movement of the push bar governs the position of the direct acting fingers and determines the amount of resistance in the regulated circuit. In the "no voltage" position, all ten fingers are closed and the regulating resistance is at the minimum value. As the voltage on the solenoid is increased, the pull of the reference springs is overcome and the fingers pushed from the associated contact bar, thereby increasing the resistance in the regulated circuit. An air dashpot, with an adjusting screw, is provided to obtain optimum speed of response.

The regulator is arranged for pin jack mounting in a suitable receptable with soldering type terminals, for connecting the external regulating resistances and the solenoid wiring.

4. Rectifier Type - Electronic Control Voltage Regulator

This equipment is used with 24 and 48 volt motor generator sets in the 302A power plant. When properly connected to the field of an appropriate motor generator set and the power plant control circuit, it provides high grade regulation of the average battery float and charge voltages, which are adjustable. In addition, this equipment automatically protects the motor generator set from excessive overload. All parts are designed for long life and, with the exception of the electron tubes, should not normally require replacements.

The voltage regulator and exciter are combined. The voltage regulator monitors the central office battery voltage and compares it to a reference voltage standard. When deviations from the standard are detected, information is transmitted to the exciter which, in turn, changes the field current of the generator to increase its output and return the battery voltage to the proper value.

Battery voltage deviations are primarily caused by changes in office load. If these deviations exceed the capacity of the regulated charging generator, the voltage regulator automatically switches from constant voltage to constant current to protect the machine from overload.

This equipment also regulates for changes in the ac input voltage rendering the output of the regulated machine virtually insensitive to ac input voltage changes. It is mounted on a framework designed to fit into the bottom of the control bay of the regulated motor-generator set. One is used for each regulated machine.

H. AUTOTRANSFORMERS

Autotransformers are used to control ac output voltage, particularly in L type carrier plants. Here constant current high voltages are required at main stations to feed a series circuit consisting of auxiliary repeater stations. The output voltages required must be maintained within close limits in certain applications. In these instances, two connected in series and referred to as Course and Fine adjustment autotransformers, are used.

They normally consist of a single-phase reversible motor which is coupled through a gearing arrangement to a brush mechanism which is moved across the commutating surface of the autotransformer.

The magnitude of the voltage output is controlled by the position of the brush on the autotransformer commutator which changes the winding ratio. With this arrangement, an output voltage may be obtained within required limits.

Limit switches are furnished which function with a motor control circuit to stop the brush travel when predetermined positions are reached on the commutator segment.

The motor of the unit may be controlled by relays or an electronic regulator, which in turn is controlled by a voltage sensitive bridge circuit.

I. METERS

To provide a visable means for determining the characteristics and the amount of current flowing in the power circuits, meters are provided. They are usually mounted on the power board or machine control panels.

Ammeters: Ammeters are used to indicate the current flow in amperes between the batteries and distributing fuse panel, between the generators and battery or at other points where such information is useful in operating the plant. Under certain conditions, an instrument switch may be used to permit one ammeter to be switched from one circuit to another, such as to a charging or discharge circuit. Where the generators vary in size, it is the usual practice to provide ammeters of the proper range for each machine. In connecting an ammeter to a circuit, an ammeter shunt (of the proper value for that ammeter) is connected in series with the circuit. The terminals of the instrument are connected to the terminals of the shunt either directly or through the instrument switch. Most of the current flows through the shunt and only a very small portion is bypassed around the shunt through the meter. When the amount of current to be measured is comparatively small, this shunt is sometimes self-contained in the ammeter case.

Voltmeters: The voltmeter is used to indicate the voltage (or potential) of a circuit. It is connected directly across the circuit to be measured by means of fused leads. An instrument switch is sometimes used to connect one meter to more than one circuit, such as to one or more generators or to a battery to which the generators may be connected.

Wattmeters: Wattmeters are used at emergency engine driven alternator installations when it is necessary to know the actual kilowatt output of the alternator when carrying the office load.

Frequency Meters: These are used to indicate the frequency of alternating current. When furnished with an emergency engine driven alternating current generator (alternator), it indicates the frequency of the alternator output and also checks on the engine speed which is directly proportional to the frequency.

Power Factor, Phase Angle and Varmeters: These are used on installations where the commercial power company imposes a penalty for operating at a low power factor, and where either synchronous motors or static condensers are provided for "boosting" the power factor. They are special ac wattmeters arranged to indicate the power available in a circuit.

18.5 RINGING, TONE AND SIGNALING EQUIPMENT

In the operation of a telephone plant, ringing, tone and interrupted currents are of almost equal importance to those obtained from the charging units and their associated batteries. These currents, which are supplied by the "ringing power plant," are used to operate the bells at subscribers' stations, to signal from one office to another for establishing trunk or toll connections and for providing the various kinds of tone and signaling current necessary in the operation of the central office. Continuous service of the ringing power plant output is therefore required. For this reason reserve equipment is furnished for use when failures occur in the regular equipment or when there is an interruption in the commercial power service.

Ringing current, tones and interrupted signal requirements differ for dial, toll and repeater equipments. The type of ringing equipment required to furnish these needs is influenced by the central office size. In general, the output of the ringing power equipment usually embraces the following types of current, or combinations:

Ringing current, at a frequency of approximately 20 cycles, is furnished for ringing subscribers' bells. For passing ringing signals over toll circuits, 1000-cycle ringing current is usually employed.

Tone current is used to audibly transmit circuit conditions such as "busy signals," "dial tone" and the like to subscribers or to the operating forces.

Interrupted signaling current is employed for the ringing and silent intervals for machine ringing, flashing supervisory signals and for other purposes where periodically interrupted or timed pulses are required in performing central office operating functions. Interruptions of 60 IPM (interruptions per minute) and 120 IPM are commonly used in many types of central offices and in addition, interruptions of one, two, three or four seconds and combinations, thereof are used in central offices arranged for machine ringing.

Coin control current is generated by the larger size ringing machine for controlling the "coin collect" and "coin return" features of pay stations. Positive and negative 120 volt direct current is used for this purpose. In smaller central offices, dry cell batteries are used to provide the coin control current.

A. RINGING SYSTEMS

Manual ringing systems are employed in small manually operated P.B.X.'s where the subscribers' bells are rung by operating a key in the operators' keyshelf. The duration of the ringing period and the method of ringing, whether a steady long ring or an intermittent series of short rings, is entirely under control of the operator. For this service, the ringing equipment provides a steady flow of alternating or superimposed ringing current to the switchboard.

Alternating ringing current of approximately 20 cycles is employed for single party lines, where the subscribers' ringers are connected across the line, and for two party selective or four party semiselective (code) ringing, where the ringers are connected from each side of the line to ground.

Superimposed ringing current is supplied for four party selective ringing or eight party semiselective ringing. The subscribers' ringers are connected from each side of the line to ground. Superimposed ringing current is alternating ringing current superimposed on a direct current by connecting the ringing current supply in series with a battery of 36-40 volts so that the ringing current becomes, in effect, pulsating direct current. This is shown graphically in Figure 18-11. The ringing current is superimposed on a positive and a negative battery, to obtain positive and negative pulsating current. The subscribers' ringers are so constructed and adjusted that each will respond to only one polarity of superimposed current. By connecting a ringer responding to negative and another responding to positive ringing current from one side of the line to ground, and two more similar ringers from the other side of the line to ground, four party selective ringing is accomplished. By doubling the number of ringers and employing "one-ring" and "two-rings," eight party semiselective ringing is obtained.

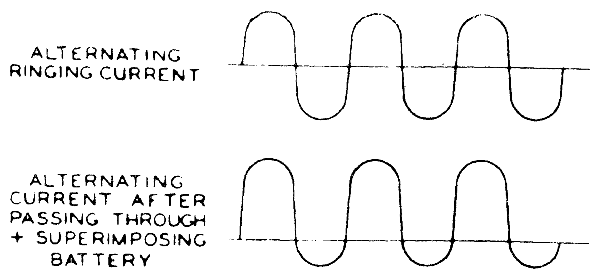


Figure 18-11 Comparison of AC And Superimposed Ringing Wave Forms

B. MACHINE RINGING SYSTEMS

The term "machine ringing" indicates that after ringing is started it continues automatically until the subscriber answers or the call is abandoned. It is employed in dial central offices and in the larger P.B.X. exchanges. In dial offices the ringing starts as soon as the connection is established to the "called" subscriber's line. The ringing current flows through a "tripping relay" circuit and when the subscriber answers, the tripping relay operates and discontinues the flow of ringing current to that line.

The ringing current supplied for machine ringing is broken up into ringing and silent intervals. These intervals vary somewhat in different types of ringing plant equipment, but in the larger plants the ringing interval is two seconds and the silent interval four seconds. For semiselective ringing where "one-ring" and "two-rings" are employed, the two rings are one second ring, one second silent. These interruptions are provided by the slow-speed interruptions which are driven by the gear ringing machine. In small plants motor driven interrupters are used.

In order that the tripping relay may function the instant the subscriber answers, tripping battery is furnished (also through the low-speed interrupters) during the silent interval. This silent interval tripping battery may be furnished by the central office battery or by separate cells. The direct current component of the superimposed ringing current, where this type of ringing current is employed, assists in the operation of the tripping relay during the ringing interval.

"AC-DC ringing" is employed to improve the operation of the tripping relays in machine ringing circuits where straight ac ringing was formerly used. This current is obtained by connecting central office 48 volt battery in series with the ac ringing generator. The dc component of the AC-DC ringing increases the tripping range and assures that positive tripping will occur during the ringing interval as well as during the silent interval.

The "pick-up" circuit arrangement, where one-ring and two-ring semiselective machine ringing is used, is devised to avoid the false ringing of the two-ring subscribers. The connecting circuits include pick-up relays which control the starting of the ringing interval. These relays are, in turn, controlled by the "pick-up" slow speed interrupted (PKU) on the ringing machine. By means of the pick-up circuit the ringing is always started so that both rings of the two-ring code are sounded initially as well as during the remainder of the ringing period.

C. TONES AND INTERRUPTED SIGNALS

Tones are used to audibly transmit circuit conditions to subscribers or operators. These are usually furnished as "high tone" and "low tone."

For certain purposes they are furnished as continuous tones such as "dial tone," "audible ringing tone," "number checking tone," etc. For other purposes the tones are uniformly interrupted by motor driven interrupters for such as "busy tone," "all trunks busy tone," etc. Howler tone, used for attracting the attention of subscribers where the receiver has been left off the switch hook, is provided by the high tone frequency. In the larger ringing plants, tones are produced by a tone alternator which is provided as part of the ringing machine. In smaller plants, these tones are produced by high speed split ring interrupters, normally driven by small ac or dc motors or by static frequency generators. Static frequency generators usually include a varistor, condensers, resistances and transformer units potted in a metal case and are used as a source of high tone, low tone, busy tone, dial tone and audible ringing tone.

The tone alternator consists of three inductors and is wound for three different tone channels. One tone channel produces low tone, a second channel produces high tone and a third channel produces audible ringing tone. The "low tone" frequency is 660-cycles/second, the "high tone" frequency is 500-cycles/second and the "audible ring" frequency is 420-cycles/second. The audible ringing tone, when used in connection with suitable repeating and retardation coils, impresses upon the ringing circuit a tone which is audible to the calling subscriber during ringing. The tone alternator consists of a case in which are mounted a common exciting structure of Alnico (a permanent magnet type), three stators, each with a separate inductor winding for supplying tones and their corresponding rotors. It produces a uniform induced tone which is taken from the stator windings without brushes. The tone alternator case is arranged for bolting to the bearing housing of a ringing machine. A rotor spider is provided with pins for driving a low-speed interrupter.

The flux through the stator poles changes as the teeth of the rotor rotate past the stator poles and thus generates the alternating voltages in the windings on the poles. The tone alternator is mounted between the ringing generator and the low-speed interrupters.

The low-speed interrupter, which controls the ringing and silent intervals for machine ringing and for providing variously timed interruptions or signals for many other purposes, consists of a worm driven reduction gear assembly and the necessary interrupting units. In the smaller plants, the interrupting units may consist of contact springs, operated by cams. The reduction gear may be driven by the ringing machine shaft or by a small motor. Figure 18-12 shows an ac motor driven spring-type interrupter used in 806F type ringing power plants. The single-phase synchronous capacitor-type motor operates at a speed of 1800 rpm and is equipped with an enclosed gear train. Depending on the gear train used, a six or eight second ringing cycle is obtained.

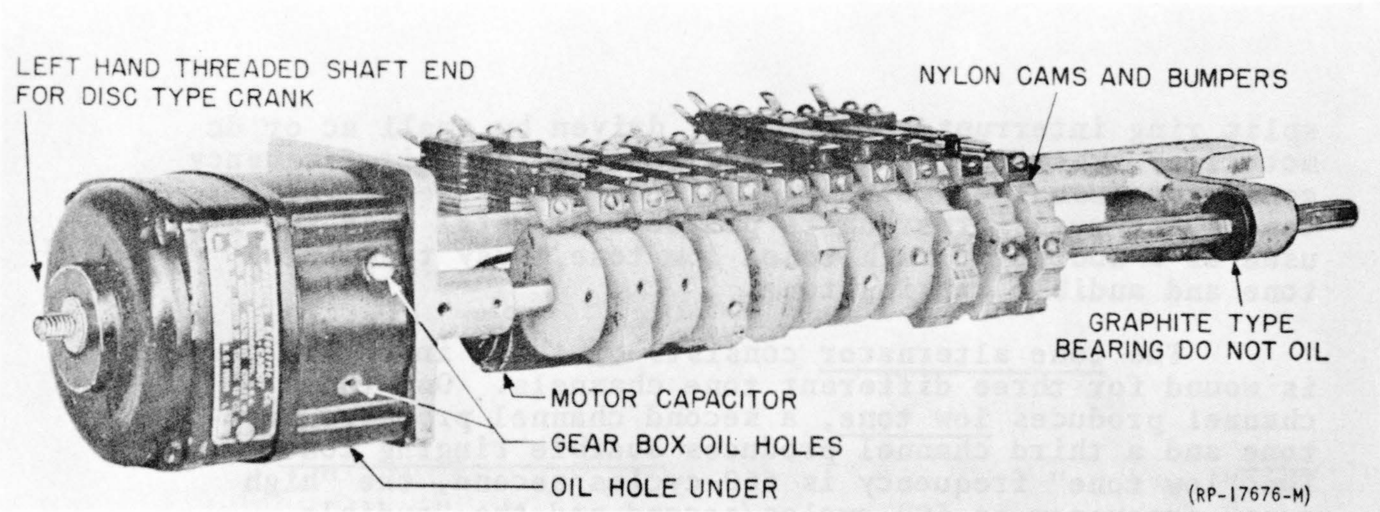


Figure 18-12 AC Motor Driven Low-Speed Interrupter

The rotary mercury type interrupter, used on the larger 803C Ringing Power Plant, consists of one or more interrupter units mounted on the low-speed shafts of a reduction gear driven by a ringing machine. The rotary mercury-type interrupter units, consist of either two or three steel discs separated by insulators placed between the discs and the whole clamped tightly together. Annular grooves or channels are cut into one side of the discs. The units are so assembled that the channel of one disc is adjacent to the channel of the next disc with the insulator separating them. The insulators have one or more openings or ports connecting adjacent channels. The grooves are partially filled with mercury. When the units are rotated, contact is made from one disc to the other by the mercury when a port of the insulator dips into the mercury pool. The port openings are provided with Lavite washers to withstand the arcing during operation. On interrupter units having 3 discs, channels are cut on both sides of the center disc. The number of ports and their spacing around the insulator, the amount of mercury in the channels, and the speed of rotation determine the timing of each interrupter unit. The rims of the discs, against which the brushes bear, present a continuous surface and, therefore, longer wear with less maintenance is obtained.

Ringing machines with tone alternators and cam-driven spring-type interrupters are used on the 804C Ringing Power Plant, In this plant, high and low tones are furnished by a tone alternator which is part of the ringing machine. One channel of high tone and two channels of low tone (one for steady tone and one for interrupted tone) are furnished. Each channel is tapped so that all tone voltages, with the exception of step-by-step dial tone (10V), may be obtained direct from the tone alternator without the necessity of additional coils. Machine and code ringing and various other interruptions are obtained from the new type nylon cam-driven interrupters which can be maintained to a greater degree of accuracy than has been previously possible with the spring-type interrupters.

D. RINGING GENERATORS

The three principal methods of generating ringing current are by pole changers, static ringing generators and motor generators. Space does not permit describing all the types of ringing generators in common use but several representative type are outlined to illustrate the scope of applications.

1. Static Ringing Generator

Static ringing generators are frequency converters and are used to convert 60-cycle commercial power to 20-cycle ringing power. Similar generators are used to convert 50-cycles to 16-2/3 cycles. They have no moving parts, except a starting relay armature which is found in some generators. This armature is in motion only at the time of starting. When a starting relay is not required, a modulating transformer is provided to start the 20-cycle oscillations.

When a 60-cycle supply is applied, the starting relay operates, opens its back contact and sets up a condition favorable for the 20-cycle oscillations. If the 20-cycle frequency is sustained, the starting relay will be held operated. If the 20-cycle frequency is not sustained, the starting relay will release and a second start will be made. In general, not more than two or three successive starts of the starting relay are required. On those generators where the input is a 50-cycle source, the same operation will give a 16-2/3-cycle output.

Sixty cycle ac is applied to the oscillating circuit, consisting of part of the output transformer, the 8 MF condenser, winding of the starting relay, and the tone coil. The circuit, with the saturated coil shorted by the starting relay back contact, has a relatively low impedance to 60-cycle current which however, operates the starting relay, placing the saturated coil in the circuit and setting up a condition favorable for 20-cycle oscillations. If the 20-cycle frequency, for which the circuit is favorably tuned, is sustained, the current at this frequency will be great enough to hold the starting relay operated. If the 20-cycle current is not sustained with the intial operation of the relay, it releases and reoperates until the 20-cycle frequency is sustained. The frequency of the 60-cycle primary supply, being equal to the third harmonic, serves to keep the train of the 20-cycle wave and its harmonics, in operation. The 20-cycle ringing output is taken from the secondary of the output transformer. With a tone coil and its condenser, proper harmonics are made to serve the useful purpose of furnishing audible ringing tone.

The static ringing generators will deliver an output up to approximately 1/2 ampere of 20-cycle ringing current continuously at 75-110 volts and will withstand temporary overloads of 100 percent. In offices where superimposed battery is connected in series with the ringing supply, a separate autotransformer is used and connected to the output transformer terminals.

2. Motor Driven Howler Interrupter

This apparatus consists of a single-phase, split-phase motor with a tone commutator mounted on the motor shaft extension. The commutator has one solid collector ring and one segmented ring with 16 live segments, each connected to the collector ring, to obtain 480 interruptions per second at a speed of 1800 rpm. The collector ring has one common brush to feed current into the interrupter, and the segmented ring has three brushes furnishing three interrupted circuits.

3. Small Motor Driven Ringing Machines

In some smaller central offices which require a continuous ringing current supply, dc motor driven ringing generators are used either as the reserve source or for both the regular and the reserve sources. They may be arranged to operate continuously or to operate under control of the telephone switching equipment. They are of the inverted rotary converter type and are used in small offices and large P.B.X.'s. Two of these machines are usually mounted on a power board panel and covered with a common sheet steel cover with circuit provisions for automatically switching from the regular machine to the reserve machine in case of failure. A dc motor driven ringing generator may be used as a reserve for the static ringing generator during a commercial power failure. However, the more recently developed plants use static ringing generators, frequency generators and ac motor driven cam and spring interrupters on a regular and reserve unit basis. In these plants, a rotary inverter is provided to furnish ac during power service failures. If the ac line voltage falls below 85 percent of normal, the plant transfers automatically to the inverter. About 15 seconds later the plant transfers back if the line has recovered to at least 90 percent of normal voltage; if not, it remains on the reserve until the line voltage does recover.

4. Tone and Interrupter Features

In central offices, the ringing machines are usually equipped for producing tones and low speed interruptions. In the large plants the ringing machines also produce coin control current. See Figure 18-13.

One quarter ampere ringing plants, developed for use in community dial offices use static machines for 20-cycle ringing and all tones. The interrupters are ac motor driven and are operated by nylon cams assuring maximum reliability and precise timing intervals. Automatic transfer to the reverse machine is included and in the event of a power failure a battery driven inverter supplies ac to operate the plant.

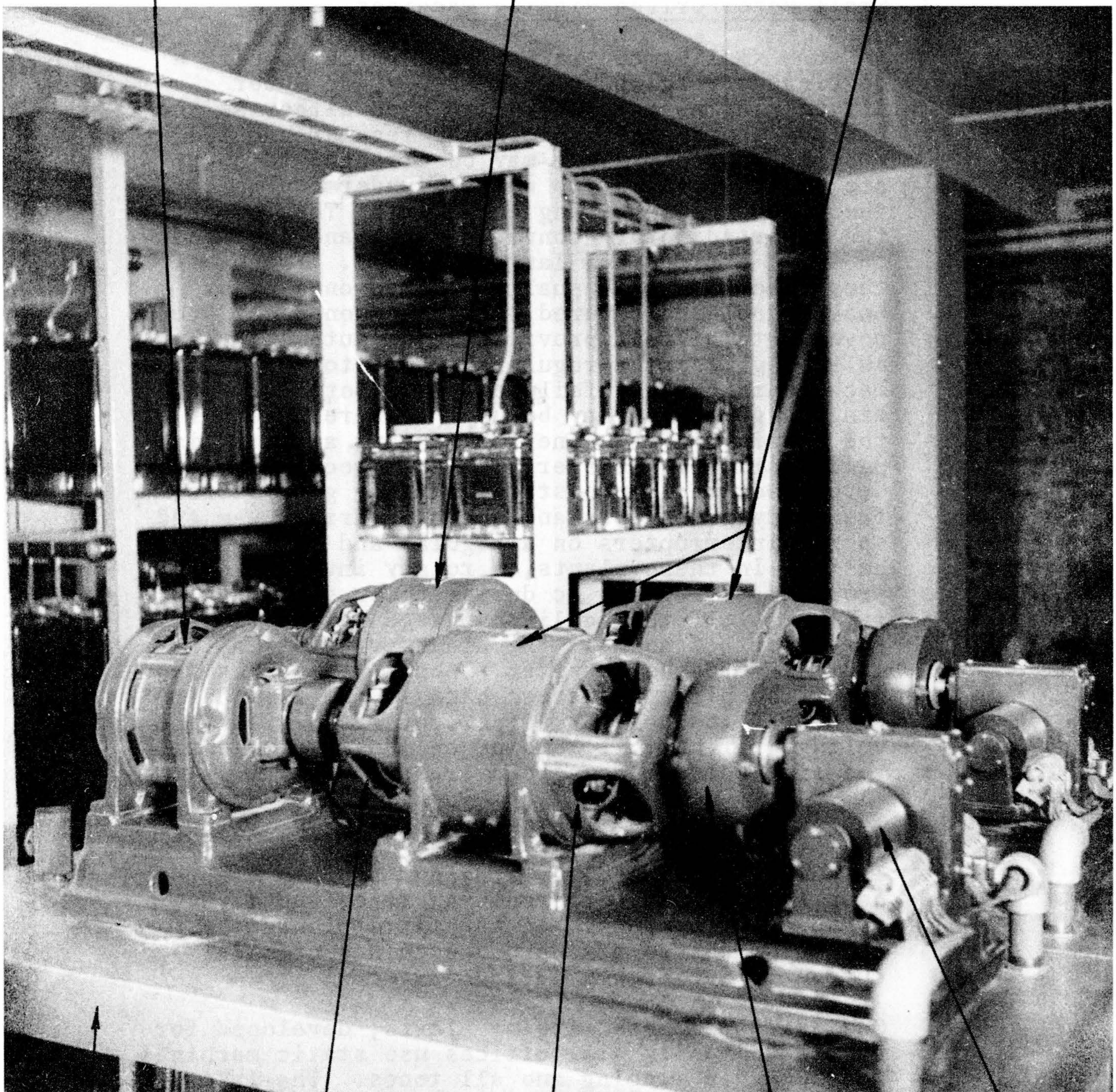


Figure 18-13 Commercial Type Ringing Machines

A larger ampere ringing plant, developed for use in No. 1 and No. 5 Crossbar, No. 1 and 350 SXS fills the gap between the 1/2 ampere plants used mainly in community dial offices and the large 2-6 ampere ringing machine. It employs a 1 ampere ringing machine which incorporates integrally mounted tone alternators for high quality dial and busy tones and adjustable type interrupters capable of a high degree of accuracy of interrupter timing intervals. There is an ac line driven ringing generator for normal supply with automatic transfer to a dc driven generator under conditions of ac service failure, dial tone failure, high or low 20-cycle ringing voltage. An electronic type voltage regulator on the ac machine and a contact type speed regulator on the dc set maintains the standard 18-1/2 to 20-cycle and 84 to 88 ringing voltage.

The ringing machines are mounted in the ringing bays on pull out sliding shelves for easy maintenance, and the complete plant is contained in two box-type framework bays having a total width of 49-1/8", a depth of 36" and a height of 8'.

The interrupters are driven from nylon cams which are machined to close tolerances and the interrupter springs are equipped with adjusting screws; thus the ringing intervals can be maintained to a greater degree of accuracy than has been previously possible with spring-type interrupters. Each machine is equipped with an enclosed tone alternator on one end. Two channels of <u>low tone</u>, one for steady dial tone and one for interrupted busy tones are provided, and one channel of <u>high tone</u>.

The 1 ampere ringing generators used in this plant do not furnish coin control battery and, therefore, a separate unit consisting of two 120 volt, 0.8 ampere rectifiers and two strings of 6 dry cells, one for positive and one for negative coin control, are furnished. The coin potential is normally obtained from the rectifiers, but in the case of power or rectifier failure, the load is automatically transferred to the batteries. Additional units of this plant may be provided as the need arises to supply ringing loads above 1 ampere.

Another large ringing plant, is furnished in the 2, 4 or 6 ampere size. The ac line driven machine normally carries the load and the reserve dc machine operates from the office 24 or 48 volt central office battery. Automatic transfer to the battery driven machine takes place when the ac commercial power fails or drops below a specified value.

The battery driven motor speed is controlled by a speed regulator mounted on the commutator end of the motor and serves to keep the motor speed within limits. A tone generator is mounted between the generator and the low-speed interrupter reduction gear which drives the rotary mercury-type interrupters. The generator furnishes ac ringing current and positive and negative direct current at approximately 120 volts for coin control. This direct current is also used to excite the field coils of the generator and for this purpose is connected through a generator field rheostat and an ac motor driven centrifugal voltage regulator for controlling the ringing current voltage.

In order to provide the various ringing voltages necessary for the continuous supply to PBX's as well as for the AC-DC or superimposed machine ringing service, an output transformer having several output voltage taps is supplied with each machine.

The foregoing descriptions did not outline certain features, frequently incorporated in ringing power plants, which are described broadly in the following paragraphs.

The division of the ringing load in machine ringing offices is accomplished by means of the slow-speed interrupters. Since the ringing interval is usually only one half as long as the silent interval (2 seconds and 4 seconds), it is possible to utilize three slow-speed interrupter units to an arrangement whereby one-third of the office is supplied ringing current during a two-second ringing period, another third of the office during the next two-seconds and a third during the following two-seconds. Thus the ringing generator can carry three times the load it could handle if the whole office were supplied during the same two-second ringing period.

Automatic Switching from the regular to reserve ringing supply is employed in most of the larger plants. While the detailed circuit arrangement may differ with various sizes and types of plants this feature provides for starting the reserve battery driven machine when the voltage of the regular ac driven machine falls below predetermined value, caused by a primary power supply failure or other trouble. The ringing supply, tone and interrupted signal circuits are transferred from the regular machine to the reserve machine by means of a multipole electrically operated transfer switch. When ringing current of the proper voltage from the regular machine becomes available, the supply circuits are automatically transferred back to it and the reserve machine stopped.

The charging of the ringing batteries is treated as a function of the ringing power plant. It was previously mentioned that batteries are employed in connection with silent interval tripping, ringing interval tripping and for superimposed ringing. In certain systems the central office battery is used for some of these functions and separate storage batteries for others. Where separate storage batteries are used as part of the ringing facilities the ringing power plant is provided with suitable types of rectifiers and auxiliary equipment to maintain these batteries in a properly charged condition.

E. NO. 1 ESS RINGING AND TONE PLANT

The use and design of solid state devices in power supply and ringing and tone plants for No. 1 ESS led to a new idea in precision dial tones and call progress tones.

In its use of precision tones, No. 1 ESS is unique among telephone central offices. An office requires four fundamental tones - a dial tone for TOUCH-TONE Calling, audible ringing tone, high tone, and low tone. High tone is a single frequency, the others are mixtures of two separate frequencies. The four component frequencies from which the mixtures are selected (see Table 18-2) are generated as pure sinusoidal signals in transistor oscillators and are added together and amplified by transistor feedback amplifiers. (Figure 18-14 shows the waveforms generated by the amplifiers.) Each oscillator contains tuned reed selectors that select the basic frequencies within 0.5 percent. The actual output of the oscillators, a square wave, is converted by bandpass filters to a sine wave with a harmonic level 60 db down from the basic frequencies.

Audible ringing tone also is generated as a combination of two precision tones. In conventional central offices, audible tone is superimposed on inaudible 20-cycle ringing power and it is interrupted and distributed from the ringing plant. In these offices the two tones often are generated simultaneously. In No. 1 ESS, 20-cycle ringing is generated in one set of generators, and audible ringing is generated and interrupted in a separate set. Audible ringing tone is distributed within the office and applied to loop and trunk circuits through balanced 900-ohm office wiring in the same manner as all other tones.

Continuous outputs from the generators and all outputs from the interrupters are fed to a transfer and control circuit which then directs the various tones to appropriate distribution circuits. Both continuous and interrupted ringing signals for ac-dc, and superimposed ringing are fed to these panels. All signaling interruptions -- 30, 60, and 120 interruptions per minute - are sent to the network via an applique circuit. All tones are routed from output transformers through splitting resistors to furnish a balanced output.

No. 1 ESS is the only system in operation with signaling plants designed on the philosophy of precision tones. The plants used in No. 1 ESS are not compatible with other systems. However, their expected performance makes it safe to consider ESS as a pioneer in a technique that will be adapted to other large switching systems. There are four primary advantages. First, in present switching systems, signaling techniques require rather wideband receivers at the distant termination of loops and trunks. No. 1 ESS signaling is received within a much narrower range than is possible in conventional systems. Second, low loss which is a vital factor in interoffice trunking gives rise to stringent return loss requirements. The No. 1 ESS signaling system easily meets them. Third, the precise nature of No. 1 ESS tones result in even less noise and crosstalk than occurs in conventional systems. Finally, the controlled harmonic content of the signals permits machine recognition of tones, a capability that may lead to new features.

TABLE 18-2

THE FOUR COMPONENT FREQUENCIES

Tones	Frequencies (CPS)
TOUCH-TONE Calling	350 + 440
Audible Ringing	440 + 480
High Tone	480
Low Tone	480 + 620
Line Busy Tone	Low Tone at 60 ipm
Paths ("fast") Busy Tone	Low Tone at 120 ipm

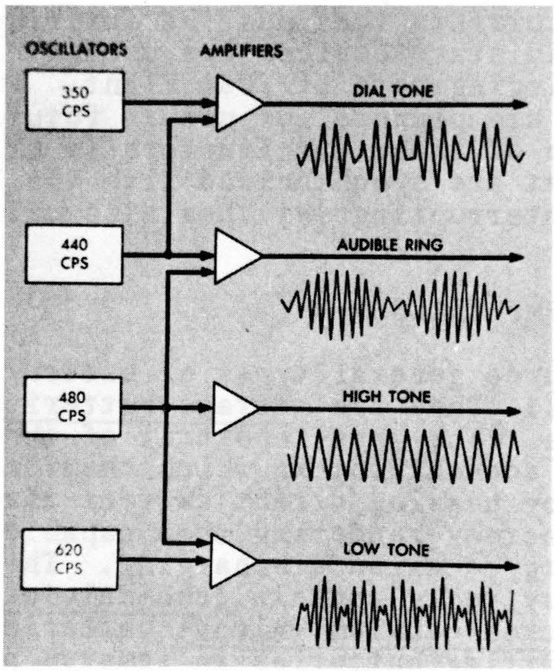


Figure 18-14 The four basic frequency components of No. 1 ESS ringing and tone signals and the waveforms generated by the transistor amplifiers when the basic frequencies are mixed to form the tones.

Two sizes of ringing and tone plants have been designed to accommodate small or large offices. A third, intermediate, rated at 1.5 amperes, size is underway for the future. At present, the 806H Plant, which has a ringing capacity of 1/2 ampere, is used for smaller offices. For large offices, there is the 808A Plant which has 6-ampere transistor generators. These large generators were recently designed to operate from -48 volt battery supply so that they will not be affected by any possible ac power failure. The tone generators are designed to supply the largest office and are the same in all offices.

Except for the small rotary interrupter, the ringing and tone plants are entirely solid state. In fact, to handle the larger currents that must be interrupted in large offices, solid state devices are used as interrupter followers in the ringing part of 808A Plant. Fully solid state interrupters are planned for use in future No. 1 ESS offices. A feature of these interrupters is all-transistor timing circuits that are synchronized with the 20 cps signal. All the interrupting switches also will be solid state devices.

18.6 BATTERY AND CEMF CELLS

There are three general types of battery cells used in telephone plants. They are <u>storage batteries</u>, <u>C.E.M.F. cells</u> and <u>dry cells</u>. The most important of these is the storage battery or accumulator in which chemical changes are brought about by passing direct current through them, called charging, thereby rendering them capable of delivering electrical energy, called discharging. The plates of some storage battery cells contain <u>lead-calcium</u> and others <u>lead-antimony</u>. <u>Nickel-cadmium (nicad) batteries</u> are being used for engine starting batteries in reserve power plants with excellent results. However, the voltage per cell is less than lead-type cells so that more nicad cells are required for any required voltage.

Associated with the storage battery in certain instances are counterelectromotive force (CEMF) cells. They do not accumulate nor store energy but develop potential or voltage when current is passed through them. Therefore, they are not charged and discharged as are storage batteries but are connected in series with them in units of one or more. They are used for <u>regulating the voltage</u> supplied to the telephone plant by the storage batteries in combination with the charging equipment.

In some instances, small amperages at voltages different from those required for the operation of the bulk of the circuits and apparatus in a telephone plant, are obtained from primary dry cell batteries.

A. STORAGE BATTERIES

Storage batteries are of great importance in telephone plants. They act as reservoirs of electricity and are, therefore, capable of supplying energy for limited periods, irrespective of interruptions in commercial power service. They are of low impedance and absorb much of the electrical noise which charging machines generate because of undulations in the voltage of their output.

A storage cell can be made by immersing lead plates in diluted sulphuric acid and passing direct current through the combination thus electrically "forming" the plates. This is an expensive method of accomplishing the results, and the storage capacity of a battery so made would be relatively small. Commercially, it is more economical to form the plates chemically.

In a commercial lead-acid storage battery, the plates consist essentially of lead with which a small amount of antimony or calcium is alloyed to increase its mechanical strength and stiffness. The plates are cast into grids to become containers for lead compounds known as active materials. There are many different designs of storage battery grids. However, the result obtained by all of them is essentially the same.

A storage battery cell is an electrolyte cell for supplying electric energy. It consists of several positive and negative plates with separators in between in a suitable container filled with an electrolyte which is dilute sulphuric acid. All positive plates of a cell are connected together and all negative plates are connected together and terminated at suitable positive and negative terminals used to connect the cell into the circuit. The number of plates in a cell will always be odd since an extra negative plate is required in each cell so that each positive plate may have a negative plate on each side, thus contributing toward the even working of the end positive plates and preventing them from buckling.

During charge a chemical action takes place within the cell between the plates and electrolyte whereby the lead sulphate on the positive plates is changed to lead peroxide and on the negative plates it is changed to sponge lead.

During discharge, a similar but opposite chemical action takes place whereby lead sulphate is formed on both sets of plates. This form of lead sulphate is in a finely divided state, and is essential to the operation of the cell. The loss of sulphuric acid from the electrolyte in the formation of the lead sulphate causes the lowering of the specific gravity during discharge while the chemical reaction producing water further dilutes the electrolyte. The relative density of electrolyte is an indication of the state of charge of a cell which may, therefore, be determined with a hydrometer.

The voltage of a storage cell varies between 1.75 volts when discharged, to approximately 2.50 volts at full charge. The normal voltage, under correct operating conditions, may be computed at approximately 2.17 volts. Therefore, the number of cells to be connected in series to obtain a desired circuit voltage requirement is in general obtained by dividing the desired voltage by 2.17.

The capacity of a storage cell is determined by the surface area of the positive plates of the cell, that is, the ampere capacity of the cell increases in direct proportion to the increase in the area of these plates. Rated capacity, or amper-hour capacity, is the number of ampere-hours which can be delivered under specific conditions as to rate of discharge, final voltage and temperature. For example, the rated capacity in ampere-hours of batteries classified under the 8 hour rate is 8 times the 8 hour discharge rate in amperes at a temperature of 77 degrees Fahrenheit when discharged to 1.75 volts per cell. If the discharge rate is 12.5 amperes, the rating is 8 hours x 12.5 amperes or 100 ampere-hours.

Sediment accumulates in the normal use of a cell which is regularly discharged and charged. The active material, mostly from the positive plates, is gradually worked loose from the plates and settles to the bottom of the cell in the form of sediment. Unnecessary overcharging, resulting in excessive gassing accelerates the wear on the plates and consequently the accumulation of sediment. If sediment piles up either on the bottom of the container or on the plate supports, so that it comes into contact with the bottom of the plates, it will produce a partial short-circuit which will shunt part of the current during charging and will also cause the affected cell to discharge continuously when not being charged. With present operating methods, particularly continuous float, there is very little sediment deposited.

Sulphation in a storage cell is due to the lead sulphate on the positive plates reaching an abnormal condition where it tends to fill the pores of the plates and make the active material hard and dense. During the normal discharge of a cell, lead sulphate is being formed on the plates. If a cell is permitted to stand completely discharged, is habitually undercharged, or is otherwise neglected, the sulphate reaches the condition called sulphation. This form of sulphate makes the portions of the plates on which it is deposited inactive, thus reducing the capacity to that which is given by the remaining good material. The harmful sulphate formed in this manner when not in too large masses, can usually be converted into lead peroxide and lead in the same manner as the finely divided useful substance by considerable extra charging.

1. Pilot Cells

   To sample the condition of each battery a pilot cell is selected. Readings are taken to note the temperature, specific gravity and voltage of the pilot cell. These readings indicate the general condition of the battery.

2. Battery Plates

   A positive plate consists of a grid and positive active material. A charged positive plate is usually dark brown in color. The terminal to which positive plates are attached is usually designated (+) or (POS) or is referred to as the plus material.

   A negative plate consists of a grid and negative active material. A charged negative plate is light gray in color. The terminal to which negative plates are attached is usually designated (-) or (NEG) or is referred to as the minus terminal.

3. Separators

It is essential that the positive and negative plates of any cell should be mechanically separated from each other in a way to prevent metallic contact or short circuit. The material used is porous and allows circulation of the electrolyte and low resistance to current flow.

Wood or microporous hard rubber separators and fine spun glass-fiber mats or perforated hard rubber retainers in various combinations are used to separate the plates. See Figure 18-15.

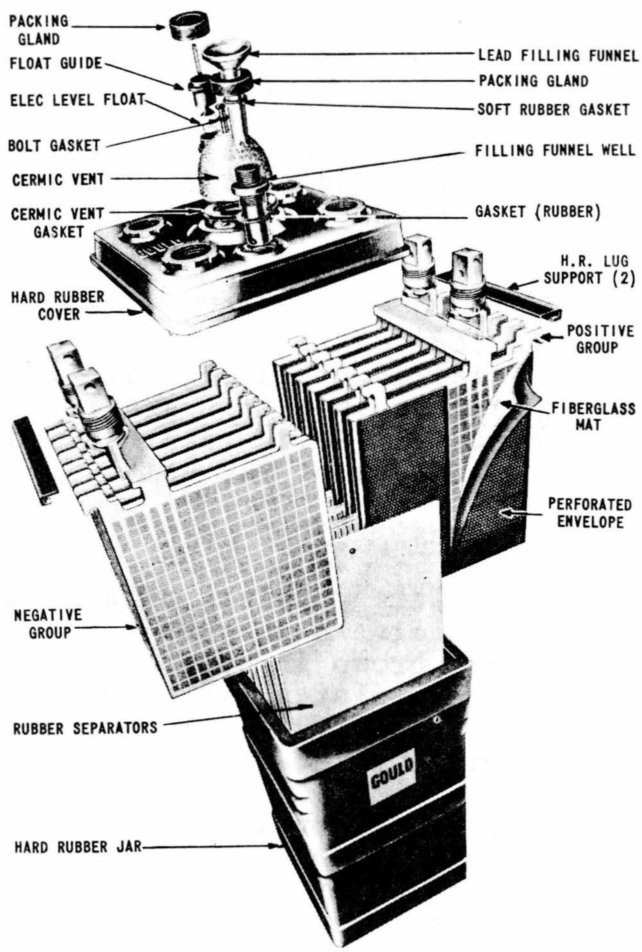


Figure 18-15 Cell Assembly

The separators deteriorate with age, becoming mechanically weak or brittle or both, so that if work is done on an aged cell, it is likely that the separators will be damaged. However, if the cell is not disturbed, the separators are likely to provide the required separation and last as long as the plates.

4. Electrolyte

The electrolyte is the solution in which the plates of a storage cell are immersed and which in combination with the active material of the plates, determines the electromotive force or voltage of the cell. This solution consists of purified sulphuric acid and approved water.

The specific gravity of the solution at any time is dependent upon the type of cell, the electrolyte temperature and the amount of charge in it. Since specific gravity varies with changes in temperature, readings must be corrected to an established base temperature of 70 or 77 degrees Fahrenheit for reference purposes.

Specific gravity is the ratio between the density of the electrolyte and the density of water. The specific gravity of the electrolyte becomes lower as the battery is discharged and rises as the battery is charged.

Water, which is lost from the electrolyte through evaporation or other reasons, must be replaced to keep the proportion of water to acid constant. If this were not done, the hydrometer readings would reflect the variation of the electrolyte density due to water loss and could not be relied upon as an accurate indication of the condition of charge.

Gravity range is the difference in specific gravity of the electrolyte of a fully charged cell and of the same cell discharged to the point where, for practical purposes, it is considered fully discharged. The amount of this difference depends upon the quantity of electrolyte in the cell as compared with the quantity of available active material in the plates. If the plates are badly sulphated, or a portion of the active material has been dissipated so that the full capacity is not available, the range in specific gravity to complete discharge is reduced in proportion to the reduction in capacity. The range also varies with the rate of discharge. Ampere-hour capacity and, therefore the gravity range, increases as the discharge rate is decreased, because more time is available for diffusion of the electrolyte in the pores of the plates, and a large part of the total active material is able to take part in the chemical action.

The nominal specific gravity of a cell is an assumed value which the cell will approximate when new, fully charged, with the electrolyte near the maximum level and temperature at 77°F. Most batteries now used in telephone power plants have a nominal specific gravity of 1.210 (1.201 to 1.225).

5. Charge and Discharge Rates

The nominal charging rate is a current value recommended by the manufacturer as a current which can be absorbed by the cell throughout the charge without overheating or harmful gassing. There is no harmful effect in charging at a rate less than the nominal. Usually, a reduced rate is more economical and tends toward greater battery life. To conserve time, a high starting rate with a low finishing rate is sometimes specified.

Because the large surface of active material and the low internal resistance, a battery can usually be discharged at any rate without injury. In general, the greatest output in ampere-hours and watt-hours is obtained when the battery is discharged over several days, since the diffusion of acid, through the active material, is more complete and a greater percentage of the active material is available to sustain the charge. Telephone batteries are usually rated to discharge to 1.75 volts per cell in eight hours.

6. Types of Storage Cells

There are two general types of enclosed storage battery cells used in the power plant: rack mounted and floor mounted. The rack mounted cells are furnished in plastic or hard rubber containers. The floor mounted cells are furnished in hard rubber containers.

B. COUNTERCELLS (C.E.M.F.)

After batteries have been partially discharged, it is necessary to charge them promptly for further use. During the charging, however, the voltage across the battery must be somewhat higher than when floating. To prevent this higher voltage from reaching the central office discharge circuits, it is necessary to employ counterelectromotive force (CEMF) cells, between the battery and the load, to reduce the potential to the desired value.

Alkaline type counter-emf cells normally function to oppose, and thereby cause a voltage drop in the main discharge battery supply; the voltage being lowered by an amount depending on the number of cells in the circuit. This drop occurs as current is passed through the cells when they are connected in series with the battery discharge supply.

The advantage of counter-emf cells, as compared to a series resistance, which may be used, is that the voltage drop through the countercells does not depend entirely on the amperage flowing through the circuit. Whereas, the voltage drop due to a series resistance (IR drop) is directly proportional to the current flow. However, the counter-emf developed is dependent to some extent on the amount of current passing through it. But, the range of the countervoltage is fairly narrow, varying from 1.85 volts per cell, at 10% rated load, to approximately 2.15 volts per cell at full load when the alkaline solution is new, at the correct level and at a temperature of 100°F. The values change with age and temperature.

Primarily, counter-emf cells are introduced in the discharge circuit, when the battery is being charged to hold the office voltage within the upper allowable voltage limits at the distribution point, and provide a reduced constant voltage supply. Briefly, their function is that of voltage regulation and, therefore, may operate in the circuit continuously or intermittently.

Semiconductor type selenium countercells are also used to supply a countervoltage in some power plants. Their use permits additional cells to be connected in the plant battery in order to obtain suitable reserve power when the battery voltage is lowered due to a power failure. Provisions are made to switch out the countercells, thereby raising the voltage as required.

Semiconductor type countercells consist of various combinations of series and parallel selenium cells arranged to produce a 2.0 volt drop in battery charging circuits. They eliminate the hazards and maintenance problems associated with the alkaline cells and can be used to replace them. The cells are made of selenium covered metal plates, specially treated so their internal resistance decreases rapidly as the current flow through them increases. The voltage drop across these cells changes very little for substantial changes in the current flow. Because of this, the cells are very effective as voltage regulators.

C. ENGINE STARTING BATTERIES

Batteries of the lead-sulphuric acid type, and the nickel-cadmium alkaline type, are designed for engine starting where the normal routine is three starts per week, with voltages maintained between starts at 2.17 volts per cell for the lead acid type and 1.45 volts per cell for the nickel-cadmium type. All batteries are shipped filled with electrolyte and charged. They are composed of a number of cells in trays (nickel-cadmium) or cases (lead-acid) depending on the voltage required to start the engine.

Nickel-cadmium batteries have been used in telephone plants for some time with excellent results and minimum maintenance. At potentials up to 1.47 volts per cell, the gassing is negligible. The gas given off is the same as that given off by lead-acid cells, namely, a mixture of hydrogen and oxygen. Since this is explosive, the same antiexplosion precautions apply to these cells as to lead-acid cells. Bell System operating routines call for no operation at voltages above 1.45. For this reason, explosions are less likely than on lead-acid cells, and antiexplosion design features have not been provided for these cells.

The alkaline electrolyte is corrosive and attacks most animal and vegetable products including clothing, the skin, and paint, as well as some metals including aluminum and zinc but excluding iron, steel, and nickel. It attacks glass very slowly (Pyrex-type glass almost negligibly), so exposure of glass other than the Pyrex type or of porcelain should be for as short duration as practicable. Glass or porcelain objects should be washed in water after exposure to electrolyte.

D. DRY CELLS

A dry cell is a primary cell. It produces electrical energy through an electrochemical reaction which is not efficiently reversible except in the earlier stages of discharge. Hence, the cell, when fully discharged, cannot be economically recharged. The electrolyte is completely enclosed in the absorbent materials within the cell.

A dry battery is a combination of two or more dry cells electrically connected together to produce electrical energy.

Ordinarily, the cell is enclosed in a zinc can. This serves as the negative electrode and is usually lined with a layer of paste and absorbent paper. The positive electrode consists of a central carbon rod surrounded by a layer of material known as the depolarizer or "mix." The "mix" consists of a mixture of ground carbon or graphite and manganese dioxide. Both the "mix" and the lining are moistened with electrolyte consisting of a water solution of ammonium chloride (sal ammoniac) and zinc chloride.

The open end of the zinc can is closed by a layer of insulating compound, or by an insulated metal top, to hold the materials in place and to prevent evaporation of the moisture in the cell.

When the external circuit, between the terminals of the cell, is closed, chemical changes within the cell produce electrical energy. These changes result in the liberation of hydrogen, which tends to collect at the carbon electrode if not absorbed by the manganese dioxide in the "mix." With use, the various constituents of the cell either become exhausted or coated with the products of chemical reactions, thereby increasing the internal resistance and lowering the operating voltage of the cell.

Local internal action is responsible for the consumption of some of the chemical energy in the cell. This loss of energy, which occurs both while on open circuit (either in storage or assembled in equipment) and while on closed circuit, is known as shelf depreciation.

The life of a cell depends upon its size, ingredients, processes of manufacture, age, and also on the frequency, duration, and rate of discharges, and the circuit voltage limits.

The chemicals in the cell, including the water, gradually become exhausted due to useful current output and to shelf depreciation. When this condition is reached, no more electrical energy can be supplied. To obtain reliable service, it is economical in most telephone application to discard cells before their capacity is completely exhausted. However, if the cell has become exhausted due to a high rate or extended period of discharge, it may recover, to some extent, if allowed to stand idle, to give further service.

When batteries are exposed to abnormally high temperatures, the voltage, both open-circuit and operating, and the rate of shelf depreciation are increased. Batteries should, therefore, be kept away from abnormally high temperatures both during storage and in use.

Low temperatures decrease shelf depreciation but also reduce the open-circuit and operating voltages. Under most operating conditions, the life of a battery may be considerably decreased if its temperature is appreciably below 70°F. Except for grid service, a cell becomes inoperative when its internal temperature falls below 0°F. Batteries subjected to low temperatures incur no permanent injury and regain their normal characteristics when their internal temperatures are restored to normal. To minimize shelf depreciation, batteries should be stored at a temperature of about 34°F to 40°F.

Batteries in low-current-drain service will deliver most of the available ampere-hour output at a relatively high operating voltage, after which the voltage drop will be comparatively rapid. Hence, in this service a high cutoff point is desirable to insure reliability. For batteries in high-current-drain service, the higher current will produce a greater internal resistance drop and a lower operating voltage. A lower cutoff point is, therefore, necessary to obtain efficient use of the available energy contained in the cells. When it is necessary to maintain the battery voltage within close limits under high current drains, it is frequently desirable to add one or more cells in series when the cutoff point is first reached, in order to take advantage of the increased output thereby obtainable from the whole battery.

Dry cell batteries are used in the telephone office for a variety of purposes. In the power plant their most common use is for tripping battery reserve, where a rectifier normally furnishes the supply, and for message register battery supply either as a reserve for use where a rectifier is furnished or as the main source of message register battery supply.

18.7 EMERGENCY AC SUPPLIES

A. ENGINE ALTERNATORS

It is essential in the design of a telephone power plant, that provisions be made to assure an uninterrupted supply of primary power within practical limitations. For this purpose, engine alternators are usually installed to furnish reserve power during emergencies. In some installations, engine sets are the sole source of primary power; this is usually due to lack of commercial power facilities. At some locations, mobile diesel engine sets are used. The engine sets are plugged into permanently installed building connections for emergency use.

Two types of engine sets have been standardized for use in the telephone central office: gasoline driven and diesel driven. Only the 5 KW unit of the gasoline type is presently being furnished. Diesel engine sets range from 10 KW to 500 KW in standard sizes and up to about 1000 KW in the nonstandard sizes. All engine sets may be obtained with manual or automatic controls. Alternators are available for single or polyphase power supplies.

The size and type of the engine alternator set and the controls are determined by the Telephone Company. The manually controlled sets are used in central offices where maintenance forces are always on hand to start the engine and switch the load on and off. Automatically controlled sets are used in unattended or partially attended offices. They are arranged to start automatically when commercial power service fails and to assume the load when ready, also to shut down when commercial power is restored. Figure 18-16 shows the gasoline driven engine set currently in use and Figure 18-17 shows the 100 KW diesel engine set.

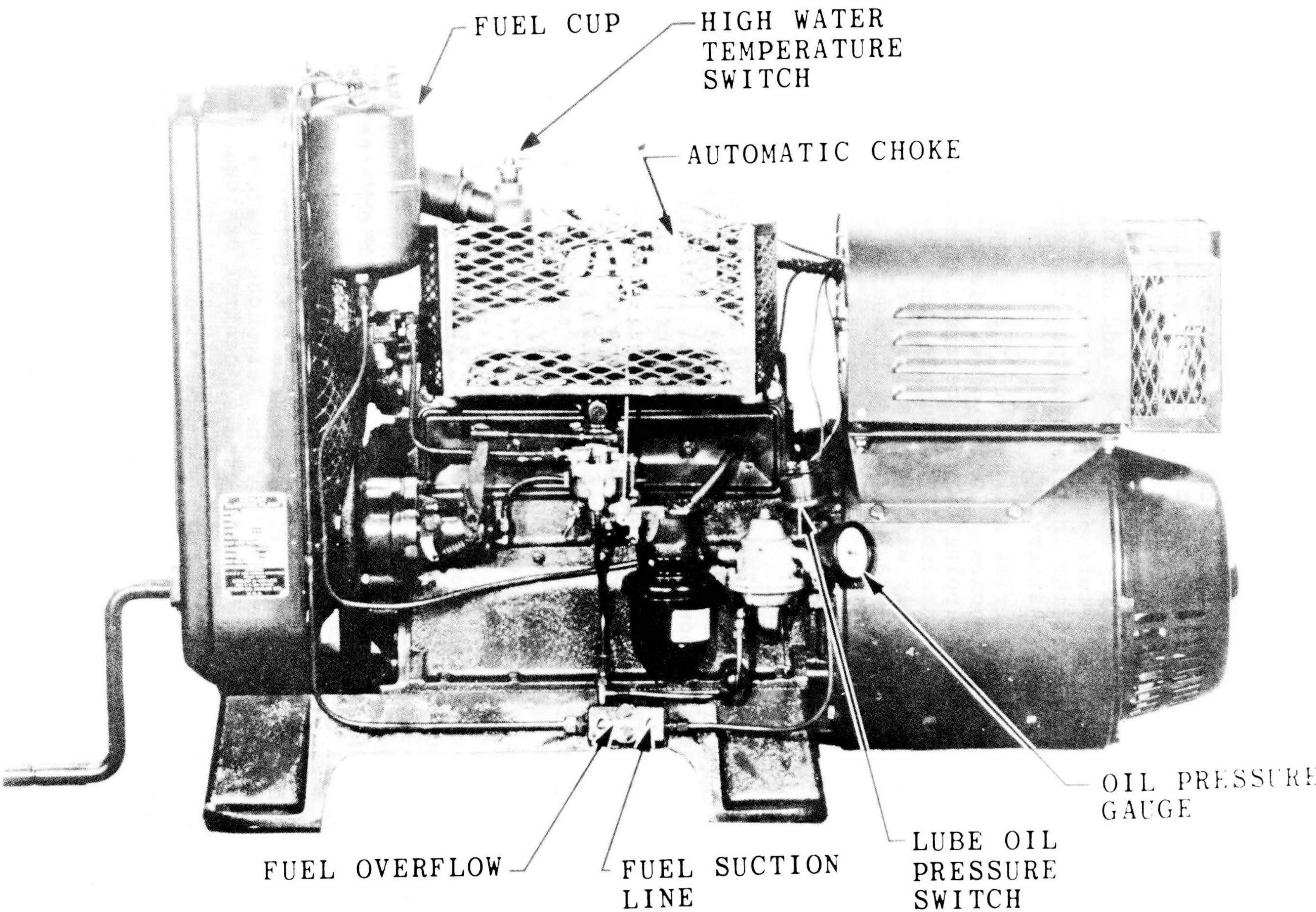


FIGURE 18-16 - 5KW GASOLINE TYPE ENGINE ALTERNATOR

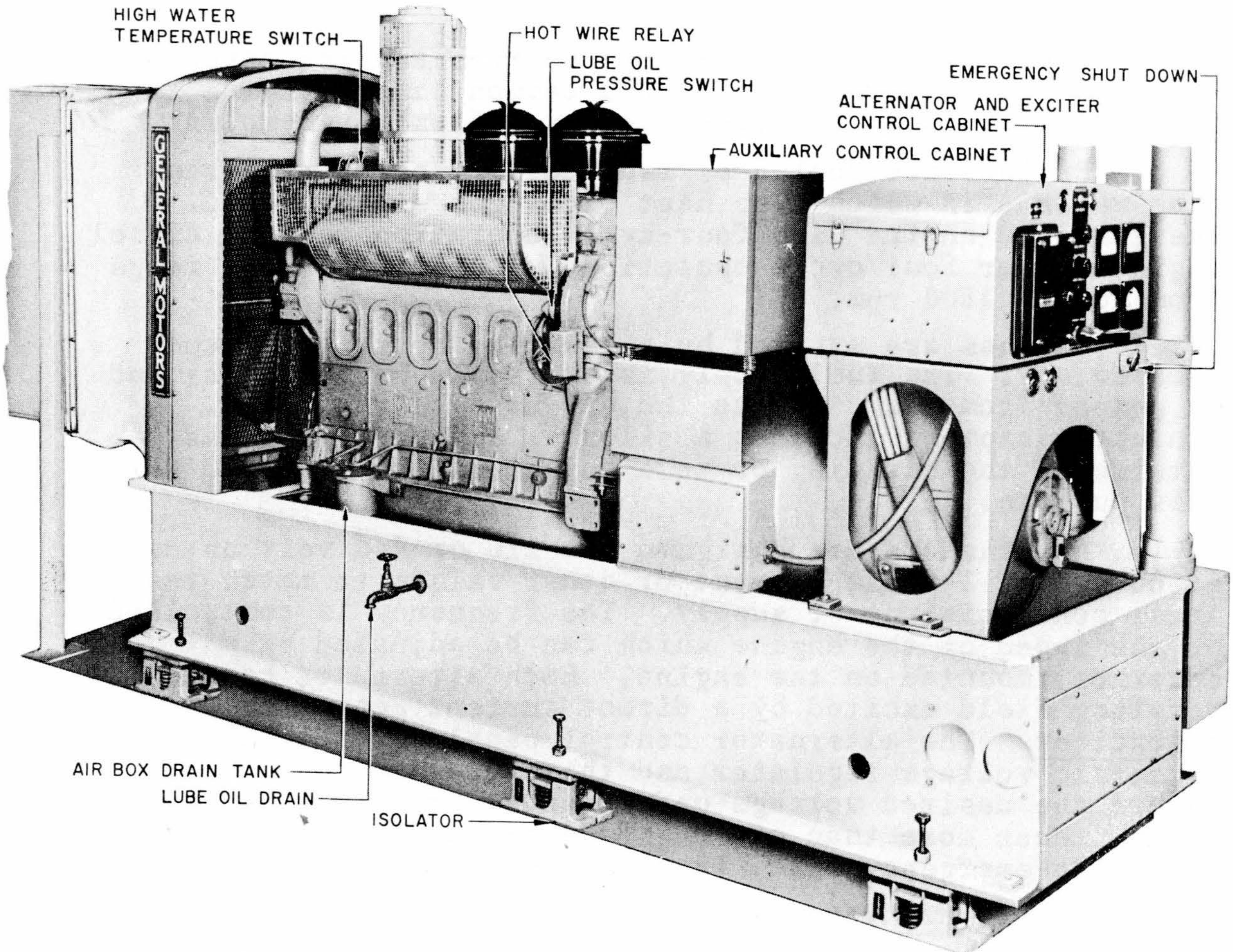


Figure 18-17 100 KW Diesel Type Engine-Alternator

The engine with its start controls and the alternator with its exciter are mounted on a common base. Engine and alternator are directly connected by a flexible coupling.

Engines are cooled by radiators, fans or city running water - in which case heat exchanges are provided. The gasoline engine uses four-cycle operation and the diesel engine two or four cycle operation. Operating speeds range from 900 to 1800 rpm.

Engines are started by a starting motor or by compressed air. The fuel supply is stored in buried tanks and is pumped from the tanks to the engine by a fuel pump. Exhaust equipment includes a silencer and piping to the outside of the building or to a building flue provided for this purpose.

Alternators are designed for 220 or 440 volt output at 60-cycle, 3-phase current or other values to match the local commercial power supply. The frequency is controlled by the speed of the engine which can be adjusted by a governor, mounted on the engine. Each alternator has a rotating field excited by a direct current generator called an <u>exciter</u>. The alternator control panel includes an automatic voltage regulator and the necessary controls to insure the desired voltage under manual or automatic operation. When more than one engine-alternator is required to carry the emergency load, they are operated in parallel.

1. <u>Diesel Micropower Sets</u>

   This set consists of an ac motor, an alternator, a large flywheel, a diesel engine and an electrically operated clutch between the engine and flywheel. Parts are mounted on a skid-type base. A control cabinet for wall mounting is furnished. The cabinet is equipped with meters, an ac motor starter, power failure relays, an electrically operated bypass switch, control relays and switches.

   Micropower sets are also known by the general term "no-break set." The unit is designed to operate unattended. The ac motor drives the alternator and flywheel from commercial power. When commercial power fails in any phase, or drops to 90% of normal line voltage, power failure relays release, in turn releasing the ac motor starter which energizes the electric clutch and the engine fuel solenoid from the alternator output. The inertia of the flywheel starts the engine by means of the clutch. The engine is brought up to speed rapidly.

About 15 minutes after the return of commercial power to a value of about 95% of normal or higher, the ac motor starter is energized, returning the alternator to ac motor drive, releasing the clutch and the engine fuel solenoid and shutting down the engine.

Units are being furnished in four sizes, 5, 10, 15 and 20 KW weighing, 2000, 2300, 3400 and 3800 pounds respectively.

2. Control Equipment

The controls for manually operated engine-alternator sets are generally mounted on the set. The controls for automatically operated sets are mounted in a separate control cabinet. These controls start the set, operate it at no load for a predetermined time and then transfer the load to the set. When the engine-alternator is no longer required, the controls shut the set off after a short time delay. All this is accomplished on an automatic, unattended basis.

Additional controls function to shut down the set when it malfunctions. At this time, connections to alarm circuits are made and the trouble indication is transmitted to an attendant for corrective action.

B. ALTERNATELY OPERATED ENGINE-ALTERNATORS

At locations where commercial power is not available, two automatically operated diesel sets are usually furnished for alternate operation. Each set operates for approximately 12 hours.

The nonrunning set is started automatically and warmed up prior to the shutdown of the running set. The load changeover is made just before the shutdown. Sets are equipped with starting motors that are supplied by a 32-volt battery which is common to both sets. The starting battery is charged by a regulated rectifier operated from the output of either set.

Complete automatic operation of the two sets is controlled by a main control cabinet which is separately floor mounted.

C. GAS TURBINE-POWERED ALTERNATOR

In addition to the gasoline and diesel engine alternators, there is the gas turbine-powered alternator. These types of turbines atomize liquid fuel to a gaseous form in their combustion chambers in the same way that a jet engine does. Until recently the largest size was 750 kilowatts, but as of 1967 sets of 2000 kilowatts size have been ordered for multistored telephone buildings. The gas turbines appear to be excellent replacements for the larger diesel powered engine-alternators. These alternators generate enough power to supply not only the switching equipment but also the lights, ventilation equipment, and other essential ac operated utility loads. Installation costs for a large gas turbine generator are lower than for a diesel engine alternator of comparable power. Though turbines use more diesel fuel per kilowatt hour, they are operated for only a few hours a year for test purposes and during commercial power failures. This makes installation costs rather than operating costs the deciding factor.

Figure 18-18 shows a schematic describing the principle of operation of the gas turbine

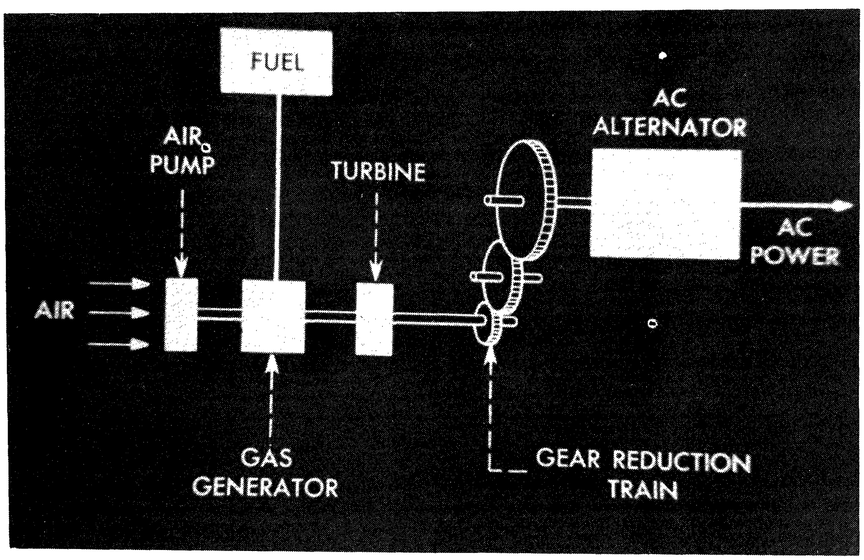


Figure 18-18 Gas Turbine Operation

Figure 18-19 is a photograph of a 750 kilowatt gas turbine running at rated speed of 23,300 rpm. The stainless steel foil surrounding the gas section acts as a heat shield.

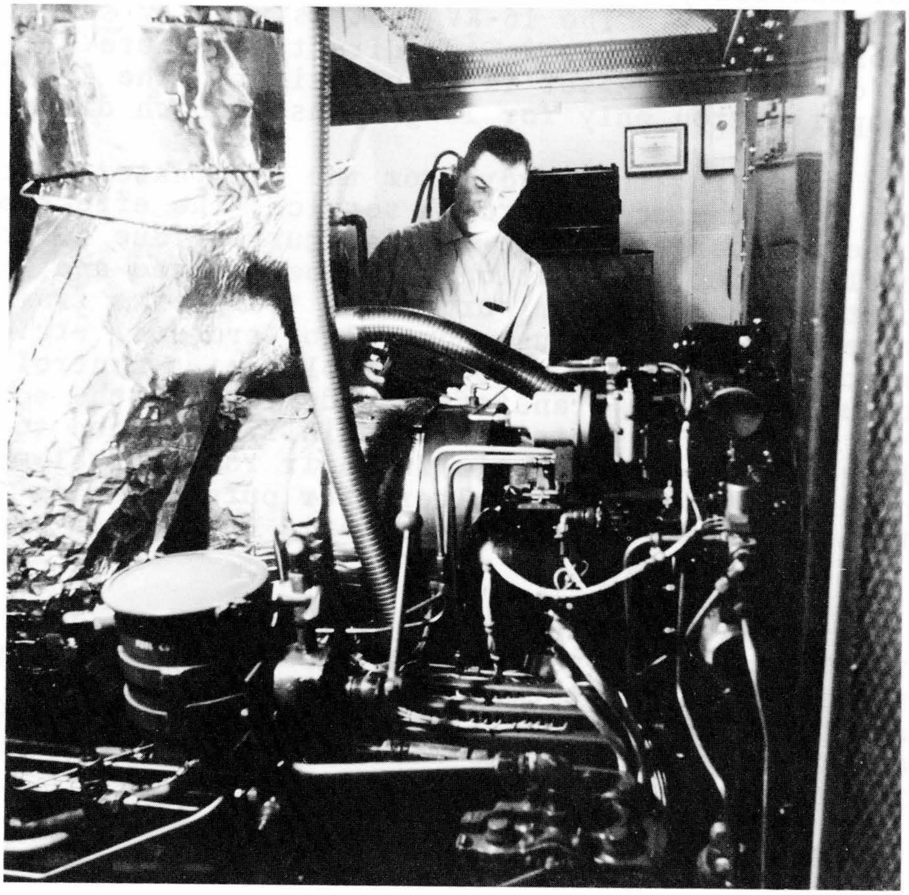


Figure 18-19 750 KW Gas Turbine Alternator

18.8 POWER SUPPLIES

A. L CARRIER

Continuous 230 volt, 60-cycle alternating current power is supplied to L carrier equipment from motor alternator sets. They consist of single-phase, self-excited alternators operated normally from commercial ac service by 3-phase induction motors and during emergencies from the 130 volt central office battery by dc motors all connected on the same shaft.

Three capacities of alternator sets are presently available, namely, 10, 16 and 21-KVA. The 10-KVA set is usually used in stations sending power in one direction for each pair of coaxials or in both directions when the number of auxiliary stations limits the power required within its capacity. The 16-KVA set is usually specified in stations sending power in two directions where the capacity of the 10-KVA set is insufficient. The 21-KVA set has application only for long spans in both directions.

By supplying the power from the alternator instead of direct from the ac commercial service, the effect of instantaneous changes in the coaxial current due to ac commercial service fluctuations will be reduced and will insulate the coaxials from surges and transients from the ac service due to lightning, power line crosses, etc. On ac commercial power failure or low voltage, a control circuit automatically transfers the drive from the ac motor to the dc motor. The sets are especially designed to include large amounts of inertia in their rotating elements to maintain nearly constant alternator output during the motor transfer and to prevent too rapid changes in the output during motor surges.

The output from the motor alternator sets is connected to one or more power control bays which supply a substantially constant current to a power section. Means are provided for manual regulation with safeguards to remove personal hazards as well as high voltages due to improper operation.

1. Two Motor Alternators

A two motor alternator set consists of a single-phase, rotating armature-type alternator with exciter, direct-connected to either a 3-phase or a single-phase ac squirrel cage induction motor and a dc shunt motor. They are mounted on a common subbase, having resilient mountings and normally operate continuously from ac line motors which have a suitable output to drive the alternator at full load and the dc motor at no load. All sets are started from the central office 130 volt battery under manual control until up to normal speed and voltage limits. Figure 18-20 shows the two motor alternator set used on L3 carrier.

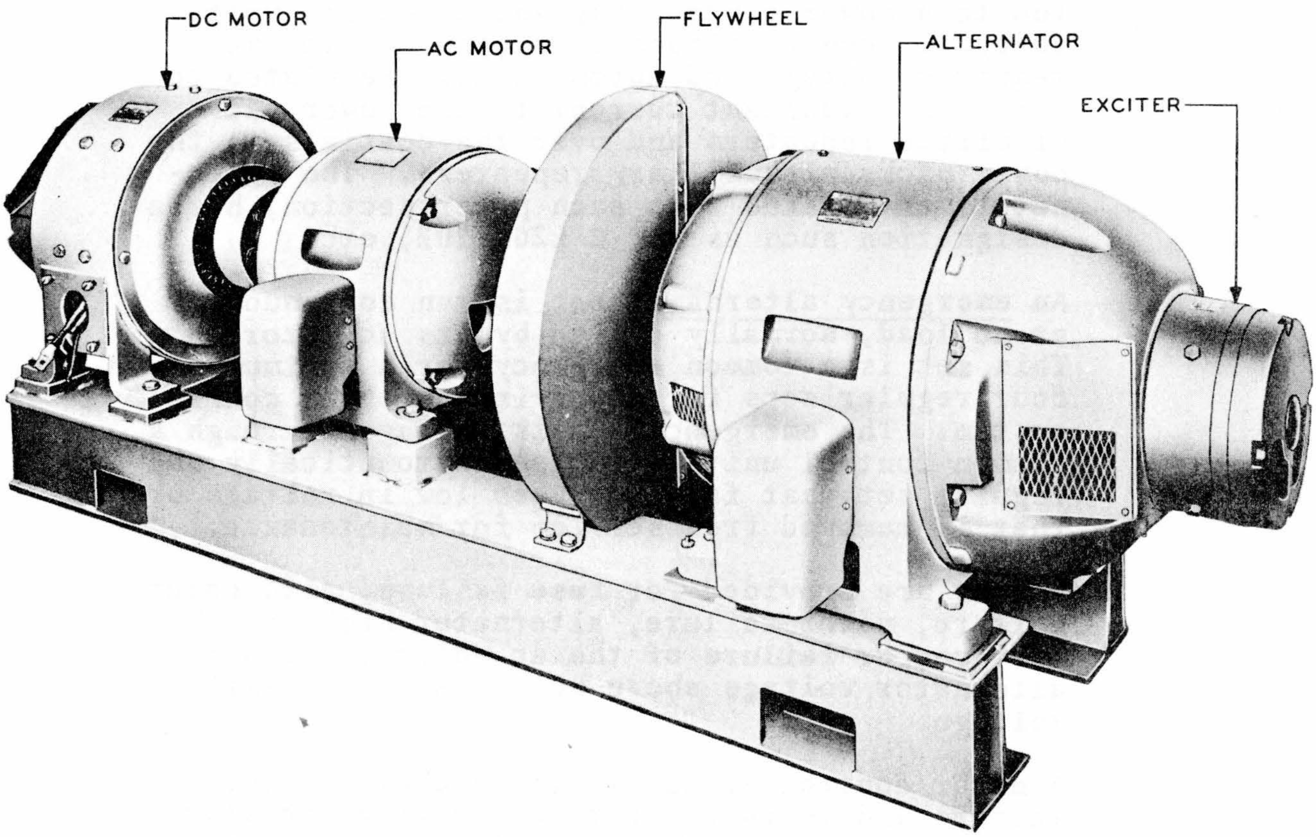


Figure 18-20 Two Motor Alternator Set

The output of the alternators of these sets is fed to a power control bay where the 230 volt, 60-cycle supply voltage is stepped up to the required voltage and automatically regulated to maintain a constant current to the power packs of office repeaters and over the coaxials to the power packs of auxiliary repeaters. The alternator, associated with each power section, has a designation such as ALT 2 L201-202, etc.

An emergency alternator set is run continuously at no load, normally driven by its ac motor. This set is a common emergency for a maximum of four regular sets for supplying an eight coaxial system. The emergency set is arranged through a common control unit to replace automatically any regular set that fails or goes low in voltage or that is removed from service for maintenance.

Alarms are provided for fuse failure, alternator failure, power failure, alternator high low voltage, or failure of the ac motor to hold the alternator voltage above 90 percent of normal voltage.

A motor controller panel, which contains the contactors and resistors for controlling the starting and running of the dc motor, is mounted on a start control panel directly associated with each motor alternator set.

Keys mounted on a transfer control bay provide means for starting and stopping, transferring the load to and from the emergency alternator, transferring the drive from one motor to the other, cutting off alarms, and testing automatic throwover due to power failure.

On ac power failure or low voltage, a marginal control circuit automatically transfers the drive of the set by opening the input to the ac motor and shorting a current-limiting resistance in the battery supply circuit of the dc motor to allow the dc motor to pick up the drive quickly. On resumption of commercial power, after a short delay, to allow the ac service to become stable, automatic transfer returns the drive to the ac motor, reinserts the resistance between the dc motor and the battery, and shorts out a portion of the field resistance to keep the dc motor field at the proper value. During the dc motor operation, the speed of the set will be determined by the battery voltage. A fixed field resistance setting on the field resistance mounted on the dc motor controller unit is required to match the ac motor speed at the mean battery discharge voltage.

Auxiliary charging equipment is required for use in recharging the 130 volt battery of the power plant where the rectifier equipment furnished to float the light normal battery load is inadequate for the heavy emergency load imposed by the motor alternators. This control brings in an automatically controlled charging generator operated from the ac service whenever the battery stays at low voltage for a period of approximately six minutes. Once connected to the battery, this generator is controlled to charge the battery to its maximum voltage and the control functions to hold this charge for a predetermined time up to six hours, after which the battery is returned to its normal float condition.

2. Power Control Bay

The power control bay receives the 230 volt ac output from the motor alternator sets and regulates it for one power section and the associated office repeaters.

A power section is a series loop through the central conductors of two coaxials with the primary windings of the auxiliary repeater transformers in series at each repeater point. The power control circuit output voltage is applied to the input of a power section, the voltage depending on the length of the power section.

Power for the L3 carrier system involves supplying regulated and unregulated 230 volts to office equipment and regulated current over the coaxials to power sections of auxiliary repeaters. Step-up transformers with secondaries, tapped at suitable increments, provide power for auxiliary repeaters at 1.5 amperes at any voltage up to 4400 volts depending on the length of the power section. Protective switches are furnished on each power control bay which open the power circuit to the high voltage transformer when the covers to the high voltage panels are removed.

The particular current for each of the two lines of each power section is usually specified on a card holder mounted just above each of the two ammeters on the power control panel shown in Figure 18-21.

A resistance in series with the coaxial current circuit provides a drop for controlling motor driven variable transformers to raise and lower supply voltage to the step-up transformers as required to maintain constant coaxial current. Two types of control are furnished; a fine $\pm$ 1 percent control using an electronic regulator to control the motor which drives a fast acting small variable transformer which has a buck-boost range of 10 percent of the total, and a coarse control using relay control of a motor driving a large variable transformer. This large variable transformer, mounted in the base of the control bay, is slower acting and normally serves to hold the fine control within $\pm$ 3 percent of a center position so that the fine control will be ready at all times to correct for anticipated changes.

The course control arrangement also provides emergency regulation within $\pm$ 3 percent in the event of fine control failure and a means for manually turning power up or down on the cables as well as shut down protection in case of trouble such as an open cable.

Suitable alarms are furnished to indicate fuse failures, high or low line current if it persists more than 1/2 second, or line current failure in either of the two coaxials. Manual controls are included with each power control panel to raise or lower the line current.

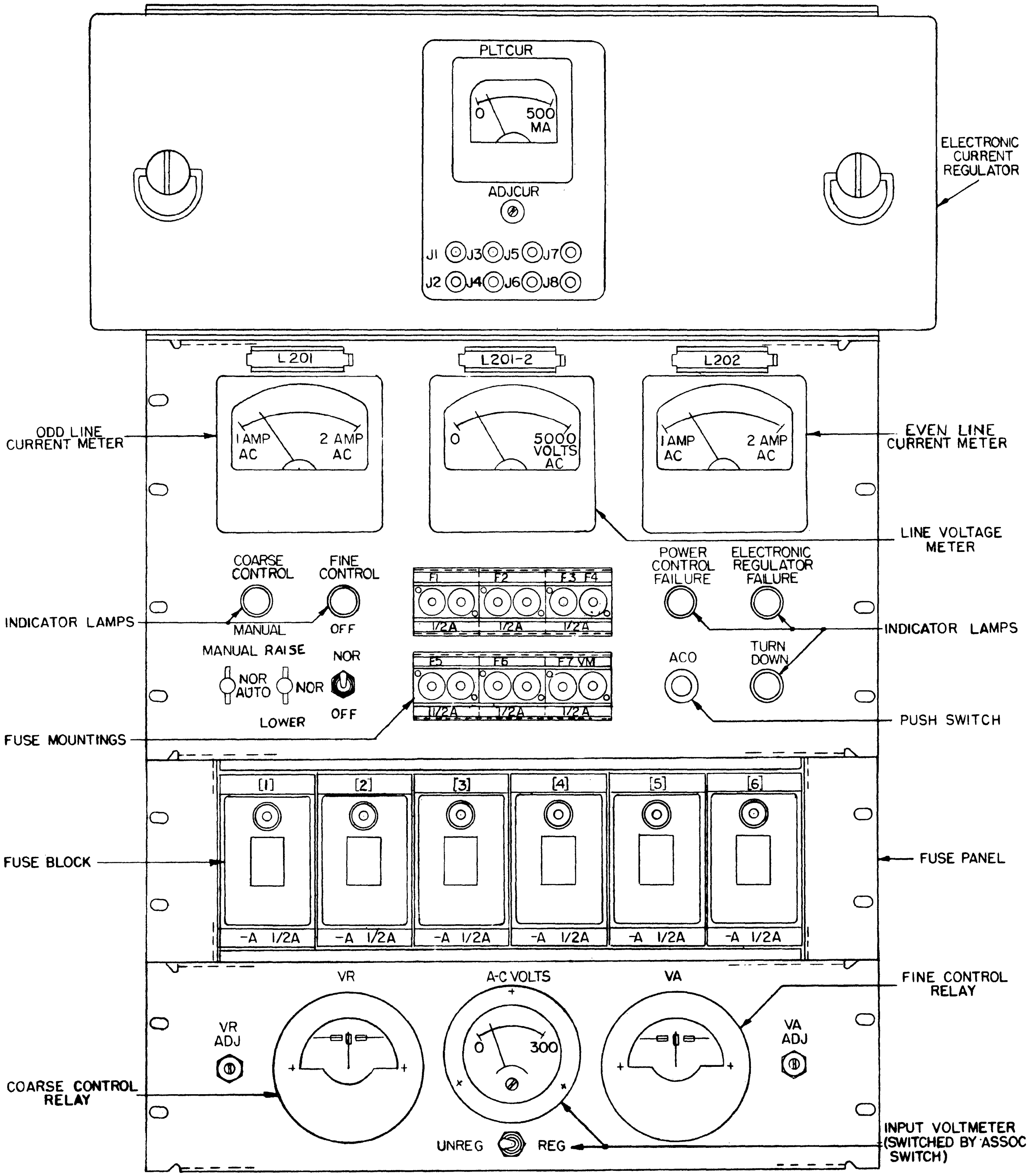


Figure 18-21 Power Control Panel

B. 508A POWER PLANT

Two-motor alternators used in the TH radio system, BMEWS (Ballistic Missile Early Warning System) and in some submarine cable systems, are designed to develop firm ac power from a commercial power source or its equivalent (engine-alternator) and when this fails, from a dc power supply.

The unit consists of a compound wound 130-volt dc motor, a synchronous type 208-volt, 60-cycle, 3-phase ac motor and a brushless, self-excited type, 230-volt, 60-cycle, single-phase alternator. The alternator uses a voltage regulator which senses output voltage and current to maintain a closely regulated output voltage.

The voltage regulator is mounted on the machine frame and furnishes dc power to the exciter field of the stator, which generates an ac voltage in the rotating exciter armature. The ac voltage is rectified by the 3-phase full wave silicon bridge to provide a dc rotating field for the alternator stator winding.

The dc motor is equipped with four brush lifting solenoids which hold the brushes away from the commutator when the alternator is driven by the ac motor. When the ac power fails the brushes are automatically dropped on the commutator and the drive is transferred to the dc motor. When ac power is restored, the drive is returned to the dc motor and the brushes of the dc motor are lifted from the commutator.

The complete plant consists of five regular load carrying two-motor alternators, one continually running spare set, operating at no load and one nonrunning spare set. Four control cabinets contain the necessary switching and control circuitry for the seven sets. Figure 18-22 shows the two-motor alternators mounted on machine tables and three control cabinets. Figure 18-23 shows the main control panel.

C. CONVERTERS AND INVERTERS

Semiconductor-type inverters and converters are now being used extensively for supplying power to various types of equipment. They vary in size from units that are mounted on a relay rack bay to floor supported units seven feet high.

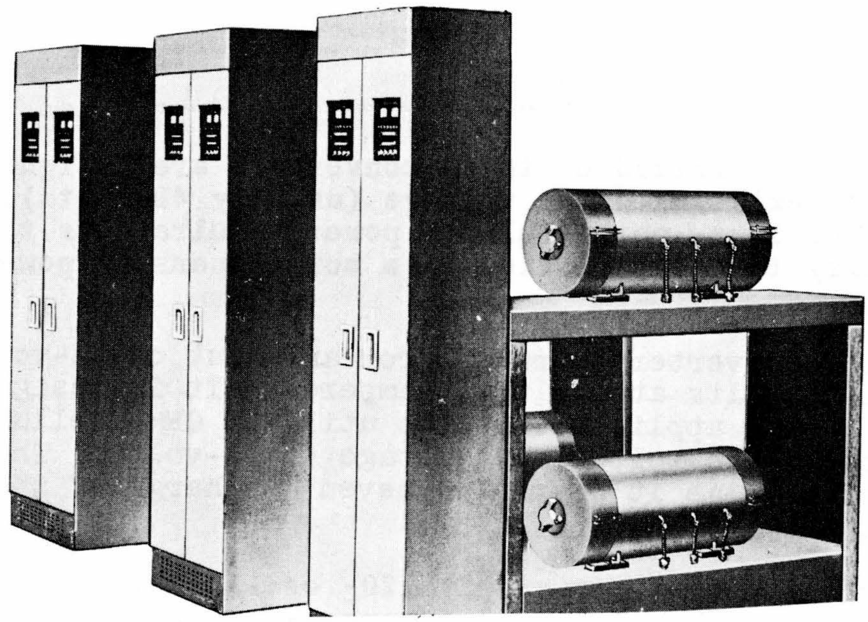


Figure 18-22 Control Cabinets and Two-Motor Alternators

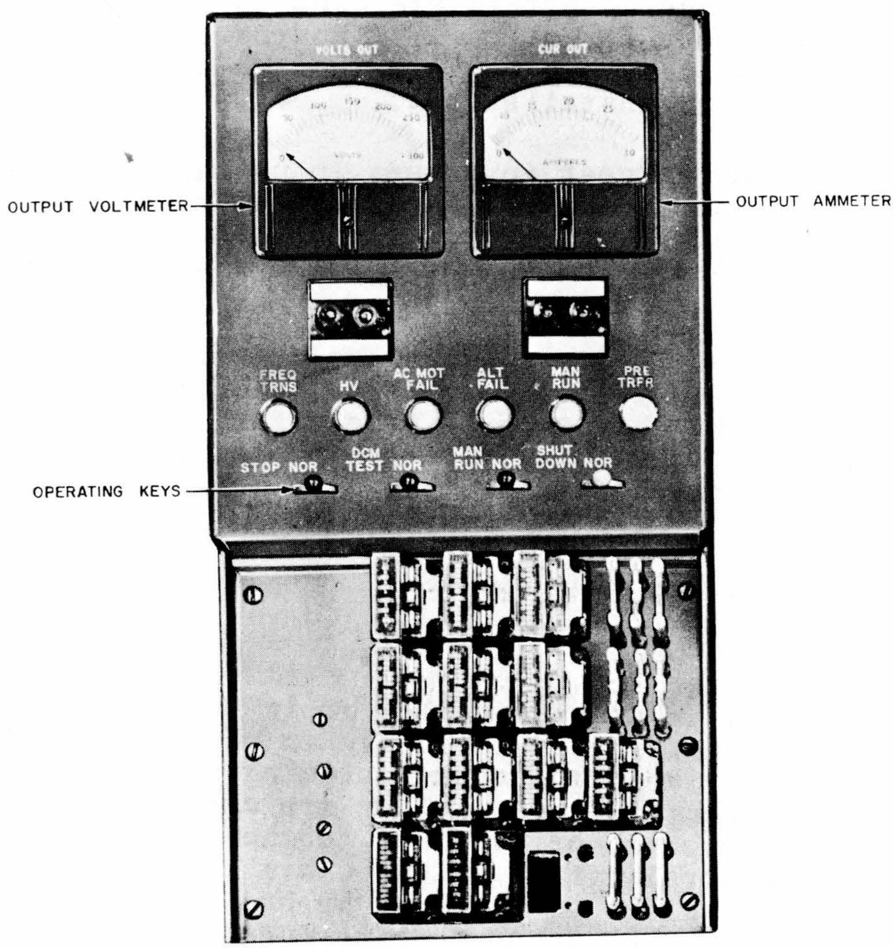


Figure 18-23 Main Control Panel

Transistorized dc to dc converters are designed to convert an existing plant voltage (usually 48-volts), to a higher or lower potential for power requirements that do not justify the installation of a more expensive power plant.

The converter operates from an input of 48-volts and supplies 24-volts at one to 15 amperes. It is designed to replace former applications that utilized CEMF cells or resistors to reduce the 48-volt plant voltage to 24-volts. The converter is more desirable as it prevents uneven discharge of the 48-volt battery.

Other converters supply 120- or 130-volts at 0.75 amperes, 130-volts at 1.5 amperes and 24-volts at five amperes.

Transistorized inverters are used to supply alternating current from a direct current source. In the SD submarine cable system they replace the two-motor alternator sets used on earlier installations.

Some of the largest inverters in use are rated at 5 KVA and invert a 42- to 52-volt dc input to 400-cycle, square wave 230-volt ac regulated and unregulated output, to supply the high voltage rectifiers of the SD submarine cable system.

A 5 VA inverter designed for relay rack mounting operates from an input of 20- to 28-volts dc and is designed to furnish output of 16.6-volts dc, 4.1-volts ac and 55-volts ac at less than one ampere, for monitoring and testing submarine cable equipment at the unpowered end of the cable.

18.9 POWER CONDUCTORS AND FILTERS

A. TYPES OF CONDUCTORS

Conductors in armored cables or in conduit are used to extend the commercial power supply to charging, ringing and other motor driven equipment including rectifiers, and to lighting and plug fixtures. They are also used to distribute converted ac or dc power to the equipment in the telephone central office. Conductors may be insulated, solid or stranded wires or they may be bus bars which depend upon spacing and nonconducting supports, for their insulation. See Figure 18-24.

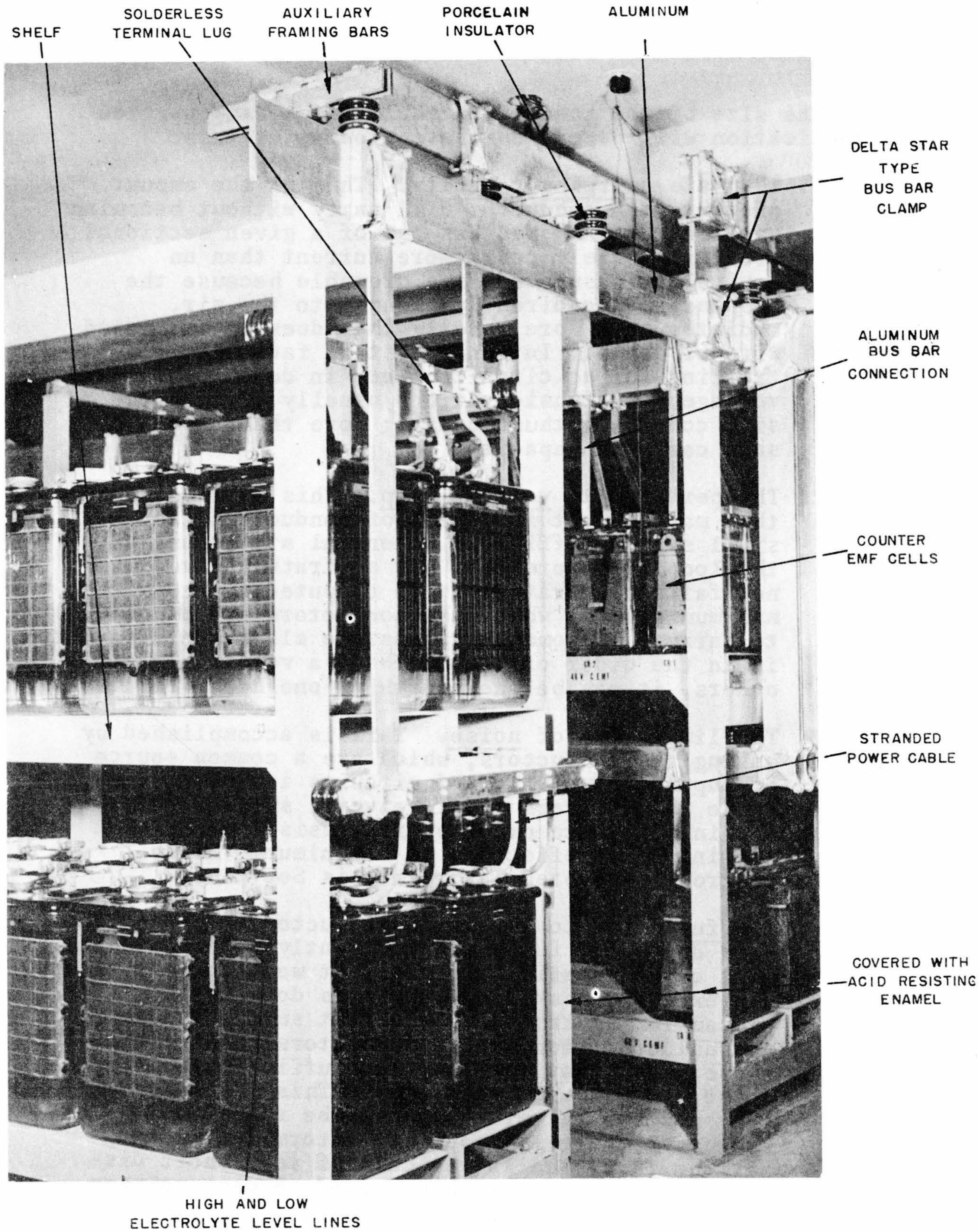


Figure 18-24 Bus Bar Connections At Battery Stand

The size of the conductor required for each particular application will depend on the following factors:

1. The safe carrying capacity. This is the amount of current a conductor will carry without becoming overheated. An open bus bar of a given sectional area will safely carry more current than an equivalent insulated wire or cable because the bus bar, being directly exposed to the air, radiates heat more readily than does an insulated wire or cable. In general, this factor is controlling for ac circuits since in dc circuits the voltage drop considerations usually dictate the size conductor thus insuring more than an adequate safe carrying capacity.

2. The permissible voltage drop. This is the amount that may be lost in a pair of conductors, and still supply sufficient potential at the end of the loop to insure that the apparatus served will not fail to operate. It is computed at the maximum current which the conductors are expected to carry. In some instances the allowable drop is in the order of one-tenth of a volt while in others, it may be one-fourth or one-half volt.

3. The limitation of noise. This is accomplished by making the conductors, which are a common source of supply to a number of circuits including telephone transmitters and receivers, sufficiently low in reactance or effective resistance so that the inductive effect is at a minimum. Noise control is covered later in this Section.

4. The fuse size to which the conductor is connected. Main discharge fuses are frequently selected which will carry indefinitely somewhat more current than the expected peak load. This is done as an extra precaution against large current surges due to unusual conditions. The conductors connected to those fuses must then be made sufficiently large to be protected by the fuses. This means that they must be larger than would be required because of carrying capacity determined by the maximum load, and in the case of very short discharge leads, larger than needed to meet voltage drop and noise requirements.

The various terms used with conductors, cables, and wire are:

1. "Armored Cable" is usually a multiconductor flexible cable consisting of flame retarding moisture - resistance wires helically wound with paper, or other fiberous covering, and a flexible metallic armor. The wire is 600 volt type "RH" braided rubber covered as defined by the National Electrical Code. Armored cable may be used in telephone power plants for power service to motors, rectifiers, for ringing and tone circuits and for frame and aisle lighting circuits where this does not conflict with local ordinances. Sizes are from No. 14 A.W.G. to 500,000 cm.

2. "Braided Rubber Covered" (BRC) cable and wire is usually 600 volt, type "RH-RW or RHW." It is made in sizes No. 14 A.W.G. to 800,000 cm and is run in power plant conduit or on racks.

3. "Cable" is an assembly of two or more conductors. Single conductors, solid or stranded, are called wire.

4. "Charge Conductors" are those that run between charging units and the battery or the point at which discharge conductors connect.

5. "Discharge Conductors" are those that carry discharge current from the battery. Counter-electromotive Force Cell (CEMF), electrolytic condenser and choke coil conductors are classified as discharge conductors.

6. "Filament Conductors" are those that carry direct current to filament circuits.

7. "Paired Conductors" are conductors of opposite polarity of a given circuit run closely together (but not necessarily twisted) so that the interlinking magnetic fluxes from currents in opposite directions neutralize each other. Three conductors (ground, 24 volts and 48 volts) are considered paired if run close together. Bus bars are considered paired if run on 3" centers, or as close as the plant equipment arrangements permit.

8. "Plate Conductors" are those carrying current to plate circuits.

9. "Service Circuits" are used to designate bus bars or wires connected to commercial power service or to a local reserve engine alternator set during power failure.

10. "Signaling Conductors" are those classified generally as telegraph, signal, ringing and tone.

11. "Singly Run Conductors" are those not paired with a conductor carrying current in the opposite direction.

12. "Sleeves" are conduit nipples or short lengths of conduit or smooth iron pipe or fiber duct. They are frequently used to protect cables or wires passing through walls or floors.

13. "Telegraph Conductors" are those carrying current to telegraph or teletypewriter equipment.

For convenience in handling, and in stocking the conductors, as well as the terminals and bus bar clamps used with them, power cables are limited to 800,000 circular mils in area, and bus bar 12 inches wide x 1/2 inch thick. Where more conductivity is required, parallel cables or laminated bus bars are used. In many instances, space considerations require the use of laminated bus bars less than 12 inches in width.

B. COMMERCIAL POWER SERVICE LEADS

Commercial power service supply leads are brought into the building and terminated on a service panel which is equipped with fuses or circuit breakers or other protective devices. From the service panel, circuits are extended to various parts of the building for lighting and other power services not directly associated with the telephone equipment and to a second service panel for telephone equipment known as the power service cabinet. All of this work is customarily arranged for by the telephone company prior to the start of the telephone installation work.

The power service supply for the telephone power plant is picked up at the power service cabinet by the installer, and extended, through fusing to the various machines, etc., with their control apparatus. Electric power service for frame and aisle lighting and for convenience outlets at frames and switchboards is usually picked up by the installer at the lighting panel boxes previously provided by the telephone company. All wiring which is either normally or intermittently connected to all commercial power supply sources or to equivalent sources such as reserve engine alternator plants located in the telephone buildings, is either run in conduit or with armored cable.

C. NOISE CONTROL

Precautions are necessary in power plant wiring, to insure that the currents flowing in or the voltages maintained on certain wires do not cause objectionable reactions on other circuits through inductive and capacity effects. The wiring connected to commercial power service, if not properly shielded and grounded, contributes to noise problems and causes other effects on talking circuits.

To reduce all these effects to a minimum, conductors are paired to neutralize their inductive effect. Talking (quiet) battery leads and signaling battery leads are run separately at specified distances apart. Conductors carrying ringing, tone and other high and low frequency ac currents having high voltage peaks including service circuits, are run in armored cable or conduit. In addition, leads which feed amplifiers are shielded since any inductive effect would be amplified along with the voice current.

The direct current required in a central office in general falls into two classes, "signaling battery" which is used to operate all the various types of electromechanical apparatus such as relays etc., and "talking battery" which supplies the medium for voice transmission. Since practically all equipment for generating direct current introduces ripples or noise in their output, it is necessary that battery filters be used to keep such disturbances at a minimum. Figure 18-25 indicates graphically the effect of a filter on an irregular wave form having high frequency ripples or noise.

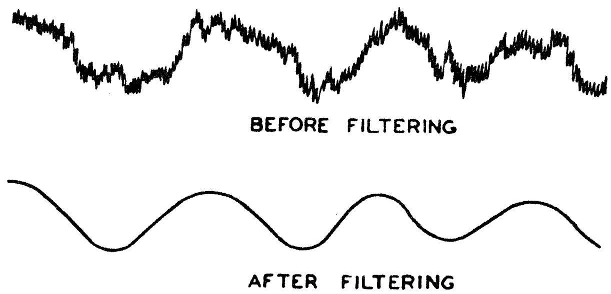
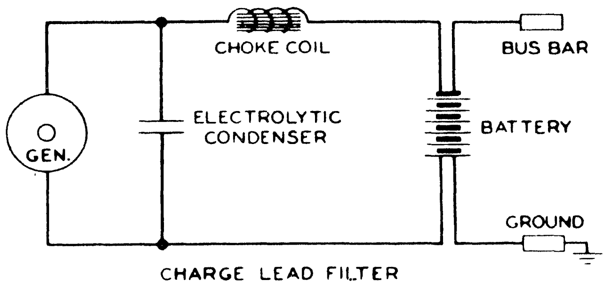


Figure 18-25 Effect Of A Filter On An Irregular Wave Form

Battery filters consist essentially of an inductor (retardation coil or coils) and a pair of (or one) electrolytic capacitors with a 20 ampere self-alarming fuse or with a 15 ampere fuse per capacitor between the filtered side of the inductor and ground. An alarm fuse is wired in parallel with each 15 ampere fuse. Filters come in capacities of 10-200 amperes. Large common filters, formerly located in the power room, have been replaced by the decentralized type which are mounted on relay rack bays, fuse bays, cable racks, on top of frames, and in switchboard turning sections, as required. The use of decentralized filters makes unnecessary separate power cable runs for signal and talking battery between the power plant and the various frames. This not only results in a saving in power cables but also improves the troublesome noise and crosstalk exposure encountered with former common filter arrangments and noise caused by a common drop.

The inductor of the filter impedes the fluctuations in the talking battery and the capacitor of the filter furnishes a bypass for the high frequency ripples (ac). A typical filter arrangement is shown in Figure 18-26.

In computing the values of the desired inductance and capacity, a combination is obtained which constitutes a "low pass" filter, that is, it will pass low frequencies that are not considered disturbing. It should be remembered that storage batteries also offer a low resistance to high frequency ripples and therefore contribute greatly in bypassing noise that might otherwise reach the discharge circuits.



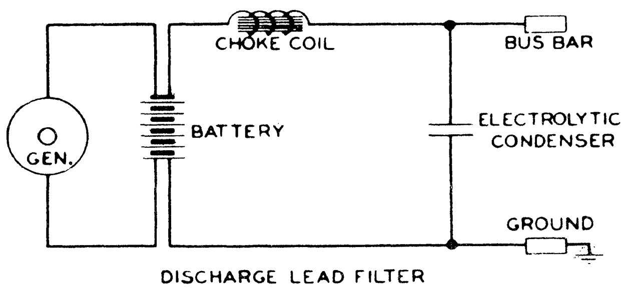


Figure 18-26 Typical Filter Arrangement

D. BUS BARS

Where space permits, in runs between charging machines, power boards and batteries, aluminum or copper bus bars are generally used. For any given current carrying requirements, an aluminum bus bar is approximately one and one-half times as large as a copper bar. Its weight is about one-half of that of the equivalent copper bar.

In addition to the weight advantage, which makes aluminum bus bars easier to handle than copper, it requires no protective finish even when located in rooms with open type storage batteries. And, it presents a very good appearance in a telephone office where most of the ironwork and apparatus is finished with aluminum paints and enamels.

To insure satisfactory contact, it is necessary to properly clean the contact area. Copper surfaces are normally cleaned with abrasive paper and then thin coat of NO-OX-ID "A" compound is applied. Aluminum surfaces are cleaned in a similar manner except that after the NO-OX-ID "A" compound is applied, the contact surfaces are scratch brushed to break up any soft oxide that may have formed. The reason for this is that metal oxidizes on exposure to the air, and if not coated with some material which will exclude the air, will cause poor electrical connections.

E. CENTRAL OFFICE GROUNDS

Earth connections or central office grounds, perform several important functions. One, it provides a low resistance path to earth, for dissipating lightning and other strong currents intercepted by lightning arrestors and protectors. Another, it grounds one terminal of the central office common battery to minimize electrical troubles in case of a cross with a high potential line. Usually, this is the positive (+) end of the batteries. If this were not done, that is, if a common battery telephone exchange were insulated from the earth, and some portion of the wiring became crossed with the wiring of an electric light, power or railway distribution system, the potential of the telephone system would be raised to that of the other system and subject the telephone apparatus to voltages which may be higher than they were designed to withstand and subject personnel to high voltages. Similarly, all frames, racks, etc., which support equipment are grounded so that they will not endanger people working in telephone central offices nor telephone apparatus and equipment.

Some circuits, used in the telephone plant, utilize the earth as part of their operating paths. This is particularly true of ringing circuits where selective and semiselective party ringing is used on subscriber sets and for dc telegraph and simplex or composited dc signaling.

Because grounds are important, it is customary to use the piping of water supply or gas distribution systems which can usually be depended upon to be of low resistance and have a high carrying capacity. In some instances, such as at repeater stations and small manual and dial offices, where water or gas system piping is not available, "made grounds" must be used. The standard method is to drive several pipes or rods into the ground, preferably in the basement of the building housing the telephone plant. The pipes or rods are spaced six to ten feet apart, and are bonded together to form a unit.

CHAPTER 19

CENTRAL OFFICE TEST FACILITIES

19.1 INTRODUCTION

Test facilities, such as testboards and test desks, are used to facilitate the location of troubles on toll and local circuits and to expedite the restoration of the service that has been interrupted. Before investigating the more common types of testboards and test desks used today, it would be helpful to examine the basic methods of measurements used in direct-current and alternating-current test circuits.

19.2 MEASUREMENTS IN D.C. CIRCUITS

A. INSULATION RESISTANCE

Measurements of faulty insulation is accomplished by connecting a voltmeter and battery in series with the wires under test. See Figure 19-1.

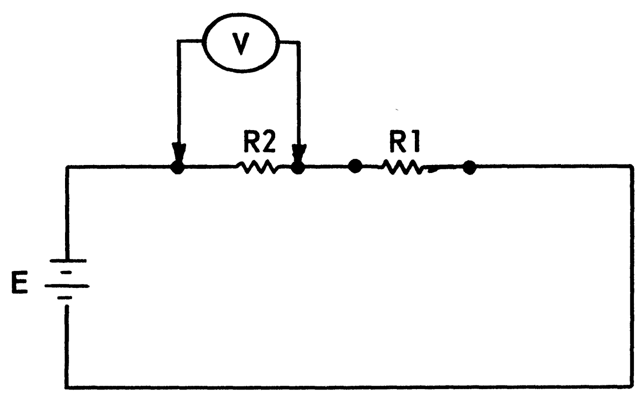


Figure 19-1 Insulation Measurement

Voltmeter V reads the drop across its own internal resistance, R2. The voltmeters used for measuring insulation are especially designed to have abnormally high internal resistances; the ones used in the standard testboard testing circuits have a resistance of 100,000 ohms. The resistance of the fault, R1, may be found by determining the voltage drop (V) across the known resistance (R_2).

B. WHEATSTONE BRIDGE

The Wheatstone Bridge is an invaluable instrument in locating the four common types of line faults encountered in the open wire and cable plant. These faults are essentially crosses, grounds, opens and resistance unbalance.

Figure 19-2 illustrates the conventional type of Wheatstone Bridge. It consists of a network of resistors with a galvanometer connected between one set of diagonally opposite corners and a battery between the other set of diagonally opposite corners.

If the resistance of the A arm is assumed to be equal to that of the B arm and the total resistance consisting of the A and X arms is assumed to be greater than the total resistance consisting of the B and R arms, more current will flow through the resistances B and R than through the resistances A and X. Consequently, the voltage drop across B will be larger than that across A, and the junction between resistances A and X will be at a higher potential than that between resistances B and R. The net result will be that an unbalance current will flow downward through the galvanometer.

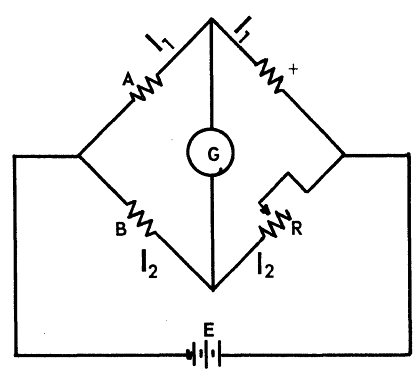


Figure 19-2 Basic Wheatstone Bridge Circuit

If the resistance of the R arm of the bridge is varied until the current flowing through the resistances B and R is equal to that flowing through the resistances A and X, the voltage drop across B will be equal to that across A. Since the junction between resistances A and X then will be at the same potential as the junction between resistances B and R, no current will flow through the galvanometer. Under this condition the bridge is said to be balanced. This is also the condition of the bridge at the completion of measurements made on cable or open wire conductors. When the bridge is balanced and the resistance of the three arms of the bridge are known, the resistance of the fourth arm may be calculated.

Wheatstone bridges are usually constructed so that the resistance in the A and B arms can be varied to suit the needs of a particular test. The A and B arms are commonly called ratio arms since by changing the ratio A/B the range of resistances which can be measured is materially increased. Mathematically, the unknown resistance X is found by multiplying the ratio A/B by R.

C. SIMPLE LOOP TEST

To make simple loop tests, the circuit shown in Figure 19-3 is employed. In this circuit, the X (unknown resistance) arm of the bridge shown in Figure 19-2 is replaced by a pair of wires which have been looped or connected together at the distant office. When the bridge is balanced, no current flows through the galvanometer and the loop resistance (L) is found by multiplying the ratio A/B by R. If the ratio arms A and B are made equal, then A/B becomes equal to one, and L is equal to R.

Measurements of the loop resistance of open wire or cable pairs thus can be made by short-circuiting the two wires of a pair at the distant office and measuring the resistance of the wires by means of the bridge at the home office.

D. VARLEY LOOP MEASUREMENTS

A Varley loop measurement is a special type of loop resistance measurement which is used for locating troubles such as grounds and crosses. A line fault location by the Varley loop method requires the use of one good wire in addition to the faulty wire. It consists essentially of the determination of the loop resistance of the conductors between the fault and the distant office.

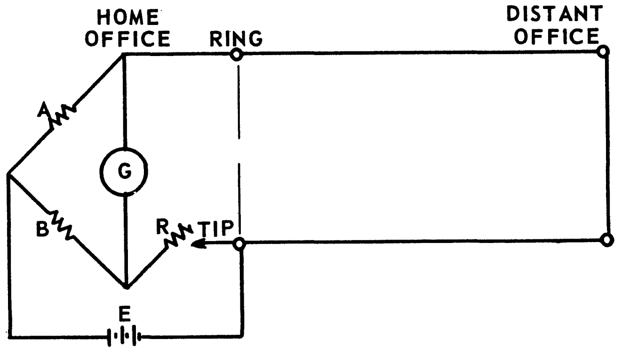


Figure 19-3 Circuit for Simple Loop Test

Figures 19-4 and 19-5 are schematics showing the equivalent bridge circuits for making grounded and metallic Varley measurements, respectively. A grounded Varley measurement, shown in Figure 19-4, is one in which the return path from the fault to the battery is through ground. A metallic Varley measurement, shown in Figure 19-5, is one in which the return path is through a wire. The magnitude of the resistance in the return path does not affect the bridge balance; however, it does affect the bridge sensitivity and, therefore, the accuracy of the measurement.

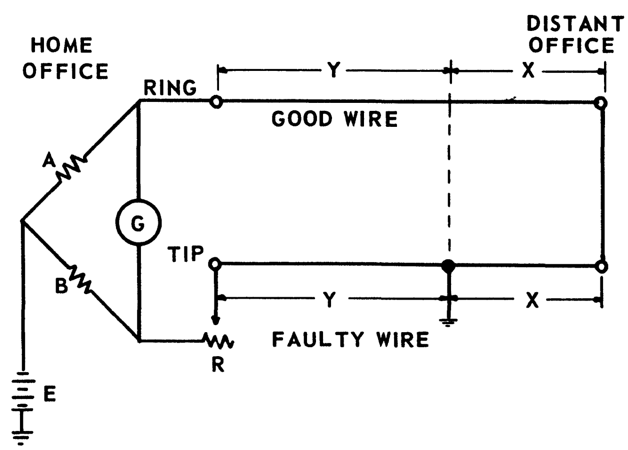


Figure 19-4 Schematic Circuit for Grounded Varley Measurement

In both figures, assume the values of the Wheatstone Bridge ratio arms A and B to be equal, the good and faulty wires to have equal conductor resistance, Y to be the resistance of one wire from the home office to the fault, and X to be the resistance of that wire from the fault to the distant office. Since the ratio A/B is equal to one, it is easily shown that

$$R = 2X = V$$

The balancing resistance, R, is equal to the loop resistance from the fault to the distant office, and is known as the Varley measurement or V.

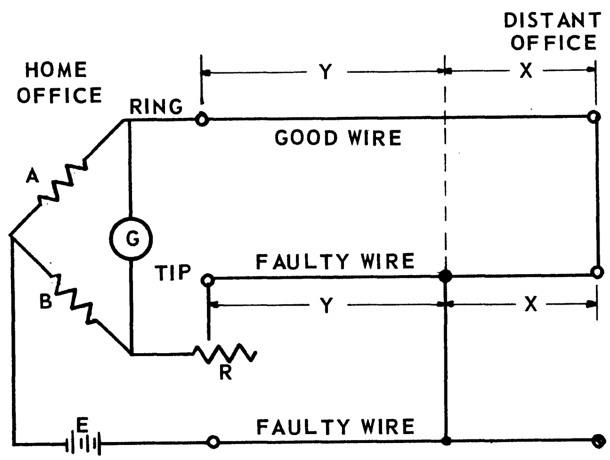


Figure 19-5 Schematic Circuit for Metallic Varley Measurement

E. MURRAY LOOP TEST

The theory of the Murray loop test is similar to that of the Varley. But instead of setting the arms A and B to have equal values and using the adjustable balancing resistance R to compensate for the difference in wire resistance between the good wire connection and the defective wire connection, the arm B is eliminated altogether and the variable resistance arm is connected in its place as shown in Figure 19-6. In this arrangement, the ratio of the reading R to the setting of the arm A, is equal to the ratio of the resistance of the defective wire from the home office to ground to the resistance of this same wire from ground, to the distant office plus the resistance of the good wire, or expressed mathematically.

$$\frac{R}{A} = \frac{X - Y}{X + Y}$$

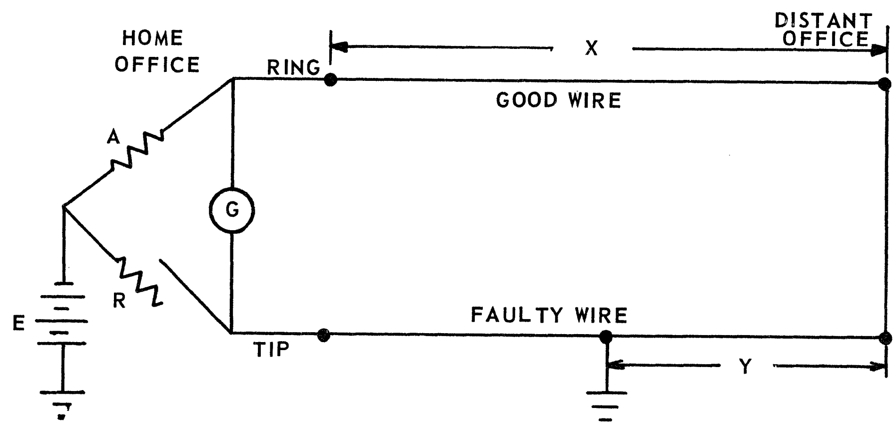


Figure 19-6 Schematic Circuit for Murray Test

The advantage of the Murray test in locating a fault is that the test does not require the use of a third wire (good wire) as would be necessary in the Varley method. Except in certain special conditions involving rural lines or one pair service cables, the Murray test is rarely used in telephone practice for locating grounds or crosses. The Murray type connection is commonly used, however, for locating opens. But since the wires here are open, it is obvious that no ordinary direct current measurement can be made. Instead, a low frequency alternating current is generated by means of an interrupter which reverses the battery voltage several times a second and simultaneously reverses the polarity of the galvanometer connections. The bridge, when balanced, then compares the capacitance of the good wire to its far end with that of the defective wire to the point where it is open.

19.3 MEASUREMENTS IN A.C. CIRCUITS

A. IMPEDANCE MEASUREMENTS

It is important to match impedances at junction points of communication circuits in order to eliminate unnecessary transmission losses or other undesirable effects. This makes it necessary, for practical maintenance purposes, to have available a device which can measure impedances accurately.

Figure 19-7 indicates the principle of a simple bridge circuit widely used in the telephone plant for measuring impedances in the voice-frequency range between 100 and 3000 Hertz. As shown, the unknown impedance is connected in one arm of the bridge and the balancing arm consists of a variable resistor and a variable inductor in series. Arms R_a and R_b are resistors of equal value. Measuring current is supplied from a variable oscillator capable of delivering satisfactory waveshape and output through the range of voice frequencies for which the bridge is designed. The values of R and L, when adjusted so that no current is in the telephone receiver, will be equal to the corresponding values of the unknown impedance. The circuit as shown in the diagram could measure only an inductive impedance. The practical circuit, however, is arranged so that the variable inductor may be switched into the other arm of the bridge in series with the unknown impedance. When the bridge is balanced in this condition, the inductometer in effect gives a measure of negative inductance, which is equivalent to capacitance. The variable units are actually calibrated to read resistance in ohms and inductance in millihenries, but the readings may readily be converted into reactance and impedance values by the application of basic a-c equations.

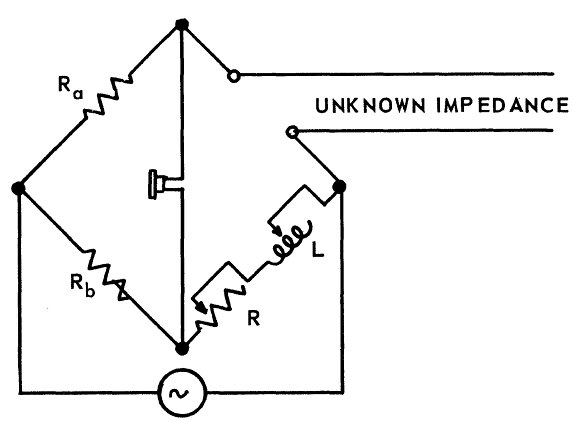


Figure 19-7 Simple Impedance Bridge

Other bridge designs, operating on a basically similar principle, are used for impedance measurements at higher frequencies. One of these, which is satisfactory for measurements between 1800 and 35,000 Hertz, is shown schematically in Figure 19-8. The bridge here is the familiar hybrid coil. When the unknown impedance connected to the "line" side of the coil is matched by the adjustable impedance connected to the "net" side of the coil, voltage applied to the series winding from an oscillator will produce no current in the bridge connection to the amplifier-detector. It will be noted that the reactance adjustment in this circuit is made by means of a variable capacitor rather than an inductometer. If the reactance of the unknown impedance is inductive, the variable capacitor is transferred by an appropriate switch to the line side of the coil in series with the unknown impedance.

Another bridge, designed for making measurements between 1 and 100 KHz, is shown in Figure 19-9 in a simplified schematic. This bridge differs from the usual circuit in that the ratio arms are four pairs of equal resistances, and the variable and unknown impedances are connected between mid-points of opposite pairs. The impedance is measured when the bridge is balanced in terms of resistance and capacitance in parallel rather than in series, and switches are provided to transfer the variable elements to the opposite side of the bridge if this should be necessary to secure balance.

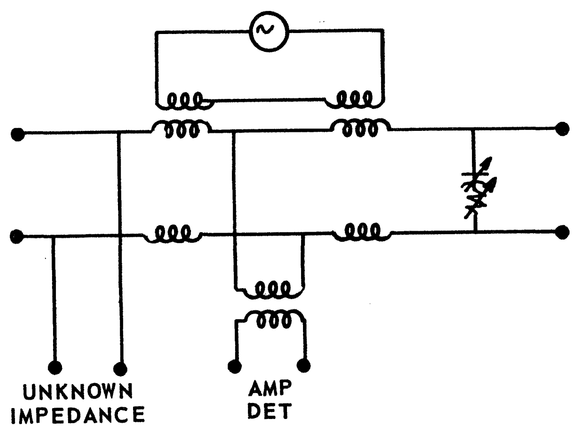


Figure 19-8 Hybrid-Type Impedance Bridge

One of the major uses of the impedance bridge in practical communications work is the location of impedance irregularities in long wire circuits. The impedance of a long line that is free from irregularities and terminated in its characteristic impedance, when measured over a wide band of frequencies, will appear as a smooth curve over the measured frequency range. If, however, there is an impedance irregularity along the line, such as might be caused by a defective or improperly located loading coil, some part of the energy applied to the line at the sending end will be reflected back from the point of irregularity. The reflected wave will add to or subtract from the initial applied wave, depending on its phase relationship when it reaches the sending end. The sending end impedance will be affected accordingly. The phase of the reflected wave with respect to the initial wave of course depends on the time it takes to travel from the irregularity to the sending end or, since the velocity of propagation is a constant for a particular type of facility, on the distance from the irregularity to the sending end.

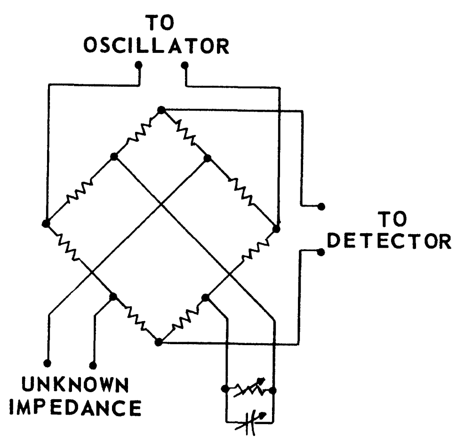


Figure 19-9 Simple Impedance Bridge

B. <u>TRANSMISSION MEASUREMENTS</u>

Most widely used, of the many types of measurements required in communications work, are those known as <u>transmission measurements</u>. These are measurements of the <u>ratio of the power at the</u> receiving end of a transmission line to the power applied to the transmitting end; this indicates the loss or gain of a circuit in terms of decibels or comparable logarithmic units. Two basic methods of making transmission measurements are commonly employed. The first is a direct method in which a known amount of power (generally 1 milliwatt) is applied to the sending end of the circuit under test and the power at the receiving end is measured by a direct-reading meter in terms of db or dbm. This is obviously the simpler method and is used wherever practicable. In situations where it is not feasible to supply a known fixed power at the sending end of the circuit, a comparison method is used in which the loss or gain of the circuit under test is measured by comparing it with a known, calibrated loss or gain.

For routine checking of telephone circuits, transmission measurements are usually made at a single frequency of 1000 Hertz and, in most cases, the direct method of measurement is employed. Fixed testing power of 1 milliwatt is supplied at the sending terminals from a 1000-Hertz source of power, which consists of a small magneto-generator. At the receiving end, the power is amplified, rectified by copper-oxide varistors, and supplied to a d-c meter reading directly in db or dbm. The detailed circuit arrangement is shown in Figure 19-10. Where measurements at frequencies other than 1000 Hertz are required, the same receiving circuit may be used, but the sending power is furnished by an appropriate variable oscillator. To insure that the test power is at 1 milliwatt, the oscillator output is calibrated against a fixed 1000-Hertz generator output for each series of measurements at other frequencies.

In situations where a fixed known testing power source is not available, as would ordinarily be true in the case of portable transmission measuring sets, the comparison method mentioned above may be employed. The general principle of this type is illustrated in Figure 19-11. The set is first calibrated by connecting a voltage to a fixed artificial line which causes a definite known loss. The entering current, after passing through this line, is amplified and rectified and passed through a potentiometer to a d-c meter. The value of the applied voltage is then adjusted to such a value as to give any desired deflection of the meter, usually at mid-scale. After calibrating, connections are changed so that the same voltage is applied to a variable artificial line in series with the circuit whose equivalent is to be determined. By cutting out sections of the artifical line, the total loss in the circuit is made the same as that in the calibrating circuit, so that the d-c meter gives the same deflection in both cases. The dials are arranged to read the loss in the unknown circuit directly.

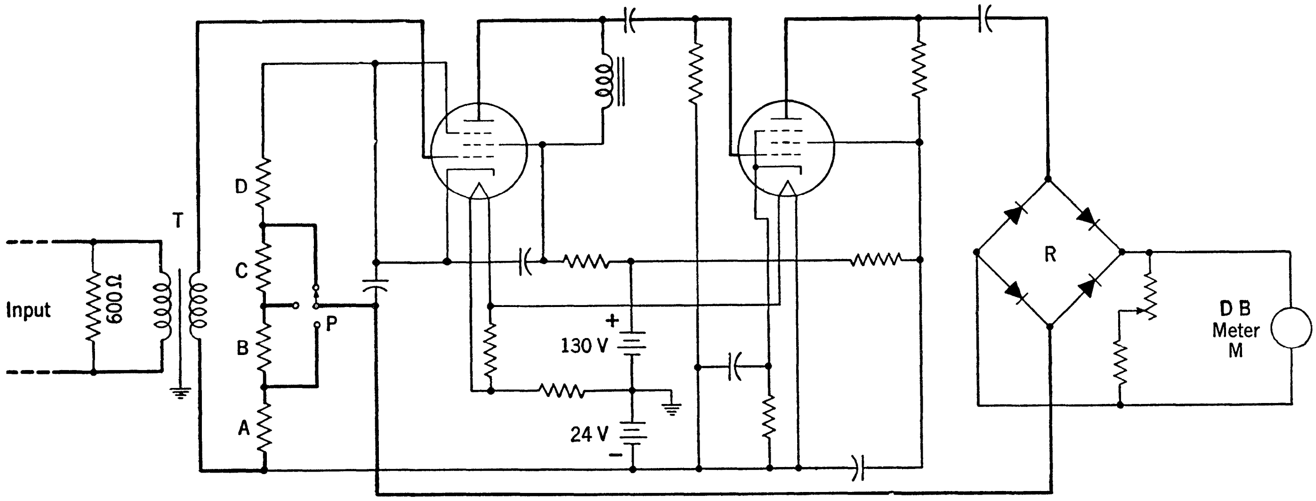


Figure 19-10 Direct Reading Transmission Measuring Set with Amplifier

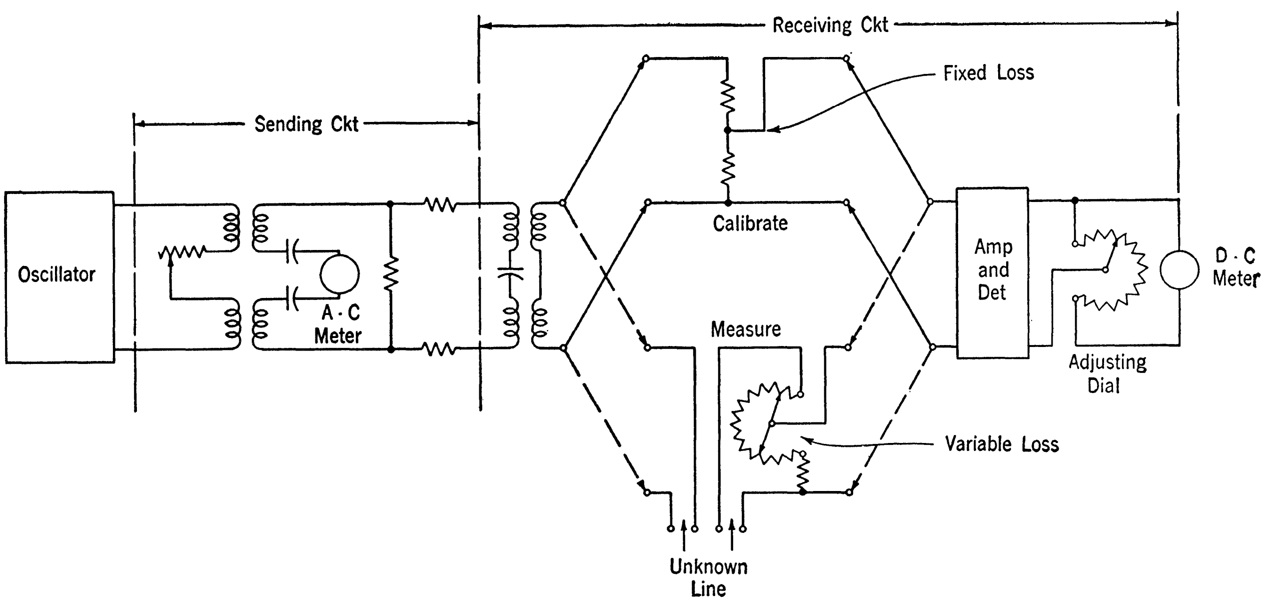


Figure 19-11 Principle of Transmission Measuring Set

For transmission measurements at higher frequencies up to 350 KHz, both comparison type and direct-reading sets are extensively used in the telephone plant. The principles involved are not essentially different from those already discussed for measurements at voice-frequencies, although the measuring sets themselves are necessarily somewhat more elaborate in design. The comparison type sets generally employ thermocouple detectors to drive a direct-reading meter. The receiving circuits of the direct-reading sets are essentially super-heterodyne detectors, the outputs of which are fed to d-c milli- or microammeters reading directly in dbm. Appropriate types of variable oscillators must be employed with each measuring set.

C. NOISE MEASUREMENTS

Voltages within the voice-frequency range, induced in a telephone circuit by electric power circuits, are manifested to a listener on the telephone circuit as noise. In many cases, crosstalk currents may also appear merely as noise. This is particularly true in the case of cable circuits where any crosstalk heard is likely to come simultaneously from a considerable number of other circuits, and appears to the listener on the disturbed circuit as a special form of noise, called "babble." In other words, it is just an unintelligible conglomeration of speech sounds coming from a large number of sources.

The disturbing effect of noise to a listener depends first, of course, upon its volume. It also depends upon the frequency of the noise currents. Figure 19-12 shows the results of tests that have been made to determine the relative disturbing effects of various noise frequencies. It will be noted that the disturbing effect peaks up rather sharply in the neighborhood of 1100 cycles. Where noise is of appreciable volume - particularly in the more sensitive frequency range - it is naturally annoying to the telephone user and may seriously reduce the intelligibility of conversation. It is accordingly necessary to keep the noise in working telephone circuits below those limits where its interfering effect on conversation will be important.

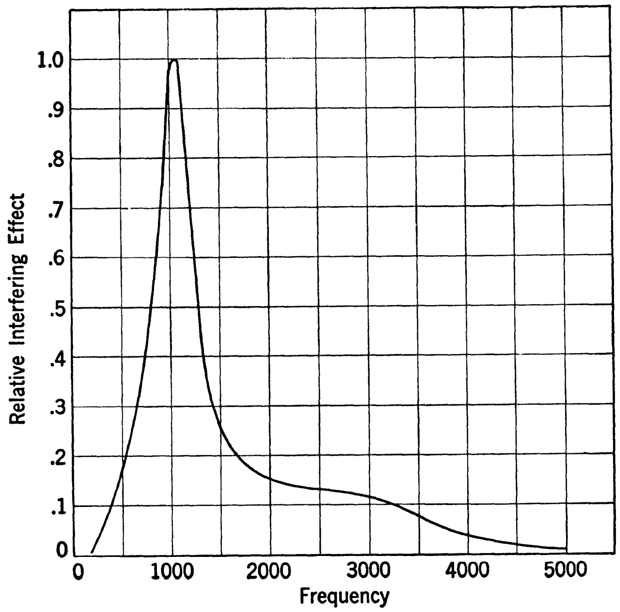


Figure 19-12 Relative Interfering Effect of Noise at Different Frequencies

Noise measurements differ from transmission loss measurements in that the received current which is introduced into the measuring circuit is much smaller and necessitates the use of a more sensitive amplifier. Since no sending power is employed and since no unusual terminations are required at the distant end of the circuit being tested, noise and crosstalk volume measurements can be made on a bridging basis with normal circuit terminations during the momentarily idle periods while the circuits are in service.

The ideal objective of the various methods for counteracting crosstalk and noise induction in telephone circuits is to eliminate their effects altogether. In practice this ideal is rarely attained. But certain practical limits are established, and every reasonable effort is made to keep the crosstalk and noise below these limits. In designing and maintaining circuits, therefore, it is desirable to be able to make definite quantitative measurements of both crosstalk and noise. As in any other kind of measurement, this requires the establishment of definite units.

The measure of either crosstalk or noise that would be of major significance is the extent of the interference or annoyance to which a listener on a disturbed circuit is subjected. Since such a measure is obviously affected by numerous subjective factors, it is clear that completely objective quantitative measurements of crosstalk and noise effects are practically impossible. It is possible, however, to make precise quantitative measurements of the crosstalk coupling between a given sending point on a disturbed circuit and a given receiving point. Essentially this is simply the measurement of the transmission loss between the two points, and like any other transmission measurement it may be made at one or more frequencies as desired. Such a measurement gives a value of what is known as "crosstalk coupling loss" in db. A more commonly used measure of crosstalk coupling employs a unit designated dbx, which expresses the coupling in db above "reference coupling." Reference coupling is equivalent, broadly speaking, to a crosstalk coupling loss of 90 db, and is formally defined as "the coupling which would be required to give a reading of zero dba on a 2-type noise measuring set connected to the disturbed circuit when a test tone of 90 dba (using the same weighting as that used on the disturbed circuit) is impressed on the disturbing circuit."

Another unit sometimes used for measuring crosstalk coupling is the "crosstalk unit," abbreviated CU. The number of crosstalk units representing any given coupling is 10^6 times the ratio of the current or voltage in the disturbed circuit to the current or voltage in the disturbing circuit at the two points under consideration; or, if the circuit impedances are not the same, 10^6 times the square root of the power ratio. The relationships between the three measures of crosstalk coupling are shown graphically in Figure 19-13.

For measuring noise, a basic reference point has been selected, which is equal to 10^{-12} watts of 1000-Hertz power. This corresponds to 90 db below 1 milliwatt (-90 dbm). Noise may then be measured in terms of number of decibels above this reference point. However, the interfering effect of noise on a listener varies with both the level and the frequency; and the relative importance of the components of noise at the different frequencies must be taken into consideration in determining the total amount of interference.

The interfering effect also varies according to the sensitivity of the receiving device that converts the noise currents into audible sound. For these reasons, in measuring noise, it is desirable to employ "weighting networks" which act to integrate the noise power over the voice-frequency range by giving each small band of frequencies a weighting proportional to its contribution to the total interfering effect. Different weighting networks may be used with different receiving devices. Even so, equal values of db reading will not necessarily indicate equal interfering effects without some adjustment of the calibration constants. In practice, an adjusted unit designed dba is employed, which measures the acoustic interfering effect of the frequency-weighted noise energy. Equal values of dba measured across any receiving device, with proper weighting used, should indicate approximately equal interfering effects.

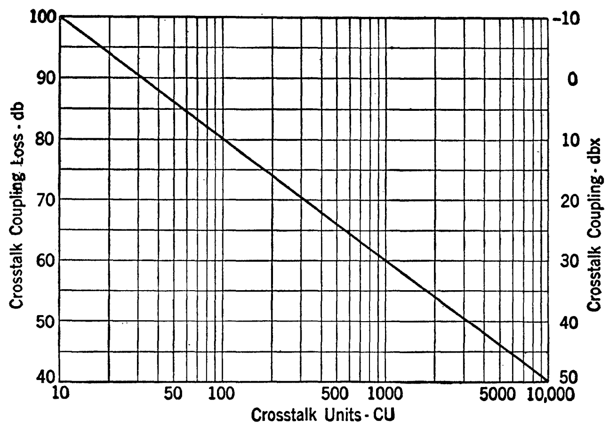


Figure 19-13 Relations Between Crosstalk Measuring Units

19.4 TOLL TESTBOARDS

A. GENERAL

Many of the toll testboards and much of the testing equipment still in use are considered obsolete and will not be described here. When engineering effort is to be expended on these obsolete items, considerable research and careful engineering is required on the part of the engineer. We will therefore consider only the more common units which are currently in general use.

B. TOLL TESTBOARD CLASSIFICATIONS

Toll testboards fall into three principle categories:

1. Primary testboards

2. Secondary testboards

3. Telegraph testboards

Primary testboard positions are used to terminate the toll line cable and open wire pairs. The primary jacks permit ready access to the line conductors to facilitate testing them and determining the type and location of any existing trouble. These jacks also permit patching on a temporary basis defective cable pairs or toll terminating equipment.

Secondary testboard positions provide an appearance of the circuit on the drop side of cable equipment or a complete appearance of open wire lines (in toll test stations equipped with both a primary and secondary testboard). Facilities are provided for monitoring, talking and signaling on circuits as desired and for patching or making operating tests on drop circuits and ringer equipment. In some cases, such as the No. 18-B type of testboard, "test and out of service" jacks are provided as an exact multiple of the toll line multiple in the toll switchboard.

The third category, telegraph testboards, service both line and subscriber telegraph circuits.

A simplified diagram giving the relationship of the primary and secondary positions of toll testboards is shown in Figure 19-14.

C. NO. 17 TOLL TESTBOARDS

The No. 17B toll testboard has been developed to replace both the multiple and nonmultiple No. 8 test and control board. From a functional point of view the No. 17B toll testboard is the same as the No. 8 test and control board, in that it continues the direct reporting of intertoll trunk (toll line) troubles by the operator to the test board attendant and provides overall toll circuit testing features.

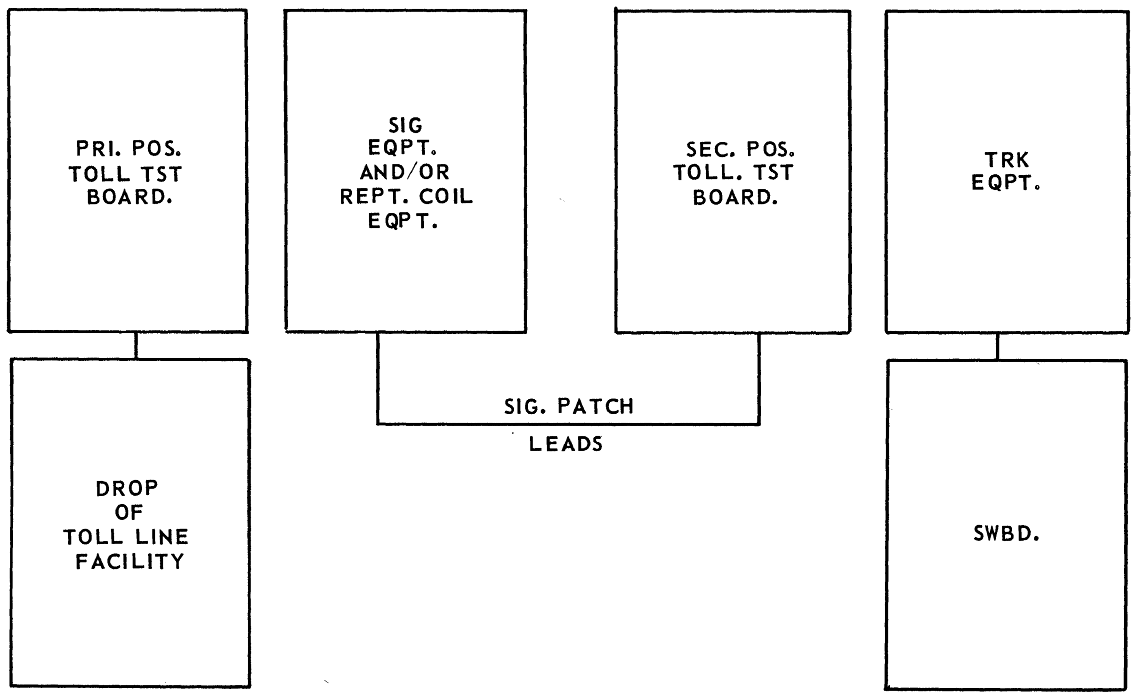


Figure 19-14 Relationship of Primary and Secondary Positions of Toll Testboard

The No. 17B toll testboard is designed for use in a No. 5 crossbar office, a crossbar tandem office at toll switching points, and is associated with switchboards such as No. 1, 3 type, or No. 11, for facilitating the location of troubles on toll circuits and to expedite the restoration of service when it has been interrupted. The testboard consists of a lower unit housing testing equipment and a jack field in which appears the intertoll trunks and community dial office trunks. In some cases patching jacks are provided.

The equipment consists of facilities for monitoring and talking on a trunk, for making 1000 Hertz transmission measurements, noise measurements, signaling, timed ringing and miscellaneous other tests. The lower unit consists generally of the keyshelf and associated cord and test circuit.

Intertoll dialing (ITD) and community dial trunks and miscellaneous test circuits are on standard jack field frameworks. Patching jacks are provided on a four-jack basis per ringdown intertoll trunk. Patching jacks are not provided for intertoll dial trunks.

The No. 17C toll testboard is a variation of the No. 17 type testboard which is designed specifically to operate with the four-wire intertoll trunks of the No. 4 crossbar toll switching systems. It is used for making over-all tests of the toll circuits. Supplementary jack bays are used for patching.

D. NO. 18B TOLL TESTBOARD

The No. 18B toll testboard is used to facilitate the location of troubles on toll circuits and to expedite the restoration of service that has been interrupted. It permits over-all testing of toll circuits and serves the purpose of a primary board, combined board, and decentralized toll, Dial System A, or crossbar tandem testboard, by providing all of the jack appearances and testing equipment usually required for the testing, patching, and maintenance of intertoll trunks and their associated office equipment. A view of this testboard is shown in Figure 19-15.

The testboard is primarily designed to be associated with switchboards, such as No. 3, 3C, 3CF, 3CL, or 11 (sleeve supervision), but may also be used with crossbar tandem offices and decentralized toll switchboards. The testboard secondary cords may be modified with an auxiliary secondary cord circuit so that the testboard may be associated with No. 1 and 2 toll switchboards or 9C, 10 and 12 toll positions in manual offices or connecting company offices. The auxiliary secondary cord converts the 48-volt ringing signal from the position circuit to 20-Hertz ringing and converts the supervisory signal in the connecting circuit to sleeve supervision required in the testboard.

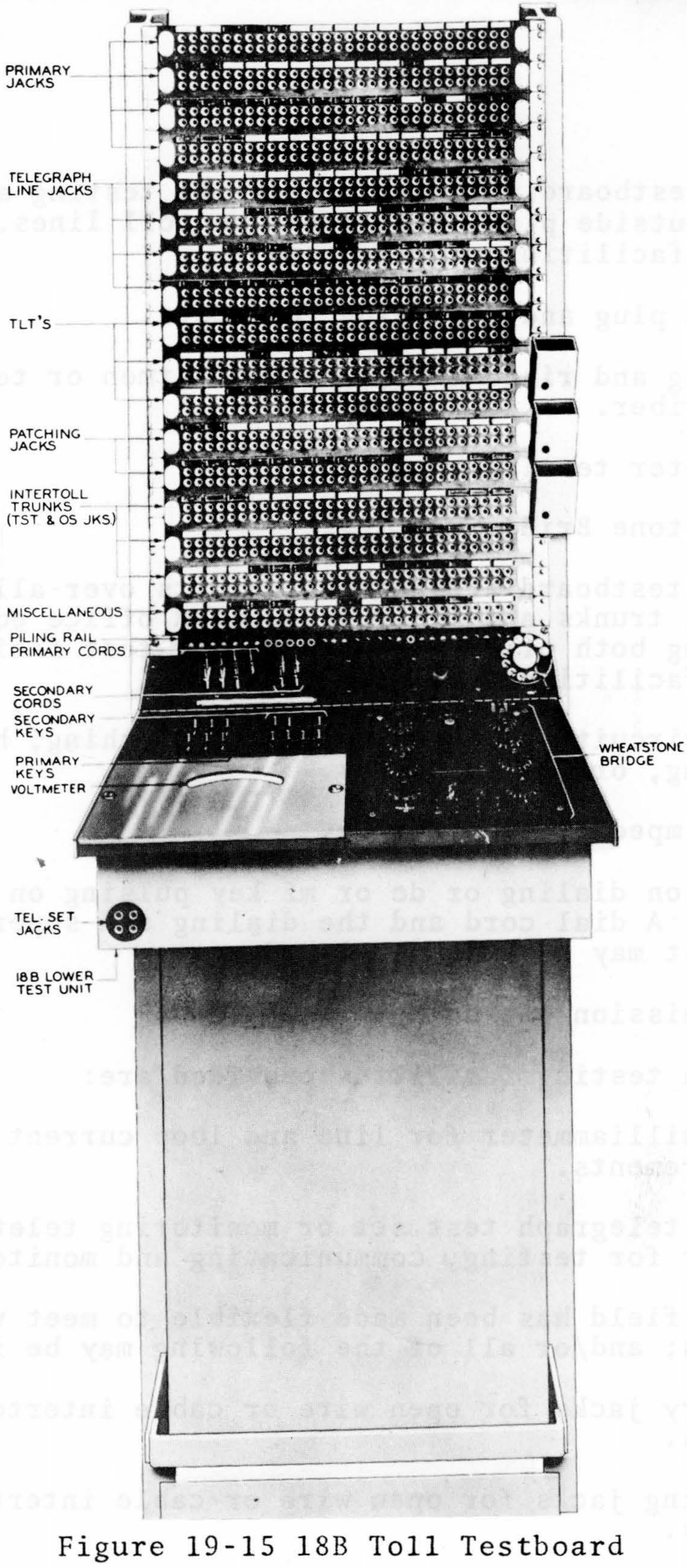


Figure 19-15 18B Toll Testboard

Primary testboard arrangement permits testing and maintenance of outside plant facilities on toll lines. Primary testing facilities provided are:

1. Single plug and twin plug test cord.
2. Talking and ringing to outside testmen or telegraph subscriber.
3. Voltmeter testing.
4. Wheatstone Bridge testing.

Combined testboard arrangement permits over-all testing of intertoll trunks and their associated office equipment by providing both primary and secondary test facilities. Secondary test facilities provide:

1. Cord circuits which may serve as patching, holding, testing, or talking cords.
2. High impedance monitoring.
3. Position dialing or dc or mf key pulsing on either cord. A dial cord and the dialing and supervisory circuit may also be furnished.
4. Transmission measuring.

Telegraph testing facilities provided are:

1. Volt-milliammeter for line and loop current measurements.
2. No. 3 telegraph test set or monitoring teletypewriter for testing, communicating and monitoring.

The jack field has been made flexible to meet various job requirements; and/or all of the following may be included:

1. Primary jacks for open wire or cable intertoll trunks.
2. Patching jacks for open wire or cable intertoll trunks.

3. Test and out-of-service jacks for intertoll trunks and community dial office trunk circuits.

4. Patching, monitoring and signal test jacks for full period talking in long line circuits.

5. Incoming and outgoing 2-way and test trunk circuits.

6. Telegraph line jacks.

7. Telegraph loop terminal jacks.

8. Miscellaneous test and out-of-service jacks.

E. NO. 19A TOLL TESTBOARD

The No. 19A toll testboard is used in No. 5 Crossbar (4 wire) toll offices for making over-all tests of the toll circuits. This testboard consists of a lower unit which houses testing and control equipment, and a jack field in which an appearance of the intertoll trunks (test jacks, patch jacks) and miscellaneous other trunks appear.

In line with the general design of the No. 5 Crossbar (4 wire) toll switching system, the circuits in this board are arranged on a 4-wire basis necessitating the use of twin jacks in the jack field and twin plugs on the cords which connect to these jacks.

The testing facilities available provide for monitoring and talking on a trunk and for making 1000 Hertz and multi-frequency transmission measurements, signaling, and miscellaneous other tests enabling the testman to diagnose the trouble which exists on a circuit, so that he may notify the proper maintenance group of the nature of the trouble.

F. NO. 9 TELEGRAPH TESTBOARD

The No. 9 telegraph testboard employs relay rack bays for mounting the jacks and testing equipment required for maintaining telegraph service. The telegraph testboard is divided into two major types as follows:

1. Telegraph Line Bays: The line bays contain generally only those jack circuits which stand between the interoffice lines or trunks and the equipment

in the telegraph office. A telegraph line bay contains a writing shelf or a test lower unit which contains cord-ended testing equipment. A jack field mounted in the upper part of the bay contains carrier and dc telegraph line jacks, interposition trunks, and miscellaneous jacks. The upper unit equipment also includes an apparatus panel, miscellaneous mounting plates, and, when so desired, terminal strips for the jack circuits.

2. Telegraph Loop Terminal Bays: The terminal bays are intended primarily for the administration of private-line telegraph service and contain jack circuits for patching and testing subscriber loops as well as directly associated equipment.

   A telegraph loop terminal bay contains either a test lower unit similar to that at a line bay or a shelf for mounting a teletypewriter. Above these is a jack field, consisting of various arrangements of 3, 4, 5, 6, 7, or 8 jack TLT circuits as well as interposition trunks and miscellaneous jacks. Above the jack field are telegraph relays and sounder and relays associated with the telegraph loop terminals. These relays operate under control of manual telegraph subscribers over their loops and are used to call in an attendant.

   In addition to the normal functions of the TLT positions, those particular positions in which the telegraph repeaters, assigned to teletypewriter switchboard ringdown, intertoll trunks, and automatic signaling trunks are terminated, are equipped with additional testing facilities. As these facilities test the teletypewriter switchboard circuits, they vary in design according to the type of switchboard.

The test lower unit equipment provides for the following:

1. Current and bias measurements in telegraph lines and loops.

2. Voltmeter tests to check continuity, voltages, polarities, loop leakage, and busy conditions on trunks.

3. Operating tests, that is, monitoring and communication with telegraph key and sounder or with teletypewriter.

4. Telephone communication with teletypewriter subscribers and with attendants in a distant office.

5. Telegraph communication with attendants in a distant office.

6. Teletypewriter orientation range scale measurements on associated teletypewriter.

Testing equipment not located in the testboard bays, but terminating there, provides facilities for making the following tests:

1. Hit indication on lines.

2. Transmission measuring.

3. Stability testing.

4. Loop current indicating.

To permit making transmission tests, sources of teletypewriter signals, biased and unbiased, and reversals signals, etc., are provided.

Means are also available whereby a testboard attendant at the line positions can associate a meter at the loop pad bay with any 130-volt subscriber loop arranged for inverse neutral operation in order to observe the current flowing in the loop. The attendant at the loop pad bay may then observe, and by means of the associated loop pad potentiometer, adjust the current to the proper value.

Several applications of jacks in the line bays and telegraph loop terminal bays are shown in Figure 19-16.

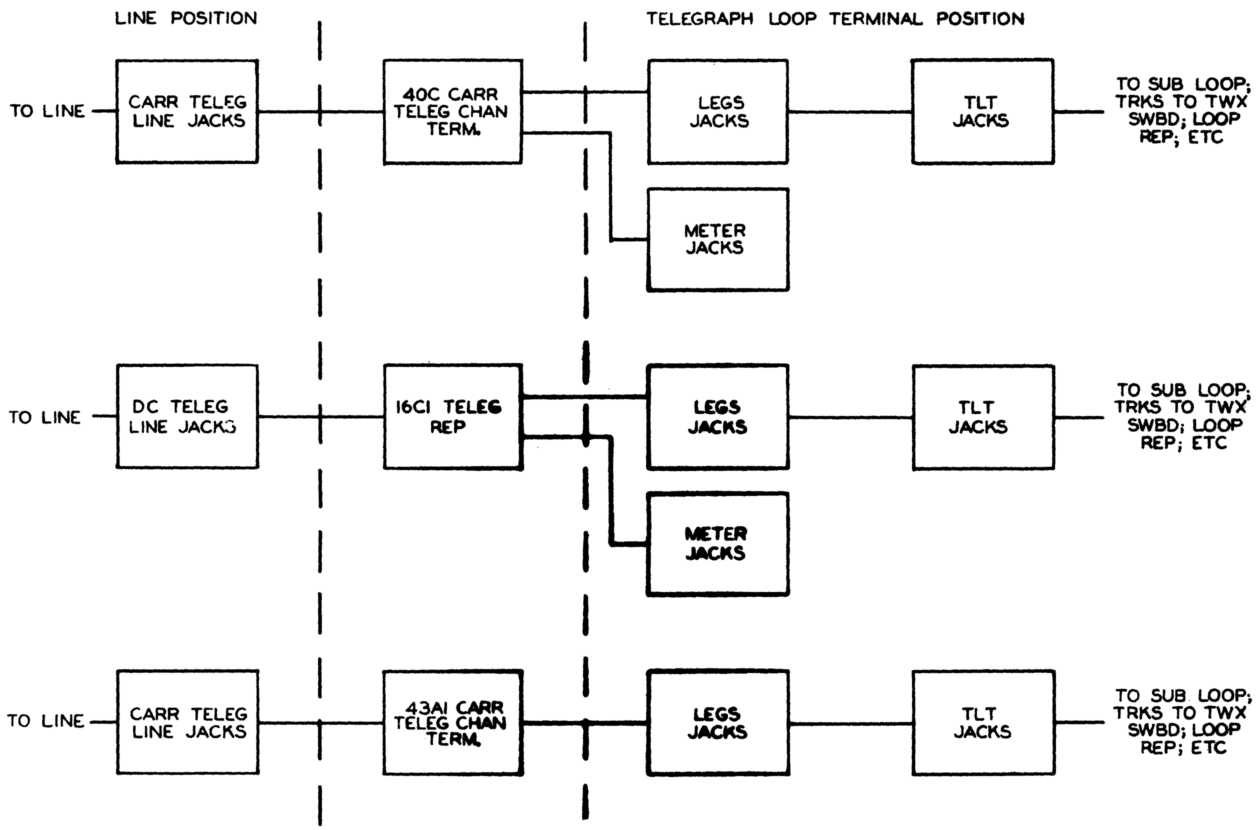


Figure 19-16 Typical Uses of Jack Circuits at Telegraph Testboard

19.5 LOCAL TESTING

A. GENERAL

Local testing facilities are furnished for the maintenance of all types of central offices, as well as the associated outside plant equipment. The testing methods used will vary in technique, from manually controlled tests to automatically controlled tests, depending upon the type and vintage of equipment being tested.

While the names of frames, cabinets and desks used for local testing would make a rather long list, only three types have been selected for discussion in this chapter. These three types of test facilities use nearly all of the techniques that would be found in a completed study of the local testing field. The testing facilities covered herein are the No. 14 local test desk, the master test frame (No. 5 crossbar), and the line insulation test frame.

B. NO. 14 LOCAL TEST DESK

The No. 14 local test desk is designed as a universal desk for use in all systems, manual, panel, step-by-step, and crossbar. The No. 14 local test desk is also universal in that it can be used on either a local or centralized basis, predominantly for outside of plant equipment. Also one test center can be arranged to serve any combination of offices.

The physical appearance of a local test desk is similar to a switchboard in that each position has a key and plug shelf, writing space and face equipment with 10-1/4 inch panels. See Figure 19-17. A number of positions may be located side by side forming a line-up.

The local test center, test desk, repair service desk and desks for supervision, are usually located in the same building, but in a separate room from the switching equipment. Local test centers may be furnished on a one per building basis; however, in metropolitan areas where the local office buildings are close together, the test centers may be furnished on a centralized basis. In centralized testing the local test center serves the building it is located in as well as a number of nearby buildings, with resultant savings in space, equipment and personnel.

The various tests are made under control of keys in the keyshelf. The connection to the line under test is obtained by single ended cords that are plugged into test trunks located in the face equipment. The cords are for the primary test circuit, secondary test circuit, and WHEATSTONE BRIDGE test circuit. An overlap exists between the test functions of the primary and secondary test circuits; each will perform some tests not performed by the other circuit as well as some of the same tests. The type of functions common to both test circuits are means of establishing connections to subscribers' lines, talking, monitoring, and ringing. By operation of the reverse key, the association of the primary and secondary cords to the primary and secondary test circuits can be reversed, except for the howler which is only associated with the secondary test cord.

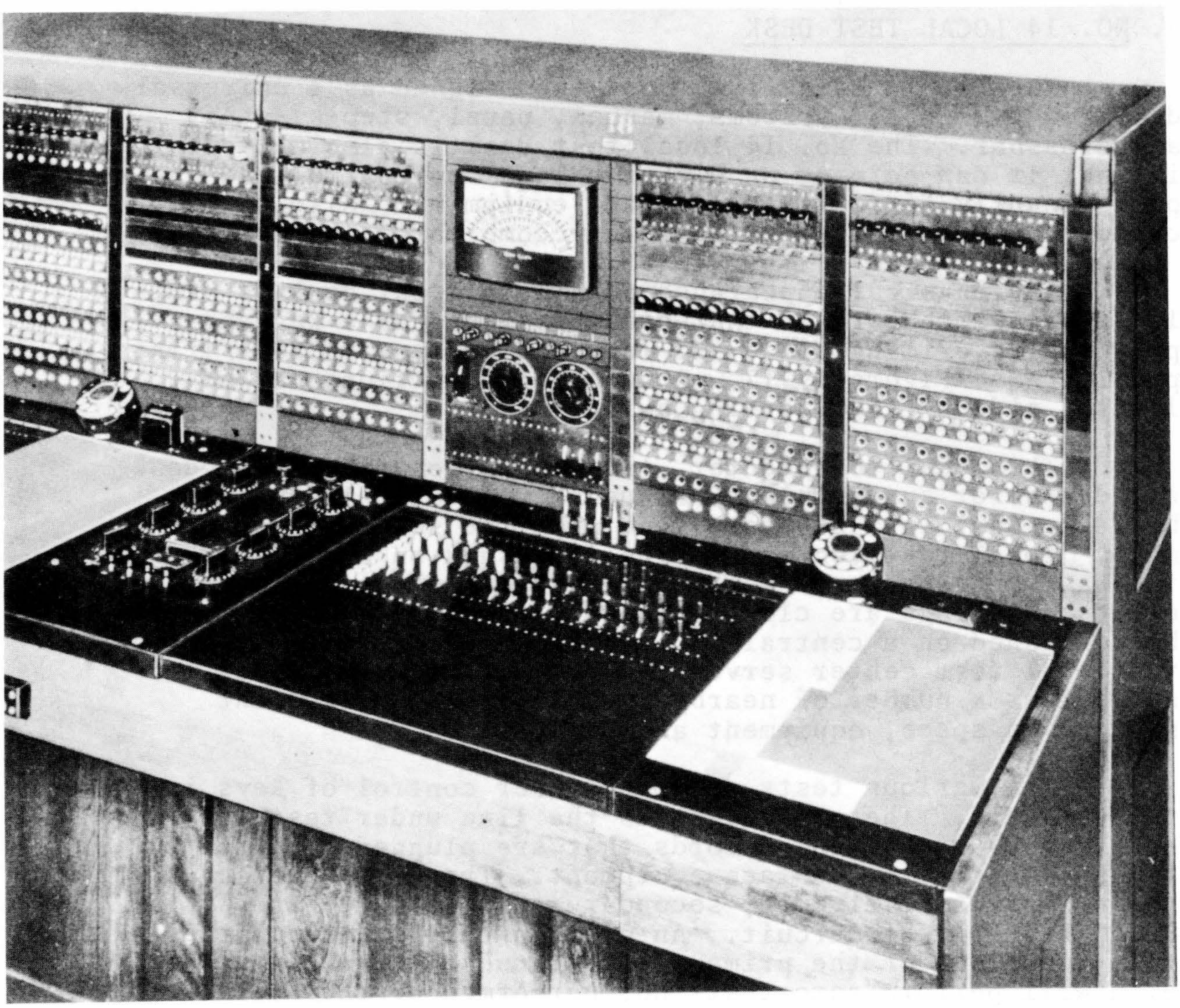


Figure 19-17 No. 14 Local Test Desk Test Position

The test trunks, which appear in the face equipment, test trunks to the MDF, in and out test trunks, intermittent trouble, wheatstone bridge test trunks, etc., terminate on distributing frames. The personnel working at the local test desk instruct the maintenance personnel what cross-connections are to be set up between test trunks and other lines or trunks. Communication between the testman and the local distributing frame is by a loudspeaker system. Call circuits and talking trunks are furnished for communication with other maintenance locations and operators at switchboards or toll testboards. The keys for controlling these talking connections are located in the top of the face equipment and multipled through the line-up but not necessarily on a position basis. The test center may also serve alarm receiving equipment and a teletypewriter for recording details of line failure from the line insulation test frame.

C. MASTER TEST FRAME

The testing facilities for mechanical switching offices have undergone evolutionary development to keep pace with the development of the switching systems. The present day facilities incorporate a considerable degree of automatic as well as manual testing techniques. For purposes of illustration in the text the master test frame of the No. 5 crossbar office will be discussed. This test frame incorporates procedures and techniques common to test frames of other switching systems, such as trouble indicator, trouble recorder, and sender test frames.

Practically all of the maintenance facilities in a No. 5 crossbar office are concentrated in several bays of equipment, known as the master test frame. This frame, together with other maintenance facilities, is located in a part of the office called the maintenance center. This center is usually located near the major common control frames, such as markers, senders and registers, to facilitate cabling and maintenance.

The principle maintenance functions performed by the master test frame are:

1. Automatically records, on punched cards, troubles encountered on service calls and equipment used on test calls.

2. Tests nearly all of the major circuits in the office.

3. Automatically monitors the pulsing performance of registers and senders during service and test calls.

4. Acts as a central control and observation point for the office.

The equipment of the master test frame consists primarily of a trouble recorder on automatic monitor, a master test circuit, and a jack bay for outgoing trunks. During unattended periods the alarms may be extended to a distant office.

D. LINE INSULATION TEST FRAME

The line insulation test equipment is arranged to operate on an automatic basis to disclose defects in cable, cable terminals, drop wire, and inside wire which may eventually affect subscriber service. The tests are controlled either by the local maintenance force or by remote control from a local test center. The test control circuit connects the test circuit successively to the subscriber lines skipping busy lines and other lines which may produce false indications or cause service interference. The test equipment stops automatically upon completion of the test cycle or when the traffic load in the office requires the use of the equipment temporarily assigned for line insulation testing. When the test control equipment locates a line that fails to meet the test condition, a record is made of the line and the test condition under which the line failed. Line locations are successively generated in the test control circuit for connecting the test circuit to the line. Any line that is found busy as well as lines assigned to toll trunks, dial PBX, test lines or other uses which would give a false trouble indication or service interference are skipped by the line insulation test control circuit. The speed of testing is approximately 12,000 lines per hour. The line insulation test frame can be started by operating keys at the test frame or from the local test desk through the test trunk and selector circuit. Access to the line link frames of crossbar offices is obtained through one of the marker multiples and the no test connector. Access to the lines of step-by-step offices is obtained through the test distributor and test connector.

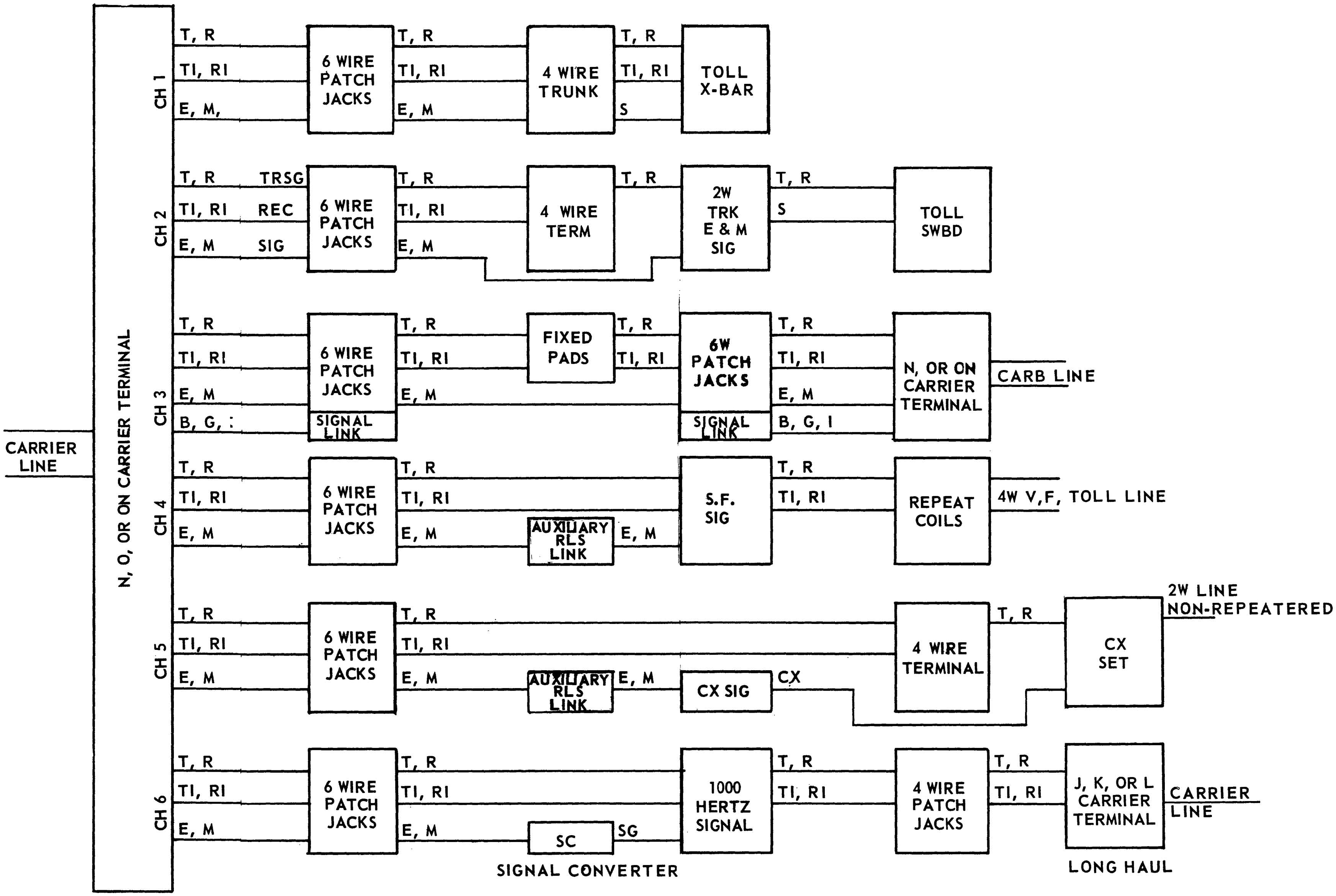


Figure 19-18 Connections at a Six-Wire Voice Frequency Patch Bay

19.6 VOICE FREQUENCY PATCHING BAYS

The voice frequency (V.F.) side of the various short-haul carrier systems may connect through six-wire voice frequency patch jacks to the assigned V.F. facilities. At the six-wire (6W) patch jacks, access to the carrier channel equipment and the V.F. equipment, or the segregation of the two equipments, may be made. The six-wire voice frequency patch bay provides a centralized monitoring, level measuring, signal testing, and patching position for the carrier system.

Figure 19-18 shows a block schematic of the connections of various types of V.F. equipment through 6W patch jacks to a carrier system. The connections as shown, illustrates the variation of facility assignment to a carrier system and does not represent a typical assignment. Channel 1 provides a line circuit for a trunk connecting to a toll crossbar switching system. Channel 2 provides a line circuit for a trunk connecting to a toll switchboard. Channel 3 shows a through connection from one carrier system to Channel 1 of another carrier system. Fixed pads, which are part of the six-wire patch bay equipment, are used to adjust the output level of one carrier system to the input level of the other carrier system. Signal link jacks and lamps, and a turn-over in the cross connection of E and M leads, are necessary to connect the signaling leads of one system to the signaling leads of the other system. Channel 4 is connected through to a 4W toll line, which is arranged for single-frequency signaling at the distant end. The toll terminal equipment necessary to connect to the carrier system is also indicated. Channel 5 is a similar arrangement that connects to a 2W V.F. line, which is arranged for composite signaling at the distant end. Channel 6 is a through connection to a carrier system which does not have built-in signaling. Toll terminal signaling equipment is provided on the J, K, and L carrier system.

Four-wire terminating sets or hybrids are provided in the channel units of the short-haul carrier systems. When the carrier system is connected through 6W patch jacks, the terminating sets or hybrids are not used.

The 6W patch bay monitoring and test equipment is shown in Figure 19-19. A voice frequency amplifier and telephone set are provided for monitoring and talking on carrier channels and for use with order wires and local trunks that are provided at the 6W patch bay. A common transmission and noise measuring system is provided per line-up or group of bays and a 1000 Hertz, one milliwatt, signal is provided as a standard level test signal. A Transmission Measuring Set (T.M.S.) circuit that contains position control relays, an amplifier-rectifier, and a projection type DB meter is used to measure a change in level of the MW signal after it has been transmitted through either the carrier facility or the V.F. facility. A patch to DEM OUT (Demodulator Out) and MOD IN (Modulator In) jacks disconnects the carrier channel from the V.F. facility and provides a test connection to the carrier channel. A patch to EQ OUT (Equalizer Out) and EQ IN (Equalizer In) jacks disconnects the V.F. facility from the carrier facility and provides a test connection to the V.F. facility. An auxiliary T.M.S. meter, under the control of a key, may be provided at the location of the carrier equipment. With it, levels adjustments may be made on the carrier equipment while the results are observed on the meter. Additional patch and test jacks, for program equipment assigned to carrier channels, may be provided at the 6W patch bay. These jacks are cross connected to the two-wire V.F. program equipment so that level measurements may be at this point. Reversing of the program equipment may be controlled by a test jack at the 6W patch bay. Testing of the channel or V.F. signaling circuits, and spare signaling circuits terminated on jacks at the 6W patch bays, is accomplished by the use of portable signal test sets. Signal test battery supplies are provided at the bays.

Although the foregoing deals with the 6 wire Voice Frequency Patch Bay other patching bays exist such as the 4 wire V.F. Patch Bay, which is similar but doesn't use the E & M lead (signaling) jacks. High-frequency patch bays are used at intermediate or end points in carrier systems as the voice-frequency is only modulated in steps up to the line frequency.

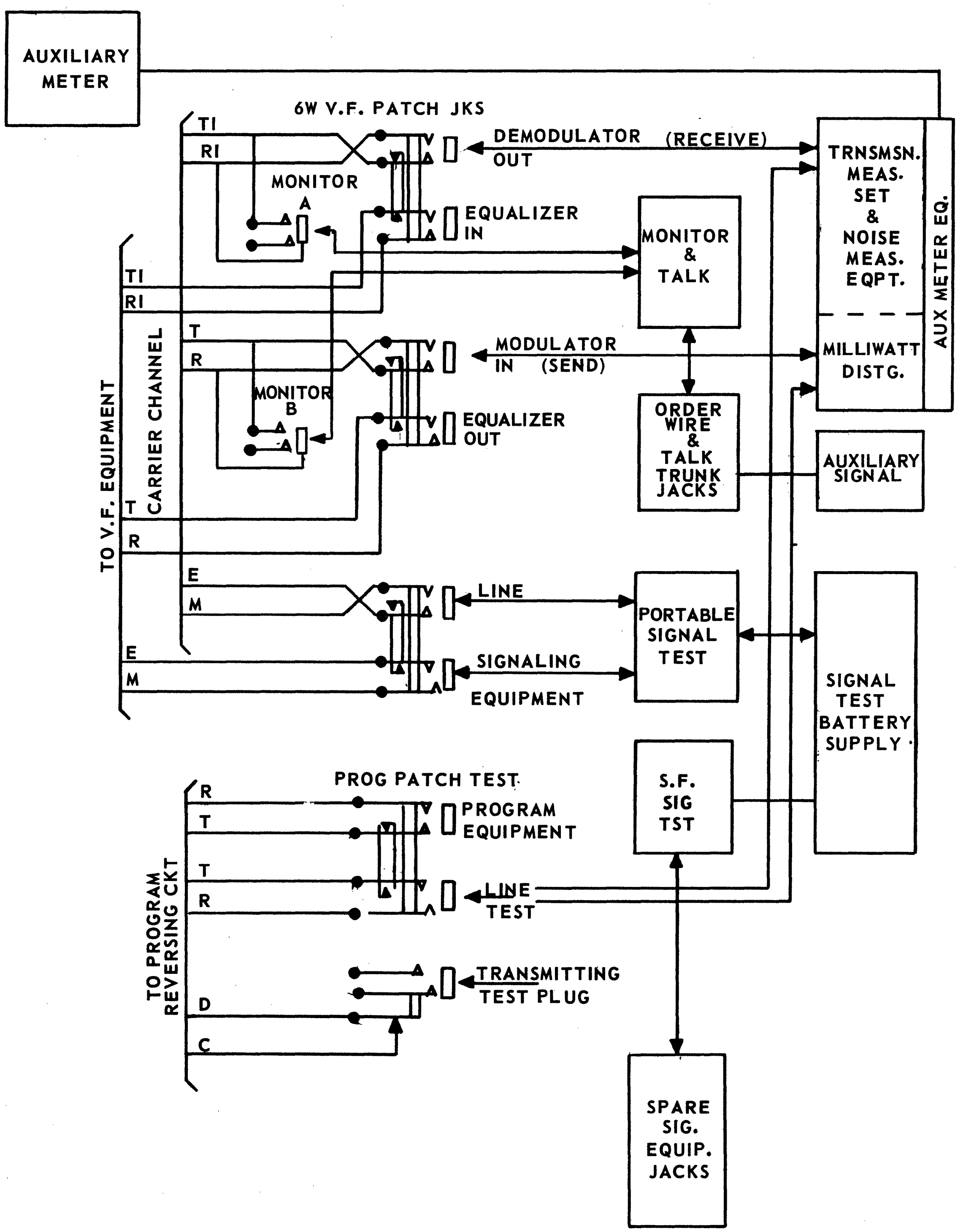


Figure 19-19 Test Equipment at a 6 Wire Voice Frequency Patch Bay

Western Electric