1995 HEAD/MEDIA TECHNOLOGY REVIEW
CONFERENCE SUMMARY

November 11-12
Stardust Resort and Casino
Las Vegas, Nevada

Presented by:
Peripheral Research Corporation
Don Mann Magnetics

Head/Media Technology Review

November, 1995

To: All *1995 Head/Media Technology Review* Attendees:

From: Dennis Waid, Peripheral Research Corporation
Don Mann, Don Mann Magnetics, Inc.

We wish to thank you for your attendance and participation at the *1995 Head/Media Technology Review.* This year's conference will be similar to last year's conference and will again include a Saturday afternoon session covering removable storage. We are pleased with the support of this event and plan to continue to include this session.

For those of you who take the time and complete the evaluation forms, thank you, and we will try to incorporate as many of your suggestions as possible into next year's conference.

The 12th Annual *Head/Media Technology Review* will be held on Saturday and Sunday, November 9-10, 1996 in the Trianon Ballroom of the Stardust Resort and Casino in Las Vegas, Nevada. This year's conference sold out early; please mark your calendars and make your reservations several months prior to the event date.

Copies of presentations that we received after the original printing of this conference summary, are available near the entrance of the conference room. Please feel free to contact us if you have any questions or comments.

Dennis Waid	Don Mann
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AGENDA

1995 HEAD/MEDIA TECHNOLOGY REVIEW

SATURDAY SESSION

12:00 **REGISTRATION**

12:30 **WELCOME AND INTRODUCTIONS**

12:35 **MARKET OVERVIEW**
Removable Data Storage Markets
Dennis Waid, President
Peripheral Research Corporation

High-Performance Subsystem Overview
Kent Winton, Director Systems Storage Division
IBM

1:00 **NEW AND EMERGING STORAGE TECHNOLOGIES**
Dennis Waid, President
Peripheral Research Corporation

High Performance Subsystems
David Skinner
Intellistor

New and Emerging Technologies--Removable Storage
Gailen Vick, Vice President Marketing
Avatar Corporation

Around the World of Tape in 1000 Seconds
Greg Ormsbee, Product Marketing Manager
Tandberg Data

New Directions: Removable Flash Storage
Leon Malmed, Senior Vice President Marketing/Sales
SanDisk Corporation

2:30 **PANEL DISCUSSION**

3:15 **BREAK**

AGENDA

1995 HEAD/MEDIA TECHNOLOGY REVIEW

SATURDAY SESSION (CONTINUED)

3:45 **ENABLING TECHNOLOGIES**
Don Mann, President
Don Mann Magnetics

Thin Film Tape Heads
Arun Malhotra, Senior Vice President and Chief Operating Officer
Aiwa R&D Inc.

Removable Media Storage--IC Issues
Alan Morton, Applications Manager
Silicon Systems, Inc.

Next Generation Optical Disk Format
Arjen Bouwman, Director of Marketing, MMCD
Philips Consumer Electronics

Head/Media Test Technology
Gerald Juskovic,- Senior Product Manager
LeCroy Corporation

Polarization Interferometer for Flying Height Testers
Robert Smythe, Director of Marketing & Sales
Zygo

5:15 **PANEL DISCUSSION,** With Above Speakers Plus:
Tim Perkins, Consultant; Hewlett-Packard
David James, Test Systems Marketing Manager; Xyratex

6:00 **ADJOURN**

AGENDA

1995 HEAD/MEDIA TECHNOLOGY REVIEW

SUNDAY SESSION

8:30 **INTRODUCTION**

8:35 **MARKET OVERVIEW AND COMPONENT TRENDS**
Dennis Waid, President
Peripheral Research Corporation

Revolution Happens
Allen Cuccio, President
Storage System Consultants

9:00 **TECHNOLOGY DIRECTIONS**
Don Mann, President
Don Mann Magnetics

Evolution of MR Media Technology
Dan Parker, Senior MR R&D Engineer
StorMedia

Future for Carbon Media
Takashi Ishii, Director, Recording and Imaging Science Laboratory*
Kao Corporation

Spindle Technology Update
Richard Prins, President
Synektron

Drive Contamination Revealed
James Smith, - Manager, Chemical Integration & Adv. Tribology
Conner Peripherals

Digital Channel for TF Inductive Head
Toan Doan, Director, R&D and Enabling Technology
Maxtor Corporation

10:45 **BREAK**

AGENDA

1995 HEAD/MEDIA TECHNOLOGY REVIEW

SUNDAY SESSION (CONTINUED)

11:15 **TEST TECHNOLOGY**
Don Mann, President
Don Mann Magnetics

Digitized PRML Test
Koichi Hatakeyama, VP of Engineering
Nihon Techno Bute Limited

Laser Based Test Technology
Ian Freeman, Chief Technical Officer
THoT Technology

11:45 **PANEL DISCUSSION,** With Above Speakers Plus:
Don Perettie, Senior Development Scientist; Dow Chemical

12:30 **LUNCH**

1:15 **LUNCHEON SPEAKER**
Arthur Zafiropoulo, President
Ultratech Stepper

2:00 **MAGNETIC HEAD TECHNOLOGY AND DIRECTIONS**
Dennis Waid, President
Peripheral Research Corporation

Double-MIG for Over 1GB/Platter
Frank Shiraki, Senior Sales Manager
Hitachi Metals America

MR Heads: A Basic Disk Drive Component Technology
Robert Scranton, Director of Magnetic Head Development
IBM, Storage Systems Division
and
The Case for Inductive Heads
David Danson, VP Engineering, Heads and Media
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Automated Suspension RSA Measure and Adjust
Jay Robinson, Director of Engineering
KR Precision

AGENDA

1995 HEAD/MEDIA TECHNOLOGY REVIEW

SUNDAY SESSION (CONTINUED)

3:15 <u>**PANEL DISCUSSION,**</u> With Above Speakers plus:
Wayne Fortun, President; Hutchinson Technology
Jaffa Tomkiewicz, VP Recording Heads Group; Quantum Corp.
Steve Lockard, Director of Marketing; ADFlex Solutions, Inc.

3:45 **BREAK**

4:15 **ADVANCED TECHNOLOGY SESSION**
Dennis Waid, President
Peripheral Research Corporation

Implementation of MR Heads in Drive Design
Aric Menon, Vice President Engineering
Seagate Technology

Dual Stripe MR Technology
Tracy Scott, Vice President Development
Headway Technologies

Tri-Pad Technology and Future of Inductive Recording
Yiao-Tee Hsia, Director of Advanced Mechanical Design
Read-Rite Corporation

Vertical MR Head
Yutaka Soda, Manager, MR Devices Section, Magnetic Devices
Sony Corporation

5:15 <u>**PANEL DISCUSSION,**</u> With Above Speakers Plus:
David Markle, Marketing Director; Ultratech Stepper
Peter Clark, President; Sputtered Films
Lamar Nix, Director of Development, Recording Heads; Quantum
Joichiro Ezaki, Executive Director; TDK Corporation

5:45 **CONCLUSION AND ADJOURN**

6:00 **EXHIBITS AND RECEPTION**
Robert Haavind, Editorial Director/Publisher
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MAXTOR CORP.
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MAXTOR CORP.
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MAXTOR CORP.
MARTY MCGOUGH

MAXTOR CORP
TONY MONTE

MAXTOR CORP.
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MAXTOR CORP
CHRISTINE PHENICIE

MAXTOR CORP.
JOHN PURKETT

MAXTOR CORP.
BRAD SCHULTZ

MAXTOR CORP.
JUAN SIFONTES

MAXTOR CORP.
DAVID SKINNER

MAXTOR CORP.
TEO CHIN TEN THOMAS

MAXTOR CORP.
DEBBIE TROUP

MAXTOR CORP.
JEFF WHALEY

MAXTOR CORP.
DAVID WHITAKER

MAXTOR CORP.
HAO ZHOU

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K. K. KIM

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MEKTEC CORP.
MINORU IDEURA

MHC-MAGNETIC HEADS CO.
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FIROUZ FELFELI

MICROPOLIS CORPORATION
DON BRUNNETT

MICROPOLIS CORPORATION
KOK-KIA CHEW

MICROPOLIS CORPORATION
ERIC DUNSTAN

MICROPOLIS CORPORATION
DEVA RAMASWAMY

MICROPOLIS CORPORATION
DAVE TERRILL

MICROPOLIS CORPORATION
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MINEBEA CO., LTD.
AKIHIRO HIRAO

MINEBEA CO, LTD.
AKINOBU SANO

MITSUBISHI CHEMICAL
RYOICHI HARADA

MITSUBISHI CHEMICAL
KAZUNAGA KOMIZO

MITSUBISHI CHEMICAL
TOSHIKI MATSUNAGA

MITSUBISHI CHEMICAL AMERICA, INC.
ZENJIRO CHIBA

MITSUBISHI CHEMICAL AMERICA, INC.
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MITSUMI ELECTRIC
SHIGERU ARAMAKI

MONTGOMERY SECURITIES
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MR CONSULTING GROUP INTERNATIONAL
MARTY HORN

MYRICA
NEAL DARRAGH

MYRICA UK. LTD.
TONY COMBE

MYRICA UK. LTD.
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MYRICA UK. LTD.
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NORIO HORIE

NHK
KOJI UOZUMI

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KAZUYA MATSUSHIMA

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NIMIC, INC -- JAPAN ENERGY CORP.
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NITTO DENKO AMERICA, INC.
VLADIMIR ALEKSIC

NITTO DENKO AMERICA, INC.
JAY NAKAMURA

NMB TECHNOLOGIES INC.
DAVID BOWE

NMB TECHNOLOGIES - RDD
ED PACKARD

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MARC FROUIN

NORTON COMPANY
ROBIN MAHAR

NORTON COMPANY
JEFF MCCARTNEY

OPTICAL SYSTEMS CORPORATION
WILLIAM MCBAIN

PERIPHERAL COMPUTER SUPPORT
BEN DAVIDSON

PERIPHERAL RESEARCH
JASON GOLZ

PERIPHERAL RESEARCH CORPORATION
GARY DAVIS

PERIPHERAL RESEARCH CORPORATION
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VLASTA CEJNA

PHASE METRICS
ART CORMIER

PHASE METRICS
WAYNE ERICKSON

PHASE METRICS
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PHASE METRICS
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PHASE METRICS
BERT MUNNIKHUIS

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ALLAN NAGY

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STEVE PENNIMAN

PHASE METRICS
VLAD POGREBINSKY

PHASE METRICS
MIKE ROGOWSKI

PHASE METRICS
JOHN SCHAEFER

PHASE METRICS
RICK SHELOR

PHILIPS CONSUMER ELECTRONICS B.V.
ARJEN BOUWMAN

QUANTUM
TERRY BURRIS

QUANTUM
MANCHI COLAH

QUANTUM
MICHAEL COLLVER

QUANTUM
RONALD DUBOIS

QUANTUM
BRYAN FONTAINE

QUANTUM
MICHAEL HANLEY

QUANTUM
BERT HIBBERD

QUANTUM
DENNIS METTE

QUANTUM
DZUY NGO

QUANTUM
TUAN NGUYEN

QUANTUM
WES SLIMICK

QUANTUM
ROBERT TEMPERO

QUANTUM
LARRY TOOMBS

QUANTUM
PAUL WEBB

QUANTUM
JIM WILSHIRE

QUANTUM CORP.
JUKKA AILIO

QUANTUM CORP
GLEN KOSAKA

QUANTUM CORP.
JOHN KOVACH

QUANTUM CORP
MARSHALL LEE

QUANTUM CORP.
JOSEPH MUELLER

QUANTUM CORP.
MARV NORMAN

QUANTUM CORP.
KEN PELOWSKI

QUANTUM CORP.
RICK PRIJATEL

QUANTUM CORP
BRYAN ROBERTSON

QUANTUM CORP.
SUSAN TONG

QUANTUM CORP.
DAVID WHEELER

QUANTUM CORP.
EARL WIGGINS

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SUNITA YADAV

QUANTUM CORP.
KEN ZARRABI

QUANTUM CORPORATION
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GUNTHER BAUBOCK

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QUANTUM CORPORATION
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QUANTUM CORPORATION
BERNIE HUTH

QUANTUM CORPORATION
AL KUBITZ

QUANTUM CORPORATION
KEN LEE

QUANTUM CORPORATION
JOSH LINDSAY

QUANTUM CORPORATION
CHRIS MARSHALL

QUANTUM CORPORATION
THANH NGUYEN

QUANTUM CORPORATION
BRIAN NIXON

QUANTUM CORPORATION
TERRY OFTEDAL

QUANTUM CORPORATION
MICHAEL PEEK

QUANTUM CORPORATION
BILLY PETTIT

QUANTUM CORPORATION
GEORGE RANIUK

QUANTUM CORPORATION
DON REDINIUS

QUANTUM CORPORATION
TIM RIENER

QUANTUM CORPORATION
LEO RIVERA

QUANTUM CORPORATION
BILL ROBBINETTE

QUANTUM CORPORATION
CHITRA SESHAN

QUANTUM CORPORATION
JOHN SQUIRE

QUANTUM CORPORATION
MARK STEINBACK

QUANTUM CORPORATION
DAVE SUTTON

QUANTUM CORPORATION
PAT TAN

QUANTUM CORPORATION
BILL THANOS

QUANTUM CORPORATION
YAFFA TOMKIEWICZ

QUANTUM CORPORATION
LARRY WILLSON

QUANTUM PERIPHERALS COLORADO INC.
KIRAN CHOPRA

QUANTUM PERIPHERALS COLORADO,INC.
LAMAR NIX

QUANTUM PERIPHERALS COLORADO INC.
TIM STUCCHI

RAYCHEM
TONY EVANS

READ-RITE
TOM HARRIS

READ-RITE
DONALD LAM

READ-RITE
DEREK YEO

READ-RITE CORPORATION
JENNY ARBOGAST

READ-RITE CORPORATION
ROBERT BONAVITO

READ-RITE CORPORATION
CHARLES BOND

READ-RITE CORPORATION
MIKE BREMSTELLER

READ-RITE CORPORATION
CRAIG COCCHI

READ-RITE CORPORATION
GREG FENNER

READ-RITE CORPORATION
STEVE FOWLER

READ-RITE CORPORATION
BRENDA FOX

READ-RITE CORPORATION
MIKE GAMBLE

READ-RITE CORPORATION
MARK GORDON

READ-RITE CORPORATION
MURRAY HARRIS

READ-RITE CORPORATION
LORI HOLLAND

READ-RITE CORPORATION
YIAO-TEE HSIA

READ-RITE CORPORATION
BRIAN JACOBS

READ-RITE CORPORATION
JAMES KANO

READ-RITE CORPORATION
JOHN KAVANAGH

READ-RITE CORPORATION
TOM KEMP

READ-RITE CORPORATION
CHAK LEUNG

READ-RITE CORPORATION
TOM LITTLE

READ-RITE CORPORATION
ALAN LOWE

READ-RITE CORPORATION
NEIL MOTISKA

READ-RITE CORPORATION
JIM MURPHY

READ-RITE CORPORATION
DOUG PEREYDA

READ-RITE CORPORATION
SCOTT PERRY

READ-RITE CORPORATION
DAVE RAUCH

READ-RITE CORPORATION
VERN RIEDLIN

READ-RITE CORPORATION
ROBERT ROTTMAYER

READ-RITE CORPORATION
PAUL SCHADE

READ-RITE CORPORATION
DAN SCHOTT

READ-RITE CORPORATION
YONG SHEN

READ-RITE CORPORATION
ERIC SLADEK

READ-RITE CORPORATION
STEVE STONE

READ-RITE CORPORATION
ROSS STOVALL

READ-RITE CORPORATION
LES THOMAS

READ-RITE CORPORATION
TUAN TRAN

READ-RITE CORPORATION
ANN WALKER

READ-RITE CORPORATION
JEFF WINSOR

READ-RITE CORPORATION
CYRIL YANSOUNI

READ-RITE CORPORATION
ZIA ZAHIRI

READ-RITE CORPORATION
MOURAD ZARDURI

READ-RITE SMI CORPORATION
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SHIRLEY MERSING

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ROUSH ANATROL, INC.
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LING CHOW

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WAI-HUNG NG

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SAE MAGNETICS
KAM WING WONG

SAMSUNG
AUDREY CHAO

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SAMSUNG ADVANCED INSTITUTE OF
IN EUNG KIM

SAMSUNG ADVANCED INSTITUTE OF
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SAMSUNG ADVANCED INSTITUTE OF
KY OOK PARK

SAMSUNG ELECTRONICS
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SAMSUNG ELECTRONICS
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SAN JOSE TECHNOLOGY
TOM STEIBER

SANYO ELECTRONIC COMPONENTS CO.
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SEAGATE TECHNOLOGY
PAT BONNIE

SEAGATE TECHNOLOGY
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SEAGATE TECHNOLOGY
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LONNIE FALLOON

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TIM GALLAGHER

SEAGATE TECHNOLOGY
PETER GOGLIA

SEAGATE TECHNOLOGY
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TOM HAYES

SEAGATE TECHNOLOGY
BRENDAN HEGARTY

SEAGATE TECHNOLOGY
GORDON HUGHES

SEAGATE TECHNOLOGY
GERRY HUMPHREY

SEAGATE TECHNOLOGY
MARK JURSICH

SEAGATE TECHNOLOGY
JEFFREY LA CROIX

SEAGATE TECHNOLOGY
JASON LI

SEAGATE TECHNOLOGY
GERALD LOPATIN

SEAGATE TECHNOLOGY
STEPHEN LUCZO

SEAGATE TECHNOLOGY
ARIC MENON

SEAGATE TECHNOLOGY
CRAIG METHEANY

SEAGATE TECHNOLOGY
EDDY MILANES

SEAGATE TECHNOLOGY
ERIC MILLER

SEAGATE TECHNOLOGY
GENE MILLIGAN

SEAGATE TECHNOLOGY
GARY MORKE

SEAGATE TECHNOLOGY
WARREN MYERS

SEAGATE TECHNOLOGY
VLAD NOVOTNY

SEAGATE TECHNOLOGY
BARRY ROSSUM

SEAGATE TECHNOLOGY
IAN SANDERS

SEAGATE TECHNOLOGY
ALAN SAUNDERS

SEAGATE TECHNOLOGY
MARK SCHAENZER

SEAGATE TECHNOLOGY
JOHN SPANGLER

SEAGATE TECHNOLOGY
DAVE SWABASH

SEAGATE TECHNOLOGY
MARK TROUTMAN

SEAGATE TECHNOLOGY
FRED VASCONCELOS

SEAGATE TECHNOLOGY
RONALD D. VERDOORN

SEAGATE TECHNOLOGY
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IAN FLEMING

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HIROSHI TAMURA

SHOWA DENKO K.K
KUNIO IZUMIYA

SHOWA DENKO K.K.
HIROSHI SAKAI

SHOWA DENKO K.K.
KAZUKI YOKO O

SIEMENS-NIXDORF
JOHANNES PLUCKROSS

SILICON SYSTEMS
STEVE FINCH

SILICON SYSTEMS
PETER MAIMONE

SILICON SYSTEMS, INC.
DAVID LACOMBE

SILICON SYSTEMS, INC.
ALAN MORTON

SILICON SYSTEMS, INC.
TIM WARD

SILMAG
ROBERTO GEMI

SINGLETRACK ENGINEERING
GEORGE POE

SONY CORPORATION
TAKEO ITO

SONY CORPORATION
YUTAKA SODA

SPECTRA-PHYSICS
TERRY ERISMAN

SPEEDFAM
BERT BENTLEY

SPEEDFAM
MARK HREDZAK

SPUTTERED FILMS, INC.
PETER CLARK

STORAGE SYSTEMS CONSULTANTS
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STORAGETEK
ROBERT RAYMOND

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DAN PARKER

STORMEDIA INC.
H. WARD HUANG

STORMEDIA, INC.
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STRATUS COMPUTER
DAVID COHEN

STRATUS COMPUTER
JOSEPH NEAZ

STRATUS COMPUTER
MARK POSSEMATO

SUMITOMO CORP OF AMERICA
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SUNCALL CORP.
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SUNCALL CORP.
TADAO OHTANI

SUNCALL CORPORATION
OSAMU KOMOTO

SUNDISK CORPORATION
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SUNWARD TECHNOLOGIES
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SUNWARD TECHNOLOGIES
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SUNWARD TECHNOLOGIES
MICHAEL GRUNDY

SUNWARD TECHNOLOGIES
RICK HIGASHARA

SUNWARD TECHNOLOGIES
H. S. KIM

SUNWARD TECHNOLOGIES
KEN MARTINI

SUNWARD TECHNOLOGIES
MICHELE MCSWAIN

SUNWARD TECHNOLOGIES
LANCE NELSON

SUNWARD TECHNOLOGIES
BOB SMITH

SUNWARD TECHNOLOGIES
RON VITULLO

SYNEKTRON
RICHARD PRINS

SYQUEST TECHNOLOGY
EFRAIM EYAL

TAE-IL
JIM SCHMIDT

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TANDON ASSOCIATES
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TANDON ASSOCIATES
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V.V. PATIL

TANDON ASSOCIATES
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MR. HAYASHI

TDK
MR. OYAMA

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TELETRAC
BARTON NORTON

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TEXAS INSTRUMENTS
RICARDO DOMINGUEZ

TEXAS INSTRUMENTS
ALLEN GIBBS

THIN SPIN
THOMAS BURNIECE

THIN SPIN
GIB SPRINGER

THIN SPIN
MARK SPRINGER

THOT TECHNOLOGIES
JIM ECKERMAN

THOT TECHNOLOGIES
IAN FREEMAN

TOSHIBA R&D CENTER, TOSHIBA CORP
JUN-ICHI AKIYAMA

TRACE STORAGE TECHNOLOGY
PHILIP YONG

TRACE STORAGE TECHNOLOGY USA CORP.
CHARLES DONG

TRACE STORAGE TECHNOLOGY USA CORP.
CHUNG-YU TING

TRACE USA
FRANK SHIAU

TRILOGY MAGNETICS, INC.
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TRILOGY MAGNETICS, INC.
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TRILOGY MAGNETICS, INC.
MIKE NERO

TULIP MEMORY SYSTEMS
RICHARD D. WEIR

TULIP MEMORY SYSTEMS, INC.
RICHARD S. WEIR

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FARIBA ABHARI

ULTRATECH STEPPER
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SUE BILLAT

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ULTRATECH STEPPER
ARTHUR ZAFIROPOULO

ULTRATECH STEPPER
KEVIN ZOLLINGER

ULTRATECH STEPPER INC.
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VANGUARD AUTOMATION, INC.
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VEECO
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W.L. GORE & ASSOCIATES, INC.
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ROBERT BRADFORD

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CARY CHEE

WESTERN DIGITAL
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ROBERT CROSS

WESTERN DIGITAL
ROBERT CUTLER

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WESTERN DIGITAL
CLYDE ELLIOTT

WESTERN DIGITAL
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WESTERN DIGITAL
KEITH GOODSON

WESTERN DIGITAL
BILL HALLETT

WESTERN DIGITAL
STEVE HUANG

WESTERN DIGITAL
YOO KIM

WESTERN DIGITAL
GOPAL KOTE

WESTERN DIGITAL
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MARC NUSSBAUM

WESTERN DIGITAL
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WESTERN DIGITAL
TOM PORTER

WESTERN DIGITAL
JOHN RAUEN

WESTERN DIGITAL
CHESTER SIEMBAB

WESTERN DIGITAL
STEVE SMITH

WESTERN DIGITAL
JEFF SNYDER

WESTERN DIGITAL
SNEHAL SUTARIA

WESTERN DIGITAL
WING TANG

WESTERN DIGITAL CORPORATION
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WALTER KEENE

WESTLAKE TECHNOLOGY CORPORATION
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MELANIE MCCLURKIN

WITTER PUBLISHING CORP.
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WYKO CORPORATION
ANTHONY MARTINEZ

WYKO CORPORATION
COLIN QUINN

WYKO CORPORATION
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XYRATEX
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YAMAHA CORP OF AMERICA
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STEVE SASAKURA

YAMAHA CORPORATION
ATSUSHI TOYODA

ZYGO
JOE WALLACE

ZYGO CORPORATION
ROBERT SMYTHE

REMOVABLE DATA STORAGE MARKETS

Dennis Waid

President

Peripheral Research Corporation

1995 Head/Media Technology Review

November 11, 12 1995

Stardust Hotel and Casino
Las Vegas, Nevada

1995 Head/Media Technology Review

Peripheral Research Corp.

Removable Data Storage Markers

(Units 000)

Product Type	1995	1996	1997	1998
Flash Memory	835.4	1,350.0	1,965.0	2,780.0
Flexible Disk Drives	70,659.0	72,465.0	75,040.0	77,246.0
Optical Disk Drives	35,320.0	46,271.4	58,584.3	67,845.7
Removable Cartridge Drives	4,272.2	5,572.2	7,252.2	9,237.2
Tape Drive Products:				
Quarter Inch	4,125.1	4,389.4	4,516.3	4,550.4
Half Inch	198.5	213.3	202.9	173.1
Helical Scan	959.9	1,027.8	1,064.3	1,044.9
Total Removable	116,370.1	131,289.1	148,625.0	162,877.3
Total Fixed	85.859.0	96,270.0	113,860.0	130,156.0
Grand Total	**202,229.1**	**227,559.1**	**262,485.0**	**293,033.3**

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Peripheral Research Corp.

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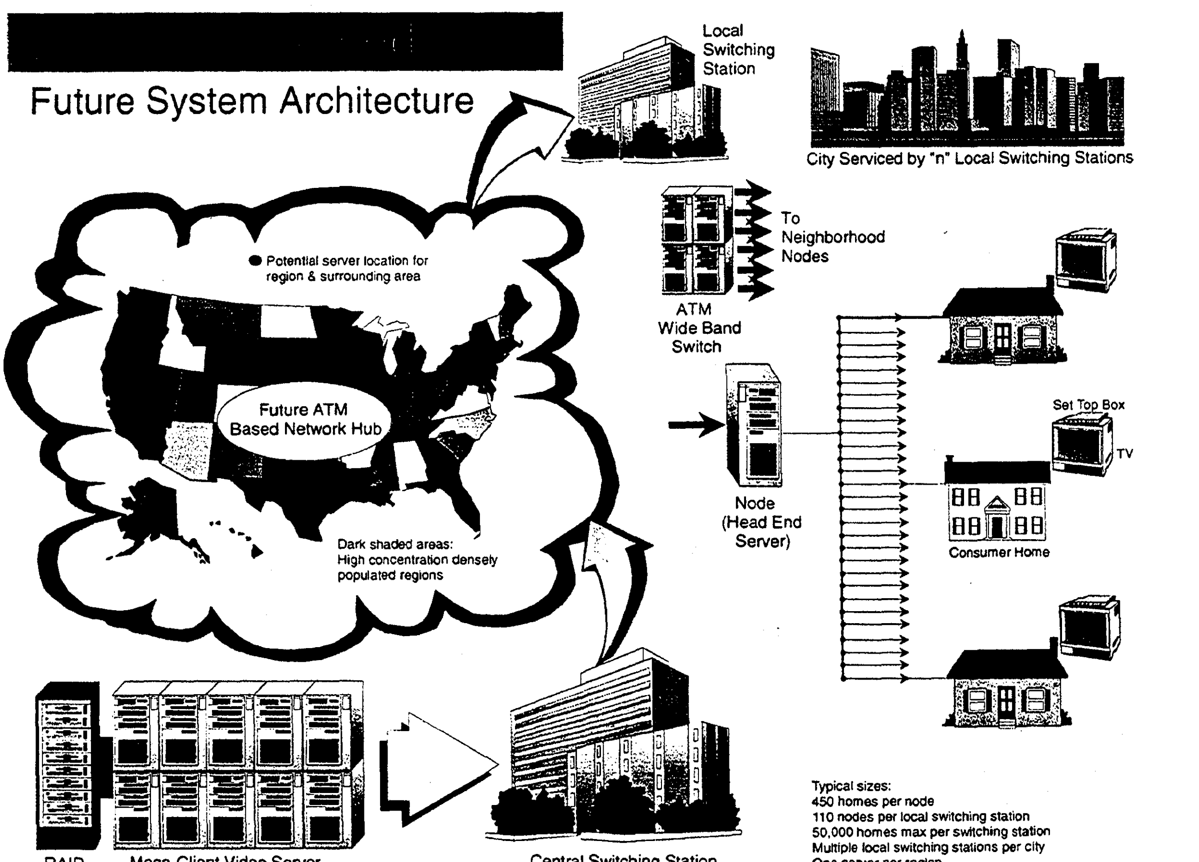
Removable Storage

- ◆ Removable Memory Markets Strong
- ◆ Technology Continues to Improve Zip, Jazz
- ◆ Newer Products Flash Memory
  - ✓ Compact Flash, Camera Applications
- ◆ PCMCIA Expanding
- ◆ Sub Notebooks Still Slow to Develop
- ◆ Optical Disk Looking Strong
- ◆ Digital Camera's, New Market
- ◆ Small Tape Drive Technology
- ◆ Video Games, Hotel



May, 1995

software associates

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TABLE
VIDEO SERVER SYSTEMS- INDUSTRIES AND ESTIMATES
(IN 000, NOT TIME FORECASTED)
1995-1999

INDUSTRY	MATURITY YEARS	GROWTH RATE**
Educational	3-4	L-M
Legal /Justice Sys.	2-3	L-M
Real Estate Mark.	2	M
Adult Entertainment	1	H
Hotel Entertainment	1-2	H
Hospitals	2-3	H
Residential	3-4	M-H
Corporate	2-3	M-H
Banking / Finance	2-3	M
Securities Industries	3	M
Consumer Malls	2-3	H
Government	2	L
Security Ind.	1-2	M

*Servers (000)
** L-10% year
M-25-35% year
H 40+% year

Products and Companies
Removable Technology Increasing

- Pioneering More New Markets
  - ✓Banking Financial
  - ✓Security Applications
  - ✓Airline Industry
  - ✓Hotel, Home T.V.
  - ✓Digital Camera Applications
  - ✓Video Games
- Newer Technologies
  - ✓Small Tape Products
  - ✓Personal Digital Assistants

Products and Companies

◆ Tape Drive Companies	20
✓ Quarter Inch Cartridge	11
✓ Half Inch Tape	6
✓ Helical Scan Tape	9
✓ Minicartridge Tape (Inc. Qtr. In.)	
✓ Other Tape	4
◆ Optical Drive Companies	60
✓ CD Rom Drives	39*
✓ Read Write < 1 GB	28*
✓ Read Write > 1 GB	9*
◆ Removable Disk	4
◆ Flexible Disk Drives	19

HIGH-PERFORMANCE SUBSYSTEM OVERVIEW

Cancelled at last minute.

Kent Winton

John

Director Systems Storage Division

IBM

HIGH-PERFORMANCE SUBSYSTEMS

David Skinner

Intellistor

NEW AND EMERGING TECHNOLOGIES
REMOVABLE STORAGE

Gailen Vick

Vice President Marketing & Sales

Avatar Corporation

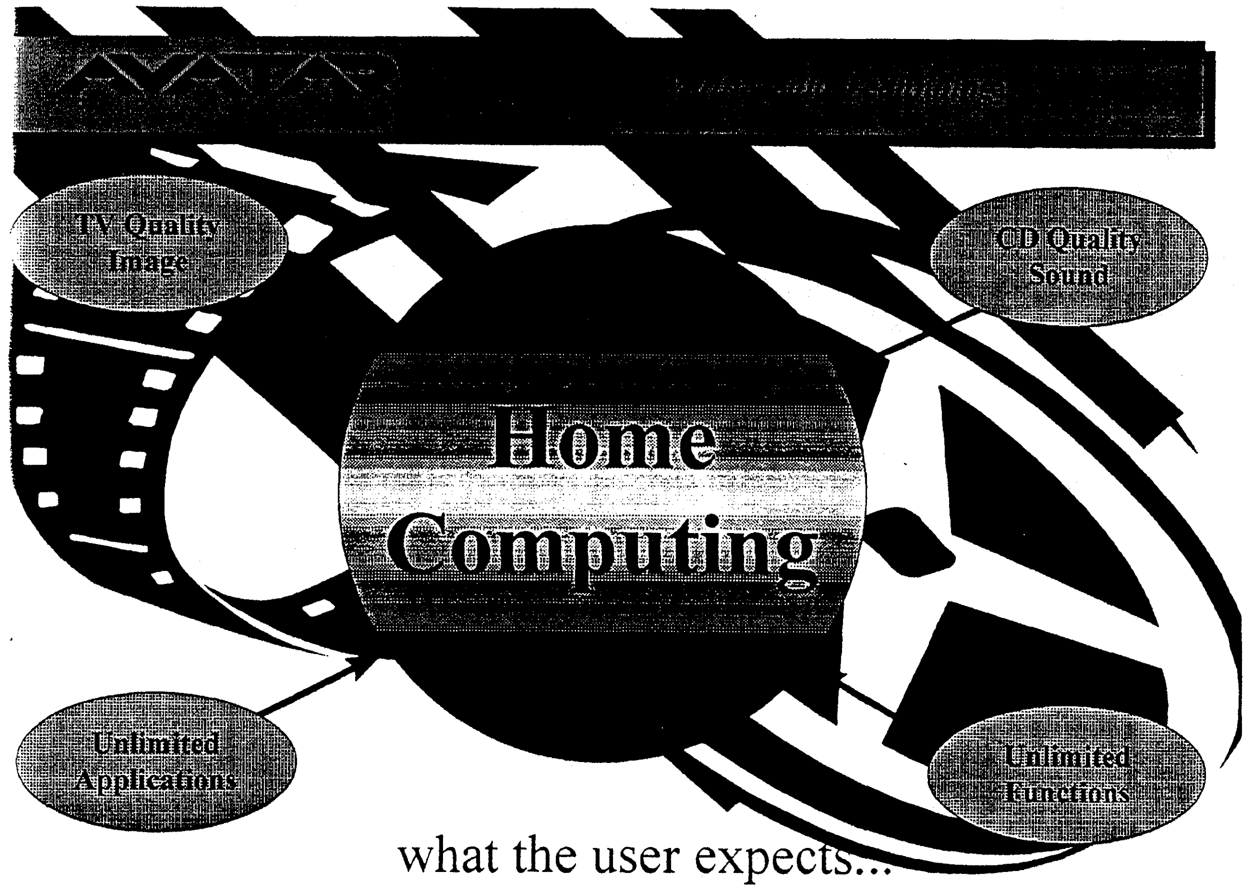
RIGID DISK HEAD/MEDIA TECHNOLOGY REVIEW

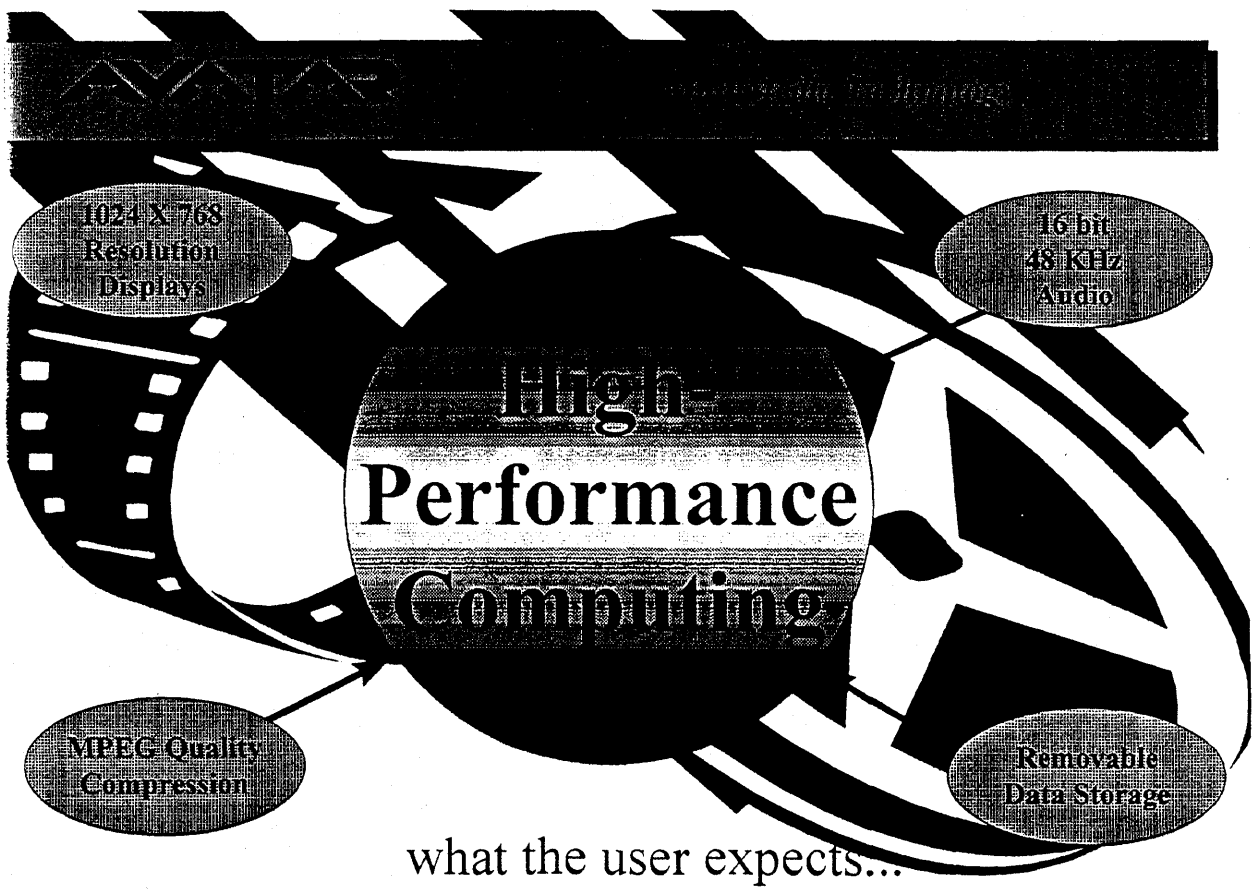
NEW AND EMERGING TECHNOLOGIES

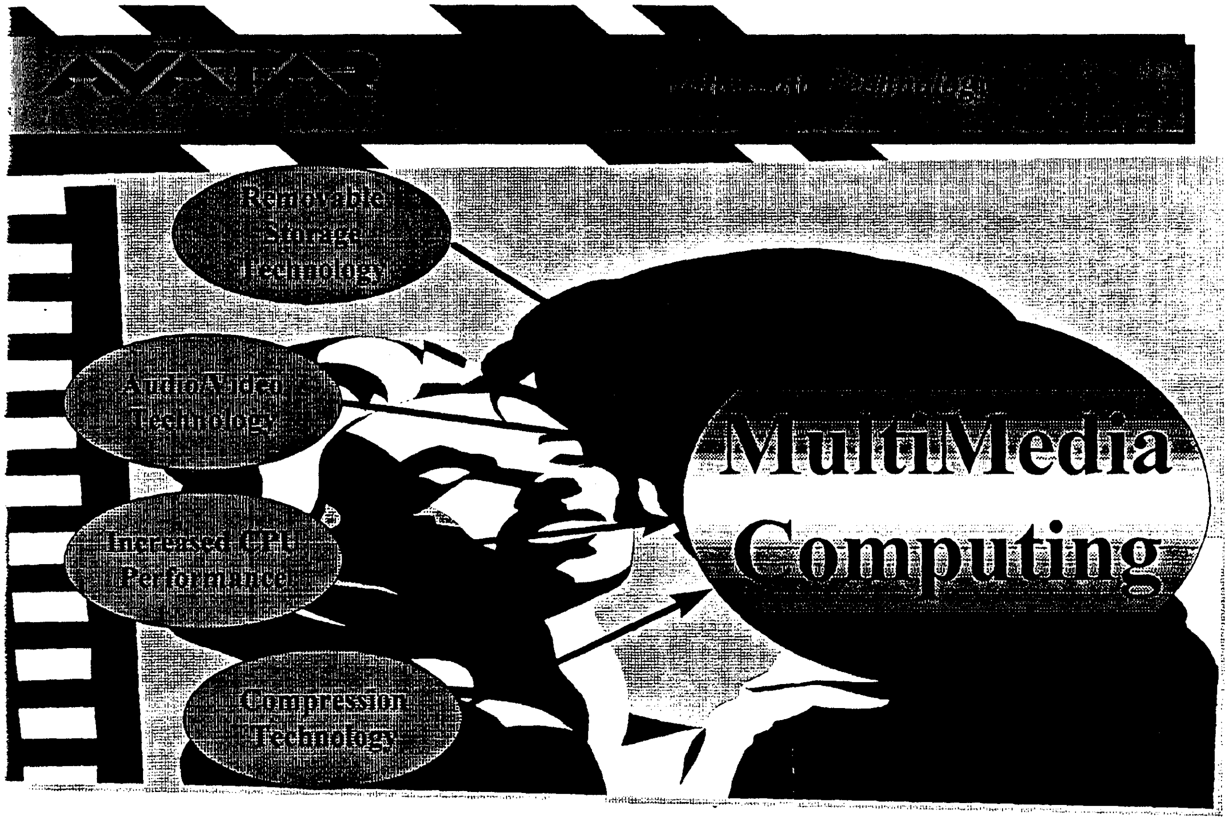
REMOVABLE STORAGE

by Gailen Vick

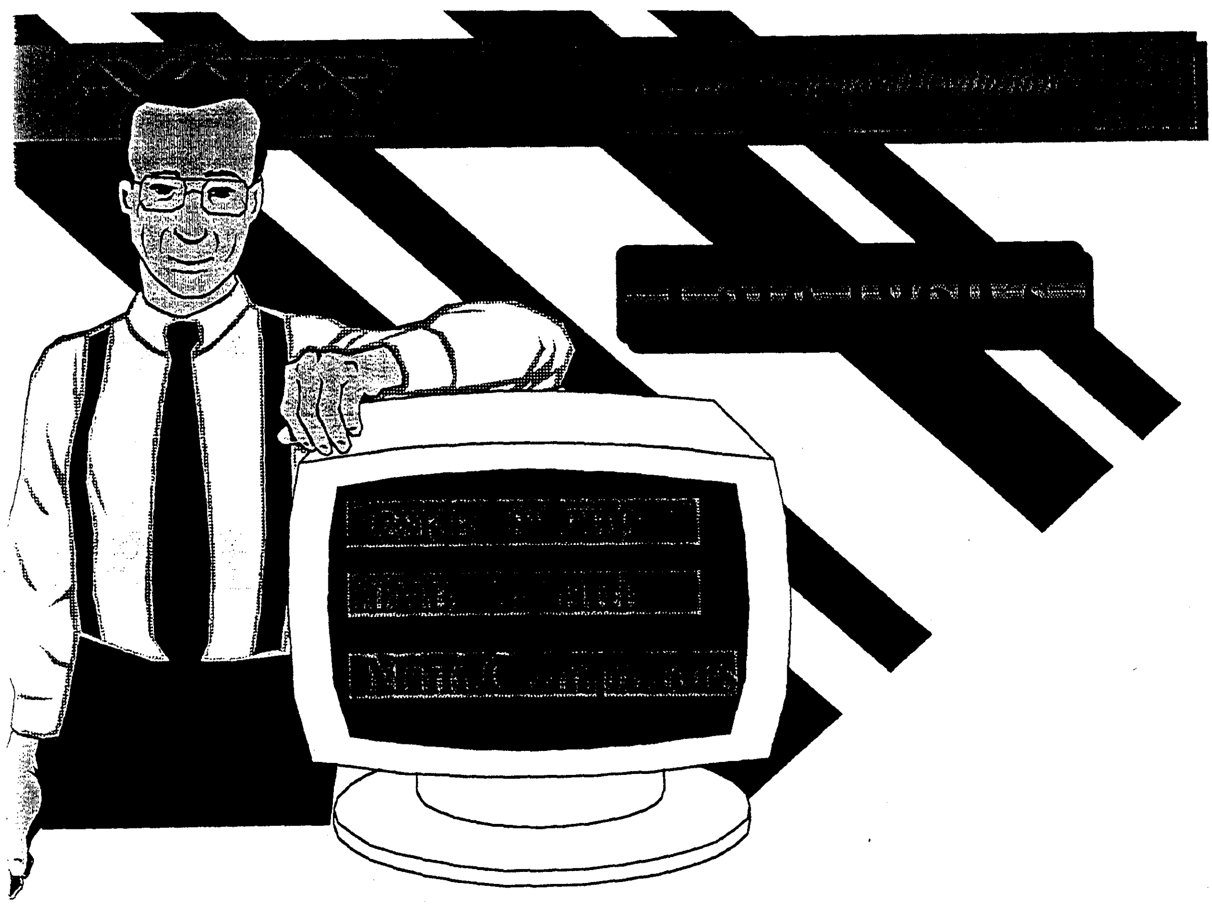
1995 Head/Media Technology Review

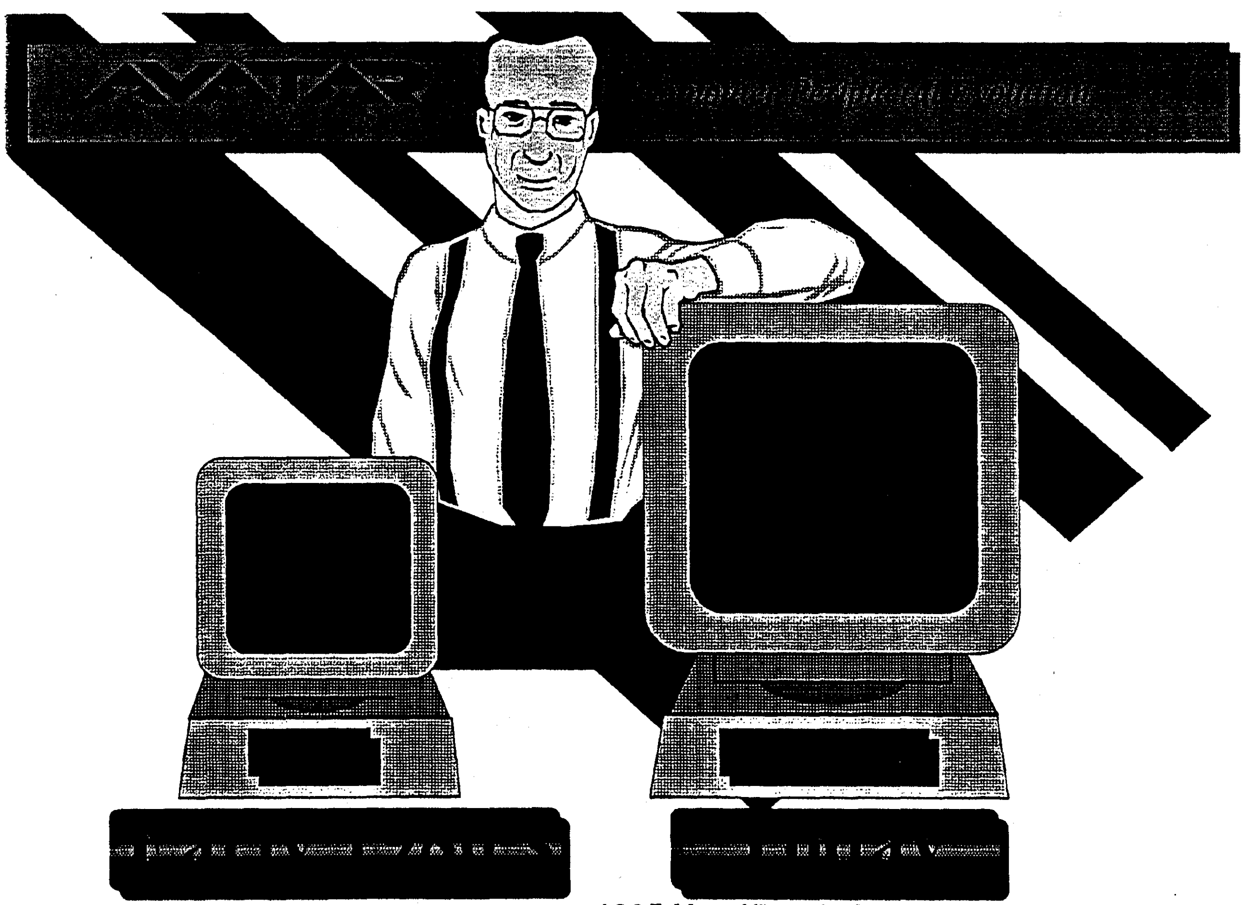

TV Quality
Image
CD Quality
Sound
Home
Computing
Unlimited
Applications
Unlimited
Functions
what the user expects...


1024 X 768
Resolution
Displays
16 bit
48 KHz
Audio
High-
Performance
Computing
MPEG Quality
Compression
Removable
Data Storage
what the user expects...

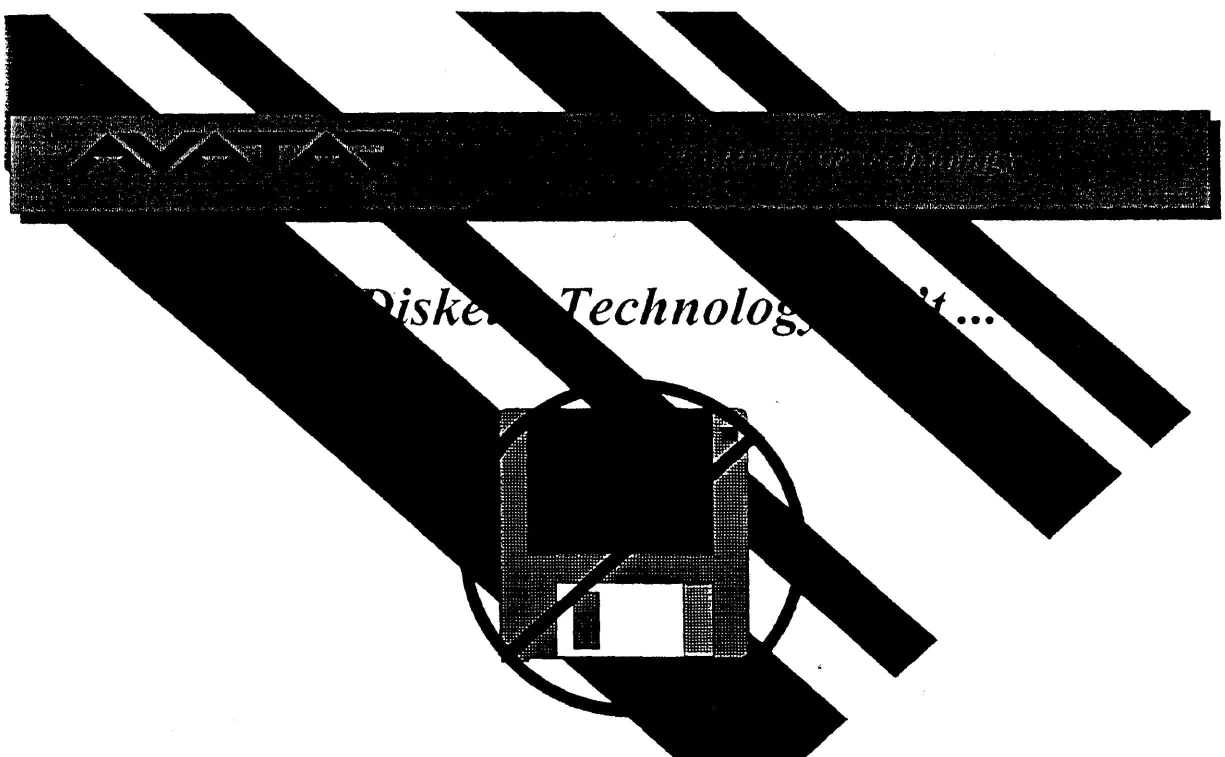


where technology takes computing...





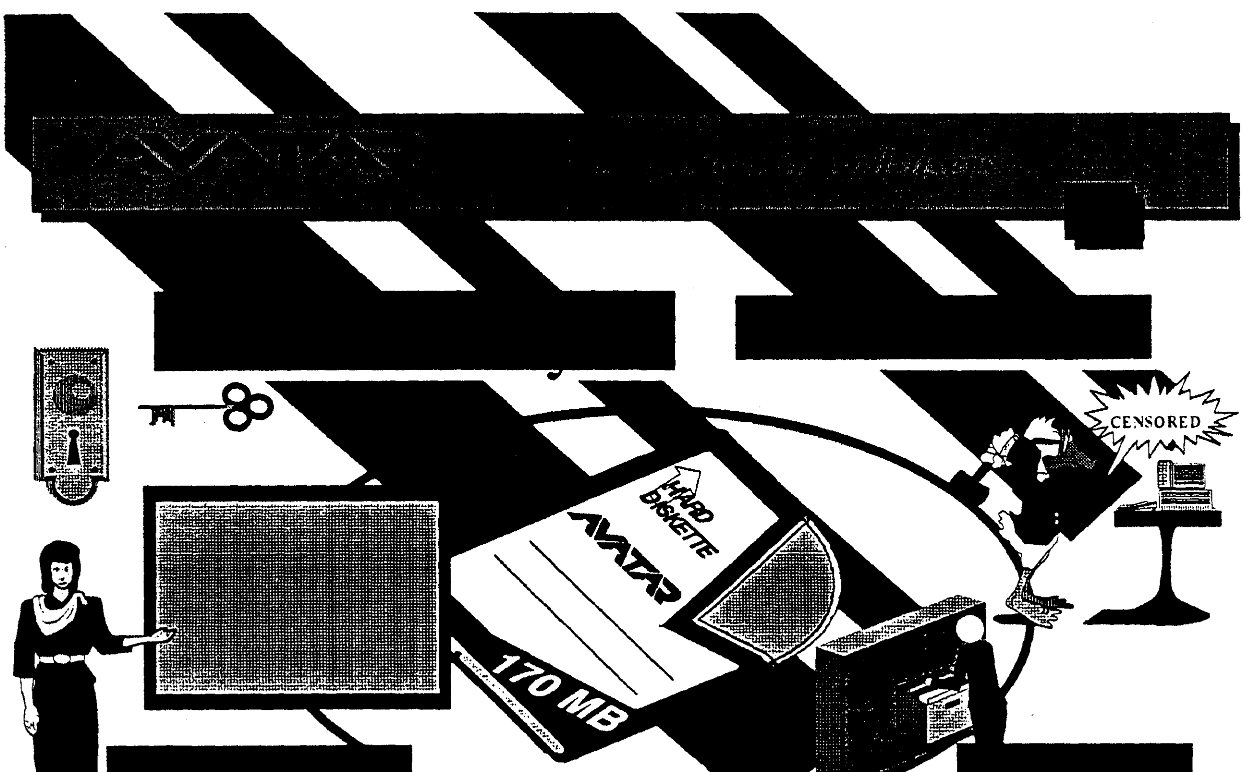
1995 Head/Media Technology Review

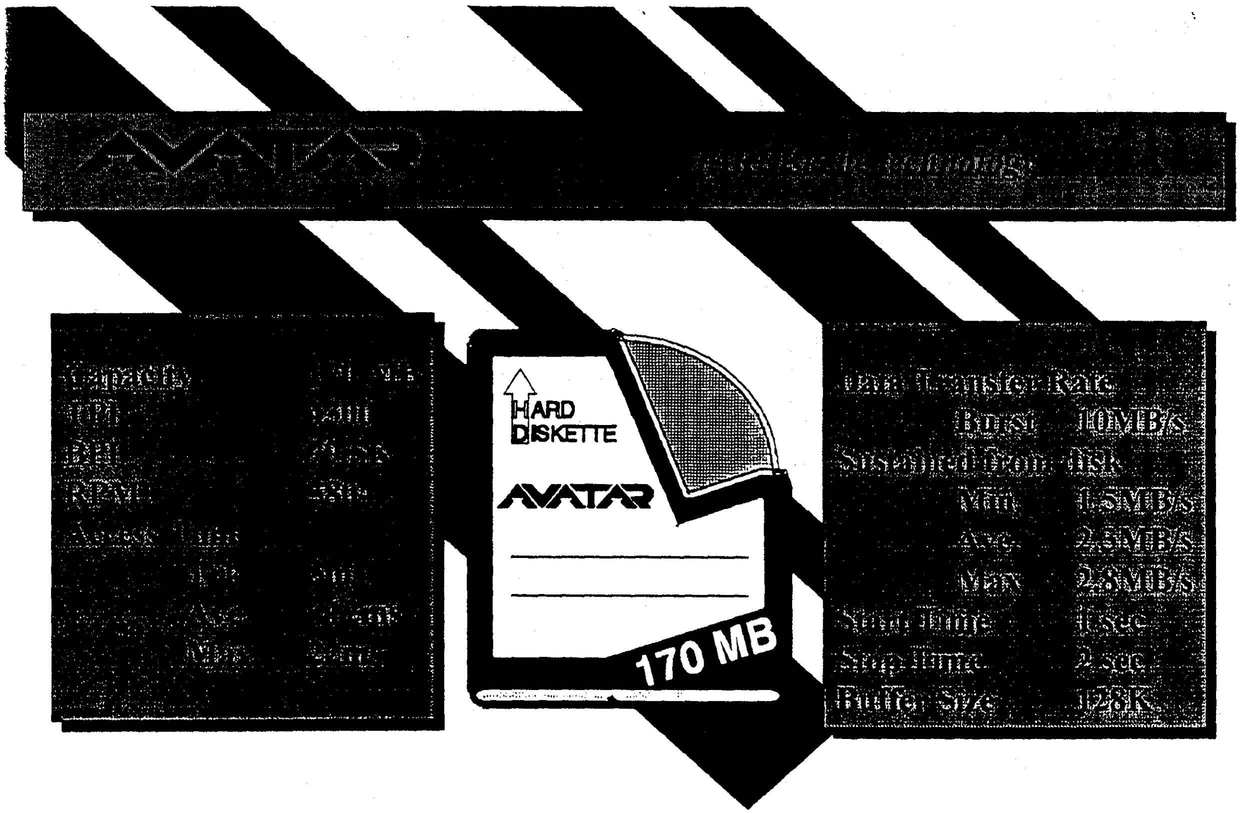


... a high-capacity 3.5” floppy

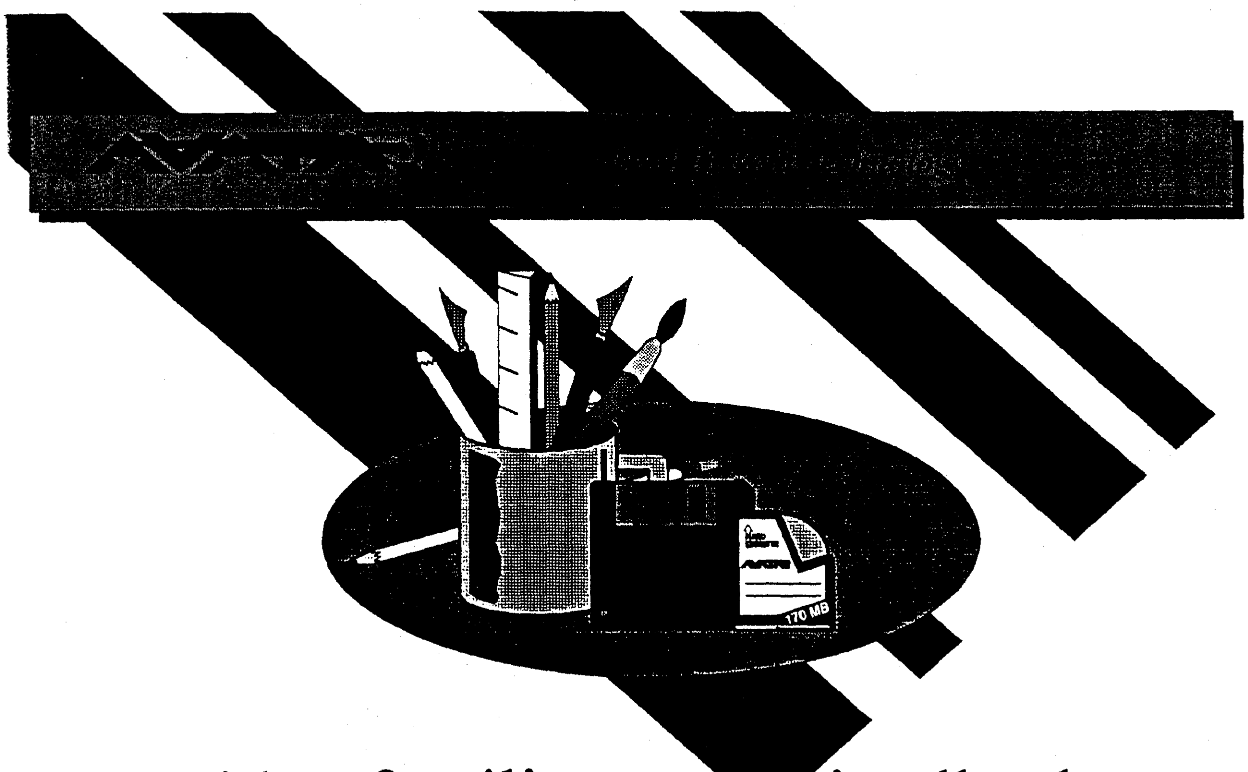
1995 Head/Media Technology Review

... a tape back-up replacement

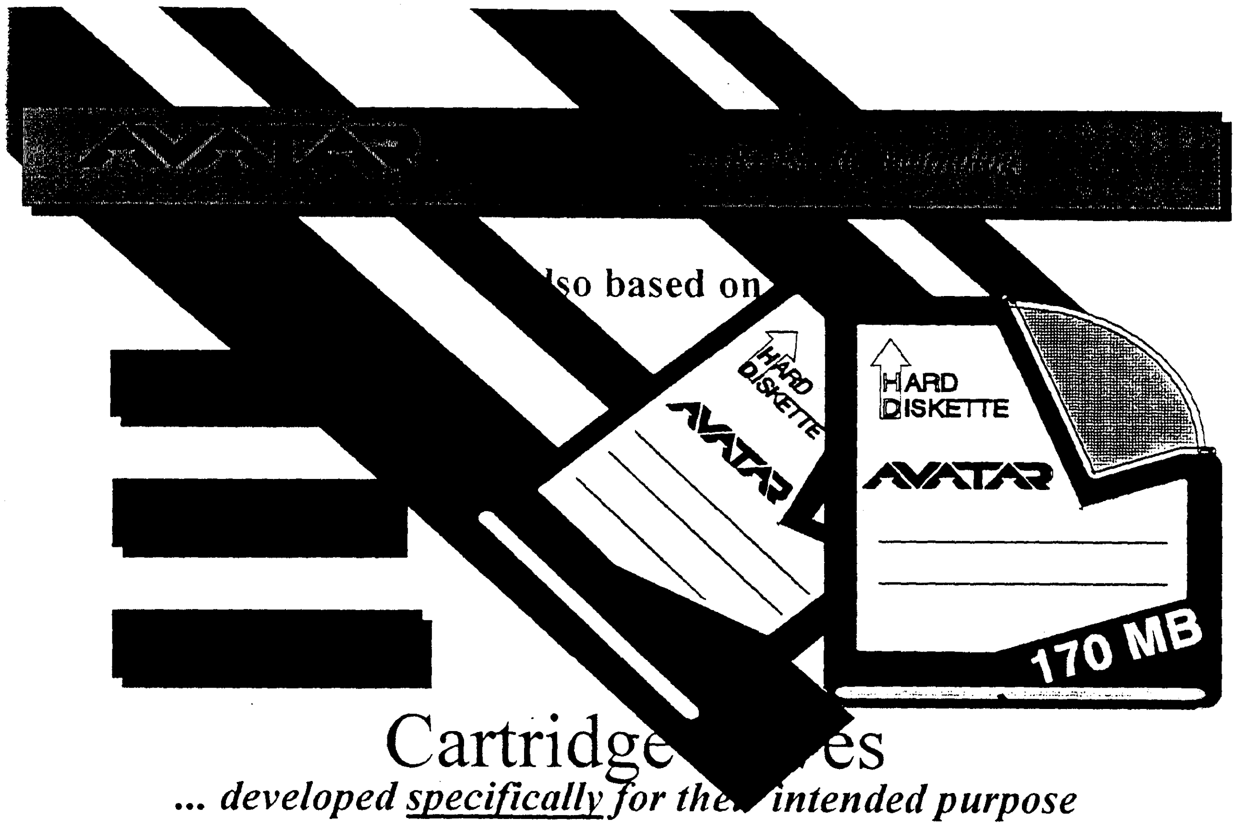

HARD DISKETTE
AVATAR
170 MB
CENSORED



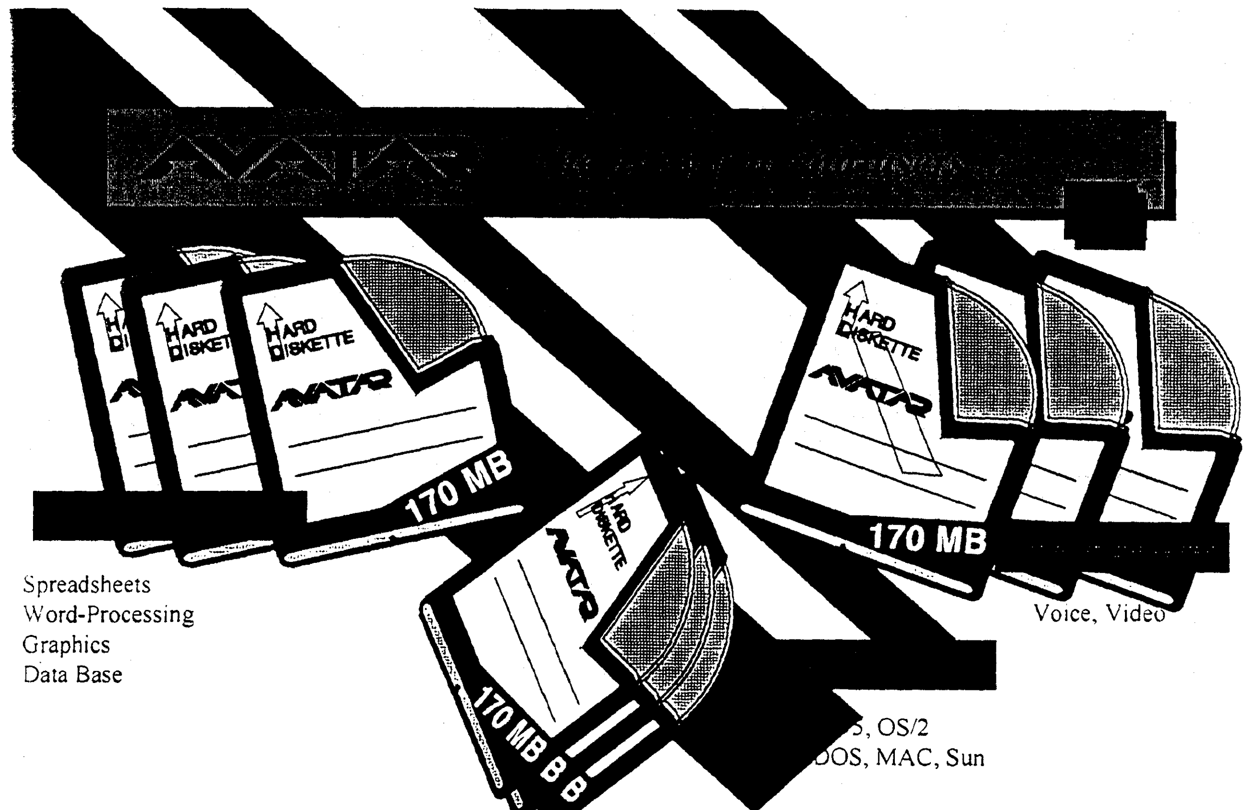
HARDiskette technology specifications



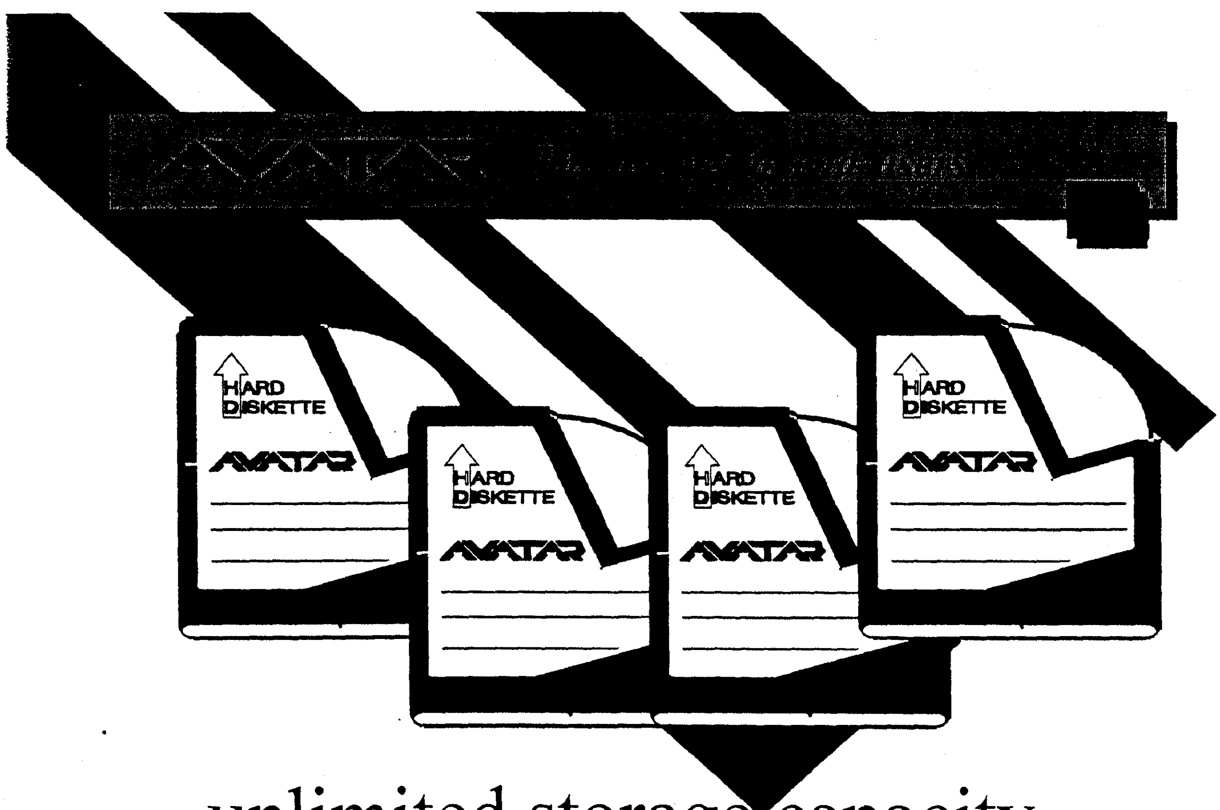
... with a familiar, user friendly shape


HARD DISKETTE
AVATAR
HARD DISKETTE
AVATAR
170 MB
Cartridge
... developed specifically for the
intended purpose

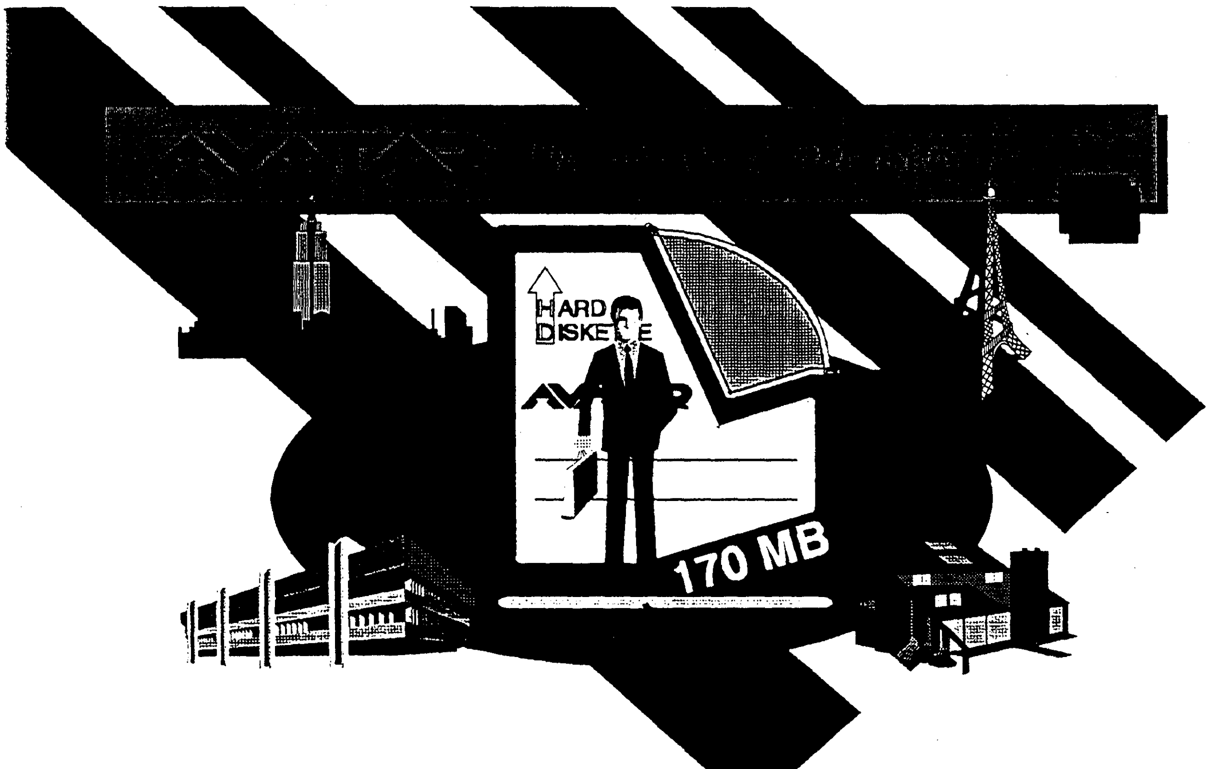

SYSTEMS CORPORATION
system



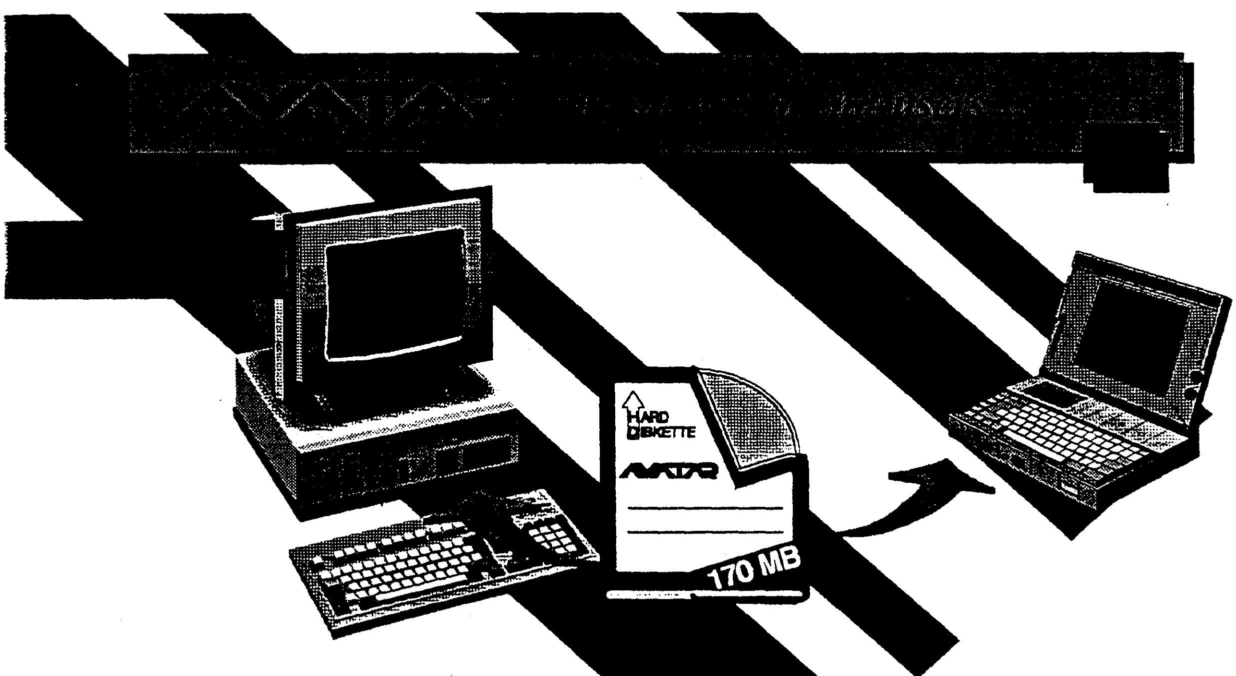
customized file segmentation...



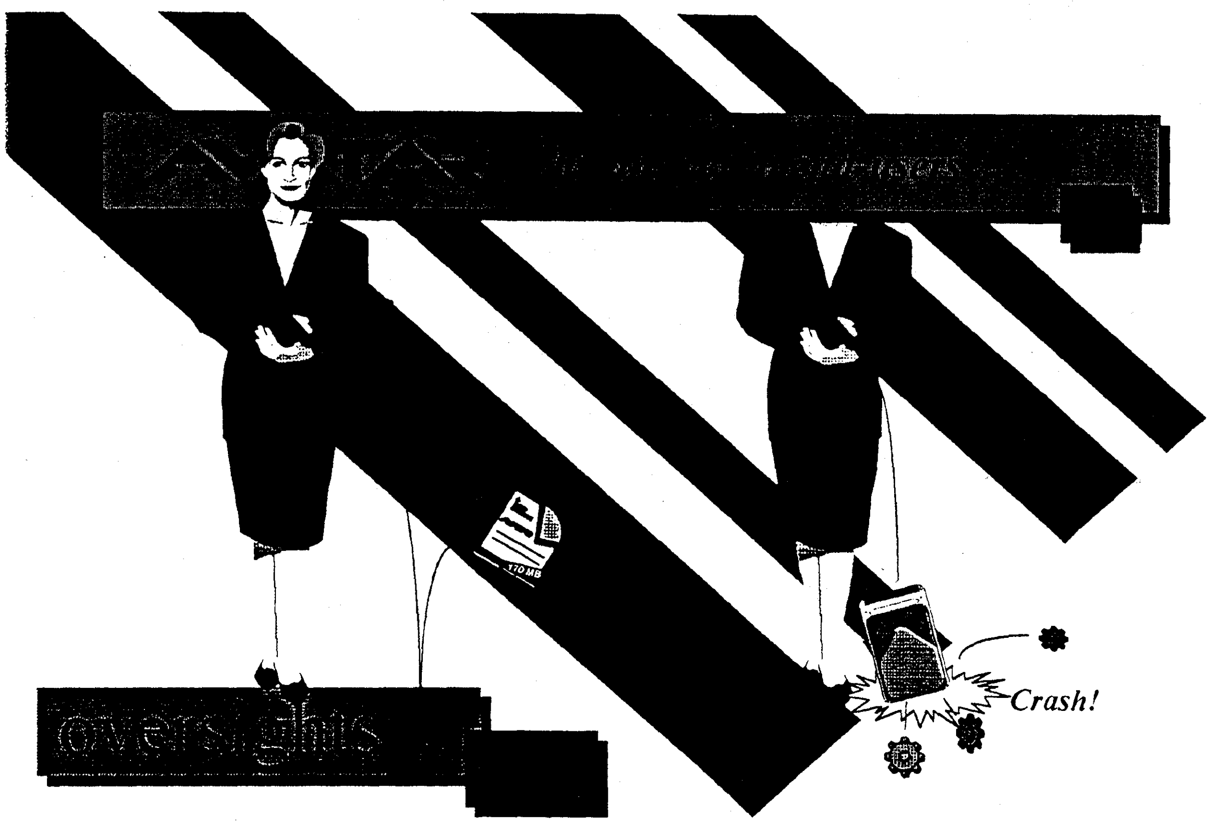
unlimited storage capacity...

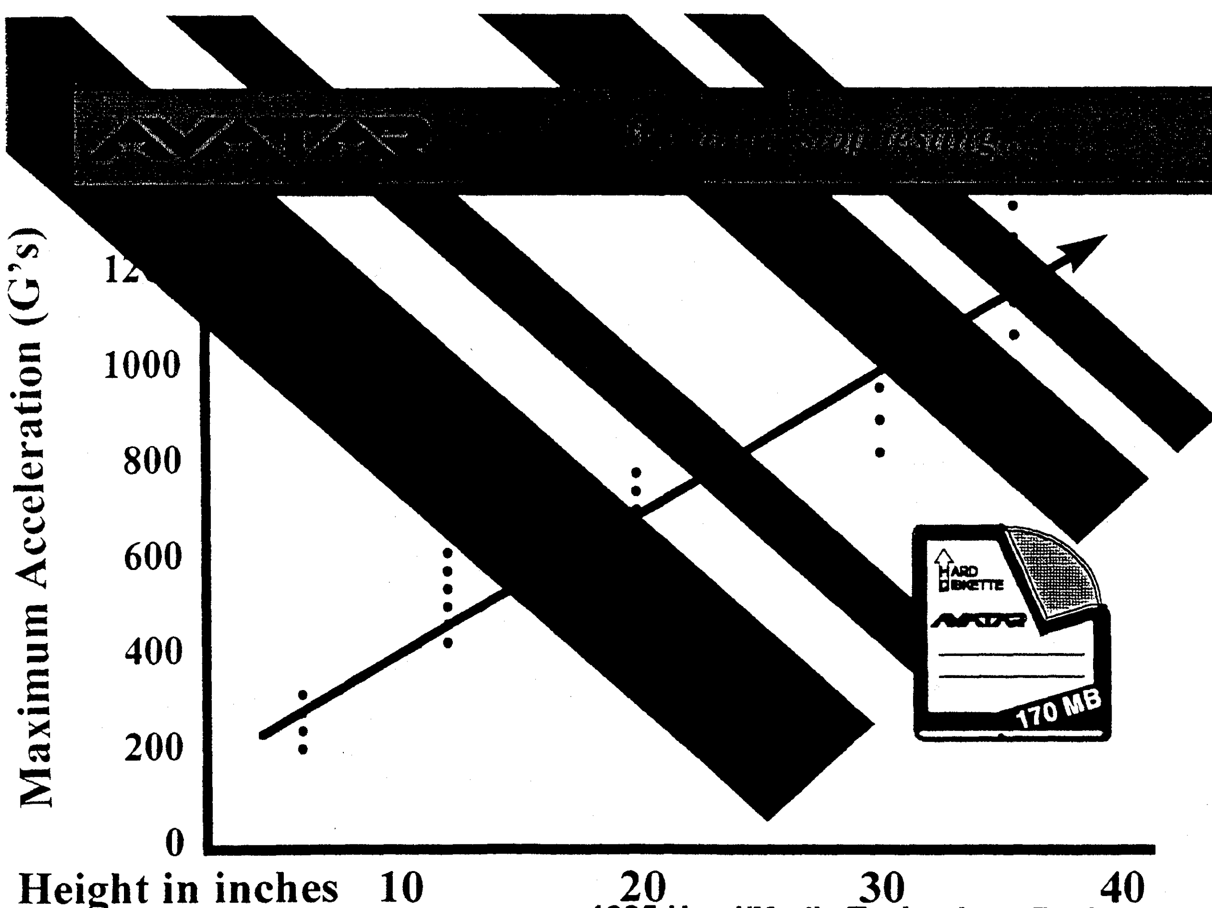


portability, mobile use...



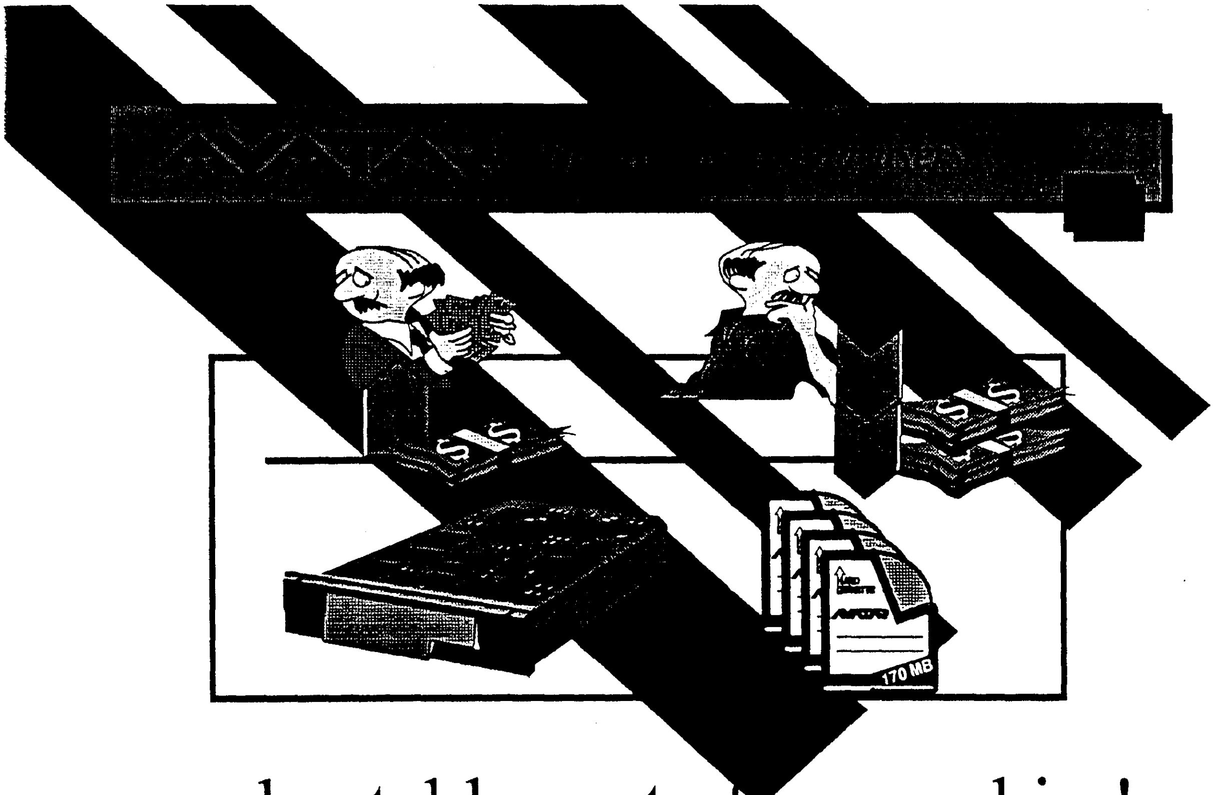
data interchange [illegible] umbilical cords...





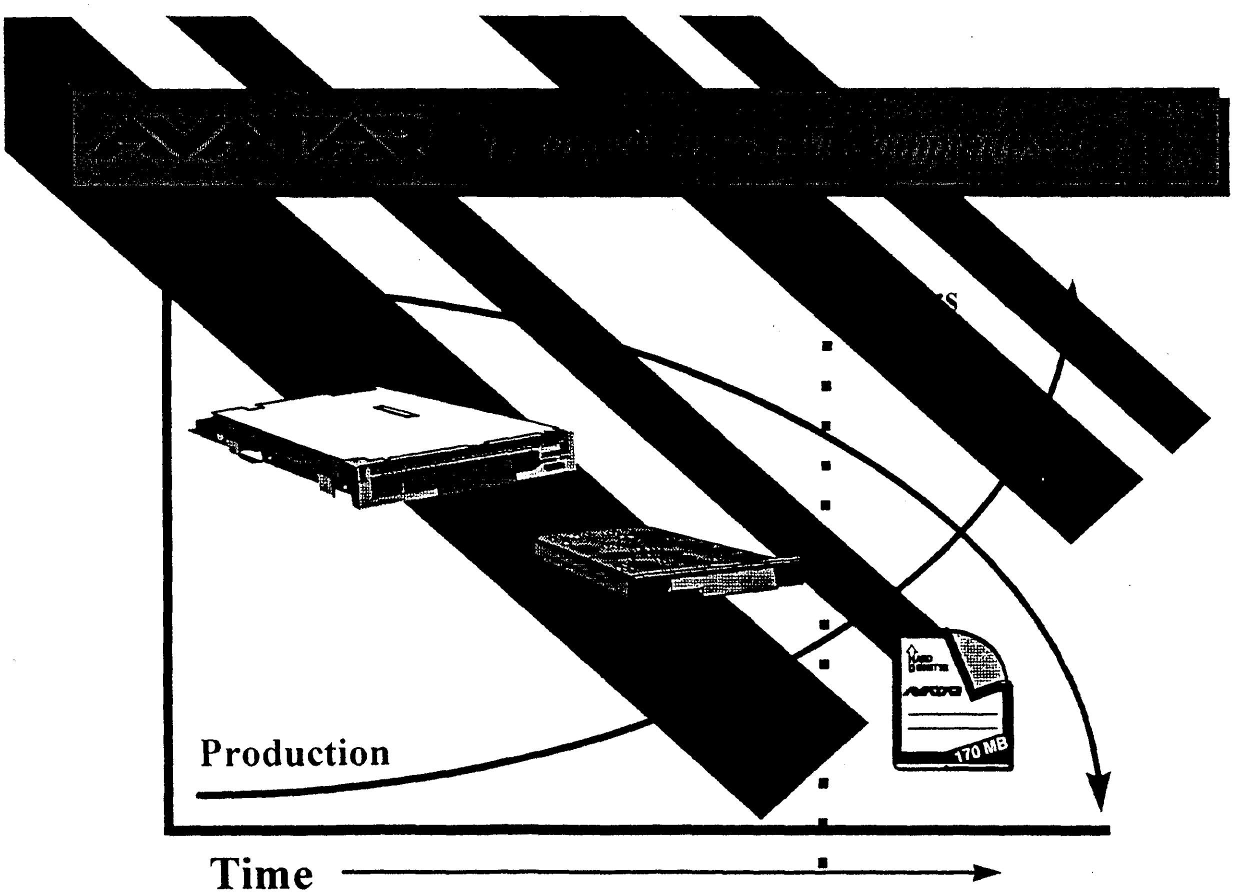
1995 Head/Media Technology Review

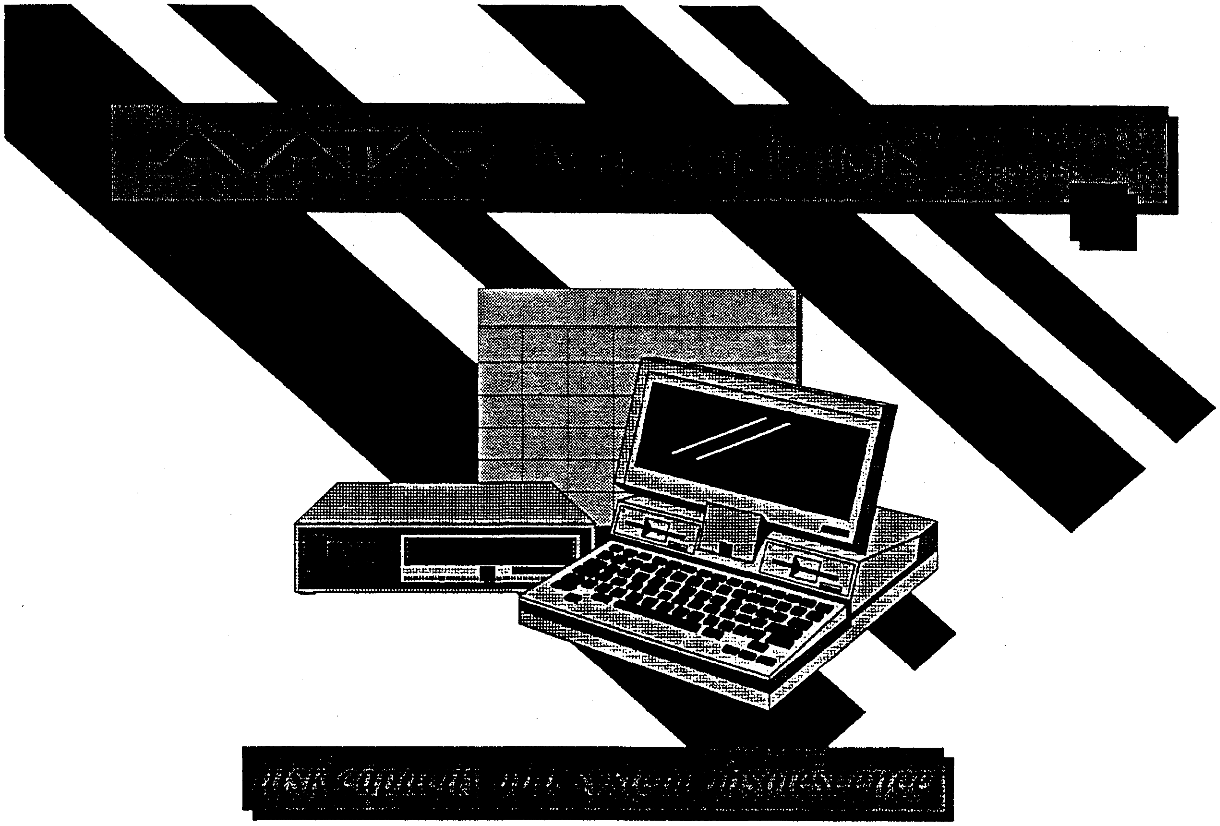
[redacted]

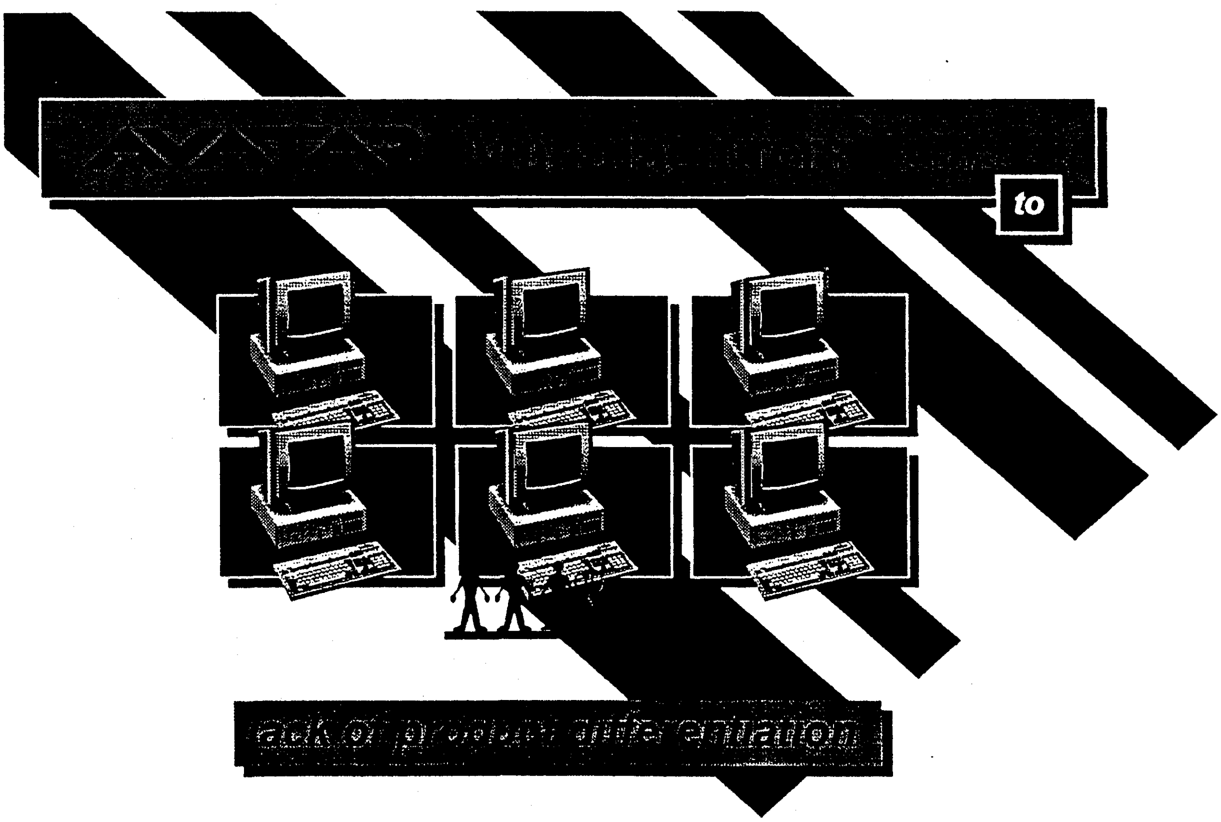


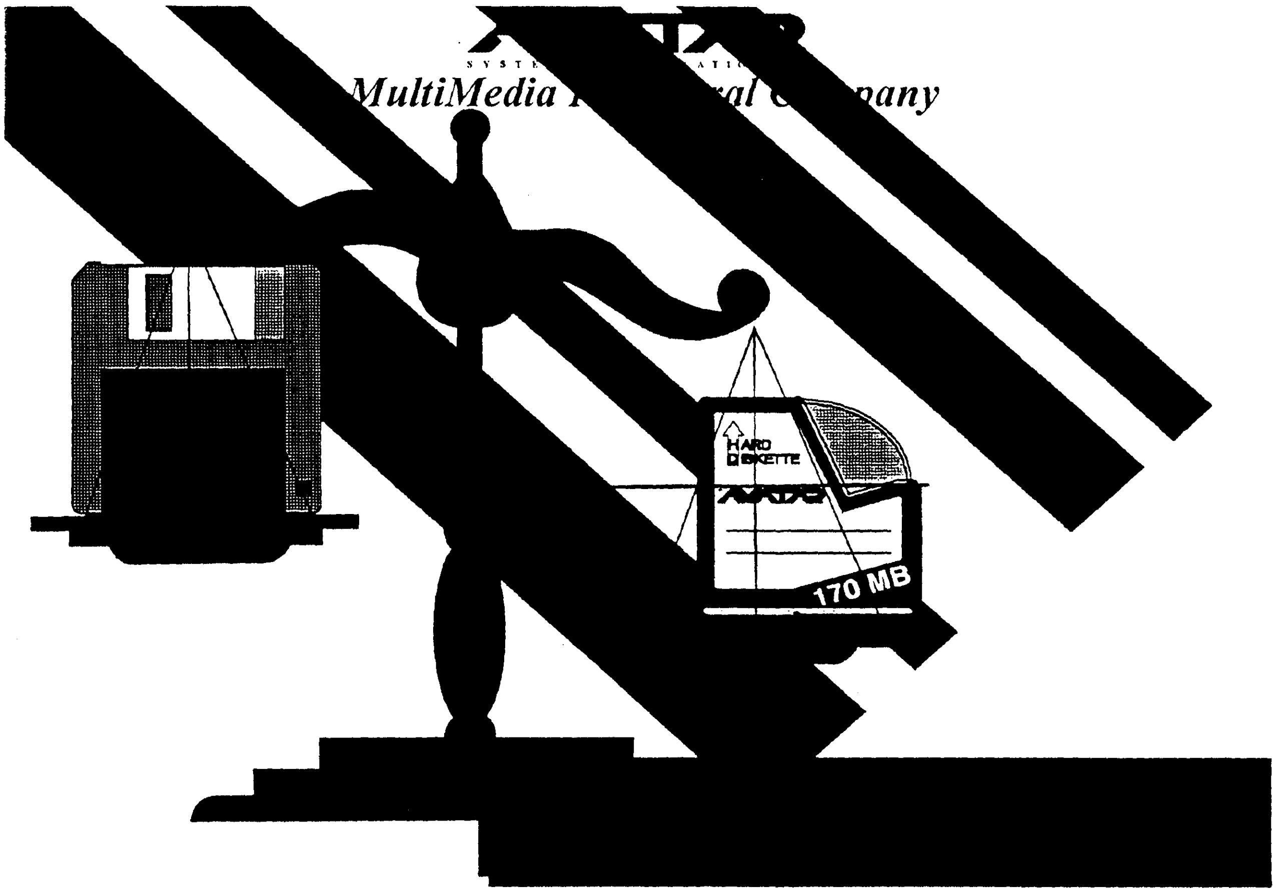
unbeatable cost o[redacted] ownership !

[redacted]






to



1995 Head/Media Technology Review

AROUND THE WORLD OF TAPE IN 1000 SECONDS

Greg Ormsbee

Product Marketing Manager

Tandberg Data

Around the World of Tape in 1000 Seconds

A brief tour of tape technology

Gregg Ormsbee
TANDBERG DATA INC.

TANDBERG DATA

Tape on the Move

- Tape Technology covers the widest range of price, performance, and capacity over other storage technologies
  - 60 MB to 50 GB per cartridge
  - 80 KBS to 11 MB per second sustained data transfer rate
  - Autochangers and Libraries are available for most media/drive styles increasing data storage capacity to multiple Terabytes

TANDBERG DATA

Tape on the Move

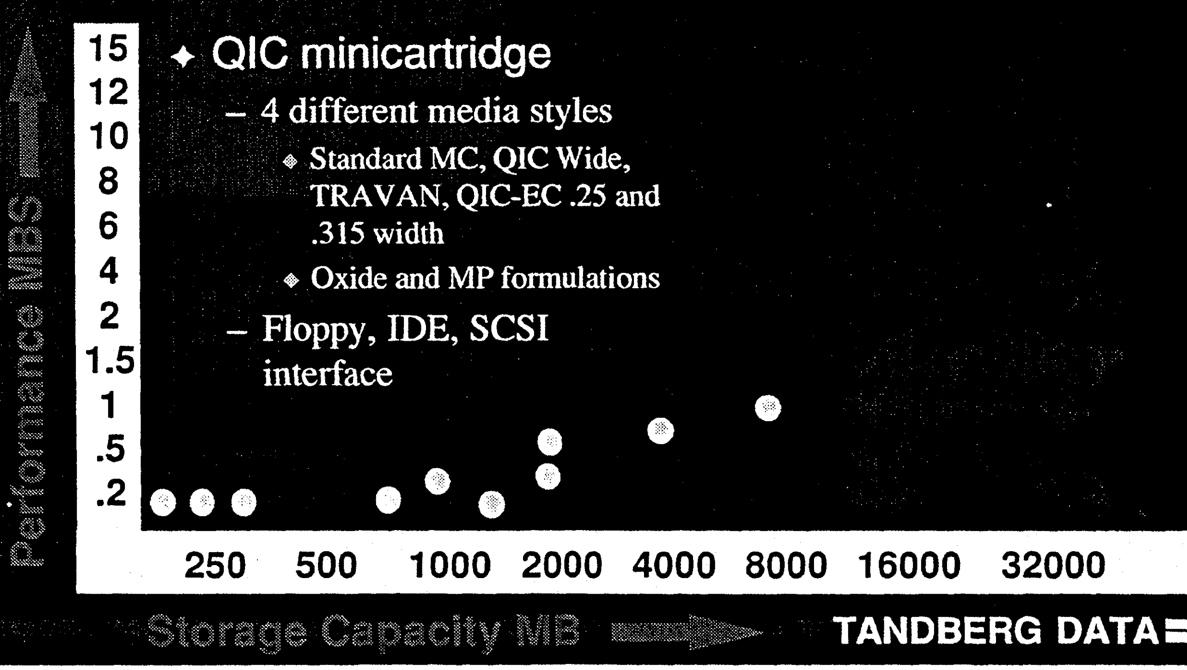
- New applications/directions are increasing awareness for tape
  - Integrated operating system support
  - Data access by DASD/OS software drivers
  - Is 1996 the year of PSM?
- TRAVAN Technology
  - Targeting the average computer user
  - Simplifying the selection process

TANDBERG DATA

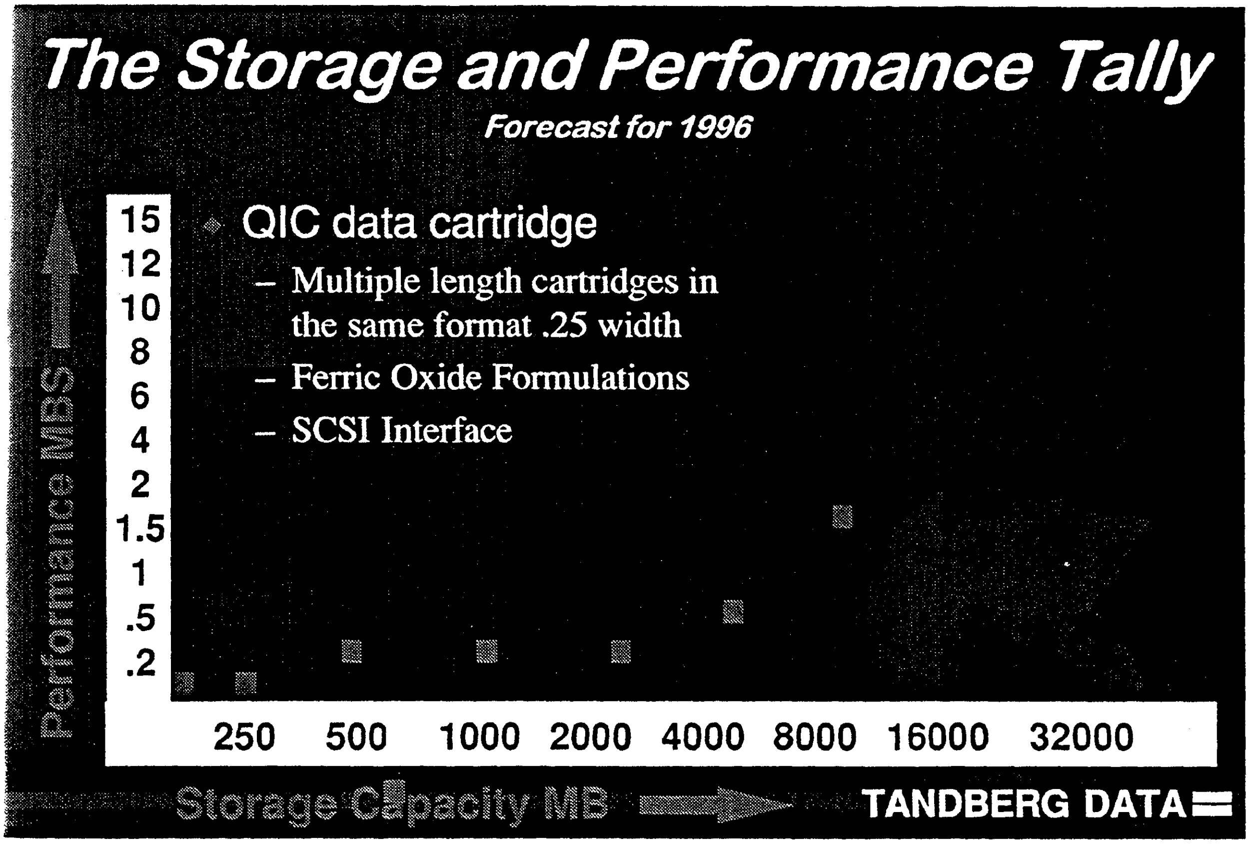
The Storage and Performance Tally

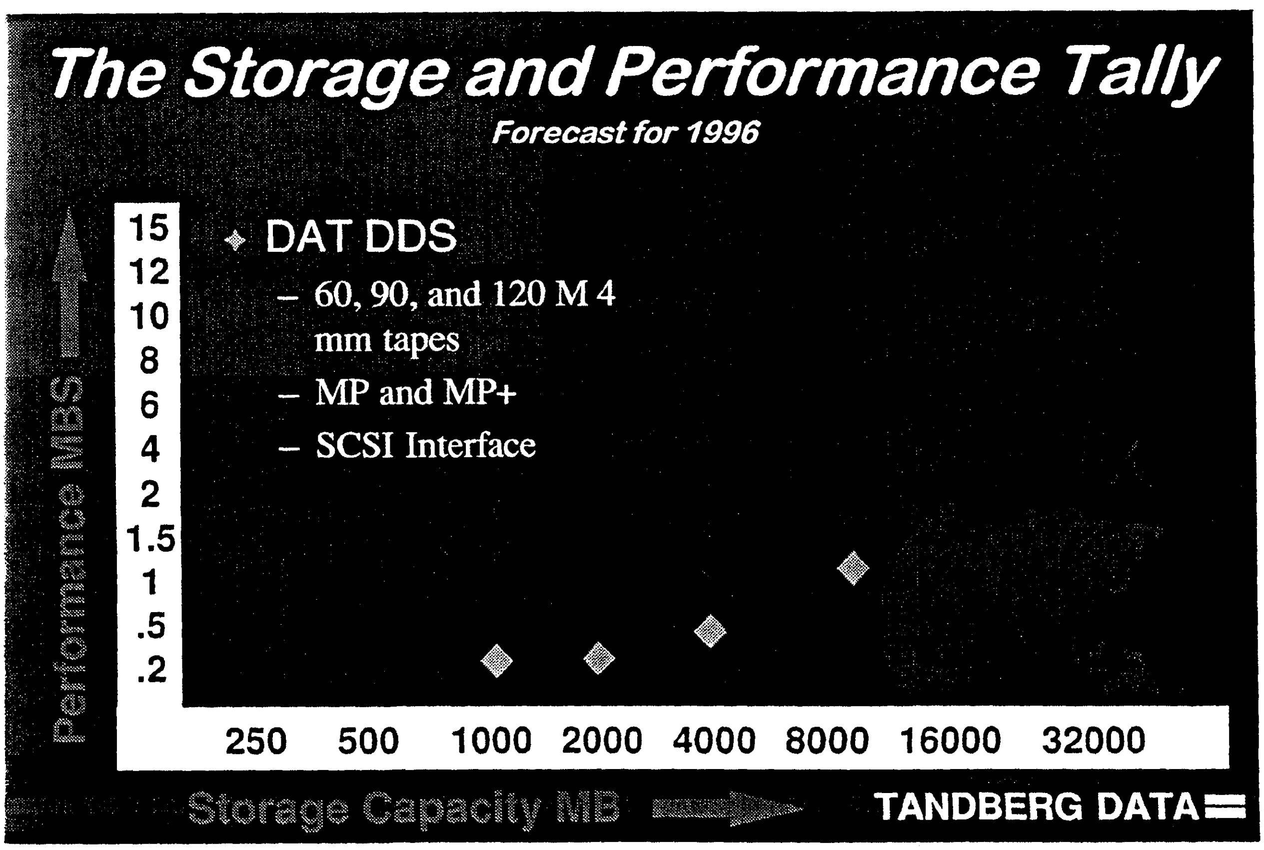
Forecast for 1996

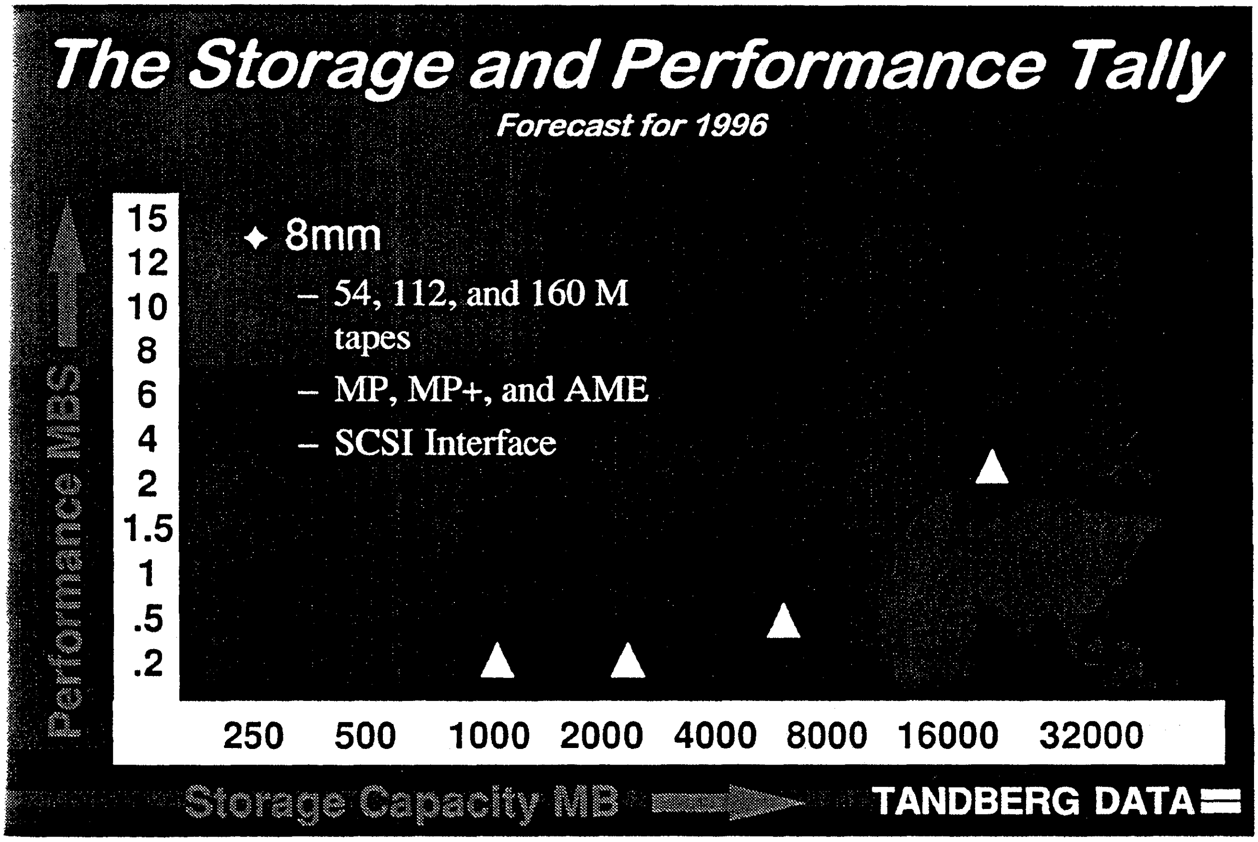
- QIC minicartridge
  - 4 different media styles
    - Standard MC, QIC Wide, TRAVAN, QIC-EC .25 and .315 width
    - Oxide and MP formulations
  - Floppy, IDE, SCSI interface

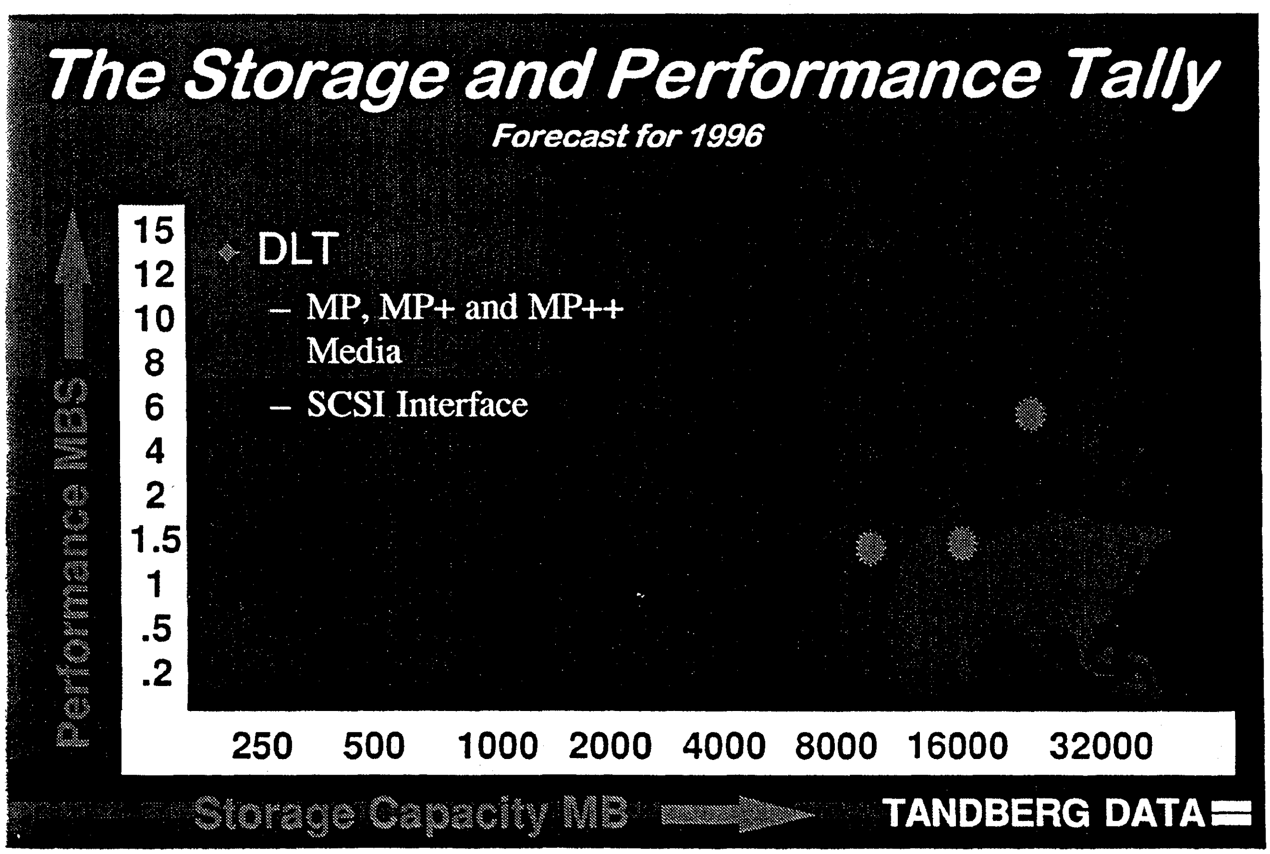


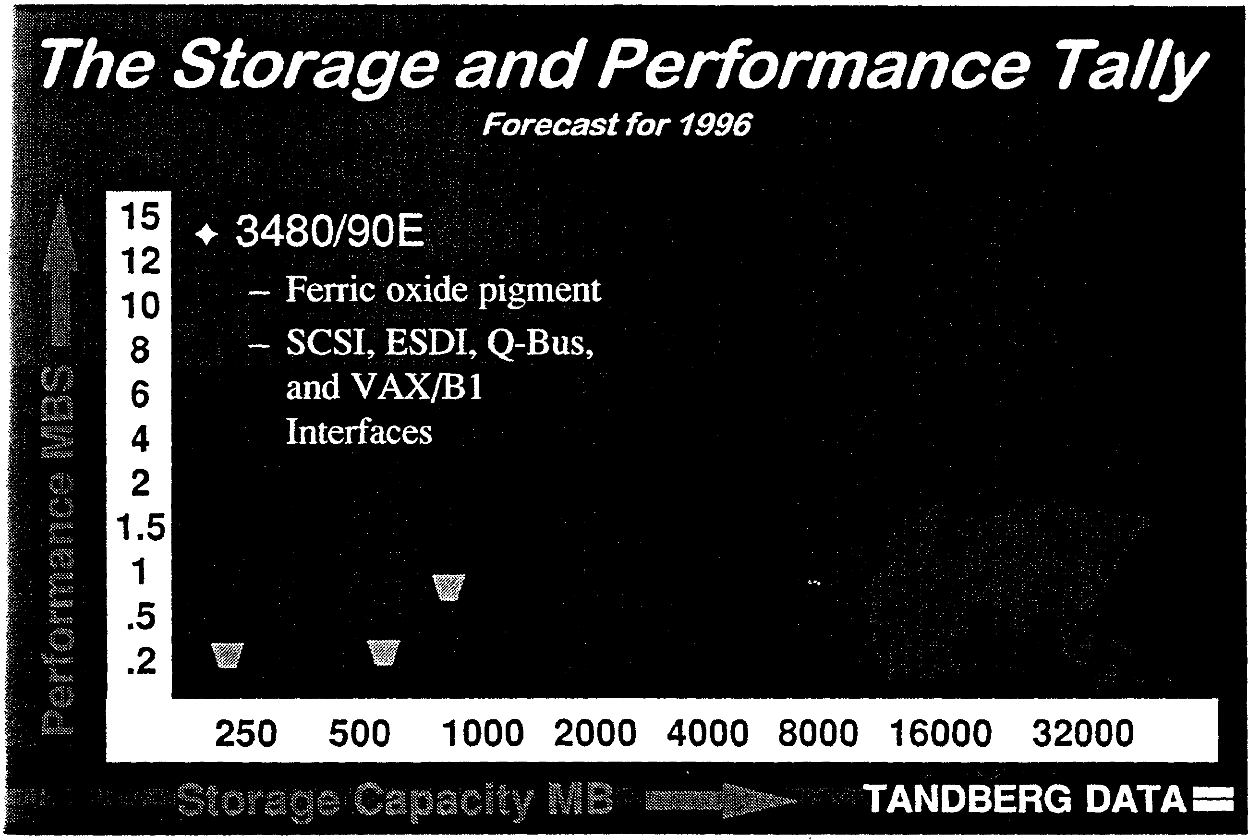
TANDBERG DATA

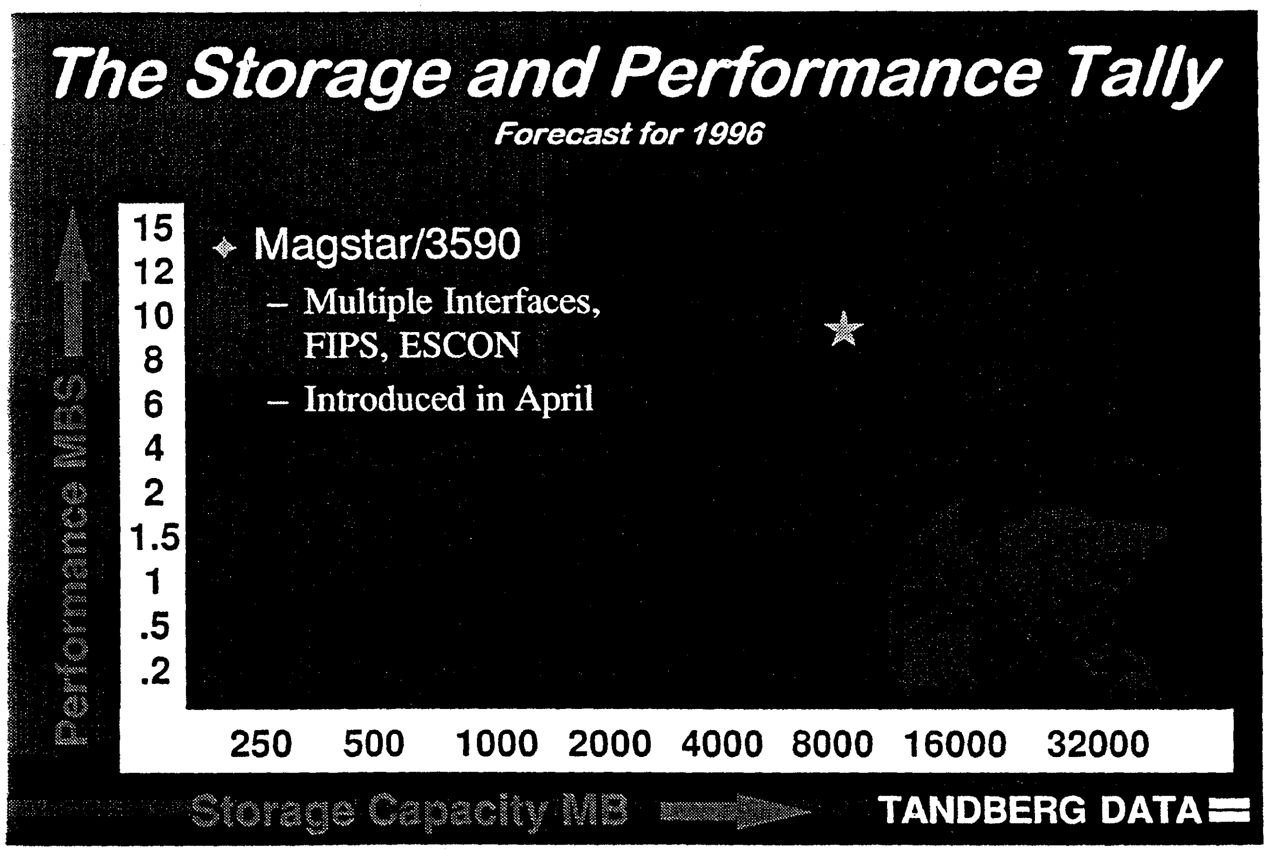

The Storage and Performance Tally
Forecast for 1996
QIC data cartridge
– Multiple length cartridges in the same format .25 width
– Ferric Oxide Formulations
– SCSI Interface
Performance MBS
15
12
10
8
6
4
2
1.5
1
.5
.2
250 500 1000 2000 4000 8000 16000 32000
Storage Capacity MB
TANDBERG DATA

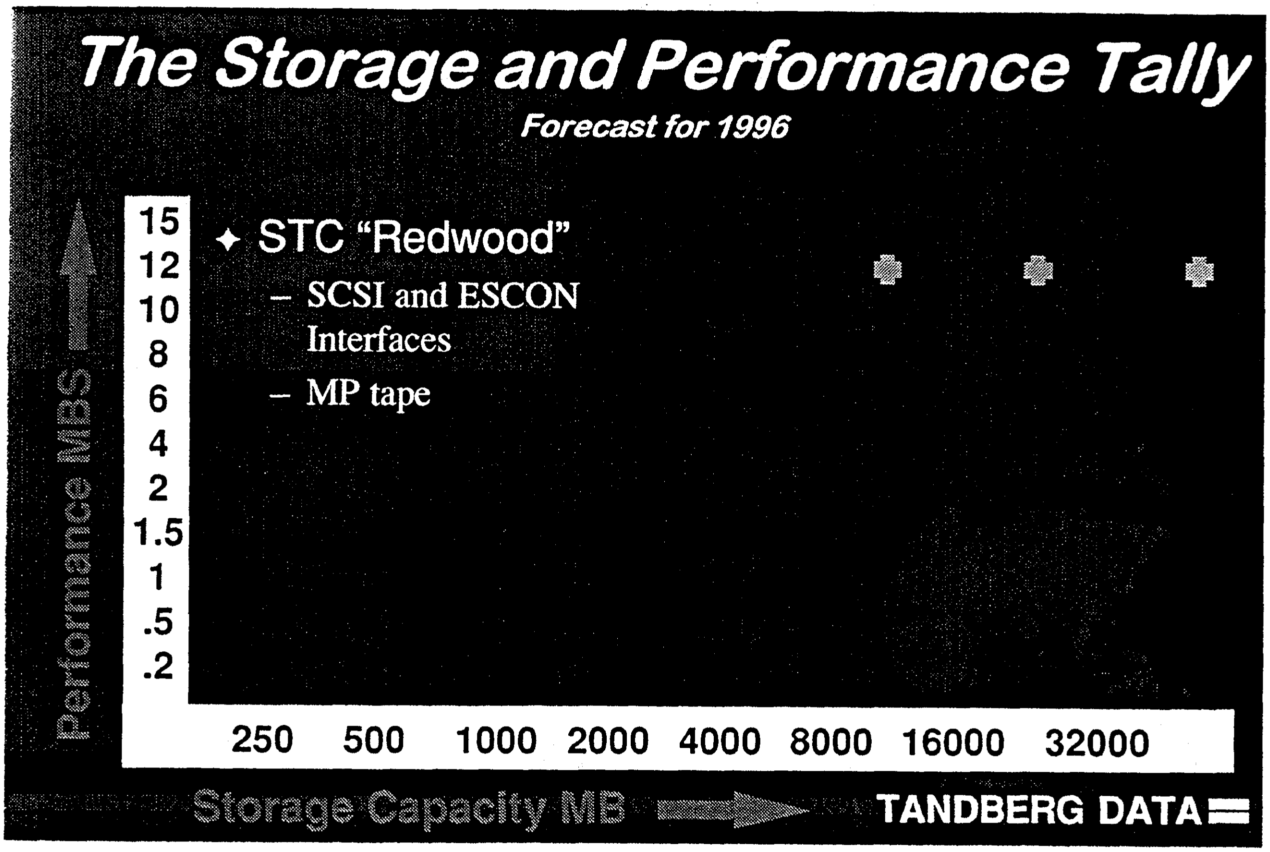

The Storage and Performance Tally
Forecast for 1996
DAT DDS
– 60, 90, and 120 M 4 mm tapes
– MP and MP+
– SCSI Interface
Performance MBS
15
12
10
8
6
4
2
1.5
1
.5
.2
250 500 1000 2000 4000 8000 16000 32000
Storage Capacity MB
TANDBERG DATA

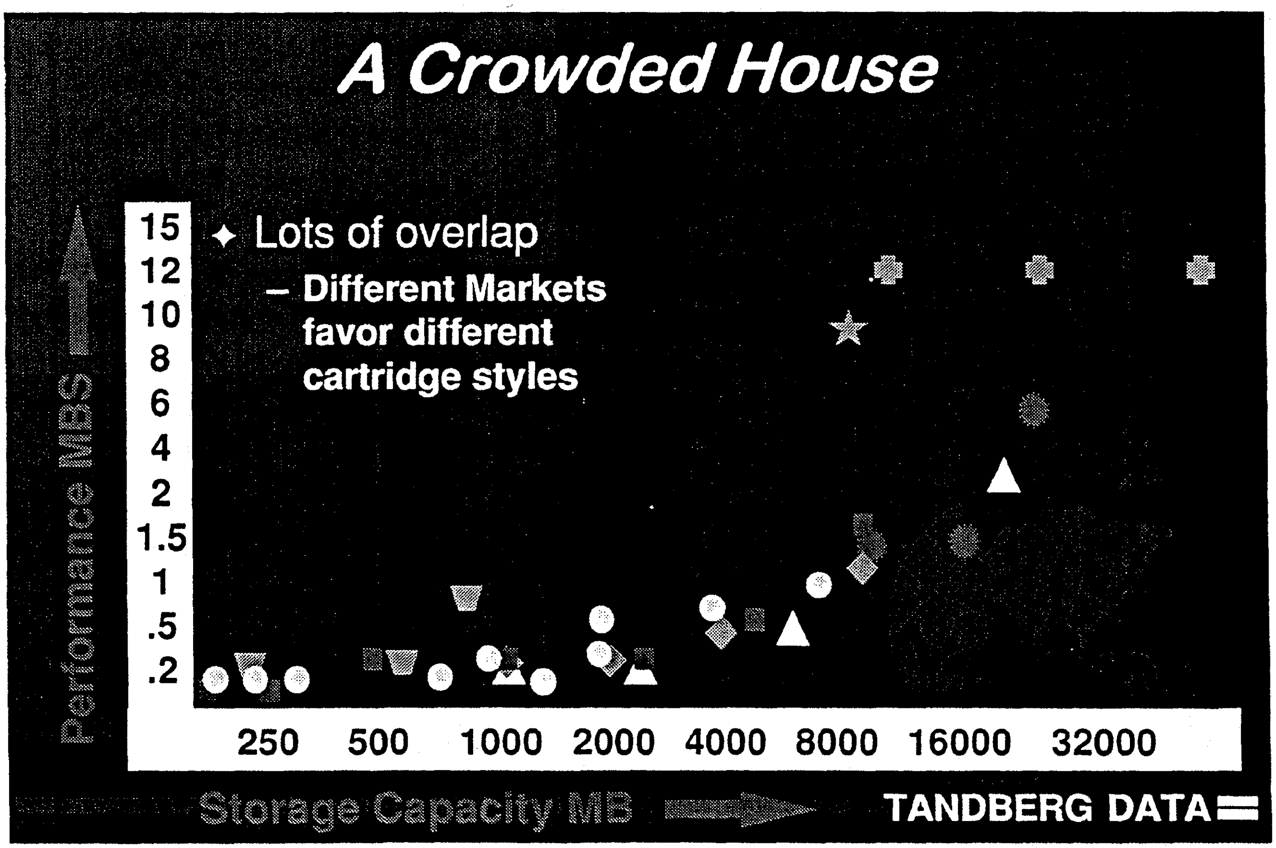

The Storage and Performance Tally
Forecast for 1996
Performance MBS
15
12
10
8
6
4
2
1.5
1
.5
.2
✦ 8mm
– 54, 112, and 160 M tapes
– MP, MP+, and AME
– SCSI Interface
250
500
1000
2000
4000
8000
16000
32000
Storage Capacity MB
TANDBERG DATA

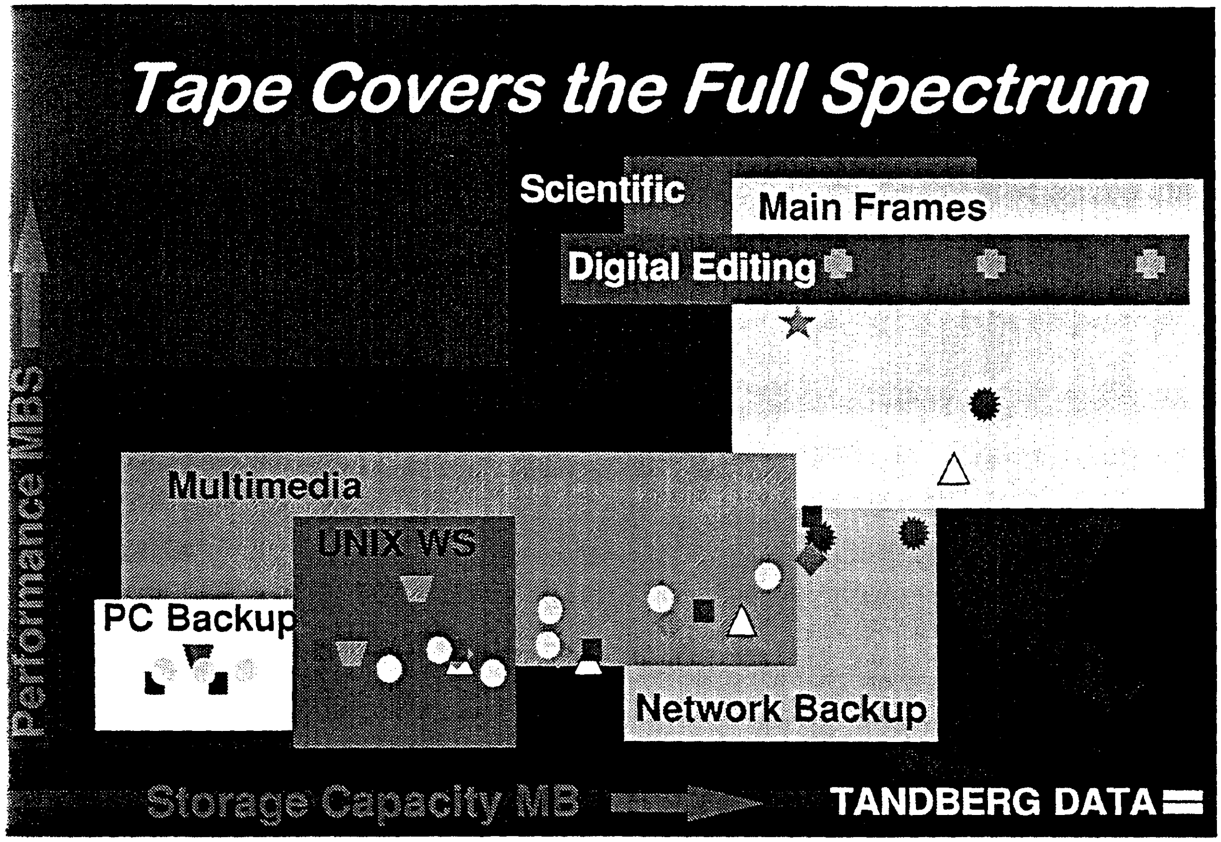

The Storage and Performance Tally
Forecast for 1996
Performance MBS
15
12
10
8
6
4
2
1.5
1
.5
.2
DLT
– MP, MP+ and MP++ Media
– SCSI Interface
250
500
1000
2000
4000
8000
16000
32000
Storage Capacity MB
TANDBERG DATA

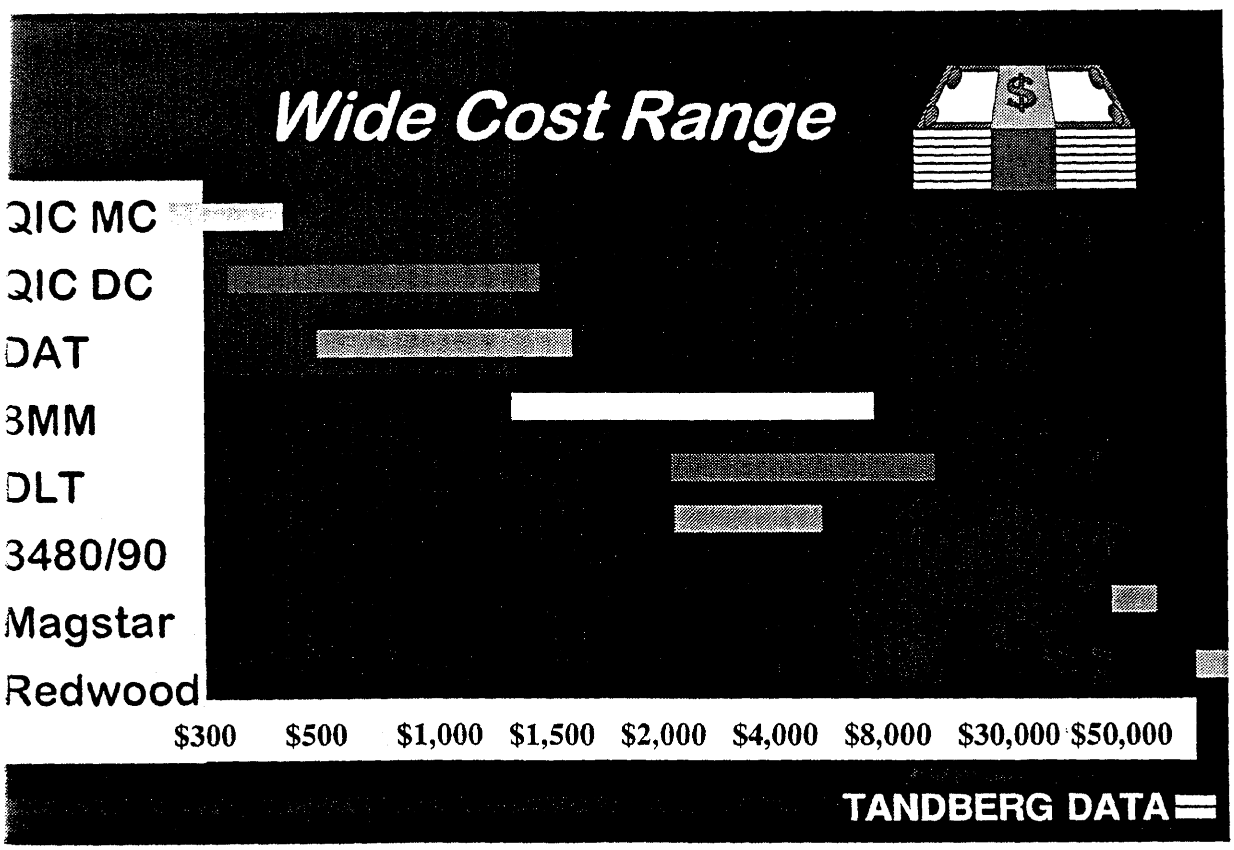

The Storage and Performance Tally
Forecast for 1996
✦ 3480/90E
– Ferric oxide pigment
– SCSI, ESDI, Q-Bus, and VAX/B1 Interfaces
Performance MBS
15
12
10
8
6
4
2
1.5
1
.5
.2
250 500 1000 2000 4000 8000 16000 32000
Storage Capacity MB
TANDBERG DATA


The Storage and Performance Tally
Forecast for 1996
✦ Magstar/3590
– Multiple Interfaces, FIPS, ESCON
– Introduced in April
Performance MBS
15
12
10
8
6
4
2
1.5
1
.5
.2
250 500 1000 2000 4000 8000 16000 32000
Storage Capacity MB
TANDBERG DATA

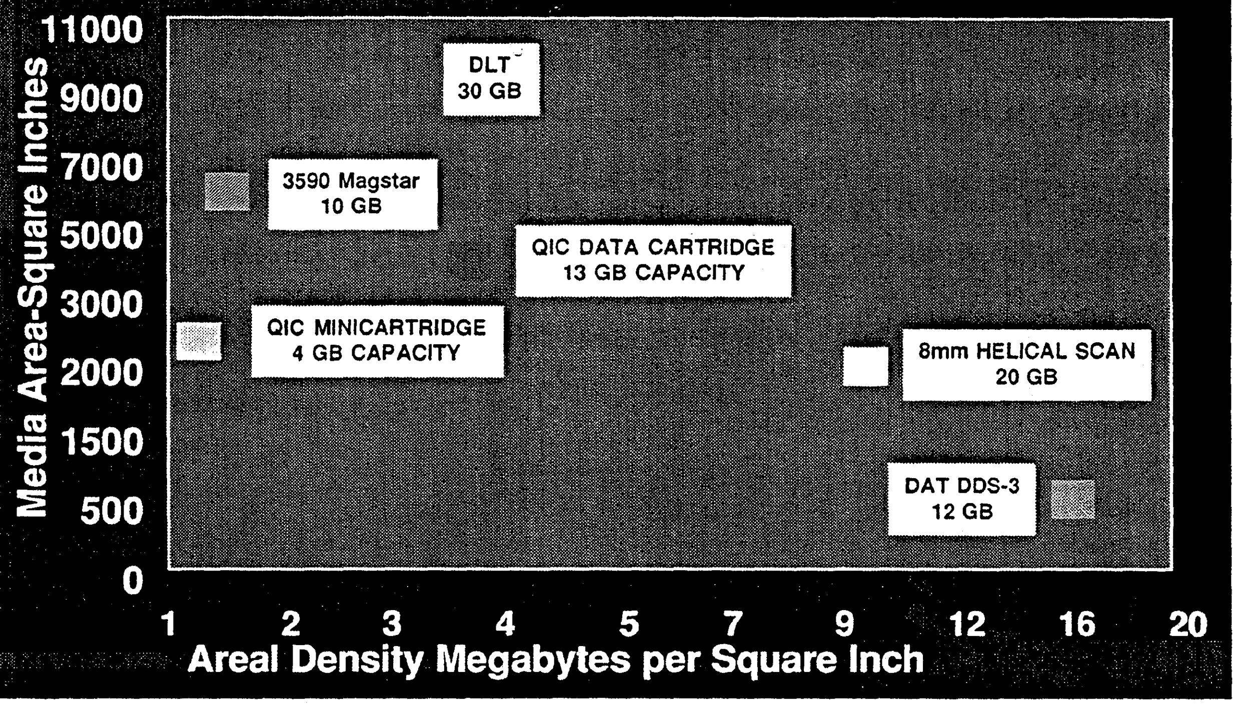

The Storage and Performance Tally
Forecast for 1996
✦ STC "Redwood"
– SCSI and ESCON Interfaces
– MP tape
15
12
10
8
6
4
2
1.5
1
.5
.2
Performance MBS
250 500 1000 2000 4000 8000 16000 32000
Storage Capacity MB
TANDBERG DATA


A Crowded House
✦ Lots of overlap
– Different Markets favor different cartridge styles
15
12
10
8
6
4
2
1.5
1
.5
.2
Performance MBS
250 500 1000 2000 4000 8000 16000 32000
Storage Capacity MB
TANDBERG DATA


Tape Covers the Full Spectrum
Scientific
Main Frames
Digital Editing
Multimedia
UNIX WS
PC Backup
Network Backup
Performance MBS
Storage Capacity MB
TANDBERG DATA


Wide Cost Range
QIC MC
QIC DC
DAT
8MM
DLT
3480/90
Magstar
Redwood
$300
$500
$1,000
$1,500
$2,000
$4,000
$8,000
$30,000
$50,000
TANDBERG DATA

Areal Packing Density



Trends in Tape

- To Achieve Higher Capacity
  - QIC Minicartridge
    - TRAVAN or QIC EX media -More Area
    - TFMR Head
    - Servo Burst - Dynamic Servo Tracking 72-200 tracks @ .315 width
    - MP++ media = 70,000-80,000 FTPI
  - QIC Data Cartridge
    - Dynamic Servo Tracking
    - TFMR Head
    - MP ++ media- 70,000-80,000 FTPI
    - Wide Tape- Tape length increased to 1500 feet

TANDBERG DATA

Trends in Tape

- To Achieve Higher Capacity
  - DAT DDS
    - PRML encoding
    - MP ++ media = 100,000 FTPI
    - 2800 Stripes per Inch
    - Tape length increased to 180 M
  - 8mm
    - AME tape
    - 160 Meter
    - 2208 Stripes per Inch
    - 77, 611 BPI

TANDBERG DATA

Trends in Tape

- Manufactures are concentrating on
  - Enhanced Features
    - Data Seek Performance
    - Variable Transfer Rates
    - Increased Reliability from Drive and Media
  - Introducing New Software
    - PSM
    - IFS
    - ISO 9660 driver emulation

TANDBERG DATA

Summary

- Multiple Technologies address the same Market
- Price-Performance and Heritage of the user determine technology selection
- Areal densities are still very low, room for growth in all tape technologies
- Recording Technology developed in the Disk Drive world is applied into tape

TANDBERG DATA

Around the World of Tape in 1000 Seconds

Thank You

TANDBERG DATA

NEW DIRECTIONS: REMOVABLE FLASH STORAGE

Leon Malmed

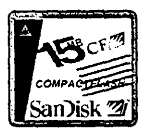
Senior Vice President Marketing/Sales

SanDisk Corporation

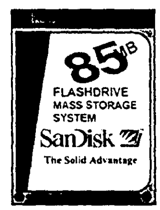
New Directions: Removable Flash Storage

Leon Malmed
Senior VP
Marketing/Sales
SanDisk Corporation

Head/Media Technology Review
Las Vegas, NV
November 11, 1995



CompactFlash
2 - 15MB



Type II
1.8 - 85MB

Type III
110 - 175MB

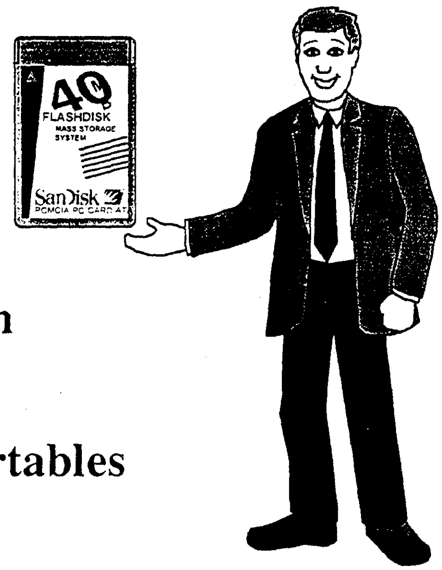
New Directions - Removable Flash Storage

- Smaller Form Factors
- Increasing Standardization
- Higher Capacities
- New Flash Generations
- 3.3 and 5 volt support

SanDisk

Benefits of Flash Mass Storage

- Instant access to data
- Data reliability
- No moving parts
- Resists shock & vibration
- No worry about disk crash
- Low power requirement
- Extends battery life of portables
- No noise



SanDisk

L. Malmed
Head/Media Tech

CompactFlash

SanDisk

L. Malmed
Head/Media Tech

CompactFlash™

- World's smallest removable data storage system based on flash technology
- Weighs 1/2 ounce & is the size of a matchbook
- Complete PCMCIA-ATA functionality & compatibility
- 50-pin CF cartridge fits in 68-pin Type II adapter card
- Available in 2, 4, 10 and 15MB cartridges

SanDisk™

L. Malmed
Head/Media Tech

CF and Adapter Card

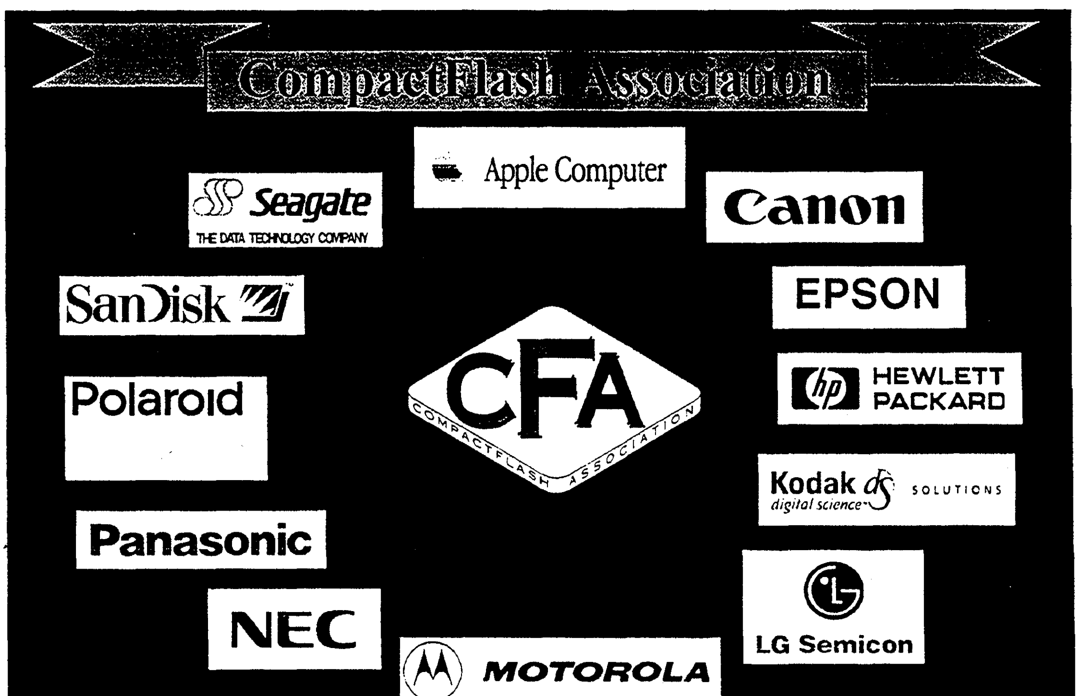
SanDisk™

L. Malmed
Head/Media Tech

CF & 5 Model Products

SanDisk

L. Malmed
Head/Media Tech



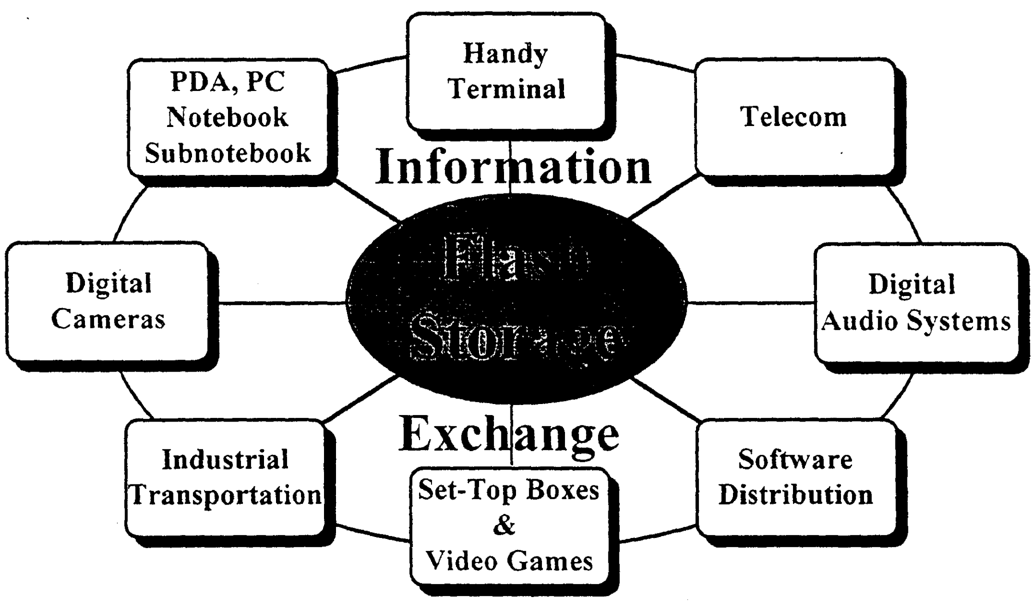
CFA Mission Statement

To promote the worldwide adoption of CompactFlash as the de facto small form factor Flash data storage standard

SanDisk

L. Malmed
Head/Media Tech

Pervasive Storage



SanDisk

L. Malmed
Head/Media Tech

ATA Standard

- Flash storage market driven by growing support for PC card ATA standard
- Support is fading for FFS & FTL storage cards

L. Malmed
Head/Media Tech

SanDisk

ATA Standard

"Windows 95 does NOT support

FFS and FTL storage cards"

Electronic Engineering Times
July, 3 1995

SanDisk

L. Malmed
Head/Media Tech

Industry Leaders Support PC Card ATA Standard

OS Vendors
- Windows 3.1
- Windows 95
- Microsoft at Work
- IBM DOS 6.1
- OS/2
- Apple System 7
- GEOS
- NEC DOS

System Vendors
- AT&T
- IBM PC Co.
- Hewlett-Packard
- Compaq
- AST
- DEC
- Toshiba
- Casio
- Tandy
- Fujitsu
- NCR
- NEC
- Apple
- Many others

Storage Vendors
- SanDisk
- IBM/Toshiba
- Seagate
- Integral
- Intel
- Samsung/Cirrus
- Hitachi
- Many others

L. Malmed
Head/Media Tech

SanDisk

ATA vs. Linear Flash Card (Non-ATA)

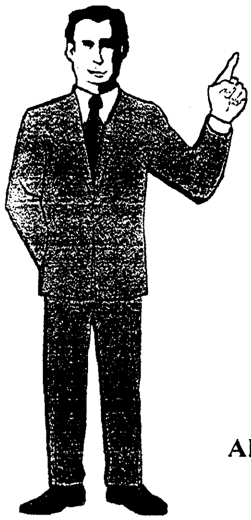
ATA
- Open industry standard
- Guaranteed forward and backward compatibility
- Guaranteed interoperability
- Guaranteed reliability

Non - ATA
- Closed proprietary architecture
- Compatibility issues
- Reduced performance

L. Malmed
Head/Media Tech

SanDisk

Flash Capacity Trends



	1995	1996	1997
FlashDisk - Type III	175MB	350MB	1GB
FlashDisk - Type II	85MB	160MB	500MB
CompactFlash™	15MB	30MB	100MB

All listed capacities can be effectively doubled with compression software

SanDisk

L. Malmed
Head/Media Tech

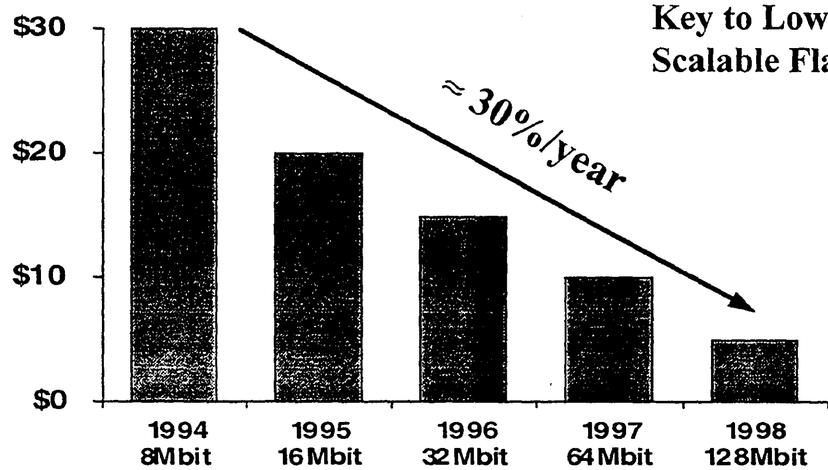
New Type II 85MB Flash Storage PC Card

- Introduced October 30, 1995
- More than doubles industry capacity for Type II Flash Cards
- First PC storage card based on 32Mbit Flash Technology

SanDisk

L. Malmed
Head/Media Tech

Key to Market Expansion: Lower Cost



Key to Lower Cost:
Scalable Flash

Chip Density

SanDisk

L. Malmed
Head/Media Tech

17

New Flash Generations

- 1995 32Mbit
- 1996 64Mbit
- 1997 – 98 256Mbit

SanDisk

L. Malmed
Head/Media Tech

Advantages of Higher Density Flash Technology

- Lower cost
- Higher capacity
- Higher performance
- Lower power

SanDisk

L. Malmed
Head/Media Tech

3.3 and 5 Volt Support

- New flash cards support both 3.3 and 5 volt systems

- Allows movement of data between many computing & consumer electronics products

SanDisk

L. Malmed
Head/Media Tech

Future for Solid-State Flash Storage

- **Very large market for rotating storage today and that will continue**

- **Explosive growth for Flash Mass Storage**

1994	1995
$85 - $100 million	$150 - $220 million
450K - 800K units	1 - 1.2 million units

Source: Various market research firms (Instat, AP Research, Frost & Sullivan, Disk/Trend)

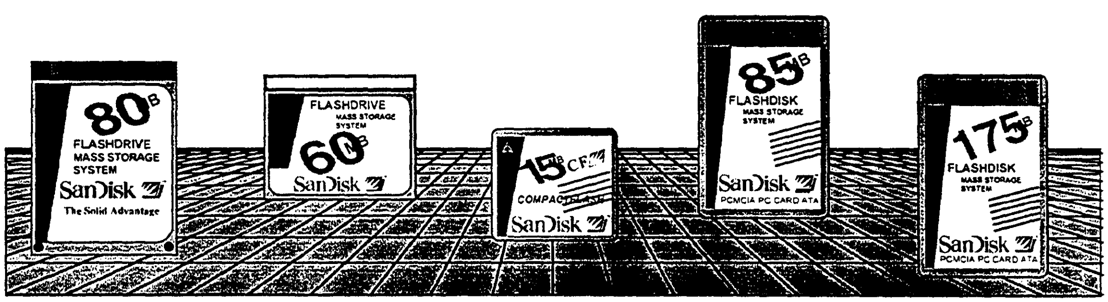
SanDisk™

L. Malmed
Head/Media Tech

Flash 5 Year Horizon

No fundamental physical barriers to 1 Gigabit (128MB) Flash chip

Flash will replace Rotating Disk Drives below 500MB



SanDisk™

L. Malmed
Head/Media Tech

THIN FILM TAPE HEADS

Arun Malhotra

Senior Vice President & Chief Operating Officer

Aiwa R&D, Inc.

THIN FILM TAPE HEADS

ARUN MALHOTRA
JANE ANG
BOB GRAY
STEVE JORDAN
KUO-NAN YANG

AIWA R & D INC.
FREMONT, CALIFORNIA

HISTORY

SPRINGER TECHNOLOGY **1985 - 1991**

FLOPPY/ HARD DISK HEADS
METGLAS

IOMEGA CORPORATION **1991 - 1993**

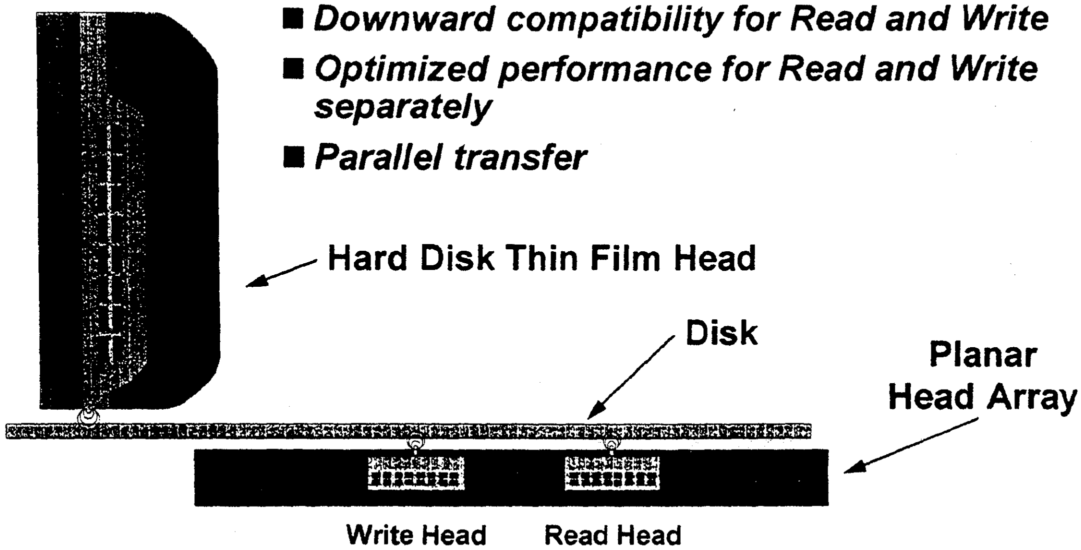
BERNOULLI HEADS
RIGID SUBSTRATE

AIWA CORPORATION **1994 - PRESENT**

TAPE HEADS
RIGID SUBSTRATE

Planar Thin Film Head

- *Downward compatibility for Read and Write*
- *Optimized performance for Read and Write separately*
- *Parallel transfer*



GOAL:

DEVELOP A MANUFACTURABLE TECHNOLOGY

BY

LEVERAGING MANUFACTURING PROCESSES:

FROM

MCM
IC
THIN FILM HEADS
FLAT PANEL DISPLAYS

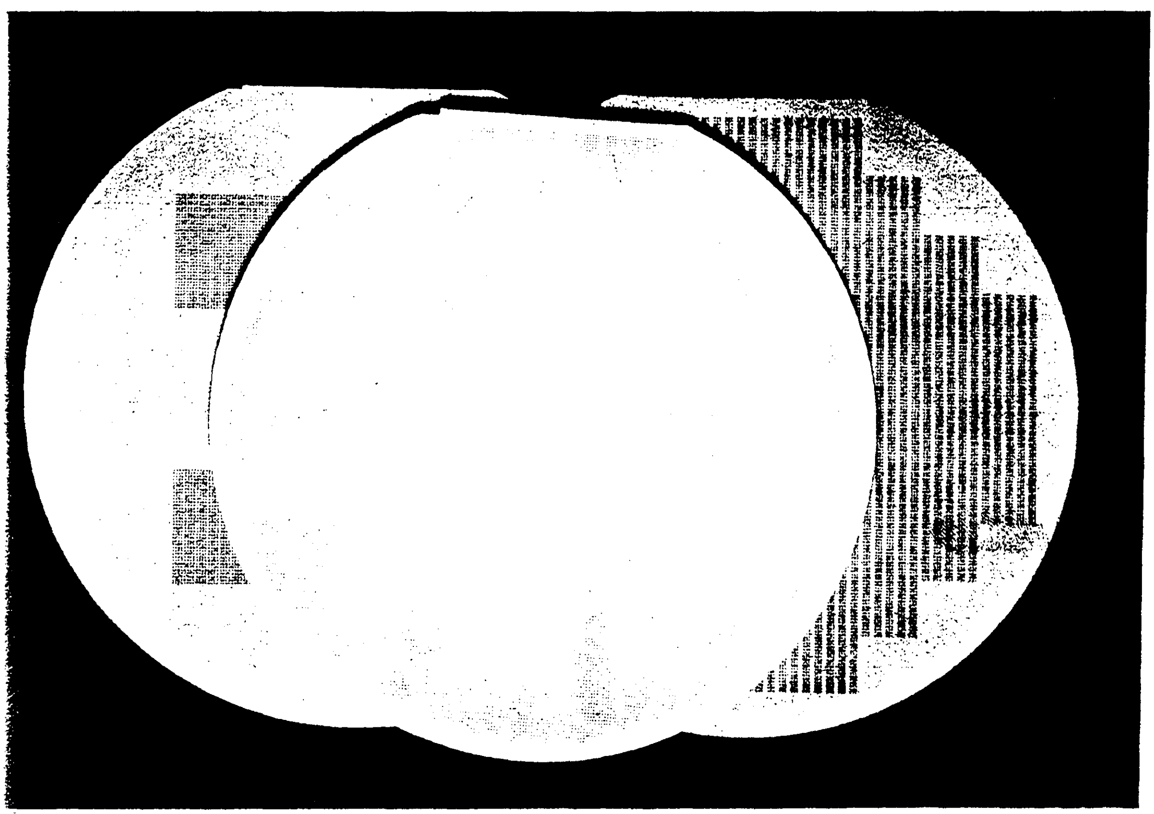
REQUIREMENTS ⟷ CAPABILITIES

SELECTION CRITERIA

FUNCTIONALITY....MEETS REQUIREMENTS
QUALITY ....CONSISTENTLY
DELIVERY ....SHORT CYCLE TIME
COST ....COMPETITIVE COST

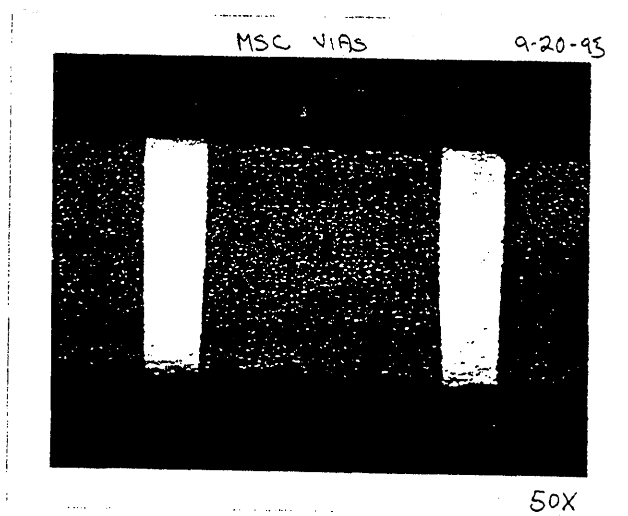
KEY MATERIAL DECISIONS:

MATERIAL	FUNCTION
150 mm AL2O3 WAFER	SUBSTRATE
LASER DRILLED/ W-CU FILLED VIAS	CONTACTS
CURED PHOTORESIST	INSULATION
ALUMINA	STRUCTURE
COPPER	COILS
NiFe	MAGNETIC CORE
DLC	STRUCTURE WEAR LAYER GAP
GOLD	BONDING PADS

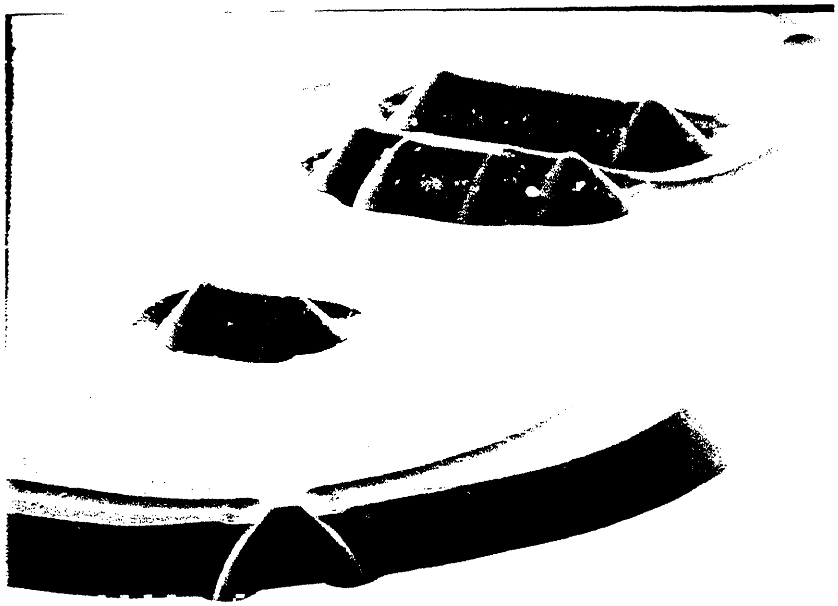


KEY EQUIPMENT/PROCESS DECISIONS

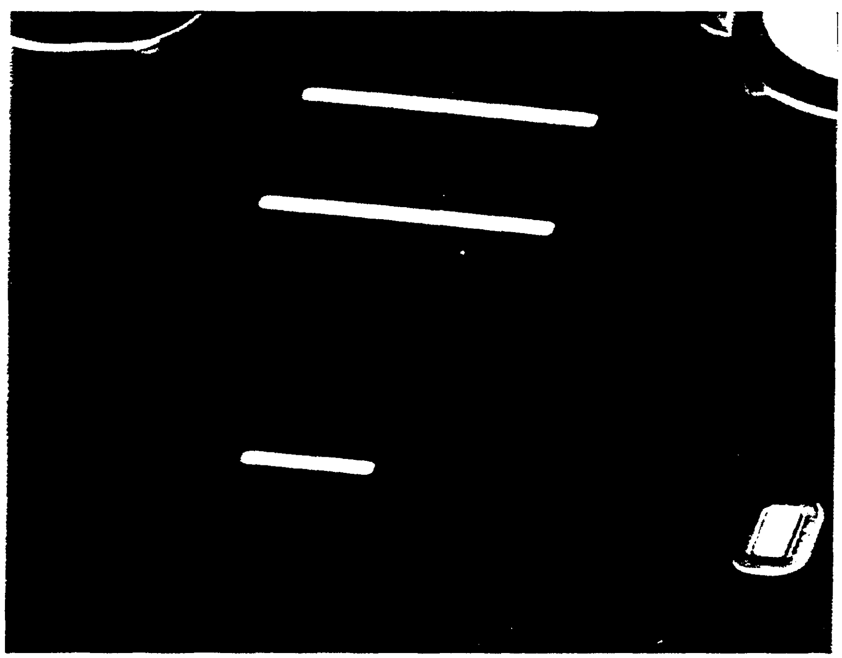
EQUIPMENT/ PROCESSES	FUNCTION
E - BEAM	RESIST CURING
SPRAY/SPIN	RESIST APPLICA.
SPUTTER	SEED LAYERS, ALUMINA
ELECTROPLATE	NiFe, Cu and Au
CMP	PLANARIZATION
PLASMA CVD	DLC DEPOSITON
PLASMA ETCH	DLC ETCH
CHEMICAL ETCH	SEED AND NiFe ETCH
STEPPER	PROJECTION & ALIGNMENT

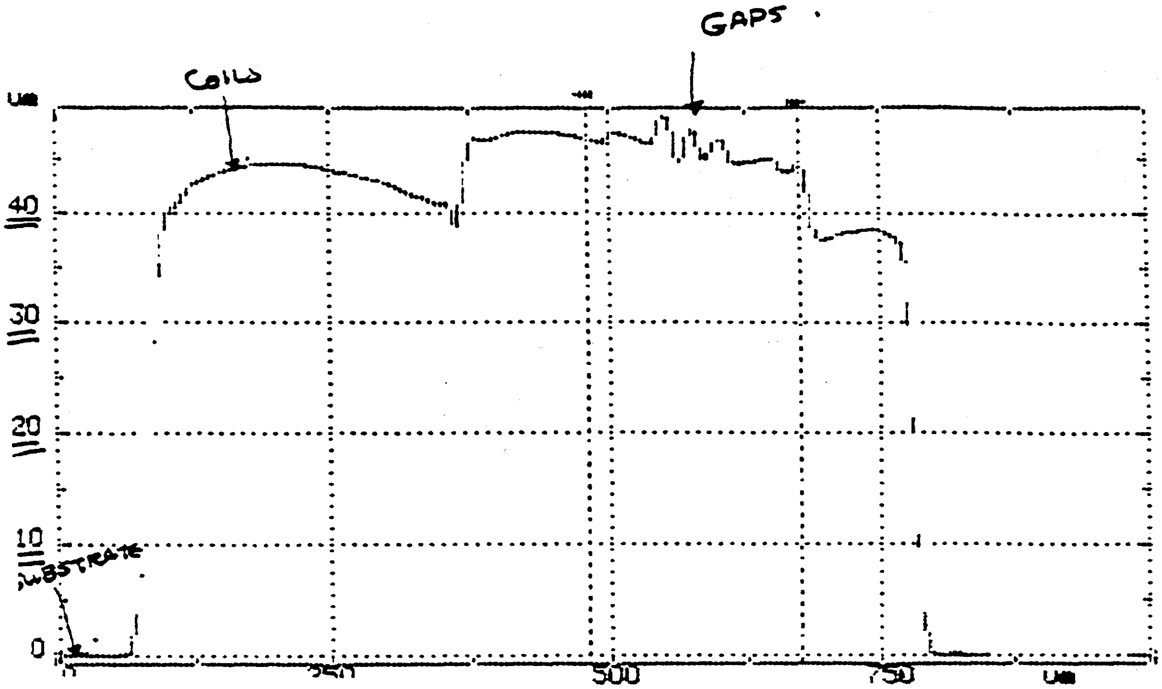


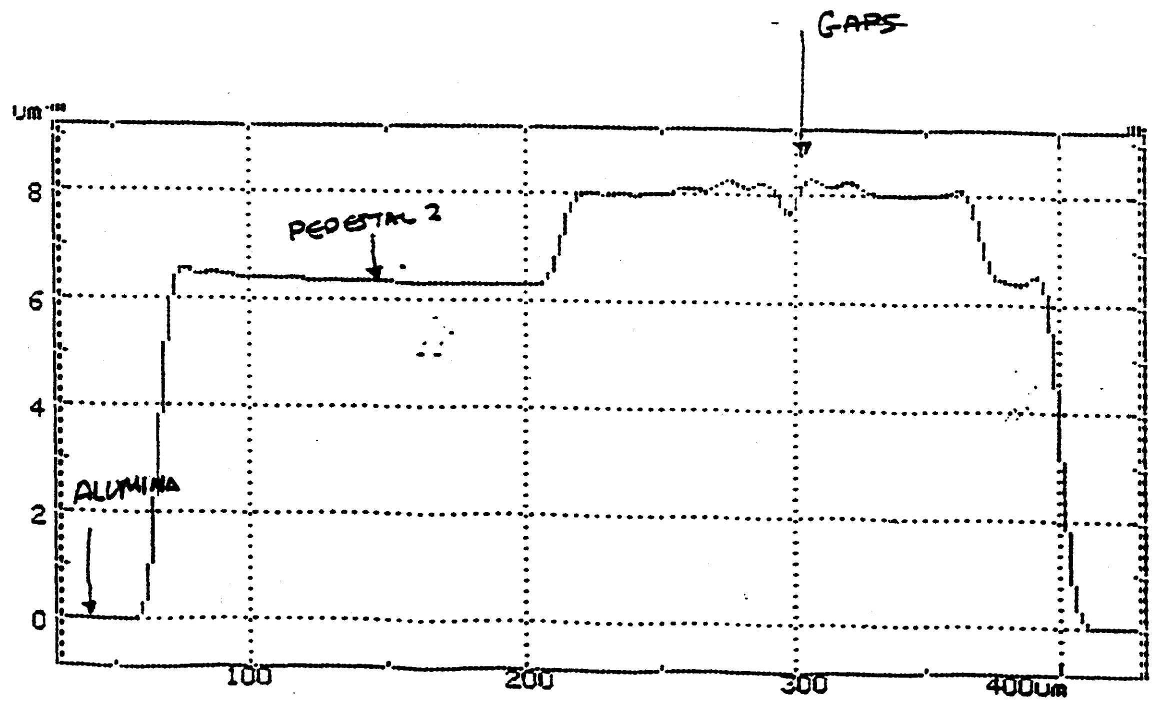
MICRO SUBSTRATES CORPORATION, TEMPE, ARIZONA, USA



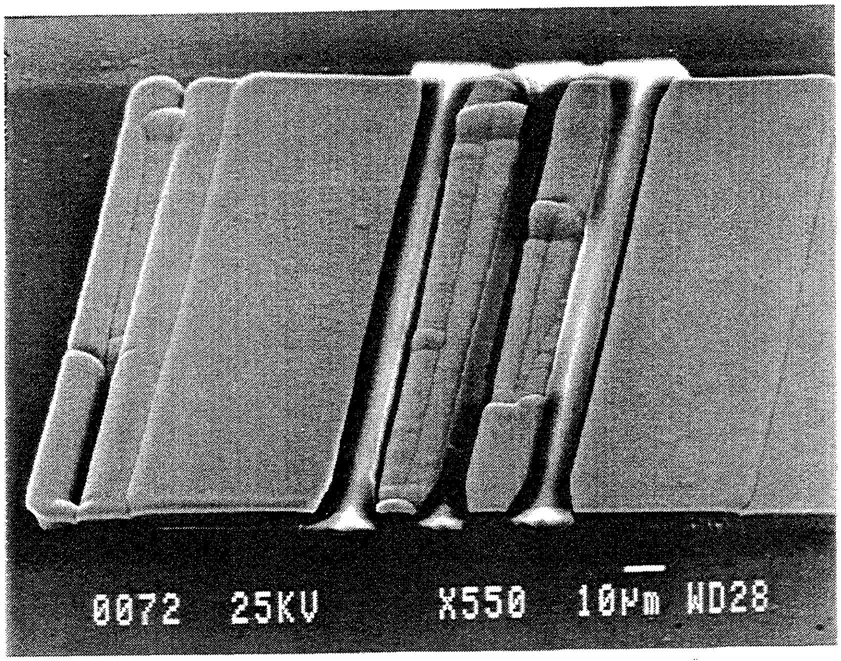
ALUMINA PLANARIZATION



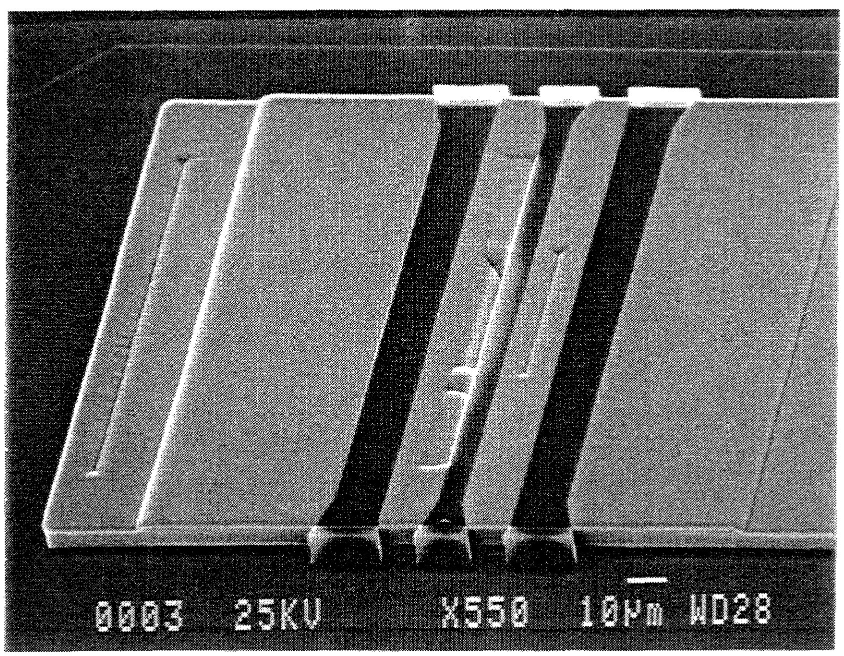


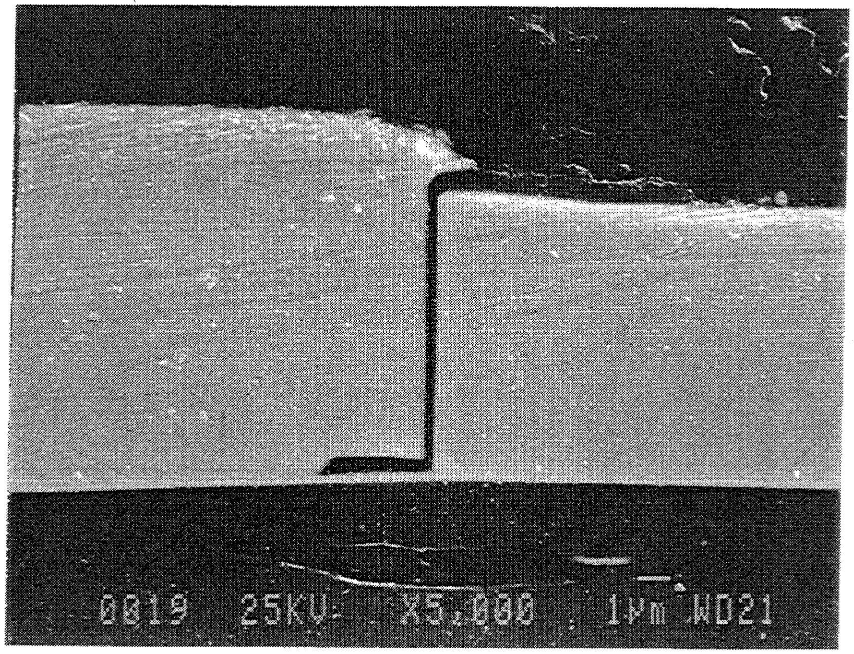


TOPOGRAPHY WITH & WITHOUT CMP

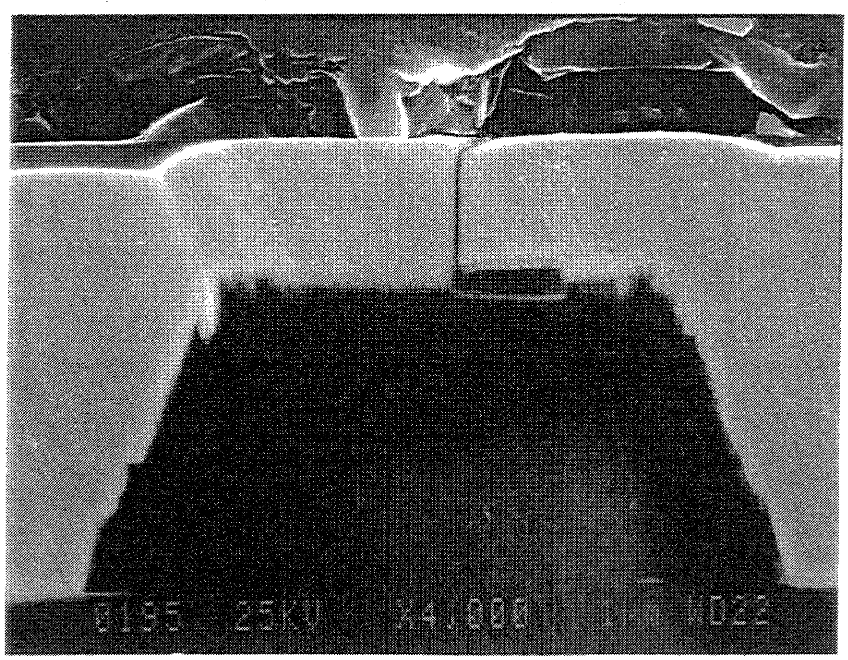


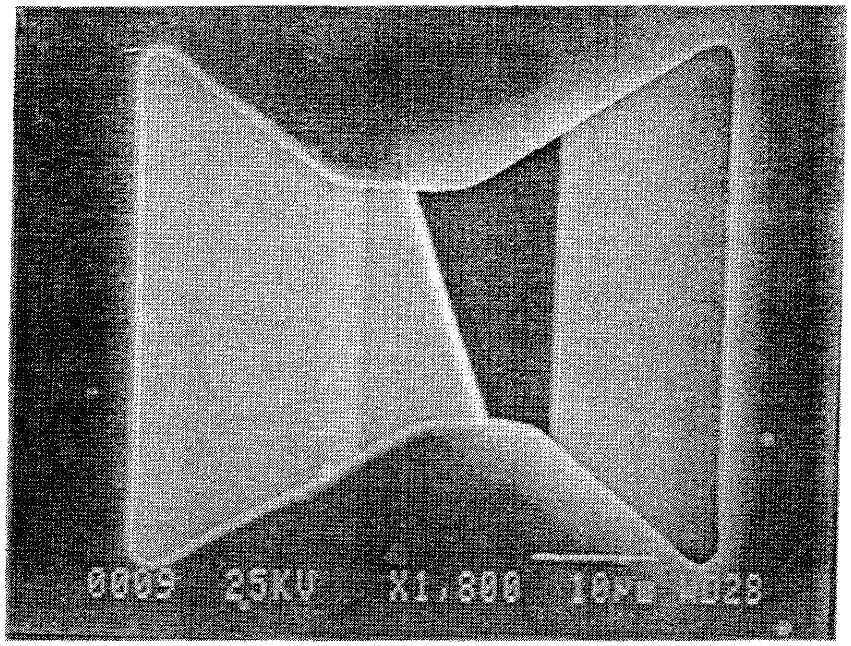
EFFECT OF CMP



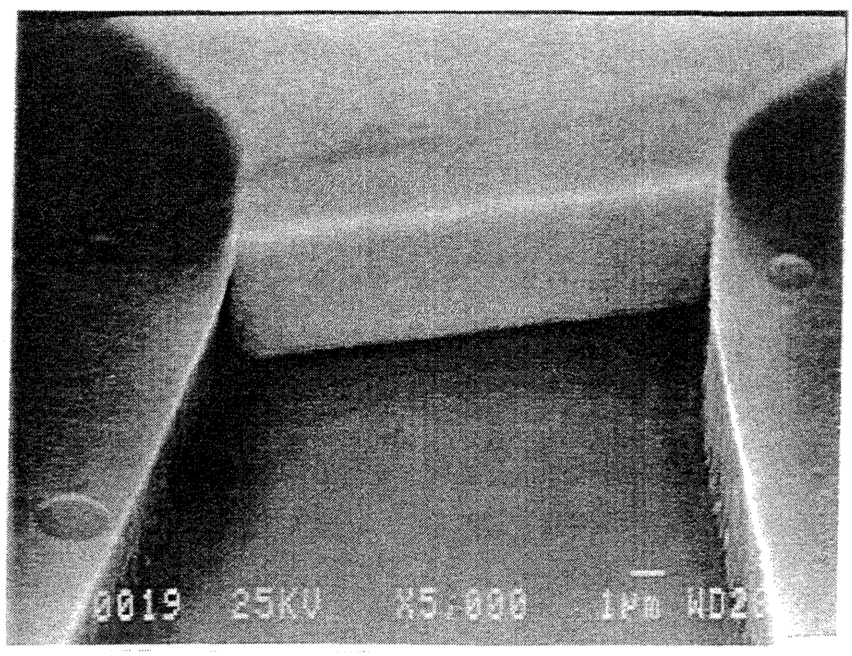


DLC GAP





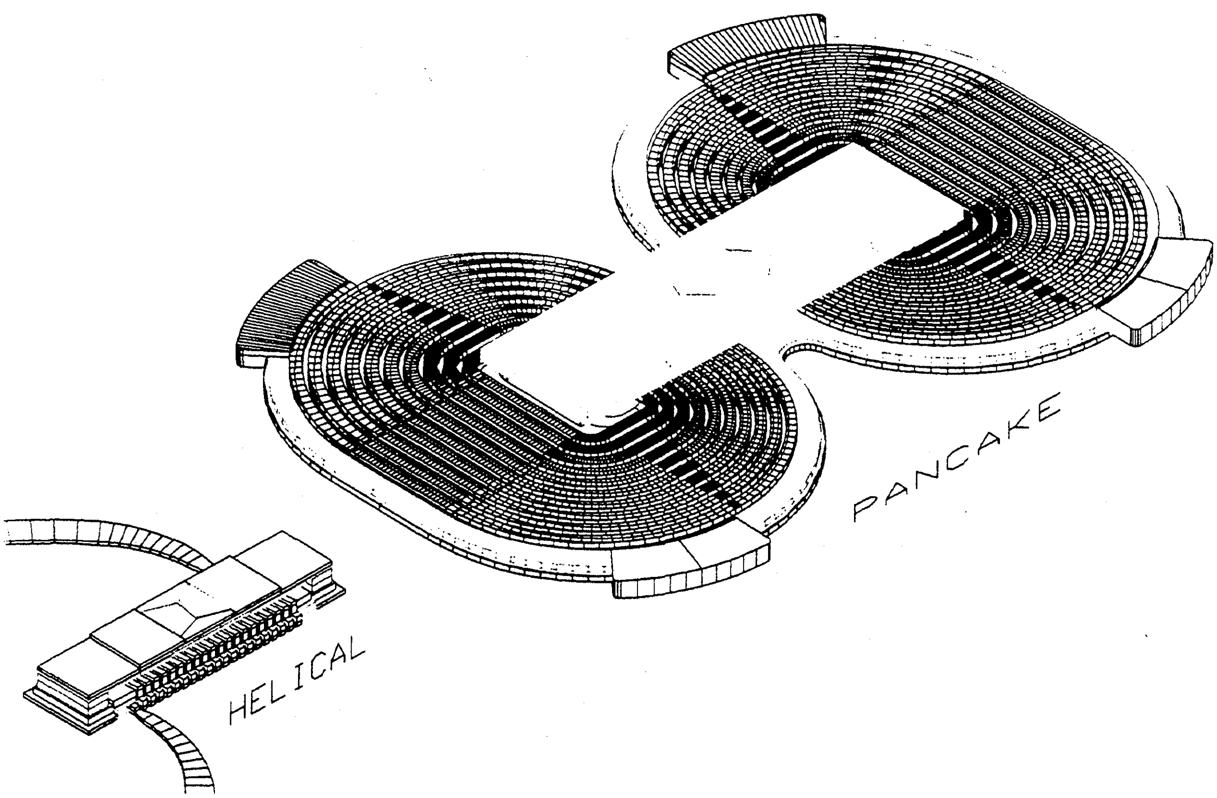
DLC FRAME (TOP VIEW)

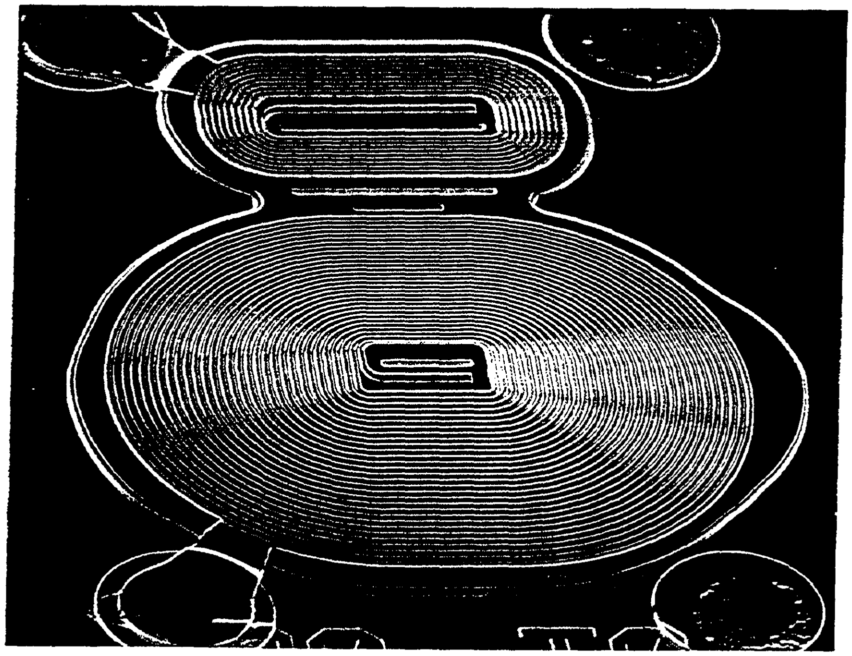


DLC FRAME (SIDE VIEW)

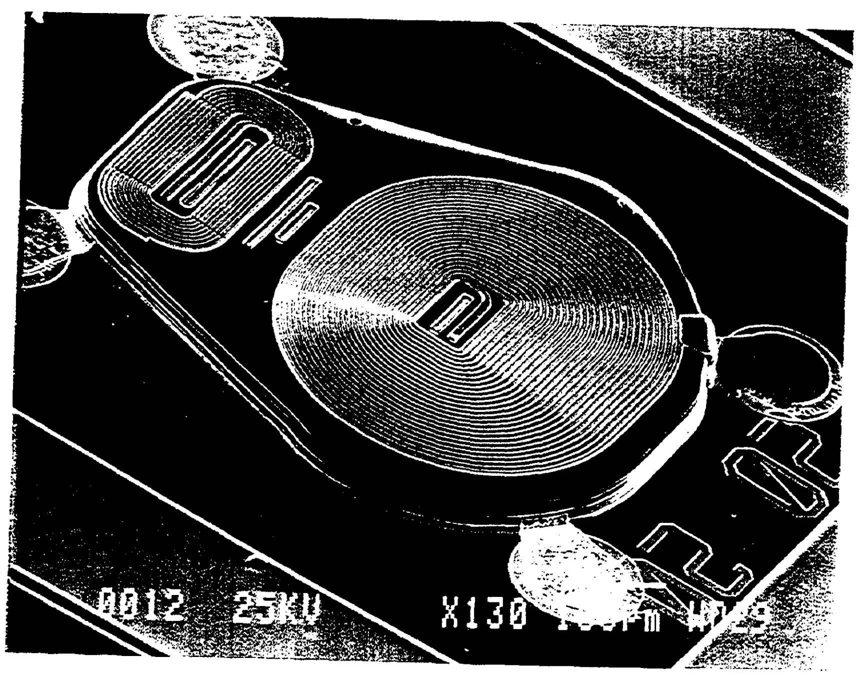
KEY DESIGN DECISIONS

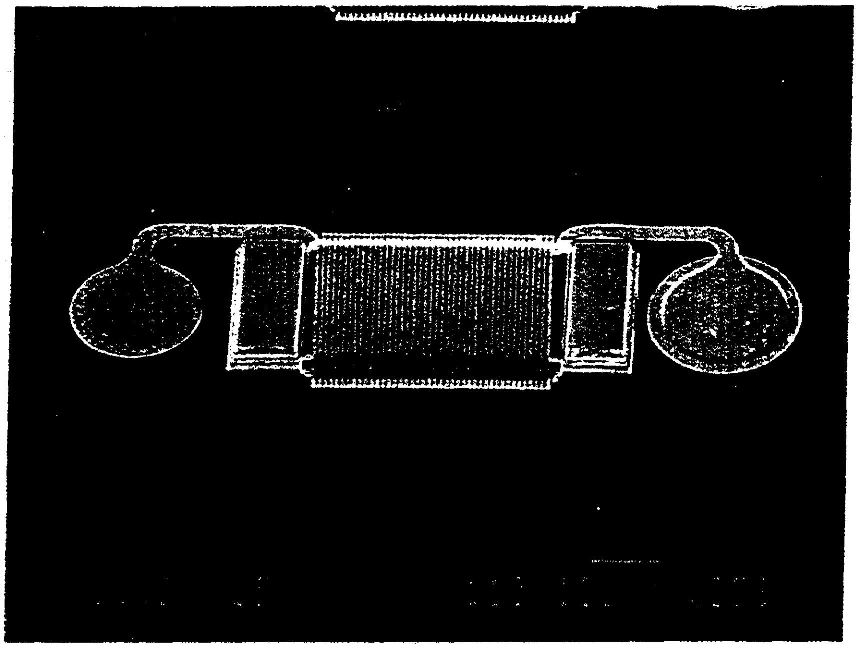
PARAMETER	SPECIFICATIONS
TOP POLE THICKNESS	< 10MICRONS
WEAR LAYER THICKNESS	< 10 MICRONS
POLES/ WEAR SURFACE AREA	<10%
P1 - P2 ALIGNMENT	0 MICRONS
HEAD CONTOURS	5 mm - 10 mm
COILS	PANCAKE AND HELICAL
NUMBER OF TURNS	20 TO 120 TURNS
NUMBER OF LAYERS	1 TO 4
GAP TO GAP DISTANCE	25 - 350 MICRONS
GAP LENGTH	0.3 TO 0.8 MICRONS
TRACK WIDTH	6 - 150 MICRONS
NUMBER OF GAPS	TWO TO THREE
GAP AZIMUTH	-20 - +20

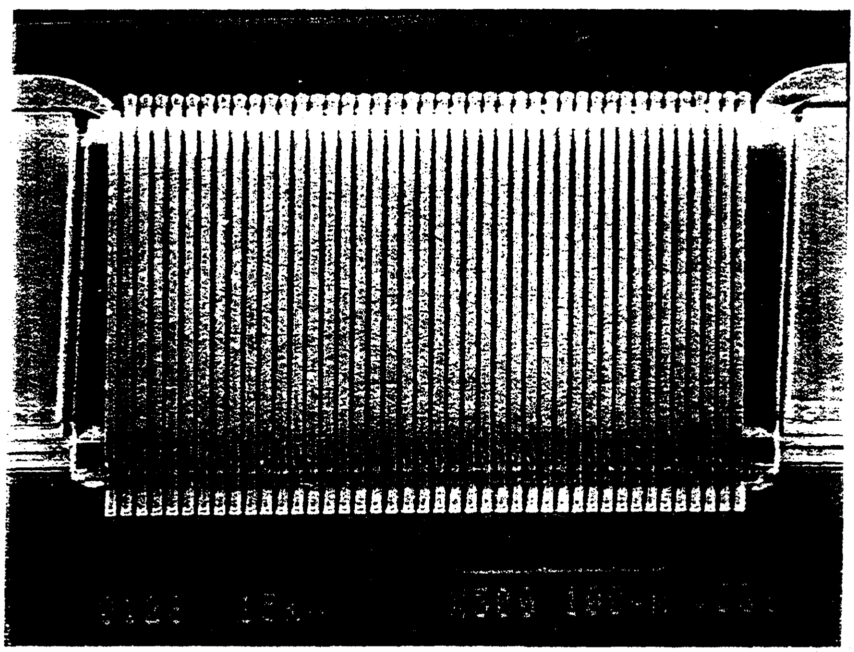




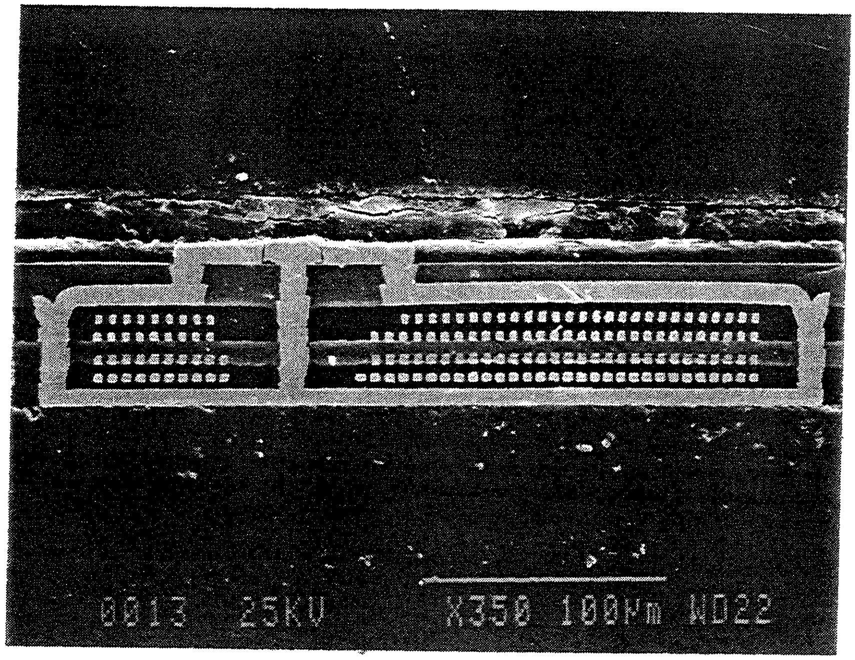
PANCAKE COIL



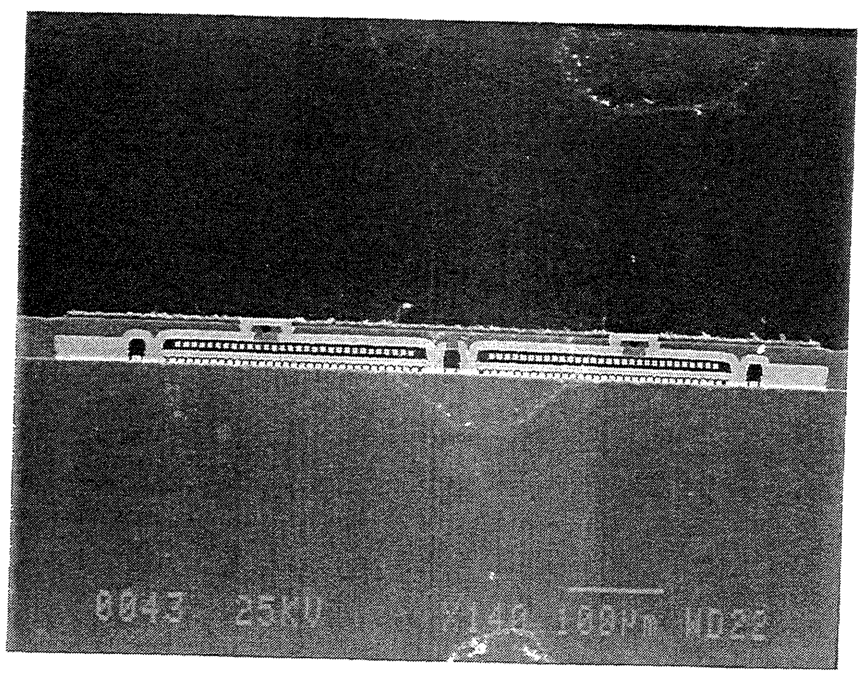


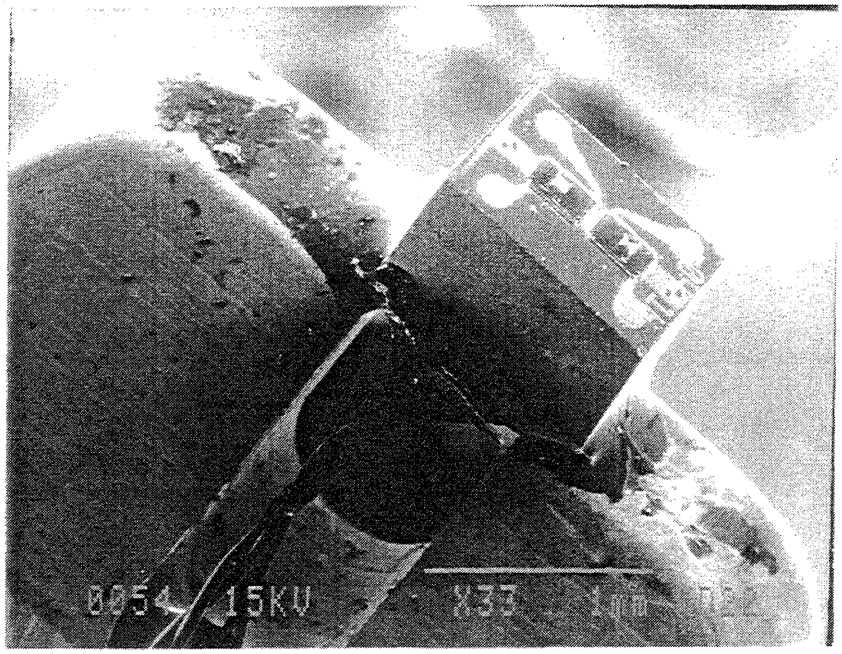


THIN FILM COIL

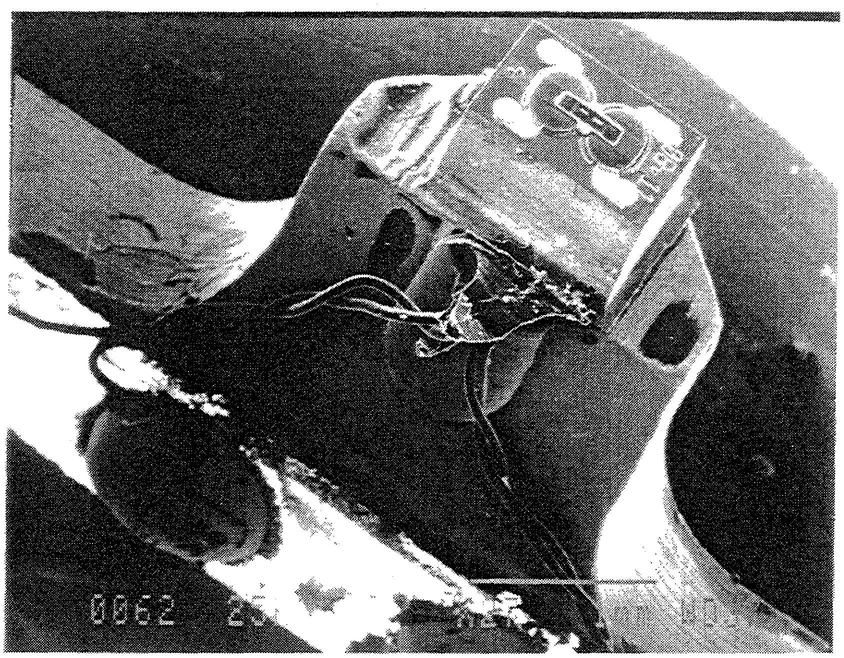


DUAL GAP HEAD STRUCTURE





HEAD ON A BLOCK



The Electrical Parameters of the Ferrite and Planar Heads

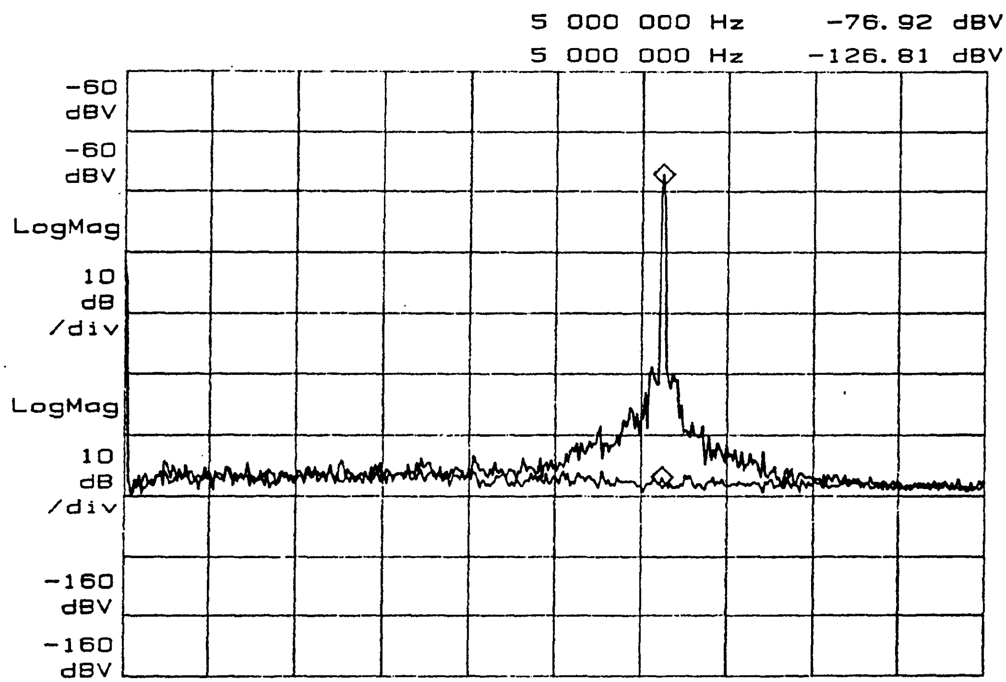
	R (1 Mhz) (Ω)	L (1 Mhz) (μH)	Output at 0.5 Mhz (μVp-p)	Output at 5 Mhz (μVp-p)
Ferrite Head	3	2.0	900	400
Planar Head	13	0.9	1100	450

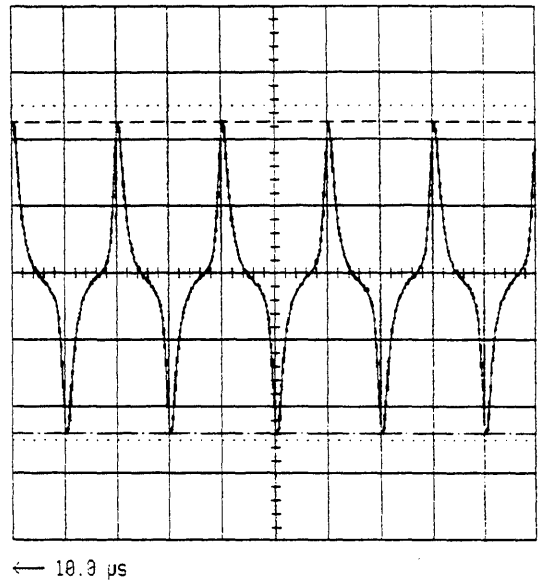
Head to Tapespeed: 5.84 M/S (VHS).

Media: VHS Tape , Hc = 620 Oe.

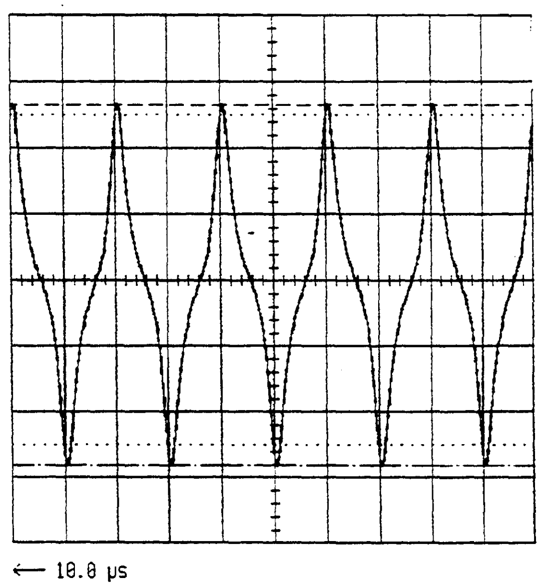
Track width: 50 μm.

NR.





FERRITE



PLANAR

APPLICATIONS

AIWA'S SEVERAL TAPE PRODUCTS

ANNOUNCEMENTS TO BE MADE SOON

TECHNOLOGY IS APPLICABLE FOR OTHER MAGNETIC STORAGE APPLICATIONS SUCH AS HARD DISK AND FLOPPY

SUMMARY

WE HAVE DEVELOPED A PLANAR THIN FILM HEAD TECHNOLOGY WHICH LEVERAGES MANUFACTURABLE PROCESSES

WE HAVE BUILT HEADS WITH MULTIPLE GAPS

THE TECHNOLOGY IS BEING DEVELOPED FOR NEW AIWA'S TAPE PRODUCTS

THE TECHNOLOGY IS GENERIC AND CAN BE APPLIED TO OTHER MAGNETIC RECORDING APPLICATIONS

THE TECHNOLOGY IS EXTENDABLE TO MR, GMR AND CMR

REMOVABLE MEDIA STORAGE--IC ISSUES

Alan Morton

Applications Manager

Silicon Systems

Removeable Media Drives;
IC Issues.

1995 Head/Media Technology Review

Presented by; Alan H. Morton

silicon systems®
A TDK Group Company

Markets Addressed

- Tape
- HD Floppy
- Optical
- Removeable Media Hard Drive

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Drive Electronics

- **Off-the-Shelf**
  Discrete (op-amps etc.)
  Extended application (HDD circuits. Audio CD circuits).
  PLD's.
- **Modified HDD**
  minor circuit change (frequency span, filter corners, etc.)
- **Application Specific**
  ground-up design for a particular type drive.

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A TDK Group Company

Major Issues

- **Standards**

  + everyone needs the same solution.
  + visible development schedule.
  – delay development time.
  – usual "committee" problems add to development risk.
  – force "trend setter or leapfrog" development.

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Major Issues

- **Backward Compatibility**
  - wide frequency span.
  - multiple codes.
- **Volume**
  - multiple solutions = fragmented market = low volume.

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Major Issues

- **Market Timing**
  - \+ developments not usually technology drivers.
  - ± HDD circuit well down learning curve.
  - – HDD circuit EOL.

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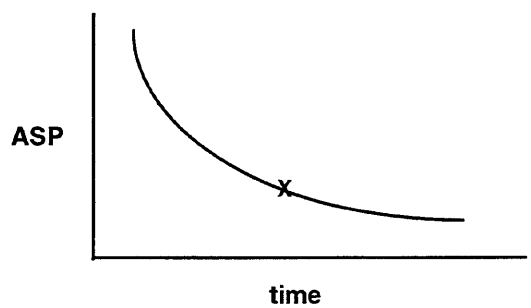
Major Issues



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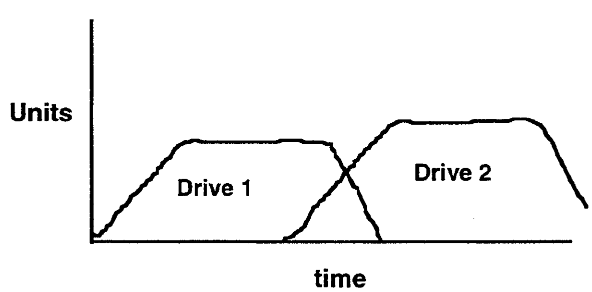
Major Issues

Drive/IC Lifetimes



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Future IC Directions

- **More growth = more standard IC's.**
  This quarter Silicon Systems will start 2, introduce 7, and qualify 3 new products.
- **DVD standards agreement = less risk.**
- **Higher data rates = more HDD circuit use.**
- **Higher levels of integration = lower cost**

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NEXT GENERATION OPTICAL DISK FORMAT

Arjen Bouwman

Director of Marketing, MMCD

Philips Consumer Electronics

Head/Media Technology Review, Stardust Las Vegas

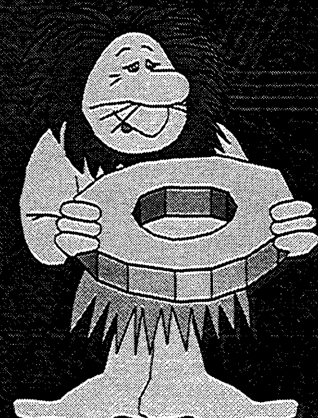
"The next generation of CD"

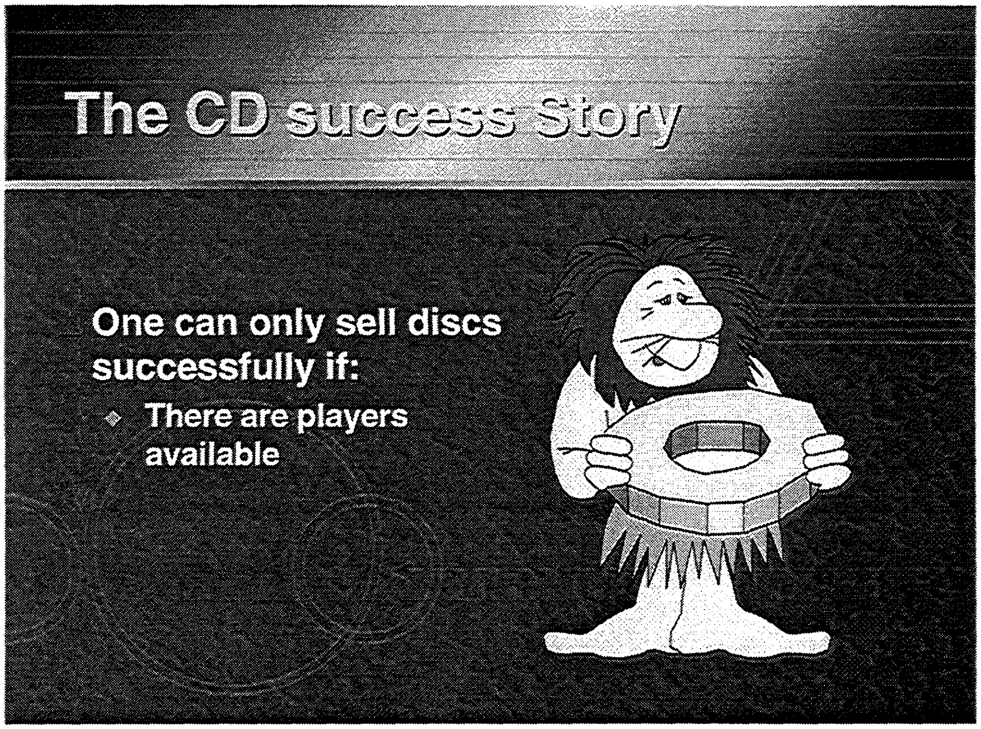
Arjen Bouwman
Director of Marketing,
high density CD

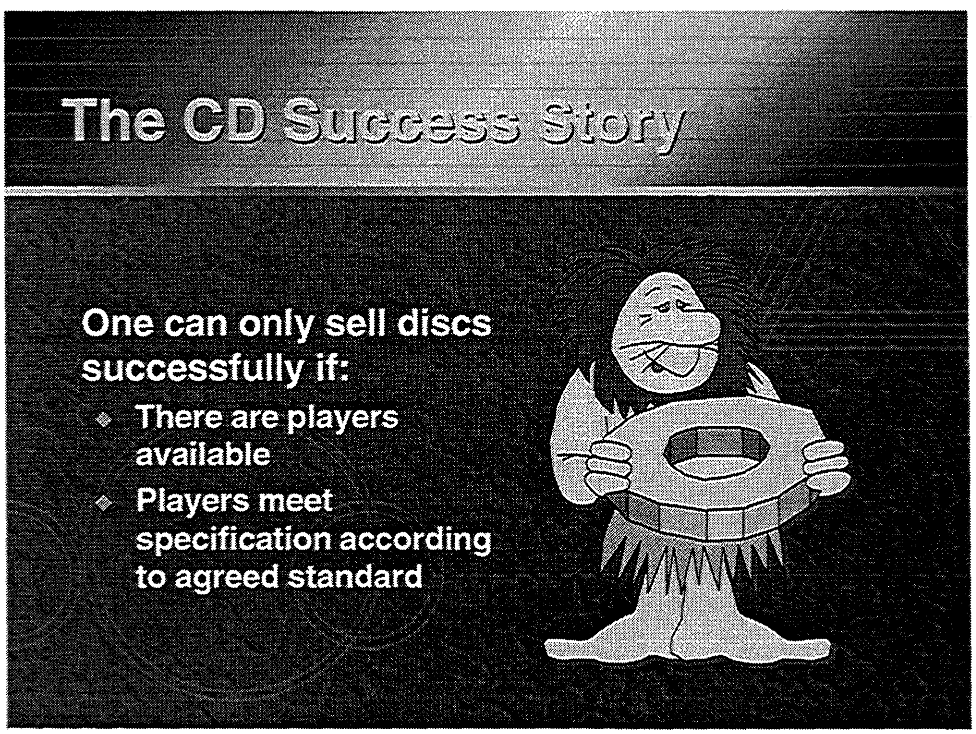
Philips

The CD Success Story

One can only sell discs successfully if:



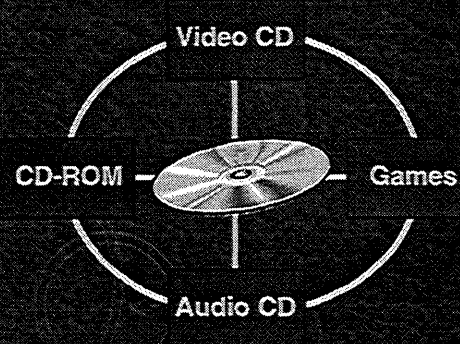

The CD success Story
One can only sell discs successfully if:
There are players available

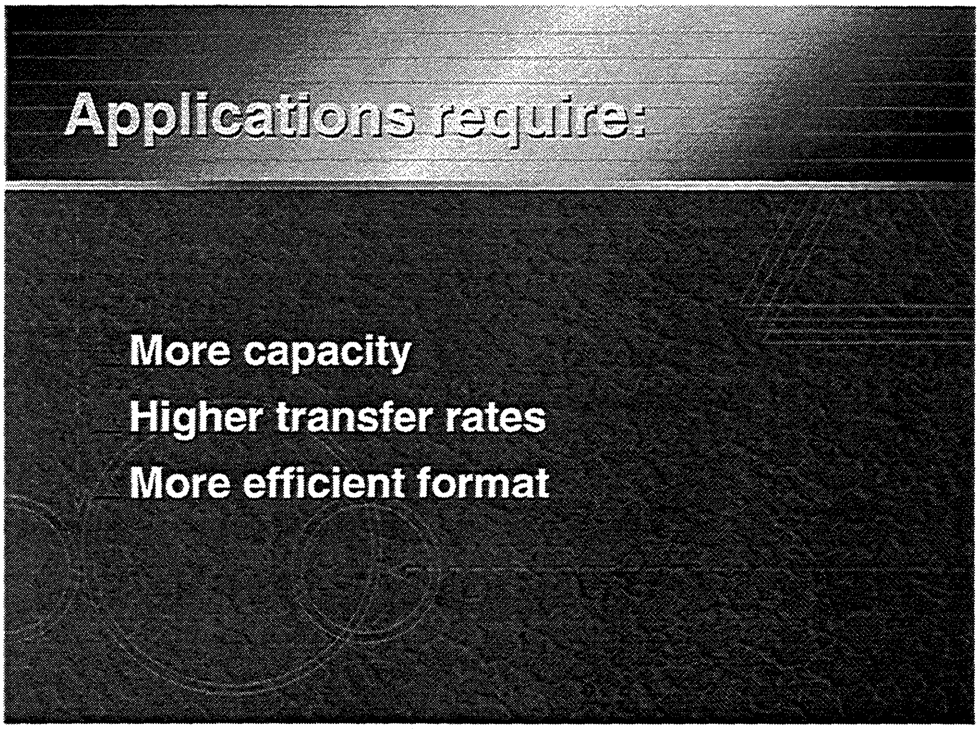

The CD Success Story
One can only sell discs successfully if:
There are players available
Players meet specification according to agreed standard

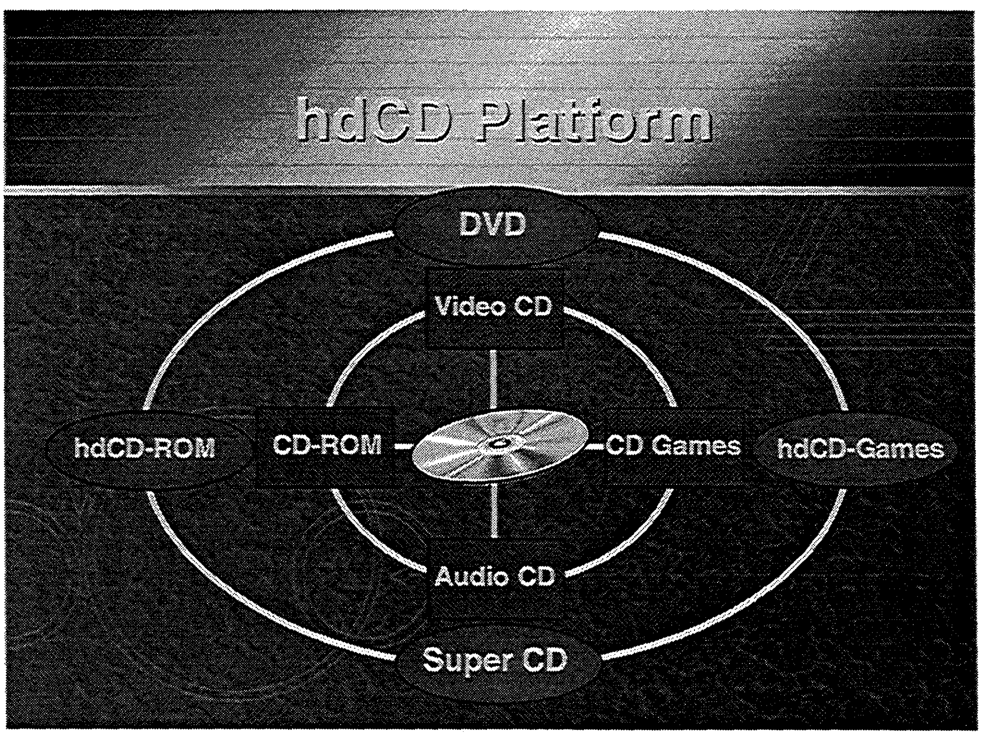
The CD Success Story

- Started in 1982 with Audio (red book)
- A major hit thanks to quality and undisputed interchangability
- Build around several applications
- Close to 500 Million players and 6 Billion discs sold
- 50 Billion $ / year industry

Basic CD Platform




Applications require:
More capacity
Higher transfer rates
More efficient format


hdCD Platform
DVD
Video CD
hdCD-ROM
CD-ROM
CD Games
hdCD-Games
Audio CD
Super CD

Two competing formats

MMCD Alliance

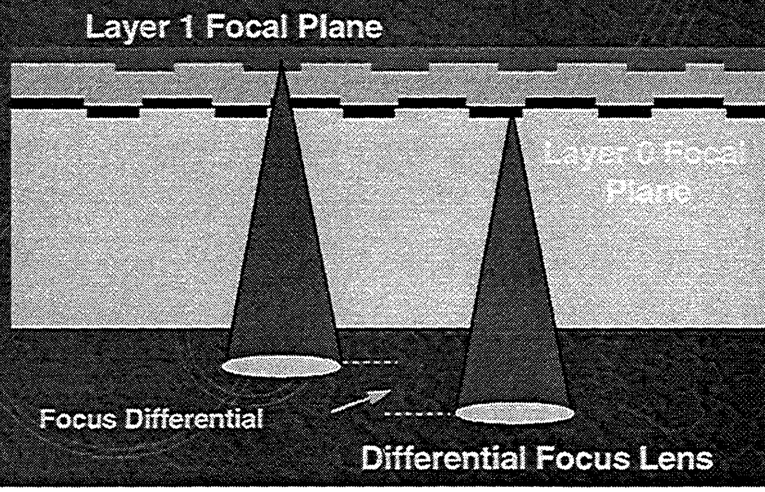
SD Alliance

Initial difference between the two format proposals

Philips focus from the beginning on:

- Backward compatibility
- Cross platform interchangability
- Interchangability (robustness)
- On-line capacity (Dual layer concept)
- Low cost manufacturing

Dual Layer Focus



Industry requirements

- **Movie industry**
  - defined by the advisory committee
- **Computer industry**
  - defined by the Technical Working Group

Most important industry requirement:

One Format !

Advantages of one format

- No risk for the consumer
- Industry more willing to invest
- Market will take off much faster
- Higher economies of scale for key components & media
- Strengths of different proposals incorporated in one format

Initial difference between the two format proposals

Philips focus from the beginning on:

- Backward compatibility
- Cross platform interchangability
- Interchangability (robustness)
- On-line capacity (Dual layer concept)
- Low cost manufacturing

Unification

On September 15th, both alliances agreed on having one format.

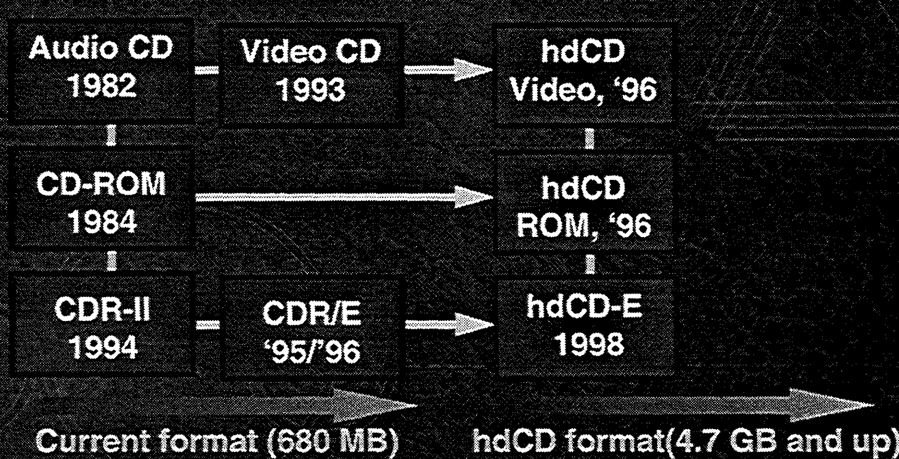
Consumer and industries win !

hdCD Specification*

Capacity	4.7 GB, one layer
Diameter	120mm
Thickness	2*0.6mm = 1.2mm
Modulation	EFM+
Error correction	RS-PC
Dual layer	Yes
Backward compatible	Yes

* preliminary

CD Road Map



CD & Standardization

CD Audio (*red book*)	1982
CD-ROM (*yellow book*)	1984
CD-i (*green book*)	1989
CD-ROM XA	1990
CD-Recordable (*orange book*)	1990
Video CD (*white book*)	1993
CD Recordable (*orange book II*)	1994

Philips invites you to:

A demonstration in the Main Hall, Booth (L230) of the:

- First fully integrated CD-ROM player
- First fully integrated DVD player

From Monday through Friday from 10.00am - 5.00pm

HEAD/MEDIA TEST TECHNOLOGY

Gerald Juskovic

Senior Product Manager

LeCroy Corporation

Head/Media Test Technology

Gerry Juskovic
Senior Product Manager
LeCroy Corporation
(914) 578-6037

LeCroy
Innovators in Instrumentation

Head/Media Signal Analysis Tools

- Digital Oscilloscope
- Timing Analyzer
- Spectrum Analyzer
- Spin Stand
- PC Software

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Innovators in Instrumentation

Head/Media Analysis Stages

- Advanced Dev - Spin Stands, DSOs, PCs
- Drive Development - DSOs, TAs, SAs
- Drive Pilot Production - DSOs, TAs, SAs
- Failure Analysis - DSOs, TAs, SAs, Analog Scope

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Innovators in Instrumentation

Head/Media Analysis Issues

- Non-Integrated measurement and waveform display
  - Were any anomalies missed in the measurements?
  - What does a measurement anomaly look like?
- Availability of drive specific measurements?
  - Timing Analyzer
  - Spectrum Analyzer
  - DSO
- Cost and complexity of multiple instruments

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Innovators in Instrumentation

Head/Media Analysis Issues (cont)

- Inability to perform measurements on integrated disk drives - Spin Stands
- Limited ability to capture and measure drive signal sub-sections
- Comprehensiveness and flexibility of measurements
- Complexity and overhead of development of PC measurement software

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Ideal Head/Media Analysis System

- Drive Specific Measurements
- Integrated Signal Display and Measurements
- Measurement Processing and Analysis Tools
- High Performance
- Low Cost
- Consistent and Accurate Measurements
- Measurement Flexibility
- Easy to Use

Long memory DSO with Integrated Drive Measurements would provide near ideal solution

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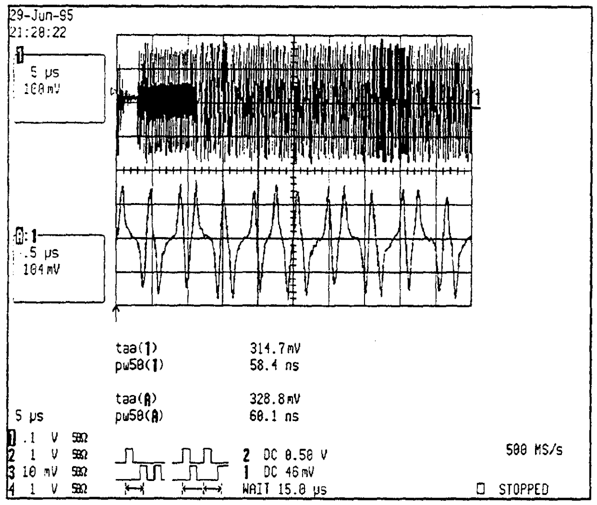
Integrated Display and Measurements



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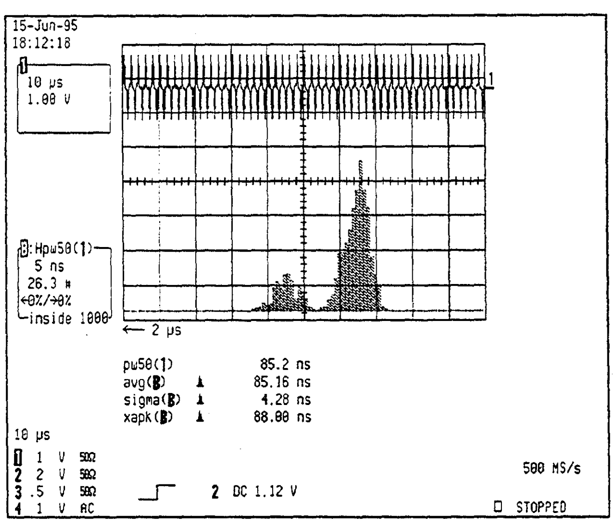
Measurement Analysis Tools - Histograms, FFTs, Correlation



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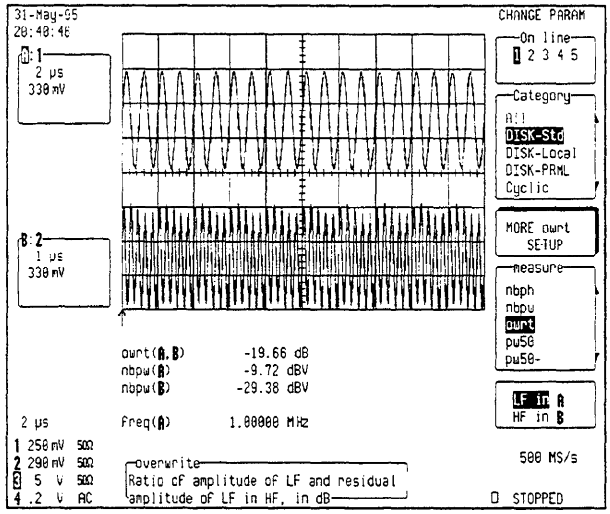
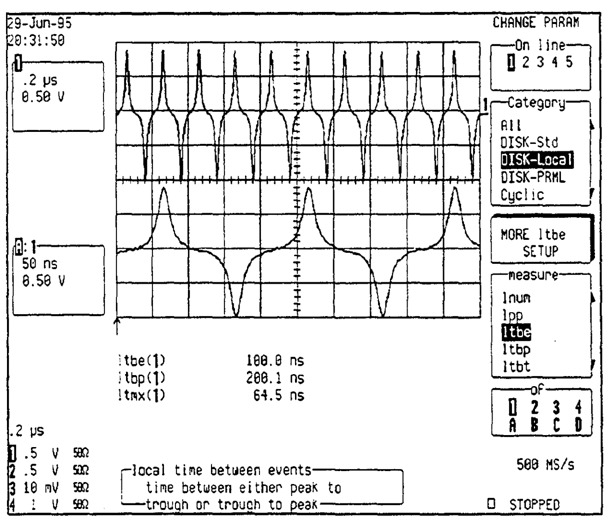
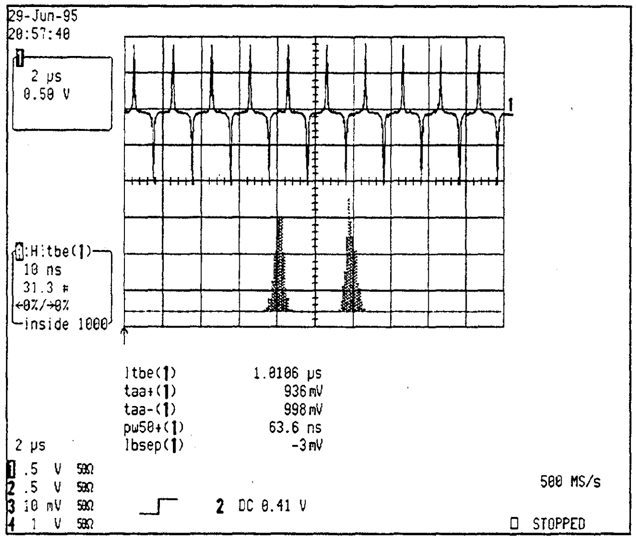
Overwrite and Narrow Band Power Measurements



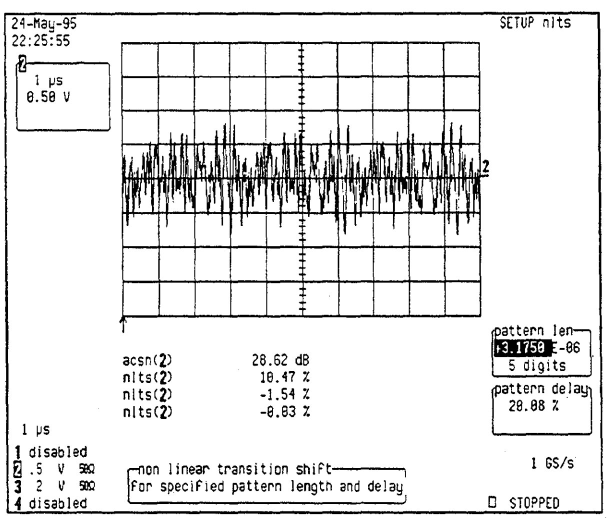
Peak Timing Analysis



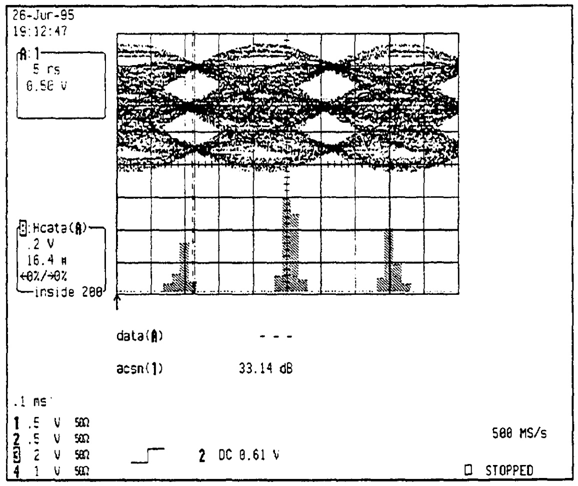
MR Asymmetries Measurements



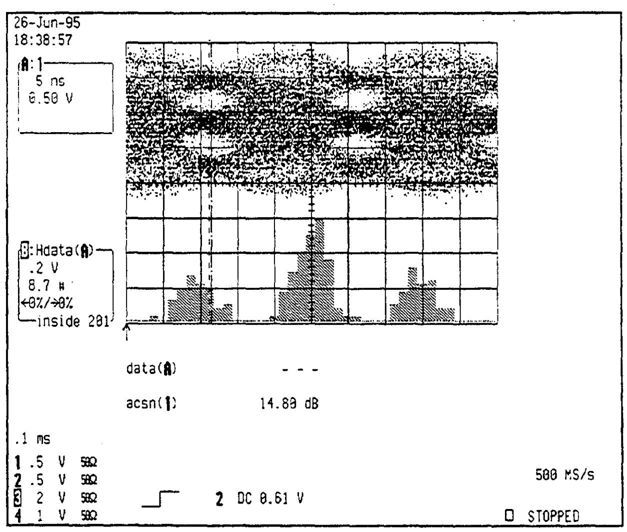
PRML - NLTS and ACSN



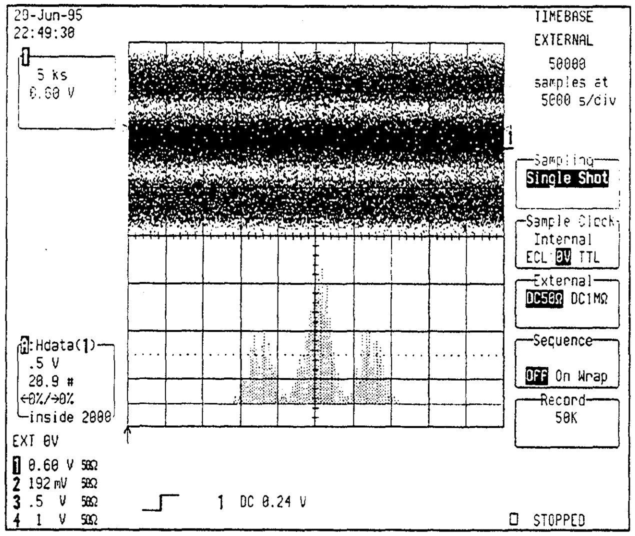
PRML Level Analysis - Clean Signal



PRML Level Analysis - Noisy Signal



PRML Level Analysis - Noisy Signal



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Recommended Drive Analysis Configuration

- Advanced Dev
  - Spin Stand - High volume testing
  - DSO w/ Integrated Measurements - Signal Analysis
  - PC - Custom Measurements
- Drive Development - DSO w Drive Measurements
- Drive Pilot Production - DSO w Drive Measurements
- Failure Analysis - DSO w Drive Measurements, Analog Scope

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Conclusions

- DSOs with integrated drive measurement capability provides significant advantages for head/media analysis
- Head/Media analysis tool configurations need to be re-examined based on new DSO capabilities

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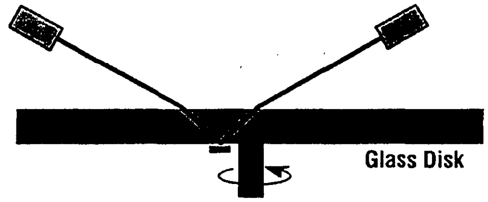
POLARIZATION INTERFEROMETER FOR FLYING HEIGHT TESTERS

Robert Smythe

Director of Marketing & Sales

Zygo

Polarization Interferometer for Flying Height Testing



Peter de Groot and Robert Smythe

coworkers:

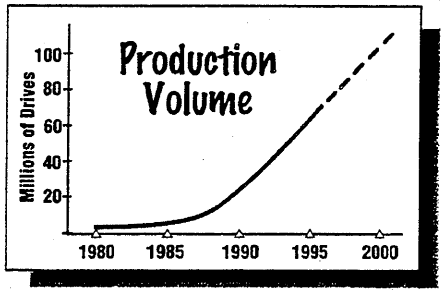
L. Deck, J. Soobitsky, J. Biegen & the Zygo Flying Height Test DIvision

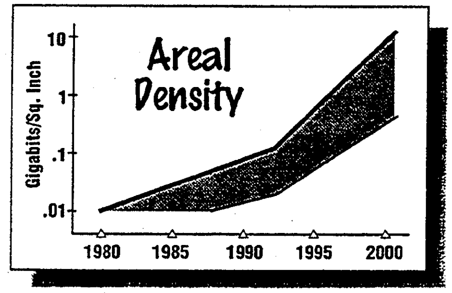
zygo®

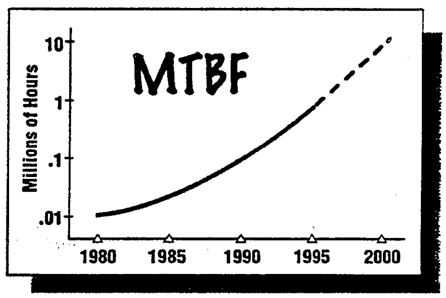
Outline

- The problem: Need improved flying height test equipment
- Traditional solution... Multiple-color intensity measurement
- Zygo solution... Polarization interferometry
- Advantages & performance tests

Hard Drive Trends

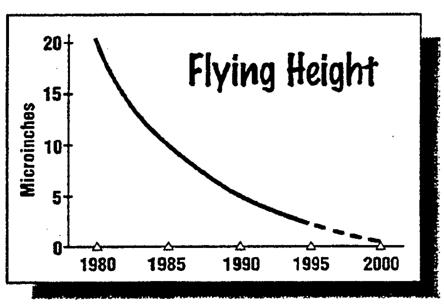


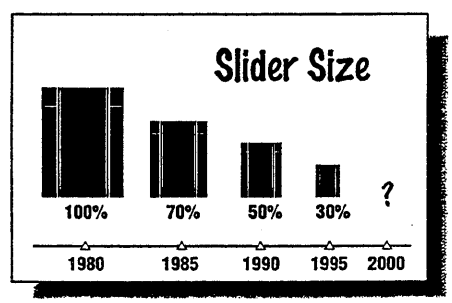


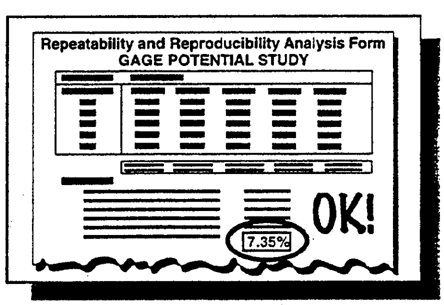


Current trends are both exciting and challenging for hard drive manufacturers.

Hard Drive Trends







Flying height control is key to disk drive performance.

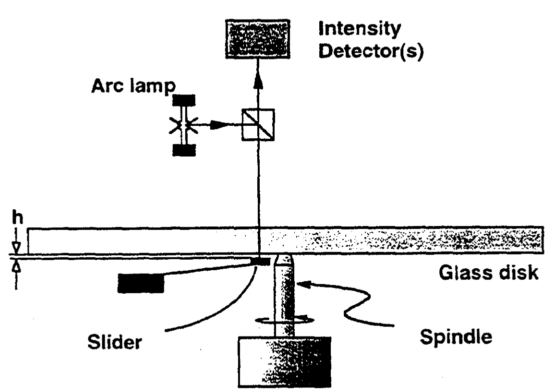
The Ideal Flying Height Tester

- Dynamic response (>200kHz)
- Gauge capability down to contact
- High throughput ≈120 parts per hour
- Ergonomic
- Low cost of ownership
- In-situ measurement & compensation for material properties (n&k)

Today's talk focuses on the sensor technology for the ideal FHT...

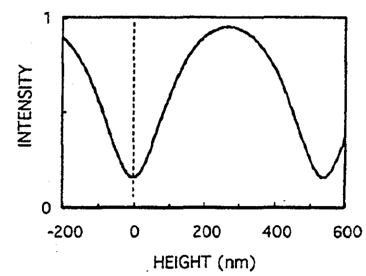
Traditional Solution

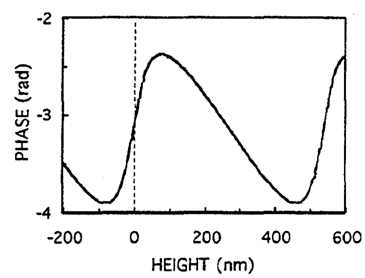
- 1921: W. Stone invents intensity-based flying height tester
- White light version introduced for data storage sliders (Fridge, 1984)
- Three-color version for dynamic testing (Lacey, 1992)



Excellent Sensitivity Down to Contact

- **Receiver measures...**
  - » Reflected intensity
  - » Interference phase
- **Phase & intensity are complementary:**
  - » When intensity is poor measure of flying height, phase takes over
- **Complementary data means...**
  - » Excellent repeatability
  - » Ideal for low flying heights
  - » Single, long-life source (> 20,000 hrs)
  - » In-situ n&k measurement





In-situ n&k

- **Accurate flying height requires n&k**
- ***Traditional method:*** **Check sliders separately with an ellipsometer**
- ***Zygo approach:*** **Measure n&k in situ using complex reflectivity**

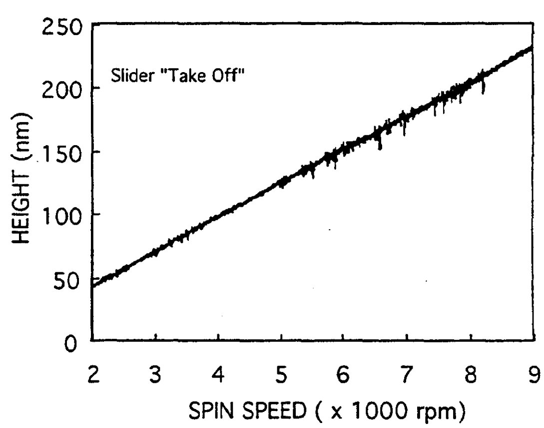
In-situ n&k

		n	k	PCOR	
Zygo in-situ measurement	Trial 1	2.642	0.115	-178.5°	
	Trial 2	2.647	0.104	-178.7°	
	Trial 3	2.829	0.144	-178.4°	
	Trial 4	2.584	0.060	-179.2°	
	Average	2.676	0.106	-178.9°	⇨ 1.7 nm
Compare with	Independent Ellipsometric Measurement	2.627	0.102	-178.7°	⇨ 2.0 nm

Silicon Carbide

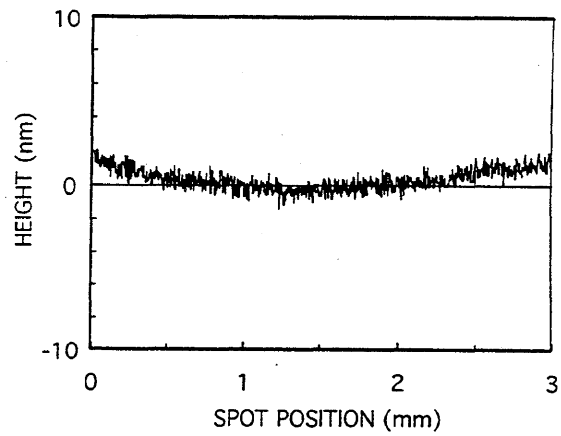
Flying Height vs Spin Speed

- **Here is the traditional "take off" test**
- **Residual scatter after linear fit is 2nm**



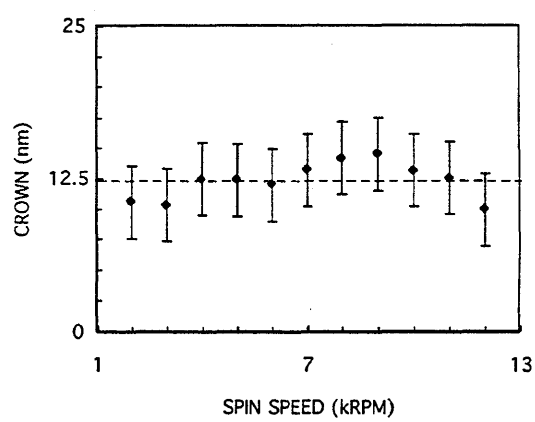
Contact Measurement

- Lateral scan of Silicon Carbide sample wrung to BK7 disk
- Data scatter at 330kHz is less than 0.5 nm RMS



ABS Crown Measurement

- Take height at trailing edge, leading edge and midpoint of standard slider
- Crown = 0.5 (lead + trail) – midpoint
- Variation with spin speed is <2 nm RMS



Summary

- **Need fast, accurate, reliable testing**
- **Traditional intensity-based method no longer a sufficient solution**
- **Polarization interferometry offers...**
  - » Excellent repeatability & reproducibility
  - » High sensitivity down to contact
  - » High reliability (> 20,000 hr source)
  - » In-situ n&k

September, 1995 Zygo introduces the "Pegasus 2000" at Diskcon

A GENERAL ERROR MARGIN THEORY

Tim Perkins

Consultant

Hewlett-Packard

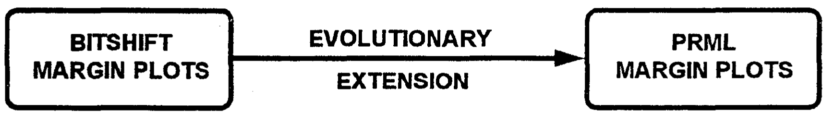
A GENERAL ERROR MARGIN THEORY

By Tim Perkins
Consultant for the
Hewlett-Packard Corporation
(805) 682-4418

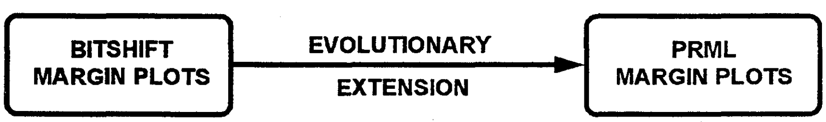
THE PRML TEST PROBLEM:

- Bitshift tests are widely used in the disk drive industry for peak detection channels.
- The industry is migrating from peak detection to PRML channels.
- Bitshift tests are inappropriate for PRML channels.
- WHAT WILL WE USE WITH PRML CHANNELS TO REPLACE BITSHIFT TESTS?

THE HOLY GRAIL OF PRML TESTS

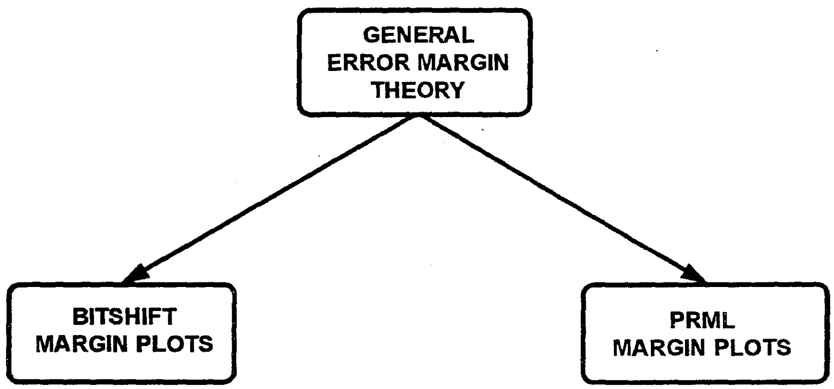


THE SEARCH IS NOT EASY!



BITSHIFT	PRML
PEAK TIMING	VOLTAGE SAMPLES
PEAK BY PEAK	VITERBI DETECTOR
ONE FLAVOR	PR4, EPR4, E^2PR4

TOP-DOWN SOLUTION



OVERVIEW

- ERRORS AND MARGINS
- SEQUENCED AMPLITUDE MARGIN (PRML)
- GENERAL ERROR MARGIN THEORY
  (Only two sentences are required!)
- DISADVANTAGES & ADVANTAGES

ERRORS ARE DISCRETE

- A BIT IS EITHER CORRECT OR INCORRECT.
- EVERY CORRECT BIT IS THE SAME.
- VERY LITTLE PERFORMANCE QUALITY INFORMATION FROM A CORRECT BIT.
- NEARLY EVERY BIT IS CORRECT.

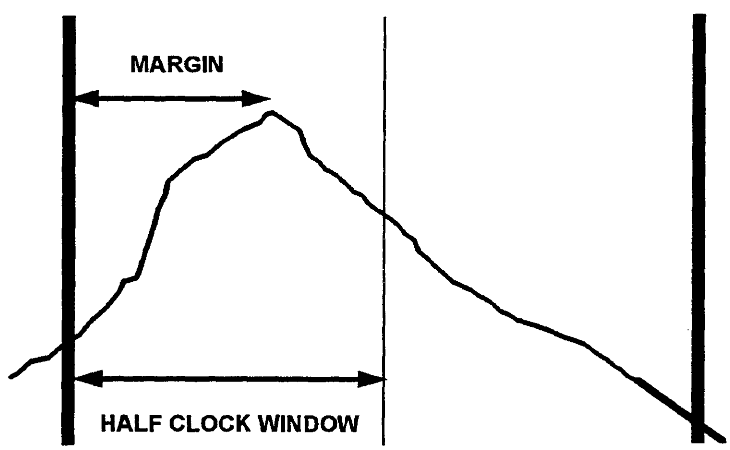
MARGIN IS CONTINUOUS

- HOW FAR ARE YOU FROM MAKING AN ERROR?
- SOME CORRECT BITS ARE BETTER THAN OTHERS.
- EVEN CORRECT BITS CONTAIN A GREAT DEAL OF INFORMATION.

MARGIN FOR A SINGLE PEAK
(peak detection)

The minimum change in the peak timing required to produce an error.

PEAK TIMING MARGIN



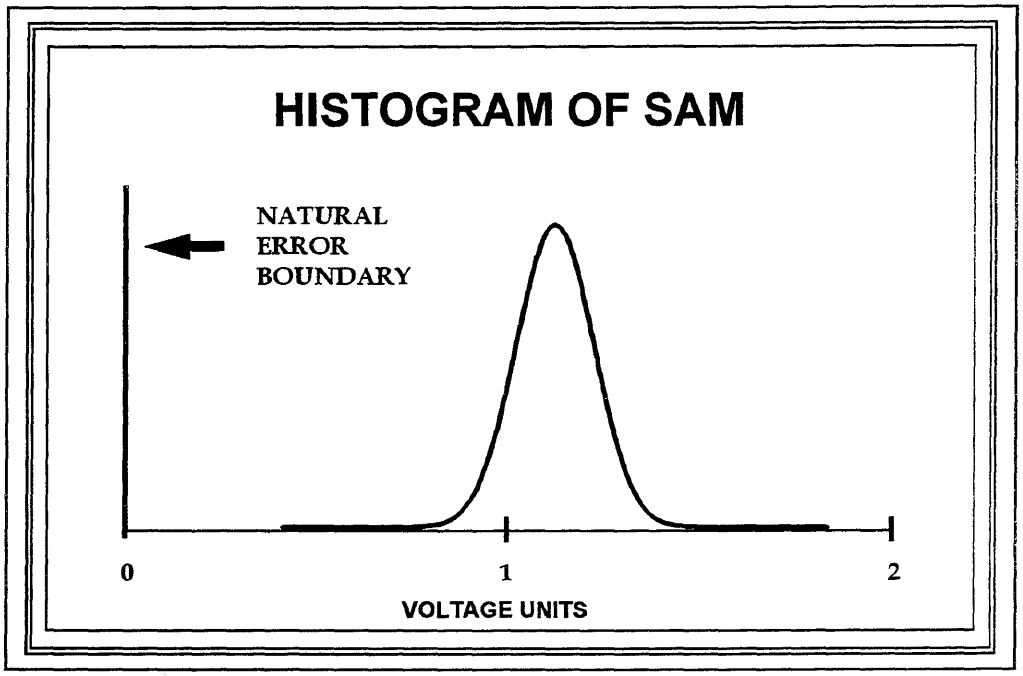
MARGIN FOR A SINGLE BIT (PRML)

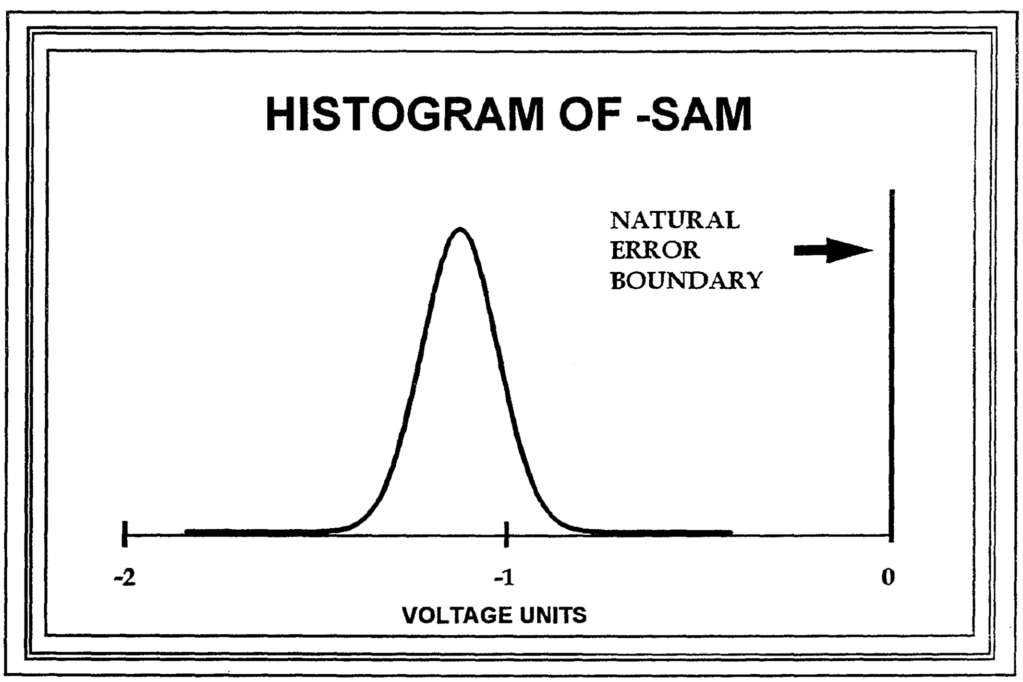
The minimum change in the sampled voltage required to produce an error.

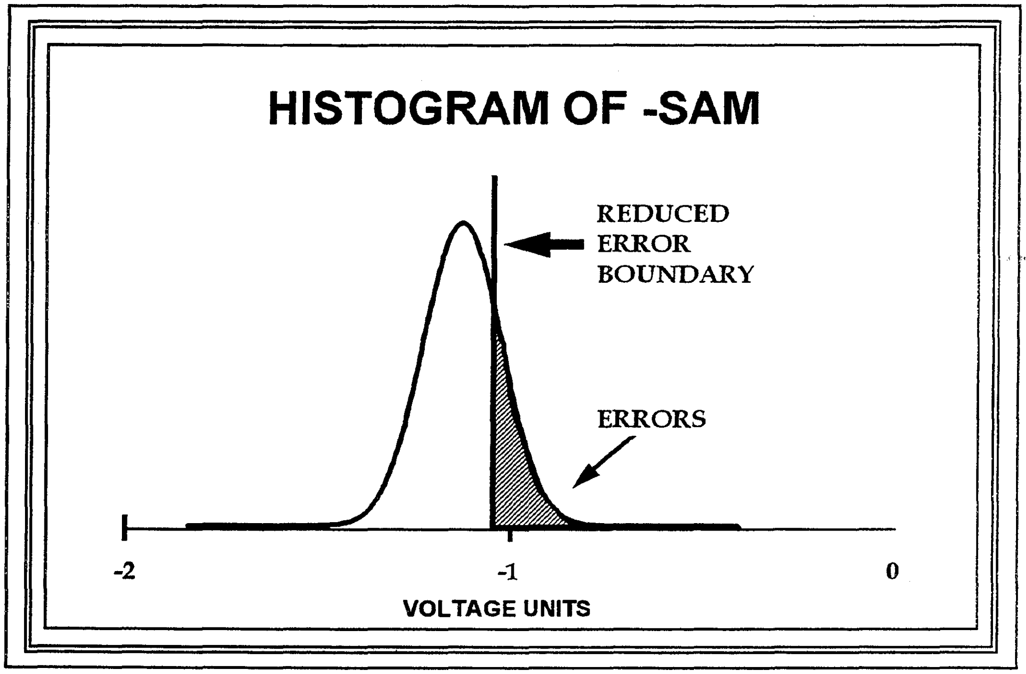
Sequenced Amplitude Margin

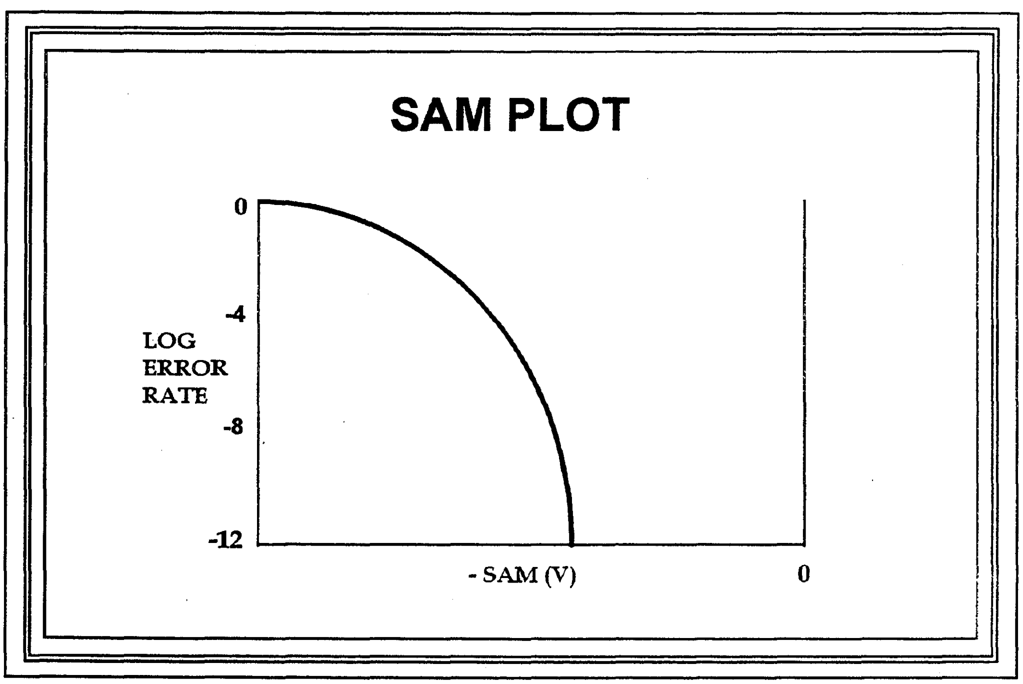
. . . -0.2 [1.1] 1.0 -0.8 -1.1 0.0 . . .

- Compute SAM one sample at a time.
- Without altering the other samples, slowly change the value of the sample of interest.
- SAM is the minimum change in the sampled voltage necessary to produce an error.

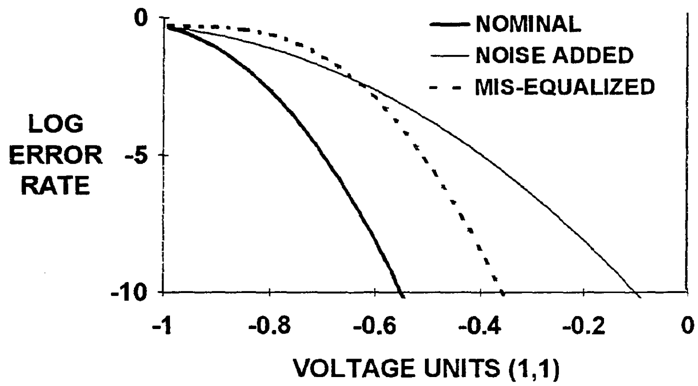

HISTOGRAM OF SAM
NATURAL
ERROR
BOUNDARY
0
1
2
VOLTAGE UNITS


HISTOGRAM OF -SAM
NATURAL
ERROR
BOUNDARY
-2
-1
0
VOLTAGE UNITS


HISTOGRAM OF -SAM
REDUCED
ERROR
BOUNDARY
ERRORS
-2
-1
0
VOLTAGE UNITS


SAM PLOT
0
-4
LOG
ERROR
RATE
-8
-12
- SAM (V)
0

SEQUENCED AMPLITUDE MARGIN



GENERAL ERROR MARGIN THEORY

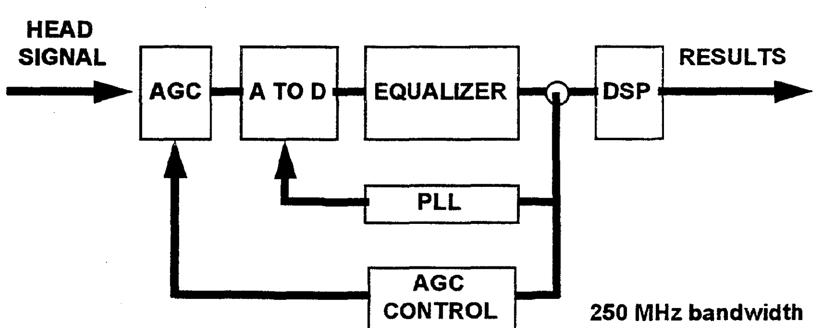
- Margin for a single bit is the minimum change in the (critical signal feature) required to produce an error.
- A margin plot for a large sample of bits is the complementary cumulative probability function of -margin values.

DISADVANTAGES OF PRML MARGIN MEASUREMENTS

- Access to the sampled voltages is required.
- Many computations are required.

(Here comes the enabling technology part.)

HP E5020S PRML READ/WRITE ANALYZER

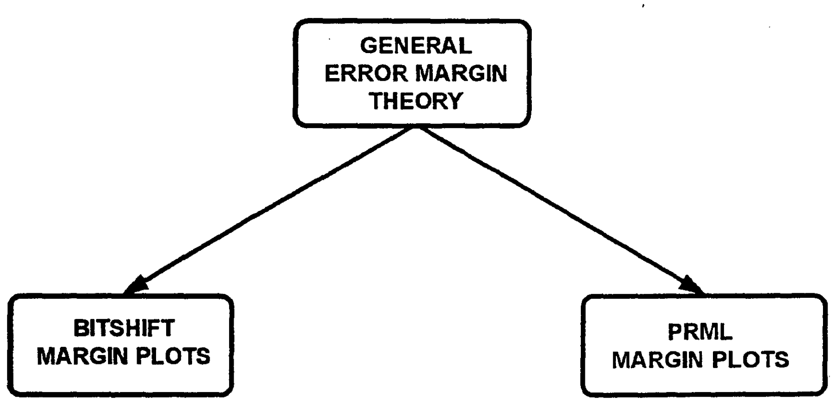


250 MHz bandwidth
8 bit a to d
500 Mega-samples/sec.

ADVANTAGES

- Bitshift margin experience can be extended to PRML channels.
- SAM can replace bitshift.
- Can extend margin techniques to any synchronously sampled channel.
  (PR4, EPR4, E^2PR4, DFE, . . .)

THIS IS SIMPLE!



Test Technology for High Speed Interfaces

Who Needs to Test Storage Devices & Subsystems - And Why

David James
Xyratex Test Systems
Havant,
U.K.

x y r a t e x

Outlook

- High Speed Serial and Parallel Interfaces require thorough testing at the development and production stages
- Measurement tools and facilities are becoming available and have much more function than previous generations
- Industry Groups e.g. SSA-IA and FC-LC are generating clear specifications and compliance requirements to allow multi-vendor components to be integrated easily

Test Systems Applications - Target Mode Emulation

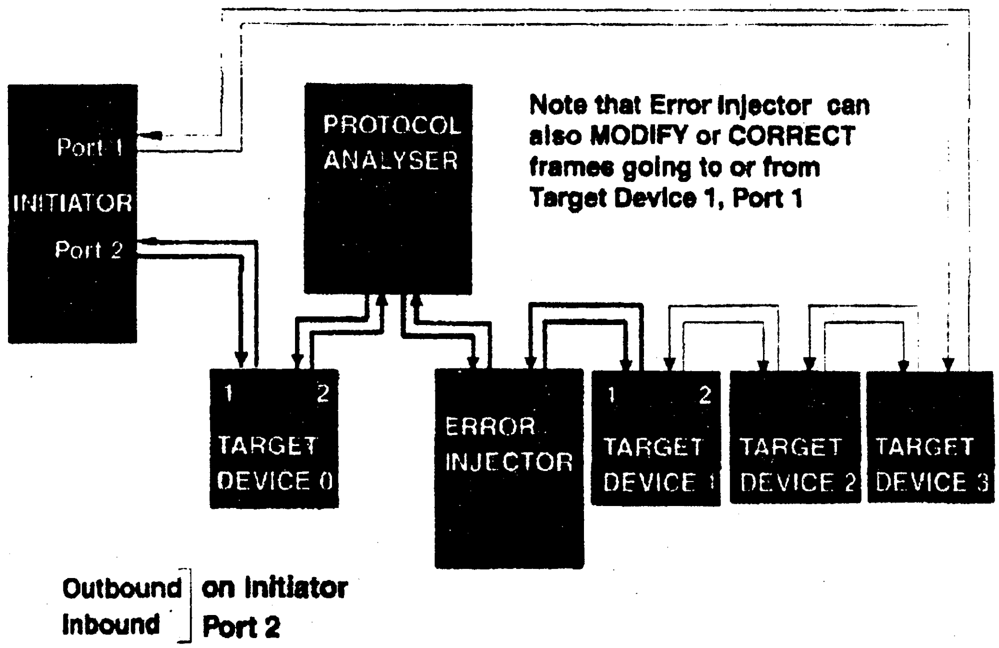
- Testing of initiators using real drives is not totally adequate
- Real drives cannot easily be made to generate specific errors
- A Target Mode Emulator to generate known errors under program control is required
- This typically a re-programmed Test Initiator Requirements are similar -

  Test Case Language
  Flexible User Interface
  High Performance

Test System Applications - Compliance Testing

- Electrical compliance testing of high speed links requires specialised knowledge and equipment
- Protocol Layer Specifications are becoming VERY complex (FC, SSA etc.)
- Analysis of error recovery and multi-initiator behaviour is non-trivial
- System designers and integrators need to qualify devices for volume useage

Example Test Configuration - SSA



Test Functions

Initiator - execute series of commands

Required - Test Case Language
Flexible User Interface
High Performance

Protocol Analysis - capture interface traffic

Required - Very High Speed Logic
Powerful Triggering Features
Optimised Display Functions

Error Injection - inject known errors or correct device errors

Required - Very High Speed Logic, State Machine
or modified controller silicon
Powerful Triggering Features

Interface Test Requirements

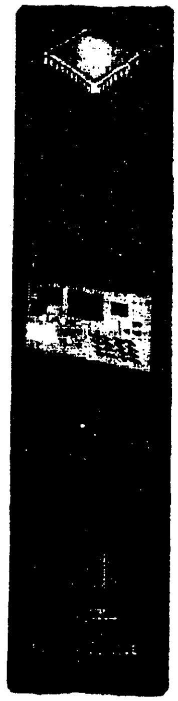
Controller & Target Silicon

Target Devices

Bus Adaptors

Subsystems

Systems



Electrical compliance :
(Signal analysis, Link error rates)
Error handling (hardware)

Electrical compliance
Error handling (hardware and firmware)
Protocol compliance
Performance and benchmarking
Manufacturing test processes
Field engineering

Device compliance (qualification)
Performance and benchmarking
Manufacturing test processes
Field engineering

INDUSTRY OVERVIEW

Dennis Waid

President

Peripheral Research Corporation

1995 Head/Media Technology Review

November 11, 12 1995

Stardust Hotel and Casino
Las Vegas, Nevada

Industry Overview

- Systems Products
  - ✔P.C. Markets Strong, 58 Million 1995
    Strong Fourth Quarter, School, Holiday's
    Compaq, IBM, Toshiba Strong, Apple Weaker
  - ✔European Markets Improving
  - ✔Advanced Interfaces Gaining
    SSA / FC-AL
  - ✔Notebook PDA Still Slow
  - ✔Disk Array Markets Increasing
  - ✔VOD Markets Increasing

Industry Overview

- Disk Drives
  - ✓1995 Demand Higher Than Anticipated
  - ✓1.8 Inch Markets Slow But Increasing
  - ✓3.5 Inch Markets Strong, Will Continue
  - ✓5.25 Inch Markets Declining, New Activity in High Performance

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Industry Changes Continue

- Joint Ventures, Expansion, Consolidations
  - ✓Seagate / Conner
  - ✓Phase Metrics, ProQuip. Cambrian, Helios
  - ✓Headway Technologies, Seagate Technology
  - ✓Xyratex Has Spun Off from IBM Havant
  - ✓Komag, Stormedia, Conner Media Expansion
  - ✓Seagate, Read-Rite Head Expansion
  - ✓Surface Technology was Acquired by Stormedia
  - ✓Possible Additional Mergers

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Industry Changes Continue

- New Products / Technologies
  - ✓Flash Memory Products
  - ✓MR Heads, Integrated Suspensions
  - ✓Fluid Film Motors
  - ✓Alternative Substrates
  - ✓Optical Disk Drive Products

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Worldwide PC Shipment Estimates

(Units Million, H&Q Data)

Category	**1994**	**1995**	**1996**	**1997**
North Am. Corporate	12.6	14.4	16.1	17.7
North Am. Consumer	7.3	9.8	12.9	16.5
Europe	11.4	13.5	15.6	17.5
Japan / ROW	16.0	21.3	27.7	35.4
TOTALS	47.4	59.0	72.3	87.1
DISK DRIVE EST.	64.0	85.3	96.2	116.8

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Peripheral Research Corp.

Forecasted P.C. Storage Requirements

(in MB)

Software Applications	1991	1995	1997
DOS	2.1	--*	--*
Windows/Win-95	10.9	75-100	130.0
Word Proc.	4.0	37.4	60.0
Spreadsheet	6.0	38.0	50.0
Networking	2.0	34.0	60.0
Desk Publishing	3.0	42.5	65.0
Presentations	4.6	30.6	42.0
Graphics	6.8	68.0	75.0
Video	--	--	275.0
Data Files	40.0	150.0	500.0
Totals	79.4	475.5	1,257.0

*Windows '95

Source: Conner Peripherals / Ind. Data

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Disk Drive Industry Forecasts 1994-2000

Units (Millions)

10-16-95 Forecasters	1994	1995	1996	1997	1998	1999	2000
Current Disk/Tr.	69.8	87.7	101.3	117.8	132.4	146.4	
Data Quest 5-95	69.3	80.1	90.8	110.5	135.5	156.4	177.0*
PRC/Others	65.2	85.4	96.5	116.8	134.2	155.0	182.0
IDC	65.8	90.0	116.0	135.0*	155.0*	175.0*	193.0

*Extrapolated

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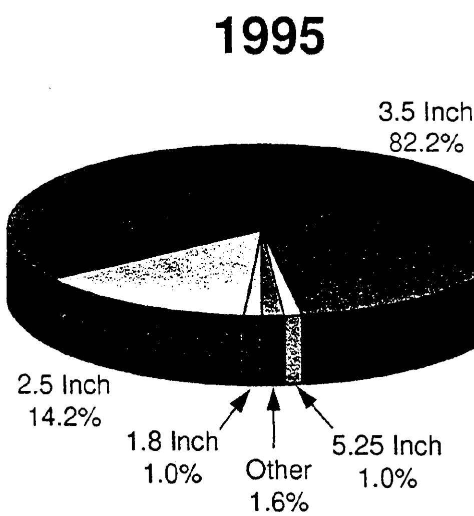
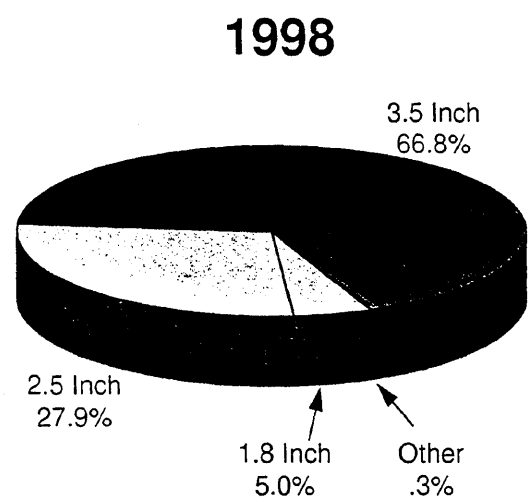
Disk Drive Market Summary

By Diameter (in %)





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Rigid Disk Drive Market Forecast by Size

(Fixed/Removable, Units 000)

10-4-95

Disk Drive Size	1994	1995	1996	1997	1998
1.8 Inch	454.9	1,194.0	2,840.0	4,605.0	6,610.0
2.5 Inch	9,294.7	12,270.0	19,630.0	28,200.0	37,432.0
3.5 Inch	53,581.7	70,636.0	73,079.0	83,565.0	89,624.0
5.25 Inch	849.2	732.8	714.0	490.0	490.0
8-9 Inch	72.2	26.5	7.0	--	
10.8-14 Inch	45.6	--	--		
Totals	64,298.3	85,859.3	96,270.0	116,860.0	134,156.0

Source: Disk. Trend/Industry Data

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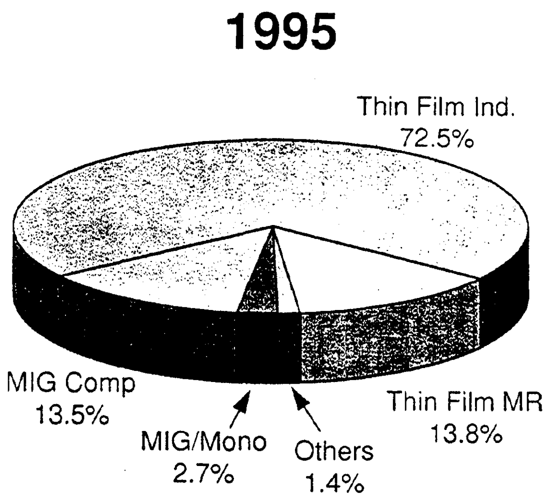
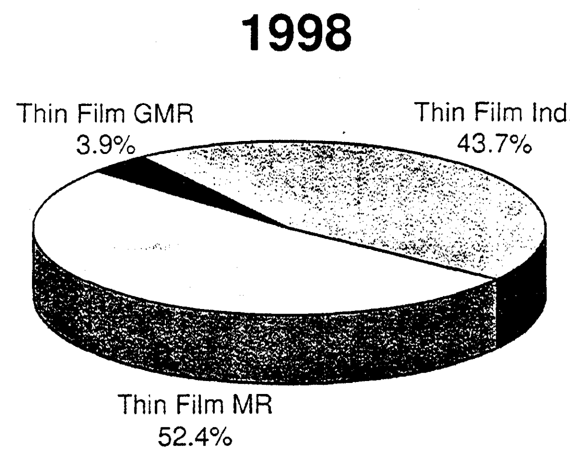
Magnetic Head Market Demand

By Head Type (in %)





Magnetic Head Summary by Technology

(Units 000)

Technology	1994	1995	1996	1997	1998
Ferrite	874.3	59.0	-	-	
MIG/Composite, Mono, LAM	56,643.3	51,900.0	41,700.0	29,300.0	20,000.0
Thin Film Inductive	231,070.1	279,546.0	262,109.5	323,038.0	476,806.0
Thin Film MR	24,260.0	56,900.0	155,036.0	254,497.8	359,975.0
Thin Film GMR	-----	-----	-----	3.2	25.0
Total	312,874.3	388,405.0	458,845.5	606,839.0	806,806.0

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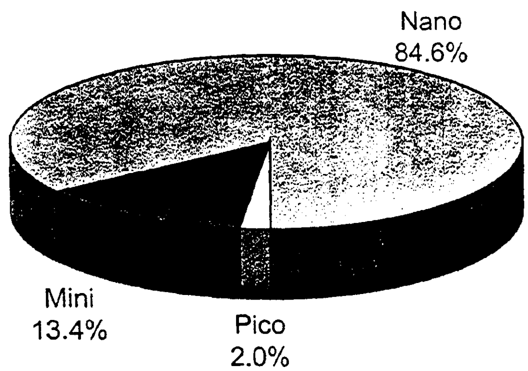
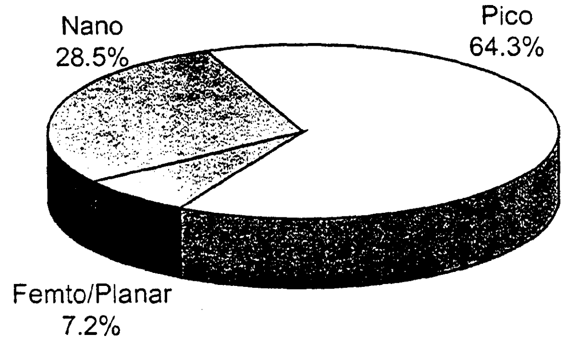
Peripheral Research Corp.

Thin Film Magnetic Head Market Shares

By Slider Size (In %)





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Magnetic Head Forecast by Slider Size

(Inductive/MR, Units Millions)

Slider Size	1993	1994	1995	1996	1997	1998
Full Size 100%	27.6	----	----	----	----	----
Mini 70%	120.6	104.9	38.0	13.5	0	0
Nano 50%	14.7	216.3	282.0	307.5	337.0	180.0
Pico 25-35%	----	0.6	13.0	72.0	172.0	406.0
Femto <25%	----	----	----	----	19.0	45.0
Total	162.9	321.8	333.0	393.0	528.0	631.5

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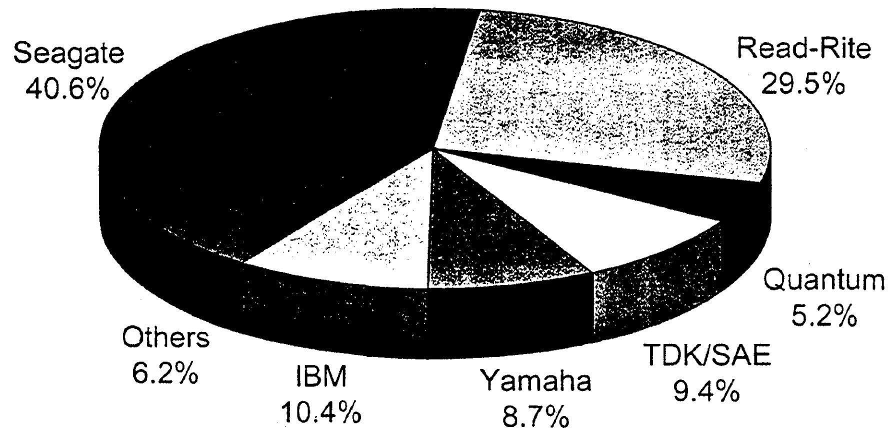
Peripheral Research Corp.

1995 Thin Film Head Market Shares By Major Supplier

Merchant / Captive in %



1995 Head/Media Technology Review | Peripheral Research Corp.

Future Magnetic Head Technology Trends

- 78% of the Market Will Use 50% Form Factor in 1995
- MR Thin Film Production Has Begun in Small Volume and Will Ramp During 1996
- HGA Automation Will Be More Important
- Disk Drives and Components Will Become Smaller
- More Components Integration Will Occur During the Next 2 Years
- A Few 30% Inductive Sliders are Being Produced, However the 30% Will Generally Follow MR Technology
- Integrated HGA's Will Be Introduced in 1996

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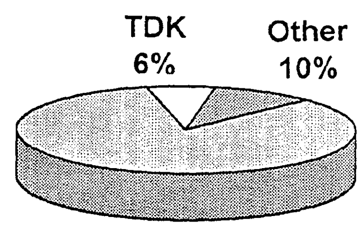
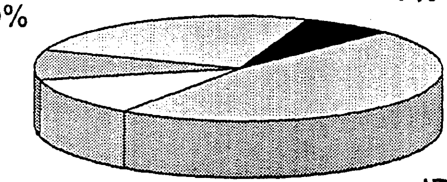
MR Head Market Shares
1995-1996
(in percent)



1995



1996

MR Thin Film Head Products
1995

- IBM Corporation
- TDK / SAE
- Fujitsu Ltd.
- Seagate Technology
- Read-Rite
- Quantum Corporation
- Applied Magnetics Corporation

1995 Head/Media Technology Review

Peripheral Research Corp.

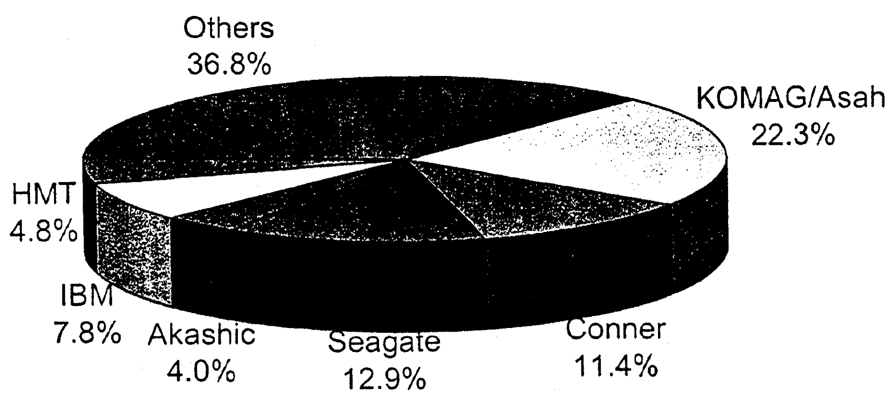
MR Thin Film Head Markets

- Markets Slow to Develop
- Technical Complexity Heads / Drives
- Production Yields Low
- Most ESD Problems Solved
- Test Data Don Mann Looks Good
- +85% of 1995 Production is IBM
- Expect Production Mid 1996

1995 Head/Media Technology Review

Peripheral Research Corp.

1995 Rigid Disk Media Market Shares In %
By Major Supplier



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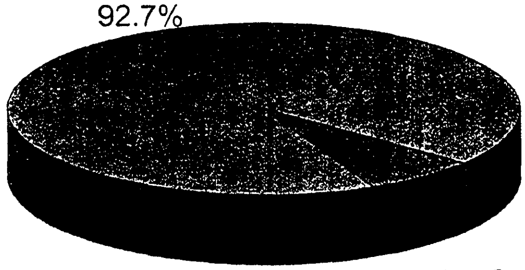
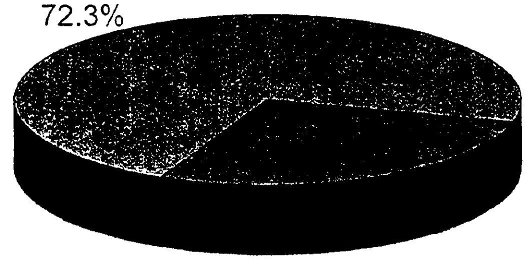
Estimated Media Shares By Technology
(in %)

1995



1995 Head/Media Technology Review

1998



Peripheral Research Corp.

Future Magnetic Media Technology Trends

- Alternative Substrates Will Be Used in Small Diameter Drives
  - ✓Some New Materials Will Be Introduced
- Concentration to Thin Substrates
- Dual Textured Media to Provide Landing Zones
- Advanced Texture Technology
- Low Flying Heights

1995 Head/Media Technology Review

Peripheral Research Corp.

Disk Media Forecast Demand Summary By Size

(Units 000)

10-16-95 **Disk Media Size**	**1994**	**1995**	**1996**	**1997**	**1998**
1.8 Inch and Smaller	899.8	2,871.0	6,000.0	10,710.0	23,930.0
2.5 Inch	23,537.4	30,615.0	42,870.7	51,540.0	70,700.0
3.5 Inch	126,983.8	168,545.5	184,952.0	200,520.0	214,440.0
5.25 Inch	5,048.8	4,661.0	4,404.5	3,815.0	2,022.0
8 Inch	459.7	114.6	----	----	
10.8, 14 Inch	666.0	84.0	----	----	
Totals	**157,595.5**	**206,891.1**	**238,227.2**	**266,585.0**	**311,092.0**
Supply	**176,506.0**	**240,600.0**	**276,800.0**	**301,500.0**	**348,971.0**

1995 Head/Media Technology Review

Peripheral Research Corp.

3.5 Inch Disk Media Forecast By Technology

(Worldwide, Units Millions)

	1995	**1996**	**1997**
Oxide Media	.1	.1	0
Thin Film Sputtered			
1200-1400 Oe.	.2	0	
1400-1600 Oe.	5.6	3.9	2.0
1600-1800 Oe.	26.3	22.2	17.8
1800-2000 Oe.	117.1	123.0	120.6
2000-2500 Oe.	19.6	35.8	55.6
2500 + Oe.			
TOTALS	168.9	184.9	196.0

1995 Head/Media Technology Review

Peripheral Research Corp.

REVOLUTION HAPPENS

Allen Cuccio

President

Storage System Consultants

HEAD/MEDIA TECHNOLOGY REVIEW

++

Las Vegas, Nevada
November 12, 1995

REVOLUTION HAPPENS

Allen Cuccio
Storage Systems Consultants, Inc.
Boulder, CO. 80301, (303) 581-9716

<u>REVOLUTION</u> ------
Replaces Evolution

SINCE 60% A.D. GROWTH ANNOUNCEMENT

MANY NEW TECHNOLOGIES

<u>HEADS</u> - TRANSDUCER, SLIDER, FLEXURE
<u>DISKS</u> - SUBSTRATES, MEDIA
<u>MECHANICS</u> - BEARINGS
<u>ELECTRONICS</u> - ARCHITECTURE, CHANNEL, SERVO, DRIVE INTERFACE

CHALLENGE

CONTINUE AT 60% GROWTH RATE

TECHNOLOGY INTERACTION

PREDICTIVE MODELING

TECHNOLOGY TRENDS

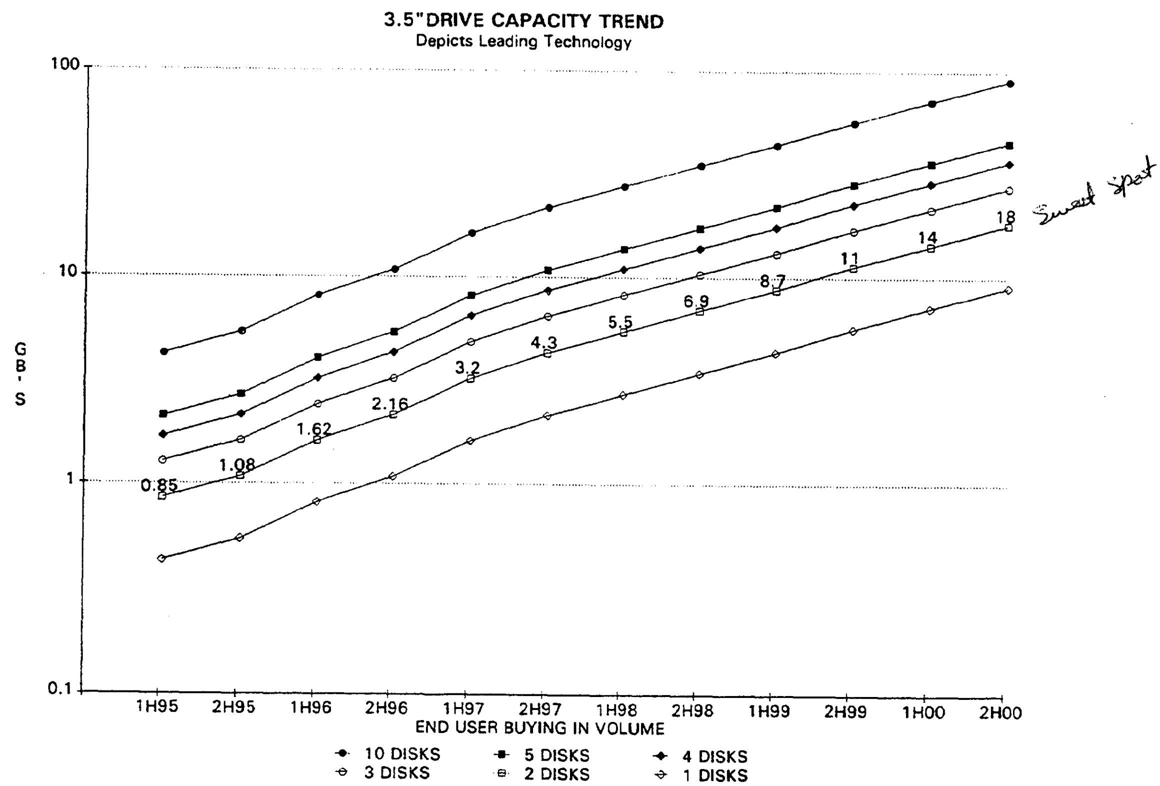
PERFORMANCE TRENDS

PRICING TRENDS

DRIVE COST TRENDS

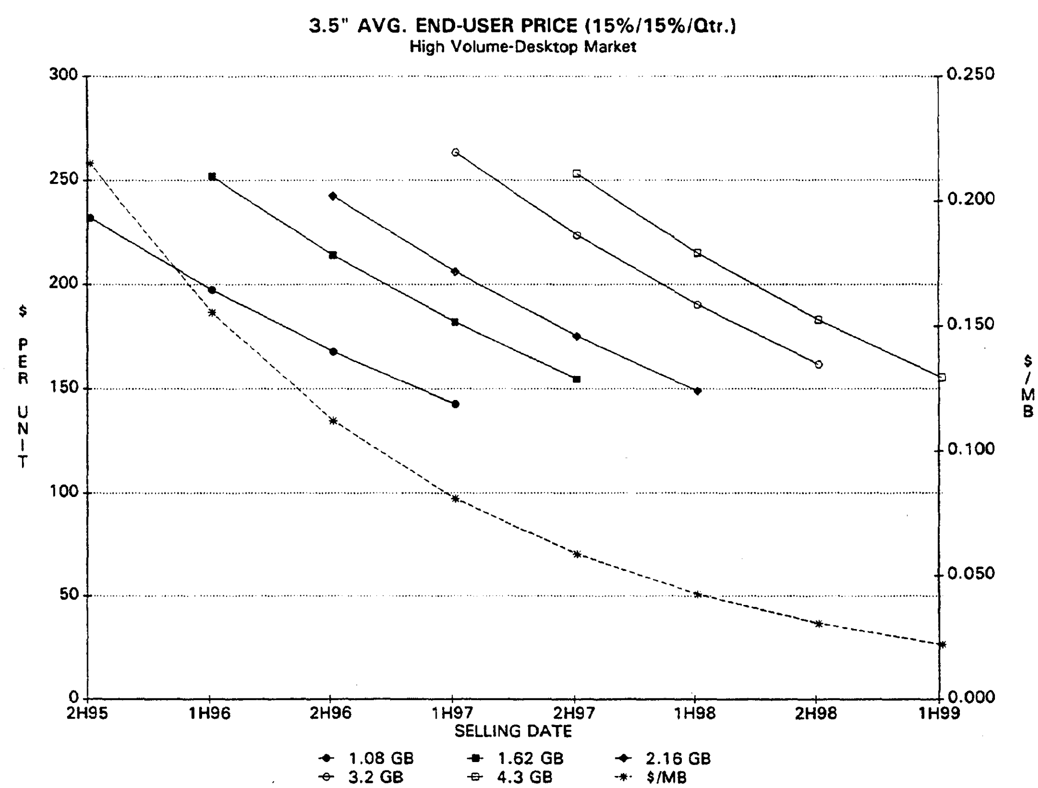
COMPONENT COST TRENDS

INTERACTION SENSITIVITIES



Storage Systems Consultants, Inc. 3Model4 -6 Allen Cuccio

5



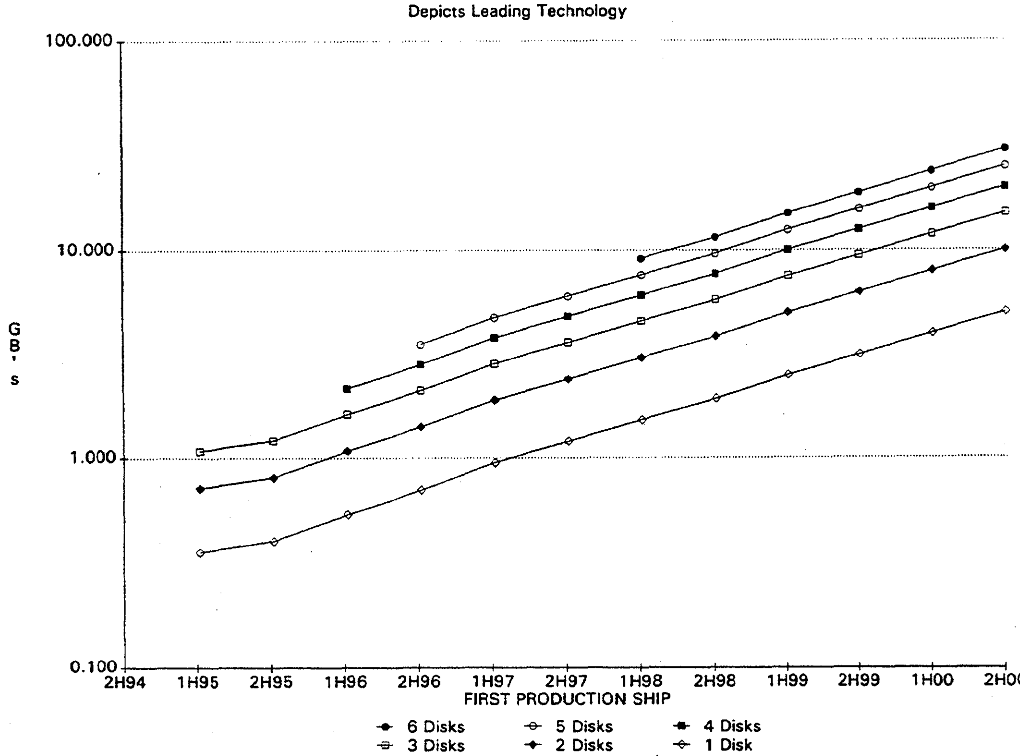
Storage Systems Consultants, Inc. 3Model4 -8 Allen Cuccio

Desk Top Application		MANUFACTURING COST ANALYSIS				
2 DISKS - one inch						
1.080	GB	INITIAL			EOL	
	2H-	1995		1H-	1997	
ASP-Box & $/MB		$186	$0.172		$121	$0.112
GROSS MARGIN	21.0%	$39		15.0%	$18	
COST OF SALES		$147			$103	
CORPORATE OH	5%	$7		5%	$5	
MFG. COST $ & $/MB		$139	$0.129		$98	$0.091
MFG. ADDED VALUE	18%	$25		12%	$12	
LABOR, IF BURDEN =	250%	$7.17		225%	$3.62	
TOTAL MATERIAL		$114	$114		$86	$86
PCB	31%	$36		31%	$27	$27
MECHANICAL	18%	$21		18%	$16	$16
HEADS & MEDIA	50%	$58		50%	$43	$43

15% = Break even point

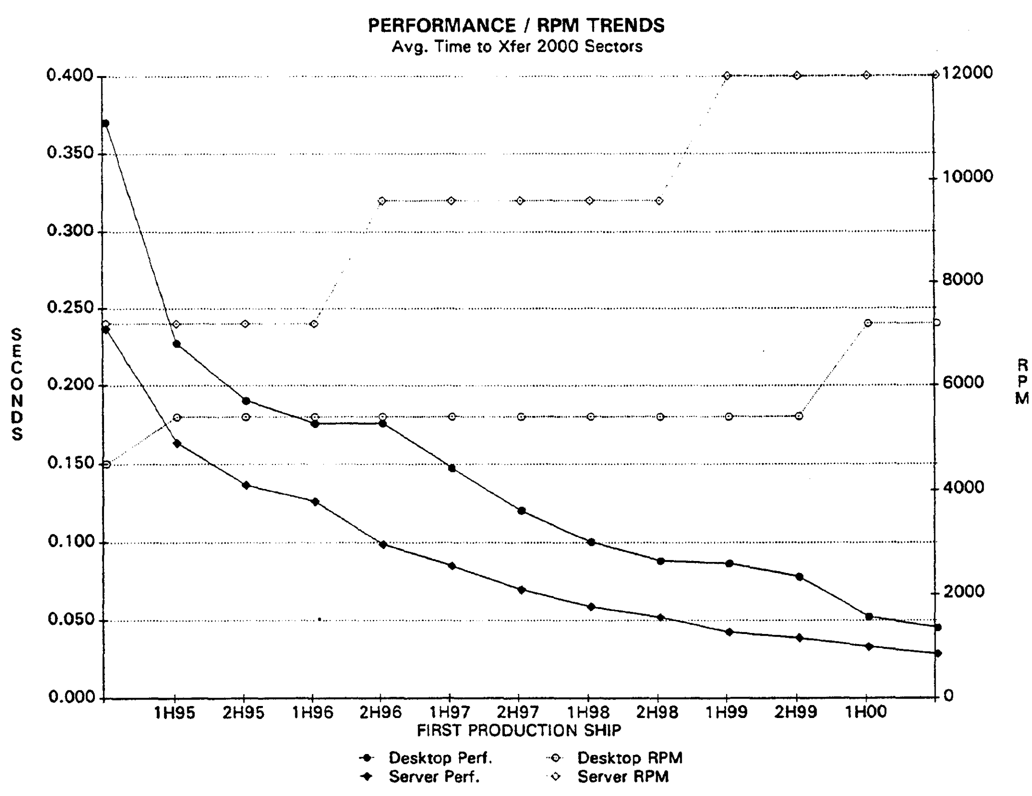
2.5" DRIVE CAPACITY TREND

Depicts Leading Technology

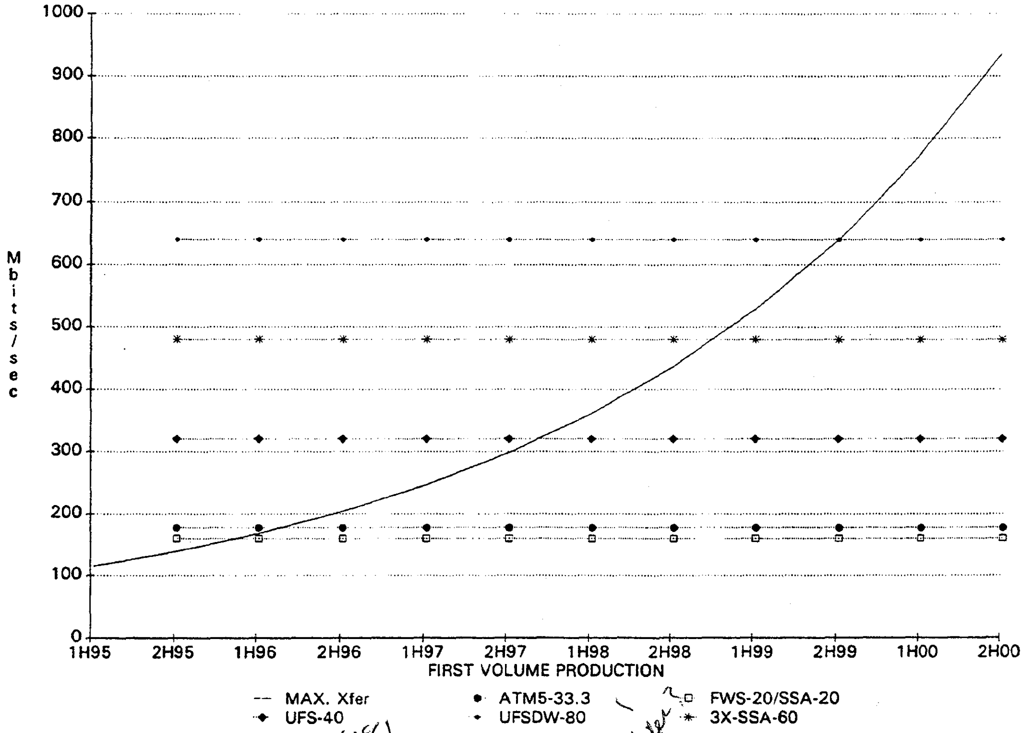


PERFORMANCE BOTTLENECKS

READ CHANNEL RATE
WRITE CHANNEL RATE
INTERFACE RATE
INTERFACE OVERHEAD
BUFFER SIZE / BANDWIDTH
CACHING ALGORITHMS
RPM / SEEK TIMES
CAPACITY / TRACK



Maximum Channel Transfer Rate
Versus Interface Bottleneck



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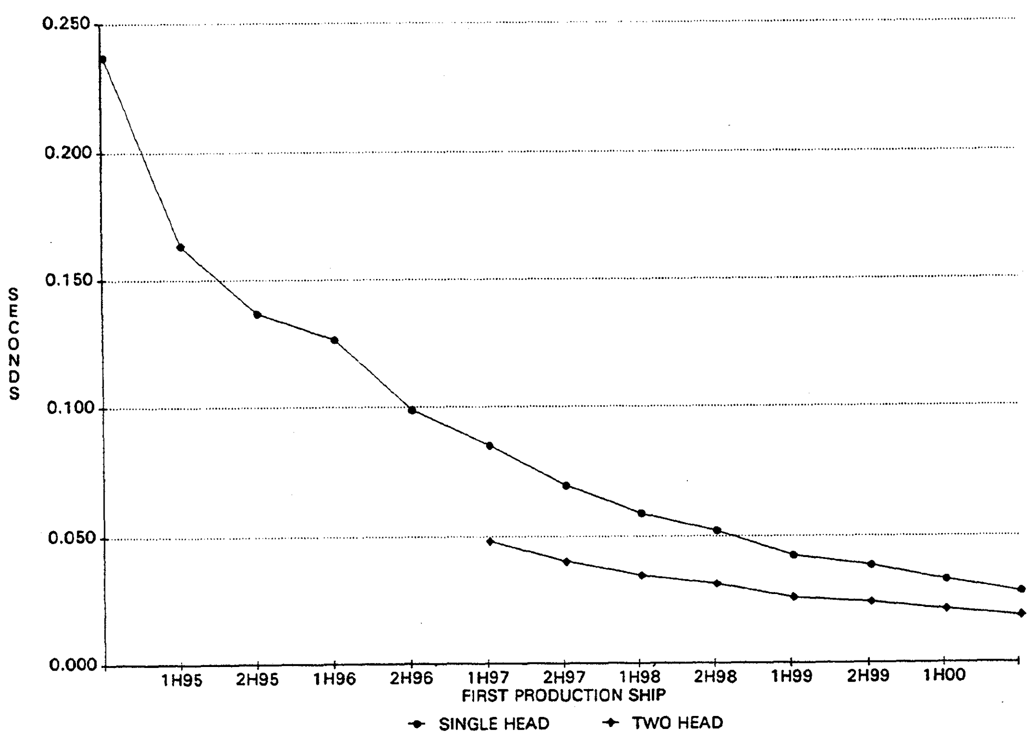
Allen Cuccio

3.5" SERVER PERFORMANCE
Effect of Two Head Parallel



Storage Systems Consultants, Inc. 3Model4 -4

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ELECTRONICS REVOLUTION

HISTORICALLY, INDUSTRY HAS USED

-Intel 196, Single Processor Architecture

-Or, 196 with DSP for Servo

RESULT

Mostly, 196 compatible firmware exists today

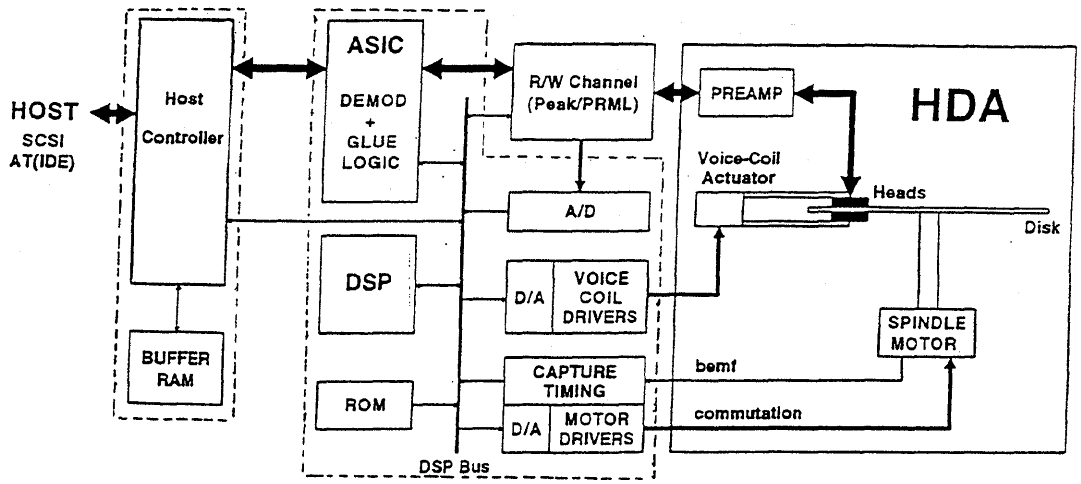
SINCE THE REVOLUTION

-196 is short on performance

-Poor cost/performance tradeoff

A NEW APPROACH EMERGING

DSP ARCHITECTURE



Storage Systems Consultants, Inc.

Allen Cuccio

15

Key is transfer rate at interface. New interfaces are running out steam. Thinks serial will be mandatory

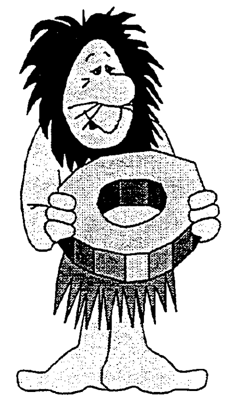
EVOLUTION OF MR MEDIA TECHNOLOGY

Dan Parker

Senior MR R&D Engineer

StorMedia

Evolution of MR Media Technology



Dan S. Parker, Ph.D.
StorMedia, Inc.
Santa Clara, CA

STORMEDIA

Acknowledgments

Dr. Atef Eltoukhy

Dr. Bryan Clark

StorMedia R&D Department

STORMEDIA

Today's MR Media

- *What is an MR Disk?*
- *How is it different from inductive media?*

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Media Advancements

- *Evolutionary, not revolutionary*
- *Exploit current technologies*
- *Some Interesting Wrinkles*
  - *Keeper Media*
  - *Patterned Media*

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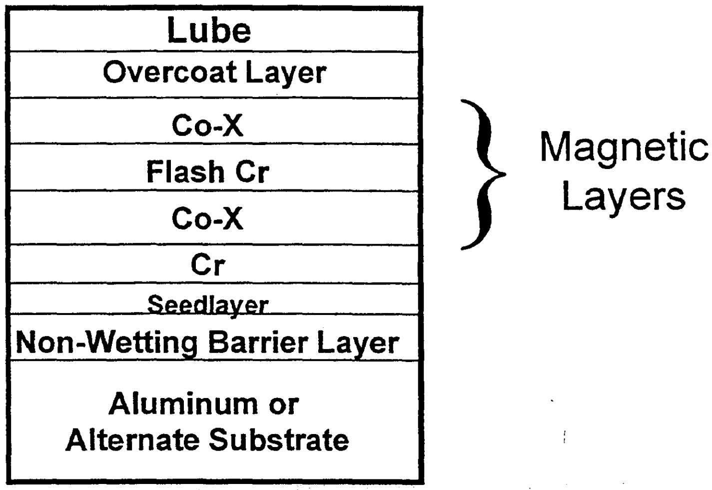
Media Design



Current Design of MR Media

- *Aluminum or Glass Substrate*
- *Full or Zone Textured*
- *CoPtCr or CoTaCr alloy*
  - *1 or 2 magnetic layers*
  - $H_c = 2000$ *Oe*
  - $M_rT = 1.0$ *memu/cm*^{2}
- *Carbon w/lube Overcoat*

Trends in MR Media

- *Higher Coercivity*
- *Lower MrT*
- *Smaller Grains*
- *Lower Fly Height*
- *Thinner Coatings*
- *Higher Durability*
- *Thinner (Alternate?) Substrates*

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Key Issues for MR Recording

- *Higher Linear & Track Density*
- *Lower Fly Height*
- *Lower Defect Levels*

STOR MEDIA

10 GB/in^2 Media Design Points

Ref: Roadmap for 10 GB/in2 Media,"
E.S. Murdock et. al, HP, Intermag '92

	Case 1	Case 2	Case 3	Case 4	Case 5
ktpi	11.0	16.7	25	31.6	40
kbpi	909	600	400	316	250
Gap (nm)	40	60	100	100	100
H/M Separation (nm)	20	30	40	60	70
PW50 (nm)	70	107	157	197	244
Hc (Oe)	4500	3500	2500	2500	2500
MrT (memu/cm^2)	0.35	0.40	0.50	0.60	1.0
			⇧ NSIC		

Comparison of Bit Sizes

100 Mb/in^2 35kfci x 2200 tpi **0.7 um**

9 um

1 Gb/in^2: 175 kfci x 6600 tpi

3 um x 0.15 um

10 Gb/in^2: 400 kfci x 25 ktpi

0.8 um x 0.064 um

Not to Scale

NSIC Media

- *Goal: Demonstrate 10 GB/in² by 1998*
- *Target Design: 400 kbpi & 25 ktpi*
  - *Aluminum Substrate: Roughness: <1 nm rms*
  - *CoPtCr: 3000 Oe & 0.6 memu/cm²*
    - *Grain Size: 10 nm*
    - *Modelling suggests 6 - 8 dB SNR deficient*
  - *Overcoat: CN or C_X < 5 nm*
  - *Lubricant: 1 nm*

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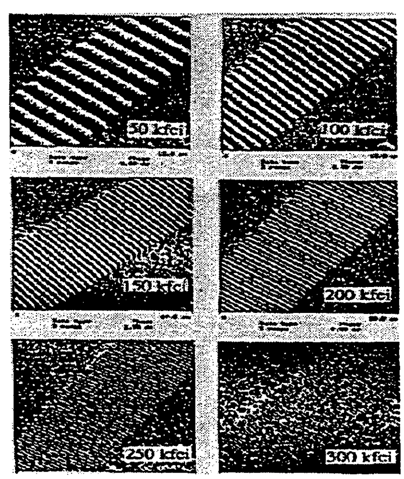
NSIC CoCrPt Media

- *MFM Images vs Linear Density*



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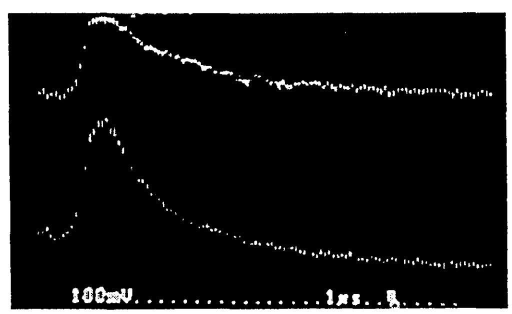
Glide Challenges

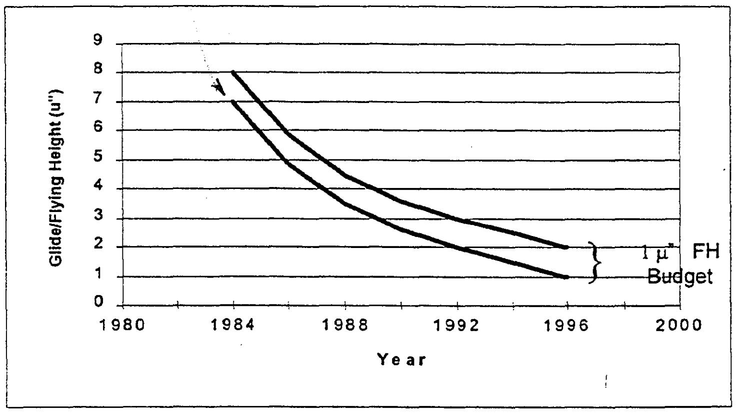
- *Near Contact*
- *Uniform Surface*
- *Reduce thermal asperities*

Thermal Asperities

- *Contact between asperity & MR sensor*
- *Large range of height & duration*
- *Caused by media & contamination sources*
- *Electronic Compensation*



Glide / Flying Height Trend



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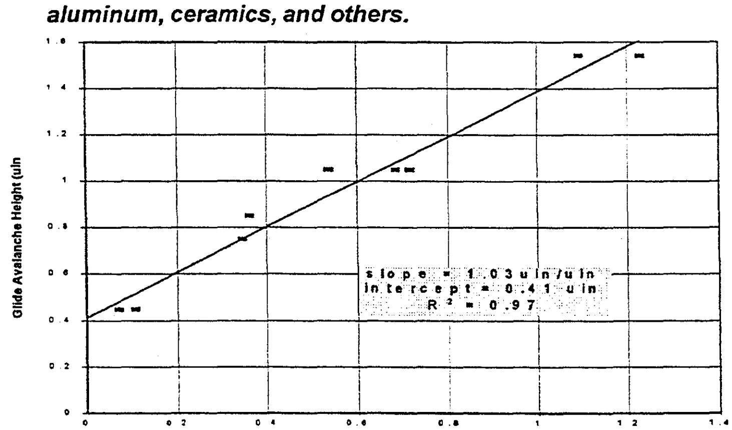
Roughness Vs Glide Avalanche

Measured across several substrate types including polished glass, sputtered texture on glass, polished aluminum, textured aluminum, ceramics, and others.



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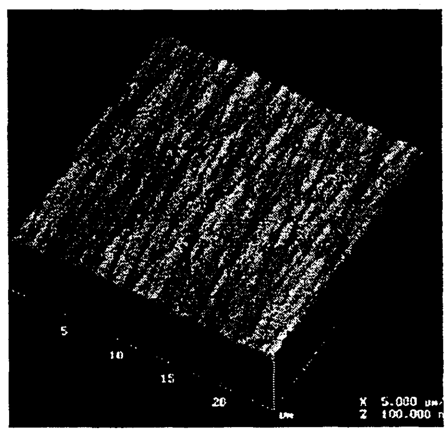
Typical Inductive Media Texture

- *Circumferential Texture w/Cross Hatch*
- *Ra = 40 A (AFM)*

roughness



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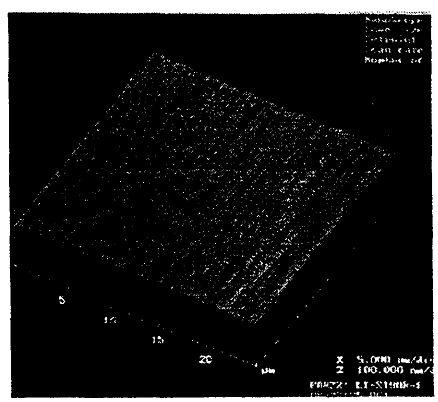
Modern Mechanical Texture

- *Light Circumferential texture*
- *Ra = 25 A (AFM)*



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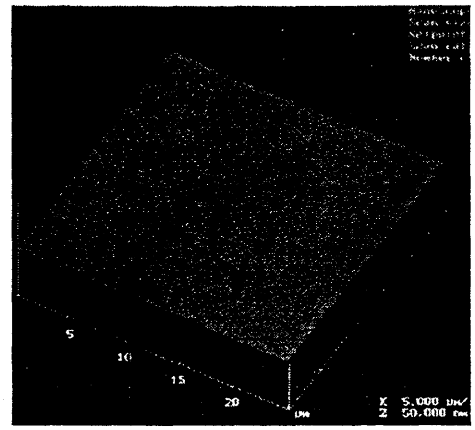
SuperSmooth Texture

- *Ra = 5 A (AFM)*
- *Isotropic*



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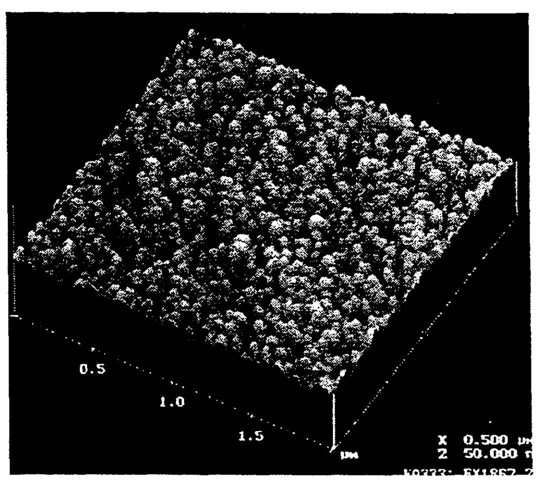
Sputtered Texture

10X over last slides



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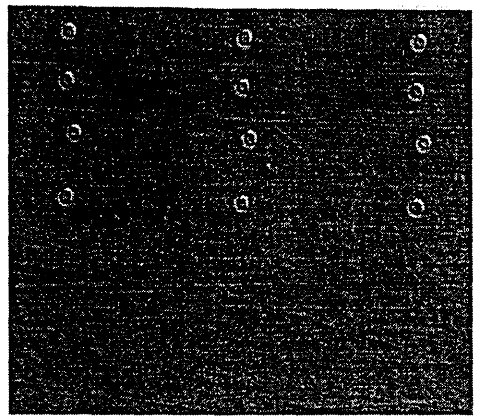
Laser Zone Texture

- Low Density Bumps
- 20 - 40 nm height
- Uniform



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Signal to Noise

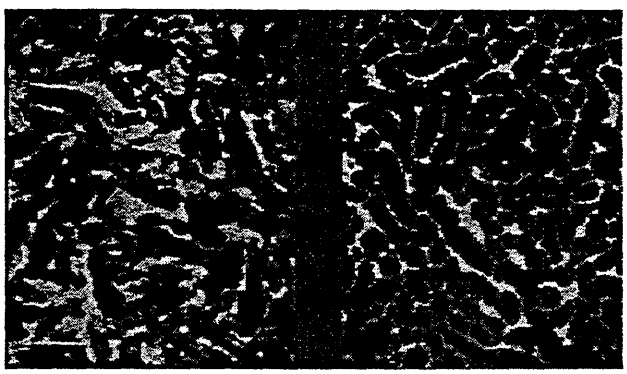
- *MR head inherently less noisy*
- *Media & Channel noise dominate*
- *Noise reduction*
  - *Multiple layers*
    - *Noise power* α 1 / # *layers*
  - *Reduce anisotropy*

STOR MEDIA

IBM 1 GB/in² Grain Structure

smaller grain structure

Conventional   1 GB/in²



50 nm

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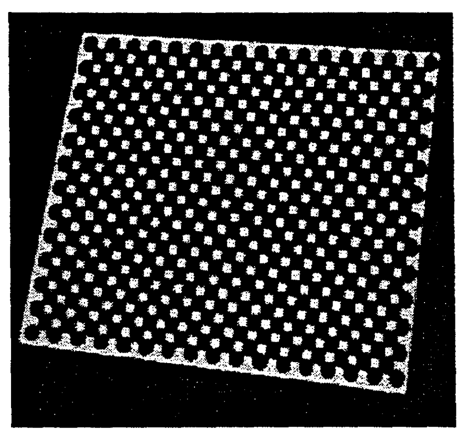
Idealized Grain Morphology

- *Small Grains*
- *Well isolated*
- *Bicrystals*
  - *High inter-grain coupling*
  - *Low intra-grain coupling*



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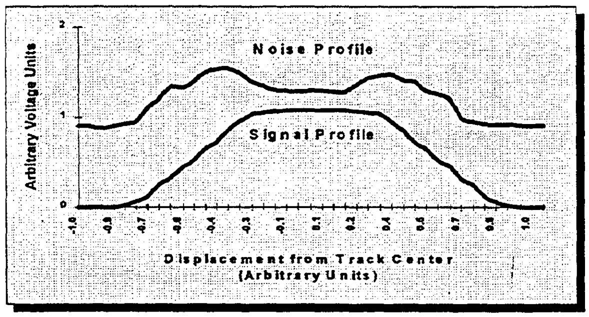
Track Edge Noise

- *Important for off-track performance*
- *May be lower for low moment media*

Edge noise problem



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Non-Linear Effects

- *PRML requires good linearity*
  - *ISI Compensation assumes Linear Superposition*
  - *Minimize non-linear effects*
    - *Non-Linear Transition Shift*
    - *Partial Erasure / Percolation*

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Superparamagnetism

small grains try to flip over

- *Spontaneous thermal demagnetization*
- *Present Cobalt Alloys:*

  d_s > 10 nm
- *Required grains ~ 8 - 10 nm*
- *Improved superparamagnetic stability required*

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Future Directions

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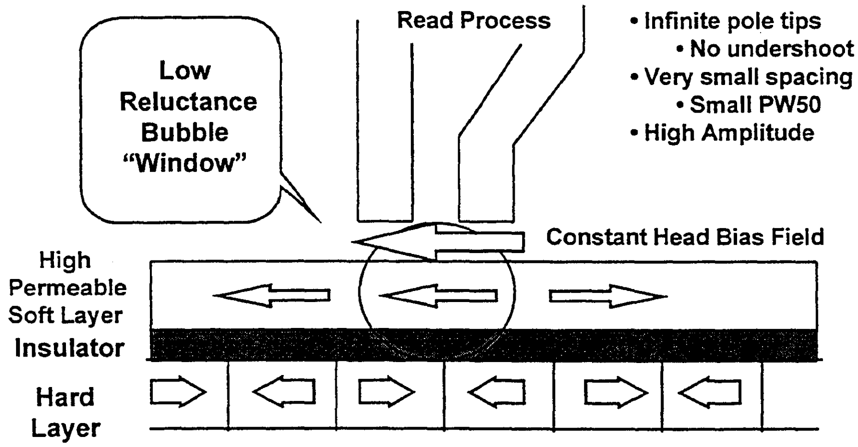
Keeper Media



Ref: Guo Mian, et.al. Conner Periph, IEEE Mag. 30:6 11/94 p.3984+

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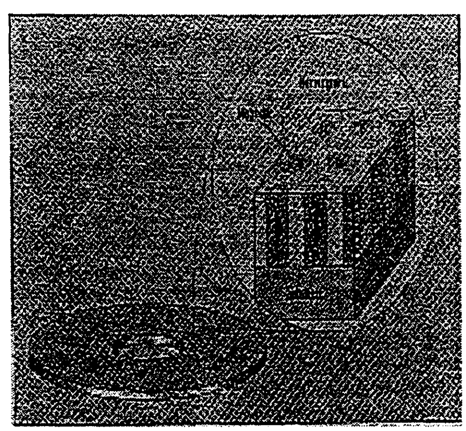
Patterned Media

- *Quantum Magnetic Disk*
- *Single Domain Nickel*
- *Electron-beam lithography*



Ref: Steve Chou, Univ of Minn., *Data Storage*, Sept. 1995

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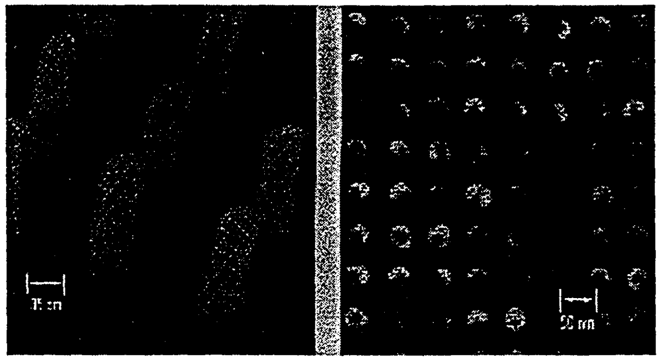
Quantum Magnetic Disk



• Nickel pillars embedded in SiO_2

STOR MEDIA

Summary

- ***Evolve Existing technology***
  - *Key Challenges*
    - *– Better SNR*
    - *– Minimize non-linear effects*
    - *– Lower Glide & Asperities*
- ***Future Revolutionary Media***

STOR MEDIA

FUTURE FOR CARBON MEDIA

Takashi Ishii

Director, Recording and Imaging Science Laboratory

Kao Corporation

Future for Carbon Media

Takashi Ishii
Recording and Imaging
Science Laboratory

KAO

Glass like Carbon Substrate

The Feature of GC Substrate

- **Super Smooth**
- **Defect Free**
- **Shock Resistance**
- **No Creeping**
- **Electric Conductivity**

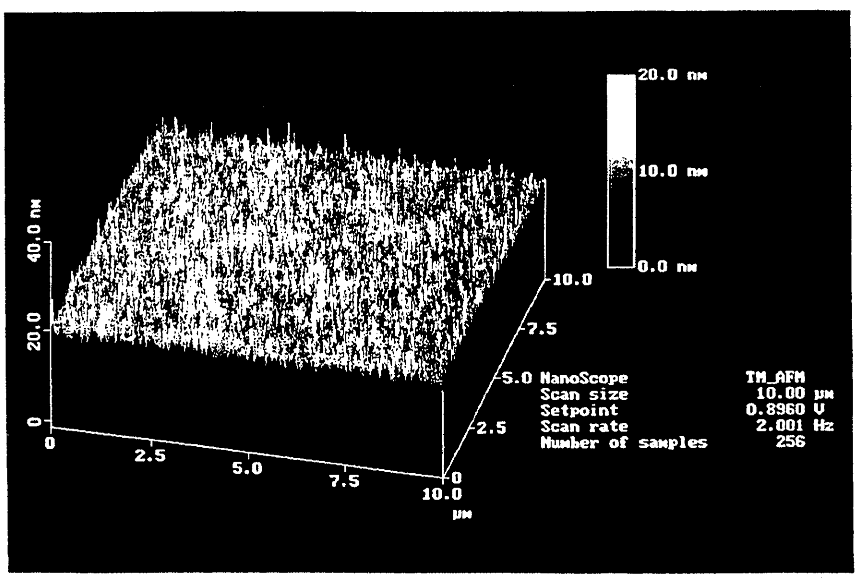
KAO

Physical Properties of Various Substrate

Item (Unit)	NiP/Al	Glass		Glass-like
		Tempered	Crystallized	Carbon
Specific Gravity	2.7	2.5	2.7	1.5
Vicker's Hardness	450	600	600	650
Surface Roughness(A)	20	6	15	7
Bending Strength(MPa)	-	350	280	200
Young's Modulus(GPa)	72	85	85	23
Specific Modulus(GPa)	27	34	31	15
(Specific Modulus)^1/2(GPa)^1/2	5.2	5.8	5.6	4.0
Heatproof Temperature(C)	280	500	500	1200
Electric Resistivity(Ohm•cm)	$2.4x10^{-6}$	$10^{10}\sim10^{14}$	$10^{10}\sim10^{14}$	$3x10^{-3}$
Shock Resistance(G)	200	600	600	>1000

KAO

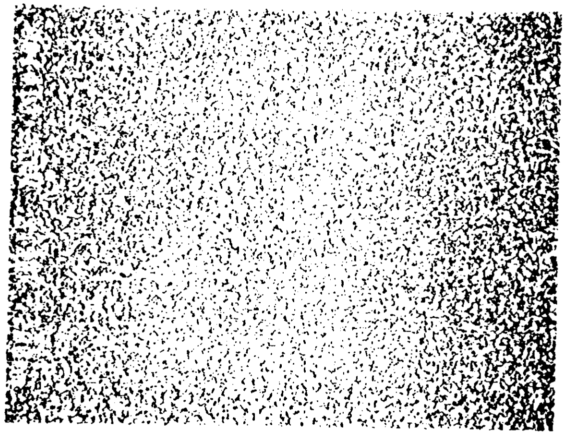
Realize Super Smooth GC Substrate



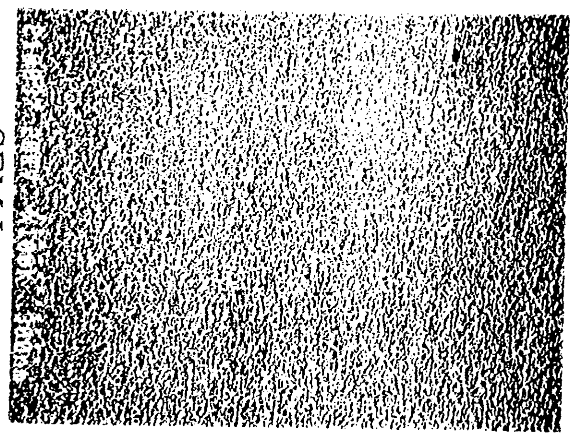
Conventional Substrate

KAO

Defect Free Substrate



SEM Image

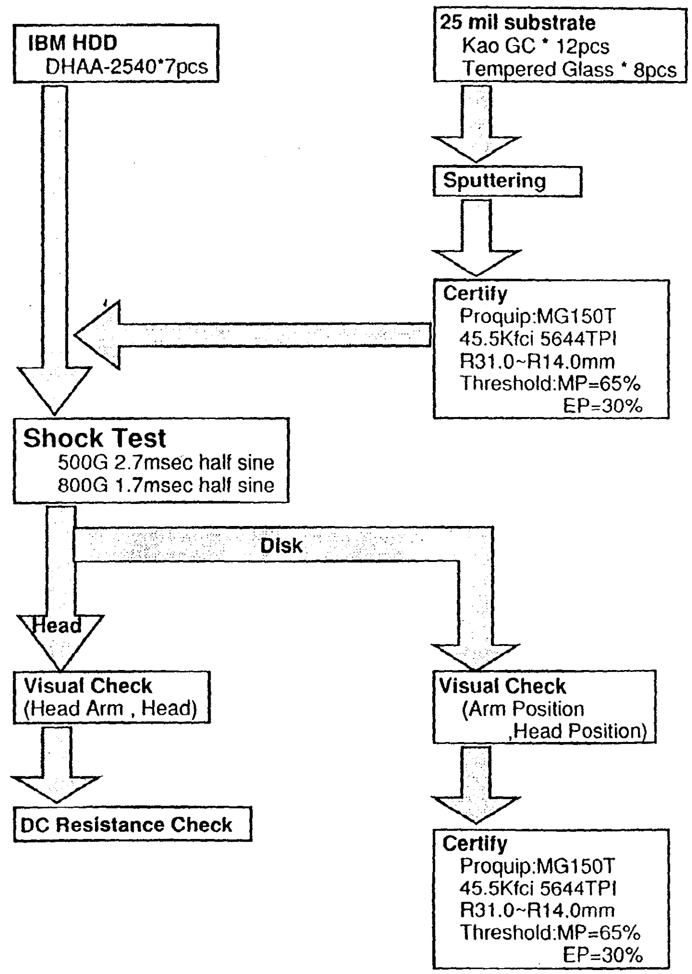


SEM Image
(specimen inclined by 50 degree)

KAO

Shock Test

Procedure



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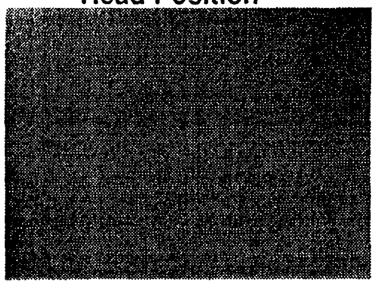
Visual Check (800G)

Kao GC No1

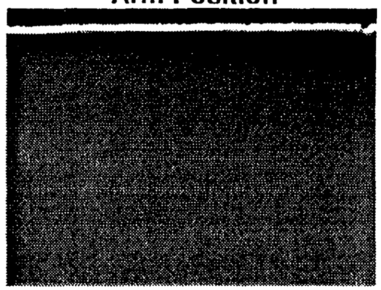
Bottom Disk - Up face

Head Position



x50

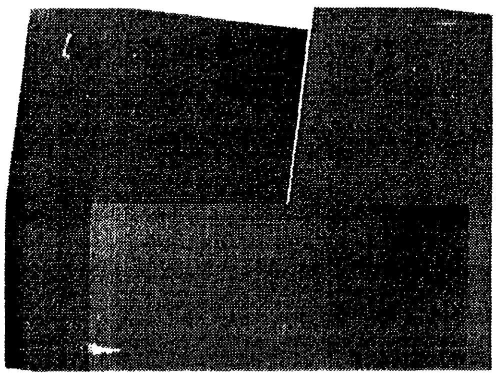
Arm Position



x50

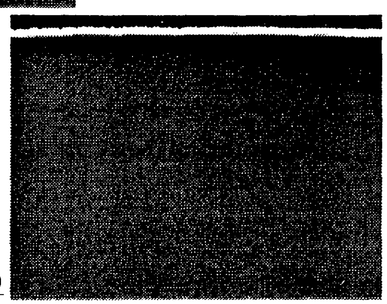
Bottom Disk - Low face

Head Position



x50

Arm Position



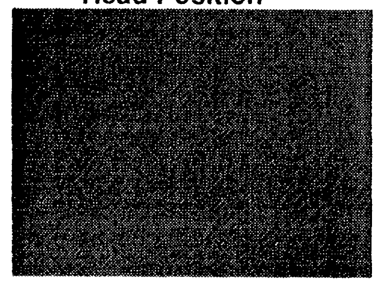
x50

Visual Check (800G)

Tempered Glass

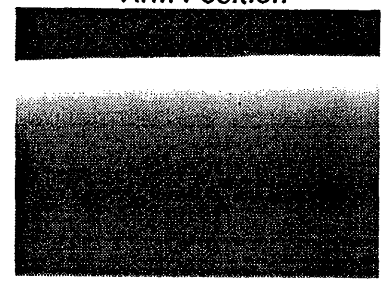
Bottom Disk - Up face

Head Position



x50

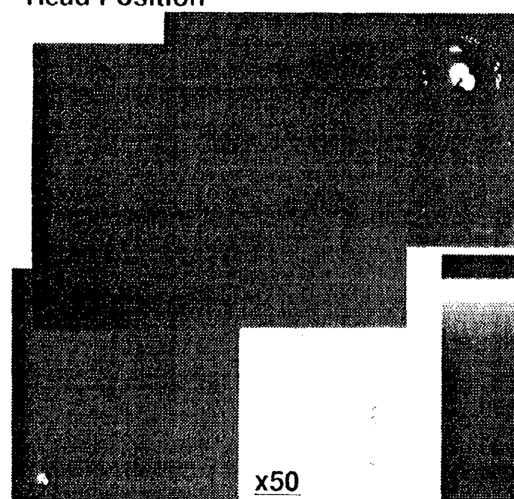
Arm Position



x50

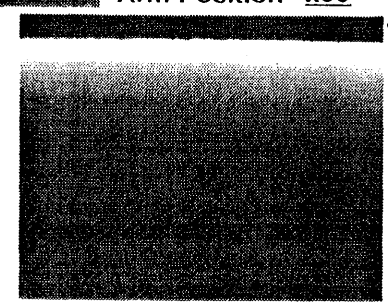
Bottom Disk - Low face

Head Position

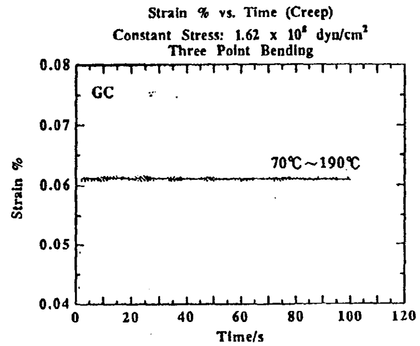


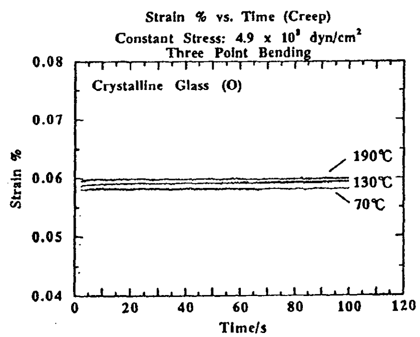
x50

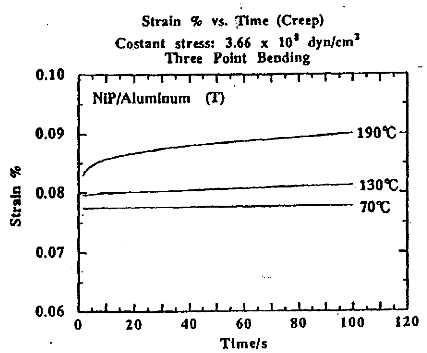
Arm Position x50



No Creeping







KAO

Shock Test

Result

DC Resistance of MR Head after shock test

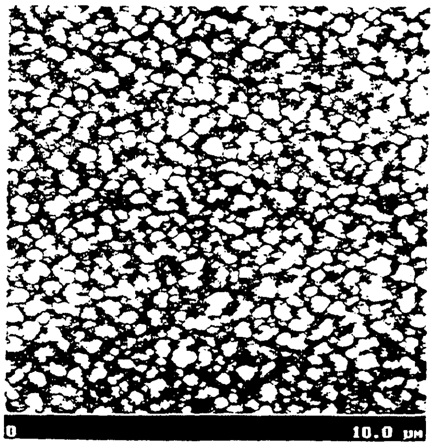
Acceleration	Substrate	Top		Bottom	
		up	low	up	low
800G	**GC No1**	—	28.9	28.6	—
	GC No2	—	30.1	—	29.8
	Tempered Glass	—	27.9	—	∞

unit : Ω

Initial Value is around 30 Ω

KAO

Current Media in production
Sputter Texture



AFM Image

TEM Image
(Cross Section)

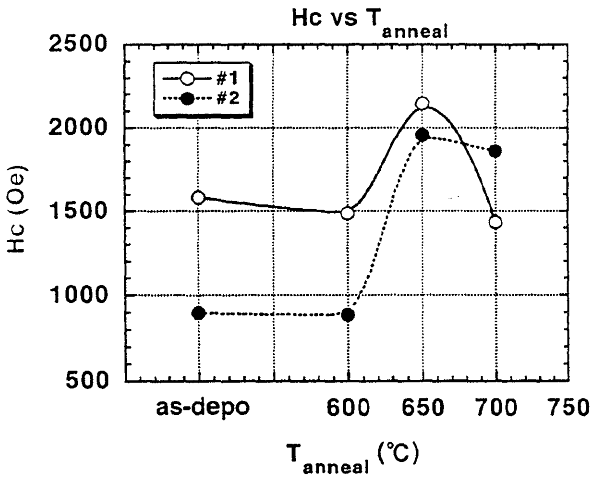
KAO

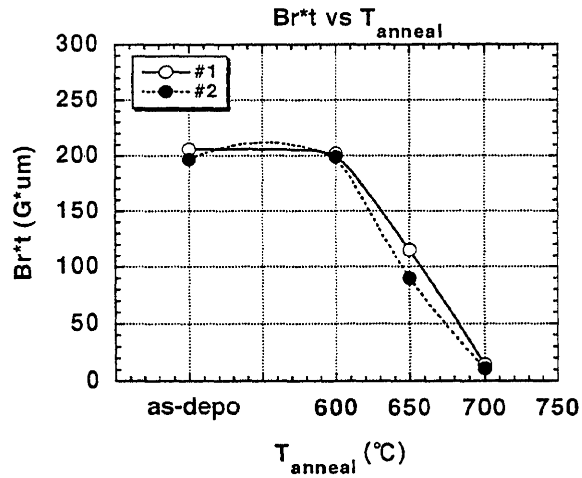
MR Media

- **Requirment:**
  - Low Media Noise
  - Narrow PW
  - Low Glide Height
- **Factor of Media Noise**
  - Intergranular and Interlayer coupling :H_k
    ⇒ Exchange Interaction / Static Magnetic Interaction
  - Fine Magnetic Grain ⇒ Magnetic Transition Region
- **Approach to Low Noise Media**
  - Magnetic Material
  - Underlayer
  - Process

KAO

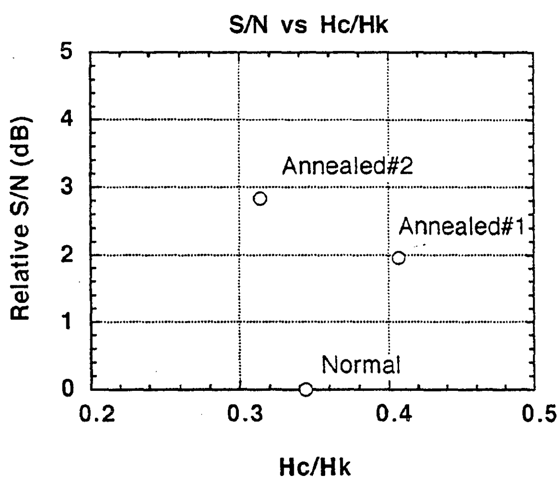
Annealing Process after sputtering

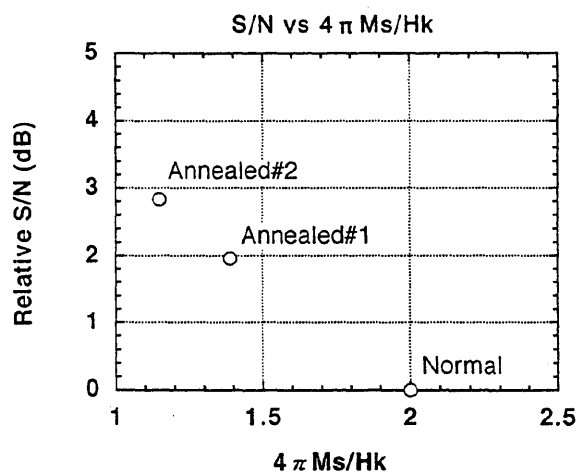




KAO

Reduce Intergranular Magnetic Coupling by Annealing process





Normal	;	Ms=970emu/cc
Anneal#1	;	Ms=580emu/cc
Anneal#2	;	Ms=570emu/cc

KAO

Summary

Substrate Merit	Media Merit	Capable Application
Defect Free	No MP	Higher than 3 Gbit/in2
No Projection	Low GH	MR Media/Drive
Smooth Surface	Low GH	Low FH
High Heat Proof	Anneal Process	Low Media Noise

- **more investigation**
  - ✓ Contamination control and cleaning process optimization
  - ✓ Defects control at Sputtering process

KAO

SPINDLE TECHNOLOGY UPDATE

Richard Prins

President

Synektron

Spindle Technology Update

1995 Head/Media

Technology Review

Richard Prins

President, Synektron Corporation

November 12, 1995

Las Vegas, Nevada

Synektron Corporation
A TDK Group Company

Focus

- Last year: PCMCIA type 2 form factor
- This year: High Performance 3.5" drives

Synektron Corporation
A TDK Group Company

Customers want higher speeds and are concerned about

- *Reliability*
- *Vibration*
- *Acoustic noise*
- *NRR (higher TPI)*
- *Cost*

Synektron Corporation
A TDK Group Company

We are addressing these concerns by

- *Refining and extending existing design rules*
- *Working with our vendors to enhance component technology - contact bearings with ceramic balls*
- *Investigating new technology - hydrodynamic bearings*

Synektron Corporation
A TDK Group Company

Refining and extending existing design rules

- *Labyrinth and bearing shield improvements*
- *E/M designs to balance forces and minimize vibration*
- *Damping materials in the spindle*

Synektron Corporation
A TDK Group Company

Enhanced Component Technology - Contact bearings with ceramic balls

- *Advantages*
  - *Light weight (60% less than steel)*
  - *Longer life than conventional bearings with steel balls (lower wear rate)*
  - *Greater survival potential under critical lubrication conditions*
  - *Reduced bearing friction (lower torque)*
- *Disadvantages*
  - *Unproved technology*
  - *Higher cost*

Synektron Corporation
A TDK Group Company

New Technology - Hydrodynamic bearings (HDB)

- *Advantages*
  - *Potentially longer life at higher speed*
  - *High Damping*
  - *Elimination of bearing defect frequencies which can excite HDD resonances*
  - *Lower Noise (10-15 dbA less than conventional bearings)*
  - *Low NRR (less than 500 nano inches)*
  - *Improved resistance to shock*

Synektron Corporation
A TDK Group Company

Hydrodynamic bearings (cont...)

- *Disadvantages*
  - *Unproved technology*
  - *Lower stiffness than ball bearings*
  - *Stiffness is temperature dependent*
  - *Bearing drag*
  - *Higher cost?*

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A TDK Group Company

Synektron hydrodynamic bearing update

- *Designed and built both top support and dead-ended HDB spindles*
- *Designed and built flat thrust plate bearings*
- *Designed conical bearings*
- *Designed and built bearings using bronze, steel and ceramics*
- *Built several hundred 1.8" Type 2 spindles*

Synektron Corporation
A TDK Group Company

Synektron hydrodynamic bearing update (cont...)

- *Began life testing 60 1.8" spindles on 4/1/95*
  - *20 units at 45 C, 20 units at 55 C and 20 units at 65 C*
  - *All spindles under full load*
  - *Spindle rotating axis is tipped 90 degrees each month*
  - *Start/stop cycle of 4 minutes on/2 minutes off*
  - *Running current and temperature are all monitored every 6 minutes*
  - *NRR checked every 1500 hours*
  - *4 failures for burrs (all at 65 C)*

Synektron Corporation
A TDK Group Company

Synektron hydrodynamic bearing update (cont...)

- *Designed and built 3.5" half height spindles for 3600, 5400, 7200 and 10000 RPM*
- *Began life testing 60 3.5" spindles at 7200 RPM on 11/1/95*
- *Developed production processes for putting herringbone grooves on the shaft OD*
- *Developed a technique for grooving sleeve ID in harder materials (production processes have been developed for bronze)*

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A TDK Group Company

Synektron hydrodynamic bearing update (cont...)

- *Developed a production filling technique that allows spindles to be subjected to a vacuum of 30 millibars to cure anaerobic adhesives and survive transportation by air*
- *Conducting large scale evaporation tests to determine life of lubricating oil*

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A TDK Group Company

Generally accepted hydrodynamic bearing "truths"

- *Desired tolerances are always tighter than the best available tolerances*
- *Harder materials offer longer life than softer materials*
- *Grooves on the rotating part are more desirable than grooves on the non rotating part*

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A TDK Group Company

Hydrodynamic bearing dimensional requirements

- *Roundness/Runout less than 1 micron*
- *Surface roughness less than .6 microns peak-to-peak*
- *Radial gap 5 microns*
- *Shaft diameter 2~4 mm*
- *Grove depth 8~18 microns +/- 2 microns*

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A TDK Group Company

Hydrodynamic bearing material choices

- *Today - Bronze sleeve/Steel shaft, grooves on ID of sleeve*
- *Development - Steel sleeve/Steel shaft, grooves on OD of shaft*
- *Development - Steel sleeve/Steel shaft, grooves on ID of sleeve*
- *Development - Ceramic sleeve/Ceramic shaft, grooves on OD of shaft*

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A TDK Group Company

What's next?

- *Assume 50% conversion to HDB's by the year 2000*
- *80 million sleeve/shaft pairs required*
- *Fabrication cycle time of 2 min for each sleeve and 1 min for each shaft*
- *Factory operation 120 hours/week, 50 weeks/year*
- *90% yield*
- *500 machining centers for sleeves @ a cost of $300K to $500K each*
- *250 machining centers for shafts @ a cost of $150K to $200K each*
- *Total cost about $250 million*

$1 billion for industry

Synektron Corporation
A TDK Group Company

DRIVE CONTAMINATION REVEALED

PhD
James Smith

Manager, Chemical Integration and Advanced Tribology

Conner Peripherals

DRIVE CONTAMINATION REVEALED

James H. Smith

Conner Peripherals
San Jose, CA

Outline

- ❑ Contamination overview
- ❑ Sampling a drive atmosphere
- ❑ Typical drive atmosphere
- ❑ Drive as a contamination source and sink
- ❑ Problems with adhesives
- ❑ Volatile sulfur source
- ❑ Summary

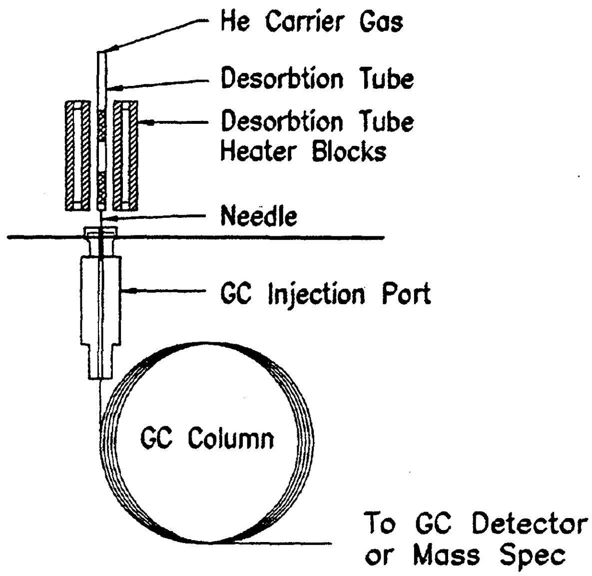
Contamination at the Head-Disk Interface

- Contaminated heads can cause drive failure; the head flies higher, causing reduced amplitude and random errors
- Failed heads often have Co, O, S, and organics on ABS
- Co and O are from corrosion of the disk magnetic layer
- Possible sources of sulfur and organics
  - Dirty parts, especially heads and disks
  - Particulates
  - Outgassing of drive components

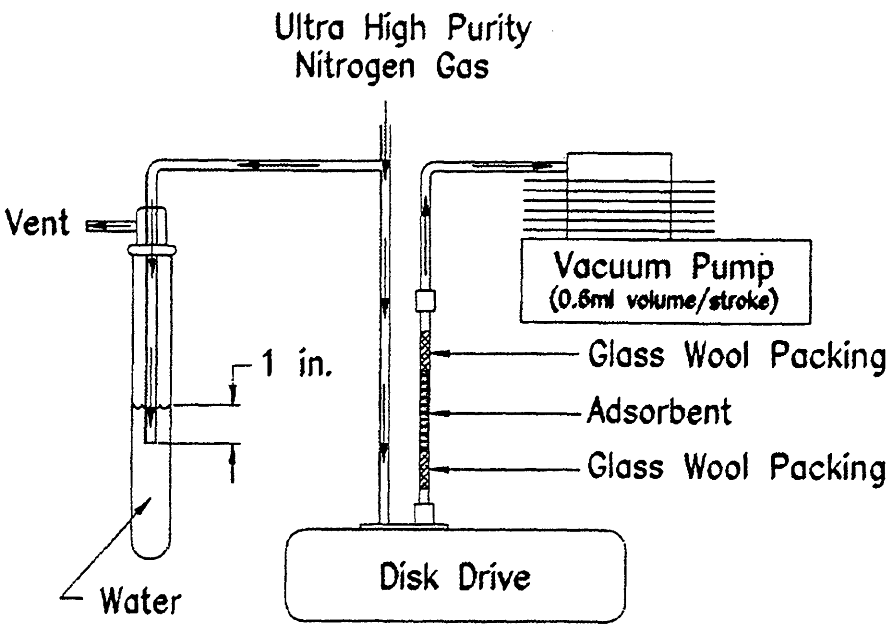
Contamination from Component Outgassing

- Vapor phase transfer of chemical compounds
- Many components outgas organics
  - Adhesives
  - Elastomers
  - Polymers
  - Bearing grease

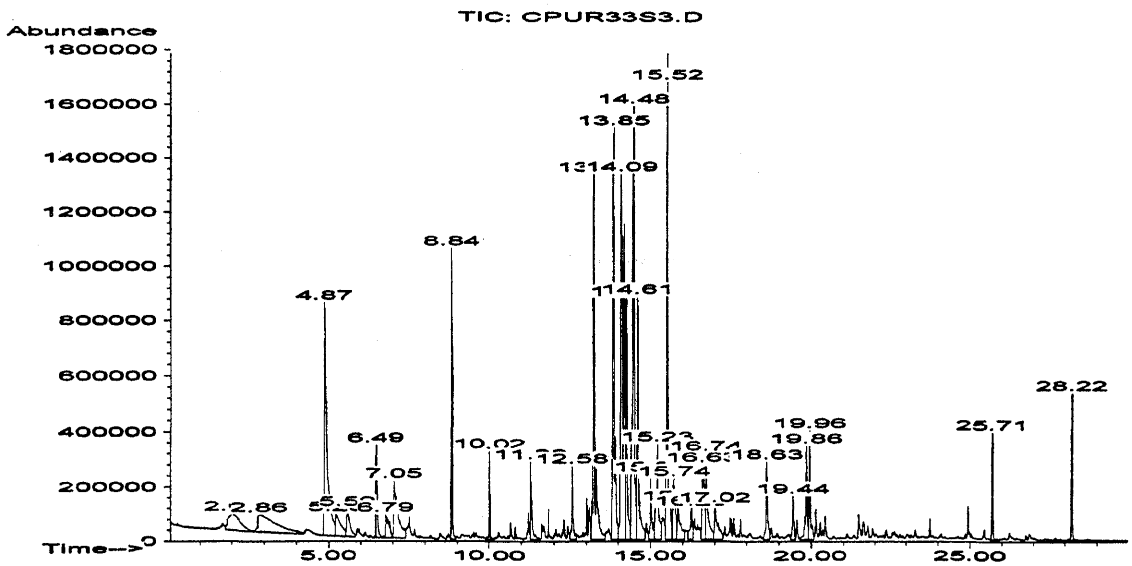
Sampling the Drive Atmosphere



Analysis of the Collected Drive Air Sample



GC-MS of a Typical Drive Atmosphere



Drive Contamination Revealed

Composition of a Typical Drive Atmosphere

- ❑ Solvents: benzene, toluene, cyclohexanone
- ❑ Breakdown products of adhesive initiators: acetophenone, *a*-methyl styrene, cumene, 2-phenyl-2-propanol
- ❑ Adhesive monomers: esters of acrylic and 2-methyl acrylic acids (HEMA, HPMA, etc.)
- ❑ Adhesive primers: amines, benzothiazol (BT)
- ❑ Elastomer monomers and telomers
- ❑ Elastomer antioxidants: phenols (BHT), aromatic amines

J.H. Smith 11/12/95

CONNER
The Storage Answer

Identification of GC-MS peaks

Time	Compound	Time	Compound
2.02	Carbon disulfide	13.32	iso-Octanol
4.87	Hexane	13.85	HEMA
6.49	Benzene	14.09	2-Ethyl-1-hexanol
7.05	1-Butanol	14.48	HPMA
8.84	Toluene	15.52	2-Phenyl-2-propanol
10.02	A siloxane	25.71	BHT
12.58	Benzaldehyde	28.22	Unknown

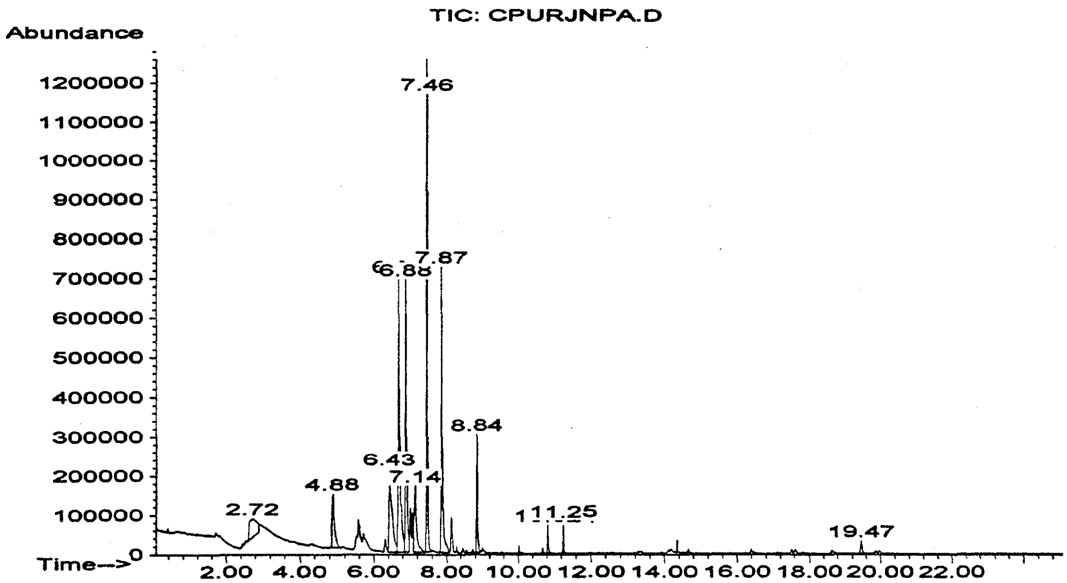
Drive Contamination Revealed

A Drive is a Contamination Source and Sink

- ❑ **Contaminants equilibrate between sources, surfaces, and the drive atmosphere**

Drive Contamination Revealed

First Sample; Drive Cold (not running)



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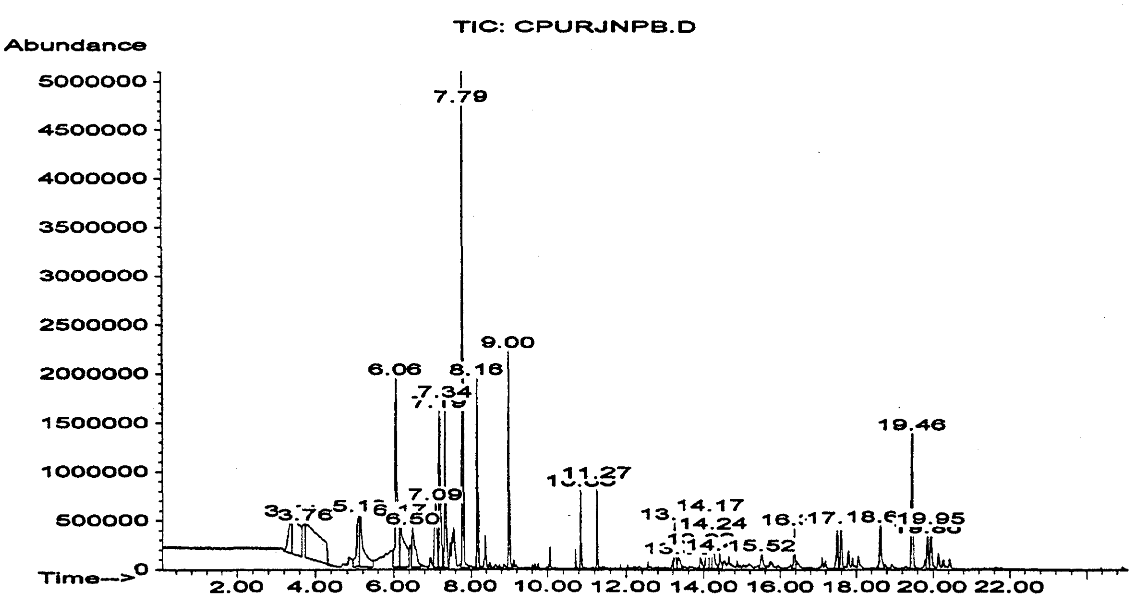
CONNER
The Storage Answer

Drive Contamination Revealed

Second Sample; Drive Running and Hot



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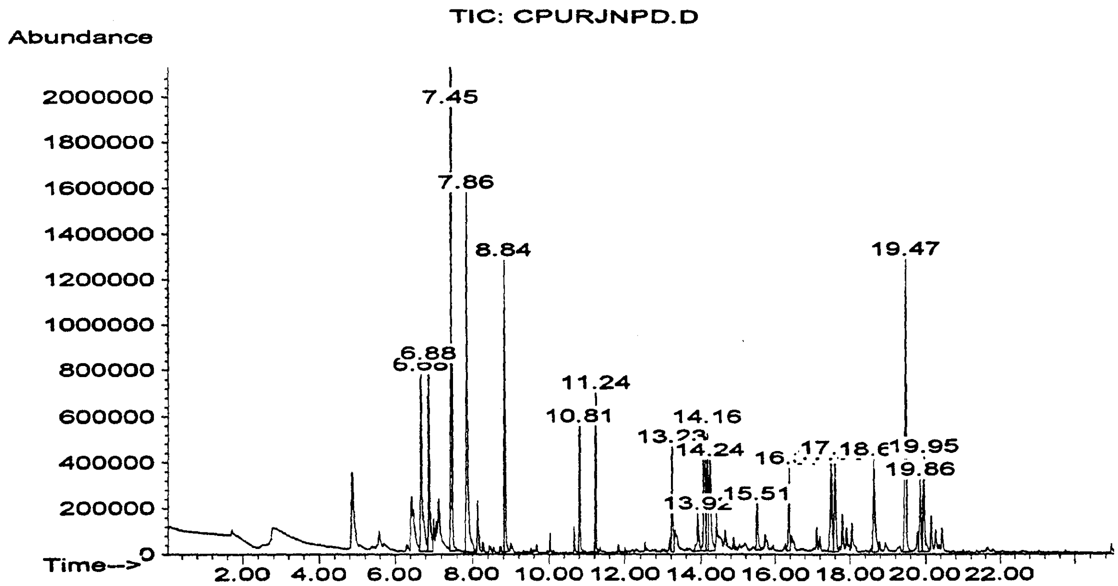
The Storage Answer

Third Sample: 30 Minutes Later



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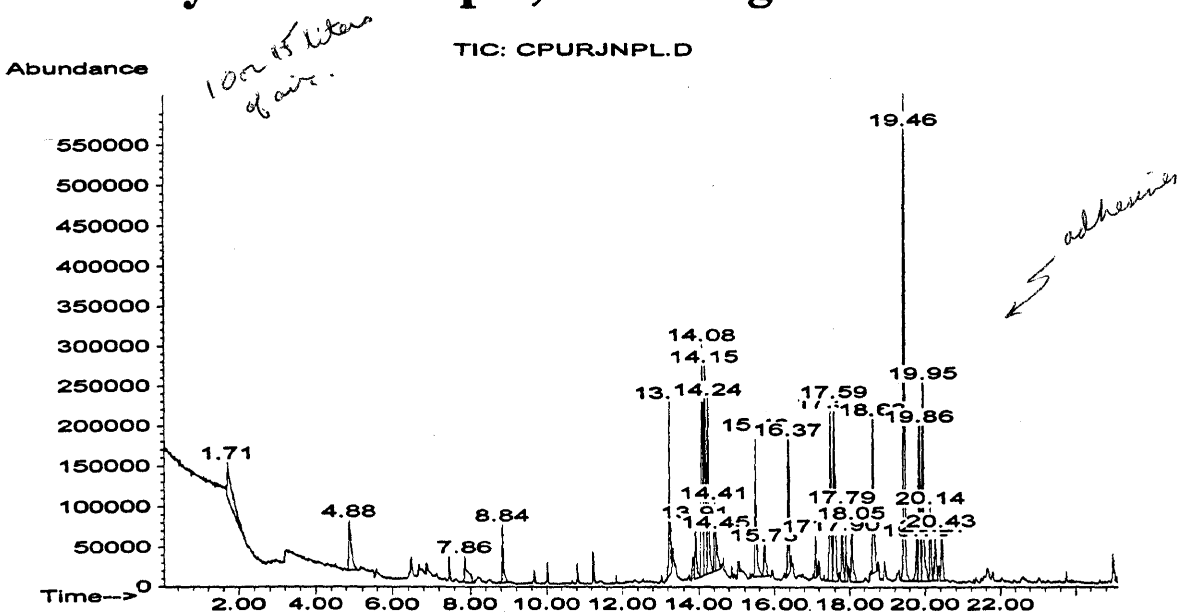
The Storage Answer

Drive Contamination Revealed

Twenty-third Sample; Running and Hot



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The Storage Answer

The Drive as Contamination Source and Sink

- ❑ Equilibration is too rapid to be bulk diffusion. Short term sources are the drive surfaces (disks, base, cover, etc.)
- ❑ Concentration of contaminants in the vapor phase is higher at higher temperature
- ❑ The amount in the vapor phase is small compared to the total amount available
- ❑ Suggests that organic contaminants:
  - ❑ Condense on the disk surfaces during storage
  - ❑ Should have the highest concentration on the disk surface during initial startup
  - ❑ Could form the highest amount of wear products at H-D interface during cold startup

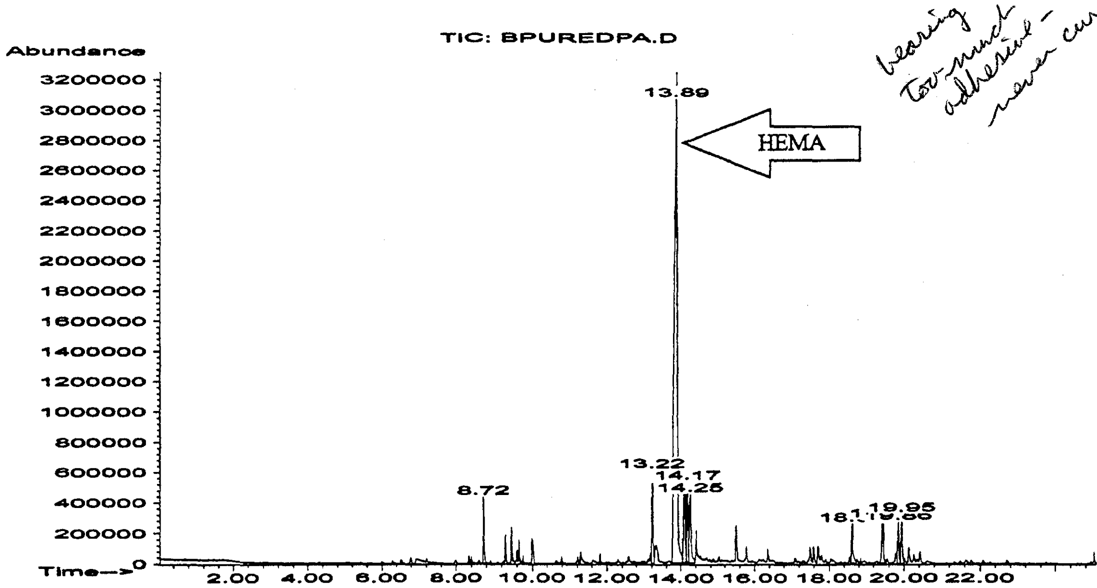
Adhesive Problems

- ❑ Wet (uncured) adhesive
  - ❑ Anaerobic cure: bearing assemblies
  - ❑ UV cure: worst in shaded areas
- ❑ Excessive outgassing inherent to formulation
- ❑ Try to use adhesives with two or more cures
- ❑ Given the high amounts of methacrylate adhesives, it is amazing that the drives work at all. But, the monomers--HEMA and HPMA--require special conditions to polymerize, which are not found at H-D interface!

Drive Contamination Revealed

Example of an Uncured Adhesive in a Drive

bearing
Too much adhesive - never cured.



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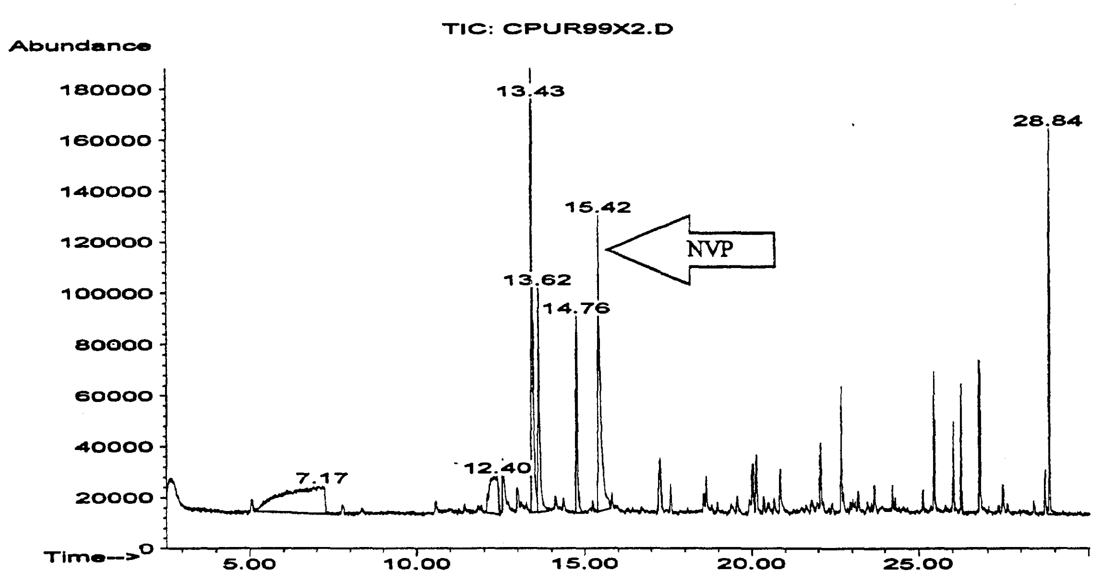
The Storage Answer

Drive Contamination Revealed

Example of Excessive Outgassing



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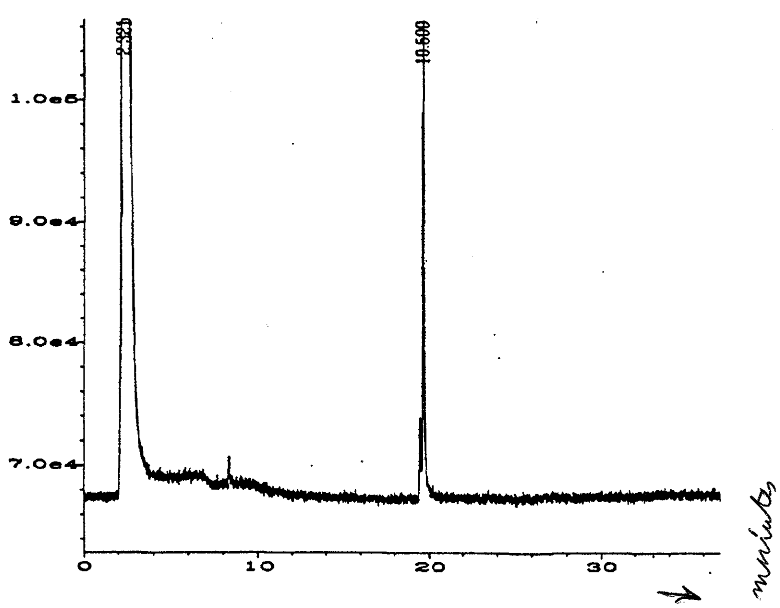
CONNER
The Storage Answer

Sulfur Contamination

- ❑ Often find $HSO_3^=$, $HSO_4^=$, and/or $SO_4^=$ on contaminated heads
- ❑ Not much $HSO_3^=$, $HSO_4^=$, or $SO_4^=$ in drive
- ❑ Vapor phase transfer from $HSO_3^=$ and $SO_4^=$ must go through SO_2 and SO_3
- ❑ Look for volatile sulfur species (H_2S, SO_2, SO_3, and ???)
  - ❑ Did not see sulfur compounds in the GC-MS
  - ❑ Sulfur-specific flame photometric detector (S-FPD)
  - ❑ Cryogenic chromatography conditions required for H_2S and SO_2
  - ❑ Test drive atmosphere
  - ❑ Then test each component

S-FPD GC Trace of a Typical Drive



A Major Source of Volatile Organic Sulfur

- ❑ H_2S, SO_2, or SO_3 were never found in any test
- ❑ Major sulfur organics identified in disk drives
  - ❑ CS_2
  - ❑ Benzothiazole (BT)
  - ❑ Cyclohexyl isothiocyanate (RNCS)
- ❑ CS_2 and RNCS outgas <u>only</u> from the sulfur-cured nitrile spindle motor bearing seal

to keep grease in

CS_2 Chemistry

- ❑ Boiling point = 46 °C; very volatile
- ❑ Flash point = -33 °C; easily oxidized to SO_2 and SO_3, which can then be oxidized to $SO_4^{=}$
- ❑ Intermediate in manufacture of elastomer vulcanization agents
- ❑ Identified by GC-MS, S-FPD, and authentic sample
- ❑ Cryogenic GC oven temperature required for analysis
- ❑ CS_2 causes rapid drive failure and formation of $SO_4^{=}$ at the H-D interface and disk surface

Summary

- The volatile organics in a drive atmosphere can be determined by collection on a solid sorbant followed by thermal desorbtion and GC-MS analysis
- The data can be used to identify contamination due to component outgassing
- The drive is both a source and a sink for contaminants
- CS_2 has been identified as a major cause of sulfur contamination at the head-disk interface

Acknowledgments

- Glenn Hammon
- JC Chang
- Regina Strener

DIGITAL CHANNEL FOR THIN FILM INDUCTIVE HEAD

Toan Doan

Director, R&D and Enabling Technology

Maxtor Corporation

Digital Channel for TF Inductive Head

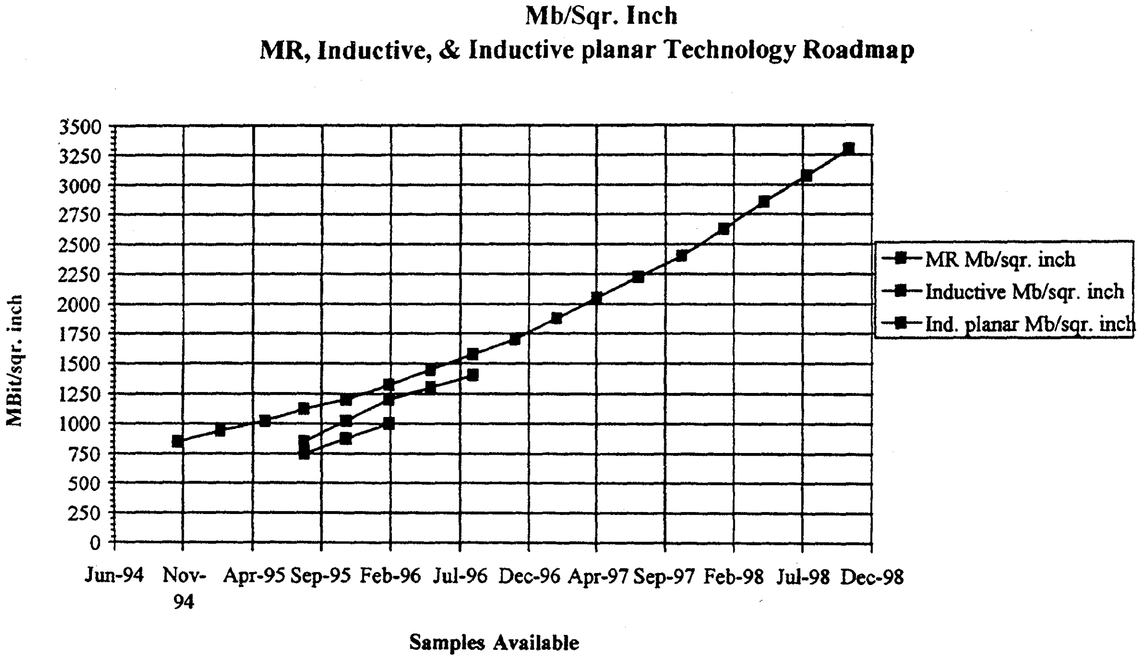
Dr. Toan Doan
Director R&D and Enabling Technology
MAXTOR

Maxtor

Why TF Inductive ?

- Prediction for TF inductive to be in most of the drives until 1997
- Can achieve areal density 1.0 - 1.5 Gbits/in^2
- Low cost

Maxtor



Conventional wisdom

- Channel technology development is independent from head/media technology
- PR4-ML channel consistently achieves 30% in density over PD with either MR or TF inductive heads
- Many drive companies have made PR4 8/9 (0,4,4) the channel of their product for both MR and TF heads

Reality is quite different

- Head/media and channel technologies are intertwined
- PR4 - ML shows 20% over Peak Detection channel using MR head and about 10% with TF head at data rate > 80 Mb/sec
- PR4 - ML with 8/9 (0,4,4) code is not the channel of choice for TF head

Maxtor

Big difference between MR and inductive heads

MR characteristics

Higher FCI

- Higher signal
- Higher resonance due to lower inductance
- Less NLTS
- No undershoot
- Write wide read narrow

TPI is limited by write width

Maxtor

Big difference between MR and inductive heads (Cont.)

Inductive head characteristics

FCI limiting factors

- Lower S/N and severe core loss at data rate > 80 Mb/sec
- Undershoot in the head's transition response
- Higher NLTS due to gap saturation, thick magnetic layer and resonance effect

Non-linear T shift Transition

TPI is limited by off-track read capability (OTRC) and erase band

Maxtor

Toan Doan
1995 H/M Technology Review

TF Digital Channel required to achieve 1.5 Gigabit/in^2

- Ability to work with lower S/N (15 - 20 db)
- Ability to deal with nonlinear distortion
- Match PR target and the head response
- Provide better OTRC

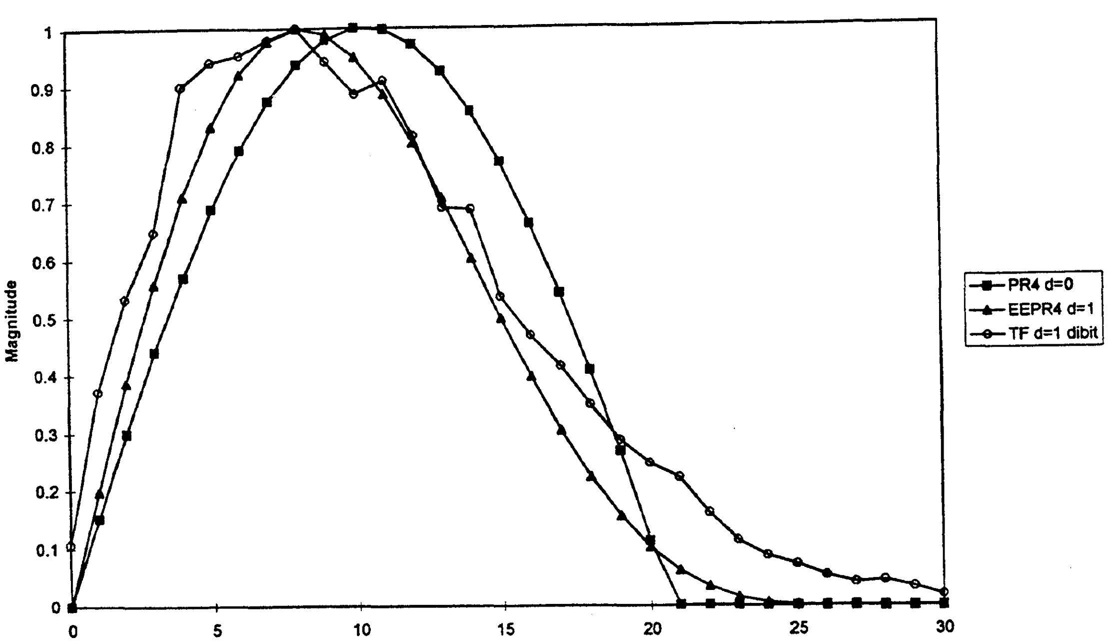
Off-track read capability

Maxtor

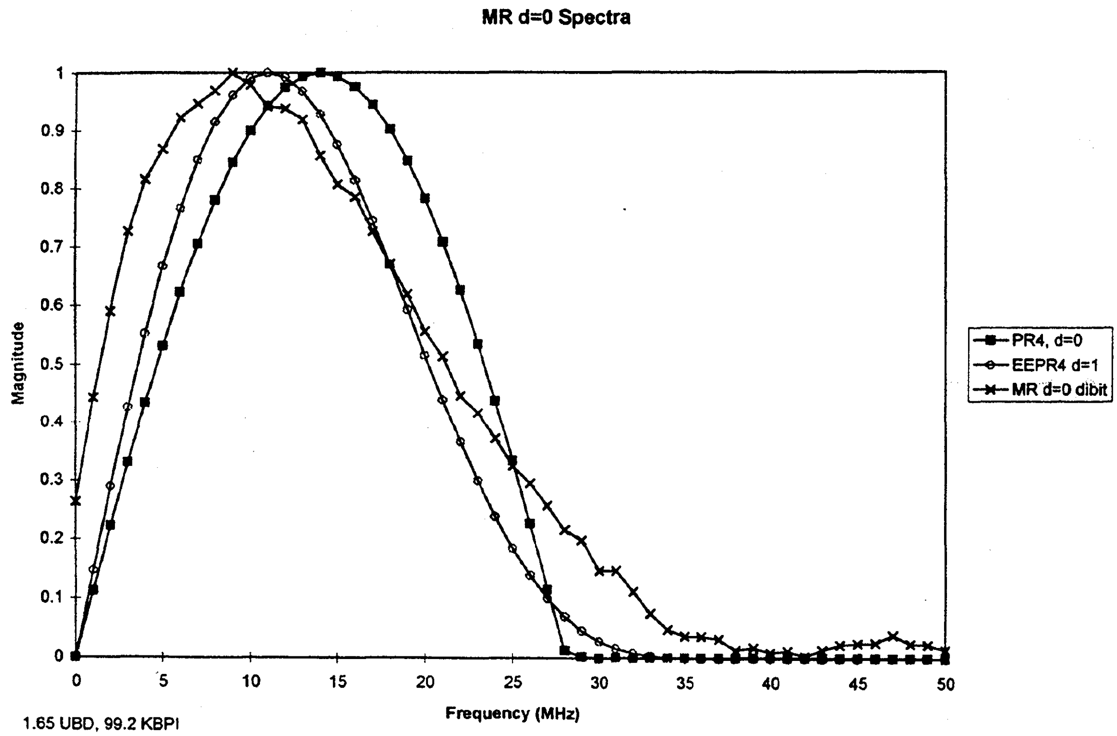
Toan Doan
1995 H/M Technology Review

Why not PR4 channel ?

- Inductive media has too much NLTS due to thicker magnetic
- TF head has less S/N for equalization, difficult to match PR4 (0,4,4) target
- TF head pulse response is more closely matched with EEPR4 target
- Nonlinear distortion is partially corrected with write precomp



1.45 UBD, 107.7 KBPI

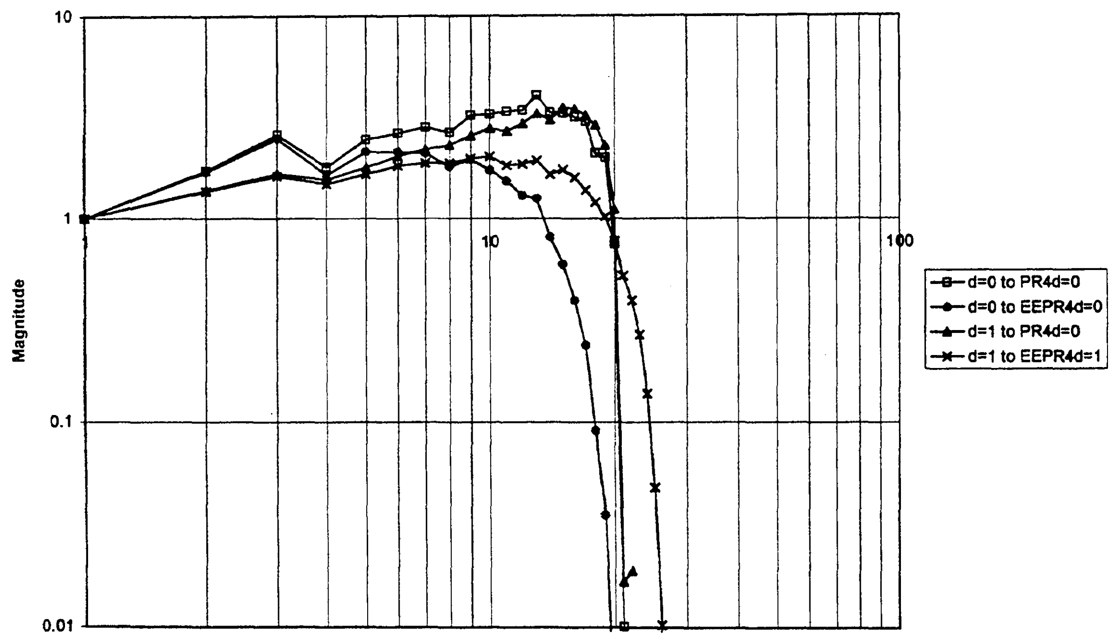


1.65 UBD, 99.2 KBPI

Limitations of equalization and Precomp

- Linear equalizer <u>can not</u> equalize to the exact PR targets
- Add significant noise (3 - 8 dB)
- Precomp can correct NLTS
- Precomp <u>can not</u> compensate partial erasure and core loss

Normalized Equalizers



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1995 H/M Technology Review

Inductive Channel Strategy

- Match the TF head response to higher order PR target (EEPR4)
- Minimize equalization to conserve the S/N
- Use an advanced technique to combat non linear distortion other than NLTS

Maxtor

Combat Partial erasure and Core loss

- keep the FCI low as possible (d = 1 is advantage over d = 0 code)
- Core loss and partial erasure can be corrected significantly by using a tuned Viterbi
- Use higher TPI to achieve the desired areal density, higher OTRC can achieve by better head pole designs (P2 > P1 gives write wide read narrow effect)

Advanced detection methods

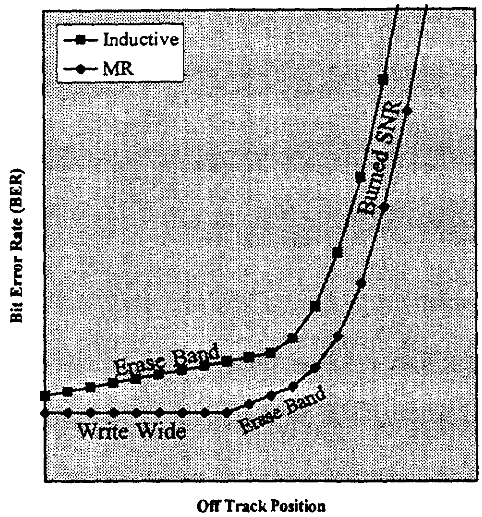
- Use tunable target Viterbi detector
- Nonlinear detector like RAM/DFE is more effective way to cope with NLTS
- FDTS/DF permits more flexible target

Tuned Viterbi , a Post Equalizer

- Method 1
  - Programmable detection threshold levels
  - Easy to implement
  - Not too effective to combat core loss
- Method 2
  - Tune all possible trellis sequences to maximize the distance between correct and incorrect path
  - Compensate for core loss and head shape change
  - Gain 10 % offtrack performance

Understanding of offtrack performance

- Write wide read narrow effect
- Erase band effect
- S/N and offtrack

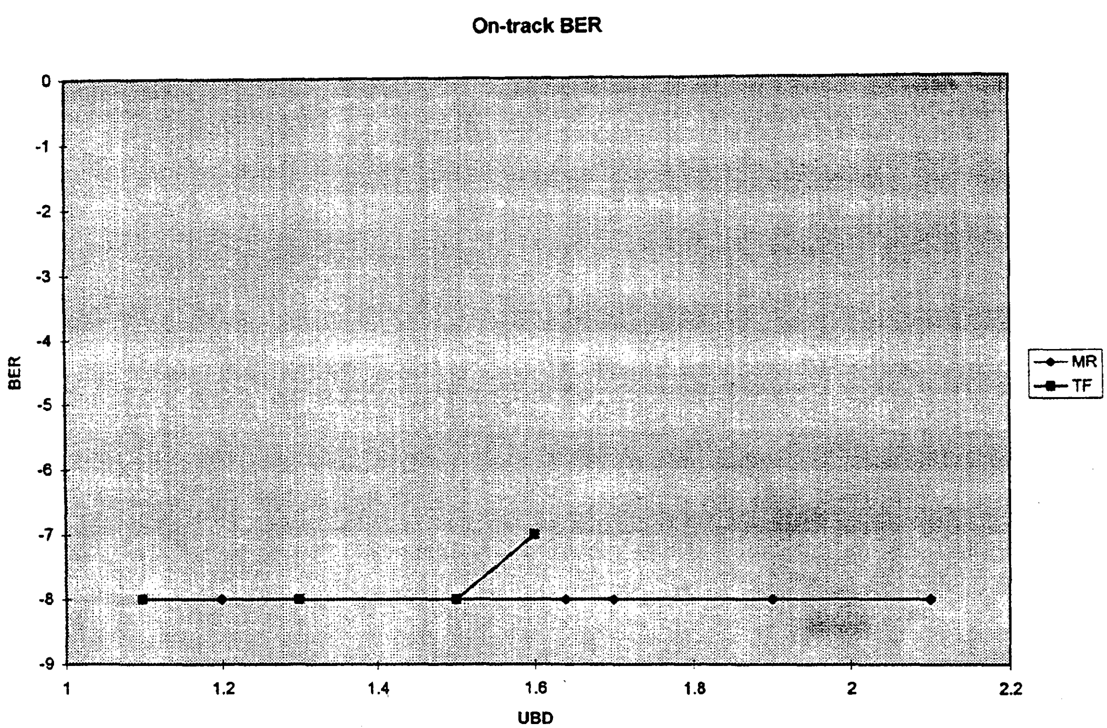


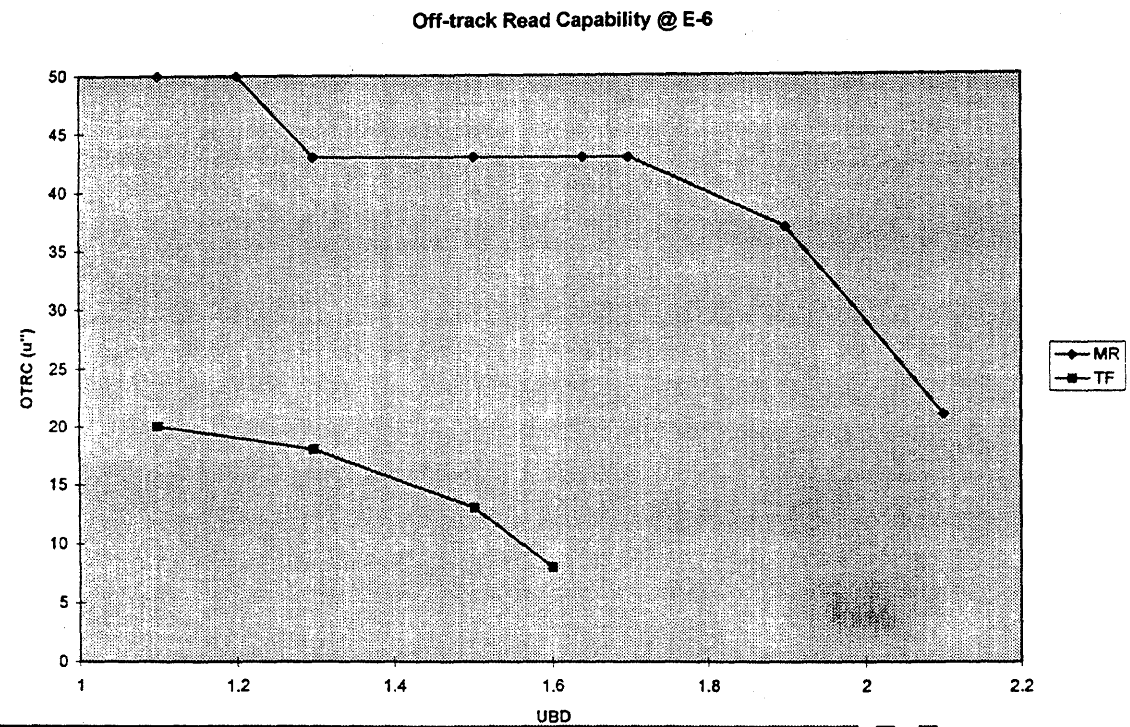
Error propagation for 8/9(0,4) versus 2/3(1,7)

- PRML with 8/9 code propagates longer error burst in comparison to 2/3 code
- For a given ECC with limited ability to correct longer burst this can result in a lower raw error rate requirement

Are these techniques useful for MR ?

- MR can still take advantage of high data rate
- At currently used linear density partial erasure is not a big problem
- Currently a PR4 - ML channel with MR head can do up to 2.2 UBD (TF is limited at 1.6)





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Toan Doan
1995 H/M Technology Review

SUMMARY

- TF head/media requires a channel that works at low S/N (15 - 20 dB)
- Code used with channel needs to minimize FCI (d = 1 is preferred)
- Channel with higher PR degree is better matched the TF head/media response (EEPR4 d =1 or FDTS/DF d=1)
- Use a tuned Viterbi to maximize distance between correct and incorrect paths

DIGITIZED PRML TEST

Koichi Hatakeyama

Vice President of Engineering

Nihon Techno Bute Ltd.

Digitized PRML Test

Nihon Techno Bute Ltd.

NTBL 日本テクノビュート株式会社
Nihon Techno Bute Limited

HATAKEYAMA Koichi

Nov.12, '95

NTBL

New Test Technology for New HDD Technology

☐ **Inductive Head ----→ MR Head**

Higher Density.	Nonlinear Distortion Signal/Transition Noise Spectrum Analysis
Higher Speed .	Higher Write Frequency Higher Read Bandwidth
Instability	Barkhausen Noise Thermal Asperity

☐ **Peak Detect ----→ PRML**

Analog Waveform.	Asymmetry (Amplitude, PWxx) Base Line Shift Nonlinear Distortion Sampled Analog Value
Software Simulation	Waveform Simulation Channel Simulation Viterbi Simulation

☐ **Digital Signal Processing Based Analyzer** is required

NTBL

Higher Write Frequency

	Data Rate			
	80Mbps	120Mbps	160Mbps	200Mbps
1-7. Coding	30MHz	45MHz.	60MHz	
.	60MFC/s.	90MFC/s.	120MFC/s	
8-9 Coding	45MHz.	67.5MHz	90MHz	112.5MHz
.	90MFC/s	130MFC/s.	180MFC/s	225MFC/s

NTBL

Peak Detect to PRML

Peak Shift Distribution is key for Peak Detect Channel performance

Sampled Analog Value Distribution is key for **Partial Response Channel Performance.**

- **Analog Waveform Distortion**
  - Amplitude Asymmetry
  - Pulse Width Asymmetry
  - Baseline Shift
  - Nonlinear Distortion
  - Any Anomalous Waveform Distortion
- **Entire Analog Waveform Data are required**

NRZ Data Error Rate is final performance after Viterbi output.

NTBL

Analog Waveform Measurement

Analog technic can't measure analog waveform.

- Peak hold technic measures only a peak value.
- Comparator technic measures only a sliced width.
- Not entire waveform data are measured.

Digital technic can measure entire waveform.

- Digitizing Analog Waveform
- Storing Entire Analog Waveform as Digital Data

Signal Processor can do everything required.

NTBL

Test outputs of Digital Waveform Analyzer for MR Head and PRML Channel

☐ **Waveforms;**

Isolated Waveform ;

Peak Value ; Vp+, Vp−, **Asymmetry**

Pulse Width ; PW50+, PW50−, PWxx+, PWxx−, **Asymmetry**

Slope ;. Tf, Tr

Waveform Distortion ;
Side Lobe, **Base Line Shift**, Base Line Noise,

☐ **Spectrum** ; Signal ; Spectrum for Track Profile
Noise ; OW Noise, **Media Noise, Head Noise**

☐ **Sampled Analog Value Distribution** of PR Equalizer output;

☐ **Nonlinear Distortion** ;

5th Harmonic Elimination

Dipulse Extraction

Autocorrelation

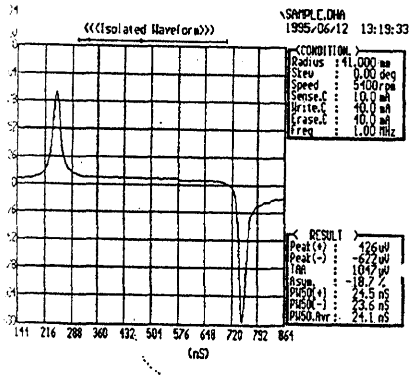
Pulse Matching

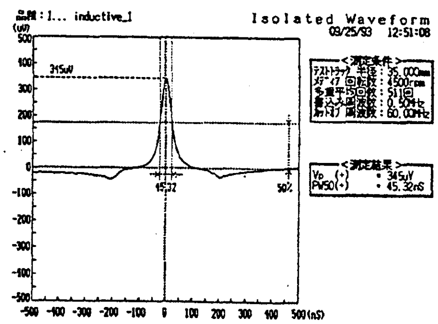
(These measuring methods are recently defined by PRML group of IDEMA)

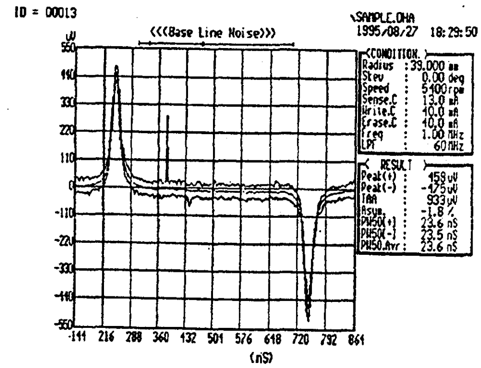
NTBL

Test outputs of Digital Waveform Analyzer for
MR Head and PRML Channel(Example 1)

- ☐ Isolated Waveform ;
- ☐ Peak Value ; Vp+, Vp−, Asymmetry
- ☐ Pulse Width ;. Pw50+, PW50−, Asymmetry
- ☐ Side Lobe
- ☐ Base Line Shift, Noise





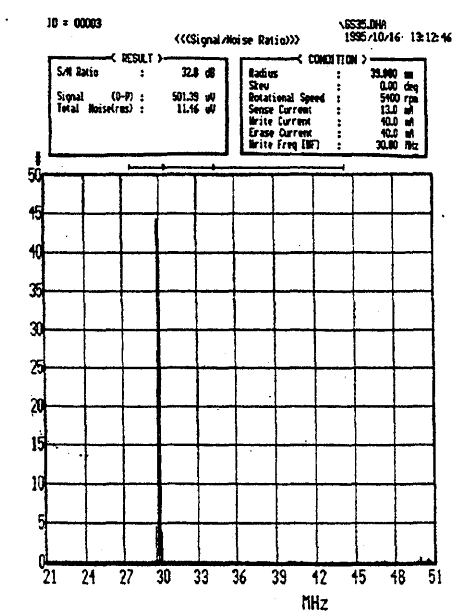


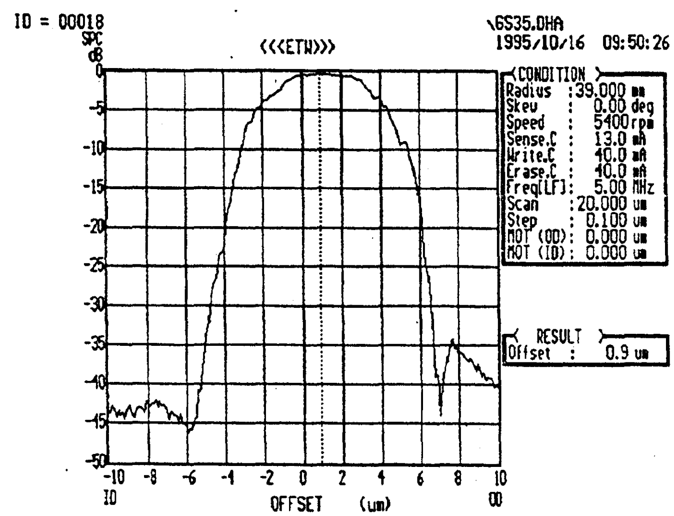
NTRL

Test outputs of Digital Waveform Analyzer for
MR Head and PRML Channel (Example 2)

☐ Signal to Transition Noise ☐ Track Profile with Spectrum

DSP technic such as digital filter and FFT give ultra flexibility for spectrum analysis and noise analysis.



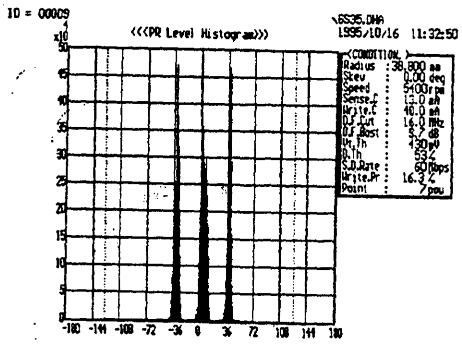


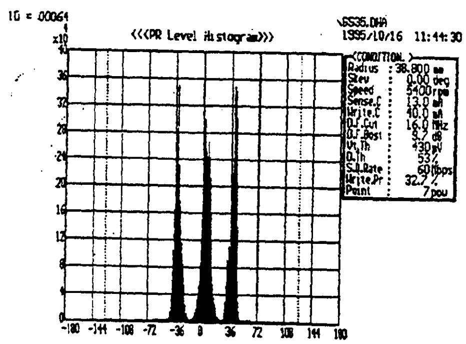
NTRL

Test outputs of Digital Waveform Analyzer for
MR Head and PRML Channel (Example 3)

☐ Sampled Analog Value Distribution Histogram of Partial Response Eq.Output

These PR characteristics combined with Viterbi performance determine total Error Rate.



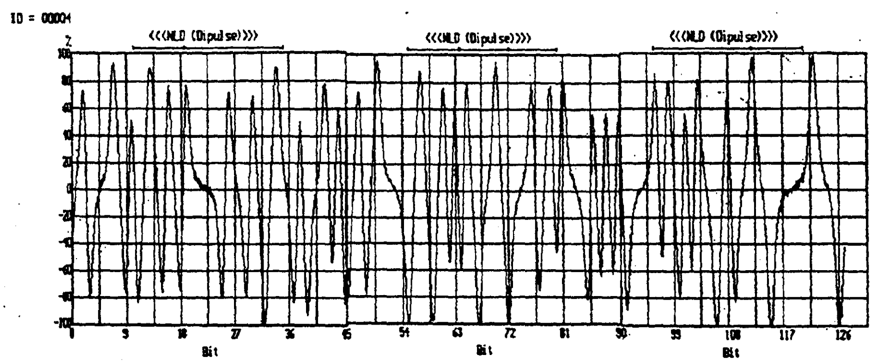


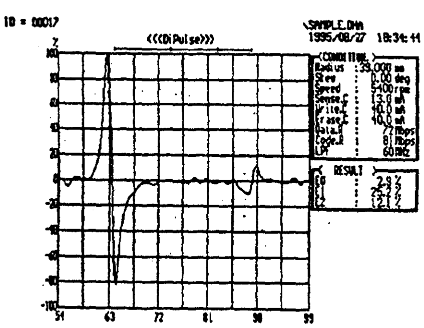
NTBL

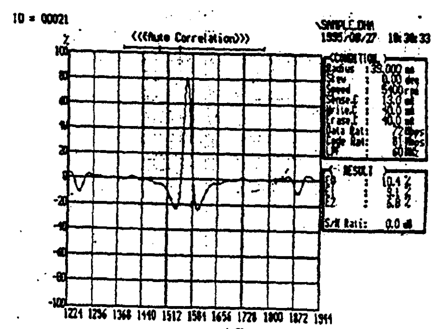
Test outputs of Digital Waveform Analyzer for
MR Head and PRML Channel (Example 4)

☐ Nonlinear Distortion; Psuedo Random Coding Analog Waveform
☐ Nonlinear Distortion; Dipulse Extraction
☐ Nonlinear Distortion; Autocorrelation

*(These measuring methods are recently defined by PRML group of **IDEMA**)*







NTBL

Digital Signal Processing based analyzer
gives the most of key measuring functions that are required for **MR head** and **PRML channel** test, theoretically.

The fact, however, is not so easy !!

- ☐ Play back signal contains so much random noise.
- ☐ Digitizing resolution is not high enough
  for our sharp pulse waveform.
  A/D conversion speed utilized is so fast as to 500MS/s ~ 2GS/s.
  So fast in industry,
  but so slow compared with PW50=10nsec.

These facts prevent analyzer to measure waveforms with high accuracy.

NTBL

To gain theoretical benefit of
Digital Signal Processing based analyzer,
key technology is to measure analog waveform with high accuracy

- ☐ Eliminate random noise
  for various reasons, such as interpolation
  Interpolation : to compensate relatively low A/D conversion speed.
  should be done after eliminating random noise
- ☐ To eliminate random noise, averaging technic is effective.
- ☐ Averaging technic generates serious phase distortion of resulting waveform.
- ☐ To eliminate phase distortion at averaging,
  each waveform should be superposed **in phase.**
- ☐ So, phase of each waveform should be detected
  before superposition,
  for instance, detecting peak position of
  fundamental component of each waveform.

NTBL

NRZ Data Error Rate Test

Overall Evaluation of Disk, Head, Channel and Drive.

Key part of disk/head tester from now on

- Performance of Disk, Head and Channel being significantly combined
- To be discussed totally for cost effective solution of each part, Disk, Head, Channel and of Drive itself.

NRZ Data Error Rate testing takes time.

Some methods to accelerate this time consuming test to find operation margin.

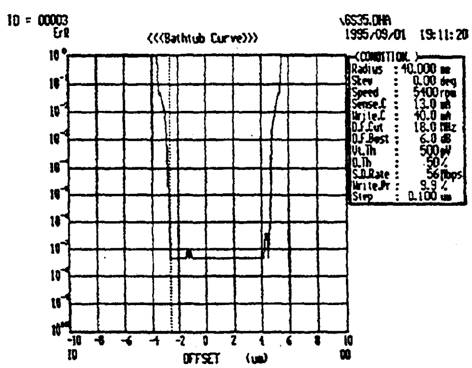
- **Error Rate vs. S/N** Curve, injecting controlled noise into play back signal
- **Error Rate vs. Viterbi Threshold** Curve
- **Error Rate vs. Bias Current** Curve
- **Error Rate vs. Taps of Equalizer** Curve
- Error Rate vs. K parameter

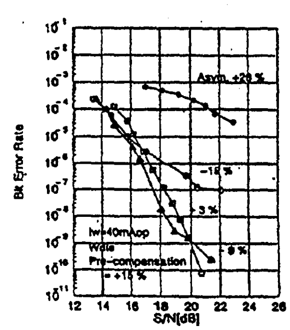
  (This method calculates Error Rate from amplitude sampling errors, on software simulation, proposed by Tim Perkins and Zachary A. Keirn, as Sequenced Amplitude Margin(SAM).)

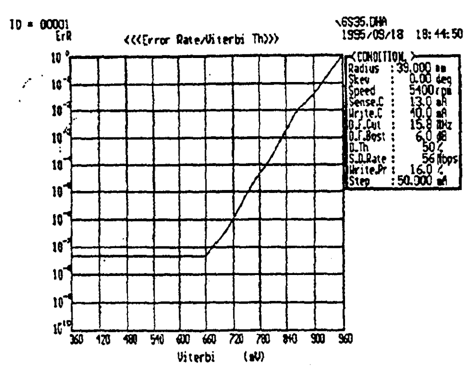
NTBL

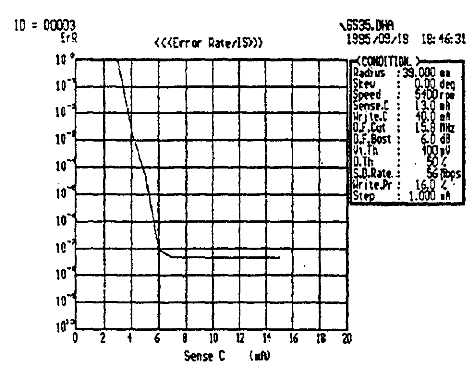
NRZ Data Error Rate Test(Examples)

- ☐ Bathtub Curve.
- ☐ Error Rate vs. Viterbi Threshold Plot
- ☐ Error Rate vs. S/N Plot.
- ☐ Error Rate vs. Bias Current Plot









NTBL

Software Simulation of Channel Characteristics

Digital signal Processing based Analyzer is capable of Simulating every part of Disk Drive system, such as

- ☐ Play back signal from Disk/Head.
- ☐ Channel characteristics, such as
  - Filters
  - PLL
  - PR4, EPR4, EEPR4, etc.
- ☐ Viterbi error correction
- ☐ Any of those part could be replaced by real hardware for comparison with software simulation and analysis.

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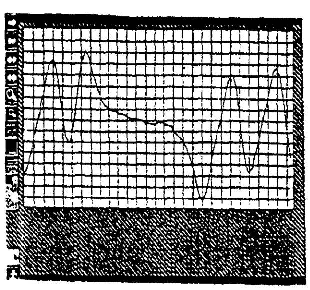
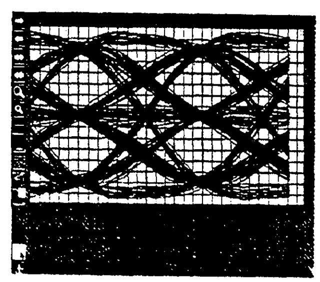
Software Simulation of Channel Characteristics

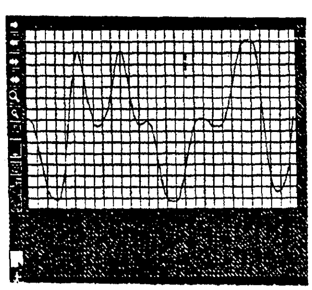
(Examples)

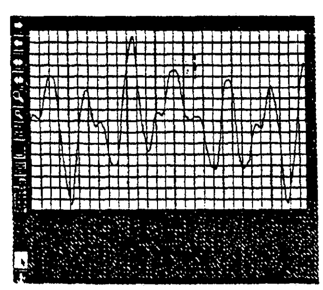
☐Simulated Play Back Signal.
☐Simulated PR4 Equalizer Output

☐Simulated PR4 Eye Pattern
☐Simulated EPR4 Equalizer Output









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Conclusion(1)

MR which gives higher density and higher speed requests

Spectrum Analysis of Signal and Noise

Nonlinear Distortion analysis

Instability Analysis

PRML which gives higher density requests

Analog Waveform Distortion Analysis

Analog Value Measurement

Resulting

Digital Signal Processing based Analyzer

which gives advantages for **analyzing MR and PRML**

(which also has some difficulty to achieve high accuracy)

NTBL

Conclusion(2)

☐ **MR and PRML** fundamental characteristics

analyzed with **Digital Signal Processing** based Analyzer

combined with over all performance

analyzed with **NRZ Data Error Rate** Analyzer

will produce cost effective solution for

all the parts, **Disk, Head, Channel integrated into Disk Drive.**

☐ Digital Signal Processing based Analyzer also gives strong environment for

simulating play back signal and **channel** characteristics.

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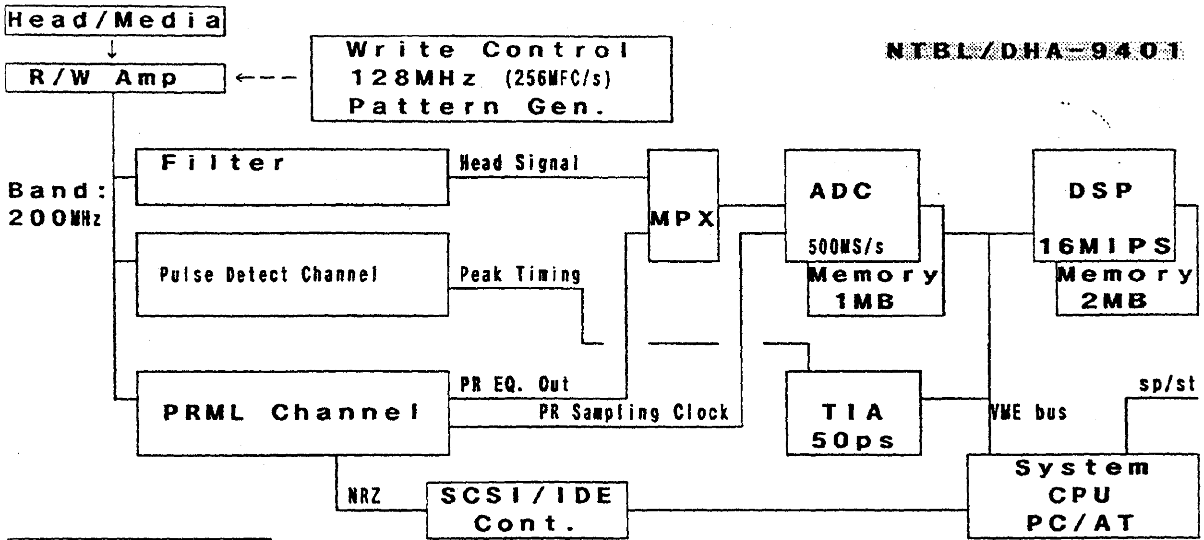
Block Diagram of NTBL/DHA-9401



Test Outputs

ADC/ DSP; Isolated Waveform, Coded Waveform
Vp+, Vp-, Amp Asymmetry, Resolution, PW50+, PW50-, PW Asymmetry, Base Line Shift, M/S Pulse, Extra Pulse
Overwrite, S/N,
Nonlinear distortion(5th, Dipulse, Autocorrelation)
Partial Response Sampled Level Histogram,
Frequency Roll off plots, Saturation plots(Iw, Is), Track profile(Taa/Spectrum, asymmetry)

NRZ; NRZ Data Error Rate(PRML),

TIA; Window Margin, Timing Asymmetry, Intersymbol Interference

NTBL

LASER BASED TEST TECHNOLOGY

Ian Freeman

Chief Technical Officer

THoT Technology

Laser based Test Technology

by

Dr. Ian Freeman

11th Annual Rigid Disk Head/Media Technology Review **November 12th, 1995**

REQUIREMENT

- ♦ ~25,000 TPI = - Servo tracking challenges
- ♦ Fluid Spindles = - <1μ" NRRO
- ♦ Flying heights = - <1μ" or contact
- ♦ Faster Access = - 7,200-10k RPM

♦ **Need: Vibration Free Drive Design**

REQUIREMENT

- ♦ Volume = - High Speed Production Testers

♦ **Need: Source of Qualified Test Equipment**

Figure 1 Approaching 10Gbits/sq"

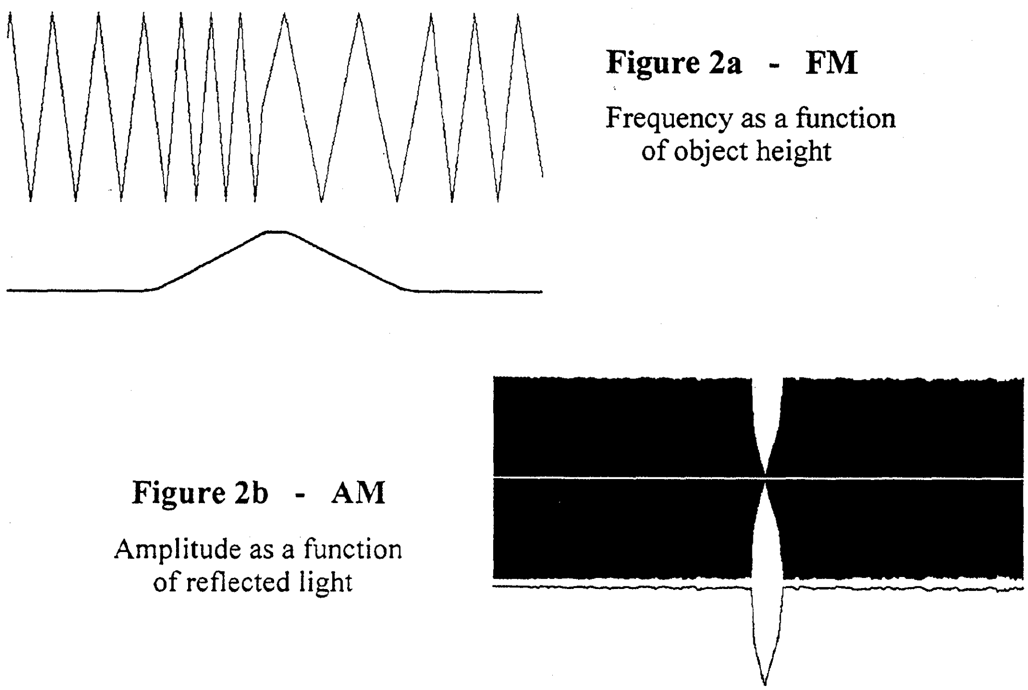


Figure 2 Doppler Laser principles

THôT Technologies, Inc.

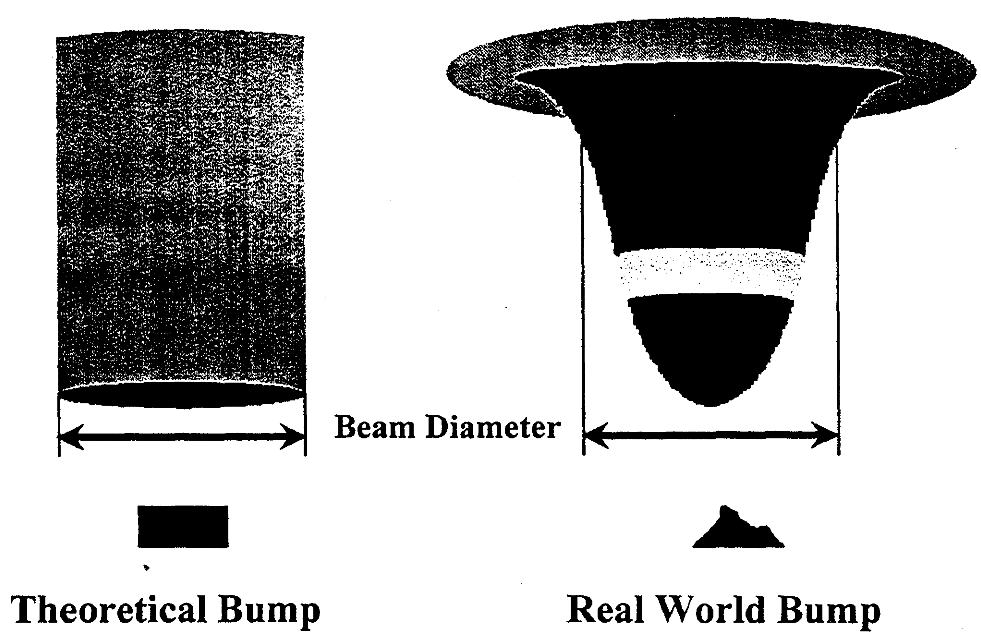


Figure 3 Laser beam and defect shapes

THôT Technologies, Inc.

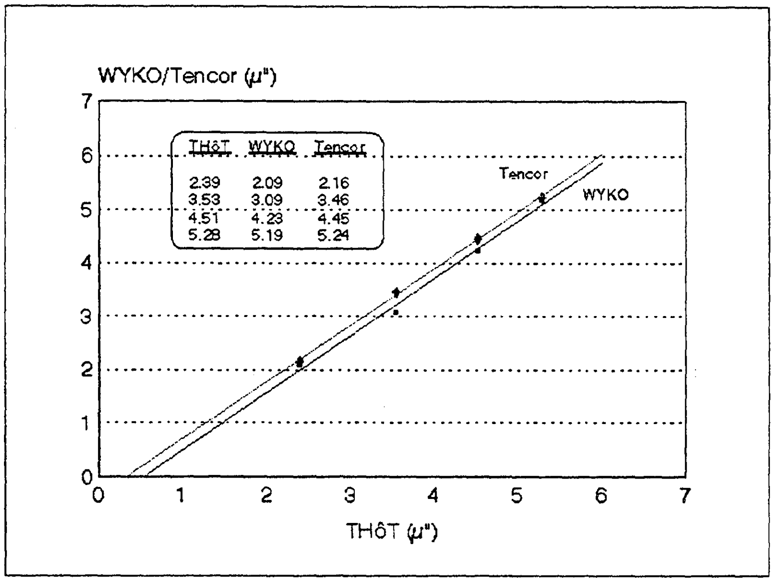


Figure 4 Calibration Data for THôT, Tencor and WYKO.

THôT Technologies, Inc.

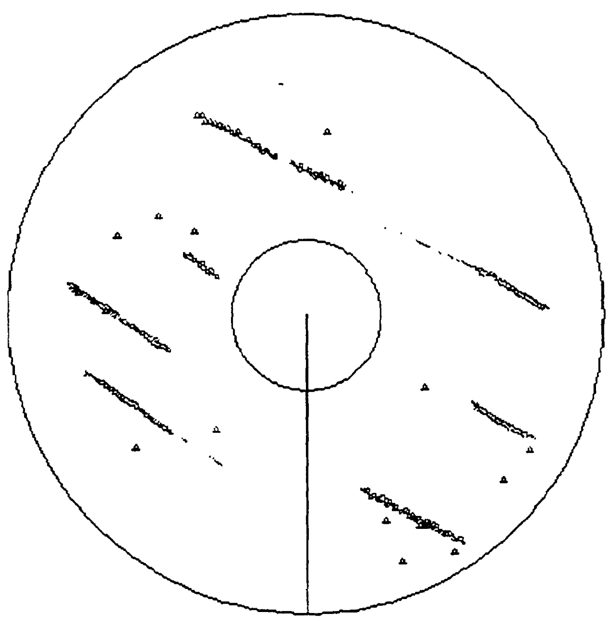
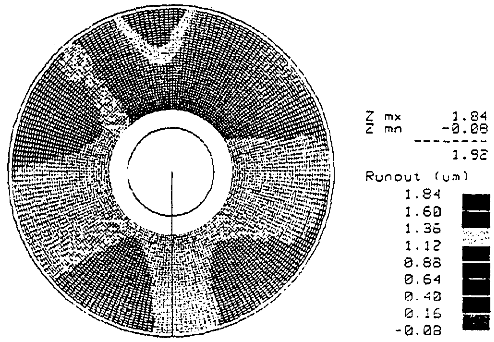
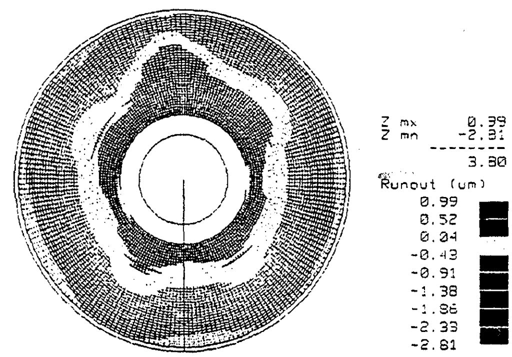


Figure 5 An example of Substrate scratches.

THôT Technologies, Inc.



6a "Standard" Runout plot



6b Runout plot with True Level

Figure 6 An Example of the True Level feature.

THôT Technologies, Inc.

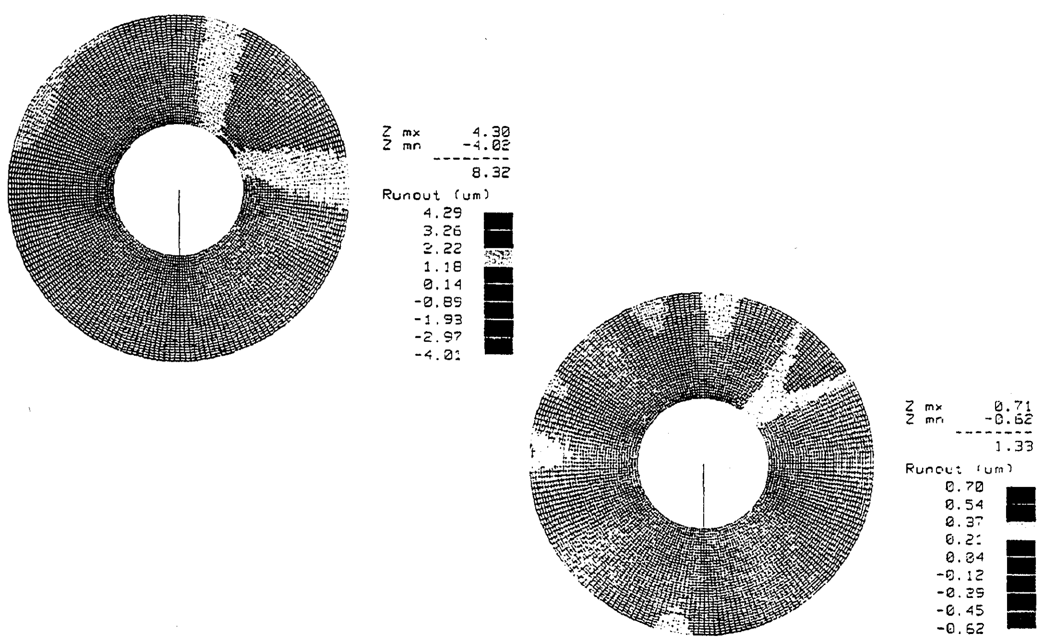


Figure 7 An Example of Flutter in a Drive.

THôT Technologies, Inc.

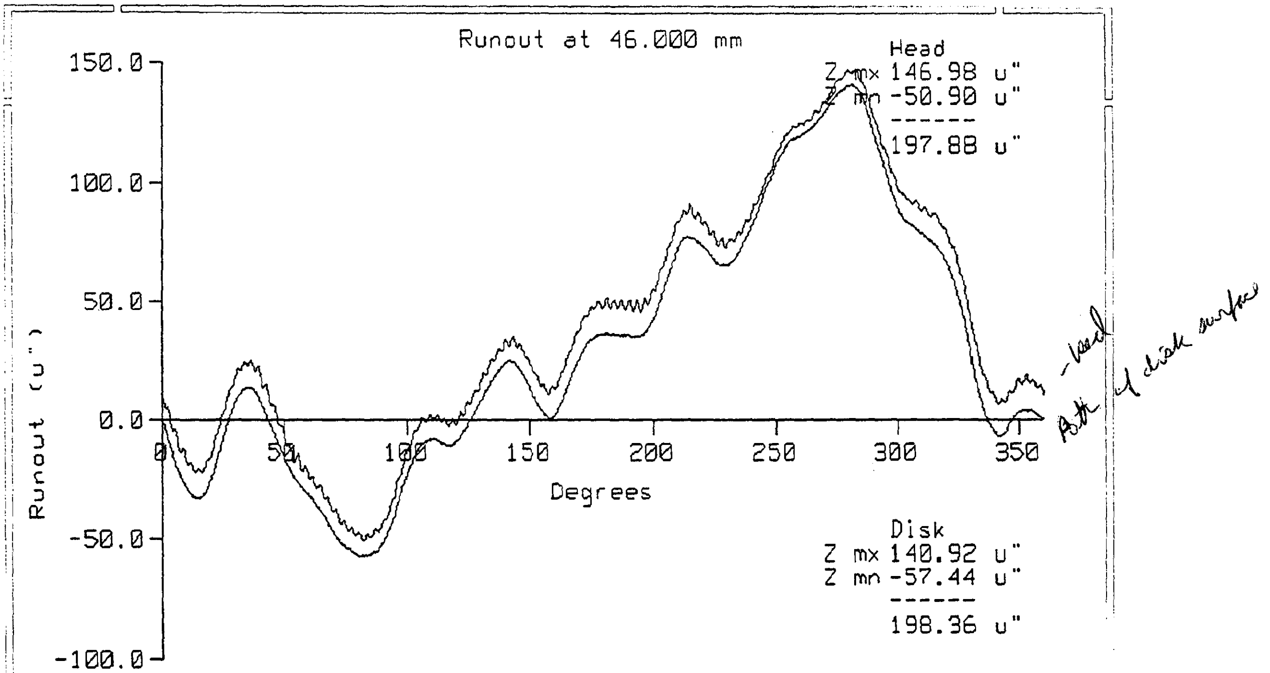


Figure 8 Flyability, measuring the head flight over the disk.

THôT Technologies, Inc.

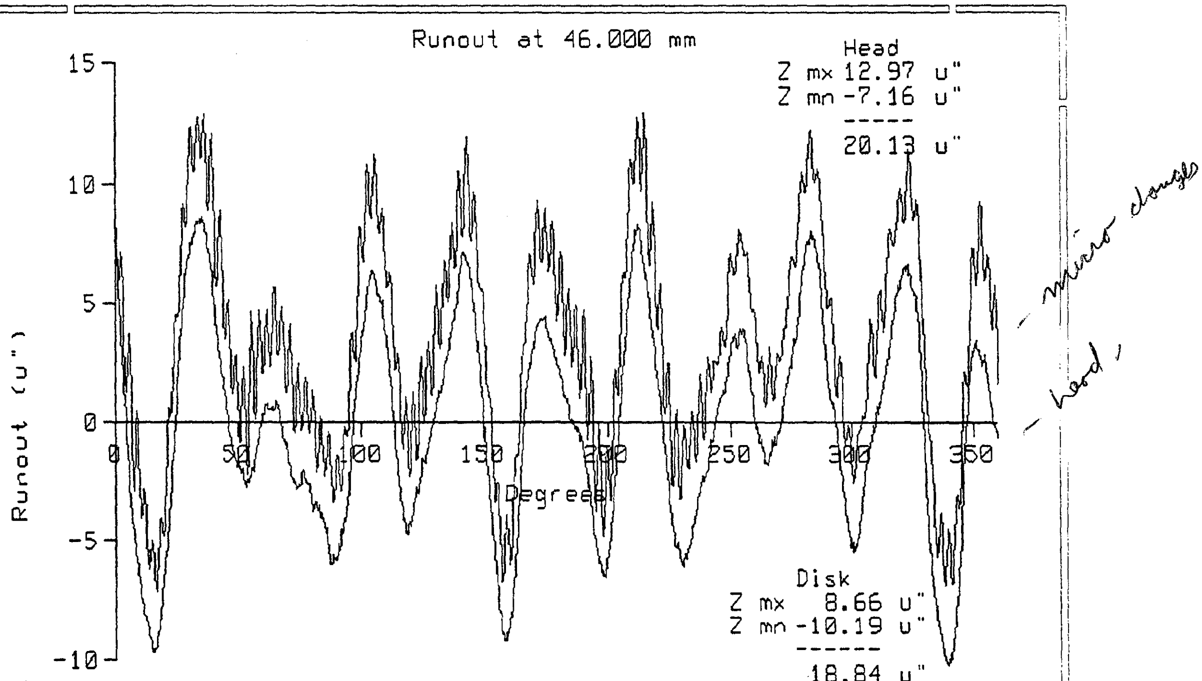


Figure 9 Flyability, terrain following of the head over the disk.

THôT Technologies, Inc.

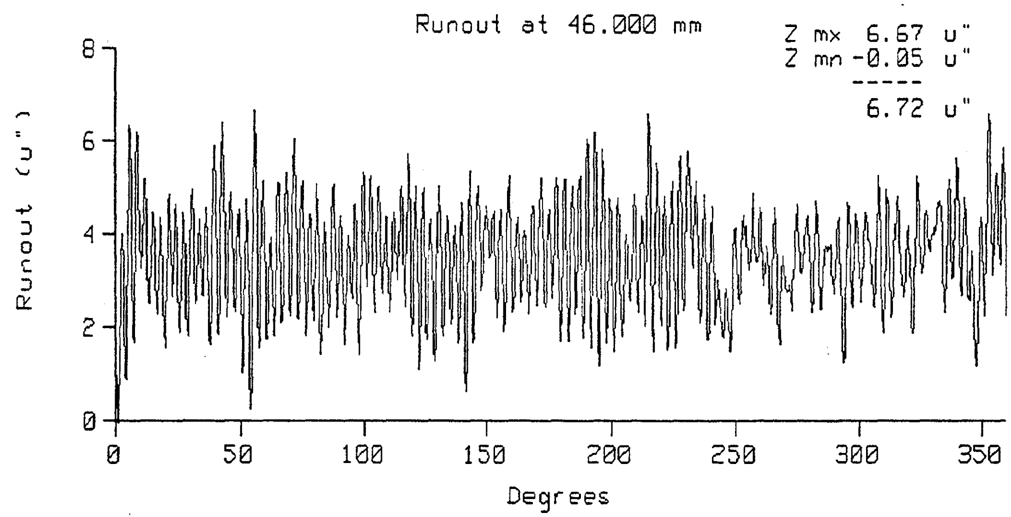


Figure 10 Flyability, Instantaneous Spacing Loss

THôT Technologies, Inc.

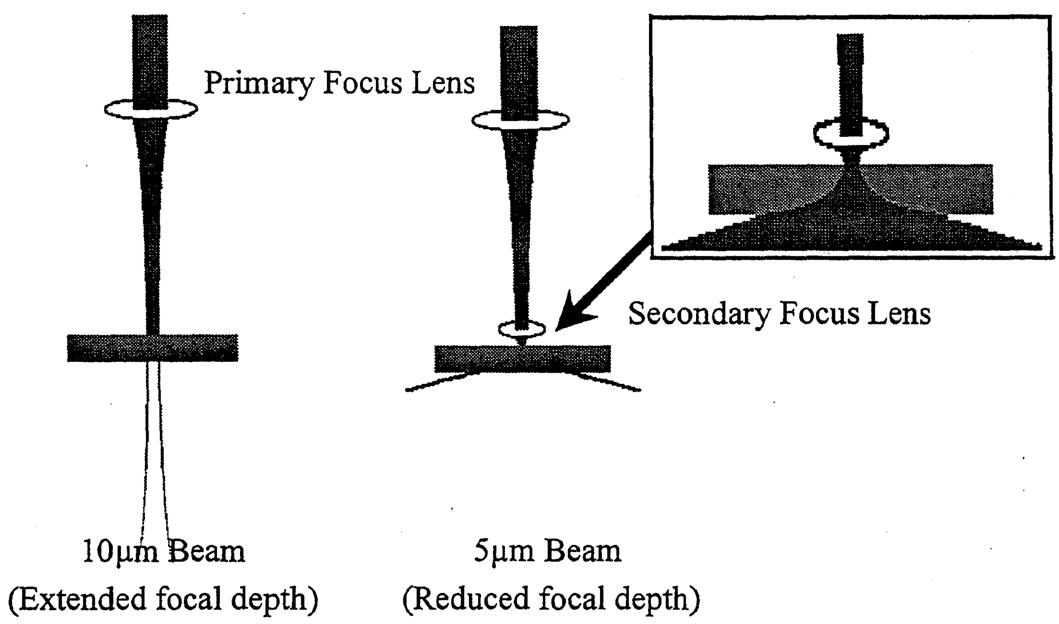


Figure 11 Glass Substrate Measurement

THôT Technologies, Inc.

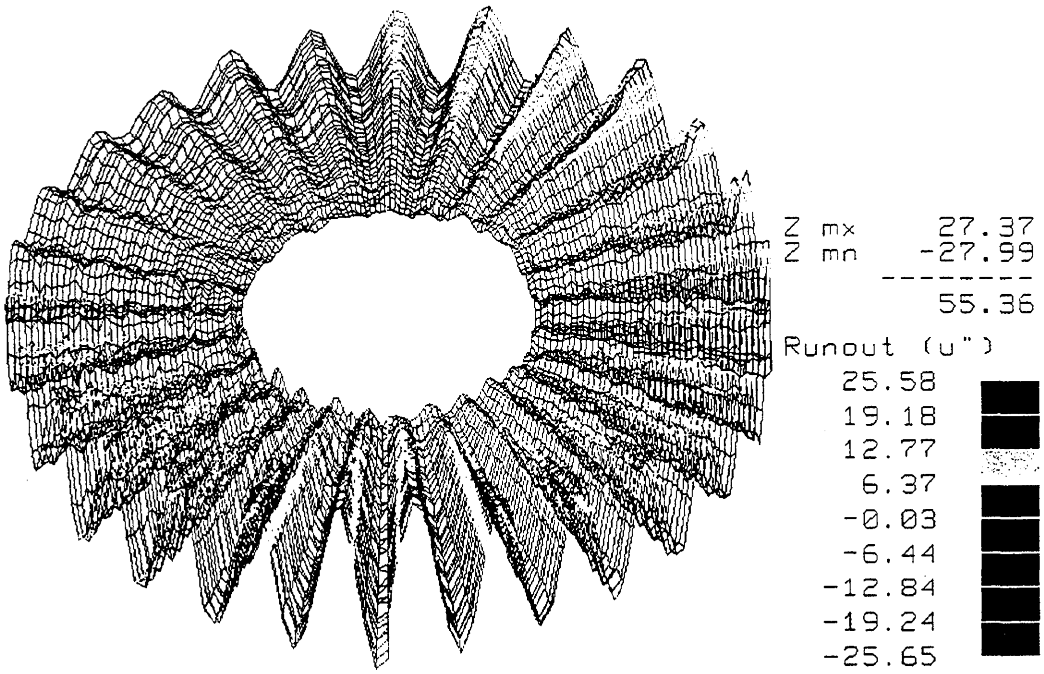


Figure 12 1000 rpm Disk Resonance

THôT Technologies, Inc.

Laser Based Test Technology

by

Ian Freeman

Ancient Chinese Curse: May you live in interesting times.

Introduction

With the advent of 10 Gbits/in^2 and the likely direction drive manufacturers will take to achieve this areal density, the industry is faced with mechanical challenges that, in any other industry, would make adults weep and tear out their hair (see Figure 1). As an example, head flying heights will be in the 0.8μ" range with an expected tolerance of ± 0.2μ", disk "textures" will approach 15Å R_a, the limits of polishing tolerances dictated by turbulent fluid flow. All this has to happen with minimal head-to-magnetic-layer spacing loss, which equates to thinner overcoats to protect the all important magnetic layer. Worst of all there are conflicting tribological and electrical conditions. The head is required to stay down on the disk, but close head to disk spacing results in premature failure through wear.

We live in interesting times!

Background

Doppler Laser Technology

Laser Doppler Vibrometers (LDV's) work on the principle of introducing a "static" reference frequency onto the laser carrier, shining the light off a moving object, detecting the slight Doppler shift in the reference frequency caused by the object moving to (or away from) the laser, and decoding this as velocity information. In the case of the Polytec LDV used in THôT Testers, a 40MHz reference frequency is superimposed on the HeNe laser beam using an electro-acoustic coupler called a Bragg cell. (We can do this without loss of laser light integrity because the 633nm laser light oscillates at $\approx 5 \times 10^{14}$ Hz, a frequency far greater than the 40MHz reference beam). Assuming that the measured object moves at a velocity that induces a frequency shift less than half the reference frequency, then we can decode the frequency shift as a unique velocity with no possibility of false frequency shifts or intensity variations caused by aliasing. The only remaining criterion for making an accurate measurement is that 2-5% of the incident beam has to return along the light path for the decoder to phase lock to the signal and decode the Doppler frequency shift (Figure 2a).

The Doppler laser system is analogous to the FM radio bands where, provided the received signal strength is above a limiting threshold, then clear decoded information will be obtained. If the signal drops below the limiting threshold then things go to hell in a handbasket very quickly. Such is also the case for the laser. However it also means that any information carried on the beam in the form of intensity variation will not be decoded and subsequently be lost. If this intensity variation could be decoded then additional information would be obtained *that does not have to contain height information.* In the radio analogy, this would be the AM section of the receiver (Figure 2b).

The laser is a very accurate tool for measuring distances and flatness (or roundness) of objects that provide good reflectivity. Typical lasers used in this application use fringe counting interferometric techniques (not the Doppler principle), have beam diameters in the 1mm to 5mm range and a working bandwidth of 20 kHz to 30 kHz. So, for simple flatness and RVA type testing, lasers provide a stable measuring tool with few limitations and have been used this way for a number of years. But in a perfect theoretical world, this laser based technology can never work for small defect detection. If we assume a perfectly collimated laser beam shines on a 1µ" high defect with perfectly vertical sides, we would require infinite bandwidth and slew rate to detect the defect.

If we now take a perfectly collimated, 5µm diameter laser beam shining on a 2µm wide, 1µ" high defect with perfectly vertical sides, then, for a 95mm disk spinning at 10,000 rpm, a laser will register the defect if we have ≈25Mhz bandwidth and an equivalent slew rate of ≈10"/Sec. (Imagine having tunnel vision and looking at the world through a drinking straw, seeing a bug flying across the field of vision and then having to identify the size and type of insect "on the fly" as it were, you would begin to get an idea of the nature of the task at hand).

But then, in this perfect theoretical world, if we add together all the tolerances in a disk drive, drives could never be manufactured in quantity. Bumble bees are an aerodynamic disaster, they can't possibly fly, only no-one told that to the bumble bee. The reason we are able to detect small defects with a less than ideal laser is that the laser beam is not cylindrical and defects do not have perfectly vertical sides (Figure 3). Returning to the tunnel vision analogy, we can now remove the drinking straw and allow ourselves to use peripheral vision so we have time to "acquire" the fly before focusing onto it for size and identification purposes.

So how can lasers be used in our quest for 10 Gbits/in^2?

The first observation is that laser technology is non-contact and therefore non-destructive. As a result measurements can be made on any surface that provides enough reflectivity to return 2-5% of the incident laser light. In practical terms, this means that lasers can be used for measurements at any step of the disk manufacturing process, from raw substrates to finished disks.

Secondly, lasers offer the potential for greater precision than current measurement technologies in a number of situations. The height resolution of the Doppler laser system is limited by the ultimate signal to noise of the laser and decoding electronics. In the case of the Polytec system, the minimum equivalent height resolution is approximately 0.1Å.

Obvious Applications for Laser Technology

Glide certification (Optical Glide®)

On a good day, if the phase of the moon is right and you have the wind at your back, a traditional glide tester will provide repeatability of the order of 0.5μ". That is, if the head does not hit an asperity and nullify the calibration. Consider this; the heads you require for your testers will need to have a flying height tolerances of ±0.25μ" and, further, if the glide tester is running in constant linear velocity (CLV) mode then you have the potential for exciting disk flutter (corresponding to excited resonance modes of the disk) at certain rotation speeds. These resonances excite the head causing phantom glide hits at discrete bands across the disk and, even further, allow the head to deposit unwanted debris onto the data recording surface - are we having fun yet?

Laser technology provides headless certification with repeatability in the 0.05μ" range and can be correlated with conventional calibration techniques such as bump disks (Figure 4). The absence of heads means no debris generation, and, because there is no head to fly at a constant height above the disk surface, there is no need for CLV operation. There is no logical reason why glide certification cannot be performed at 10,000 rpm using a 5μm (200μ") track pitch, in 30 seconds. In fact it already is.

Substrate certification

One of the prime concerns for high density recording is the quality and evenness of the substrate grinding and the subsequent NiP coating integrity. For a ground substrate it is very difficult to visually detect a deep scratch that follows the grinding pattern and should be rejected as a viable substrate. Conversely, it is very easy to visually detect a shallow but insignificant scratch that crosses the grinding pattern and reject a perfectly functional substrate.

In the first case the deep scratch would be partially filled in the plating process and subsequently polished as a shallow (<1μ") depression. The depression would ordinarily be almost undetectable. But as heads begin to fly across the 1μ" depression the concomitant spacing loss of that depression, that started life as a deep grinding scratch, becomes significant for the read/write channels and ultimately the data integrity of the drive. Figure 5 shows an example of a defect map of such scratches detected at the substrate level.

Traditionally, substrate inspection is a manual task performed by a battery of trained visual inspectors and is, by default, a subjective operation that also has the potential for handling damage. With laser technology it is possible to measure substrate quality using non-contact methods, assign real non-subjective numbers to defects and weed out the truly defective parts early in the manufacturing process. Additionally, machine certification is easily adapted to robotic operation with correspondingly less handling damage.

Drive Studies

The high standoff distances (i.e. the distance from the lens to the object to be measured) inherent in laser technology makes laser technology ideally suited for "in drive" measurements where the close proximity of a capacitive or inductive sensor would easily result in contact damage. It is possible to scan the disk surface from ID to OD and evaluate the drive for spindle problems, clamping problems, disk cupping and/or coning and disk instabilities (fluttering), all at drive speeds and under actual operating conditions.

Figure 6a shows a laser generated runout plot of a disk running at 3600 rpm. Since RVA testing is by definition a single cylinder test and all tests have an arbitrary zero, there is no displacement information carried over from cylinder to cylinder. Figure 6b shows how a combination of an RVA test and a single profilometer scan at index allows the user to compensate for the lack of displacement information from cylinder to cylinder and to examine the true disk shape, in this case, coning caused by clamping distortion, a feature we call True Level®.

Figure 7 shows a runout plot of the top disk in a problem drive. The drive is a medium capacity drive spinning at 3600 rpm. The total runout in this case is quite good at 8.3μm but underlying this, the disk is resonating (fluttering) with an amplitude of 1.3μm. The fluttering of the disk in this case causes the head to lose its ability to effectively "terrain follow" the disk's path and leads to servo tracking problems. It will also cause unwanted head impacts that lead ultimately to drive failure.

Flyability®

Flyability is a term coined by THôT Technologies to describe how the head responds dynamically to the perturbations on the disk surface. This test is used to check the suitability of the head/disk combination for stable flight, an idea first proposed by Don Mann. In Flyability testing, one laser beam is aimed at the slider and a second laser beam is aimed at an adjacent part of the disk. When measurements are taken in a *...head-disk-head-disk-head-disk...* fashion, then the path the head follows can be tracked simultaneously with the disk path and any discrepancies recorded and examined.

Such is the case shown in figure 8. The upper trace shows the path the head is taking while the lower trace shows the path of the disk. Note that the total excursion in each case correlates to within 0.5μ" and that there is some evidence of disk flutter. Note also the "minor" perturbations in the path of the head. Figure 9 shows the same head and disk, this time with the gross runout removed using our "Modulation Removal" filter, so we can more closely examine the way the head responds to the flutter. In general, the head does a commendable job of terrain following but is suffering from unstable flight at a equivalent frequency of 10kHz, which substantially affects the instantaneous spacing loss (Figure 10). Yes, it really does have an instantaneous spacing loss as high as 6.7μ".

Not so Obvious Applications for Laser Technology

Alternate Substrate Certification

Because the laser tester only requires a semi-reflective surface to return 2-5% of the incident light needed for accurate measurements; and, further, since there are no inductive or capacitive limitations requiring a grounded or metallic surface, the measurement of alternate substrates *including transparent or translucent glass*, becomes a "no-brainer". For skeptics who believe that there will be a portion of the incident beam reflected off the bottom surface causing destructive interference and false measurements, I refer you to figure 11. Ordinarily those skeptics would be correct and a 10μm diameter beam with a large standoff distance does indeed suffer these limitations. However if an additional focusing lens, with a substantially shorter focal length is used, then the focus "saddle" is maintained for a much shorter depth. If the disk is thick compared with the focus saddle then, by the time the laser light reaches the lower surface of a transparent substrate, the beam has diffused to such an extent that only a fraction of 1% of this unwanted beam can return along the light path and will be ignored by the phase detection circuitry.

Visual Inspection

By using the changes in intensity of the return portion of the laser beam (the AM section in our radio analogy) we can locate and map defects that have no height information associated with them. A well trained visual inspector can reliably detect a high contrast anomaly with a diameter of about 20μm. With the small beam diameters currently in use (down to 5μm), a visual (intensity) resolution of 1μm is achievable giving an areal resolution 200x greater than the human eye.

Magnetic Certification

Consider the premise that a discontinuous magnetic film will give rise to a magnetic defect. Consider also that any magnetic defect has a mechanical anomaly associated with it (why else would we do failure analysis?), then it follows that if the laser can detect small enough pits/asperities or reflectance changes, then disk certification using a laser beam is possible. Practical tests at several installations have shown that a defect map of a disk generated using laser certification is directly correlatable with a defect map generated conventionally using read/write technology. Therefore certifying the disk at 10,000 rpm is readily achievable since laser technology is not constrained by read/write channel limitations and flying height variations. Laser certification provides a faster and more consistent test than current read/write head technology. Since laser glide testing is already well established, then this new insight opens the door to combining both glide and magnetic certification into one operation. This test method offers substantial advantages over conventional testing as there are no heads to crash, no heads to change, no heads to deposit debris on the disk, no periodic re-calibration is needed, the annual head budget is $0.$^{\underline{00}}$ and, best of all, test times for 100% surface coverage, double sided testing of a 95mm disk can be accomplished in 30 seconds.

Nevertheless it is necessary to give credit to conventional test technology in the sense that only the "random" (unpredictable) defects would be located in this fashion. Any "defect" of a design nature e.g. H_c, Overwrite, 2fTAA etc. would need to be tested conventionally, hopefully only on an audit basis because each time the track density doubles, the volume requirements for testers doubles, and the cleanroom floor space requirement also doubles.

Disk Resonance, (flutter, head slap and MR head read element degradation)

One of the lesser known problems of encountered in both disk testers and actual drives is that, as the disk spins up to speed, it goes through "resonance bands" where specific resonance modes of the disk are excited. This is disk flutter. The inherent resonant frequency (*f*) of the disk is a function of the specific modulus (E/ρ);

$$f \propto \sqrt{\frac{E}{\rho}}$$

where E is the elastic modulus and ρ is the material density,

and resonance is sustained if the condition;

$$f = \mathrm{N}\frac{\mathrm{RPM}}{60}$$

is met. Where N has integer values.

Under these conditions standing waves are set up within the disk that perturb the flight of the head. Unfortunately, for 95mm thin disks, one of these resonances occurs at or around 1000 rpm while others occur at (or around) 3600, 4500, 5400 and 7200 rpm. Ignoring the ones that occur at drive operating speeds (will they really go away if I ignore them?), the calculated linear speed at 1000 rpm at the landing zone is approximately 75 ips. So the resonance occurs at the same speed where the head is starting to lift off. (Figure 12).

It seems that "head slap" is a common buzz word these days and the phenomenon is causing problems for reliability in drives using thin film heads, in the form of soft errors, servo tracking problems and head dings. For drives using MR technology, the read channel is suffering from data loss caused by thermal spiking and MR read element degradation.

Spindle Testing (Asynchronous Spindle Motion, or NRRO)

Fluid spindles are rapidly gaining favor for the next generation of drives. They offer superior NRRO performance approaching that of high quality commercial air bearings. However spindle testing is not without its own set of challenges. Firstly, capacitance probe technology has S/N limitations when attempting to measure NRRO's in the <5μ" range and secondly, the size of the active element is too large for spindles designed smaller form factor drives.

Laser testing of spindles can offer superior S/N ratios (>80dB), much smaller measurement transducer diameters (10μm), and allow the user to measure axial and radial components of runout at the same angular location, on large or small spindles, simultaneously. The possibility of simultaneous measurement of these orthogonal components enables us to generate a 3-D graphic out of the conventional axial and radial planes. But you don't get something for nothing. One of the biggest challenges facing laser testing of spindles is the depth of the grinding marks on the spindle surfaces. A 10μm beam is able to resolve these grinding marks and the depth of these marks is far deeper than the NRRO of spindles. Couple this with a less than perfect speed stability (especially running a spindle without an inertial load) then it is not possible to rotate the spindle and measure the runout in exactly the same location revolution to revolution unless the spindle is rigidly coupled to an external encoder. So at any sampling instant, the laser may alternately be at the peak of a grinding mark or in a valley, and there is no way to predict which it will be. Unfortunately this will appear as, and be indistinguishable from, any NRRO measurement. However on the bright side, techniques developed for Flyability testing (axial and radial measurements added or subtracted vectorally) and Optical Glide testing (sectoring, signal tracking and peak holding and/or integrating) can readily be adapted for spindle testing without loss of precision. It is now possible to measure spindles with runouts of <1μ" to a precision of the order of 10Å or less.

DOUBLE-MIG FOR OVER 1GB/PLATTER

Frank Shiraki

Senior Sales Manager

Hitachi Metals America

Double-MIG
for Over 1 GB/Platter

Frank Shiraki Hitachi Metals America
Ryo Goto Hitachi Metals, Ltd.

Hitachi Metals

Double-MIG

- For Higher Density with Super Hi Bsat Metal
- Still More Improvements for More Generations
- Performance Improvements Now on
  - Cost
  - Electrical Performance
  - Production and Design Flexibility

Hitachi Metals

MIG Slider Progression

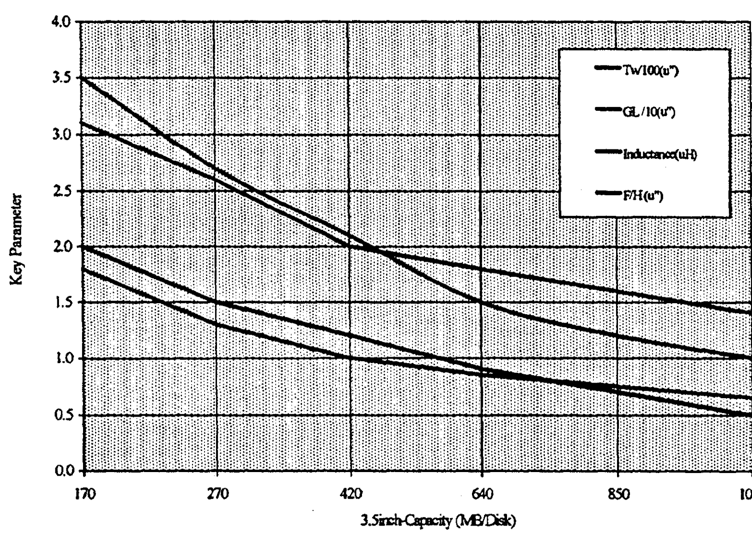
Ferrite	PC SC	Improved SC	
Film	Sendust(TG) TK S-MIG D-MIG	Super Hi Bsat(EM-1)	
Slider	TiCaO	MN-2	New
Size	100% 70%	50%	
ABS		O.B.	Extended Rail
Winding		Manual Winding	Plated Coil

40 80 120 170 210 270 420 640 850 1080

Capacity (MB/3.5 in. Disk)

Hitachi Metals, Ltd.

Requirements for Over 1 GB/ 3.5 in.



Inductance
>>>> 500 nH

Track Width
>>>> 140 u-in.

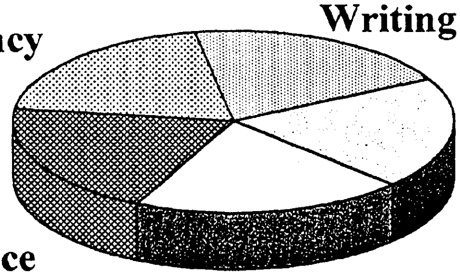
Gap Length
>>>> 8 u-in.

Fly Height
>>>> 1.0 u-in.

Hitachi Metals

Technology Road Map

- Improvements on Double MIG
  - Material - Super Hi Bsat, Slider Material
  - Configuration - Core and ABS Design



Hitachi Metals

Key Issues - Advantages

- Writing Ability/ Signal Stability
  - Super Hi-Bsat Film
  - No Track Trimming
- High Efficiency
  - Smaller Core Configuration
- Low Inductance on Conventional D-MIG
  - Winding Method
- Pseudo Contact/Proximity
  - New Slider Material
  - New ABS Design / "Extended Rail"
- "Plated Coil" Technology
  - Even Lower Inductance
  - No Manual Winding

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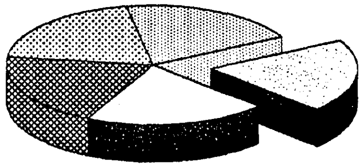
Improved Slider Material

Pseudo Contact



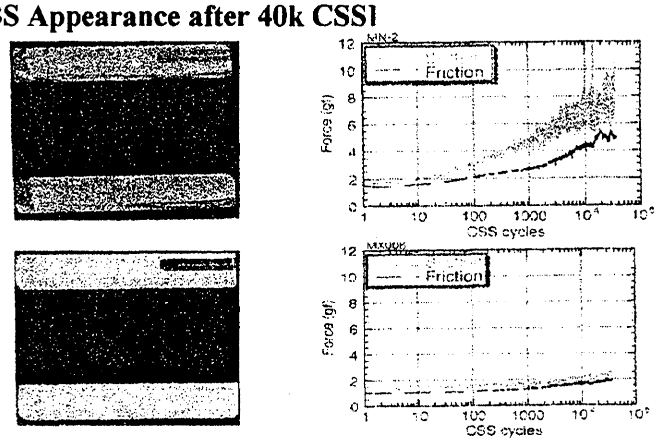
- **New Slider Material realizes Pseudo Contact without Overcoating**

[ABS Appearance after 40k CSS]

Conventional

New Material

F/H < G/H



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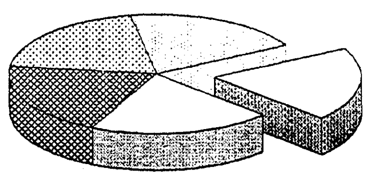
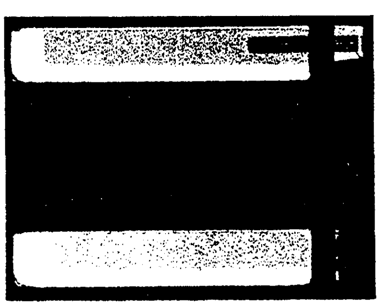
Extended Rail - Pseudo Contact

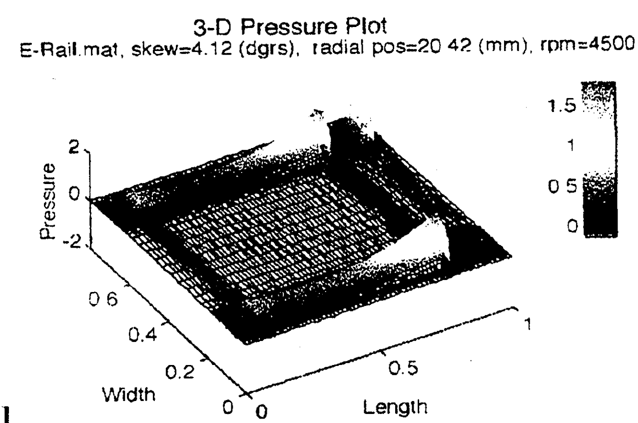
Pseudo Contact



- **"Extended Rail" Realizes Pseudo Contact and Constant Fly Height**



[Extended Rail Configuration]



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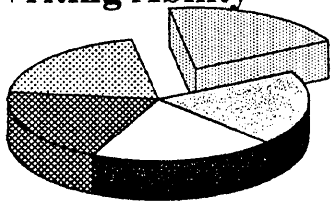
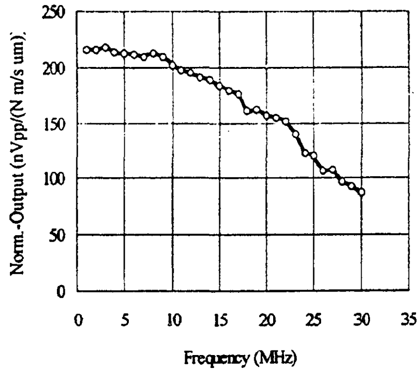
Super High Bsat Film

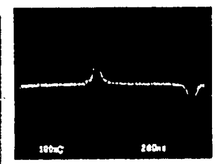
Writing Ability



- Bs = 1.6 Tesla
- Signal Stability (Improved Acov)
- Smooth Frequency Roll-off

[SKEM Image of Gap Area Cross section]

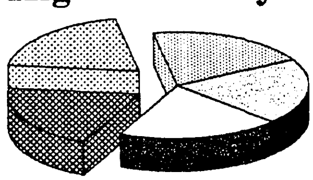




Hitachi Metals

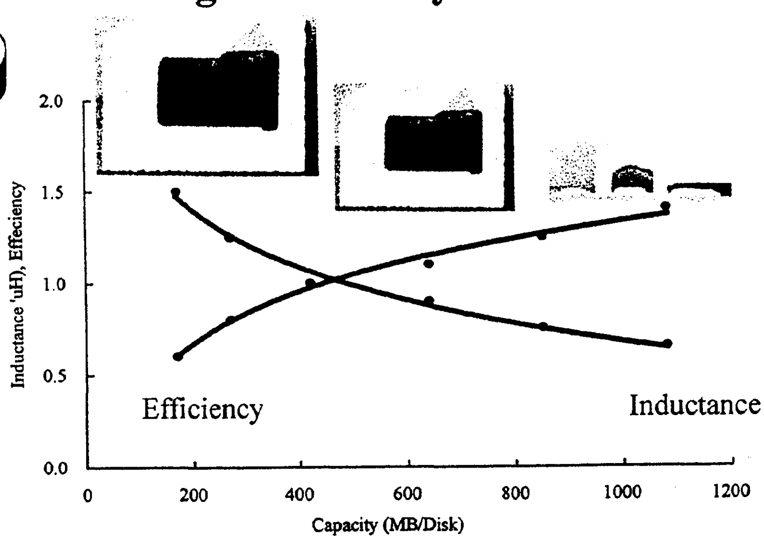
Improved Core Configuration

High Efficiency



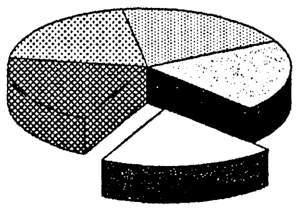
Low Inductance

- **High Efficiency/ Low Inductance**



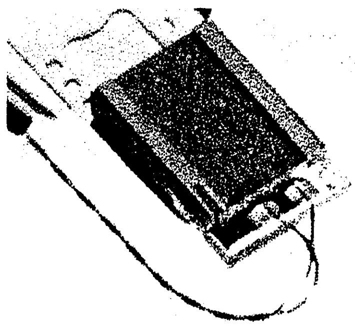
Hitachi Metals

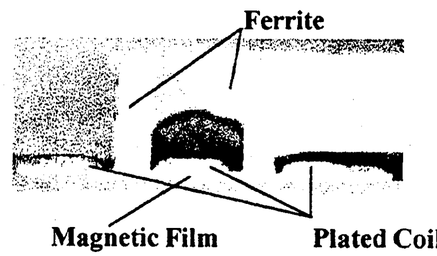
“Plated Coil” Technology



“Plated Coil” Slider

- Possible to Achieve over 1 GB/ 3.5 in. Disk
  - Low Inductance - Balance Winding
  - Small Magnetic Circuit
  - No need Manual Winding
  - Can Have Pseudo Contact Design





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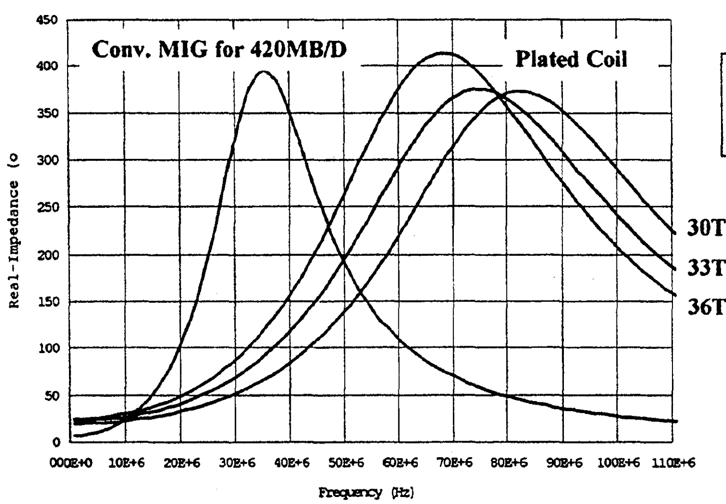
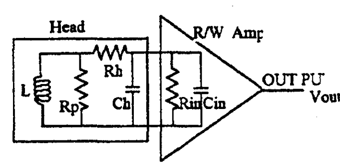
“Plated Coil” Slider for 1GB/ 3.5 in.

- “Plated Coil” Slider has High Resonant Frequency





Preamp. Cin : 7pF
Rin : 850ohm
Head Rh : 0.61ohm/T
(P slider) Lh : 0.6 uH/T2
(40MHz)

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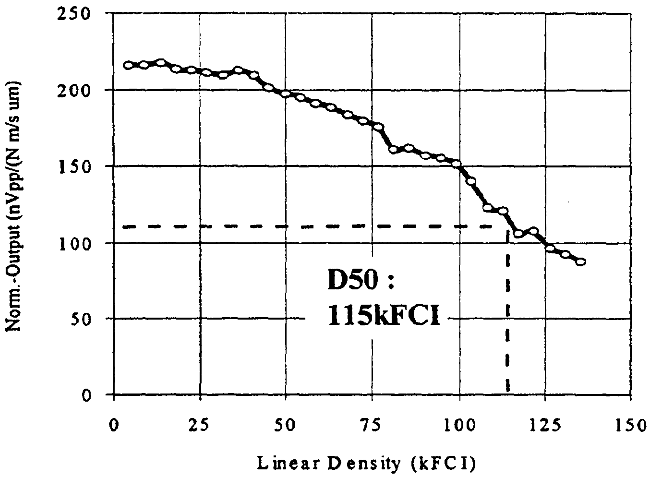
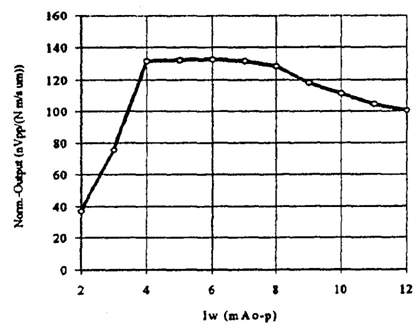
"Plated Coil" Slider for 1GB/ 3.5 in.

➤ **"Plated Coil" Slider has Higher Output**



[Condition]

•F/H	20	nm
•Tw	3.9	nm
•GL	0.208	um
•Turns	36	T
•VEL.	11.3	m/s
•Hc	2100	Oe



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Conclusion

- **High frequency (70MHz) is now achieved on Double MIG slider by improvement on core configuration and "Plated Coil" Technology. This can be further improved by selection of periphery ... such as preamplifier, flex wire and etc. ...**
- **Double MIG and/or "Plated Coil" can serve as high performance component for more generations of heads beyond 1 GB/Disk**

Hitachi Metals

MR HEADS: A BASIC DISK DRIVE COMPONENT TECHNOLOGY

Robert Scranton

Director, Magnetic Head Development

IBM/Systems Storage Division

Magnetoresistive Heads

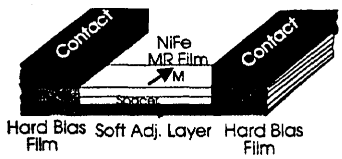
A Basic Disk Drive Component Technology

Robert A. Scranton

Director of Magnetic Head Development and Manufacturing

IBM Storage Systems Division

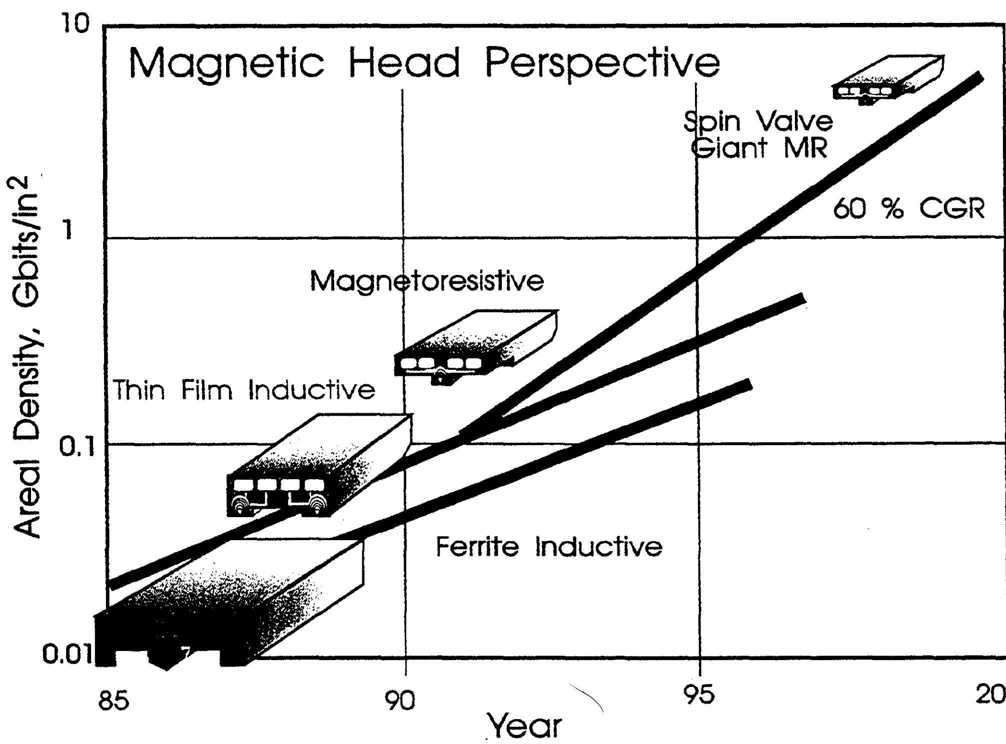
5600 Cottle Road, San Jose CA 95193



Soft Adj. Layer, Hard or Exchange Bias

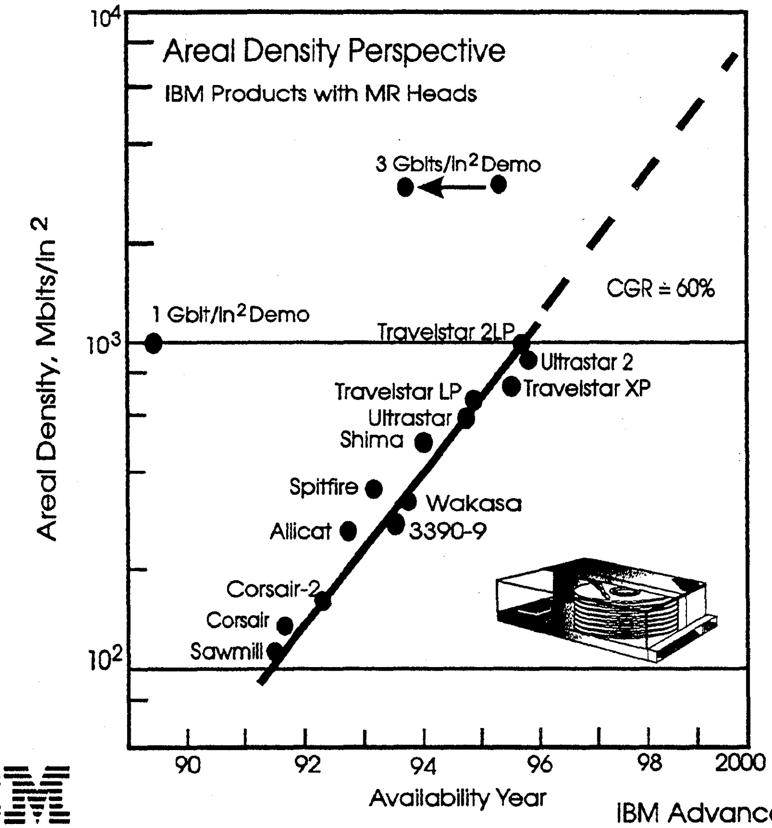
IBM

Head/Media Technology Review
Stardust Resort-Las Vegas
November 12, 1995



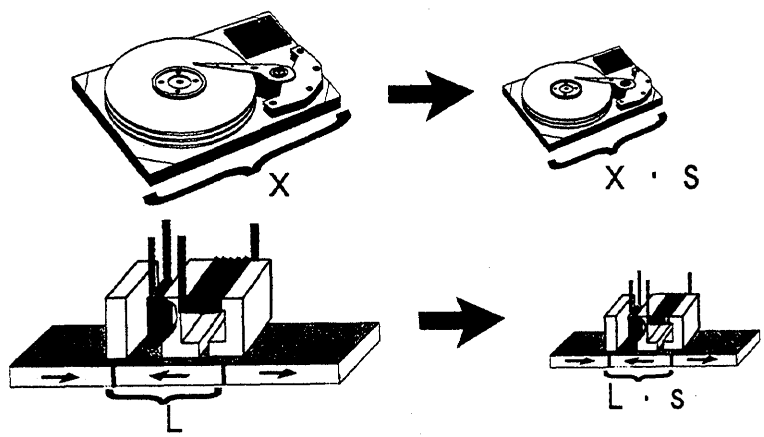
IBM

IBM Advanced Technology



IBM Advanced Technology

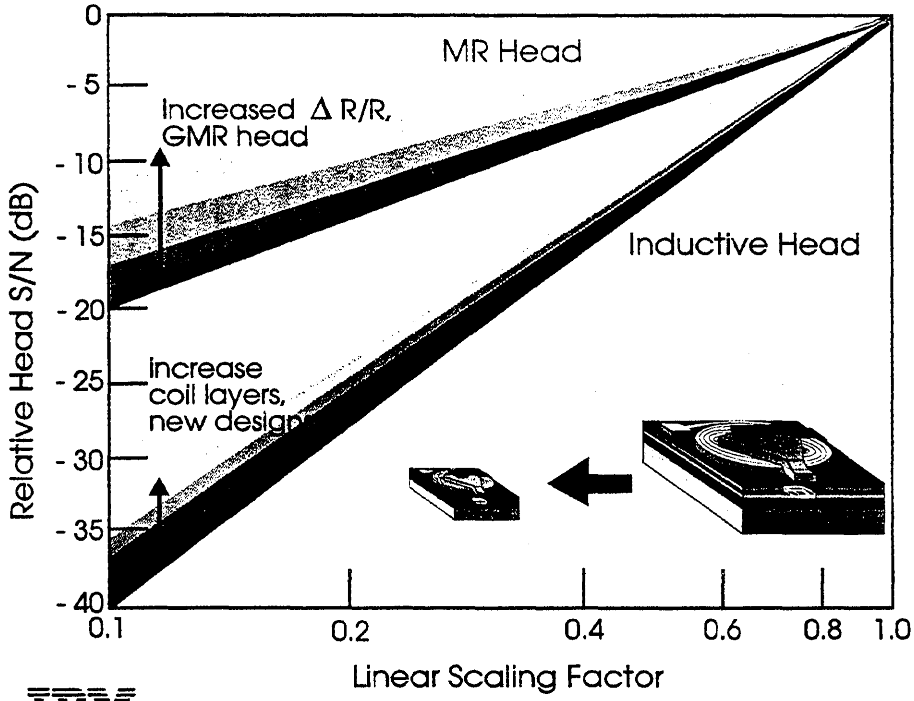
Magnetic Recording Scaling



- Shrink everything, including tolerances by scale factor, s
  - Requires improved processes
- Recording system works, at higher areal density, $1 / s^2$
  - Requires improved disk, head and electronics materials and designs
- Signal to noise decreases by factor s^2

IBM Advanced Technology

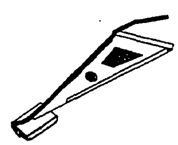
MR and Inductive Head Signal/Noise Scaling



IBM

IBM Advanced Technology

Magnetoresistive Heads - Why Isn't Everyone Using Them



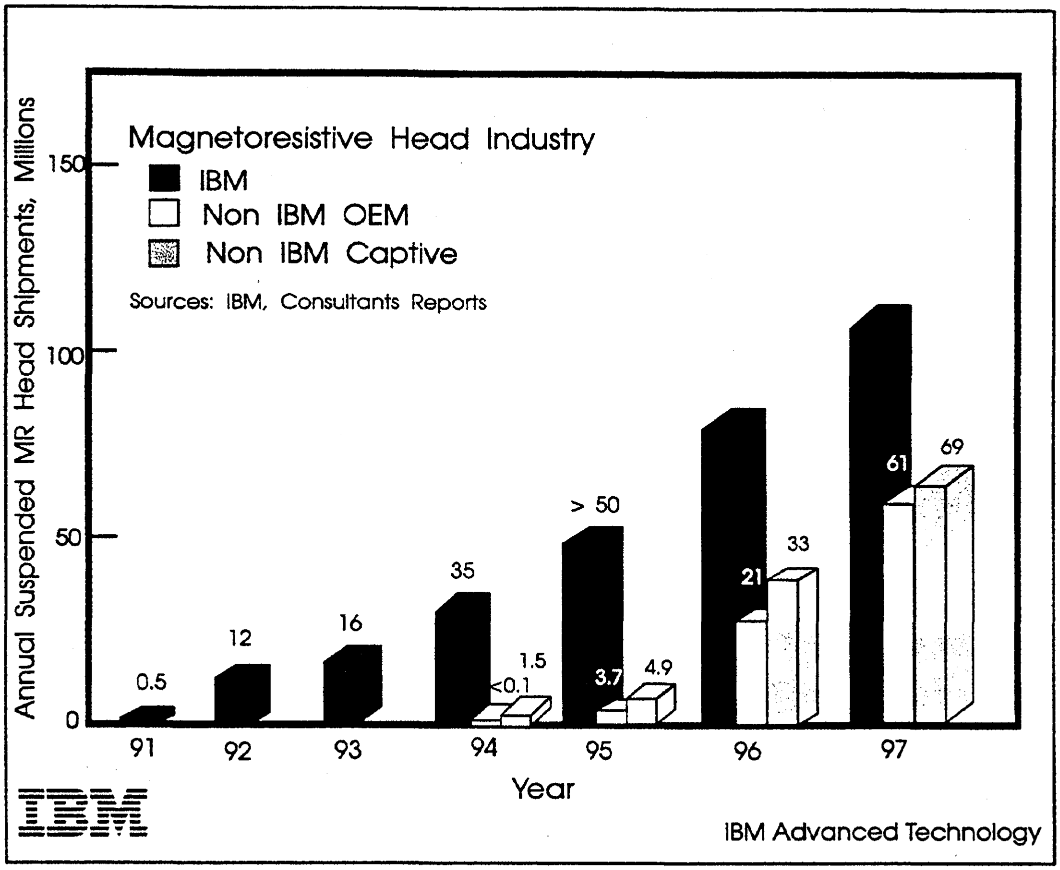
- No Supplier/Source of MR Heads
- New Integration Challenges
  - Servo and Positioning
  - Thermal Asperities
  - Track Format (data, sync., servo)
  - Track Format (retries, ECC)
  - ESD/Handling
  - Preamplifier Electronics
  - Data Detection Channel for Asymmetry
  - Disk Magnetics and Defects

IBM

IBM Advanced Technology

GRCHWSKI at ALMADEN

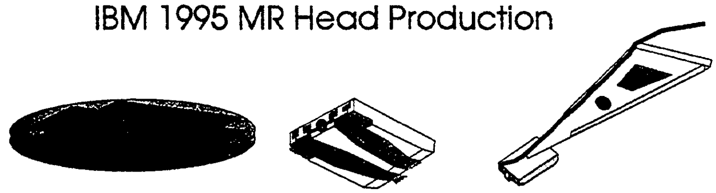
MRHD95W.PS8IN



GRCHWSKI at ALMADEN

MRMFG95X.PS8IN

IBM 1995 MR Head Production

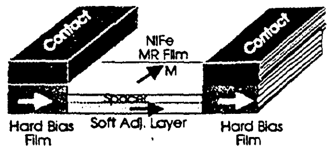
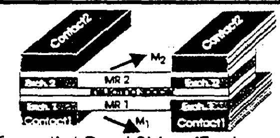
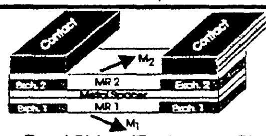
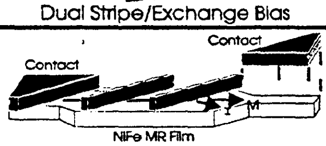


	Wafer Process	Slider Fabrication	Suspension Assembly
Start	Polished substrate	Wafers with candidate sliders	Sliders
Process	Multiple film depositions, photolithography	Grind rows, lap stripe height, form air bearing, slice into individual sliders	Add suspension, wires, bond, test
Ship	Completed wafers	Finished sliders	Functioning, wired HGA
Location	San Jose, Mainz	San Jose, Mainz	San Jose, Mainz. SE Asia

IBM Advanced Technology

GRCHWSKI at ALMADEN

Magnetoresistive Head Biasing Alternatives

Technology	Advocate	Advantages
 Soft Adj. Layer, Hard or Exchange Bias	IBM Quantum Seagate Hitachi Read Rite Fujitsu TDK AMC	Over 100M heads in operation 3 Gbit/sq.in. demo Simple, high yield process
 Differential-Dual Stripe/Exchange Bias	Headway	Large output Thermal spike protection
 Dual Stripe/Exchange Bias	Kodak (Tape Drives)	Unshielded structure Resolution by Spacer
 Barberpole	Philips (Tape Drives)	Simple structure Single level MR film

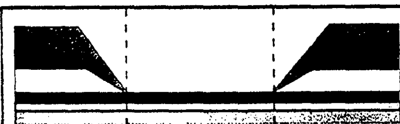
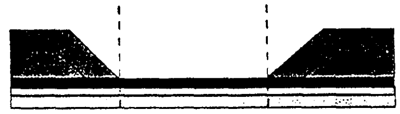
IBM

IBM Advanced Technology

MRHDP95W.PS8IN

GRCHWSKI at ALMADEN

MR/SAL Longitudinal Biasing and Trackwidth Definition

Patterned Exchange (Exchange and Contact Films Aligned) IBM Corsair	
Contiguous Junction (Contact and Stabilization Films Self Aligned) IBM Allicat-Ultrastar2	
Patterned Hard Bias (Contact Film Defines Trackwidth)	
Contiguous Junction (Contact Film Defines Trackwidth)	
Patterned Spacer Defines Trackwidth	

Contacts — NIFe - MR
Exchange — Spacer
Hard Bias — Soft Film

-IBM

Quantum crop off

Seagate

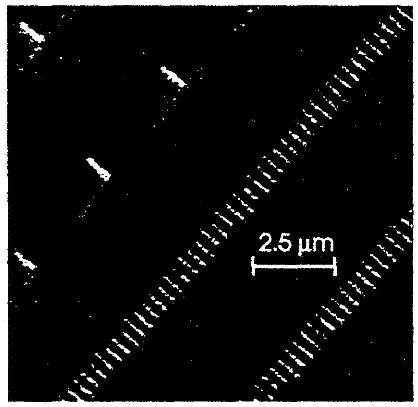
IBM

IBM Advanced Technology

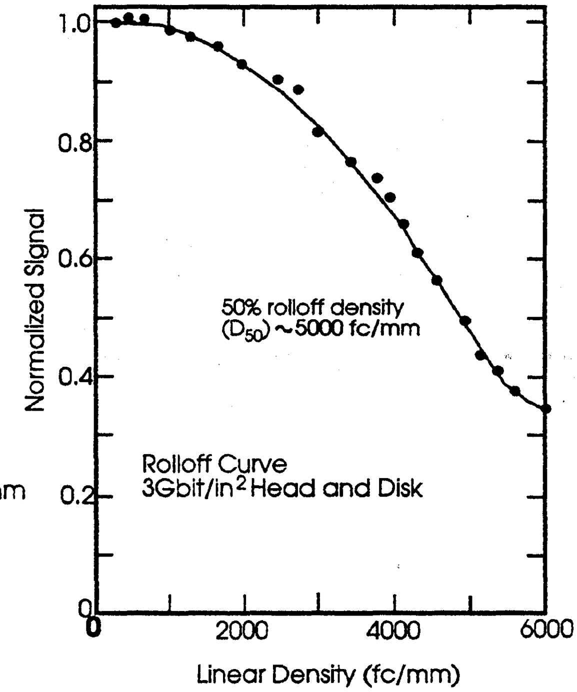
MRBIASB.PS8IN

GRCHWSKI at ALMADEN

3 Gbit/in^2 MR Head Linear Resolution



MFM image of 500 and 5000 fc/mm transition patterns



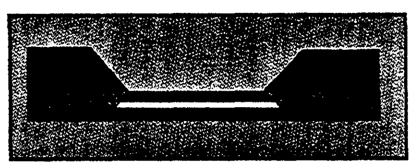
IBM

IBM Advanced Technology

3GBIT3W.PS8IN

GRCHWSKI at ALMADEN

Conclusion
Magnetoresistive Head Strategy



- Lowest manufacturing cost/MB
- Areal density - 60 % CGR
- Highest capacity per form factor
- High yield manufacturing process
- Extendable to beyond gbit areal densities

IBM

IBM Advanced Technology

MRSTRATB.PS8IN

THE CASE FOR INDUCTIVE HEADS

David Danson

Vice President Engineering, Heads and Media

Maxtor Corporation

Technology Advantages:
Inductive vs. M.R.

The Case For Inductive Heads

Dr. David Danson
V.P. Engineering, Heads & Media
MAXTOR

Maxtor

Reports of the Death of Inductive Thin Film Heads Have Been Greatly Exaggerated!

- In The Style of Mark Twain

Maxtor

M.R. Introduction
Where is the industry?

- Captive head manufacturing companies appear to be fully committed - or close to, for internal programs.
- Merchant market head vendors getting ready. Shipment volumes are small.
- A great deal of uncertainty over the **real** availability / demand for 1996!

- If there are problems - **Watch OUT!**

Maxtor

Why Not Continue With
Thin Film Inductive Heads?

- **Flying heads - not really the way to go:**
  - Pushing the practical limits of today's technology - especially if the digital channel card has already been played.
- **Proximity heads - the way to extend inductive:**
  - With the correct choice of head / disk tribology parameters, Maxtor has proven this technology to be extremely reliable.
  - Now used in high volume production at two major drive manufacturers.

Maxtor

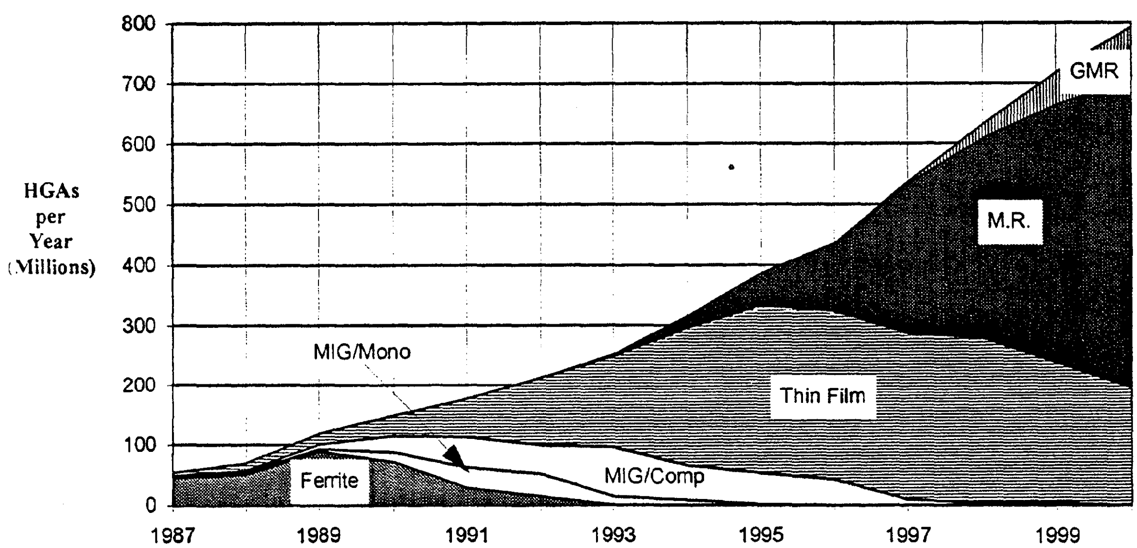
Merchant & Captive Head Suppliers Have Different Constraints

- Merchant suppliers are required to meet **a variety of** head technology requirements.
  - Often there are benefits to extending technologies, for both vendor and customer
- Captive suppliers may have less flexibility in technology choices:
  - Justification of sunken development costs can force an early technology transition
  - A single customer focus is driving requirements

Maxtor

Magnetic Head Market - HGAs By Type

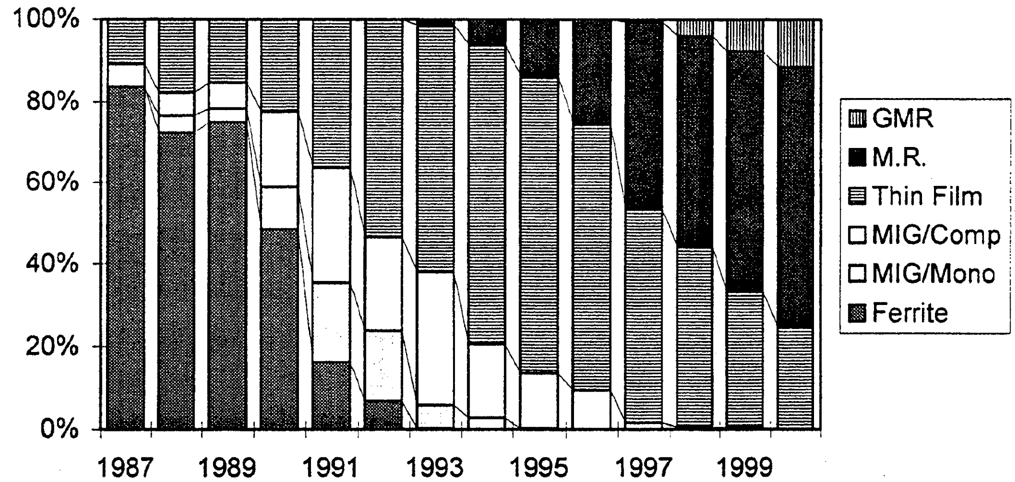
(Peripheral Research Corp.)



Maxtor

Magnetic Head Market - % By Type

(Peripheral Research Corp.)



Maxtor

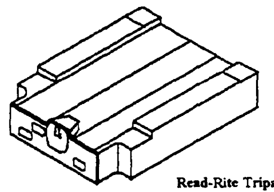
Inductive Head Development

- Pole trimming:
  - widely available
  - work continues to improve tolerances
- Gap length capability - in place

➔ **Proximity recording:**
  - **Available**
  - **Proven to be reliable**
- Magnetic core improvements - especially for high frequency performance.

Maxtor

Pseudo-Contact Head Technology



Read-Rite Tripad

- Head is designed for normal CSS operation
  - Has lower take-off velocity than usual taper-flat designs
- Transducer positioned on a separate pad, in the center of the trailing edge of the slider.
- A small residual force (difference between airbearing and gram load) holds the pad in contact with the disk surface.

Maxtor

Pseudo-Contact Head-Disk Interface is Very Reliable

- **Correct choice of carbon O/C, texture & lubricant is critical.**
- **CSS performance is superior to flying heads:**
  - Design results in low take-off velocity.
  - >100k CSS achieved with one head-disk supplier combination.
- **Pseudo-Contact tests show a very reliable interface:**
  - New "pseudo-contact" tests developed. A large population of drives has been used to demonstrated reliability,
    eg. >1,000hrs single track dwell -
    no grown defects, error rate unchanged.
- **Rapid initial burnishing (<150 Å) occurs on back pad (behind gap), with minimal wear volume. Wear rate then decreases to zero.**

Maxtor

Inductive Head Development

- Pole trimming:
  - widely available
  - work continues to improve tolerances
- Gap length capability - in place
- Proximity recording:
  - Available
  - Proven to be reliable

➔ **Magnetic core improvements - especially for high frequency performance**

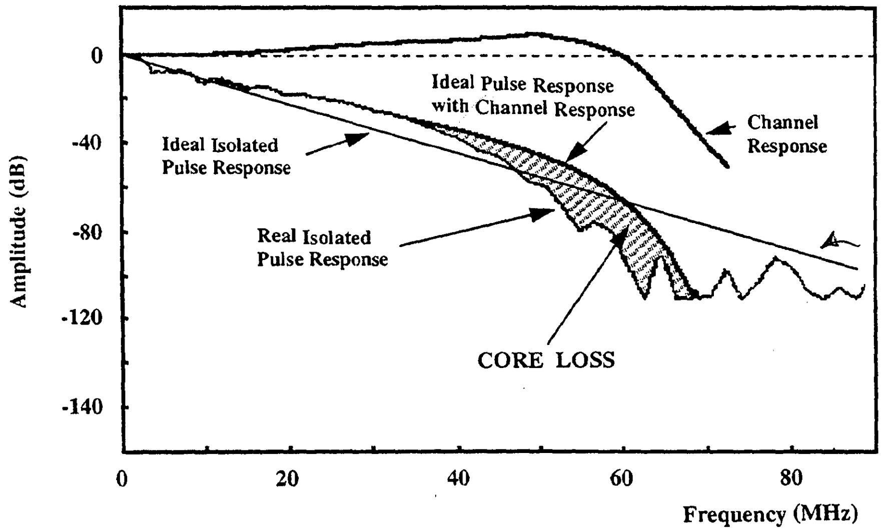
Maxtor

Core Loss - One Of The Major Issues Now Being Resolved

- High recording frequencies are required at the outer zones of a 3.5" disk.
- Core losses are becoming significant (Eddy Current or micro-magnetic losses) with standard permalloy poles.
- Advanced magnetic cores now being developed:
  - Laminations
  - Higher efficiency core geometries
  - High B_s / higher resistivity materials
- Eventually, this work will also be needed for M.R. writers.

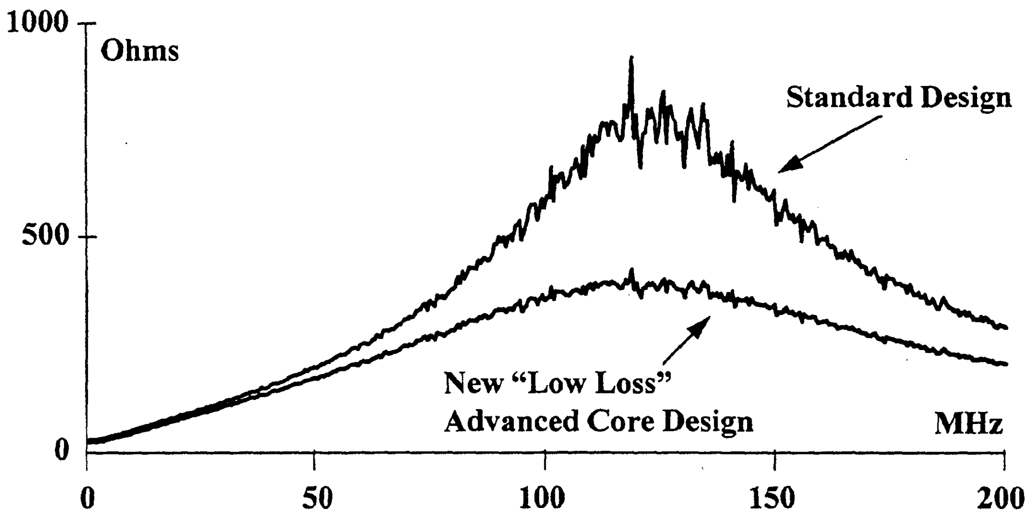
Maxtor

Core Loss:
The difference between Ideal & Real Isolated Pulse Responses



Maxtor

Impedance vs. Frequency Effects of Core Improvements

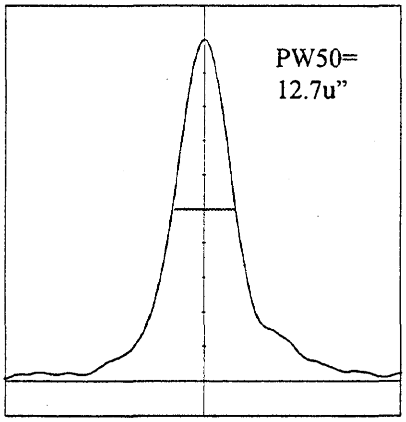


Maxtor

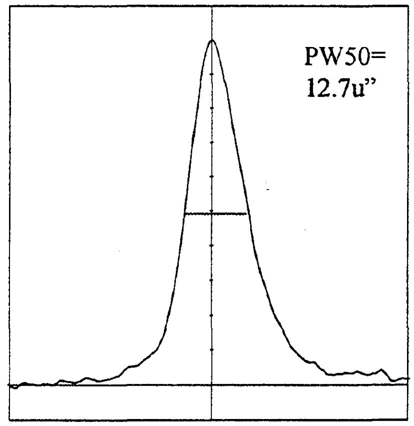
Effects of Core Loss on Pulse Shape

At Disk I.D. - No Difference Seen in PW50

Head 1 (Standard)



Head 2 (Advanced Core)

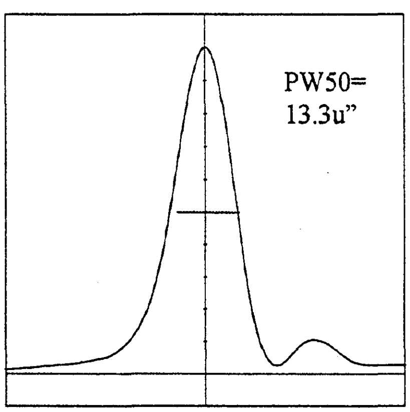


Maxtor

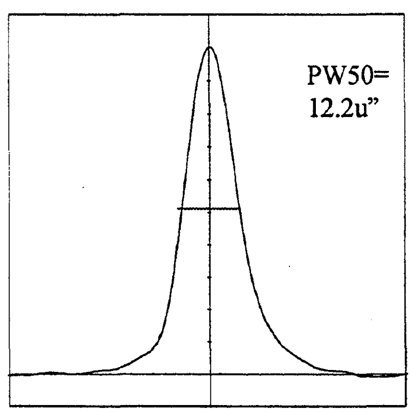
Effects of Core Loss on Pulse Shape

At Disk O.D. - Advanced Design Shows Improved PW50

Head 1 (Standard)



Head 2 (Advanced Core)



Maxtor

Limits to Inductive Technology

- Projected M.R. availability, will drive development of inductive technology to beyond 1Gbit/in^2
- Head manufacturers now investing to meet this goal:
  - laminated pole structure & high B_s material - being developed.
  - Incremental improvements to track width control.
- Eventual technical limit is unclear ... but:
  - Silmag projects 1.5 Gbit/in^2 with planar technology.

Maxtor

What Drives Head Technology Choices?

- Perceived technology maturity & availability.
- Target market segment / drive capacity required.
- Performance criteria, eg. RPM, data rate, CSS
- Projected drive selling price / margin.
- Opportunities to optimize the drive as a system, around the chosen head technology.
- Extendibility to future products.

Maxtor

What Will Force The Total Transition To M.R.? (In the non-captive world.)

Satisfactory answers to the items on the previous slide!

Obviously, all drive companies must develop the necessary M.R. integration technologies, for gradual introduction.

The final death of Thin Film Inductive Heads

(predicted to be beyond 2000AD by Peripheral Research)

Will depend on the true-cost-of-ownership of TFI vs. M.R.

Maxtor

Conclusions...

- Inductive thin film heads will continue to be used for several years. The technology is being extended, with a goal of >1 Gbit/in^2 .
- Pseudo-contact heads are now used in high volume production and have proven reliable.
- There will be a gradual transition to M.R. for non-vertically integrated drive companies.

Maxtor

AUTOMATED SUSPENSION RSA MEASURE AND ADJUST

Jay Robinson

Director of Engineering

KR Precision

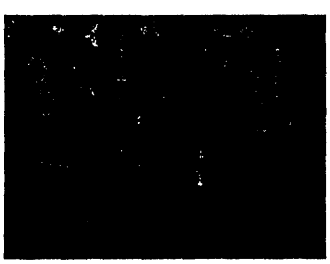
Automated Suspension RSA Measure and Adjust

A Preview of Future Suspension Manufacturing Capabilities

Suspension Manufacturing Today

Etching

Stamping



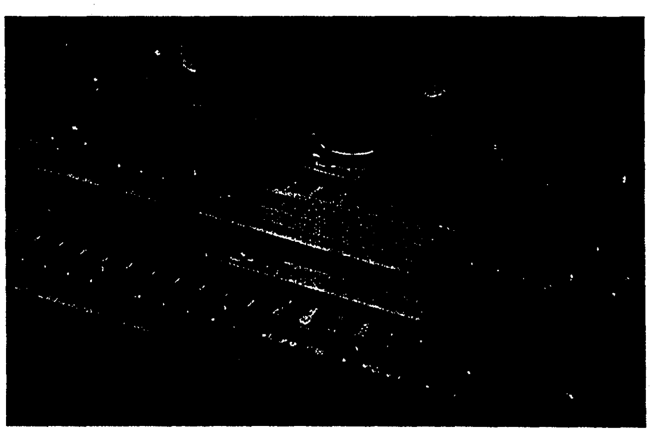
Welding

Gram Adjust

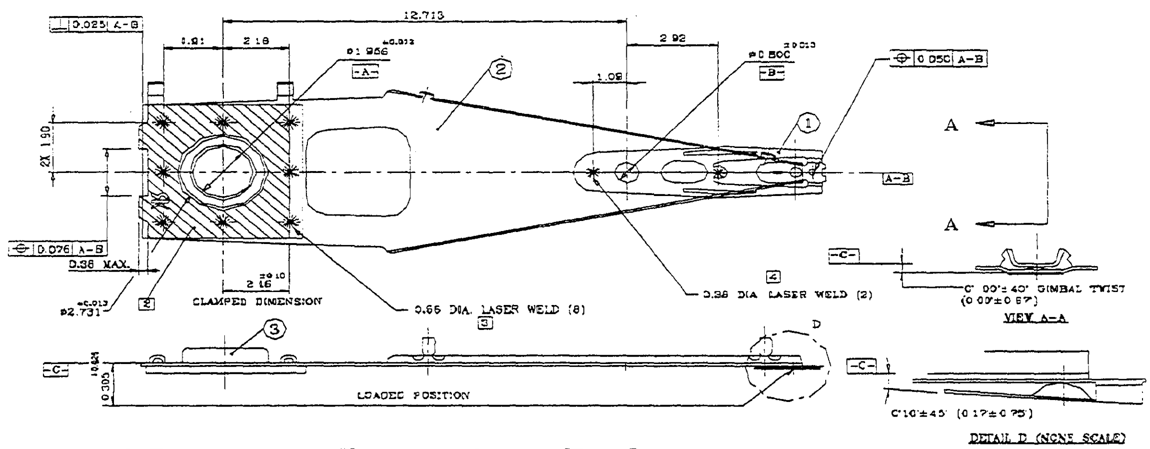
Measuring Equipment is Key

- Profile Projector
- Tool Makers Microscope
- Optical CMM
- CyberOptics
- Advanced Imaging
- Other...

Fixturing is Critical



Typical Specs...Today

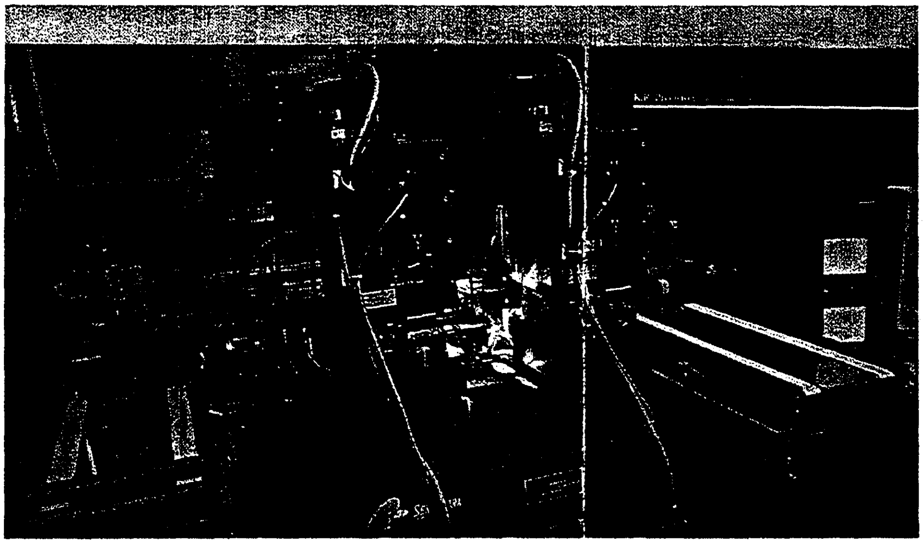


- Load Beam or Baseplate Reference
- +/- 40~45 Min Roll
- +/- 40~45 Min Pitch

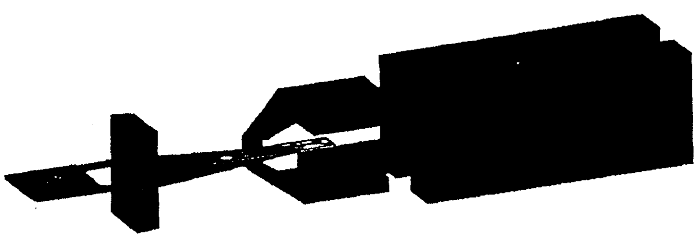
Typical Process Tracking

- Which Lot Was That?
- When Did You Ship it?
- What Did the SPC Chart Look Like When it was Built?

The Twist Adjuster



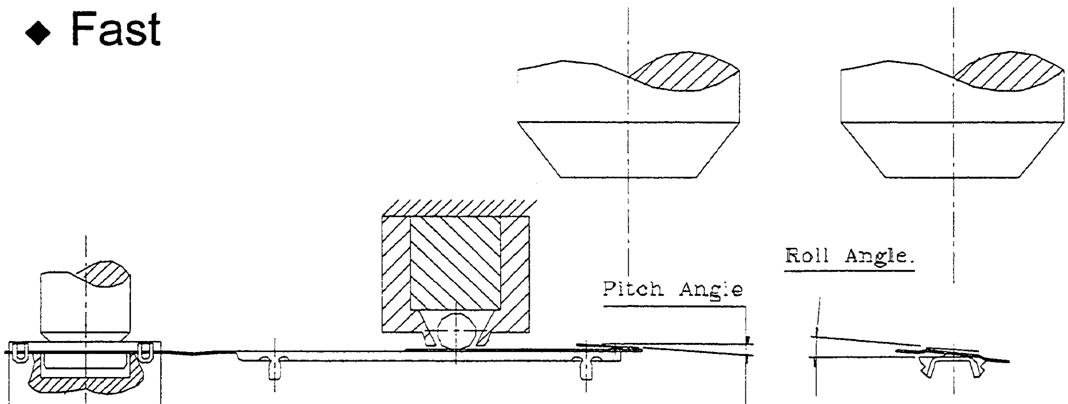
IR/Twist Mechanics



- Support the Preload Area
- Grasp the Gimbal Region
- Apply Heat to the Load Beam
- Twist

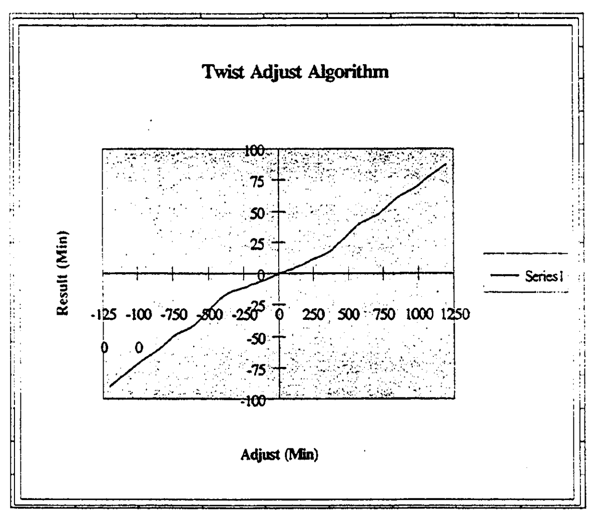
Measurement Mechanics

- Should Be No/Low Bias Design
- Repeatable and Accurate
- Fast



Twist Algorithm

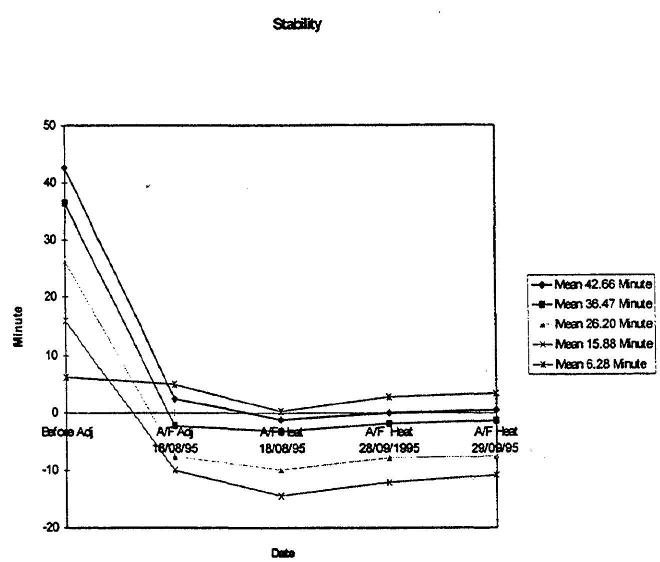
- Graph of Resultant Twist vs Input Angle
- The Relationship Wanders
- Unique Control Methods



FEA Studies

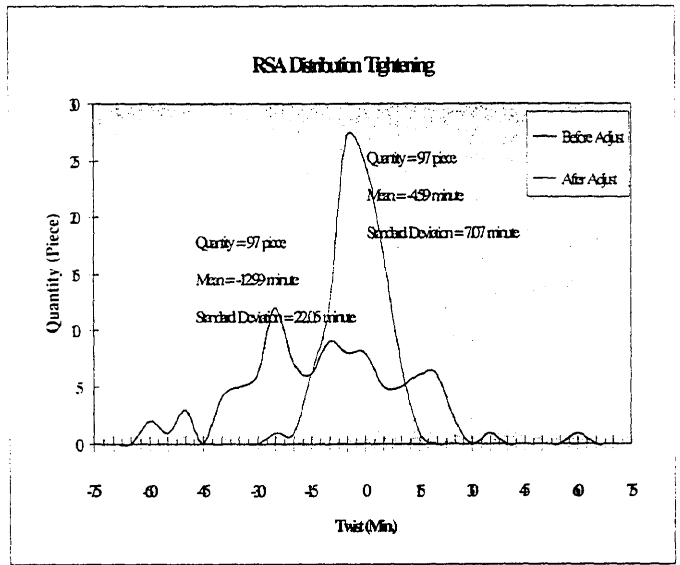
Stability Looks Good

- Range of Shifts
- Humidity/Temp Cycling Insensitive
- Similar to IR Gram Adjust

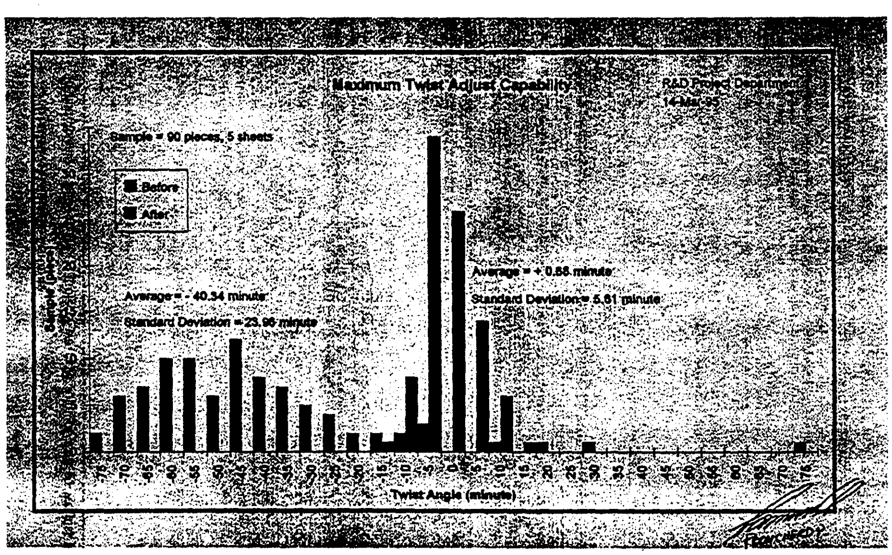


RSA Distribution Tightening

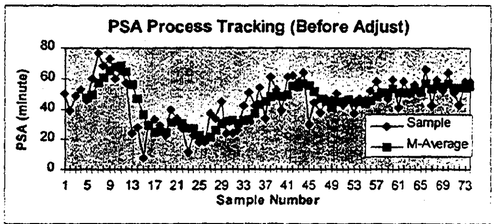
- Adjusts Only >1 Sigma Parts
- Adjusts for Material, Temp, Thickness Variation

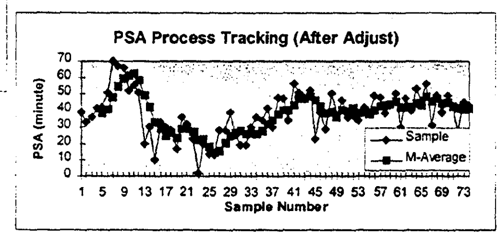


RSA Distribution Shifts



PSA Process Tracking





- Insensitive to Roll Adjust
- Summary Data Saved for Review
- Correlation Studies are Much Easier
- Feedback for Stamping/Laser Welding

Susp RSA vs HGA RSA Fly Distribution

Graphs Indicating Relative Fly Distributions

- Process Targeting vs "to spec"
- +/- 20 min vs +/- 45 min Tolerance
- Optical vs Gram Load Delta Should Be Considered

Major Benefits

- Minimal/No RSA Adjust
- Improved Fly Distributions
- Improved In Process Tracking
- Supplier/Customer Tuning of RSA/PSA
- Historical Data by Lot Number

When Do You Need It?

- Cost/Benefit Issues
- Nano ->Pico
- Reduced Fly Height, Pseudo-Contact Requirements
- Other Issues?

MR INTEGRATION--HEAD PERSPECTIVE

Aric Menon

Vice President Engineering

Seagate Technology

MR Integration - Head Perspective

Aric K. Menon
Vice President Engineering

Recording Heads Operations
Seagate Technology
Minneapolis, Minnesota

Impact of Utilizing MR Heads

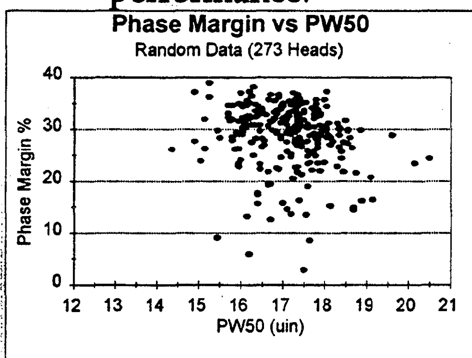
- Impact on Head Test Methodology
- Assuring Reliability
  - Joule heating
  - Electromigration
  - ESD
- Impact of Media/Channel choices

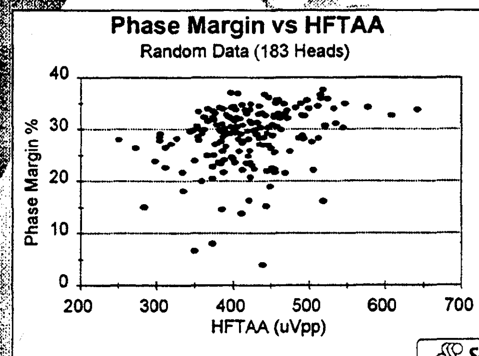
Head Test Methodology

MR head Characteristics which Affect Head Qualification Testing

① Head Non-linearity

- Non-linear nature of the read element hides the true impact of pulse shape on intersymbol interference and bit resolution.
  - As a result parametrics do not adequately predict on-track performance.





Head Test Methodology

MR head Characteristics which Affect Head Qualification Testing

① Head Non-linearity (cont.)

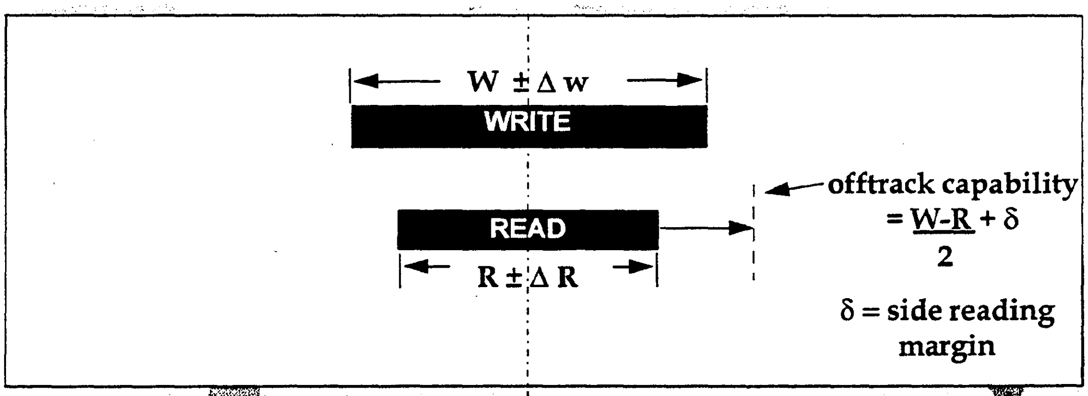
- However, on-track performance must still be adequate and quantified.
  - For Peak Detect systems, phase margin testing can be used.
  - For PRML systems
    - Mean Squared Error (MSE), if supplied by the channel
    - Sample Amplitude Margin (SAM)
    - Some form of stressed error rate testing

Head Test Methodology

MR head Characteristics which Affect Head Qualification Testing

② Separate Read and Write Elements

- **Ontrack performance does not adequately predict offtrack performance**



- **As a result offtrack performance must be assured, independent of ontrack performance**

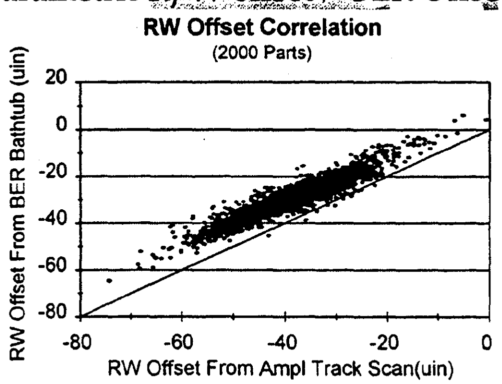
Head Test Methodology

MR head Characteristics which Affect Head Qualification Testing

② Separate Read and Write Elements (cont.)

- R/W offset must be quantified and controlled to meet drive micro positioning specification limits
  - Care must be taken to measure the correct R/W offset since

    Parametric R/W offset ≠ BER Offset

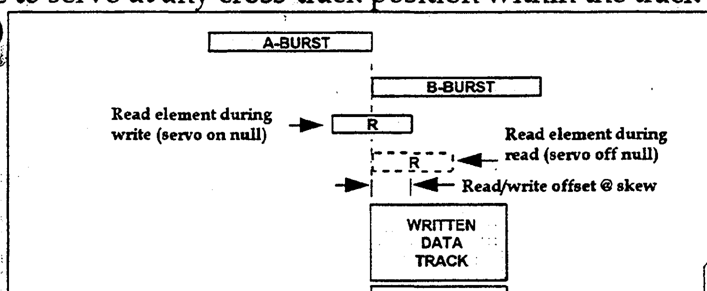


Head Test Methodology

MR head Characteristics which Affect Head Qualification Testing

③ MR Servo Requirements

- R/W offset varies significantly from ID to OD within the drive from 2 sources:
  - Reader to Writer separation combined with change in skew angle over cylinders
  - Per head variability of read/write offset
- To minimize overhead, the reader must be able to servo on the same pattern during both write and read operation
  - ⇒ Must be able to servo at any cross-track position within the track (not just the null)



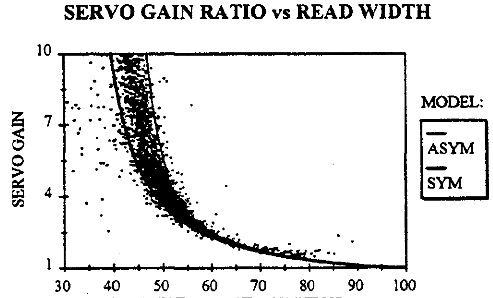
Seagate THE DATA TECHNOLOGY COMPANY

Head Test Methodology

MR head Characteristics which Affect Head Qualification Testing

③ MR Servo Requirements (cont.)

- The result is a servo linearity-over-range requirement for the head
  - Because of write wide / read narrow nature of MR head, the reader width is significantly narrower than the track pitch and some linearization algorithm(s) must be employed
  - The servo specification limits and distribution depends critically on the servo scheme and linearization technique that will be used in the drive.



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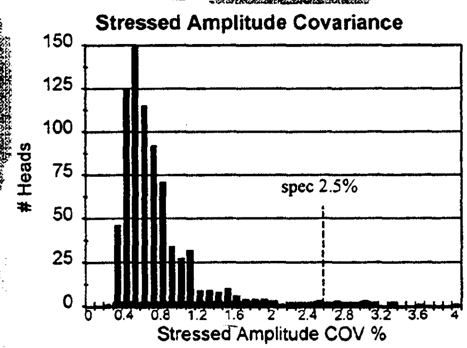
Head Test Methodology

MR head Characteristics which Affect Head Qualification Testing

④ MR Head Stability

- Multi-domains in MRE stack or shields can result in metastable states which affect:
  - offtrack capability
  - servo offset
- Tests need to be designed to characterize stability of parts



A.K.Menon 1995 H/M Tech. Review 11/12/95

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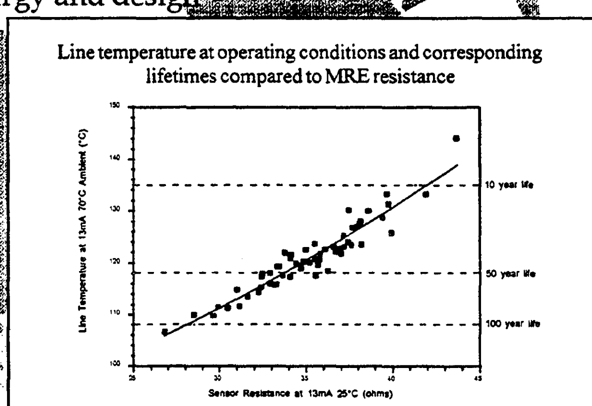
Assuring MR Head Reliability

- MR head is an "Active" device
  - Excessive bias current joule Heating at elevated temperatures can lead to permanent resistance change
    - Head D.C. resistance is key factor: resistance depends on stripe height, stripe width, MRE stack thickness, contact and permanent magnet metallurgy and design



A.K.Menon 1995 H/M Tech. Review 11/12/95

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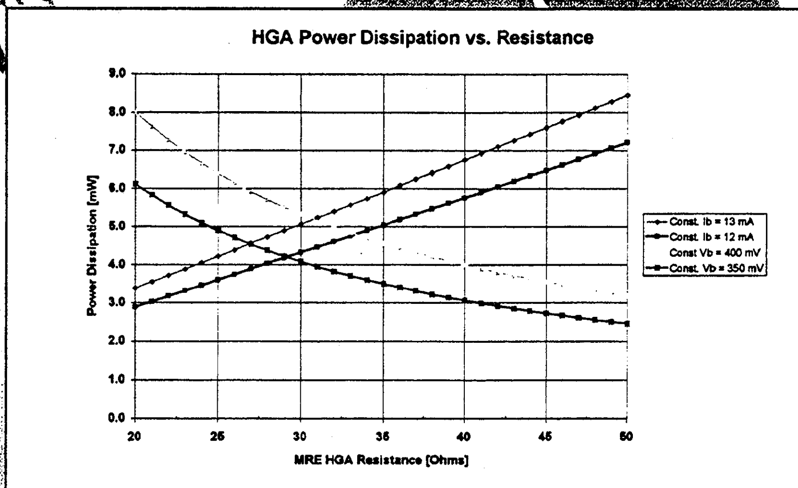
Assuring MR Head Reliability

- MR head is an "Active" device (cont.)
  - Choice of upper or lower specification limit dependent on constant current vs constant voltage bias scheme



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Assuring MR Head Reliability

- MR head is an "Active" device (cont.)
  - Electromigration
    - Combination of metallurgy choice, high current density and temperature can result in high mobility of metallic ions.
    - Improper head design can result in an increase in local resistance leading to failure

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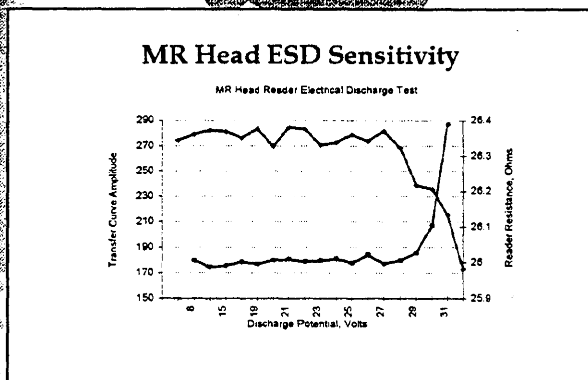
Assuring MR Head Reliability

- ESD Sensitivity
  - MR devices are significantly more sensitive to ESD than inductive heads due to very small, thin geometries in the sensor
    - Performance changes can occur at lower discharge levels than would cause resistance changes



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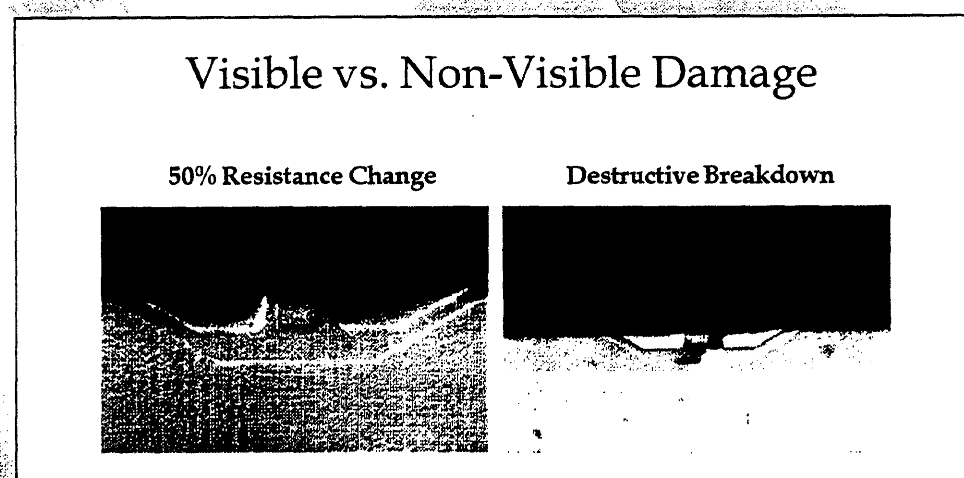
Assuring MR Head Reliability

- ESD Sensitivity (cont.)
  - Large Resistance changes can occur with no visible damage!



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Assuring MR Head Reliability
MR ESD Readiness

- MR ESD Readiness requires a consciousness for *all* parts of the organization
  - Head Organization
    - Wafer Factory
    - Slider Factory
    - HGA Assembly and Test factory
    - Shipping Department
  - Drive Organization
    - Receiving Department
    - Stack Assembly Operation
    - HDA Assembly Operation

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Assuring MR Head Reliability
MR ESD Readiness (cont.)

- Corporate Wide Top Level Support Required
  - Training
  - Documentation
    - Handling, Shipping and Cleaning specifications
  - Audits
    - ESD Teams
    - Process Reviews
    - Area Audits
  - Test Equipment Review
  - Consumables Control
    - Approved Materials

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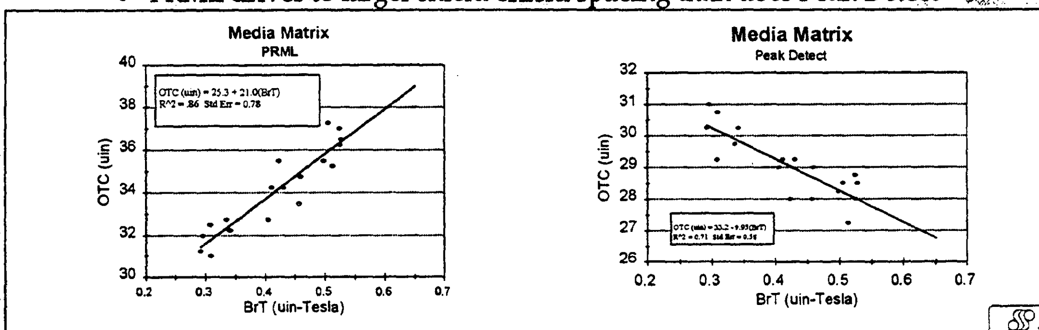
Effect of Channel/Media Choice

- Peak Detect vs PRML
  - PRML puts more pressure on small transition length and low noise due to earlier onset of "percolation" and Non-Linear Transition Shift
    - this in turn puts more pressure on writer performance
  - For PRML S/N is much more important than resolution which drives the designer to different design points
    - PRML drives to higher Hc, Brt media than Peak Detect, which also puts more pressure on the writer
    - PRML drives to larger shield-shield spacing than does Peak Detect



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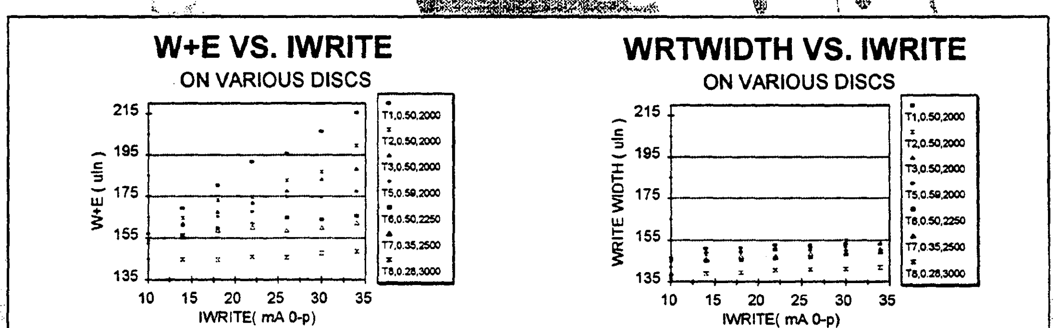
THE DATA TECHNOLOGY COMPANY

Effect of Channel/Media Choice

- "Erase" Band affects tpi capability and head width/throat height optimization. Controlled by:
  - Coercivity
  - Brt
  - Orientation Ratio



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Conclusions

- The decision to integrate MR heads in drives has profound implications on the head supplier beyond the design and manufacture of MR heads
  - The entire methodology on how to electrically qualify heads for the application must be reviewed and modified to meet drive requirements
  - Reliability concerns not normally addressed with inductive heads must be dealt with
  - A company wide culture shift with regard to ESD control must occur
  - The choice of channel and media by the drive team will have significant impact on head design point, head test methodology and head yields

DUAL STRIPE MR TECHNOLOGY

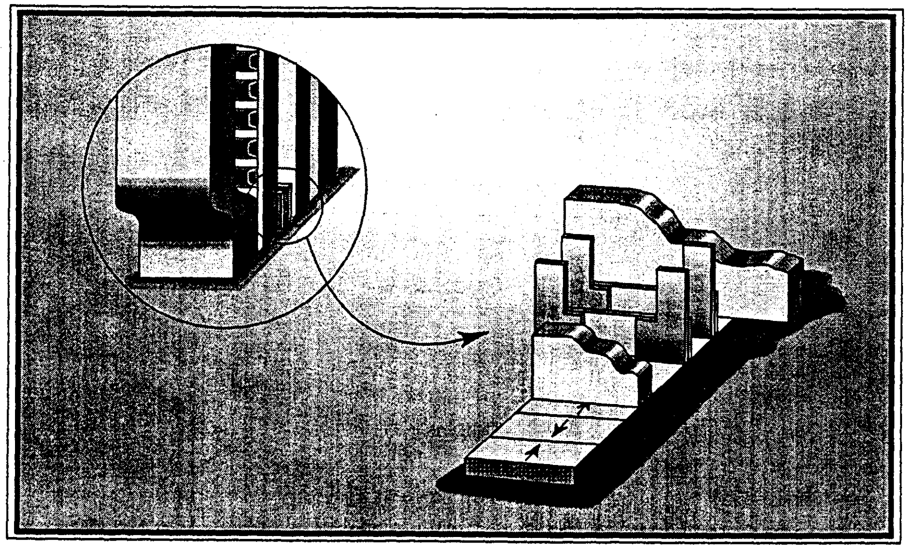
Tracy Scott

Vice President Development

Headway Technology

HEADWAY
TECHNOLOGIES, INC.

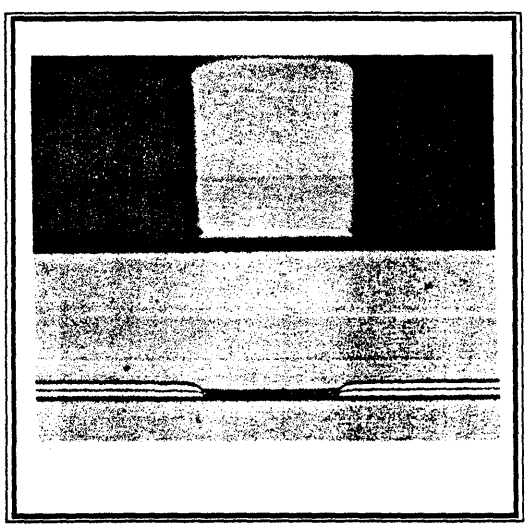
Dual Stripe MR Heads



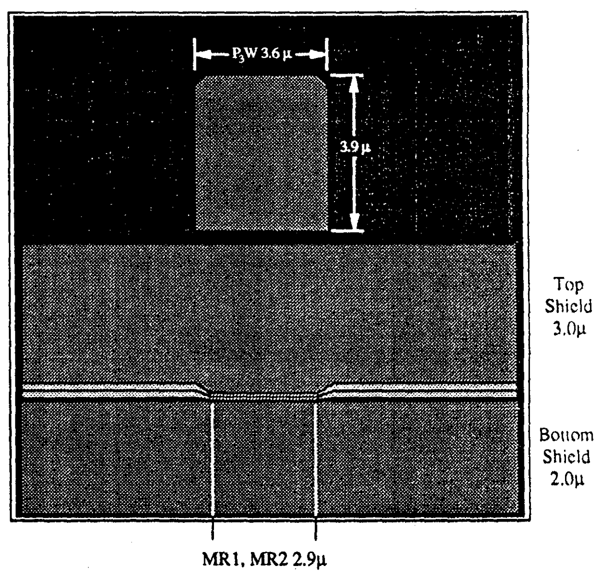
Tracy Scott
Headway Technologies

HEADWAY
TECHNOLOGIES, INC.

Dual Stripe MR Heads - 800 Mbits/in^2



SEM-ABS View



Illustrated -ABS View

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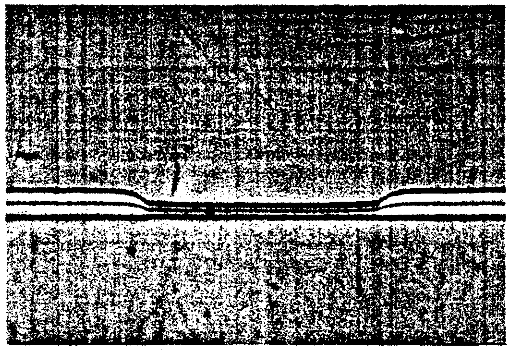
TECHNOLOGIES, INC.

High Resolution SEM of Dual Stripe MR Elements

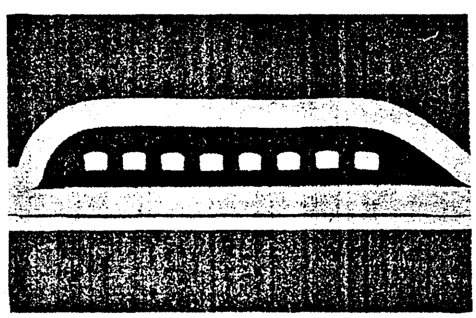


1μm

HEADWAY
TECHNOLOGIES, INC.

Dual Stripe MR Heads - 800 Mbits/in^2

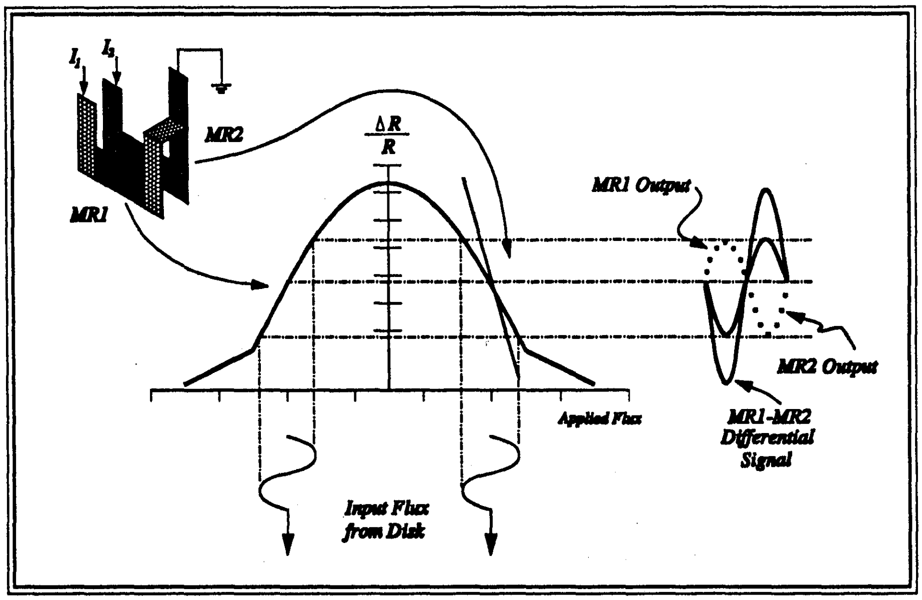
SEM
Cross Section



10μm

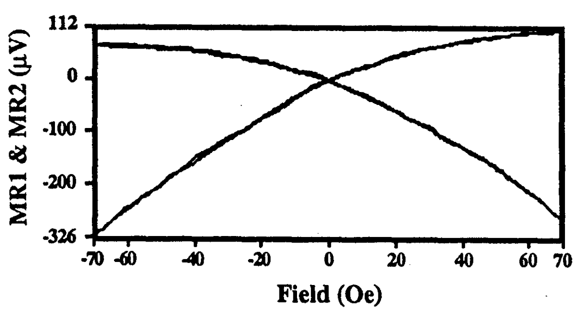
MR Stripe Height ~ 2.00 μ

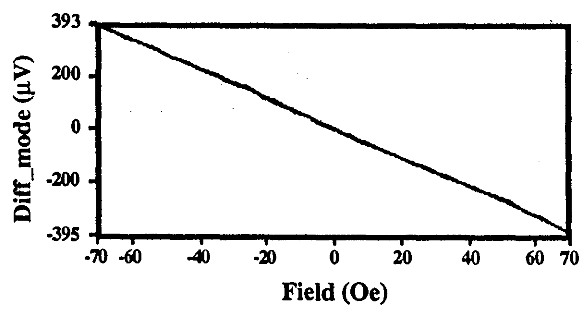
Theory of Operation



HEADWAY
TECHNOLOGIES, INC.

Resulting R-H Performance of Headway's DSMR Head

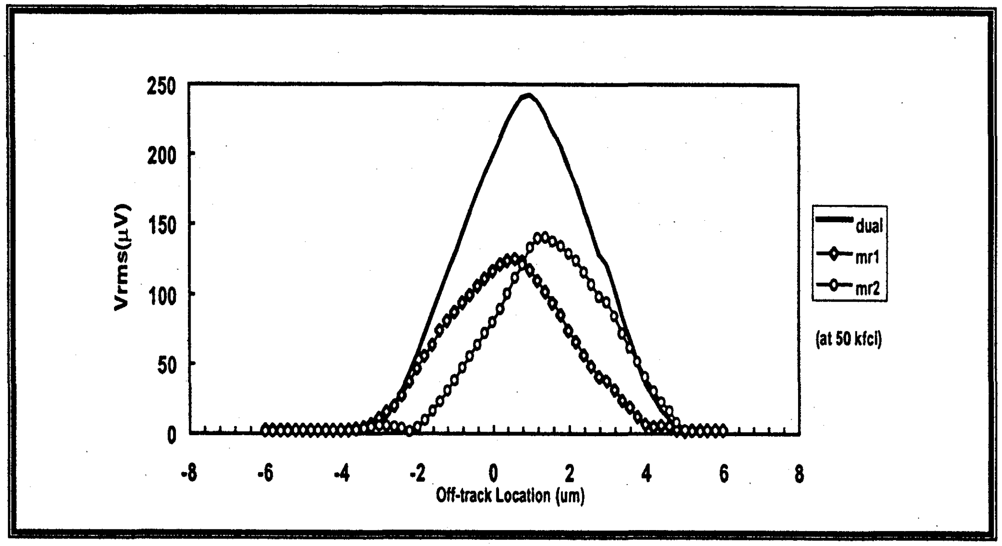




HEADWAY TECHNOLOGIES, INC.

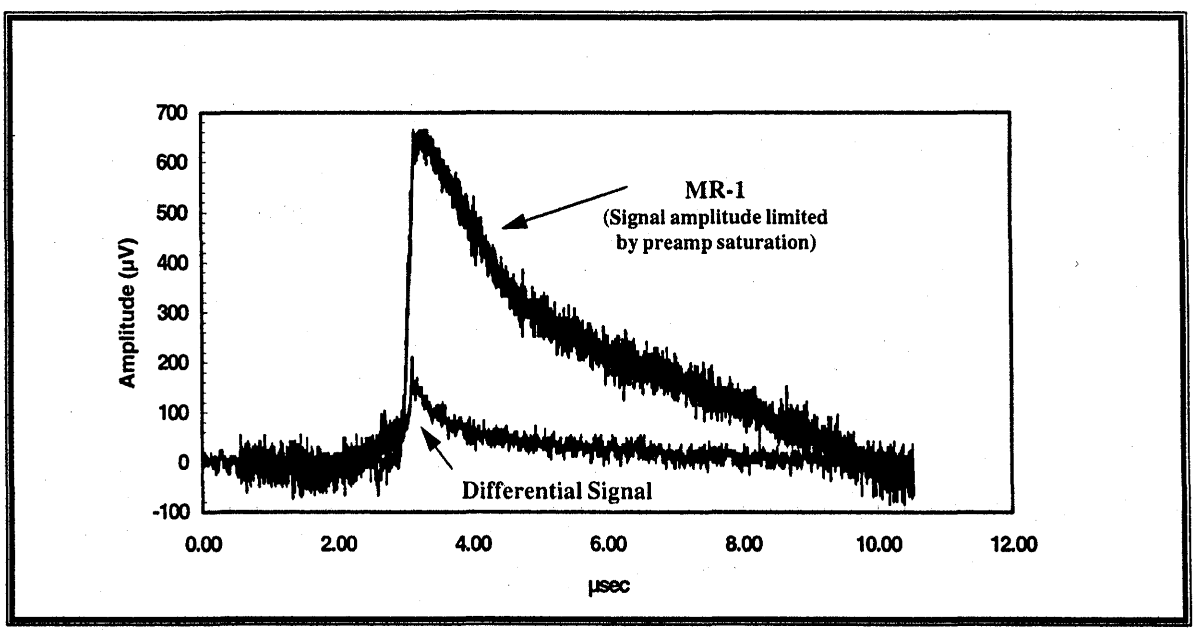
Well-Known Advantages of DSMR Recording Heads

Differential Mode of Operation
Symmetric and Linear Cross Track Response



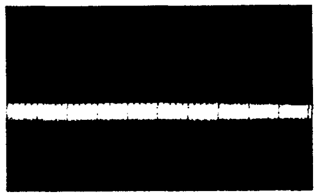
HEADWAY TECHNOLOGIES, INC.

Differential Mode of Operation
Thermal Asperity Spike Cancellation of DSMR

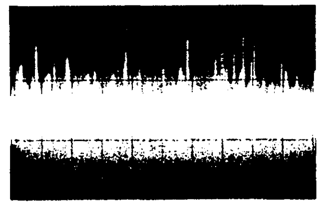


HEADWAY
TECHNOLOGIES, INC.

Thermal Asperity Signals from DSMR at Near-Contact



In Dual-Stripe Mode



In Single-Stripe Mode

TEST CONDITIONS

- Radius = 0.8095", RPM = 7750
- On textured medium with glide height = 1.5 μ"
- Gap fly height = 0.4 μ" on glass disk
- Media Avalanche = 1.0 μ"
- Medium was DC erased
- MR bias current = 10 mA
- Scope settings:
  - Vertical 50 mV/div
  - Horizontal total width = 1 revolution

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Less Well-Known Advantages

Ease of integration with other components in HDD

- Common end of MR stripes near ground potential
  - Minimize head/media electrical interface problems
- Common mode rejection possible without elaborate preamp scheme
  - Examples:
    - Stray fields
    - Inductive read (MR is one-turn coil)

Less Well-Known Advantages *(continued)*

Pulse Asymmetry

- **Matching stripes result in symmetric positive and negative pulse amplitudes**
- **Fundamental operating principle assures peak symmetry during wide-range of operating conditions**

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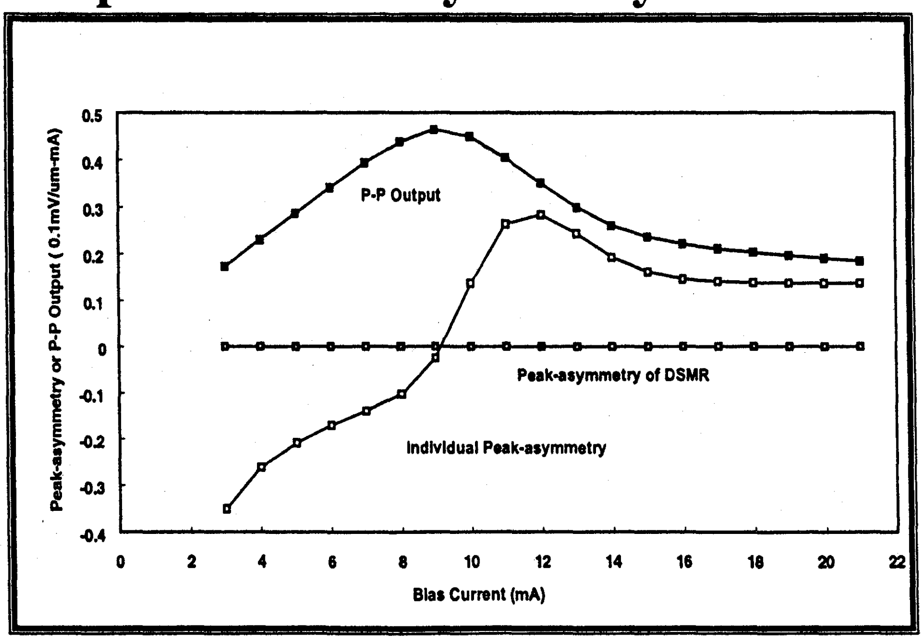
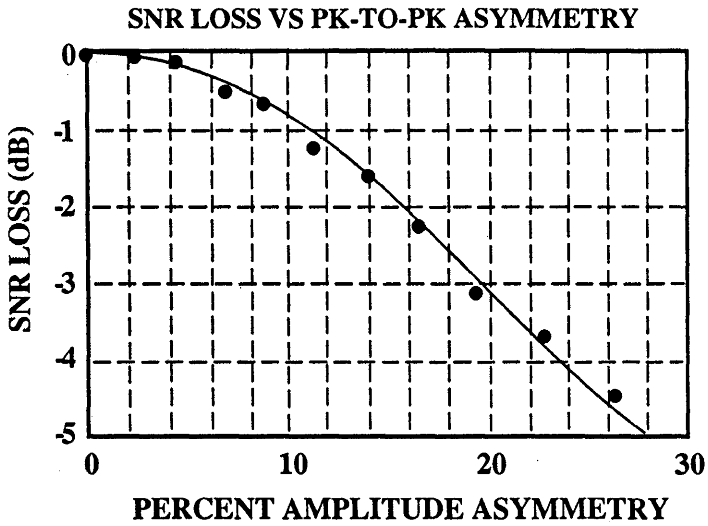
Output & Peak Asymmetry of DSMR



Yimin Guo, et. al. (3)

Asymmetry Effects on PR4ML Performance



Courtesy of Hewlett-Packard

conditions:
- ideal PR4 superposition with non-linear distortion
- AWG noise added to input
- 512 byte sectors simulated
- analog filter optimized to reduce noise

5-tap LMS FIR allowed to adapt from ideal initial taps (impulse)

channel behavioral simulator includes all loops (PLL and AGC)

each SNR calculated from five sectors' MSEs

Less Well-Known Advantages *(continued)*

- DSMR provides higher signal sensitivity while maintaining equal Joule heating or current density compared to SAL/MR heads

Less Well-Known Advantages *(continued)*

- **DSMR head exhibits less sensitivity to manufacturing process variations than SAL/MR heads**

DSMR and SAL/MR - Process Sensitivity

Simmulation Results - Peak Asymmetry

DSMR		SAL/MR	
Stripe Thickness Mis-match	Peak Asymmetry	SAL Thickness Variation	Peak Asymmetry
+8.0%	-2%	+4.0%	-5%
+4.0%	-1%	0.0%	-8%
-4.0%	+1%	-4.0%	-12%

Yimin Guo, et. al. [3]

(Bias Current 10 ma)

Drive Program Results

- "Hewlett-Packard.....has apparently beat its competition by shipping the first production model of its new 8.7 GB rigid disk drive"

  Phil Devin - Dataquest, 10/16/95

- "By delivering evaluation units of an 8.7 GB, 7,200 rpm product, HP has demonstrated an ability to deliver leading edge capacity and performance products ahead of the high-end market share leaders"

  IDC Analyst - Crawford Del Prete, 10/16/95

Manufacturing Performance

Yield is Everything!

<u>Example</u>

60 wafer starts/day

10% Yield = 1.2M nano HGAs/ month

80% Yield = 10.1M nano HGAs/ month

Process Comparison

DSMR	SAL/MR
• 3 Dielectric Layers	• 2 Dielectric Layers
• 2 Identical MR Metal Layers	• 3 Metal Layers (MR-Spacer-SAL)
• 2 Identical Longitudinal Bias Layers	• 1 Longitudinal Bias Layer

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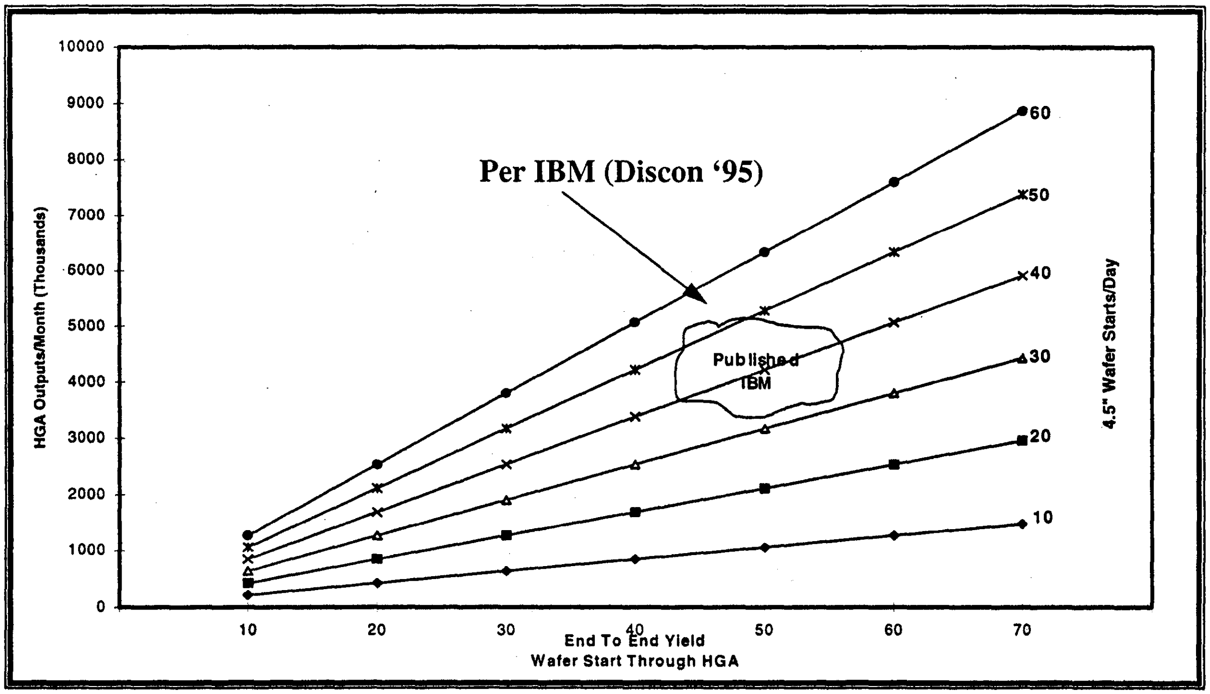
DSMR Manufacturing Summary

- Design-in process tolerance
  - Symmetry
- DSMR requires 2 additional high yield masking steps
- DSMR employs two (2) identical films with identical processes resulting in a relatively easy to manufacture device with high process yield

Nano HGA Output per Month



HEADWAY
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Headway, working closely with system design teams and slider/HGA manufacturing team, has IBM's yield and capacity benchmark in sight and is gaining ground rapidly.

DSMR Recording Heads

- 800 Mbits/in^2 design has been stable since April, 1994
- Earlier discussed advantages have enabled drive program to move into leadership position
- Yield results have been very positive and continuously improving
- Factory output is ramping as predicted

HEADWAY
TECHNOLOGIES, INC.

Additional Information

Headway Technologies' Dual Stripe MR Head Publications

1 "Performance Characteristics of Dual Stripe MR Heads," Digests of TMRC 1993 — T. C. Anthony, S. Naberhui, J. Brug, L. Tran, M. Bhattacharyya, Jerry Lopatin

- Also published in IEEE Transactions Magnetics 30,303 (1994)

2 "Dual-Stripe MR Heads for One Gigabit per Inch Square Recording Density," Intermag '95 — Y. Hsu, et. al.

3 "Recording Performance & Process Tolerance of Dual-Stripe MR Heads," TMRC 1995 — Y. Guo, et. al.

4 "Dual Stripe MR Heads," IDEMA MR Heads Symposium, February 15, 1995 — Kochan Ju

- To be published in IEEE Transactions Magnetics

TRI-PAD TECHNOLOGY AND FUTURE OF INDUCTIVE RECORDING

Yiao-Tee Hsia

Director, Advanced Mechanical Design

Read-Rite Corporation

1995 Head/Media Technology Review

Tripad Technology
and
Future of Inductive Recording

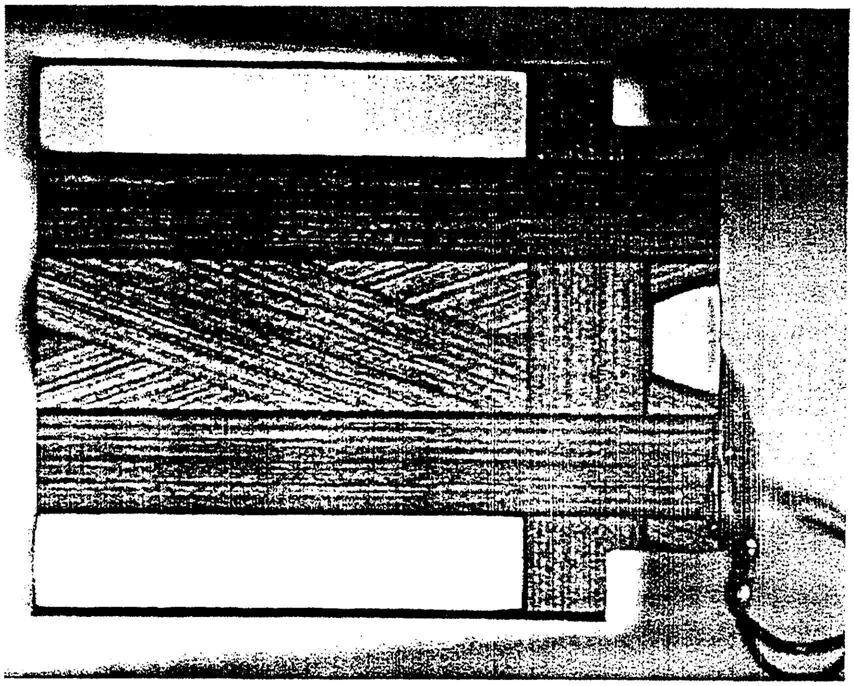
November 12, 1995

By
Yiao-Tee Hsia, Ph.D.
Director, Advanced Mechanical Design
Read-Rite Corporation

Outline

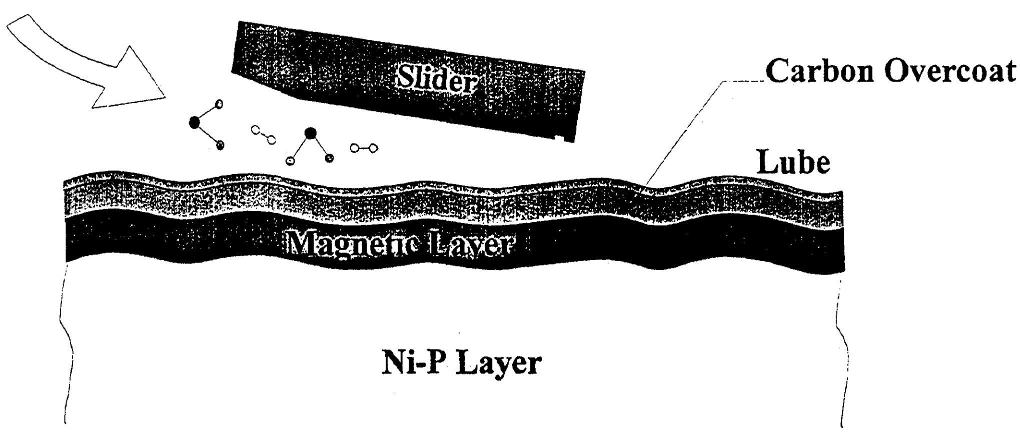
- **Tripad ABS**
- **Tripad Tribology**
  - Contact Force Measurement
  - Tripad Head/Disk Interface Mechanism
- **Next Generation Tripad**
- **Future of Inductive Technology**
- **Summary**

Tripad Air Bearing Surface



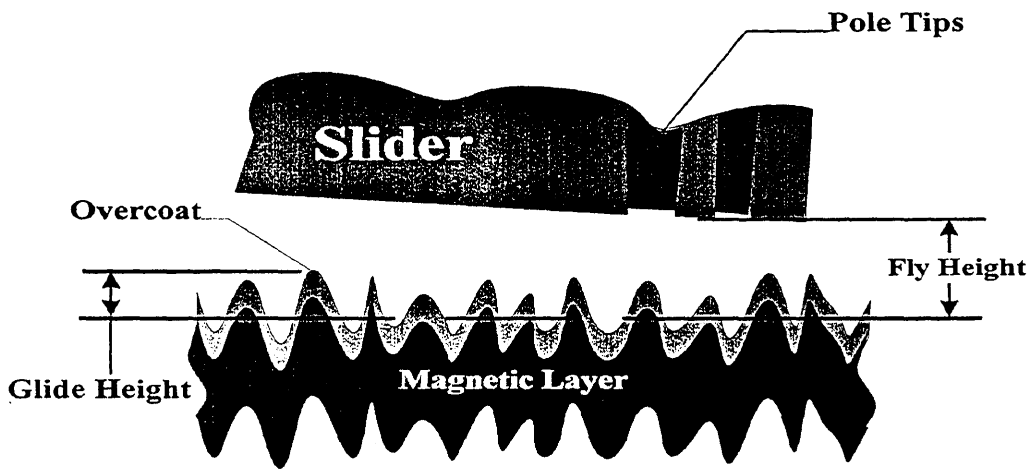
Leadership → Quality → Continuous Improvement READ-RITE

Head/Disk Interface



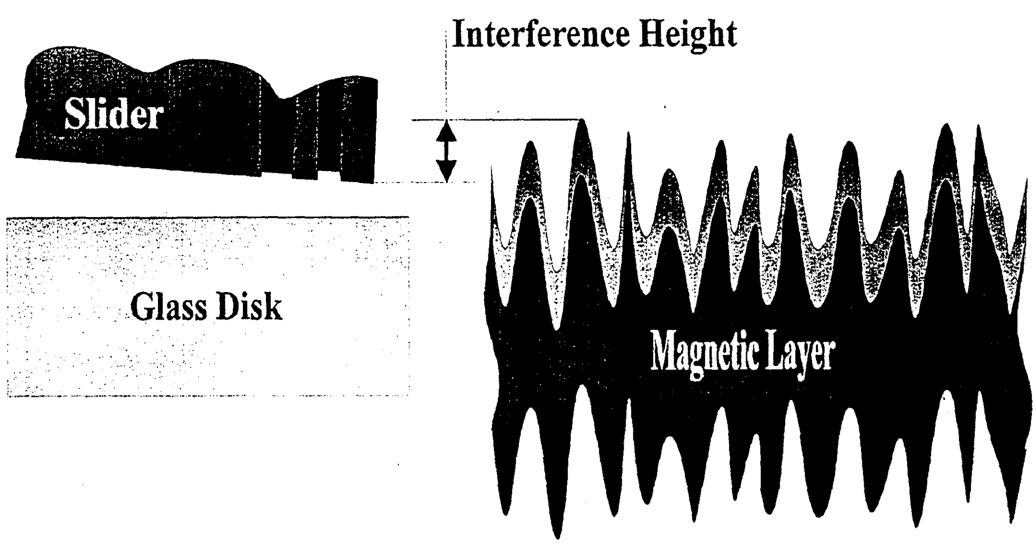
Leadership → Quality → Continuous Improvement READ-RITE

Head/Disk Interface: Flying



Leadership → *Quality* → *Continuous Improvement* READ-RITE

Head/Disk Interface: Contact



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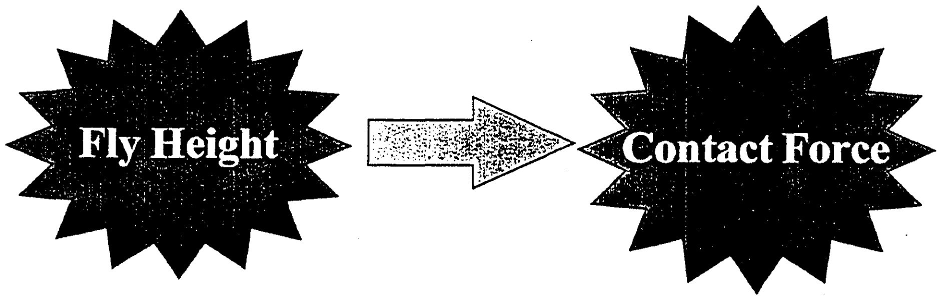
A New Magic Number



In order to evaluate the mechanical reliability of the head/disk interface, we need to be able to measure the contact force.

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Intuitive Expectations

- **Contact Force should be inversely related to fly height**
  - Flying sliders will exhibit zero contact force
- **As the velocity of the disk increases, contact force will decrease until the slider completely takes off**
- **Over time the contact force will diminish due to wear of the slider and burnishing of the disk**
- **Contact force will increase with altitude**

Leadership → *Quality* → *Continuous Improvement* READ-RITE

Contact Force Measurement Technique

- Use Acoustic Emission to detect slider body resonances
- The slider body resonant energy is proportional to the slider-disk collision energy
- Slider-disk collision energy depends on the disk velocity and the contact force between the slider and the disk

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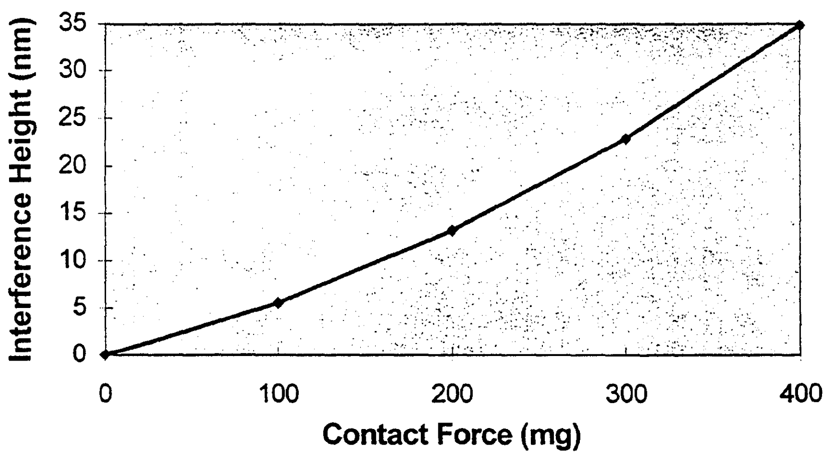
Predicted Contact Force



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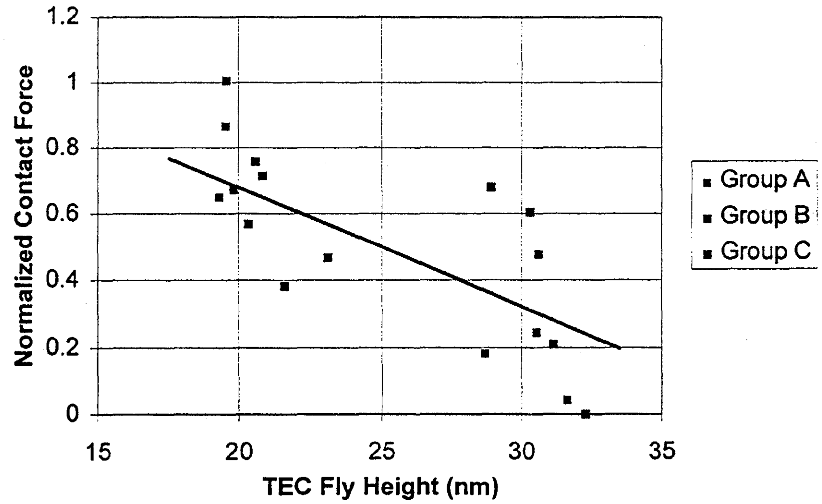
Variation of Contact Force with Fly Height



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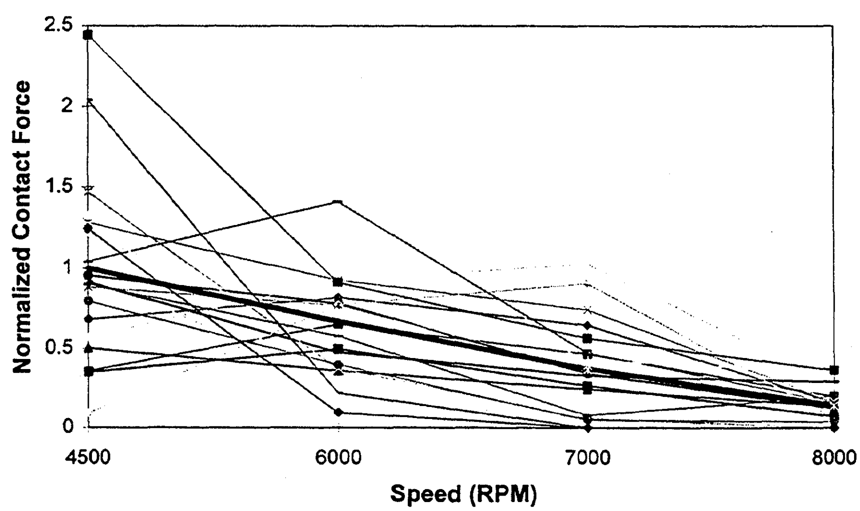
Contact Force vs. Disk Velocity



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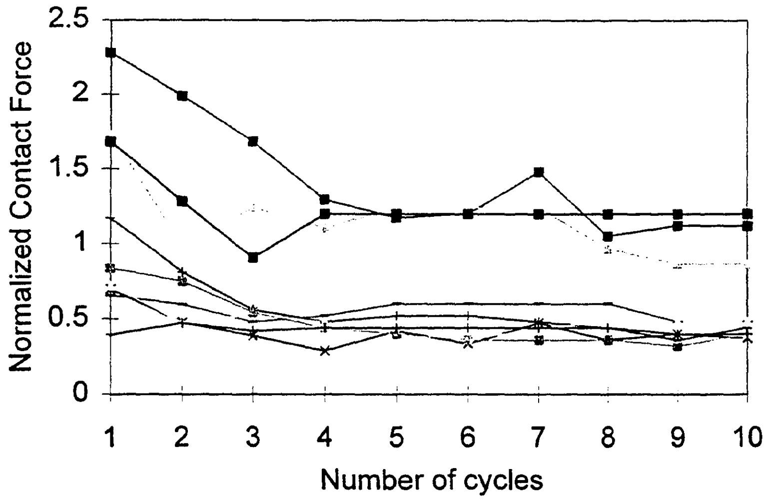
Change in Contact Force Due to Disk Burnishing



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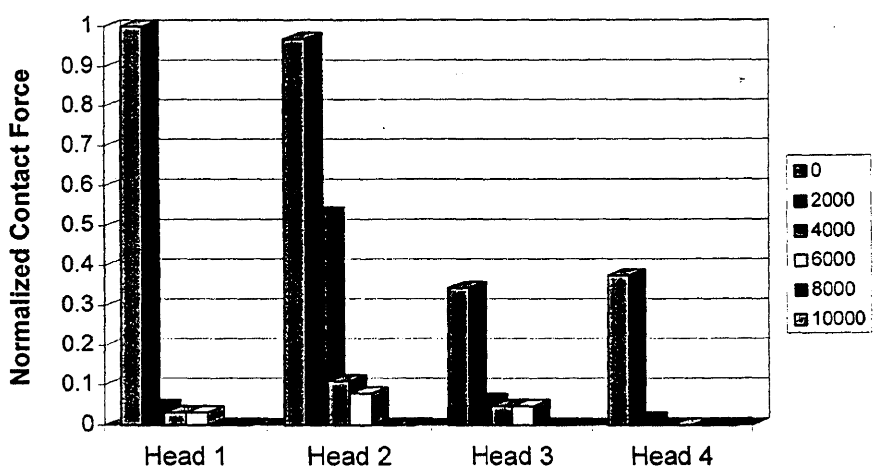
Reduction of Contact Force as a Function of CSS Cycles



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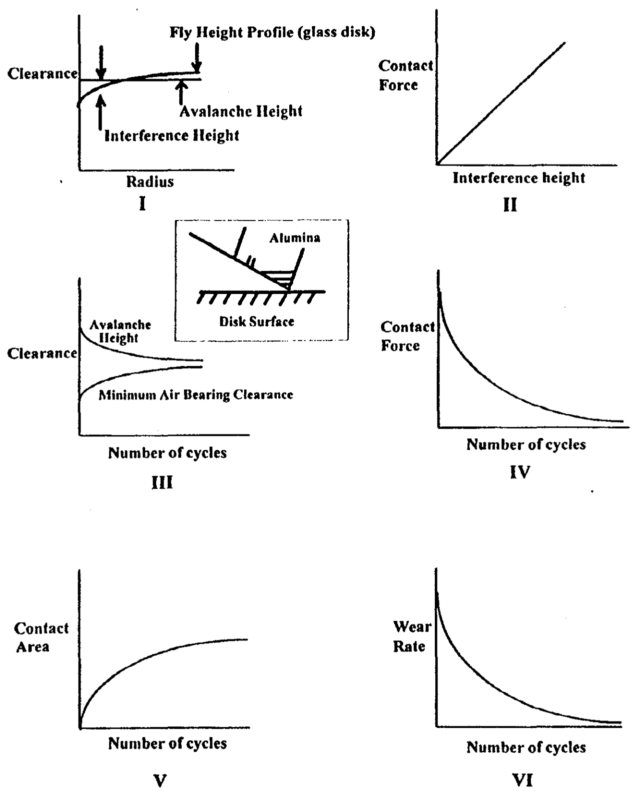
Tripad HDI Mechanism



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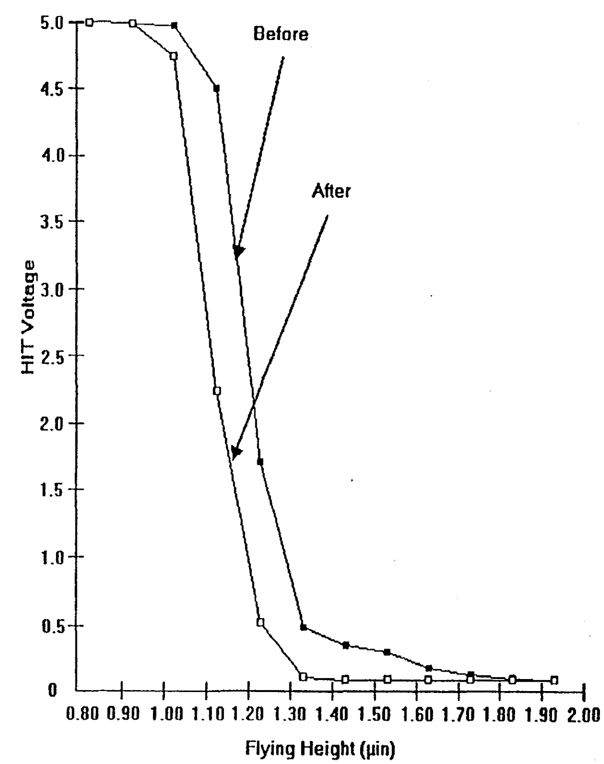
Disk Glide Avalanche Profile

Before & After Test



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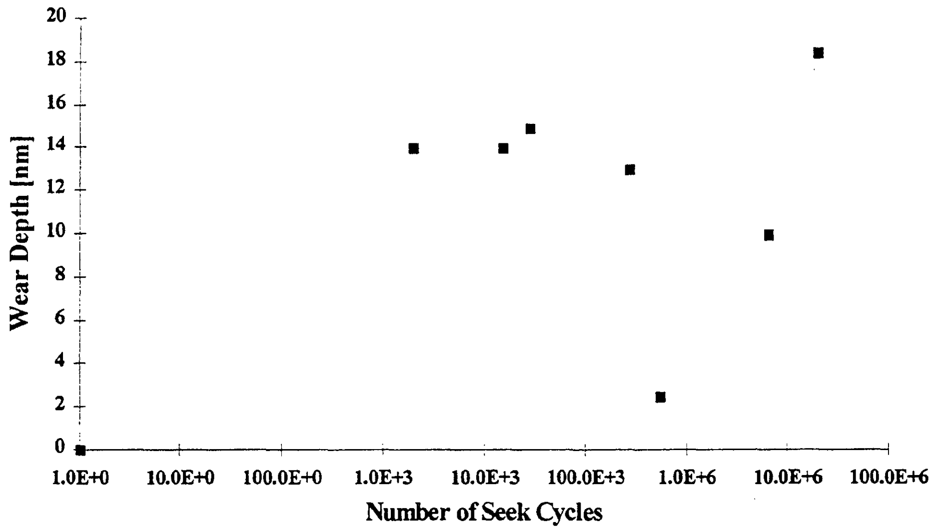
Wear Depth vs Number of Cycles



Extending Inductive Recording Technical Challenges

- Trackwidth Control
- Laminations
- High Bsat Materials
- Lower Inductance
- Even Lower Magnetic Spacing

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Inductive Transducer - Technical Challenges

Features	700 Mb/in^2	840 Mb/in^2	1 Gb/in^2
Pole Trim	Yes	Yes	Yes
Lamination	Yes	Yes	Yes
Hi B_{sat}	-	Yes	Yes
Inductance	~ 0.34 nH/T^2	~ 0.30 nH/T^2	~ 0.27 nH/T^2
Spacing	~ 1.6 μ"	~ 1.4 μ"	~ 1.2 μ"

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Air Bearing Design - Technical Challenges

- Lower Magnetic Spacing
- Head Disk/Interface Reliability
- Altitude Insensitivity
- Pico Slider

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Direction for Future Pseudo-Contact Air Bearings

- All Etched Air Bearing
- Constant Gap Spacing
- Reduced Altitude Sensitivity
- Pico (30%) Form Factor

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Summary

- **Tripad Head/Disk Interface Phenomenon is understood**
  - There is **finite** amount of wear on the Tripad slider
  - There is **finite** amount of additional burnishing on the media
- **Pseudo Contact Recording Does Work**
- **Tripad Air Bearing can be the vehicle to**
  - extend the life of Inductive Recording
  - push the MR Recording Technology to even higher limits

Leadership → *Quality* → *Continuous Improvement* READ-RITE

Acknowledgment

I wish to thank the following people for helping to put this presentation together -

Peter Bischoff

Mark Donovan

S. K. Ganapathi

Collins Lee

Robert Rottmayer

Tuan Tran

Ed Williams

Leadership → *Quality* → *Continuous Improvement* READ-RITE

VERTICAL MR HEAD

Yutaka Soda

Manager, MR Devices Section

Sony Corporation

Vertical MR Head

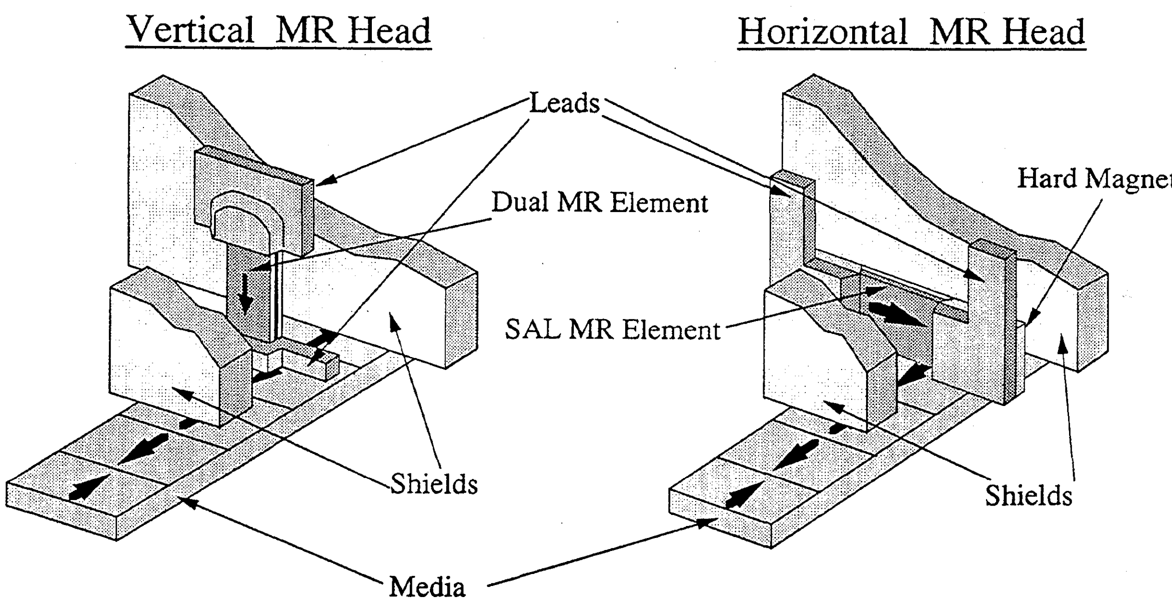
Yutaka Soda

Electronic Components Dept., Magnetic Devices Div.
Components Company
Sony Corporation

Vertical MR Head Design Concept

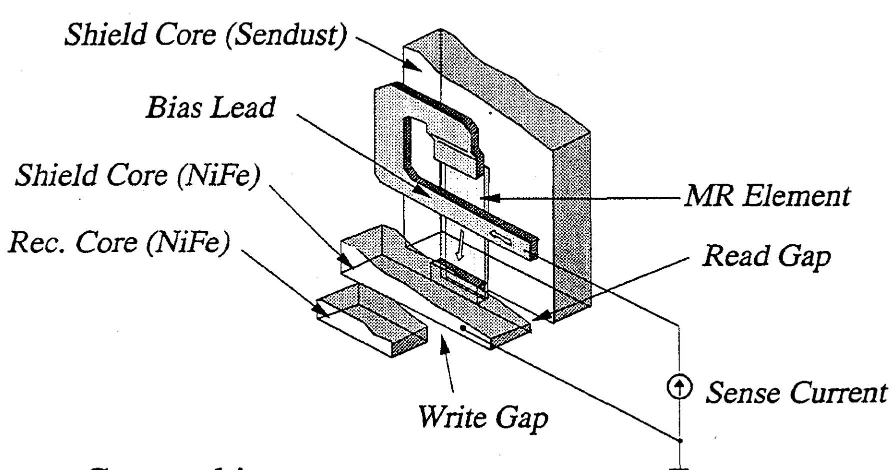
- ☐ Higher Areal Density
- ☐ Higher Reliability
- ☐ Simple MR Structure

Structures of MR Heads



SONY

MARIN Head

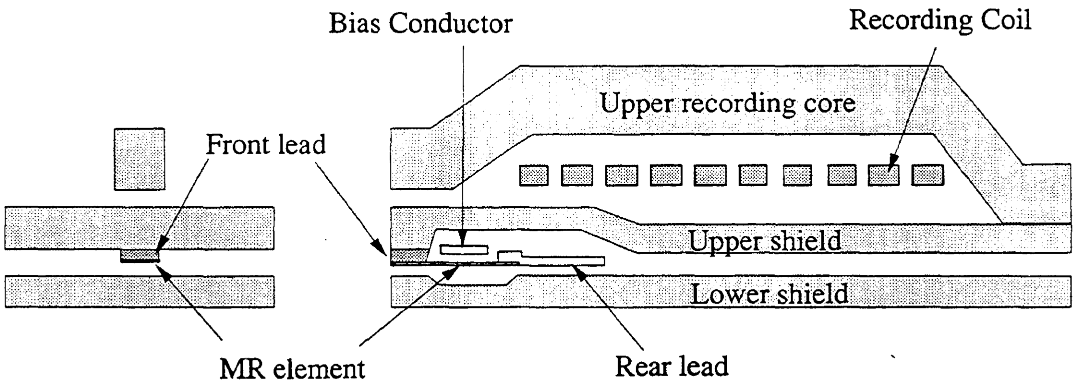


- Current bias
- MR element and bias lead are connected in series
- Grounded front lead

SONY

MARIN Head

MARIN Head



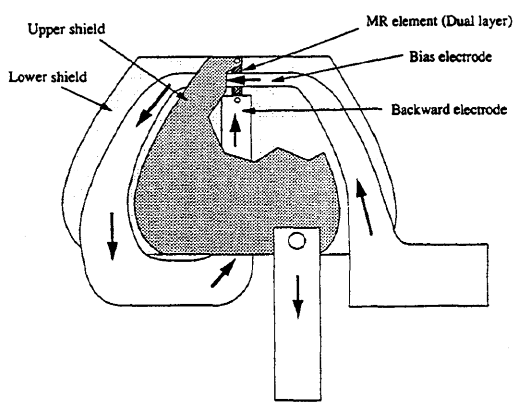
Front View

Cross Section View

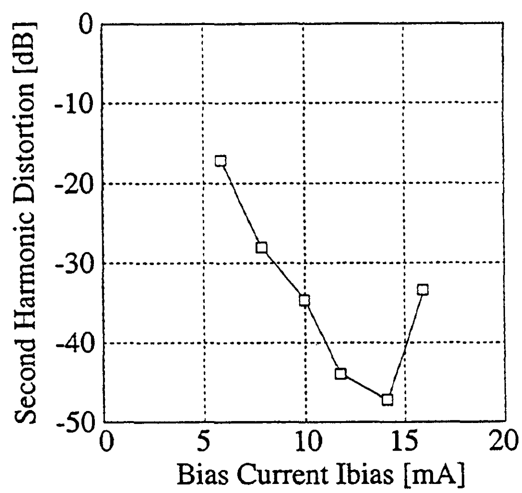
SONY

MARIN Head

2-Terminal MR Head



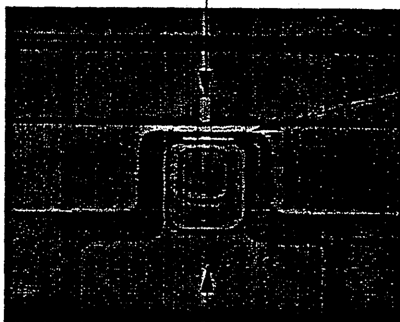
I sense = I bias

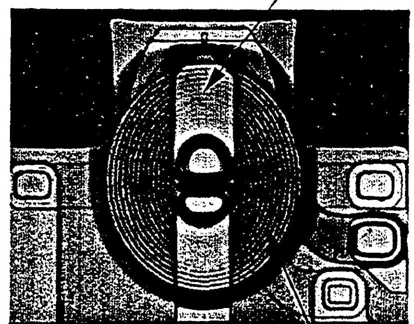


SONY

MARIN Head

Planer Views of Vertical MR Head

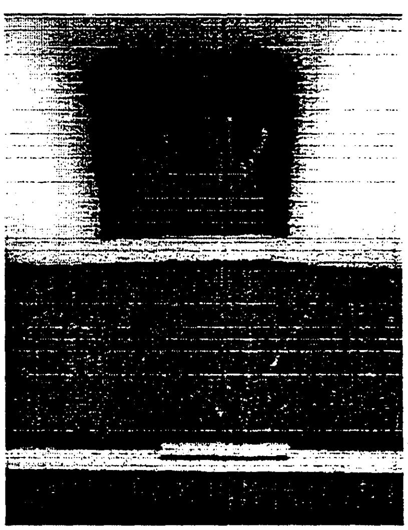




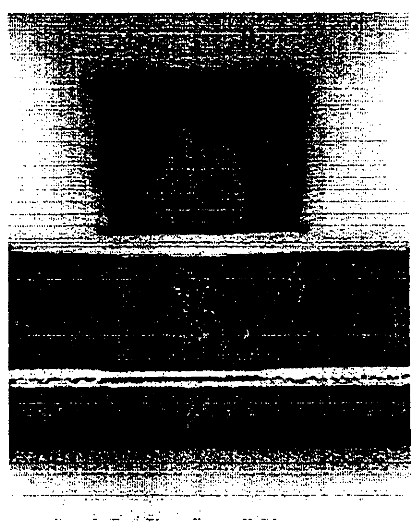
SONY

MARIN Head

MFM Images of MR Heads



Vertical MR Head



Horizontal MR Head

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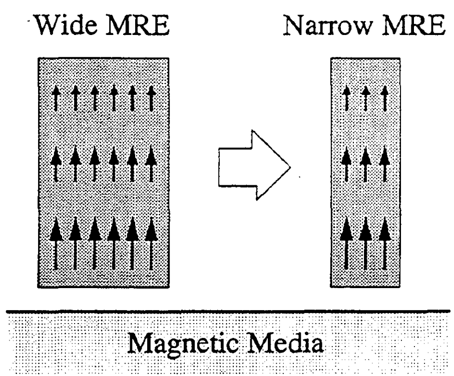
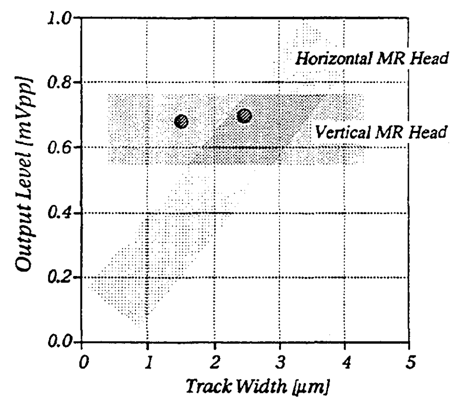
MARIN Head

TAA is Independent of Track Width

Media Flux in the MR Element



Output Level
at Constant Current Density



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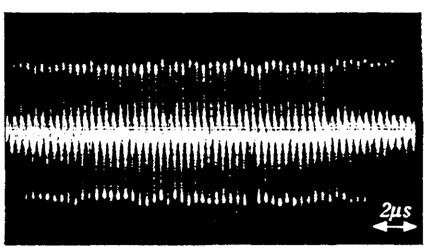
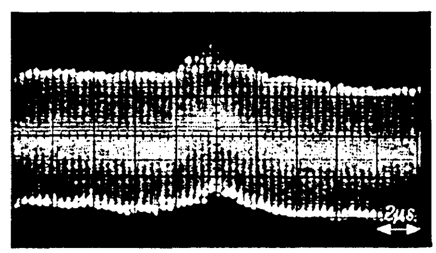
MARIN Head

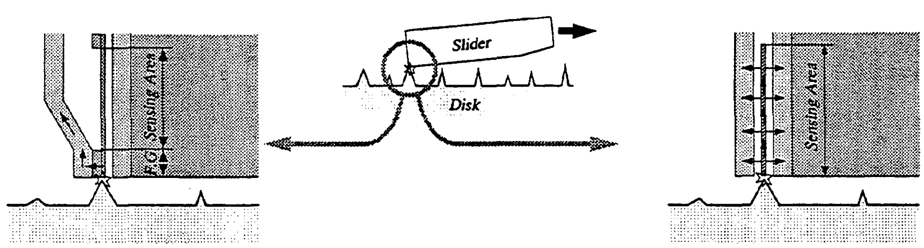
Thermal Asperities

Vertical MR Head



Horizontal MR Head





- *Heat flows toward the shield.*
- *Sensing area is not affected by TA.*

- *Heat flows into the MR element.*
- *Sensing area is affected by TA.*

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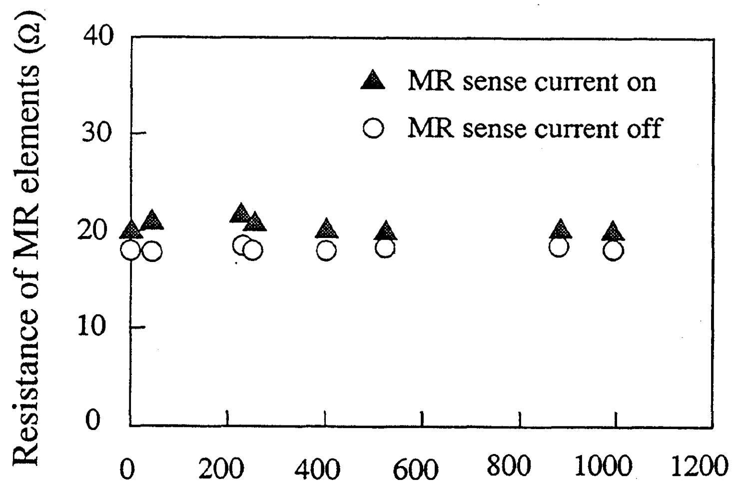
High Reliability

Temperature and Humidity Test

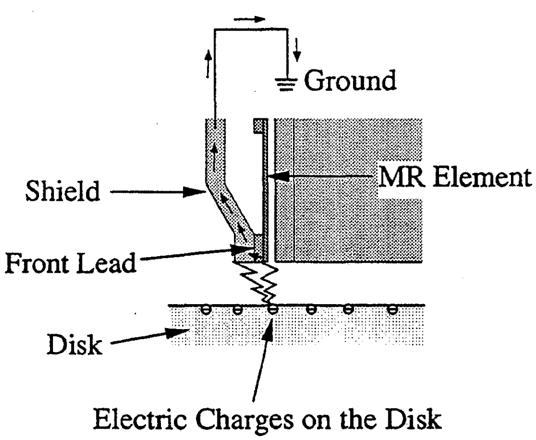


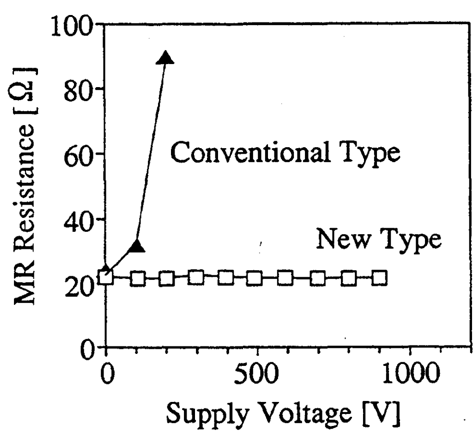
Test Condition

Temperature 60°C
Humidity 90%

MARIN Head

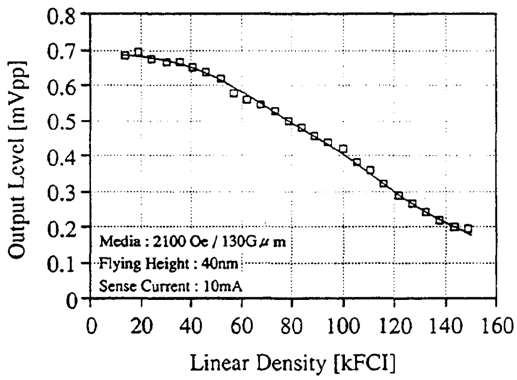
MR Breakdown Voltages >1000V

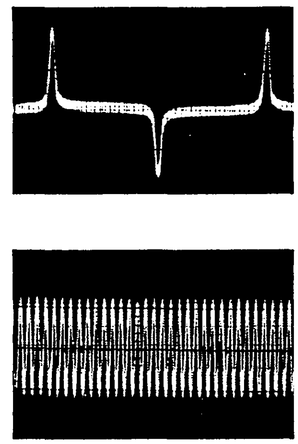




MARIN Head

Frequency Response of Vertical MR Head





MR Track Width = 1.5 μ m

PW50 = 0.32 μ m

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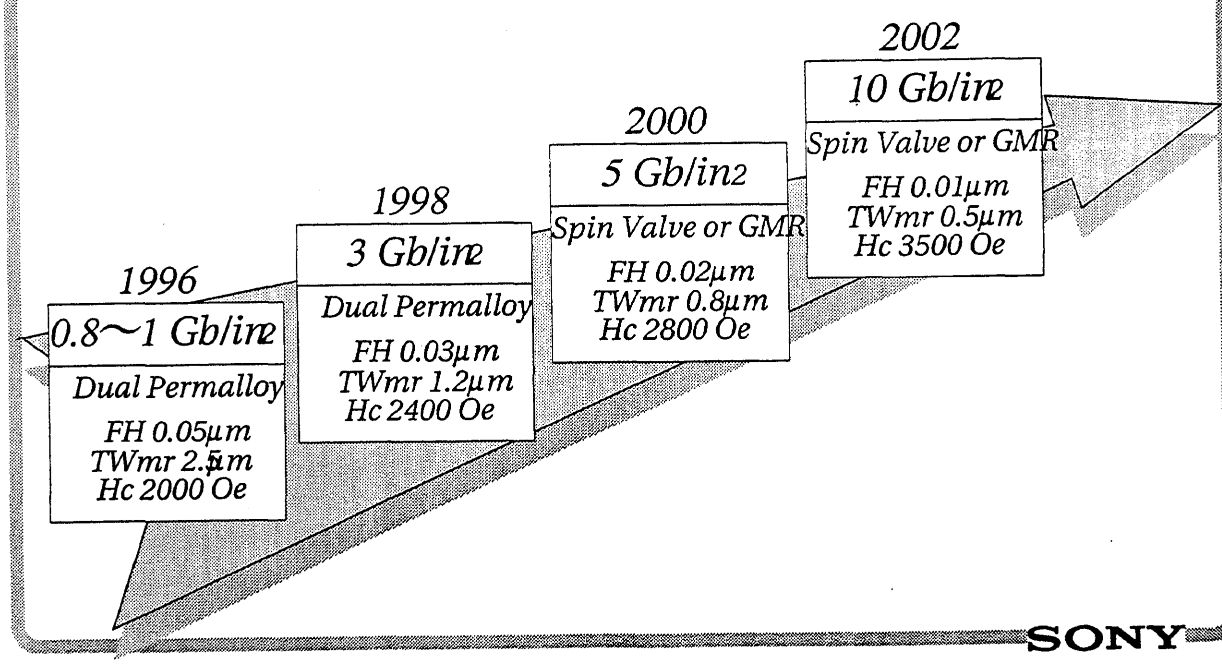
MARIN Head

Vertical-MR Head Migration



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Conclusions

Vertical MR Heads realize;

- ☐ High Areal Density
  - High Output
  - Narrow Track
  - Low Fly Height
  - Narrow Gap
- ☐ High Reliability
  - Environmental
  - Electrical
  - Thermal
  - Mechanical

SONY

LITHOGRAPHY FOR THIN FILM HEAD APPLICATIONS

David Markle

Vice President Advanced Technology

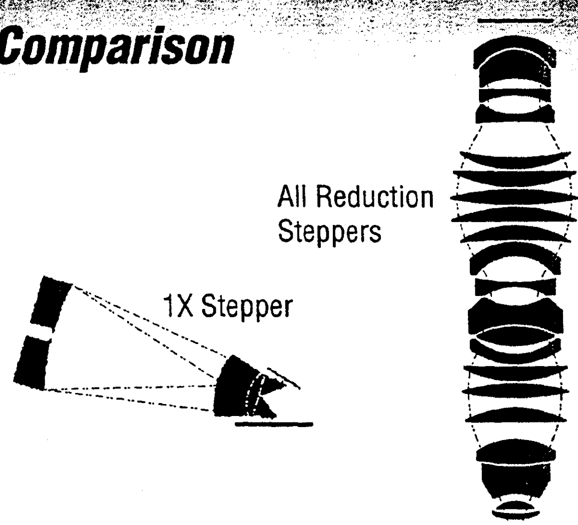
Ultratech Stepper

Lithography for Thin Film Head Applications

Dave Markle
V.P. Advanced Technology
Ultratech Stepper

UltratechStepper

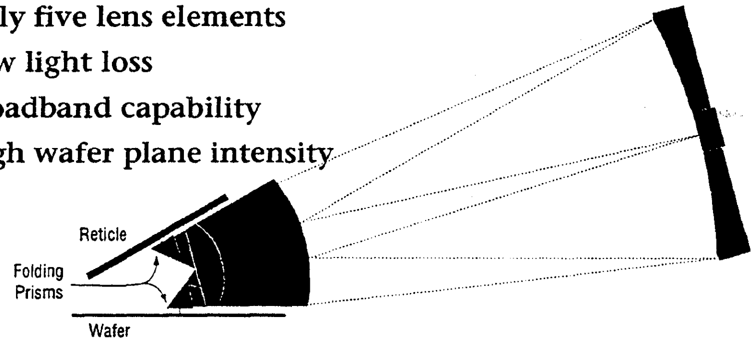
Lens Comparison



UltratechStepper

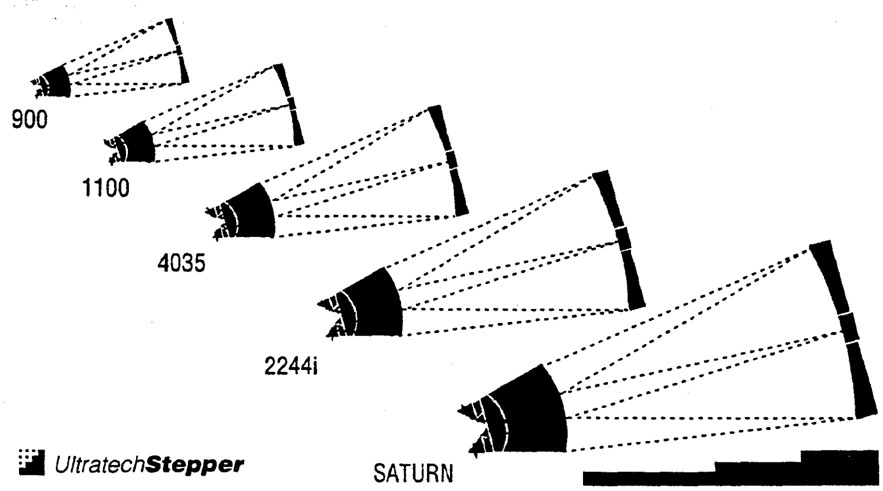
Folded Wynne Dyson System

- Large field size
- Only five lens elements
- Low light loss
- Broadband capability
- High wafer plane intensity



UltratechStepper

Five Generations of Ultratech Lenses

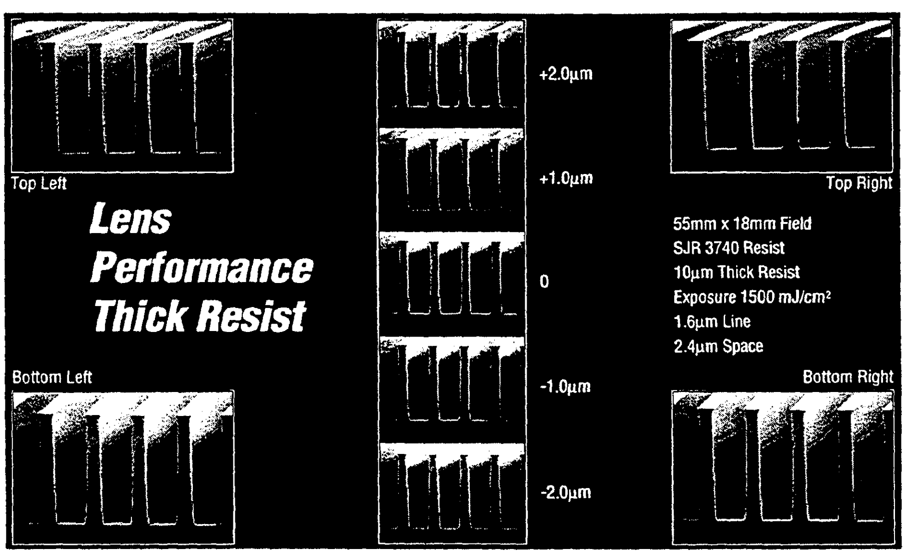


UltratechStepper

Important Projection System Parameters

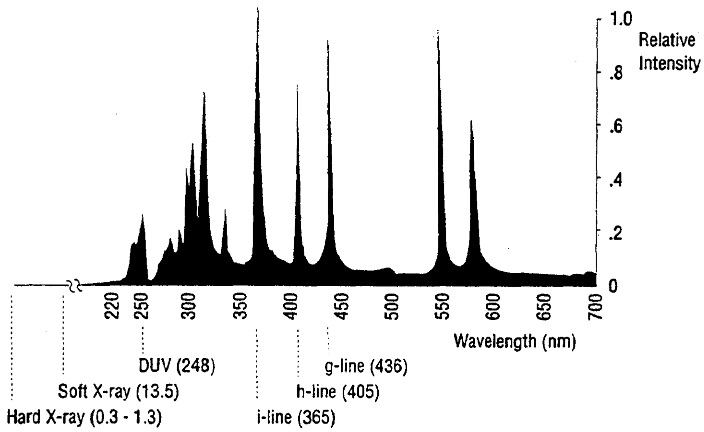
- Resolution
- Field size
- Exposure wavelength
- Spectral range
- Wafer irradiance
- Partial coherence

*Ultratech***Stepper**



*Ultratech***Stepper**

The Mercury Spectrum



UltratechStepper

Thin Film Head Lithography

Model ***4700***

55 x 18mm field size

80nm colinearity

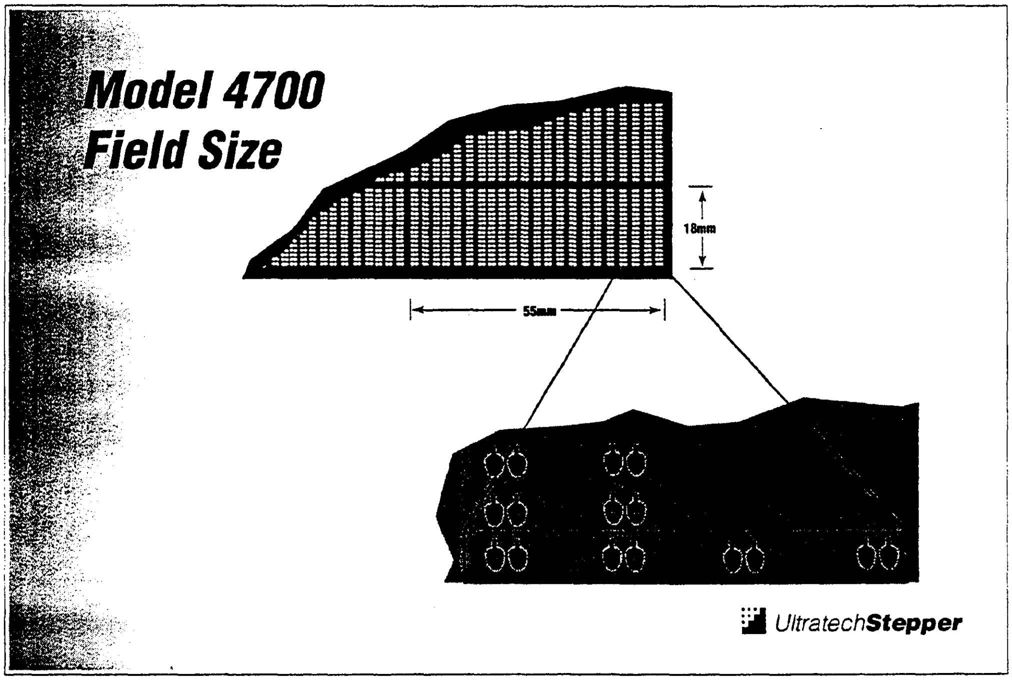
Wafer plane intensity
≥1250 mW/cm²

Applications

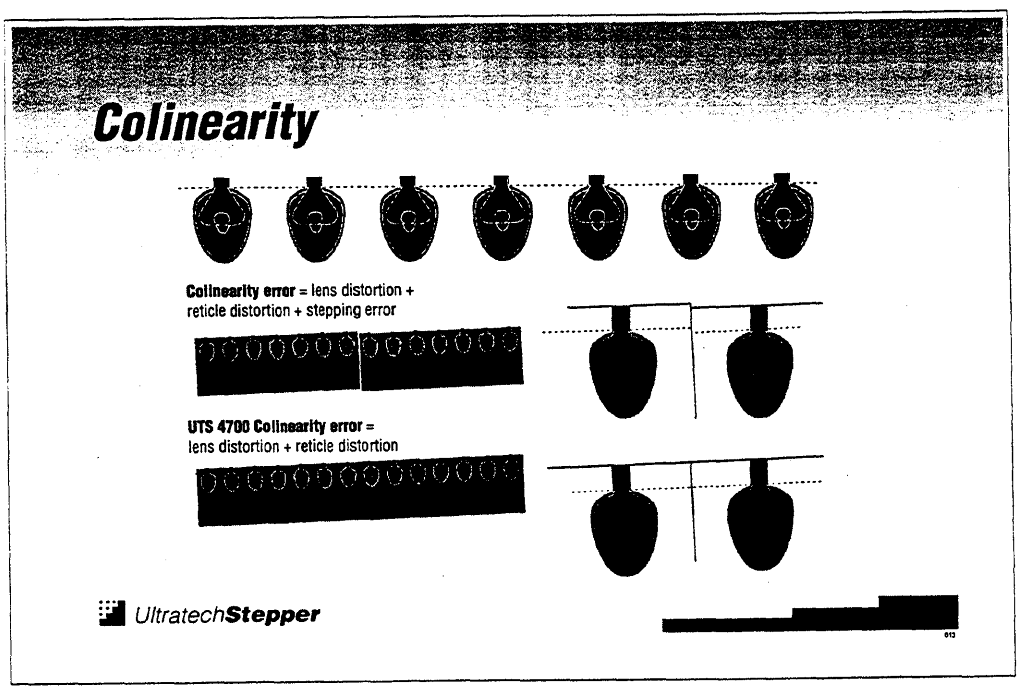
Advanced inductive head

MR head

UltratechStepper

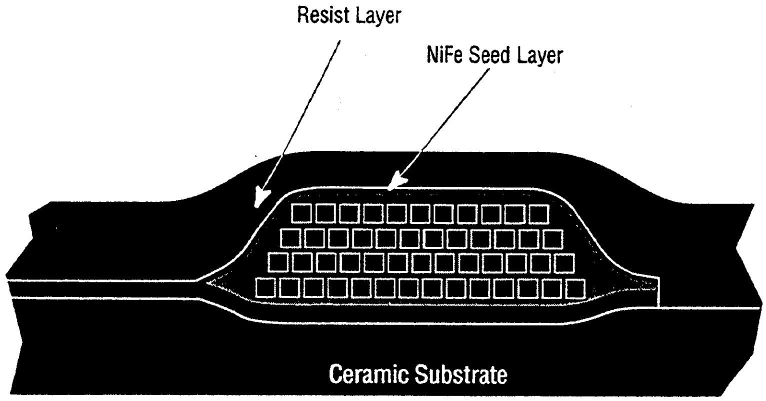


Model 4700
Field Size
18mm
55mm
UltratechStepper



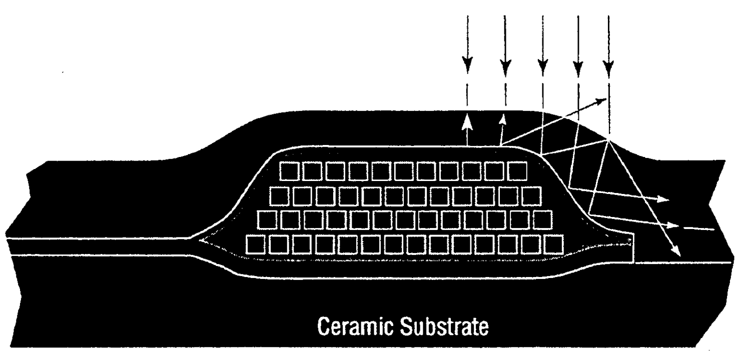
Colinearity
Colinearity error = lens distortion + reticle distortion + stepping error
UTS 4700 Colinearity error = lens distortion + reticle distortion
UltratechStepper

Real World Lithography Challenges



*Ultratech***Stepper**

Real World Lithography Challenges (Cont)



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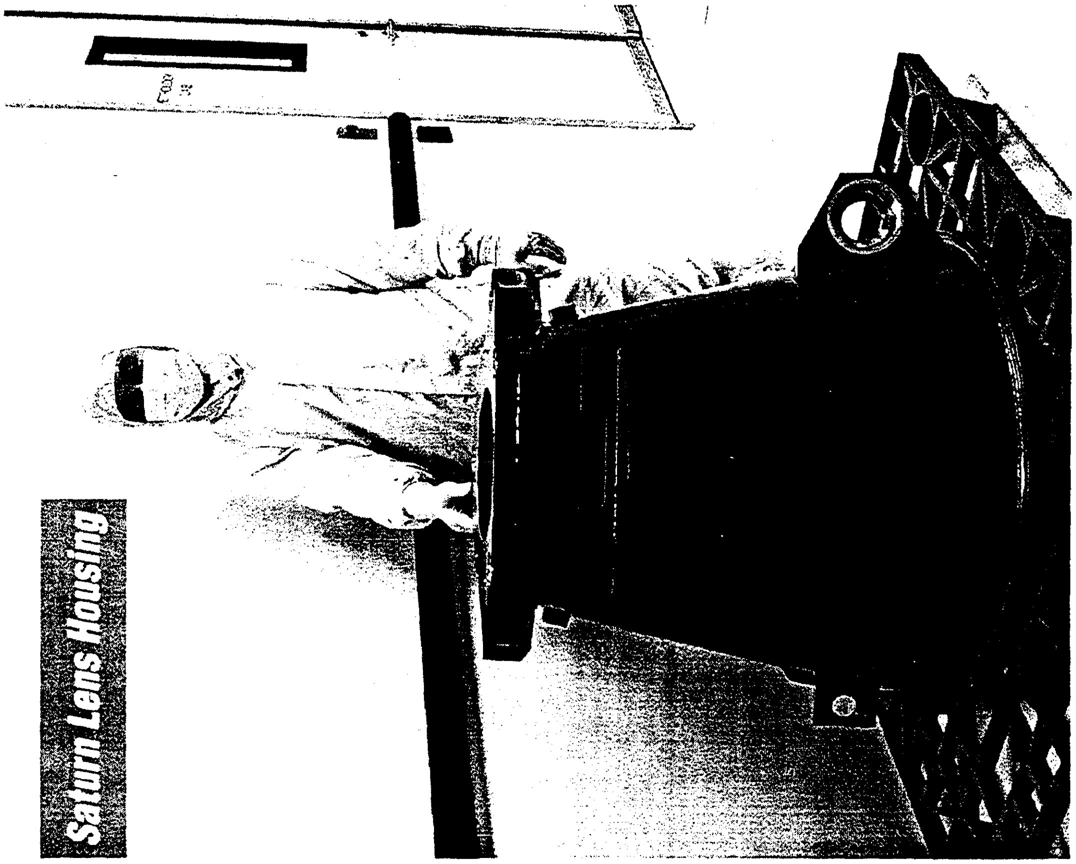
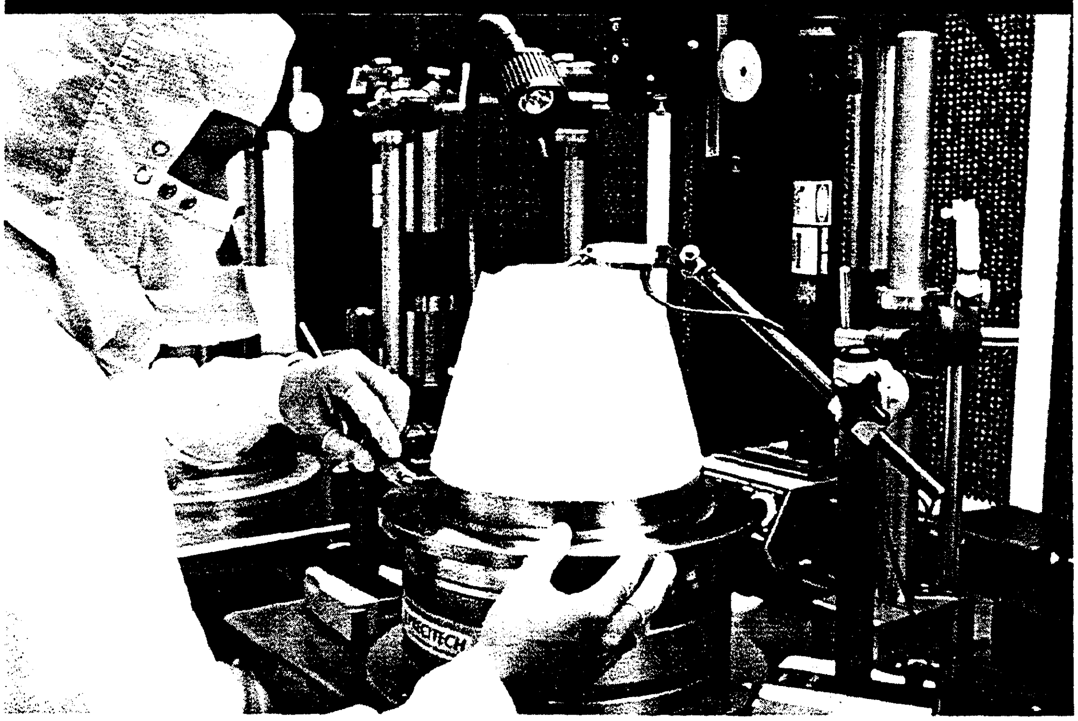
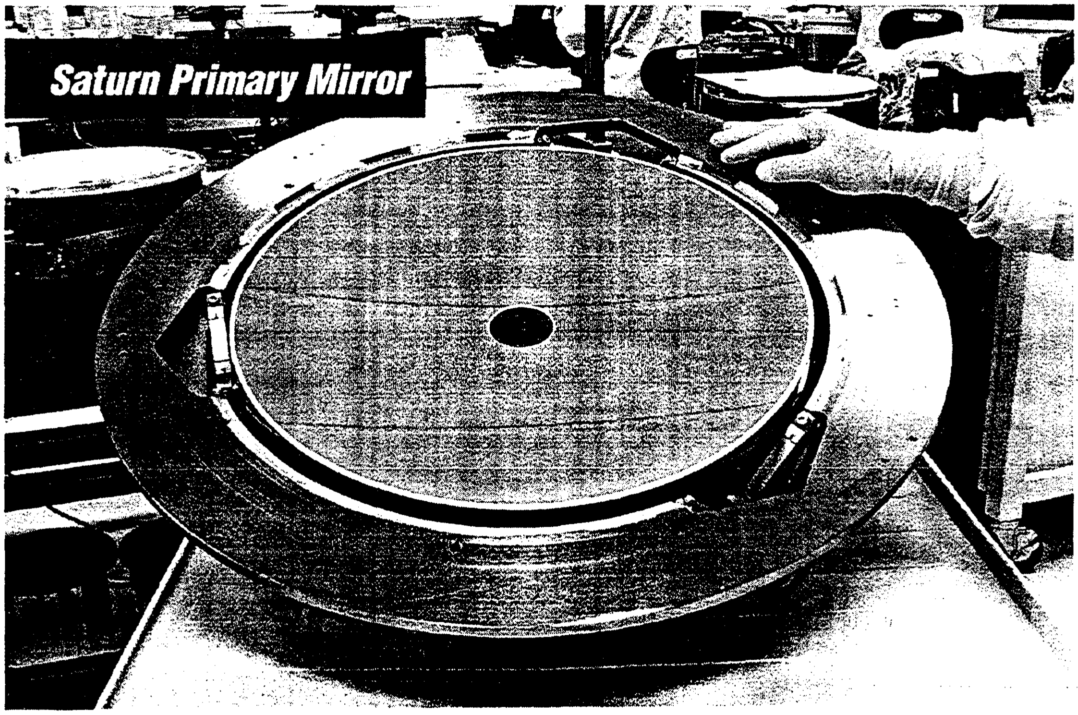


Saturn Lens Housing

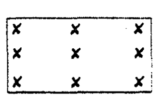
Saturn Doublet Lens Assembly



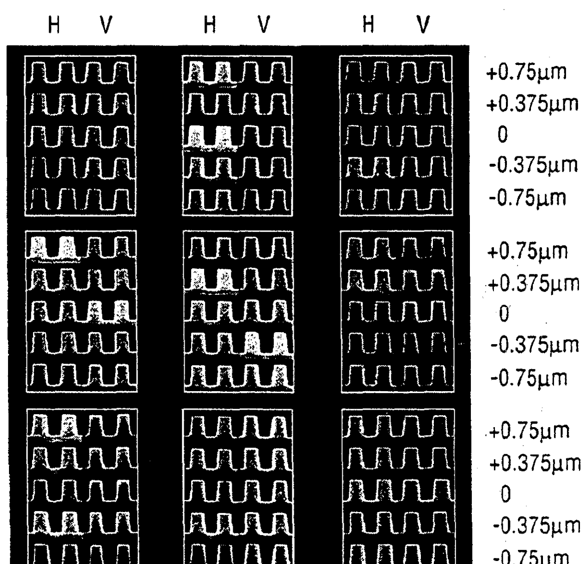


Saturn Resolution Through Focus

- 0.65µm L/S Structures
- 9 points in field
- horizontal and vertical lines
- 1.5µm focus range

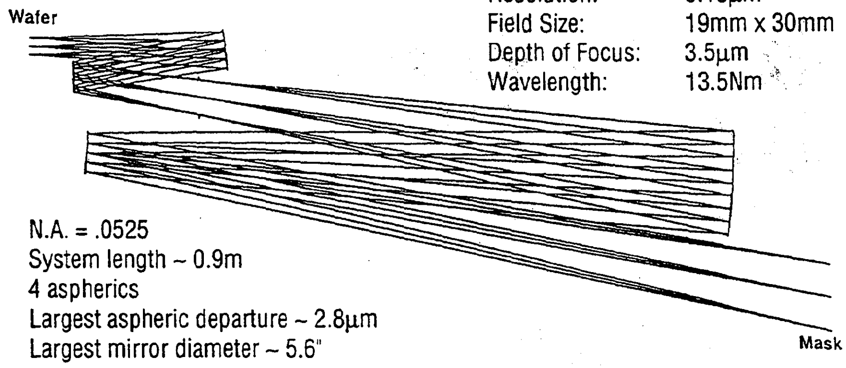


22 x 44mm



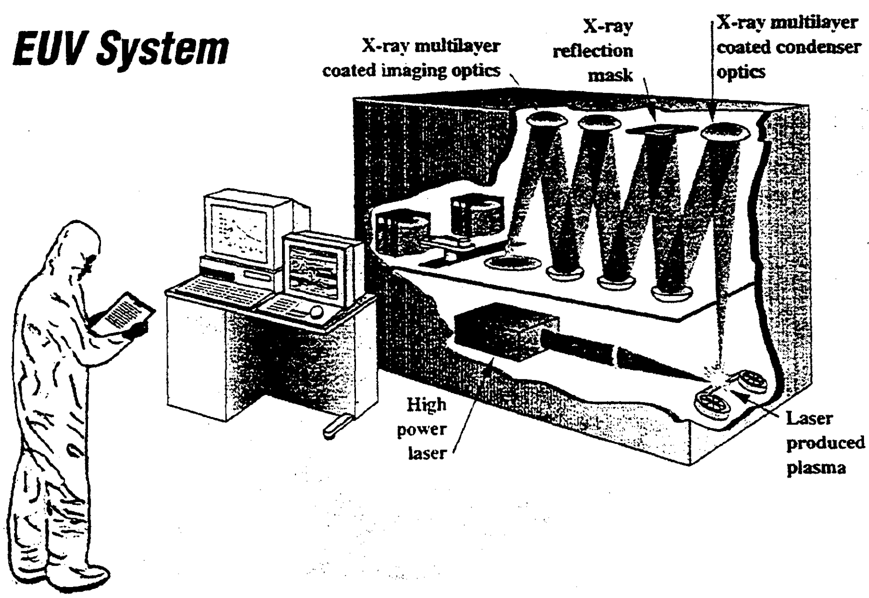
EUVL System Design: Full Field @ 0.18μm

Resolution:	0.18μm
Field Size:	19mm x 30mm
Depth of Focus:	3.5μm
Wavelength:	13.5Nm



N.A. = .0525
System length ~ 0.9m
4 aspherics
Largest aspheric departure ~ 2.8μm
Largest mirror diameter ~ 5.6"
Telecentric @ wafer
Accessible pupil

EUV System



Summary

- Thin film head lithography requirements are different from IC lithography requirements
- The resist layer is a key part of the lithography system
- The end of optical lithography is not in sight

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