The Physics of Magnetic Recording

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OUTLINE

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4. REPRODUCE PROCESS (RECIPROCITY)
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6. RECORD MODELS
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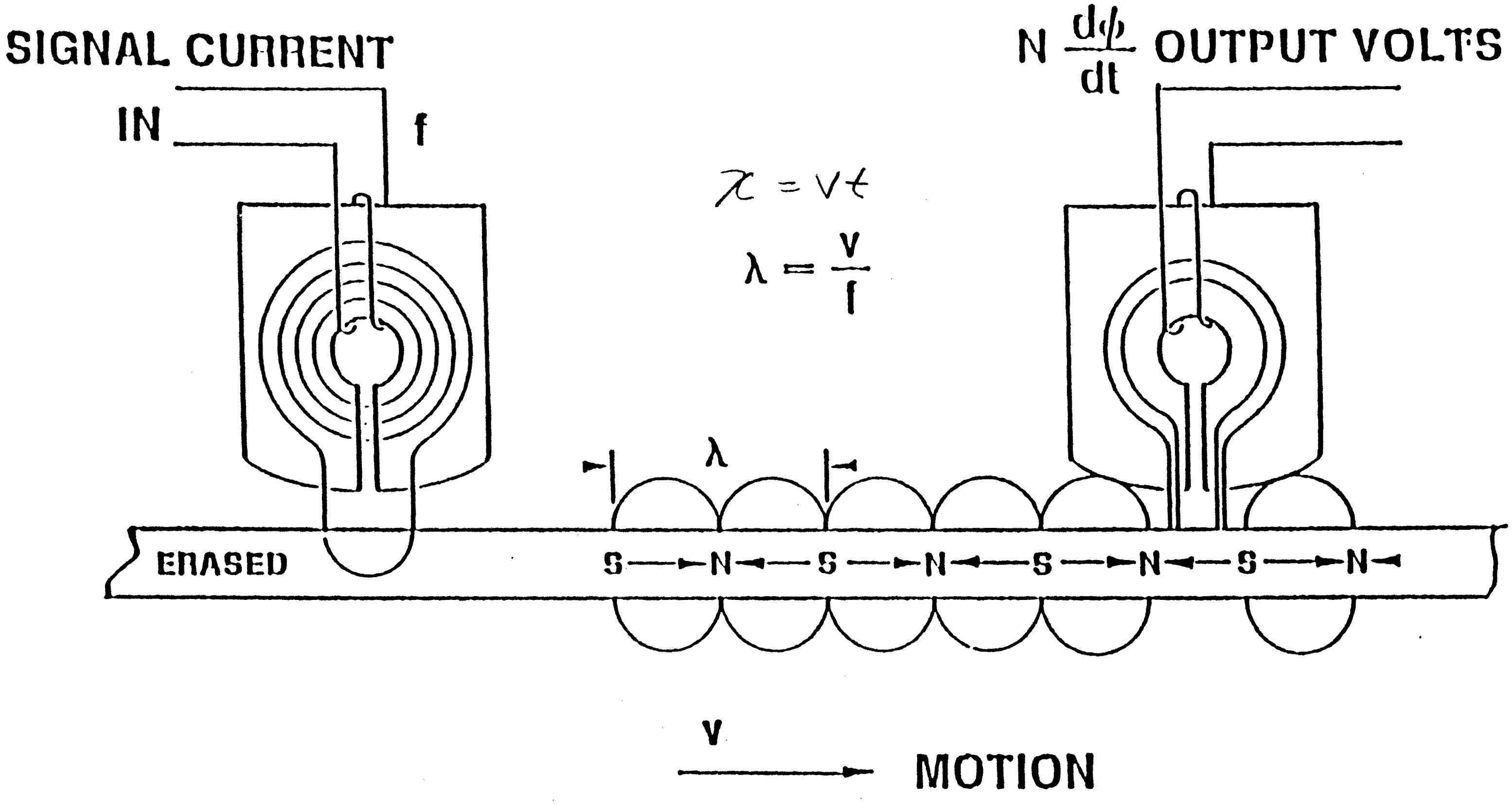
FUNDAMENTAL PROCESSES



$\lambda = vt$

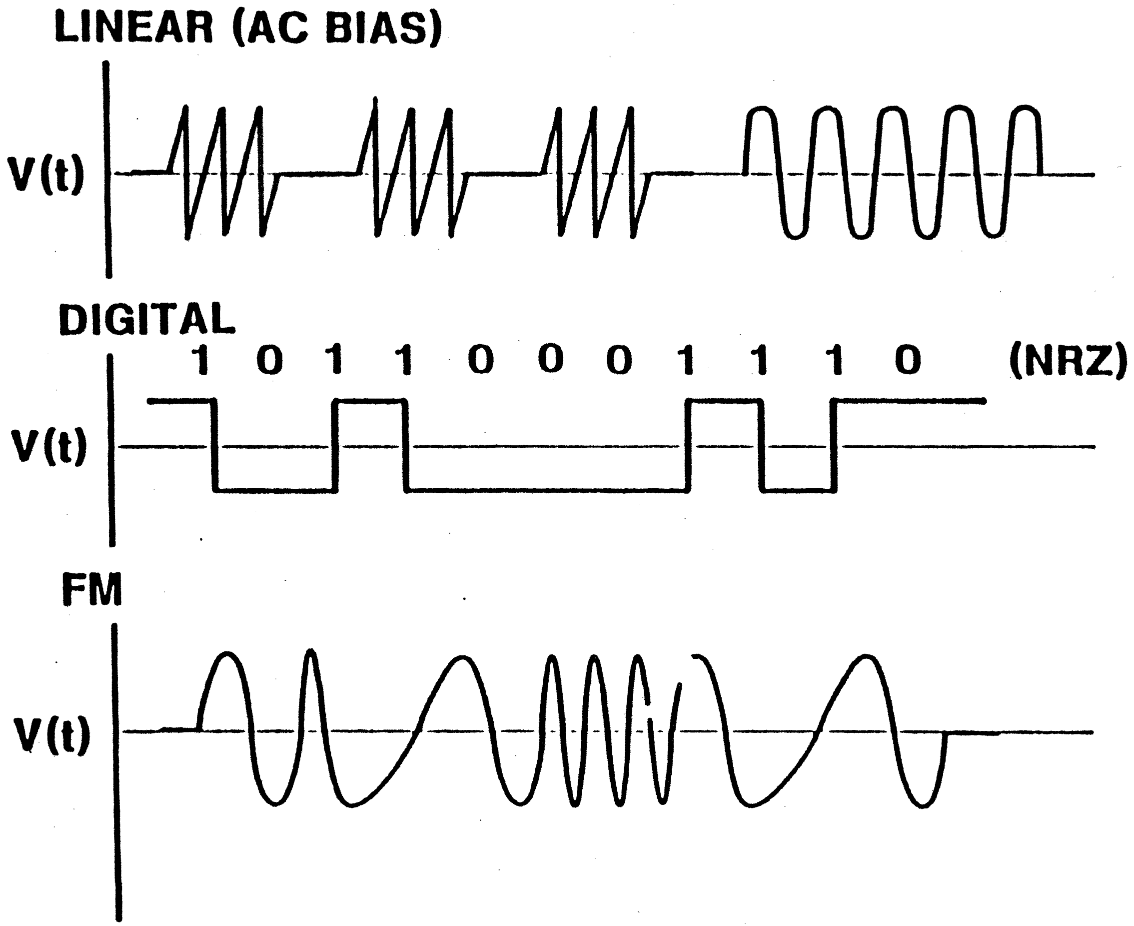
$\lambda = \frac{v}{f}$

STORAGE

WRITING
OR RECORDING

READING
OR REPRODUCTION

SIGNAL WAVEFORMS

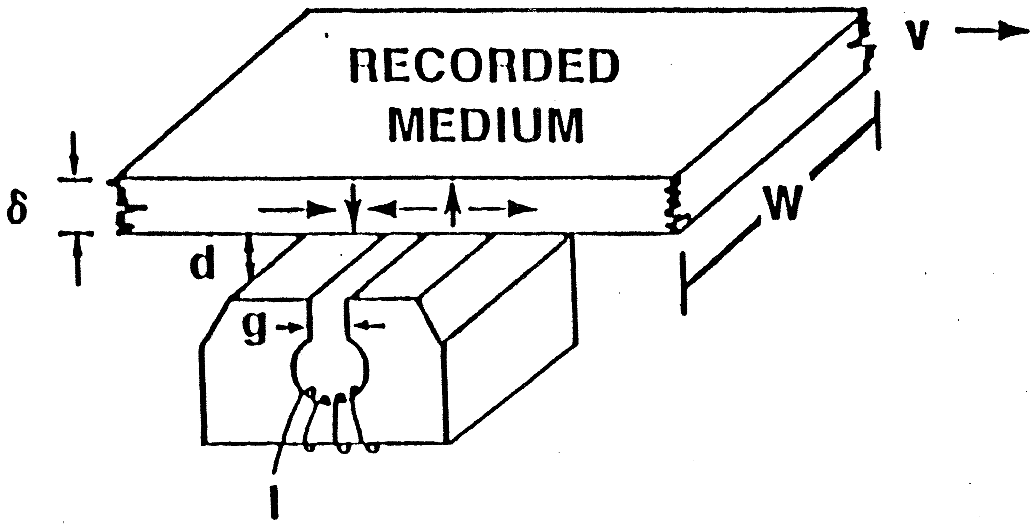


RECORDING DENSITIES

HIGH DENSITY

RECORDER	SPEED	MAX f	MIN λ	SIGNAL
INSTRUMENTATION	1-120 ips	2 MHz	60 μ" (33 KFRI)	DIGITAL
QUAD VIDEO	1500 ips	15 MHz	100 μ"	F.M.
CONSUMER VIDEO	220 ips	7 MHz	30 μ"	F.M.
AUDIO CASSETTE	1-7/8 ips	20 kHz	80 μ"	LINEAR
DAT	123 ips	5 MHz	25 μ" (61 KBPI)	DIGITAL
COMPUTER DISC	1000 ips	10 MHz	100 μ" (20 KFRI)	DIGITAL

RECORDING GEOMETRY



g = GAP LENGTH
d = FLYING HEIGHT
δ = MEDIUM THICKNESS OR RECORD DEPTH
W = TRACK WIDTH

DEMAGNETIZATION FIELDS

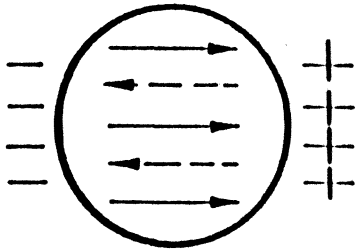
FOR CONTINUOUS MEDIA USE $\vec{H}$, $\vec{M}$

"FLUX DENSITY" $\vec{B} \equiv \mu_0 (H + M) \quad \vec{\nabla} \cdot \vec{B} = 0$

$$\vec{\nabla} \cdot \vec{H} = - \vec{\nabla} \cdot \vec{M} \equiv \rho_M$$

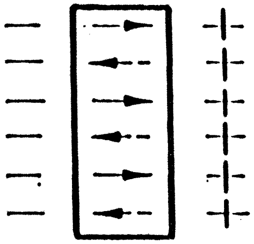
ρ_M AS A "CHARGE DENSITY" IS A CONVENIENT WAY TO DESCRIBE FIELDS FROM ELECTRONS IN A CONTINUUM

SPHERE



$H_D \approx -M/3$

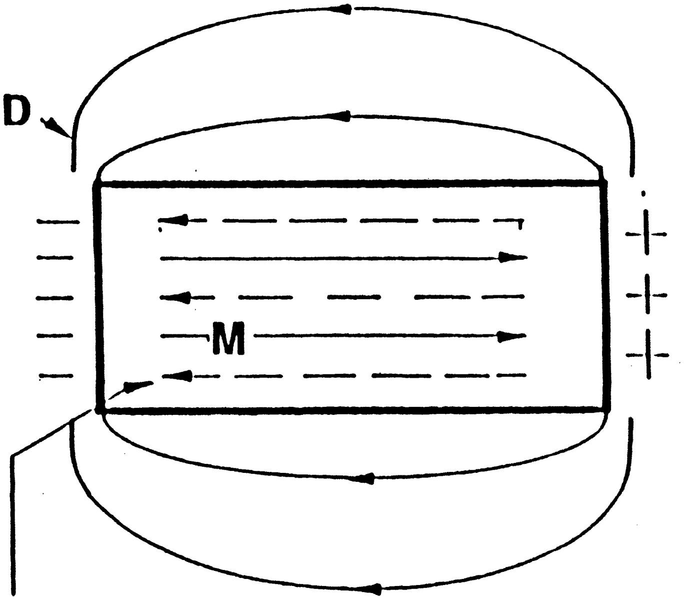
PLATE



$H_D = -\vec{M}$

BAR MAGNET:

FRINGING FIELD

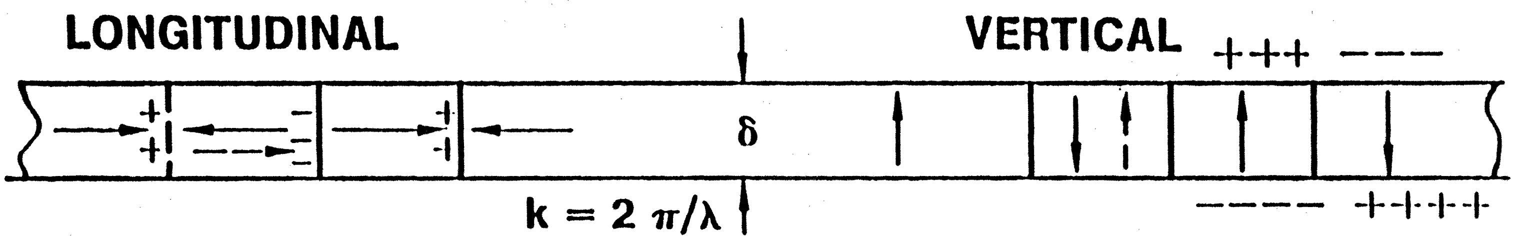


DEMAGNETIZATION FIELD

DEMAGNETIZATION FIELDS (Continued)

$$\vec{H}(\vec{r}) = -\frac{1}{4\pi}\int_{\text{VOLUME}} \frac{\vec{\nabla}'\cdot\vec{M}'\,(\vec{r}-\vec{r}\,')\,d^3r'}{|\vec{r}-\vec{r}\,'|^3} + \frac{1}{4\pi}\int_{\text{SURFACE}} \frac{\vec{n}\,'\cdot\vec{M}'\,(\vec{r}-\vec{r}\,')\,d^2r'}{|\vec{r}-\vec{r}\,'|^3}$$

EXAMPLES OF TAPE PATTERNS



$M = M_o$ SIN kx

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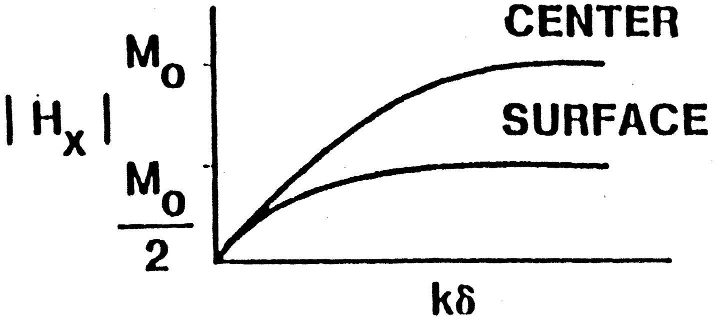
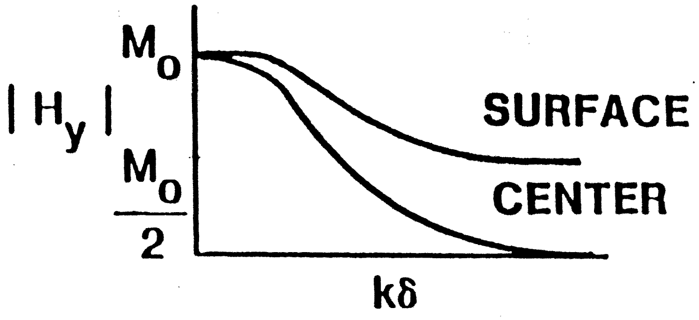
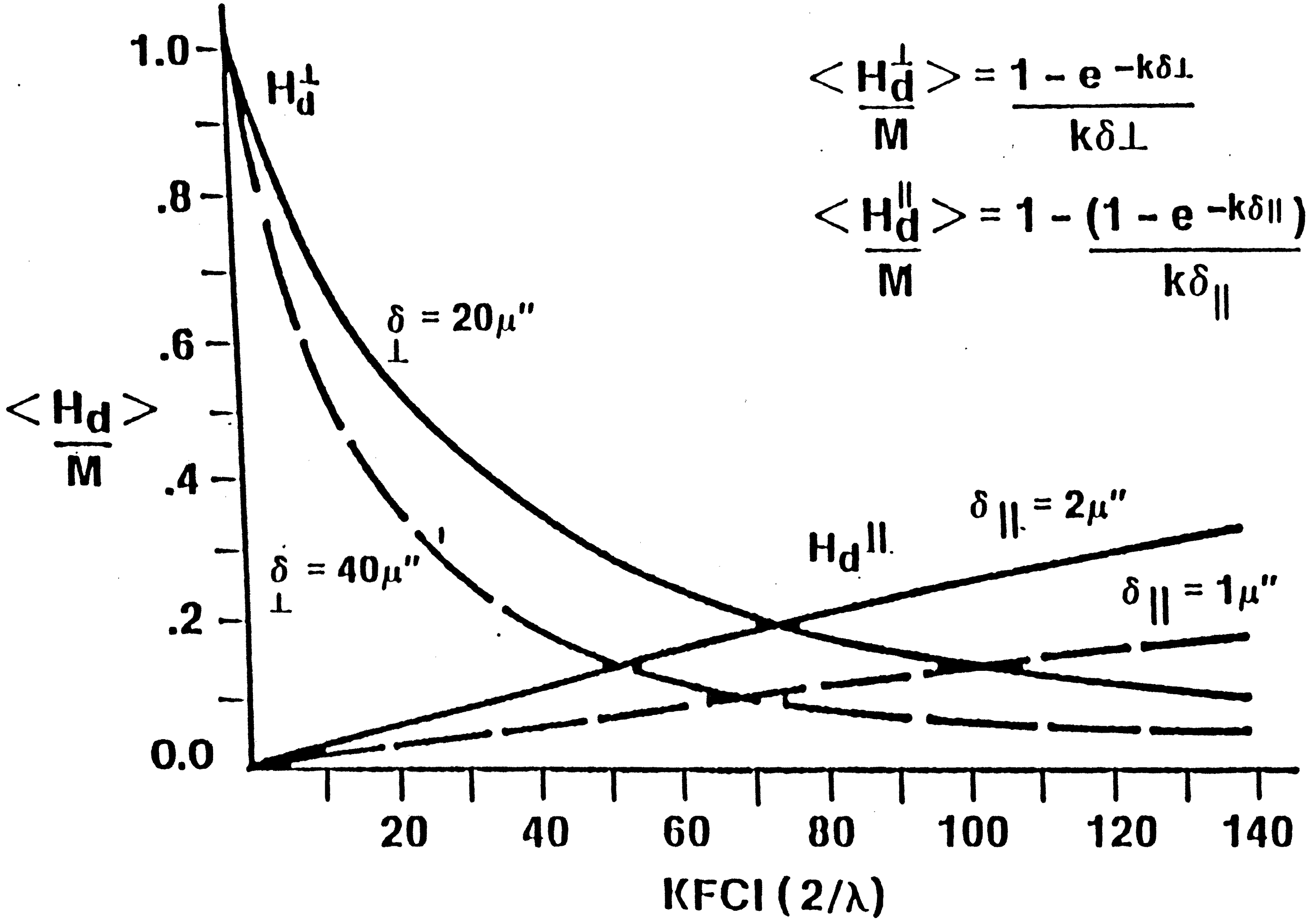




$$H_x^{\text{SURFACE}} = -\frac{M_o}{2}\left(1-e^{-k\delta}\right)\text{SIN}kx$$

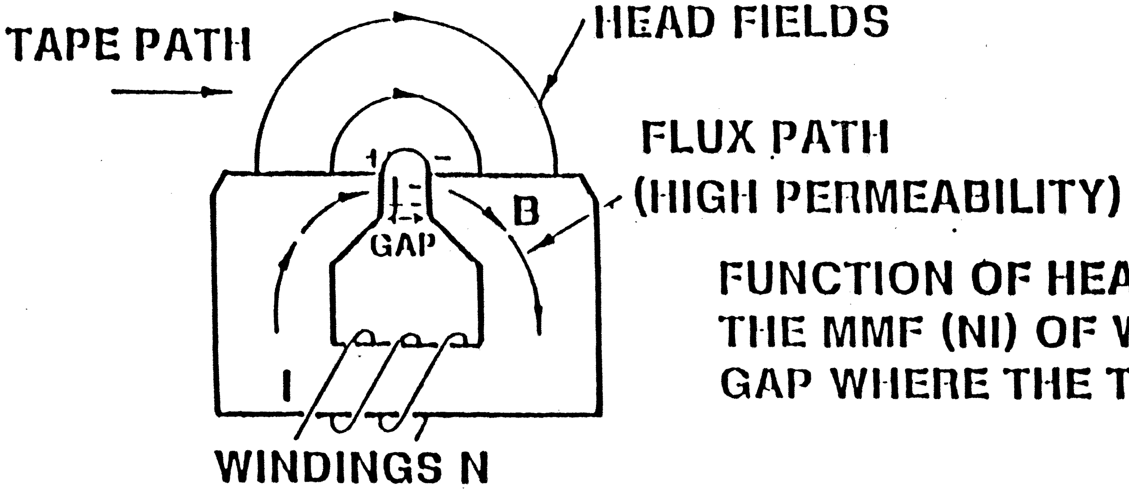
$$H_y^{\text{SURFACE}} = -\frac{M_o}{2}\left(1+e^{-k\delta}\right)\text{SIN }kx$$

AVERAGE DEMAGNETIZATION FIELD



MAGNETIC HEADS

FUNDAMENTAL STRUCTURE



FUNCTION OF HEAD IS TO TRANSLATE THE MMF (NI) OF WINDINGS TO THE GAP WHERE THE TAPE PASSES

SIMPLEST APPROXIMATION (WIRE FIELD)

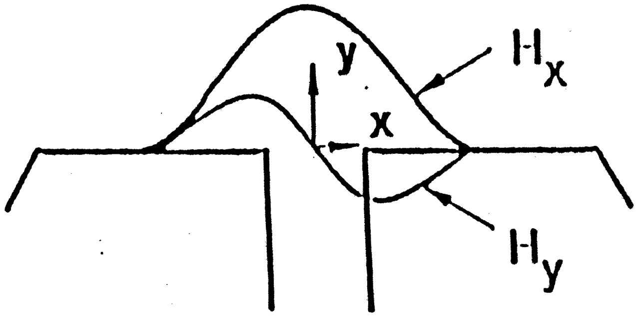
$$\oint H\cdot dl = NI \Rightarrow H = \frac{NI}{\pi r}$$

CONSTANT MAGNITUDE FOR EACH RADII r

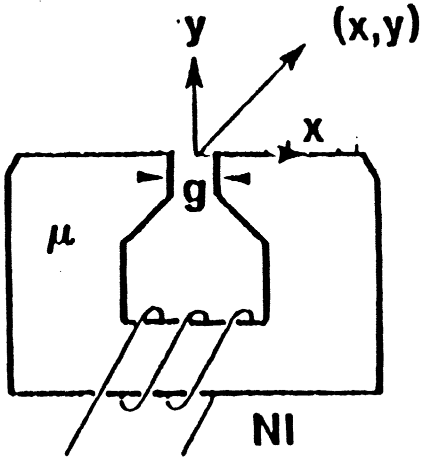
$H_0 \equiv$ DEEP GAP FIELD $\Rightarrow$ $NI = H_0 g$ or $H_0 = \frac{NI}{g}$

$$H_x = \frac{NIy}{\pi\left(x^2+y^2\right)}$$

$$H_y = \frac{-NIx}{\pi\left(x^2+y^2\right)}$$



HEAD FIELD EXPRESSION



I SOLVE POTENTIAL PROBLEM FOR FINITE PERMEABILITY μ

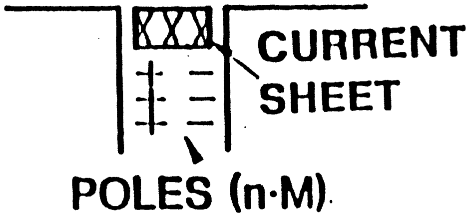
II FOR $\mu \rightarrow \infty$ AWAY FROM WIRES CAN SOLVE:

$$\nabla^2 \phi = 0, \vec{H} = -\vec{\nabla} \phi, \phi_s = \pm \frac{NI}{2}$$

ON OPPOSITE SURFACES

III KARLQUIST APPROXIMATION:
2 DIMENSIONAL, NO END AFFECTS, GIVES FIELD ABOVE HEAD TWO WAYS:

1) SOURCE SHEET OF CURRENT WIDTH g
2) UNIFORM POLES ON GAP FACE



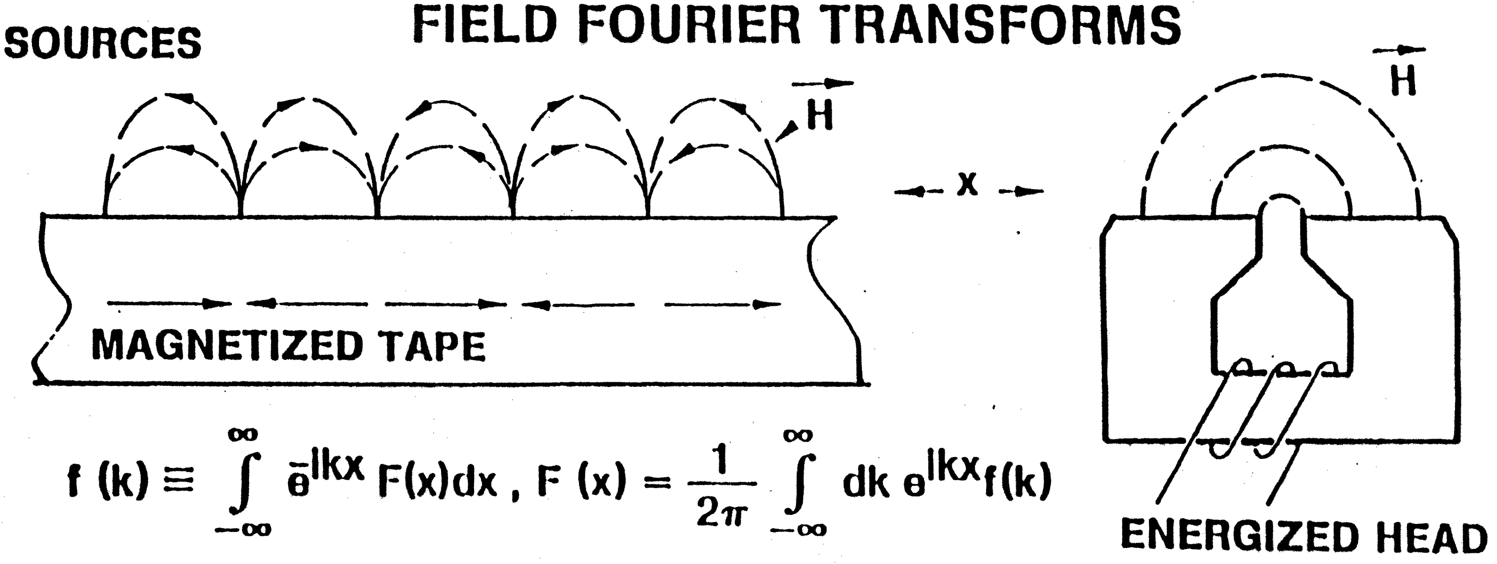
RESULT

$$H_x = \frac{H_o}{\pi} \left\{ \tan^{-1} \frac{g/2+x}{y} + \tan^{-1} \frac{g/2-x}{y} \right\}$$

$$H_y = \frac{H_o}{2\pi} \ln \frac{(g/2-x)^2+y^2}{(g/2+x)^2+y^2}$$

$$H_o = \frac{NI\epsilon}{g} \quad \epsilon \equiv \text{EFFICIENCY}$$

FIELD FOURIER TRANSFORMS



$$f(k) \equiv \int_{-\infty}^{\infty} e^{-ikx} F(x)dx \text{ , } F(x) = \frac{1}{2\pi} \int_{-\infty}^{\infty} dk \, e^{ikx} f(k)$$

IN TWO DIMENSIONS:

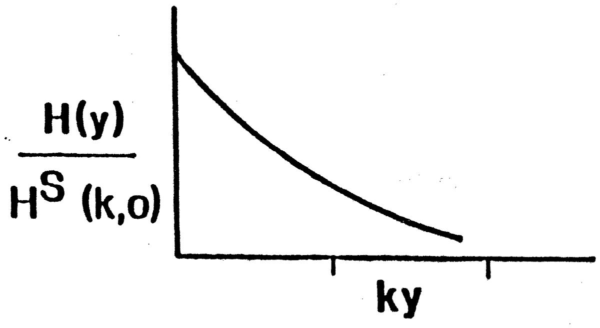
$$\nabla^2\phi = \frac{\partial^2}{\partial x^2}\phi + \frac{\partial^2}{\partial y^2}\phi = 0$$

TRANSFORMING

$$-k^2\phi(k,y) + \frac{\partial^2\phi}{\partial y^2}(k,y) = 0$$

$$\phi(k,y) = \phi(k,o)e^{-ky}$$

$$H_{x,y}(k,y) = H^S_{x,y}(k,o)e^{-ky}$$

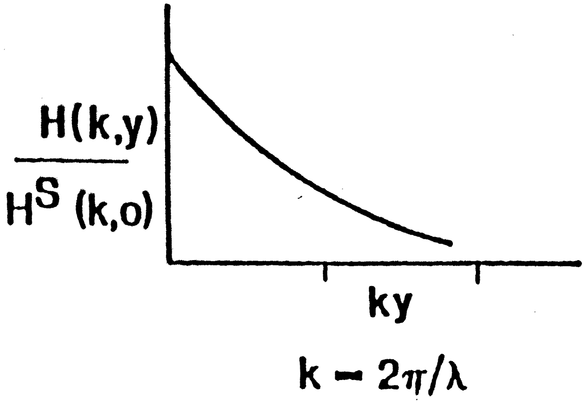


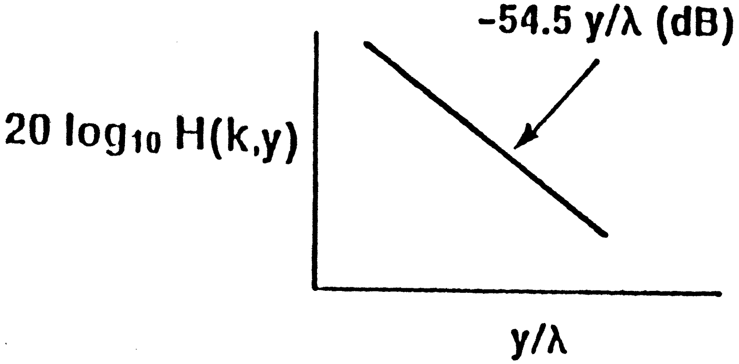
$k = 2\pi/\lambda$

"SEE" EFFECTS TO $y \approx \lambda/3$

SPACING LOSS

- Applies to 2D fields with no permeable media (keeper or recording medium) above source
- Applies to harmonic analysis only
- Linear on a log-linear plot

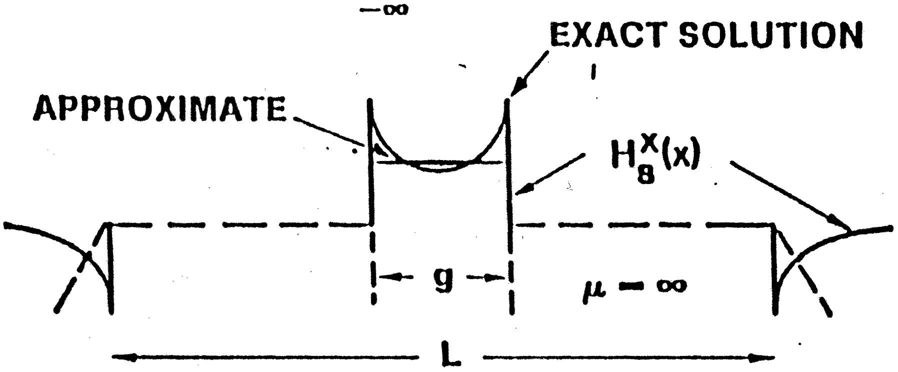




HEAD SURFACE EFFECTS

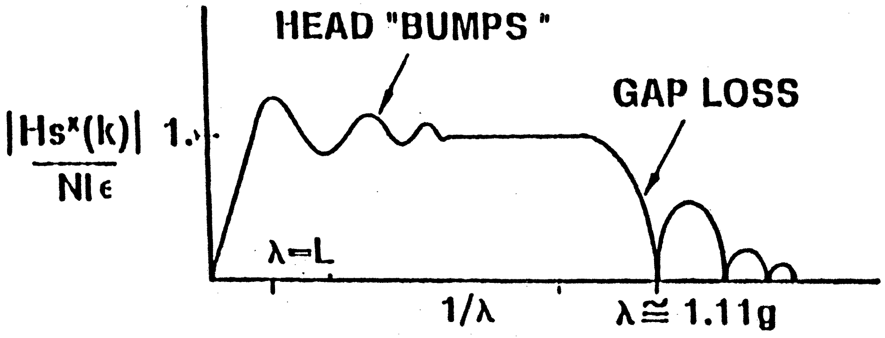
CAN SHOW (2D) $H_s^y(k) = iH_s^x(k)$ (ONLY A 90° ROTATION)

$$H_s^x(k) = \int_{-\infty}^{\infty} e^{-ikx} H_s^x(x)dx$$



$$\Rightarrow \frac{H_s^x(k)}{NI} \cong \frac{\sin 1.11\, kg/2}{1.11kg/2} \cdot \text{EDGE EFFECTS } (KL)$$

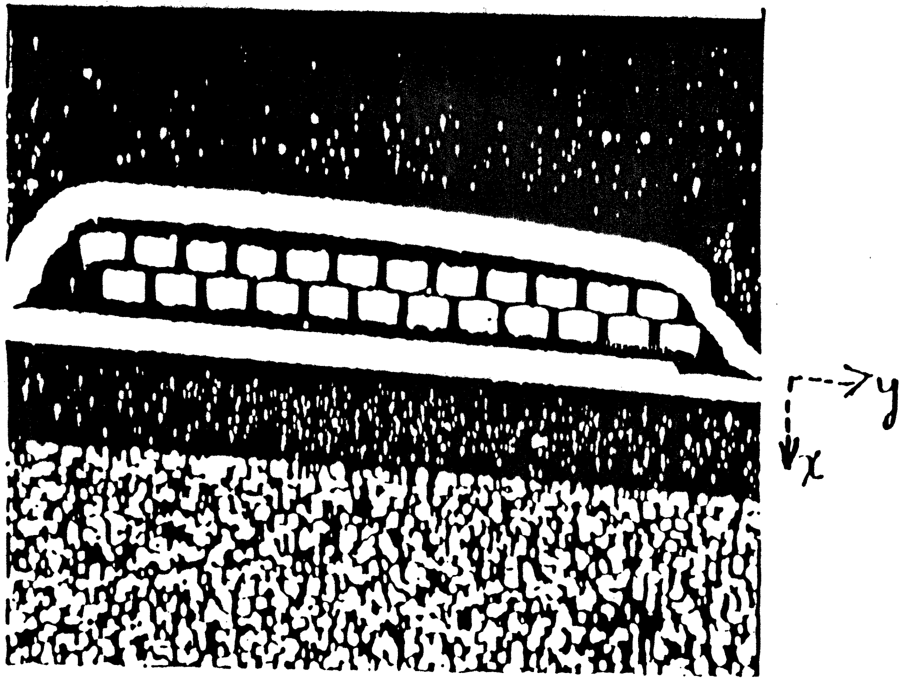
$H_s^x(k) \to 0$ AS $k \to 0$ SINCE $\int_{-\infty}^{\infty} H_s^x(x)dx = 0$



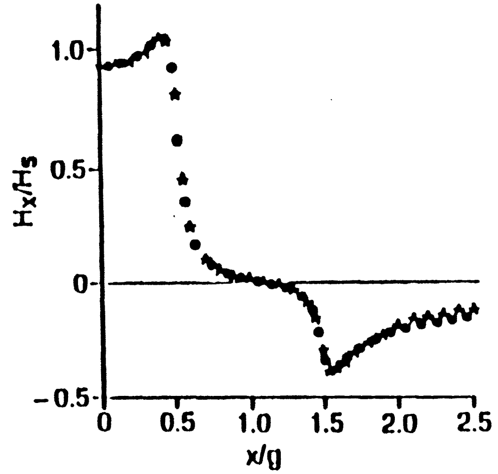
THIN FILM HEAD RESPONSE

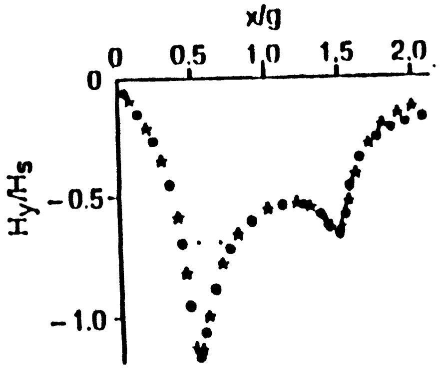
CROSS-SECTION OF A COMMERCIAL
THIN FILM INDUCTIVE HEAD

(COMPLIMENTS OF THE READ-RITE CORP.)



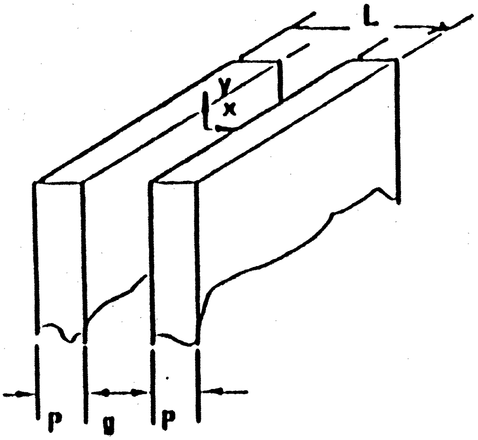
FIELD SKETCH
(SZCZECH)





THIN FILM HEAD TRANSFORM at surface

SYMMETRIC HEAD

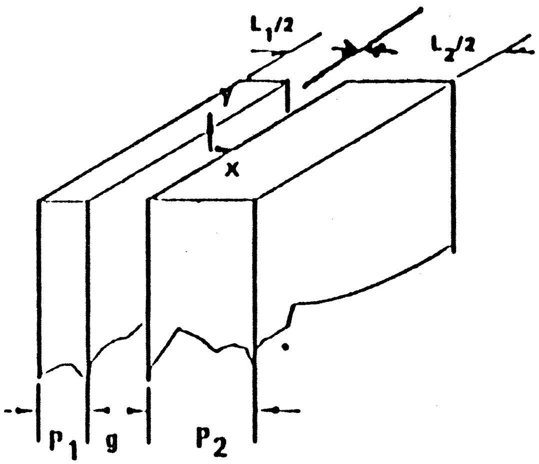


$$h\left(\frac{1}{\lambda}\right) \cong \frac{\sin 1.11\pi\frac{g}{\lambda}}{1.11\pi\frac{g}{\lambda}} - \frac{.205\cos\pi\left(\frac{L}{\lambda}+\frac{1}{3}\right)}{\left(\frac{L}{\lambda}\right)^{\frac{2}{3}}}$$

frequency response

also: Lindholm

ASYMMETRIC HEAD



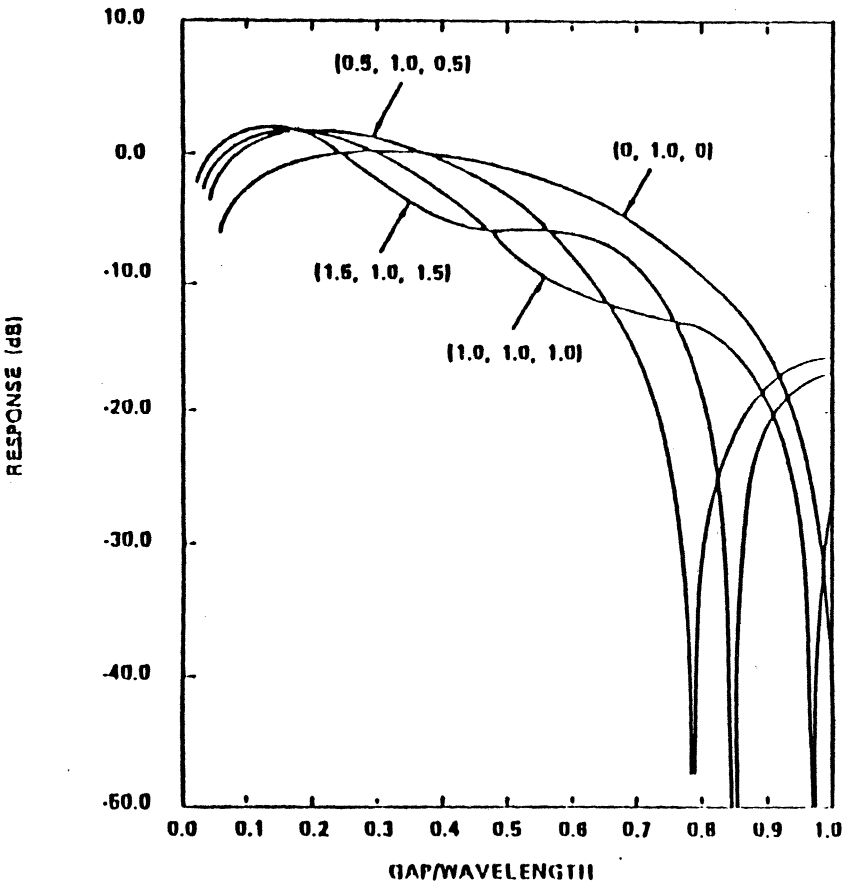
$$h\left(\frac{1}{\lambda}\right) = \frac{\sin 1.11\pi\frac{g}{\lambda}}{1.11\pi\frac{g}{\lambda}} - .1025\left\{\frac{\cos\pi\left(\frac{L_1}{\lambda}+\frac{1}{3}\right)}{\left(\frac{L_1}{\lambda}\right)^{\frac{2}{3}}}\right.$$

$$\left. + \frac{\cos\pi\left(\frac{L_2}{\lambda}+\frac{1}{3}\right)}{\left(\frac{L_2}{\lambda}\right)^{\frac{2}{3}}} + i\left[\frac{\sin\pi\left(\frac{L_1}{\lambda}+\frac{1}{3}\right)}{\left(\frac{L_1}{\lambda}\right)^{\frac{2}{3}}} - \frac{\sin\pi\left(\frac{L_2}{\lambda}+\frac{1}{3}\right)}{\left(\frac{L_2}{\lambda}\right)^{\frac{2}{3}}}\right]\right\}$$

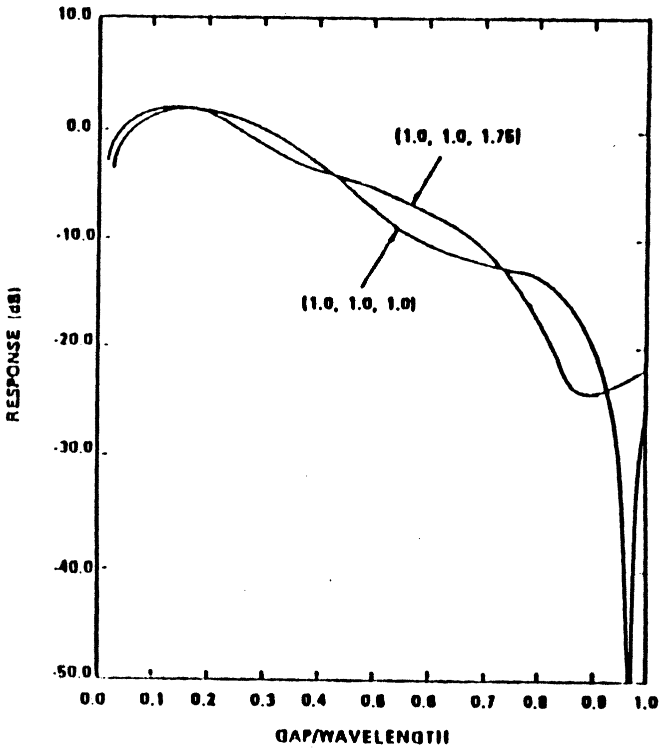
T F H RESPONSE EXAMPLES

SYMMETRIC

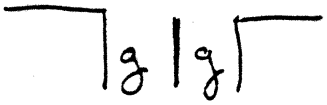
(p_1, g, p_2)



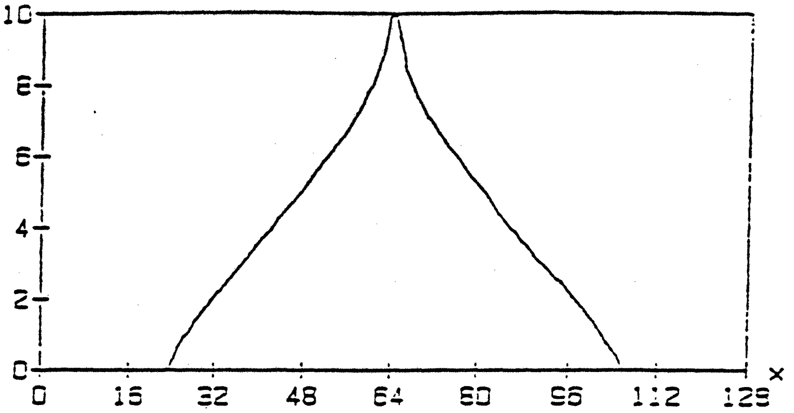
ASYMMETRIC



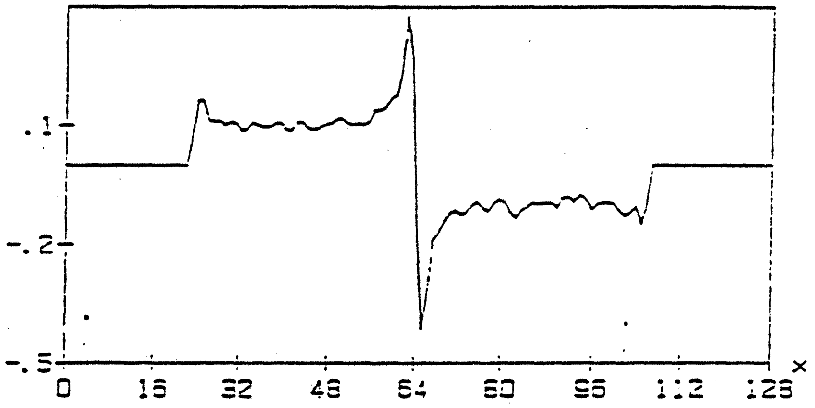
MR RESPONSE



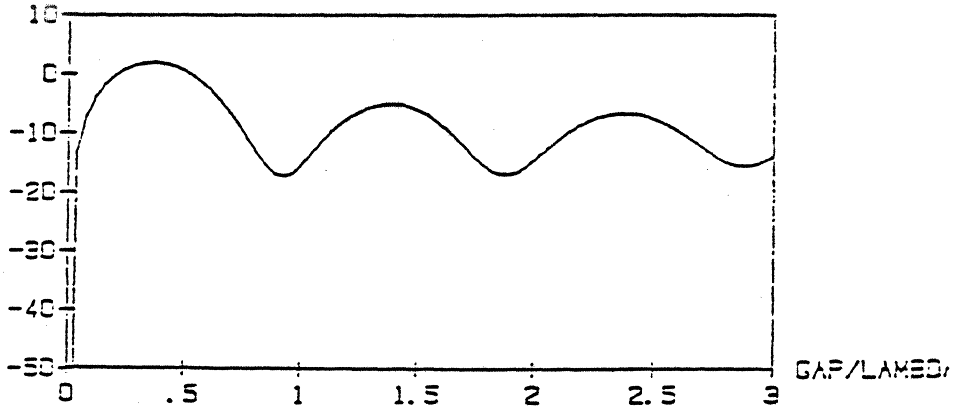
MR Wide Gap "Voltage"



MR Wide Gap "Field Plot"



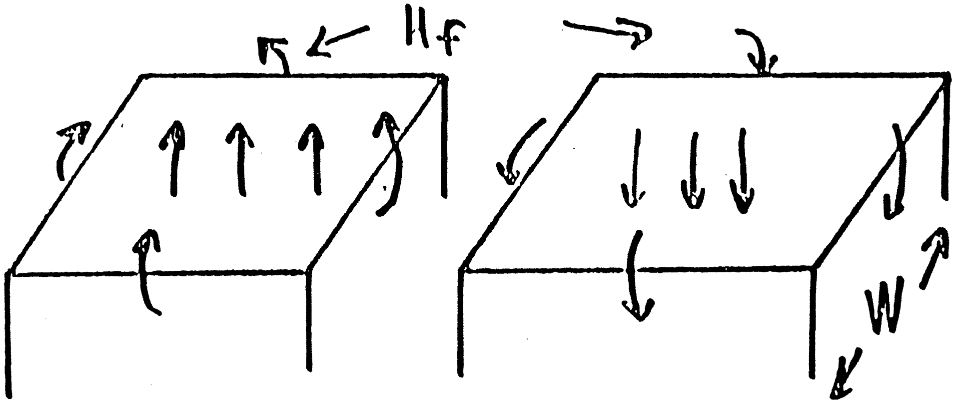
MR Wide Gap "FFT"



REPRODUCE FLUX DEFINED

ϕ_s = flux entering head at surface

H_f = field from medium at head surface



$$\phi_s \cong \iint_{\text{area at top surface}} da\, B_{normal} = \mu_0 W \int H_f\, dx$$

Total flux ϕ is that through windings or that entering all surfaces (net flow!)

$H_o = NI\,\varepsilon/g$

$\phi_{rep} = \mathcal{E}\,d_s$

REPRODUCE PROCESS

(GENERAL)

$$V^{OUT} = -N\frac{d\phi}{dt}$$

RELATIVE HEAD TAPE MOTION SPEED

$$v = \frac{dx}{dt}$$

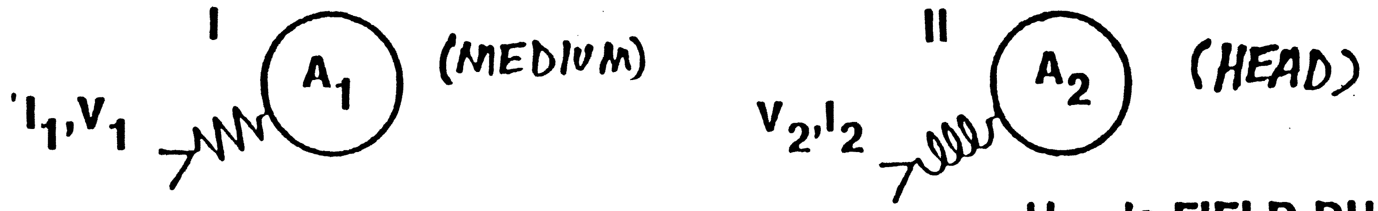
$$\Rightarrow\ V = -Nv\frac{d\phi}{dx}$$

or

$$\boxed{V = -N\,\varepsilon\,v\,W\,\frac{d\phi}{dx}\ \begin{array}{l}\text{surface}\\ \text{per track width}\end{array}}$$

RECIPROCITY

EQUIVALENCE OF MUTUAL INDUCTANCE FOR TWO SOURCES



FOR CURRENT IN I (I_1) $\quad \phi_2 = \int_{A_2} da \cdot H_{21}$ $\quad H_{21}$ Is FIELD DUE TO I_1 EVALUATED AT A_2

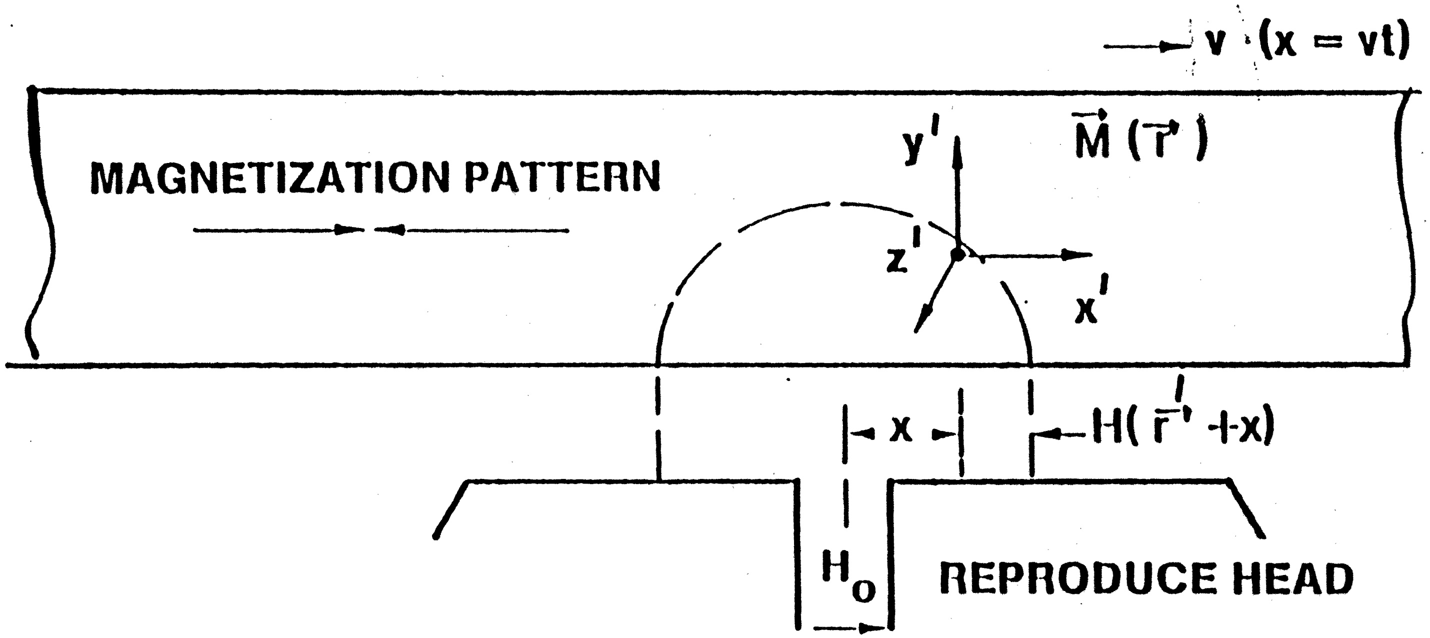
FOR CURRENT IN II (I_2) $\quad \phi_1 = \int_{A_1} da \cdot H_{12}$ $\quad$ CONVERSE FOR H_{12}

$$\frac{\phi_2}{I_1} = \frac{\phi_1}{I_2} \Rightarrow \phi_2 = \frac{\phi_1 I_1}{I_2} = \int_{A_1} \frac{da I_1 \cdot H_{12}}{I_2}$$

I CAN BE MAGNETIZED TAPE SINCE CURRENT LOOPS CAN BE EQUIVALENT (EXTERNALLY) TO MAGNETIC DIPOLES

II CAN BE REPRODUCE HEAD

RECIPROCITY (cont.)



REPRODUCE FLUX EXPRESSED AS:

$$\phi(x) = \mu_0 \iiint_{\text{TAPE}} \vec{M}(\vec{r}') \cdot \vec{H}(\vec{r}' + x) d^3r'$$

1) H IS EVALUATED WITH UNIT NI APPLIED TO HEAD
2) RECIPROCITY IS A CORRELATION OF M & H
3) PROCESS MUST BE LINEAR

RECIPROCITY WITH PERMEABLE MEDIA

How is the head field $\vec{H}\ (\vec{r})$ defined?

What constitutes the medium $\vec{M}\ (\vec{r})$?
(Wessel-Berg-Bertram, Smith)

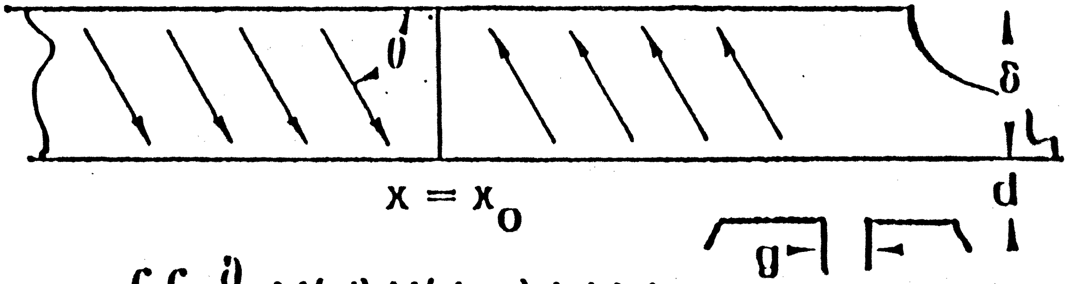
SEVERAL POSSIBILITIES!

1. Head is due to wires only and "medium" is all magnetization:"
   medium, head, keeper, etc.

2. Head is due to wires and all reversible magnetizations: head core,
   keeper, reversible M in medium
   "medium" is remanent magnetization only (preferred-easier)

Be careful!

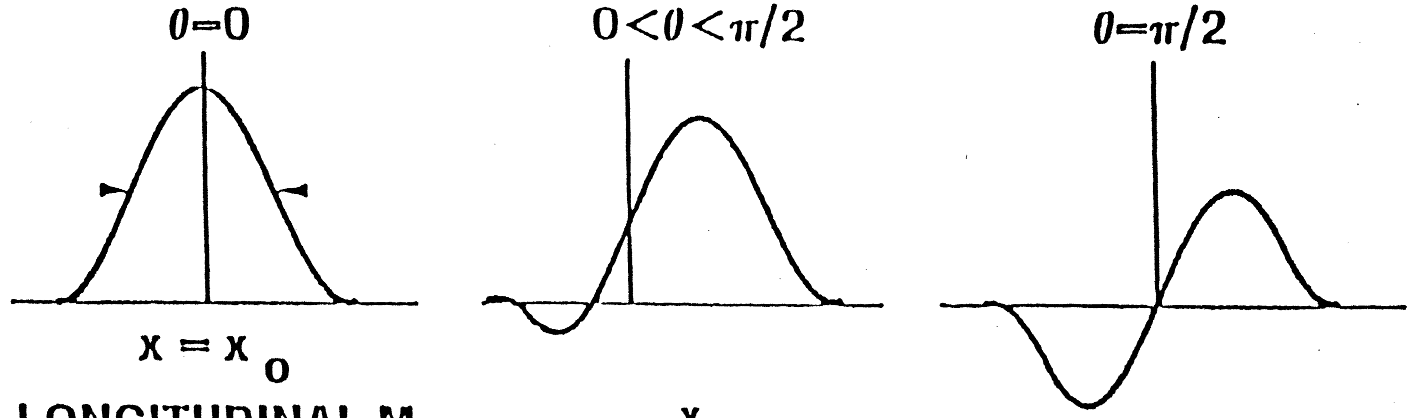
REPRODUCTION OF SINGLE PERFECT TRANSITION



$$\frac{V}{N\epsilon W v} = \mu_0 \iint \frac{\partial}{\partial x'} M(x') \cdot H(r'+x)\, dx' dy'$$

FOR THIN MEDIA

$$\frac{V(x)}{vN\epsilon W} = 2\mu_0 M_0 \delta \left\{ H_x(x_0+x, d+\delta/2)\cos\theta - H_y(x_0+x, d+\delta/2)\sin\theta \right\}$$



LONGITUDINAL M

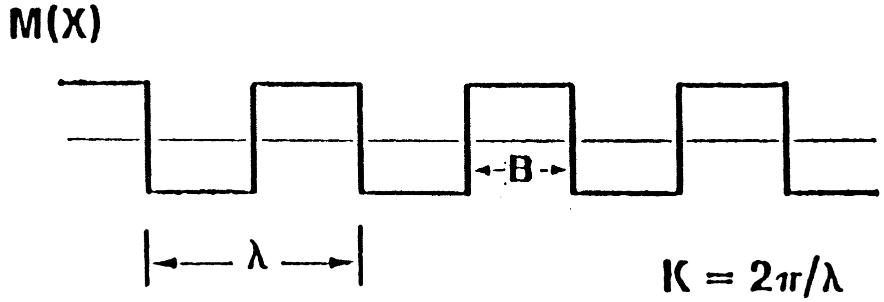
INTERMEDIATE

VERTICAL M

$$PW_{50} = \sqrt{g^2 + 4d(d+\delta)}$$

SPECTRAL RESPONSE

SQUARE WAVE RECORDED



$K = 2\pi/\lambda$

RMS FUNDAMENTAL VOLTAGE

$$V^{rms} = .707 \frac{2}{\pi} K \quad V^{pulse}(K)$$

$$\frac{V^{pulse}(k)}{NW\epsilon v} = \mu_0 \int_{d}^{d+\delta} dy'\, kM_k(y')\cdot H_s(k) e^{-ky'}$$

$$\frac{V^{rms}}{NW\epsilon v} = .707 \times \frac{4}{\pi} \times \mu_0 M_0\, K\delta \quad \frac{\left(1-e^{-k\delta}\right)}{k\delta}\, e^{-kd}\, \frac{\sin 1.11kg/2}{1.11kg/2}$$

MAGNETIZATION LEVEL

HEAD DIFFERENTIATION

THICKNESS LOSS

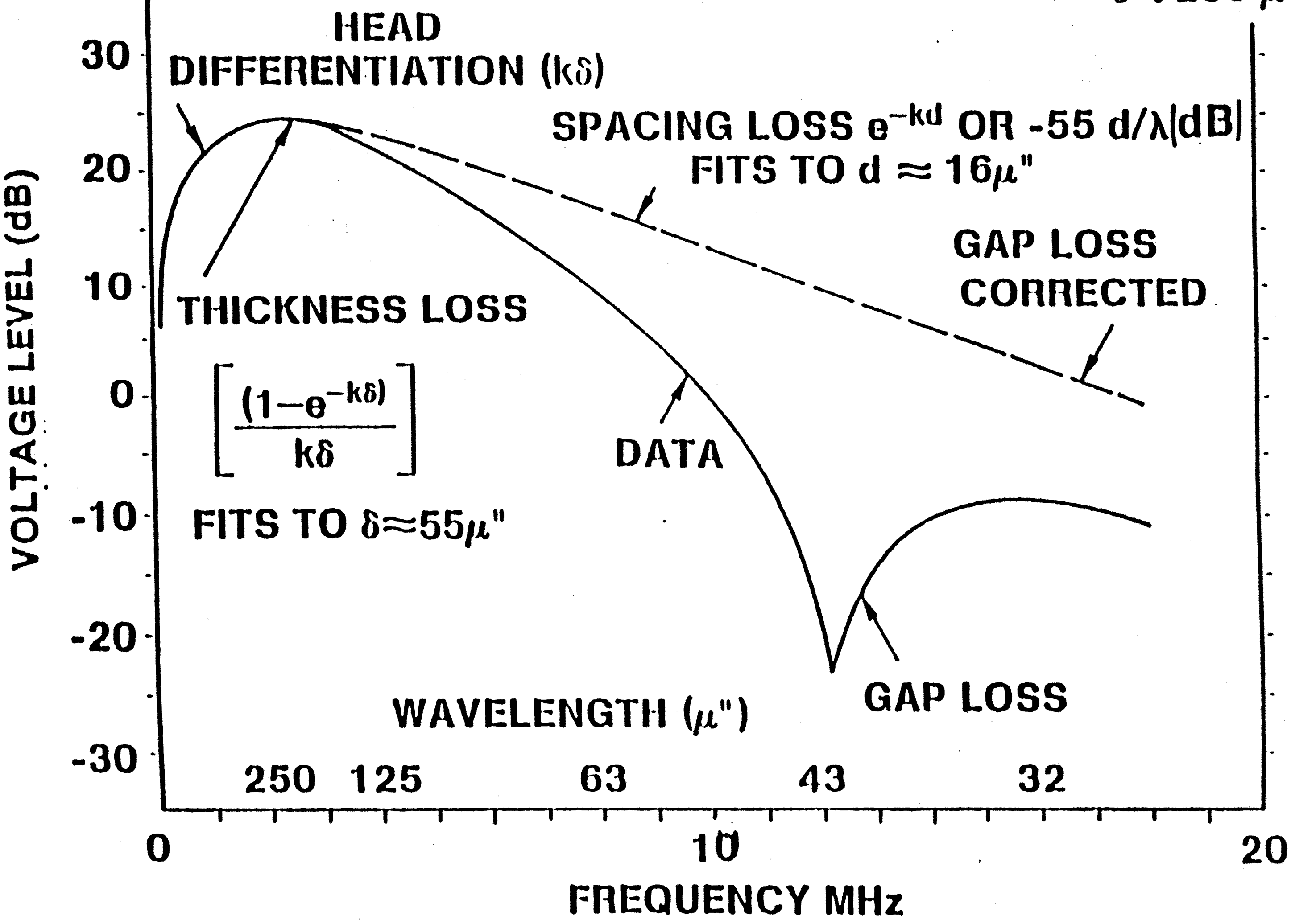
SPACING LOSS

GAP LOSS

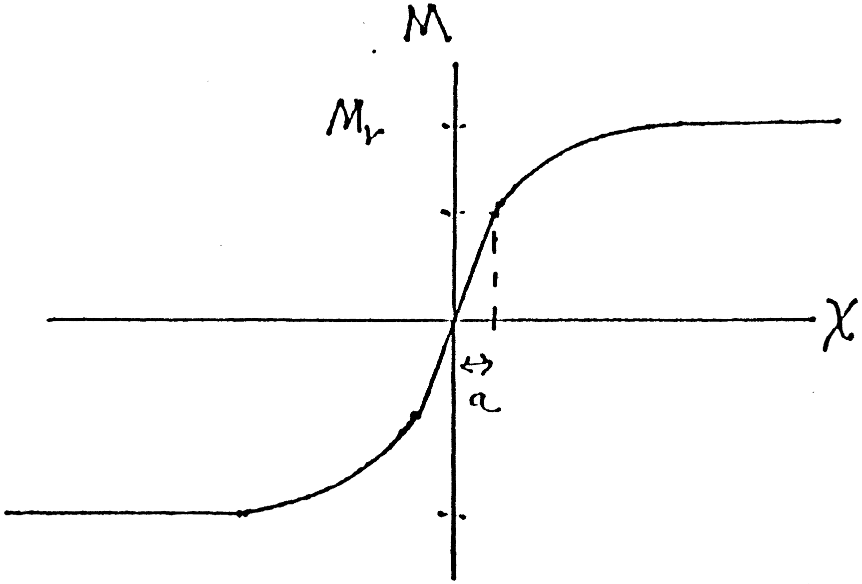
EXPERIMENTAL SPECTRAL CURVE

v = 500 IPS
OPTIMIZATION @
60 μ" WAVELENGTH

TAPE: M_r ~ 1200 G
H_c ~ 700 Oe
δ ~ 200 μ"



FINITE TRANSITION LENGTH



ARCTANGENT

$$M(x) = \frac{2M_r}{\pi} \tan^{-1} \frac{x}{a}$$

$$\tilde{M}(k) = \frac{2i\, M_r\, e^{-ka}}{k}$$

$$e^{-kd}\ e^{-ka} = e^{-k(a+d)}$$

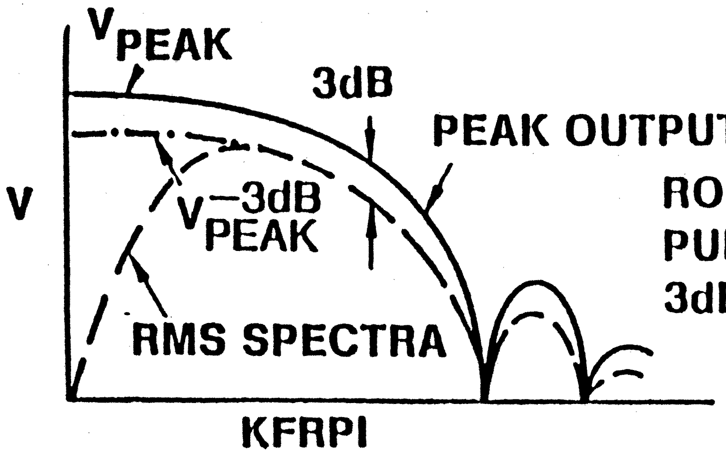
$$\Rightarrow \quad d \quad \rightarrow \quad d + a = d_{eff}$$

$$PW_{50}^{\text{Long.}} = \sqrt{g^2 + 4(d+a)(d+a+\delta)}$$

Note: If arctangent is not a good fit (e.g., erf (x)

$\Rightarrow$ no simple effecive spacing !

"ROLL-OFF" CURVE



ROLL-OFF CURVE JOINS SPECTRA WHEN PULSES BEGIN TO OVERLAP (EXCEPT FOR 3dB PEAK TO RMS SHIFT)

D_{50} IS DEFINED BY DENSITY WHERE PEAK OUTPUT DROPS 50%

SIMPLE FORM: FROM PULSE EQUATIONS FOR THIN MEDIA ($\alpha = 0$)

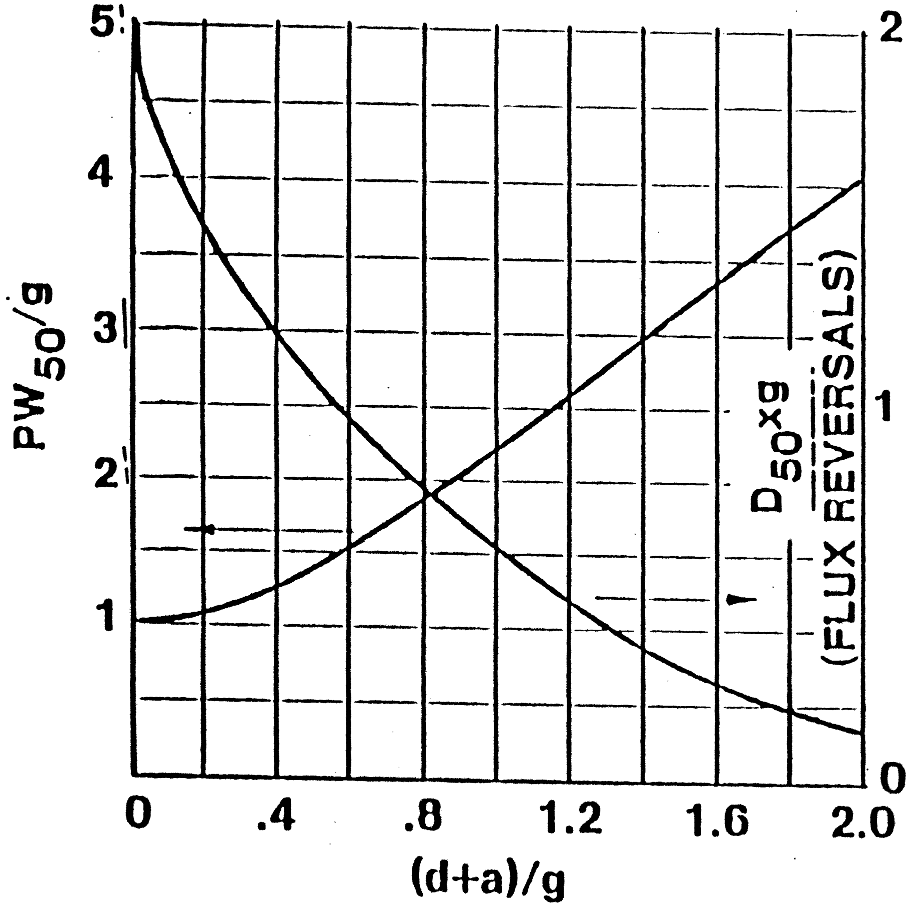
$$V_{PEAK} \cong \frac{4\delta}{\pi g} M_o \tan^{-1} \frac{g}{2(d+a)}$$

$$V_{rms} \sim \frac{1}{\sqrt{2}} \frac{4}{\pi} M_o k\delta e^{-k(d+a)} \frac{\sin kg/2}{kg/2}$$

D_{50} OCCURS FOR THAT k WHERE

$$\frac{V_{peak}}{\sqrt{2}} = 2V_{rms}$$

APPROXIMATE D_{50} CURVE



EXAMPLES g = 27 μ"
d = 10 μ"

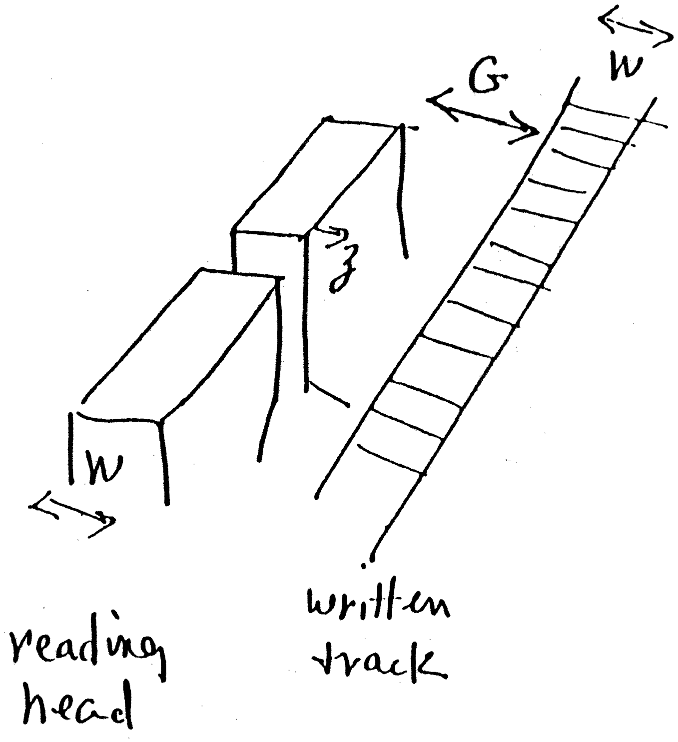
DISK	PW_{50}	D_{50}
H_c 450 Oe δ 3 μ" M_r 10,000G a_{th} 22 μ"	67.5 μ"	20 KFRPI
H_c 900 Oe δ 1.1 μ" M_r 10,000 G a_{th} 5 μ"	40.5 μ"	35 KFRPI

APPLIES TO LONGITUDINAL RECORDING

D_{50}xg IS FLUX REVERSALS PER INCH TIMES INCH

OR FLUX REVERSALS PER METER TIMES METER

SIDE READING



W = track width

G = Guard band

(LINDHOLM, Ichiyama)

$$H(k,z) \approx \frac{1}{2} e^{-kz}$$

For G not too small!

$$\phi_{SR} \propto \frac{1}{2} \int_{G}^{G+W} e^{-kz} \, dz$$

$$\phi_{OT} \propto W$$

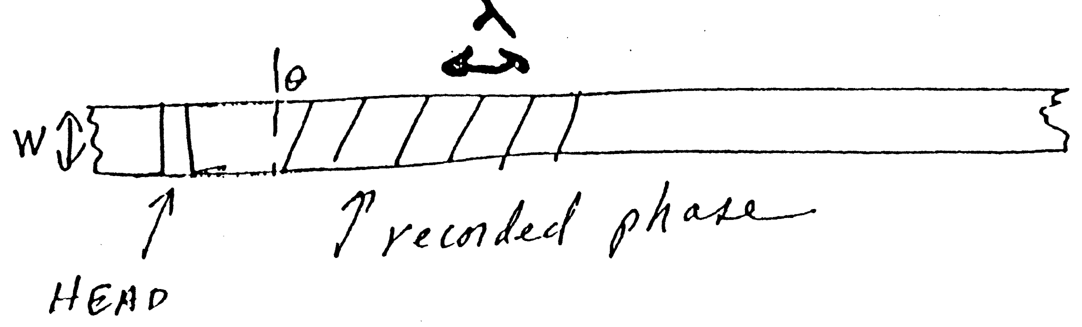
$\Rightarrow$ WORST CASE SIDE READING SPECTRAL RESPONSE

$$SRR = e^{-kG} \frac{\left(1-e^{-kW}\right)}{kW}$$

$\Rightarrow$ A LONG WAVELENGTH PHENOMENON

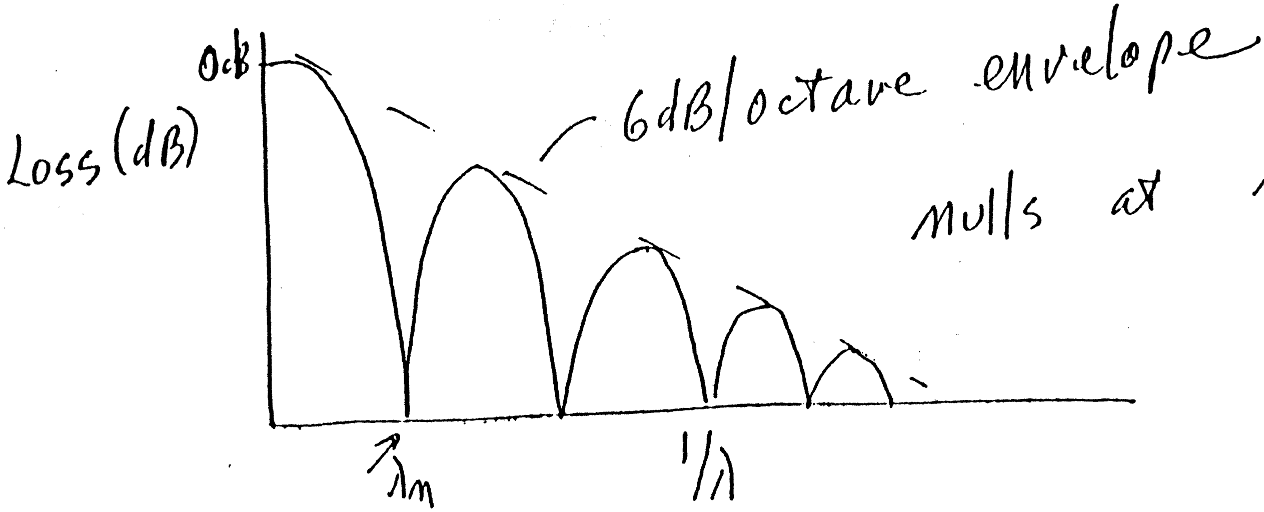
AZIMUTH LOSS

HEAD ANGLED WITH RESPECT TO TRACK PHASE



(DAT-OHTAKE)

$$\text{LOSS} = \frac{\sin(\pi W \tan\theta / \lambda)}{(\pi W \tan\theta / \lambda)}$$



6dB/octave envelope

nulls at $\lambda_n = \frac{W \tan\theta}{n}$

$n = 1, 2, 3, 4, 5 \ldots$

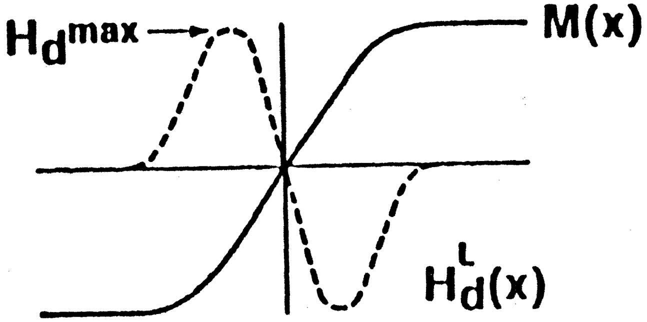
RECORD PROCESS

ULTIMATE DEMAGNETIZATION LIMIT

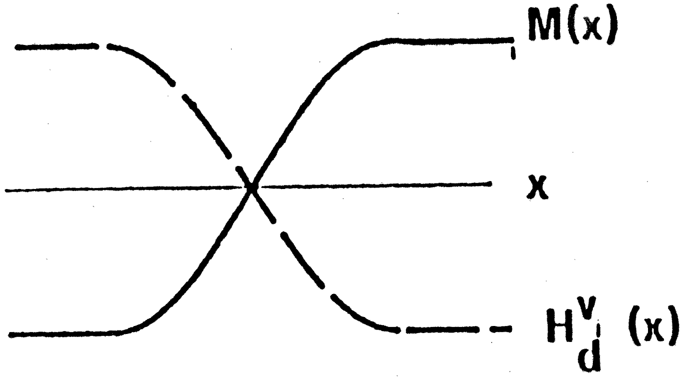
$$H_{demag} \leq H_c$$

ISOLATED TRANSITION

LONGITUDINAL



VERTICAL



OVERLAPPING TRANSITIONS (SINEWAVE):

H_d (SURFACE) $= M/2 \leq H_c$ (BOTH L & V)

RECORD PROCESS DOES NOT PERMIT THIS
LIMIT TO OCCUR!!

DEMAGNETIZATION LIMIT – LONGITUDINAL

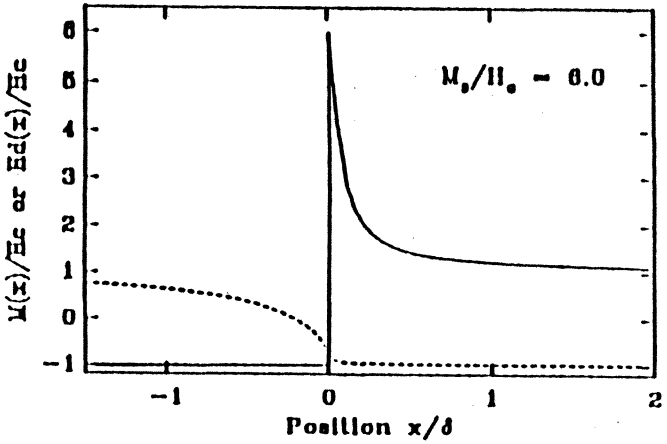
- contact $d/g \sim 0$
- isolated pulse
  linear superposition
- arctangent demagnetization

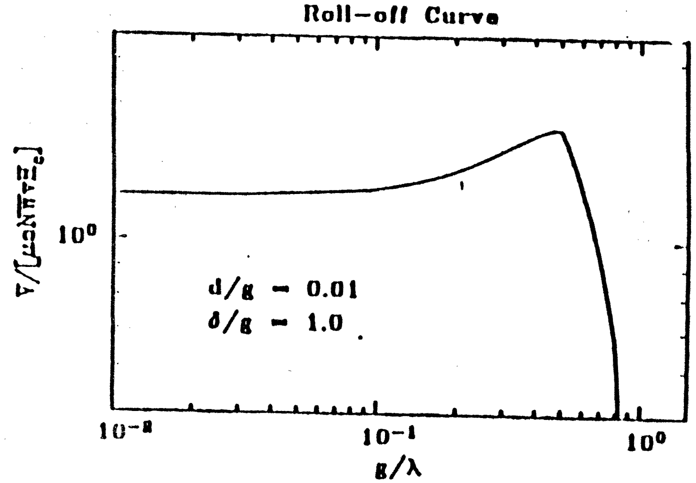
  $a_{min} \sim 4\pi M_r \delta / 2\pi H_c$
- $\delta = 2\mu''$, $4\pi M = 10{,}000\ G$, $H_c = 1000$
- $V^{peak} \simeq \frac{4}{\pi} N W \varepsilon v \mu_0 M\delta/g \tan^{-1} \frac{g}{2a_{min}}$

g		V^{peak} (mV/mil-ips-turn·eff)	D_{50}
g	$10\mu''$	44 dB	FCI 125 KBPI
	$30\mu''$	37 dB	FCI 57 KBPI

DEMAGNETIZATION LIMIT – PERPENDICULAR

- CONTACT $d/g \sim 0.0$
- $\delta/g \sim 1$
- Isolated pulse linear superposition





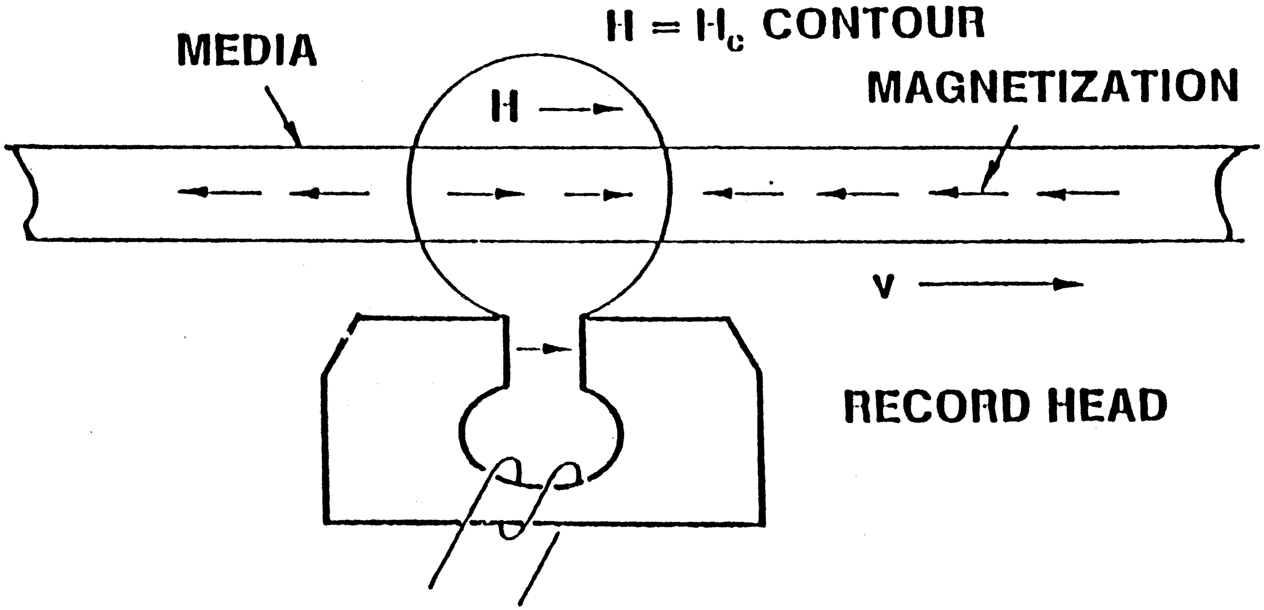
$\delta = g$, $H_c = 1000$ Oe

V peak (mvolts/mil-ips-Turn-pff) = 30 dB

D_{50} ($g = 10\mu''$) ~ 140 KFCI

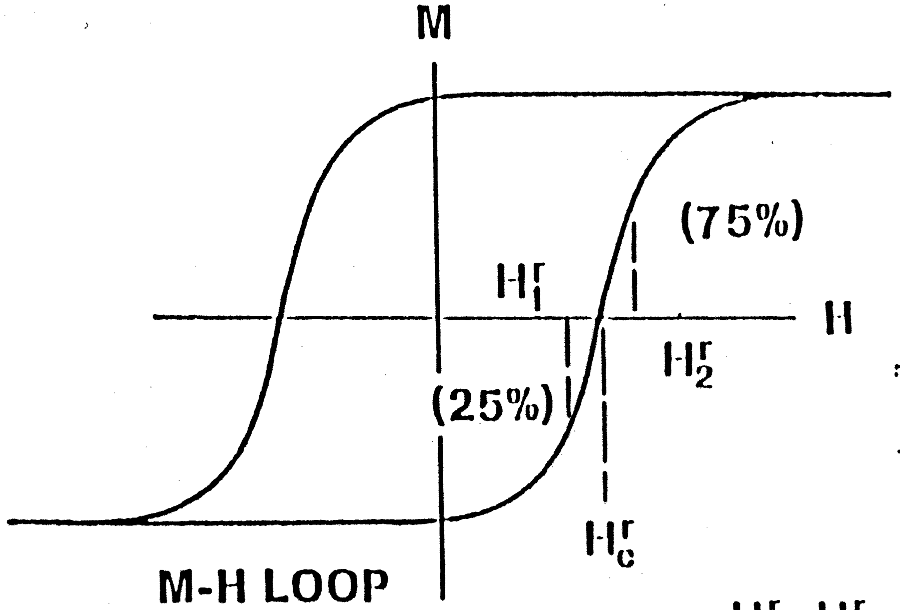
- should do probe-keeper!!

BASIC RECORDING CONCEPTS



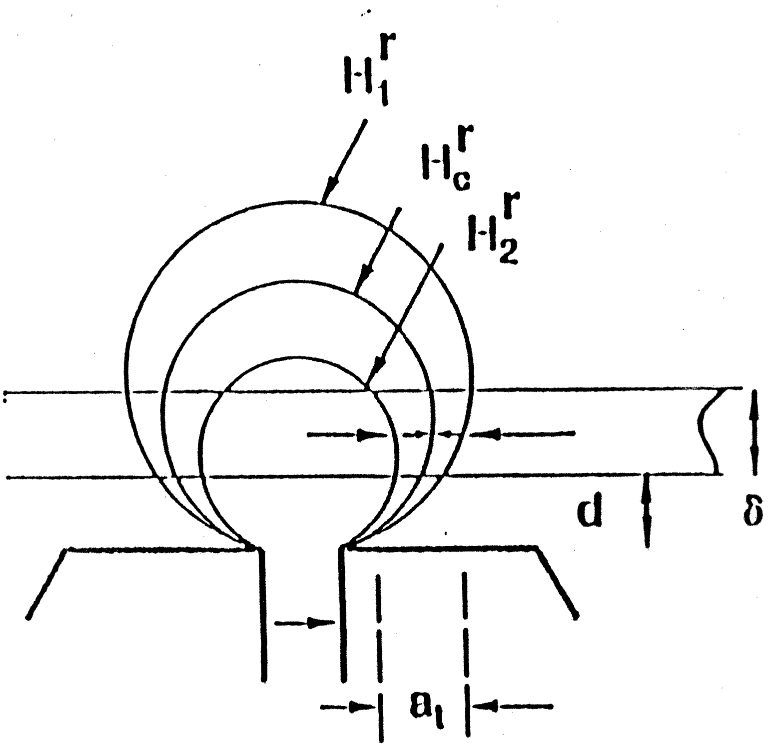
BUT REVERSAL LENGTH IS NOT ZERO!

BASIC RECORDING CONCEPTS (Continued)



M-H LOOP

$$SFD \equiv \frac{H_2^r - H_1^r}{H_c^r}$$



$a_t \equiv$ TRANSITION WIDTH

SHORT WAVELENGTH VOLTAGE: $V \propto \delta e^{\frac{-2\pi(a_t+d)}{\lambda}}$

a_t DECREASED IF -

1) SFD DECREASES
2) HEAD GRADIENT SHARPENS ($d \to 0$)
3) DEMAGNETIZATION IS REDUCED

ROLE OF DEMAGNETIZATION FIELDS

1) Hd REDUCES NET FIELD GRADIENT (dH/dx) AT TRANSITION POINT x_o AND THEREBY BROADENS THE TRANSITION(dM/dx).

2) Hd IS ZERO AT TRANSITION CENTER AND (TO FIRST ORDER) DOES NOT MOVE THE TRANSITION.

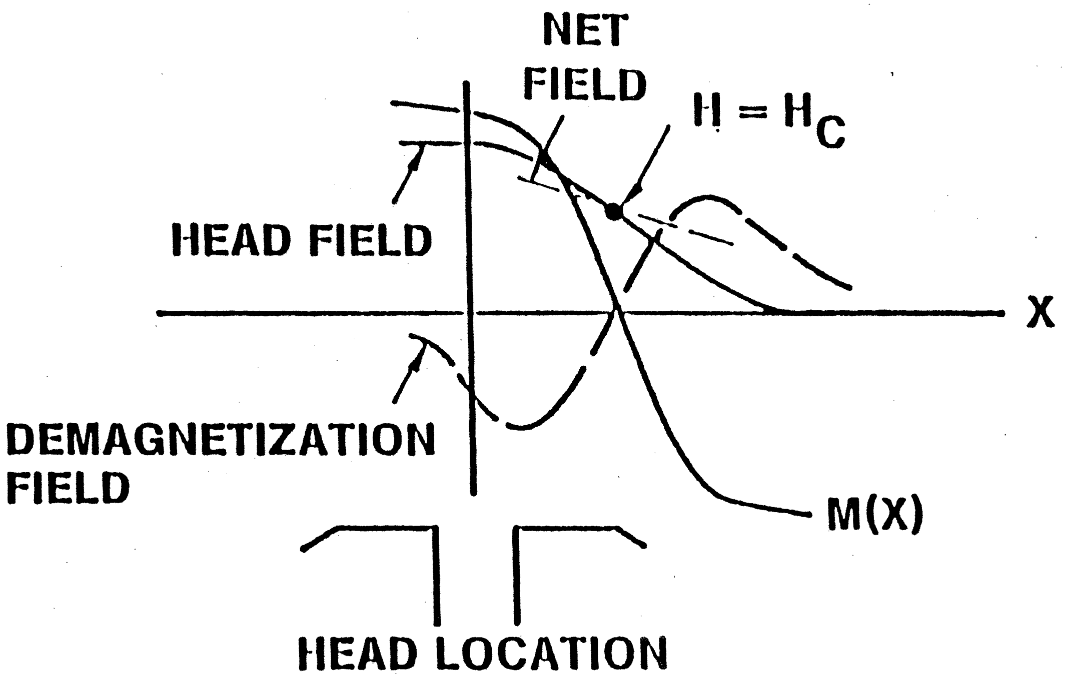
TECHNIQUES TO SOLVE NON LINEAR M(x) PROBLEM:

1) FULL ITERATIVE CALCULATION AT EACH TIME INSTANT $H_h \rightarrow M \rightarrow Hd \rightarrow H_{TOTAL} \rightarrow M_{NEW} - Hd^{NEW} \rightarrow \ldots$ UNTIL CONVERGENCE

2) ASSUME SHAPE OF TRANSITION WITH A FEW UNKNOWN PARAMETERS AND SOLVE USING A SIMPLE CRITERION

ARCTANGENT MODEL:

$$M(x) = \frac{2}{\pi} M_r \tan^{-1} x/a_t \Longleftrightarrow M_k(k) = 2IM_r e^{-ka_t}/k$$



SLOPE CRITERION

$$\frac{dM}{dx} = \frac{dM}{dH}\left[\frac{dH_h}{dx} + \frac{dH_d}{dx}\right]$$

SLOPE MODEL (Continued)

$$\frac{dM}{dx} = \frac{2}{\pi}\frac{M_r}{a}, \quad \frac{dM}{dH} = \frac{M_r}{H_c(1-\underset{0.8}{S^*})}$$

$$\frac{dH_h}{dx} = \frac{\overset{0.75}{Q}H_c^r}{d}, \quad \frac{dH_d}{dx} = -\frac{M_r\delta}{\pi a^2}$$

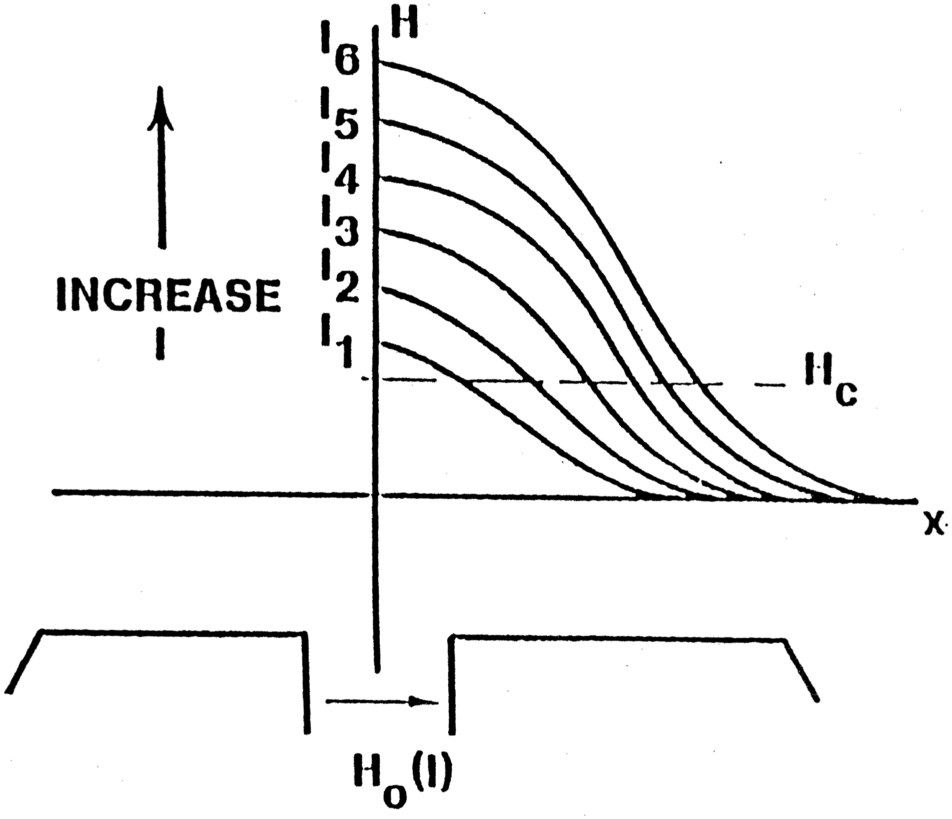
SOLVING SLOPE CRITERION YIELDS

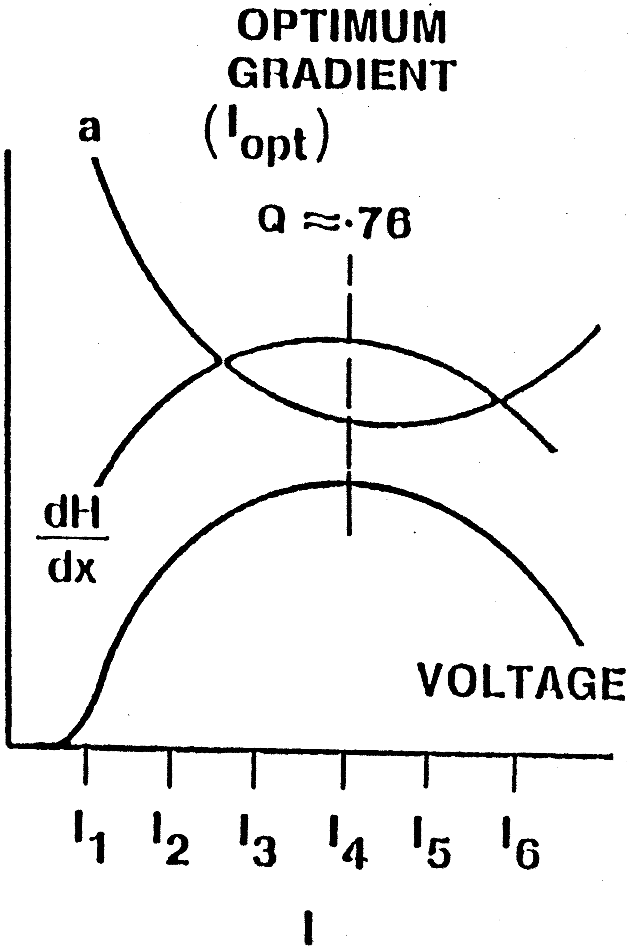
$$a = \frac{d(1-S^*)}{\pi Q} + \left\{\left[\frac{d(1-S^*)}{\pi Q}\right]^2 + \frac{M_r\delta d}{\pi Q H_c}\right\}^{1/2}$$

SHARP GRADIENT	$Q \to \infty$	$\Rightarrow$	$a \to 0$
ZERO SPACING	$d \to 0$	$\Rightarrow$	$a \to 0$
SHARP LOOP	$S^* \to 1$	$\Rightarrow$	a DECREASES
REDUCE DEMAG	$M_r/H_c \to 0$	$\Rightarrow$	a DECREASES
REDUCE THICKNESS	$\delta \to 0$	$\Rightarrow$	a DECREASES

CURRENT OPTIMIZATION - SHORT WAVELENGTHS

$$V \propto M_r \, k\delta \, e^{-ka}$$

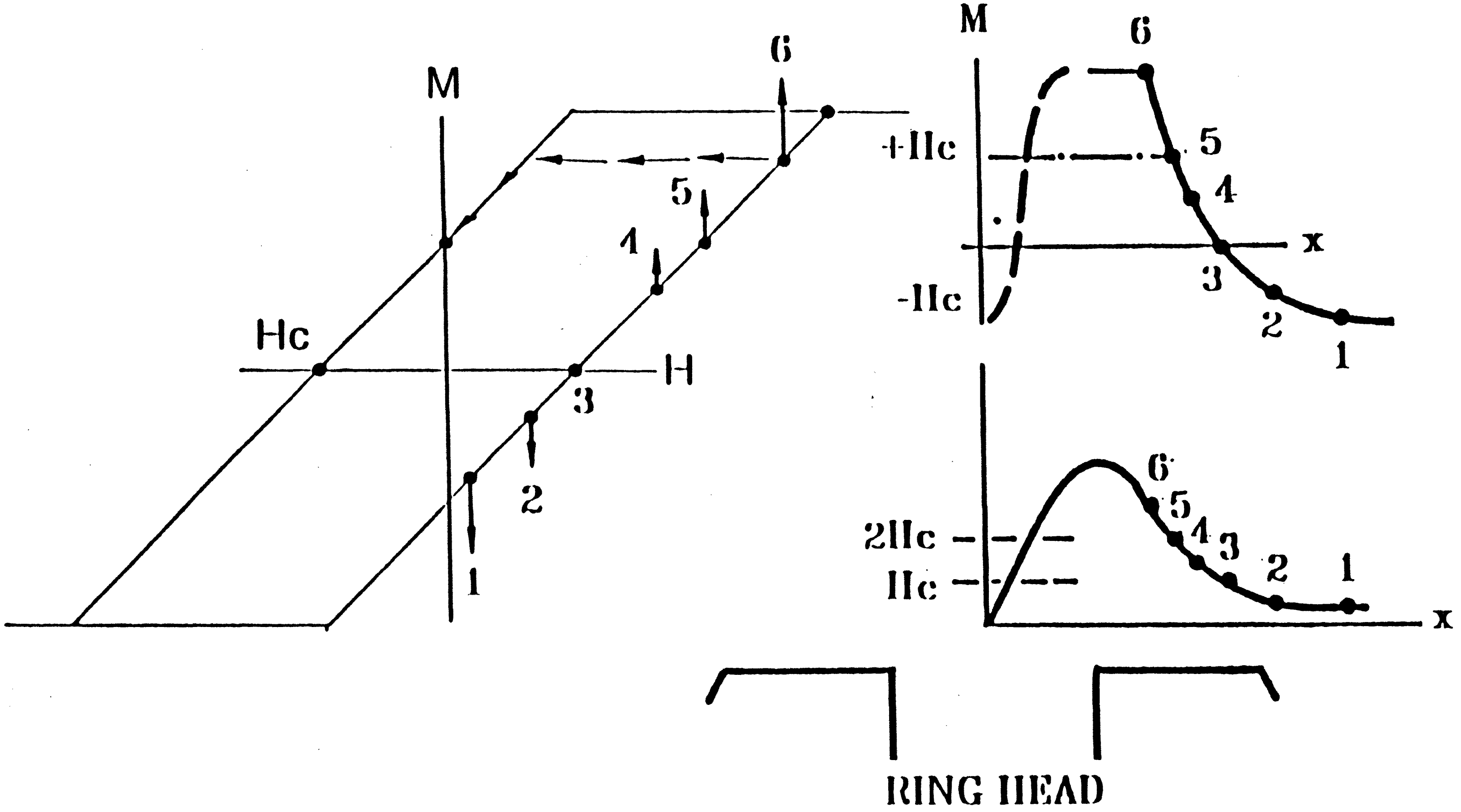




PERPENDICULAR RECORDING

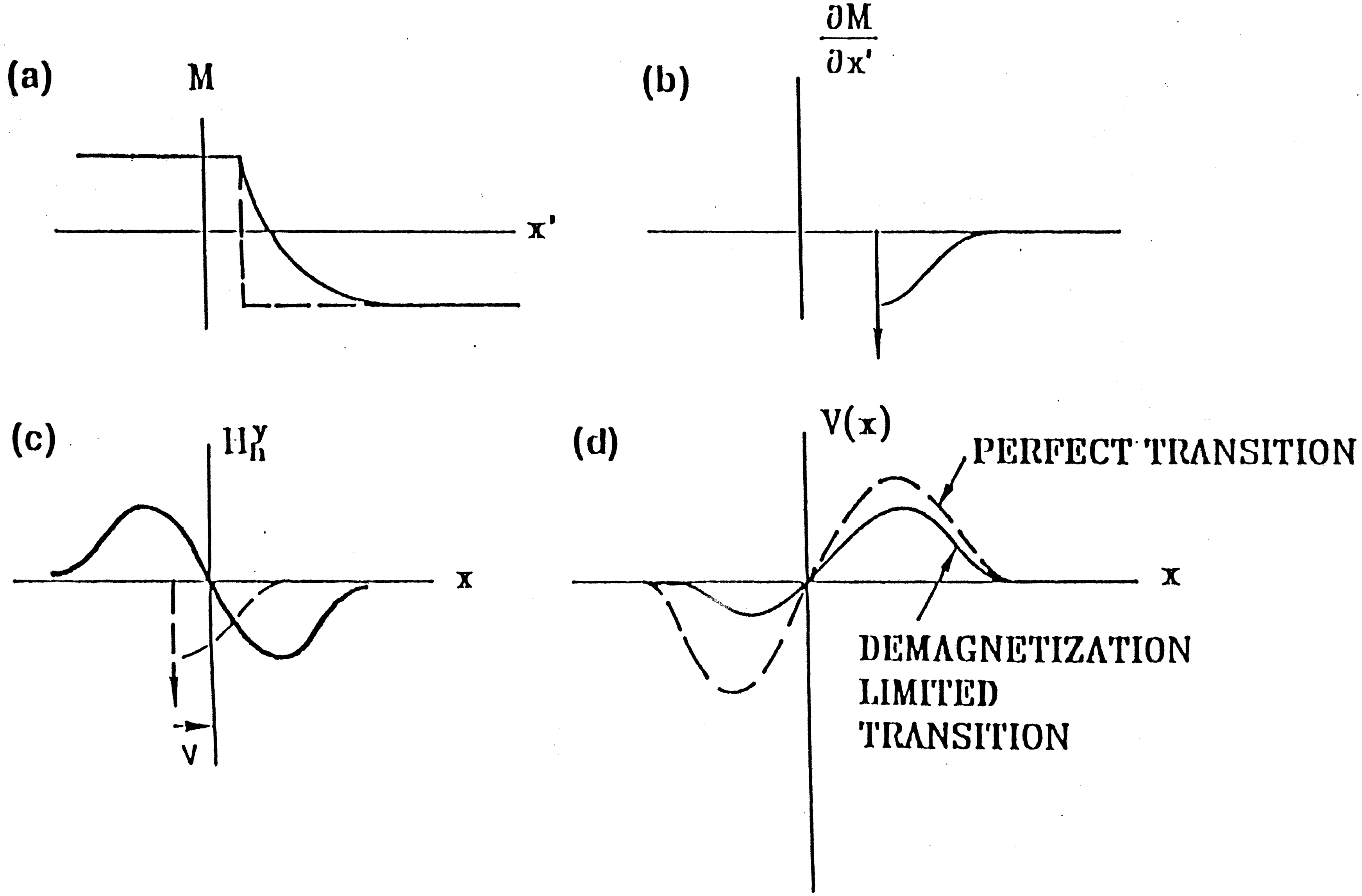
THIN MEDIA

$H_D = -M$ FOR ALL M(x)



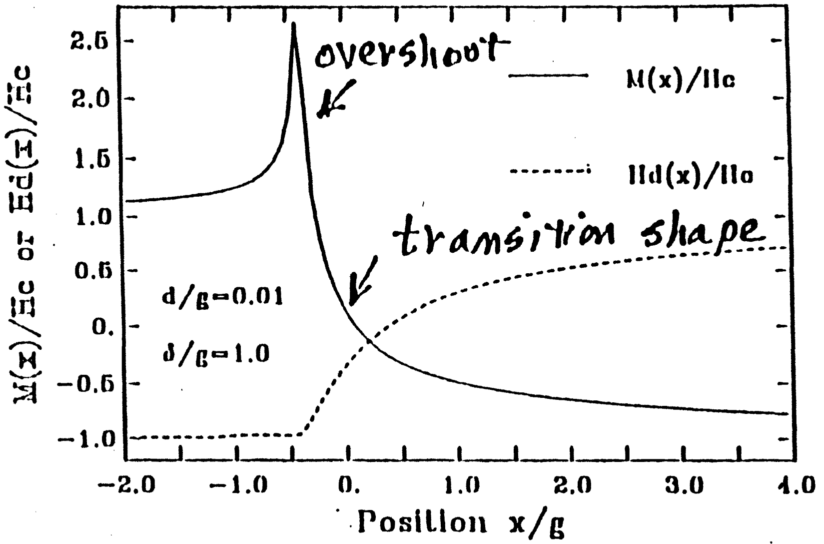
ISOLATED PULSE

$$V(x) \;\alpha \int_{-\infty}^{\infty} \frac{\partial M}{\partial x'} \cdot H_h^y\,(x+x')$$



PERPENDICULAR RECORDING

- THICK MEDIA - RING HEAD
- DEMAGNETIZATION FIELDS ARE REDUCED IN REGION OF TRANSITION



REDUCTION OF DEMAGNETIZATION FIELD CAUSE:

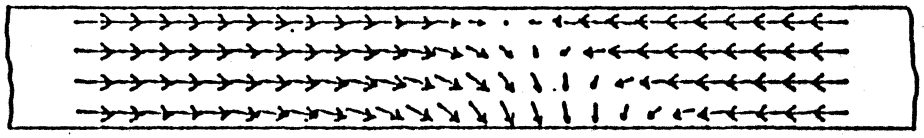
1. TRANSITION SHAPE TO RESEMBLE <u>SURFACE</u> HEAD FIELD (Lopez,Middleton)
2. OVERSHOOT TO OCCUR DURING RECORD PROCESS RELAXATION

FULL 2D CONTINUM VECTOR RECORDING MODEL

(Potter and Beardsley)

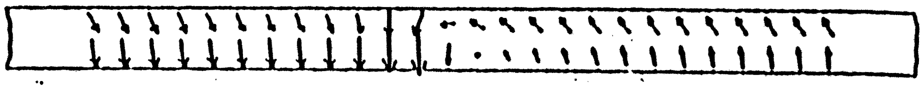
DEMAGNETIZATION COMPLETELY INCLUDED

LONGITUDINAL



SIDE VIEW

PERPENDICULAR



Perpendicular appears sharpest

Longitudinal has significant perpendicular component in transition

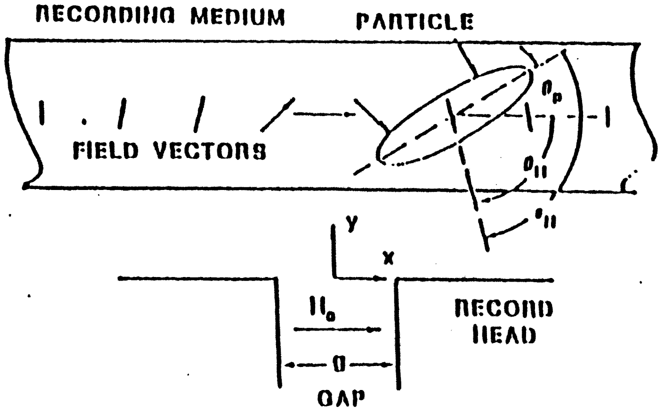
Who wins ?

RECORDING ON THICK PARTICULATE MEDIA

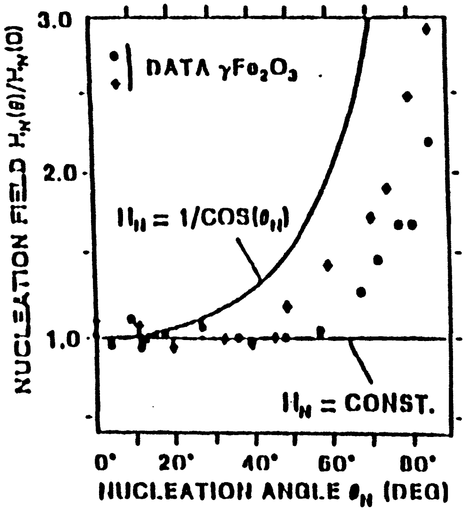
- FIELD HISTORY IS A ROTATION IN RECORDING PLANE

- ANGULAR DEPENDENCE OF COERCIVITY MONOTONICALLY INCREASES

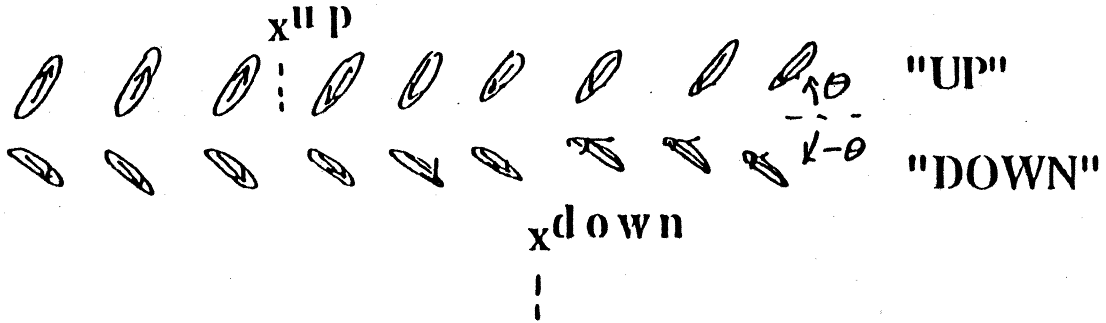
FIELD HISTORY



ANGULAR DEPENDENCE



CONSIDER TWO PARTICLE REPRESENTATION



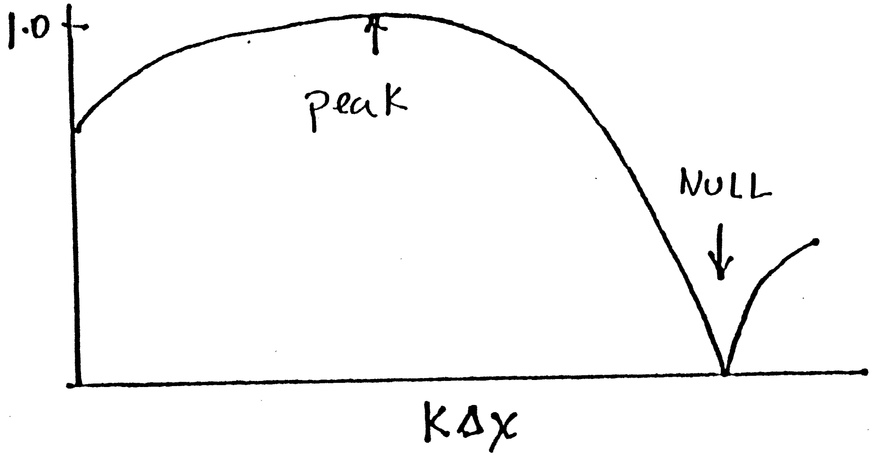
NET → → → ↓ ↓ ↓ ← ← ←

$x^{down} - x^{up} = \Delta x > 0$!

$2\theta = \Delta\theta$

x and θ both affect replay voltage

$$\Rightarrow V(k) = V^{Orig.}_{(k)} \cos\left(\frac{\Delta\theta - k\Delta x}{2}\right)$$



$$\cos\left(\frac{\Delta\theta - K\Delta x}{2}\right)$$

PEAK AT $k \Delta x = \Delta 0$

NULL AT $\pi/2 = (k \Delta x - \Delta 0)/2$

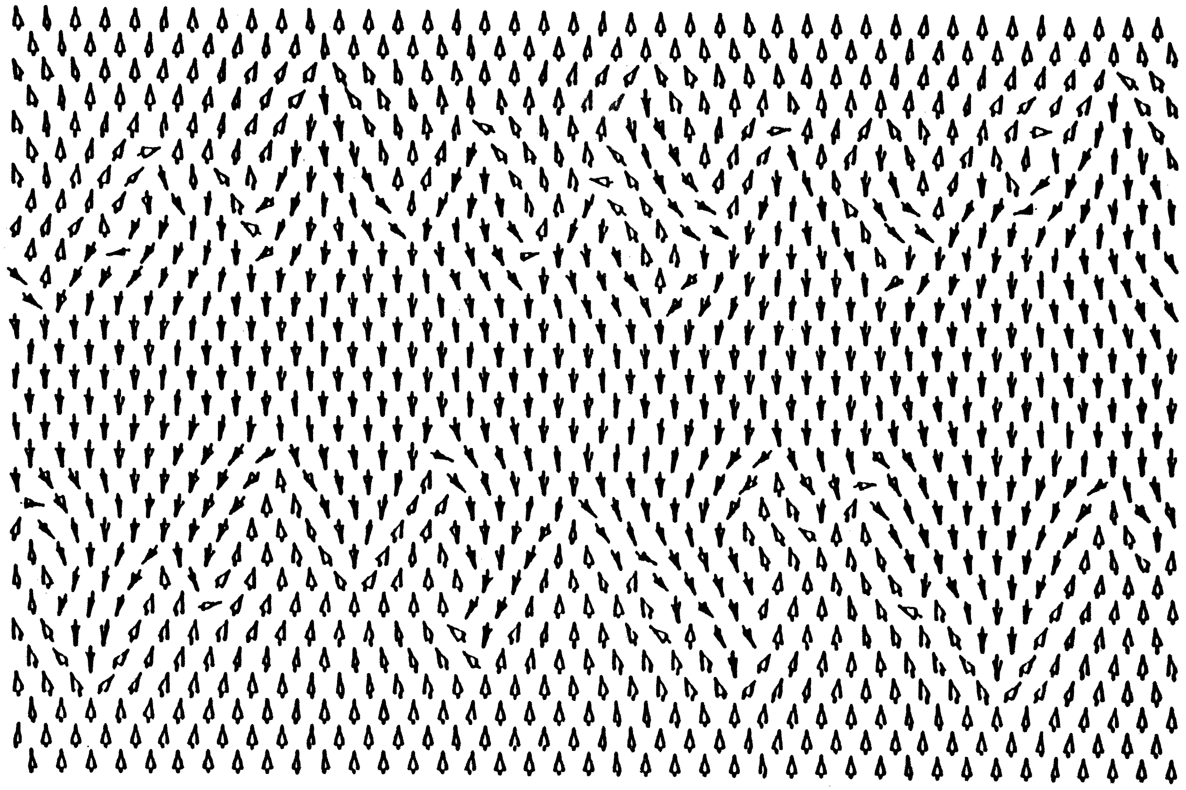
D.C. LEVEL IS COS 0 OR SQUARENESS

ESSENCE OF MODEL

PHASE SHIFT BY FREQUENCY (K) OR RECORD CURRENT (Δ X) INCREASES OUTPUT TO COMPENSATE FOR REDUCED ORIENTATION IN THE RECORDING PLANE !!

MICROMAGNETICS -- THIN MEDIA (top view)

(Zhu, Bertram)



REVIEW OF UNITS

SI (MKS)	C.G.S.
$B = \mu_0 (H+M)$	$B = H + 4\pi M$
B: TESLA	GAUSS 1 TESLA = 10^4 G
H: AMPS/METER	Oe 80 A/M = 1 Oe
M: AMPS/METER	GAUSS 1kA/M = 1G (emu/cc)
$\mu_0 = 4\pi \times 10^{-7}$ HENRYS/METER	

E.G. FIELD H FOR N = 10, I = 30 mA, g = 30 μ"

$$H = \frac{NI}{g} = 400 \text{ kA/M OR } 5000 \text{ Oe}$$

MAGNETIZATION γFe_2O_3 $\mu \approx 70$ emu/g, $\rho \sim 4.5$g/cc

$M_p = 70 \times 4.5 \sim 350$ emu/cc

$M_{TAPE} = pM_p = \frac{1}{3} \times 350 \sim 110$ emu/cc ~ 110G OR 110 kA/M

$B_r = 4\pi M \cong 1500$G or .15TESLA

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