THIN FILM TAPE HEADS FOR PCM RECORDERS

1636 (J-2)

K. Kanai, N. Kaminaka, N. Nouchi, N. Nomura
and E. Hirota
Matsushita Electric Industrial Co., Ltd.
Osaka, Japan

Presented at
the 66th Convention
1980 May 6 through 9
Los Angeles

AES

AN AUDIO ENGINEERING SOCIETY PREPRINT

THIN FILM TAPE HEADS for PCM RECORDERS

K.Kanai, N.Kaminaka, N.Nouchi, N.Nomura
and E.Hirota
Matsushita Electric Industrial Co., Ltd.
1006 Kadoma, Osaka, Japan

ABSTRACT

New configurations of a thin-film head with 20 tracks per a quarter inches are proposed. The write head has a groove structure formed into the magnetic substrate to obtain good flux efficiency in the magnetic thin-film effectively to reduce the signal write current. Measured and calculated characteristics are given for this thin-film write head.

A high performance magnetoresistive(MR) read head with narrow track width is achieved. The MR elements are required proper preparations to succeed in a simple common biasing configuration. These thin-film heads can realize extremely reliable PCM audio recorders.

INTRODUCTION

The number of windings of thin-film magnetic heads is limited to several-turns since they are substantially formed on a planner substrate by techniques of deposition and photolithograph. Multi-turn thin-film heads of multi-layered coil[1)] or spiral coil[2),3)] were reported to reduce the write current, but, it was difficult to obtain high track density on a substrate due to spread of the coil area.

One of the important features of the thin-film heads must be to realize multi-tracks heads. In this paper, we describe the development results of a thin-film multi-track write head which all tracks can be worked on simultaneously with low signal write current at each track. And practical performances of the MR read heads are also discussed.

WRITE HEAD

Two different types of deposition will be considered to realize the multi-turn configuration: 1) a multi-layer type in which a signal lines are formed near the front gap by conductive layers insulated from each other, and 2) a one-layer type in which a signal lines are formed on the same surface level by one conductive layer.

The multi-layer type is called a step structure, in which the core efficiency will be good with a rather small gap depth[7),8)], but to protect firmly the front gap portion from tape wear will be difficult due to the large step structure which will include a thick adhesive layer for bonding a protective cover in the recessed portion and between tracks. Moreover, saturation problems will be increased by a thinner evaporated magnetic-film at the step portion than that of a flat configuration.

The one-layer type will have the following feature: small variation of the magnetic-film thickness, minimizing the adhesive layer near the front gap portion and simplifying the thin-film processes. However, it will be difficult for this flat configuration to obtain a better core efficiency than for a step structure, and it will have a serious saturation problem since the signal coil will be located far from the front gap. It will be important to consider the saturation of the write head for a thick coating medium such as a tape. The write field intensity will be limited by the saturation flux at the rear part of the magnetic thin-film[5),7),8)].

From the view point of the operational reliabilities for tape heads, a rigid gap will be required (in which no conductive layer should be included) and a gap depth (throat height) d must be selected to be more than 10 μm for a high wear resistance. Previous structures are not fully suited to realize a high track density thin-film write head for a tape medium. Therefore, a different structure is presented in the following.

To solve the above problems a new configuration is proposed; thin-film layers are formed on a physically planar but magnetically grooved substrate along an array line of the unit heads. A perspective view of this write head is shown in Fig 1.

DESIGN CONSIDERATIONS

A theoretical analysis of thin-film heads is by now well established by means of Maxwell's equations[4)] and transmission line equations[3),5),6)]. To design this groove structure thin-film head, transmission line equations are applied here to obtain the optimum groove height, groove width, and other parameters.

For simplifying the calculations, an analysis model has a groove of a flat bottom filled by the conductive layer above the groove portion and no current source in the gap portion, as shown in Fig.2. The groove shape can be changed as desired. It is assumed that the magnetomotive-force(MMF) source, while writing , is uniformly distributed along the magnetic thin-film, the track width is infinitely wide, and the reluctance of the magnetic ferrite substrate is negligibly small. As one of boundary conditions, it is also assumed that the front gap is terminated by a concentrated reluctance $Z_t = g/\mu_0 pW$ since the front gap portion is not open but will be shunted by a semicircular leakage path.

Final solutions of the magnetomotive force u normalized by the write current I and the flux ϕ normalized by the flux at the rear gap part ϕ_r, as a function of position x are given by

$$\frac{u(x)}{I} = \frac{1}{\frac{\gamma\ell}{\alpha}+\frac{\gamma\ell}{\tanh\gamma\ell}} \frac{\sinh\gamma(\ell+d-x)}{\sinh\gamma\ell} \tag{1}$$

$$\frac{\phi(x)}{\phi_r} = \frac{1+\alpha\left[\frac{1}{\tanh\gamma\ell} - \frac{\cosh\gamma(\ell+d-x)}{\sinh\gamma\ell}\right]}{1+\alpha\tanh\gamma\ell/2} \tag{2}$$

for the region containing the conductive layer; $d < x < \ell+d$, and

$$\frac{u(x)}{u(d)} = \cosh\gamma_1(d-x) - \frac{1}{\alpha_1}\sinh\gamma_1(d-x) \tag{3}$$

$$\frac{\phi(x)}{\phi(d)} = \cosh\gamma_1(d-x) - \alpha_1\sinh\gamma_1(d-x) \tag{4}$$

for the gap portion; $0 < x < d$, where

- μ permeability,
- W track width,
- g gap length,
- p thickness of magnetic thin-film,
- d gap depth,
- h groove height,
- ℓ groove width,
- $\gamma_1 = 1/\sqrt{\mu pg}$,
- $\gamma = 1/\sqrt{\mu ph}$,
- $\alpha = \sqrt{g/h}\ \alpha_1$,

$$\alpha_1 = (\alpha_2 + \tanh\gamma_1 d)/(1 + \alpha_2 \tanh\gamma_1 d),$$
$$\alpha_2 = \sqrt{\mu g/p}, \qquad (5)$$

and α, α_1, and α_2 are termination factors at gap apex, gap portion, and front gap, respectively.

The flux density Bm ($=\phi_r/pW$) at the rear part of the thin-film is given by

$$Bm = I\,\frac{\mu\mu_0}{\ell}\,\frac{\sinh\gamma\ell + \alpha(\cosh\gamma\ell - 1)}{\sinh\gamma\ell + \alpha\cosh\gamma\ell} \qquad (6)$$

Calculated results for flux distribution and MMF are shown in Figs. 3 and 4 as functions of the groove height h and the groove width ℓ. Fig. 5 shows flux efficiency, defined as the ratio of front flux ϕ_f in the magnetic thin-film to rear flux ϕ_r for $g = 1$ μm. The circle in the figure indicates the parameters for the experimental head.

The grooved substrate decreases the shunt flux between the magnetic thin-film core and the magnetic substrate so that a good flux efficiency is obtained with a deep groove.

Transmissible flux to the gap portion can be expected to be more than 80 percent of the rear flux with $h \gtrsim 50$ μm. Fig. 6 also shows that a good flux efficiency is obtained even with a wide conductive layer, indicating that the groove structure will be suitable for multiturn configurations.

The transmissible magnetomotive force to the gap apex u(d) is derived by

$$\begin{aligned} u(d) &= Z_d \cdot \phi_f \\ &= Z_d \cdot \left(\frac{\phi_f}{\phi_r}\right) \cdot \phi_r \\ &= Z_d \cdot \eta\phi \cdot \phi_r \end{aligned} \qquad (7)$$

where Z_d is the reluctance from the gap apex to the front gap, ϕ_f is the flux in the magnetic thin-film at $x = d$, and $\eta\phi$ is the flux efficiency:

$$Z_d = \alpha_1 \cdot \alpha_2/\mu_0 W \tag{8}$$

where Z_d is determined by dimensions of the gap portion and $\mu \cdot \phi_r$ has a maximum value determined by the saturation induction of the magnetic thin-film. Therefore, by the higher the flux efficiency, the more magnetomotive force u(d) is obtained. A good flux efficiency in the groove structure and a step structure is an important factor for writing well on a tape medium.

EXPERIMENTAL RESULTS

The writing characteristics are compared by the relative output of a reproduce head for a Co-γ-Fe_2O_3 tape at 133 flux changes per mm.

Fig. 6 shows the experimental results of two types of thin-film head: a) the groove structure thin-film head, $h = 50$ µm, $\ell = 130$ µm; b) flat structure $h = 2$ µm, $\ell = 130$ µm, $p = 3$ µm, $g = 1$ µm, and $d = 10$ µm. When signal conductors and magnetic thin-film are formed on a conventional, magnetically flat substrate, the write level is limited to a low value because of saturation of the magnetic thin-film.

The maximum write current is determined by the saturation of the magnetic thin-film according to (6), when $Bm = Bs$; the saturation flux density of the magnetic thin-film. Fig. 7 shows the calculated results of the effective maximum write currents I, I_f, I_r, and the magnetomotive-force u at the front gap for I versus the gap depth d derived from (6), when $Bs = 1T$ and $\mu = 1000$.

I_f is the effectively maximum write current for a concentrated current source at the gap apex and I_r at the rear gap portion. Both indicate the expected maximum difference of the write efficiency with respect to the coil positions. Circles and squares indicate measured values of the relative write level for two sample heads. The experimental results agree well with the calculated results.

This thin film write head has good overwrite capability that is smaller overwrite modulation (OVWM) than -30 dB; the OVWM is the residual 1F component in 2F signal, after 2F is written without erasing function on the same track previously recorded 1F.

READ HEAD

A conventional inductive read head generates the output voltage proportional to the relative speed between the head and medium. On the other hand, output voltage of a magneto-resistive(MR) read head[9)] is independent on the relative speed v. This relation shows in Fig.8 as to the frequency response for an inductive head having the track width $W = 160$ μm and the number of windings $N = 14$ turns, and a MR head having same track width and the current density of the MR element $J = 2$ mA/μm^2.

For instance, the inductive head needs more than 1000 turns to obtain the order of mV output voltage at the conditions of $v = 15$ ips and $W = 160$ μm. It means that the inductive type of the thin-film is not suitable for the read head.

As to the x'talk problem, it is not sufficient to obtain good x'talk characteristics for the conventional magnetic head in which the track location pitch is less than 600 μm, because the adjacent head cores face each other in the configuration of the bulk materials' head.

The MR head has the excellent x'talk characteristics even in the conditions of the small track pitch, such as less than 100 μm.

Some investigations will be required from the operational stand points of the MR head.

MR heads require magnetic bias fields to obtain an approximately linear read-back. Magnetic domains in the MR element should not be disturbed by the poor orientation or the edge roughness of the MR stripe, in order to succeed in the simple biasing configuration which uniform field is generated over all tracks by means of a common biasing method of one conductive current layer or one hard magnetic film layer, such as Fe_3O_4 film, or one permanent magnet block.

Fig. 9 (a) shows the experimental results of second harmonics vs. biasing field at each track as an example of multi-track MR head with complicated domains in the element. Good sample shown in Fig. 9 (b) requires almost same optimum biasing field at all tracks.

The maximum output voltage from the MR head with track width W can be estimated by

$$emax = \Delta\rho max \cdot J \cdot W, \qquad (9)$$

where $\Delta\rho max/\rho \simeq 2\%$ for 83Ni-17Fe and its resistivity $\rho = 22\ \mu\Omega\cdot cm$ J is current density. For instance, the output at 2F is measured more than 1 mVpp for $J = 4\ mA/\mu m^2$.

The resolution of this MR head is more than 65% at the recording density of 20kBPI.

The components of x'talk from the adjacent tracks in this configurations cannot be detected, since hidden in the noise level, in which the signal to noise ratio is more than 35 dB.

An out-look of the 20 tracks MR head for a quarter inches wide tape shows in Fig.10. Fig.11 shows typical output waveform and its spectrum written on Co-γ-Fe_2O_3 tape, 6 μm coating thickness. 600 Å thick 83Ni-17Fe is deposited on a substrate and finished 10 μm wide MR element.

The track format for the 4 CH PCM recorder comprising 4 tracks per channel[10] is shown in Fig.12. It includes 16 data tracks and 4 auxiliary tracks in a quarter inch wide.

CONCLUSION

The groove structure for a thin-film head is effective for attaining good flux efficiency when using a wide coil in the head design. In addition,

1) the groove structure is suitable for multiturn configurations;

2) good wear resistance can be obtained since the groove structure can minimize the adhesion space of a structural support and a substrate and have an effectively deep gap depth;

3) a flattened magnetic thin-film on a groove structure shows better saturation characteristics than a film on a step structure, and good overwite performance.

Such thin-film magnetic head structures have the potential for achieving even higher track density than this sample of 20 tracks per quarter inch wide on one substrate as reported here.

The multi-tracks MR heads have the excellent x'talk characteristics even in the conditions of the small track pitch.

One of new applications of those thin-film heads will be expected for parallel bit prossesing recorder systems. For instance, they can realize extremely reliable audio PCM recorders, because of rather low linear density, supported by their high track density, having proper areal density and drop-out free format in which data bits can be written in tracks apart from each other.

ACKNOWLEDGMENT

The authors wish to thank S.Hayakawa and H.Sugaya for their encouragement and suggestions, and to thank H.Matsushima, T.Kogure, T.Miura, K.Imanishi, Y.Inoue and S.Ishikawa for their supports.

REFERENCES

(1) J.P.Lazzari, "Integrated magnetic recording head application", IEEE Trans.Magn., vol.MAG-9, pp.322-326, 1973.

(2) G.W.Brock and F.B.Shelledy, "Batch-fabricated heads from an operational standpoint", IEEE Trans.Magn., vol. MAG-11, pp.1218-1220, 1975.

(3) J.C.van Lier et at., "Combined thin film magnetoresistive read, inductive write heads", IEEE Trans.Magn., vol. MAG-12, pp.716-718, 1976.

(4) A.Paton,"Analysis of the efficiency of thin film magnetic recording heads", J.Appl.Phys., vol.42, pp.5868-5870, 1971.

(5) D.A.Thompson, "Magnetoresistive transducers in high-density magnetic recording", in AIP Conf.Proc., vol.24, p.528, 1974.

(6) K.Kanai and H.Sugaya, U.S.Patent 8,696,216, filed 1972.

(7) E.R.Katz, "Finite element analysis of the vertical multiturn thin-film head", IEEE Trans.Magn., vol.MAG-14, pp.506-508, 1978.

(8) R.E.Jones, Jr., "Analysis of the efficiency and inductance of multiturn thin film magnetic recording heads", IEEE Trans.Magn., vol.MAG-14, pp.509-511, 1978.

(9) R.P.Hunt, "Magnetoresistive read out transducer", IEEE Trans.Magn., vol.MAG-7, pp.150-154, 1971.

(10) H.Matsushima et al., "A new digital audio recorder for professional applications", AES 62nd Convention, No.1447 (G-7).

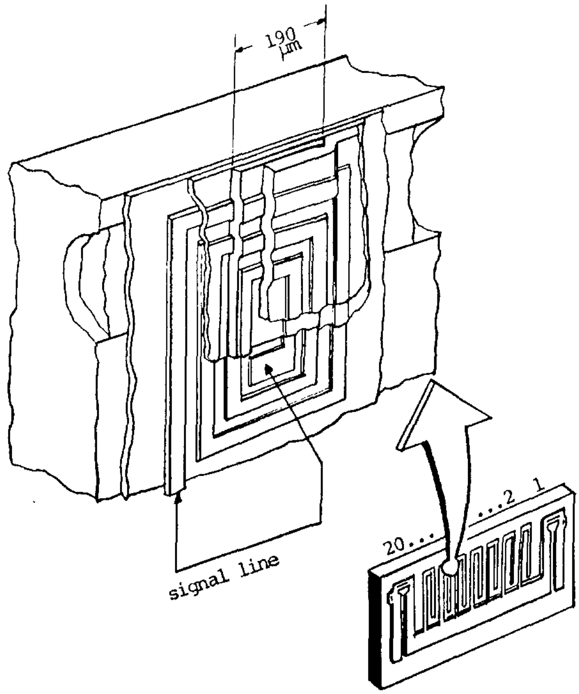


Fig. 1. Perspective view of a thin-film write head on a magnetically grooved substrate.

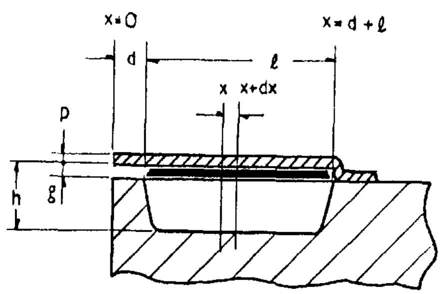


Fig. 2. Sectional view of the groove structure thin-film head for a simplified analysis model.

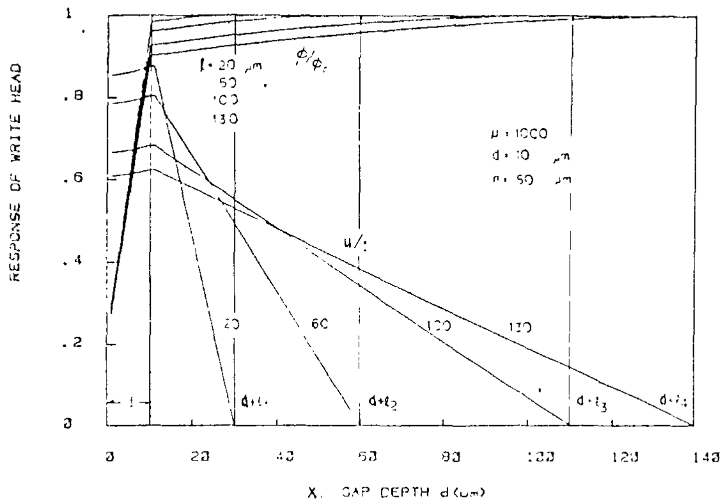


Fig. 3. Calculated results of flux distribution and magneto-motive-force in the groove structure thin-film head versus groove width ℓ.

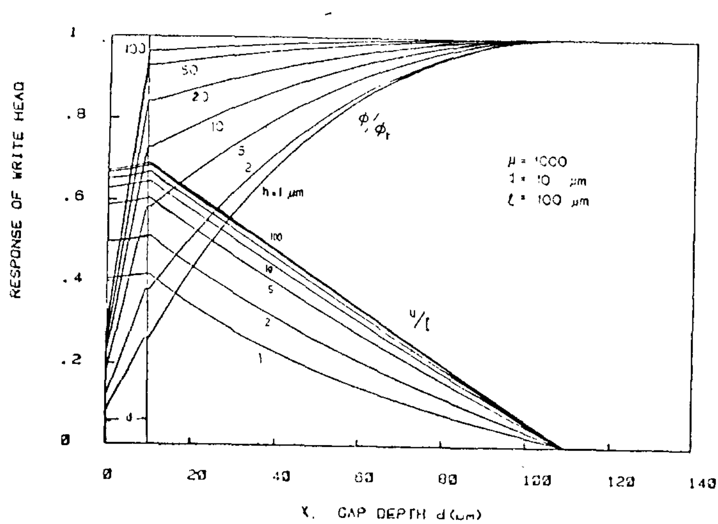


Fig. 4. Calculated results of flux distribution and magneto-motive-force in the groove structure thin-film head versus groove height h.

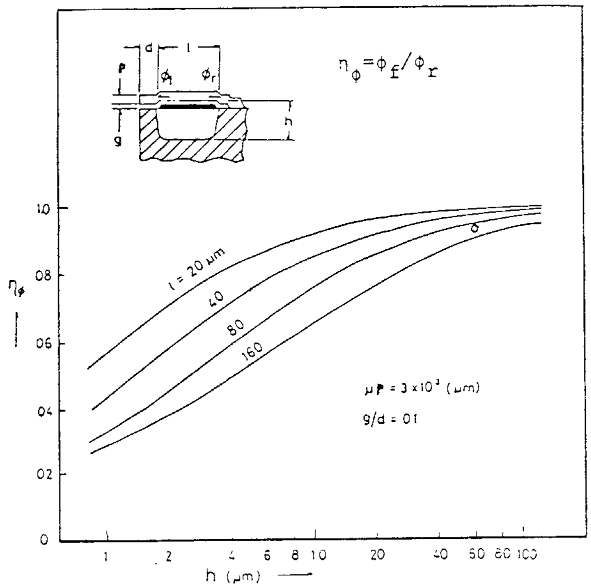


Fig. 5.

Calculated flux efficiency of the thin-film write head versus groove height h, circle indicates the model head.

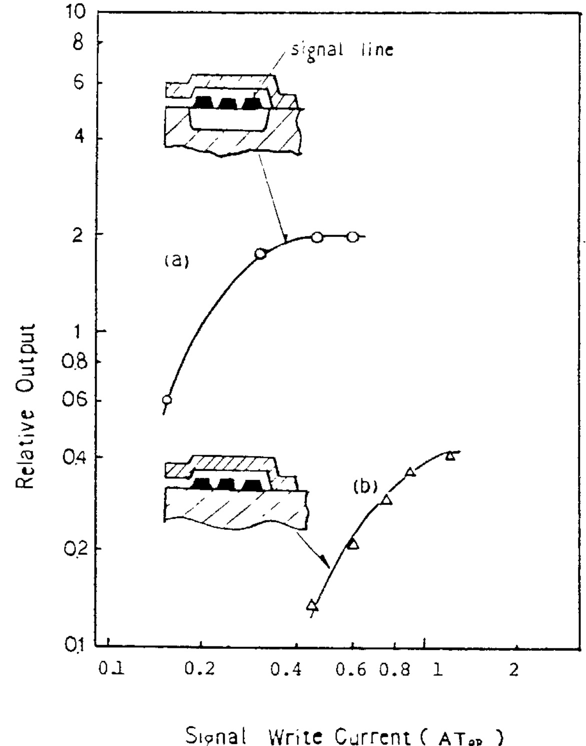


Fig. 6.

Measured results of thin-film write heads. (a) thin film head on a grooved substrate. (b) conventional thin-film head on a flat substrate.

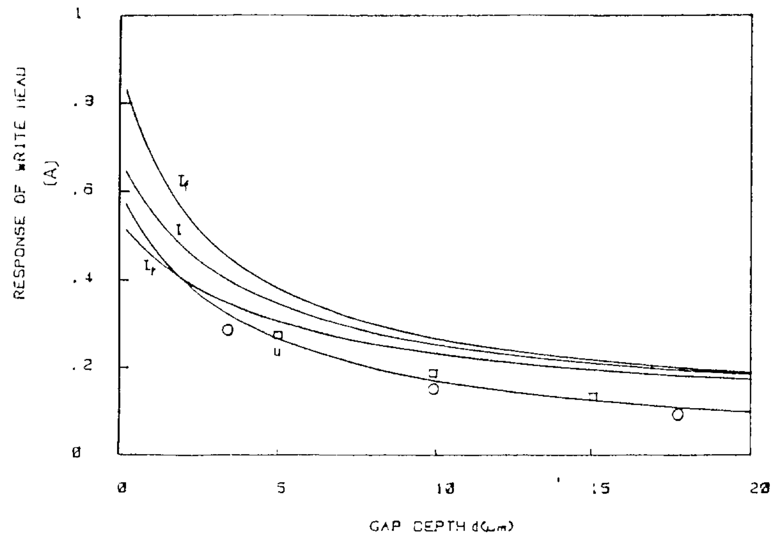


Fig. 7. Effectively maximum write currents I, I_f, I_r, and MMF u at the front gap versus gap depth d. Circles and squares indicate measured results.

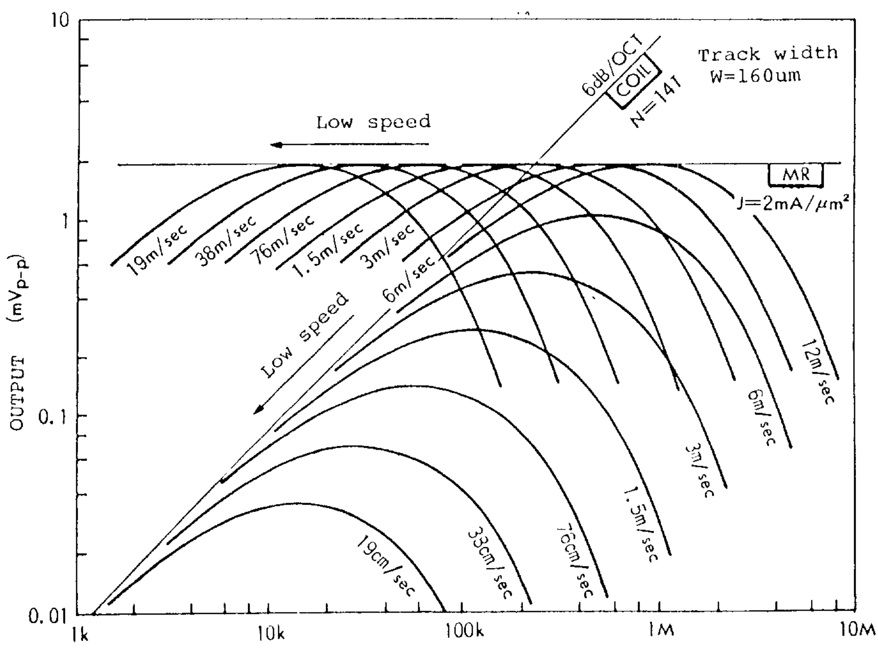


Fig. 8. Output responses of inductive head and flux-sensitive MR head vs. relative speed between head and tape.

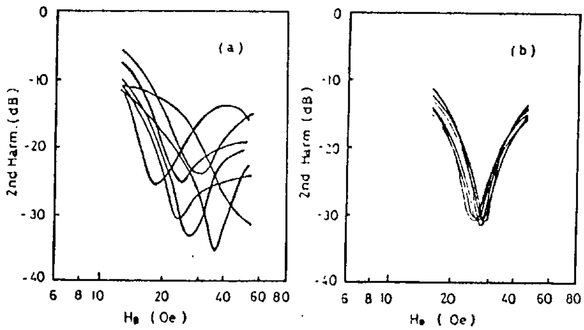


Fig. 9. Second harmonic distortion vs. bias field.

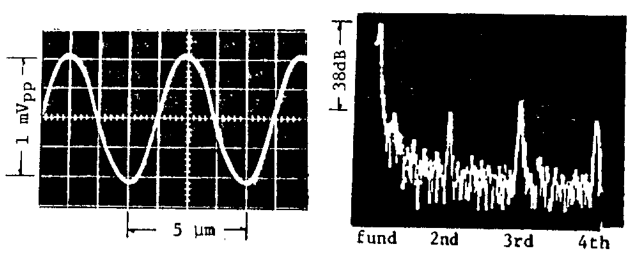
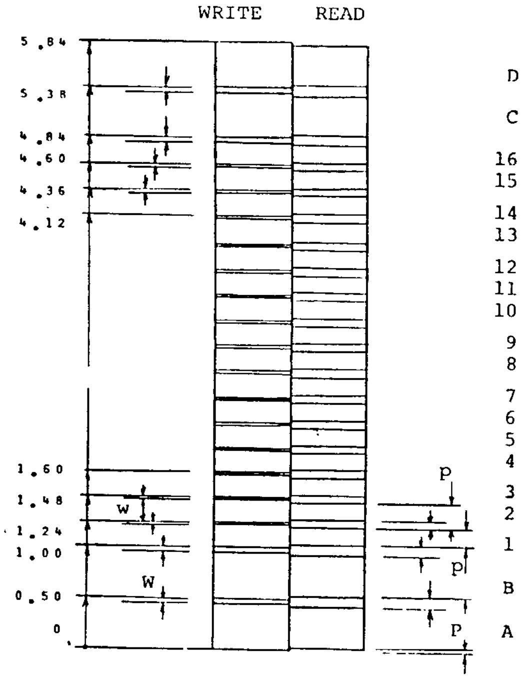


Fig.11. Output waveforms (and their harmonic spectrum) of magnetoresistive head for the sinusoidal magnetization.



16 data tracks + 4 analog tracks
for 4 channels / 1/4"

Fig.12. Track format of thin-film magnetic heads for a PCM recorder of the "4 track per channel" system.

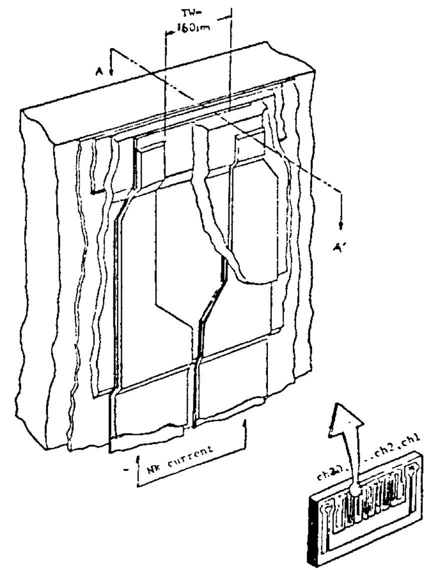


Fig.10.
Perspective view of magnetoresistive read head with multi-track configuration.