Carrier-to-Noise Ratio in Magneto-Optic Transfer Readout Using Magnetic Garnet Film

T. Nomura¹, M. Kishida², N. Hayashi², K. Iwasaki³, H. Umezawa³

¹Shizuoka Inst. Sci. & Tech., 2200-2 Toyosawa, Fukuroi-shi, Shizuoka 437-8555, Japan

²STRL NHK, 1-10-11 Kinuta, Setagaya-ku, Tokyo 157-8510 Japan

³FDK Corporation, 2281 Washizu, Kosai-shi, Shizuoka 431-0495, Japan

The play back system of digital video signal which transfers the information stored in magnetic tapes to garnet film and reads out it magneto-optically is being developed. To put the system to practical use, it is expected that the signal recorded with wavelength of shorter than $0.8\mu\text{m}$ is read out with sufficient carrier-to-noise ratio (CNR). We confirmed that it was possible to read out a signal with wavelength of $0.77\mu\text{m}$ experimentally and analytically as well. To achieve a good CNR we measured spectra of readout signal by using a transfer readout exerciser. On the bases of a series of experiments, we found that dominant noise was polarized noise due to granularity of magnetic tape. By elongating the readout spot in the direction of recorded track width by three times that of normal, improvement of CNR more than 10 dB was obtained.

Key words: garnet film, magneto-optic transfer readout, carrier to noise ratio, video tape, granularity

1. Introduction

Magnetic tapes have been widely used to record many kinds of video signal such programs as drama, news, documentary, etc. particularly in broadcasting stations. A drawback of magnetic video recorder is its poor accessibility, that is, access to the objective part of information is made by sequentially.

To solve this problem, a system which transfers information stored in magnetic tapes to other memories having good accessibility such as HDD and optical disk is to be developed. One of the candidates is such a system that information in tape is transferred to an in-plane magnetic garnet film and the transferred information is read out by optical method¹⁾. Advantages in using a magnetic garnet film (abbreviate as garnet film, hereafter) are the ability to read out multi-tracks simultaneously and possibility of high resolution readout.

For this system, following two problems must be considered. One is to know the lower limit of transferable recorded wavelength. The other is to know the obtainable carrier-to-noise ratio (C/N) in reading out the transferred information. But the relationships between magnetic properties of garnet film and readable recorded wavelengths are not necessarily clear. And also noise characteristics in readout are not well understood.

In this paper, we describe briefly a transfer model of magnetic information from magnetic tape to a garnet film, and focus on a carrier, i.e., signal, and noise in transfer readout.

2. Transfer model

When magnetic tape in which signals are recorded is in contact with garnet film, spin in garnet film cants

Fig.1 Wavelength dependence of signal level

into the normal direction to the film surface by the perpendicular component of magnetic leakage field from a tape. We calculated the cant angle θ of spin for a given transferred wavelength based on magnetic energy in film under the influence of magnetic field²⁾. Readout signal level is proportional to the product of $\sin \theta$ and modulation transfer function of objective lens. Fig.1 shows an example of the dependence of signal level on wavelength. From Fig.1 we can see that the signal level decreases rapidly with decrease in wavelength. Transfer of signal having wavelength of around $0.8\mu\text{m}$ to garnet film takes place and the cant angle for the wavelength is few degrees. Dots in Fig.1 are experimental results obtained using a transfer readout exerciser¹⁾. We can see that signal levels calculated based on the transfer model agree well with the experimentally obtained values. This indicates that if magnetic parameters of garnet film are properly chosen we can readout the signal having recorded wavelength down to $0.7\mu\text{m}$.

3. Carrier to Noise Ratio

Readout of transferred signal is made by usual magneto-optical readout method. In this case readout signal, i.e. carrier, level C is proportional to readout laser power P_r . Noise N in readout may consists of shot noise from the photo detectors, diode laser noise, electronic circuit noise and polarized noise which is defined later. Shot noise and polarized noise are proportional to $P_r^{1/2}$ and P_r , respectively. Both laser noise and electronic circuit noise have no relation with P_r . Thus, ratio of $C(V_{rms})$ to total noise $N(V_{rms})$ can be written as follows:

$$C/N \propto P_r / (\alpha P_r + \beta P_r^2 + \gamma)^{1/2} \quad (1)$$

where α, β, γ are arbitrary constants. These constants are determined by measuring C level and N level obtained from the readout experiments for two or more different readout powers.

4. Experiments

A schematic of transfer readout exerciser is shown in Fig.2. Details of the system have been described previously¹⁾. Major assemblies include a green laser (operating at 532nm and output of 20mW), the stationary optics, and a video cassette recorder (VCR). A linearly polarized beam from the laser is directed to objective lens of numerical aperture of 0.7 and focused onto the Bi-substituted garnet film of thickness 0.2 μ m. On the surface of the garnet 70nm thick reflective layer is formed. The spot diameter on the garnet film and reflectivity of the reflective layer are about 0.8 μ m and about 70% respectively.

In readout experiment, magnetic tape (D-3 format videotape) was transported at a speed of 33.35mm/s. First, we measured spectra obtained from readout system when laser was on and off without running the magnetic tape. Then we ran the tape and measured the readout spectra for two cases. One case was that no signal was written on the tape and the other case was that signal with wavelength of 0.77 μ m was recorded. Finally, we measured spectra of readout signal for the several readout laser powers.

Fig.2 Schematic of transfer readout exerciser.

Fig. 3 Dependence of C/N on transferred wavelength.

5. Experimental Results and Discussion

Fig. 3 shows the relationship between C/N (resolution band width RBW=1 KHz) and transferred wavelength which is equal to recorded wavelength. As we can see in Fig. 3, C/N for the transferred wavelength of 0.77 μ m is smallest and not sufficient value for reproducing a digital video signal correctly. Thus we measured readout spectrum under several conditions while we paid attention to C/N of 2T signal (wavelength $\lambda=0.77\mu$ m).

Spectra of the readout system for laser is on and off are shown in Fig. 4. From this figure we can see that electronic noise level is below -75dBm over the frequency range measured. Two curves are indistinguishable for any frequency. This means that laser noise is lower enough compared with the electronic noise.

In Fig.5 two spectra of readout signal are shown for the case when no signal is recorded (erased state) and that for the case when 2T signal is recorded. 2T signal is corresponds to the readout frequency of 0.043 MHz. Both curves show similar characteristics with respect to frequency, that is, noise level is high in the low frequency region and decreases gradually with

Fig. 4 Spectra of readout system when laser is on (solid curve) and off (dashed curve).

Fig. 5 Spectra of readout signal for the case when no signal is recorded (dashed curve) and the case when 2T signal is recorded (solid curve).

frequency up to about 0.08 MHz. When signal is recorded the output noise increases by some 6dB compared with that obtained when no signal is recorded. In addition, we measured the spectrum when the tape was run while the back side of the tape was in contact with the garnet film. The spectrum in this case was almost the same as that of laser on in Fig.5.

To investigate the origin of this noise, we measured the both surfaces of the tape by an AFM. The surface roughness ($r_{av}=9.4\text{nm}$) of back side of the tape was rather larger than that ($r_{av}=6.5\text{nm}$) of the side of magnetic coating. This indicates that surface roughness is not primarily responsible for the readout noise. Next, we observed the magnetic domain of garnet film through GGG substrate under a polarizing microscope. NA and light source of the microscope are 0.55 and high pressure Hg lamp respectively. Fig.6 (a) shows a magnetic domain of garnet film itself. We can see uniform and smooth domain and can not find any characteristic domain structure. But when magnetic tape which is AC erased is in contact with the garnet film, Fig.6 (b) is obtained. In Fig. 6(b), we can see that the domain contrast randomly fluctuates a little over the field of view. It should be noted that this fluctuation of contrast is observed by only a polarizing microscope. Therefore, we can not distinguish the noise caused by the fluctuation from magneto-optic signal. We name

Fig. 6 Micrographs of magnetic domain. (a) Garnet film itself. (b) Magnetic tape is in contact with garnet film.

Fig. 7 Readout spectra of 2T signal for two readout laser powers.

this type of noise polarized noise.

Since D-3 format tape is particulate recording media, we consider the fluctuation is attributed to the granularity of magnetic tape. Particulate noise due to the granularity is one of the principal medium noises. The noise, however, does not become to be a dominant noise, when signal is read out with the magnetic head having enough wide head width compared to the size of granularity. We consider that transferred magnetic pattern in the garnet film caused by the tape granularity becomes significant noise when we read out a signal with a spot size of less than $1\mu\text{m}$.

In order to evaluate the degree of contribution of each noise to total noise, we carried out readout of 2T signal with laser powers ranging from 0.1mW to 2.8mW. Two of these spectra of readout signals are shown in Fig.7. In this experiment maximum C/N was obtained at a laser power of approximately 1mW. Both carrier level and noise level saturated at a laser power of 2mW and decreased as the laser power was increased more than 2mW. We consider that these decreases are attributed to the temperature rise of the garnet film taking place the absorption of laser beam in both garnet film and reflective film (thickness : 70nm). We see from Fig.7 that carrier (noise) level for laser power of 0.5mW and 1mW are -46.1 (-68.8)dB_m and -39.5 (-64.4)dB_m respectively. Electronic noise level is measured to be -85.5 dB. Using these figures, we calculated the values of α , β and γ . Finally we found that C/N(dB_m) for readout laser power P_r (mW) is given by

$$C/N \cong 20\log [19P_r / (0.3P_r + P_r^2 + 0.01)^{1/2}] . \quad (2)$$

The coefficient of second term in denomination on right side of (2) is considerably larger than that of other two terms. This means that polarized noise due to granularity dominates in this readout system. In this point, our system is quite different from usual magneto-optic readout systems in which shot noise from the detector is dominant. The polarized noise can not be

eliminated by the differential detection arrangement that is usually used in readout system of magneto-optic disk.

Thus to improve C/N in our system we have to look for other methods. Because polarized noise is statistical random noise, there is a possibility to reduce the noise by elongating the readout spot into the direction of track width. Here, we note that the track width recorded on the magnetic tape we concerned is $20\mu\text{m}$. To estimate the effect of elongation of spot, we make a theoretical consideration. For simplification, we considered that to elongate a spot by a factor of n is equivalent to arrange n spots in the direction of the track width. If we read a signal with n spots, of course these n spots are condensed onto one photo detector, and laser power of each spot is P_r , carrier level C and shot noise are increased by a factor n and the square root of n , respectively. Since polarized noise is considered to be random noise, the noise increases in proportion to not n but the square root of n . This fact is similar to the recording medium noise that is one of the major noises in reproduction of signal in magnetic recording systems, where the medium noise is proportional to the square root of track width of reproduce magnetic head⁴⁾. The resulting expression of C/N for the elongated readout spot can be given, with use of (2), by

$$C/N \cong 20\log [19nP_r / (0.3nP_r + nP_r^2 + 0.01)^{1/2}]. \quad (3)$$

According to (3), C/N increases with increasing n . For example, in case of $P_r = 1\text{mW}$ and $n = 3$, we can expect the improvement in C/N by about 4.5dB compared with that of $n = 1$.

To confirm the above mentioned improvement, we carried out readout experiment with elongated spot. In this experiment laser spot was shaped into oval by inserting a slit (width: 0.5mm) between an optical expander and objective lens. On the basis of optical simulation, width and length of spot were estimated to be $0.8\mu\text{m}$ and about $2.4\mu\text{m}$ respectively. Fig.8 shows the spectra obtained when 2T signal was read out with two different spot sizes for $P_r = 1\text{mW}$. We see that when readout spot is elongated in the direction of track width carrier level is increased by 10dB and noise level is decreased by about 3dB. These results indicate that C/N

Fig. 8 Frequency dependence of output for two spot sizes (normal: $0.8 \times 0.8\mu\text{m}^2$, 0.5mm: $0.8 \times 2.4\mu\text{m}^2$).

is improved by about 13dB compared with that obtained with the spot of $0.8\mu\text{m}$ in diameter. Increase in carrier level is reasonable but at present we can not find a plausible explanation for the decrease in noise level.

6. Conclusion

Readout of signal with wavelength shorter than $0.8\mu\text{m}$ is possible by using in-plane garnet film which has suitable magnetic properties. Dominant noise in transfer readout is polarized noise. The noise source is granularity of magnetic tape. We demonstrated that this kind of noise is reduced by elongating the readout spot in the direction of track width. When spot size was elongated by three times that of normal spot, C/N was improved more than 10 dB.

References

- 1) M. Kishida, N. Hayashi, K. Iwasaki, H. Umezawa, and T. Nomura: *IEEE Trans. Magn.*, **44**, 3289 (2008).
- 2) T. Nomura, K. Nagai, M. Kishida, N. Hayashi, K. Iwasaki, and H. Umezawa: IEICE Tech. Rep., MR2008-63(2009-3) [in Japanese].
- 3) M. Kishida, N. Hayashi, K. Iwasaki, H. Umezawa, and T. Nomura: IEICE Tech. Rep., MR2008-52(2009-1) [in Japanese].
- 4) C. D. Mee and E. D. Daniel: *Magnetic Recording*, Vol.1, (McGraw-Hill, New York, 1987), Chap.5.

Received May.14, 2009; Revised July.1, 2009;

Accepted August.11, 2009