GHz-Frequency Electromagnetic Interference Suppression Technique using Magnetic Absorber for Hard Disk Interconnector

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Abstract **─** An electromagnetic interference (EMI) suppression technique for gigahertz (GHz) frequency region of hard disk interconnector, namely trace suspension assembly interconnector (TSAI) is presented. The BSR-1 absorber is selected and filled in between conductor traces of the interconnector. The attenuation of radiated and conducted EMIs are calculated and analyzed by using simulation software based on finite integral technique. From the results, it is found that the proposed technique can suppress radiated EMI from 16 μV to 0.5 μV in all frequency regions up to 20 GHz and the conducted EMI can be suppressed up to 0.7 Watt in a range of 0.9 GHz – 4.0 GHz with the same structure of TSAI.

Index Terms - Electromagnetic coupling, electromagnetic interference, interconnector, and interference suppression.

I. INTRODUCTION

To improve the data transfer rate of high speed hard disk drives (HDDs), the operating frequency has to be increased. However, the effects of EMI have to be suppressed because these effects can degrade the recording head in HDD as reported in [1, 2]. EMI can be classified as two types, which are radiated and conducted EMI. The EMI mechanism of both, including the three components includes source, path, and victim [3].

The radiated EMI from a cell phone, which causes the recording head degradation, has been reported [1, 2]. As the results, the signal integrity affected by an external EMI can cause latent failure to the sensitive components in HDDs [4, 5]. For conducted EMI, the EMI can interfere with both analog and digital signals, which is used in the read/write channels of HDDs [6]. In addition, the write-to-read crosstalk in trace suspension assembly interconnector (TSAI) is an example of the conducted EMI, which is reported in [7, 8]. Consequently, the effects of radiated and

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conducted EMI on the TSAI are a new challenge to design with low EMI.

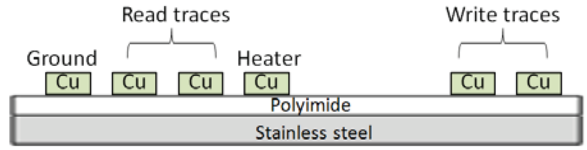
A flexible printed circuit ribbon without a cover layer connects the HDD heads to an amplifier via TSAI behaving like an antenna [9]. Then, the TSAI can pick up the EMI signal and can cause failures in magnetic recording heads, which are severe problems [3]. Thus, one approach to mitigate the EMI is the overcoat of the interconnector traces with absorbing magnetic material [10, 12]. A drawback of this technique is an increase in the size of the TSAI, hence, it is undesirable for HDD applications.

The aim of this study is to find a new EMI suppression technique on TSAI based on the filling commercialized BSR-1 [13] absorber in the gap between copper traces of TSAI. A physical advantage over the previous approach [10, 12] is that the original TSAI dimensions have not been changed. The absorption properties of the BSR-1 with the radiated and conducted EMI on TSAI are presented. The results throughout this study are determined by using the finite integral technique in CST Microwave Studio [14].

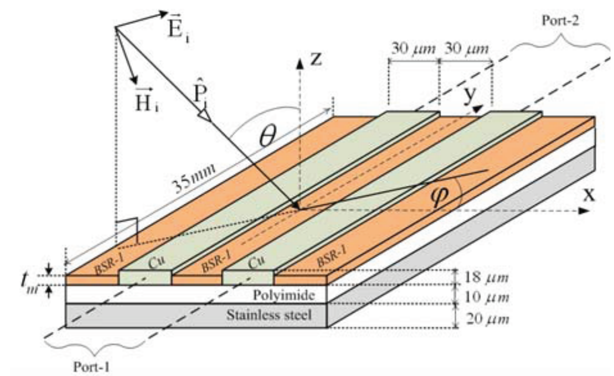
II. INTERFERENCE MODEL FOR TSAI

The form factors of HDD have several dimensions, which consist of 1.8-, 2.5-, and 3.5-inch. The 2.5-inch drive is the main market of HDD technology that mostly uses in present [15]. Then, the selected TSAI is approximately 35 mm in length, which is used in 2.5-inch drives and is used in this simulation. As show in Fig. 1 (a), the TSAI is comprised six copper traces, which are 1 heater trace for flying height control, 2 read traces, 1 ground trace, and 2 write traces. From Fig. 1 (b), it is only two out of six copper traces, which are chosen to exhibit the effect to the active components of radiated [16] and conducted EMI [10].

The selected TSAI structure is supported by a 20 μm of stainless steel with the grooves being filled by BSR-1 between two copper traces are modeled. A 10 μm polyimide dielectric substrate has a permittivity of 3.5 and a dielectric loss tangent of 0.003. To investigate the EMI suppression properties of BSR-1 on TSAI, the simulations begin with the magnetic film thickness (t_m) of zero (no filling BSR-1 absorber), 3, 6, 9, 12, 15, and 18 μm (100% filling BSR-1 absorber).



(a)



(b)

Fig. 1. (a) Cross-sectional geometry of TSAI [8] and (b) model of conduction EMI and radiation EMI.

The simulations of the radiated EMI are shown in Fig. 1 (b). The TSAI is exposed to the 1 V/m incident field of 20 GHz bandwidth Gaussian pulse. It achieves the maximum coupling, when the propagating field is oriented, such that an E-field is perpendicular to the plan of incident (the elevation angle θ = 90°, and azimuth angle φ = 90°) [17].

The radiated noise can be measured when the 50 Ω of load impedances are terminated at both ends of TSAI. The occurrence of the radiating noise voltage at the far-end terminal of the TSAI is determined by coupling voltage (V_{FE}) where the active components are located [17]. The radiated EMI suppression effected by using BSR-1 on the TSAI is defined as the shielding effectiveness (SE), which is given by equation (1) [18],

$$SE = 20\log(V_{FEwithout-filled} / V_{FEwith-filled}) \ . \quad (1)$$

For the conducted EMI simulation, the port label is defined to calculate S-parameters obtained from the CST simulation software as shown in Fig. 1 (b). Both reflection coefficient (S_{11}) and transmission coefficient (S_{12}) are evaluated to analyze the conducted EMI on the interconnector [11]. The evaluation of conducted EMI suppressed on TSAI by using BSR-1 can be estimated by power absorption, which is defined as the ratio of loss power to input power (P_{loss}/P_{in}), using the following equation [13],

$$P_{loss}/P_{in} = 1 - \left(\left|S_{11}\right|^2 + \left|S_{21}\right|^2\right) . \quad (2)$$

The electromagnetic properties of BSR-1 are depicted in Fig. 2. The major parameters determining the absorbability comprise a real-part permeability (μ') an imaginary-part permeability (μ'') and a magnetic loss tangent (tan δ_m). The tan δ_m represents an absorption performance of the material. As seen in Fig. 2, the maximum tan δ_m occurs around 10 GHz – 14 GHz, this means that the material provides a good absorption performance around 10 GHz [19].

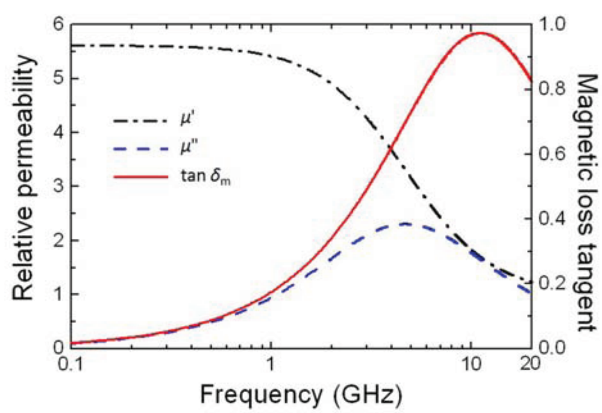


Fig. 2. Material properties of BSR-1.

The absorption ability of BSR-1 material is indicated by reflective loss (*RL*). It is given by equation (3) [19],

$$RL = -20\log\left|\frac{Z_{in}-50}{Z_{in}+50}\right| \quad (3)$$

$$Z_{in} = \sqrt{\frac{\mu' - j\mu''}{\varepsilon' - j\varepsilon'' - j\sigma/(\omega\varepsilon_0)}} \cdot \tanh\left(\frac{jd\omega}{c}\sqrt{(\mu' - j\mu'')(\varepsilon' - j\varepsilon'' - j\sigma/(\omega\varepsilon_0))}\right) , \quad (4)$$

and

$$\omega = 2\pi f \quad , \quad (5)$$

where $Z_{in}, \mu', \mu'', \varepsilon', \varepsilon'', \varepsilon_0, \sigma, f, d,$ and c represent impedance of incidence wave, real part of permeability, image part of permeability, real part of permittivity, image part of permittivity, permittivity of vacuum, conductivity, frequency of electromagnetic wave, thickness of material, and light speed, respectively [19].

As seen in Fig. 3, the *RL* of BSR-1 significantly decreases with increasing t_m and frequency according to the details in [19]. This can be explained by the magnetic loss, which is inversely proportion when frequency and t_m were increased [19]. It is likely to be one of good candidates for EMI suppressor at this frequency region. Hence, the EMI absorption ability on TSAI is also explained in this study.

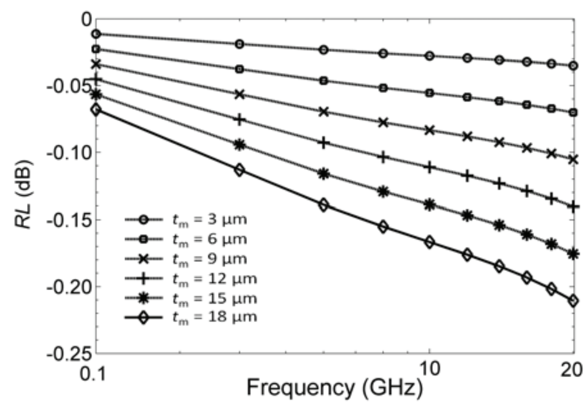


Fig. 3. Reflective loss of BSR-1with various magnetic film thickness (t_m).

III. RESULTS AND DISCUSSIONS

A. Suppression characteristics for the radiated EMI

In this section, the effects of BSR-1 absorber on the coupling voltage (V_{FE}) and shielding effectiveness (SE) are analyzed. The V_{FE} versus frequency with various t_m for the examined structures are shown in Fig. 4. A considerable amount of decoupling at GHz is observed with increasing t_m because the decrement of V_{FE} with increasing t_m is evaluated. For $t_m \geq 15$ μm, the lowest of V_{FE} is obtained at all frequency regions. Besides, the fluctuation of V_{FE} from dimensional resonance at around 17 GHz – 19 GHz is removed. It is a desirable characteristic for the decoupling signal because both fewest and smoothest of V_{FE} are achieved. This effect is due to a higher magnetic loss from a higher surface impedance of absorber with increasing absorber thickness [19]. In addition, the suppression of radiated EMI is obtained by increasing t_m because of the attenuated V_{FE} by increment of t_m. Furthermore, the TSAI with $t_m \geq 15$ μm can suppress a large of coupling voltage from 16 μV into 0.5 μV at all regions.

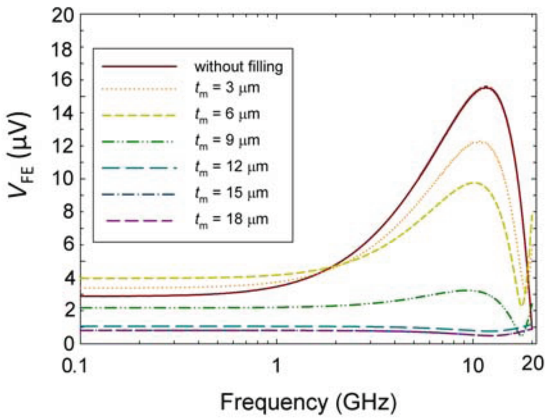


Fig. 4. Coupling voltage (V_{FE}) with various magnetic film thicknesses (t_m).

Figure 5 shows the SE of TSAI, which is calculated from equation (1). It is seen that the SE is above 10 dB for frequency below 1 GHz as well as rapidly increasing as a function of frequency from 1 GHz to 10 GHz. In addition, the SE reaches the maximum of 30 dB at 12 GHz. After that, SE is dramatically decreased from frequency over 13 GHz and attains 10 dB at 19 GHz. However, the SE is decreasing below 10 dB for 19 GHz – 20 GHz range, which is the undesirable characteristic for the radiated EMI suppression. As the results, the shielding of radiated EMI over 10 dB at 0 GHz – 19 GHz and the highest of 30 dB at 12 GHz are achieved for TSAI with 100% filling BSR-1 absorber. Hence, TSAI with 100% filling of BSR-1 absorber is the best choice to suppress the radiated EMI, which is appropriate at 0 GHz to 19 GHz region with the greatest performance at 12 GHz.

B. Suppression characteristics for the conducted EMI

The S_{11} and S_{21} versus frequency with various t_m are depicted in Fig. 6. Both S_{11} and S_{21} decrease with the increasing of t_m and frequency. This is because the absorption of the conducted currents caused by magnetic loss (see in Fig. 3) is proportional to t_m and frequency [19]. From Fig. 6, it is clearly observed that a magnitude of S_{11} and S_{21} decrease with increasing t_m. For all regions, the S_{11} obtains below -10 dB with the t_m above 3 μm and provides the minimum with t_m of 18 μm (100% filling BSR-1 absorber). For the S_{21}, it decreases as frequency increases, however, the level of S_{21} decreased when t_m increased. In addition, the maximum attenuation at over 1 GHz is achieved with 100% filling BSR-1 absorber. Also, the suppression ability of TSAI in case of conducted EMI can be controlled in 1 GHz to 20 GHz by varying t_m.

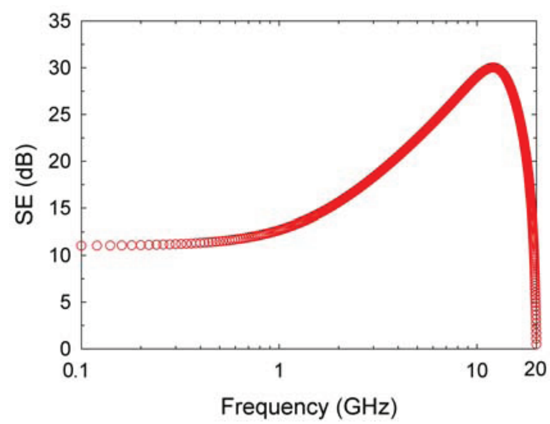


Fig. 5. Frequency dependence of shielding effectiveness (SE) in dB.

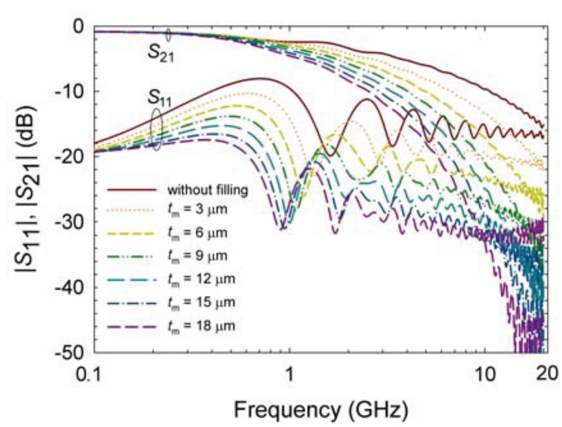


Fig. 6. S-parameters with various magnetic film thickness (t_m).

Figure 7 shows P_{loss}/P_{in} as a function of frequency with various t_m. It is found that the P_{loss}/P_{in} rapidly increases as frequency increases. It is according to the results shown in Fig. 6. From Fig. 8, P_{loss}/P_{in} of the 100% filling BSR-1 on TSAI begins to rise up to 0.7 GHz and tends to decrease around 0.3 GHz. This means that the filling BSR-1 absorber on TSAI can tune the absorption frequency region. Furthermore, the pure power absorbed is calculated by the difference between P_{loss}/P_{in} with and without 100% filling BSR-1 absorber, which is represented by $\Delta P_{loss}/P_{in}$ as a solid line in Fig. 8. It is found that the $\Delta P_{loss}/P_{in}$ initiates rise at 0.1 GHz and rapidly increases to 0.7 W. This means that the conducted EMI can be suppressed up to 0.7 W and normalized by 1 W of the input power in a range of 0.9 GHz – 4.0 GHz. Thus, the proposed technique is an outstanding approach to suppress the conducted EMI in the GHz region.

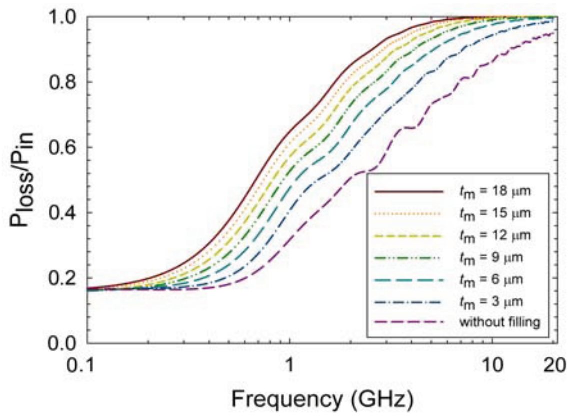


Fig. 7. The ratio of loss power to input power (P_{loss}/P_{in}), with various magnetic filling thickness (t_m).

IV. CONCLUSIONS

A novel electromagnetic interference suppression technique using magnetic material in the gap between the trace suspension assembly interconnector (TSAI) is proposed. The attenuations of radiated and conducted emissions are analyzed by using simulation software based on finite integral technique. From the radiated results, it is found that the proposed technique, especially the 100% filled TSAI provides the lowest of 0.5 μV of the coupling voltage. In addition, the shielding effectiveness of the 100% filled TSAI shows the greatest performance at 12 GHz according to the electromagnetic properties of the absorber material. For conducted emission, the results show that the power absorption decreased with increasing the absorber thickness and the large of absorbability of 0.7 W in a range of 0.9 GHz – 4.0 GHz is provided. Hence, this technique is an alternative technique that is suitable for practical TSAI design to provide a good immunity for EMI reduction at GHz region.

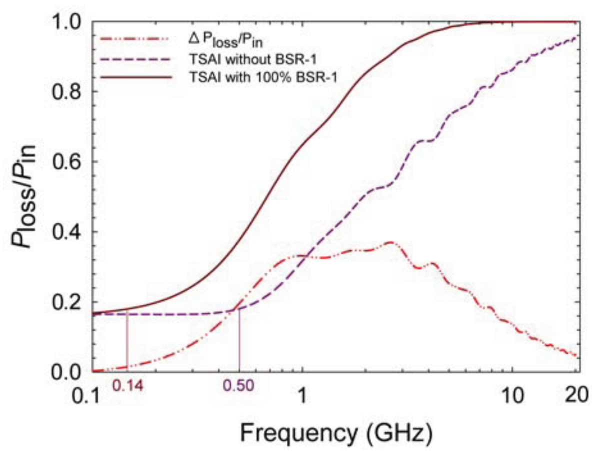


Fig. 8. The ratio of loss power to input power (P_{loss}/P_{in}) and the difference of P_{loss}/P_{in} between TSAI with and without 100% filling BSR-1 absorber ($\Delta P_{loss}/P_{in}$).

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