A Methodology to Identify Crosstalk Contributor from 6-Line Suspension Assembly Interconnect of Ultra-High Capacity Hard Disk Drives

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Abstract **─** The crosstalk phenomenon on the suspension assembly interconnecting trace (SAIT) in hard disk drives (HDD) causes the signal to deform and/or degrade the recording head. For the purpose of analyzing the crosstalk contributions from SAIT using the 3D electromagnetic simulation tool, SAIT is divided into 4 sections which are bend section (BS), far-end section (FS), straight section (SS), and near-end section (NS). The length of each section is selected based on the physical shape of the trace and characteristic impedance. From the results, it was observed that the lowest crosstalk occurs at the BS and the highest crosstalk occurs at the NS. NS is necessary during a HDD quality evaluation and is removed before the SAIT installed in the HDD. With such high crosstalk, the test results can indicate poor head performance even when the head is working properly. Moreover, the crosstalk can be suppressed up to 14 dB and 33 dB for the near-end side and the far-end side, respectively when the NS with a 100% filled stainless steel backing layer is applied to the SAIT. Hence, to improve the accuracy of the recording head test performance, the designer should put more effort to design the SAIT near-end section to minimize crosstalk.

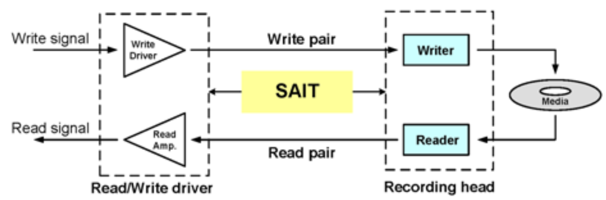

Fig. 1. A diagram of the interconnect links between the recording head and the read/write driver.

Index Terms **─** Crosstalk, hard disk drive, head gimbal assembly, scattering parameters, suspension assembly interconnecting trace.

I. INTRODUCTION

In the recording head based on tunneling magneto-resistive (TMR) technology, SAIT is used to transfer the data signal between the read/write (R/W) and the recording head, as shown in Fig. 1. To improve the R/W performance in the ultra-high capacity hard disk drive [1], a heating circuit is integrated in the present design. As the result, the space between the traces is made even closer to each other to accommodate the heating lines. Unfortunately, the crosstalk which is an unintended signal from one circuit coupled to the adjacent circuit will increase [2]. The crosstalk

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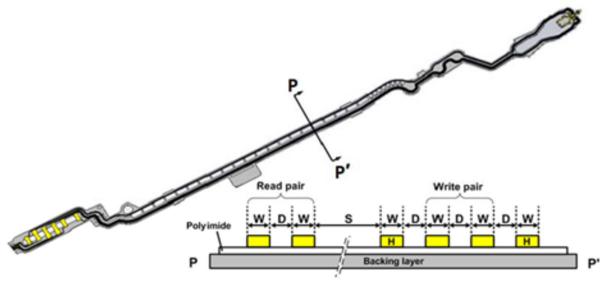

Fig. 2. A 6-trace SAIT 3D model and a cross sectional view along P-P′ plane.

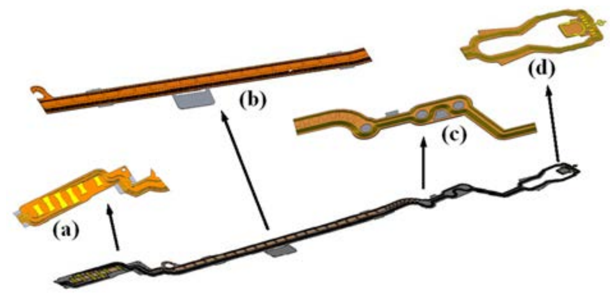

Fig. 3. The 4 sections: (a) NS, (b) SS, (c) BS, and (d) FS.

on the SAIT is reported in [3-10] and the mechanisms are explained in [3 and 11]. Due to the narrow spacing and the TMR recorder's extreme sensitivity, the crosstalk posts more challenges to the SAIT designer.

Before a better SAIT design can be sought, a crosstalk contribution along the trace must be understood. In this paper, a methodology to identify a dominated generating crosstalk portion along the SAIT is proposed. Since the traces along the SAIT structure are non-uniform, one approach is to divide the SAIT according to the physical shape and the characteristic impedance. By using a 3D electromagnetic simulation tool, the scattering parameters (S-parameters) are calculated and the parameters are used to be the crosstalk indicator.

II. THE SUSPENSION ASSEMBLY INTERCONNECTING TRACE STRUCTURE

The 3D model of SAIT, commercially used in the HDD industrial, and the cross section are shown in Fig. 2. It is composed of 3 layers, i.e. the insulator layer, conductor line layer, and backing layer which included polyimide, copper, and stainless steel. The 6 conductive traces consist of a write pair, a read pair, and a heating circuit line (H). The trace width (W), the distance of edge-to-edge between traces (D), and the distance of edge-to-edge between the read trace and the heater trace (S), are 30.5, 30.5, and 535 μm, respectively. The thicknesses of the stainless steel, polyimide, and copper are 20, 10, and 18 μm, respectively. The relative permittivity of polyimide is 3.2, while the conductivity of stainless steel and copper are 1.1×10^6 S/m and 5.8×10^7 S/m, respectively [12].

Although the length of SAIT in the 3.5″ HDDs is only 5 cm, the structure and shape of interconnect is complex and non-uniform, as shown in Fig. 2. Therefore, in order to analyze the write-to-read coupling sensitivity of this structure, the SAIT is divided into 4 sections according to the physical structure, that is the near-end section (NS), straight section (SS), bend section (BS), and far-end section (FS), as shown in Fig. 3.

NS includes two read pads, two write pads, and the heating pads. The pads are used during the electrical test of the head gimbal assembly process. It is edged in the hard drive assembly process. For SS, the conductor lines on this section are straight and the write and read pair spacing is kept constant. Around BS, the conductor lines on this section are bent and the write-read pair spacing are varied. FS consists of the read pads, the write pads, and the heating pads connected with the pads on the recording head whereas the spacing between the write-read pair is not constant.

In the cases of a differential line pair, it is characterized by the differential impedance (Z_{diff}). In the SAIT segmentation length, Z_{diff} is selected as the criteria to locate the section-to-section demarcation. The Z_{diff} is the calculating impedance viewing from the left side of each section with a 50-Ω load at the other end. The segment length is determined such that the change of Z_{diff} is less than only 3% hence, the terminal location between two sections has no effect on the crosstalk levels of each section as reported by Hentges [10].

III. THE CROSSTALK PHENOMENON ON THE INTERCONNECT

The electromagnetic coupling mechanisms on the SAIT are reported in [3]. It is the transport of

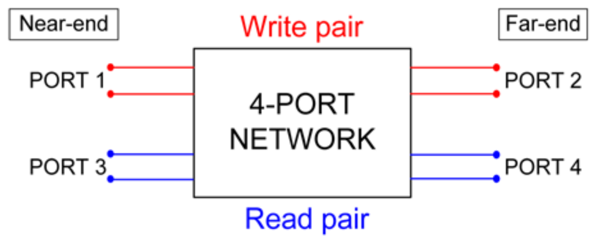

Fig. 4. The 4-port network diagram representing the write and read pairs.

energy from one line to another line via capacitive and inductive couplings which can be expressed by equations (1)-(2).

$$i = C_m \frac{dv}{dt}, \tag{1}$$

$$v = L_m \frac{di}{dt}, \tag{2}$$

where C_m and L_m are mutual capacitance and mutual inductance, v and i are induced voltage and current on the adjacent read line.

In the event of the coupling between the differential line pairs, such as the write-to-read coupling, mutual- capacitance, and inductance of two differential line pairs are represented by the mutual capacitance C_{md} and mutual inductance L_{md}, respectively [13].

The S-parameters are calculated and are utilized as the indicator of energy coupled from the write pair to the read pair due to the crosstalk phenomenon. It has been reported that S-parameters given in (3) give more accurate results at high frequency than other parameters [14].

$$S_{ij}(dB) = 20\log\left(\frac{V_i^-}{V_j^+}\right)\Bigg|_{V_k^+=0 \ for\ k\neq j}, \tag{3}$$

where S_{ij} is the transmission coefficient from port j to port i and all remaining ports are terminated in the matched load ($V_k = 0$ for $k \neq j$). The V_i^- is a reflected voltage and V_j^+ is an incident voltage.

Generally, the coupling on the victim line (the read line) is represented by two parameters, i.e. the near-end crosstalk (NEXT) and the far-end crosstalk (FEXT), which is the write-to-read signal coupling observed at the near-end side and the far-end head side of the read lines, respectively. Figure 4 shows the 4-port network diagram. Therefore, NEXT in terms of S_{31} is the ratio between an incident voltage applied at port 1 to a reflected voltage from port 3. Similarly, FEXT in

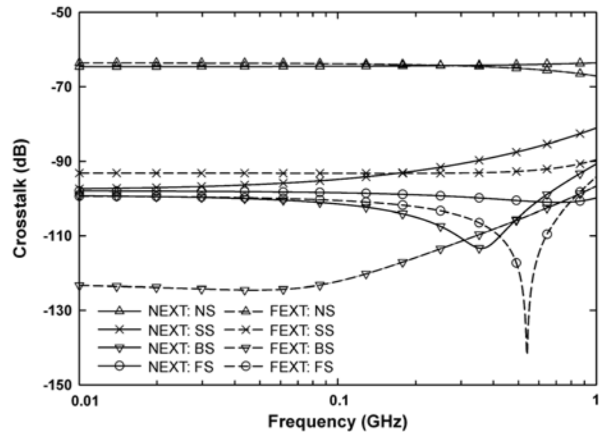

Fig. 5. The NEXT and FEXT of 4-SAIT sections.

Terms of the S parameters is the ratio between an incident voltage applied at port 1 to a reflected voltage from port 4, S_{41}.

IV. THE SIMULATION SETTING

The signal source in the simulation is a Gaussian pulse and it is fed into port 1 of each section. The crosstalk amplitudes based on the S-parameters are both NEXT and FEXT on the read pair and are obtained from CST Microwave Studio [15], which is based on the finite integral technique. The number of cuboids is about 10^6 cells. The operating frequency in this study is 0.01-1.0 GHz, which is compatible with the test procedure in industrial. The boundary condition is set as the magnetic wall for all directions which is recommended for the signal integrity problem [15].

V. RESULTS AND DISCUSSIONS

A. The crosstalk on each SAIT section

The crosstalk levels of 4 portions of SAIT are shown in Fig. 5. It is found that the crosstalk at NE of BS is calculated to be -96 dB, in a frequency range of 10-560 MHz. Also, a very low FEXT of -124 dB is observed in a range of 10-400 MHz. For FS, the crosstalk trace indicates a sharp null of -146 dB at the FE side and occurs around 550 MHz, It might be contributed from the FS acts like the LC resonator of the defected ground structure due to the aperture in the backing layer [16]. While at the NE side, it is almost constant at a level of -99 dB. For BS at NE and FS at FE, it is shown that the crosstalk is in an acceptable range.

Table 1: The self- and mutual- crosstalk parameters of 4 sections at 0.12 GHz

Parameter	Section			
	NS	SS	BS	FS
C_{md} (μF)	0.47700	0.06110	0.00120	0.00923
L_{md} (μH)	0.0256	0.0461	0.1580	0.1030
C_{sd} (pF)	1.360	4.420	1.410	0.871
L_{sd} (μH)	1.290	0.398	1.240	2.580
C_{md}/C_{sd}	351,917.40	13,826.99	7,892.50	10,604.38
L_{md}/L_{sd}	1.99×10^{-5}	1.16×10^{-4}	1.27×10^{-4}	4.01×10^{-5}

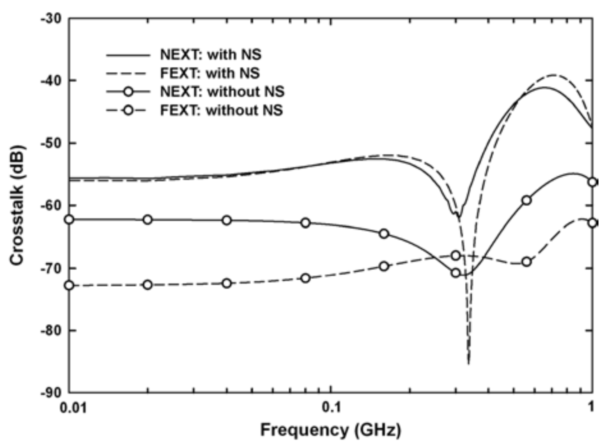

Fig. 6. The crosstalk levels on SAIT in case with and remove NS.

The crosstalk at the NE side of SS is increased with the increasing of frequency and is calculated to be -81.1 dB at 1 GHz, while the crosstalk at FE side is observed as constant at -89.6 dB. For NS, it processes the highest crosstalk of -64.3 dB at NE and -63.9 dB at FE. This can be explained in terms of the spacing between the write and read pair that the narrowing space between the write and read pair possess a stronger coupling and this is in agreement with the result in [13].

This spacing can be represented by C_{md} and the corresponding parameters obtained from the CST are shown in Table 1. NS has the largest C_{md}, and hence, the crosstalk levels are the highest. In addition, it is observed that the crosstalk levels of the portions are correlating to C_{md}/C_{sd} ratio of the induced voltage [17]. The L_{md}/L_{sd} ratio is very small in every section analyzed when compared against the C_{md}/C_{sd} ratio and hence L_{md}/L_{sd} can be neglected. The C_{md}/C_{sd} ratio correlates with the crosstalk level depicted in Fig. 5. In summary, the highest to the smallest crosstalk levels are NS, SS, FS, and BS, respectively.

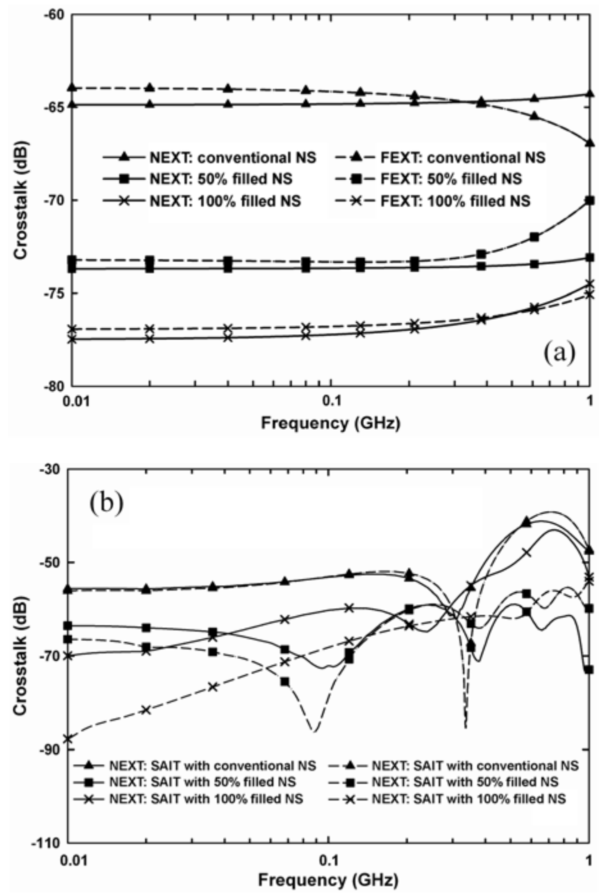

Fig. 7. The crosstalk levels of (a) NS with filled and conventional backing layer and (b) SAIT with filled and conventional NS backing layer.

B. SAIT with and without the near-end section

In industrial practice, NS is removed from SAIT before it is installed in the HDD. However, NS is necessary during the recording head testing processes. There are many test steps where the write-to-read coupling level from the crosstalk can be ascertained. The crosstalk levels with and without NS are compared and are shown in Fig. 6.

From Fig. 6, NEXT and FEXT voltages with NS are higher than SAIT with NS being removed by about 5 dB and 16 dB at 1 GHz, respectively. This is due to the fact that NS is the first section connected to the source in the testing process. The crosstalk levels are higher than SAIT without NS. Hence, a strong crosstalk effect occurred on the SAIT used in the testing process may cause inaccurate test results or totally misinterpreting a recording head performance before being installed in a HDD.

C. The effect of stainless steel filled backing layer of the near-end section

Instead of analyzing using a conventional windowed backing layer at NS, the percentage of stainless steel of backing layer is also used. The crosstalk of the filled percentage and conventional backing layer is compared and is shown in Fig. 7a. The crosstalk levels of the conventional NS are in the range of -64 - -65 dB, while 50% filled and 100% filled are about -74 dB and -77 dB, respectively. This is in agreement with the results described in [10].

The crosstalk levels of the entire SAIT with the filled and conventional backing layer of NS with the conventional, 50% filled with stainless steel, and 100% filled with stainless steel backing layer are shown in Fig. 7b. It can be noticed that at 10 MHz, the NEXT and FEXT of the entire SAIT with 100% filled with stainless steel are suppressed 14 dB and 33 dB, respectively, when compared with the conventional SAIT. In addition, the crosstalk levels of SAIT decreased when the crosstalk levels of NS are also low. Therefore, to avoid the recording head degradation and to improve the performance, the designer must suppress the NS crosstalk.

VI. CONCLUSIONS

The methodology to identify the crosstalk effect on the 6-trace SAIT is proposed. Since the SAIT structure is complex and non-uniform, it is divided into 4 sections according to the physical shape and Z_{diff}. The crosstalk levels represented by *S*-parameters obtained from the commercial software of all sections are enumerated. It is determined that the BS has the lowest crosstalk levels whereas the NS has the highest crosstalk levels. This strong coupling exists at the NS which elevates the crosstalk level of the entire SAIT. Consequently, the presence of the NS may lead to the wrong test results and/or the interpretation of recording head performance. Finally, in order to minimize the crosstalk, the designer should put effort to mitigate crosstalk at the NS.

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