Effect of Write Current and Capacitive Coupling on Write-Read Traces

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Abstract: This study aims to investigate the effect of write-read coupling between write-read traces of recording head. It has been reported that a high data rate causes a serious coupling. Since a write-current is a main coupling source, the study of this current on the coupling is to investigate in association with the effect of capacitive-coupling. The results and discussions are explained.

1. Introduction

In a Head Gimbal Assembly (HGA), a space between traces on the suspension interconnect have a narrow space. As a result, a crosstalk between write-read traces is presented.

The suspension interconnect links the recording head to the Read/Write Module as shown in Figure 1. Currently, HGA have 6 traces consist of w+, w-, r+, r-, heater and GND as shown in Figure 2. For heater and GND, it is not interested because it uses direct current (DC) that is not relative with crosstalk.

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The sources induced in the jth trace of the read line are represented by the term on the right-hand-sides of Eq. (5) and (6). As seen in Figure 4(a), the mutual capacitance between the lines is

\[
\frac{\partial V_x(z,t)}{\partial z} = -\frac{m_j}{L} \frac{\partial I_y(z,t)}{\partial t} - L \frac{\partial d_j(z,t)}{\partial t}
\]

\[
\frac{\partial V_y(z,t)}{\partial z} = \frac{c_{ij}}{L} \frac{\partial V_x(z,t)}{\partial t} - \frac{\partial c_{ij}}{L} \frac{\partial V_y(z,t)}{\partial t}
\]

Hence, it is assumed that the traces are weakly coupled and then, Eq. (3) and (4) can be rearranged for the read traces as

\[
\frac{\partial V_x(z,t)}{\partial z} + \frac{m_j}{L} \frac{\partial I_y(z,t)}{\partial t} = \frac{c_{ij}}{L} \frac{\partial V_x(z,t)}{\partial t}
\]

\[
\frac{\partial V_y(z,t)}{\partial z} + \frac{\partial c_{ij}}{L} \frac{\partial V_y(z,t)}{\partial t} = c_{ij} \frac{\partial V_y(z,t)}{\partial t}
\]
c_{ijl} and the mutual inductance is m_{ijl}, where l is the total lengths of the suspension interconnect.

Figure 4. Equivalent circuit of [1]
(a) write and read traces,
(b) write-read coupling and
(c) PSPICE model of write-to-read coupling.

In Figure 4(b), the capacitance c_{ij} between the i^{th} trace of the write line and the j^{th} trace of the read line causes a current I(t) to flow into the j^{th} trace, which is given by [1]

\[ I(t) = c_{ij} \frac{dV_{w}(t)}{dt} \]  \hspace{1cm} (7)

where V_{w}(t) is the write voltage between i^{th} write trace and the reference.

Similarly, the write current, I_{w}(t), of the write line induces a voltage in series with the read trace, which is given by

\[ V(t) = m_{ij} \frac{dI_{w}(t)}{dt} \]  \hspace{1cm} (8)

3. Results

The simulated model used for this study is shown in Figure 4(c). From this model they are considerably floating nodes on capacitive and inductive coupling. Therefore, both capacitive and inductive coupling are grounded. A \pi -(p)-equivalent-circuit of read trace is shown in Figure 5 and connected to the end of read trace, in Figure 4(c). In Figure 5, R is resistance in j^{th} trace of the read line, L is inductance in j^{th} trace of the read line, C is capacitance in j^{th} trace of read line and R_h is resistance of reader. The voltage and current produced from write-to-read coupling in Figure 4(c) acts as an input of read trace in Figure 5.

Figure 5. \pi -equivalent-circuit of read trace [3].

In this experiment, a current flowing to the head, called head current (I_{Rh}), is studied when write current (I_w) and mutual capacitance (c_{ij}) are varied at 1 kHz and 100 kHz frequencies. For signal analysis, 3 parameters to be measured; decay time (t_d), rise time (t_r) and fall time (t_f).

3. 1 Write current dependence

An adapted circuit for write current effect is shown in Fig. 6

A write current (I_w) is varied from 1 mA to 40 mA, a mutual capacitance (c_{ij}) is fixed at 0.58 pF and 1kHz frequency. The result is shown in Figure 7(a) where the result of 100 kHz frequency is shown in Figure 7(b).

From Figure 7(a), where the frequency is 1 kHz, it is seen that I_{Rh} is increased as I_w increases. The other 3 time-parameters are in a range of 0.01 μs to 1 μs; t_d ~ 1 μs, t_r ~ 0.1 μs and t_f ~ 0.01 μs. In Figure 7(b), where the frequency is 100 kHz, the dependence of I_{Rh} on I_w is similarly to that in Figure 7(a) but the time-parameters exhibit differently. It is seen that the 3 time-parameters are in a range of 0.00001 μs to 0.0001 μs; t_d ~ 0.0001 μs, and t_r, t_f ~ 0.00001 μs.
Gain (Time Ratio /100 kHz frequency) as shown in Table 1 and Figure 8.

Table 1. Time-Sensitive-Frequency Gain of write current

<table>
<thead>
<tr>
<th>f</th>
<th>1 kHz [μs]</th>
<th>100 kHz [μs]</th>
<th>Time Ratio = ( \frac{t_{f} at 1kHz}{t_{f} at 100kHz} )</th>
<th>TSFG (TimeRatio / 100kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>t_f</td>
<td>0.01</td>
<td>0.000001</td>
<td>(10^4)</td>
<td>0.1</td>
</tr>
<tr>
<td>t_r</td>
<td>0.01</td>
<td>0.000001</td>
<td>(10^4)</td>
<td>0.1</td>
</tr>
<tr>
<td>t_d</td>
<td>0.1</td>
<td>0.000001</td>
<td>(10^5)</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 8. Time-Sensitive-Frequency Gain of write current.

From Figure 8, it is seen that the time-parameters at 100 kHz are much lower than those at 1 kHz and so, the Time-Sensitive-Frequency Gain means that how fast a signal is in 2 comparable frequencies. Thus, it is seen that \(t_f\) is most sensitive whereas \(t_r\) and \(t_d\) are in the same order of sensitivity.

3.2 Mutual capacitance dependence

A trace of each head type is not the same space and this may cause different electric coupling. Therefore, a mutual capacitance, \(c_{ij}\) represented the capacitance between trace spaces is used for evaluation. That means a narrow space between 2 traces results in a large mutual capacitance or vice versa.

A mutual capacitance \((c_{ij})\) is varied from 0.1 pF to 500 pF, a write current is fixed at 5 mA and 1 kHz frequency. The result is shown in Figure 9(a) where the result of 100 kHz frequency is shown in Figure 9(b).

From Figure 9(a), where the frequency is 1 kHz, it is seen that \(I_{Rh}\) is increased as \(c_{ij}\) increases. The other 3 time-parameters are in \(0.01 \mu s; t_d \sim 0.01 \mu s, t_r \sim 0.01 \mu s\) and \(t_f \sim 0.01 \mu s\). In Figure 9(b), where the frequency is 100 kHz, the dependence of \(I_{Rh}\) on \(c_{ij}\) is similarly to that in Figure 9(a) but the time-parameters exhibit differently. It is seen that the 3 time-parameters are in a range of \(0.00001 \mu s to 0.0001 \mu s; t_d \sim 0.0001 \mu s, t_r \sim 0.0001 \mu s, t_f \sim 0.0001 \mu s\).

It is observe that the Time Ratio of 3 time-parameters are fascinatingly interested and also the Time-Sensitive-Frequency Gain (Time Ratio /100 kHz frequency) as shown in Table 2 and Figure 10.

Table 2. Time-Sensitive-Frequency Gain of mutual capacitance

<table>
<thead>
<tr>
<th>f</th>
<th>1 kHz [μs]</th>
<th>100 kHz [μs]</th>
<th>Time Ratio = ( \frac{t_{f} at 1kHz}{t_{f} at 100kHz} )</th>
<th>TSFG (TimeRatio / 100kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>t_d</td>
<td>0.01</td>
<td>0.00001</td>
<td>(10^2)</td>
<td>0.001</td>
</tr>
<tr>
<td>t_r</td>
<td>0.01</td>
<td>0.00001</td>
<td>(10^3)</td>
<td>0.01</td>
</tr>
<tr>
<td>t_f</td>
<td>0.01</td>
<td>0.00001</td>
<td>(10^3)</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Figure 10. Time-Sensitive-Frequency Gain of mutual capacitance.

From Figure 10, it is seen that the time-parameters at 100 kHz are much lower than those at 1 kHz and the Time-Sensitive-Frequency Gain of \(t_d\) is least sensitive whereas \(t_r\) and \(t_f\) are in the same order of sensitivity.
4. Conclusion

From the result, it is shown that a write current ($I_w$) and a mutual capacitance ($C_{ij}$) affects a head current due to write-to-read coupling. When a frequency increases, an amplitude of head current ($I_{Rh}$) also increases but a decay time, rise time and fall time is decreased. It means that at high data rate, amplitude of head current ($I_{Rh}$) is higher than that at low data rate. Since a range of read and write frequencies are in MHz to GHz, amplitude of head current ($I_{Rh}$) can be large enough to degrade recording head. The Time-Sensitive-Frequency Gain means that how fast a signal is in 2 comparable frequencies. In the result of head current dependence on write current, it is shown that $t_f$ is most sensitive whereas $t_r$ and $t_d$ are in the same order of sensitivity. However, for Time-Sensitive-Frequency Gain in the result of head current dependence on mutual capacitance, it is shown that $t_d$ is least sensitive whereas $t_r$ and $t_f$ are in the same order of sensitivity.

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