Signal Induced EMI in Fibre Channel Cable-Connector Assemblies

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Abstract: The EMI performance of cable-connector assemblies designed for FC–0 transmission has been studied. Two types of cable and two connector styles were evaluated. Experimental results show that the dominant radiation mechanism for short cable lengths is the common-mode current caused by source and PCB skew that leaks to the exterior of the shield via the transfer impedance of the connector. However, the cable imbalance becomes a more significant source of common-mode current than the source skew when the cable assembly is tens of meters long.

INTRODUCTIONS

The Fibre Channel FC-0 protocol provides a data transmission rate of 1.0625 Gigabits/second over a copper interface. Differential signaling helps to minimize problems due to unintentional radiation. Radiated emissions from systems employing FC-0 data transmission can result due to imperfections in the cable–connector assembly as well as signal skew and imbalance in the board layout. High-speed board layout issues are well understood. The skew imbalance of differential signals at 1GB/s has also been studied [1]. This paper examines signal-induced EMI in the cable-connector assembly.

Ideally, a perfect cable-connector assembly driven by a perfect differential source with zero imbalance will never radiate at any frequency. Radiated emission is the result of common-mode current induced on the exterior of the cable shield. Two basic mechanisms are responsible for this effect: imbalance and non-zero transfer impedance. Imbalance causes skew in magnitude, phase, and/or wave shape between two differential driving currents resulting in common-mode current on the interior of the cable-connector shield. Non-zero transfer impedance, which is the result of imperfect field containment, allows this current to leak to the exterior surface of the shielding. The cable itself acts as an antenna and can result in radiated emission problems.

The common-mode spectral components for a 1.0625 GB/s continuing 101010 waveform, particularly the fundamental 531.25 MHz component, are relatively insensitive to the rise time but greatly dependant on delay skew [1]. Delay skew has three primary sources: imbalance inherent in the differential signal source, imbalance induced by the PCB layout, and distributed imbalance in the cable-connector assembly. Cables intended for FC-0 protocol provide two pairs of conductors to carry bi-directional data. What serves as the transmission pair on one end of the assembly becomes the receiving pair on the other end, and vice versa. Both pairs contribute to the total distributed imbalance. A parasitic EMI coupling path model for the cable-connector assembly has been developed and is shown in Figure 1.

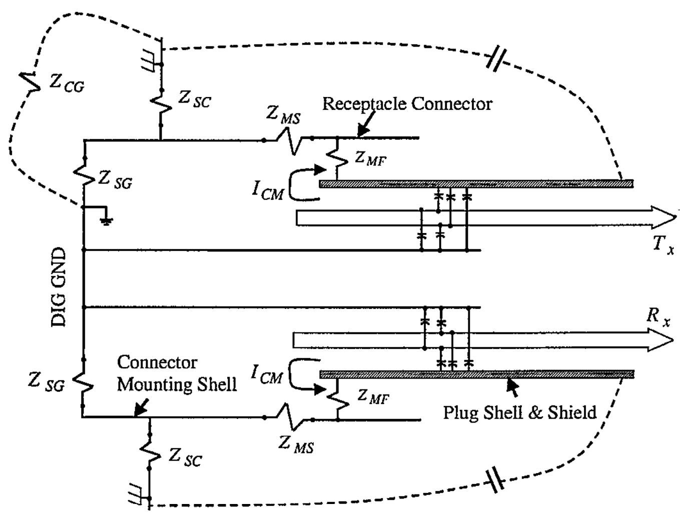


Figure 1: Parasitic EMI Coupling Path Model for Cable-Connector Assembly

The non-zero transfer impedance within the cable-connector assembly is due to imperfect cable shielding, imperfect connector shielding, the connector back-shell-to-panel-ground impedance Z_{SG}, and the plug-receptical impedance Z_{MF}. The dominant EMI mechanism depends on the specific situation. A part of the engineering effort for designing high

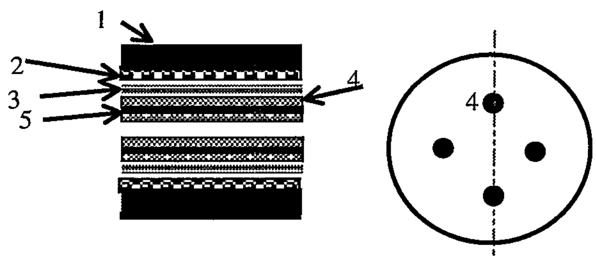
3speed interconnects is to locate the dominant factor responsible for introducing EMI. Hence effective remedies can be designed to improve the EMI performance of the system.

EXPERIMENTAL SETUP

Cables intended for Fibre Channel transmission employ untwisted wire pairs for impedance control and shielding to preserve signal integrity. Two cable types were evaluted:

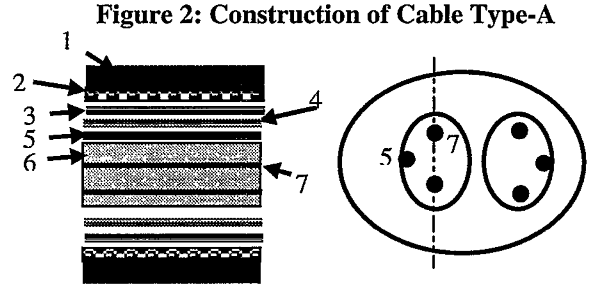
- Cable Type-A: 150-Ω differential balanced quad with a combination of copper braid and aluminized plastic foil as the overall shield.
- Cable Type-B: 150-Ω differential double shielded cable. Each signal group, composed of an untwisted pair and a drain wire shielded by an inner aluminized foil. The outer shield was composed of foil and braid.

The cable constructions are illustrated in Figures 2 and 3.



1: external PVC insulation
2: braid shielding
3: foil shielding (outer side was aluminized)
4: plastic insulation
5: one transmission/receiving conductor

Figure 2: Construction of Cable Type-A



1: external PVC insulation
2: braid shielding
3: exterior foil (outer side was aluminized)
4: internal foil (inner side was aluminized)
5: drain wire
6: plastic insulation
7: one transmission/receiving conductor

Figure 3: Construction of Cable Type-B

Connectors under evaluation include:

- Connector Type-R: a high-speed serial data connector shielded by a rectangular metal can, which provides a small PCB in the plug to accommodate equalization circuitry. Connectors of this type from two manufacturers were evaluated in this study.
- Connector Type-M: Micro-D Subminiature connector with fully enclosed EMI back shell.

At 531.25 MHz, the transfer impedance of Type-R Connectors is approximately 250 mΩ, which is about 15 dB higher than that of Type-M Connectors. The transfer impedance of Type-B cables is approximately 25 mΩ/meter, which is lower than that of Type-A cables [2,3]. Transfer impedance measurements are useful for EMI prediction. However, standard measurement procedures are limited to several hundred megahertz. In addition, significant variations have been observed in the transfer impedance measurement results for cable-connector assembly samples with the same construction [4]. This makes it difficult to relate transfer impedance measurement results to EMI performance at frequencies as high as 1.0625 GHz. As a result, it is necessary to make electromagnetic radiation measurements in order to evaluate the EMI effect of various cable and connector design features at high frequencies.

Cable assemblies in real applications can be tens of meters long. In this situation, the radiated electric field is highly sensitive to details such as the routing and coiling pattern of the cable. Therefore, in most experiments throughout this study, cables were cut to 4-ft lengths, which is approximately 1.22m or 2.18 times the wavelength at 531.25 MHz. The transmission conductor pair was terminated with a 150-Ω resistor simulating the driver/receiver impedance. The truncated cable end and the load resistor were then shielded with copper tape soldered to the braid shield of the cable.

When long cable assemblies were studied, a specially designed dummy load totally shielded with copper tape was used as the far end termination. An aluminum enclosure was used to shield most of the additional cable length with just 4 feet of cable exposed between the driving device and the enclosure. With this setup, the imbalance and the transfer impedance associated with the full cable length contributed to the radiated emissions. However, the effective antenna length was still just 4 feet. Furthermore, it was much easier to perform repeatable experiments with this setup on cable assemblies that were tens of meters long. The measurement configuration is shown in Figure 4.

The driving source is a complex unit installed in a shielded metal enclosure that produces a differential 1.0625 GB/s signal. The driving unit and the cable-connector assemblies under test were placed inside a 3-meter shielded room. The radiated emissions were measured with a BiConiLog antenna and a spectrum analyzer. Although the antenna factor was not calibrated for this non-standard shield room, the measurement results provide relative levels of radiated emission from sample-to-sample. A typical radiated emission measurement result is shown is Figure 5. The dominant component is at the fundamental frequency of 531.25 MHz. This primary component was used as a basis for comparison throughout this study.

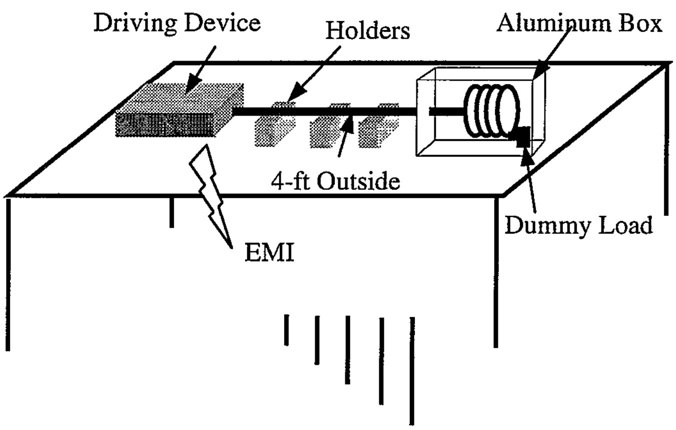


Figure 4: Test Configuration for Long Cable Samples

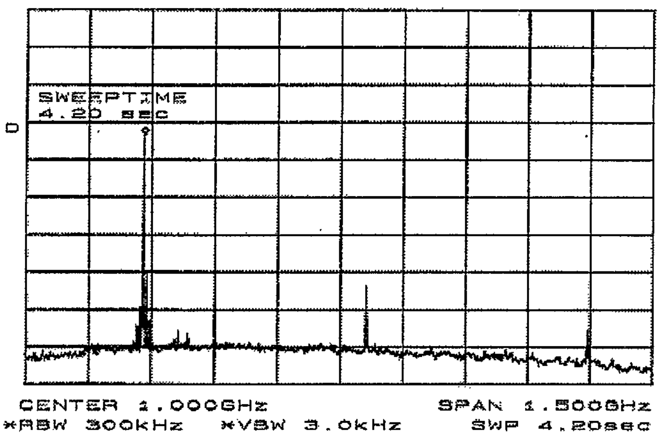


Figure 5: Typical Radiated Power Measurement

MEASUREMENT PROCEDURE AND RESULTS

The first EMI performance study was made on 4-ft samples from three cable-connector assembly types:

- 8 samples of cable Type-A with connector Type-R
- 8 samples of cable Type-B with connector Type-R
- 6 samples of cable Type-B with connector Type-M

Radiated emissions from these 22 samples were measured and each configuration was measured twice. The same driving source was used for all samples of the same assembly type. The measurement results are displayed in Figure 6. Table 1 summarizes these results. The radiation levels from the two cable assembly types with the Type-R connector are in the same range. However, the cable assembly samples employing Type-M connectors produce at least 15 dB less radiation than those samples employing Type-R connectors. This significant difference is due to the transfer impedance associated with the connector, particularly, the plug-receptacle impedance and the connector back-shell-to-panel-ground impedance.

Figure 6 also indicates that substantial variations are observed from sample-to-sample in all three assembly types. The difference between the best and the worst case for the three cable assemblies is 13.17 dB, 10.15 dB and 6.25 dB, respectively. On the other hand, the variation between two measurements of the same sample never exceeded 3 dB.

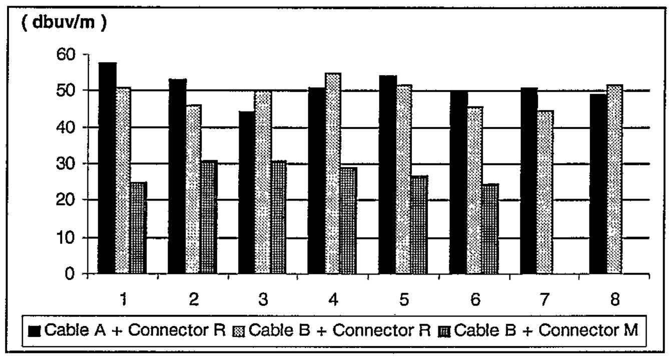


Figure 6: Radiated Emission Population Study

Table 1: Analysis of Population Study Results

Index	Cable A Connector R (dBμv/m)	Cable B Connector R (dBμv/m)	Cable B Connector M (dBμv/m)
The worst	57.5	54.92	30.73
The best	44.33	44.77	24.48
Difference	13.17	10.15	6.25
Mean	51.27	49.48	27.74

In order to establish a "noise floor," a measurement was made with the driving device operating, but no cable assembly attached. There was no measurable radiated emission at 531.25 MHz or any of its harmonic frequencies. Then four 4-ft cable samples, two from Type-A and two from Type-B, which employ Type-R connectors were cut to 1-inch lengths, terminated and shielded in the same manner as the 4-ft cable assemblies. Radiated emission measurements were repeated. The results are displayed in Figure 7.

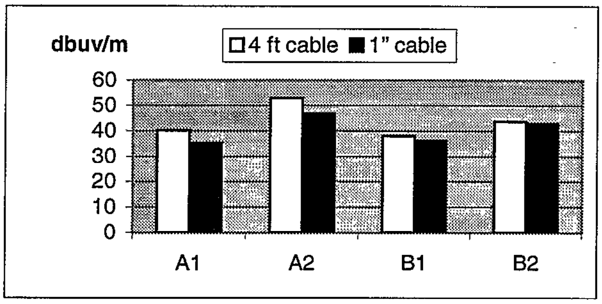


Figure 7: Radiated Emissions from 4-ft and 1-inch Cables

With the 1-inch sample plugged into the receptacle, the total length of the cable-connector assembly outside the shielded enclosure was about 2.5 inches, or one-ninth of a wavelength at 531.25 MHz. Although this is not a particularly effective antenna, the radiated emission level was at least 15 dB above the noise floor. Assuming that the additional skew introduced by the 1-inch cable was not substantial, the plug-receptacle impedance was the main contributor to the 15-dB increase. Note that the radiated emissions from the Type-R connector with a 1-inch cable are higher than the emissions from the Type-M connector with a 4-foot cable. This suggests that the Type-M connector has a much lower plug-receptacle impedance.

In order to evaluate the effect of imbalance associated with the cable, artificial imbalance was introduced in the 4-ft cable samples to emulate cable imbalance. For each Type-A cable sample, a 1-nF capacitor was added between one transmission conductor and the outer shield at the truncated end. For each Type-B cable sample, first the 1-nF capacitor was added between a transmission conductor and the outer shield. Then the capacitor was connected between a transmission conductor and the inner shield. The radiated emission measurements were repeated for each case. The results are presented in Table 2.

For Type-A samples, the increase in radiated emissions after the artificial imbalance was introduced was more than 30 dB. For Type-B samples, the radiated levels increased about 20 dB due to a connection with the inner shield and about 9 dB due to a connection with the inner shield. This result confirms the value of double shielding for better current containment. In addition, the increase in radiation level caused by artificial imbalance suggests that the imbalance associated with the cable may play an important role for EMI from longer cable lengths.

Table 2: Radiation Measurement Results of Imbalance Experiments

Index	4 ft cable dBμv/m	add 1000 pF dBμv/m	Difference dBμv/m	Comment
A3	61	93.7	32.7	1-nF to outer shield
A4	57.3	93.3	36	1-nF to outer shield
B3	52.7	61.7	9	1-nF to outer shield
		74.7	22	1-nF to inner shield
B4	53.3	62.1	8.8	1-nF to outer shield
		76.3	23	1-nF to inner shield

To verify the effect of the distributed imbalance associated with a long cable, a common-mode choke was added to the driving device between the differential signal driver and the connector. The choke was used to reduce the skews inherent in the signal source and board layout. Hence, the radiated emissions depended mainly on cable-connector assembly. First four 20-m long cable assemblies (two Type-A and two Type-B) with Type-R connectors were terminated with the dummy load, and their radiated emissions with and without the common-mode choke were measured. The same procedure was repeated on 4-ft cable samples terminated with 150-Ω resistors. The results are summarized in Table 3.

Table 3: Results of common-mode choke experiments

Index	No choke dBμv/m	With Choke dBμv/m	Difference dBμv/m	Comment
A5	44.32	39.23	5.09	4-ft
A6	50.48	49.15	1.33	4-ft
B5	37.57	24.57	13.00	4-ft
B6	44.9	26.48	18.42	4-ft
LA1	51.48	49.15	2.33	20-m
LA2	55.23	54.73	0.50	20-m
LB1	42.48	38.65	3.83	20-m
LB2	48.65	45.98	2.67	20-m

With 4-ft cables, the common-mode choke had much less effect on Type-A cables than on Type-B cables. The measurement results of 4-ft cable samples show that the common-mode choke has more effect on the cables with less imbalance and/or transfer impedance. This conclusion is supported by the measurements of the 20-m samples. For all four 20-m cable assemblies, no significant EMI improvement was found after inserting the common-mode choke. This indicates that the imbalance due to the cable was more significant than the source imbalance. Therefore, remedies focused on reducing source and/or PCB layout imbalance (e.g. common-mode chokes) should not be counted on to significantly reduce radiated emissions from long cables.

CONCLUSION

High-speed signal-induced EMI in cable-connector assemblies is the result of imbalance and non-zero transfer impedance. Common-mode current is generated by imbalance inherent in the differential signal source, imbalance induced by the PCB layout, and distributed imbalance in the cable-connector assembly. Non-zero transfer impedance allows this common-mode current to develop a noise voltage that drives current on the exterior of the cable shield.

A parasitic EMI coupling path model for cable-connector assemblies was developed and the effect of various potential EMI source mechanisms was evaluated for two types of cable and two connector styles intended for FC-0 transmission. The dominant EMI mechanism depends on the specific situation. Experimental results showed that the dominant source of EMI in the Type-R connector-cable assemblies was the common-mode current within the cable. This common-mode current created a voltage across the connector's plug-receptacle impedance that drove a current on the exterior of the cable shield resulting in radiated emissions. For short cable lengths, the dominant source of this common-mode current was the source and PCB skew. However, for long cable lengths (20 m in this case), the common-mode current was primarily due to the distributed imbalance in the cable.

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