ELECTROMAGNETIC CROSSTALK PENALTY IN SERIAL FIBER OPTIC MODULES

Xiaomin Jin, Keith D. Lystad, and Musoke H. Sendaula
Department of Electrical and Computer Engineering
Temple University, Philadelphia, PA19122

ABSTRACT

Electromagnetic crosstalk poses a serious problem within today's advanced serial communication modules. A major detrimental effect is the degradation of receiver sensitivity in the presence of crosstalk noise. The mitigation of crosstalk penalty becomes increasingly more challenging as data rates increase for higher throughput and as module sizes shrink for increased port density. This paper is a study of the primary sources of crosstalk penalty in a 2.5 GB/s serial fiber optic transceiver *and a 10Gb/s serial fiber optic transponder. A novel method for quantifying crosstalk penalty by observing a receiver's bit-error-ratio (BER) versus transmitter to receiver signal phase is proposed. A simple coupled microstrip transmission line model is explored to demonstrate inductive crosstalk coupling.*

I. INTRODUCTION

As the industry advances in circuit and assembly technologies, module sizes are shrinking; concurrently, receiver dynamic range is expanding to be competitive in the communication component marketplace. The resulting outcomes are that receivers are becoming increasingly more sensitive while the transmitter and receiver are being packaged in closer proximity, increasing the risk of experiencing crosstalk penalty. The crosstalk between two channels is defined as the ratio of the output channel A (with no input signal) divided by the output of channel B (excited by input signal). [1]-[3] In this paper, channel A would represent the output of the receiver pre-amplifier and channel B would be the output of the transmitter driver, as depicted in Figure 1. The crosstalk penalty is defined as receiver sensitivity degradation due to electromagnetic susceptibility to conducted and/or emitted transmitter radiation. The crosstalk measurement is a very difficult task in fiber-optic module due to the nature of the signals that are involved. It is not always feasible to direct measure crosstalk, which requires direct access to the involved interconnects. [4] [5] A method for quantifying crosstalk in terms of relative receiver BER penalty is proposed, mostly using equipment that would be standard in a well-equipped communication module development lab. A similar approach is taken for two different applications: a 2.5GB/s fiber optic transceiver and a 10Gb/s fiber optic transponder. These applications were chosen as a cross-section of high-speed communication modules that are available today. They do not represent the entire population, but they may serve as a basis for measurement methods that can easily be modified for similar modules.

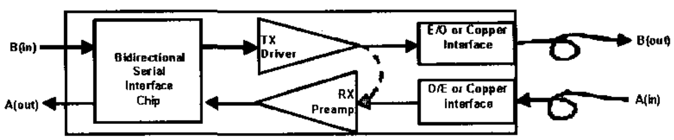


Figure 1 Simplified bidirectional communication module, depicting crosstalk from transmitter (Channel B) to receiver (Channel A).

II. EXPERIMENT RESULTS

Figure 2 shows the setup for measuring crosstalk penalty of a 2.5 GB/s serial fiber optic transceiver. The device-under-test (DUT) is a pluggable device. The input to the device's optical receiver is a 1310nm laser transmitter modulated by a 2.488GB/s pattern generator. The pattern is a pseudo-random bit stream (PRBS) with a seed of 2^{31}-1. The laser source is fed to an adjustable optical attenuator with a power tap to measure the power to the DUT. *The receive path of the transceiver contains* an avalanche photodiode (APD) to create an output current proportional to photon illumination, a transimpedance amplifier (TIA) to convert the current to an analog voltage, and a limiting amp (LIA) to create a digital output from the analog voltage. The output is differential, where the non-inverting signal is sent to a clock and data recovery (CDR) unit, which derives clock and data for the error detector. The inverting output is fed to a phase delay element. The variably delayed signal is then fed to the transceiver's transmitter. The phase relationship between transmitter and receiver can then be adjusted to maximize of minimize the crosstalk penalty, as seen by the bit error ratio (BER) at the error detector.

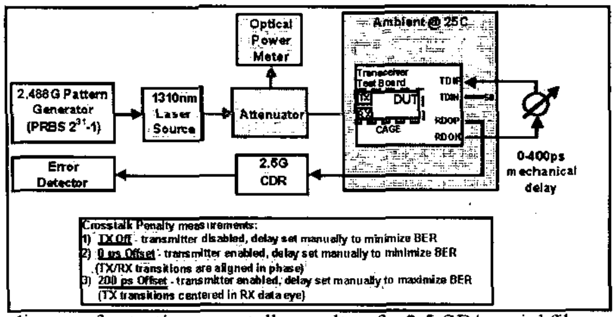


Figure 2 Setup diagram for testing crosstalk penalty of a 2.5 GB/s serial fiber optic transceiver.

The sensitivity of the transceiver's receiver was obtained by adjusting the optical attenuation in 0.5 dB increments and measuring the resulting BER. To measure the transmitter to receiver crosstalk penalty, three sensitivity curves were measured as shown and described in Figure 3. In this particular device, the best sensitivity of −31dBm was measured when the transmitter was disabled. The best-case crosstalk penalty of 0.3dB was when the transmitter transitions were phase-aligned with the receive transitions. The worst-case penalty of 1.3dB was when the transmit transitions were in the center of the receive data eye, or 200ps offset for a 2.5GB/s signal (400ps bit period).

TITLE: 2.5GB/s OPTICAL TRANSCEIVER, 1310nm, PRBS2^31-1, 25C

Pwr,dBm	TX off, BER	0ps offset, BER	200ps offset, BER	Units
-34.0	3.21E-05	6.04E-05	7.10E-04	
-33.5	7.69E-06	1.67E-05	2.79E-04	
-33.0	1.58E-06	3.61E-06	9.24E-05	
-32.5	2.69E-07	6.31E-07	2.64E-05	
-32.0	3.11E-08	8.53E-08	5.57E-06	
-31.5	2.98E-09	7.78E-09	8.99E-07	
-31.0	1.62E-10	5.52E-10	1.12E-07	
-30.5			8.82E-09	
-30.0			4.45E-10	
-29.5				
-29.0				
-28.5				
-28.0				
-27.5				
-27.0				
-26.5				
-26.0				
Sensitivity @ 1.00E-10	-31.00	-30.70	-29.70	dBm
Penalty		-0.30	-1.30	dB

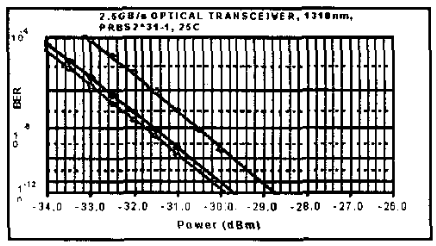
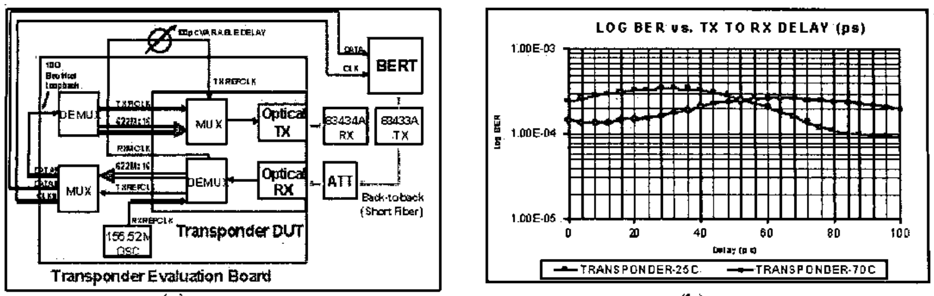


Figure 3 Sensitivity penalty measurement of a 2.5GB/s, 40km serial optical transceiver with a) transmit data disabled b) transmit data enabled with transitions phase-aligned with the receiver and c) transmit data enabled with 0.5 UI (400ps) phase offset from the receiver.

The block diagram of the crosstalk test setup for a 10 GB/s fiber optic transponder is depicted in Figure 4 (a). Although these devices are not fully serial, they contain a serial transmitter and receiver pair for transmission over optical fiber. The serial transmitter and receiver optical engines are respectively mated with a 16:1 multiplexer and a 1:16 demultiplexer. The setup is similar to that of the 2.5 GB/s transceiver with some notable exceptions: the line rate is at 10 gigabits per second, the data on the electrical module interface is parallel at 1/16 of the line rate, and reference clocks are required for data recovery and retiming. The data originates from a PRBS 2^{31}-1 pattern generator at 9.95328 GB/s (OC-192 SONET rate), which drives a 1550 nm laser transmitter. The optical data is then sent to an optical attenuator with a calibrated power tap for monitoring the input level to the transponder under test. The receive path of the transponder uses a reference clock to perform clock and data recovery, then it demultiplexes the serial data into 16 parallel channels. The parallel data is electrically looped back with a parallel data clock to the transmitter path multiplexer, through an external multiplexer/demultiplexer pair on the evaluation board. The reference clock for the transmitter, which retimes the data for serial transmission, is a delayed copy of the receive path recovered clock; a data FIFO enables the transmitter parallel clock and serial clock to be different. The phase relationship of the serial transmit data to the serial receive data can then be manually adjusted for the crosstalk measurement. The Bit Error Rate Tester (BERT) is driven directly from an external 16:1 multiplexer on the test set receive path, allowing the bit error ratio of the receiver to be measured independently of the transmitter while experiencing crosstalk from the transmit path. The resulting BER variation as the serial transmit delay is swept from 0 to 100ps in relation to the serial receive data is shown in Figure 4(b). The measurement was taken at 25C and an elevated temperature of 70C with similar results; the BER variation is approximately one half decade at an error ration of 1e-4 (1 error per 10,000 bits). This BER variation translates to approximately 0.3dB sensitivity penalty.

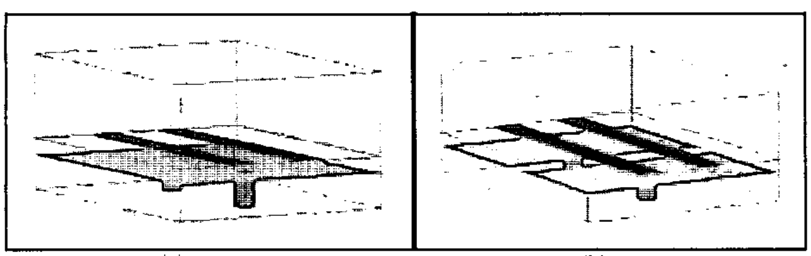


(a) (b)

Figure 4 (a) The setup diagram for testing crosstalk penalty of a 10GB/s multiplexing/demultiplexing fiber optic transponder. (b) Bit error ratio variation of a 10GB/s multiplexing / demultiplexing fiber optic transponder as the transmitter to receiver delay is varied by one unit interval (100ps), measured at 25C and 70C.

III. COUPLED MICROSTRIP CROSSTALK SIMULATION

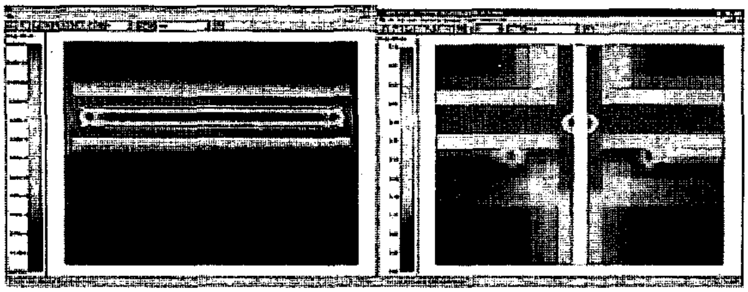
To simulate our bidirectional communication module, use a bidirectional microstrip transmission pair, a structure is shown in Figure 5. The reader should imagine a bidirectional transmission, from Port 1 to Port 2 and from Port 3 to Port 4 (two blue lines). One case has a solid ground plane. The other has a 10-mil cleave in the ground plane underneath. Slots in the ground and other metallization planes are a common feature in densely packaged PCBs and multi-level on-chip integrated circuits, often caused by vias and thru holes. This diverts the ground plane return current, which can cause undesirable effects such as crosstalk, EMI noise and impedance changes. In high-speed circuits, current flows in the path of least inductance; in a microstrip line current in the ground plane tends to flow directly under the signal trace. A slot in the ground plane causes the return current to take a circuitous route around the slot, which translates into increased inductance. The increased area of the return current loop causes EMI emissions that are directly proportional to the loop area.



(a) (b)

Figure 5 (a) 3-D view of a bidirectional microstrip transmission pair on a 10-mil thick bismaleimide triazine (BT) substrate, with a solid ground plane underneath. The ground plane is suspended above absolute ground and connected by vias to enable cleaving of the ground plane. (b) 3-D view of a bidirectional microstrip transmission pair on a 10-mil thick BT substrate, with a 10-mil cleave in the ground plane underneath.

A cleave in microstrip ground was found to have a profound effect on port isolation, which would become visible as sensitivity penalty within a communication module. Crosstalk is inevitable within any enclosure with bidirectional transmission, but by employing good RF design practice the penalty experienced by crosstalk noise can be substantially reduced. [6] [7] As technology advances enable smaller and faster electronic devices, more emphasis must be placed on designing for crosstalk isolation to maintain the high level of signal integrity that will be required by future advanced communication systems.



(a) (b)

Figure 6 (a) Microstrip interconnect electric field at 10GHz with a solid ground plane, Port 1 to 2 active. Field was obtained by placing a high impedance sense layer 0.1 mils above the surface. There is minimal fringing to the trace from Port 3 to 4. (b) Microstrip ground plane return current density with a cleaved ground plane, Port 1 active. There is large inductive coupling to the neighboring trace from Port 3 to 4 since return current is forced around the cleave.

III. CONCLUSION

Crosstalk in bidirectional serial communication modules is a complex and elusive phenomenon that is not easily quantified. Direct measurement of crosstalk in the time domain or frequency domain by probing is not always possible within a module, and removal of the housing would change the environmental conditions. The crosstalk measurement method proposed in this paper allows the module to be tested as a complete entity, in its native operating condition. This provides an accurate and realistic measurement of the maximum crosstalk penalty that would be expected in a real application. A simplified crosstalk model was presented to demonstrate inductive coupling of a bidirectional microstrip transmission pair.

V. REFERENCES

[1] A. Vittal, L. H. Chen, M. Marek-Sadowska, K.Wang, and S. Yang, "Crosstalk in VLSI Interconnections". *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, Vol. 18, No. 12, pp. 1817-24, December 1999.

[2] H. Johnson and M. Graham, *High-Speed Digital Design: A Handbook of Black Magic*. Prentice Hall PTR: Upper Saddle River, NJ, pp. 189-211, 1993.

[3] R.F. Drayton, R.M. Henderson and L.P.B. Katehi, "Monolithic Packaging Concepts for High Isolation in Circuits and Antennas", *IEEE Transactions on Microwave Theory and Techniques*, Vol. 46, No. 7, July pp. 900-06 ,1998.

[4] K.M. Coperich, J. Morsey, V.I. Okhmatovski, A.C. Cangellaris and A.E. Ruehli, "Systematic Development of Transmission-Line Models for Interconnects With Frequency-Dependent Losses", *IEEE Transactions on Microwave Theory and Techniques*, Vol. 49, No. 10, October 2001, pp. 1677-85.

[5] D.E. Bockelman and W.R. Eisenstadt, "Direct Measurement of Crosstalk Between Integrated Differential Circuits", *IEEE Transactions on Microwave Theory and Techniques*, Vol. 48, No. 8, August 2000, pp. 1410-13.

[6] L.G. Maloratsky, "Reviewing the Basics of Microstrip Lines", *Microwaves and RF*, March 2000, pp. 79-88.

[7] J.H. Wu, J. Scholvin, J.A. del Alamo and K.A. Jenkins, "A Faraday Cage Isolation Structure for Substrate Crosstalk Suppression", *IEEE Microwave and Wireless Components Letters*, Vol. 11, No. 10, October 2001, pp. 410-12.