AC Coupled Connectors

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Abstract

AC coupling can be used to build high density contactless board-to-board connectors to communicate between daughtercards across 30cm to 120cm FR4 backplanes at Gbps+ data rates.

1. Introduction

Traditionally the backplane industry has relied on press-fit style connector designs which are easy to assemble and are a well understood technology. However, these connectors require plated through hole vias, for mating with pins, which present impedance discontinuities that cause reflections and disrupt the return path. This increases the return path inductance and crosstalk, particularly at Gbps+ data rates [1,2]. Surface mount backplane connectors offer electrical advantages over conventional press-fit style designs, but they suffer from coplanarity issues and offer less mechanical robustness and reliability [2]. Mechanically mated connectors are also subject to wear and tear due to insertion force associated per contact.

AC coupled interconnects show promise to enable multi-gigabit/second data rates between high pin count IC's within a multi-chip module while achieving significant power savings as well [3]. The focus of this paper is their use as high-density contactless daughtercard to backplane interfaces across 30cm to 120cm FR4 backplanes. AC coupling can be realized with planar inductive or capacitive elements or through a combination of both. Coupled inductors and capacitors act as high pass filters and their response can be used to equalize the low pass response of the cable depending on the frequency content of the signal. Through proper system design, this could eliminate the need for complex active circuitry used for equalization. Section 2 of the paper briefly discusses some of the tradeoffs in inductive and capacitive coupling. Section 3 discusses how a combination of inductive and capacitive coupling can be used to signal random 2Gbps NRZ data across a 1m 50 Ω transmission line on FR4 without the need for complex active circuitry for equalization. Shown in section 4 are experimental results for a prototype board-to-board coupled inductor.

2. Capacitive (vs) Inductive coupling

Capacitors are easier to model compared to coupled spiral inductors. However, the input impedance of the coupled capacitors is more sensitive to the gap spacing compared to coupled inductors. This is due to the inverse relationship of capacitance with gap spacing, while for inductors the magnetic coupling coefficient decreases less rapidly. In a board-to-board application the achievable gap spacing between the coupling elements is limited by the surface roughness of FR4 and the thickness of the interlayer dielectric used to isolate the coupling elements. The surface roughness of FR4 can range from 1µm to 10µm [6], which produces a large and unpredictable variation in the gap spacing. Connectors are also evaluated in the frequency domain using performance metrics such as insertion loss and return Loss. In capacitive systems high impedance terminations can be used more beneficially to tune the return loss at low frequencies while this is more difficult in the case of an inductive system because an inductor is low impedance at low frequencies. However, the problems associated with this impedance mismatch at low frequencies can be offset by using inductive coupling when signaling across long serial links so that the reflections are attenuated sufficiently over the round trip delay of the link. In addition, the use of pulsed signaling schemes where low frequency energy is minimized helps to reduce the reflected energy in the interconnect.

3. AC coupled system

A complete AC coupled system including coupled inductors on the transmitting side, a series coupling capacitor on the receiving side, with 1cm stubs representative of daughtercards, was simulated in Hspice over a 1m long 50 Ω transmission line on FR4. The W model was used to capture the behavior of the transmission line in Hspice. Figure 1 shows the system level view of the simulation setup. The choice of inductance values is influenced by the signaling data rate as well as the lowest frequency content of the random NRZ data stream. An ideal transformer is a high pass filter and its 3dB coupling frequency (f_{3dB}) is determined by the chosen values of inductance. In the time domain, the step response of the ideal transformer provides information about the decay rate of the output signal waveform. This is used to determine, to a first order, if the inter-symbol interference is acceptable for a given value of inductance at a particular signaling data rate. Figure 2 shows the circuit model for the optimal transformer on the transmitting side obtained using commercial CAD tools. The model parameters shown in Figure 2 can be realized with a spiral coil having an outer diameter of 1.1mm with 1 turn. This can be manufactured in a nominal PCB process using 4mil trace width, 4mil inter-turn spacing with 8mil via holes for signal to ground connections. Magnetic coupling coefficient between the coils is 0.7 when the vertical gap spacing is 50μm which can be achieved in a board-to-board application. In simulation the transmitter is an ideal voltage source while the receiver is represented by a 200 Ω resistor. A 50 Ω parallel termination was also used on the transmission line to suppress reflections. Due to low frequency content in the NRZ random data stream, the receiving side needs a coupling element with a wide passband in the frequency domain, therefore, a 2pF series capacitor was used. A 2pF board-to-board series coupling capacitor can be realized using a 1.7mm by 1.7mm area and a gap spacing of 50μm with a material which has a dielectric constant of 4. Alternatively a transformer using high inductance values of about 25nH can be used on the receiving side to obtain similar performance. However, long winding lengths, leading to distributed behavior, are needed to realize high inductance values in the previously outlined PCB process. This increases complexity from a modeling perspective. Figure 3 shows the simulated "AC Coupled" eye diagram obtained at 2Gbs for 4000 bits of random data, with a maximum run length of 7 bits. While there is some information in the eye indicated by the vertically bunched lines at the center, it is below 50mV. The receiver would be designed so that information below this threshold would be rejected. The signal swing at the receiver input is 400mV peak to peak.

4. Experimental Results

Board- to-board transformers of outer diameters ranging from 1.7mm to 1cm were built in an inexpensive two-layer PCB process. Large diameter transformers were chosen due to PCB process limitations, and to achieve sufficiently high magnetic coupling over a large range of vertical gap spacing between the boards. Figure 4 shows an example of the test-setup for measuring these transformers. A sheet of paper, approximately 90μm thick, was used as an interlayer dielectric between the two inductors. Screw holes and alignment traces were used on the boards to align the coils during measurement. Figure 5 shows insertion loss and return loss for one of the test structures between 2GHz to 4GHz. TRL was used for deembedding the transformer measurement in this frequency band. This structure has acceptable return loss and insertion loss between 2.5GHz to 4GHz. Bandwidth and frequency band of operation can be optimized further by tuning the crossover capacitance and the magnetic coupling coefficient by varying dielectric constants and thickness of the interlayer dielectric.

5. Conclusion

Measured results demonstrate that the AC coupled board-to-board system could be realized with a more advanced PCB process. Future work includes experimental demonstration to validate the AC coupled system simulation results and optimizing return loss and insertion loss bandwidth of board-to-board coupled inductors.
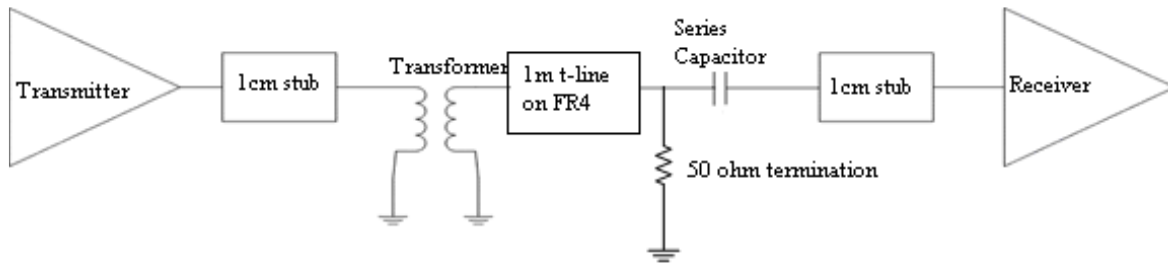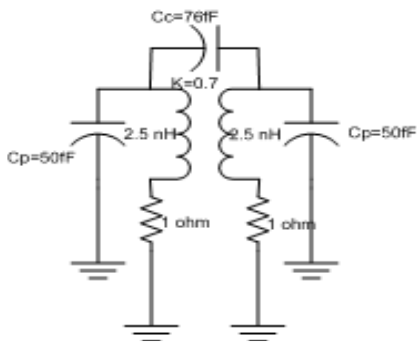
Figure 1:   AC Coupled system

Figure 2:   Circuit Model for the Transformer
used on the transmitting side in the
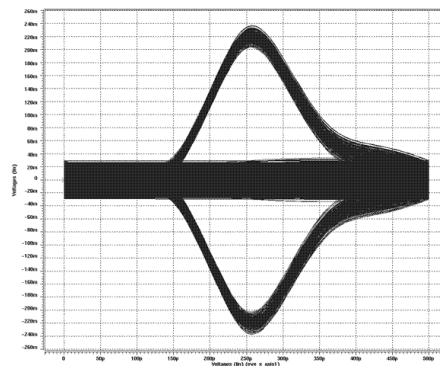AC Coupled system simulation

Figure 3:   "AC Coupled" eye opening for
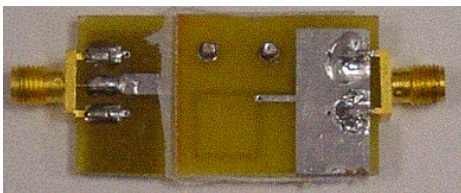4000 PRBS at 2Gbps

Figure 4:   Example of test setup

Figure 5:   Frequency Domain Measured data

3

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