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Designing external cabling for low EMI radiation

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Designing external cabling for low EMI radiation

The advent of integrated circuits that compensate for cable loss (equalizers) allows systems to send high-speed data over very long copper cables. The use of integrated circuits for equalization[1] of cable loss has enabled a major reduction in the cost of interconnects for communications systems. For optimum performance, such systems must minimize any radiated emissions from the cables and connectors.

Distances and data rates that once were associated only with optical-fiber links can now be spanned with copper cables, thereby avoiding the high cost of optical modules. “Copper modules” are now available as direct replacements for fiber modules. With the combination of copper lines and equalizer devices, you can now receive 3.2Gbps data over long cables with very little signal distortion. Note the dramatic improvement to a 3.2Gb/s digital waveform propagating through a 115-foot cable, when equalization is added (see Figure 1). Maxim equalizer devices operate to rates as high as 12.5Gbps.

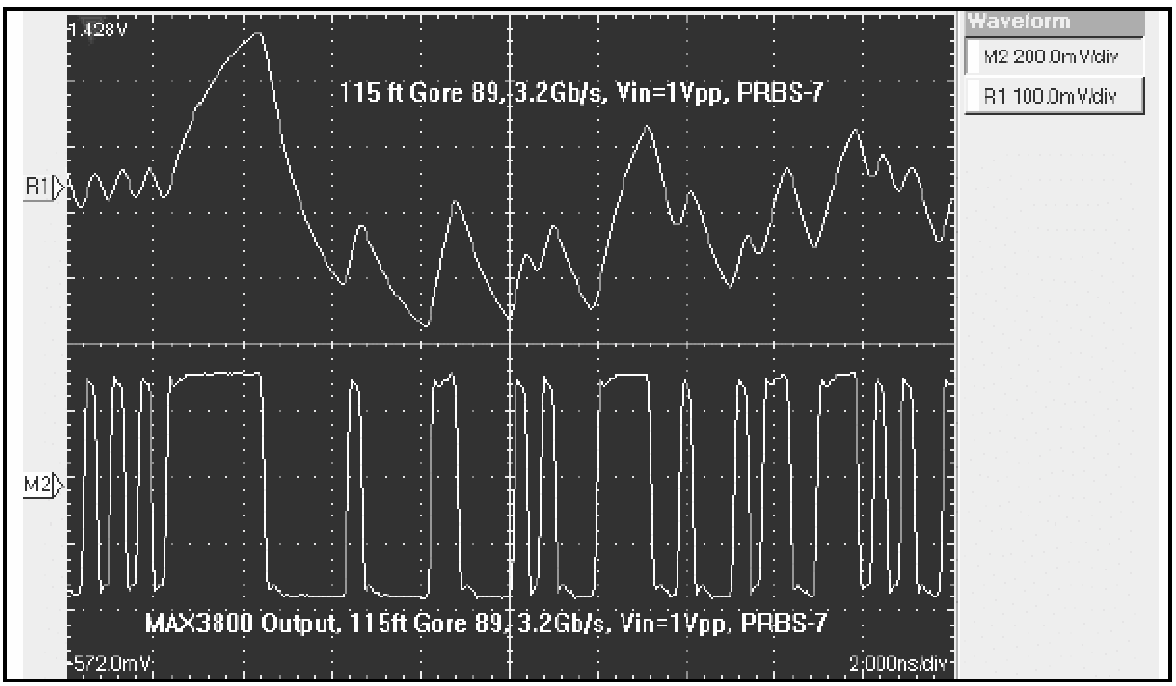

Figure 1. 3.2Gbps signal through 115-ft cable, before and after equalization.

At high bit rates, copper-cable interconnect assemblies must act as well-behaved transmission channels exhibiting deterministic signal integrity and delivering maximum power to the receiver (with minimum leakage). Signal leakage from such assemblies becomes electromagnetic interference (EMI) to the outside world, and EMI is a major consideration for equipment that must meet EMC compliance declarations with regard to FCC[2] and EC[3] standards. The following discussion, which includes cable equalization to

[1] Equalization is the compensation of frequency-dependent attenuation in a communications circuit, with the purpose of establishing equal signal attenuation over the circuit’s operating frequency range.
[2] Federal Communications Commission.
[3] European Council

extend transmission distance and lower system costs, presents simple methods for reducing radiation to low levels.

Cables and connectors that interconnect various pieces of equipment should be specified to prevent interference and to prevent the reciprocal effect of susceptibility to radiated energy. For cable systems with copper interconnects, the following measures are effective in reducing radiation:

- Balance the signal lines
- Add ferrite beads
- Twist the cable
- Shield the cable
- Use termination connectors for cable and backplane

Balanced Systems

A balanced cable system consists of two wires carrying signals that are negative and positive (bipolar) with respect to a third wire (or ground). Ideally, the two signal wires contain all the signal currents. Because differential line drivers are not perfect, however, they allow inclusion of unwanted signals such as noise, hum from the power supplies, and temperature effects common to both signal lines. The ability of a differential receiver to reject such common signals is expressed in a figure of merit called the common-mode rejection ratio (CMRR). CMRR is the ratio of difference-mode gain to common-mode gain, usually expressed in decibels.

Another factor that affects the performance of balanced systems is time skew between the signals, caused by differences in length of the two signal wires. By misaligning the edges of the differential signals, a length difference can cause small voltage spikes in the ground system.

For systems without balanced outputs, you can produce one by introducing a transformer on the output (see Figure 2). The transformer is usually placed near the output of the system. It provides DC isolation, an additional benefit when connecting to a system whose ground potential may differ from that of the original single-ended system.

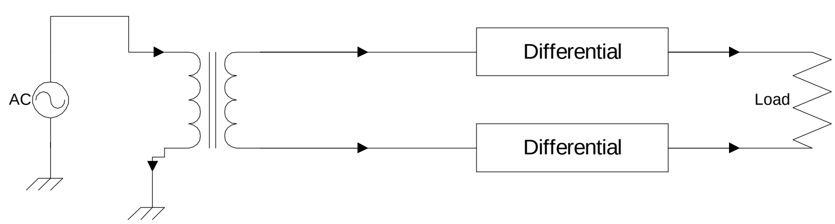

Figure 2. Transformer conversion, single-ended to differential output.

Like amplifiers, transformers are not ideal. They all allow a small amount of primary current to appear as a differential-mode current at the output. This mode-conversion effect is most common at higher frequencies. Another unavoidable feature of transformers is capacitance between the primary and secondary windings. Such capacitance increases unwanted radiation by allowing a common-mode coupling of energy (increasing with frequency) to the output.

Ferrite Beads

A small ferrite bead or toroid slipped over the wires of a differential signal reduces common-mode currents by acting as a longitudinal (loss) transformer. Ferrite beads are useful in damping the high-frequency content of switching transients and other high-frequency signals. They often appear inside power supplies and on the cables used for video monitors to reduce EMI in those systems.

Ferrite beads work best in low-impedance circuits, where a bead impedance as high as 500Ω at 50Mhz can be achieved. Care should be taken not to decrease the effectiveness of the bead cores by allowing them to saturate. The use of ferrite beads on multipair cables, however, may increase the crosstalk between those pairs. To illustrate, consider the insertion loss for a common bead with various load impedances (see Figure 3).

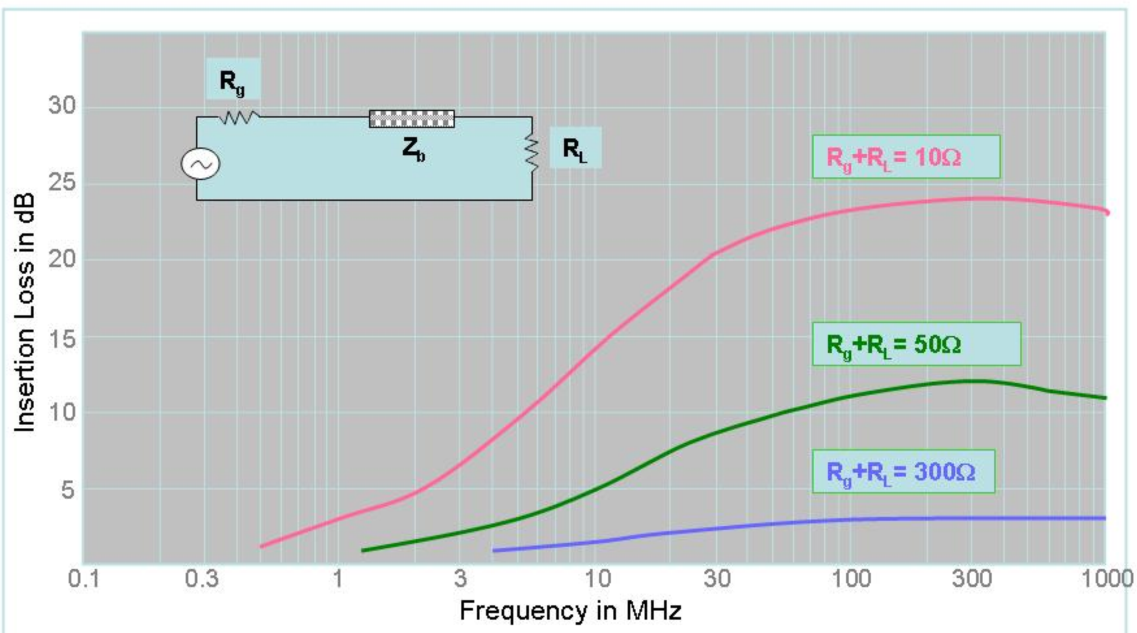

Figure 3. Bead insertion loss vs. frequency[4].

Twisting the Cable

Twisting the two wires of a signal pair together greatly reduces differential-mode radiation while leaving the common-mode radiation virtually unaffected. Differential (vs. single-ended) signaling reduces radiation by 20dB to 30dB. For each twist in a signal pair, the magnetic field emanating from it cancels

[4] Adapted from Michel Mardiguian, "Controlling Radiated Emissions by Design," pp 221-255, Van Nostrand Reinhold.

the field from the twist in an adjacent pair. As a result, the field coupled to an adjacent pair is nearly zero if the twists are in the same direction.

For most cables that incorporate multiple twisted pairs in a single bundle, the pairs exhibit different twist rates. This variation tends to cancel the coupling caused by slight asymmetries in the twisting process. As an example, it is possible to observe the different twist rates of pairs in a typical Category 5 cable used for most Ethernet networks.

Shielding the Cable

Cable shielding is a key parameter in controlling radiation, and shielding effectiveness is characterized by the transfer impedance. Transfer impedance relates the current flowing on a shield surface to the voltage it develops on the other side of the surface. That voltage is due to diffusion current through the shield thickness.

The effectiveness of a braided shield is also affected by leakage inductance, which is related to the thickness and density of the shield. This causes the effectiveness of the shield to diminish as the frequency is increased. The best shield is a thick-walled solid tube such as semi-rigid coax. The transfer impedances of several types of coax cable are shown in Figure 4.

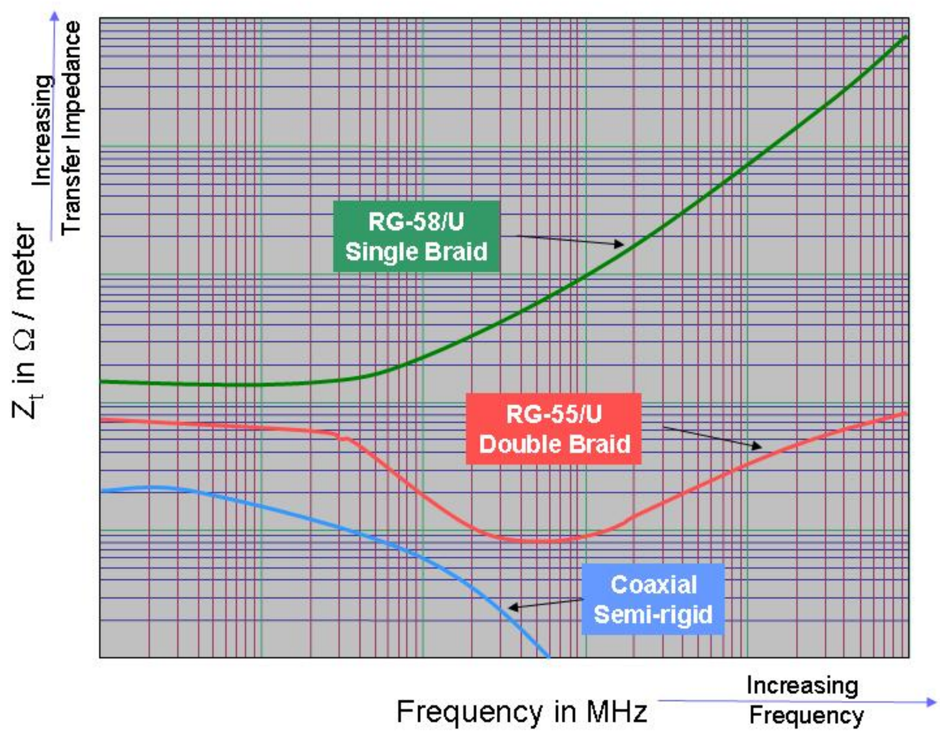

Figure 4. Transfer impedance of various cable types.[5]

[5] Adapted from Michel Mardiguian, "Controlling Radiated Emissions by Design," pp 221-255, Van Nostrand Reinhold.

The use of a shielded and balanced line such as a shielded twisted pair, or twinax, provides an additional reduction in radiation, because the shield is no longer used as a return path. The only current then flowing in the shield is that due to asymmetry in the balanced lines. Radiation is therefore reduced by the percentage of shield current to total signal current in the signal lines.

Cable- and backplane-termination connectors

In the cable assembly, the final connection to the load or source can be just as important to the performance of the cable. A connector that provides good shielding and a low impedance connection to the system ground is very important because the connector is in series with the signal path.

Table 1. Connector Resistance versus Frequency

Connector Type	DC to 10MHz	100MHz	1GHz
BNC Connector	1mΩ to 3mΩ	10mΩ	100mΩ
N Connector	< 0.1mΩ	1mΩ	10mΩ
Shielded Multiconductor	10mΩ to 50mΩ	10 to 50mΩ	300mΩ
Pigtail, 5 cm	Z = 3mΩ + j0.3Ω x frequency (MHz)	⇐ same	⇐ same

For backplane applications that require high-speed multiple-termination connectors, a number of manufacturers produce connector systems that operate with signal rates up to 12Gbps. They contain differential pairs and ground systems with good controlled impedances and shielding. Teradyne and Molex, for example, make several series of connectors called VHDM, VHDM-HSD, and Gbx, which make use of ground planes integrated into the connector housing. In turn, this construction allows controlled impedances and high levels of shielding. The International Engineering Consortium (IEC) has produced a tutorial on the capabilities of these connector types. (See their website, listed in the Reference section.)

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