Signal Conditioning with Value-added Connectors

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INTRODUCTION

With the astonishing rate at which electronic devices increase in performance and are integrated into day-to-day business and domestic life, the effects of electromagnetic noise on electronic systems and the environment become more critical. Systems have become smaller, faster, and able to achieve higher levels of performance. While it is possible to pack thousands of transistors onto an integrated circuit, chips alone cannot drive equipment. Signals must be sent through many layers of interconnection, and every level of interconnection potentially interferes with those signals.

Ensuring signal integrity poses serious performance, design and cost considerations to design engineers and systems manufacturers. Value-added input/output (I/O) connectors that protect equipment from the effects of electromagnetic interference (EMI) and prevent the equipment from introducing EMI to the environment, can increase signal reliability and provide cost-effective solutions to many of the problems associated with traditional board-level methods of signal conditioning.

SYSTEM PERFORMANCE

On a printed circuit board (PCB), discrete electromagnetic compatibility (EMC) components require some length of circuitry for signal transmission to the I/O connector. As little as 2 cm of circuitry contain enough inductance to act as an antenna under high frequencies (typically 100 MHz to 1 GHz). The longer the trace, the lower the

Value-added connectors increase signal reliability and solve problems associated with traditional board-level signal conditioning.

frequency that will cause these effects. This antenna places a conditioned signal at risk of recontamination before it leaves the board, and enables a contaminated signal coming onto the board to affect the system performance before it is cleansed by EMC components.

Ideally, signal conditioning should occur at the source of electromagnetic interference, eliminating EMI effects on electronic systems; however, the nature of electromagnetic energy and known methods of interconnection have limited this approach. It is possible, however, for signal conditioning to occur at an exact point of interface, so that an outgoing signal moves through the PCB prior to conditioning, and an incoming signal is conditioned prior to introducing its effects to the board. Not only does this minimize potential problems, but when problems do occur, they are confined and more readily detected in a manageable sub-level of the system.

While cost considerations and limited space sometimes impose restrictions on signal conditioning at the I/O connector interface, protection at any point within the interface moves signal conditioning closer, minimizes stray inductance and antenna effects, and improves signal reliability and system performance.

COST-EFFECTIVE CONNECTOR SOLUTIONS

Manufacturers who may not need high-performance connector-level solutions still find that protective connectors offer considerable advantages over board-level conditioning components. The most obvious advantage is that value-added connectors are typically 15 to 20% less expensive than discrete board components. Savings to the systems manufacturer, however, go beyond the direct cost of product.

Fewer components translate into fewer solder joints on the PCB, which lowers manufacturing costs and increases electrical reliability. Inventory is likewise simplified when the original equipment manufacturer (OEM) replaces multiple part numbers with equivalent, less expensive, and more manageable protective connectors.

Relocating signal conditioning from the board to the connector also frees board space for additional functions. Board real estate value is considerable in small devices like notebook or palm-top computers or cellular phones. Although the same is not as true of devices such as desktop computers, some value can be attached to a cross-sectional area of any circuit board if it allows increased usage or can be eliminated to spur miniaturization.

Connector solutions not only simplify board assembly and real estate management, but shorten the entire process of product development. Signal conditioning problems are generally dealt with in a time-consuming fashion in the manufacturer's EMC lab, with a prototype typically undergoing several stages of re-design and testing before an acceptable level of performance is achieved. Connector-level solutions allow OEMs to address those problems with standardized solutions. Engineers can use performance surveys to accurately predict how a value-added connector will perform within a given set of parameters. They can then approach their board design confident that they can build their latest circuitry to pass FCC testing, without the iterations which are commonly part of the design cycle, and without having to tune the circuitry for every board configuration (Figure 1).

BOARD-LEVEL SOLUTION	INTEGRATED CONNECTOR SOLUTION	
DIRECT COST*	DIRECT COST*	INDIRECT COST SAVINGS
CONNECTORS (3) = \$2 CAPACITORS + INDUCTORS = \$5	SIGNAL CONDITIONED CONNECTORS	PC BOARD SPACE PLACEMENT COSTS COMPONENT INVENTORY TIME-TO-MARKET IMPROVED PERFORMANCE
TOTAL = \$7	TOTAL = \$6	

* *Customer supplied figures*

Figure 1. *Cost Comparison between Board Level Solution and Integrated Connector Solution.*

FILTERED CONNECTOR ALTERNATIVES

A broad range of value-added I/O connectors that meet regulatory requirements such as FCC Part 15, Part 68 or the IEC 801 series are available as "drop-in" replacements to standard counterparts. This range includes products that incorporate ceramic and composite materials technologies.

The footprint of the unprotected connector imposes space and shape limitations that determine, to some extent, what materials can be used to enable a drop-in protected replacement of a standard connector. Additional criteria are the same as those used to specify materials for other signal conditioning devices. EMI filtration materials selection is always based on capacitance/inductance or impedance, cutoff frequency (3 dB point), and desired attenuation at certain frequencies. Likewise, waveform, energy levels, clamping voltage, peak voltage, and leakage current must be considered when designing electrostatic discharge (ESD) protection into any device. Configurations of the same elements commonly used to construct discrete on-board components, as well as newer composite materials, can be incorporated into connectors for a wide variety of applications.

Ferrite is the ceramic material predominantly used, alone and in combination with other materials, to introduce inductance into filtration devices. Its filtering function depends on frequency as well as material characteristics and mass. At low frequencies, ferrite increases impedance and generates an impedance mismatch to perform EMI filtration. At high frequencies, ferrite also becomes lossy. Ferrite filtration is a bulk phenomenon, so its isolated use in the limited space of most connectors is for low-attenuation applications, such as to dampen resonance caused by parasitic inductance or capacitance of a circuit.

Many different geometries or forms of capacitive elements are available, and offer more flexibility than ferrites for packaging in the limited space available on a connector. However, since capacitance distorts or "rounds off" signals, it is important to consider how much signal loss a system can tolerate before determining whether or not a particular capacitive filtering technique should be applied.

Chip and tubular capacitors are common low-pass filtration devices. Chip capacitors that can be used on the PCB can also be packaged individually in a connector, and are sometimes formed into a planar array to facilitate their integration. Dielectric material is extruded and fired to form a tubular capacitor. A connector pin is soldered to the inner diameter of the tube so that noise passing through the pin shunts to ground. Tubular capacitors, like chips, can be formed into an array for drop-in assembly into a connector. Tubular and chip capacitors provide first-order filtrating, i.e., insertion loss of 20 dB per decade. Some variations in performance are caused by the planar or tubular shape of the device. Figure 2 shows how the tubular configuration lends itself to a low ground path impedance that virtually eliminates resonance.

The flexible film capacitor is a newer, less expensive, polymer ceramic composite approach developed specifically for connector-level filtration. Flexible film, as the name implies, is flexible enough to facilitate its use in a variety of connector configurations. Thin foil sheets

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are coated with composite material, laminated together, plated and photo-etched for an economical and convenient way of incorporating low-performance filtration into a connector.

When second-order filtration (40 dB per decade insertion loss) is desired, two types of ferrite block with capacitive array are available for connector-level, inductive/capacitive (LC) filtration. The first is multilayer chip (MLC) on ferrite. The MLC is comprised of several layers of dielectric stacked into a single structure and assembled onto the ferrite block. A conductive metal layer is deposited on each dielectric layer, with conductive layers alternately attached to an outer metal strip soldered to ground or an inner metal strip soldered to connector pins running through the capacitor.

The second is a thick film array. This is ferrite block with a capacitive array, a monolithic capacitor comprised of a ceramic substrate on which several layers of material are deposited. A layer of metallization over the substrate serves as a ground plane on which a dielectric is deposited. A second layer of metallization, deposited over the dielectric and soldered to the connector pin running through the array, forms the capacitor's other electrode.

Manufacturers use MLCs more often than thick film devices as a means of filtration at the connector level, although both types provide equal performance. Multilayer chip capacitors have been in use for some time, and manufacturers can depend on their reliability, but as awareness of its smooth, connector-friendly configuration increases, thick film could become the preferred package for high-density or small-profile connectors.

Where frequencies are too high for lumped-element filtration to provide effective EMI control, distributed-element filtration can be applied to the connector.

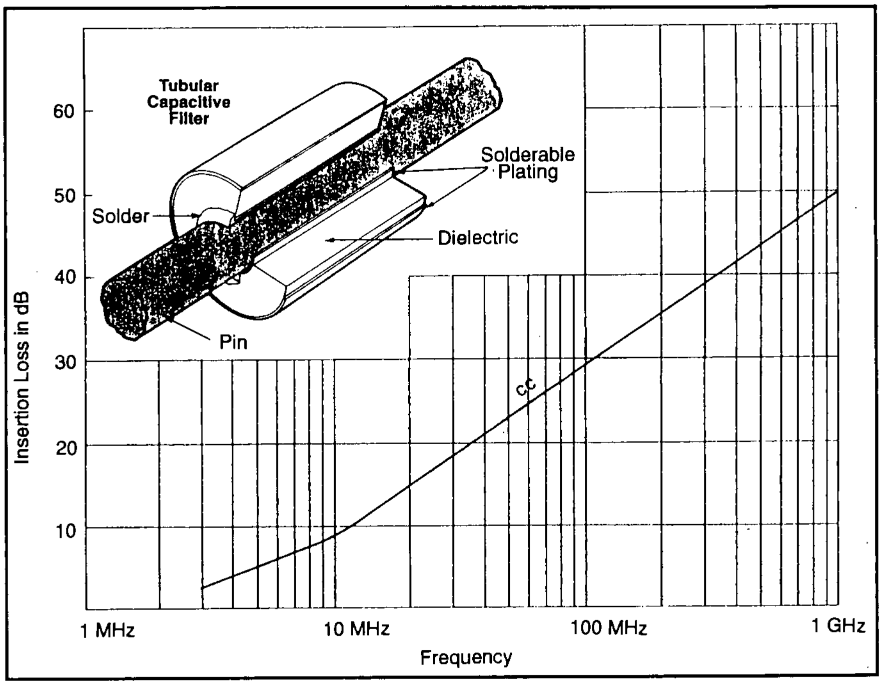

Figure 2. *Calculated Insertion Loss vs. Frequency (No Load at 25°C), 1,300 pF - 2,500 pF Range.*

Distributed-element filtration at the connector level involves a one-piece tubular arrangement with an inner core of lossy ferrite and a capacitive outer surface. A connector pin is soldered to the inner diameter of the tube, and as noise is shunted toward ground along the length of the tube, the lossy ferrite absorbs it and dissipates it as heat. This configuration provides superior insertion loss, and because of its one-piece construction, minimal resonance compared to high-performance LC devices such as the common Pi filter. And since it is primarily absorptive, it eliminates extraneous energy that might otherwise be reflected back into the circuitry (Figure 3).

TVS CONNECTOR ALTERNATIVES

Just as connector-level alternatives for EMI filtration incorporate many materials and technologies used for board-level filtration, transient voltage suppression (TVS) at the connector can involve existing components such as metal oxide varistors (MOVs), diodes, gas discharge tubes, etc., to protect against high-energy surges such as lightning, power line surges, or low-energy ESD (Figure 4).

Value-added connector technology is not, however, limited to reconfiguring existing components to fit into an existing connector. Research and development of signal-conditioning solutions has yielded cost-effective, flexible alternatives that, in some instances, provide superior performance than their more expensive, board-level counterparts.

One example is an inexpensive, highly moldable material that has enabled the integration of ESD protection into most connector designs, with little or no extra space required. A composite material comprised of an elastomeric binder with closely spaced conductive particles, this material responds to an ESD event within the sub-nanosecond range, for a protective function comparable or superior to diodes or varistors. The benefits of using this filled polymer composite for ESD protection in the connector go

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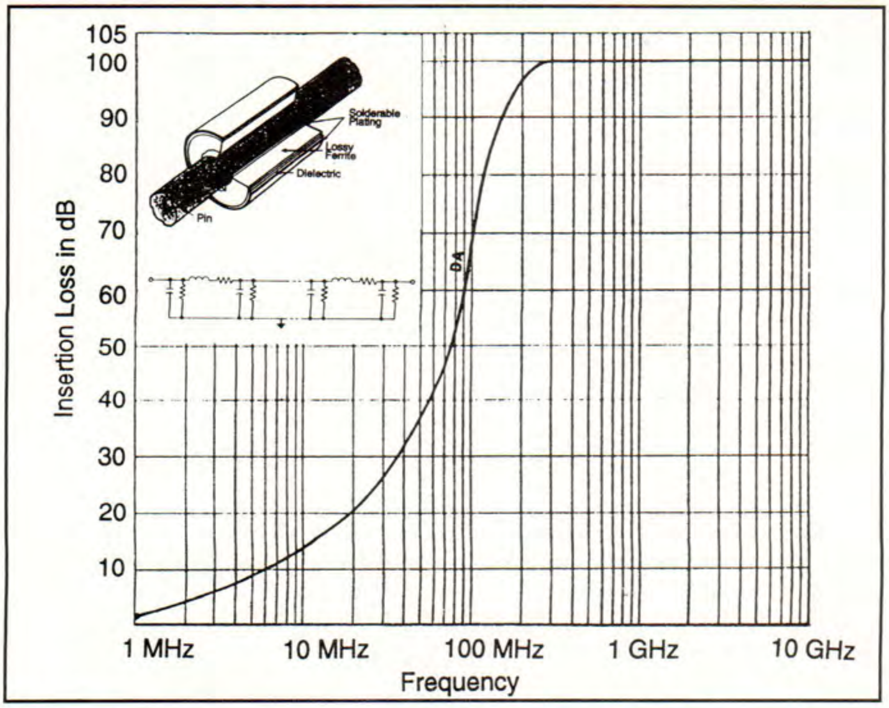

Figure 3. *Calculated Insertion Loss vs. Frequency (No Load at 25°C), 3,000 pF - 8,000 pF Range.*

beyond saving board space and cutting the costs of inventory and installation of discrete elements. Extraneous capacitance encountered with diodes or varistors can distort high-speed signals. This material is low in capacitance (typically within 2 to 30 pF depending upon design), and virtually eliminates unwanted effects on high-speed signals (Figure 5).

CONCLUSION

The nature of electromagnetic energy and known methods of interconnection dictate that systems can only approach theoretical efficiency or signal generation. Placement of signal-conditioning devices at or near the point of interface minimizes circuitry antenna effect and improves signal reliability and system performance.

Manufacturers who replace board components with equivalent, less expensive, standardized connector solutions lower manufacturing and inventory costs, facilitate design cycles and time-to-market, and gain valuable PCB real estate for miniaturization or functional upgrade of equipment.

A wide range of connector configurations is available to meet the vast array of today's low-, intermediate-, and high-performance applications. And as microprocessors and memory chips double in performance every 18 months, and businesses and households become more automated, research continues to seek superior methods to achieve EMC in connector-level solutions that will help manufacturers keep pace.

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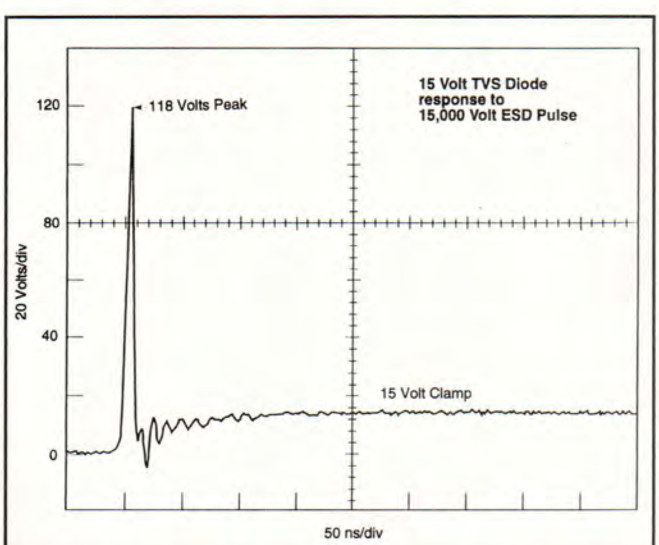

Figure 4. *15-volt TVS Diode Response to 15,000-volt ESD Pulse.*

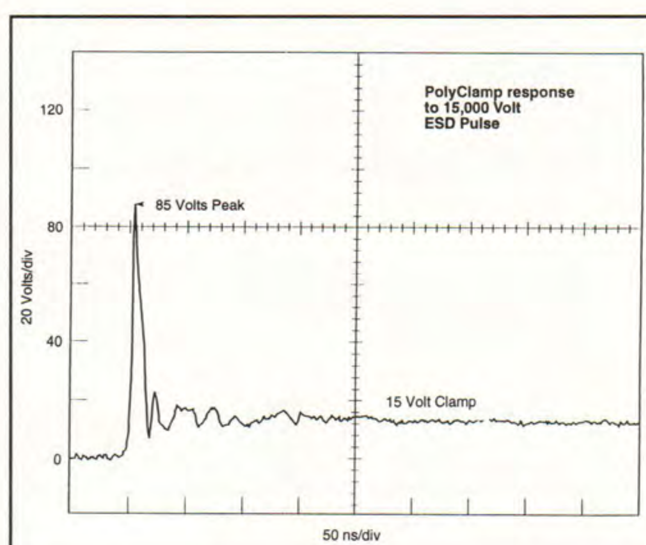

Figure 5. *Filled Polymer Composite Response to 15,000-volt ESD Pulse.*