TECHNICAL PAPER

Passive Component Advancements for SPE Connectors and Circuit Protection Devices

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Abstract
As Single Pair Ethernet (SPE) begins to roll out there will be a need for easy to implement, yet reliable wire-to-board interconnects. Purchasing finished cable and connector assemblies is not always economical or viable. However, it is also undesirable to work with time consuming and difficult to process connectors. Insulation Displacement Connectors (IDC) and Press-Fit technology (images below) require no crimping or soldering processes, and is easily converted to a streamlined process, while maintaining the versatility of cable lengths and positioning. In addition to reliable retention forces and gas tight seals afforded by the cold weld mechanism of IDC, signal integrity is preserved and performs beyond transmission standards set for SPE connectors.

INTRODUCTION

Single pair ethernet (SPE) is a new standard of data transmission which uses a two-copper wire system. This technology has the power to deliver data at up to 1 Gb/s while simultaneously providing power to the system. Various systems can take advantage of the SPE standard, including twisted pair cable, shielded twisted pair, unshielded twisted pair, and single pair. The shielded twisted pair provides protection against electromagnetic interference (EMI) or radio frequency (RF) interference. SPE has been specifically designed to be valuable in industrial applications as a replacement for both data and power connections. This single solution provides consistent power and signal to fixed circuits and components and reduces weight across the system.

As SPE begins to roll out there will be a need for easy to implement, yet reliable wire-to-board interconnects. Purchasing finished cable and connector assemblies is not always economical or viable. However, it is also undesirable to work with time consuming and difficult to process connectors. Insulation Displacement Contacts (IDC) with SMT or Press-Fit technology (images below) require no crimping or soldering processes, and is easily converted to a streamlined process, while maintaining the versatility of cable lengths and positioning. In addition to reliable retention forces and gas tight seals afforded by the cold weld mechanism of IDC, signal integrity is preserved and performs beyond transmission standards (IEC 63171-6) set for SPE connectors.

Selecting passive components for circuit protection on ethernet networks will also be challenging, but recent MLV (multilayer varistor) advancements like OPEN (One Pair Ether-Net) qualified devices will make this process easier. OPEN qualified devices meet strict size, weight, overvoltage suppression, and signal integrity standards for ethernet networks set by the automotive industry. It is important to consider OPEN qualified devices because the OPEN Alliance and the SPE group are organizations comprised of leading manufacturers and adopters of single pair ethernet communications; OPEN concerned with exclusively automotive applications and the SPE group focused primarily on industrial applications. Some of the overlap of transient suppression requirements and bit rates of automotive and industrial applications will ease circuit protection device selection.

MLVs are significant because silicon based TVS (transient voltage suppression) diodes are commonly used to protect circuits, but shortages are expected to impact these devices along with IC (integrated circuit) shortages. An example of inherent size and reliability advantages of MLVs is implied below.

SPE IP20 Jack | SPE IP20 Full Assembly | SPE IP20 Coupler

Figure 1. Renders of various SPE connector technologies

INTRODUCTION

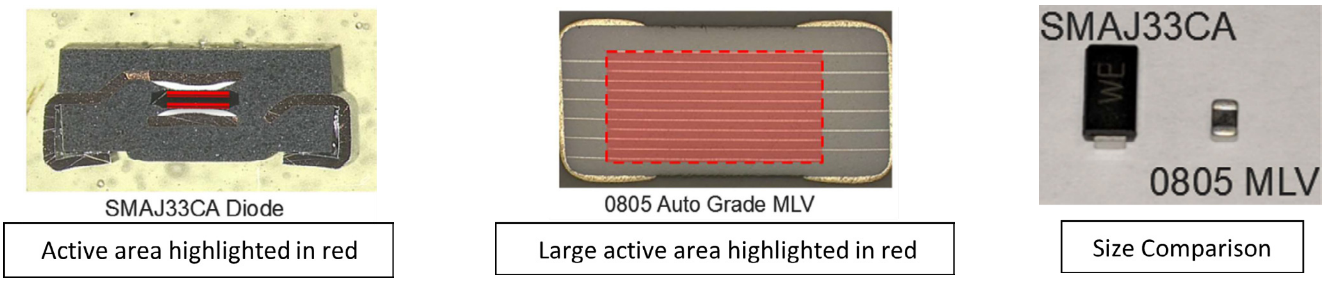

Figure 2. Cross-section of TVS Diode (left), MLV (center), and size comparison (right)

The purpose of this paper is to detail IDC and Press-Fit technology to expose designers to alternative SPE connector solutions that provide easy to implement processing with virtually no penalty to signal integrity. IDC implementation and cold weld mechanism will be explained. Press-Fit pin design and capability of solderless mounting will be discussed for SPE connectors terminated on boards. Single ended and differential signaling scattering parameters of these connectors will be reviewed to show performance against SPE transmission standards. The second half will provide an overview of MLV technology in comparison to TVS diodes and provide supporting material that present the size, weight, cost, and reliability advantages of this circuit protection device. This paper will be of interest to robotics, sensor, and industrial automation design engineers, component engineers, and program managers due to its impact on system design and performance.

IDC & PRESS-FIT CONNECTORS

The IDC connection termination has been designed to make wire and termination connection mating simpler and more efficient. Manufacturing with IDC takes time and complexity out of the assembly process by removing the need to solder (Figure 3). Soldering can require highly skilled technicians in the case of small gauge coaxial cables, introduces heat to peripheral components, and includes the risk of solder bridges if not performed correctly. These steps can be replaced by implementing IDC terminations that simply require manual pressure to create a connection.

KYOCERA AVX 9176-800 low profile IDC (Figure 4) are examples of connectors designed to meet the harsh environments and intense demands associated with the automotive and industrial markets. These connectors have been tested to high levels of shock, vibration, and temperature cycling to ensure their reliability and robustness while providing an air-tight connection.

ADVANTAGES OF IDC:

- IDC are quicker to manufacture than other connectors due to their ability to terminate many wires into one connector. IDC does not require stripping prior to termination, soldering, or crimping saving manufacturing time and money.
- Can be processed by basic manual or other simple tools and therefore requires less time to terminate ribbon cables.
- Can increase the durability of components such as locking clips, ejection latches, stress relief, and polarization functions.
- Provides a gas tight insulation seal on wire terminations.

LIMITATIONS OF IDC:

- Due to the stiffness and rigidity of ribbon cables, they can be difficult to propagate them throughout the circuit and terminate them with IDC.

IDC & PRESS-FIT CONNECTORS

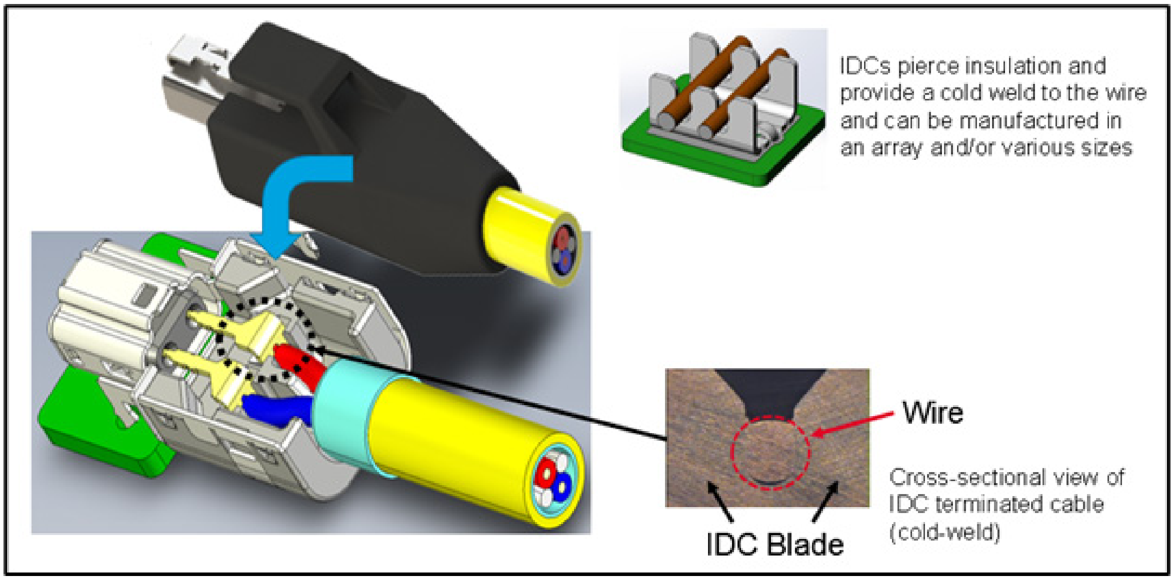

Figure 3. Depictions of wire terminated to IDC connectors

Figure 4. Various IDC connectors for wire-to-board solutions

Press-Fit technology is another component advancement which will benefit SPE applications. Press-Fit provides a mechanical fastening connection between the connector and mounting surface through the mating of unique contact pins into plated through-holes on a PCB (printed circuit board).

The connector uses a needle eye construction to stay firmly in place once embedded. The Press-Fit pins exert a normal force on the non-plated through holes on a PCB to remain in place (Fig. 5). Due to the nature of how Press-Fit is installed, they are only able to be removed and reinstalled a limited number of times. Press-Fit technology also provides increased signal integrity and easy assembly relative to other component surface mounting techniques. Press-Fit only uses physical force to attach to a PCB, it removes any risk of thermal exposure due to soldering to other components on the board (Fig 6). In order to reduce whisker caused by the stress of forcing the pin into the board KYOCERA AVX offers AgSn20 and Indium plating proven in the Automotive industry.

ADVANTAGES OF PRESS-FIT:

- Pins of short length can be assembled on thick boards.
- Signal Integrity requirements call for short pin lengths.
- Prevents thermal exposure of connector header housing since soldering is eliminated.
- Prevents solder paste and flux application to nearby connector terminals.
- Environmentally friendly, especially in the case of thick backplanes.
- No shadow effect on SMT (surface mount technology) components if done as post-solder operation.
- Prevents solder defects like bridges, bad wetting, flux residue, thermal expansion, and cold joints.
- Hybrid assembly possible but should be considered early in design.
- Press-Fit blade connections can carry high currents.

IDC & PRESS-FIT CONNECTORS

LIMITATIONS OF PRESS-FIT:

- Needs initial design considerations to be addressed and the use of special tooling in assembly.
- PCB Press-Fit holes require controlled plating of via wall thickness, strict control on additional plating and overall tolerance of finished hole diameter.
- Poor assembly may damage via hole walls and subsequently hinder connection reliability.
- Connector price is slightly higher than solderable connectors.
- Connector removal is possible only twice in controlled repair environments.

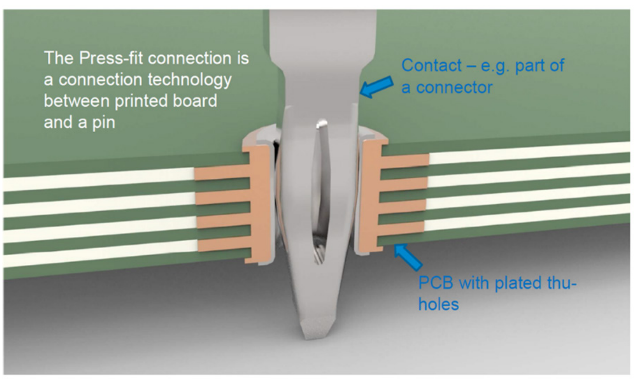

Figure 5. Render of Press-Fit connection to plated through-hole

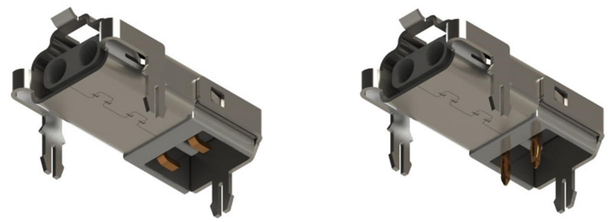

Figure 6. Comparison of SPE Jack with SMT terminations (left) and Press-Fit terminations (right)

These SPE connectors comply with signal integrity requirements defined in IEC 63171-6. Figure 7 shows the insertion loss and return loss performance of the KYOCERA AVX 6780 Series devices that are SPE IP20 connectors. The connectors were mated and terminated onto a test board and subjected to scattering parameter tests in differential signaling orientation. The losses fall well within the requirements defined by the IEC to ensure clear communication of modules on an ethernet bus. In addition to the IEC requirements, performance was compared to 100BASE-T1 and 1000BASE-T1 insertion/return loss limits that are stricter than the IEC requirements. The IEC and 1000BASE-T1 limits end at 600 MHz, but the IP20 connectors were tested well beyond this frequency in anticipation of increasing bit rates and signal integrity requirements that are further into the frequency spectrum.

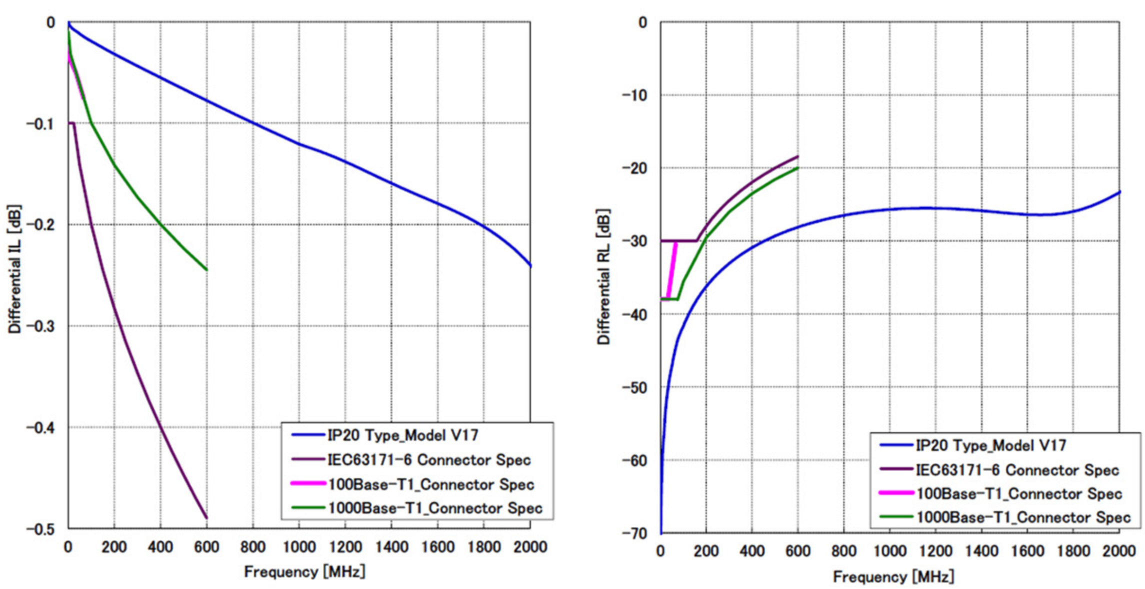

Figure 7. Differential Insertion/Return Loss of KYOCERA AVX IP20 SPE Connector Assembly (6780 Series)

TVS DIODES VS MLV

The urgency for improved circuit protection devices is compounded by the increased quantities of ICs in an electric vehicle, but also by the fact that a common circuit protection implement is a silicon-based device; the TVS (Transient Voltage Suppression) Diode. Shortages are expected to impact TVS diodes as well, and the Multilayer Varistor (MLV) is a viable alternative, and worthwhile to explore the design, performance, and the pros/cons of MLVs versus TVS diode technology to expand solutions that prevent overvoltage damage to ICs from ESD (electro-static discharge), switching transients from inductive loads such as small motors, relays, latches, and servos.

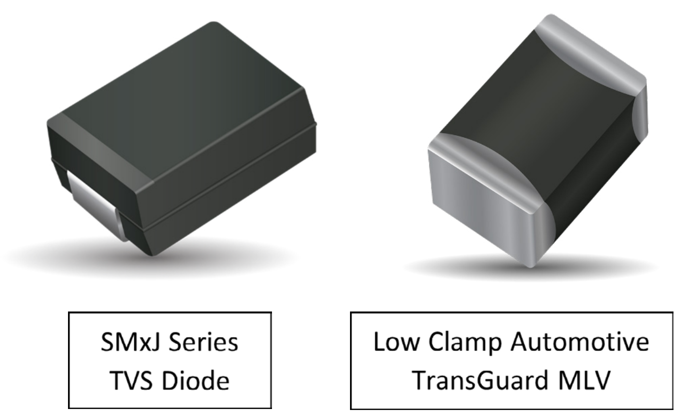

Figure 8. Depiction of molded TVS diode and SMD MLV

The MLV is constructed in a very similar fashion to MLCCs (Multilayer Ceramic Capacitor) albeit a different material set. At a predefined voltage level, the MLV will begin to shunt current to ground and subsequently clamp voltage to protect sensitive ICs. MLVs can be designed for a wide range of clamping voltages and magnitudes of transient energy. Some additional advancements of MLVs include low ratios of operating to clamping voltage, flexible terminations, 175°C operation, and OPEN Alliance qualified (automotive grade) devices that are designed to preserve signal integrity on single pair ethernet lines, in addition to overvoltage protection. MLVs can also be packaged in arrays, allowing for space savings by consolidating keep-out areas for multiple signal lines needing protection to be terminated on one device. Advancements in passive component technology like the ASPGuard® Series of OPEN qualified MLVs from KYOCERA AVX will alleviate the selection process because they comply with IEEE 100BASE-T1 and 1000BASE-T1 standards. SPE networks for harsh industrial applications requiring high temp., high frequency, and high reliability will find a wide breadth of circuit protection solutions in MLV technology.

One of the biggest advantages of MLV technology is the very volumetrically efficient active areas that are dissipating transient energy. TVS diodes rely on a single P-N junction to clamp voltage. Even if it is a bidirectional diode with 2 P-N junctions, only one of them will activate during a transient event. The large internal volume of active material becomes increasingly significant for MLVs in highly repetitive transient environments, like an I/O, HMI (human machine interface) or consider the number of transients suppressed for a complex combustion chamber that can generate varying magnitudes of sparks based on fuel/air mixture to provide a desired level of performance. The multiple layers of an MLV distribute transient energy evenly across all layers e.g., if there are 10 layers then each layer will dissipate 1/10 of the incoming transient. These layers also provide redundancy if one of the layers begins to degrade making for an extremely reliable device.

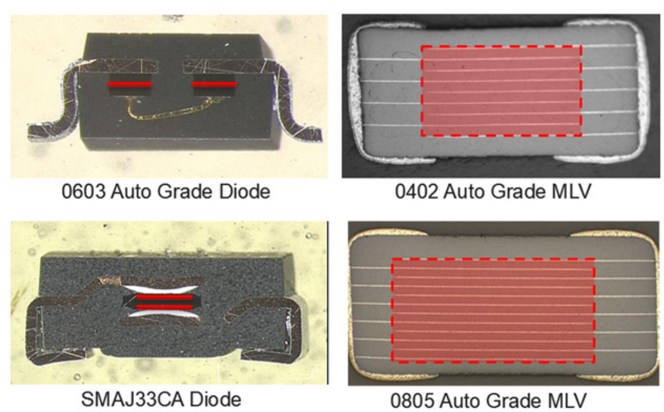

Figure 9. TVS Diode & MLV cross sections with active areas highlighted in red

MLVs also require no temperature derating until rated operating temperatures are reached, very much unlike typical TVS diodes that must derate their transient energy capability for anything above room temperature (25°C). The chart below

TVS DIODES VS MLV

shows a comparison of peak power/current derating curves, which has unique implications for MLV technology in high temperature applications. An EIA 0805 MLV can actually outperform an SMA packaged diode at high temperatures despite being much smaller. MLVs have no temperature derating up to their maximum operating temperature and have 0 failures when subjected to the same transients across temperature which was expected. TVS diode failures began at 65°C and were all short circuit failure modes, reinforcing the fact that derating rules for TVS diodes should be strictly followed. Additionally, larger or heat sink integrated TVS diodes would need to be used to maintain reliability, but size or cost constrained designs would benefit from the use of more thermally efficient MLVs.

There are a few unique features of MLVs that set them distinctly apart from TVS diodes. MLVs have inherently higher capacitance than TVS diodes, but this quality can be exploited as a dual-purpose EMC capacitor and circuit protection element to consolidate the number of components to perform the same function. But for those high-speed signal lines that cannot tolerate capacitive loading, low capacitance designed MLVs would be used. MLVs also have intrinsically low parasitic inductance or ESL (equivalent series inductance), allowing for fast conduction times meaning transients are suppressed as soon as possible. Some transients are characterized by sub-nanosecond rise times and impedance contributions by ESL of these devices become significant at these high frequencies. MLVs and unpackaged Si die of TVS diodes have comparable response times, except for silicon TVS diodes that are wire bonded. Therefore packaged TVS Diodes respond slower to suppress fast rise time transients because of higher ESL due to the material, arc length, and the stitch or ball bond of the wire to the silicon die.

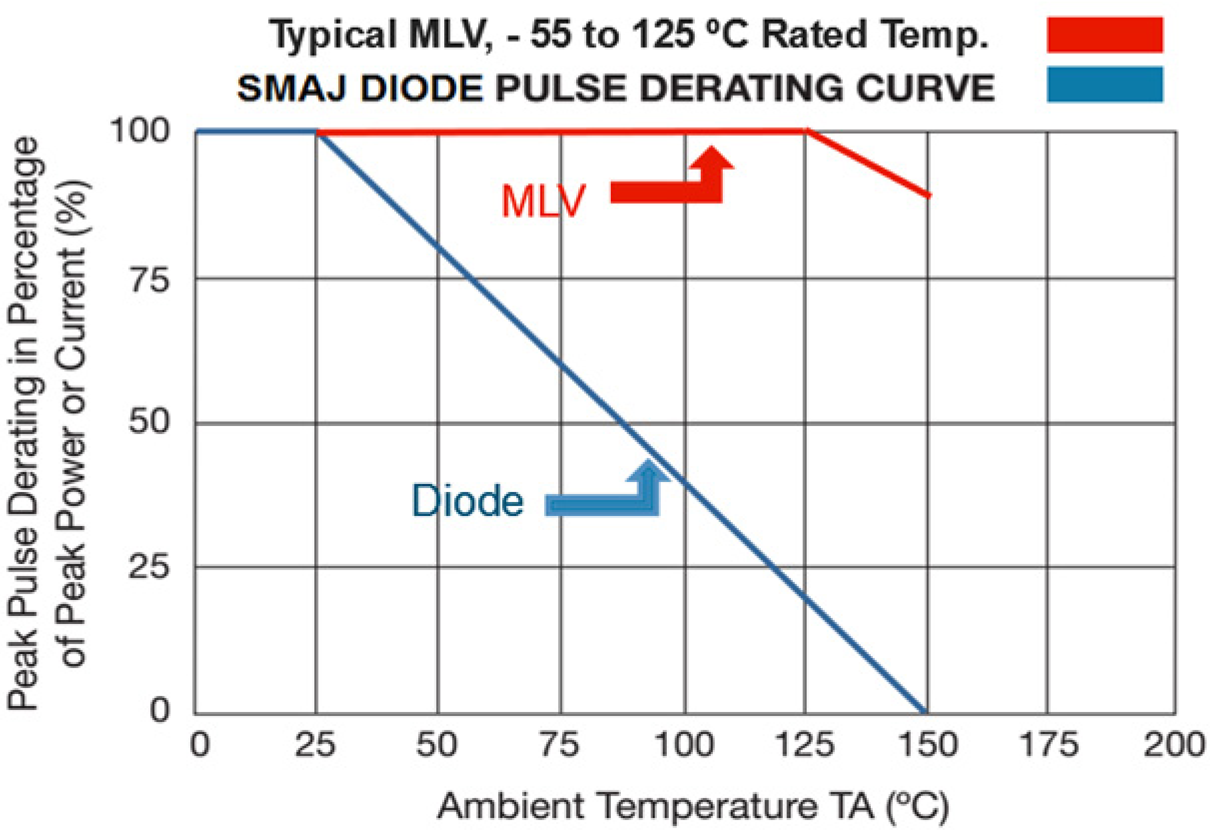

Figure 10. Comparison of MLV and TVS diode derating curve(s)

TVS DIODES VS MLV

ADVANTAGES OF MLVS:

- Covers a wide range of clamping voltages and magnitudes of energy.
- Larger energy dissipation surface area.
- Requires no temperature derating.
- Low parasitic inductance.

LIMITATIONS OF MLVS:

- In some instances, possibly more expensive than TVS diodes.

ADVANTAGES OF TVS DIODES:

- Universal sizing versatility.
- Historical acceptance in TVS applications.
- Lower operating to clamping voltage ratios.

LIMITATIONS OF TVS DIODES:

- Only has a single P-N junction to clamp voltage.
- Wire bonded die causes slower transient suppression response time.

CONCLUSION

In summary, Insulation Displacement Connectors (IDC) excel at wire-to-board assembly speed and simplicity due to their design requiring no wire preparation like clamping or soldering terminations on wires. Press-Fit connectors have excellent board placement versatility due to their short pin lengths that have high retention forces and no soldering requirements making it convenient for boards going through multiple reflows and prevents connectors from undergoing multiple temperature cycles. There are SPE connectors, like the 6780 Series of devices, that utilize both IDC and Press-Fit technology to accommodate designers with unique termination options for size and time constrained assemblies which may provide opportunities for cost reductions compared to other connector types.

It was also discussed that MLVs provide a strong alternative to TVS diodes for circuit protection due to the ongoing silicon shortage which is projected to impact the TVS diode industry. But in addition to availability, MLVs are capable of surviving highly repetitive strikes, require no temperature derating, can be designed for low capacitance loading for high frequency signal lines, and are extremely volumetrically efficient when compared to TVS diodes. SPE networks on automated assembly lines, robotics, or Industrial IoT applications, will certainly have EMI requirements along with circuit protection, and MLVs have intrinsic capacitance which can be used during nominal operation as an EMC capacitor. This means a traditional TVS diode(s) + MLCC(s) combination can be consolidated into one MLV device that performs both filtering during normal operation and clamping in the event of a transient. As SPE picks up steam, solderless process connectors and Ethernet qualified MLV arrays will be able to support unique design constraints.

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