Next-generation circuit protection for industrial Ethernet interfaces

Circuit protection devices, using a combination of thyristors, TVS diodes, and steering diodes, provide better protection for industrial Ethernet interfaces.

Ethernet is one of the most commonly used communication protocols, and as a result, it has increased the exposure of devices to overvoltage events. The two most common causes of overvoltage events are electrostatic discharge (ESD) and surge pulses. A common occurrence of ESD is by simple human contact, which can happen many times daily. Surge pulses are typically caused by the discharge of inductances.

According to an ESD Association reference article, it was estimated that ESD can cost as much as 10% of the annual revenue of electronics manufacturers in repairs. This runs into the billions in costs for the electronics industry. With ever-evolving standards to guard against such events, engineering must evolve with them.

Figure 1: The widespread Ethernet communication port (Source: ProTek Devices)

Ethernet market growth and application threats

The common Ethernet interface is not immune from such potential losses in revenue. With the potential for ESD to occur daily and Ethernet also being a commonly used interface in computing applications, as well as in the industrial sector, the risk of damage is high.

According to a research report by Straits Research, the market for industrial Ethernet applications was $12.6 billion in 2024. It is expected to nearly double to $24.6 billion by 2033. This includes Ethernet's growth in manufacturing plants, IoT devices, edge computing, and more. So a lot is riding on the reliance of Ethernet in critical infrastructure, particularly industrial applications.

It is not possible to address overvoltage circuit protection without clarifying what types of threats from electrical transients might be applied to an electronic system. The IEC 61000-4-X compliance standard series guides this identification and transient simulation.

The IEC 61000-4-2 standard defines the different voltage levels in the case of ESD. It is categorized by severity from Levels 1 through 4. It is further divided into two test conditions: contact and air discharge.

Aside from ESD transients, the largest threat to an electronic system can be caused by secondary surge events such as switching transients, inductive loads, and even lightning strikes. A surge event can have a longer duration of 20 µs and a higher surge current. This can cause visible damage or destruction to downstream circuitry and printed-circuit-board traces.

Classification of surge events in communication interfaces

From a design point of view, an overvoltage protection scenario requires serious caution. First, the developers must determine the environment where the final device will be used. The IEC 61000-4-5 compliance standard provides guidance to specify the right environment by class. It indicates the voltage levels of the potential threats.

Most consumer Ethernet applications are Class 2, determined at a 1-kV voltage level. However, to design an adequate circuit protection solution, determining the peak current value of the event is as important as knowing the voltage level. To meet compliance on communication interfaces, IEC 61000-4-5 states that the impedance value should be 42 Ω. Therefore, a Class 2 Ethernet interface under a 1-kV condition with a 42-Ω impedance will require a circuit protection device that meets a 24-A 8/20-μs peak surge current.

Class	Environment	Voltage Level
0	Well-protected environment, often in a special room	25 V
1	Partially protected environment	500 V
2	Electrical environment where the cables are well-separated, even at short runs	1 kV
3	Electrical environment where power and signal cables run in parallel	2 kV
4	Electrical environment where the interconnections include outdoor cables along with the power cable, and cables are used for both electronics and electronic circuits	4 kV
5	Electrical environment for electronic equipment connected to telecommunication cables and overhead power lines in a non-densely populated area	Test level 4

Figure 2: Classes 1–5 are stated on IEC 61000-4-5. (Source: IEC 61000-4-5 Compliance Standard)

Design layout of a circuit protection device

Circuit protection engineers try to limit the energy at the entry point to the equipment, the RJ-45 socket, to ensure fewer stresses are applied to the circuit. Suppose the saturation of the quad transformer is not reliable for a surge pulse. In that case, the overvoltage protection device exhibiting adequate surge capability should be moved to the RJ-45 connector side, as illustrated in **Figures 3** and **4**. It is even more critical if the communication protocol is in the high-speed region.

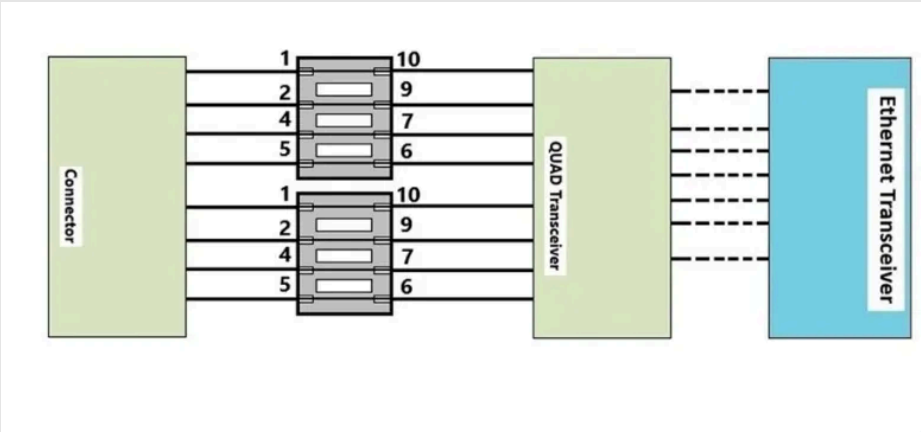

Figure 3: Differential-mode application (Source: ProTek Devices)

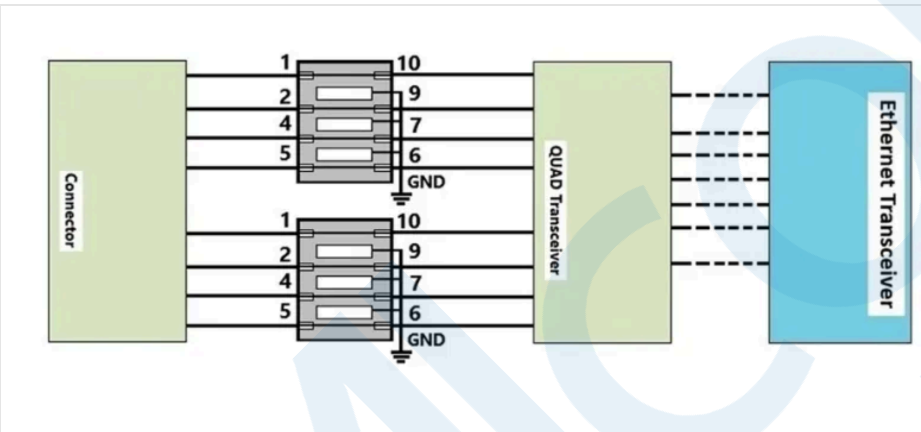

Figure 4: Common-mode application (Source: ProTek Devices)

New semiconductor technology, shown in **Figure 5**, uses a combination of thyristors, TVS diodes, and steering diodes. These newer circuit protection devices offer a lower clamping voltage, higher surge capability, and ultra-low capacitance values required to meet new 2.5-V or 3.3-V PHY operating requirements.

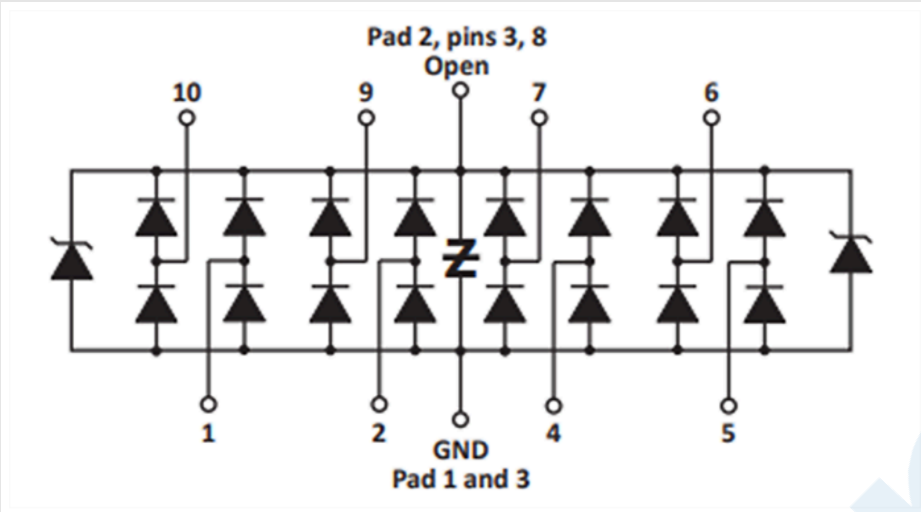

Figure 5: Possible structure of a combination technology circuit protection device

(Source: ProTek Devices)

Real-world surge transient event

Figure 6 illustrates the Ethernet interface circuit protection in operation when presented with a real-world surge event across the Ethernet data pair signal frequency of 125 MHz. The square wave is DC 50%, with a maximum voltage of 3.6 V. The 3.3-V transient circuit protection hybrid steering diode/thyristor array used in this scenario is in differential mode, under the operation of a high-energy pulse. This meets the conditions of a Class 2 event: 1 kV with 24-A peak pulse current 8/20-μs waveform.

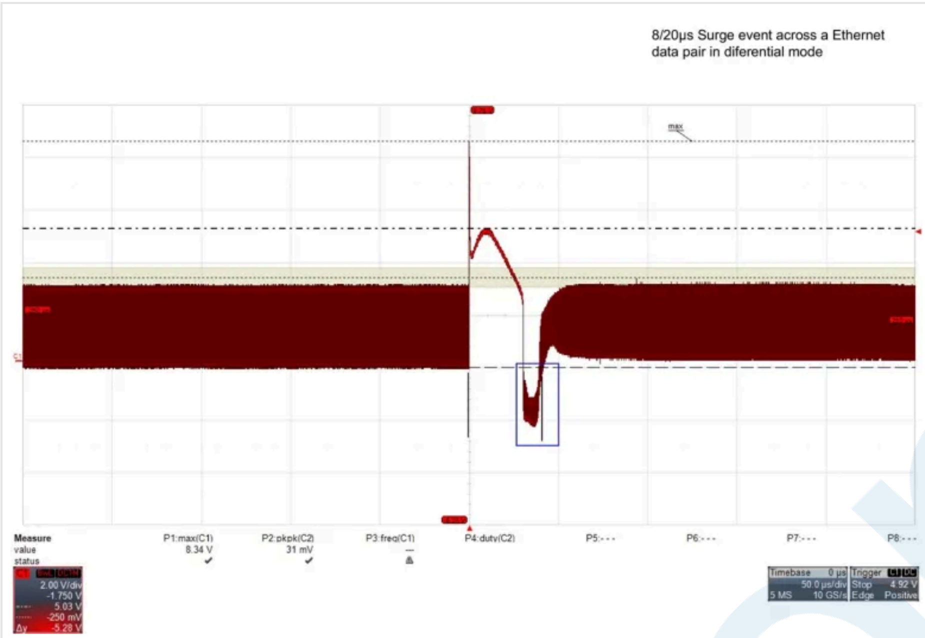

Figure 6: 8/20-µs surge event across an Ethernet data pair in differential mode

(Source: ProTek Devices)

The curve shows that the 1-kV overvoltage event starts rising, goes above 8 V, and reaches 8.34 V before the device responds quickly by switching on the thyristor. The voltage immediately clamps about 5 V; the maximum clamping voltage value on the curve is 5.28 V. The device recovers the off-state condition after about a 45-µs duration.

The two most common types of overvoltage events are ESD and surges, which are described by the IEC 61000 compliance standard for industrial applications. When designing surge circuit protection, many factors need to be considered. The IEC 61000-4-5 compliance standard provides guidance, helping to define the parameters of the actual event more accurately.

Older circuit protection technologies are not up to the task of protecting lower operating voltages on PHY chipsets with higher sensitivity to applied transients. New [hybrid semiconductor devices]() now exist to offer adequate circuit protection against most common events. This is the 8/20-µs waveform with a voltage level of 1-kV, 24-A peak current.