Using commercial lightning protectors in defense applications

Commercial lightning protectors can protect wireless communications systems for defense and homeland security systems against damaging lightning energy.

By George M. Kauffman

The operational frequency range and associated RF performance is one of the most important parameters for selecting a lightning protector for wireless communications systems. Military and related security communication frequencies span a large range from HF, VHF and UHF to above 3 GHz. Terrestrial communications continue to use 30 MHz to 400 MHz due to superior wave propagation characteristics and compatibility with legacy equipment. Higher frequencies are more popular for local or line-of-sight communication and for elevated tower-, airborne- or satellite-based relay communication. This article will introduce the fundamentals of over-voltage protection for coaxial interfaces, and discuss the specific challenges of protecting critical defense or security communication links. In addition, key points will be addressed for selecting the optimal COTS protectors.

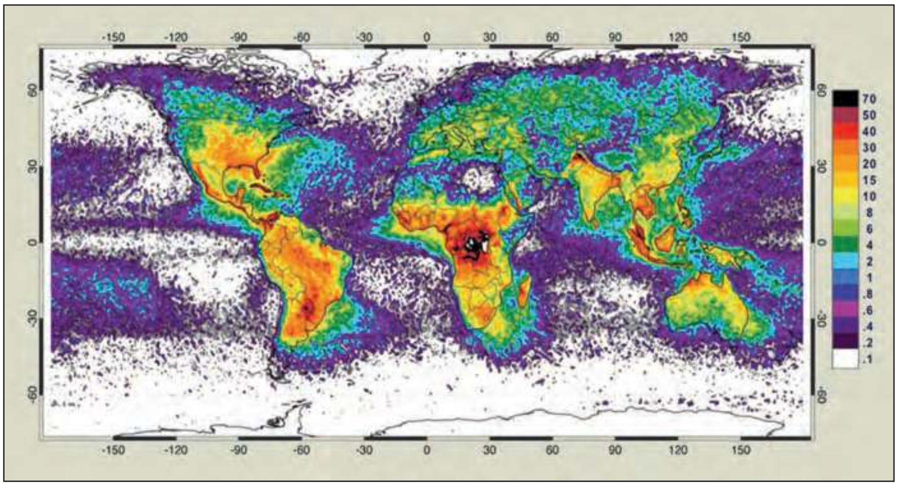

Figure 1. World lightning strike density.

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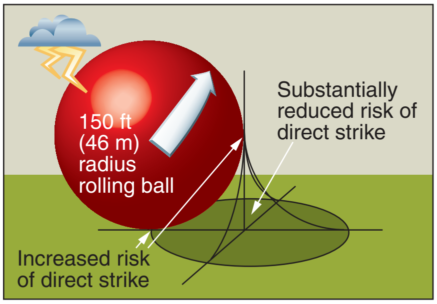

Figure 2. Rolling ball model.

Susceptibility

Most radio equipment antenna ports are usually susceptible to three failure modes:

1. High-voltage failure with circuits or components interfacing to the series transmission line or ground; or
2. Overheating due to current flow in the transmission line circuit, shunt or series components; and
3. Conductor distortion or breakage, particularly for coils.

Furthermore, once high electrical energy is inside the enclosure or structure, excessive voltages can propagate beyond the RF front-end and damage nearby circuits.

The susceptibility of a radio input can vary significantly based on several factors. Receivers with sensitive amplifiers can be susceptible to remarkably low voltage levels, sometimes on the order of a few tens of volts. Most RF ports have input filters that can tolerate or reduce the magnitude of limited impulses. For example, a 500 V series capacitor input stage can tolerate transients of 1000 V for 10 µs. In addition, detection diodes and ESD protection can boost immunity for short-pulse-width events. The operational frequency has a significant effect on lightning coupling or rejection, since most receivers have bandpass characteristics that can block unwanted energy, but only within limits.

Risk assessment

Lightning damage risk is primarily related to the mission environment (climate), the platform type, antenna location and the equipment interface susceptibility. In general, the humid regions of the tropical equator tend to have the highest lightning activity, while more polar and benign climates typically have much lower levels of lightning activity. Figure 1 illustrates world lightning strike density in strikes/km^2/yr. For specific deployments, such as aviation, naval and ground communications, accumulated data and experience have been used to develop lightning protection standards.

The largest single factor in a lightning protection risk mitigation assessment is determining the probability of a lightning strike to the cable center conductor, either directly

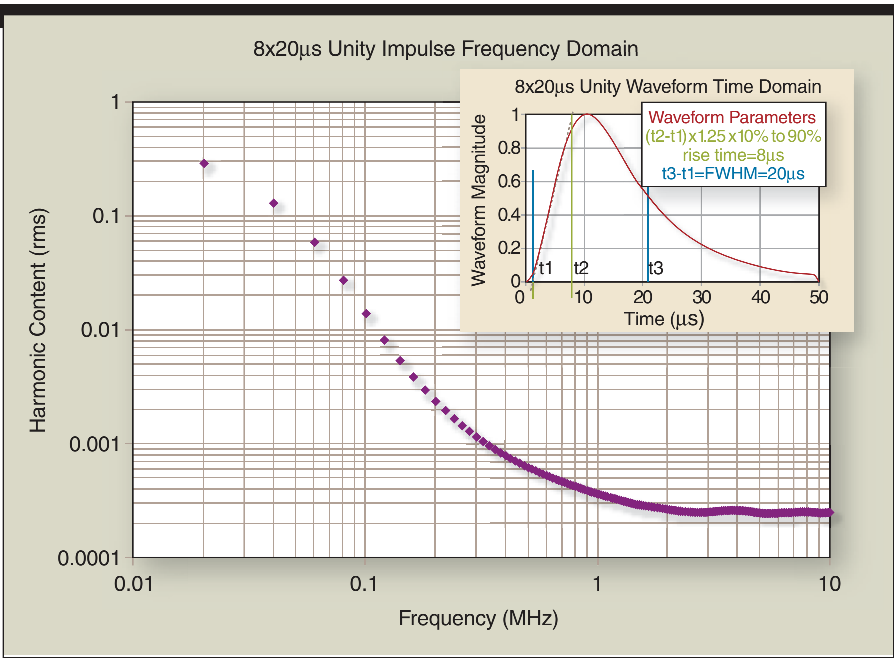

Figure 3. Typical lightning waveform.

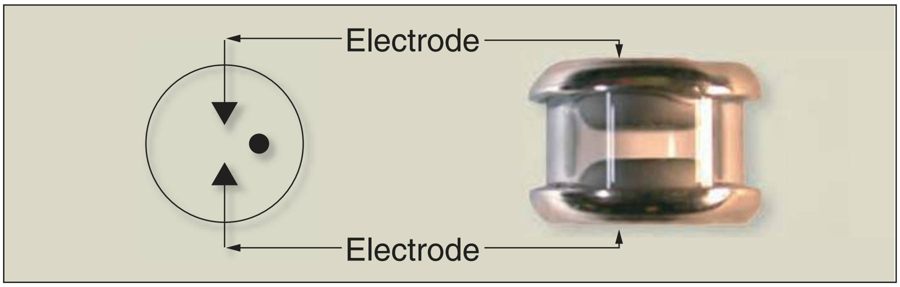

Figure 4. GDT-based protector.

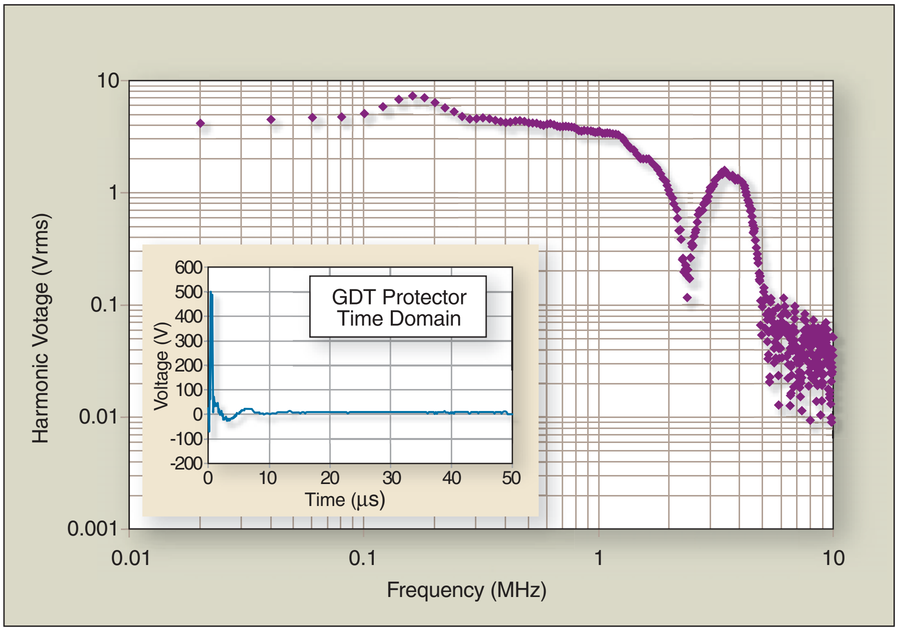

Figure 5. GDT protector output response during a test transient input.

or indirectly such as through an attached antenna. For stationary objects, the rolling ball model, per NFPA780-1995 is widely used to predict where lightning is less likely to attach, as shown in Figure 2. Areas in contact with the surface of the ball are at the greatest risk for a direct lightning strike. Therefore, if the antenna is below or otherwise protected by vertical or horizontal air terminals, or other grounded metallic structures, the threat risk of lightning attachment to the center conductor will be reduced. The implications of full-strike lightning current on the center conductor are dramatic. If lightning is likely to attach to the critical communications link, and the mission profile requires survival, then the redundant protection of upsized conductors (able to take the current) and possibly redundant exposed circuits (cables, antennas and protectors) are needed. If lightning is not likely to attach to the center conductor, then the potential energy exposure is reduced, and normal protection will usually be adequate.

While the specifics of each lightning pulse can vary significantly in both the transient waveforms and magnitude, the vast majority of strikes have rise-times of slightly less than 1 µs to more than 10 µs, and pulse durations of several tens of microseconds to nearly 1 ms. Figure 3 shows the time and frequency domain of a unity 8 µs x 20 µs pulse (10% to 90% rise time of 8 µs, after scaling by 1.25, then returning to 50% at 20 µs total elapsed time), which is the most popular for lightning modeling and testing. Note that the magnitude of voltage or current represented by this figure should be multiplied by the actual peak value. In the absence of a specific customer specification, the 8 µs x20 µs waveform is adequate for first-pass engineering work.

In many cases, the customer has specific requirements, including MIL-STD-461 or RTCA DO-160. In some cases, such as MIL-STD-464, the direct lightning parameters are provided and the coupling to conductors must be modeled or measured.

Protection technology

There are two principal protector technologies that operate above 30 MHz and are capable of protecting against high transient currents. These are the gas discharge tube (GDT) and the quarter-wave protector. Both will dramatically reduce the transient on the center conductor by shunting current to ground.

A GDT is a gas-filled envelope containing two electrodes separated by a precise gap, as shown in Figure 4. The gas will break down or arc when a pre-determined voltage is applied to the electrodes. The GDT is a high-transient-current device with low capacitance for minimal disruption to the RF transmission lines operating below 2.5 GHz and, in some cases, to about 4 GHz. Some unique configurations are available with excellent RF operation to 6 GHz or even up to 12.5 GHz, but these are exceptions within the industry. Figure 5 shows the output of a GDT-based protector with a 6kV/3kA transient input. Notice the higher frequency content of the output compared to the input waveform in Figure 3. The 6 kV input fundamental (referring to Figure 3) is ~0.3 x 6000 V or 1800 V; the output fundamental is ~4 V, or a reduction of 99.8%.

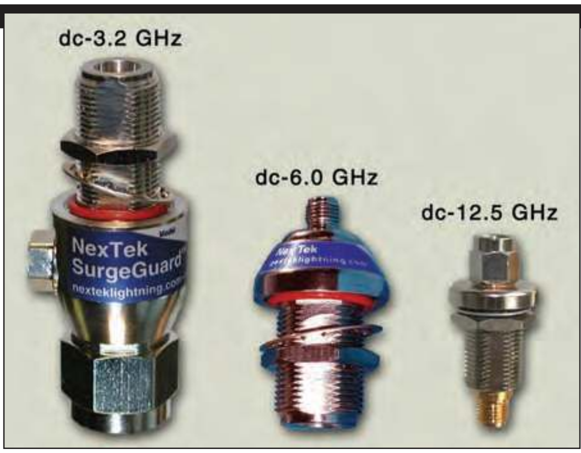

Figure 6. Commercial GDT devices.

NexTek makes other protectors for unique applications that overcome the limitations of the GDT or shunting devices, including protectors with bias T functionality and multiple- stage protectors.

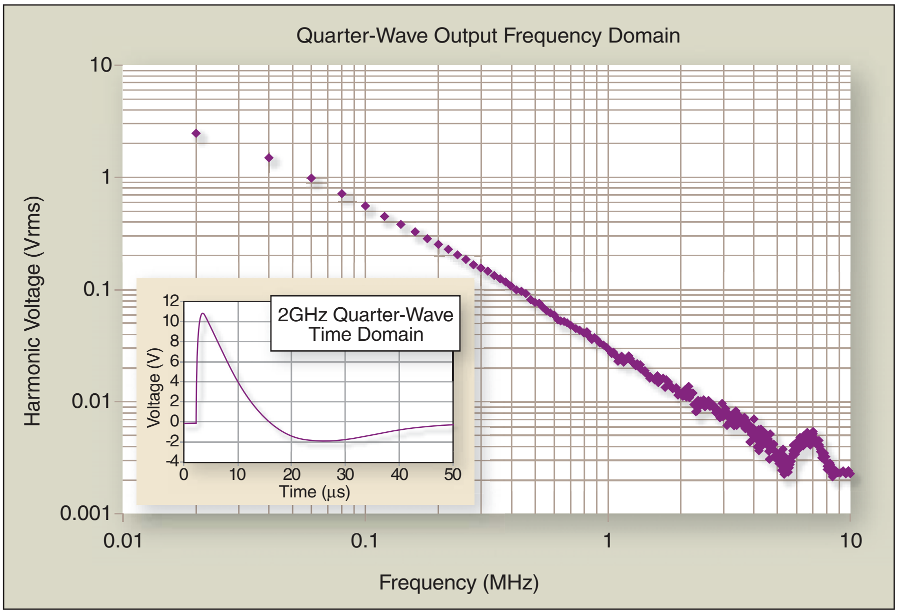

Figure 7. Typical output of a quarter-wave protector.

Figure 8. Commercial quarter-wave stub protectors.

When lower voltages are present on the center conductor, the GDT behaves as an open circuit. Therefore, GDT-based protectors can be used where dc voltages are required on the center conductor. GDT's are triggered to an active state by the voltage exceeding the particular rating of the GDT. Be aware that the GDT gas will take a small amount of time to ionize and react to the transient. Therefore, a portion of the leading edge of the transient will get past the protector (although the vast majority of the transient energy and voltage is eliminated). Figure 6 displays COTS GDT lightning protectors for various frequencies, with N connectors and SMA connectors.

Protectors based on GDT technology should be selected with a trigger voltage rating that allows for enough margin above the anticipated RF and dc voltage such that normal transmission power will not trigger the GDT.

The second protection technology is a shunting device, which has a conductor connected from the center conductor to the outer grounded conductor. These protectors are called quarter-wave or filter protectors. The shunting member must be sized to take the significant current available in a transient. The operational frequency of these shunting devices is typically from 400 MHz to more than 6 GHz. Narrowband protectors can usually pass over a 20% bandwidth. Wideband protectors with bandwidths of more than 100% (the center frequency ± more than 50% of the center frequency) are also available. Figure 7 shows the typical output of a quarter-wave protector with a 6 kV/3 kA transient. The output shows a low peak voltage, and only a slight amount of upward frequency shifting. Protectors at frequencies of less than 200 MHz tend to make the voltage clamping action less effective, due to excessively long and high-inductance shunts. Since the quarter-wave protector is shorted internally, these devices are not compatible with dc applications. Quarter-wave stub protectors must be selected based on the required RF transmission frequencies. Examples of commercially available quarter-wave protectors are shown in Figure 8.

NexTek makes other protectors for unique applications that overcome the limitations of the GDT or shunting devices, including protectors with bias-T functionality and multiple-stage protectors. For example, multiple-stage protectors are available to further reduce the let-through voltages, with simplified circuits, as shown in Figure 9. This figure also shows the output of a multiple-stage protector during a 6 kV/3 kA transient. Notice that the peak voltage is strictly limited to about 18 V in this model. The drawback of multiple-stage protectors is that they are unidirectional: they accept transients from one side only. Bi-directional protectors are usually a better choice unless very low transient let-through is required, and precautions are in place to ensure the proper installation and orientation of the protector.

Applications

Lightning protectors for several applications are shown in Table 1. The first application requires frequencies too low for a quarter-wave device, so a GDT-type protector is appropriate. The first example (SINCGARS & Ter/SAT) has a peak RF voltage of 225 V, which increases to about 270 V with a VSWR of 1.5. The 3.2 GHz GDT-based protector in Figure 6 with a rating of 470 V would allow for the necessary voltage margin. The second application (JTTY) could use a quarter-wave or a GDT-based protector. If a GDT-based protector is preferred, any of the protectors shown in Figure 6 can be used. The very low

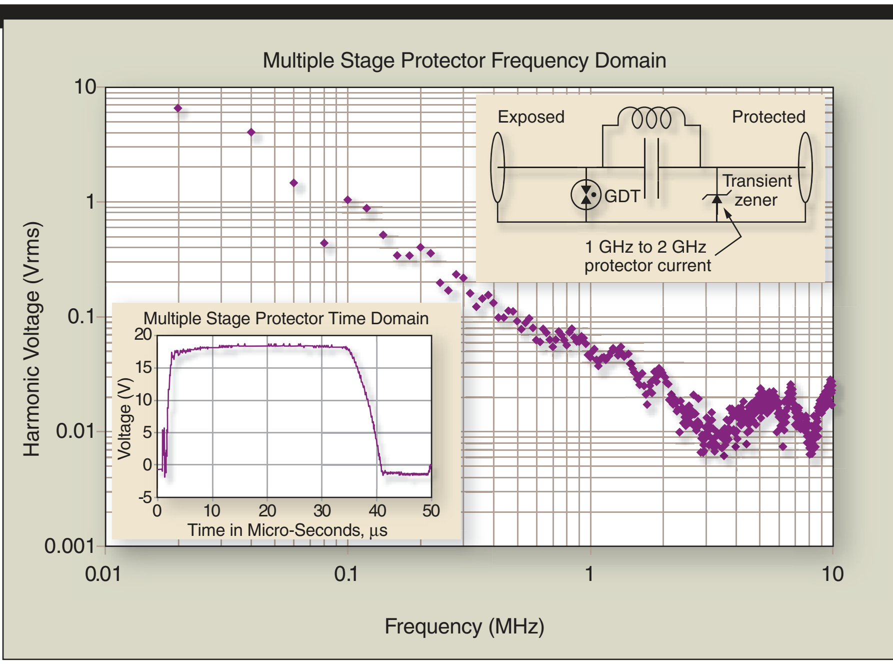

Figure 9. Multiple-stage protector output's response to a transient input pulse.

Table 1. Defense communications applications.

Application	Frequency	Preferred	Protection Technology		Power
			Alternate	Connector	
SINCGARS & Ter/SAT	30-88 MHz & 120-156 MHz	GDT	-	N	500 W
JTTY	225-400 MHz	GDT	-	N	10 W
Digital WB Transmission	1350-1850 MHz	Quarter Wave	GDT	N	50 W
Public Safety	4.94-4.99 GHz +dc	GDT (6 GHz)	-	N to SMA	2 W

Table 2. Typical environmental requirements.

Requirement	Typical MIL-STD
Corrosion (Salt Spray)	MIL-STD-202 Method Condition B or A
Immersion	MIL-STD-202 Method 104A Condition B
Moisture Resistance	MIL-STD-202 Method 106E IEC 529/IP68
Thermal Shock	MIL-STD-202 Method 107D Condition A-1 or B-1
Sand and Dust	MIL-STD-220 Method 110A
Vibration	MIL-STD-202 Method 204D Condition D, or MIL-STD-202 Method 214 Condition A
Shock	MIL-STD-202 Method 213B Condition A or G

peak RF voltage would be compatible with a commercially available 90 V protector.

The digital wideband (WB) transmission application has a high enough frequency that a quarter-wave device would be the best choice. The required bandwidth is 31%, so a wideband protector is preferred. A commercially available protector, such as that shown on the left side of Figure 8, would be an optimum choice. The clamping action and capacity of the quarter-wave device is superior to a GDT device of the same frequency.

The fourth application in Table 1 relates to public safety and requires a GDT protector rated for at least 5 GHz, since the RF frequency and dc power is passed. Considering the RF voltage is low due to the low power, a 90 V protector would be acceptable. The middle protector shown in Figure 6 would be preferred if the desired external connection is an N connector (other connector types are also available).

Protection coordination

Compatibility of the radio with the protector let-through voltage and energy is required to ensure survivability. There are two ways to approach this task. The analytical process is to measure the input parameters of the radio and confirm that the interface will not shunt current and thus will allow the protector to operate; in addition, the radio must tolerate the predicted voltage let-through. For most interfaces, a sufficient rule of thumb for current limiting is to have an impedance greater than 10 Ω to ground at 1 MHz. You can satisfy this requirement with the following:

- Measuring a resistive impedance component of more than 10 Ω to ground, or
- For series capacitive inputs measuring a capacitance of less than 0.15 µF, or
- For shunt inductive inputs, measuring an inductance greater than 2 µH to ground.

These values will force the *protector* to conduct the vast majority of the transient current. In addition, for series capacitor RF inputs, a capacitor with a dc voltage rating of 500 Vdc or higher should be used for maximum protection.

The empirical approach is to test the protector with a transient current input connected to the device to be protected. This eliminates any uncertainty of measurements and potential non-linear behavior of the radio input. This testing is performed at either the system or sub-system level.

These approaches can be augmented by comparing the frequency domain of the let-through voltage with the input-filtering insertion loss. The lightning source impedance, when clamped by a protector, is a fraction of an Ohm, so 50 Ω insertion loss plots may not be directly applicable, but only give an approximation of let-though reduction through the radio front end. If the radio has very low voltage impulse tolerance, then a multiple stage protector may be required to further limit the let-through to just above the RF or dc voltage of the application.

ABOUT THE AUTHOR

George M. Kauffman is VP, engineering. He leads NexTek's engineering team developing lightning arrestor and dc power-conditioning products. Kauffman is a recognized leader in the lightning protection industry and holds multiple patents in the EMC field.

Prior to NexTek, George spent 18 years at Digital Equipment Corporation in numerous roles including manufacturing, product development, product management and software development. He holds a BS in Mechanical Engineering and an MS in Engineering Management from the University of Massachusetts/Amherst. He is registered in Massachusetts as a Professional Engineer.

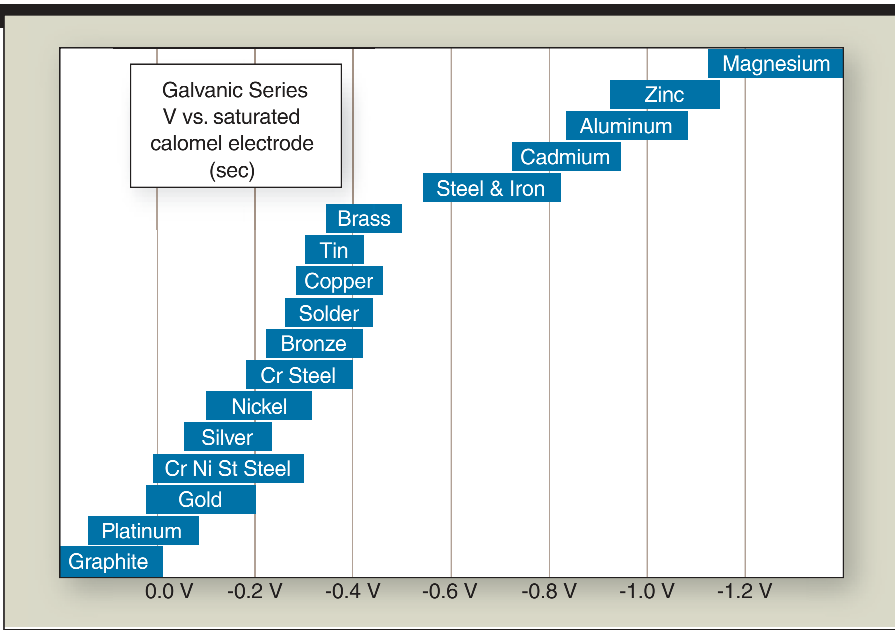

Figure 10. Galvanic series.

Environmental considerations

The more rugged physical environment associated with military applications requires designs qualified for thermal exposure, water and moisture resistance, corrosion, shock and vibration and physical strength. Compliance with military specifications for the parameters defined in Table 2 is available in higher-grade commercial lightning protectors.

One consideration for long-term reliability is material compatibility. The galvanic series is useful to indicate compatible materials. Figure 10 shows the galvanic series, which indicates the sacrificial materials near the top of the chart. Metal pairs with a potential difference greater than 0.4 V can be subject to corrosive degradation. This corrosion may seriously affect not only the RF path, but also the critical lightning current bonding connections. Since cables and connectors are all in the copper alloy family, the use of aluminum in the protector or bonding should be avoided.

COTS and cost-effectiveness

Some COTS lighting protectors are more than adequate for use in military applications. Selecting the most appropriate protection device is a decision that has significant implications and one in which all of the relevant parameters should be carefully weighed. If the protector is selected to meet the RF, protec-tion and environmental requirements, high reliability and long service life will be available at the most reasonable cost. **DE**