EMP Protection Against Lightning and Nuclear Pulses

PARLAN L. McGIVERN, Huber + Suhner, Inc., Essex, Vermont and
HEINZ WULLSCHLEGER, Huber + Suhner AG, Herisau, Switzerland*

INTRODUCTION

The development and utilization of LEMP (lightning electromagnetic pulse) and NEMP (nuclear electromagnetic pulse) protection devices have increased dramatically in the past 10 years. To evaluate the need for LEMP and NEMP protection, the characteristics of these pulses must be understood.

EMP WAVEFORMS

Rise Time. Lightning EMP has a typical rise time of 10 µs with a pulse duration of up to 100 µs. During this time, the electric field intensity can reach 500 kV/m while the magnetic field intensity can reach over 30 kA/m. This combination of electric and magnetic fields can cause a current flow in unprotected circuits of up to 20 kA. The key factor in the severity of LEMP is the pulse rise time (typically 5 kA/µs) and the resultant very high current.

The nuclear EMP has a typical rise time of 2 to 5 ns with a pulse duration of 200 to 600 ns. During this time, the E-field intensity can reach 50 kV/m while the H-field intensity can reach over 130 A/m. The NEMP pulse reaches its peak approximately 5000 times faster than LEMP (Figure 1).

Frequency Spectrum. The frequency spectrum of LEMP is considerably narrower than the NEMP. Figure 2 shows that a lightning strike contains very little energy past 100 kHz while the nuclear pulse contains energy up to 100 MHz. Figure 3 illustrates the NEMP energy distribution vs frequency.

Factors such as bandwidth, dc currents and the size of the protected unit must be considered in order to choose the optimum EMP protection device.

TYPES OF PROTECTORS

Perhaps the two most effective types of EMP protection devices are the *spark gap* and *the quarter-wavelength shorting stub,* which react to pulse rise time and pulse frequency, respectively. The spark gap and quarter-wavelength shorting stub are similar in that they both are bulkhead (chassis panel) mounted with a soft copper V-groove washer to ensure low contact resistance and good grounding between the protector body and the mounting wall (Figure 4). To choose between

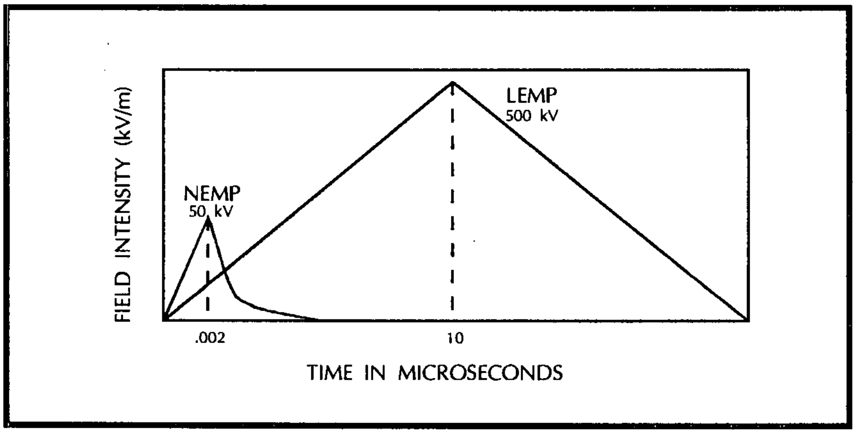

FIGURE 1. Time Domain Comparison of Nuclear and Lightning Electromagnetic Pulses.

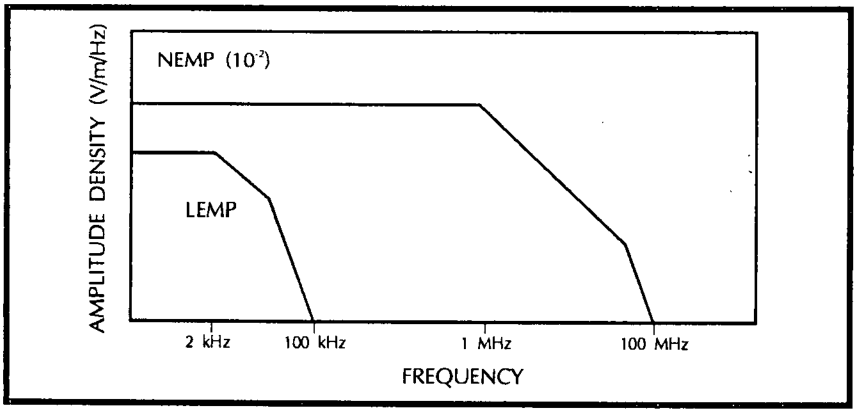

FIGURE 2. Frequency Spectrum and Waveform Analysis, extracted from DNA EMP Awareness Notes.

* See Advertisement on Page 305.

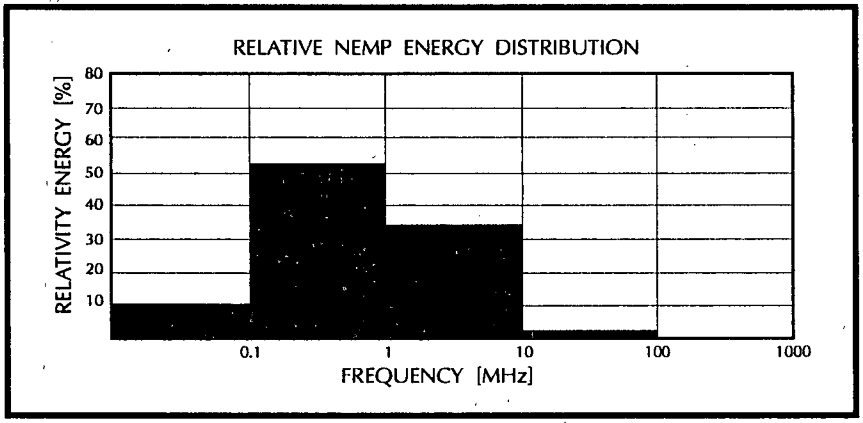

FIGURE 3. NEMP Energy Distribution vs Frequency Expressed in the Relative Percent of Energy Present.

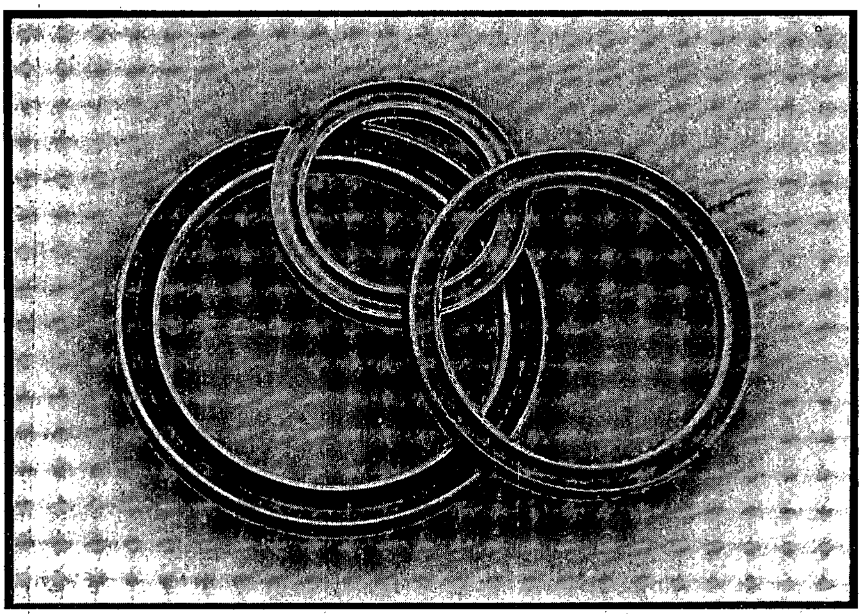

FIGURE 4. Grounding Washers Used to Ensure a Low-resistance Ground Between the Protector and the Chassis Wall. An excellent ground contributes to a low residual pulse.

the spark gap and the shorting stub, factors such as bandwidth, dc currents, and physical size of the unit being protected must be considered. For example, a quarter-wavelength protector cannot be used with a system that provides a dc current over its transmission line without special precautions, and may be too large for use in a VHF hand-held or portable system. A spark gap protector with a single or double changeable capsule may also be too large for a small unit. Those requirements involving dc current can be satisfied by a spark gap, while the least stringent requirements can be met with a miniature protector, which is filled with gas to permit a smaller footprint and which is discarded when no longer functional.

SPARK-GAP PROTECTORS

Design. The spark-gap design consists of a coaxial line with an overvoltage arrester installed directly between the center and outer conductors. Spark-gap protectors are designed as coaxial feed-throughs for bulkhead mounting. A V-shaped washer of annealed copper provides low resistance to ground between the protector housing and the mounting plate. Installation and removal of the protector capsule is relatively easy. The capsule holder has a spring-loaded cover which maintains a resistance-free path for the pulse current. Up to 20 kA can flow from the center conductor across the protector capsule and RF seal to the grounded metal wall (Figure 5). The protectors are exactly matched to 50 or 75 ohms, and the capacitance of the arrester capsule is compensated to ensure a low-reflection factor for the device while the inductance-minimizing mounting principle guarantees the shortest response time. The arrester capsule can be replaced without the use of special tools and a complete range of surge arresters is available covering spark-over voltage levels (V-static) from 90 to 1500 volts.

Operation. The operation of the spark-gap protector is based on the gas discharge principle. The fast pulse rise time of a LEMP or NEMP will cause ionization of the gas within the capsule at a voltage level between 90 to 1500 volts depending on the capsule selected. Ignition of the gas causes the resistance of the protector to drop from gigaohms to milliohms within an extremely short time. Voltage across the arrester measures approximately 70 to 90 volts at currents of a few milliamps (glow discharge), or 10 to 20 volts at higher currents when the glow discharge develops into an arc.

When an overvoltage pulse of LEMP or NEMP travels along the protected line, the arrester responds by short-circuiting the center conductor to the outer conductor, thus diverting the EMP pulse to ground. Approximately 30 seconds later, the protector is ready for use again, with full protection and without the necessity of replacing components. The 30-second recovery time allows heat dissipation.

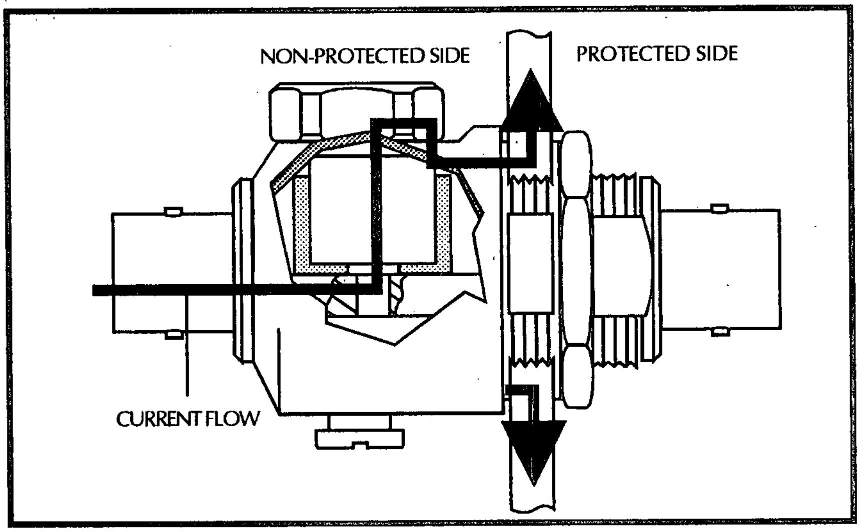

FIGURE 5. Sectional View of Spark-gap Protector Showing Flow of Energy Through the Capsule to Ground.

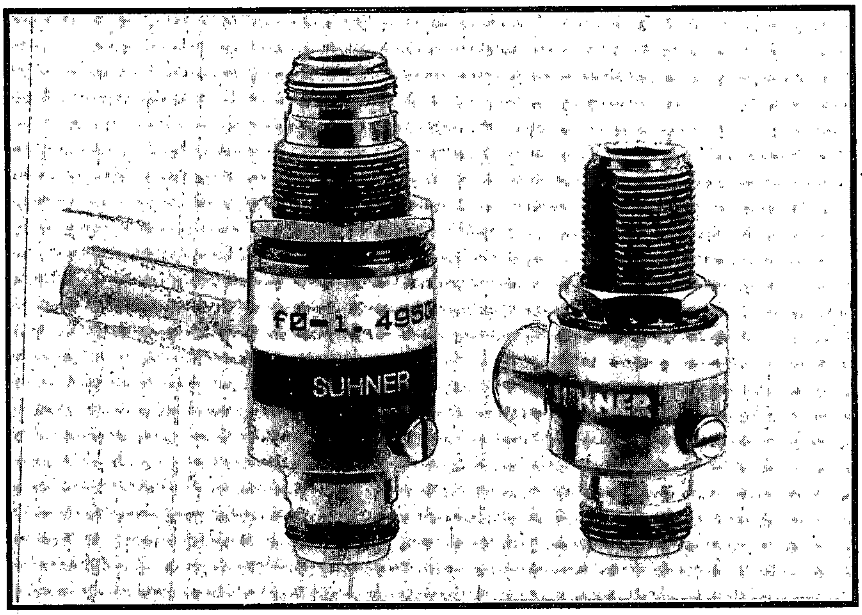

FIGURE 6. Examples of Quarter-wavelength Shorting Stub Protectors.

QUARTER-WAVELENGTH SHORTING STUB

Design. The quarter-wavelength shorting stub is designed for use between 400 MHz and 12 GHz (Figure 6). Optimized at the center frequency of the passband, it is bandwidth limited with typically a 1 to 20 percent bandwidth for frequencies of 400 MHz to 5 GHz and 10 to 20 percent bandwidth for frequencies of 1 to 12 GHz.

Operation. In normal use (no EMP pulse), the signal arrives at the input end of the shorting stub. It then travels along the quarter-wavelength shorting stub (90° phase angle rotation), is reflected at the short (180° p.a.r.) and finally travels back to the center conductor, (another 90° p.a.r.). The incident and the reflected signal are in-phase and the operating signal does not see the short. However, a signal induced by an electromagnetic pulse, which has a much lower frequency spectrum, is short-circuited to ground because it does not see the 180° p.a.r. In effect, this protector acts as a bandpass filter. The stub is, therefore, cut to a quarter wavelength of the center frequency of the signal of interest (Figure 7).

Figure 8 illustrates the bandwidth that can be achieved by quarter-wavelength shorting stubs. The bandwidth is highly dependent on the impedance of the shorting stub. Impedance values exceeding 75 ohms are difficult to achieve. Protectors of this type are custom-built based on center frequency, bandwidth, VSWR and connector type.

SELECTION CRITERIA

When planning the use of protectors, the following should be considered.

Residual Pulse. The spark-gap protector requires a short time interval until ignition occurs (Figure 9). As a consequence, the output pulse of the EMP protector, called the residual pulse, reaches the object to be protected. The amplitude and energy content of the residual pulse are dependent upon the rise time of the incident overvoltage pulse, and the response characteristics of the arrester itself.

The typical pulse rise time of an NEMP is approximately 1 to 2 kV/ns. The pulse rise time of LEMP equals 5 kA/µs.

Current Handling Capability. The current handling capability is defined by the impulse discharge current (Is). The values are given by the surge arrester capsule manufacturer for specific standard pulse shapes (e.g., 8/20 µs/IEC 60-2) as peak currents.

Because of its small capacitance, the spark-gap protector can be used for broadband applications up to 2.5 GHz, provided well-matched coaxial housings are used.

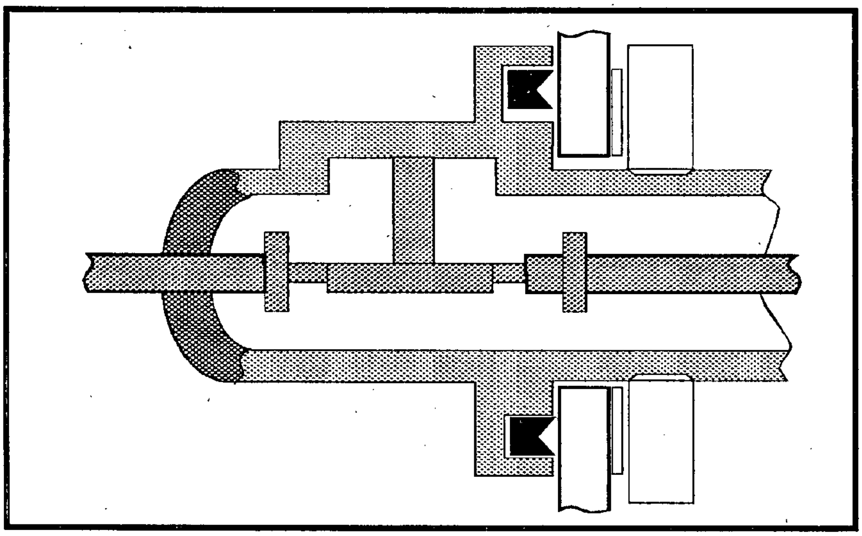

FIGURE 7. *Sectional View of a Quarter-wavelength Shorting Stub.*

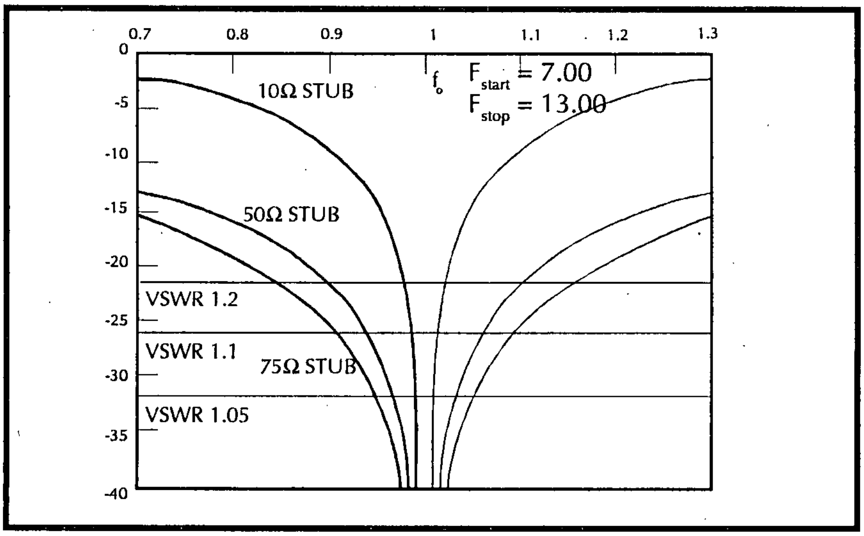

FIGURE 8. *Typical Bandwidths Achieved with the Quarter-wavelength Shorting Stub Protectors.*

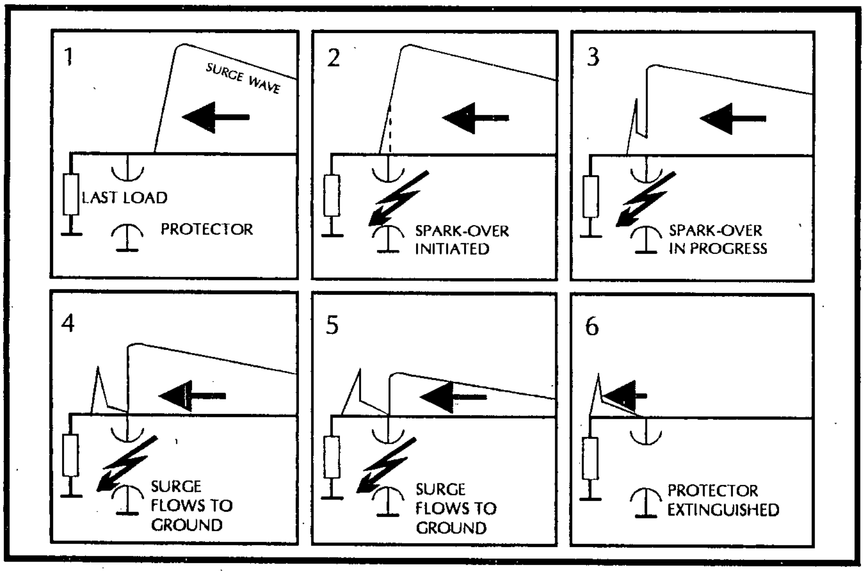

FIGURE 9. *Development of the Residual Pulse in a Spark-gap Protection Line.*

The fast switching time of the gas-filled surge arrester capsules in the spark-gap protector allows a reduction of the impulse energy by a factor of 3200 (or 35 dB). During lightning strikes, such capsules can divert a single 40 kA current impulse or multiple 20 kA impulses to ground without being destroyed.

Performance. The RF performance of EMP protectors is determined by the mechanical structure of the protector and by the connector series. The capsule in the spark-gap protector greatly influences the return loss. In principle, the static sparkover voltage (V stat) should be as low as possible, but not less than 1.5 times the existing peak voltage during transmission. For receiving systems, the capsule with the lowest dynamic sparkover voltage of 750 volts should be used.

Electrochemical Potential Between Surface Metals (Intermodulation). The prevention of intermodulation is of key interest to systems planners. One source of intermodulation is corrosion between contacting materials. Corrosion can be prevented by careful attention to the electrochemical potential and, therefore, low contact resistance between the protector body and the mounting wall.

Figure 10 illustrates potential voltage between 8 different materials. As a general guideline, the potential between two contacting metals should not exceed 0.25 volts.

Grounding. To guarantee a low contact-resistance between the protector body and the mounting wall a minimum torque of $\geq$6 Nm is recommended to tighten the hexagonal nut as well as the surge arrester cap-

Continued on page 305

sule holder. This torque leads to a contact resistance of ≤ 0.2 mΩ (for nickel-free plating on a stainless-steel mounting wall).

CONCLUSION

LEMP and NEMP can induce high earth currents in transmission lines, EMP protectors and mounting walls. The spark gap and quarter-wavelength shorting stub are two effective types of EMP protectors. While they are similar in their mounting mechanism, their performance characteristics offer distinct advantages and disadvantages.

VALUES IN VOLTS	GOLD	SILVER	NICKEL	STAINLESS STEEL	SUCO-PLATE	CHROMIUM	TIN	ALUMINUM
GOLD	0	0.15	0.3	0.35	0.4	0.6	0.65	0.75
SILVER	0.15	0	0.15	0.2	0.25	0.45	0.5	0.6
NICKEL	0.3	0.15	0	0.05	0.1	0.3	0.35	0.45
STAINLESS STEEL	0.35	0.2	0.05	0	0.05	0.25	0.3	0.4
SUCOPLATE®	0.4	0.25	0.1	0.05	0	0.2	0.25	0.35
CHROMIUM	0.6	0.45	0.3	0.25	0.2	0	0.05	0.15
TIN	0.65	0.5	0.35	0.3	0.25	0.05	0	0.01
ALUMINUM	0.75	0.6	0.45	0.4	0.35	0.15	0.1	0

FIGURE 10. *Potentials in Volts Resulting from Two Contacting Metals. Maximum voltage should not exceed 0.25 volts.*

PARLAN L. McGIVERN *(Mac) is the Manager of Customer Sales and Service at Huber + Suhner, Inc. in Essex, Vermont. He holds a BS from the University of Nebraska at Omaha and an M.A. in Business Management from Central Michigan University. He has extensive experience in microwave, radar, fire control and satellite systems, in both operations and sales. He is a former Lt. Colonel in the U.S. Army Signal Corps and served in the Research and Development Directorate of the Pentagon. (802) 878-0555.*

HEINZ WULLSCHLEGER *is the Product Manager for Microwave Products at Huber + Suhner AG in Herisau, Switzerland. He holds a B.S. in Electronic Engineering from Neutechnikum Buchs, Switzerland. Prior to joining Huber + Suhner, he spent 4 years at the European Headquarters of Precision Monolithics Inc. as a customer support engineer and 4 years with Landis and Gyr, a Swiss company. 071/534351.*