# Application of Shielding Effectiveness Methodology to Unit Design

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***An estimate of the shielding effectiveness of a box is required for an overall EMI analysis.***

## INTRODUCTION

Typical methods of calculating enclosure (box) shielding effectiveness (SE) do not provide information as to the means of combining the data into a useful single plot of the projected overall SE. This article is intended to provide one approach towards achieving a first approximation solution of a box's SE by showing how to combine material SE data to arrive at the total box/unit SE.

The following presents a fundamental approach for calculating the SE of basic enclosures (boxes). This methodology makes use of several different techniques from multiple sources. It is not intended to be all-inclusive and does not cover all the factors involved in determining the SE of an arbitrary box (Figure 1).

The calculation of the box's SE is necessary for determining the overall compliance of the unit to the EMI requirements of radiated emissions and radiated susceptibility. This is required in apportioning the overall shielding (i.e., isolation) of the design. The SE of the overall enclosure can be said to provide the top-level control of radiated emissions and radiated susceptibility. To facilitate interpretation of the methodology, the article is divided into two parts. The first analyzes SE of an enclosure without any seam or aperture defects, and the second addresses SE of an enclosure with both seams and apertures.

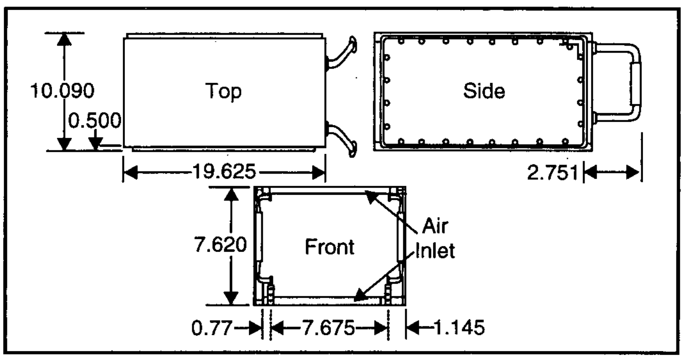


***Figure 1**. Arbitrary Box.*

## AN ENCLOSURE WITH NO SEAMS OR APERTURES

The following concepts are from "New Dimensions in Shielding"[1] and "RF Shielding Design."[2] The presentation and calculation of the information is made via MathCad 4.0.

Theoretical SE of homogeneous material is composed of three factors: reflective losses (R), absorption losses (A), and secondary re-reflection losses (B). These factors are calculated separately in decibels and are added to yield the SE as follows:

$$SE = R + A + B$$

When absorption losses exceed 10 dB, the secondary reflective loss term (B) can be neglected, and the SE is simply the sum of the reflective and absorptive losses. Using the parameters and equation below, the absorption loss is calculated:

| | |
|---|---|
| $n := 1,2..8$ | Frequency counter |
| $t := 50$ | Thickness of material, mils (0.001" = 1 mil) |
| $f_n := 10^n \cdot 100$ | Frequency given in Hz based on frequency counter, n |
| $Freq\_(MHz) := \frac{f_n}{10^6}$ | Convenient name used in graphs for frequency in MHz |
| $\mu_o := 4 \cdot \pi \cdot 10^{-7}$ | Permeability of free space (H/m) |
| $\mu_r := 1$ | Material relative permeability with respect to air |
| $\mu := \mu_o \cdot \mu_r$ | Material permeability (H/m) |
| $\sigma_o := 5.8 \cdot 10^7$ | Conductivity of copper (mhos/m) |
| $\sigma_r := 0.61$ | Material relative conductivity with respect to copper for 6061 aluminum |
| $\sigma := \sigma_o \cdot \sigma_r$ | Material conductivity (mhos/m) |

$$A_n := 0.003338 \cdot t \cdot \sqrt{\mu_r \cdot \sigma_r \cdot f_n}$$ Material absorption loss (dB) with respect to frequency

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As the equation illustrates, absorption loss is a function of the physical characteristics of the shield: permeability, conductivity, thickness, and the frequency of the source. This loss factor is independent of the type of field — plane wave, magnetic (low impedance), or electric (high impedance). For a specific depth of material, high permeability (magnetic) materials will provide higher absorption losses than low permeability (non-magnetic) materials.

The reflection loss term of the SE equation is analogous to the transmission line reflective loss when a terminating impedance is not matched to the characteristic impedance of the line (cable). Magnetic and electric field losses, $R_h$ and $R_e$, respectively, are calculated with the equations given below:

$r := 3.81$ Source-to-shield distance in inches

$$R_{h_n} := 20\cdot\log\left[\left(\frac{0.462}{r}\right)\cdot\sqrt{\frac{\mu_r}{f_n\cdot\sigma_r}} + \frac{0.13\cdot r}{\sqrt{\frac{\mu_r}{f_n\cdot\sigma_r}}} + 0.354\right] \quad \text{Magnetic Field } r \le \frac{\lambda}{2\cdot\pi}$$

$$R_{e_n} := 354 - 10\cdot\log\left[\frac{(f_n)^3\cdot\mu_r\cdot r^2}{\sigma_r}\right] \quad \text{Electric Field } r \le 2\cdot\lambda$$

where
$R_h$ = Magnetic field reflection losses (dB)
$R_e$ = Electric field reflection losses (dB)
$r$ = Source-to-shield distance (inches)

In addition to being a function of the shield material characteristics and frequency, the electric and magnetic field reflective losses are also dependent on the source-to-shield distance.

Finally, the plane wave reflective loss, which is a function of material characteristics and frequency, is calculated as follows:

$$R_{p_n} := 168 + 10\cdot\log\left(\frac{\sigma_r}{\mu_r\cdot f_n}\right) \quad \text{Plane Wave } r > 2\cdot\lambda$$

Table 1 gives the results of calculating the above formulas.

| Freq. (MHz) | $A_n$ | $R_{h_n}$ | $R_{e_n}$ | $R_{p_n}$ |
|---|---|---|---|---|
| 0.001 | 4.122 | 22.002 | 250.235 | 135.853 |
| 0.01 | 13.035 | 31.83 | 220.235 | 125.853 |
| 0.1 | 41.221 | 41.776 | 190.235 | 115.853 |
| 1 | 130.353 | 51.759 | 160.235 | 105.853 |
| 10 | 412.213 | 61.753 | 130.235 | 95.853 |
| 100 | $1.304\cdot10^3$ | 71.751 | 100.235 | 85.853 |
| $1\cdot10^3$ | $4.122\cdot10^3$ | 81.751 | 70.235 | 75.853 |
| $1\cdot10^4$ | $1.304\cdot10^4$ | 91.751 | 40.235 | 65.853 |

***Table 1**. Reflection Losses.*

The material re-reflection correction term, $B_n$, is given below for those cases where the absorption term, $A_n$, is less than 10 dB. This correction is due to successive re-reflection within the shielding material at low frequency, and can add or subtract from SE. In this article, this term has not been included in the calculation, but is presented to show the magnitude of the correction which should be applied for this specific case.

A plot of the absorption loss, reflection losses (magnetic and electric), and plane wave reflection losses from Table 1 is given in Figure 2.

$$t_B := \frac{\left(\frac{t}{1000}\right)\cdot 2.54}{100}$$ Changing the thickness term, t, from inches to meters for the material correction term calculation

$$j := \sqrt{-1}$$ Defining the imaginary term "j"

$$Z_w := 120\cdot\pi$$ Wave impedance (approx. 377 ohms)

$$\eta_n := (1+j)\cdot\sqrt{\frac{\pi\cdot\mu\cdot f_n}{\sigma}}$$ Intrinsic impedance of metal (ohms)

$$k_n := \frac{Z_w}{\eta_n}$$ Impedance ratio

$$\gamma_n := (1+j)\cdot\sqrt{\pi\cdot\mu\cdot\sigma\cdot f_n}$$ Propagation constant in metal (1/m)

$$B_n := 20\cdot\log\left[\left|1-\frac{(1-k_n)^2}{(1+k_n)^2}\cdot e^{-2\cdot\gamma_n\cdot t_B}\right|\right]$$ Material re-reflection correction term

| $B_n$ | Freq. (MHz) |
|---|---|
| -1.555 | 0.001 |
| 0.417 | 0.01 |
| $6.533\cdot10^{-4}$ | 0.1 |
| $-1.379\cdot10^{-13}$ | 1 |
| 0 | 10 |
| 0 | 100 |
| 0 | $1\cdot10^3$ |
| 0 | $1\cdot10^4$ |

***Table 2**. Material Re-reflection Correction Term.*

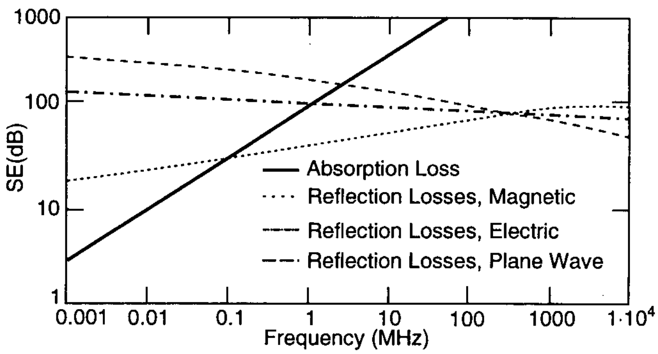


***Figure 2**. Losses at Various Frequencies.*

For the purposes of the SE analysis, it is given that the predominant field below

$$\frac{\lambda}{2\cdot\pi}$$

is the absorption loss plus the magnetic field loss. Between this and the plane wave region is the transition (Fresnel region) dominated by the electric field. Therefore,

| | |
|---|---|
| $r \le \frac{\lambda}{2 \cdot \pi}$ | Frequency range for the absorption plus magnetic losses |
| $\frac{\lambda}{2 \cdot \pi} < r \le 2 \cdot \lambda$ | Transition region defined by the electric field |
| $r > 2 \cdot \lambda$ | Plane wave region |
| $S1_n := A_n + R_{h_n}$ | Absorption plus magnetic losses |
| $S2_n := R_{e_n}$ | Electric field losses |
| $S3_n := R_{p_n}$ | Plane wave losses |

Therefore, the overall SE, without regard for seams or apertures, is given as:

$$SE_n := -10 \cdot \log\left(10^{\frac{-S1_n}{10}} + 10^{\frac{-S2_n}{10}} + 10^{\frac{-S3_n}{10}} + 2 \cdot 10^{\frac{-S1_n - S2_n}{20}} + 2 \cdot 10^{\frac{-S1_n - S3_n}{20}} + 2 \cdot 10^{\frac{-S2_n - S3_n}{20}}\right)$$

This is expressed graphically in Figure 3.

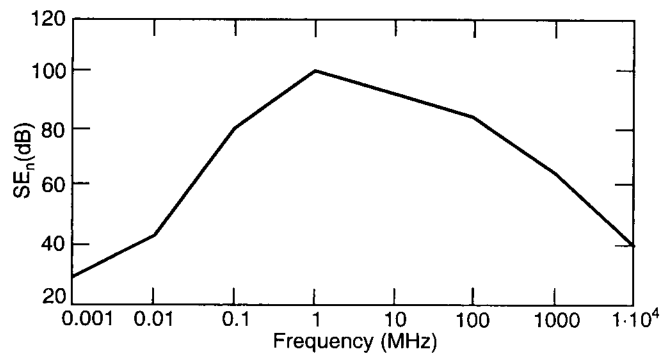


***Figure 3**. Shielding Effectiveness.*

## AN ENCLOSURE WITH SEAMS AND APERTURES

### FIXED SEAMS

The next aspect of the box's shielding effectiveness which must be accounted for is the fixed seam (brazed, welded, etc.) factor. The following is a mathematical approximation of the fixed seam factor S5. It is worth noting that the access seam factor S6 = S5 if the access seam equals the fixed seam in length. This is both an empirical and extrapolated function. Up to 1 MHz it is real measured data; beyond 1 MHz it is extrapolated. The given data is for a 1 cm dipped, brazed aluminum seam.

| | |
|---|---|
| $S5_{1_n} := (0.0018 \cdot f_n) + 51.7$ | 1 kHz to 10 kHz |
| $S5_{2_n} := (1.49 \cdot 10^{-4} \cdot f_n) + 73.81$ | 10 kHz to 100 kHz |
| $S5_{3_n} := (5.92 \cdot 10^{-6} \cdot f_n) + 88.08$ | 100 kHz to 1 MHz |
| $S5_{4_n} := (1.48 \cdot 10^{-7} \cdot f_n) + 93.85$ | 1 MHz to 10 MHz |
| $S5_{5_n} := (2.97 \cdot 10^{-8} \cdot f_n) + 95.03$ | 10 MHz to 100 MHz |
| $S5_{6_n} := (1.48 \cdot 10^{-9} \cdot f_n) + 98.9$ | 100 MHz to 1 GHz |
| $S5_{7_n} := (1.0 \cdot 10^{-10} \cdot f_n) + 93.32$ | 1 GHz and beyond |

The overall fixed seam factor, S5, given above is summed in the following equation to provide a reasonable approximation of the actual data in Figure 4, with tabular values given in Table 3.

$$S5_n := -10 \cdot \log\left(10^{\frac{-S5_{1_n}}{10}} + 10^{\frac{-S5_{2_n}}{10}} + 10^{\frac{-S5_{3_n}}{10}} + 10^{\frac{-S5_{4_n}}{10}} + 10^{\frac{-S5_{5_n}}{10}} + 10^{\frac{-S5_{6_n}}{10}} + 10^{\frac{-S5_{7_n}}{10}}\right)$$

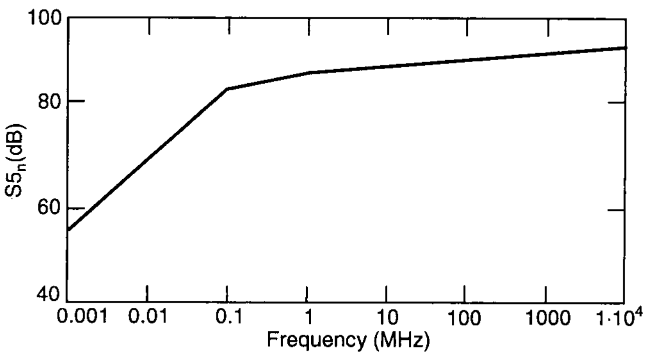


***Figure 4**. Shielding Effectiveness.*

| $S5_n$ | Freq. (MHz) |
|---|---|
| 53.458 | 0.001 |
| 68.554 | 0.01 |
| 83.955 | 0.1 |
| 87.689 | 1 |
| 89.28 | 10 |
| 91.185 | 100 |
| 92.621 | $1 \cdot 10^3$ |
| 94.27 | $1 \cdot 10^4$ |

***Table 3**. S5 Calculated Points.*

The actual values for S5 (real and extrapolated) are as follows:

| | |
|---|---|
| 1 kHz | 53.3 |
| 10 kHz | 69.3 |
| 100 kHz | 82.67 |
| 1 MHz | 88.0 |
| 10 MHz | 89.3 |
| 100 MHz | 92.0 |
| 1 GHz | 93.3 |

Additionally, there is a loss in SE as a function of seam length which is given as:

| | |
|---|---|
| S5 := Fixed_seam_factor | From Figure 4 (length of longest seam) |
| $B5 := 10 \cdot \log(\text{seam\_length\_in\_cm})$ | Seam length normalizing term (normalize to 1 cm) |
| $B5_m := -20 \cdot \log(\text{no\_of\_parallel\_seams})$ | Seam multiplicity term |
| $S5T := B5 + B5_m$ | Total fixed seam factors for calculation of SE |
| $Seam := 19.625 \cdot 2.54$ | Longest seam length (cm) |
| $B5 := -10 \cdot \log(Seam)$ | Seam length normalizing term |
| $B5_m := -20 \cdot \log(4)$ | Seam multiplicity term |
| $S5T_n := S5_n + B5 + B5_m$ | Total fixed seam factor |

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Total shielding effectiveness minus any slot and gasket factors may be expressed as:

$$SE1_n := -10 \cdot \log\left[10^{\frac{-SE_n}{10}} + 10^{\frac{-S5T_n}{10}} + 2 \cdot 10^{\frac{-(SE_n + S5T_n)}{20}}\right]$$

The equation is presented graphically in Figure 5 and again in Table 4.

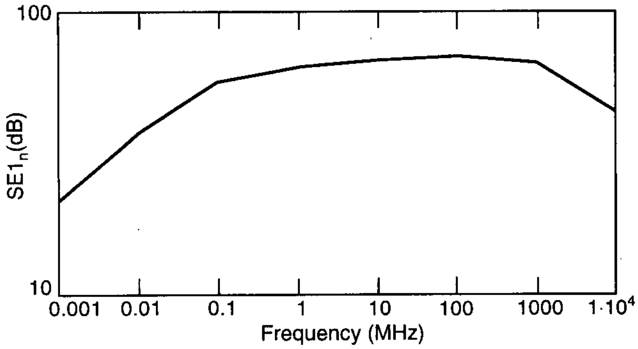


***Figure 5**. Shielding Effectiveness as a Function of Seam Length.*

| $SE1_n$ | Freq. (MHz) |
|---|---|
| 19.221 | 0.001 |
| 35.777 | 0.01 |
| 54.593 | 0.1 |
| 58.633 | 1 |
| 60.117 | 10 |
| 61.516 | 100 |
| 58.943 | $1 \cdot 10^3$ |
| 39.34 | $1 \cdot 10^4$ |

***Table 4**. Shielding Effectiveness.*

## ACCESS SEAMS

The next part of the calculation of a box's SE is the determination of leakage factors due to the access seams (e.g., screw spacing on cover). For this calculation, the formulas from MIL-HDBK-419,[3] "Design EMI Shielding More Accurately,"[4] Tecknit's *EMI Shielding Design Guide*,[5] and "EMP Shielding Effectiveness and MIL-STD-285"[6] were used.

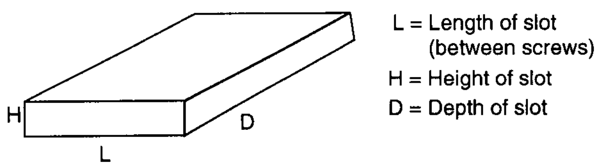


***Figure 6**. Dimensions of a Slot.*

For a complementary dipole model, the dipole characteristics are defined as half the slot and half the height. The SE of the slot is defined as the reflection losses of the slot; an approximation for this is given below rather than using the detailed formula based on Babinet's principle. Consideration was also given to the number of parallel holes and the wave guide effects. Additionally, the slot SE calculations are only good up to the slot cutoff frequency. Note that the total number of holes equals both parallel seams of the longest side of the cover. The following calculates the slot leakage for the screw spacing based upon the complementary dipole for the slot given the general conditions shown in Figure 6.

$d := 0.75$ Depth of seam, inches (arbitrary value)

$L := 0.75$ Width of seam, inches (e.g., screw spacing) [arbitrary value]

$f_c := \dfrac{3 \cdot 10^8}{L \cdot 2 \cdot 0.0254}$ Cutoff frequency based on the longest seam dimension (usually screw spacing, L)

$f_c := 7.874 \cdot 10^9$ Cutoff frequency in Hz

$Longest\_side := 19.625$ Longest side of box (inches)

$Number\_holes := floor\left(\dfrac{Longest\_side}{L}\right) \cdot 2$ Total number of holes equals both parallel seams of longest side of cover

$A_a := 27.3\left(\dfrac{d}{L}\right)$ Wave guide attenuation

$CF_{number\_holes} := -10 \cdot \log(number\_holes)$ Correction factor for total number of slots

$RF_{slot_n} := 20 \cdot \log\left(\dfrac{f_c}{f_n}\right)$ Reflection from slot

$SE_{slot_n} := RF_{slot_n} + A_a + CF_{number\_holes}$ The total slot SE

Figure 7 depicts the slot SE; Figure 8 shows the slot and box SE.

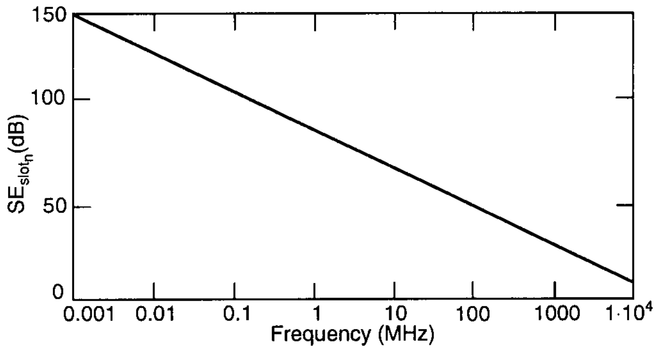


***Figure 7**. Shielding Effectiveness of Slot.*

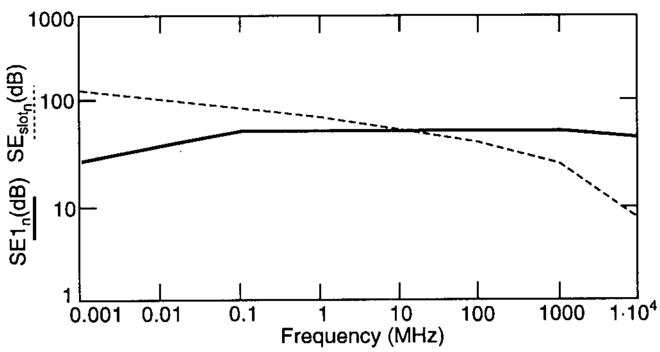


***Figure 8**. Box SE and Slot SE.*

The total box shielding effectiveness (SET), including the effects of screw spacing and seams, is given in the following equation and is illustrated in Figure 9.

$$SET_n := -10 \cdot \log\left(10^{\frac{-SE1_n}{10}} + 10^{\frac{-SE_{slot_n}}{10}} + 2 \cdot 10^{\frac{-SE1_n - SE_{slot_n}}{20}}\right)$$

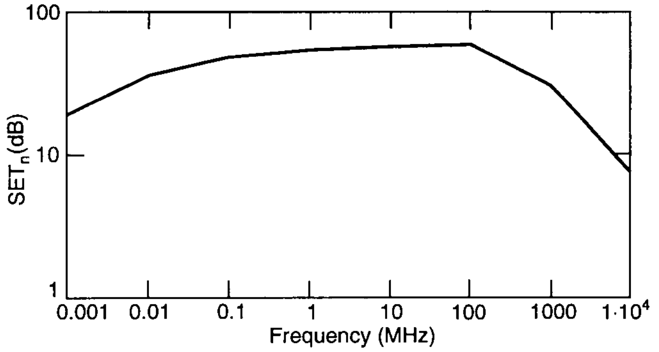


***Figure 9**. Total Box Shielding Effectiveness.*

Table 5 represents the projected SE of the enclosure without gaskets. This SE calculation does not include all potential contributors to the SET (e.g., cables, air inlets, honeycomb, and other penetrations). It does not take into account the polarization and angle of the incident field, but rather assumes worst-case conditions. It does not take into account any box resonances. These other contributors to the overall SE may improve or reduce the final calculated SE, and need to be considered in the final SE analysis.

| $SET_n$ | Freq. (MHz) |
|---|---|
| 19.221 | 0.001 |
| 35.777 | 0.01 |
| 54.575 | 0.1 |
| 58.345 | 1 |
| 57.191 | 10 |
| 46.39 | 100 |
| 27.819 | $1 \cdot 10^3$ |
| 7.83 | $1 \cdot 10^4$ |

***Table 5**. Shielding Effectiveness without Gaskets.*

## CONCLUSION

An effective first approximation methodology for calculating the shielding effectiveness of an arbitrary enclosure has been presented. This basic technique can be applied to many varied conditions to allow approximation of a box's top level EMI/EMC performance.

## REFERENCES


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2. Richard B. Schultz, George C. Huang and Walter L. Williams, "RF Shielding Design," *IEEE Transactions on Electromagnetic Compatibility*, Vol. EMC-10, No. 1, March 1968.
3. MIL-HDBK-419, *Grounding, Bonding, and Shielding for Electronic Equipments and Facilities*, January 21, 1982.
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5. *EMI Shielding Design Guide*, Tecknit, 1982.
6. Richard L. Monroe, "EMP Shielding Effectiveness and MIL-STD-285," Harry Diamond Laboratories, Report # AD-771 997, July 1973.



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***STRUCTURE AND OPERATION METHOD OF SURGE ARRESTERS** . . . Continued from page 174*


## NUMEROUS ADVANTAGES

The entire protection circuit is then incorporated in a housing which is designed to offer the user all possible installation and maintenance advantages. These include:

- Two-part construction made up of a base element and plug section, so that the surge-arresting components installed in the plug can be replaced without interrupting the circuit if they are overloaded
- Ease of component testing using a special test device, avoiding lengthy laboratory tests
- Installation of the final coupling impedances in the base element, so that they remain neutral in the measurement circuits even during the test procedure or when replacing the component
- Asymmetrical plug pins which preclude incorrect IN/OUT alignment
- Use of a grounding foot which makes the ground potential connection to DIN rails while it is being installed

Other surge arrester types are notable because they use the same physical connection technology as the units they are protecting. This is generally the case for surge arresters which are inserted in the cabling, and which use the same connectors, such as BNC connections on shielded cables.

Experience has shown that two steps are advisable for the planning and installation of surge voltage protection. The surge arrester must be selected in accordance with the dielectric strengths of the electronic and electrical equipment. The correct installation location must be specified by dividing the entire area requiring protection into surge voltage protection zones.


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