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Circuit Components Inc.

FILTERING AND SURGE SUPPRESSION FUNDAMENTALS
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SURGE CONTROL®
A PRODUCT OF CCI

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I. ELECTRICAL OVERSTRESS – THE THREAT

It would be difficult, at best, to find someone in today's high-tech electronics world who hasn't been affected by electrical overstress. The small geometry and high density of circuit components in this electronic age is susceptible to transient overvoltage of a few volts. High-density microcircuits routinely operate at three or five volts and have low tolerance for transient overvoltage.

Published studies have demonstrated that annual costs of electrical disturbances exceed $30 billion in the USA alone. Data processing downtime attributed to power quality has increased from 27% in 1980 to almost 50% at present.

Almost every user of electronic equipment has observed that equipment either fail outright, go “off-line”, go to “reset”, or experience shortened life. Computers, from industrial control to personal computers frequently lose their way, act strange or require soft re-start if not exhibiting outright “hard failure”.

Since there is no “wear-out” phenomena in solid state devices, equipment essentially should never fail. Studies show that 75 to 90% of all electronic failure is due to overvoltage stress alone. The balance of failures is usually heat related due to faulty designs.

An agreement on common terms to describe electrical overstress has largely eluded the industry; however, the Institute of Electrical and Electronic Engineers (IEEE) and the American National Standards Institute (ANSI) refer to “Surge Voltages” and “Switching Transients” in their discussions of recommended practice for protection of electronic equipment in an AC power and data line environment.

1. SOURCES OF TRANSIENT OVERVOLTAGE

Sources of transients range from natural phenomena to power disturbances to normal operation of “noisy” electrical equipment.

<u>Switching Transients</u> - Whenever the flow of current is interrupted, transient overvoltages are created. As the magnetic field of an inductor collapses, stored energy is released causing a voltage rise that attempts to maintain the current flow. Solenoids, relays, transformers, inductors, motors and so forth, are all devices that release energy when turned off. Contacts opening, fuses clearing, circuit breakers tripping etc. are other examples of current interruption which generate transient voltages. Power utility line faults, load shedding equipment activity and capacitor bank switching are also frequent sources of transient overvoltage. High frequency switching power supplies, found in almost all new equipment, are a powerful transient generator and have caused regulatory agencies to issue standards to control conducted emissions into AC lines.

<u>ESD Transients</u> - Electro-static discharge phenomenon is generated from the friction of two dissimilar materials. This triboelectric effect is observed when electric charges of opposite polarity build up between two surfaces, and then the surfaces are separated. The human body can store as high as 15,000 volts as one walks across a nylon carpet. Generally, only transients of over 3,000 volts would be noticed as the discharge into electronic equipment or another surface occurs. Lower voltage discharges would continue to occur but go unnoticed.

Nuclear Electromagnetic Pulse - Similar to a lightning generated EMP, but with a much faster risetime. The electromagnetic pulse is generated when nuclear ordinance is detonated. This threat has caused the military to “radiation harden” most military weaponry and tactical equipment.

Lightning Transients - (The most awesome and most damaging source of all transients). Lightning transients are most often discussed by industry transient suppression “experts” because they represent the greatest threat and source of transients known. If protective apparatus were designed to withstand the effects of lightning in a harsh industrial environment, then certainly all other threats of lower magnitude would be eliminated as well.

Lightning occurs when friction within clouds raises the charge potential to a level sufficient to ionize air and provide a conductive path either from cloud to cloud or cloud to ground.

Studies show that the current during the first stroke can exceed 200,000 Amps. Average strikes produce over 20,000 Amps during the first return stroke. **(See Figure 1)**

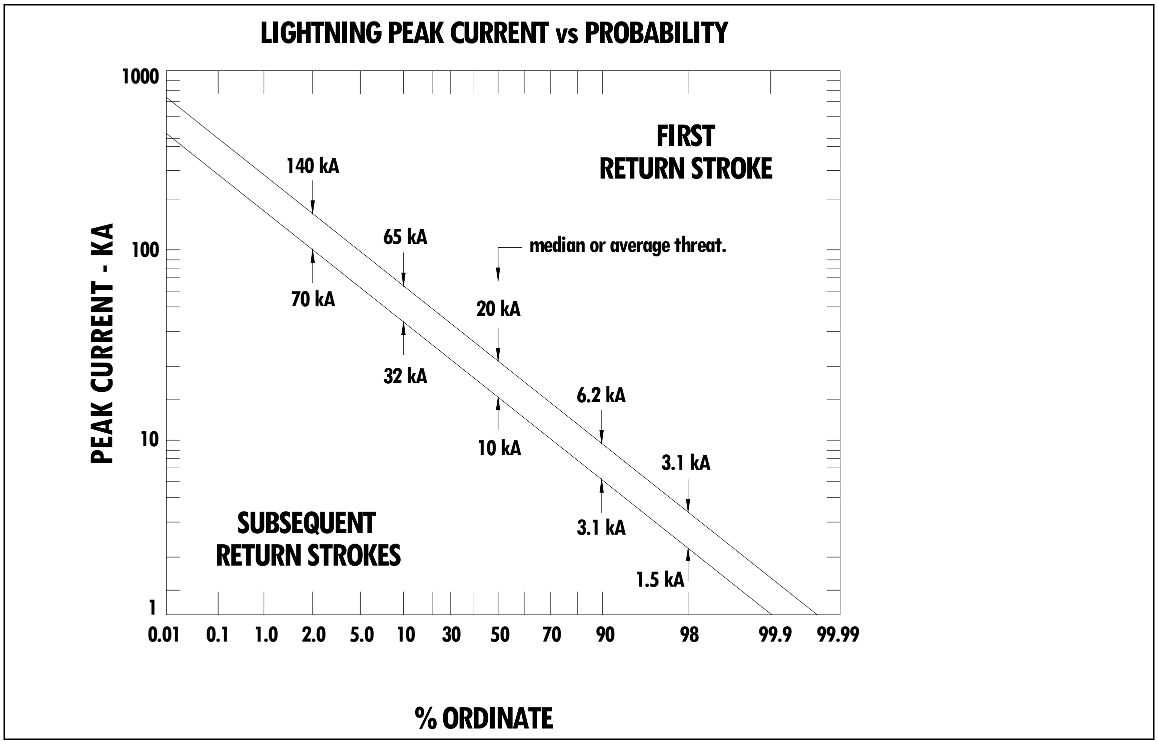


FIGURE 1

Electromagnetic waves are formed by the discharge and radiate at 90 degrees from the path of the strike. So we see electromagnetic waves propagating through air directly away from the discharge. We also observe ground (Earth) currents propagating away from the point of ground strike. Direct strikes on power cables inject high currents into primary circuits producing voltage transients by flowing through ground resistance or through the impedance of the primary circuit. **(See Figure 2)**

MEDIUM STRIKE			
Distance to Strike		Vertical E Field, VM	Induced Voltage in 1 M (39") of Wire, V
Km	Miles		
10	6	110	20
1	.6	1100	200
0.1	.06	11,000	2000

FIGURE 2

Thus, we observe lightning-generated transients flowing into primary circuits through electromagnetic coupling or direct injection. In addition, we observe ground currents flowing into equipment through the equipment ground from nearby ground strikes. These ground currents can cause transient voltage differences of high magnitude across the various ground points within a structure or from structure to structure.

In summary, this most severe threat of all can enter equipment via power lines, telephone lines, telecom or data lines, signal or current loop lines and the earth ground connection as well.

2. RESULTS OF TRANSIENT OVERVOLTAGE

"Walking Wounded" (Latent failure) - Probably the most disturbing of the effects of transients is that they often go unnoticed. As we have shown, overvoltage transients exist in our everyday world. Unless we have outright equipment failure or very frequent operating disturbances, most users assume they are "safe". As equipment is bombarded with destructive transients, its life is shortened. We may see no effects or observe any strange behavior, and, therefore, not become concerned about the degradation occurring to our equipment.

Equipment may survive a damaging transient by showing small or no upset, only to fail in six months or so as metallization creepage eventually shorts out the "punch through" hole in the micro circuit junction.

Soft Failure - This most common failure of all types, which at best leads to shortened equipment life, and at worst shows latent catastrophic failure. Transient generated soft failures include going "off-line", reset, run error, communication error, measurement or reading errors, lock-up, lost or corrupted files, latch or lock-up, output errors and so forth.

Hard Failure - This failure is easily observed and generally causes concern. The result may be a charred mass of molten electronics, a component with its lid blown off, a cracked or burned component, a vaporized circuit board trace or wire, but sometimes leaves no visible effects. The equipment is just out of service. **(See Figure 3)**

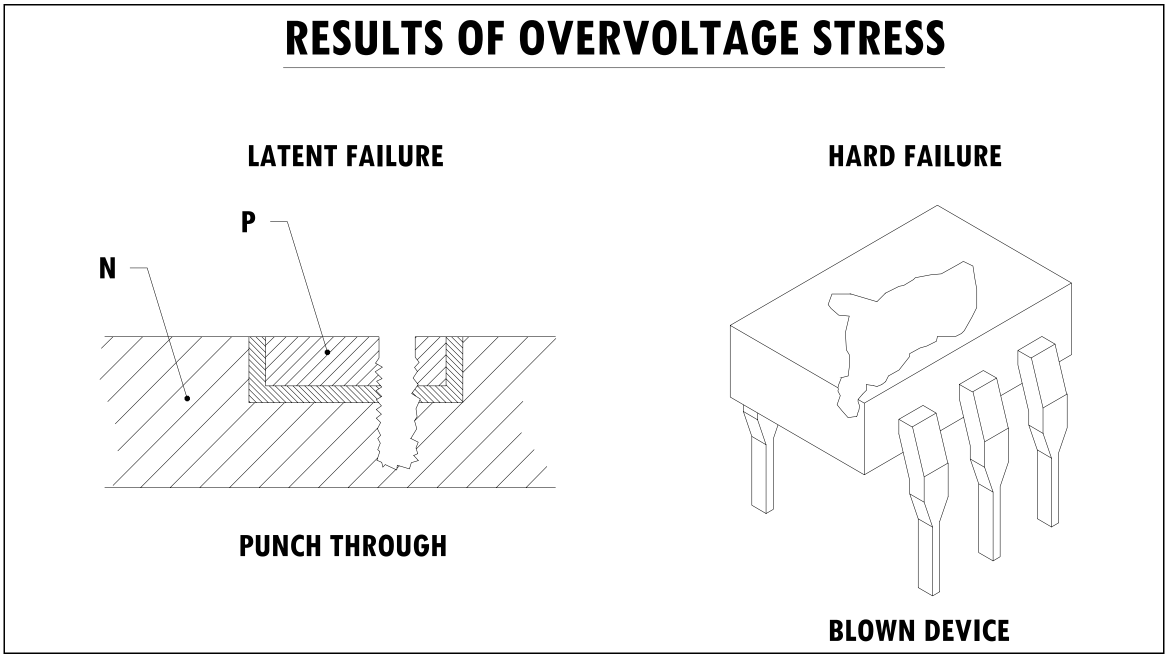


FIGURE 3

II. SUPPRESSION DEVICES

As described previously, an electrical overstress may be described as a transient voltage, spike, glitch, etc., but is in reality a short-term deviation from normal operating voltage or signal level. As transient voltages increase in amplitude, the risk of disrupting or damaging today's sophisticated electronic equipment increases.

Transient voltage surge suppression (TVSS) devices, also called surge protective devices (SPD), are available in many forms and protection levels.

A quality TVSS device will lower the threat level and "clamp" or "let through" only voltages that will not harm protected equipment.

Obviously, one must consider all paths to entry when planning protection against the TVSS threat.

1. CHARACTERISTICS

Figure 4 shows a summary of TVSS device characteristics

DEVICE KEY CHARACTERISTICS							
Device	**V-I Response Curve**	**Speed**	**Insertion Loss (Cap)**	**Energy Capability**	**Follow-on**	**Leakage**	**Cost**
Ideal	Sharp/Flat	Fast	None	Infinite	None	None	Free
MOV	Sharp/Non-Linear	Medium	High	High	None/High	High	Low
SAD	Sharp/Flat	Fast	Low	Low	None/High	Low	Mod
GDT	Erratic/Non-Linear	Slow	Low	High	High	Low	Mod
S.C. Block	Erratic/Non-Linear	Slow	Low	High	None	Low	Low
Air Cap	Erratic/Non-Linear	Slow	Low	High	None	Low	Mod
Thyristor	Sharp/Flat	Medium	Low	High	None/High	Low	Mod
Hybrid	Sharp/Flat	Fast	Low	High	Low	Low/High	Mod

FIGURE 4

a) **Ideal Device** - This product is not available, of course, but identifying key desirable features provides us with performance targets.

b) **Metal Oxide Varistor (MOV)** - A voltage-dependent resistor made of metal oxide particles (usually zinc) compressed together. The contact portion of these particles acts like a semiconductor junction (P.N.). Millions of these junctions act like diodes that turn on at different voltages. As voltage increases more and more junctions conduct. The voltage (V) to current (I) relationship is very non-linear. Even manufacturer's curves, which are plotted on log graphs to flatten the curve, show a pronounced non-linear relationship.

The large number of semiconductor junctions allows a high current leakage rate, but also provides excellent power handling capability.

Key features are:

- High device capacity - each PN junction has capacitance; e.g., 1500pF per MOV.
- Response is fairly fast but non-linear (higher "let-through" voltage as higher current is applied).
- High power handling capability, e.g. 6500 Amps @ 8x20 µs pulse for a 20 mm MOV.
- A great deal of the transient energy is dissipated as heat by the MOV.
- Follow-on current is low except when the device fails, then quite high.
- Leakage is high, e.g., 5 mA at operating voltage for a 20 mm MOV.

- MOV's performance degrades with exposure to transients. The effect of exposure is for the MOV actual operating voltage to become lower with each large transient until it equals the applied voltage at which time follow on current will destroy it. This phenomenon can be eliminated by careful test and selection of MOV's, then configuring them in parallel/redundant circuits. Life can be extended for over 15 years in real-world applications.

- Failure mode - the MOV fails short when overstressed, then follow-on current normally causes catastrophic rupture and an open circuit. So much heat is generated that, unless protected, the PCB may carbonize and allow some leakage current, although the MOV has "opened". Therefore, proper fusing or circuit breaker selection is essential for MOV based TVSS devices which do not employ integral fusing.

c) **Silicon Avalanche Diode (SAD)** - A specialized semiconductor device that acts like a zener diode in turn on and current avalanche mode. However, the SAD utilizes a very large silicon chip sandwiched between large metal pellets giving it thousands of times more current carrying capability than a zener.

Key features are:

- Fastest turn-on of any device available.

- Response is essentially flat, that is as higher voltage is applied, more current will flow in a linear fashion up to the point of device failure.

- Capacity is low. Capacitance is limited to a single PN junction capacitance; e.g., 100 pf for a 24V LCE SAD. Capacitance may be lowered by putting additional diodes in series, however lead inductance must then be accounted for in clamping or "let-through" performance.

- Energy capability is low, devices are offered in 500, 1500, 5000 and 15000 watt sizes. High wattage devices are expensive.

- Energy dissipation is low in conjunction with low wattage capability; e.g., 15kW devices often require heat sinking. Junction resistance at avalanche is low resulting in minimal heating during normal "within spec" pulses.

- Leakage is extremely low in the order of μ amps.

- Follow-on current is nil except should the device fail.

- Failure mode - SAD devices fail short and normally remain "shorted" even with high current follow-on flow. The pellets simply weld together.

d) **Zener Diode** - The standard Zener device should never be used in transient suppression applications. The PN junction area and metal disc size are very small and incapable of handling significant transient current.

e) **Gas Discharge Tube (GDT)** - These devices function similar to air or carbon gap devices except they are hermetically sealed and charged with an argon/hydrogen mixture at about 0.1 Bar. Radioactive gases are often added to control spark-over. Construction is usually two large metal electrodes spaced at about 1 mm and sealed in a ceramic material.

Key features are:

- Response is somewhat inconsistent and a bit non-linear.
- Speed is slow; e.g., using the standard 8/20 µs pulse, a 90-volt gas tube will turn on or fire at about 400 volts (striking voltage).
- Thus the overshoot or “let-through” voltage of a gas tube alone can exceed 400 volts for a low voltage tube and 800 volts for a 230-volt tube usually used in Telco applications.
- Capacitance of a GDT is negligible.
- Energy capability is quite high; e.g., 2, 5, 10, 20 and 40 kA GDT’s @ 8 x 20 µs pulses are available.
- Energy dissipation is high – in the presence of a transient, when the tube has fired or “spark-over” occurs, energy is dissipated as heat and light.
- Follow-on current is high since after spark-over the ionized path has low resistance and small voltages can keep the tube “ON” – some method of extinguishing the “glow” is generally required in the form of parallel devices or a series resistor which must be large. Note that a series resistor adds significantly to “let-through” voltage.
- Leakage current at operating voltage is negligible at 1 pf @ 60 Hz.
- Failure Mode - The GDT generally fails open. The device will have its gas charge compromised or depleted. Under extreme lightning, the GDT may fail short.

f) **Silicon Carbide Block** – an air gap conductor designed years ago as a lightning arrestor.
Generally not used for suppression any longer.

Key features are:

- Unpredictable turn on and response characteristics.
- Very slow to fire or “spark-over”.
- Low to medium capacitance.
- High-energy capability.
- High-energy dissipation.
- No follow on current.
- Medium to low leakage.

g) **Air Gap** – Construction is two conductive elements placed in close proximity with air (atmosphere) in between. Spark over occurs when the air is ionized by a sufficient voltage potential applied across the terminals – used in extremely high lightning risk areas as the primary protection in a multi-stage TVSS device.

Key features are:

- Unpredictable turn-on and response characteristics.
- Very slow to fire or "spark-over".
- Low capacitance.
- High-energy capability.
- Extremely high-energy dissipation.
- No follow-on current.
- Low leakage.

h) **Fuses** – Generally not considered as a TVSS device because of the time required to operate or "clear" and significant currents can flow during this period. These devices are usable only once and must be replaced. Hybrid TVSS devices, however, often utilize fuses in their circuitry to prevent catastrophic rupture of MOV devices.

i) **Surge Relays** – these devices are utilized to disconnect signal lines in the event of a high current surge – their speed, because of the mechanical motion of contacts (several milliseconds), renders them too slow for normal induced transients. Contacts can "cold weld" during a large surge or "bounce" creating additional problems. These relays are generally used to disconnect power surges caused by failures in the power system, which are of significant duration.

j) **Circuit Breakers** – used to disconnect power from electronic equipment. Speed of response is in the tens of milliseconds rendering them too slow for normal transient protection.

k) **Thyristors** – these silicon semiconductor devices appear in a variety of forms and wattages. Sometimes two silicon-controlled rectifiers (SCR's) are utilized to increase power capability. Often transistors, zeners, SAD's or Diac's are used as gate drivers to turn them "ON".

Key features are:

- Response is sharp, predictable turn-on and linear within specified power limits.
- Speed is fast especially when turned on via DIAC drive.
- Low capacitance.
- High-energy capability.
- Low energy dissipation due to "crow-bar" effect and very low device resistance after turn-on.
- Follow-on current is high until device is turned off. Design must take into account the requirement for turn-off as low energy may keep device "ON".
- Leakage is low.
- Failure mode is a short circuit.

l) **Hybrid Devices** – These designs are multi-stage units utilizing a variety of the available TVSS discrete devices. The number of combinations possible is quite large although a few key designs typically dominate available commercial devices. When designed properly, these units will provide all of the best characteristics of each discrete device. The primary stages will absorb the brunt of the transient while later stages provide predictable low clamping or “let-through” voltage. Generally, discrete devices by themselves are inadequate because of either “too high let-through voltage” or insufficient power capability.

Components may be selected to cause the unit to fail short or open. If the TVSS fails open, indication that service protection has been lost is crucial.

III. EMI/RFI FILTERING

A keen knowledge of filter designs requires years of study and contains more design variables than meet the eye. This introduction will provide basic concepts.

Many suppressor companies claim EMI/RFI filtering when in reality their products contain only an “X” or “Y” capacitor, or worse an unapproved device. Requirements for X and Y capacitors are found in the following documents: IEC 384-14, UL 1414 and CSA 22.2.

Class “X” capacitors are used where a short circuit in the capacitor will not cause a dangerous electrical shock hazard. They are rated X1 (most demanding in terms of peak voltage) and X2. This class is used in line to line or line to neutral installations.

Class “Y” capacitors are used where a short in the capacitor may cause electrical shock hazard. There are four sub classes. Y1 is the most rigorous, must endure an 8kV pulse, and is constructed with double insulation. These capacitors normally install between line and ground.

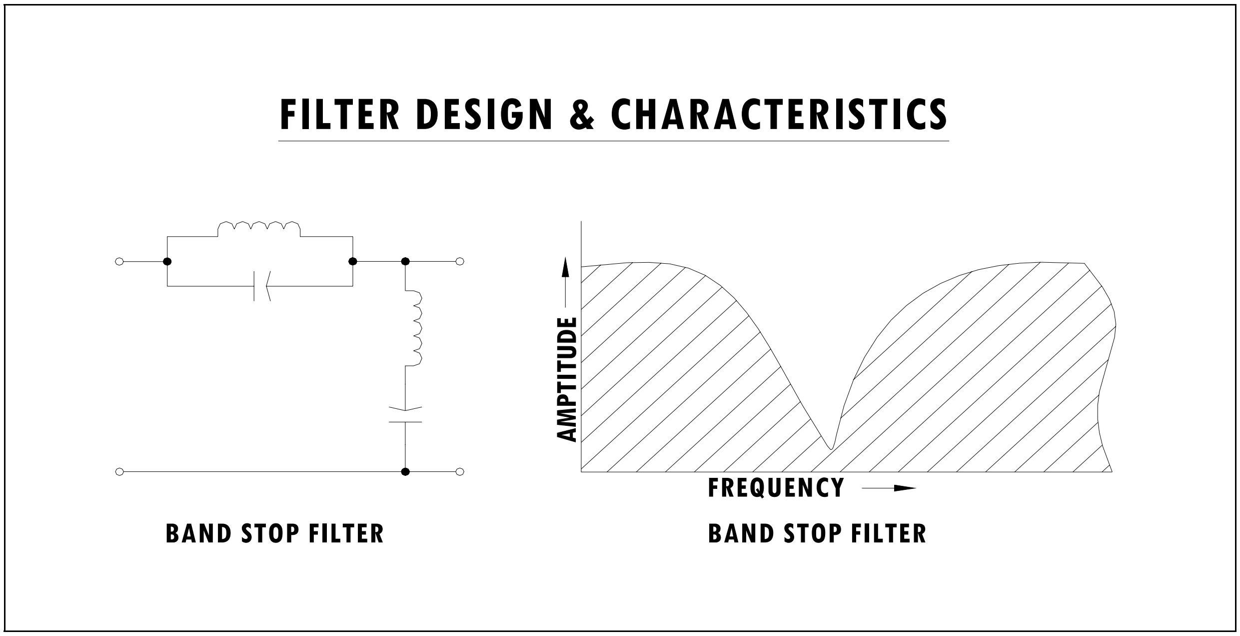
There are a large number of capacitor manufacturers who offer a line of X and Y capacitors. Our lab testing shows marked differences among manufacturers in dv/dt response time, actual value and consistency.

Effective filters for today’s electronic circuits generally require more sophisticated filter designs than a simple capacitor.

1. FILTER CHARACTERISTICS AND DESIGN

A filter may be considered to be a combination of capacitors, coils and resistors in a circuit that will impede or pass certain frequencies.

a) The **“shape factor”** of a filter is the ratio of its bandpass 60 dB down from the midband value to its bandpass 6 dB down. The steeper the skirts, the smaller the shape factor. **(See Figure 5 below)**



FFIGURE 5

b) When the **inductive reactance** (X_L) in ohms of a coil equal's the capacitance reactive (X_c) in ohms of a capacitor in a circuit condition known as resonance occurs.

$$X_L = X_C \text{ or } 2\pi f L = \frac{1}{2\pi f C}$$

Where: f = frequency in Hz, L = inductance in H, and C = capacitance in Farads.

Figure 6 below shows a series resonant circuit and a parallel resonant circuit

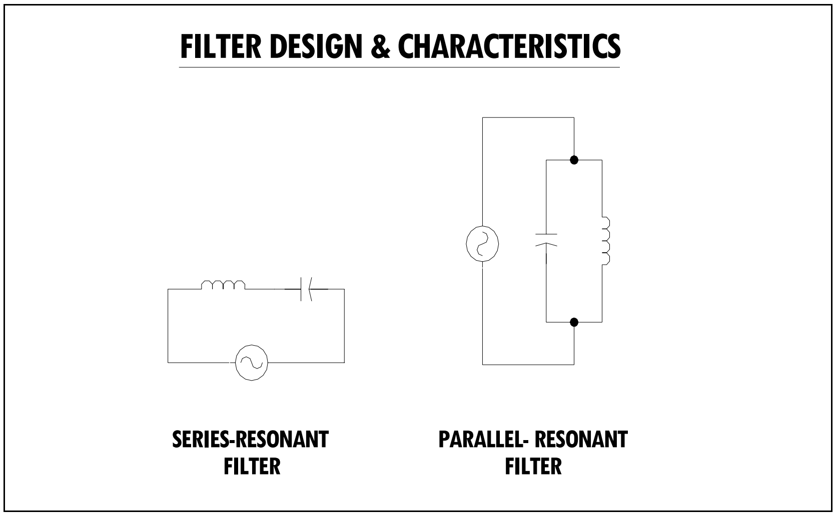


FIGURE 6

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Inductive reactance is directly proportional to frequency while capacitive reactance is inversely proportional. The frequency at which a coil and capacitor will resonate is found by the formula:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

At any frequency where the X_L of a coil equals the X_c of a capacitor, the secondary will appear as a low impedance circuit to this frequency. Thus this one frequency produces significant current in the secondary. With high current flowing, relatively high amplitude voltage will be developed across the reactances.

In a parallel-resonant circuit, the same voltage is across both the coil and capacitor. However, current lags the source voltage by 90° in the coil and leads by 90° in the capacitor. Since the two currents are 180° out of phase, a "fly wheel effect" of currents occurs where current flowing down out of the coil must equal the current flowing into the capacitor.

c) A term often applied to inductor/capacitor circuits is "**Q**". The symbol Q can be considered to mean Quality. A coil with no resistance or other losses would be a perfect inductor and would have an infinitely high Q. Since a coil without losses is impossible, the Q of a coil will always have some finite value. Q value of a coil is the ratio of reactance to resistance or

$$Q_L = \frac{X_L}{R} = \frac{2\pi fL}{R}$$

Where R = resistance in Ohms, f = frequency in Hz, and L = inductance in Henrys.

At higher frequencies; however, electrons flowing in a wire or coil travel near the surface. This increased resistance, known as "skin effect", is one cause of a lower Q value in a coil. This effect can be reduced by: (using larger wire, silver plating the wire, using fewer turns while increasing core permeability or using "Litz" or multi stranded insulated wire.

Capacitors also have a Q value. The formula used for capacitors is

$$Q_C = \frac{X_C}{R} = \frac{1}{2\pi fCR}$$

d) In industrial measurement and control applications the most common requirement is for a “low-pass” filter. This filter passes low frequency AC or signals and attenuates or “strips off” high frequencies. A simple low pass filter consists of a coil and capacitor sized to provide “cutoff” at a desired frequency. (See the Constant –K Low pass filter on **Figure 7 below**).

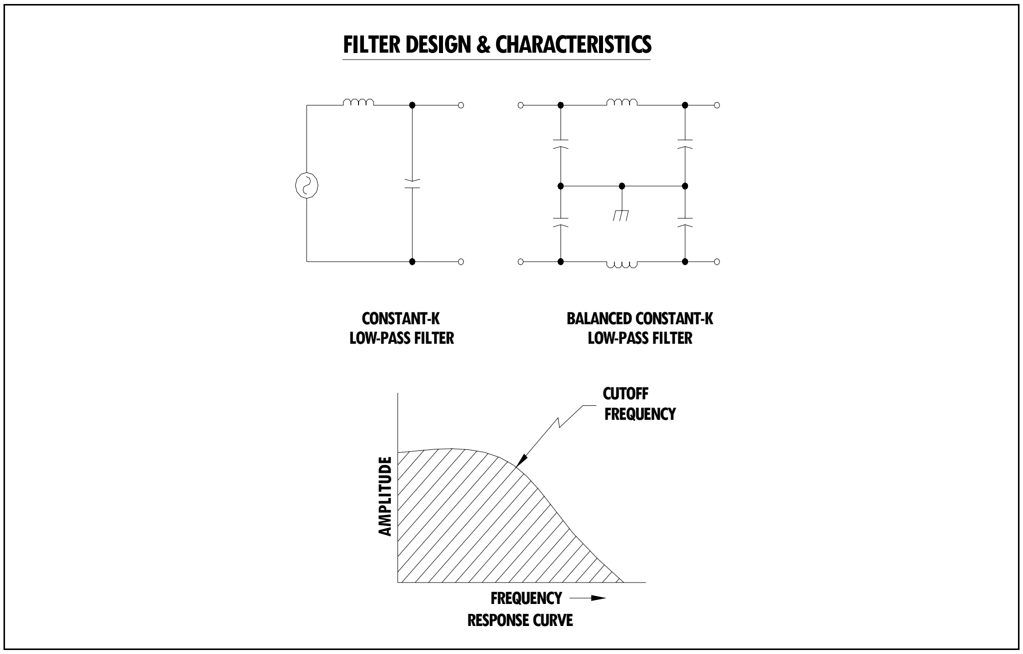


FIGURE 7

This filter is called constant K because the product of X_L times X_c is constant at all frequencies. L and C values may be computed using the formulas

$$L = \frac{R}{\pi f_C} \qquad C = \frac{1}{\pi f_C R}$$

Where L = inductance in Henrys, C = capacitance in Farads, R = impedance, of both source and load in Ohms, f_c = cut off frequency.

Simple filter designs assume source and load impedances to be equal. In practice this is rarely the case and filter design must accommodate variations in source and load impedance.

The higher the Q of the reactances, the sharper the cutoff. For sharper cutoff more sections are used. A balanced constant-K low pass filter may be constructed as on Fig 15 above

For a sharper cutoff than a constant-K filter provides, an M-derived filter may be used. The M may be considered to be a ratio of the cutoff frequency to the frequency of infinite attenuation (zero output). In a low pass filter, M will be between 0 and 1 in value. An M value of 1 will provide the same curve as a constant-K filter. **(See Figures 8, 9)**

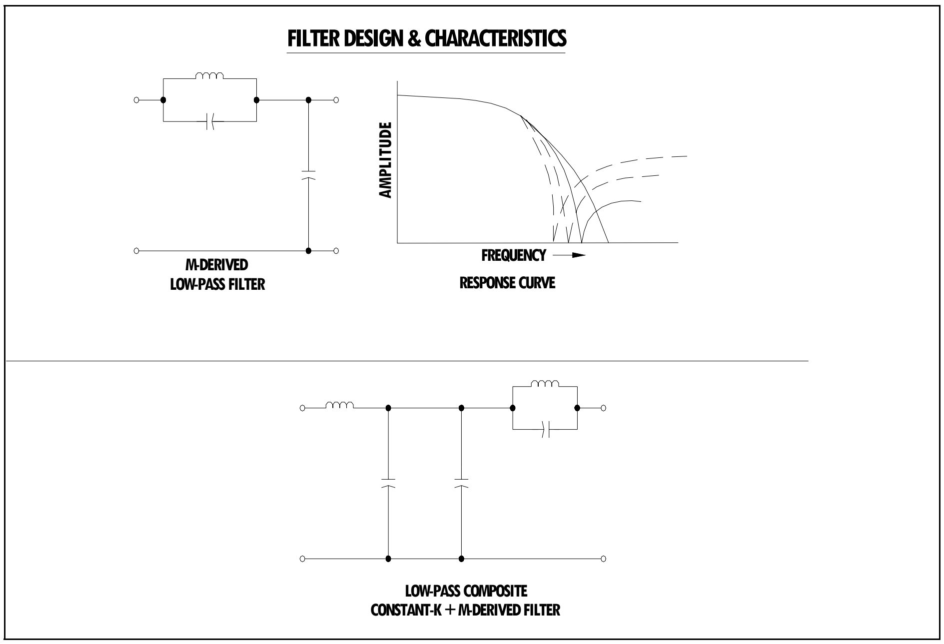


FIGURE 8

Practical filters are made up in sections. There are three very basic configurations. Variations of these will be seen to accommodate source or load impedance matching as well as two line or multi-line applications. **(See Figure 9 below)**

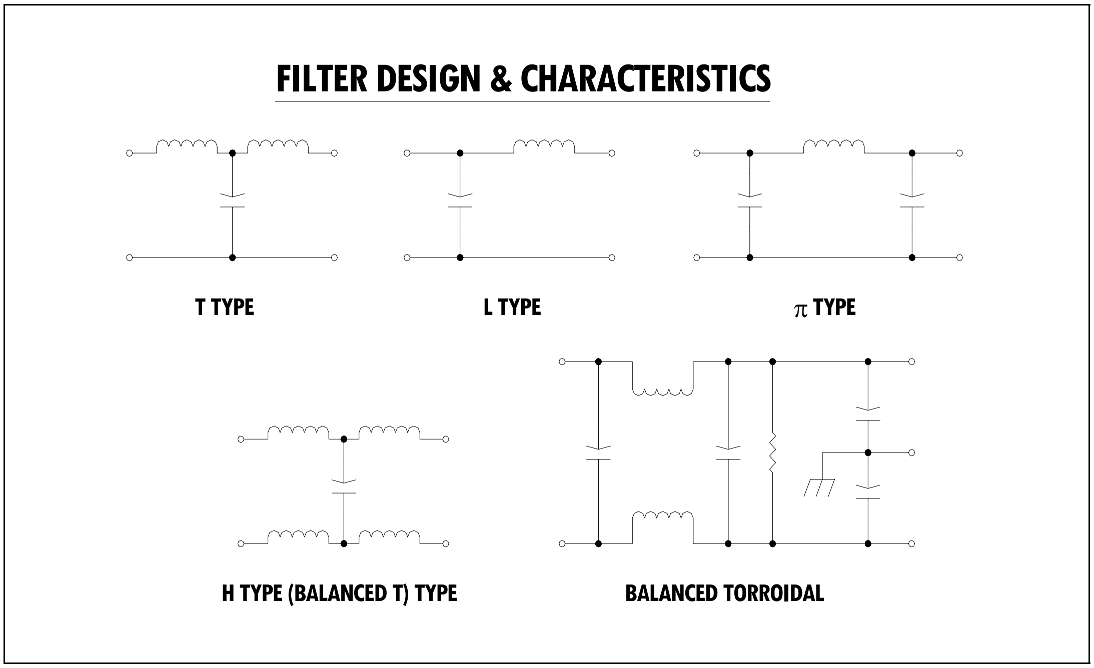


FIGURE 9

Effective filter designs require consideration of a large number of variables and generally present a challenge even to veteran designers. Design calculations rarely exactly match actual derived designs due to losses, impedance imbalances manufacturer's variations and tolerances etc…

Veteran designers provide extensive testing under a variety of conditions in order to properly profile actual filter response. Understanding filter response to variations of source and load impedance is particularly important.

IV. **AGENCY WAVEFORMS AND THREAT LEVELS**

Performance standards have been developed over a 20+ year period by key agencies in order to 1) make recommendations relative to testing of TVSS equipment and 2) provide standards for comparison of claimed performance.

Three key waveforms are utilized as primary in the industry. Test waveform terms refer to rise-time (from 10% or 30% to 90% of crest rise time) and decay (50% of fall time from 10% or 30% of start of rise).

The most common waveform is the “Combination Wave” which has a voltage waveform of 1.2 μsec rise (30% to 90% of crest), 50 μsec duration (30% rise time to 50% decay) into an open circuit, and a current waveform of 8 μsec rise (10% to 90% of crest) and 20 μsec duration (10% of rise to 50% of decay) into a short circuit. This standard is referenced by ANSI 62.41, IEC 1000-4-5, UL 1449 2nd edition and CECC 42000. **(See Figure 10)**

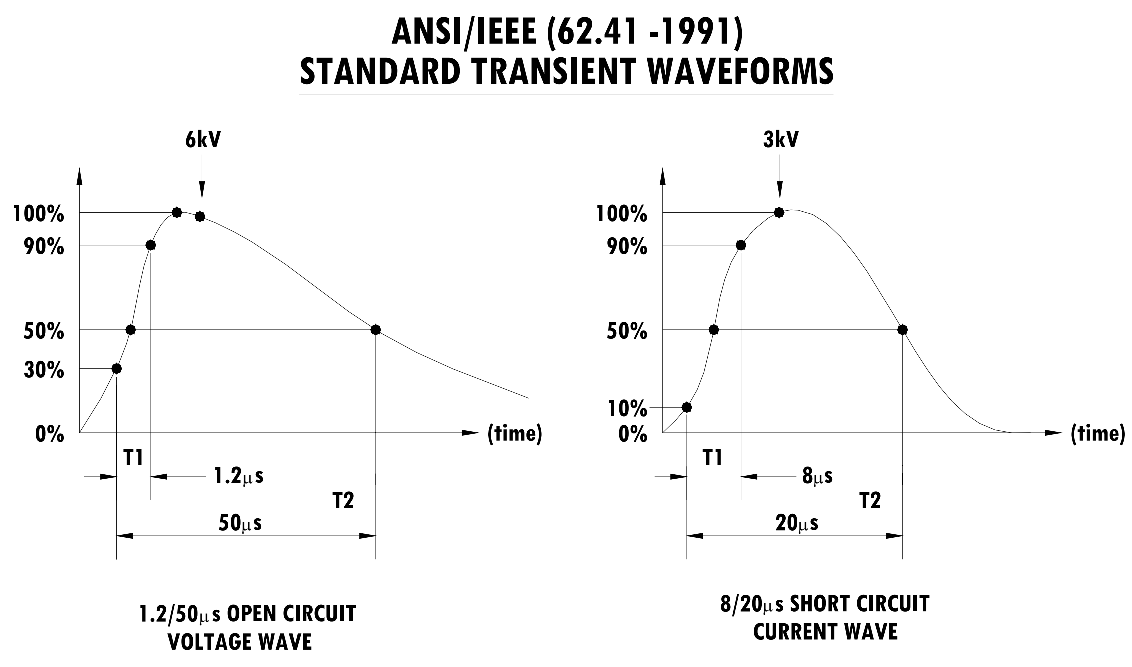


FIGURE 10

The "Ring Wave" has a damped oscillation with a rise time (10% to 90% of crest) of 0.5 μsec and a frequency of 100 kHz. The decay factor is 0.6 during each half cycle. **Figure 11**(Left) shows a ring wave (See ANSI Standard C62.41).

The "electrical fast transient" (EFT) represents transient bursts which occur during inductive load switching or relay contact bounce. The pulse is a burst of individual waveforms of 5 x 50 nsec for a 15 msec duration and repeated every 300 msec. **Figure 11** (Right**)** shows an Electrical Fast Transient/Burst train (Referenced in IEC 1000-4-4 1 1989).

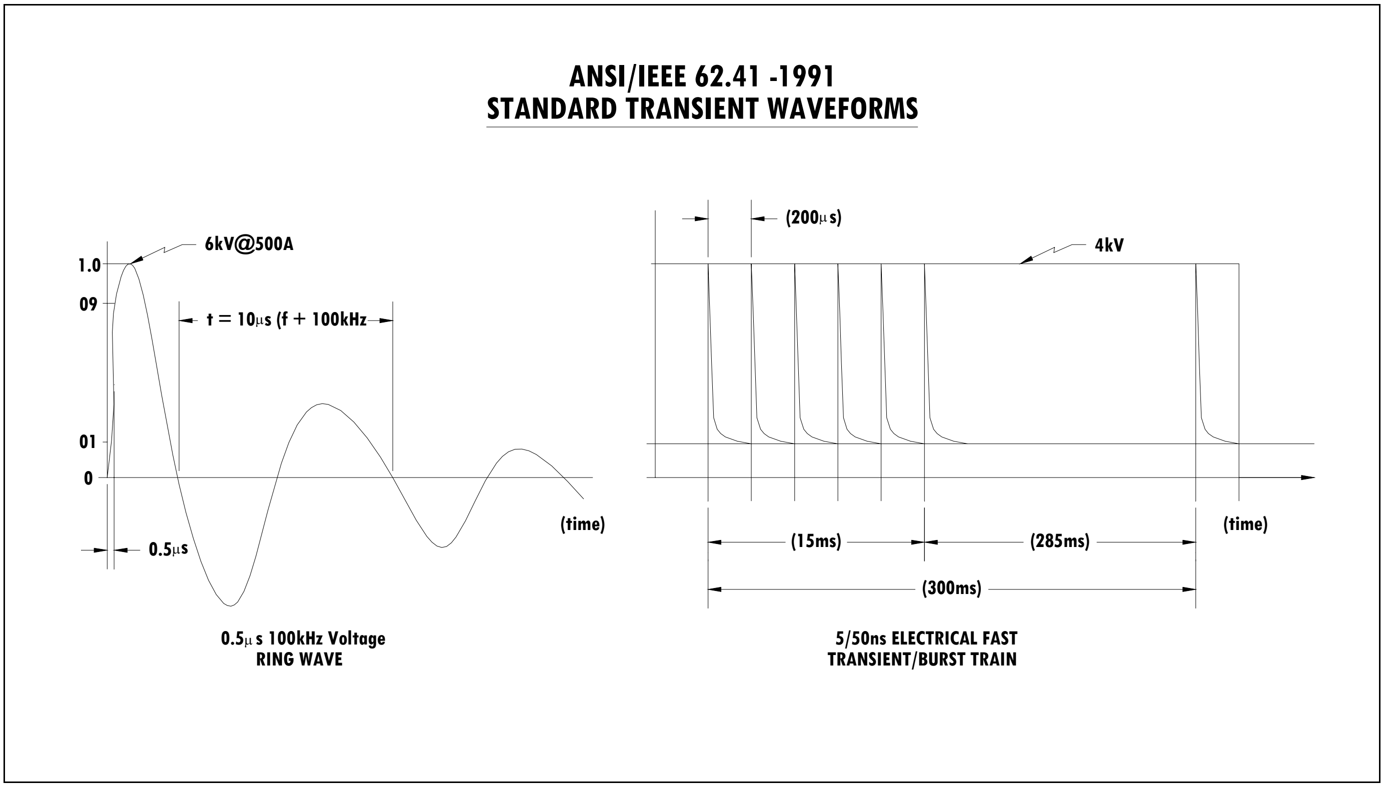


FIGURE 11

Additional waveforms referenced on ANSI/IEEE C37.90.1-1989 are shown on **Figures 12 and 13.**

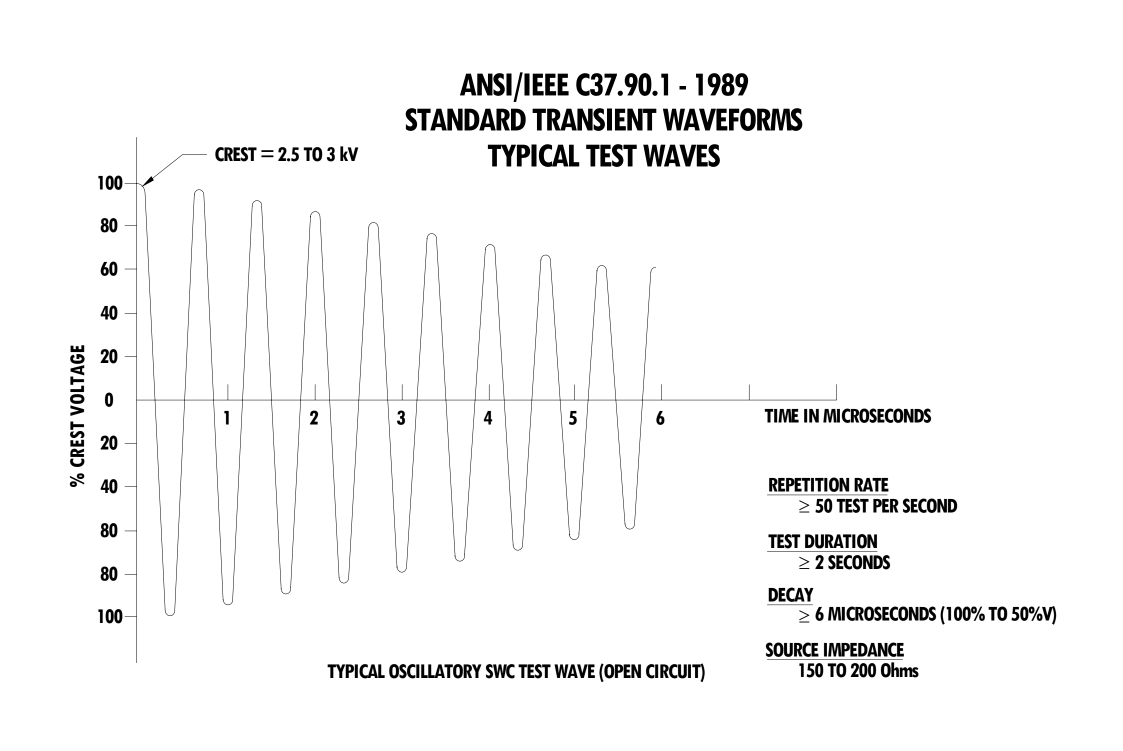
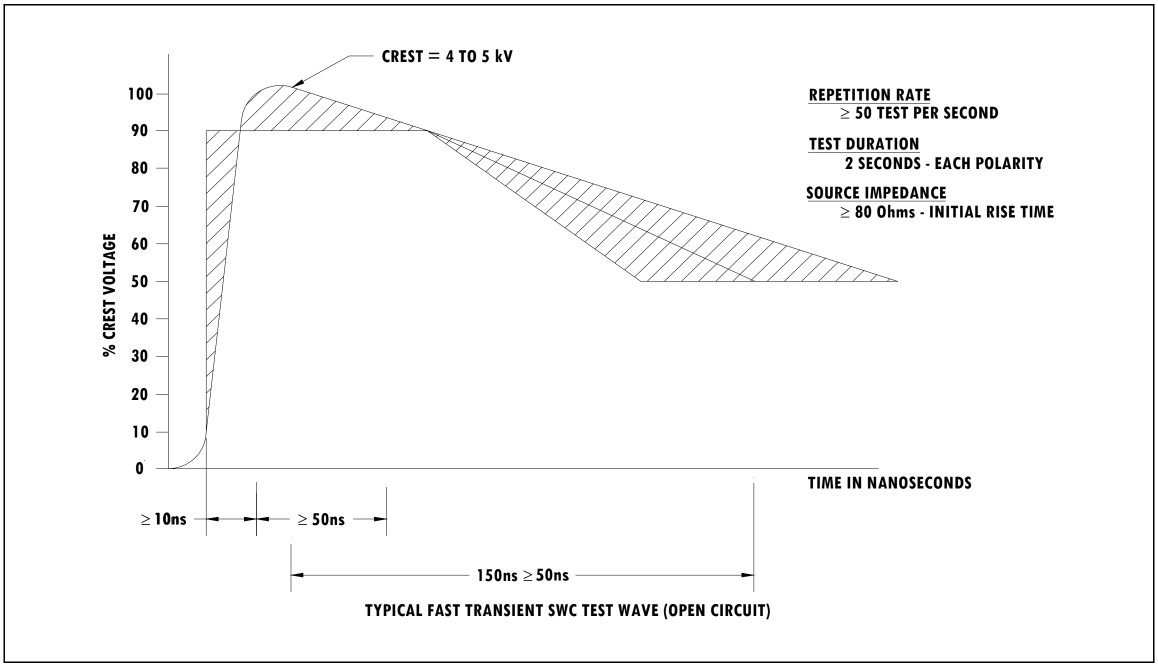


FIGURE 12



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The set up for test utilizing these key waveforms is quite complex and expensive. Test equipment capable of forming the very specific high current voltage waveforms repeatedly is required along with great care in lead and probe set up. Specified test layout, use of filters and impedance devices and so on is critical and requires significant training.

The waveforms for the ANSI Standard are slightly different; also an oscillatory test wave (open circuit) is added.

Threat levels as defined by IEC are shown in **Figure 14**

IEC 1000-4-4 Electrical Fast Transient

Open-circuit output test voltage (+/- 10%) and repetition rate of the impulses (+/- 20%)				
Level	On power supply port, PE		On I/O (input/output) signal, data and control ports	
	Voltage Peak kV	Repetition rate kHz	Voltage peak kV	Repetition rate kHz
1	0.5	5	0.25	5
2	1	5	0.5	5
3	2	5	1	5
4	4	2.5	2	5
x[1]	Special	Special	Special	Special

1) "x" is an open level. The level has to be specified in the dedicated equipment specification.

The electrical fast transient (EFT) is a 5x50 nS waveform.

Level 1 Well shielded protected environment (e.g., computer room).

Level 2 Protected environment - separation of power and control cables from signal and communication cables (e.g., control room).

Level 3 Typical industrial environment (e.g., industrial process equipment, power plants).

Level 4 Severe industrial environment (e.g., outdoor industrial process equipment, power stations).

FIGURE 14

Threat levels as defined by ANSI/IEEE are shown in **Figures 15a and 15b**

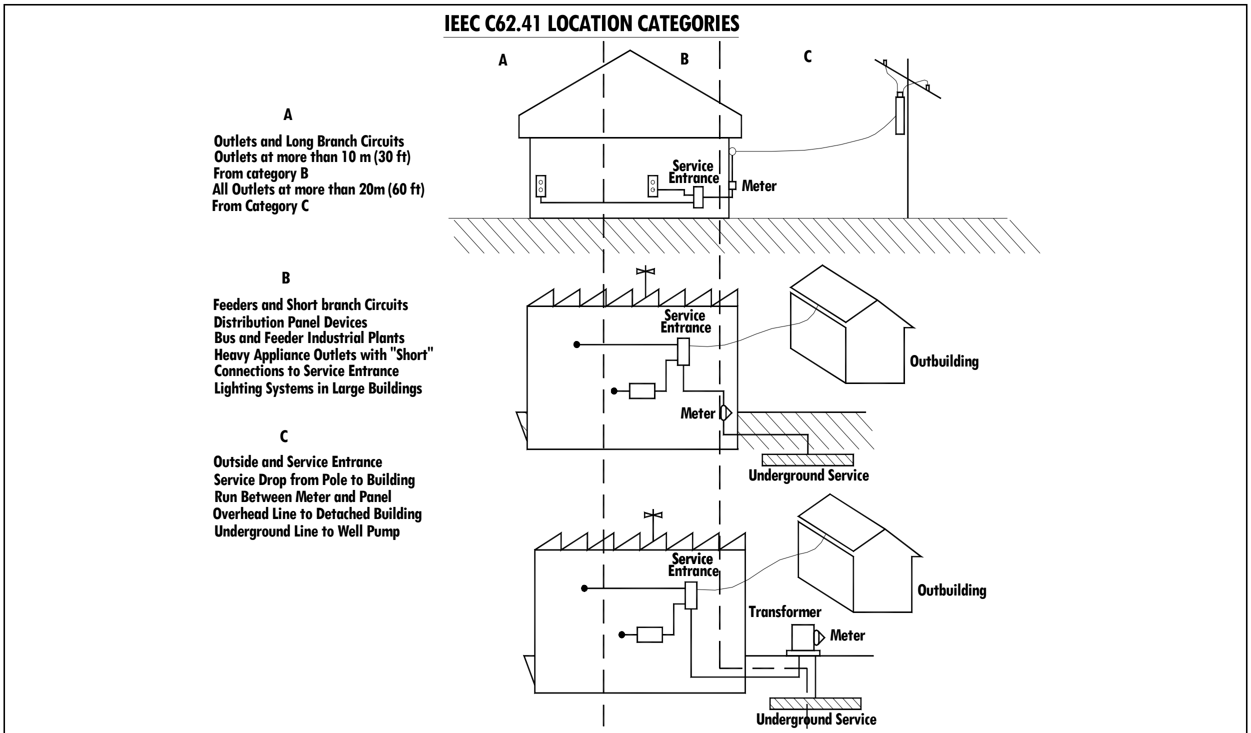

FIGURE 15a

IEEE Location Category Test Values

Location Category*	System Exposure	Voltage (kV)	Current (kA)	Effective Impedance (Ohms)
A1	Low	2	0.07	30
A2	Medium	4	0.13	30
A3	High	6	0.2	30
B1	Low	2	0.17	12
B2	Medium	4	0.33	12
B3	High	6	0.5	12

Standard 0.5 us-100 kHz Ring Wave

Location Category	System Exposure	Voltage (kV)	Current (kA)	Effective Impedance (Ohms)
B1	Low	2	1	2
B2	Medium	4	2	2
B3	High	6	3	2
C1	Low	6	3	2
C2	Medium	10	5	2
C3	High	20	10	2

Standard 1.2x15 microsecond - 8x20 microsecond combination wave.

FIGURE 15b

V. EQUIPMENT FAILURE PRINCIPALS

Once we realize that today's microcircuits fail when exposed to transients of even a few volts, (see TVSS Filtering and Protection Introduction) we need to understand how transients enter equipment. This is key to proper selection of transient suppression equipment and its installation.

1. PATHS OF ENTRY

Transient current flows into equipment via electrical conductors **(See Figure 16).** These lines or wires may be AC power hot, neutral or ground, telephone lines, data-com lines, measurement or control lines or DC power busses.

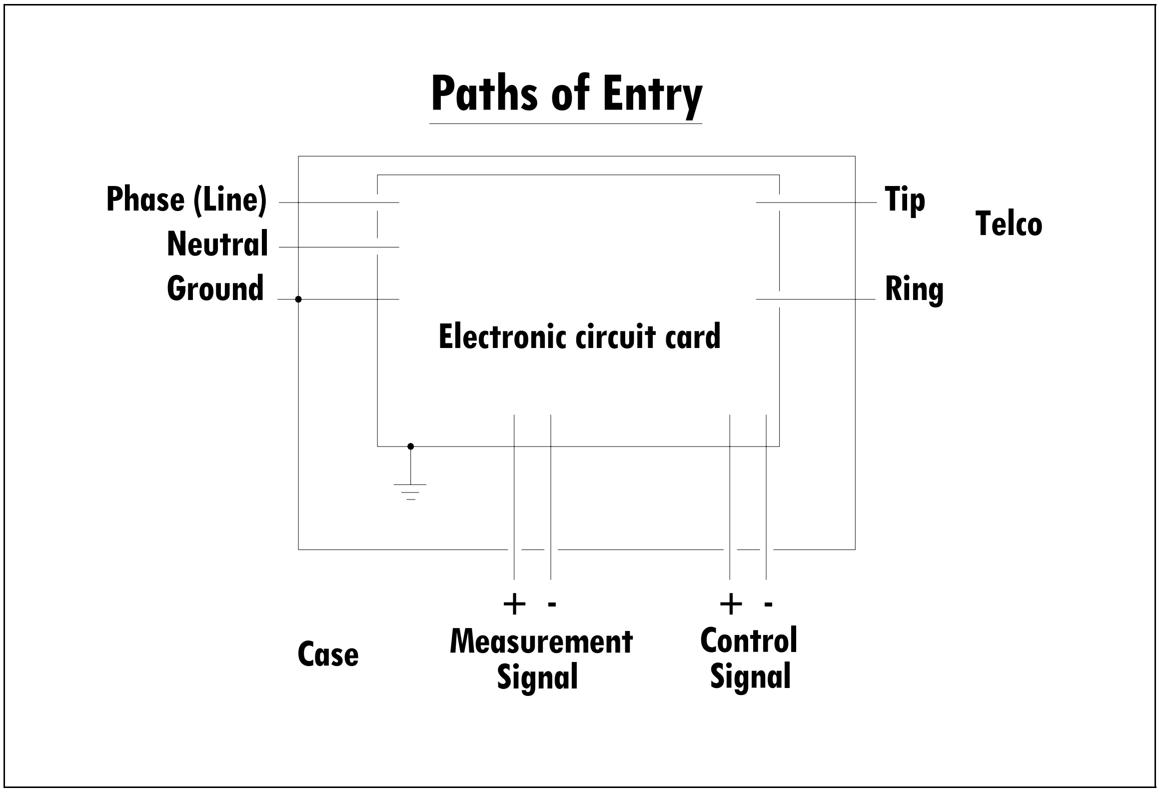

FIGURE 16

Wires connected to equipment from outside of buildings represent the greatest threat, next are lines feeding building to building and secondary threats exist where wires are contained within the building. **(See Figure 17).**

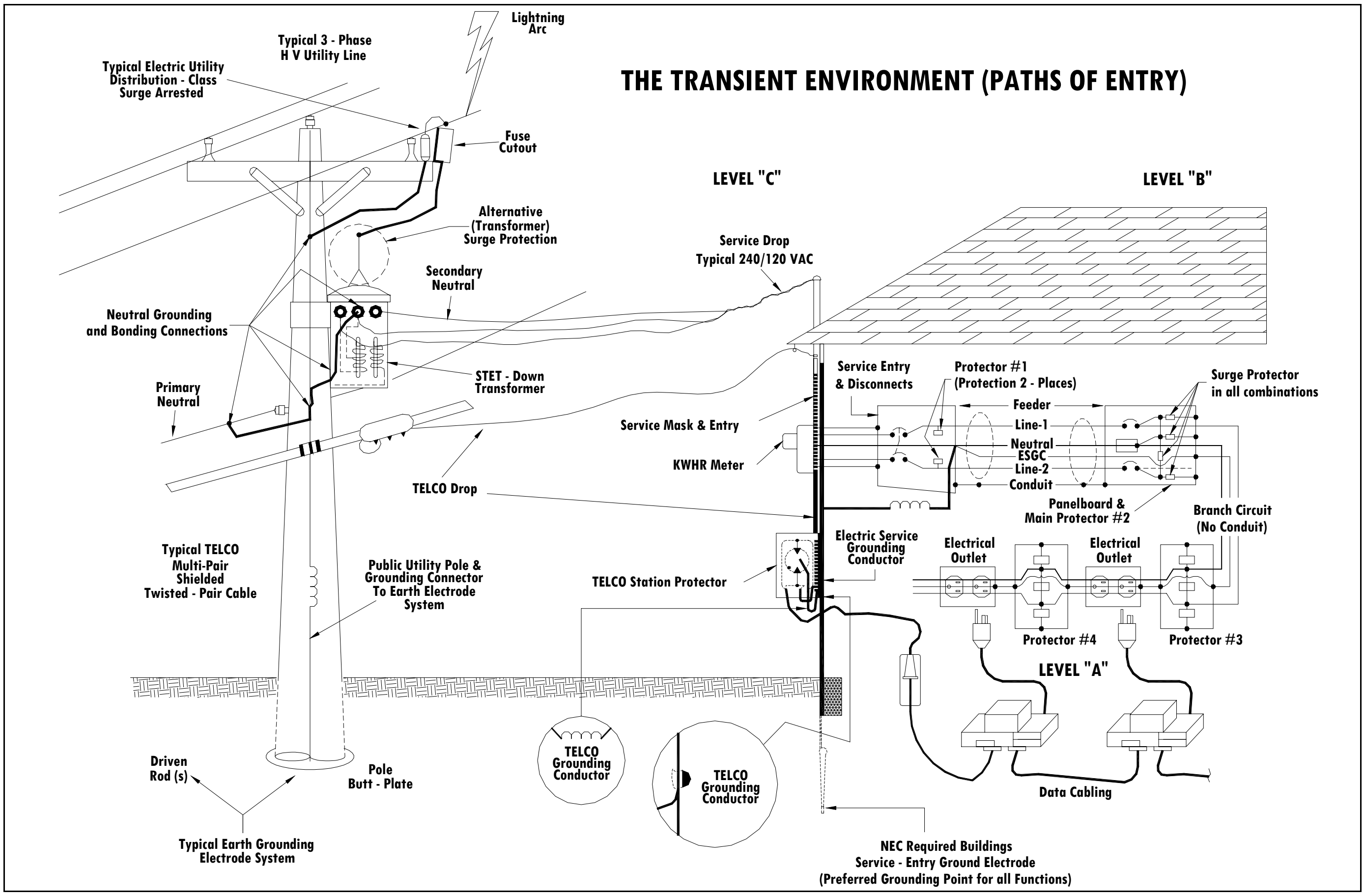

FIGURE 17

Under methods and recommended practice, we will discuss matching transient voltage surge suppressors (TVSS) to the threat level. However, at this point we should recognize that any electrical wire connected to electronic circuitry is a potential path of entry and should be carefully analyzed prior to deciding whether it should have protection **(See Figure 18).**

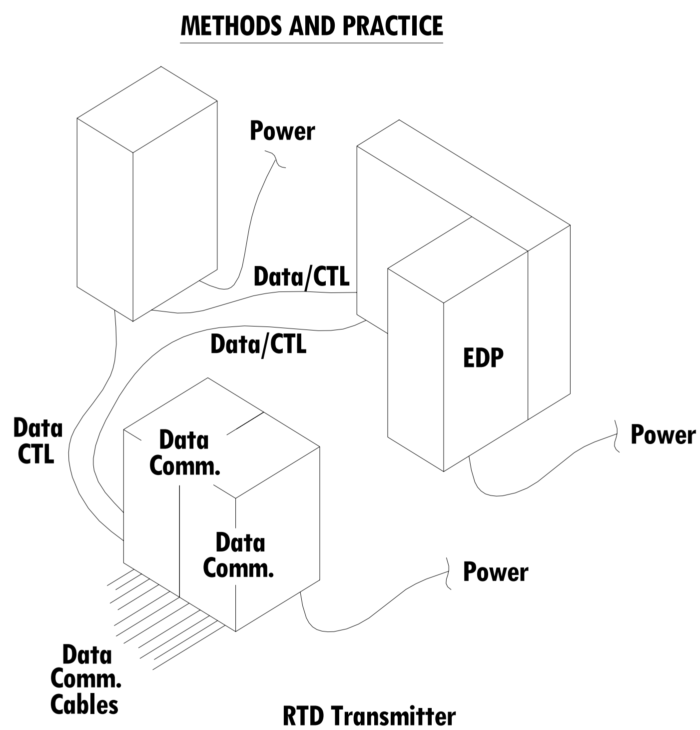

FIGURE 18

A practical approach, which seems to reduce the complexity in analyzing placement of TVSS devices is as follows. Remember that voltage potential applied across an electronic circuit is the base cause of failure. When this potential exceeds the withstand voltage of the weakest component, breakdown or punch through occurs.

The principal then is to design TVSS devices, which connect to all points of potential voltage threat and clamp or limit both differential and common mode transients to a level below the equipment failure threshold. **(See Section VIII)**

For example, in power entry, voltage transients must be limited between line to neutral, line to ground, and neutral to ground. In the case of two data lines (telephone wire pair, current loop, telco) both line to line and line to ground modes must be protected.

VI. GROUNDING PRINCIPALS

Books have been written on this subject and excellent reference works are available. In this discussion we will address some common errors or misconceptions

First, many believe “If it is properly grounded “ (good earth ground of less than 10 ohms) you won’t have transient problems. In an oil production field in New Mexico, the transmitters were “grounded” by sometimes over a mile of earthed pipe. (It would be difficult to imagine a better "ground" than this). The company was losing 100 transmitters per month. The problem was of course related back to our principal of transient overvoltage occurring on the current loop with respect to ground. (Transient ground current flow in this case).
Sometimes an individual will remove the ground in hopes of avoiding the overvoltage problem. In this case the equipment is still subject to line to line transients and the ground threat normally remains. The ground threat remains because an insulation between two conductors (Equipment - Isolator - Earth) forms a capacitor, which at lightning frequencies may conduct energy into the equipment **(See Figure 19).**

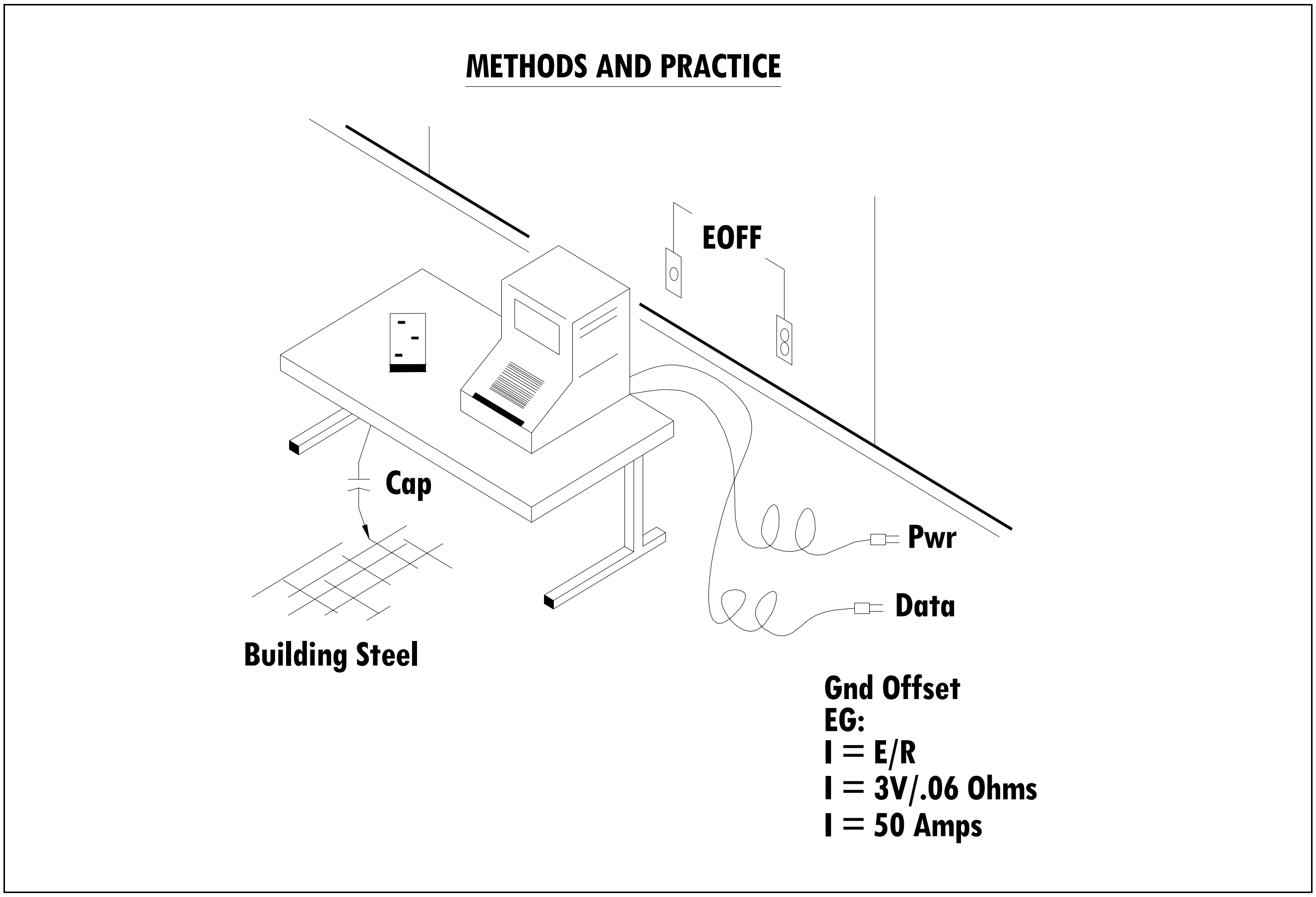

FIGURE 19

Electrical transients that are not absorbed by a suppressor eventually dissipate into the earth. In grounding then, the principal is “get the best earth ground you can” but don’t expect it to significantly reduce transient overvoltage failures without using a suppressor.

The National Electrical Code (NEC) provides for good earthing or grounding at the building entry, and at large sites, driving a ground rod at intervals. When various pieces of electronic equipment are connected via communication lines but have different ground points, voltage differences can be generated. An electromagnetic wave propagating from a lightning strike to earth can elevate ground potentials to several thousand volts with respect to other grounds or power or data lines.

VII. SHIELDING PRINCIPALS

Many believe that “if equipment is properly shielded” (shield wire plus conduit) you won’t have transient problems**.** Of course, experience shows this not to be true. The reason is that when the EM wave passes the shielded wires, currents are induced into conduit or shield and travels to the best “earth ground” available. The transient currents are then coupled inductively to the inner conductors, which lead directly to unprotected electronic components **(See Figure 20)**

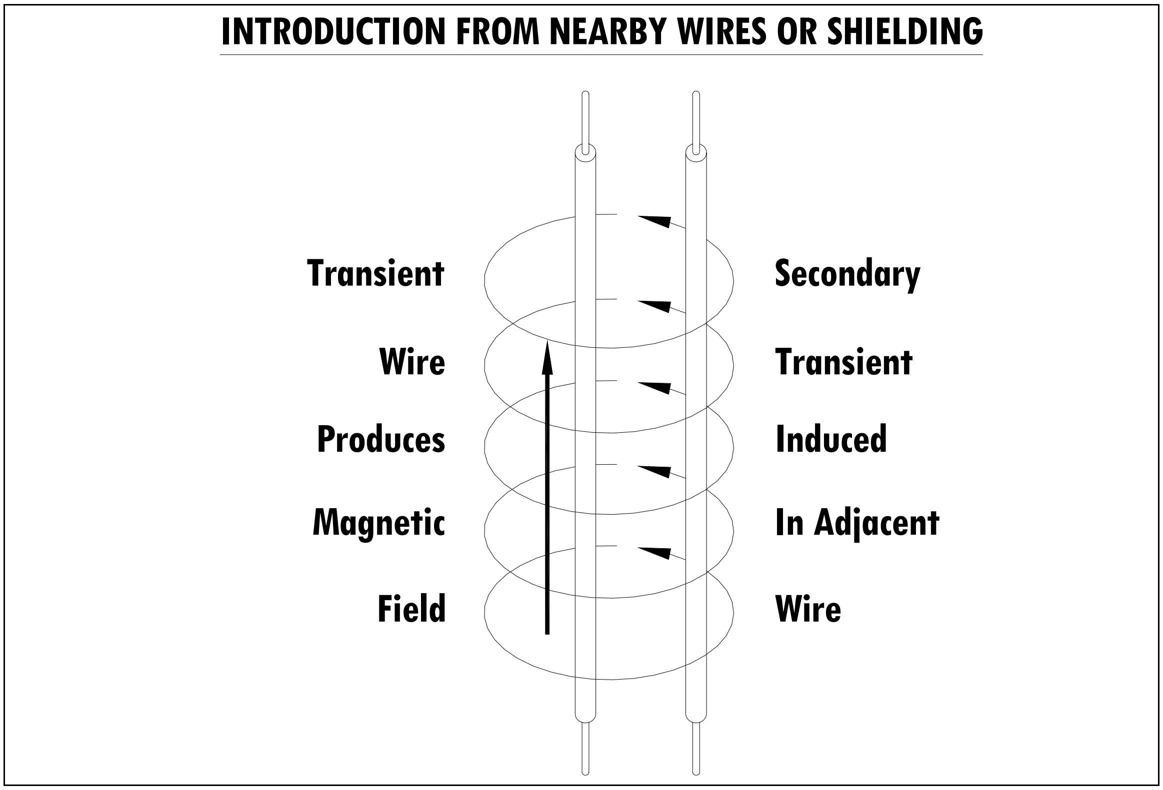

FIGURE 20

Another fallacy is the belief that burying the cable in the earth will prevent transient problems. The earth is essentially transparent to a lightning EM wave so very little attenuation is observed.

In shielding then, the principal is to use good shielding on sensitive data lines and ground only one end. Shielding will attenuate RF and help some with lightning. Always ground the shield at the receiving or measurement side, not both ends. When both ends of a shield are grounded, ground currents can flow, conducting noise or creating “ground loops” **(See Figure 21)**

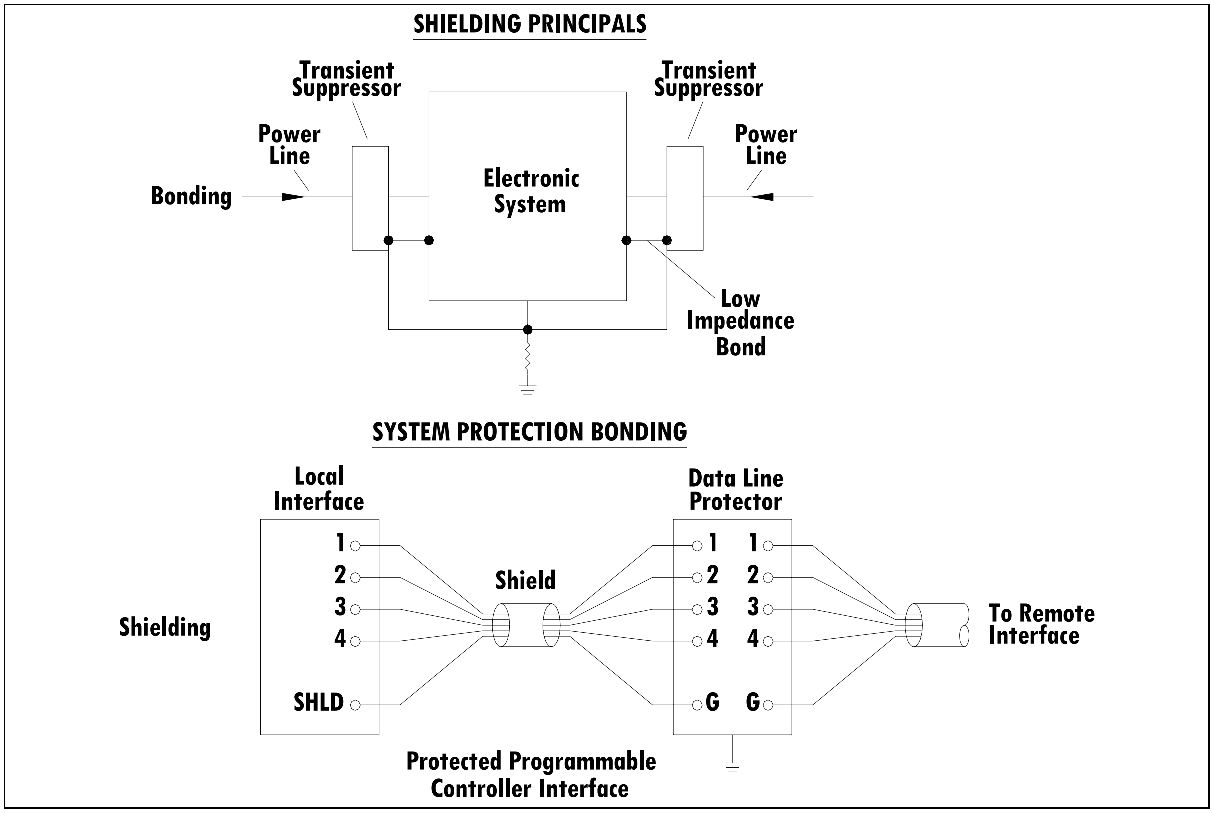

FIGURE 21

VII EQUIPMENT PROTECTION

Once we understand that there exists a life shortening or outright destructive threat to our electronic equipment and the ways this equipment is vulnerable **(See Figure 22),** we need to examine the choices and principals in the selection of protective equipment.

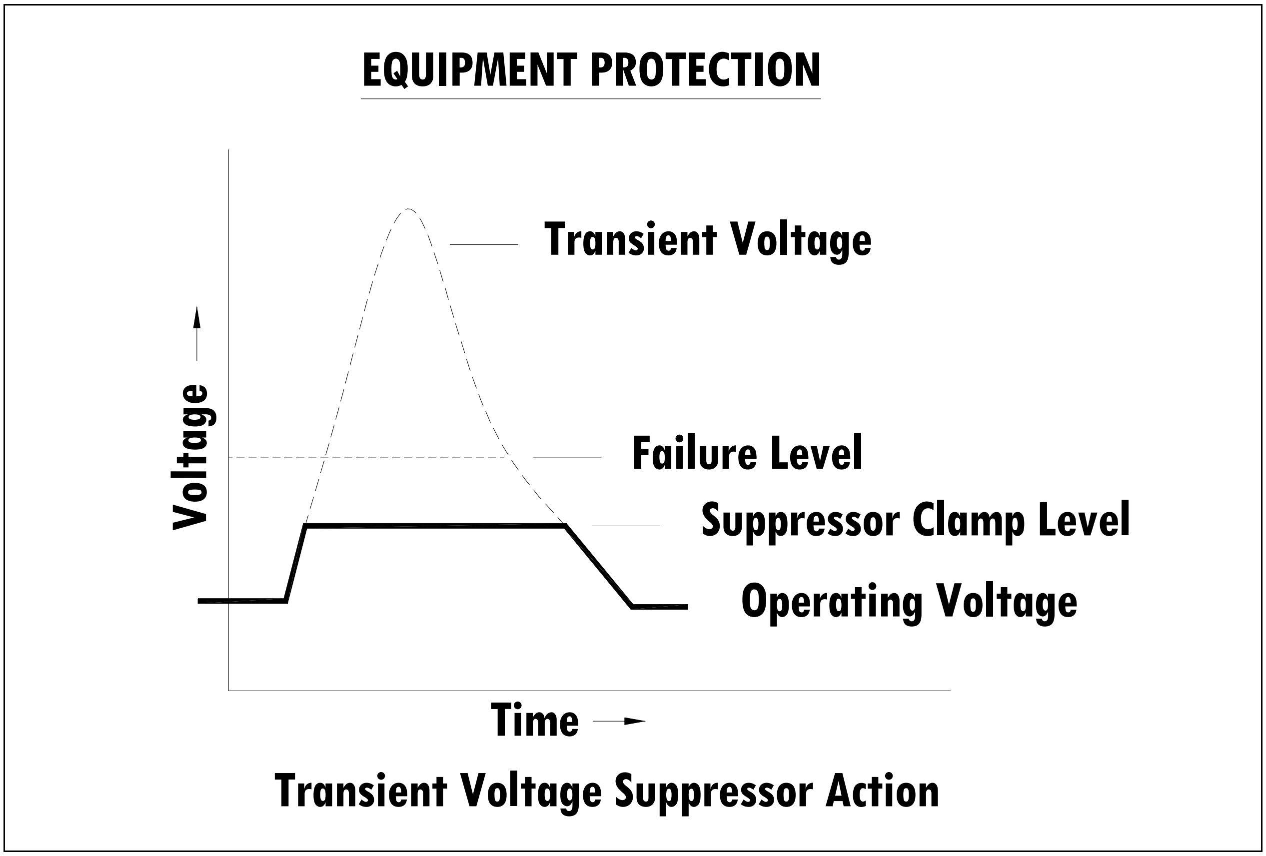

FIGURE 22

1. PRINCIPALS IN EQUIPMENT PROTECTION

Many questions arise as one considers purchasing transient voltage surge suppressors for his equipment or system. Should I buy protection, how much do I need, where should it be placed, how do I connect it? And so on.

One must consider the cost of equipment replacement whether immediate or through shortened life. The costs of down time or out of service time and cost of repair must also be examined. The threat level in this location should be examined, isokaunaric maps consulted for lightning frequency, power quality examined and industrial environment examined for switching/inductive transient generators such as HVAC systems, copiers, motors, pumps, control equipment, etc.

A study is not required to determine whether we need suppression, of course, if we have already experienced failures or upset.

The key is to match the TVSS equipment to the threat level and then be certain all doors or paths of entry are closed, or if some are left open, the risk has at least been examined. (A good general guide is found in **Figure 23)**.

<u>Equipment Protection</u>

1) Do I need it?

- **Equipment Replacement Cost**
- **Downtime Cost**
- **Length of lines**
- **Threat Level (Lightning, Power Quality, Transient Environment)**
- **Problem Experience**

2) How much do I need?

- **Primary & Secondary Threats**
- **Cost Vs Equipment or Downtime Value**
- **Standards Agencies Recommendation**

3) How does it install?

- **Main Entry**
- **Branch**
- **Local Panel**
- **Equipment**
- **Field Protection**

FIGURE 23

2. METHODS AND RECOMMENDED PRACTICE

Because of the unpredictable nature of transients the threat level and frequency of occurrence may vary widely for a given location. For this reason, it is good practice to use primary protective suppressors for all outdoor and building entry areas. It is also good practice to put primary suppression on any lines going between buildings **(See Figure 24).**

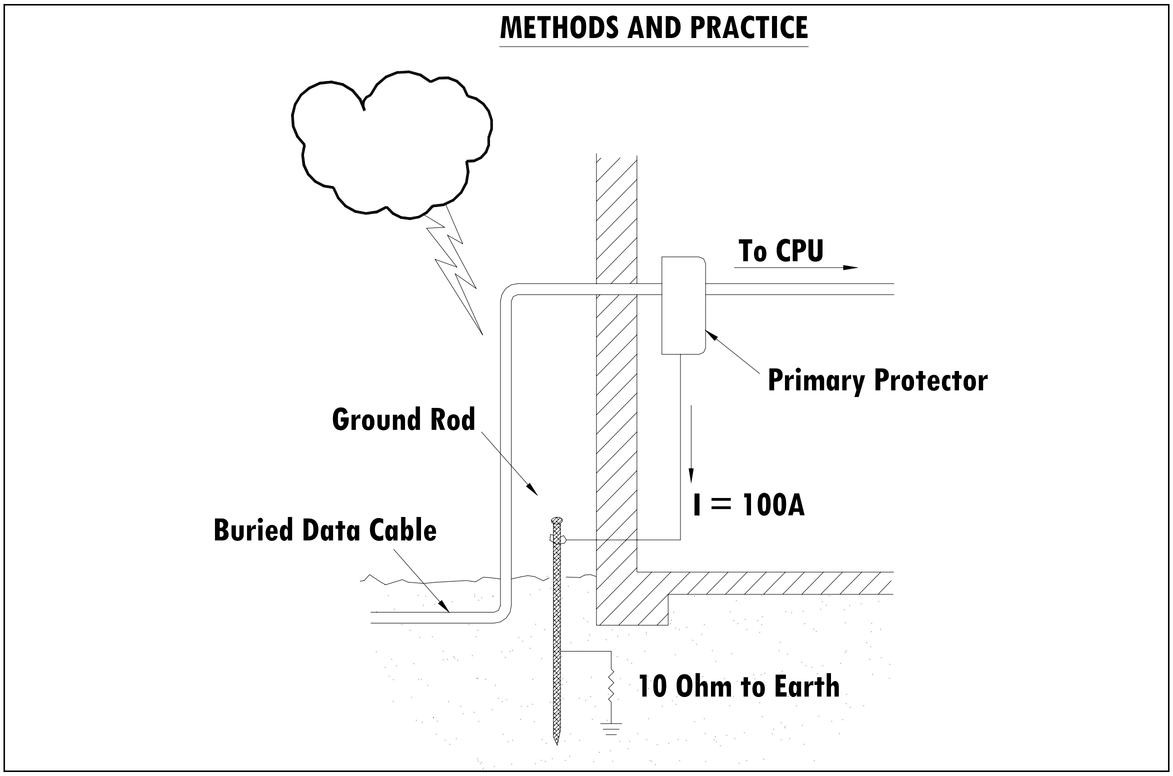

FIGURE 24

Previously, we noted all modes should be suppressed and clamped together during a transient. Since the path to ground is several ohms of impedance at transient frequencies at any protected device, clearly the voltage produced can be reflected back into the equipment on the opposite end of the data or telco line. Therefore it is always good practice to put suppression on both pieces of equipment that are connected together.

Suppression equipment must always be located as close as possible to the equipment it is to protect and the suppressor ground made common to the chassis. A good earth ground should be provided at this common point where possible **(See Figure 25)**

<u>Equipment Protection Principals</u>

Key Instructions Notes

- **When mounting TVSS Devices inside an instrument or panel orient the output of the device toward electronic circuiting to be protected. This minimizes radiant energy.**
- **Dress input/output leads well apart from each other.**
- **Connect the suppressor to a good earth ground.**
- **Use the largest gauge and shortest ground wire possible.**
- **Mount the suppressor, as close to the equipment it is to protect as possible.**

FIGURE 25

The recommended practice as noted in ANSI/IEEE C62.41.1991 for AC power is to place primary protection (main power entry) at the building entrance, branch panel protection at each branch panel and equipment level protection right at the equipment. All distributed outlets (duplex receptacles) that power sensitive electronic equipment (telephone systems, computers, fax machines, measurement or control equipment, office equipment, medical equipment) should have protection added. All signal/data, telco phone lines, current loops and control signal lines should have primary suppression **(See Figure 26).**

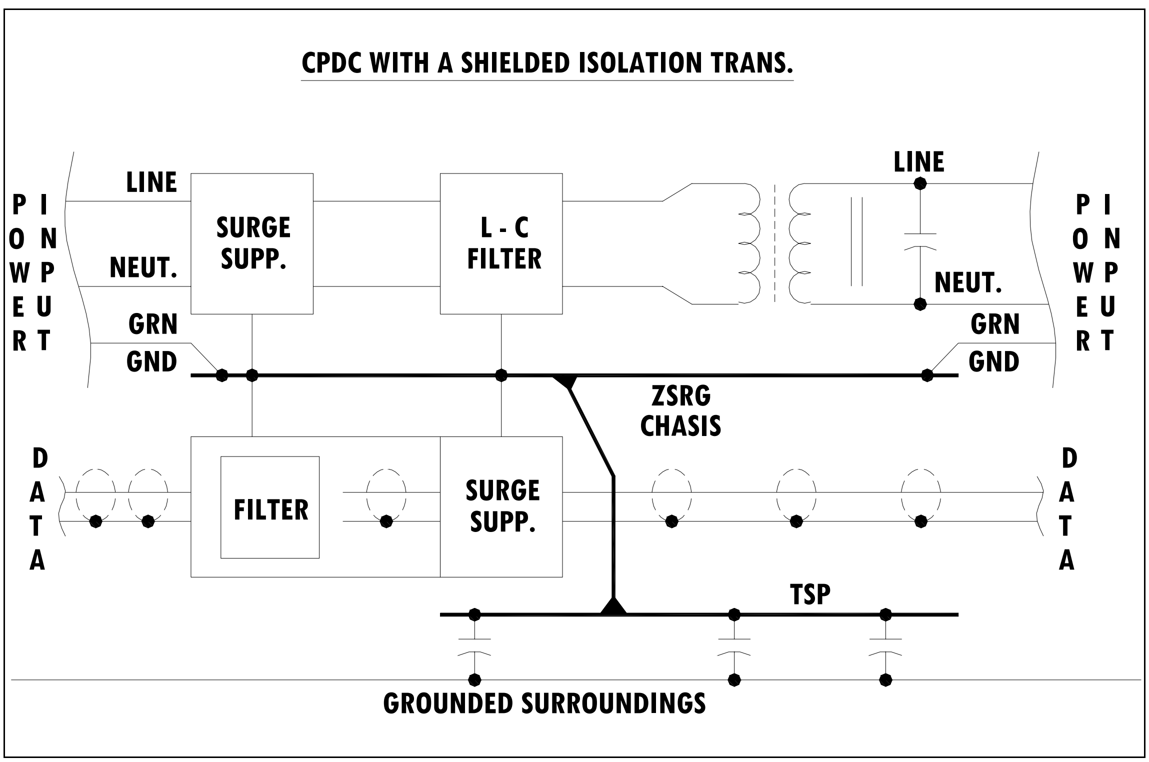

FIGURE 26

Figures 27 & 28 show typical applications of TVSS devices protecting field transmitters and receiver/recorder PLCs

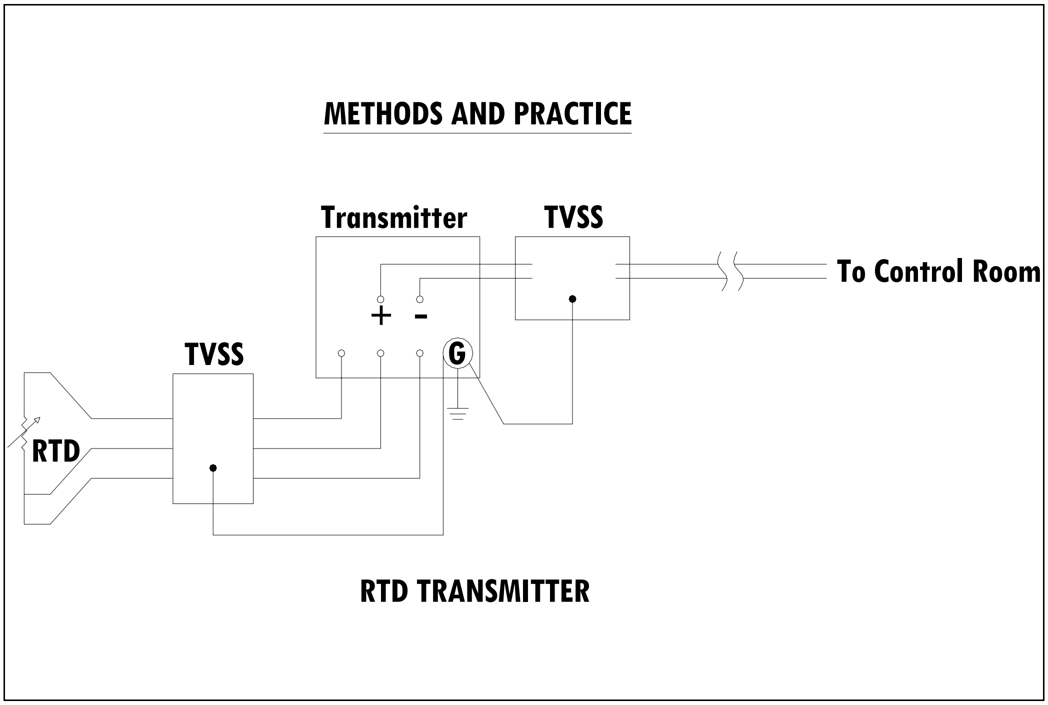

FIGURE 27

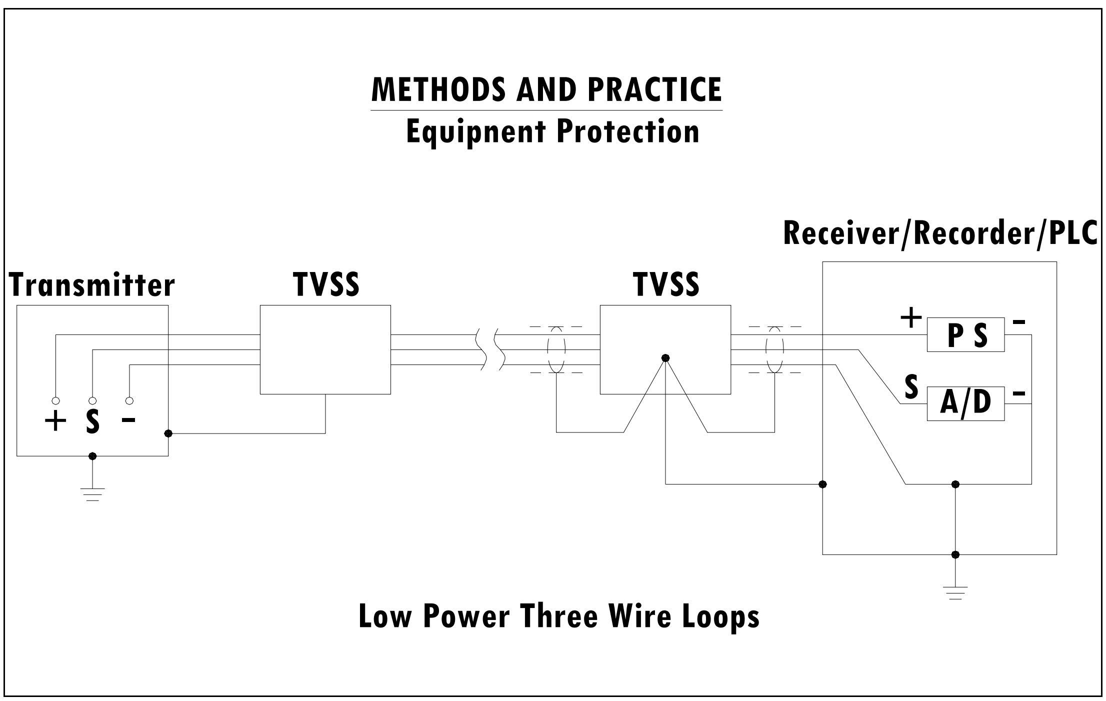

FIGURE 28

VIII. TRANSIENT VOLTAGE SURGE SUPPRESSOR (TVSS) DEVICES

- A number of discrete electronic devices may be used as a suppression device or used in hybrid TVSS units.
- Each type of device has strengths and weaknesses. Hybrid devices take advantage of the strengths of each and minimize the weakness.
- Metal oxide varistors (MOV's) and gas discharge tubes (GDT's) are able to withstand severe transients. Silicon avalanche devices (SAD's) are unable to withstand severe transients but clamp at very predictable levels, experience no wear out and fail safe (short).
- MOV's are offered in a wide variety of AC and DC operating ranges from a few volts to hundreds of volts. GDT's are offered in wider increments starting at 75 volts and going to several thousand volts. SAD's are offered in very fine increments from 5 volts to around 400 volts. All three devices may be stacked in series to provide alternate total voltages.
- Resistors or inductors are often used in TVSS units to force the bulk of the transient into the primary device and protect the second or third stage. Multi-stage suppressors provide for high-energy absorption, low predictable clamping and often electrical filtering as well.
- AC main and branch power TVSS devices are normally a shunt type because of the load currents involved. MOV's and GDT's are normally used in these locations. Some vendors will use a massive number of SAD type devices in these locations. Data/signal and Telco applications will generally be hybrid multi-stage TVSS units.
- After one considers the threat, evaluates the risk and decides to procure a TVSS device, a reputable manufacturer or representative knowledgeable in the field should be consulted. TVSS suppliers who are competent in this industry will provide excellent advice regarding adequate design and model selection.
- Great care should be given in the selection of the TVSS supplier and TVSS model. One should carefully examine specifications in performance since performance claims sometimes are worded to sound good but actual performance to accepted standards is often not referenced or is exaggerated.