SURGE CONTROL PRODUCTS

TVSS, FILTERING AND PROTECTION INTRODUCTION

CCI

Circuit Components, Inc.
2400 South Roosevelt Street
Tempe, Arizona 85282
Tel: 480-967-0624
Fax: 480-967-9385
Web: www.surgecontrol.com
Email : Info@surgecontrol.com

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I. COMPANY PROFILE

Circuit Components, Inc. (CCI) was established as a division of Rogers Corporation in 1978, and became an independent company in 1992. CCI is headquartered in its 32,000 square foot manufacturing plant in Tempe, Arizona, and also has a 30,000 square foot manufacturing plant in Monterrey, Mexico. CCI has served the electronics industry from its inception, providing specialty Micro-Q™ decoupling capacitors and printed circuit board bus bars. The company's President is Norman L. Greenman, who prior to his current position was President and CEO of Rogers Corporation for 26 years.

In 1997, CCI acquired Surge Control Limited, which was established in 1990; and the design and manufacturing of Surge Control products are now incorporated into CCI's capabilities. Sam Johnson, the former owner of Surge Control Limited, is serving as a long-term consultant to CCI.

CCI provides the broadest surge control product line of suppression and filtering devices, with over 200 product solutions. We are a leader in this industry, and have a rapidly expanding family of satisfied customers.

Regional distribution channels and factory sales reps service the US, Canada, and Mexico. Customers in areas with no representatives contact our factory directly

The company provides its products to industrial OEM's and System integrators, as well as to end users of measurement and control instrumentation, data processing, medical and communication equipment, electrical distribution and other electronic device manufacturers. We have recently introduced the SAB and SPU families of products for Allen-Bradley I/O modules and are a member of Rockwell Automation's Encompass program.

CCI's ongoing, customer-oriented engineering supports our customers in meeting their individual requirements. With a commitment to total customer satisfaction, CCI provides customers with high-quality, superior-performance filtering and suppressor products at economical prices.

Our customers can be assured that CCI's engineers, who have devoted their careers to this specialized industry, will exert their best efforts to provide cost effective-effective and reliable solutions to transient suppression requirements.

II. 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. Most of these terms are listed in Section 5.

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 phenomena is generated from the friction of two dissimilar materials. This triboelectric effect is observed as electric charges of opposite polarity built 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 below)**

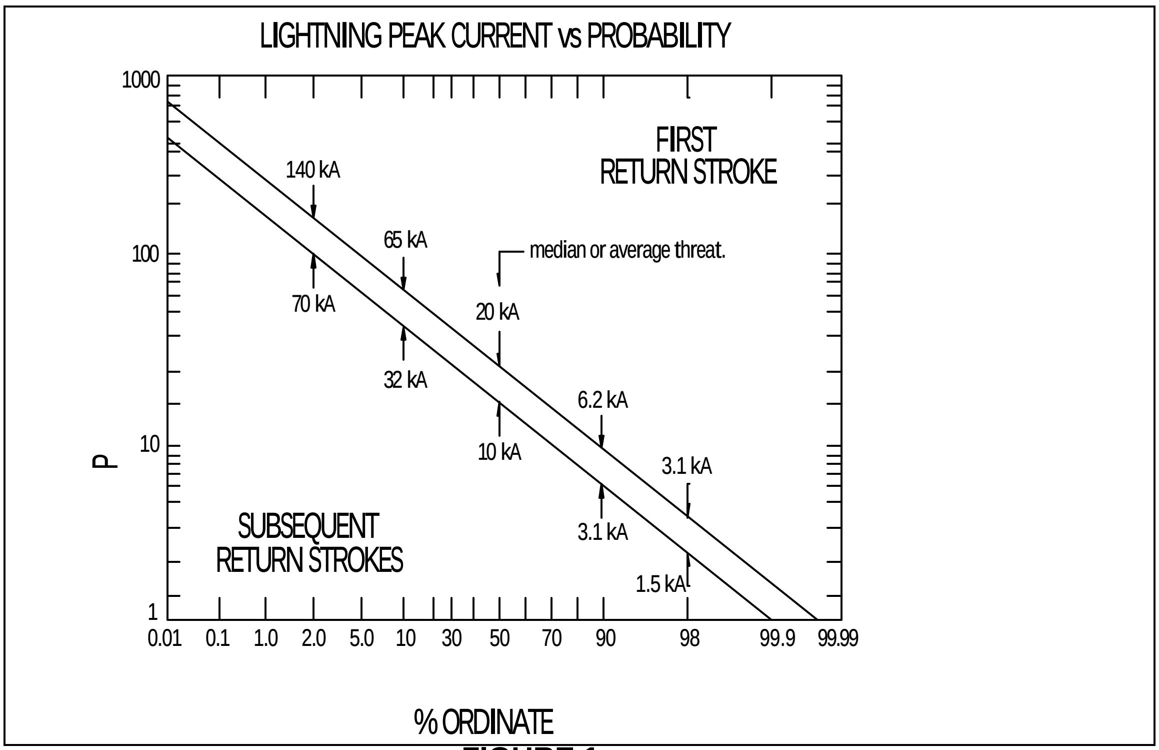

FIGURE 1

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 below)**

MEDIUM STRIKE			
Distance to Strike		**Vertical**	**Induced Voltage**
Km	**Miles**	**E Field, VM**	**in 1 M (39”) of Wire**
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” - 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 strange behavior and 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 below)**

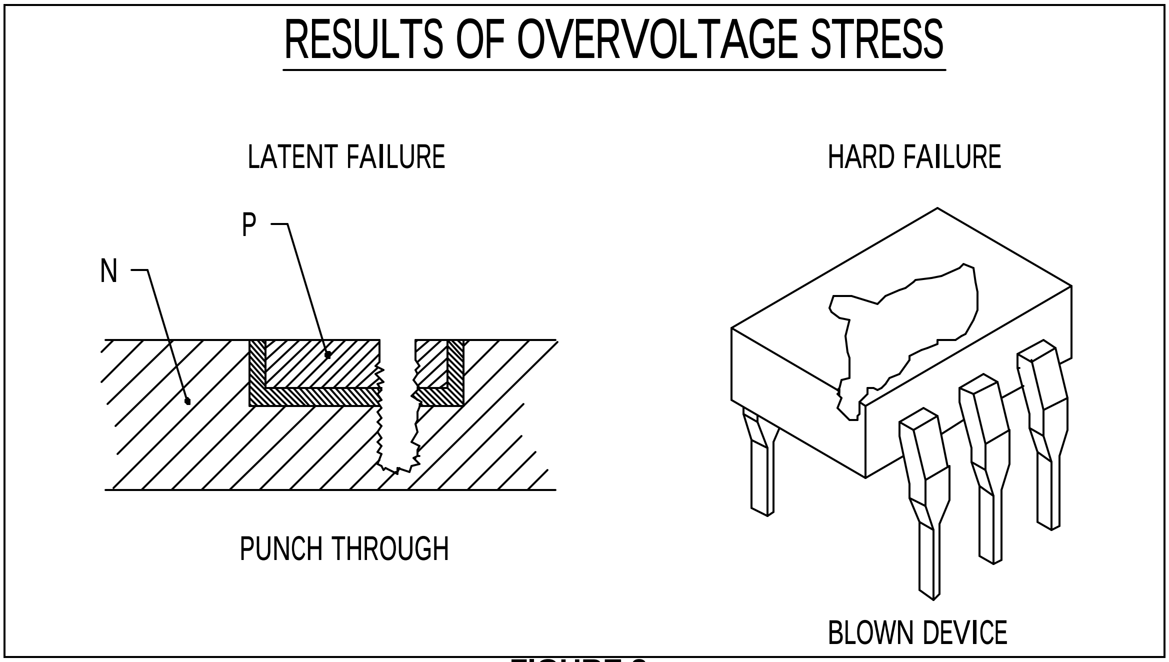

FIGURE 3

III. 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 sometimes 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 below 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.

<u>Key features are:</u>

- 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 @ 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 with-in 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.

2. DEVICE DESIGN

Figure 5 below depicts common discrete devices that are used for TVSS applications.

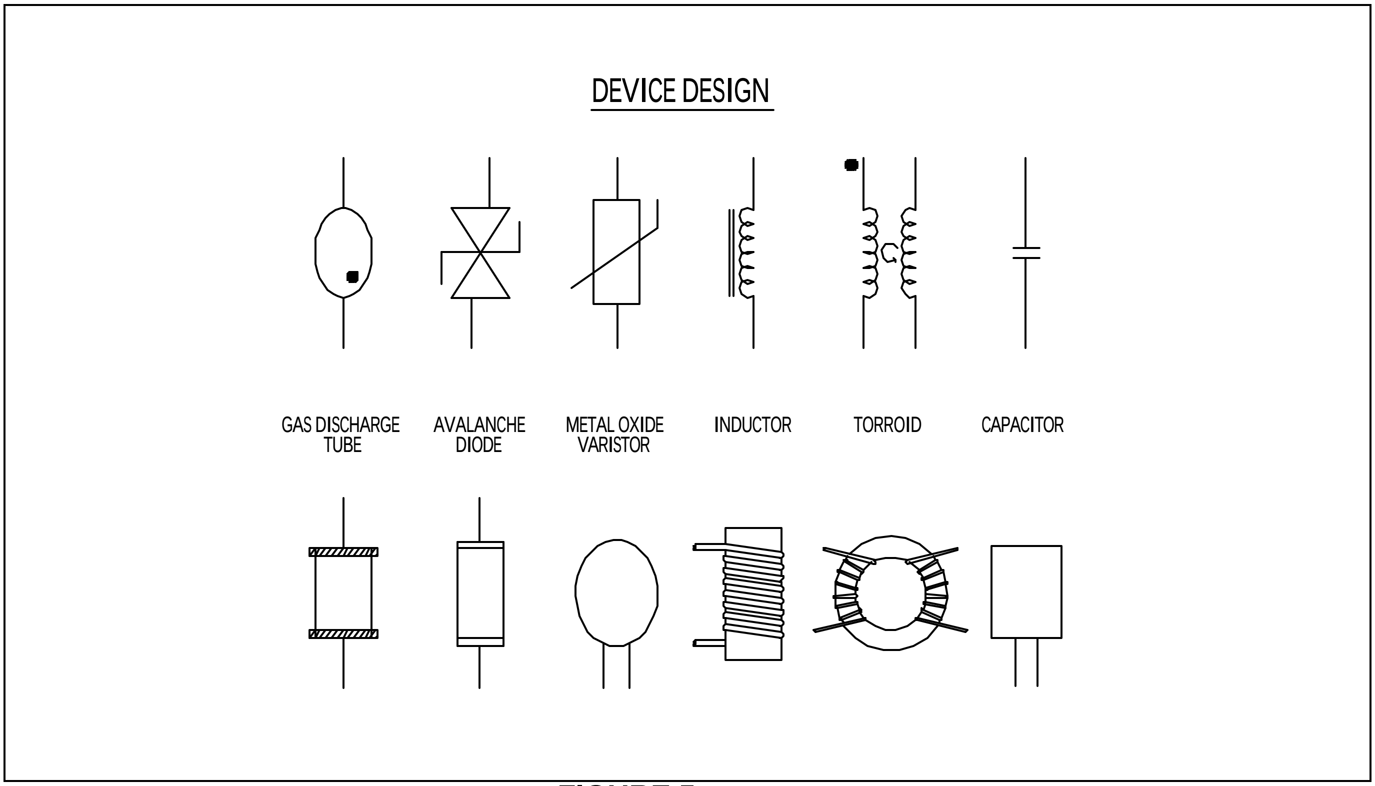

FIGURE 5

Figure 6 below depicts desirable properties for TVSS devices.

HYBRID DEVICE PROPERTIES

Desirable Properties of TVSS (SPD) Devices

- Negligible effect on the system during normal operation (insertion Loss)
- Good clamping of voltage in all modes
- Lightning rated SPD will not fall
- Fast Response
- No routine maintenance
- Compact package size designed for proper environment
- Protection against continuous overvoltages can be specified
- Low "let-through" or remnant voltage
- Excellent connector and mounting selection
- Low leakage current and capacitance
- Long life design
- Cost effective
- "Fail-safe" design

FIGURE 6

Figures 7 and 8 below depict common hybrid designs that are used for TVSS applications.

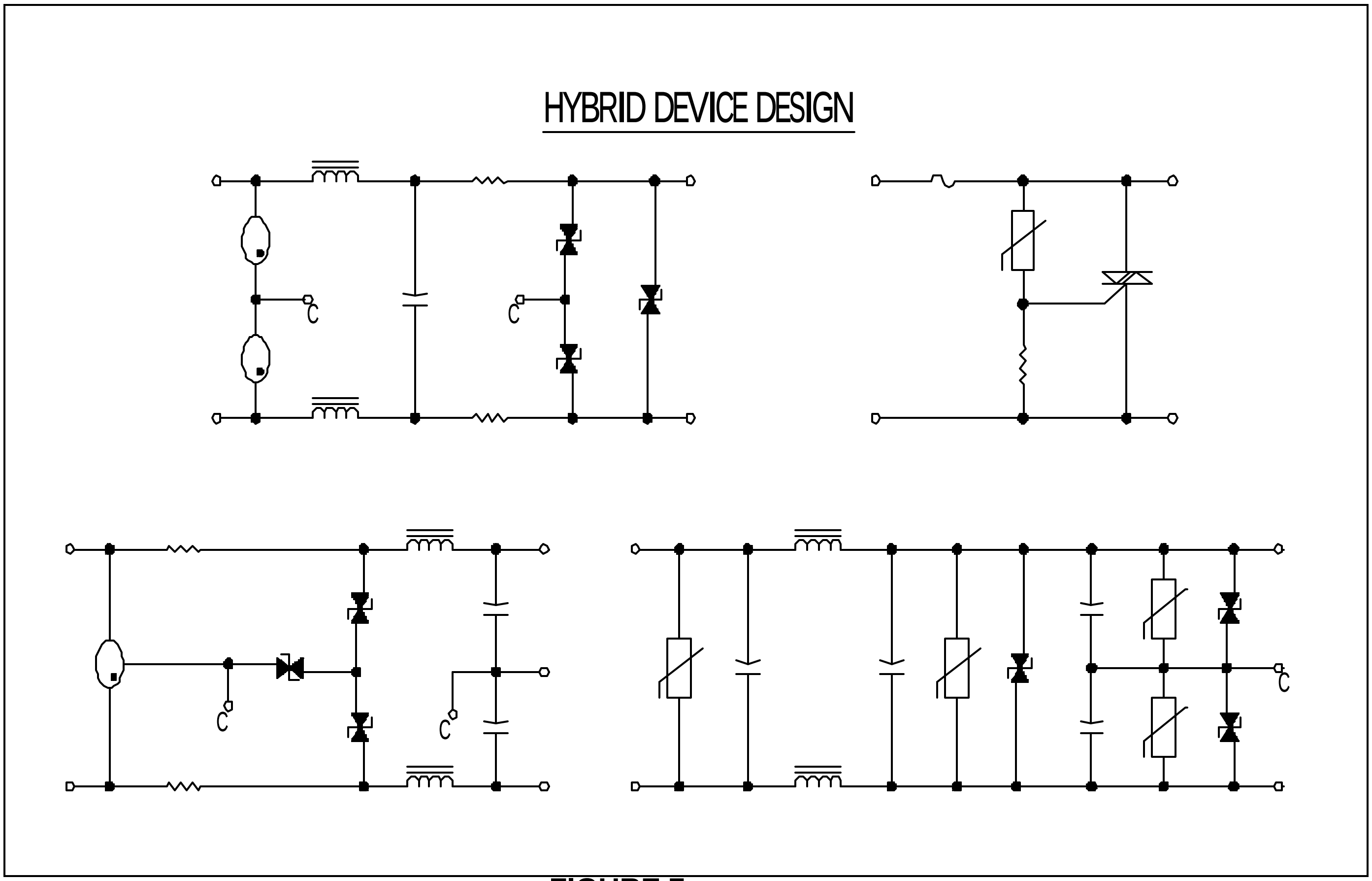

FIGURE 7

Note that in multistage designs one or several in-line impedance devices may be used (Resistor, fuse, resettable fuse, inductor, torroid, etc.). Stage one is designed to take the main power surge while secondary stages clamp or limit let-through voltage to a level below the failure threshold of protected equipment.

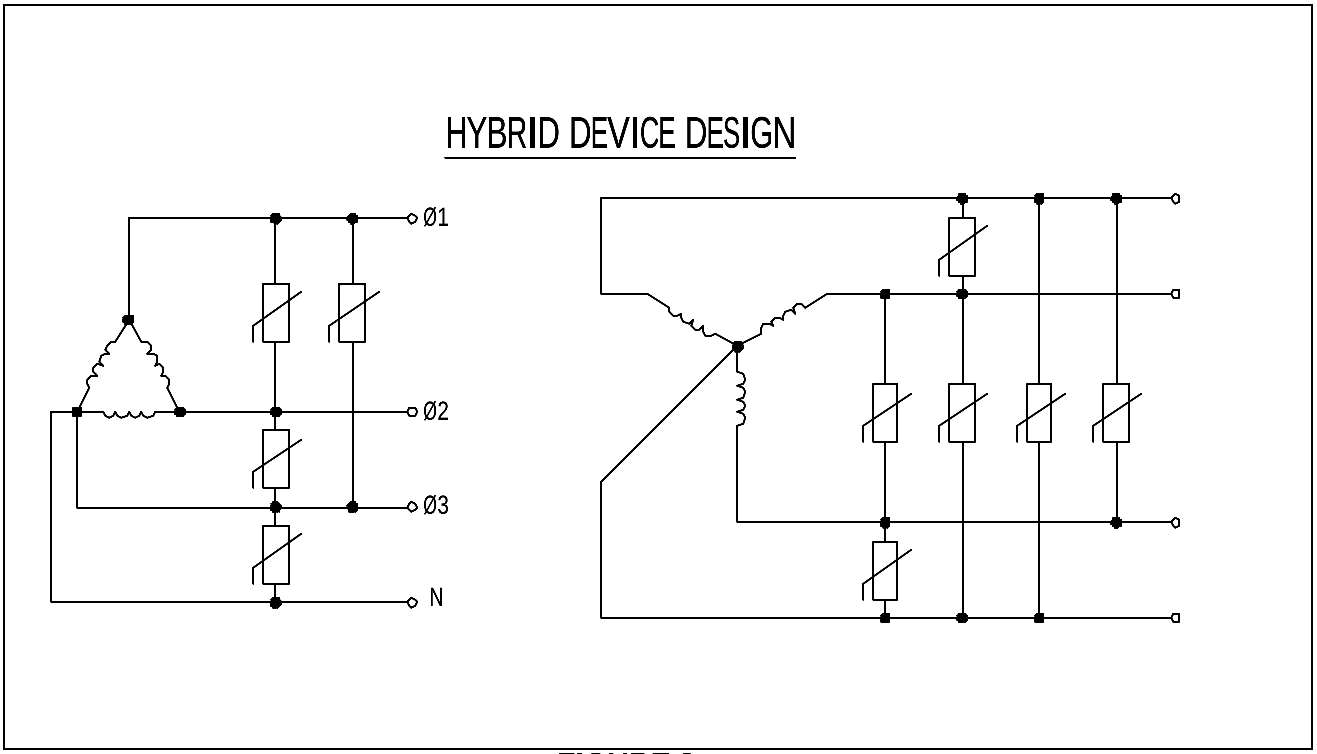

FIGURE 8

Designs available are quite numerous and often made more complex by adding sophisticated filtering and detection circuits.

For high-speed data and Telco applications, components and layout must be chosen with care to avoid “loading” the lines. Low capacitance devices and steering circuits must be used while giving consideration to insertion loss as well as source/load impedance values.

IV. 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 9 below)**

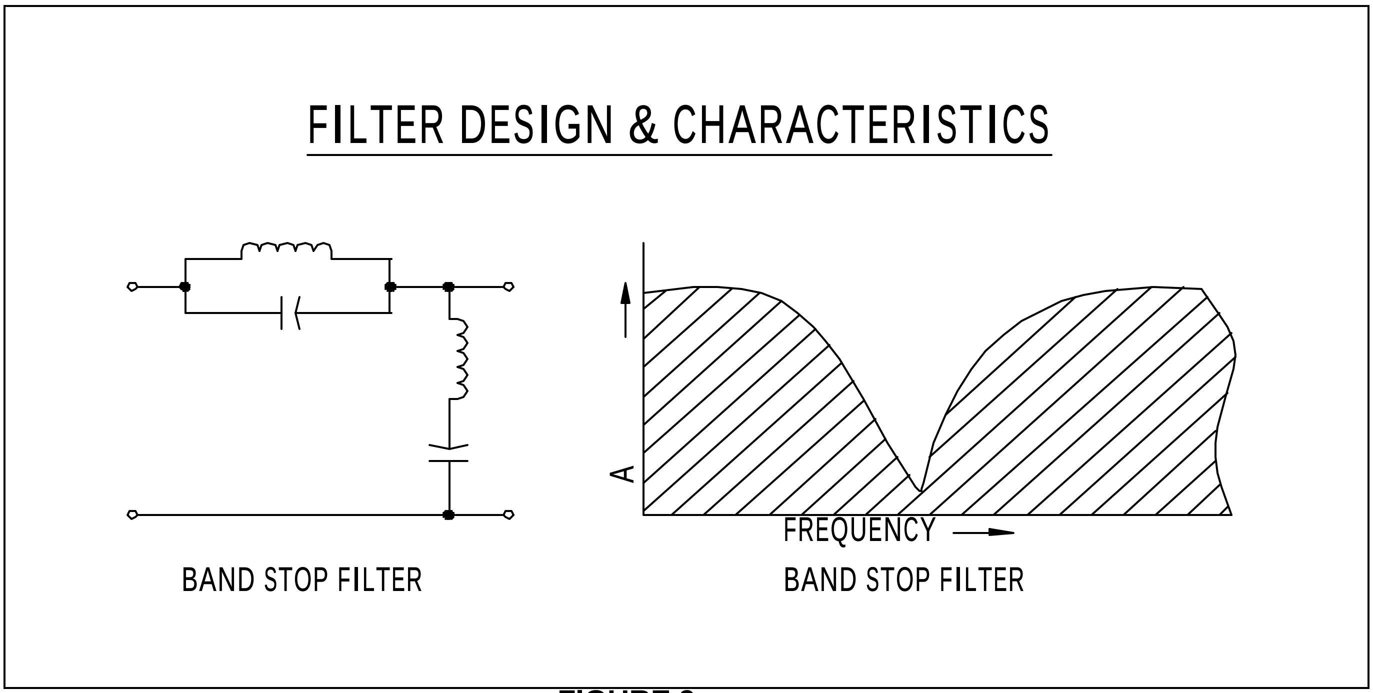

FIGURE 9

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 F.

Figure 10 below shows a series resonant circuit and a parallel resonant circuit

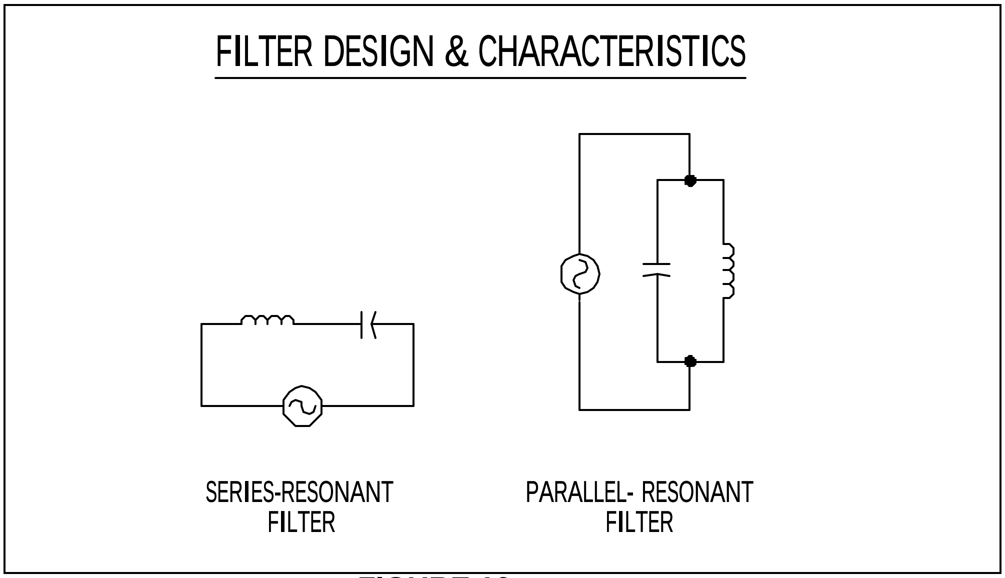

FIGURE 10

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

$$Q_L = \frac{X_L}{R} = \frac{2\pi f L}{R}$$

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

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

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

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 11 below**).

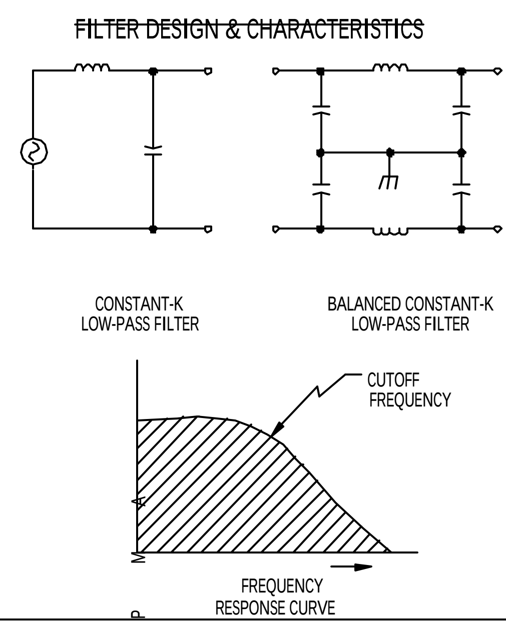

FIGURE 11

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 H, C = capacitance in F, 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 12, 13)**

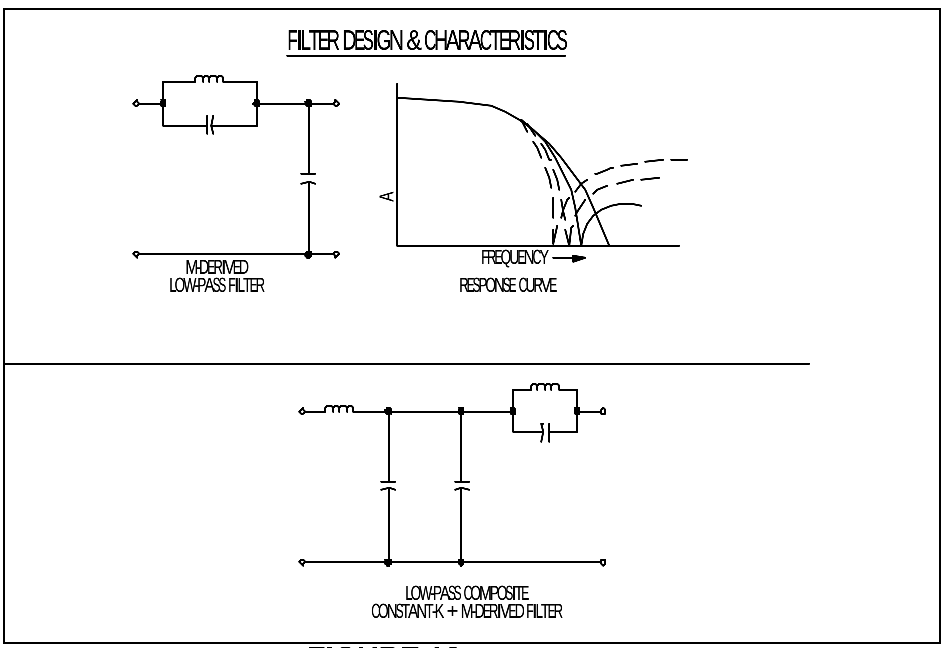

FIGURE 12

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 14 below)**

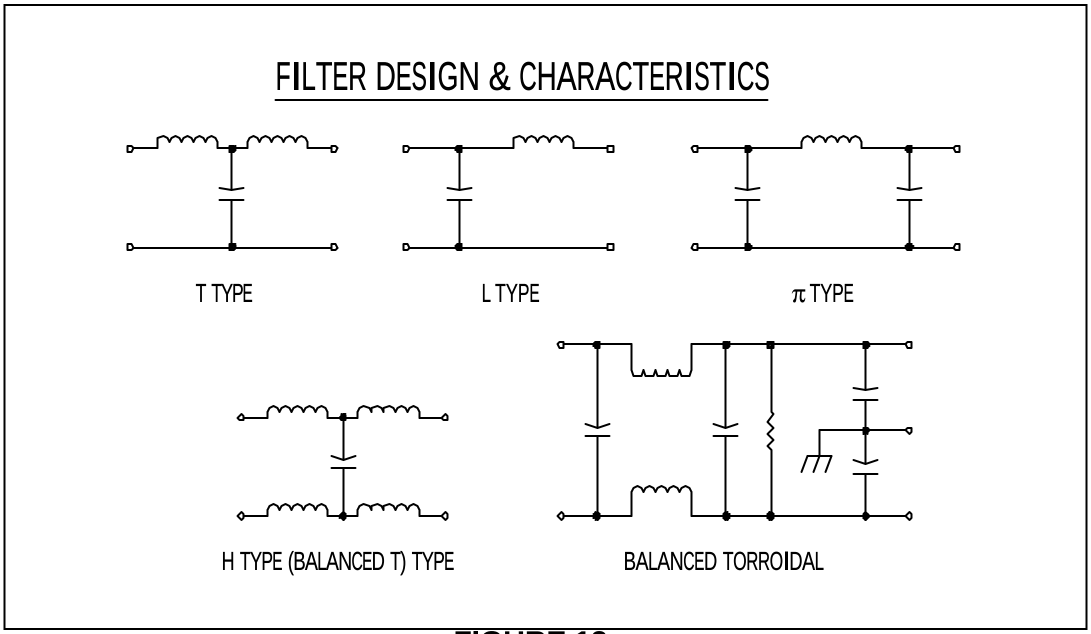

FIGURE 13

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.

V. TERMINOLOGY AND DEFINITIONS

Surge Suppression Terms Defined by Common Usage

INDUSTRY TERMS

- Breakdown
- Clamping Voltage
- Let-through Voltage (remnant)
- Suppressed Voltage
- Joule Rating
- Protection Modes
- Operating Line Voltage
- Response Time
- Leakage
- Surge Current
- Surge Voltage

FIGURE 14

Blackout: Extended zero voltage conditions caused by lightning, generator failure, transformer failure, and ground faults.

Breakdown Voltage: Voltage at which active device conduction begins.

Brownout: Long term undervoltage caused when peak demand exceeds generating capacity.

Capacitance: Capacitance between two terminals measured at specified frequency and bias.

Category or Zone Protection: Category A: long branch circuit (more than 30 feet from a category B location). Category B: Major feeders and short branch circuits (distribution panels, industrial bus/feeder, heavy equipment service location) Category C: outside service entrance (main service panel and overhead lines to separate structures).

Clamping Action Turn-On: Threshold voltage at which the suppression device starts to conduct or turn-on. Protection starts at this level; however true protection is specified by the maximum clamping voltage.

Clamping Voltage: usually the same as "suppression voltage". "Caution"; however, some companies (Not Surge Control) use the term to mean the breakdown voltage at very low current levels (1 milli-Amp). Be certain performance specs state current/voltage waveforms and values.

Combination Wave: Use of the ANSI/IEEE waveforms of open circuit surge voltage and short circuit current.

D.C. Holdover Voltage The maximum D.C. voltage across the terminals of a GDT that will allow the GDT to clear and restore its state of high impedance within 150 ms or less after a surge.

DC Sparkover: Static sparkover or "striking voltage" is the voltage at which the GDT fires when the electrode voltage increases slower than 100v/ms.

Discharge Current: Maximum peak current or transient current at specified waveform (with line voltage applied) without causing device failure.

E Field: Electrical field usually expressed in volts per meter generated by an electromagnetic pulse.

EMI/RFI: (Electro Magnetic Interference / Radio Frequency Interference) Inductive or Radio Frequency electrical noise commonly occurring which can create erratic behavior in electronic circuits.

EMI/RFI Noise Rejection: Most suppressors are poor filters of EMI/RFI noise. This is because if any filtering is added it is just a capacitor and then usually an inexpensive and ineffective one with high ESR value (Internal Impedance at RFI levels or poor dv/dt response). A few companies like Surge Control offer true balanced multi-section networks designed for filtering.

Expected Life: Number of years of expected service based on probable exposure to known electrical stress. Usually lightning activity since this is the worst case threat.

Fail-Safe: A provision within the suppressor that protection is not lost should the suppressor fail. Most Surge Control designs fail short thus removing the equipment from service either by tripping a breaker or fuse or shorting the signal. All of Surge Control's non-shorting shunt models have failure indication or optional alarm.

GDT: Gas discharge tube, sometimes called a spark gap - See Section III.

Glitch: A transient overvoltage.

Impulse Sparkover: Dynamic sparkover or "dynamic striking voltage" is the voltage at which the GDT fires when the electrode voltage increases at a rate exceeding 100 V/ms. As the rise time of the applied voltage increases, the dynamic striking voltage increases.

Joule Rating: Peak energy rating at 10/1000us waveshape applied (along with rated rms voltage) without causing device failure. The higher the joule rating the longer the expected life of the device. In some devices, joule rating will effect clamping voltage performance.

Latent Failure: Damaging electrical overstress (transients) can cause upset or go undetected yet degrade electronic equipment. A known phenomenon where equipment that has been exposed to electrical overstress typically fails within 6 months. Generally components within damaged equipment continue fail at an unpredictable rate.

L-G: Line to Ground.

L-N: Line to Neutral.

Maximum Operating Voltage: Maximum system operating voltage that may be connected to the suppressor.

Maximum Transient Current: Maximum current (see Surge Current) that may be applied to a device at a specified waveform.

Maximum Transient Voltage: Maximum Voltage (see Surge Voltage) that may be applied to a device at a specified waveform.

Modes of Protection: Common mode means lines (inputs or outputs) compared to ground. Normal (Differential or transverse) mode means across the lines of input or output. For AC circuits, Surge Control protects all modes: Line to Ground, Line to Neutral, and Neutral to Ground.

MOV: Metal Oxide Varistor. See Section III.

N-G: Neutral to Ground.

Noise: Various high frequency impulses ranging from a few milli-volts to several volts in amplitude.

Operating Line Voltage: DC voltage or rms voltage normally expected to be applied to a device.

Operating Line Voltage Rating: Maximum continuous sinusoidal rms voltage that may be applied to a device. In the case of DC Voltage, maximum voltage level.

Peak Power: Peak voltage times Peak current. Used to specify maximum power a suppressor will handle in Watts.

Response Time: Sometimes called dv/dt response (change in voltage with respect to time). It is the time it takes a suppressor to sense the leading edge of a wave front and clamp the line to a specified “let through” voltage. Device response and lead inductance should be taken into account.

Reverse Leakage: Current flow through a suppressor in the reverse bias or normal operating circuit configuration. High leakage can shorten life or interfere with protected electronic equipment. Some leakage is necessary in filter designs and will increase as X or Y capacitor values increase.

Reverse Standoff Voltage: The applied reverse voltage to assure a non-conductive condition.

SAD: Silicon Avalanche Diode. Zener diode type characteristics, except designed for high-energy transient suppression. See Section III.

Sag: Short-term undervoltage normally occurring when peak demand exceeds generating capacity can also be caused by lightning when primary gas suppressors fire.

Sine Wave Tracking: ANSI/IEEE, UL and the International Standard IEC do not make recommendations regarding this method of suppression. This is because the peak suppressed voltage (combination of the operating voltage plus suppressed transient) value is the performance criteria for protection. High-speed noise contained within the AC waveform is best eliminated through good filtering design.

Spike: A transient overvoltage.

Suppression Voltage: The maximum peak voltage that will be seen across the active terminals of a suppressor at a specified waveform and source current. It is the "**Let through**" or remnant voltage the suppressor allows to be applied to protected equipment. A key criteria in performance specification.

Suppressed Voltage Rating: Determined through testing by regulatory agency (UL, CSA, VDE, Etc.) or independent laboratory to specifications of ANSI/IEEE, IEC and UL. For permanently connected devices UL performs tests using a combination waveform 3000 Amps/6000 volts. For plug-in or cord connected devices the same combination wave 500 Amps/6000 Volts is applied. A rating is then granted according to performance.

Surge: Greater than 8.3 milli-seconds in duration.

Surge Current: ANSI/IEEE C62.41-1991 provides test waveform recommendations for evaluating surge suppressors. Test waveform is (8 x 20 micro-seconds) 8 milli-seconds rise time from 10% to 90% of crest and 20 micro-seconds from 10% of rise time of crest to 50% of fall (decay) time applied as a current wave into a short circuit.

Surge Voltage: Test ANSI/IEEE C62.41-1991 waveform is (1.2 x 50 microseconds). Rise time of 1.2 microseconds from 30% to 90% of crest and 50 microseconds from 30% of rise to 50% of decay time applied as a voltage wave into an open circuit.

Transient: Less than 8.3 milli-seconds (1/20 second in duration).

TVSS: (Transient Voltage Surge Suppressor) A protective device used on electronic equipment to absorb transient energy before entering the electronics through power, data, communication or ground lines.

VI. STANDARDS AND REGULATORY AGENCIES

After over thirty years of field observation and research, much data has been assimilated to describe the occurrence of transients in AC Power circuits, telecom and telephone lines and data transmission as well as current loop lines. A number of agencies provide excellent guidance in the selection of transient overvoltage (Surge Suppressor) equipment. Exposure levels are well defined and design guidance is readily available.

Users are cautioned to carefully examine performance claims against recommended standards when comparing TVSS devices from various manufacturers.

Reputable manufacturers of surge suppressors rely on published standards and recommendations for design/test guidance. The number of years of field experience is also a valuable criterion in the selection of a device manufacturer.

1. AGENCY

a) Institute of Electrical and Electronic Engineers, Inc. (IEEE)
345 East 47th Street
New York, NY 10017, USA
Approved by American National Standards Institute (ANSI)

2. DOCUMENTS

ANSI/IEEE C37.90.1 1989 Standard surge withstand capability (SWC) tests for protective relays & relay systems.

C62.11-1993 IEEE Standard for Metal-Oxide Surge Arrestors for Alternating Current Power Circuits.

C62.22-1997 IEEE Guide for the Application of Metal-Oxide Surge Arrestors for Alternating-Current Systems.

C62.31-1987 (R1993) IEEE Standard Test Specifications for Gas-Tube Surge-Protective Devices.

C62.35-1987 (R1993) IEEE Standard Test Specifications for Avalanche Junction Semiconductor Surge Protective Devices.

C62.36-1994 IEEE Standard Test Methods for Surge Protectors Used in Low-Voltage Data, Communications, and Signaling Circuits.

C62.38-1994 IEEE Guide on Electrostatic Discharge (EDS): ESD Withstand Capability Evaluation Methods (for Electronic Equipment Subassemblies)

C62.41-1991 (R1995) IEEE Recommended Practice of Surge Voltages in Low-Voltage AC Power Circuits.

C62.42-1992 IEEE Guide for the Application of Gas Tube and Air Gap Arrestor Low-Voltage (Equal to or less than 100 vrms or 1200 Vdc Surge Protective Devices.

C62.34-1996 IEEE Standard for Performance of Low-Voltage Surge Protective Devices (Secondary Arrestors).

C62.37-1996 IEEE Standard Test Specification for Thyristor Diode Surge Protective Devices.

C62.48-1995 IEEE Guide on Interactions Between Power Systems Disturbances and Surge-Protective Devices.

C62.64-1997 IEEE Standard Specifications for Surge Protectors Used in Low-Voltage Data Communications, and Signaling.

3. AGENCY

International Electrotechnical Commission (IEC)
Bureau Central de la Commissions Electrotechnique Internationale

3 rue de varembe'
Gen'eve Suisse

4. DOCUMENTS

555: - Disturbances in supply systems caused by household appliances and similar electrical equipment.

816 (1984) Guide on methods of measurement of short duration transients on low voltage power and signal lines.

1000-1-1 (1992) Part 1: General. Section 1: Application and interpretation of fundamental definitions and terms.

1000-2-1 (l990) Part 2: Environment. Section 1: Description of the environment - Electromagnetic environment for low-frequency conducted disturbances and signaling in public power supply systems.

1000-2-2 (1990) Part 2:Environment. Section 2: Compatibility levels for low frequency conducted disturbances and signaling in public low-voltage power supply systems.

1000-2-4 (1994) Part 2: Environment. Section 4: Compatibility levels in industrial plants for low-frequency conducted disturbances.

1000-4-1 (1992) Part 4: Testing and Measurement Techniques. Section 1: Overview of immunity tests..

1000-4-2 (1995) Part 4: Testing and Measurement Techniques. Section 2: Electrostatic Discharge Tests..

1000-4-4 (1995) Part 4: Testing and Measurement Techniques. Section 4: Electrical Fast Transient/Burst immunity tests.

1000-4-5(1995) Part 4: Testing and Measurement Techniques. Section 5: Surge Immunity Test.

1000-4-7 (1991) Part 4: Testing and Measurement Techniques. Section 7: General Guide on Harmonics and Inter-Harmonics Measurements and Instrumentation for power supply systems and equipment connected thereto.

1000-4-9 (1993) Part 4: Testing and Measurement Techniques. Section 9: Pulse Magnetic Field Immunity Tests..

5. AGENCY LISTING

a) Canadian Standards Association (CSA)
Standards Division
178 Rexdale Boulevard
Rexdale, Ontario, Canada M9#1R3

b) Underwriters Laboratories Inc.
1655 Scott Blvd

Santa Clara, CA 95050-4159
408-985-2400

c) UL 1449 Second Edition (Transient Voltage Surge Suppressors)
UL 1440 Telephone Apparatus
UL 497A Surge Immunity
UL 498 Hospital Grade High Abuse Standards

d) National Archives and Records Administration
Office of the Federal Register
US Government Printing Office
Washington DC 20402
Title 47 Part 15 Radio Frequency Devices
Title 47 Part 68 Connection of Terminal Equipment to Telephone Network

e) Asociacion Nacional de Normalization y Certification del Sector Electrico A.C. (NOM-ANCE)
Insurgentes Sur 664 3er Piso
Col. Del Valle
03100 Mexico D.F.
Phone: 011-525-227-1110
Fax: 011-525-227-1177

6. AGENCY CODES

a) **National Electrical Manufacturers Association (NEMA)**
Enclosure Types for Atmospheric Protection (Most Common)

b) **Applications (NEMA)**

Type 1	Indoor use limited	Falling dirt.
Type 2	Indoor use limited	Falling water and dirt.
Type 3	Outdoor use	Rain, sleet, windblown dust, external ice.
Type 3R	Outdoor use	Falling rain, sleet, and external ice formation.
Type 3S	Outdoor use allow operation device when ice laden.	Rain, sleet, windblown dust, of external
Type 4	Outdoor use	Windblown dust & rain, splashing water, hose directed water, external ice formation.
Type 4X	Outdoor use	Corrosion, windblown dust & rain, splashing water, hose directed water and external ice.
Type 5	Indoor use	Airborne dust, falling dirt, dripping non-corrosive liquids.
Type 6	Outdoor use	Hose directed water, temporary submersion at limited depth, external ice.
Type 6P	Outdoor use	Hose directed water, prolonged submersion at limited depth, external ice.

Type 7	Indoor use	Class I.
Type 9	Indoor use	Class II.
Type 12	Indoor use	Dust, falling dirt, dripping non-corrosive liquids.
Type 12K	Indoor use	Knockouts, circulating dust, falling dirt, dripping non-corrosive liquids.
Type 13	Indoor use	Dust, spraying water, oil, non-corrosive coolants.
Class I	Gases & vapors	Division 1 Normally hazardous.
Class II	Combustible dusts	Division 1 Normally hazardous.
Class III	Easily ignitable fibers and fillings.	
Division 1 & 2	Hazardous.	
Division 2 of Class I & II	Not normally hazardous.	

c) **Conversion of NEC Types to IEC Classification**

NEMA type	IEC Classification (Ingress Protection)
1	IP-10
2	IP-11
3	IP-54
3R	IP-14
3S	IP-54
4, 4X	IP-56
5	IP-52
6,6P	IP-67
12, 12K	IP-52
13	IP-54

7. CERTIFICATION AGENCIES

UL	Underwriters Laboratories, Inc.
CSA	Canadian Standards Association
ANCE	National Association of Normalization and Certification of Electrical Sector
TUV	TUV Rheinland of N.A., Inc.
VDE	Verband Deutscher Elektrotechiker
BSI	British Standards Institute
FM	Factory Mutual
NRTL	National Recognized (by OSHA) Testing Laboratory.
NOM-ANCE	Association Nacional de Normalizacion y Certification del Sector Electrico A.C.

8. STANDARDS DEVELOPMENT ORGANIZATIONS

IEC	International Electro-technical Commission
IEEE	Institute of Electrical and Electronics Engineers, Inc.
ANSI	American National Standards Institute
CANENA	Consejo de Armonizacion de Normas

ISA	Instrument Society of America
ISO	International Standards Organization
BSI	British Standards Institution (United Kingdom)
IMQ	Instituto Italiano del Marchio di Quality (Italy)
MITI	Ministry of International Trade & Industry (Japan)
SEMKO	Svenska Elektriska Material Kintrollanstalten (Sweden)
VDE	Verbank Deutscher Elektrotechniker (Germany)
CENELEC	European Community for Electrical Standarization (generates documents called "European Noyns" (EN)

VII. 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 15 below)**

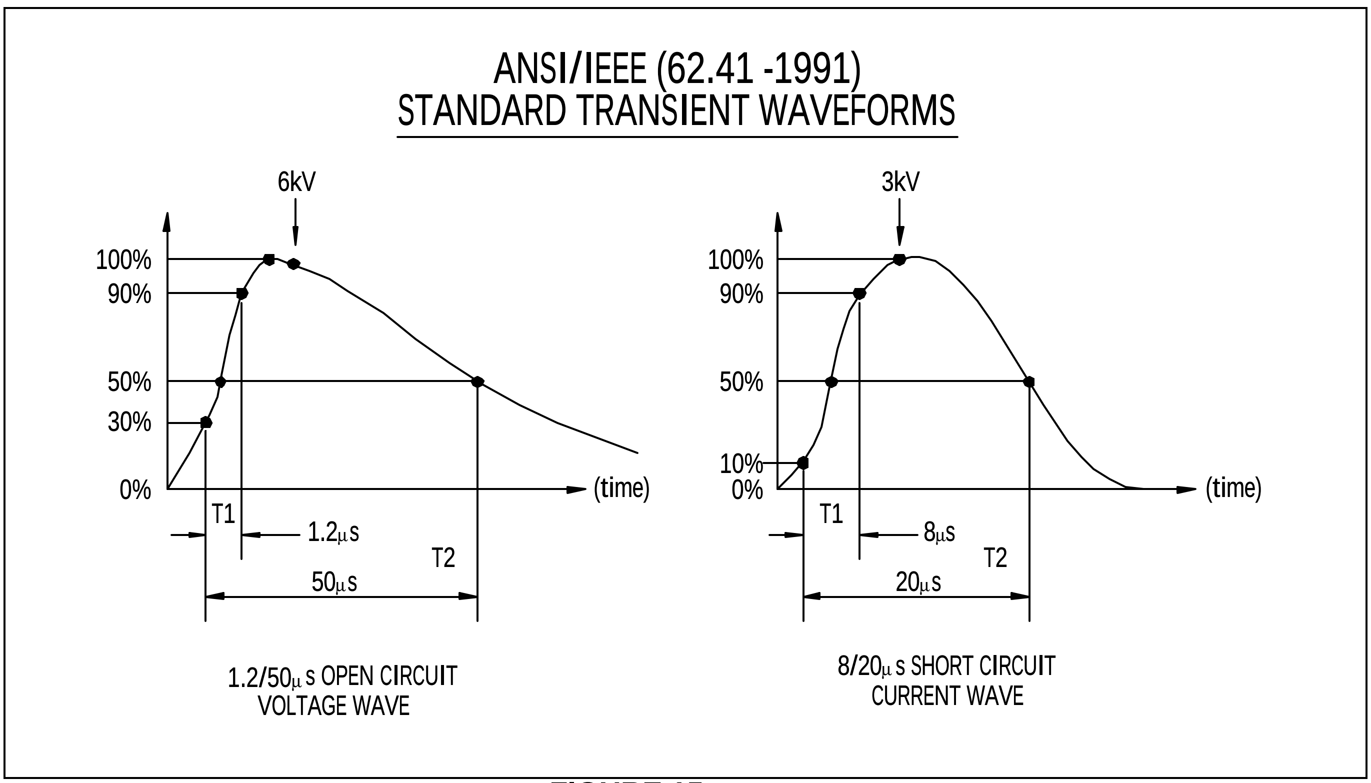

FIGURE 15

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 16 below** 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 16 below** shows an Electrical Fast Transient/Burst train (Referenced in IEC 1000-4-4 1 1989).

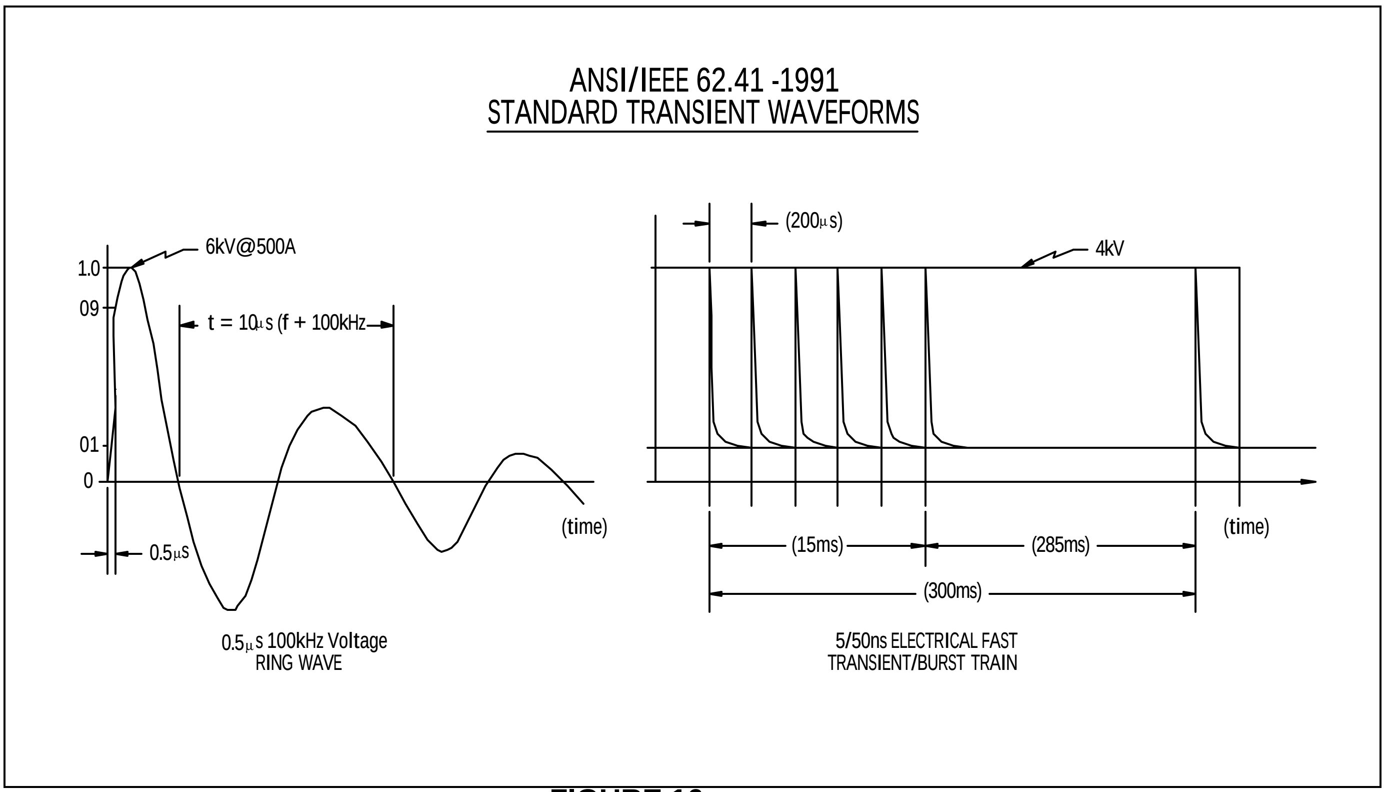

FIGURE 16

Additional waveforms referenced on ANSI/IEEE C37.90.1-1989 are shown on **Figures 17 and 18 below.**

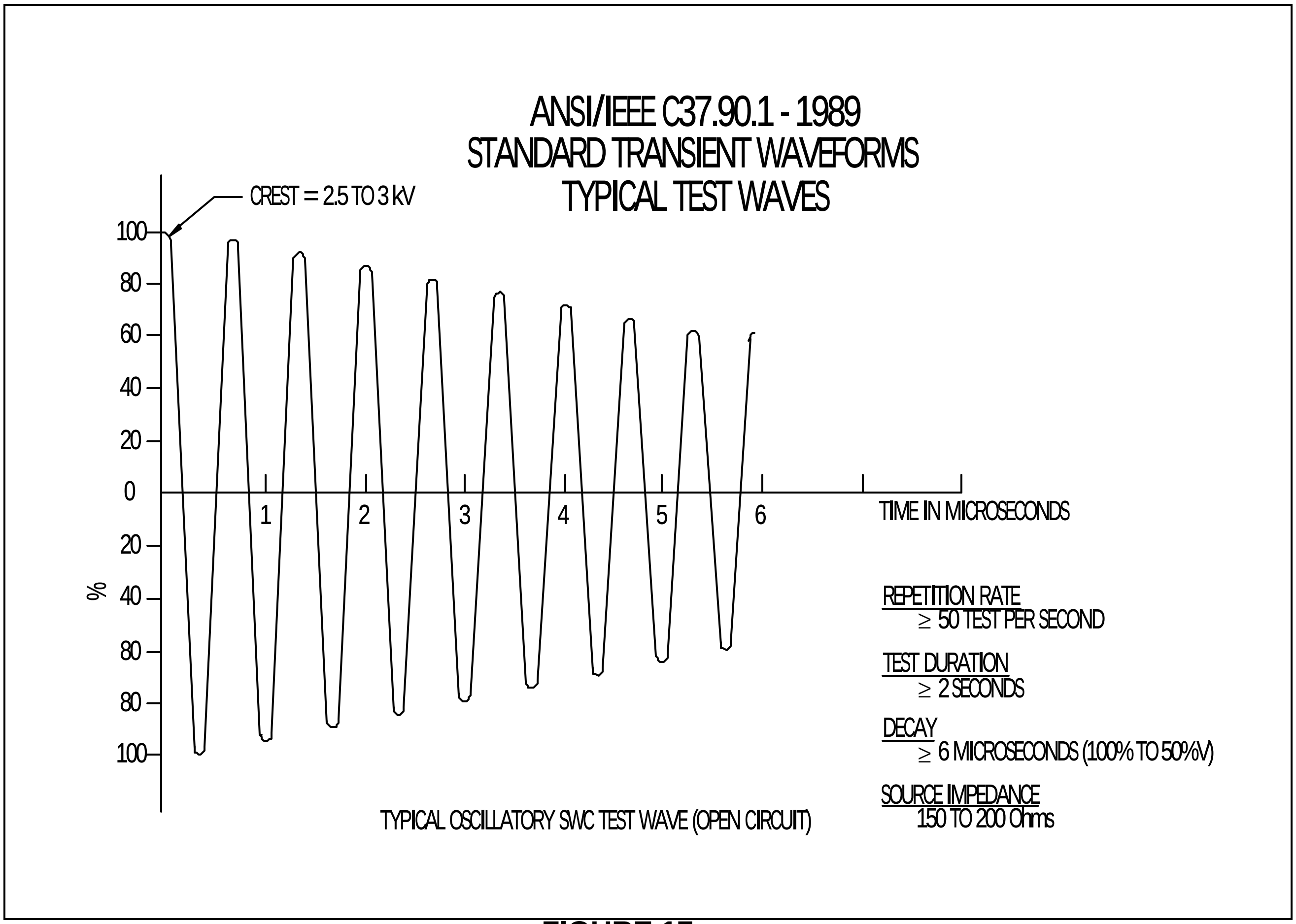

FIGURE 17

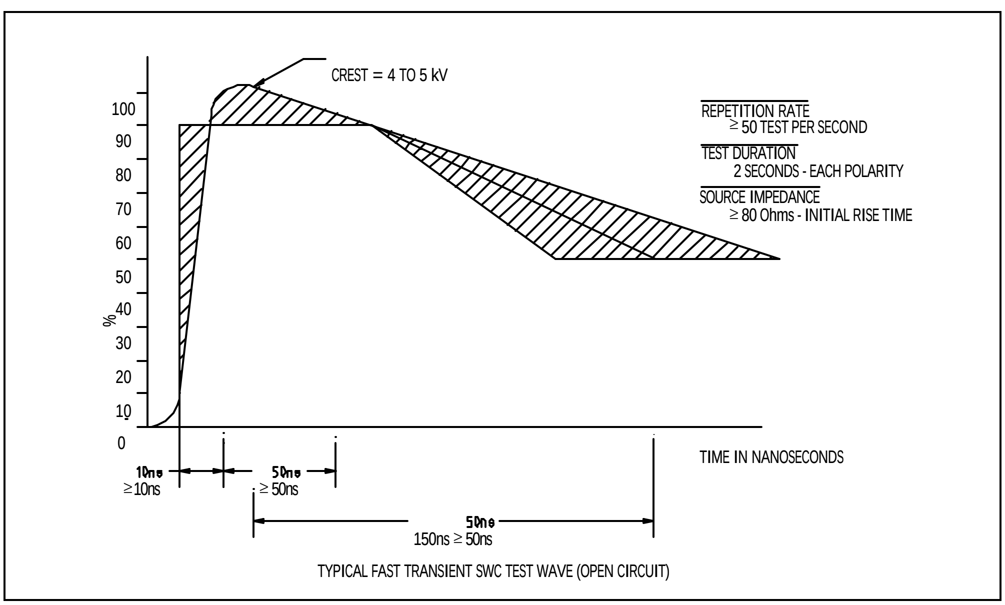

FIGURE 18

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

Threat levels as defined by IEE are shown in **Figure 19.**

IEE 1000-4-5 1995 Surge Immunity

Installation Class	Test Levels in kV							
	Power Supply		Unbalanced Circuits/Lines, LDB		Balanced Circuits/Lines		SDB, DB[1]	
	line to line	line to line	line to line	line to line	line to line	line to line	line to line	line to line
0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1	N/A	0.5	N/A	0.5	N/A	0.5	N/A	N/A
2	0.5	1.0	0.5	1.0	N/A	1.0	N/A	0.5
3	1.0	2.0	1.0	2.0[3]	N/A	2.0[3]	N/A	N/A
4	2.0	4.0[3]	2.0	4.0[3]	N/A	2.0[3]	N/A	N/A
5	[2]	[2]	2.0	4.0[3]	N/A	4.0[3]	N/A	N/A

1) Limited distance, special configuration, special layout, 10 m to max. 30 m.
2) Depends on the class of the local power supply system.
3) Normally listed with primary protection

DB data bus (data line)
SDB short-distance bus
LDB long-distance bus
NA not applicable

The surges (and test generators) related to the different classes are as in the following:

Classes 1 to 4: 1.2/50 µs (8/20µs).

Class 5 1.2/50 µs (8/20 µs) for ports of power lines and short-distance signal circuits/lines.
(10/700 µs) for ports of long-distance signal circuits/lines.

FIGURE 19

Threat levels as defined by IEC are shown in **Figure 20.**

IEC 1000-4-4 Electrical Fast Transient

Open-circuit output test voltage (+/- 10%) and repetition rate of 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	5.0	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 installation environment (e.g., industrial process equipment, power plants).

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

FIGURE 20

Threat levels as defined by ANSI/IEEE are shown in **Figure 21 and 22 below.**

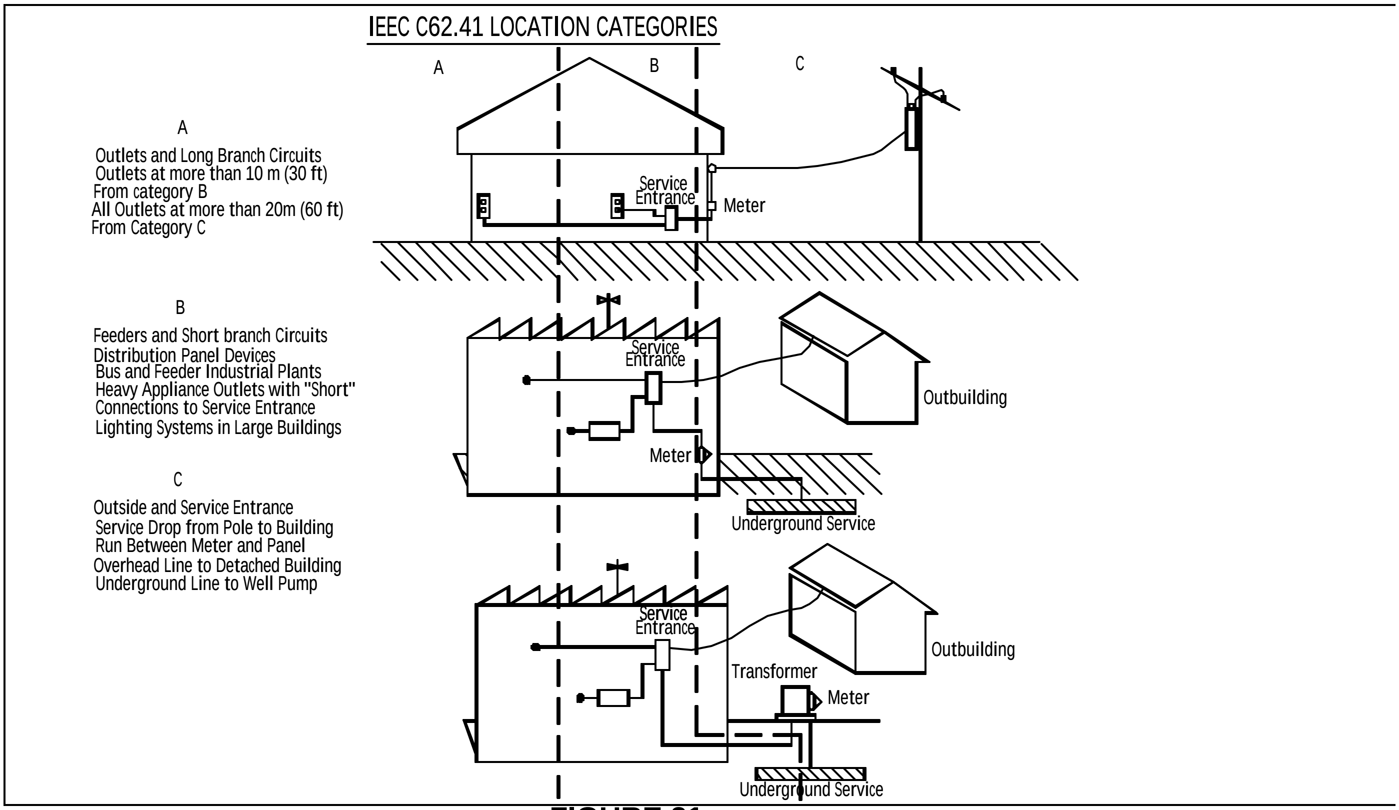

FIGURE 21

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 22