# Why use surge protection?

Surge protectors protect personnel and equipment from damaging high-voltage surges from lightning, inductive switching, nuclear electromagnetic pulse, electrostatic discharge, or interference from power supply lines.

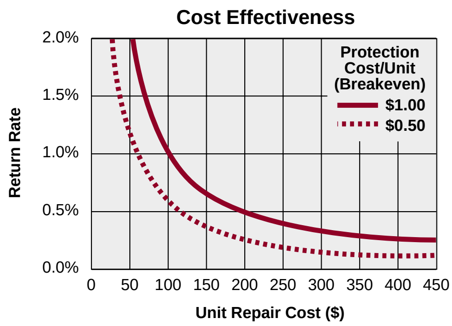
From a design point of view, protection circuits only cost money and, if customer requirements or regulatory agencies do not require them, they will easily be forgotten. Yet, appropriate surge protection is beneficial. Protected equipment will not be affected by the high-voltage surges listed above. This will result in

- Reduced field failures
- Improved product quality and reliability
- Reduced cost of quality

The figure below illustrates the cost effectiveness of adding surge protection by demonstrating the unit repair cost to break even over a range of return rates for added protection costs of $0.50/unit and $1.00/unit:

Through ongoing research and engineering improvements, Clare has developed a family of Surge Protection Products that offer impressive characteristics for a variety of applications. Four differentiating characteristics are found in every Clare Surge Protection Product:

- High surge current rating
- Long life
- Fast response
- Rugged construction



# A Comparison of Surge Arrester Technologies

**COMGAP GAS DISCHARGE TUBE ■ AIR GAP ■ CARBON BLOCK ■ SCR ■ ZENER DIODE ■ MOV**

In today's world of sensitive electronics, an increasingly important topic has become the protection of electronic components from overvoltage surges. There is a multitude of devices on the market for this purpose but what are the differences between them and which is best for what application? The following describes, analyzes, and compares these devices in detail.

Basically there are two types of surge protection classifications with each consisting of its own group of devices:

CROWBAR
- Air Gap
- Carbon Block
- Gas Discharge Tube (GDT)
- Silicon Controlled Rectifier (SCR)

CLAMP
- Zener (Avalanche) Diode
- Metal Oxide Varistor (MOV)

## CROWBAR PROTECTION

A crowbar device limits the energy delivered to the protected circuit by abruptly changing from a high impedance state to a low impedance state in response to an elevated voltage level. Having been subjected to a sufficient voltage level the crowbar begins to conduct. While conducting, the voltage across the crowbar remains quite low (typically less than 15 volts for gas discharge tubes usually higher for the air gap and carbon block protectors) and thus, the majority of the transient's power is dissipated in the circuit's resistive elements and not in the protected circuit nor the crowbar itself. This allows the crowbar to be able to withstand and protect loads from higher voltage and/or higher current levels for a greater duration of time than clamping devices.

## AIR GAP PROTECTOR

An air gap protector consists of two conductive surfaces with a spacing between them that will permit an arc when a specified potential is placed across the surfaces. The air gap is not a sealed device and therefore it must operate at atmospheric pressure and under the effects of the environment. Since the electrodes are exposed to the environment, they will often experience oxidation and corrosion which is not a problem common to a gas tube such as Clare's Comgap. These factors contribute to the air gap's high nominal breakdown voltage, wide breakdown voltage tolerance, and poor impulse response. Often an air gap is placed in parallel with a gas discharge tube or carbon block protector to provide back up protection in the event that the primary protection fails.

## CARBON BLOCK PROTECTOR

A carbon block protector consists of a pair of carbon elements separated by a 0.003-0.004 inch air gap. When a specified potential is placed across the carbon surfaces an arc will be initiated. Like the air gap protector, the carbon block is an unsealed device and its performance suffers in the same manner as the air gap. Carbon block protectors are used mainly for telephone line protection but are being replaced, in most installations, with the more reliable and consistent gas discharge tubes.

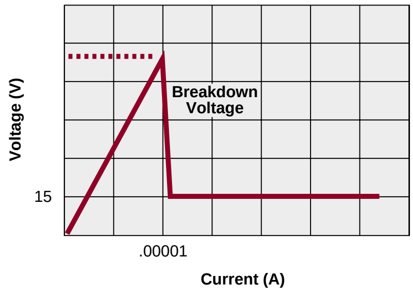
## Comgap GAS DISCHARGE TUBE

Clare's Comgap, a hermetically sealed gas filled ceramic tube with metal electrodes, is recognized for:

- Stable electrical parameters
- High insulation resistance
- Low capacitance
- High current capability
- Low leakage current
- Low arc voltages

For a gas tube to begin conduction, an electron within the sealed device must gain sufficient energy to initiate the ionization of the gas. Complete ionization of the gas takes place through electron collision. The events leading up to this phenomenon occur when a gas tube is subjected to a rising voltage potential. Once the gas is ionized, breakdown occurs and the gas tube changes from a high impedance state to a virtual short circuit and thus, any transient will be diverted from and will not reach the protected circuit. The arc voltage (the voltage across the gas tube while the gas tube is conducting) will typically be 15 volts. After the transient has passed, the Comgap will extinguish and again appear as an open circuit. In order to insure gas tube turn off at the zero crossing in AC applications, the current through the Comgap once the transient has passed, must be less than the follow-on current rating of the gas tube. The follow-on current requirement can easily be met by placing a resistor in series with the gas tube. Clare's AC series of gas discharge tube surge arresters were developed specifically to protect AC power lines and normally will not require additional components to limit follow-on current. In DC applications, the gas discharge tube will extinguish as long as the device is operated within the specified holdover conditions. Holdover conditions involve the maximum bias voltage that can appear across a gas discharge tube under specified current conditions and still allow the gas discharge tube to turn off. Under normal operating conditions, the Comgap shunted across a circuit, will act like an open switch with a high insulation resistance.

**Comgap Gas Discharge Tube Voltage vs. Current Characteristics**



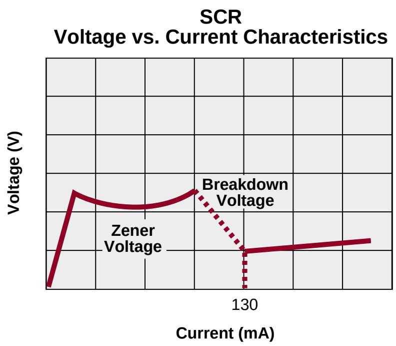

The Comgap's breakdown voltage is determined by electrode spacing, gas type (usually neon and/or argon), gas pressure (less than atmospheric), and the rate of rise of the transient. Breakdown voltage is defined as that voltage at which a crowbar type of surge arrester changes from a high impedance state to a low impedance state. The Comgap series is categorized by the breakdown voltage of each gas tube when a slowly rising transient is applied. For example: Clare's CG2-230L gas tube will breakdown at 230V (+/- 15%) when subjected to a ramp with a rate of rise of 500V/second. The breakdown voltage response of a crowbar to transients with ramp rates of 1V/microsecond or less is referred to as the DC breakdown voltage level. Due to the nature of gas discharge tubes, the same gas tube will experience breakdown at a higher voltage as a transient's ramp rate increases. For example: At 100V/microsecond, the CG2-230L gas tube will breakdown at 600V maximum. The breakdown voltage response of a crowbar to transients with ramp rates greater than 1V/microsecond is referred to as the impulse breakdown voltage level.

Due to the Comgap's rugged construction, it can handle currents that far surpass other transient suppressors' capabilities - greater than 10 pulses of a 20,000 peak amperes pulse having a rise time of 8 microseconds decaying to half value in 20 microseconds (also referred to as an 8/20 wave form). The surge life of the Comgap is at least 1000 shots of a 500 amperes peak 10/1000 pulse. Because it is being used in a repetitive switching application, the ETS series Comgap has been designed for surge life greater than 100,000 shots. With a maximum inter-electrode capacitance of 1 picofarad, the Comgap can easily be designed into RF circuits. The Comgap is the practical device for the protection of telephone circuits, AC power lines, modems, power supplies, CATV and almost any application where protection from large and/or unpredictable transients is desired.

## SILICON CONTROLLED RECTIFIER (SCR)

Unlike the crowbar devices discussed above, the SCR is a semiconductor. Like the Comgap, the SCR will have a very low voltage drop across it while conducting. The SCR does require a trigger signal when a surge is present before it can begin to conduct. This trigger signal is usually supplied through the use of a zener diode. Packages that combine the SCR and zener diode are now available. These packages are monolithic devices and often contain an SCR-type thyristor with a gate region that acts like the avalanche diode. Once triggered, the SCR begins to conduct, dropping the voltage across the zener diode to a value below the zener's operating voltage and thus causing the zener to stop conducting. The SCR will conduct until the applied voltage drops to zero (zero crossing of AC) or until the current falls below a specified value (sometimes referred to as a holding current).

# A Comparison of Surge Arrester Technologies




Although typically having a faster response time than a GDT, the SCR package is subject to higher leakage current and capacitance. The SCR package can handle currents of several hundred amperes of an 8/20 wave form and packages are available that offer bi-directional protection.

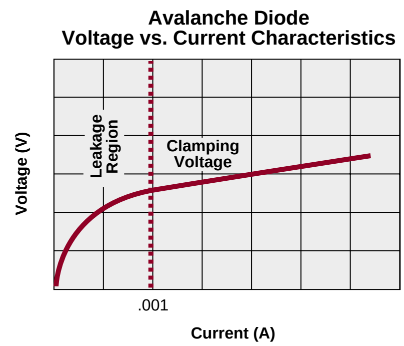
## CLAMPING PROTECTION

A clamping device actually limits the voltage transient to a specified level by varying its internal resistance in response to the applied voltage. A clamping device must absorb the transient's energy and therefore, cannot withstand very high current levels. Although these devices have quick response times, they are subject to leakage currents and their capacitance values are higher than those found in the Comgap.

## ZENER (AVALANCHE) DIODE

The zener diode comes closest to modeling the ideal constant voltage clamp. It responds quickly to a fast rising voltage potential and is available for a fairly wide range of clamping voltages (from less than 10 volts up to several hundred volts). The zener is placed in parallel with the circuit to be protected and will not operate until a surge exceeds the zener's breakdown voltage. The surge, causing the zener to conduct will be clamped to the zener's rated voltage. The zener is a good protector for circuits operating at low voltages. Caution is advised when designing the device into RF circuits due to the diode's high capacitance.

Also available are silcon avalanche suppressers which are referred to as transient voltage suppressers (TVS) diodes. These diodes consist of fairly large junction zeners which have been designed specifically for surge protection. The TVS diodes are rated for higher current surges than zener diodes and they can carry these currents for periods of 2-10 microseconds.



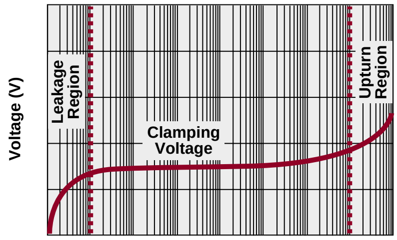

For use in AC signal lines, two zeners are required. These are available as packaged devices. Avalanche diodes are often used to protect IC's from static discharge and other forms of transients in power supplies computer buses, and data lines.

## MOV (METAL OXIDE VARISTOR)

As its name suggests, the MOV is a voltage variable resistor made from sintered metal oxides. The grains produced in the sintered metal oxide material of the MOV can be thought of as a network of series and parallel diodes. As the voltage potential across the MOV increases, some of the diodes experience avalanche breakdown and begin to conduct and as a result, reduce the net resistance of the MOV.

The MOV can handle current pulses of higher peak values and for a longer duration than a diode, but the MOV can experience cumulative degradation and performance changes after it is exposed to large current pulses when not properly selected. The high peak current surges tend to fuse the oxide grains and thus alter the MOV's performance. Some engineers recommend that a fuse be used with an MOV as a large current surge could damage the grain structure, fuse the grains together and result in the protected circuit being shorted out.

The MOV is available in a wide range of voltages and experiences a quick turn on time when subjected to a fast rising surge. The MOV is subject to leakage current and high capacitance (10's to 1000's of picofarads). When designing with a MOV it is necessary to remember that as the current through the device increases, the voltage which the MOV clamps at is greatly increased.




## GDT and MOV PROTECTION

In summary, there is no one ideal surge arrester device type that meets all of the key performance parameters for every application. Due to their complementary performance characteristics, however, a GDT and MOV can be combined in a circuit to provide the ultimate in surge suppression performance. The MOV quickly clamps a fast rising voltage surge while the GDT crowbars to safely dissipate the large peak current to ground. (See Application Note entitled "Surge Protection of AC Power Lines.")

## SUMMARIZED COMPARISON OF TECHNOLOGIES

| | GAS TUBE CG2-230L | SCR | MOV | DIODE |
|---|---|---|---|---|
| Type of Device | CROWBAR | CROWBAR | CLAMP | CLAMP |
| Response Speed | <1 uSEC. | <100nSEC. | <100nSEC. | <100nSEC. |
| Capacitance | 1pF MAX. | 50pF | 45pF | 50pF |
| Leakage Current | <1 pAMP | 50 nAMPS | 10,000 nAMPS | 10,000 nAMPS |
| Maximum Surge Current (8/20 µsec wave form) | 20,000 AMPS | 500 AMPS | 200AMPS | 50 AMPS |
| Relative Cost | $1.00 | $1.50 | $0.50 | $1.50 |

The CLARE product engineering department provides objective technical expertise and application assistance to designer's of switching the surge protection systems. Our mission is to assist you in designing the best solution to your specific application problem, regardless of manufacturer. To access our team of engineering professionals call toll free 1-800 CPCLARE.

# Basic Construction and Theory of Gas Discharge Tubes

## Construction

Gas Discharge Tube (GDT) surge arresters commonly employ hermetically-sealed enclosures utilizing either ceramic-to-metal or glass-to-metal seals. The many advantages of ceramic-to-metal units have made them the norm for gas discharge tube surge arresters such as Clare's Comgaps. Along with being low cost, they offer high product uniformity capable of handling extreme levels of shock, vibration, and temperature.

The ceramic for Comgaps is alumina ranging from 94-98% $Al_2O_3$. The ceramic-to-metal seals are prepared by moly-manganese or tungsten metallizing processes with nickel plating and the final seal is made in a gas-filled vacuum furnace using braze preforms made of copper-silver eutectic. The electrodes used for Comgaps are either copper or a nickel-iron alloy, often with a coating to lower the work function and/or add gettering capability. Stripes or bands of semi-conductive material are applied to the inner surfaces of the ceramic to improve stability and high-speed response.

In contrast, most devices in Clare's High Energy Devices product line are glass-to-metal units. This allows greater flexibility in configuration and is ideal for the production of standard and custom parts in more limited quantities. The electrodes of High Energy Devices are usually made of refractory metals such as tungsten or molybdenum to meet more extreme life and surge capacity requirements.

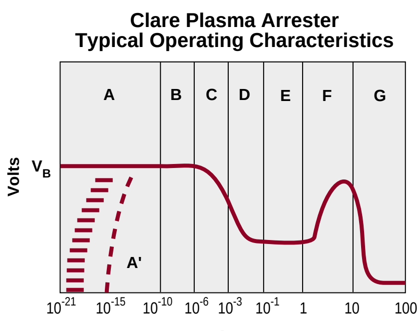



*Figure 1. A generic V-i characteristic of a plasma device.*

## Theory

The basic operation of gas tube surge arrestors such as Clare's Comgaps is best understood by referring to the schematic form of the voltage-current (V-i) relationship of a generic gas discharge device such as the one depicted in Figure 1.

### Description of Regions of a Generic V-i Characteristic of a Plasma Device

A For voltages below the breakdown voltage, the gas provides a good insulator. Very low leakage currents ($10^{-12}$A) occasionally encountered result from ionization by cosmic rays, high energy photons, etc; and is, therefore, subject to statistical fluctuations.

A' The current is higher due to supplementary electron sources such as photoemission.

B The discharge is self-sustaining due to gas ionization -- if external agents such as those mentioned for regions A and A' are removed, the current will not change (Townsend discharge). This occurs at the breakdown voltage of the device.

C The transition region. As the electric field increases, more secondary electrons are generated, decreasing the voltage drop until the glow voltage (region D) is reached. Stable operation can only be maintained with active current regulation because of the negative slope of the V-i characteristic.

D The glow region (or normal glow region). In this region, the glow voltage is roughly constant with respect to small changes in current.

E The abnormal glow region. In contrast to the normal glow region, the glow voltage begins to increase as the current is increased.

F The glow-to-arc transition region.

G The arc region. In this region, the arc voltage will quickly drop and the arc current will quickly increase within the limitations of the drive energy and impedance.

If the current through the gas discharge device is adjusted over the range of values of $10^{-18}$ to $10^{2}$ amps, the voltage across the device will also vary. When a gas discharge device is operated as a transient voltage protector, the modes of operation of greatest significance are in regions A, F, and G. The applied voltage is normally less than the breakdown voltage of the device, $V_{BD}$, at which time the current through the device is in the A region. The charged carriers of electric current in this mode originate from the cathode by photon emission and within the fill gas by collisions of gas particles with cosmic rays (or radioactive decay particles if an isotope is used in the device).

As soon as the applied voltage across the device exceeds the breakdown voltage, the current through the device increases rapidly to values of several amps or greater. The rate of current rise and the level reached is limited by the source capacity and the series impedance of the circuit. The voltage across the device at this time is very low with typical values of 20V or less.

# Surge Protection of Main Distribution Frame

Transient voltages induced in the telecommunication cable network can cause considerable damage to main distribution frame and telecommunication equipment. Effective surge protection can avoid expensive repair work and improve product reliability.

This article describes the possible transient sources which can occur on the telecommunication network and how to take preventive protective measures on the main distribution frame, based on tests and practical experience.

## INTRODUCTION

Modern telephone systems are fast, efficient, and complex. Many developments have been made in control office equipment which involve solid state circuitry.

Unfortunately, solid state devices are much more susceptible to malfunction or failure due to transient voltages. In addition, the increased usage of telephone lines for data transmission has produced a further intolerance for transient voltages.

Telephone networks, having a wide cable distribution, are highly exposed to voltage transients and therefore require protection components with maximum power capability, long life and high reliability.

For these reasons gas discharge tube (GDT) surge arrestors find an increasing use as the primary protector in telephone systems, replacing older types of protectors (air gaps, carbon blocs) and being designed into nearly all new and future equipment systems.

## CAUSES AND EFFECTS OF TRANSIENTS ON TELEPHONE EQUIPMENT

### Direct Lightning Strike

The earth's surface continuously experiences electrical disturbance activities. The extent of this activity is significant as it is estimated that 100 lightning flashes strike the earth every second. It is therefore not surprising that lightning is the most common source of overvoltage surges in communication systems.

The effects of a direct lightning strike are devastating. It has been estimated that the energy dissipation per unit length of channel in a single lightning stroke is 100 KJ/m. The average length of a lightning stroke is 3 km. The average duration of a stroke is 30µs with 4 strokes per lightning. Therefore, the peak power per stroke is $1x10^{13}$W.

The destructive power of lightning arises from high pressure generated in the lightning channel. In open air, energy deposited by a single stroke is equivalent to approximately 22g of TNT per meter, or 1/10 ton of TNT for the average channel. Most of this energy, however, is converted along the lightning channel leaving only a fraction of it at the end of the channel.

Four lightning parameters have to be considered when studying the effects of direct lightning strikes:

- Current amplitude (I): responsible for ohmic voltage drop in earth ground resistance.
- Steepness of the lightning current rise (di/dt): determines inductive voltage drops.
- Electric charge ($\int idt$): is a measure of the energy transmitted by the lightning arc to metallic surfaces, causing melting effects.
- Current square impulse ($\int i^2dt$): is at the base of every mechanical effect and electrical impulse heating of ohmic resistors.

*Table 1: Lightning Parameters*

| Percent of strokes | 90% | 50% | 10% |
|---|---|---|---|
| Crest current i | 2-8kA | 10-25kA | 40-300kA |
| Rate of current rise di/dt | 2kA/µs | 8kA/µs | 20-300kA/µs |
| Duration of single pulse | 100-600µs | 0.5-3ms | 20-400ms |
| Total stroke duration | 10-100ms | 100-300ms | 0.5-1.5s |
| Number of pulses per stroke | 1-2 | 2-4 | 5-34 |

Reference: Ezell, T.F., survey of lightning characteristics SC-TM-67-630 (August 1976).

## Indirect lightning:

The most noticeable and frequent interference in telephone systems is due to the inductive effect of lightning strikes. Although the induced effect of lightning is more common on overhead lines, buried lines are still susceptible through resistive coupling.

Overvoltages, mostly induced by cloud-to-cloud discharges, can be as high as several kilovolts with kiloamperes short circuit current. The surge voltage that appears at the end of the cable depends on the distance to the source, the type of cable, the shield material, and its thickness and insulation, along with the amplitude and waveshape of the lightning current in the shield.

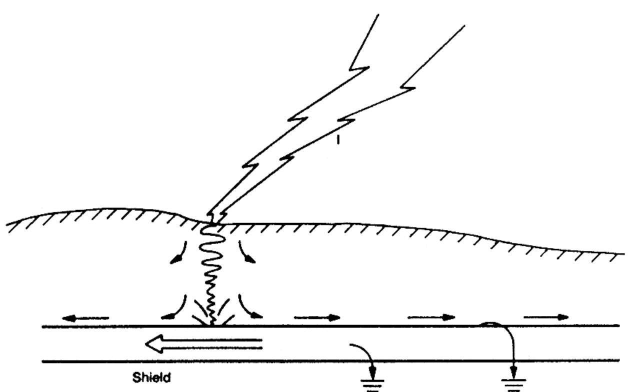



*Figure 1 - Indirect Lightning In Buried Cables*

## Power System Induced Transients:

Overhead telephone lines often share a utility pole and ground wire with the commercial AC power system. Buried telephone and power cables often share the same trench. Because of this, three types of overvoltage transients induced into the telephone lines can occur in conjunction with power system faults:

- Power contact or power cross: power lines make direct contact with telephone cables.
- Power induction: electromagnetic coupling of a heavy fault in the power system (this can be solved with proper shielding).
- Ground potential rise: heavy ground currents of power system faults flow in the common ground connections and cause substantial differences in potential.

Protection engineers have defined the power cross situation as the most severe condition. Therefore, the many requirements call for the suppression device to withstand 10A rms for a duration ranging from 10 to 60 cycles of the power system frequency.

## PROTECTION OF MAIN DISTRIBUTION FRAME

The telephone system is made up of a central switching network which interconnects the different subscribers through repeaters, multiplexers, and concentrators. The cable network which links the subscribers makes the system vulnerable to damaging transients. The cables consist of conductors in shielded cables, which are suspended on poles or buried in earth.

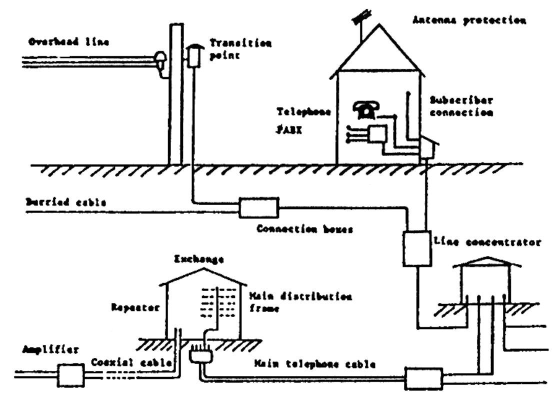



*Figure 2 - Telecommunication network*

Along with the cable network, antennas on wireless equipment connected to the telephone system are also a potential source of transients to the network. Additionally, the power used by a telecom system is usually obtained from commercial power lines which are subjected to the same possible overvoltage surges as the telephone signal lines.

As one can see, the complexity and exposure of the telephone system makes it highly susceptible to all types of overvoltage transients. From a practical standpoint, however, the cost of installing and maintaining a 100% protection system would not be cost effective. Therefore, network planners usually develop a location's network protection level plan based upon the implementation cost, stroke factor, ground resistance, type of facilities, desired reliability of service, and the exposure to lightning.

## Surge Protection of Main Distribution Frame

The main distribution frame (MDF) (see figure 3) is the link between the cables coming from anywhere in a local telephone network and the cable coming from the exchange switching equipment. The MDF rack consists of tubular and angular rails for the various MDF devices to be attached. On the line side (mostly accommodated on vertically rails), local cables are terminated. On the exchange side, horizontal arranged terminal blocs are connected to the exchange switches. An overvoltage protection magazine installed on the line side protects the exchange switching equipment against harmful overvoltage transients when connected to the external cable network.

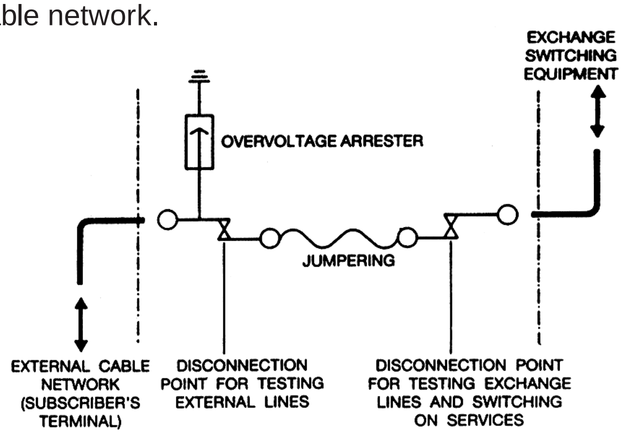



*Figure 3: Main distribution frame*

### Protecting the MDF with GDTs:

Of the devices available for transient protection, the gas discharge tube (GDT) protector reliably offers the highest surge current dissipation that is required to protect against lightning. GDT devices are unique in their ability to handle transient currents many times beyond the capability of solid state devices.

In the presence of a fast rising voltage surge, the GDT crowbars (switches) from its normally high impedance state to short circuit the transient safely to ground. Once in their fired state, GDT surge arrestors act like low voltage clamping devices (10-20V) whose clamping voltage is essentially independent of the transient's current magnitude. In the non-operating mode, the GDT surge arrestors are essentially transparent to the network's performance since they offer extremely high isolation resistance and very low line capacitance.

For these reasons the GDT arrester can be considered the best solution to provide the telephone network the primary protection against direct or induced high voltage transients.

Typical performance requirements of the GDT protector are:

- Environmental:
  - Temperature: -40 to +90°C
  - Relative Humidity: up to 95%
- Electrical:
  - DC Breakdown: 250V nominal
  - Impulse Breakdown at 100 V/µs: 900V max.
  - Insulation Resistance: > 1000 MΩ
  - Capacitance: ≤5pF
  - Life Tests:
    - Impulse 8/20, 10 shots, 10 kA peak
    - Impulse 10/1000, 300 shots, 100A peak
    - AC, 15-62 Hz for 1 sec., 5 shots, 10A rms

In many situations, a fail safe system is specified on GDT devices so the line is permanently grounded after excessive heating of the surge arrester by an extensive power cross. If this situation occurs, the GDT device and fail safe mechanism must be replaced.

### Two Electrode Configuration:

CP Clare's Comgaps are used in many telecommunication networks around the world for main distribution frame protection. The Comgaps are constructed of two metal electrodes hermetically sealed in a gas filled, rugged ceramic cylinder. Through ongoing research and engineering improvements, CP Clare has developed a variety of surge arrester families that offer impressive characteristics for MDF protection.

The two electrode CG2 series can best be used where microsecond transient rise times are expected. They provide fast response time, high holdover voltage and high follow-on current capacity.

*Figure 4: Clare's bipolar comgaps*

# Surge Protection of Main Distribution Frame

## CG-230L Performance:

Nominal DC Breakdown Voltage: 230 Vdc
Impulse Breakdown at 100V/ms: 600V max.
Insulation Resistance: 1000 M Ohm min.
Maximum Capacitance: 1pF max.
Surge Life:

Impulse 8/20, 10kA, 10 shots
Impulse 10/1000, 500A, 1000 shots
AC, 15-62 Hz for 1 sec., 10 shots, 20A rms.

CP Clare is ISO9000 certified and our automated production techniques are tightly controlled to assure a consistent, highly uniform product. Electrical testing is conducted on 100% of our products prior to shipment to our customers.

## Three Electrode Configuration

In a telephone cable, signals are conducted through pairs of copper wires. Therefore, transient voltages induced into the conductors will be common to both signal wires (typically called “tip” and “ring”). This is shown in Figure 5A.

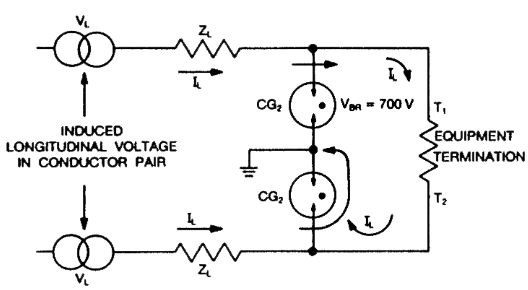



*Figure 5a - Unbalanced line protection*

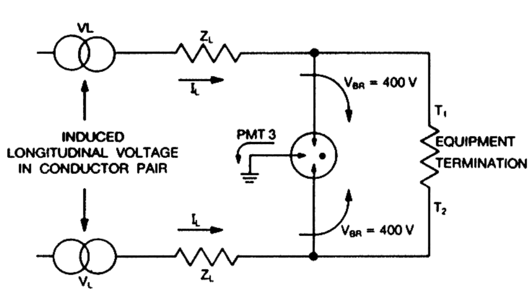



*Figure 5b - Balanced line protection*

If protector $CG_1$ should breakdown at 400V while $CG_2$ requires 600V to breakdown, the difference would cause a transient current to flow through the load. To eliminate the problem of unbalanced line breakdown, dual gap or three electrode tubes like the PMT3 and PMT8 have been developed. See Figure 5B.

The PMT3(310) series from Clare are three electrode, medium duty surge arrestors designed to protect electronic equipment from damage due to excessive voltages and current. The PMT3(310) products have extremely fast response times characterized by the impulse breakdown voltage, which describes their dynamic behavior. For ease of mounting on PC boards, the devices are available in many different lead configurations.

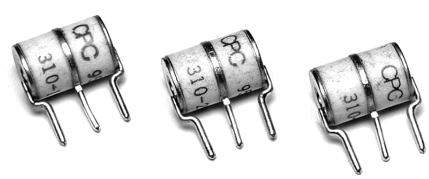


*Figure 6 - Clare’s tripolar comgaps*

## PTM3(310)230-04 Performance

Nominal DC Breakdown Voltage: 230 Vdc
Impulse Breakdown at 100V/ms: 600V
Insulation Resistance: 1000 Mohm min.
Maximum Capacitance: 1 pF max.
Surge Life:

Impulse 8/20, 10kA per side, 20kA total
Impulse 10/1000, 500A, 400 shots
AC, 15-62 Hz for 11 cycles, 65A

The voltage rating of the surge arrester is determined by the voltage applied between the tip and ring signal wires. Most telecommunication systems have 48 Vdc with a super imposed ring voltage of 100V rms (154V peak) maximum which results in a minimum breakdown voltage of 202V. Therefore, the PMT3(310)230 or PMT8-230 would be appropriate three electrode selections for this application.

# Surge Protection of Main Distribution Frame

## Protection Verification

In actual field operation, surge arrester devices are subjected to transients which, by their nature, are unpredictable in magnitude and duration. In order to best simulate transients such as lightning, international committees have developed standard lightning wave shape tests which can be conducted to evaluate protection components. Figure 7 illustrates the standard characteristics of these wave slopes. CP Clare utilizes these recommendations and standards when specifying, qualifying, and testing our GDT devices.

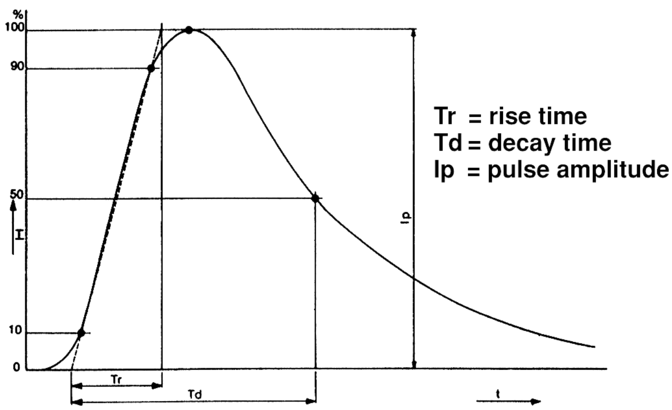



*Figure 7 - Description of surge current*

## Maintenance of Protection Devices

Most components utilized in lightning protection systems degenerate gradually due to the effects of repetitive surge damage and weather exposure. Component deterioration can cause a loss of protection resulting in unexpected system damage as well as performance degradation in the power and signal circuits. Periodic maintenance will help insure that the protection system remains at its original design and installation performance capability. Unlike semiconductor devices, the deterioration of GDT protectors can easily be measured. A GDT's performance can gradually degenerate due to erosion of its metallic electrodes. The degeneration, which is a function of lightning stroke frequency and magnitude, may easily be detected by measuring a lowering of the insulation resistance value across the electrodes of the device.

# Surge Protection of AC Power Lines

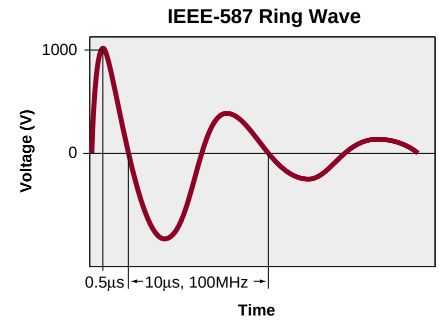
AC power line disturbances are the cause of many equipment failures. The damage can be as elusive as occasional data crashes or as dramatic as the destruction of a power supply, computer terminal, or television set. Power line disturbances go by many names -- transients, surges, spikes, glitches, etc -- but regardless of the name, an understanding of their characteristics and the operation of the various protection devices available is necessary to design an effective protection circuit. This Application Note will illustrate how to design high-performance, cost-effective surge protection for equipment connected to AC power lines. The role of gas discharge tube (GDT) surge arresters specifically designed for AC power line protection will also be discussed.

The first step in providing an effective defense against power line transients is to accurately characterize the transients. One good reference is IEEE C62.41-1991 entitled “IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits” (formerly IEEE Standard 587). This standard defines the open circuit voltage and short circuit current waveforms which can be expected to occur on AC power lines of 1000 Volts (RMS) or less. The standard defines three levels of increasing transient activity, labeled Location Categories A through C, dependent on the distance of the equipment from the service entrance. Line cord-connected equipment will usually be covered by Location Category A or, occasionally, Location Category B. There are two standard waveforms which define the types of transients expected in these Location Categories:

- 0.5ms-100 kHz Ring Wave (see Figure 1A) — an oscillatory waveform having a peak open circuit voltage of up to 6kV[†], a risetime of 0.5ms, a ring frequency of 100kHz, and a “Q” of three. Though a short-circuit current is not specified, peak currents of up to 0.5kA can be expected.[†]

- 1.2/50ms-8/20ms Combination Wave (see Figure 1B) — a unidirectional impulse waveform having a peak open-circuit voltage of up to 6kV[†] with a rise time of 1.2ms and a duration of 50ms[‡] AND a peak short-circuit current of up to 3kA[†] with a rise time of 8ms and a duration of 20ms[§].

Test waveforms for evaluation of a surge protection system should conform to these standard waveforms as closely as possible to ensure valid results. The use of test waveforms having slower rise times or lower peak currents/voltages may result in a false sense of security concerning the level of protection actually provided under field conditions.



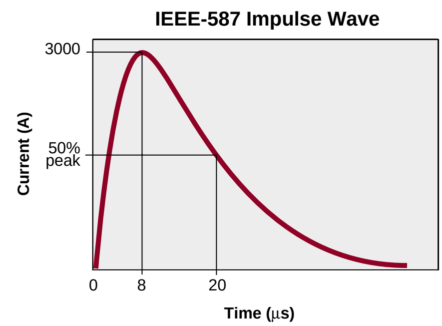
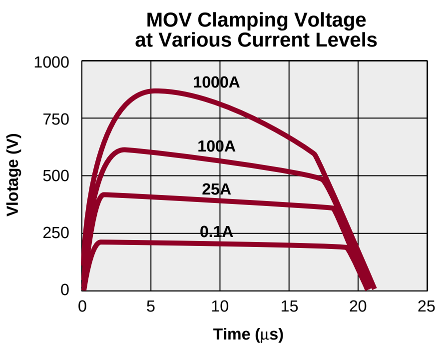




*Figure 1. IEEE Test Waveforms.*
*(A) 0.5ms-100 kHz Ring Wave.*
*(B) 1.2/50ms-8/20ms Combination Wave.*

The second step in designing an effective surge protection circuit is to choose which type(s) of surge protector to use. Surge protection devices can be divided into two basic types: Crowbar-type devices such as gas tube surge arresters, spark gaps, and SCRs; and Clamp-type devices such as avalanche diodes, transient absorption zener diodes, and metal oxide varistors. (See Application Note entitled “Comparison of Surge Protection Technologies”.)

## Surge Protection of AC Power Lines

The clamp-type devices have faster response times but are limited in their current handling ability because most of the energy of the transient must be dissipated by the clamping device. Also, the voltage drop across a clamp-type surge protector increases with the conducted current as shown in Figure 2A.



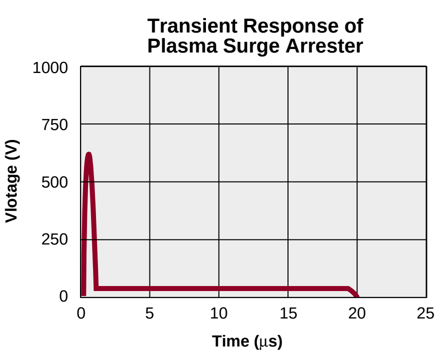




*Figure 2. Transient Voltage Drop*
*(A) For a Metal Oxide Varistor*
*(B) For a Gas Tube Surge Arrester.*

Crowbar-type devices such as gas tube surge arresters have slightly slower response times but can handle much higher current because they act as a low impedance switch which diverts the transient energy away from the protected equipment to be dissipated externally. While the peak voltage experienced by the protected circuit during the leading edge of some transients may be higher than with a clamp-type device; the duration, and thus the total energy delivered to the protected circuit, is much lower when using a crowbar-type device as shown in Figure 2B.

This peak voltage is a function of the rise time of the leading edge of the transient. Faster rise times will result in higher peak voltages due to the response time of the protector. Although Zener-gated SCRs and thyristors are available which offer faster response times, their use is limited to telecom and signal line applications due to their relatively low peak current ratings. A major benefit of the gas tube surge arrester is that the voltage drop across the device remains essentially constant (<20V) regardless of the conducted current.

The ideal surge protector would overcome the current handling and energy diverting characteristics of the crowbar type device with the speed of the clamp type device. This approach has been difficult and expensive to realize with traditional crowbar type devices because their designs were optimized for the ability to turn off in the presence of a low-current DC bias. While that is appropriate for protecting a telecom line, additional components (such as a series resistor or parallel-connected series-RC network) were required to ensure that the gas tube surge arrester would extinguish when placed across an AC power line with its relatively low source impedance and the resultant follow-on currents.[#] These components invariably decreased the performance of the protector while increasing its installed cost.

These shortcomings have been resolved with the Clare's AC series of gas tube surge arresters specifically designed for AC power line applications. These devices provide the low impedance switching action and high peak current capabilities of traditional gas tube surge arresters while optimizing the ability to extinguish in the presence of AC follow-on currents in excess of 300A. In most applications, no additional components are required other than those of the basic surge protection

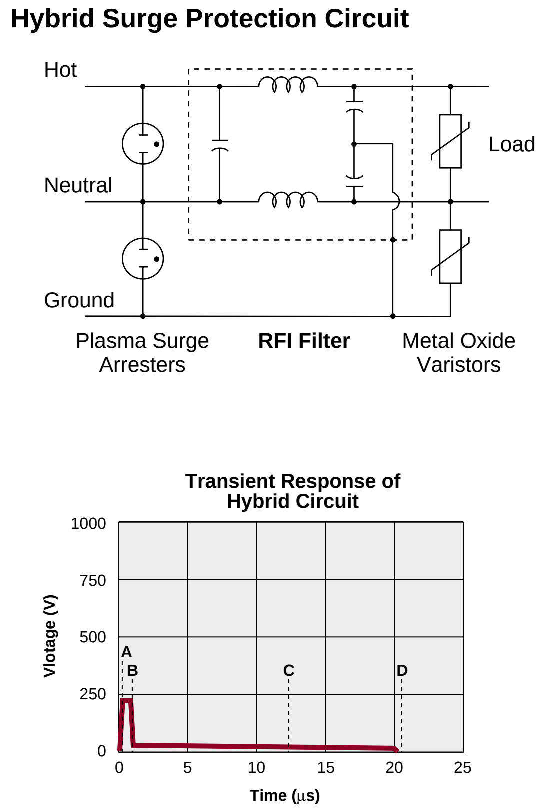



*Figure 3. (A) A typical hybrid surge protection circuit (B) Its response to a transient.*

circuit. A surge protection circuit with sub-nanosecond response time, precise control of transient energy let-through, and a peak current rating of 20,000A is now practical even for cost-sensitive applications such as power supplies, home stereos, monitors, and printers.

A typical installation is illustrated in Figure 3A. This is a two stage hybrid circuit consisting of a gas tube surge arrester as the primary protector and a Metal Oxide Varistor (MOV) as the secondary protector£. These elements must be separated by an isolating impedance. This impedance may be either resistive (>10Ω) or inductive (>0.1mH) to ensure proper coordination of the protective devices. Most AC applications utilize an inductive element to minimize power dissipation and voltage drop during normal operation.

The inductor used in this example is part of the RFI filter already required by the design. The output of the protection circuit during a transient is illustrated in Figure 3B.

The following sequence of events is depicted in Figure 3B:

- The leading edge of the transient is clamped by the MOV to a value just above the normal operating voltage.
- As the current through the MOV increases, a voltage is developed across the inductor which causes the gas tube surge arrester to fire. The energy of the transient is now quickly shunted through the gas tube surge arrester and away from the protected circuit.
- The gas tube surge arrester remains in full conduction for the duration of the transient.
- When the transient has passed, the gas tube surge arrester extinguishes—ready for the next transient.

This circuit uses each component to do what each does best: the gas tube surge arrester diverts the high-energy portion of the transient and the MOV provides the fast, accurate clamping of the low energy leading edge.

The cost effectiveness of this protection circuit is enhanced by three factors:

1. The use of an AC Series gas tube surge arrester eliminates the need for additional components to ensure turnoff.
2. The isolating impedance is supplied by an existing component (the RFI filter).
3. A small diameter MOV (lowest cost) is used since the gas tube surge arrester handles the high-energy portion of the transient.

The example duplicates the circuit between Neutral and Ground in addition to the Hot-to-Neutral circuit. This provides protection against Common Mode (both lines surged relative to ground) as well as Normal Mode (Hot-to-Neutral) transients. This is important because both types of transients are frequent occurrences in the real world. The failure to provide Common Mode protection is one of the leading causes of failure in many otherwise solid designs.

# Surge Protection of AC Power Lines

The critical points in the selection of the gas tube surge arrester are the minimum DC breakdown voltage (which must be higher than the highest normal voltage expected on the protected line) and the follow-on current rating (which must be higher than the expected fault current of the incoming supply line). In this example, the minimum DC breakdown voltage is calculated by multiplying the normal line voltage (120VRMS) by 1.414 to obtain the peak voltage and then adding an appropriate guard band to allow for normal variations in the supply voltage.

120VRMS x 1.414 = 170Vpeak
170Vpeak x 1.15 (15% guardband) = 196V minimum

The MOV should be selected using the same formula. When used in a properly designed hybrid circuit, a 3mm device is normally adequate to handle the small leading-edge currents until the gas tube surge arrester goes into conduction.

The inductor should have a value of at least 0.1mH. If the inductance is too low, the MOV may clamp the transient voltage at a level that does not allow the gas tube surge arrester to go into conduction. The result is usually the overloading and destruction of the MOV. Tests have been conducted using several common RFI filters having inductances or 1-2mH with excellent results.

Hybrid surge protection circuits incorporating AC Series gas tube surge arresters can provide cost-effective protection against transients that exceed even the tough guidelines of IEEE C62.41-1991 for Location Categories A and B.

Notes

† The exact value is a function of the Location Category and System Exposure level. See the IEEE spec for more detailed information.

‡ The rise time for an open-circuit voltage waveform is defined as $1.67 \times (t_{90} - t_{30})$ where $t_{30}$ and $t_{90}$ are the 30% and 90% amplitude points on the leading edge of the waveform. The duration is defined as the time from the virtual origin, $t_0$ (where a line through $t_{30}$ and $t_{90}$ intersects the zero voltage axis), to the 50% amplitude point of the trailing edge of the waveform, $t_{50}$.

§ The rise time for an short-circuit current waveform is defined as $1.25 \times (t_{90} - t_{10})$ where $t_{10}$ and $t_{90}$ are the 10% and 90% amplitude points on the leading edge of the waveform. The duration is defined as the time from the virtual origin, $t_0$ (where a line through $t_{10}$ and $t_{90}$ intersects the zero current axis), to the 50% amplitude point of the trailing edge of the waveform, $t_{50}$.

# If the current supplied by the AC power line exceeds the maximum follow-on current of the gas tube surge arrester (typically, ~20A), the device will continue to conduct, even at a zero crossing of the AC voltage signal, causing the gas tube surge arrester to overheat and fail.

£ A transient absoprtion zener diode should also work as the secondary protector.

# Spark Gaps for Energy Transfer Applications

Many applications in electronic circuits require a fast-acting switch capable of transferring stored electrical energy, usually from a storage capacitor to a load circuit. Typical applications include the following:

- Discharge Lamp Ignitors (HID or Glow Lamps)
- Gas Ignitors (Gas Dryers or Water Heaters)
- Pulsed Light Sources (Xenon Photo Flash)
- Exploding Bridge Wires (EBW)
- Crowbarring Power Supplies

When the voltage level is low (<100V) and currents do not exceed 1A, transistor circuits may be used. When the voltages exceed several hundred volts and currents exceed 1-10A, spark gaps become especially suitable in terms of cost, size, standby readiness, and minimum associated circuit requirements. Spark gaps may be designed to handle extremely high currents for short durations and at high voltage levels while still contained in a relatively small space. These devices can operate over wide temperature extremes (as great as -55°C to +125°C), they are unaffected by variations in pressure and humidity, and can withstand high levels of shock and vibration. Since these devices are made for cold cathode operations, no heater circuits or standby power is required.

A two-electrode spark gap requires the least amount of associated circuitry (see Figure 1A). For energy transfer, the storage capacitor must begin to charge from time zero until the breakdown voltage of the "switch" is reached. At this point, the impedance of the spark gap quickly drops from several thousand megohms to a few ohms and the storage capacitor discharges at a rate limited by the circuit impedance. (For more information, please see our Application Note entitled "Use of Energy Transfer Switches.")

In applications where "instantaneous" switching is required, a triggered spark gap is used (see Figure 1B above). Here, the storage capacitor is charged prior to the energy demand. Since the self-breakdown voltage of the triggered spark gap is greater than the charge voltage of the storage capacitor, the storage capacitor remains charged. Upon application of an appropriate trigger pulse, the "switch" will rapidly close (typically 0.1µs delay time) and the stored energy will be transferred to the load circuit. (For more information, please see our Application Note entitled "Use of Triggered Spark Gaps.")

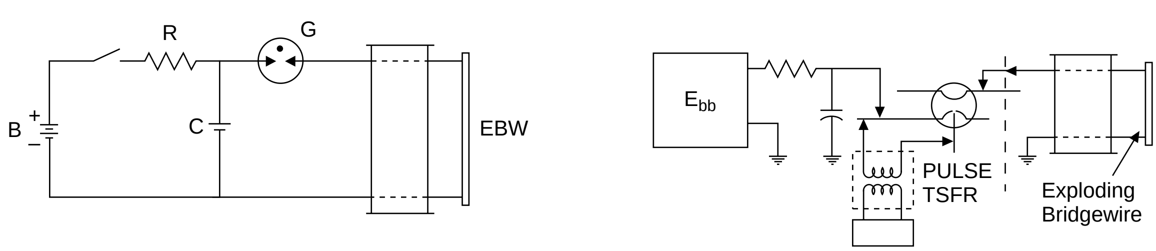



*Figure 1. Connection of Two-Electrode (A) and Triggered (B) Spark Gaps for Energy Transfer.*

# Use of Energy Transfer Switches

The Energy Transfer Switch (ETS) gas discharge tube product line from CP Clare has been developed to provide a cost-effective device for switching applications requiring:

- Long life when subjected to low energy discharges
- Narrow firing voltage limits over life
- Low cost
- Rugged construction

Typical applications for Energy Transfer Switches include:

- HID lamp ignitor
- Glow discharge ignitor
- Gas ignitor
- Flash tube trigger

Each of these applications uses the Energy Transfer Switch in a relaxation oscillator similar to the generic HID lamp ignitor circuit depicted in Figure 1 below. The storage capacitor must begin to charge from time zero until the firing voltage of the Energy Transfer Switch is reached. At this point, the impedance of the Energy Transfer Switch quickly drops from several thousand megohms to a few ohms and the storage capacitor discharges at a rate limited by the circuit impedance. The current through the primary of the pulse transformer creates the high voltage ignition transient across the secondary of the transformer.

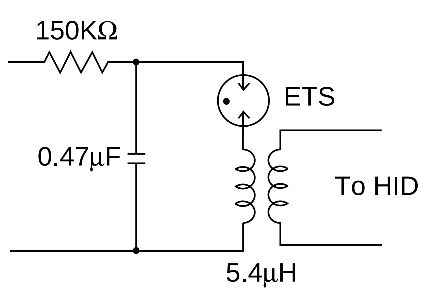



*Figure 1. Generic HID lamp ignitor circuit using an Energy Transfer Switch.*

The engineers at CP Clare have developed custom instrumentation for conducting automated life testing of Energy Transfer Switches in customer-supplied modules where every firing voltage is recorded for up to 100,000+ shots. Two typical life test regimens are:

**Continuous Repetitive Pulses**

Typically in this test regimen, there is continuous firing at a slow rate (< 0.5 pulses/second).

**Repetitive Pulse Bursts**

Typically in this test regimen, there is a brief (< 1 second) burst of up to 30 fires followed by a longer pause (5-10 seconds).

Entire waveforms including a single charge-discharge cycle (continuous) or a burst of charge-discharge cycles (burst) are recorded during each life test. Subsequent post-processing determines the voltage of each firing for plotting and analysis. Below is a graph depicting actual life test data for an Energy Transfer Switch.

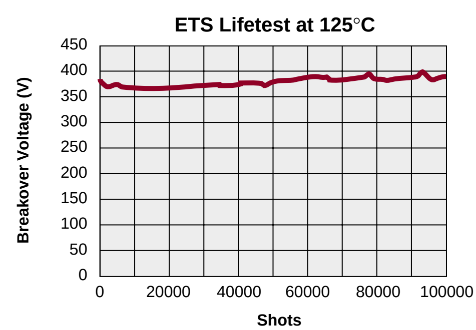



*Figure 2. Typical life test plot for an Energy Transfer Switch.*[1]

As illustrated in Figure 2 above, the firing voltage does not vary greatly over the 100,000 shots.

Notes:

[1] The circuit used for this life test had $V_{PS}$=450V, R=68kΩ, and C=0.47μF with the primary of the pulse transformer simulated by a 5.4μH inductor (yielding a 250 Amp peak discharge current, a initial pulse width of 0.7μs, and a nominal relaxation frequency of 15 pulses/second). The test was performed in repetitive burst mode with 0.7 second bursts and a 10 second delay between bursts at 25°C.

# Electromagnetic Compatibility for Industrial-Process Measurement and Control Equipment

## Introduction

The purpose of the IEC 1000-4 (previously known as IEC-801) standard is to establish a common reference for evaluating the performance of industrial-process measurement and control instrumentation when exposed to electric or electromagnetic interference. The types of interference considered are those arising from sources external to the equipment.

The interference susceptibility tests are essentially designed to demonstrate the capability of equipment to function correctly when installed in its working environment. The type of test required should be determined on the basis of the interference to which the equipment may be exposed when installed while taking into consideration the electrical circuit (i.e., the way the circuit and shields are tied to earth ground), the quality of shielding applied, and the environment in which the system is required to work.

The IEC 1000-4 standard is divided into six sections:

- IEC 1000-4-1. Introduction
- IEC 1000-4-2. Electrostatic Discharge Requirements
- IEC 1000-4-3. Radiated Electromagnetic Field Requirements
- IEC 1000-4-4. Electrical Fast Transient (Burst) Requirements
- IEC 1000-4-5. Surge Voltage Immunity Requirements
- IEC 1000-4-6. Immunity to Conducted Disturbances Induced by Radio Frequency Fields Above 9KHz

Sections IEC 1000-4-2 through IEC 1000-4-5 will be discussed in this application note.

### Test Severity Level

| Level | Test voltage: Contact discharge | Test voltage: Air discharge |
|---|---|---|
| 1 | 2kV | 2kV |
| 2 | 4kV | 4kV |
| 3 | 6kV | 8kV |
| 4 | 8kV | 15kV |
| x | Special | Special |

"x" is an open level.
The test severity levels shall be selected in accordance with the most realistic installation and environmental conditions.

### Characteristics of the ESD generator

| Level | Indicated voltage | First peak current of discharge (+/- 10%) | Rise time with discharge switch | Current at 30 ns (+/- 30%) | Current at 60 ns (+/- 30%) |
|---|---|---|---|---|---|
| 1 | 2kV | 7.5A | 0.7 to 1 ns | 4 A | 2 A |
| 2 | 4kV | 15 A | 0.7 to 1 ns | 8 A | 4 A |
| 3 | 6kV | 22.5 A | 0.7 to 1 ns | 12 A | 6 A |
| 4 | 8kV | 30 A | 0.7 to 1 ns | 16 A | 8 A |

## Electrostatic Discharge (ESD) Requirements

The purpose of this test is to find the reaction of the equipment when subjected to electrostatic discharges which may occur from personnel to objects near vital instrumentation.

In order to test the equipment's susceptibility to ESD, the test set-up conditions must be established. Direct and indirect application of discharges to the Equipment Under Test (EUT) are possible, in the following manner:

a) Contact discharges to the conductive surfaces and to coupling planes.
b) Air discharge at insulating surfaces.

Two different types of tests can be conducted:

1. Type (conformance) tests performed in laboratories.
2. Post installation tests performed on equipment in its installed conditions.

The only accepted method of demonstrating conformance to the standard is the of type tests performed in laboratories. The EUT, however, shall be arranged as closely as possible to the actual installation conditions.

Examples of laboratory ESD test set-ups can be seen in Figure 1 for table-top equipment and in Figure 2 for floor standing equipment.

# IEC-1000-4 Application Note

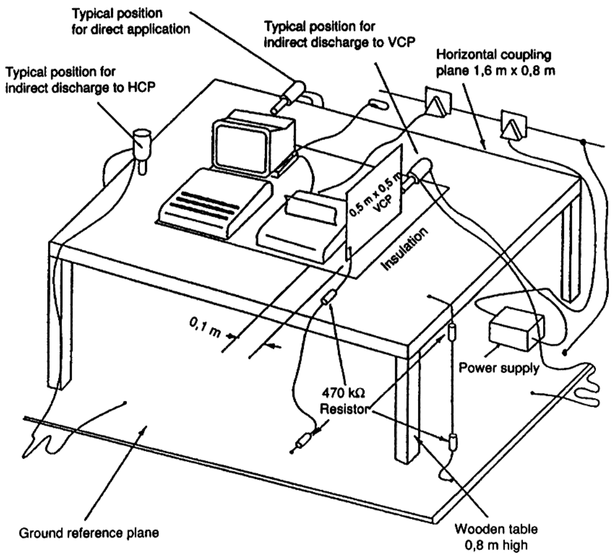



*Figure 1. Example of test set-up for table-top equipment, laboratory tests.*

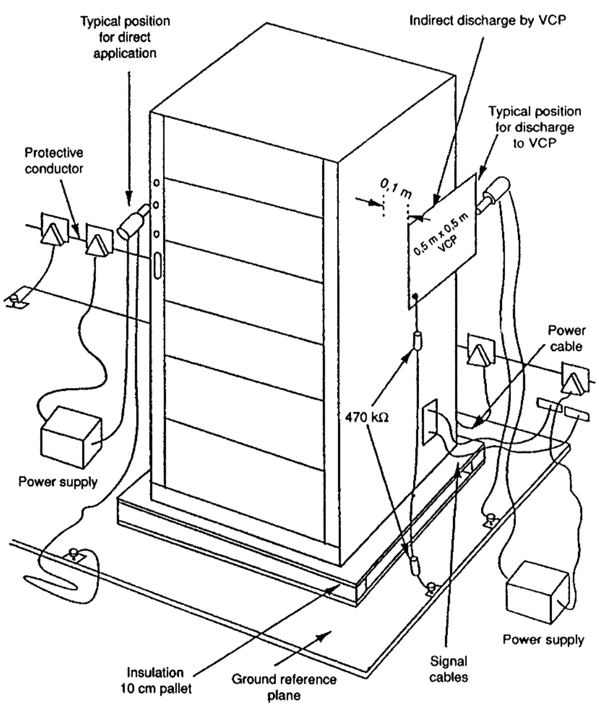



*Figure 2. Example of test set-up for floor-standing equipment, laboratory tests.*

Post installation tests are optional and not mandatory for certification. If a manufacturer and customer agree post installation tests are required, a typical test set-up can be found in Figure 3.

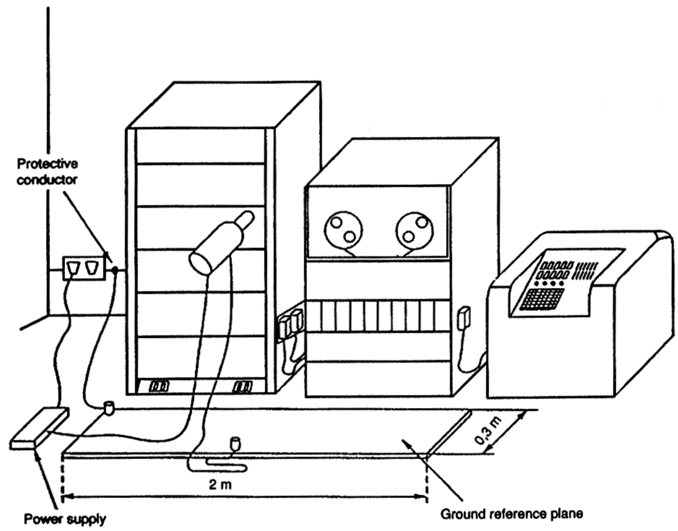



*Figure 3. Example of test set-up for equipment, post-installation tests.*

## Test Procedure

- For conformance testing, the EUT shall be continually operated in its most sensitive mode which shall be determined by preliminary testing.
- The test voltage shall be increased from the minimum to the selected test severity level.
- Number: at least 10 single discharges (in the most sensitive polarity).
- Time interval: initial value 1 second, longer intervals may be necessary.
- Direct application of discharge to the EUT:
  The static electricity discharges shall be applied only to those points and surfaces of the EUT which are accessible to the human operator during normal usage.
- Indirect application of the discharge: Discharges to objects placed or installed near the EUT shall be simulated by applying the discharges to a coupling plane (a horizontal coupling plane under the EUT or a vertical coupling plane).

## Test Results

The results of the ESD tests are reported as follows:

1. Normal performance within the specification limits.
2. Temporary degradation or loss of function or performance which is self-recoverable.
3. Temporary degradation or loss of function or performance which requires operator intervention or system reset.
4. Degradation or loss of function which is not recoverable, due to damage of equipment (component) or software, or loss of date.

## IEC 1000-4-3

## Radiated Electromagnetic Field Requirements

This test shows the susceptibility of instrumentation when subjected to electromagnetic fields such as those generated by portable radio transceivers or any other device that will generate continuous wave (CW) radiated electromagnetic energy.

**Test Severity Levels**

Frequency band : 27 MHz to 500 MHz

| Level | Test field strength (v/m) |
|---|---|
| 1 | 1 |
| 2 | 3 |
| 3 | 10 |
| x | Special |

"x" is an open class.
The test severity levels shall be selected in accordance with the electromagnetic radiation environment to which the EUT may be exposed when finally installed.

## Test set-up

Examples of the test configuration for radiated electromagnetic fields can be found in Figure 4 and Figure 5.

- The procedure requires the generation of electromagnetic fields within which the test sample is placed and its operation observed. The tests shall be carried out in a shielded enclosure or anechoic chamber. The test procedure assumes the use of biconical and log-spiral antennae or stripline.
- All testing of the equipment shall be performed in conditions as close as possible to the actual installation.

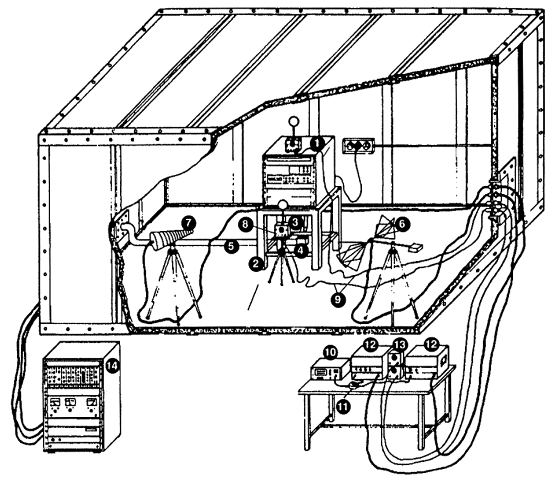



*Figure 4. Test set-up for radiated electromagnetic field tests in a shielded room where the antennae, field strength monitors and EUT are inside and the measuring instruments and associated equipment are outside the shielded room.*

Small objects (25cm x 25cm x 25cm) can be tested using a striplineantennae. This is a parallel plate transmission line to generate an electromagnetic field as shown in Figure 6.

## Test Procedure

- The test is performed with the EUT in the most sensitive physical orientation.
- The frequency range is swept from 27 MHz to 500 MHz. The sweep rate is in the order of 1.5 x $10^{-3}$ decades/sec.

## Test Results

The results of the radiated electromagnetic field include:

1. The effect of the electromagnetic field on the output of the EUT,
   – As a consistent measurable effect.
   – As a random effect, not repeatable, and possibly further classified as a transient effect occurring during the application of the electromagnetic field and as a permanent or semi-permanent field after the application of the electromagnetic field.
2. Any damage to the EUT resulting from the application of the electromagnetic field.

The qualitative evaluation of the resultant data needs to be assessed in terms of the existing local ambient electromagnetic level and the specific operating frequencies.

# IEC-1000-4 Application Note

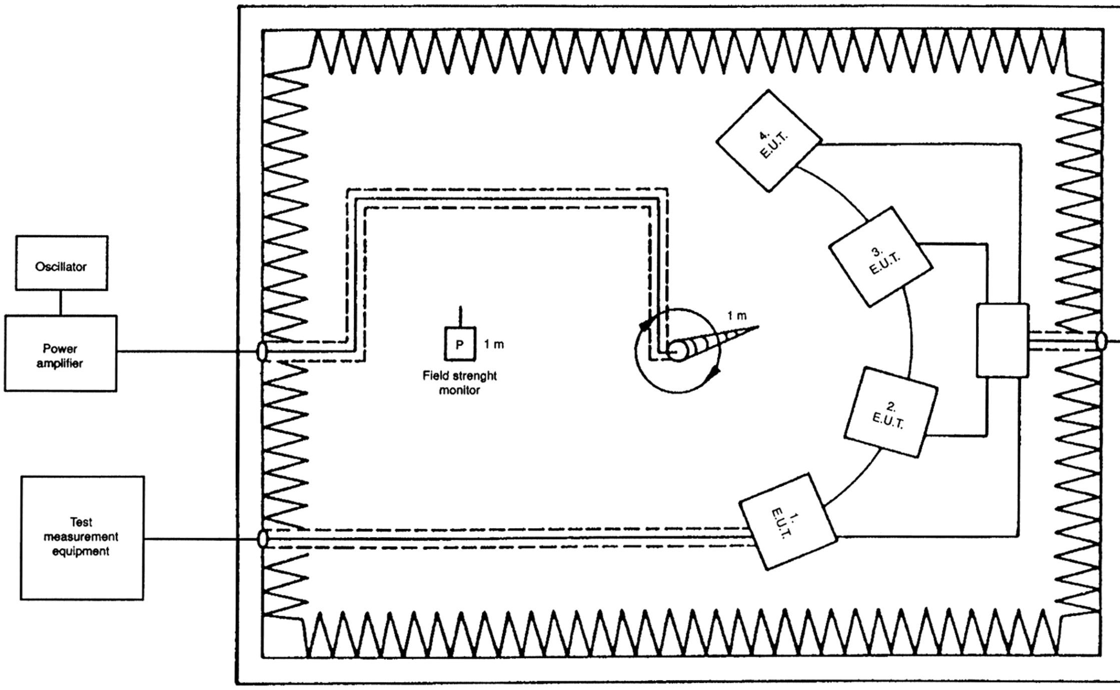



*Figure 5. Test set-up for radiated electromagnetic field tests in an anechoic chamber, general arrangement of the EUT, field strength monitor and antennae.*

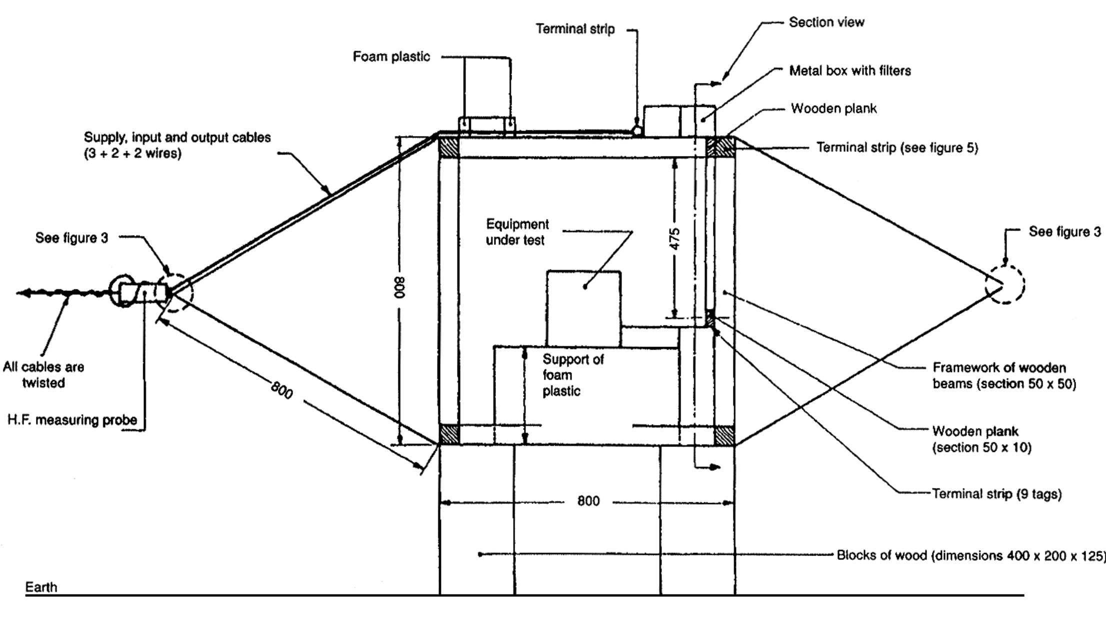



*Figure 6. Test set-up with stripline circuit.*

## IEC 1000-4-4

## Electrical Fast Transient (Burst) Requirements

This test is intended to demonstrate the immunity of the equipment when subjected to interference originating from switching transients.

### Test Severity Levels

Open circuit output test voltage: +/- 10%

| Level | On power supply | On Input/Output signal data and control lines |
|---|---|---|
| 1 | 0.5 kV | 0.25kV |
| 2 | 1kV | 0.5kV |
| 3 | 2kV | 1kV |
| 4 | 4kV | 2kV |
| x | Special | Special |

“x” is an open level.
The test severity levels should be selected in accordance with the most realistic installation and environmental conditions.

### Characteristics of the Fast Transient/Burst Generator

- Risetime of one pulse: 5 nSec +/- 30 %
- Impulse duration (50% value): 50 nSec +/- 30%
- Repetition rate of the impulses and peak values of the output voltage:
  - 5 kHz +/- 20% at 0.125 kV
  - 5 kHz +/- 20% at 0.25 kV
  - 5 kHz +/- 20% at 0.5 kV
  - 5 kHz +/- 20% at 1.0 kV
  - 5 kHz +/- 20% at 2.0 kV
- Burst duration: 15 mSec +/- 20%
- Burst period: 300 mSec +/- 20%.

### Test Set-up

For laboratory testing, the test set-up for type testing can be shown in Figure 7 and Figure 8.

- Power supply lines (See Figure 7): If the line current is higher than 100 A, the “field test” shall be used.
- Earth connections of the cabinets: The test point on the cabinet shall be the terminal for the protective earth conductor. (See Figure 7)
- Input/Output circuits and communication lines (See Figure 8).

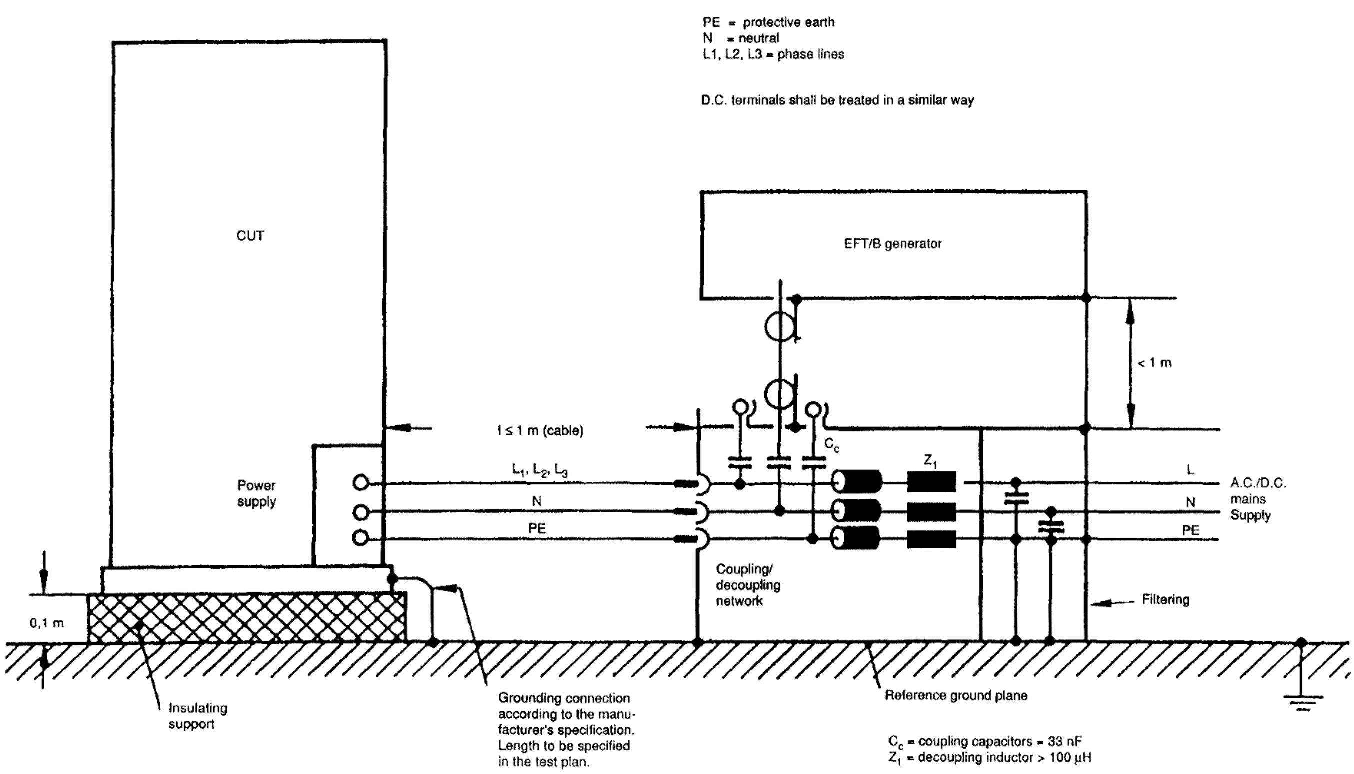



*Figure 7. Example of test set-up for direct coupling of the test voltage to a.c./d.c. power supply lines/terminals for laboratory test purposes.*

# IEC-1000-4 Application Note

For field testing, the equipment or system shall be tested in the final installed conditions without coupling/decoupling networks.

- Power supply lines and protective earth terminals
  – Stationary, floor-mounted EUT: The test voltage shall be applied between a reference ground plane and each of the power supply terminals, AC or DC, and on the terminals for the protective or function earth on the cabinet of the EUT. (See Figure 9).

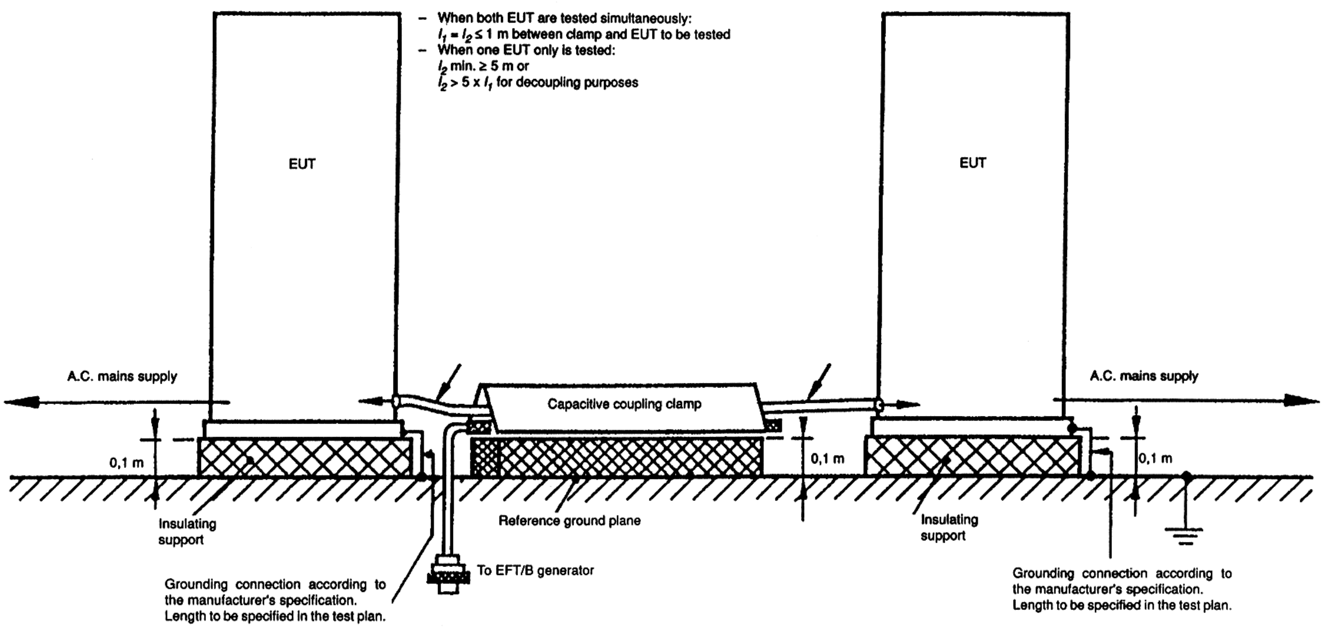



*Figure 8. Example of test set-up for application of the test voltage by the capacitive coupling clamp for laboratory test purposes.*

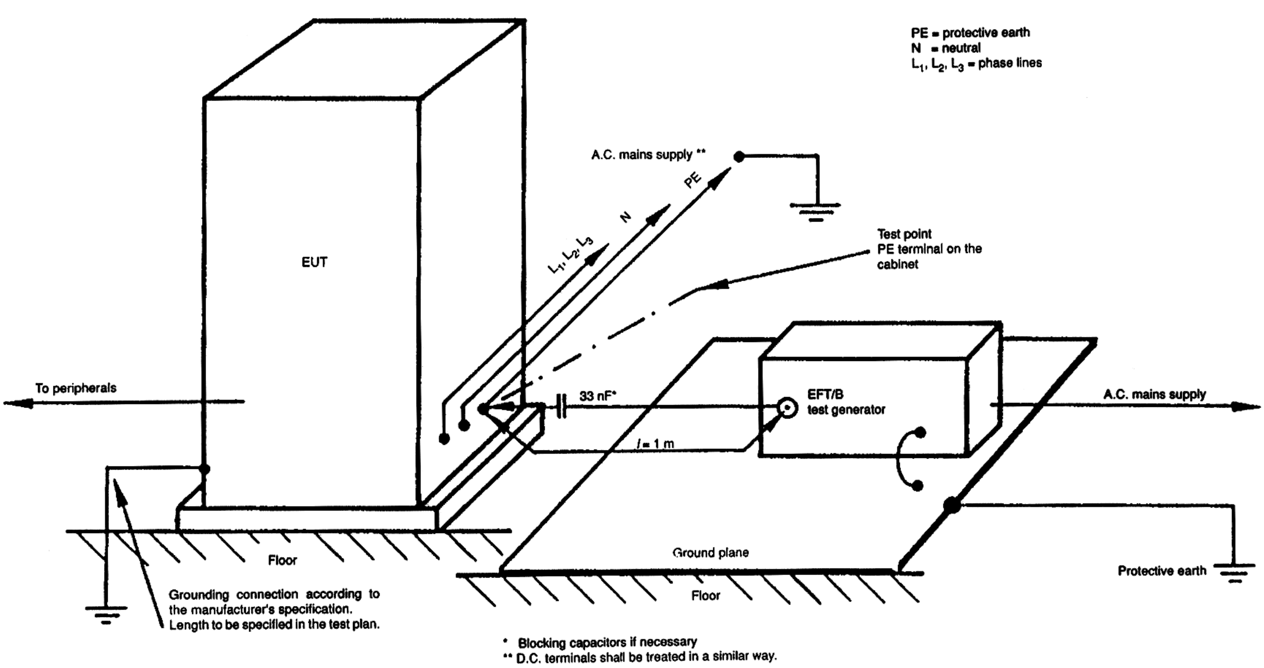



*Figure 9. Example for field test on a.c./d.c. power supply lines and protective earth terminals for stationary, floor mounted EUT.*

– Non-stationary mounted EUT, connected to the mains supply by flexible cord and plugs: The test voltage shall be applied between each of the power supply conductors and the protective earth at the power supply outlet to which the EUT is to be connected. (See Figure 10).

■ Input/Output circuits and communication lines:
– A capacitive clamp shall be used for coupling the test voltage into the lines. However, if the clamp cannot be used due to mechanical problems in the cabling, it may be replaced by a tape or a conductive foil enveloping the lines under test. (See Figure 11).

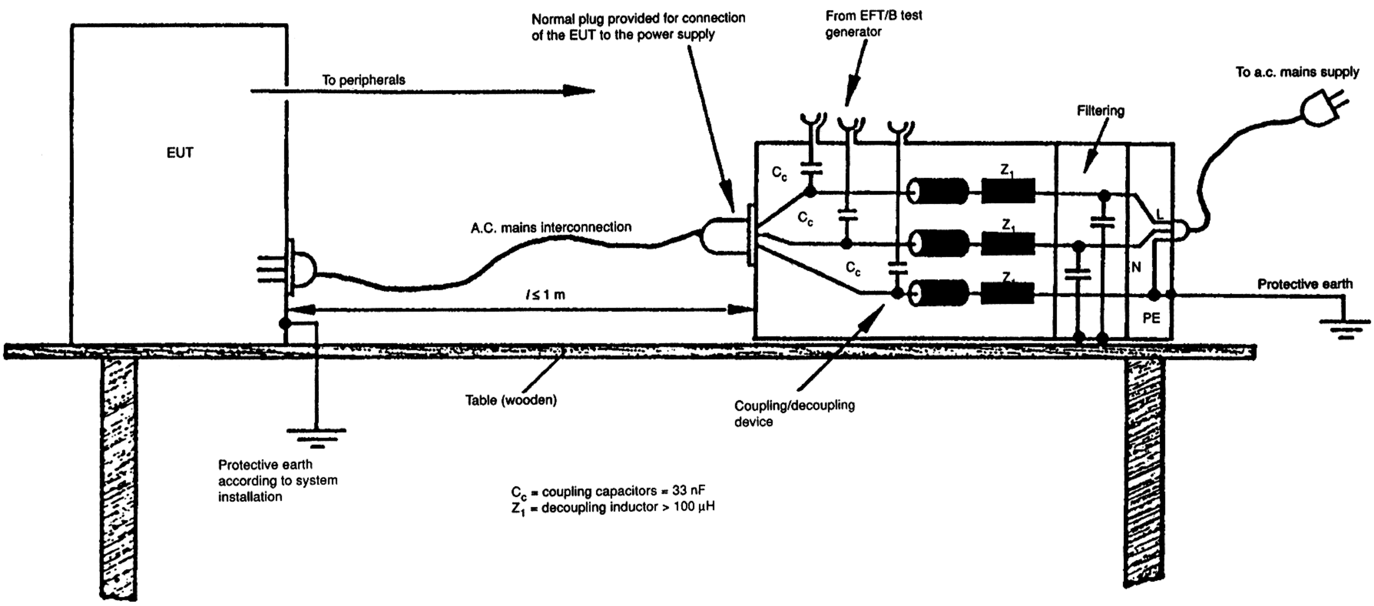



*Figure 10. Example for field test on AC mains supply and protective earth terminals for non-stationary mounted EUT.*

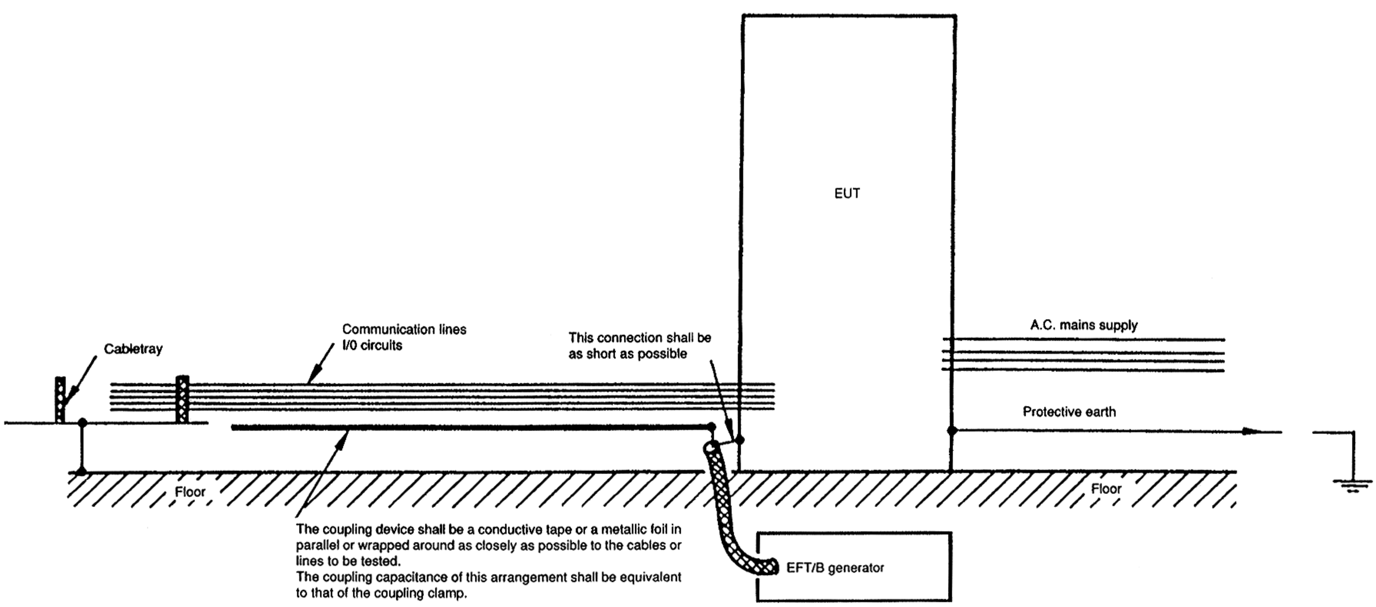



*Figure 11. Example for field test on communications and I/O circuits without the capacitive coupling clamp.*

# IEC-1000-4 Application Note

## Test Procedure

- Polarity of the test voltage : both polarities are mandatory.
- Duration of the test : at least 1 min.

## Test Results

The results are reported as:

1. Normal performance within the specification limits.
2. Temporary degradation or loss of function or performance which is self-recoverable.
3. Temporary degradation or loss of function or performance which requires operator intervention or system reset.
4. Degradation or loss of function which is not recoverable, due to damage of equipment (component) or software, or loss of data.

## IEC 1000-4-5

## Surge Voltage Immunity Requirements

The goal of the laboratory test is to determine the equipment's susceptibility to damage caused by overvoltage surges caused by circuit switching and lightning strikes.

### Test Severity Levels

| | Power Supply | | Unsym. Lines Long Data Bus | | Symmetrical Lines | Data Bus (Short Dist) |
|---|---|---|---|---|---|---|
| Class | Line to Line Z = 2Ω | Line to Ground Z = 12Ω | Line to Line Z = 42Ω | Line to Ground Z = 42Ω | Line to Ground Z = 42Ω | Line to Ground |
| 0 | No test is advised | | | | | |
| 1 | - | 0.5kV | - | 0.5kV | 1.0kV | - |
| 2 | 0.5kV | 1.0kV | 0.5kV | 1.0kV | 1.0kV | 0.5kV |
| 3 | 1.0kV | 2.0kV | 1.0kV | 2.0kV | 2.0kV | - |
| 4 | 2.0kV | 4.0kV | 2.0kV | 4.0kV | - | - |
| 5 | * | * | 2.0kV | 4.0kV | 4.0kV | - |
| x | Special | | | | | |

Z is the source impedance.
*Depends on the class of the local power supply system.
"x" is an open level that has to be specified in the product specification.
The class depends on the installation conditions.

### Characteristics of the Test Instrumentation

- Combination wave test generator:
  Open circuit output voltage: from 0.5kV to 4.0kV
  Short circuit output current: from 0.25kA to 2.0kA

| | in accordance with IEC60-2 | | in accordance with IEC469-1 | |
|---|---|---|---|---|
| | Front time | Time to half value | Rise time (10%-90%) | Duration (50%-50%) |
| Open circuit voltage | 1.2µs | 50µs | 1µs | 50µs |
| Short circuit current | 8µs | 20µs | 6.4µs | 16µs |

- Test generator 10/700 µs (according to CCITT):
  Open circuit output voltage: from 0.5kV to 4.0kV
  Short circuit output current: from 12.5A to 100A.

| | in accordance with IEC60-2 | | in accordance with IEC469-1 | |
|---|---|---|---|---|
| | Front time | Time to half value | Rise time (10%-90%) | Duration (50%-50%) |
| Open circuit voltage | 10µs | 700µs | 6.5µs | 700µs |
| Short circuit current | - | - | 4µs | 300µs |

The surges (and test generators) related to the different classes are: Class 1 to 4: 1.2/50 µs (8/20 µs)
Class 5: 1.2/50 µs (8/20 ms) and 10/700 µs

## Test set-up

A decoupling network is used to prevent surge energy from being propagated to the other equipment operating from the same source during testing of the EUT. The test set-up for evaluating the EUT power supply is shown in Figures 12 - 15. A capacitive coupling network (preferred) or an inductive coupling network is used for this test.

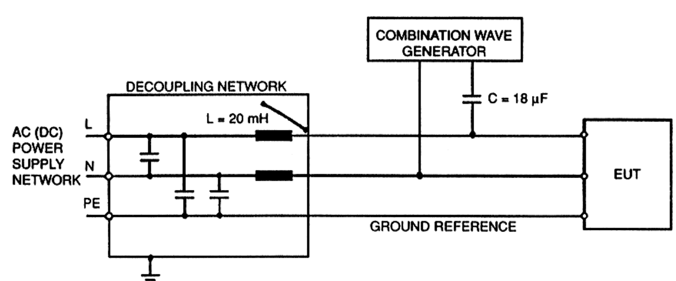



*Figure 12. Test set-up for capacitive coupling on AC/DC lines; line to line coupling according to 7.2.*

## IEC-1000-4 Application Note

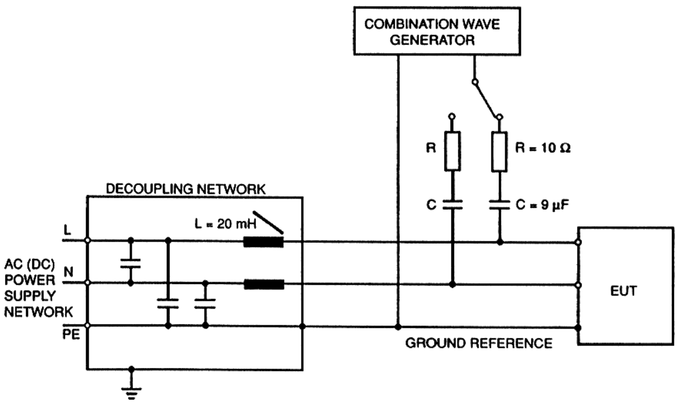



*Figure 13. Test set-up for capacitive coupling on AC/ DC lines; line to ground coupling according to 7.2 (generator output floating or earthed).*

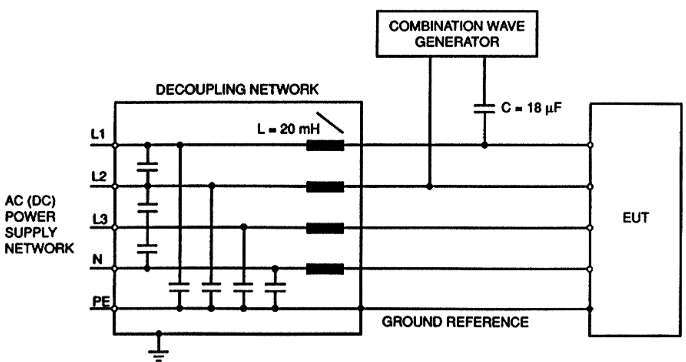



*Figure 14. Test set-up for capacitive coupling on AC lines (3 phases); line to line coupling according to 7.2.*

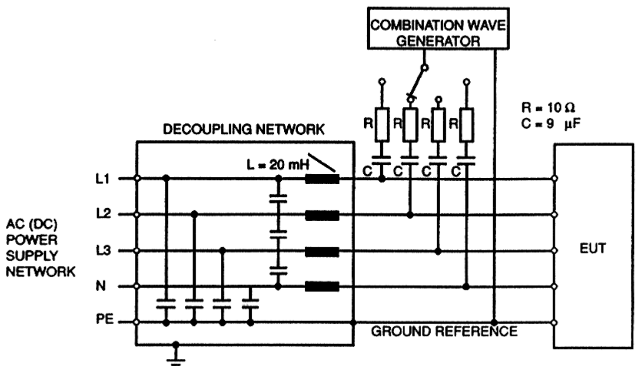



*Figure 15. Test set-up for capacitive coupling on AC lines (3 phases); line to ground coupling according to 7.2.*

The test set-up for evaluating the unshielded interconnection lines of the EUT is illustrated in Figures 16-20. Usually, capacitive coupling is used, but inductive coupling or coupling via gas discharge tube (GDT) surge arrestors is also possible.

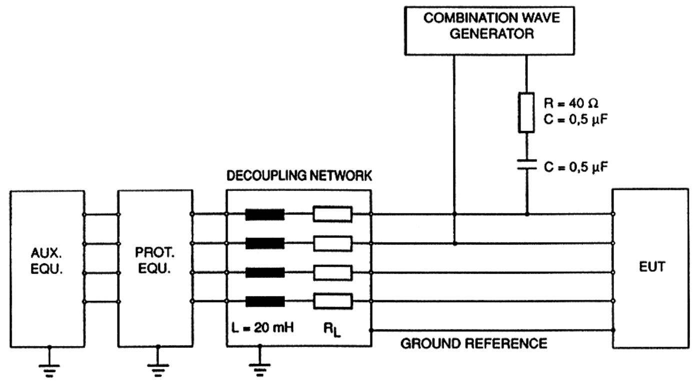



*Figure 16. Test set-up for unshielded interconnection lines; line to line coupling according to 7.3; coupling via capacitors.*

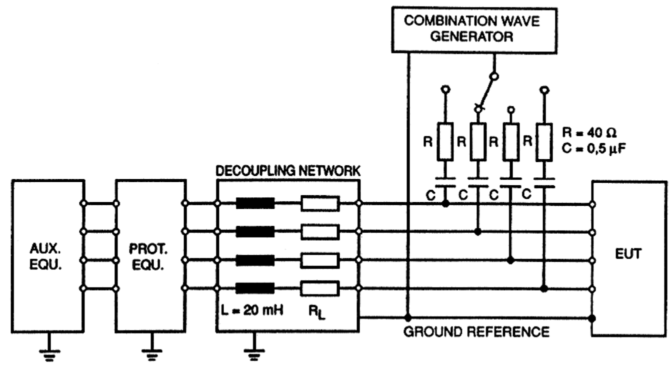



*Figure 17. Test set-up for unshielded interconnection lines; line to ground coupling according to 7.3; coupling via capacitors.*

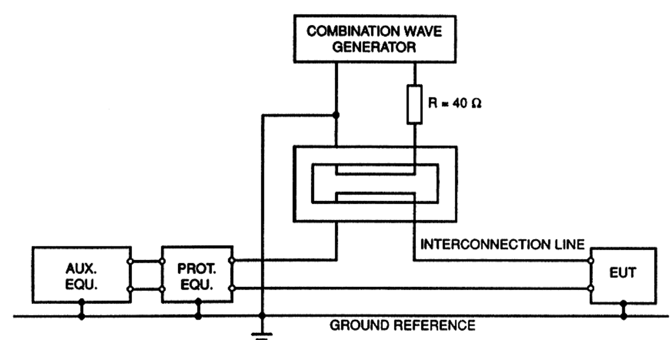



*Figure 18. Test set-up for unshielded interconnection lines; line to line coupling according to 7.3; inductive coupling for high impedance circuits.*

# IEC-1000-4 Application Note

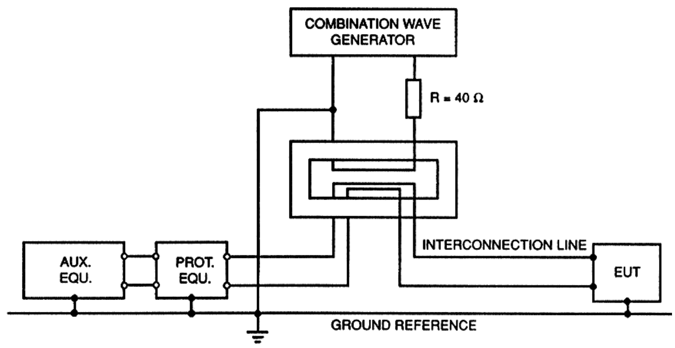



*Figure 19. Simplified test set-up for unshielded interconnection lines; line to ground coupling according to 7.3; inductive coupling for low impedance circuits.*

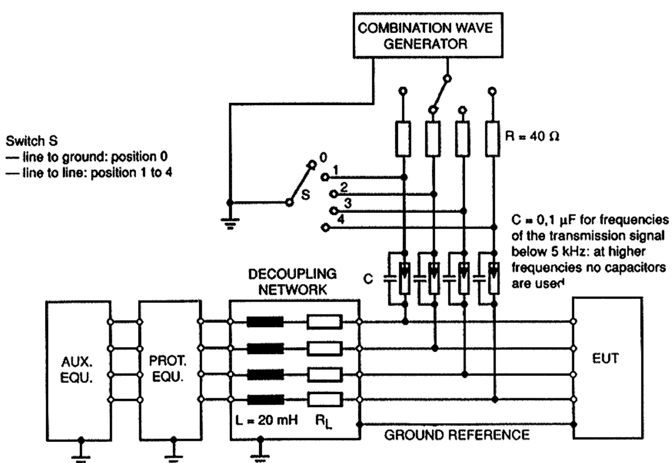



*Figure 20. Test set-up for unshielded unsymmetrically operated lines; line to ground coupling according to 7.3; coupling via gas arrestors.*

The test set-up for evaluating the unshielded symmetrically operated interconnection and telecommunication lines of the EUT is shown in Figure 21. The coupling is performed via a gas discharge tube (GDT) surge arrester.

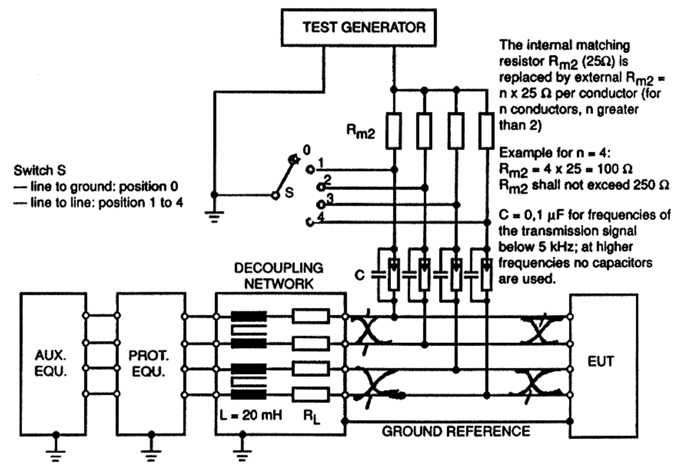



*Figure 21. Test set-up for unshielded symmetrically operated lines (telecommunication lines); line to ground coupling according to 7.4; coupling via gas arrestors.*

Two test configurations should be considered:

- Equipment level immunity test: 0.5kV or 1kV.
  The test shall be carried out in the laboratory on a single EUT. The voltage must not exceed the specified capability of the insulation to withstand high voltage stress.
- System level immunity test: 2kV or 4kV.
  The EUT used in the equipment level testing above is integrated with the rest of the system equipment used to simulate the actual installation configuration. The simulated system installation includes protective devices and the real length and type of the interconnection lines.
  This test is aimed at simulating as closely as possible the installation conditions. The test is also intended to show that secondary effects produced by the protective devices (change of waveshape, mode, amplitude of voltages, or currents) do not cause unacceptable effects on the equipment.

In order to test shielded lines, the test voltage/current shall be applied to the shields (housings) of the EUT's and to the connected shields of the lines. The test set-up used to apply potential differences is shown in Figure 22.

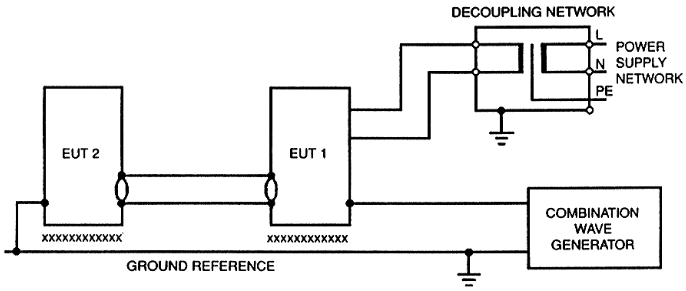



*Figure 22. Test set-up for tests applied to shielded lines and to apply potential differences according to 7.5 and 7.6; galvanic coupling.*

## Test Procedure

- Number of tests: at least 5 positive and 5 negative at the selected points.
- Pulse repetition: max. 1/min.
  The maximum repetition rate depends on the built-in protection devices of the EUT.
- The surge will be applied between lines and between lines and ground.
- All lower levels including the selected test level must be satisfied. For testing the secondary protection, the output voltage of the generator must be increased up to the worst case voltage break down of the primary protection.

## Test Results

The results of the test are reported as follows:

1. Normal performance within the specification limits.
2. Temporary degradation or loss of function or performance which is self-recoverable.
3. Temporary degradation or loss of function or performance which requires operator intervention or system reset.
4. Degradation or loss of function which is not recoverable, due to damage of equipment (component) or software, or loss of data.

## Application on CP CLARE for Products

Selection guide :

IEC 1000-4-2: Electrostatic Discharge (ESD)
IEC 1000-4-4: Electrostatic Fast Transient/Burst (EFT)

| Installation Levels | | Peak Severity Current | CP CLARE Solution |
|---|---|---|---|
| ESD | EFT | | |
| 1 | 1 | ≤10A | CG2 - PMT3 |
| 2&3 | 2 | ≤22.5A | CG2 - PMT3 |
| 4 | 3 | ≤40A | CG2 - PMT3 |
| - | 4 | 80A | CG2 - PMT3 |

IEC 1000-4-5: Surge

### On Signal Lines

| Installation Class | | | | Peak Severity Current | CP CLARE Solution |
|---|---|---|---|---|---|
| Unsym. Lines LDB | | Sym. Lines | DB SDB | | |
| Line-Line | Line-Ground | Line-Ground | Line-Ground | | |
| 2 | 1 | - | 2 | 12A | CG2 230L-PMT3 230 |
| 3 | 2 | 1&2 | - | 24A | CG2 230L-PMT3 230 |
| 4&5 | 3 | 3 | - | 48A | CG2 230L-PMT3 230 |
| - | 4&5 | 5 | - | 95A | CG2 230L-PMT3 230 |

LDB = Long Distance Bus
DB = Data Bus
SDB = Short Distance Bus

# How to Test Spark Gaps

Often, commercial equipment is not available to test spark gaps (GDTs). This Application Note describes how to design and build instruments for performing several of the more common tests.

## DC Breakdown Voltage

This is the voltage level at which the spark discharge occurs when the voltage across the gap is slowly increased. A linear ramp rate is usually specified and typically increases at a rate of 1000 volts per second or less. For most purposes, any adjustable voltage DC power supply (with adequate voltage output) can be used for DC breakdown voltage testing by slowly increasing the output voltage.

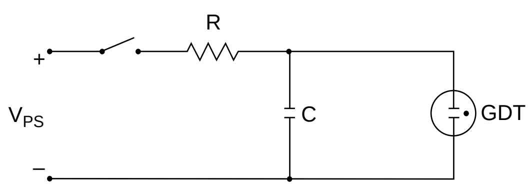



*Figure 1. Simple DC breakdown voltage test circuit using an R-C circuit to set the ramp rate.*

For more repeatability of the ramp rate, consider adding an R-C circuit to the output of the power supply as depicted in Figure 1. If the output voltage of the power supply is quickly increased to $V_{PS}$, then the voltage across the capacitor, $V_C(t)$, is given by:

$$V_C(t) = V_{PS}\,(1 - e^{-t/RC}) \quad \text{(eqn 1)}$$

The instantaneous ramp rate is given by:

$$\frac{dv_C}{dt} = \frac{V_{PS}}{RC}\, e^{-t/RC} \quad \text{(eqn 2)}$$

If equation 1 is solved for $e^{-t/RC}$ and substituted into equation 2, then

$$\frac{dv_C}{dt} = \frac{V_{PS}}{RC}\left(1 - \frac{V_C(t)}{V_{PS}}\right) \quad \text{(eqn 3)}$$

If the power supply voltage is set to 150% of the nominal breakdown voltage, then the quantity in parentheses in equation 3 is equal to 1/3 at breakdown. Substituting this into equation 3 yields

$$\left.\frac{dv_C}{dt}\right|_{@BDV} = \frac{V_{PS}}{RC} \times \frac{1}{3} = \frac{1.5V_{BDV}}{RC} \times \frac{1}{3} = \frac{V_{BDV}}{2RC} \quad \text{(eqn 4)}$$

If the circuit uses a 0.01µF capacitor and a 25MΩ resistor (with the spark gap to be tested connected across the capacitor) and a 375V power supply to test a 250V spark gap, then the ramp rate will be 500V/s according to equation 4. Equation 3 can be used to check the ramp rate for breakdowns different from the nominal value. For a 212.5V (0.85 x 250V) breakdown, the ramp rate using the values given above would be 650V/s. For a 287.5V (1.15 x 250V) breakdown, the ramp rate using the values given above would be 350V/s.

For a more linear ramp, we suggest using a power supply with remotely controlled output voltage (which can function essentially like an operational amplifier) controlled with a low voltage linear ramp generator.

## Impulse Breakdown Voltage

Building test equipment for impulse breakdown voltage testing is not as straightforward as for DC testing. One common approach is to use a pulse transformer (such as Clare's PT-5311). In its simplest form, the tester consists of a 0-500 volt DC power supply which charges a capacitor that is discharged through the primary of the pulse transformer. The gap under test is connected directly across the secondary of the pulse transformer. Coarse adjustment of the ramp rate can be accomplished by adding a capacitor (a few picofarad) across the gap under test. Fine adjustment can be accomplished by adjusting the output of the DC power supply.

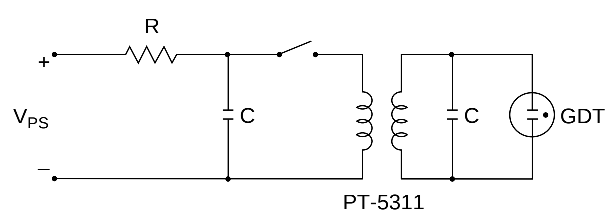



*Figure 2. Simple circuit for generating impulse breakdown voltage waveforms.*

Another common approach (especially for faster ramp rates) uses a high-energy spark gap (such as Clare's SB-4.0) as a switch to quickly discharge a capacitor with the test voltage existing across the discharge resistor as depicted in Figure 3. In this circuit, the ramp rate can vary greatly depending on the capacitor inductance and stray impedances.

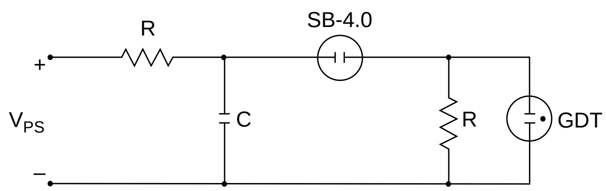



*Figure 3. Simple circuit for generating faster impulse breakdown voltage waveforms.*

## Insulation Resistance

To make this measurement at the rated voltage (often 100V, but never exceeding the breakdown voltage of the gap) requires specialized equipment. A megohmmeter can be used to directly measure insulation resistance. A power supply and a sensitive ammeter can be used to measure the leakage current at the rated voltage. Dividing the leakage current into the voltage will yield the insulation resistance. For example, if a gap with 100V across it yields a leakage current of 10nA, then its insulation resistance is 10GΩ (100V/10nA).

In situations where the insulation resistance limit is much lower (during life testing), insulation resistance measurements can often be reasonably made using a basic ohmmeter.

# Use of Triggered Spark Gaps

Triggered spark gaps such as Clare's TA and TB Series can be used for a variety of applications where low levels of control energy are used to rapidly switch high levels of stored energy. Typical applications include:

- Active switch in exploding bridgewire (EBW) systems
  - Ordnance firing
  - Rocket ignition
  - Oil field exploration
- Active switch in flash tube triggering
  - Provide high energy, high voltage trigger from low voltage, low energy control
- Active switch for capacitor bank discharging
- Electronic crowbar protection against current faults
  - Interelectrode arcs in magnetrons, TWTs, etc
  - Power supply components

The triggered spark gap is an electrical component that permits high levels of stored energy to be switched in fractions of a microsecond. These high levels of stored energy can be switched on command by low energy control pulses. Triggered spark gaps require no standby power, are relatively small in size, and are extremely rugged for severe environmental requirements. Ambient temperature, humidity, and pressure variations do not affect the electrical characteristics. Triggered spark gaps are designed to operate after long periods of shelf life without need of electrode conditioning.

## Modes of Operation

A triggered spark gap normally discharges energy through a pair of main electrodes[1]; triggered by a pulse applied to the trigger electrode relative to the adjacent main electrode. The four modes of operation, A through D, denote the four possible combinations of trigger pulse polarity (+/-) and main discharge polarity (+/-) as defined in the table below:

| Mode | Trigger Pulse Polarity (rel. to adj. main electrode) | Main Discharge Polarity (rel. to opp. main electrode) |
|---|---|---|
| A | + | + |
| B | - | - |
| C | + | - |
| D | - | + |

The positive trigger pulse and main discharge polarities of Mode A are depicted in the figure below:

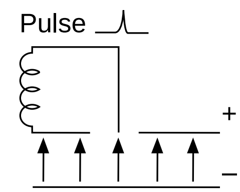



*Figure 1. Illustration of positive trigger pulse and main discharge polarity conventions (Mode A).*

Of the modes with a positive trigger pulse polarity (A and C), Mode A is the more commonly used -- largely because the time delay is usually shorter and the minimum trigger voltage is usually lower in this mode.

However, Mode C is often chosen over Mode A for practical reasons. In Mode A, the direction of the gap field is the same as that of the trigger field. For relatively high adjacent main electrode voltages, the discharge of the trigger may take place at the opposite electrode which results in very efficient coupling of the charged products into the main gap. Mode A requires that the secondary of the pulse transformer be floating above ground or capacitively coupled. In Mode C, however, one side of the pulse transformer secondary can be tied to ground (along with the adjacent main electrode) for greatly simplified operation.

Of the modes with a negative trigger pulse (B and D), Mode B yields shorter time delays and smaller minimum trigger voltages.

## Triggered Spark Gap Behavior in Circuits

As with two electrode spark gaps, the spark gap between the main electrodes of the triggered spark gap presents a near infinite impedance to the circuit when unfired. When voltage is applied across the main electrodes (less than the "self" breakdown voltage of the main electrodes), the circuit operation is unaffected by the presence of the triggered spark gap. When a sufficiently large trigger pulse is applied and the main discharge takes place, the tube drop (the voltage across the main electrodes) falls to values on the order of tens of volts for currents of up to several kiloamperes.

The source energy that is available for discharge in the gap circuit will be dissipated totally in the triggered spark gap unless series resistance is included. By the inclusion of series resistance, the use of lower energy triggered spark gaps may be extended to higher energy circuits. For example, a typical tube drop might be 30V for a peak current of 3kA with a resultant effective main gap impedance of 0.01Ω. Therefore, if a 1Ω resistor was installed in series with the main gap, the triggered spark gap would only dissipate about 1% of the available energy (if the peak current is unchanged).

The trigger voltage required to cause main gap breakdown decreases as the applied voltage increases. A typical relationship between the minimum trigger voltage required for reliable main gap breakdown and the voltage applied across the main gap is shown in Figure 2:

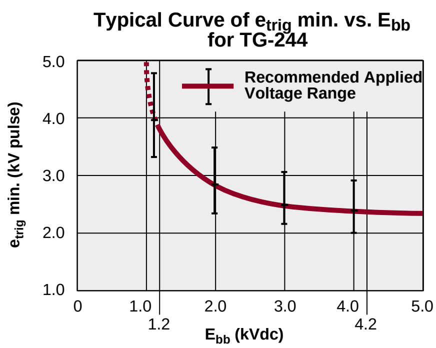



*Figure 2. Minimum trigger voltage versus applied voltage for reliable operation for a TA-5.0 .*

A typical electronic crowbar application is depicted in Figure 3A.

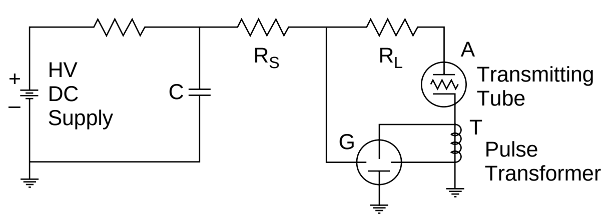



*Figure 3A. Typical electronic crowbar application.*

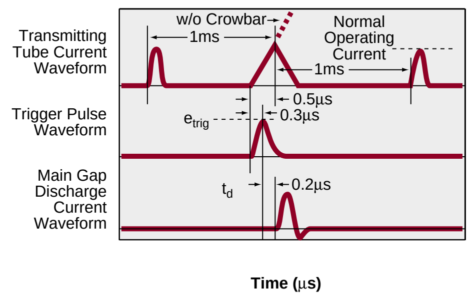



*Figure 3B. (B) Various waveforms of crowbar operation.*

A grid-to-plate arc in the high vacuum transmitting tube, A, creates a fast-rising current arc. When this occurs, the capacitor, C, can supply enough current to totally destroy the tube unless the plate supply is crowbarred in a sufficiently short period of time. The initial rise of the current surge through the primary of the pulse transformer, T, creates a pulse across the secondary of the pulse transformer that triggers the triggered spark gap, G. {Though depicted in Mode A or D (depending on the trigger pulse polarity), a ground-referenced pulse transformer could be used in Mode B or C by connecting the plate supply to the *opposite* main electrode and ground to the *adjacent* main electrode.}

The fault current waveform, the trigger pulse waveform, and the main gap discharge current waveform are shown in Figure 3B. Crowbarring of the plate supply is accomplished in a total time of 0.5µs. The time delay of the triggered spark gap is shown as 0.2µs and a delay in the pulse transformer is shown as 0.3µs. The magnitude and duration of the fault current have been sufficiently limited within the transmitting tube to be harmless and the energy stored in the capacitor has been dissipated in the triggered spark gap and the source resistance, $R_s$, instead of the transmitting tube.

Notes:

[1] Triggered spark gaps consist of three electrodes including the trigger electrode and two main gap electrodes. The Adjacent Main Electrode is the main gap electrode adjacent to the trigger electrode. The Opposite Main Electrode is the main gap electrode opposite from the trigger electrode.

# Use of Microwave Noise Sources

## INTRODUCTION

Noise sources are the element in a microwave RF system that make it possible to accurately measure the noise figure of the receiver or its components. The requirements of a device used for making such noise figure measurements include broad bandwidth inherent in the active element, stability, ease of operation, and long life. When the gas discharge tube is mounted and terminated normally, it presents a "white signal" of constant intensity over a bandwidth limited only by the system or mount. In general, the range of usefulness of these noise sources permits measurements of noise figures from about 2 to 30 dB. Existing mountings provide a useful frequency range of approximately 100 MHz to 220 GHz.

The noise tube and/or noise source should meet the following general requirements:

- When not operating, it should present a low insertion loss and VSWR to the system.
- When operating, it should provide an adequate signal level.
- Its output should be frequency independent, or at least known, over the prescribed bandwidth.
- Its output should exhibit minimum spurious oscillations.

## DEFINITIONS AND BASIC DISCUSSION

*Noise Source Tube or Noise Tube* — An electron tube filled with a rare gas (generally argon, neon, or a mixture) and operated in a positive column discharge mode at currents normally from 35 to 250 mA.

*Noise Source or Noise Generator* — A noise tube mounted in an appropriate waveguide or coaxial mount.

*Noise Power* — The available noise power from a noise source tube is essentially $kT_eB$ power coupled to the waveguide from the positive column of the discharge, where k is Boltzmann's constant, $T_e$ is the effective electron temperature of the discharge, and B is the bandwidth. To some extent, $T_e$ can be estimated by the method of von Engel and Steenbeck.[1]

In microwave power measurements, consideration is given to the noise temperature, $T_n$, which when multiplied by k gives the power per unit bandwidth of a noise source. $T_n$ is determined by comparison of the noise source against a thermal load.[2] Appropriate corrections must be made if the noise of the tube only is desired. Though $T_n$ is often considered equal to $T_e$, such an approximation has been shown to have limited usefulness and the noise temperature of an individual noise tube or complete noise source should be measured rather than calculated for accurate results.[3]

*Excess Noise Ratio {ENR or (Nr-1)}* — The most important characteristic in microwave measurements, the excess noise ratio, is the ratio of the difference between the operating and non-operating temperatures to the non-operating temperature (the latter of which is assumed to be 290K). (Nr-1) is this ratio expressed in dB as

$$(Nr - 1) = 10 \text{ x } \log_{10}\left[\frac{T_n - 290K}{290K}\right]$$

At common pressures and operating currents, (Nr-1) for an argon noise tube is approximately 15.5 dB and for neon is approximately 18.0 dB. The exact value for any noise source is influenced by the tube radius and pressure and, to some degree, by current.[4] The available noise from any given tube-mount combination depends as much on the characteristic of the mount and the method of coupling the tube into the mount as on any tube parameter.

*Noise Figure {F} and Y-Factor {Y}* — The noise figure of any network is defined as the ratio of signal to noise at the input to the signal to noise at the output[5,6] as

$$F = \frac{S_i / N_i}{S_o / N_o}$$

For calculation purposes, the input signal generated by the gas discharge noise source can be rewritten as $S_i = [S_i + N_i] - N_i$. The total input when the noise source is ON is $[S_i + N_i] = kT_nB$ as defined for noise power. When the noise source is turned OFF, the input is thermal noise of $N_i = kT_oB$ where $T_o$ is the operational temperature (290K). Therefore, $S_i = k[T_n - T_o]B$.

Again, for calculation purposes, the signal output of the device can be rewritten as $S_o = [S_o + N_o] - N_o$. In this case, $P_{ON} = [S_o + N_o]/B$ is the noise tube ON condition and $P_{OFF} = N_o/B$ is the noise tube OFF condition. Therefore, $S_o = [P_{ON} - P_{OFF}]xB$ and $N_o = P_{OFF}xB$.

Substituting into the noise figure equation above yields

$$F = \frac{k[T_n - T_o]B \big/ kT_oB}{P_{ON} - P_{OFF} \big/ P_{OFF}} = \left[\frac{T_n - 290K}{290K}\right]\left[\frac{P_{OFF}}{P_{ON} - P_{OFF}}\right]$$

The Y-factor is defined as $Y = P_{ON}/P_{OFF}$. The quantity in the second pair of brackets of the noise figure equation above can be expressed in terms of Y as

$$\frac{P_{OFF}}{P_{ON} - P_{OFF}} = \frac{1}{P_{ON}\big/P_{OFF} - 1} = \frac{1}{Y - 1}$$

Substituting this relation into the noise figure equation yields

$$F = \left[\frac{T_n - 290K}{290K}\right]\left[\frac{1}{Y - 1}\right]$$

or, expressed in dB,

$$F = 10 \times \log_{10}\left[\frac{T_n - 290K}{290K}\right] - 10 \times \log_{10}[Y - 1]$$

$$F = (Nr - 1) - 10 \times \log_{10}[Y - 1]$$

The last equation states that the noise figure of the system in dB is simply the excess noise ratio of the noise source, in dB, minus the value of (Y-1), in dB, as determined from a (Y) to (Y-1) logarithmic conversion. We now have the noise figure of the receiver defined in terms of all known quantities.

## TYPES OF OPERATION

*DC operation of filamentary cathode noise tubes* — The DC supply in Figure 1 is fed to the tube through an inductance, L, and current limiting resistances, $R_1$ and $R_2$. Upon closing the starting switch, SW, current flows through the inductance, resistance $R_2$, and the filamentary cathode. When the switch is opened, the collapse of the magnetic field in L provides a high voltage spike that ionizes the gas in the tube and establishes the discharge from anode to cathode. The anode current is then limited by $R_1$. SW must be capable of fast break operation and withstanding the high peak voltage developed. The DC supply must be capable of supplying the rated current at voltages greater than the tube drop.

The alternate configuration in Figure 2 uses a DC supply with a potential greater than the starting voltage to eliminate the need for the inductor and switch of Figure 1.

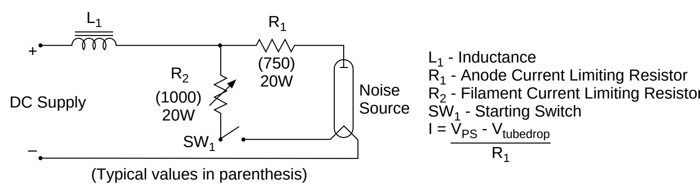



*Figure 1. Circuit for DC operation of filamentary cathode tubes.*

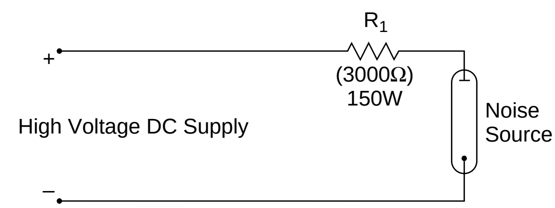



*Figure 2. Typical circuit for high voltage DC operation of noise tubes.*

*Pulse operation of hollow cathode noise tubes* —These tubes are capable of operating for hundreds of millions of starts. Primary parameters are pulse width, pulse current, and pulse repetition rate. The circuit in Figure 3 uses a high voltage transistor Q driven into saturation. The diode is added to help ensure discharge turn-off.

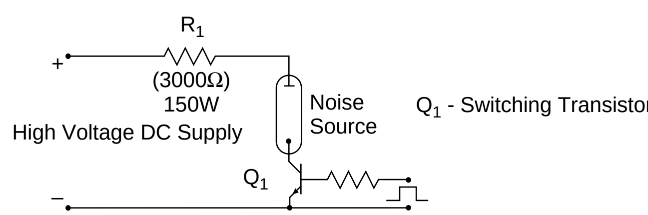



*Figure 3. Simple circuit for pulse operation of noise tubes.*

# Use of Microwave Noise Sources

The circuit in Figure 4 adds current regulation via feedback through a second transistor, $Q_2$.[7] The resistor $R_1$ reduces the power that the high voltage transistor $Q_1$, driven here in active mode, dissipates but it must be is sufficiently small in value to avoid saturating $Q_1$.

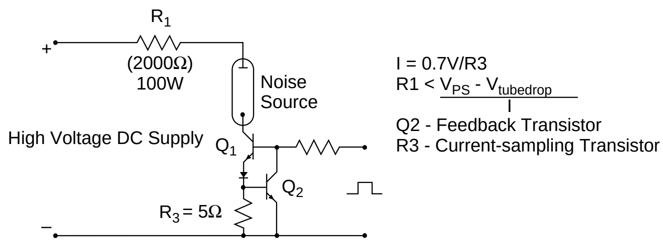



*Figure 4. Circuit for pulse operation of noise tubes with current regulation.*

*DC or pulse operation of indirectly-heated cathode noise tubes* — These tubes may be operated by the circuit in Figure 1 modified to include a continuous filament voltage (often 6.3VAC). The circuits in Figures 2 through 4 may be used without modification.

*Grounded anode operation* — For all previous methods of operation and cathode types, the polarity can be reversed when desirable so the anode may be operated grounded. In the circuit in Figure 1, under reversed polarity conditions, the inductor L would be moved to the cathode side as would the limiting resistor $R_1$. Similar modifications would be made to the circuits in Figures 2 through 4 with the NPN transistors replaced with PNP transistors.

The advantage of operating with a grounded anode is that the anode potential is distributed along the length of the tube by the metal tube holder of the mount which results in a 10-50% decrease in the starting voltage depending upon the particular tube type and mounting arrangement.

*AC operation of noise tubes with dual filamentary cathodes* — When operation directly from an AC source is desired and AC modulation of the noise is not objectionable, the circuit of Figure 5 is suitable. Transformer T must provide sufficient voltage to strike the discharge. L may be included in the transformer as leakage reactance but should be of a size to limit the average tube current to the specified value. SW can be eliminated if the secondary voltage of T is made high enough to provide a cold start without filament preheat.

Operation of a single-ended tube in this circuit will result in excessive anode heating with probable failure of the anode seal.

## OPERATIONAL PARAMETERS

*DC operation of filamentary cathode noise tubes* — In the circuits of Figures 1 and 2, these tubes generally require 700-2500V starting spikes, operate at anode currents of 50-250mA DC, and exhibit tube drops on the order of 40-150VDC. Their life under conditions of essentially continuous operation, with only occasional starts, is generally in excess of 8000 hours and may be as high as 20,000 hours. Their life under pulse conditions is short. The circuits in Figures 3 and 4 can also be used for DC operation.

*Pulse operation of hollow cathode noise tubes* — In the circuits of Figures 3 and 4, these tubes usually require starting spikes of 700-3000V, operate at peak currents from 75-175mA, and have tube drops of 100-250V. Under pulse conditions with duty cycles of up to 50%, their life is typically 2000-5000 hours. In general, under intermittent DC conditions, they have adequate life of at least 500-1000 hours.

*DC or pulse operation of indirectly-heated cathode noise tubes* — In the circuits of Figures 1 through 4, these tubes can be operated with very long life under either DC or pulse conditions. This particular cathode assembly utilizes an electrostatic shield around the cathode resulting in minimum ion bombardment of the active cathode surface area. The coated area is such that the maximum current density for any tube of this type is ultra-conservative. These tubes generally require starting pulses on the order of 500-2000V,

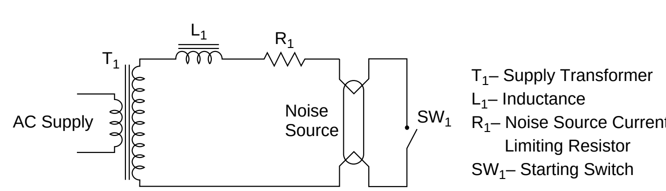



*Figure 5. Circuit for AC operation of noise tubes with dual filamentary cathodes.*

operate typically from 35-200mA DC or 50-150mA peak pulse, and have tube drops from 40-200V. Under intermittent DC conditions, life is generally in excess of 10,000 hours and may be as high as 50,000 hours. Under pulse conditions, at duty cycles up to 50%, their life is typically 3000-7000 hours.

*Grounded anode operation* — As mentioned previously, grounded anode operation reduces all starting voltage requirements.

*AC operation of noise tubes with dual filamentary cathodes* — In the circuit of Figure 5 driven by 60-400Hz sine waves, these tubes generally require starting voltages on the order of 1000-2500VAC, operate at currents of 100-250mA AC, and exhibit tube drops on the order of 40-150VAC. Typical life under 60Hz conditions is 100-1000 hours, depending on the circuit parameters.

## IONIZATION TIME

Because of the presence of the rare gas, there is a finite time required for the discharge to become stable in any gas discharge noise tube. In argon-filled tubes, the discharge will normally become stable in 50-150ms after the completion of the starting spike. For neon, these times are on the order of 80-300ms.

These times may be modified drastically by the drive circuit, however. If there is appreciable ringing in the circuit, or if the supply voltage is only slightly greater than the tube operating voltage at the rated current, the time for a tube to establish a stable discharge may be much longer. In general, by proper circuit design, these indicated times can be attained for any of the types of operation mentioned above.

The ionization time is an important factor in making pulsed noise figure measurements (discussed later in this note).

## DEIONIZATION TIME

Again because of the presence of the rare gases, these tubes have finite deionization times. In argon at 200mA current and 20 Torr pressure, the deionization times are on the order of 70-300ms, depending on tube diameter. In neon at the same current and pressure, deionization times are normally 150-500ms. These deionization times can be improved by the application of a slight negative voltage when the tube is being turned off, in a pulse application for example. Deionization times generally increase with current.

## MICROWAVE CHARACTERISTICS

*General considerations* — The level of the ENR that can be attained from any noise source is determined by the available ENR from the noise tube itself and by the coupling of the noise tube in the mount. The available ENR from the noise tube is determined principally by the type of fill gas, the gas pressure, and, to some small extent, by the tube current. The coupling in the mount is determined by the insertion angle of the tube through the mount, by the type of gas fill, and by the ratio of the tube diameter to the maximum guide dimension.[8] The coupling is also affected by the gas pressure and the tube current. The mounting is so important that the success with which any combination of noise tube, mount, and termination meets the general requirements at the end of the Introduction section of this note depends as much on the mounting method as on any other single feature.

*Mounting methods* — The most common methods and their relative advantages and disadvantages include:

- 0° to 30° E-plane insertion
  Advantages include extremely broad bandwidth (within the tolerances of the ENR specified for tube-and-mount, this style of mounting yields a frequency independent noise source), very low VSWR, very low non-operating insertion loss, and high operating insertion loss (therefore, very little reduction in the available ENR[9] from the noise source itself). Disadvantages include relatively large size, high voltage starting spike, and relatively high tube drop.
- 90° E-plane insertion, transmission-type
  Advantages include fair VSWR, very small size, low voltage starting spike, low tube drop, and low non-operating insertion loss. Disadvantages include low operating insertion loss (therefore, appreciable reduction in the available ENR), and relatively narrow bandwidth (~10-20%).
- 90° E-plane insertion, shorted-type
  Advantages include small size, low voltage starting spike, low tube drop, and high operating insertion loss (therefore, negligible reduction in the available ENR). Disadvantages include poor

# Use of Microwave Noise Sources

VSWR and very narrow bandwidth (~5-10%).

- 90° H-plane insertion, transmission-type
  Advantages include low non-operating insertion loss, fairly small size, good non-operating VSWR, and moderate voltage starting spike and tube drop. Disadvantages include poor operating VSWR, low operating insertion loss (with a resultant reduction in the available ENR), and very narrow bandwidth.
- Coaxial, helix-coupled
  Advantages include permitting the use of noise tubes originally designed for waveguide bands down into the UHF region, relatively broad bandwidth, good operating insertion loss, relatively good operating VSWR, and fair non-operating insertion loss and VSWR in the prescribed bands. Disadvantages include relatively large size, high voltage starting spike, and relatively high tube drop.
- Coaxial, direct-coupled
  The advantages and disadvantages of this type are the same as for the helix coupling except that the direct coupling approach, with the toroidal cross section tube family used in this approach, presents much lower non-operating insertion loss than the helix coupling approach. Since these types are almost all transmission types used directly in front of the receiver, the low non-operating insertion loss yields two advantages. First, there is less attenuation of the incoming signal during system operation and, secondly, there is no correction necessary to the available ENR as a result of significant non-operating loss.[10]

*Comparative noise measurements* — Comparative noise measurements are made by Clare in a test system shown schematically in Figure 6. Since these measurements depend ultimately on the stability of the gain set (which can be checked by visual observation of the output meter over a period of time long compared with the measurement time), the tolerances to which Clare ENR specifications are written are at least five times greater than the system capability.

*System noise figure measurements* — Noise figure has been summarized completely by Mumford and Scheibe[11] and reviewed in the Definitions and Basic Discussion section earlier in this note. Our discussion here will be concerned only with precautions to be taken with pulsed noise sources in making noise figure measurements.

The voltage and current curves of Figure 7 show typical pulsed tube performance as a function of time. The voltage across the tube rises to a very high value, at which point the tube breaks down. The voltage then falls to almost zero and, eventually, stabilizes at the tube drop after several tens of microseconds. The current usually stabilizes faster than the tube drop.

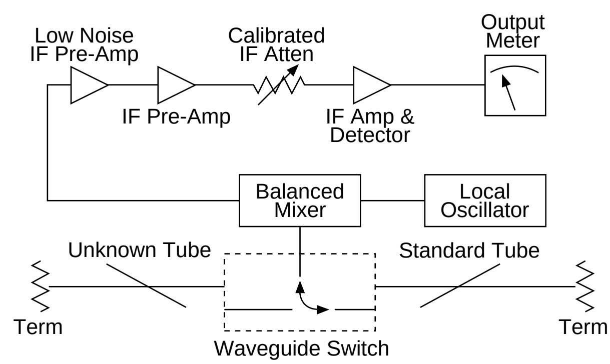



*Figure 6. Schematic diagram of set-up for measuring ENR.*

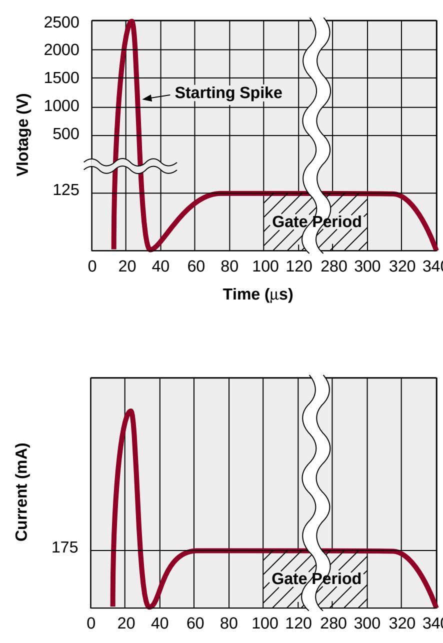



*Figure 7. Typical voltage and current waveforms for TD-72 pulse type noise tube (argon filled).*

If the "on" time of the receiver gating period starts too soon, there will be a fraction of the total gate period during which the noise power will not have the rated noise output of the tube at the given current because the tube drop, and consequently the field in the positive column, will not have been stabilized. Whenever possible, therefore, the total gating period should be long, ideally a few hundred microseconds, and the initiation of the gating period should be delayed as long as possible following the high voltage starting spike.

Another consideration is that the gating period during which the receiver looks at the cold, non-operating, noise source should be as long as possible after the main transmitter pulse (for a unit being used in the transmitter arm through a directional coupler) so that the lapsed time definitely is long compared with the deionization time of the tube.

Finally, use of a noise source for which there is the smallest possible difference between the operating and non-operating match is important when the noise source is the element being viewed as the cold reference for the system.

*Variations with tube current*—Since a change in current causes a slight change in tube drop, and thereby a slight change in the field in the positive column, there is a small correction to the ENR of a tube as a result of an actual change in the effective electron temperature. Further, there is an additional small change to the available ENR from the tube-in-mount as a result of the changing insertion loss caused by the change in current.

- Noise vs. current
  For most noise tubes, there is a decrease in ENR with current of 0.003-0.005 dB/mA.
- Tube drop vs. current
  For most noise tubes, the tube drop tends to decrease about 0.13-0.26 V/mA.
- Insertion loss vs. current
  Nominal values of operating and non-operating insertion loss for argon noise tubes in specific waveguide mounts are given in Table 1. Also, the tube-to-tube variations of operating insertion loss for typical operating insertion loss values of <20dB, 20-30dB, and >30dB are ±0.2-0.6dB, ±0.4-1.0dB, and ±1-3dB, respectively.

*TABLE 1. Cold and Hot Insertion Loss for Argon Noise Sources*

| Band | Types (TD-) | Mount & Meas't Freq (GHz) | Typical Insertion Loss (dB) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | I = 0 | 125 | 150 | 175 | 200 | 250mA DC |
| S | 12,38 | WR-284, 10°E; 3.3 | 0.12 | 12.3 | 13.5 | 14.0 | 14.5 | 15.1 |
| C | 10,39 | WR-187, 10°E; 5.5 | 0.11 | 14.8 | 16.9 | 17.3 | 18.8 | 20.8 |
| J | 10,39 | WR-137, 10°E; 7.0 | 0.16 | 20.4 | 22.8 | 23.8 | 25.4 | 28.1 |
| X | 40 | WR-90, 10°E; 9.0 | 0.18 | 18.2 | 20.8 | 22.8 | 24.4 | 26.0 |
| X | 11,72 | WR-90, 10°E; 9.0 | 0.06 | 23.2 | 25.7 | 27.6 | 29.5 | 32.2 |
| Ku | 18,41 | WR-62, 10°E; 16.0 | 0.07 | 32.0 | 37.9 | 44.1 | 51.0 | 54.5 |
| K | 13,42 | WR-42, 10°E; 24.0 | 0.10 | 25.8 | 31.7 | 37.8 | 44.0 | 57.5 |

# Use of Microwave Noise Sources

## APPLICATIONS AND GENERAL OPERATING NOTES

*Determination of the noise figure* — This is the basic use of noise sources; for either a single component or an entire system. This determination stems from the relation: (F) = (Nr-1) - (Y-1), where (F) is the system noise figure, (Nr-1) is the ENR of the noise generator, and (Y) is the output meter reading; all quantities in parentheses being in dB and $Y = 10^{[(Y)/10]}$. See the Definitions and Basic Discussion for more detail.

Noise sources are the basic component of noise figure test sets. They are also used as built-in receiver monitors in radar systems directly in the receiver and/or antenna arms as depicted in Figure 8.

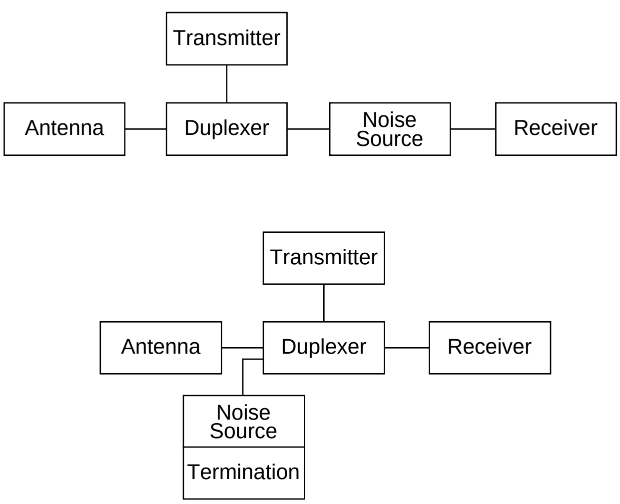



*Figure 8. Block diagrams of noise sources in (A) the receiver arm and (B) the antenna arm of a radar system.*

*Polarity* — Since all noise sources are polarized devices, except those specifically designed for AC operation, they should never be operated in reverse. Under conditions of reverse operation, the life will be extremely short with failure due to anode seal breakage as the result of excessive heating.

*Ambient temperatures* — All rare gas filled noise tubes can be operated over a temperature range of -55°C to +125°C. Some noise sources cannot be operated over this entire range because built-in shorting plates or terminations may present temperature-dependent characteristics.

*Life* — The life of a noise tube depends principally upon the type of cathode, the mode of operation (CW or pulse), and the gas pressure. Under CW conditions, the indirectly heated cathodes exhibit extremely long life because their surface area is such that the current density is ultra-conservative. Similarly, the filamentary cathodes are conservatively rated with respect to current density.

Under pulse conditions, again the indirectly-heated cathodes have very long life for two reasons. The first is the lower starting spike required in a tube with this style cathode and the resulting drastically reduced ion bombardment of the cathode during the starting spike. The second is the conservative design with respect to the current density. The hollow cathodes exhibit good life under pulse conditions because the design of these cathodes causes the cathode coating which is sputtered during the starting spike to be re-deposited on another part of the cathode between pulses. Filamentary cathodes typically last only a few hundred thousand discharges of normal starting spikes. In a typical pulsed noise figure setup operating at a rate of 500 pps, one hundred thousand pulses are achieved in less than one hour. Therefore, this type cathode definitely is not recommended for pulse operation.

The principal mode of failure of gas discharge noise tubes is loss of cathode coating with its consequent increase in tube drop and starting voltage. The second failure mode is gas pressure reduction with its consequent change in tube drop and ENR.

Fortunately, the changes in tube drop and starting voltage occur long before there is any significant change in gas pressure. If the starting voltage increases by 20% or if the tube drop increases by 10%, end-of-life may be considered as having been reached. Within this period of time, negligible change in the ENR will have taken place.

*For noise tubes with filamentary or indirectly-heated cathodes*—For argon-filled noise tubes with indirectly-heated cathodes, the life is in excess of 10,000 hours and may be as long as 50,000 hours when operated DC. The life drops to 3000-7000 hours when pulse operated.

For argon-filled noise tubes with filamentary cathodes, the life is in excess of 8000 hours and may be as long as 20,000 hours when operated DC.

Neon-filled noise tubes with either type of cathode have roughly half the life of similarly constructed and operated argon-filled noise tubes.

*For pulse-operated noise tubes with hollow cathodes-* For argon-filled noise tubes, the life is typically 2000-5000 hours. For neon-filled noise tubes, the life is typically 1000-2000 hours.

*For AC tubes with dual filamentary cathodes*—Though usually rated for 100 hours of operation under 60-400Hz conditions, the life is typically on the order of 500-1000 hours with as little as 0.05-0.10dB change in the ENR.

*Notes:*

[1] A. Von Engel and M. Steenbeck, *Electrische Gasentadungen,* Springer, Berlin, vol. 2, p. 86; 1939.

[2] J. S. Wells, et al, “Measurement of effective temperature of microwave noise sources”, *IEE Trans on Instr and Meast*, vol. IM-13, No. 1, pp. 17-28; Mar 1964.

[3] K. W. Olsen, “Measured noise temperature vs theoretical noise temperature for gas discharge noise sources”, *IEEE Trans Micro Th and Tech,* Vol. MTT-16, No. 9; Sept 1968.

[4] *Ibid.*

[5] C. K. S. Miller, C. W. Daywit, and M. G. Arthur, “Noise standards, measurements, and receiver noise definitions”, *Proc IEEE,* Vol. 55, No. 6, pp. 865-877; Jun 1967.

[6] W. W. Mumford and E. H. Scheibe, Noise Performance Factors in Communications Systems, Chapters VI-VIII, Horizon House, Dedham, Mass.; 1968.

[7] R. B. Bartlow, et al, “Increased analytical precision in the hollow cathode discharge source by improved discharge current control”, *Anal Chem,* Sept 1991.

[8] H. Johnson and K. R. deRemer, “Gaseous discharge super high frequency noise sources”, *Proc IRE,* vol. 39, pp. 908-917; Aug 1951.

[9] W. D. White and J. G. Greene, “On the effective noise temperature of gas discharge noise generators”, *IRE Corres,* pp. 939, Mar 1956.

[10] *Ibid.*

[11] Mumford and Scheibe, *loc. cit.*