TRANSIENTS

Definition of a Transient

Webster's Dictionary defines a transient as something "passing quickly into and out of existence". This definition is applicable for momentary electromagnetic transients which are the subject of this paper. The transient suddenly appears, seemingly lasts only a moment, and then is gone. Their peak applitudes can be very small, or can be measured in the thousands of volts. A bolt of lightning, which is a sudden static discharge, is a transient.

An electrical engineer will define transient terms as physical quantities necessary to preserve the dynamic equilibrium expressed by Kirchhoff's potential laws, during the period of transition from one mode of circuit operation to another. This is due to the fact that the current in any inductance and the potential of any capacitance cannot change instantaneously. Kirchhoff's potential laws for a circuit composed of constant series parameters are as follows:

$$e = L\frac{di}{dt} + Ri + \frac{1}{C}\int idt \qquad (1)$$

$$e = L\frac{d^2q}{dt^2} + R\frac{dq}{dt} + \frac{q}{c} \qquad (2)$$

As an example, consider the simple case of a battery, perfect switch, and an inductor as shown in figure 1.

For this example, it is assumed that the inductor has a small resistance R which limits the DC current in the steady state condition while the switch is closed. It is also assumed that the inter-winding capacitance of the inductor is negligible. The instant the switch is opened, the current very rapidly decreases and a large negative di/dt is created thus a transient. This can be expressed as:

$$e = -L\frac{di}{dt} + Ri \qquad (3)$$

Inductive kicks such as illustrated above and the general effects of suddenly collapsed magnetic fields produce transients ranging from subaudio to megahertz region depending on the effective inductance and capacitance in the path of the current produced by the collapsing field. The resistance in the path controls the damping, which in turn controls the envelope of the oscillatory discharge.

Frequency Spectra

High-frequency transients frequently have a spectrum that extends into the megahertz region. These pulse widths are so narrow that they exceed the response time (rise time) of today's circuitry. As transistor and tube capability is extended upwards into the 1000-MHz region these transients will prove troublesome. If the frequency of the carrier is high, an intermittent burst of CW interference has the effect of a transient. Its waveform is detected by nonlinearities in the circuits into which it couples. Continuous wave interference will also appear as a transient when its path of propagation is intermittent or transient.

Harmful Effects of Transients

If the transient were completely contained at its source, (i.e. at the relay) the harmful effects of the high voltage spike would be limited. However, the transient has many means of propagation and can be measured at remote points throughout a system.

TYPES OF INDUCTIVE SUPPRESSION	VOLTAGE INPUT	RELAY CONTACTS CLOSING	DROPOUT	REMARKS
A RESISTANCE DAMPING	AC or DC	NO EFFECT	FUNCTION OF RESISTANCE	Increase in power consumption. Resistance should be as low as practicable. Observe power rating E^2/R and heat dissipation.
B CAPACITANCE SUPPRESSION	DC	SLIGHT EFFECT	SLIGHT EFFECT	Need series resistance of a few ohms. Capacitance value around .01 to $1\mu f$. Capacitance rated 10 times input voltage.
C RC SUPPRESSION	DC	SLIGHT EFFECT	FUNCTION OF RESISTANCE	Combination of A and B above.
D DIODE SUPPRESSION	DC ONLY	NO EFFECT	SLIGHT EFFECT	Polarity critical, diode put in backward or nonconductive direction. PIV should be higher than any transient voltage plus safety factor. Series resistance of a few ohms might be needed to increase inductance life.
E BACK-TO-BACK DIODE SUPPRESSION	AC	NO EFFECT	NO EFFECT	Avalanche voltage should be above input voltage. Power dissipation should be sufficient for transient current. Cost of device is much greater than any of the above divices.

Figure 1: Comparison of Various Suppression Devices Across an Inductor

Active solid state components can readily be damaged by unwanted transients. Diodes and transistors which have rated peak-inverse voltage ratings less than the peak value of the transient will go into the avalanche condition and/or will be burned out. Meters can be damaged after being pegged. Digital and analog systems are especially susceptible to transients since the spike may be interpreted as a digital pulse. Computers' registers have been known to shift due to the transient from the cycling of air conditioners. The many undesirable effects which result from transients, are too vast in number to be presented in this article.

Suppression Devices

Figure 1 shows the various suppression devices that can be used across coils to minimize transients. A properly matched RC circuit across an inductive load should make the load appear as a pure resistance. The resistance R in series with the capacitor should be 1/4 to 1/2 of the DC load or coil resistance. The value of the capacitance C can then be found with:

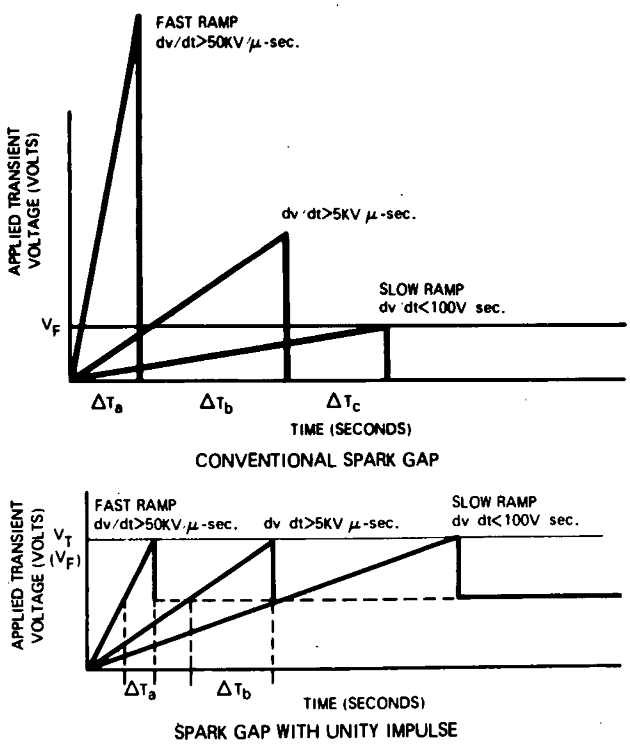

Figure 2: In a conventional gas-filled spark gap (top), the trip voltage increases as the ramp rate of the transient pulse increases. Extremely fast pulses may damage or destroy components or circuitry because of the high firing level of the conventional gap. With a gap that has a 1:1 impulse ratio (bottom) no variation in the trip voltage is experienced regardless of the rate of rise of the transient pulse.

$$RC = L/R_L \qquad (4)$$

where:

L is the inductance

R_L is the DC resistance of the load.

If R is chosen as 1/4 R_L, C can then be found with:

$$C = 4L/R_L \qquad (5)$$

If the computed capacitance is very large, use the closest practical smaller capacitor. Capacitance between .01 to 1 μf is usually sufficient to minimize most transients.

For more information on Transient suppression, see Signalite on page 3.

SPARK GAPS

There is quite a variety of devices which fall within the category of "spark gaps." The spark plug in your car is a spark gap using air as the dielectric. The carbon block type of surge arrestor, familiar in electric utility and telephone applications, also uses air as a dielectric. In this discussion we shall confine ourselves to the gas-filled type of device which contains two or more electrodes sealed in a chamber filled with various gas mixtures. Because of its unique characteristics this type of device has two basic applications in electronic and electrical circuitry: as a protective device to prevent damage to circuits and components against sudden voltage overloads, and as a high energy voltage sensitive switch.

Spark gaps are cold-cathode discharge devices which operate as high energy, short duration, low loss switches. Normal operation is in the arc mode with tube drops (operating voltage during current conduction) in the order of tens of volts for currents in hundreds to thousands of amperes.

For many years designers of electronic equipment have turned to the spark gap as a last resort when some internal fault or externally applied power surge has caused a failure or threat of failure in the equipment. Recent developments and progress in the design and process control of hermetically sealed spark gaps now provide the equipment designer with components for protective or active switching in his circuit which can reduce the cost of his equipment and improve its reliability.

The spark gap, as a protective or energy transfer device, is a switch which presents very high unfired impedance, 10^9 ohms or greater, to a circuit and low operating impedance (ohms or fractions of an ohm) in its normal operation. High and low voltage switching requirements in electronic equipment vary from fast acting protection of other components during fault conditions to transfer of energy under controlled conditions.

Spark Gap Operation

Operation of the spark gap occurs when the voltage applied is sufficient to ionize the gas in the envelope permitting a discharge from one electrode to the other. The degree of ionization is a direct function of the current through the gap during operation. Since the amount of current available is proportional to the source impedance, the "turn-off" of the gap is dependent upon the source impedance. Deionization requires a finite amount of time and is dependent upon the current level of the previous pulse, i.e., the higher the current, the longer the turn-off time. In a situation where voltage is reapplied quickly, such reapplication may find the gap not fully deionized and the gap would break down at a lower voltage level. If the source impedance is low enough to maintain conduction through the gap, provision must be made for circuit interruption before excessive energy is dissipated in the gap, ultimately destroying the unit. Spark gaps are typically designed for short term operation and should not normally be used on long duty cycle applications.

A term that is often heard in descriptions of spark gaps is "impulse ratio." This is the ratio between the voltage at which a gap fires in the presence of a steep wavefront (rapid pulse) and the voltage at which the gap fires on a slowly rising DC voltage. A ratio of unity (1:1) means that the device will trip at its rated breakdown voltage regardless of the rate of rise of the wavefront of the transient. (Note: Breakdown voltage, firing voltage and trip voltage are synonymous terms referring to the point at which the gap begins to conduct and are used interchangeably throughout this discussion.) Impulse ratios greater than 1:1 define the amount of overshoot the gap will permit before tripping when the wavefront is very steep. See Figure 2.

The material on Spark Gaps was excerpted with permission from application notes published by Signalite, Neptune, N.J.

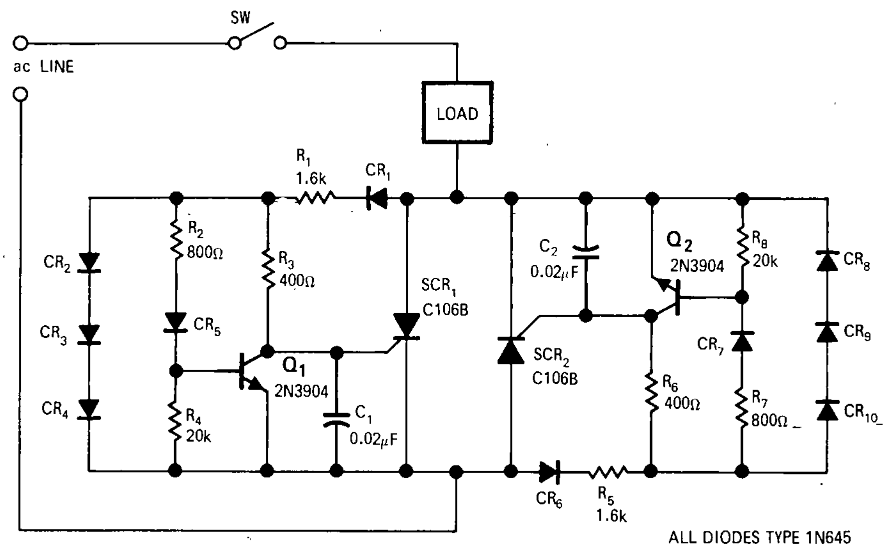

Figure 3. Simple Zero-Crossing Switch

Impulse ratio is of critical importance to the designer who is using a gap to protect sensitive components. The impulse ratio of some gaps can be as high as 10:1. Such a poor impulse ratio could easily permit destruction of the circuit or component it is supposed to protect since harmful spikes with steep wavefronts can by-pass the gap before it can operate. If the gap is chosen on the basis of its high impulse ratio, transients with slow wavefronts will cause the gap to trip prematurely at lower voltages causing unnecessary shut-down of the circuit. Obviously, the closer the impulse ratio is to unity (as shown in Figure 2), the more reliable will be the protection.

Zero-Cross Switch

A zero-crossing switch eliminates the high surge currents and transients that normally occur when switching line voltage to a load. For example, the surge current in an incandescent lamp that is switched on at peak line voltage is many times the peak current for a lamp switched on at a zero crossing. A simple zero-crossing switch design in shown in Figure 3. It is line-voltage powered and has low enough dissipation for fabrication as an integrated circuit.

Measuring Transients

Transient detectors are frequently self-contained units within the probe which measures and holds the peak amplitude. Some units operate continuously, unattended, and provide hard copy data which is calibrated in dB above a particular reference. Current transients, appearing in one or more conductor cables, may be sensed by a current probe and fed to the transient detector. A high-impedance probe, operated as a two-terminal voltmeter, may be connected across a conductor to drive a transient detector. Typical applications include EMI cable wire transient identification, permanent recording of power-line transients; spacecraft and aerospace systems checkout; environmental shock, vibration and temperature peak recordings; DC bus transient measurements; maximum switching currents during actuation of control circuits; and related measurements requiring memory of signal conditioning for recording on low-frequency readout devices.

The transient detector and recorder may also be used to provide time-domain, radiated-field measurements. For example, a high-impedance probe may be directly connected to a monopole antenna for the purpose of sampling electric-field peak signals in a local area for EMI culprit identification or for lightning and high-voltage discharge measurements. For magnetic field measurements, a loop or a ferrite probe may be connected to the input of a transient detector to permit culprit source location and identification preparatory to performing EMI fixes. While not an EMI problem, acoustic transient data can be obtained by using a microphone as the sensor feeding a transient detector. This arrangement is useful in determining the peak amplitude of acoustical noise sources such as aircraft jet engines, sonic booms, missile skin noises, factory machinery noise levels, and other high-engery, broadband acoustical sources.

When it is desired to record transients as low as 1 mV, such as required for some EMI applications on signal circuits or power buses, a base-band logarithmic amplifier is driven from the wideband FET amplifier. It provides 20 dB gain to 1 volt signals when no RF attenuation is inserted, and 60 dB gain to 1mV signals. Outputs correspondingly swing from 1 to 10 volts to drive a peak detector. When the transient detector is designed to accommodate peak voltages of not less than about 0.5 volts, the logarithmic amplifier may then be a D-C type and follows the peak detector rather than precedes it. In either event, a log amplifier is important since it is generally desired to measure transients over a 60 dB range (e.g: 60 dBuV to 120 dBuV as in the above EMI example. or 1 uV to 1,000 uV for power-line applications).

The peak detector has a rise time faster than that of the preceding amplifiers, or typically from 10 to 1000 nsec. It stretches pulses to result in a decay time of about 1 sec so that handover, without amplitude integration loss, can be made to a very in-expensive strip-chart recorder having typically a 1 Hz response. To permit coupling to a wide variety of recorders, the peak detector and stretcher feeds a coupling amplifier having a high input and low output impedance.