INSTRUMENTING SURGE TESTS FOR CIRCUITS AND SYSTEMS

Surge Test Wave Types

A wide variety of waves exist in the literature for simulating electromagnetic surges of various kinds. One reason for the different shapes is, naturally, the assumed source of the disturbance—lightning, EMP, switching and so forth. A second reason is the different application areas involved, including a long list headed by telecommunications, power, aircraft and auxiliary lines of many kinds. A third reason is that some of the data have been taken with test equipment of limited capability by today's standards. Hence some information of even recent vintage may have been test-equipment-limited, particularly when fast rise times are involved.

Still a fourth reason has surfaced of late. It may not be widely appreciated, however, and may even be partially misunderstood. It is the classic distinction that must be drawn between two basically different levels of failure:

1. *susceptibility* to malfunction, and
2. *vulnerability* to damage.

If even one malfunction must be avoided—as with auto-pilot zero settings, automatic alarm systems and anti-skid automotive and aircraft braking devices as examples—then *susceptibility* tests to anticipated types of surge interference will be required. But if equipment malfunction—like static on a communication channel—can be tolerated during a surge so long as performance automatically returns to normal immediately thereafter, a *vulnerability* test is sufficient; i.e., total failure of component or system is all that need be tested for.

The point sometimes missed is that vulnerability tesing is *always* required in *either* case, to insure against total equipment failure. Naurally, it will ordinarily be carried out at higher power/energy/voltage levels than mere susceptibility testing. The misunderstanding referred to above, relates to possible misuse of rather mild and limited rf-type susceptibility tests when higher-power vulnerability tests should be recognized as a *simultaneous* requirement. That is, even if susceptibility tests must be run, vulnerability tests cannot be ignored. Passing the first *in no way* guarantees passing the second—or vice versa, for that matter.

This susceptibility/vulnerability confusion may also help account for the apparent discrepancies between certain MIL specs, with emphasis on long pulses and apparent lack of emphasis on leading edge or attack characteristics let alone ac surges, versus far greater attention to these high-frequency characteristics evident in field studies including those specifically relating to aircraft transients.

At least four basic types of surge test waves can be defined: impulsive, linear ramp or front-chopped impulse, ringing or ac, and finally arc- or breakover-type. Figures 1, 2, 3 and 4 show representative waves of all four types respectively, as generated by modern instrumentation specifically designed for surge simulation and test.

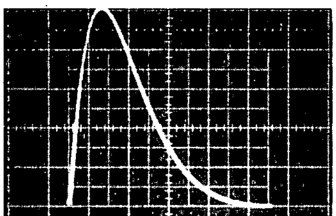

Figure 1
Impulse Wave, 8 × 20
1000V Peak, 5μsec/div

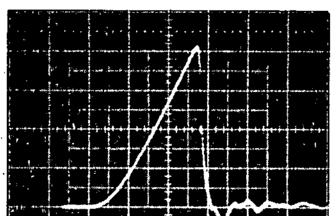

Figure 2
Front-Chopped Impulse, 10 kV/μsec
100 V/div, 20 nsec/div

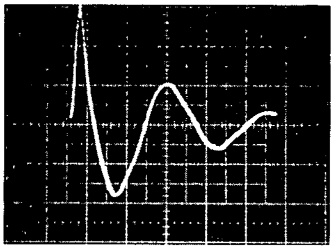

Figure 3
100 kHz AC Surge, 6 kV Peak
(500 kHz Leading Edge)
Successive Peaks Down by 40%
1 kV/div, 2 μsec/div

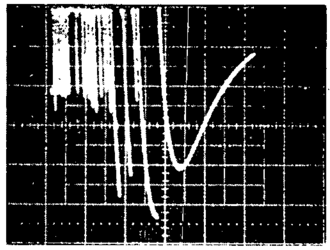

Figure 4
Arc or Breakover Wave
5 kV Peak

For all of the wave types, critical amplitude parameters include peak voltage and total pulse energy; others may sometimes include peak power and peak current. Important time parameters include leading-edge characteristics, duration or time to decay, frequency and finally decay or chop time for truncated waves.

Depending on circuit configuration and the components involved, a given wave characteristic can result, effectively, in either a susceptibility or a vulnerability test or both. Without a specific circuit analysis, it is ordinarily impossible to say. However it is *generally* true that amplitude parameters are typically used to define limits of vulnerability, while time parameters most often perform the susceptibility portion of the testing function. (An important exception can occur for devices that are rate-of-rise dependent: gas tubes, SCR's, etc.)

Some waves—the 10 × 1000 of telecommunications usage for example, seem almost specifically designed for vulnerability tests—knockout blows in effect. They have relatively slow edges, and long durations to provide plenty of energy—tens or hundreds of joules. This makes good sense for a telecommunications plant where susceptibility may be of relatively lower concern. It *also* makes good sense, however, as pointed out above, for those instances in which susceptibility is of utmost importance—since vulnerability must be verified too.

Other waves, including some ringing types, have extremely low energy content—one or two tenths of a joule. They nevertheless have significant high-frequency content, albeit usually at only one frequency, hence seem specifically aimed at susceptibility.

Still other waves, notably the 8 × 20 and 1.2 × 50 impulses, fast linear rate-of-rise chopped impulses like 10 kV/μsec (when gas-tube chopped), and the ringing 100 kHz proposed UL wave for ground-fault-interrupter testing, can perform both susceptibility and vulnerability testing in sequence or simultaneously, depending on the amplitude parameters selected for the test program.

So if there is a key word for needed surge test waves, it is *variety*. As new ones continue to be discovered and developed, test instrumentation must be highly versatile in order to forestall early obsolescence or limited applicability.

Pulsed-Energy-Handling Capabilities: Components and Protectors

Energy—designated W and measured in watt-seconds or joules—may not be as familiar a parameter as voltage, current or power. Semiconductors, even husky ones like power SCR's, can be wiped out with millijoule pulses if applied just right (or just wrong!). More delicate semis can withstand pulses only at the microjoule level. For another point of reference it is useful to look at the pulse energies ordinary carbon composition and metal film resistors can repetitively withstand. Table 1 summarizes data on these types from two particular sources. Note the vast disparity between pulse-energy-withstand ruggedness for the two different resistor constructions. For a 1-watt nominal rating, for example, carbon comp can handle 9 joules, film only 1/60 of a joule—the film rating being for a 10-μsec pulse.

TABLE 1

ALLOWABLE REPETITIVE PULSE ENERGIES
CARBON COMP AND METAL-FILM RESISTORS

Rated Watts	Joules, Carbon Comp	Joules, Metal Film		
		10 μsec	100 μsec	1 msec
1/4	1/2	1/500	1/100	1/20
1/2	2	1/200	1/50	1/8
1	9	1/60	1/12	1/3
2	13	1/40	1/7	1

Also note the pulse-duration dependence of the film type, not evident for carbon comps. Thus the same 1-watt metal film rated at 1/60 joule for a 10 μsec pulse, can handle 1/3 joule for a 1 msec pulse—still well below the 9-joule carbon comp energy-handling capability.

A *peculiar* sensitivity like pulse-width-dependence or of some other nature, or a failure mode unexpected and often unexplained, is often characteristic of component performance in high pulse-energy applications. With carbon comps themselves, for example, nominal allowable pulse energies can be exceeded by rather large factors for *some* resistors for *some* number of shots, with no apparent degradation. Following that number of impulses, however, they can split open on the very next pulse!

Protectors, of course, come in varying joule capabilities. Silicon avalanche devices are typically rated in peak current for a 10×1000 μsec pulse, but calculations show they're typically one- to two-joule components, with assemblies ranging to many times that figure. (Their extremely low impulse ratios can make them more effective in many applications than higher joule, higher-impulse-ratio devices, however.)

Varistors handle from about 1 to 80 joules, with experimental units at even higher levels, and with typical units lying in the 10-20 joule range.

The smaller gas-tube protectors that find application on electronic circuit boards can take single shots to 20,000 joules. They also have "lifetime" joule ratings that are often in about this same ballpark—the effects can be cumulative.

Wave Energies

An upper limit for the energy delivered in a pulse can be calculated from the energy stored on the capacitor which is discharged, one way or another, to generate the burst. This capacitor energy is given by:

$$W_C = (1/2)CV^2$$

A 1500V, 60A, 10×1000 impulse, for example, can be derived from a capacitor of about 58 μfd. *Stored* energy is therefore $(1/2)\times(58\times10^{-6})\times(1500)^2$ or about 65 joules. Maximum transfer via resistor coupling to a load—the circuit or protector under test—gives 1/2 the stored energy. This maximum transfer occurs for a protector clamping at 1/2 the stored voltage; for protectors clamping (or breaking down to) other voltages, the energy delivered to the protector will differ, perhaps markedly. (As an extreme example, consider a protector that breaks down or crowbars to 0 volts. Ignoring the breakdown edge, it will absorb zero energy.)

A protector clamping an impulse generated by discharging a capacitor, will absorb an amount of energy that is independent of the resistor that couples it to the capacitor. This energy, W_{clamp}, is given by:

$$W_{clamp} = V_{clamp}\,(E_{stored} - V_{clamp}) \times C$$

where V_{clamp} is the clamping voltage of the protector, E_{stored} is the stored capacitor voltage and C the capacitance. (In the case of breakdown or crowbar devices, V_{clamp} is *not* the breakdown voltage, but the sustaining voltage once the crowbar has actuated.)

If the capacitor value isn't known but the wave is, energy can be calculated, again for an impulse, from:

$$W_{wave\ maximum} = (1/1.4)\,E_{peak}\,I_{peak}\,T$$

where E_{peak} and I_{peak} are peak voltage and current respectively, and T is the decay time to half of peak value. thus a 1500V, 60A, 10×1000 wave will have *maximum* energy of $(1/1.4)\times1500\times60\times1000\times10^{-6}$, or essentially the same 65 joules stored by the 58 mfd capacitor in the previous $(1/2)CV^2$ example. *Actual* energy delivered by the wave to the circuit will be a function of the clamping voltage, as before, but will now *also* be a function of the assumed coupling resistor—or in effect, the maximum assumed current under specific test or field conditions.

As further examples, an 8×20 wave at 1 kV and 500A supplies a maximum energy of about 6 joules; a 1.2×50 at 1500V and 150A, about 8 joules.

By contrast, the 1.5 MHz ringing SWC wave starts from a 0.015mfd capacitor charged to about 5kV. This results in a stored energy of about $(1/2)\times0.015\times10^{-6}\times(5000)^2$ from the $(1/2)\,CV^2$ relation. This calculates as about 0.2 joules, with less than half typically delivered—or less than 100 millijoules; hence the previous statement that SWC may be considered a susceptibility test in many instances.

The 100 kHz proposed UL ringing wave with 0.5 μsec rise time can start from as low as a 0.025 mfd capacitor charged to 8 kV; yielding $(1/2)\times0.025\times10^{-6}\times(8000)^2$; or about 0.5 joules stored. Very possibly this wave does most of its "damage" via high voltage rather than energy transfer: the suggested test requires no susceptibility up to a 3 kV peak wave, and no vulnerability up to a 6 kV peak wave. This is an example of combined susceptibility and vulnerability testing via the same wave at different levels. The wave itself incorporates what appears to be a susceptibility component—the sharp, essentially 12 kV/μsec leading edge (see Figure 3), and a vulnerability component—the lower-frequency, 100 kHz ringing portion.