Electronic products must pass some level of immunity tests when subjected to conducted or radiated energy. Some of those tests include subjecting the equipment under test to electrical impulses--short duration single events using defined voltage and current waveforms. Engineers also use impulse tests to verify electrical spacings on PCBs and to periodically check motor-insulation.

Several international standards define impulse waveforms, but only at certain points in how a voltage or current will rise and fall. The waveform shape, peak voltage, impedance, and application of the pulse varies among standards. The test pulse you use depends on the standard you apply because standards define impulses differently.

**Waveform Definition**

The IEC (International Electrotechnical Commission) has at least two standards that define impulse tests and their waveforms. Use [IEC 60060-1](http://example.com), "High Voltage Test Techniques" when testing insulation systems and use [IEC 61000-4-5](http://example.com), "Testing and Measurement Techniques - Surge Immunity Test," for switching and lightning-transient tests. Many standards that define testing of specific products reference either of these two standards because these two standards.

In some end-use Standards, both the insulation system of the DUT (device under test) and the ability of the device to withstand lightning and switching transients are important. The requirements of IEC 60060-1 and IEC 61000-4-5 are different, so the authors of the end-use standard must decide which standard to reference. A relevant example is [IEC 61730-2](http://example.com), the Standard for photovoltaic (PV) panels, which references IEC 60060-1 as its impulse standard definition, which is applicable to insulation systems. In the PV standard, the authors note that the test is "To verify the capability of the solid insulation of the module to withstand over-voltages of atmospheric origin. It also covers over-voltages due to switching of low-voltage equipment." While this scope would be closer to that of IEC 61000-4-5, the authors elected to conduct the test under the requirements of an insulation impulse test, which they deemed a better definition of their test program.

**IEC 60060-1; Insulation System Testing**

IEC 60060-1, the insulation system definition standard, defines a waveform by a rise time, peak value, decay time, and tolerances. These parameters are all that is needed to completely define a
voltage or current waveform. Since these insulation tests are conducted on open circuits, this is all that is needed, and IEC 60060-1 notes that the specified waveshape should be delivered to the DUT. Footnotes to Paragraph 19.2 give guidance should the DUT be capacitive or reactive and allow some deviation in waveform shape and peak voltage in that case. Because the waveform will check an insulation system, no significant capacitance or reactance is anticipated, so no the standards gives no impedance specification. Thus, no current requirement exists in the case of a voltage tester. This may seem to be a problem if the DUT is capacitive, but in our experience raising power offers little improvement in the resulting waveform.

The end-use standard defines peak voltage. Furthermore, these tests are always conducted on equipment that's not connected to mains power or otherwise energized.

**IEC 61000-4-5: Lightning and Switching Transient Testing**

IEC 61000-4-5, the definition standard for lightning and switching transient testing, defines a waveform by a rise time, peak value, decay time, impedance, and tolerances. Because the tests can be conducted in many configurations, the waveform is judged into an open circuit (voltage waveforms) and/or short circuit (current waveforms). IEC 61000-4-5 specifies only a 2 Ω, 1.2x50/8x20 combination generator, but by Appendix 2, guidance regarding the tester's impedance is given depending on the location of the test application:

- 2 Ω, mains testing
- 12 Ω, mains to ground testing
- 42 Ω, secondary to ground testing

IEC 61000-4-5 provides for powered and unpowered testing, and gives guidance for maximum impulse levels depending on the application in Annex B. the standard also provides guidance for judging of the DUT's performance, given in Annex C. But, the authors of the end-use standard define these points.

While the IEC gives end-use standards authorities tools to administer impulse tests in a standardized fashion, authorities are under no requirement to adopt them in their standards. For example, the medical standard **IEC 60601-1** implements a impulse test that simulates a defibrillator. The input voltage and circuit components are defined, while the output waveform and voltage aren't. Although the guidance in IEC 60060-1 and 61000-4-5 is well written and well received, the standards can't cover every instance.

In addition, some standards use different impedance values for their testing. In some cases, the impedances provide a special current level at a breakdown voltage. Sometimes, the authors chose an impedance value to minimize breakdown damage, or they shoe a value in response to a known circuit parameter. For example, a purely resistive load such as a meter socket is tested with a 500-Ω impedance tester.

**Impulse Waveform Uses**

If an end-use standard references either IEC 60060-1 or IEC 61000-4-5 or a standard otherwise defines a pulse by rise time, peak, decay time, and possibly impedance, the resulting waveform will be as shown in **Figure 1**. One of the most popular voltage waveforms is the 1.2x50, where the rise time is 1.2 µs and the decay or duration time to half value is 50 µs. Tolerances for this waveform are 1.2 µs to rise from 30% to 90% of peak ±30%, and time to half value is 50 µs ± 20%. Both reference
standards use the same definitions and tolerances for this waveform, except IEC 61000-4-5 specifies
delivery into a short circuit, and IEC 60060-1 requires this waveform with the DUT attached. Voltage
impulse testing is used to find dielectric breakdowns in insulation systems and to test for
performance when transients are present.

Figure 1. Specifications such as rise time, peak value, and time to decay to 0.5 of peak
define voltage and current test waveforms. "U" in the vertical scale indicates portion of
peak value. (Click image to enlarge.)

Figure 2 shows the popular current waveform of 8x20 has a rise time of 8 μs ±20% into a short
circuit (IEC 61000-4-5) or with the DUT attached (IEC60060-1). The waveform has a decay to half
time of 20 μs ±20%. Use a current pulse with a known the breakdown voltage. The test is designed
to stress the breakdown components with a specific current. In these cases, the impedance
requirement of the tester may be tailored to provide the desired test current to the DUT at the
breakdown point. Specifically, one of the impulse tests for gas-tube devices requires a 100-Ω
impedance to provide a 10-A pulse at a breakdown voltage of 1000 V.
The waveform for test current into a short circuit rises within 8 µs ±20% (value of T) and can go negative by as much as 30%. (Click image to enlarge.)

The popular combination waveform impulse tester is defined in IEC 61000-4-5, and both the voltage and current waveforms are defined. As noted above, the standard defines only a 2-Ω tester, but the standard notes other output impedances as well. The impedance of a surge tester is defined as the ratio of the peak open-circuit voltage to the peak short-circuit current. These values will change when a device is being tested.

**Coupling-Decoupling Networks**

When conducting a powered test in accordance with IEC 61000-4-5, use a Coupling-Decoupling Network (CDN) to present a high back impedance to the surge waveform toward the supply. That still lets the impulse flow to the DUT. The standard presents circuits for CDNs used for various tests, and the CDNs have to be designed to provide a waveform which is within tolerances specified in IEC 61000-4-5. Because of these performance requirements, CDNs have to be designed for specific waveforms, voltages and currents, or there is a chance the CDN may not perform to the specifications. Always use a CDN when performing mains-powered tests. IEC 61000-4-5 has various CDN illustrative schematics for use with other ports as well. A CDN isn't required for unpowered tests because there's no power supply to protect.

Depending on which of these two standards your end-use standard references, the tester you select
can vary greatly. If the scope of your end-use standard uses IEC 61000-4-5 as the referee document for impulse waveforms, then the pulse will be defined without the device being tested in place. That is, the tester's voltage pulse will be evaluated when delivered into an open circuit, and the current pulse will be evaluated into a direct short. If, however, IEC 60060-1 is the referee document, then the pulse will be evaluated with the device being tested as part of the circuit. This can cause huge differences in the pulse if the device being tested presents anything other than an open circuit to the impulse tester in its tested configuration. Although IEC 60060-1 does allow waveforms to vary when the load is capacitive, these variances are limited. In these cases, the limiting factor may not be impulse tester power, but the lead and internal tester impedance, which may be difficult to decrease.

**Waveform verification**

If the end-use standard covering the equipment being tested specifies either IEC 61000-4-5 or IEC 60060-1 as the referee document, then you can verify correct operation by using an oscilloscope and comparing the waveform to the standard. Some waveforms in end-use standards, however, are defined by specifying the input voltage and circuit components. These pulses have undefined output peak voltage. While this is a valid method for defining a pulse, it is difficult to verify correct pulse delivery unless the source voltage can be accessed, and component tolerances can be checked.

Some end-use standards use proprietary circuits that include the impulse tester and a CDN. The tester controls component values and input voltages. In these testers, however, you may have difficulty finding the correct output as well. In these cases, comparison of the waveform to a waveform record taken at the last equipment calibration may be the best verification method.

There are many definitions of impulse waveforms, and different referee documents are very different in the way they treat the application of the impulse to the device being tested. Some waveforms are used to evaluate insulation systems, or determine behavior at an expected breakdown voltage, or to evaluate systems when presented with a mains transient.

Impulse waveforms can be defined differently, and the definition scheme may make the waveform difficult to verify that it was delivered correctly. If the source voltage is the defining value, comparison of the waveform to calibration records may be the best way to evaluate the delivered waveform.

Check the scope of your end-use standard to see which standard defines the impulse waveforms used. Be sure to read that standard to make sure your test will be in compliance of all required standards. T&MW

---

**Jeffrey D. Lind** has over 33 years of electrical engineering experience. He launched his career working at Underwriters Laboratories (UL) and then for Atari™ and Sega Gremlin™. In 1997, Lind started Compliance West. He received his Bachelors of Science in electronic engineering from Cal Poly San Luis Obispo.