10 April, 2016

Impulse Testing Waveforms and Relay Performance

Background: Over the years, Compliance West USA has used a number of different relays to switch impulse waveforms. Relay choice varies depending primarily on the voltage that is being switched, and the maximum current than can flow. Other considerations include whether a single-pole or double-pole relay is needed. The range of voltages and currents varies greatly. The purpose of this document is to provide a better understanding of the switching event, and provide guidelines for the interpretation of measured results.

Terminology: The following definitions are used in this document:

> Switching time - The time delay starting at the point that the normally-closed contact (NC) opens, until the normally-open contact (NO) initially closes.
>
> Pre-arcing - During switching, the arc-over that occurs from the Common (COM) contact to the NO contact before the NO contact initially closes.
>
> Contact bounce - After the NO contact has initially closed, the contact may re-open because of the mechanical impact between the COM contact and the NO contact. Contact bounce may be reduced by dampening and spring-loading contacts.

Pre-arcing creates plasma. Plasma (according to Wikipedia) is highly conductive and can generally be considered a short-circuit. Most research in the area of electrical arcs is generally focused on circuit breakers and contactors that are moving from a closed state to an open state in order to disconnect the power source from the load. In this case arcing occurs and plasma is created when the contacts begin to open. This causes the currently to be maintained even while the contacts are open because of the low impedance of the plasma. While this is interesting, the understanding of this event is of limited use when considering contacts that are closing rather than opening.

For high voltage relays, switching time is relatively long, on the order of 10-20mS. This is because the COM contact moves at a finite speed over a large contact gap distance. Therefore it is reasonable to expect that the power source (that is charging the capacitor) is fully disconnected from the stored-energy component (capacitor) before pre-arcing takes place.

During switching, as the COM contact is moving towards the NO contact, arcing starts. The contact gap at which arcing occurs depends on voltage, gas composition (air or some other gas, or partial vacuum), and contact geometry (sharp points will arc at larger distances than smooth, rounded surfaces). In fact, *for fast impulse waveforms (such as 1.2 x 50uS) the entire waveform output will be generated during pre-arcing, and the output waveform will have dropped to near-zero before the COM contact closes with the NO contact.*

This is a very important observation to understand, as it greatly impacts the interpretation of disturbances that are measured during relay switching.

Consider a relay with a contact-gap distance ℓ that is closing at a speed V = dℓ/dt. As soon as the gap distance is smaller than the breakdown voltage of the air gap (or other gas), plasma is generated and the circuit can be considered closed (COM is essentially connected to the NO contact). At this point the stored energy may start to discharge (depending on the size of the storage capacitor) and the output voltage will certainly start to rise, as energy is transferred from the storage capacitor to the waveshaping network. Keep in mind that at this point, the relay contacts are still moving at speed V and have not yet initially closed.

At the same time that the COM contact is approaching the NO contact, the voltage of the waveshaping network (connected to the NO contact) is rising from zero to the voltage of the storage capacitor (connected to the COM contact). Current is flowing in the arc as energy is transferred from the COM contact to the NO contact. The arc will be sustained as long as there is "significant" current flowing. However *if the waveshaping network becomes "charged" such that the current drops below the threshold needed to maintain the arc, the arc will be extinguished*. For high-energy impulse tests, there is a large amount of current flowing, which allows the arc to be maintained. Figure 1 shows a test circuit schematic, Figure 2 shows the ideal (simulated) output waveform, and Figure 3 shows the actual output, highlighting the point at which the arc is extinguished.

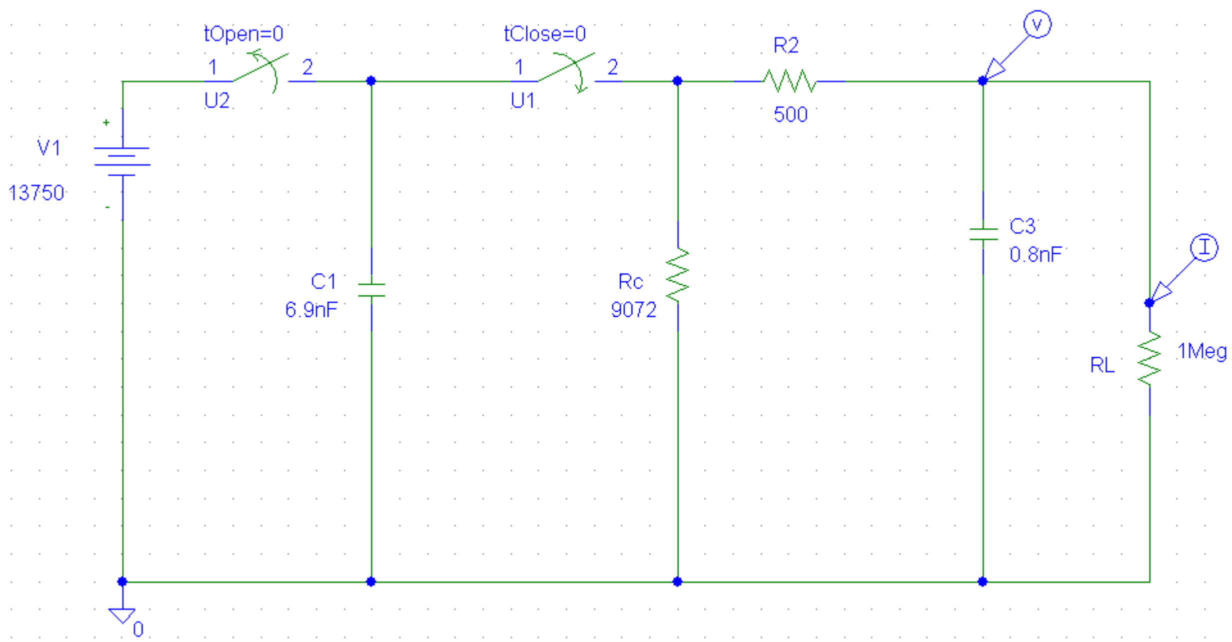

Figure 1: test circuit

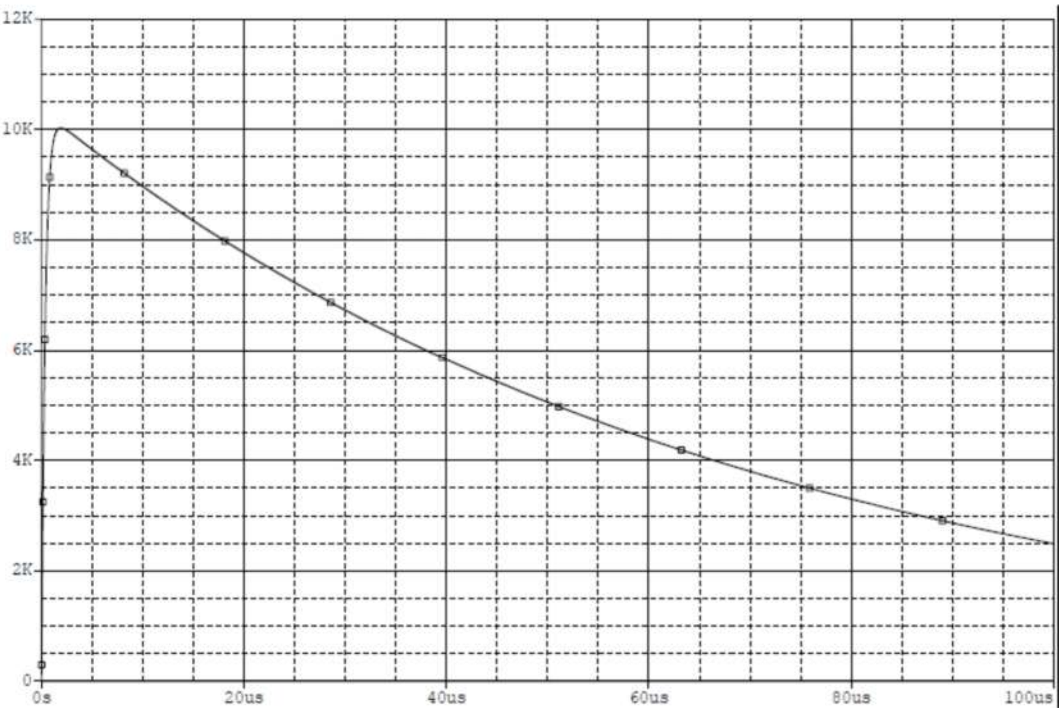

Figure 2: Simulated output waveform

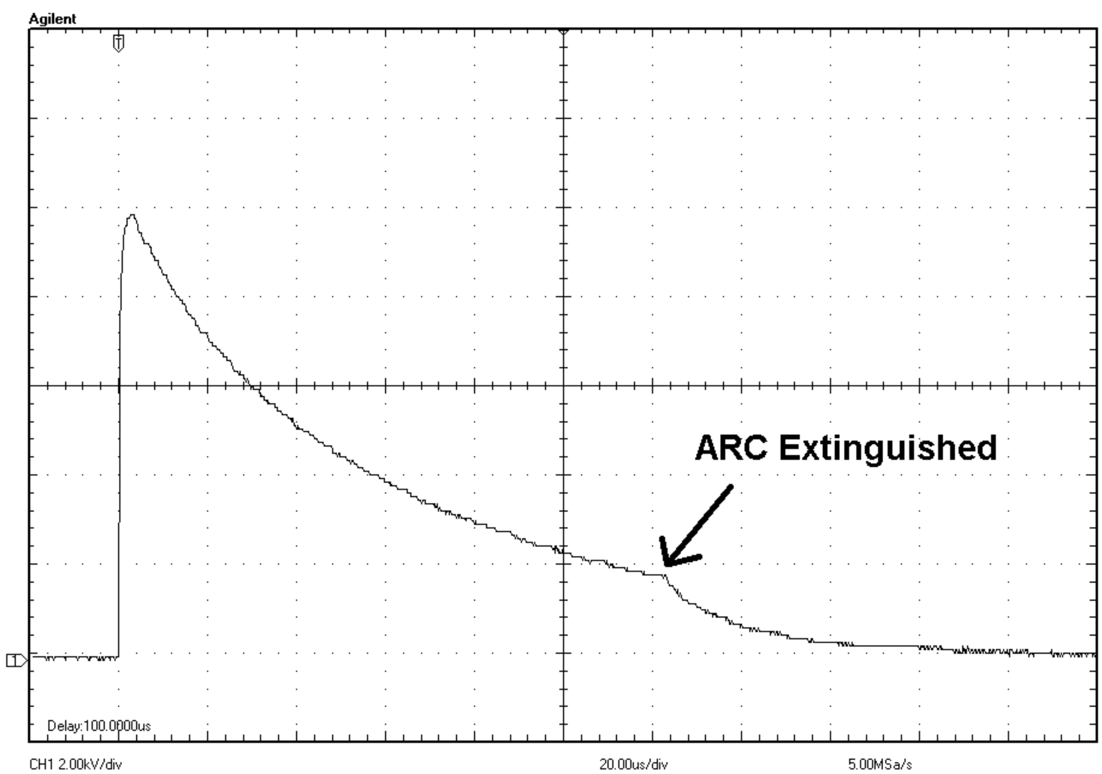

Figure 3: Actual output showing the arc being extinguished as the contact is closing

The reason the output voltage drops more quickly when the ARC is extinguished can be understood by reviewing the circuit schematic in Figure 1: While there is an arc, C1 is connected in the circuit, and the RC time constant is: (Rc + R2) x (C1 + C3). When the arc is extinguished, the circuit has a shorter time constant: (Rc + R2) x (C3).

As soon as the arc is extinguished, a high impedance exists again between the COM contact and the NO contact. Therefore a voltage difference will again develop between the two contacts. Keep in mind that at the same time, the contacts are still approaching each other at speed V: *at some point before the contacts close, the contact gap will be small enough that breakdown may again occur across the contact gap*. This arcing - extinguish - re-arcing cycle may repeat more than once during the switching time. This condition is shown in Figure 4.

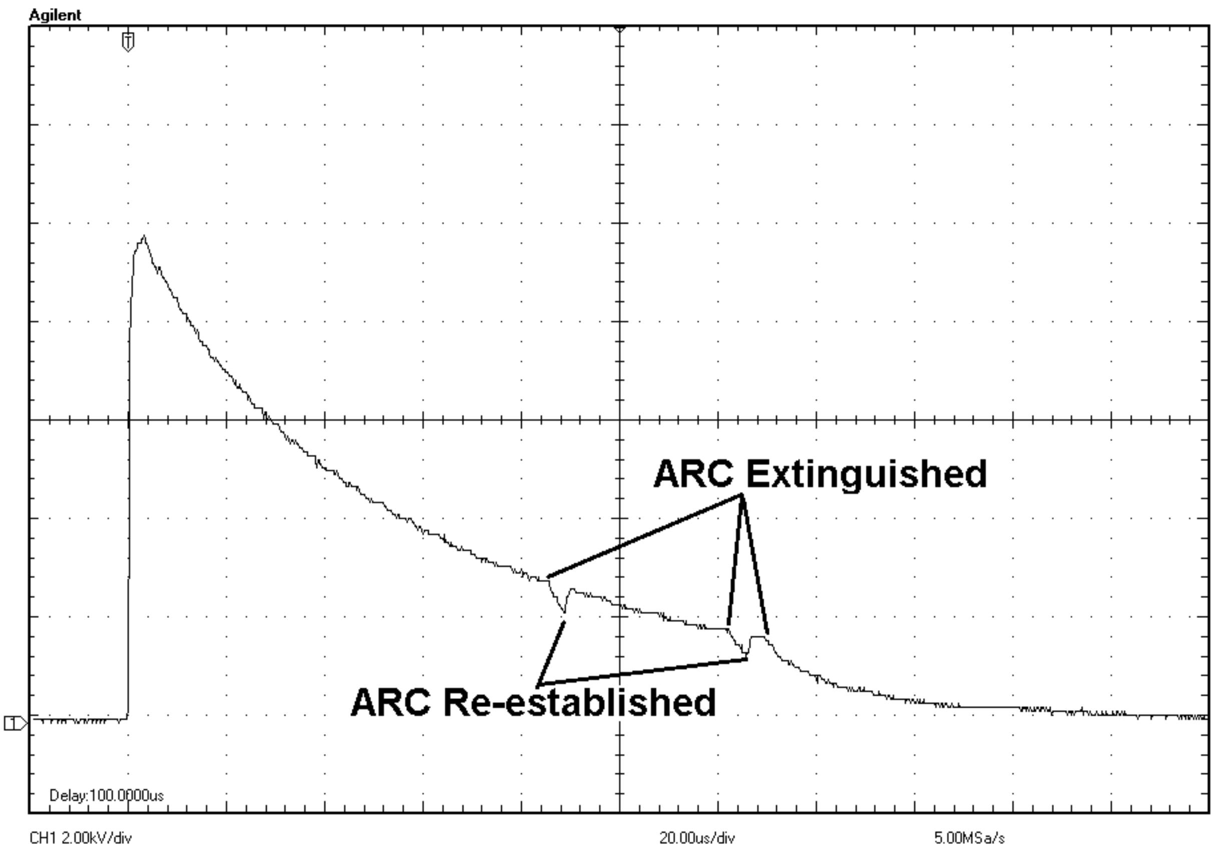

Figure 4: arc - extinguish - re-arcing cycle

In the case of the "antenna discharge" impulse test, a relatively small capacitor (1nF) is used and yet the duration of the waveform is long (~50mS or greater) because the load impedance is very high. The time base of the measurement device (oscilloscope) is long and therefore pre-arcing events (arcing - extinguish - re-arcing) are not visible. Rather, contact bounce becomes critical. Large improvements in contact bounce have been made on the "IEC relay" (a.k.a. black relay). Mechanical dampening minimized bouncing and keeps the gap small when the contacts do bounce.

Because of the circuit topology, these arc-extinguish transients will take place only at the tail of the waveform, when the voltage is less than 50% of the peak output. Because the output is "clean" from the peak to the 50% voltage level, the duration of the waveform is easily measured and calculated; the transients have no effect on the calculation. In fact, the waveform definitions (from IEC 60060-1 and other standards) do not specify the wave shape after the voltage has decayed to below 50% of the peak value.

In practice, these transients have no effect out the test being conducted however *these transients should not be confused for a dieletric breakdown of the EUT*. A dielectric breakdown occurs near the peak of the impulse waveform as the voltage is still rising, or immediately after the peak. Figures 5-7 show typical waveforms when a breakdown occurs. These can be used as a guide for interpreting "failing" test results.

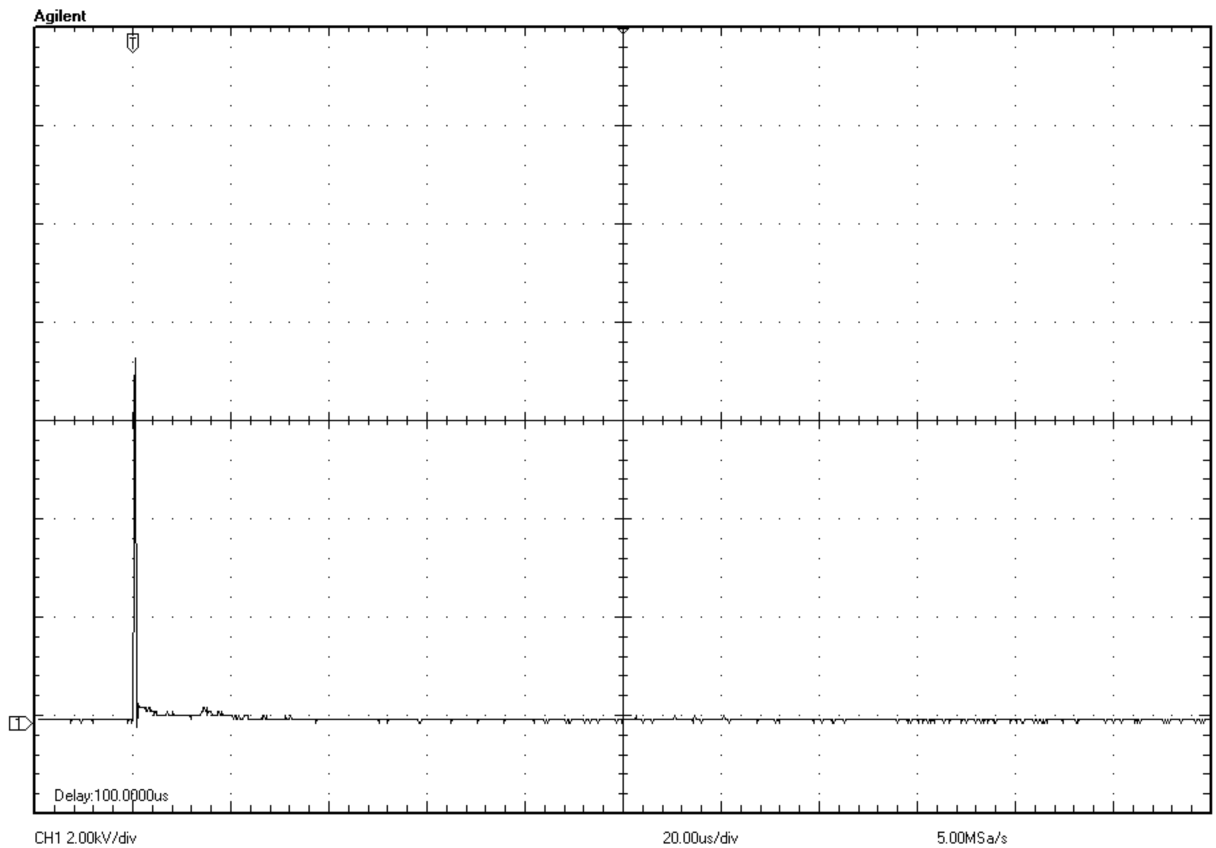

Figure 5: breakdown as the voltage is rising

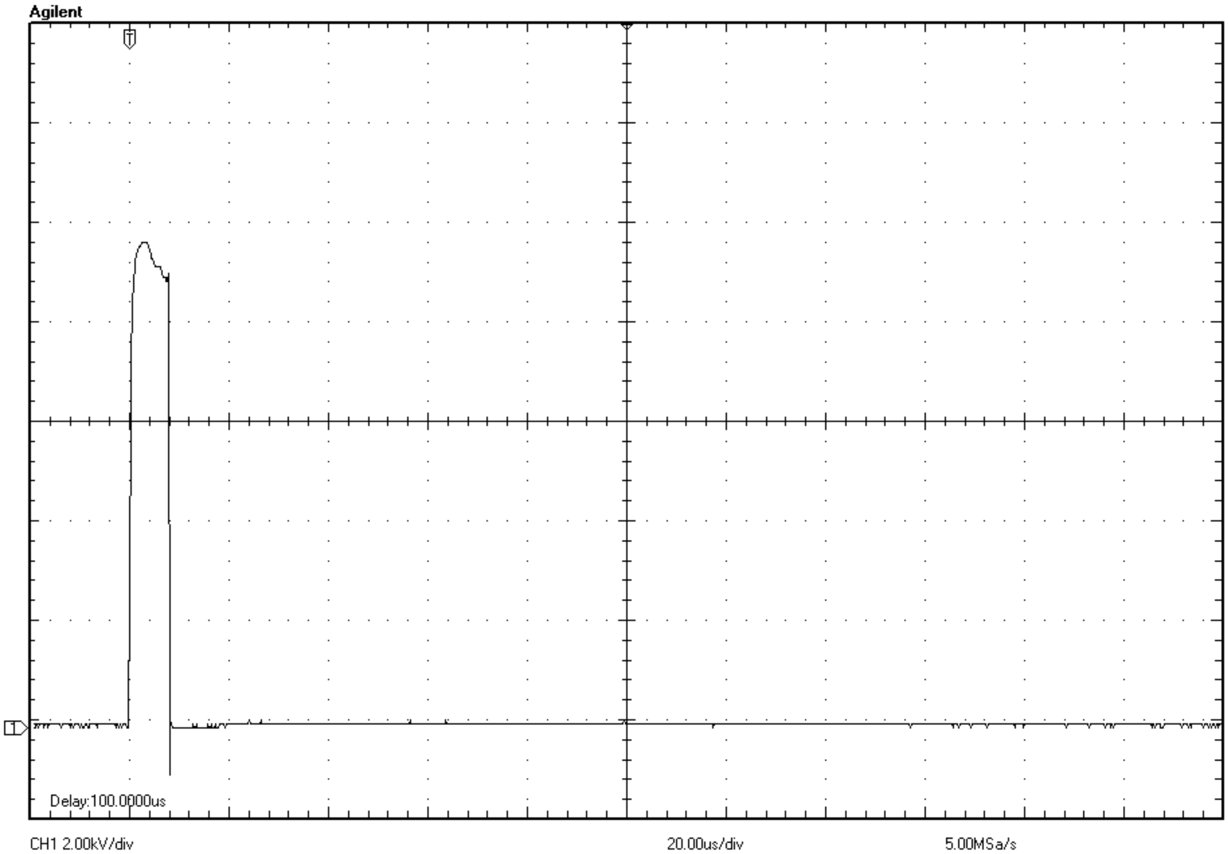

Figure 6: dieletric breakdown immediately after Vpeak

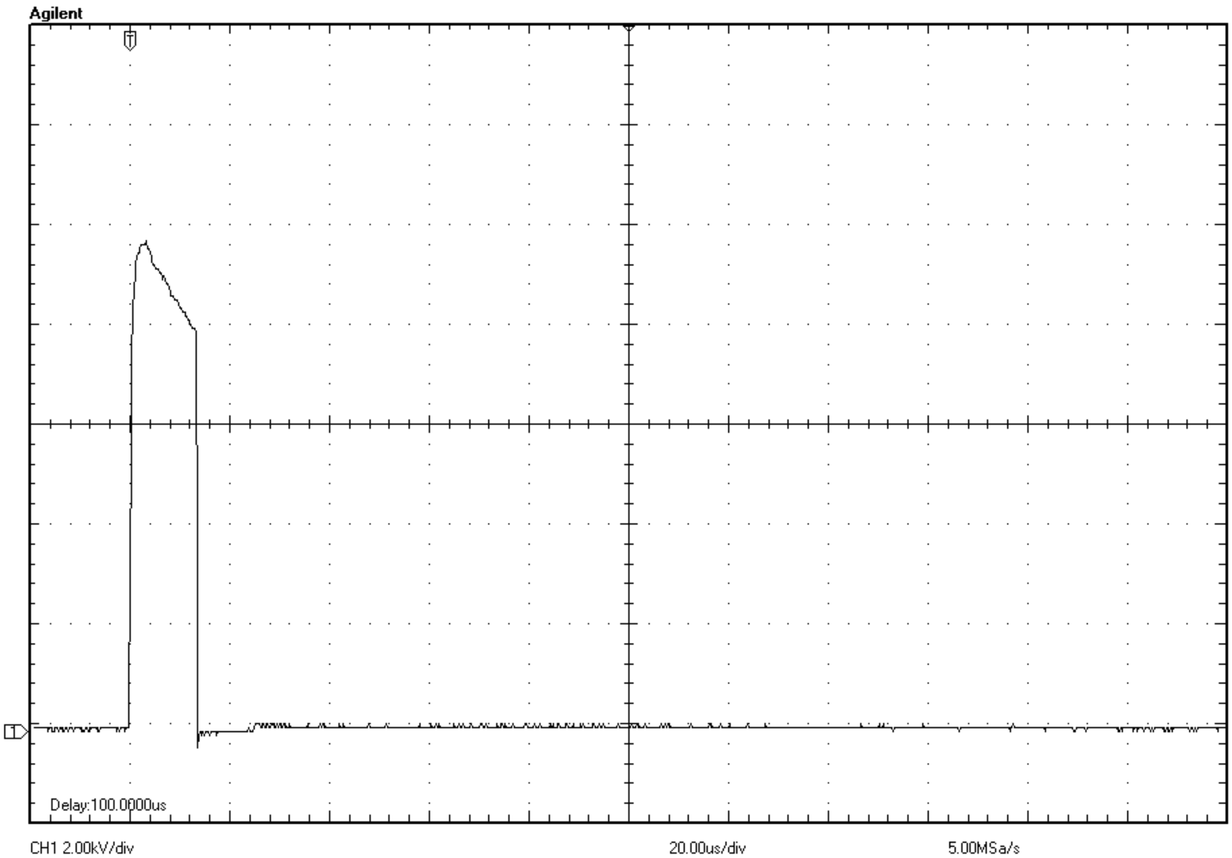

Figure 7: dielectric breakdown after Vpeak (delayed breakdown)