Application Note 108

Dielectric Replacement in Tektronix P6015 HV Probes

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Tektronix P6015 high-voltage probes utilize halocarbon C-114 (1,2,-Dichlorotetrafluoroethane, $C_2Cl_2F_4$, CAS 76-14-2) as the dielectric fluid. This chemical was chosen because of its dielectric strength and vapor pressure. It is originally supplied as a small container of liquid; when the probe body is filled, the liquid partially vaporizes thereby filling the interior volume with a gas that is resistant to electrical breakdown. At room temperature (21.1 C), the vapor pressure is 1429 mmHg, which means that probe body is only subjected to moderate stress and there is no danger of a pressure explosion. The probe body is sealed with a standard O-ring and the gas "charge" leaks very slowly. It does require refilling over the years but unfortunately purchase of C-114 is now restricted by the EPA due to its harmful effect on the earth's ozone layer.

Tektronix solved this problem with the introduction of their model P6015A probe that employs a Silicone rubber dielectric. Without the dielectric gas charge, however, the original model P6015 probe is only usable at voltages up to 20 kV. There are probably thousands of abandoned and un-repaired P6015 probes sitting on the shelves in laboratories and electronics shops world-wide. This Application Note describes modifications that return the P6015 probe to full functionality (40 kV) without employing hazardous and/or environmentally harmful chemicals. There are three steps:

1. Replacement of the dielectric gas with a dielectric fluid (Silicone oil),
2. Modification of the compensation box, and
3. Calibration using a revised procedure.

A competent electronics professional with access to the necessary instrumentation should be able to perform this modification and calibration without any difficulty. For a hobbyist, the degree of difficulty is moderate to difficult, especially if the required instrumentation is unavailable. In the latter case, our Company will perform this service for a moderate service fee that is certainly less than the price of a new P6015A probe.

Misinformation

There are several internet blogs filled with errors and misinformation concerning the P6015 probe and its dielectric gas.

Myth #1: We need to find a replacement gas with the same dielectric constant as C-114. In their liquid state, dielectric media have widely varying dielectric constants, however in their gaseous state, all dielectric constants are very close to the value for air ($\varepsilon \approx 1$). Therefore any attempt to find a substitute dielectric gas with a "match" is completely misguided. One blogger claims satisfactory results using lighter-fluid butane as a substitute for C-114, but the dielectric strength will be unsatisfactory and the probe will not function properly at 40 kV.

Pressurizing the probe body with sulfur hexafluoride (SF_6) or octofluorocyclobutane (c-C_4F_8, halocarbon C-318) is an entirely viable approach and these gases are readily available from many commercial sources, but there is danger of over-pressurization and likely damage to the probe body. Both of these gases have a Relative Dielectric Strength (RDS) greater than for C-114.

Myth #2: Compensation boxes are interchangeable between the P6015 and P6015A probes. This is total poppycock. The respective compensation boxes are specifically engineered by Tektronix for the electrical parameters of the HV resistor and surrounding structure within the probe body. Even with readjustment, swapping the compensation boxes will yield completely erroneous wave forms on your oscilloscope.

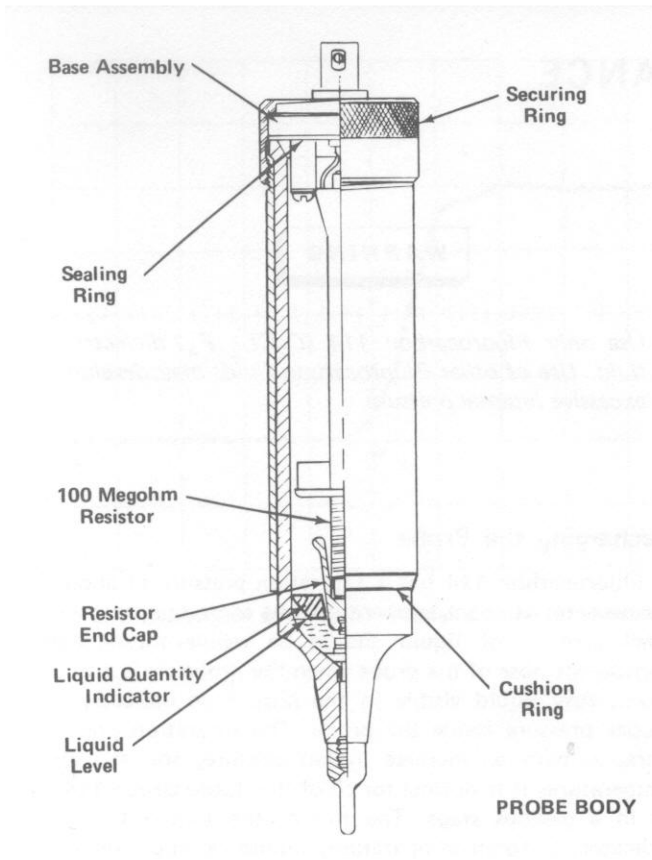

Figure 1. Probe body assembly.

Filling the Probe Body with Dielectric Fluid

Most "transformer oils" (mineral-oil based compounds) contain anti-rust and scavenger agents. They are usually irritating to the skin and some may harm the components within the P6015. Although more expensive, Silicone oils are preferred and we recommend Dow Corning Xiameter® PMX-561 (www.xiameter.com). The procedure is as follows:

1. Disassemble the probe body and inspect the components for evidence of damage. A cutaway drawing is shown in Figure 1. In particular, inspect and measure R100, the 100-MΩ high-voltage resistor. Replace any defective components.
2. Remove the liquid quantity indicator (float ring).
3. Layout the components as show in Figure 2. While holding the clear insulator tube upright, fill with Silicone oil to within 4 mm of the top.

4. Slowly immerse the resistor assembly until the sealing ring mates with the lip of the insulator tube. Wipe any overfill from the exterior of the insulator tube. It is important to fill completely and minimize the volume of any air bubble.
5. With the threads facing up, slide the aluminum shield over the insulator tube and tighten the securing ring until snug. Wipe any overfill from the assembly and then slide the cushion ring into position.
6. Set this assembly aside until work on the compensation box is completed.

Figure 2. Disassembled probe tip.

Modification of the Compensation Box

The original schematic diagram of the compensation box is shown in Figure 3. The high-voltage divider resistor R100 has a parasitic parallel capacitance of about 2.3 pF and a parasitic capacitance to ground of about 2.3 pF. These values change significantly when the dielectric gas is replaced with Silicone oil. The values of C1, C2, and C3 must be modified to obtain proper compensation. The procedure is as follows:

1. Disassemble the compensation box by removing the two screws holding the cover plate. R6 is recessed within the oscilloscope connector – unsolder the resistor wire that connects to the circuit board. Using a 5/16" nutdriver, remove the two #10 nuts and lock washers that attached the circuit board to the standoffs on the rear plate. The disassembled compensation box should look like the photograph in Figure 4.

2. The circuit board is now fully accessible for modification. Use only high-quality silver-mica capacitors. We used Cornell Dubilier series CD10, CD15, and CD16 capacitors here, but similar products are available from several other manufacturers. Identify the locations of trimmer capacitors C1, C2, and C3.
3. Solder a 270-pF in parallel with C3. Minimize the lead lengths.
4. Solder a 180-pF capacitor in parallel with C2.
5. Similarly, solder a 68-pF capacitor in parallel with C1. Your circuit board should now appear similar to the photograph in Figure 5. Note that we did not have a 68-pF capacitor in stock, so 50- and 33-pF capacitors in parallel were used.
6. Reattach the circuit board and solder R6 into place. Reassemble the compensation box – proper calibration is not possible with an open box.
7. Connect the coaxial cable and reassemble the probe body.

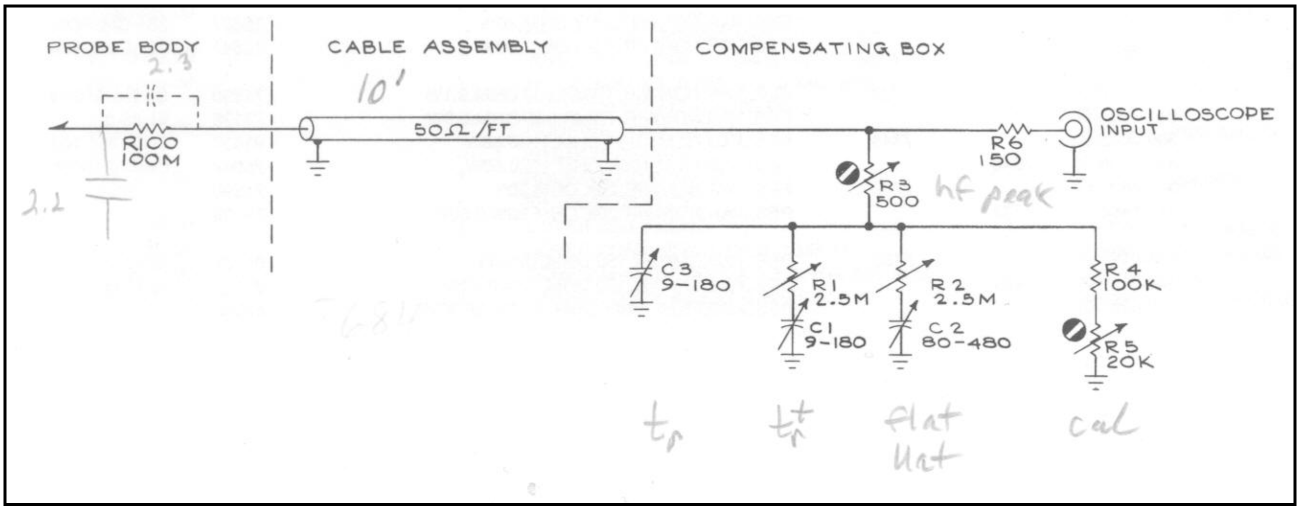

Figure 3. P6015 schematic diagram.

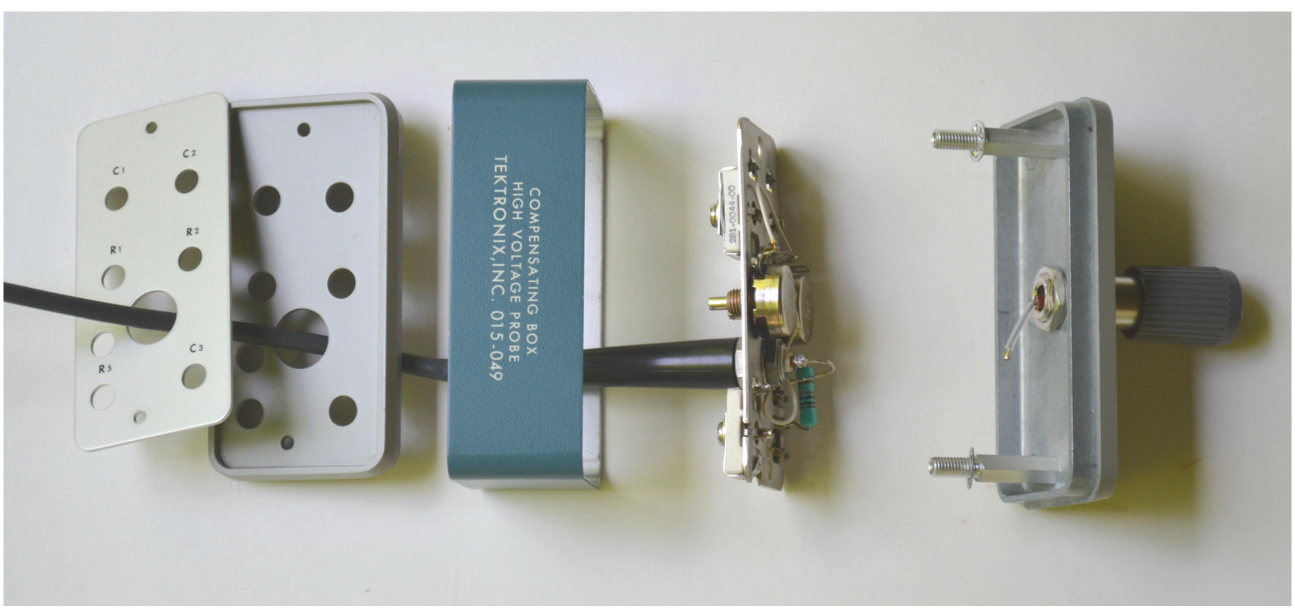

Figure 4. Disassembled compensation box.

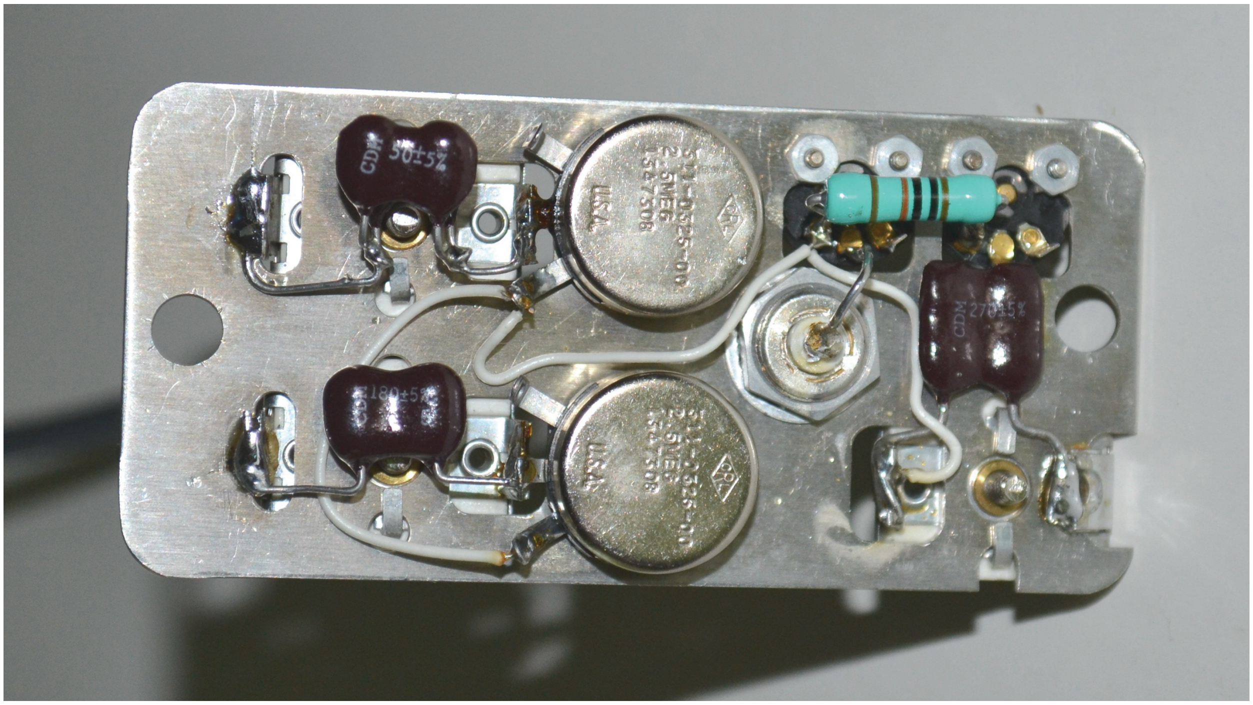

Figure 5. Modified compensation circuit: C1 –upper left, C2 – lower left, C3 – right (added mica capacitors are brown).

Revised Calibration Procedure

The recommended calibration procedure differs from that given in the Tektronix instruction manual. Required instrumentation includes a precision HV power supply, pulse generators, and a fast oscilloscope. The oscilloscope inputs should be 10 MΩ, DC coupled. A low-inductance 50-Ω ceramic resistor, such as an AHV type C2130A, is also needed for the high-frequency compensation. A second HV oscilloscope probe, such as a LeCroy PPE 2kV (x100), is useful for comparing wave forms. In the following scope traces, the LeCroy probe is channel 1 and the Tektronix probe is channel 3.

1. **DC Calibration:** With the P6015 probe connected to the oscilloscope, set the trigger to "auto-run" and the vertical to 200 or 500 mV/division with DC coupling. Set your HV power supply to 500-2000 V (2000 V recommended) and measure the voltage on the scope. Adjust R5 until the measured voltage is precisely 1/1000th of the power supply setting. For this calibration, we used an HP model 6515A power supply.
2. **Long-Pulse Compensation (leading edge):** Apply a 20- to 40-V, ≈300-μs pulse directly to the probe tip. Here, we employed a Tektronix model PG-507 generator. Set the sweep rate to 50 μs/div. Referring to Figure 6, progressively adjust R1, C3, and C1 for the sharpest leading corner. Leading-edge undershoot or overshoot should be minimized. It may be necessary to repeat these adjustments in the order given to achieve optimum result. Figure 7 shows a comparison of the two probes prior to adjustment. Distortion on the reference wave form (channel 1) arises from the slight inductance of the flying leads used to connect the pulse generator.
3. **Long-Pulse Compensation (trailing edge):** Now set the sweep rate to 100 μs/div. Adjust R2 and C2 to level the trailing 2-3 divisions of the pulse.

4. **Long-Pulse Compensation (flat top):** Next set the sweep rate to 500 μs/div. Adjust C3 and C1 to obtain the flattest top of the square wave. The final result is shown in Figure 8.
5. **Short-Pulse Compensation:** Using the alligator clip, connect the probe tip across the ceramic resistor. Use a short-pulse, HV generator to apply a fast rise-time pulse to the resistor. Here, we used an Avtech AVIR-4-C generator which is capable of producing 200-V, 200-ns pulses. Adjust R3, the high-frequency peaking adjustment, to give the most faithful pulse reproduction. See Figure 9 for a comparison.

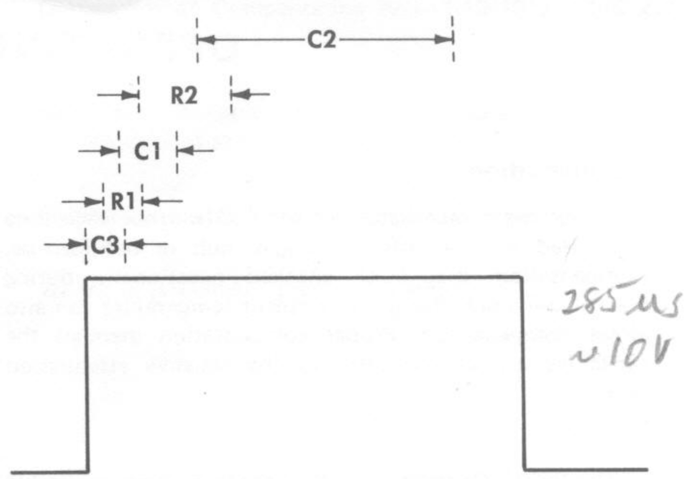

Figure 6. Effect of compensation RC's on the pulse wave form.

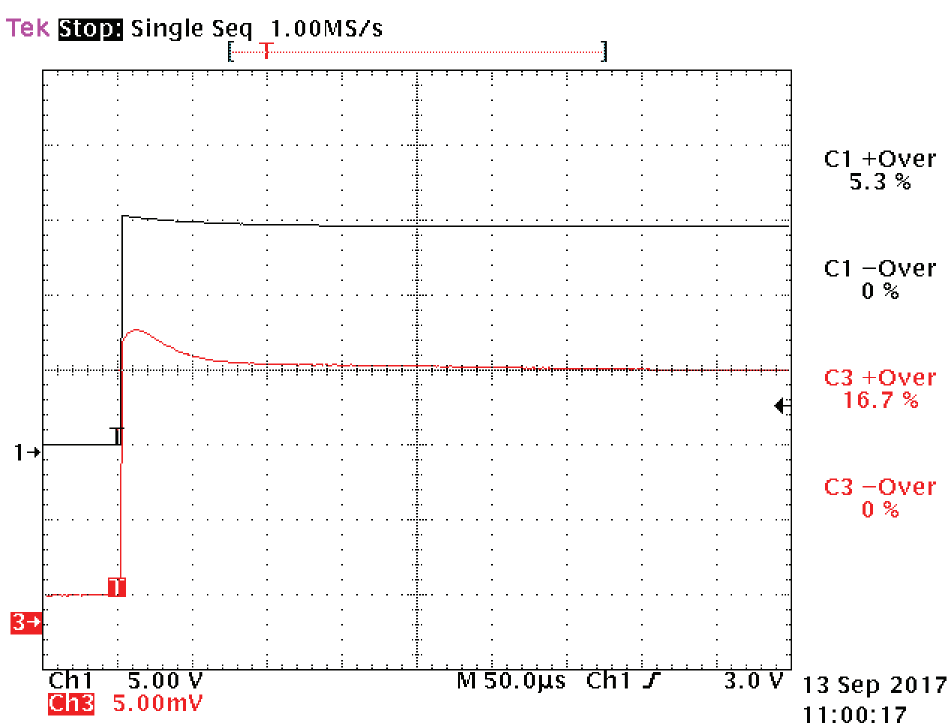

Figure 7. Pulse comparison prior to adjustment of R1, C3, and C1.

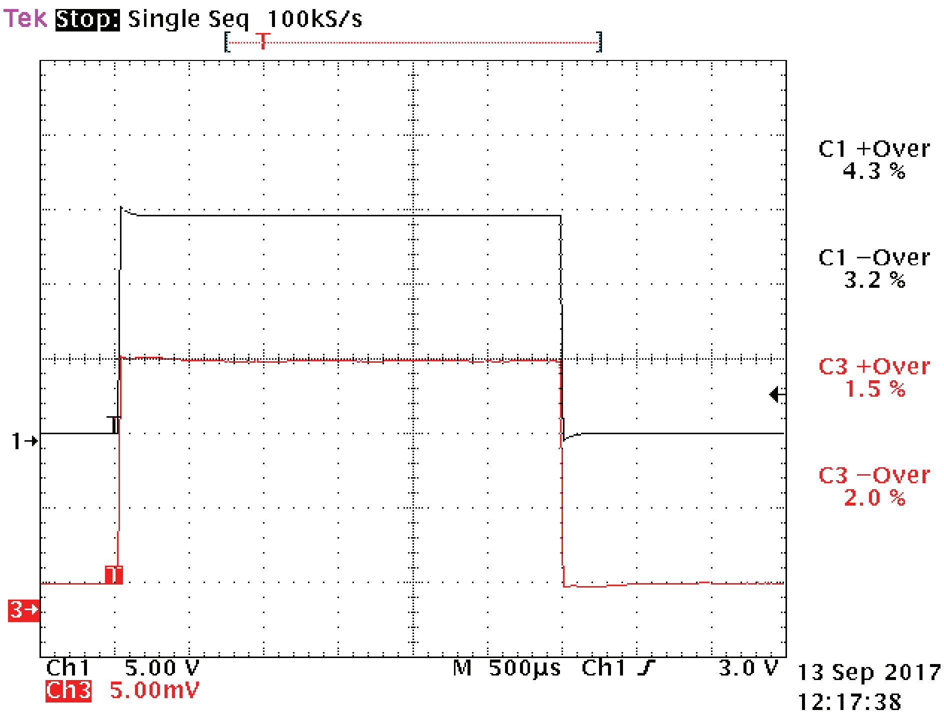

Figure 8. Final probe compensation wave forms.

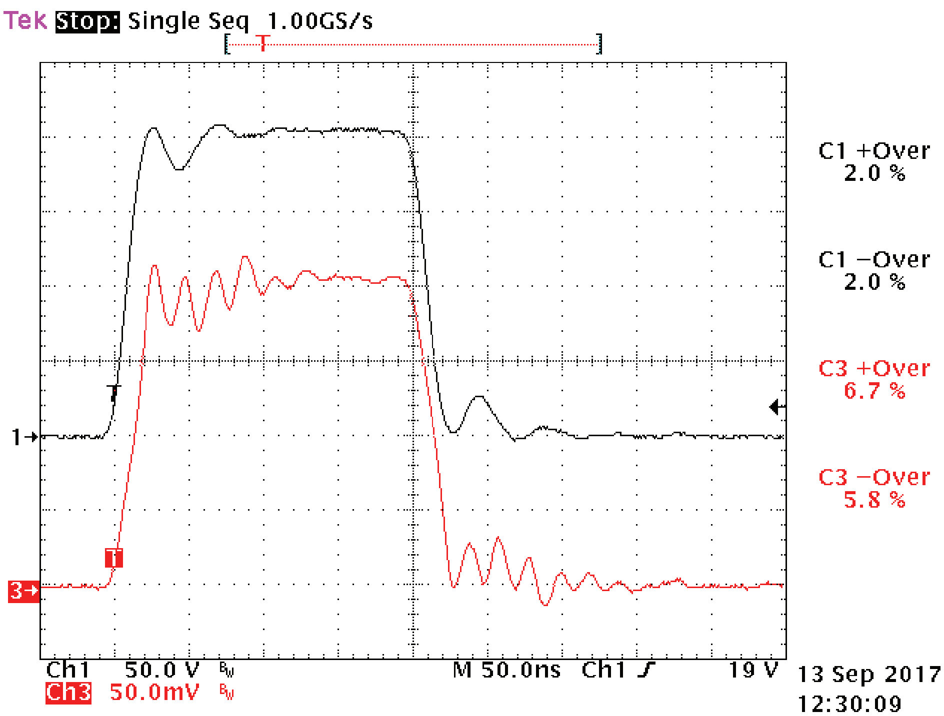

Figure 9. HF compensation.