QuietPower columns

What Can You Do with Solder-wick?

Simple Fixtures for Bypass Capacitor Testing

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Bypass capacitors are used in the largest numbers in power distribution networks. The good news is that component vendors have come a long way to provide more detailed data on them. Most vendors today supply not only typical characteristics, but also various simulation models. Nevertheless, doing our own characterization of these components is still useful and important. In this short article I show you a couple of simple fixture options for these measurements.

When we want to characterize bypass capacitors, usually measuring the impedance of the component in a reasonably wide frequency range is the way to go. This will give us a small-signal equivalent behavior of the part, which most of the time is sufficient. By post-processing the complex impedance, we can obtain the capacitance, the Effective Series Inductance (ESL) and Effective Series Resistance (ESR) of the parts as a function of frequency. In case we are interested in a more detailed picture, DC and AC bias voltage dependence and temperature may be added to the mix of input parameters. All these have been described and explained in detail in earlier publications, see e.g., [1]. Similarly, the instrumentation and measurement setup for this purpose is well established [2]. To measure the impedance of bypass capacitors with high capacitance and low ESR, a good choice is a suitable vector network analyzer, for instance [3], in the Two-Port Shunt-Through connection.

Bypass capacitors come in many different package shapes and sizes. Once we have our instrumentation ready, one of our next challenge is to decide how we connect our sample to the instrument. For two-terminal brick-style components fixtures may be available for the instrument [4]. For quick and simple measurements, we could use home-made fixtures.

Solder-wick Fixture

This is a very simple and rudimentary fixture that we can put together in minutes, yet it works amazingly well at low frequencies, where most bypass capacitors have their interesting details. We can start with two coaxial cables, preferably thin and flexible to allow easy handling, with connectors at one end and open pigtail at the other end. For instance, we can take a six-foot long RG178 cable with SMA connectors at both ends and cut it in the middle. This gives us two cables with identical length, connector at one end and open cut at the other end. The type of connector does not matter much at low frequencies; we can use whatever we feel comfortable with and use adaptors if the instrument has a different style of connector. SMA connectors are relatively small, low cost and readily available. After cutting, the three-foot cables will be long enough to nicely bridge the distance between the network analyzer and a fixture placed on the bench in front of it. (Side note: if we have a choice, we should always opt for the shortest cable that can make the connection.) We strip the plastic jacket at the open ends, untangle the braid for a length of a quarter of an inch and create pigtail connections at the ends of the cables. Next, we cut two pieces of one-inch long solder-wick, slide on short heat-shrink tubes and solder the two coax cables in a series fashion, slide the heat-shrink tubes in place and finally activate the heat-shrink tubes with a heat gun. We get a flexible fixture shown on the left of *Figure 1*. Somehow we need to mark the strips; which is the one connecting the center wires and which is connecting the braids of the coax cables. For instance, we could use colored heat-shrink tubes. Alternately, on the sample shown in *Figure 1*, the somewhat longer heat-shrink tubes mark the return (braid side of the coax).

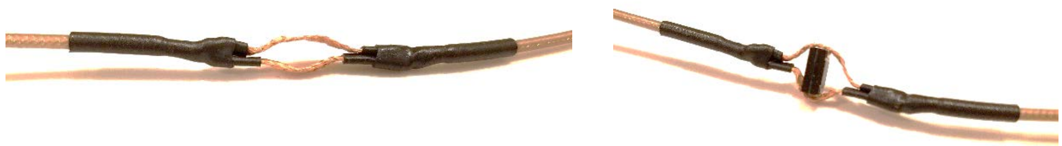

Figure 1.: *Photo of solder-wick fixture (left) and a D-size capacitor in the fixture (right).*

The capacitor can be placed between the two exposed solder-wick conductors; this will create a Two-Port Shunt-Through measurement scheme. On the right of *Figure 1* a D-size (7.3mm x 4.3mm) capacitor is shown in the fixture. To make sure we get reliable connection, we have to either solder the capacitor sample to the flexible braids or press the solder-wick conductors against the component terminals. This fixture with direct through-connect between the two ports of the instruments is best suited for pressure-mount connections, not for soldering. The benefit of using flexible solder-wick strips is that we can use pressure contacts, avoiding the heat stress to the component and/or allowing us to swap out samples very quickly. The pressure-mount connection can be done by spring-loaded plastic or wood clips, or we can just squeeze the fixture tight between our fingers with the component in place. If we are worried about the error caused by our body resistance, we can grab the solder-wick electrodes with our fingers but without a capacitor in place and take the impedance reading. As long as it is much higher than the impedance of the capacitor, we can ignore this error.

If we use short cables and limit the frequencies to below 10 MHz, we can get away with a simple Response Through calibration on the Vector Network Analyzer. Note that a huge benefit of this simple fixture is that the calibration and measurements are done without changing/disconnecting the cables, which helps the consistency of the measurements.

We should also make additional checks and reference measurements before we collect data on DUTs: we have to measure the fixture with no DUT in place (OPEN) and with a SHORT, similar in size to the DUT we want to measure later. *Figure 2* shows the impedance readings for the reference cases: fixture open and fixture shorted. The photo of a shorting device is shown in *Figure 3*. The shorting device should match the size of the DUT; in this case an extra capacitor sample was taken and the terminals on the bottom of the part were shorted with a strip of metal.

Note that as any real-life SHORT reference piece, its impedance is not exactly zero; it has finite resistance and inductance. If we want to measure really low impedances, we would need to characterize our shorting device, which can be done with a full four-point connection, and do a more complex calibration afterwards.

Also, in this very rudimentary fixture there is direct connection between the two VNA ports through the braid, which creates a 'sneaky path,' partially around the DUT when we attach a reference piece or a device to be measured. As a result, what we get for the SHORT reading (and for all other readings) is a mix of the a) actual impedance of the DUT, b) some contact resistance and c) the residual error created by the sneaky path. The OPEN and SHORT readings give us a good indication of the DUT impedance range we can trust when we measure it with this fixture with just a Response Through Calibration: the DUT impedance should be at least 3x … 5x (preferably 10x or more) away from these limits. The traces corresponding to OPEN and SHORT run around 20 kOhm and 2 mOhm at low frequencies, respectively. Note that the rising tail of the SHORT impedance trace is due to the inductance of the shorting piece. Note also that the 2 mOhm reading of the SHORT reference piece is the sum of the actual resistance of the shorting strip plus any error coming from the 'sneaky path' through the braid. The lower measurement limit set by the instrument noise was around 0.1 mOhms.

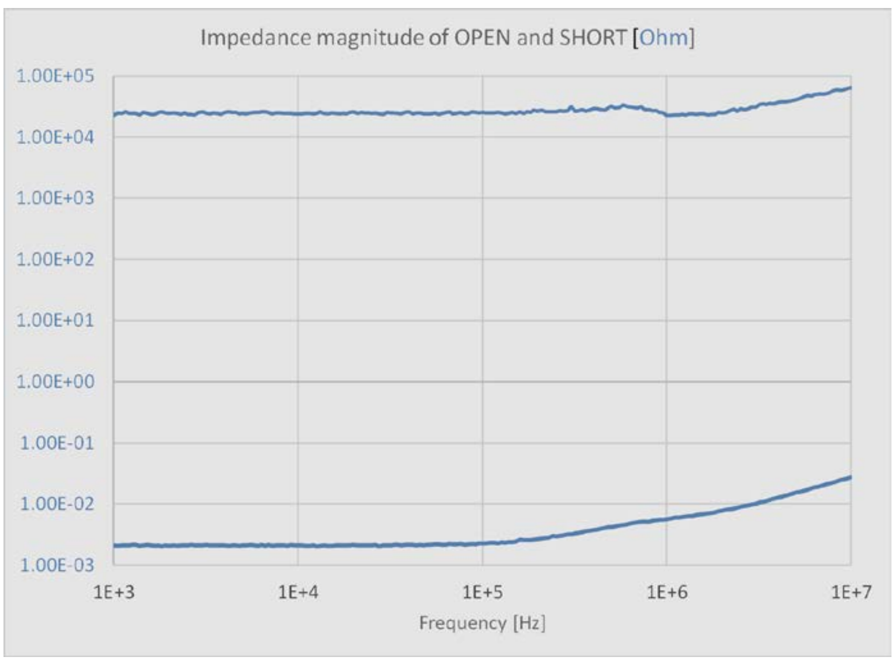

Figure 2.: *Impedance magnitude of Open and Short.*

Figure 3.: *Photo of a D-size Short reference piece. This is a D-size capacitor with a metal strip across its terminals.*

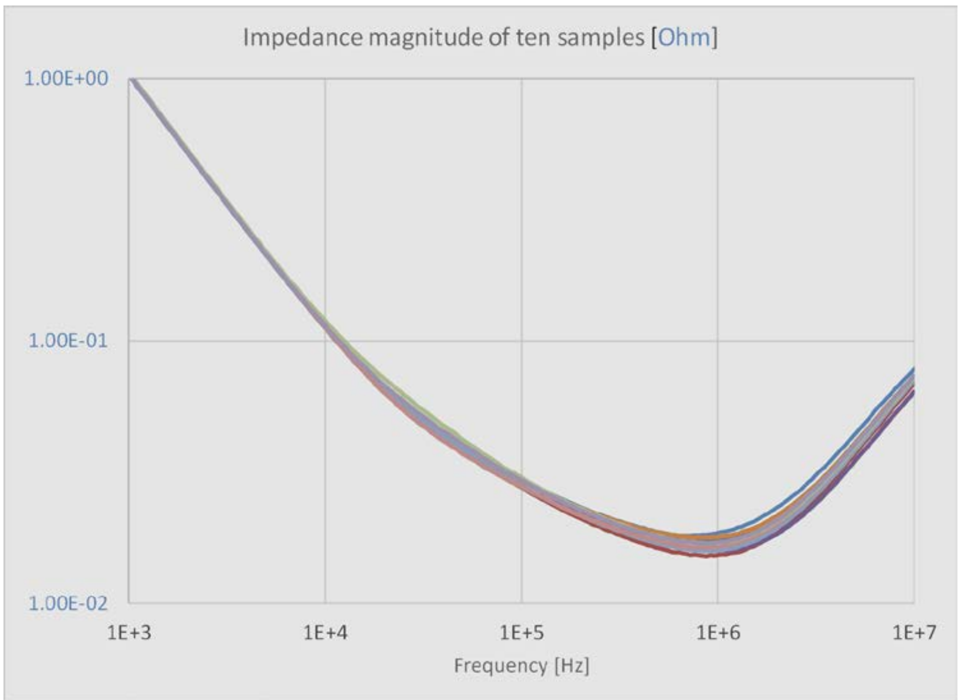

Figure 4.: *Statistical comparison of impedance magnitudes of ten capacitor samples.*

Figure 4 shows the impedance magnitude of ten DUTs measured with this fixture. The data was collected with pressure connections, by pressing the solder wick against the capacitor terminals by hand.

The spread of the impedance magnitude lines is an indication of the consistency of the samples, and in this case, also of the consistency of our pressure-mount connection. All ten lines start out very tight at 1 kHz, indicating that the capacitance, 470 uF nominal value for these samples, came out very close for all samples. The lines begin to deviate a little beyond 10 kHz and hit the maximum spread around the series resonance frequency at 1 MHz. Considering that for such bulk capacitors the data sheet guarantees only a maximum value of ESR (but no typical or minimum), the spread we see here is considered to be typical. Of course, with this simple fixture, using pressure-mount connection, we also need to consider the spread and consistency of contact resistance. Above the Series Resonance Frequency (SRF) the spread continues. The upslope between one and ten megahertz represents inductance. Inductance is related to current-path geometry, but the body size and shape of these capacitors is very consistent. The likely source of inductance spread is the variation of the loop size as we push the fixture and DUT together.

Once we collected data on all samples, we can go back to those samples, which appear to be outliers and retake the measurement, possibly multiple times. This way we can convince ourselves whether the data needs to be updated or in fact the particular sample was an outlier.

Periodically we need to clean the surface of the solder-wick strips to remove contamination. In addition, we have to make sure that the component terminals are clean. If the component is de-soldered from a system so that we can measure it in the fixture, we must clean the terminals with flux-remover solvent, otherwise the terminals may be coated with non-conductive residue.

Beyond the 'sneaky path' raising the error floor, the simple solder-wick fixture has other obvious disadvantages as well: the length of the solder wick strips must be long enough so that the loop can accommodate the biggest components we want to measure. This creates an unnecessary discontinuity at the cable end for smaller components, when shorter fixture would be sufficient. (However, since this fixture takes just a few minutes to make, either we can change it often or can prepare multiple fixtures to accommodate a range of component sizes with optimum fixture sizes). The flexible open connections make the end discontinuity more uncertain, and we need to be careful with the contact resistance.

A more consistent solution can be achieved if we use a fixed-geometry fixture, such as little PCB fixtures. The two typical kinds of PCB fixtures are: a) generic fixtures, which can take a large variety of different DUT bodies in the same fixture, and b) fixtures with dedicated footprints for specific DUTs, such as described in [6]. Here in the next section we show generic fixtures, available from [7].

Generic PCB fixtures

Generic PCB fixtures can be created from small co-planar 50-ohm traces that have exposed trace and ground next to each other on the same side of the fixture. The DUT can be connected between the trace and the ground shape, allowing us to use the Two-Port Shunt-Through connection topology. Having a sufficiently large ground shape next to the trace, we can accommodate a large number of different case styles and sizes. Having connectors at the ends of the trough trace will allow for quick connections, though we could also use permanently attached (soldered) cables. Soldered cables would eliminate the need for separate cables with connectors at both ends, but would make the calibration a little bit more difficult. The photo on the left of *Figure 5* shows the un-assembled panel of fixture boards. On one panel we get eight identical fixture boards (though they carry different labels) that we can break away. Three of them labeled for calibration (OPEN, SHORT, LOAD) and five are labeled for measuring components (DUT). The panels are available with SMA male-female connectors attached, or with the loose connectors shipped in the same package for us to solder them on. The coplanar traces are close to 50 ohms and have only 160 ps delay, which means for a lot of measurements up to 10 MHz a simple Response Through calibration is enough. With soldered connections and a rigid fixture geometry, if we are willing to do more complex calibrations, this setup now can be used reliably up to higher frequencies as well. The tradeoff is between the start and stop frequencies of the sweep and the nature of components we want to measure. If we want to start the sweep anywhere below a few times ten kilohertz ***and*** we want to measure components that have low impedance at low frequencies, such as low-ESR high-capacitance components, we run up against the cable-braid loop error. Dependent on how we reduce the cable-braid loop error, the chosen solution may come with its own limitation at high frequencies. For this column a home-made common-mode choke was used, with an upper bandwidth of approximately 50 MHz. The data was collected in the 300 Hz to 30 MHz frequency range with OPEN, SHORT, LOAD calibration. The OPEN, SHORT, LOAD calibration and high-frequency characterization of the fixture will be described in later columns.

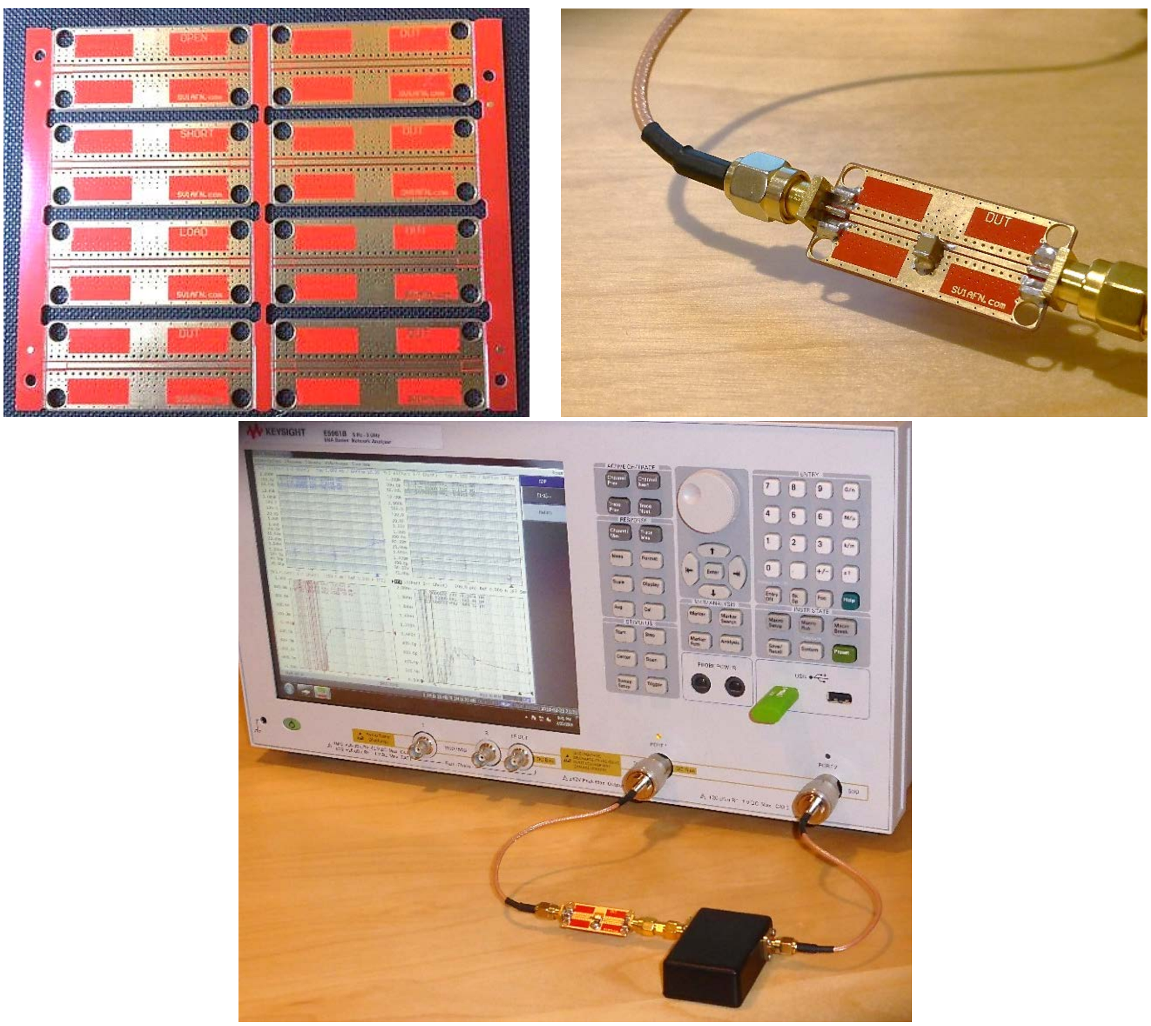

Figure 5.: *Photo of generic co-planar component fixture [7]. Full panel as delivered (upper left) and DUT soldered on one finished fixture (upper right). Measurement setup with network analyzer and common-mode toroid (lower middle).*

The fixtures can take any component size from 0402 (1 mm long) to D-size (7.3 mm long). The DUT sample on the upper right photo of *Figure 5* was a 1210-size ceramic capacitor. With these fixtures we also have the option of connecting the DUT in different ways. Mechanically and electrically we get the most robust and most reliable connection if we solder the part to the fixture. If we want to re-use the fixture and want to speed up the swapping of components, we can opt to use simple pressure mount, like we did with the solder-wick fixture, and maybe we can reduce the contact resistance and improve consistency of our collected data by applying a dot of silver paste each to the component terminals. If we decide to solder the component, we can improve the repeatability of the measurement by pushing down the parts on the pads during soldering. *Figure 6* shows the measurement result from the setup and DUT shown in *Figure 5*. We make use of the Impedance Analysis Option [5] and the screen is set up for four simultaneous traces: Impedance magnitude (upper left), Effective Series Resistance, Rs (upper right), Equivalent Series Capacitance, Cs (lower left) and Equivalent Series Inductance, Ls (lower right). The logarithmic horizontal scale starts at 300 Hz and ends at 30 MHz. The 70 Hz IFBW setting provides a good compromise between fast sweep and low noise floor.

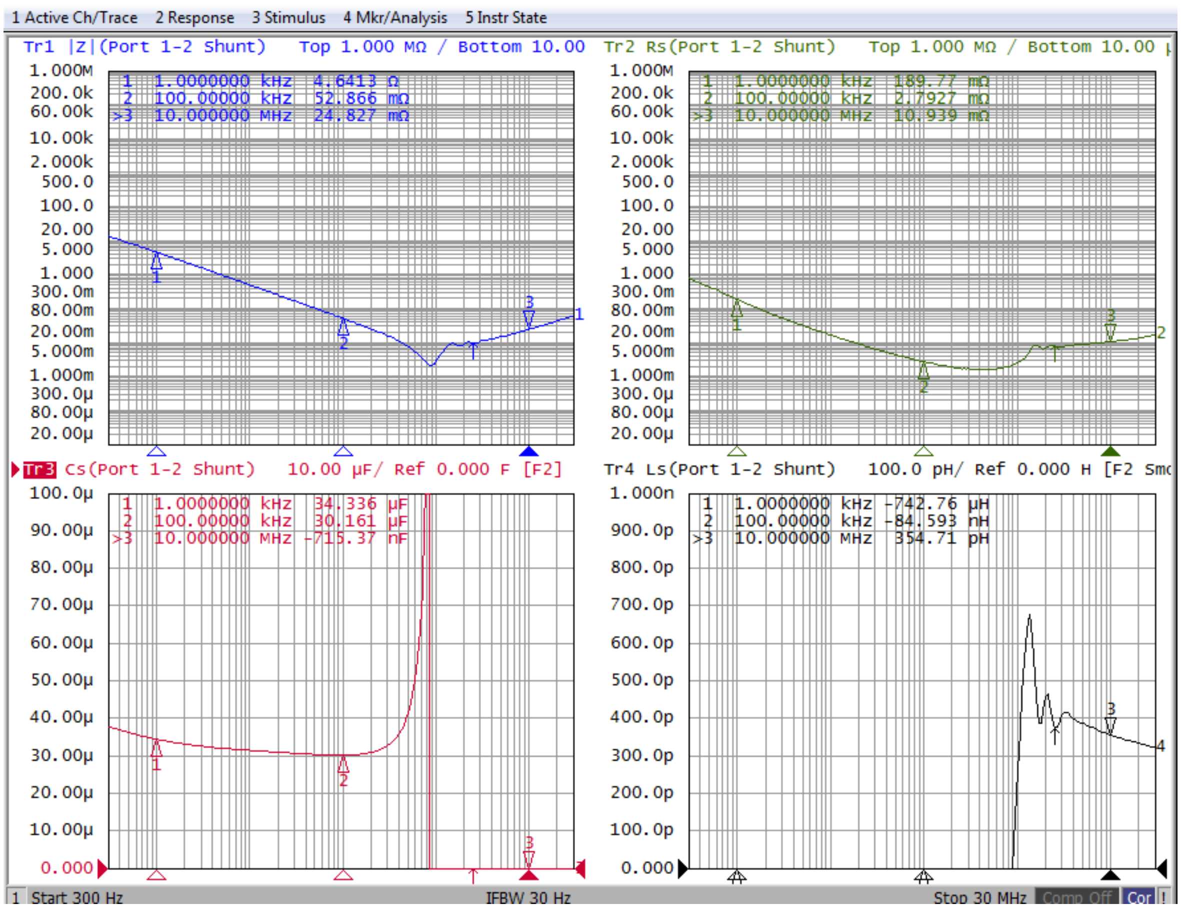

Figure 6.: Measurement data of a 47 uF 1210 size ceramic multi-layer capacitor taken in a co-planar fixture.

These co-planar fixtures are very universal, but this also carries some limitation. Similar to the solder-wick fixture, the co-planar trace represents not only a convenient way to attach a DUT, it also creates a ‘sneaky path’ between the two VNA ports. Second, being generic, these fixtures will not match the geometry of our finale usage in our design. This latter, however, has an impact only on the inductance; the capacitance and ESR can be assessed with high confidence. If we need a fixture that will represent the mounted inductance of the part correctly in our design, we need dedicated fixtures for each part, matching the stackup, via structure, footprint and all horizontal connections between the capacitor and the power planes [8].

References

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