Accurate Feedthrough Capacitor Measurements at High Frequencies Critical for Component Evaluation and High Current Design

A shielded measurement chamber allows accurate assessment and modeling of low pass filters

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The shunt capacitor is the critical element in almost all low pass filters. Feed-through capacitors are configured as a center electrode passing through a grounded housing, which contains the desired capacitance from the electrode to the grounded housing, and practically eliminates lead inductance. This article will explain the importance of feedthrough capacitors, and provide improved methods for testing the high frequency performance of these critical components. Testing the insertion loss performance of feedthrough capacitors in a repeatable fixture is necessary to evaluate components for design, application qualification, and incoming inspection or quality audits. High current and high performance filters represent unique challenges for component testing. High current here refers to current ratings of significantly over 30 Amperes, up to and exceeding 400 Amperes. High performance generally refers to insertion losses of greater than 30dB at frequencies up to at least 1GHz.

Lower frequency performance may require series inductors with the shunt capacitor. For example, these components could be arranged according to Butterworth criteria to reduce the cut-off frequency and maximize slope of the insertion loss curve. For example, the ever popular π filter with a 16 kHz -3dB cutoff frequency, and 60dB per decade roll-off would consist of the components shown in Figure 2.

While the value of an inductor has a constant relationship of μH = 5 x μF for an optimized π filter; in many cases the inductor is a lower value than optimum during actual use due to weight, size, or cost constraints. The inductor can be susceptible to saturation at high current, thereby reducing the inductance value further. The other benefits of a series inductance is to increase the high frequency performance above the level achievable from a capacitor alone. The feedthrough capacitor is substantially immune from any effects of through current, and usually only has minor and predictable changes with applied voltage. For the lowest cost and size, and to eliminate through current performance variations, the feedthrough capacitor alone is the preferred, or initial, solution for high current and high frequency filtering requirements.

There have been several articles written regarding improved methods for measuring the low frequency performance of filters. A useful recommendation, particularly at frequencies below 100kHz, is to use current injection according to IEEE 1560 Method 10.5 at full current. Since high performance feedthroughs are functional well over 100MHz, measuring the component ac-

Figure 1. Typical feedthrough installation example.

curately is an important part of qualification. This article will address some of the concerns regarding measuring high frequency insertion loss of filters, particularly well above 30 MHz, while also accounting for high current levels.

An industry standard insertion loss measurement set-up is shown in Figure 3. This circuit has been successfully used in the bands from about 300kHz to over 30MHz. The challenge with this test set-up is the use at currents exceeding 30 amperes or greater, and at greater than 100MHz. Even though the test circuit is on a ground plane, the high frequency coupling across the power taps can have significant effects on the results. This high frequency coupling is shown in Figure 4.

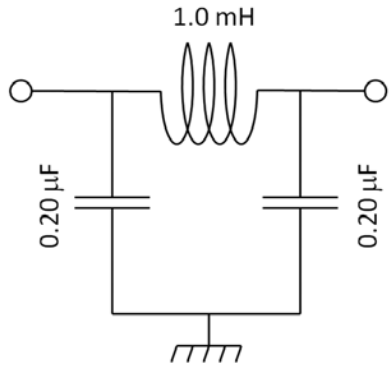

Figure 2. 16 kHz Pi filter.

The "open" DUT (Device Under Test) zone can cause measurement limitations at high frequencies. This is particularly true for high current filters, as the geometry of the end electrodes and attaching wiring can extend for 2.0" (50mm) or more on either side. As frequencies usually exceed 30MHz the parasitic capacitance across the filter (from one side of the capacitor to the other) can cause significant coupling around the filter. Consider that the feedthrough capacitor effectively shunts the center of the through conductor to ground, resulting in what are essentially opposing linear Beverage antennas.

The coupling around a filter can be modeled as either capacitance or antenna coupling. The parasitic capacitance shown in Figure 4 couples higher frequencies around the filter shown in the center of the figure. The parasitic capacitance is proportional to several factors, including exposed areas, and inversely related to separation of the two sides of the filter. Antenna-type coupling around the filter is related to several factors including, principally, separation and exposed length. The free path loss is inversely proportional to the square of the separation and frequency, which is the coupled signal reduction with distance. The antenna efficiency of the radiating surface is complex and improves to a maximum at λ/4 and harmonics thereof. This factor, and several others, can combine to produce a maximum value of coupling at an array of frequencies. In order to get an estimate of this coupling effect,

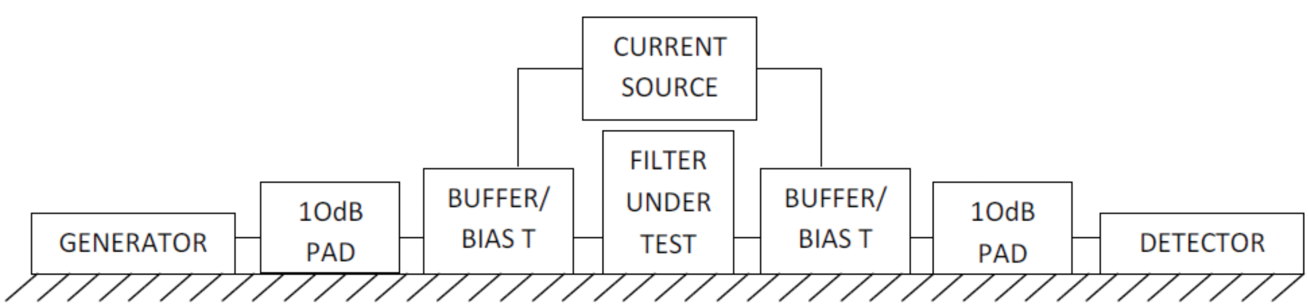

Figure 3. Insertion loss test set-up according to MIL-STD-220B with load current and buffer networks.

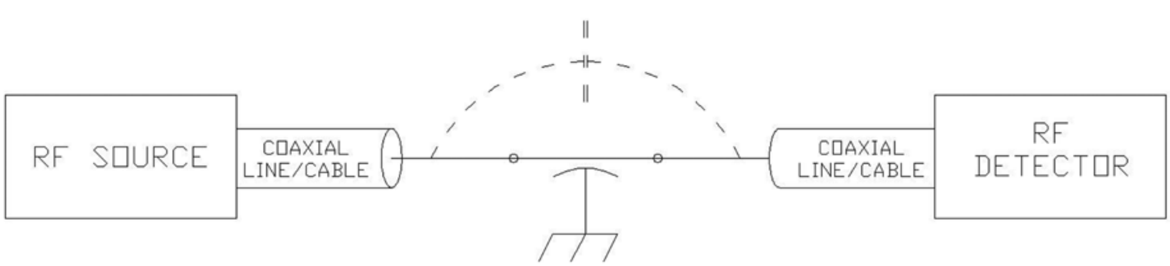

Figure 4. Coupling across a DUT, when measuring insertion loss.

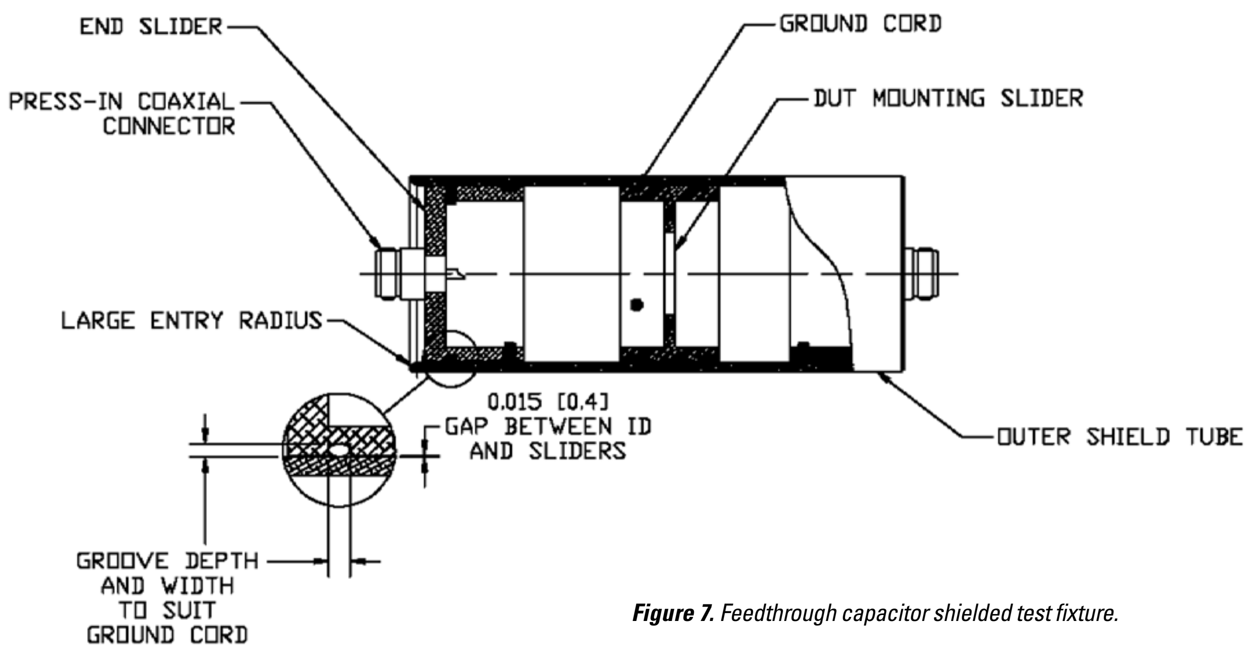

Figure 7. *Feedthrough capacitor shielded test fixture.*

feedthrough filter capacitors. Since the insertion loss of a C-type feedthrough is substantially unaffected by through current levels, it is advantageous to accurately evaluate the performance of a high current filter using less-than- full-scale test techniques. NexTek has also developed a method of accurately measuring the insertion loss at the component level with no load current being required and very accurate high frequency results.

The high frequency performance of capacitors requires a fully shielded enclosure for testing, including shielding of one side of the filter from the other. A fixture such as this is shown in Figure 7, and can be found at www.nexteklightning.com/FilterTestFixture.html).

The TEM cell inspired test fixture has an outer shield tube that is fashioned from a convenient diameter of metal pipe or tubing to fit around the largest expected filter. The inside will generally have to be precision turned and polished, and the inside entry edges should be well rounded. There are three internal sliders, which are piston shaped objects. Good results have been obtained with sliders and tubes made from nickel plated aluminum. The end sliders have coaxial connectors for connection to a network analyzer or source and detector. The coaxial connectors might have small springs, pogo pins or discs soldered onto the inner side of the center pins to make contact to the Device Under Test (DUT). The DUT slider should keep the capacitor centered by having a tapered face on one side, and/or a through hole which just fits the component. All three sliders have outer circumferential grooves, to hold ground cord in position, with holes through to the ID of the pistons, for securing the ends of the ground cord ends. With the adequate groove depth and width, and a small gap between the sliders and inside diameter of the shield tube, at least two complete circumferential shield grounds can be established between the sliders and the shield tube. Successful results have been obtained with both spiral and knit mesh type ground cord; however, silicone foam core with double layer SnCuFe mesh seems to work best. The ground cord effectively isolates left side from the right side of the middle slider, and the internal region of the test fixture from the external environment. The feedthrough capacitor is mounted on the middle slider, which is inserted near the midpoint of the shielding tube. The end sliders are inserted and advanced until contact is made with the end electrodes of the filter, when measurements can be taken.

Figure 8. *An HPR Filter being installed in test fixture.*

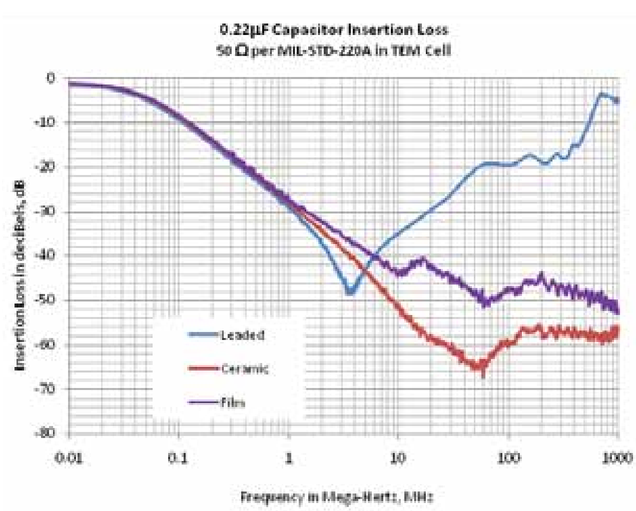

Figure 9. *Comparison of various filter capacitors.*