QuadTech

# Application Note

## Building the Perfect Component Test Fixture

Creating the right test setup feels rather like building the perfect beast at times. Making the mistake that a more accurate, elaborate and expensive instrument will improve the accuracy of the measurement system is an all too common occurrence. In some cases a more expensive design is necessary but in most cases, it will provide no appreciable improvement. Consider not only the test instrument but also the test fixture to improve measurement accuracy. The right fixture can reduce errors associated with the device under test, cables or test instrument itself thereby increasing accuracy. Another benefit of the right fixture especially in a production environment is increased throughput when testing similar devices. Read on for an example of fixture importance then review the initial considerations before you start designing your test & measurement system.

### An Example

Consider measurements on a standard capacitor as illustrated in Figure 1. This particular standard is a 1nF capacitor with a value known to 0.01%. Connections on the capacitor are 3-Terminal guarded banana plug connections. Measurements are performed using an LCR meter with a basic accuracy of 0.02% at 1kHz. The fixturing consists of a standard off the shelf 1-meter Kelvin cable with BNC-T's and adaptors for termination in 2 banana plugs plus 1 shield. Seems easy enough so far, good instrument and cable should equal an accurate measurement. The main consideration here is the fact that we need to accurately measure down to 0.2pF to achieve 0.02% accuracy. Stray capacitance is everything in this measurement. Performing an OPEN calibration will compensate for stray capacitance if it is constant. If the stray capacitance varies measurement to measurement then an accuracy of 0.02% simply cannot be achieved. So to make this measurement the cables must be fixed with ideally **no** movement.

The importance of keeping cable movement or spacing from changing cannot be ignored if accurate and consistent results are desired. This is just one consideration of the right fixture. For the purpose of this discussion a fixture is defined as the mechanical/electrical interface between the measurement instrument and the component or DUT being tested. We'll also limit this discussion to "low frequency" measurements (those below 2MHz).

## What's That Look Like?

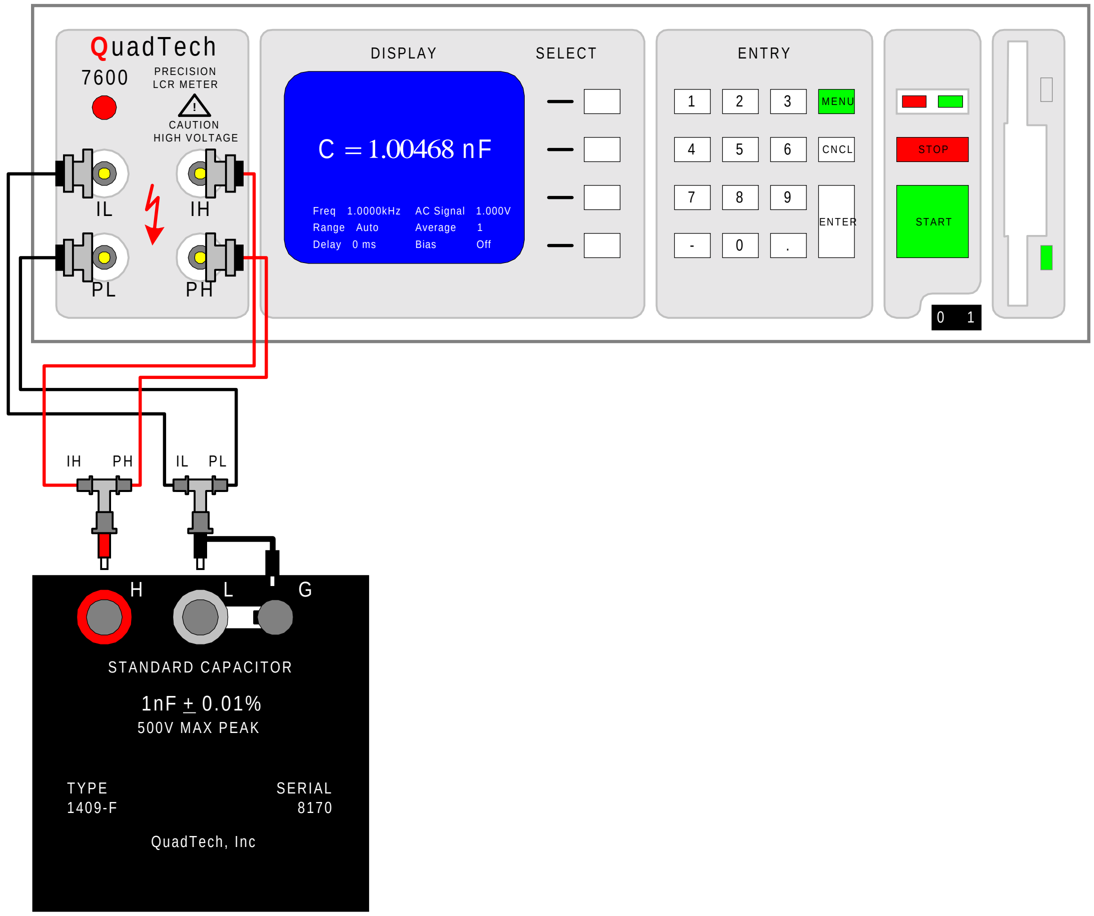


**Figure 1: Capacitor Measurement & Cable Error**

### So What Does A Good Fixture Make?

Review the following questions to form the initial considerations in the design of the right fixture for your test & measurement system.

- Is a commercially available fixture already available?
- What are the physical dimensions and tolerances of contact areas?
- What is the ease of loading and unloading of DUT?
- What parameters are being measured?
- How does the instrument measure these parameters?
- What might effect the measurement such as electrical noise, contact resistance, stray capacitance and leakage resistance?
- How will the fixture be attached to the work surface?

# What You Need to Consider:

## Commercial Fixtures

Commercial fixtures may be more expensive however someone has already put in the time, effort and thought into insuring a good quality fixture. Before purchasing a commercial fixture review the physical dimensions of the DUT, the connection to the DUT, the usable frequency range of the fixture, the maximum test voltage/current ratings of the fixture and any effects of residuals. Common commercial fixtures include SMD fixtures, axial/radial component fixtures, dielectric cells and a wide range of test cables.

## Measurement Parameters

Just what kind of a device (DUT) is being measured? And which test parameters are the most important in the characterization of the particular device? The accuracy of different parameters is affected by different sources of error. Capacitors, inductors and resistors exhibit unique characteristics depending on many test variables including frequency, core material and cable length to name a few. So repeatability of exact test conditions is necessary for consistent measurements. A good fixture can provide that consistency.

## Capacitors

When measuring relatively low values of capacitance (<100pF), the resultant high impedance and effects of stray capacitance are significant. The effects of series resistance due to relays and/or cabling are insignificant in comparison. However the equivalent series resistance (ESR) or dissipation factor (Df) of a capacitor can be effected by greater than 100% error due to changes in series resistance on the same capacitor.

High values of capacitance (>10µF) are affected by series inductance. Adding series inductance will effectively increase the apparent value of the capacitor being measured. The resultant measurement error depends on the test frequency. The greater the test frequency, the greater the measurement error due to series inductance. Let's do the math.

For example measure a 100pF capacitor at 1MHz with 1µH of lead inductance. The ESR, $R_S$, is equal to 100mΩ. What is the resultant measurement error?

| | |
|---|---|
| Actual Capacitive Reactance: | $X_{C\ ACT} = 1/j\omega C$ |
| Measured Capacitive Reactance: | $X_{C\ MEAS} = X_{C\ ACT} + X_L = 1/j\omega C + j\omega L$ |
| Actual Capacitance: | $1/j\omega C_{MEAS} = 1/j\omega C_{ACT} + j\omega L$ |
| Measured Capacitance: | $C_{MEAS} = C_{ACT}/(1-j\omega L)$ |

$$C_{MEAS} = C_{ACT}/(1-\omega^2 LC_{ACT}) = 100\text{pF}/[1-(j2\pi f)^2 (1\mu\text{H} \bullet 100\text{pF})]$$
$$= 100\text{pF}/[1-(4\text{x}10^{-3})] = 100.4\text{pF}$$
$$= 0.4\% \text{ error}$$

# More Parameters to Consider

## Inductors

High values of inductance (>1H) represent relatively high impedances so techniques applicable to high impedance measurements become appropriate in this case. These techniques include shielding of the test leads and fixture and minimizing shunt or stray capacitance. In addition, secondary effects of temperature, DC bias current, test signal level, stabilization time and frequency should be considered when dealing with ferrous core type inductors.

Small value inductors (<1mH) on the other hand have low impedance and steps should be taken to reduce the series inductance and cable length when testing these inductors. One should also consider the effects of the inductor being in close proximity to metal, hands or any other conductor.

## Resistors

Resistors come in all shapes, sizes and materials. There exist a number of secondary effects that are unique to specific types of resistors that we shall not include in this discussion. Generally resistance measurements are based on Ohm's law (V= R/I) or solving for resistance R=V/I. A test signal of known voltage or current is applied to the device under test (DUT) and the resulting current or voltage is measured and the resistance then calculated.

AC or DC test signals can be used to measure resistance. The use of a DC test signal such as those used in megohmmeters negates any concern of stray reactances that will affect the indicated value. On the other hand, when an AC test signal is used you can usually consider the resulting indicated value to represent the equivalent series resistance (ESR). Error due to stray reactances and affects of frequency must now also be considered.

Special considerations must also be taken into account when measuring resistance values at either end of the spectrum, either extremely low values (<1μΩ) or extremely high values (>1MΩ). For low resistance measurements a constant current source is normally used. The affects of contact resistance, thermal EMFs and mutually induced EMFs should be factored in when designing a good test fixture. High resistance measurements are normally performed with a constant voltage source. Shielding and/or guarding is generally required to minimize the affects of external electrical noise.

## Frequency Plays An Important Role

In most cases, rather than talking about capacitance, resistance or inductance it is more realistic to discuss these parameters in terms of their impedance values. At any specific frequency an impedance may be represented by either a series or parallel combination of an ideal resistive element and an ideal reactive element which is either capacitive or inductive. Figure 2 illustrates the equivalent circuit representations and phase diagrams for impedance and its reciprocal, admittance. The value of these elements (parameters) depends on whether a series or parallel equivalent circuit is used to represent them. It is very rare to have a component that is purely resistive or purely reactive.

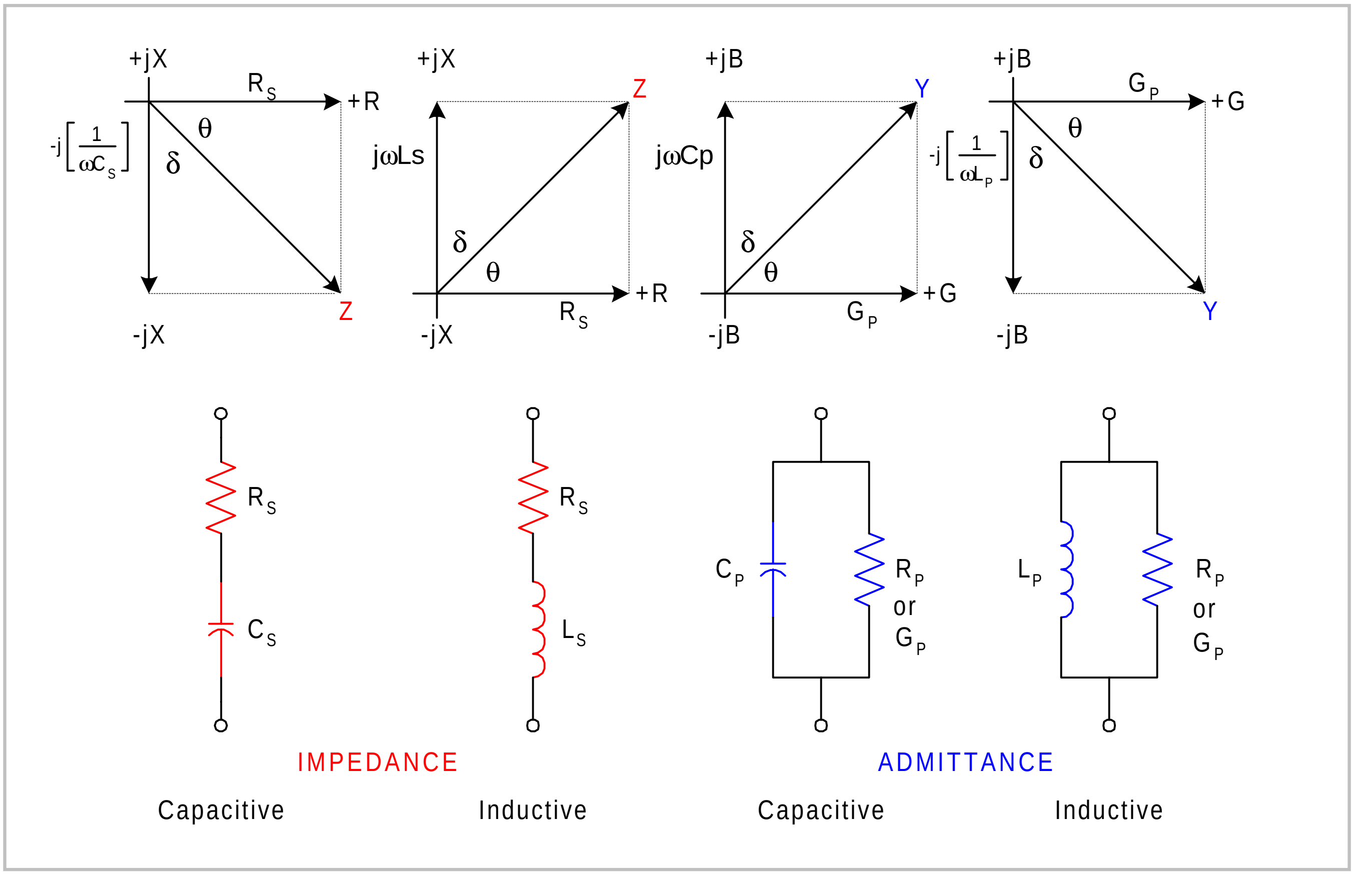


**Figure 2: Impedance Phase Diagrams and Equivalent Circuits**

### Impedance

Rather than looking at a DUT's C, L & R parameters, it may be easier to characterize the DUT in terms of impedance. Impedance values above 100kΩ are usually treated as high impedance parallel equivalent circuits with the primary sources of error due to stray capacitance and external electrical noise. Series equivalent circuits generally represent low impedance values (those below 100kΩ). These low impedance values are generally affected by series inductance, contact resistance, thermal EMFs and mutually induced EMFs.

## What Does Phase Have To Do With It?

When using an AC test signal, the affect of phase shifts must be accounted for. This is normally only an issue when measuring a complex component at frequencies greater than 100kHz. Most LCR meters are calibrated to maintain a known phase relationship between measurements of voltage and current. If longer or shorter cables are used as part of the measurement system, then cable compensation must be used to correct for the phase shift.

### Phase Shift Example

Is there any affect when 1 meter of cable is added for an impedance measurement at 1MHz? When additional cable is added to an LCR meter the signal must travel the additional length out to the DUT and then back. So an addition of 1 meter of cable increases the signal path by 2 meters (round trip) and causes a resultant phase shift in the signal of 2.4° at 1MHz. The LCR meter measures the voltage across and the current flowing through the DUT as well as the phase between the two signals. From these three measurements all impedance parameters are the calculated. The phase shift does not cause an appreciable error in the capacitance measurement however it does cause an error in the secondary parameters of Df and ESR of greater than 100% as illustrated in Figure 3.

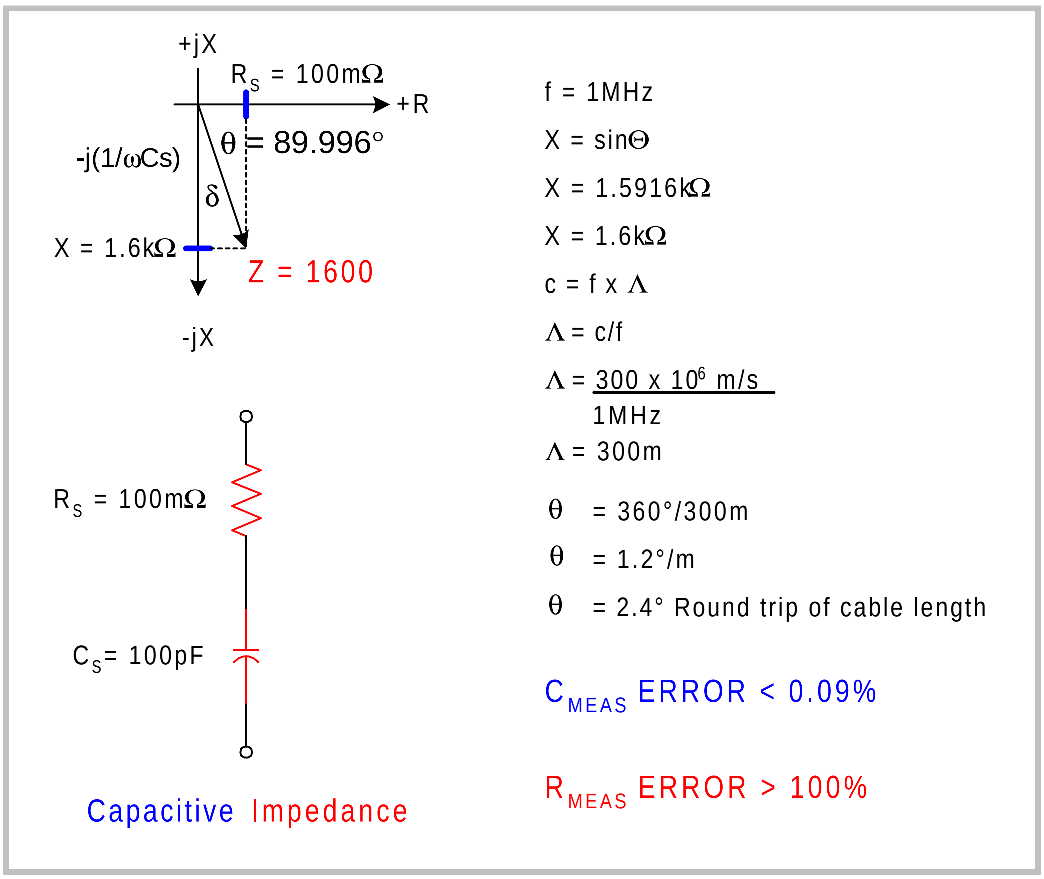


**Figure 3: Impedance Measurement Phase Shift Error**

## What Does Impedance Have To Do With It?

Okay so what does all this discussion of parameters have to do with building the perfect fixture? Simply, you have to know what device you are testing and what characteristics effect its measurements. In the real world there are no electrical components that are purely resistive or purely reactive. All devices contain real and imaginary components. So the complex values of impedance have to be used for accurate device characterization. Frequency can throw a real monkey wrench into the works! One simply can't get away from it.

### General Considerations

There are many fixture considerations too numerous to mention however here are a few broad range tips. When designing your test fixture consider:

- Physical Dimensions and Tolerances of the DUT
- Mechanical Stresses on the DUT
- Ease of Loading/Unloading the DUT
- Materials for Temperature, Humidity, Chemicals and other Environmental factors
- Operator Safety
- Stability of Mechanical Components of Fixture
- Attachment of Fixture to the Work Surface

### Show Me an Example

One starting place for a large test fixture is the Nema-4 hinged enclosure. You may expect to find this type of fixture hanging on a wall or pole not necessarily face up on a workbench. Its benefits are many including ease of mounting it to a wall or test bench and its construction of waterproof and durable materials. The main benefit of a Nema-4 hinged enclosure is its serviceability. If a relay or other component of the fixture breaks down, then just release the latch to open the fixture and replace the part. There are no screws or other hassles in opening up the fixture. Enclosures of this type may be a little expensive at the onset but their value increases in the lack of fixture downtime. These fixtures are usually produced as ordered assuring the specific design and quality you stipulate.

Operator Safety is an important aspect to consider when designing your test fixture especially when dealing with High Voltage instruments such as Hipot Testers and Megohmmeters. Manufacturers of todays HV test equipment have incorporated a number of operator safety features into their new instrumentation. Features such as interlocks provide a wide variety of choices when designing a fixture. If the connection between interlock terminals is open the instrument will not perform a measurement or will immediately stop a measurement in progress. The fixture can incorporate a hood and micro-switch to connect and disconnect the interlock. The interlock can also be used with palm switches and/or a light curtain to keep the operator's hands away from the fixture during test. Figure 4 illustrates a typical HV fixture with a hood and micro-switch. Operator safety is increased when this type of fixture is used with a megohmmeter that has an interlock.

**Figure 4: HV Test Fixture with Interlock**

## Reducing Errors

In attempting to reduce measurement error, the three key points to consider are:

- Guarding and Shielding
- Relays
- Cables

Residuals such as stray capacitance, series inductance and extraneous resistance must be minimized so that the measurement is most purely the DUT's characteristics. Contact resistance due to connection to the DUT and relays should be minimized. Errors associated with the fixture must be consistent and stable over time. If the errors are inconsistent there is no way to compensate. Open, Short and Load Compensation (or Correction) can be very effective in reducing residuals BUT only if the errors are consistent.

## Guarding and Shielding

Guarding and shielding are one way to reduce the affects of stray capacitance and resistance. It is important to note that Guarding and Shielding are **not** the same. Shielding minimizes the amount of electrical interference introduced into a measurement circuit as a result of external EMI. Shielding consists of some type of metal enclosure around the measuring instrument and the component being tested. The enclosure is usually then connected to earth ground. This can be accomplished with a metal fixture with a hood to completely enclose the DUT. It is highly recommended that coaxial cables be used for carrying low-level signals.

## A Guard or a Shield?

Figure 5 illustrates the front panel connectors on the QuadTech 1865 Megohmmeter and a simplified internal connection diagram of the Guard Terminal. Picture the Guard Terminal as a real physical barrier in the measurement circuit and a shield as merely an enclosure connected to earth ground.

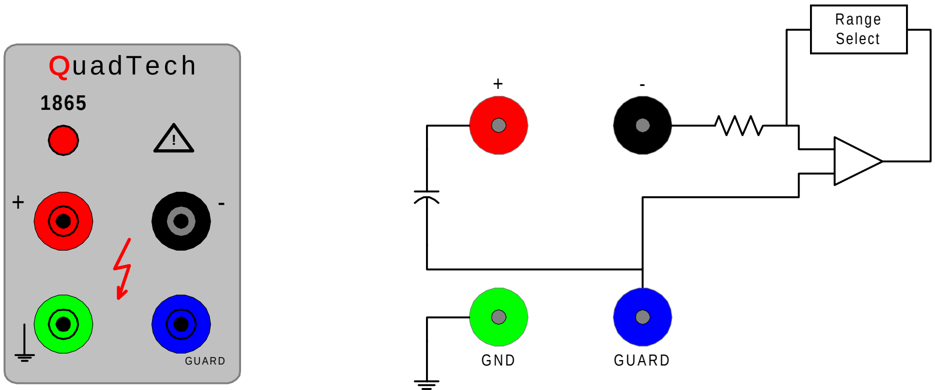


**Figure 5: Guard Terminal 1865 Megohmmeter**

Guarding is similar to shielding and helps reduce errors caused by stray resistance and common-mode signals. A floating measurement instrument is termed 'guarded' when it has an additional shield between its low terminal and ground. When properly connected the guard shunts common-mode currents away from the measuring circuit. One common application for use of a guard is in high resistance measurements using a megohmmeter. A metal guard plane can effectively negate alternate resistance paths when used in parallel with the resistance being measured. The use of a guard becomes very clear when performing volume resistivity measurements in accordance with ASTM D257. Figure 6 illustrates an ASTM D257 sample test cell. In this measurement, the resistance through the sample material is measured from top to bottom with one electrode placed on top of the sample and one electrode placed on the bottom. If only two electrodes are used then the resistance measured is a parallel sum of the resistance through the sample, the resistance across the top surface, the resistance down the side and the resistance back across the bottom of the sample. This method may result in a lower than expected volume resistivity measurement. To minimize the surface resistance path a guard ring is placed around one of the electrodes and effectively eliminates that resistance path. Similar guard techniques can be applied to testing PC boards, cables within a fixture as well as the entire fixture.

Picture This Sample

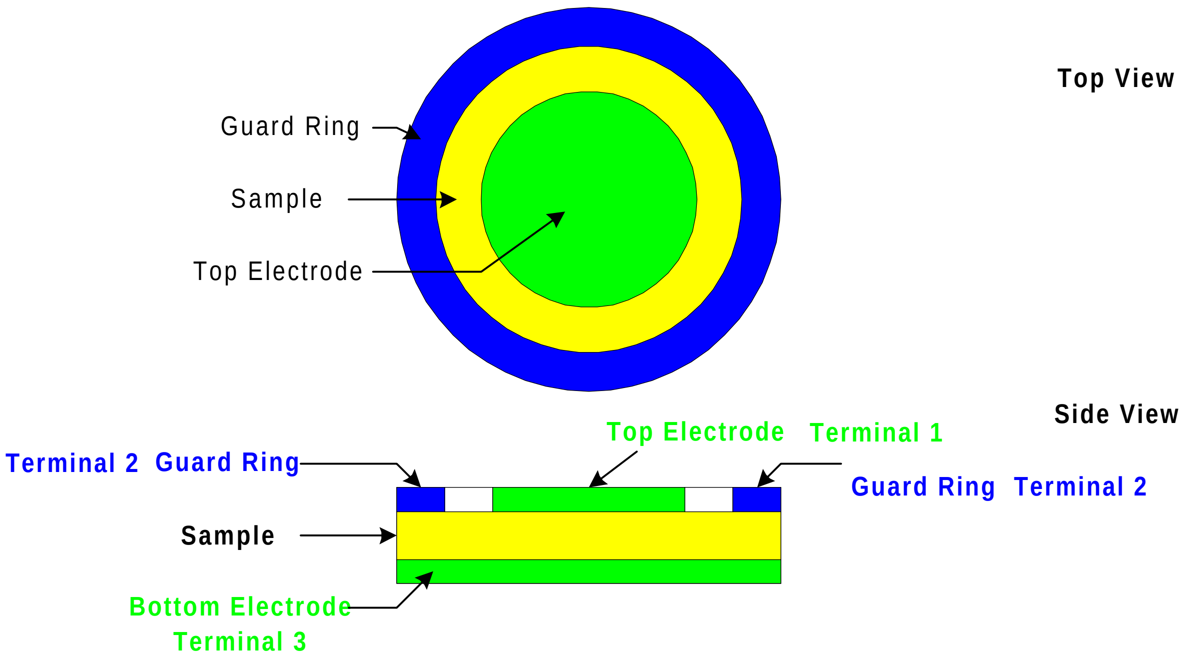


**Figure 6: ASTM D257 Test Cell Sample**

## Relays

Relays are still a mainstay in switching certain analog signals. Relays are used most often with low level current and voltage signals as well as high voltage and current signals. Though a common component, some thought must be given when using relays for these applications. When choosing relays for a fixture consider the contact resistance, insulation resistance (especially in terms of humidity), thermal EMF, relay life and electrical ratings. Generally, relay life and electrical ratings are the first parameters everyone looks at when choosing a relay and thus will not be emphasized here.

When measuring high impedance values, insulation resistance can begin to affect measurements. Most relays have an insulation resistance on the order of $10^9$ (1GΩ) or greater. Measurement of insulation resistance using a megohmmeter can easily exceed 100GΩ making the use of relays extremely difficult. It is still possible to compensate for the low resistance of the relay as long as the insulation resistance is constant. This is why it is important to remember that the insulation resistance of relays will be affected by humidity. If the fixture is to be placed in a production environment where the humidity levels may exceed 85%RH, then select relays rated for these humidity levels, otherwise test results can be inconsistent on an hour-by-hour basis. High humidity levels also reduce the overall life expectancy of the relay. A combination of electrical arcing and high humidity can produce nitric acid in environmentally sealed relays. This consequence can corrode the contacts resulting in early failure of the relay.

# More on Relays

Contact resistance should also be minimized as much as possible, however it is relay variability in contact resistance that can cause the most problems. Contact resistance is especially important when measuring low impedance devices. Mercury-wetted reed relays that have low variation of contact resistance are an ideal option for low impedance, low signal level applications.

A voltage will develop at any transition where dissimilar metals come on contact with each other, hence thermal EMF. The magnitude of thermal EMF (voltage level) depends upon both the type of metal and the temperature difference between the junctions. When measuring low level voltage signals, as with milliohmmeters and LCR meters, the thermal EMF factor must be considered in trying to reduce error. Low EMF relays are manufactured for this particular reason and are commonly available from a wide range of sources.

No matter what kind of relays best serve your fixture needs, it is extremely important to choose relays that are readily available and easily replaced. In a production environment, relays need to be replaced on a regular basis to maintain consistent test results. Who's going to tell the operations manager that the production line needs to be shut down because a relay has to be ordered?

## Cables

Consider these three cable characteristics when designing your test fixture:

- Cable Length
- Cable Motion
- Cable Shielding

In any fixture design, determining cable length should be given serious consideration. If an instrument is designed for use with a specific length of cable, then every effort should be made to keep to the required length. If a cable length is not specified, try to keep the cables neatly organized, as short as possible and spatially separated by different signal types. Organizing cables will save significant time in troubleshooting measurement errors. Separate and shield cables of different signal types and keep them physically apart. Although it may be convenient to run all the cable from the fixture to the instrument within one piece of conduit, this method can induce both measurement and system errors. Large analog signals can easily interfere with digital control lines just as digital lines can provide interference with low-level analog signals. Separating cables up front is far less time consuming than trying to determine why the PLC or computer sporadically hangs.

Restricting cable motion using tie-wraps (or another means of tying down the cable) will reduce triboelectric noise. Triboelectric noise, the noise generated by movement of shielded cables, can be a significant source of erratic measurements on high impedance DUTs. Take this recommendation of tying down and physically separating cables into consideration when choosing fixture cables.

# Cable Shields and Service

A cable shield is another highly effective way of reducing unwanted EMI. A wide variety of shielded cable designs and configurations are commonly available. Each type of shielding has its advantages and disadvantages that warrant consideration in the design of your component test fixture. A braided shield is one of the most popular solutions for fixture cables. If the shield on a coaxial cable is the braided type, remember that it does not provide 100% coverage against EMI. The higher percentage of braid coverage, the more effective the shield.

## Service

Consider these Service points when designing your test fixture:

- KISS (Simplicity)
- Common Parts
- Spares

Most people are familiar with the KISS concept from a design point of view. But term 'stupid' doesn't apply here. In terms of designing your test fixture it is equally (if not more) important to consider how you're going to service that fixture. "Keep it Simple for Service" is a good motto. A fixture is a mechanical device and is commonly used in a less than ideal laboratory environment. On the production line floor, fixtures will be used by inexperienced personnel with limited (if any) understanding of electrical concepts. The fixture will break or be broken and need to be repaired quickly.

If at all possible use common off the shelf parts in building your test fixture. My choice is to use parts that are available from stock from larger distributors such as McMaster Carr or Newark Electronics. The selection is not always there however when the fixture breaks and individuals are asking why the production line is down, so having parts delivered overnight is worth the investment.

There will be times where components being used in the fixture are not readily available. If the components being used in the fixture have a long lead-time from the manufacturer it is recommended that spares be kept. Again this can depend upon how long you can be without using the fixture but generally plan for no longer than two days.

It is important to remember that consistency in measurement is the product of technique, instrumentation and fixturing. Designing the perfect fixture does not have to be difficult, just determine what parameters you are measuring and what sources of error will affect that measurement. Once you understand this concept, a little thought and some common sense will provide the fixture design that's right for your test & measurement system.

For complete product specifications on the 7600 instrument or any of QuadTech's products, please visit us at [http://www.quadtech.com/products](http://www.quadtech.com/products). Call us at 1-800-253-1230 or email your questions to [info@quadtech.com](mailto:info@quadtech.com).



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Printed in U.S.A. P/N 035094/A2 July 2003