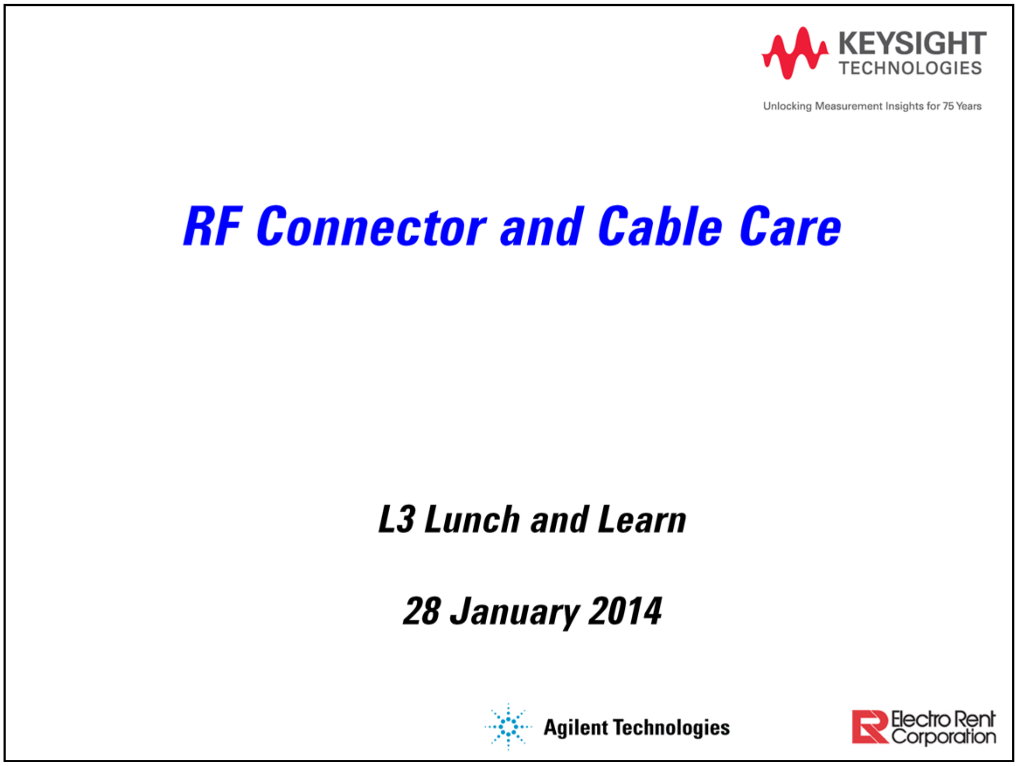
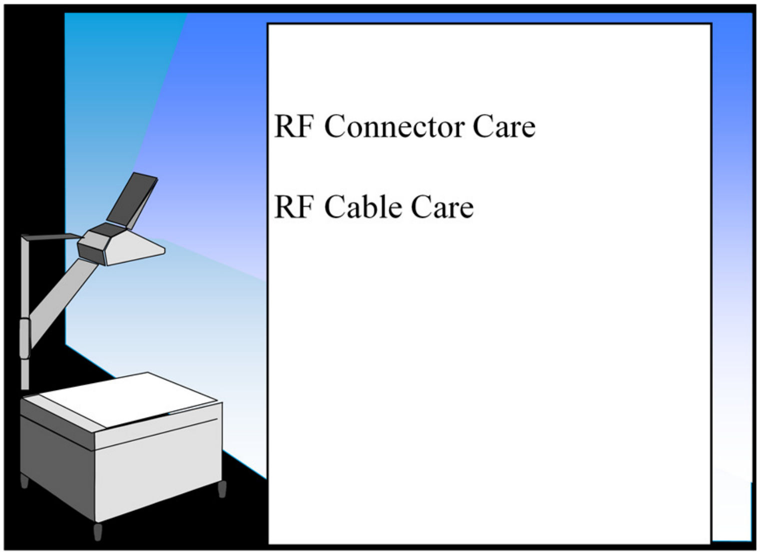


Welcome to the Lunch and Learn presented in conjunction with L3, Agilent Technologies (Keysight) and Electro Rent.

Todays topic covers Connector and Connector Care.

Agenda

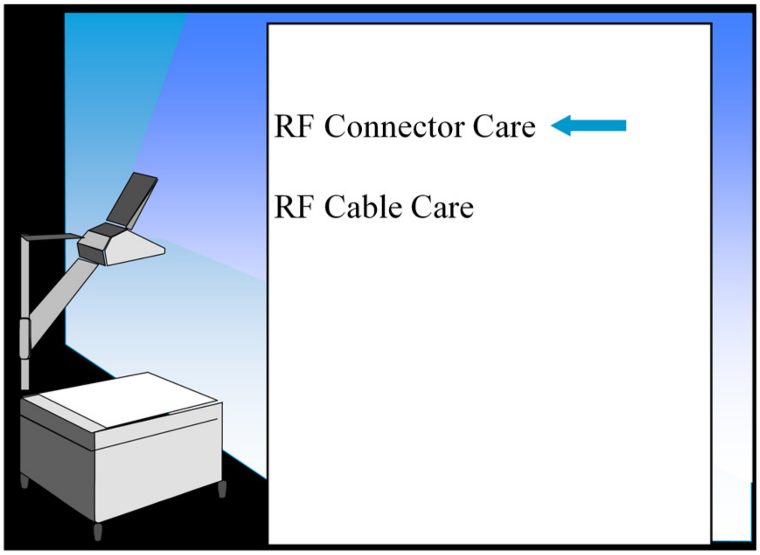
Unlocking Measurement Insights for 75 Years

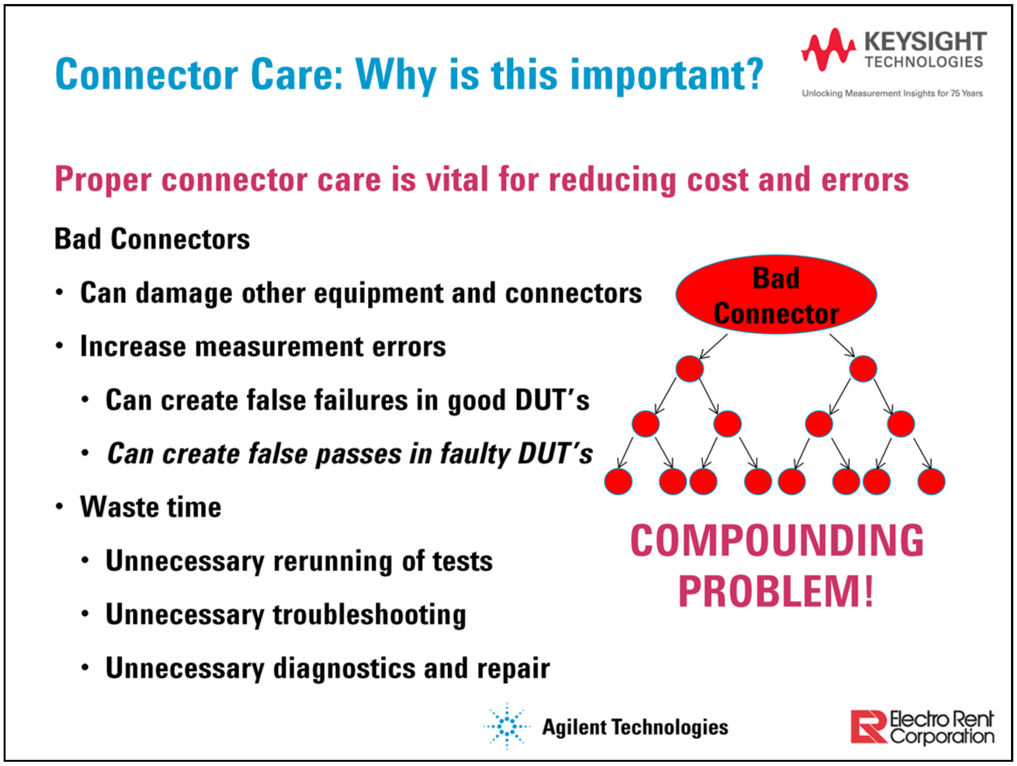


Agilent Technologies

Electro Rent Corporation

Agenda





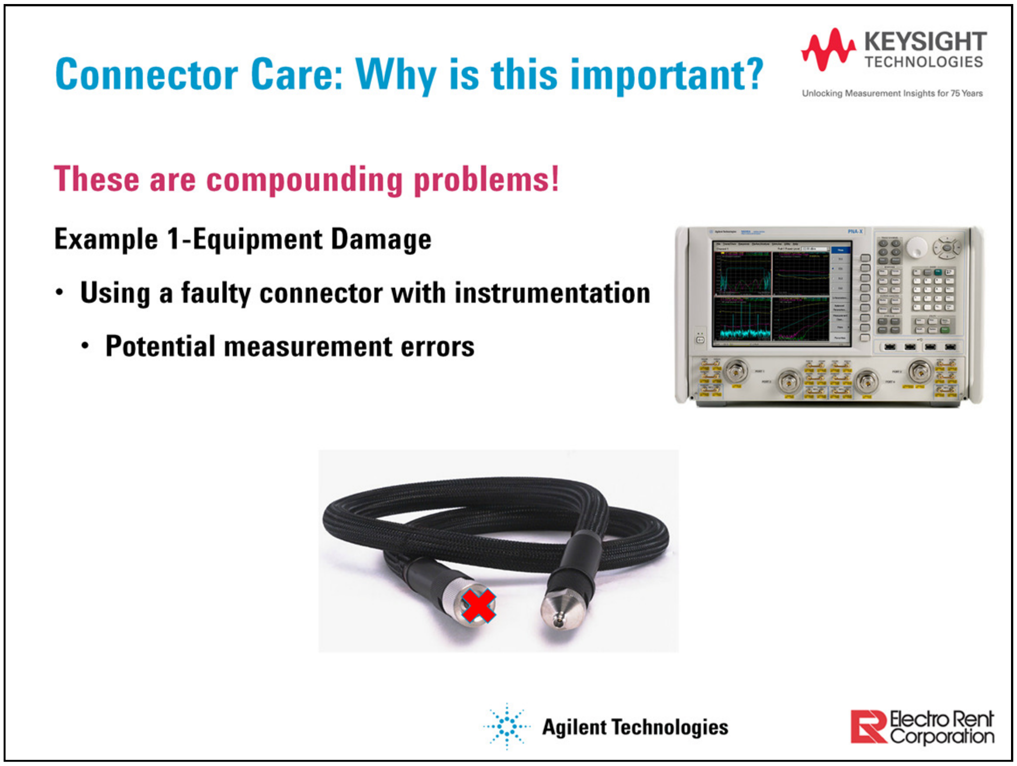
So why is caring for connectors important?

They're just connectors, they're (relatively) cheap, they just get my signal from point A to point B right?

Well, as this presentation will hopefully show, these often falsely assumed trivial pieces of your measurement system are far more important than you think!

A bad connector will not only ruin your measurement, it can damage your equipment, adversely reduce quality by potentially false passing good items under test, and waste a lot of time in the rerunning, troubleshooting, and diagnostics of tests.

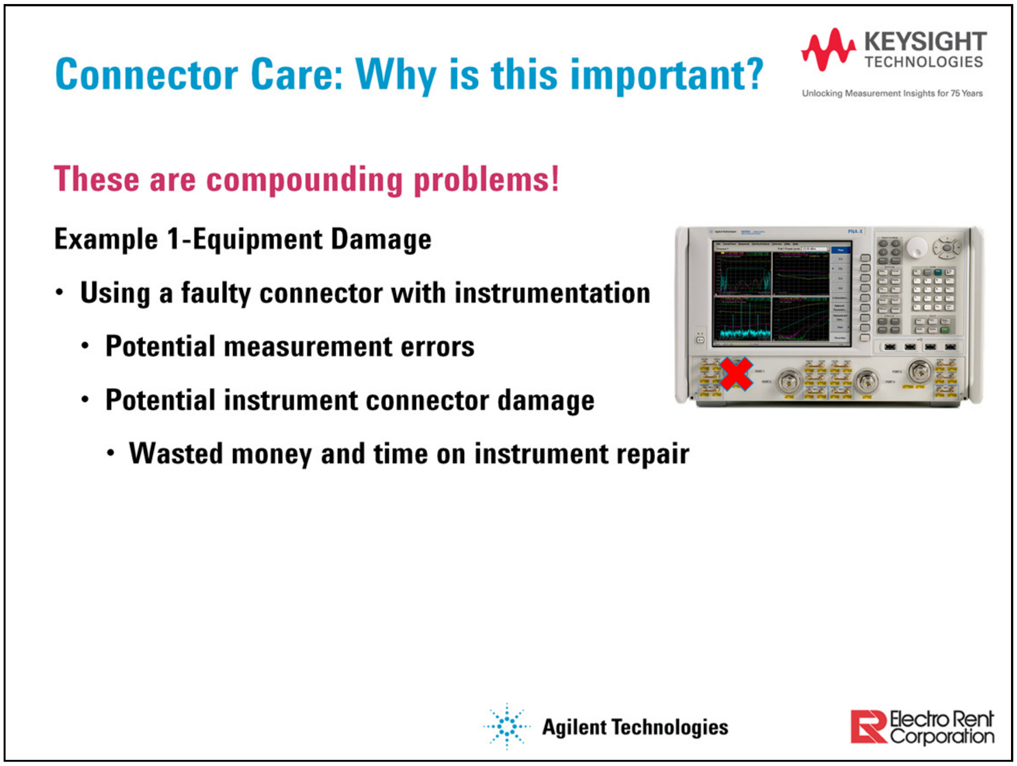
As these following examples will show, this is a compounding problem.



Our first example will show what a broken connector can do to your equipment, and how it can compound into more damage.

Let’s say we are using a cable with a broken connector an connecting it to a high end Network Analyzer such as a PNA-X.

Well, that broken connector is going to cause impedance mismatches and all types of measurement errors, but it doesn’t stop there.

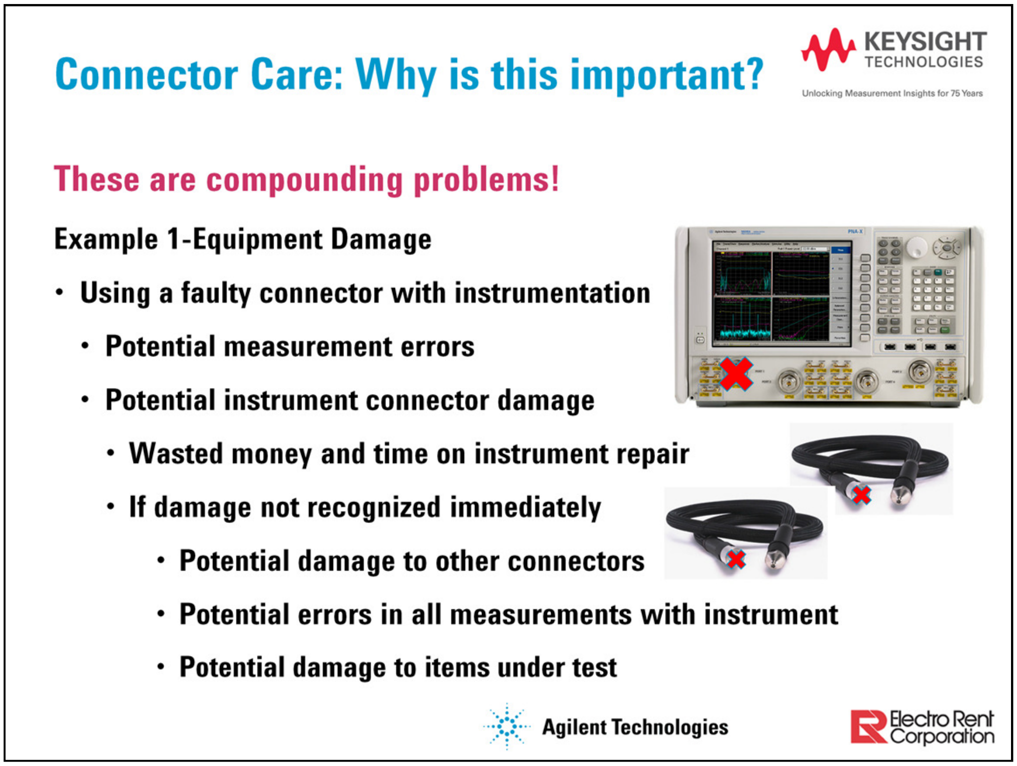


If the cable's connector damage is severe enough, let's say the center pin is bent, it could damage the mating connector on the Network Analyzer.

Now our Network Analyzer is damaged as well, along with the cable's connector.

We'll have to ship the instrument out for repairs, which wastes money and time.

But it can get even worse.



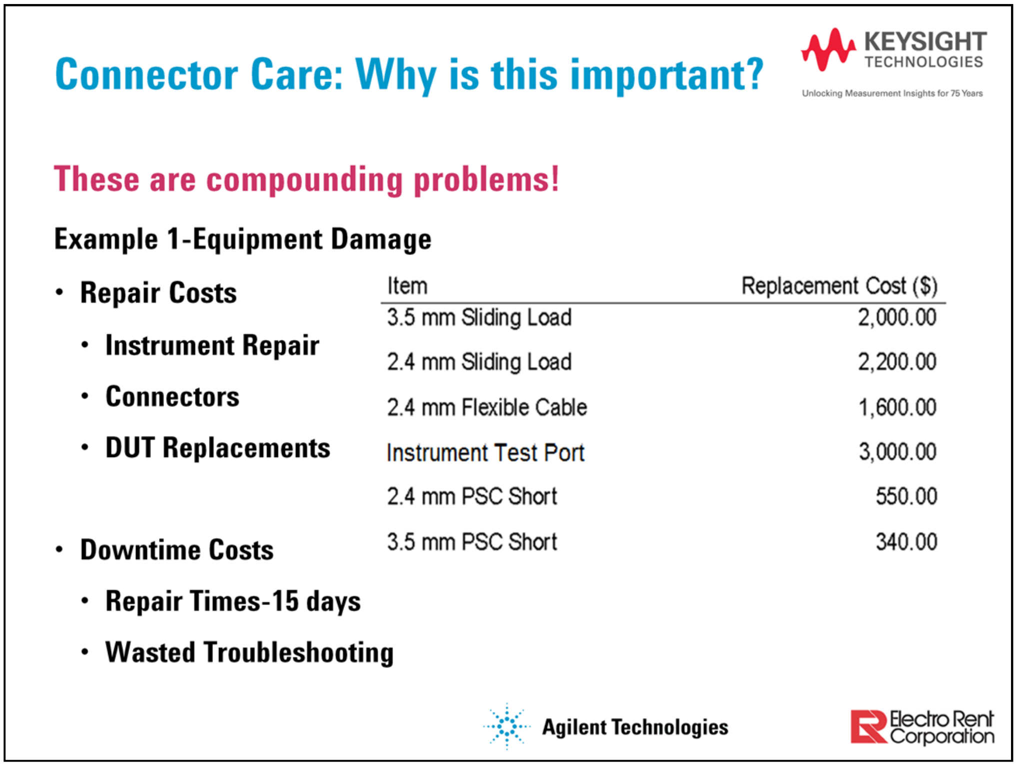
What if the connector damage on both the cable and Network Analyzer wasn't immediately noticed?

This could damage any other connectors, ranging from items under test, test instruments, other cables, and anything these damaged connectors would connect to.

It could create systematic errors in every measurement made.

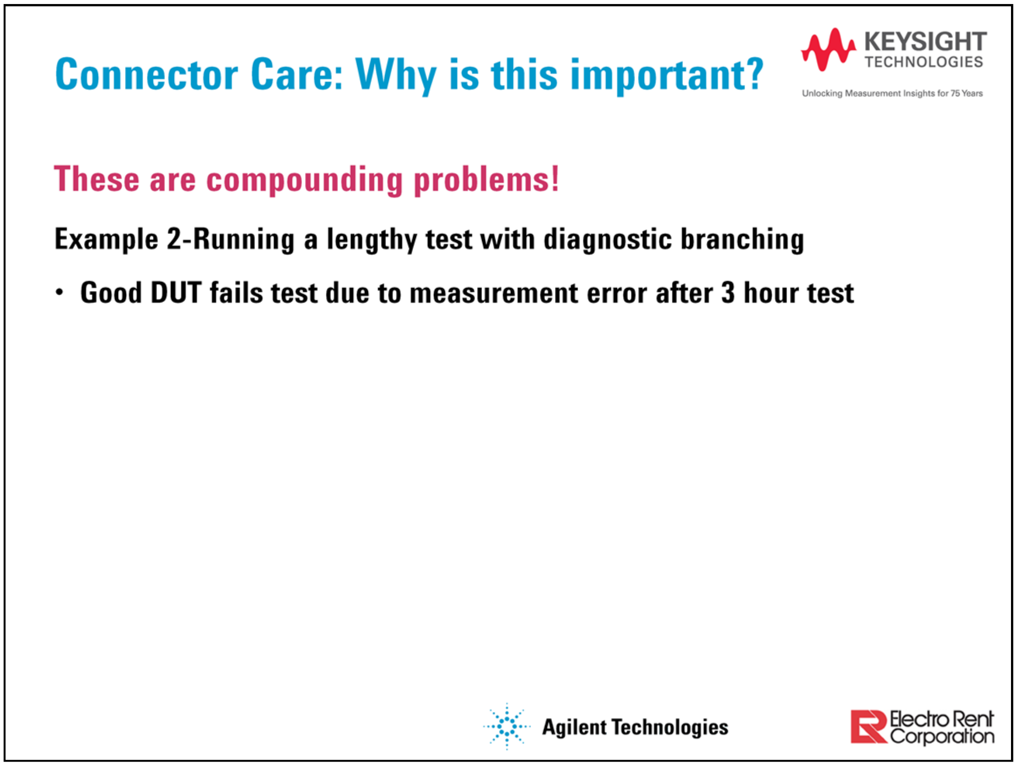
And the anything these potentially newly damaged components will connect to will also create the same risks of measurement uncertainty and damaged.

As you can see, this is a compounding problem.



Shown here are some common prices for connector repairs, as you can see they are not exactly cheap in some cases.

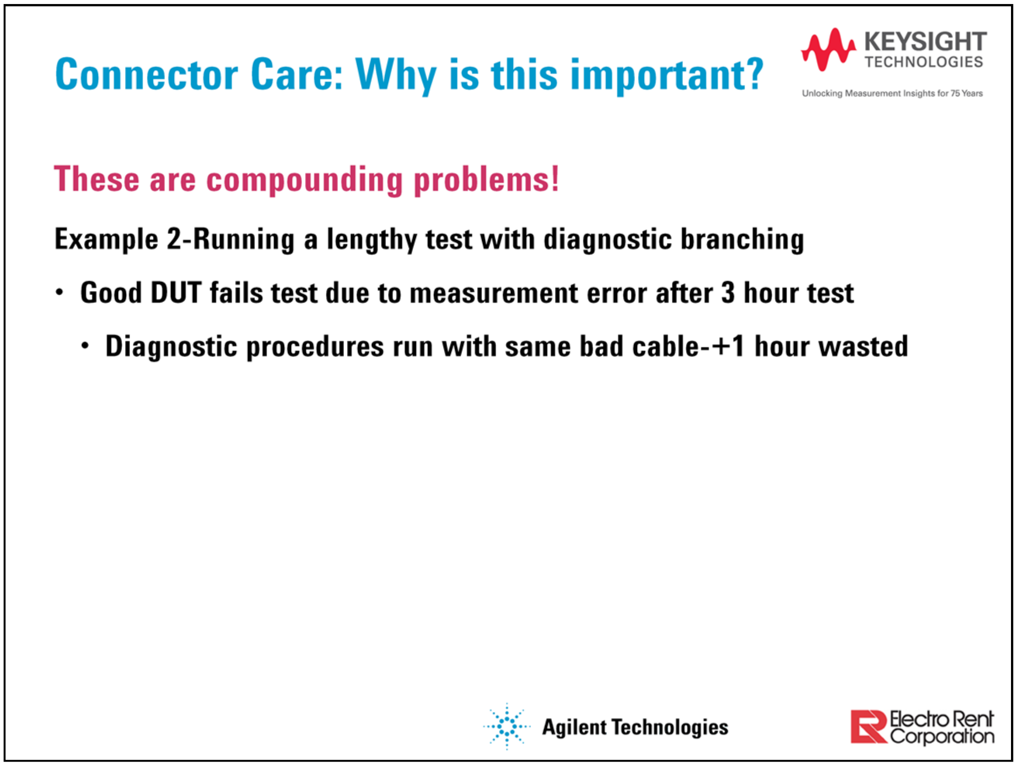
This doesn't paint the whole picture in regard to cost, however, as potential damage to the items you are testing, and the associated downtimes created from waiting for repairs and troubleshooting are also quite expensive.



Here is another example, this time stressing the enormous amounts of wasted time a bad connector can create.

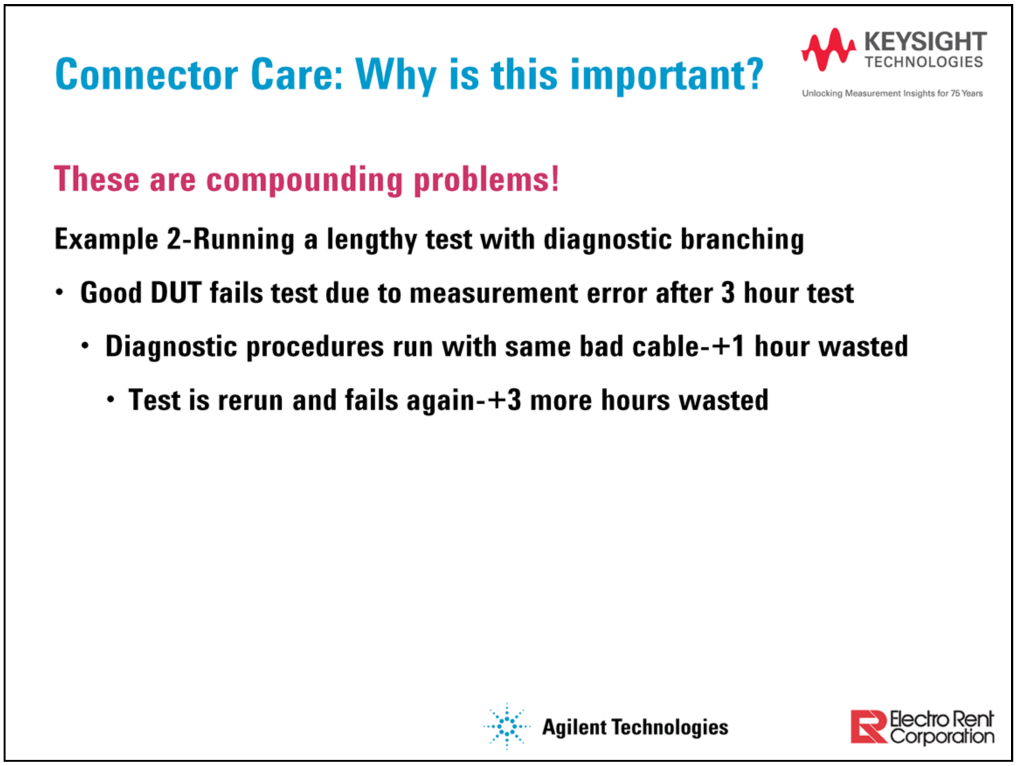
Let’s say we’re performing a long test with diagnostic branching (if the device fails, then diagnostic steps are run), and there is a faulty connector in the measurement path.

The faulty connector affects the measurement adversely and the device fails.



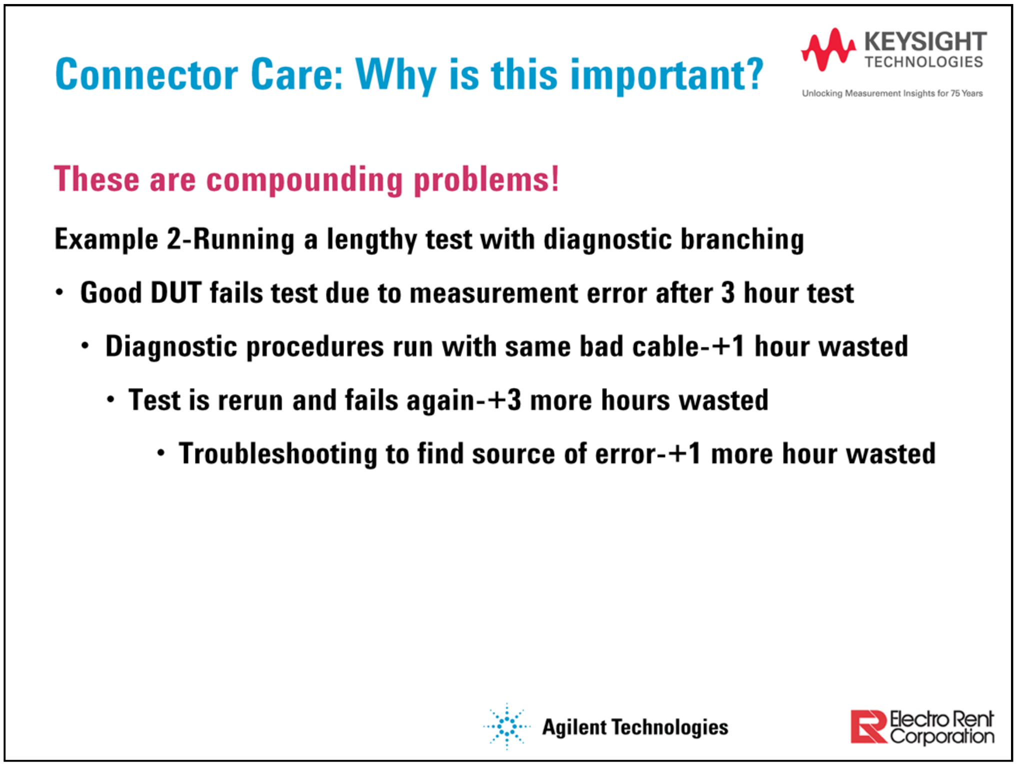
So now the falsely failed good item under test will have to undergo diagnostic tests to determine why it failed, thus far we have wasted hours of test time.

If there are adjustments that need to be made on the device under test, they would then be unnecessarily done and potentially make the device under test non-functional!

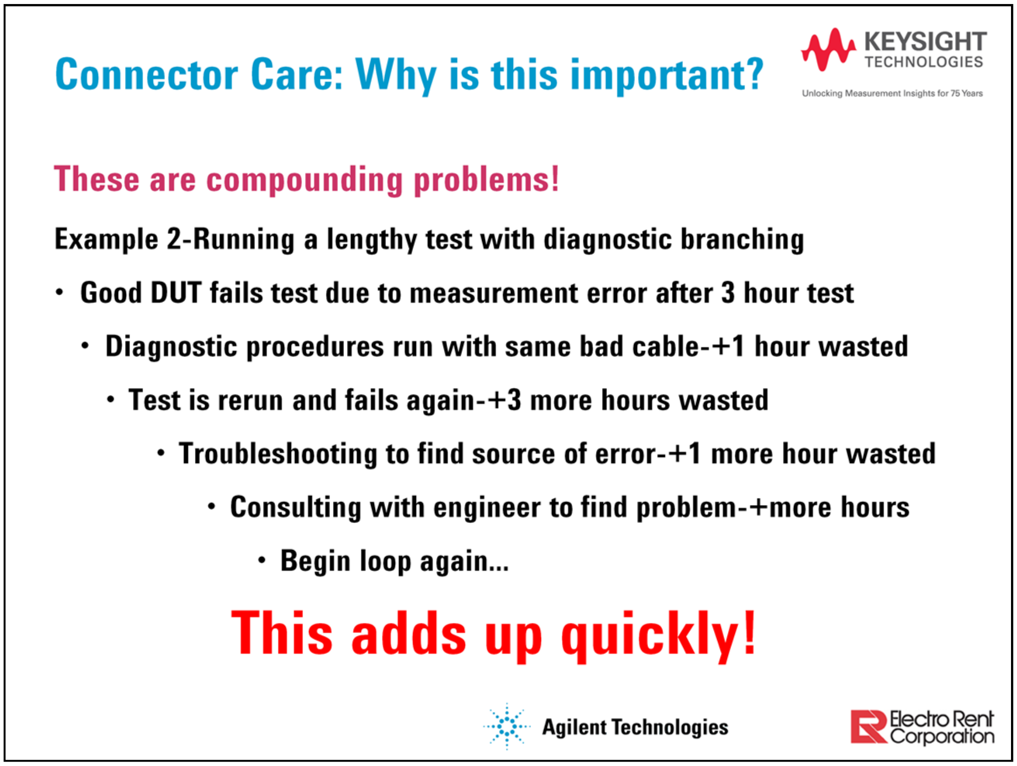


So then the test is run again, with the same faulty connector, and it fails again, either due to the faulty connector or potential adjustments made.

This is another few hours wasted. (Can you notice the wasted hours steadily growing?)

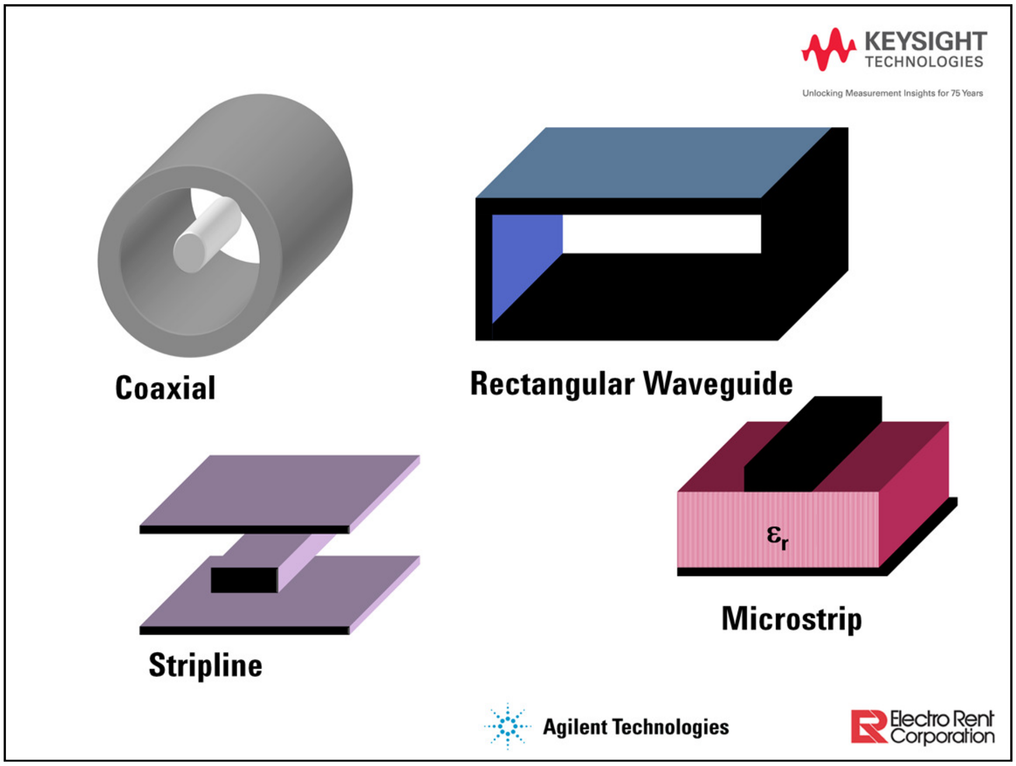


This process could be a reoccurring one, with the purpose of this slide to show the redundancy of this bad connector problem.



Finally, an engineer is called in to troubleshoot the problem, adding another element of downtime to the equation.

These examples show how much time a faulty connector can waste, and although they seem like exaggerations, they are based on real stories from customers.



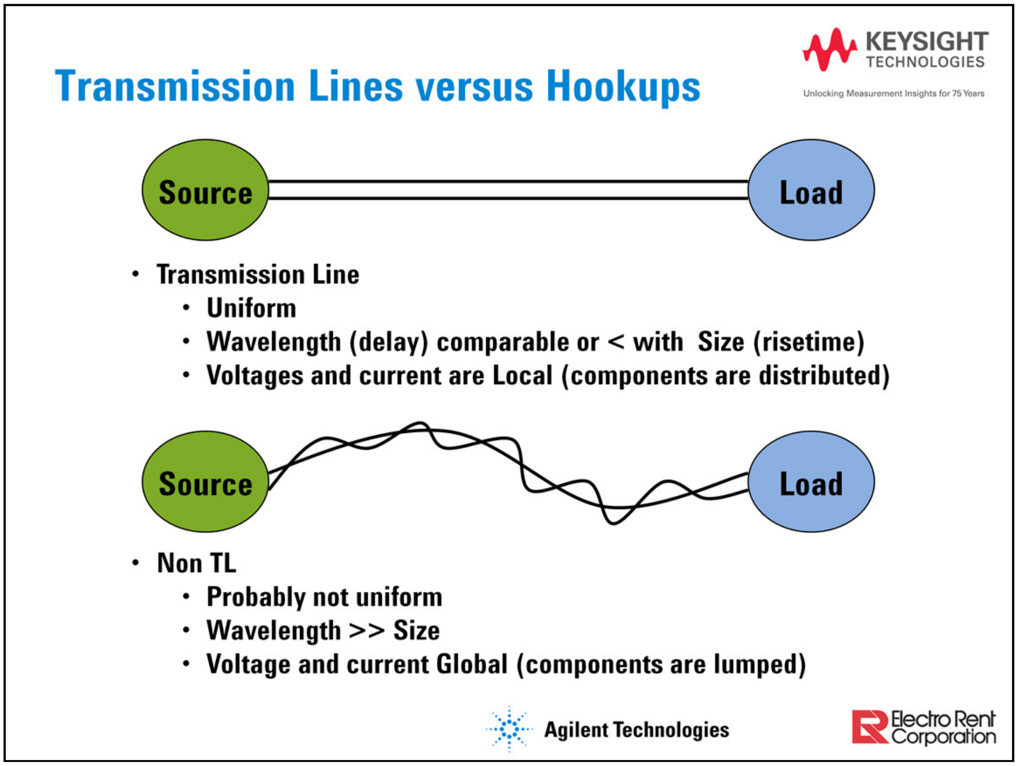
Transmission lines are used to transmit high frequency electromagnetic energy between components.

There are a variety of transmission line types, and their usages are dependent upon the characteristics of the waveform (such as frequency and power), and the applications they are used in (from cell phone chips to RADAR systems).

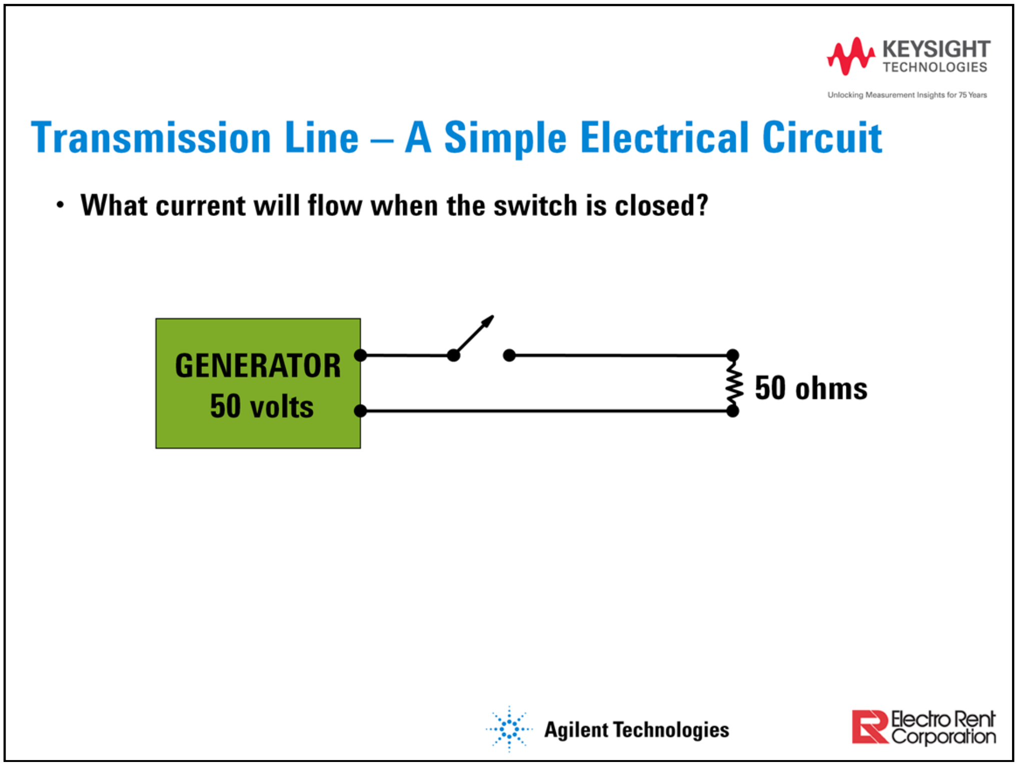
Examples include:

1. Coaxial
2. Rectangular Waveguide
3. Striplines
4. Microstrip

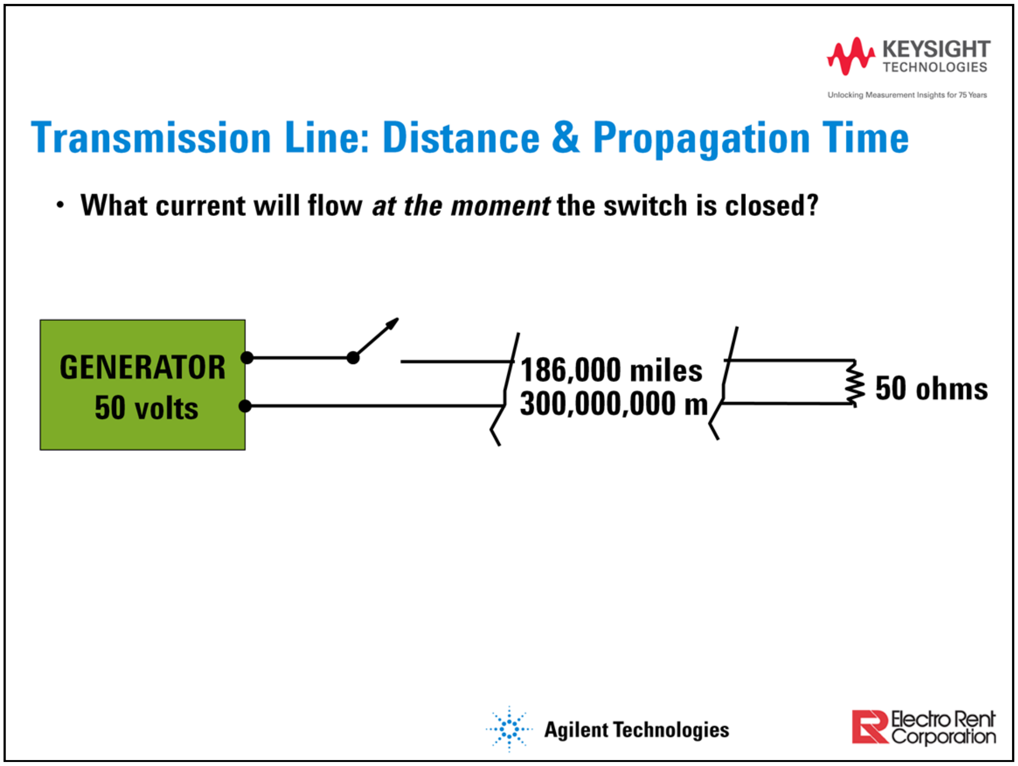
We will focus on coaxial cables and connectors in this presentation, as they are commonly used in test environments and are on the front ends of the vast majority of Agilent instrumentation.



When we first learn about circuits, voltages and currents, the loops and branches contain lumped components, and the loops and branches may be treated discretely. For example a current path would exist from the source to the load and back again. With transmission lines, Ohm's law and Kirchoff's laws are still valid from the local point of view only.



When the switch is closed a current of 1 Amp will flow. This result is based on Ohm's law and will be the basis for our understanding of transmission lines.



The difference between this and the preceding picture is only one of perception, to force us to think about what happens at the moment and a few moments after the switch is closed.

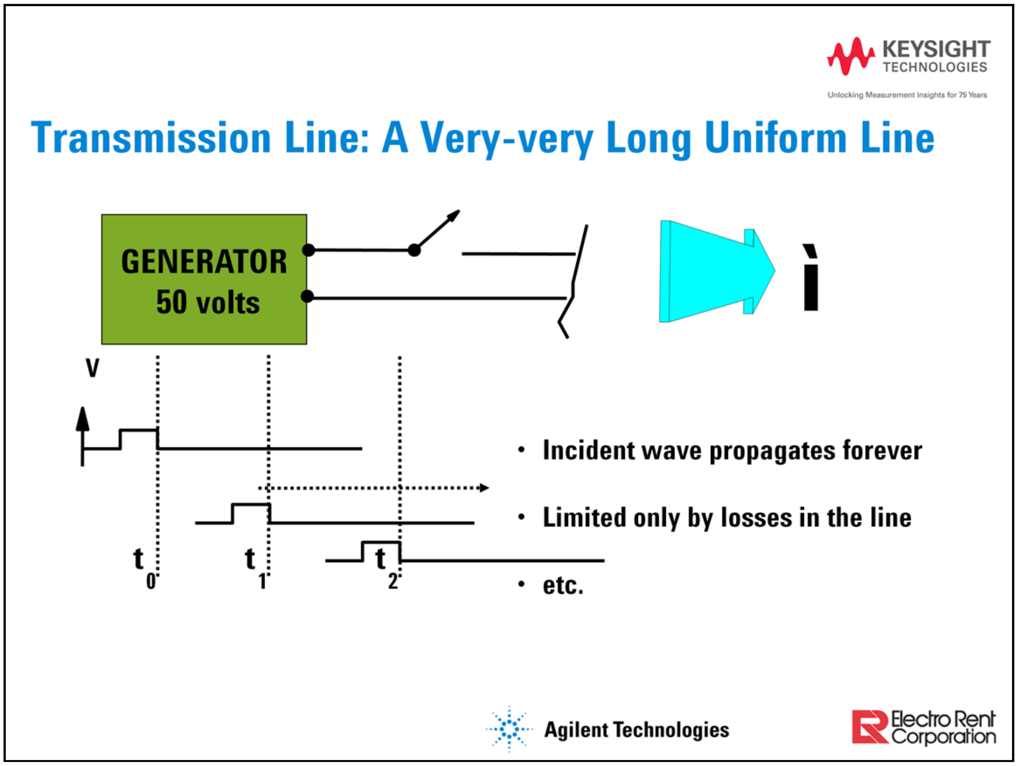
No information can travel faster than the speed of light, this speed is very close to 186,000 miles/second, or 300,000,000 m/second.

Even if the information about the switch closure moved with the speed of light, the generator would still supply the one amp due to the load, but this condition could only be true at a minimum of two seconds after switch closure. What happens up to this time will be the subject of the following presentation.

The following assumptions are made:

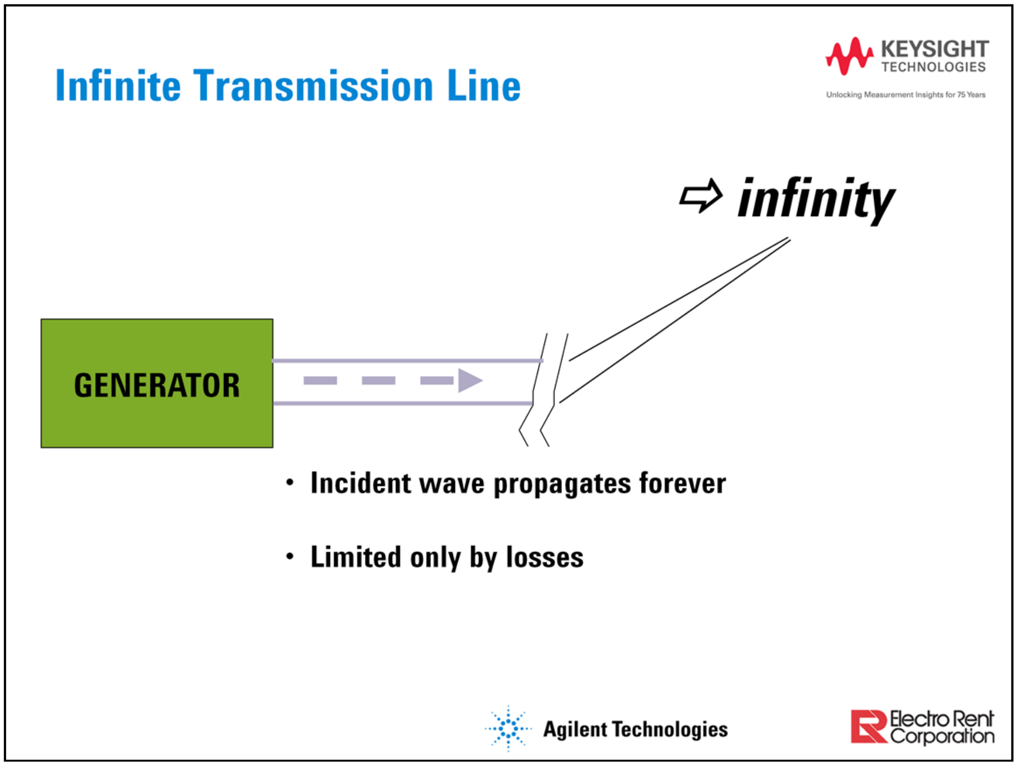
The line is lossless

The line is uniform

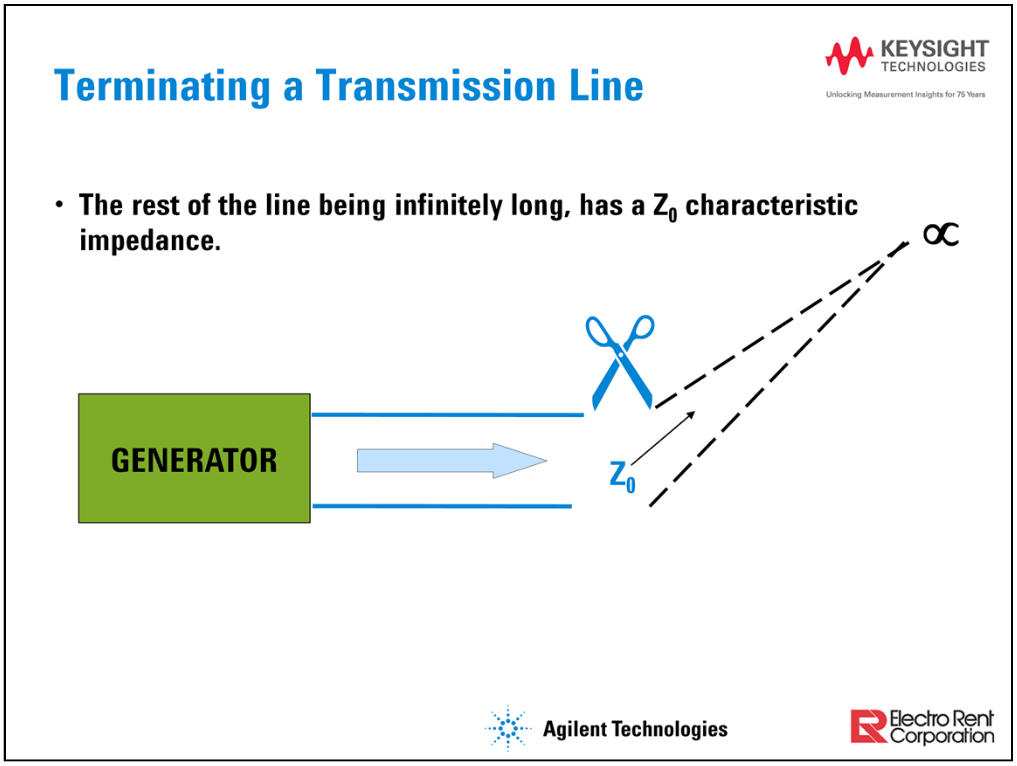


Imagine that this uniform lossless line is infinitely long. By uniform we mean it looks the same wherever it is cut, the same conductor size, the same material etc. If the switch closed then opened, causing a pulse to be created. We can think of this pulse travelling down the line forever.

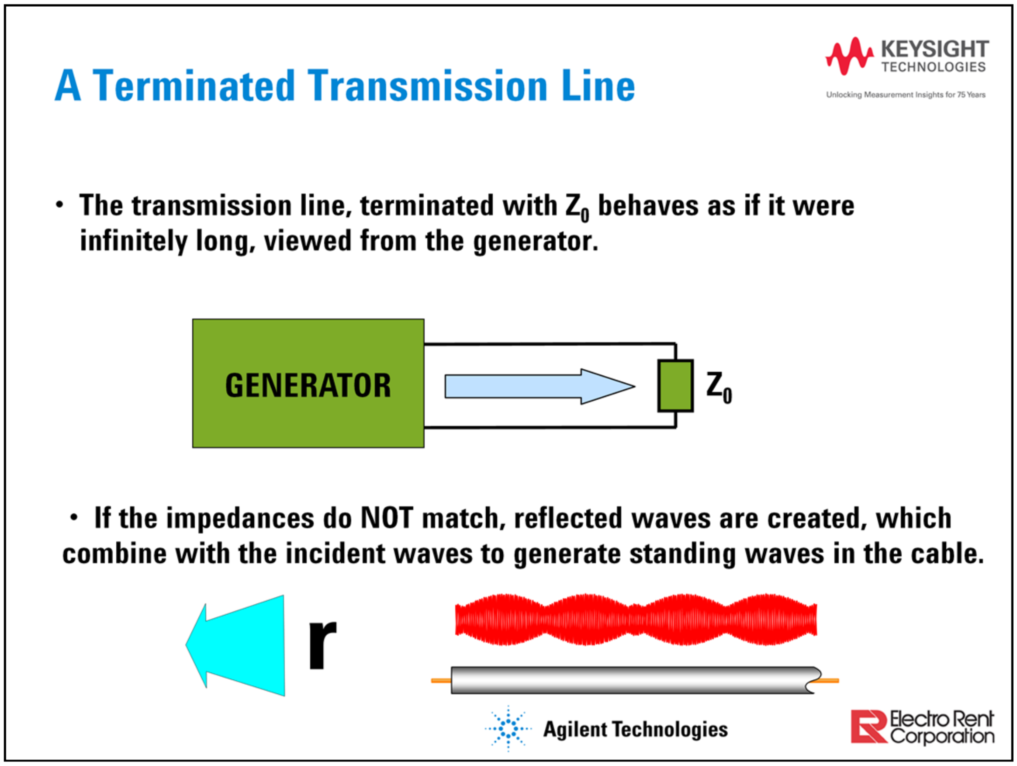
This is the *incident* signal or *incident wave.*



Imagine that the incident wave propagates forever, the relation between the voltage and current described by Z_0.

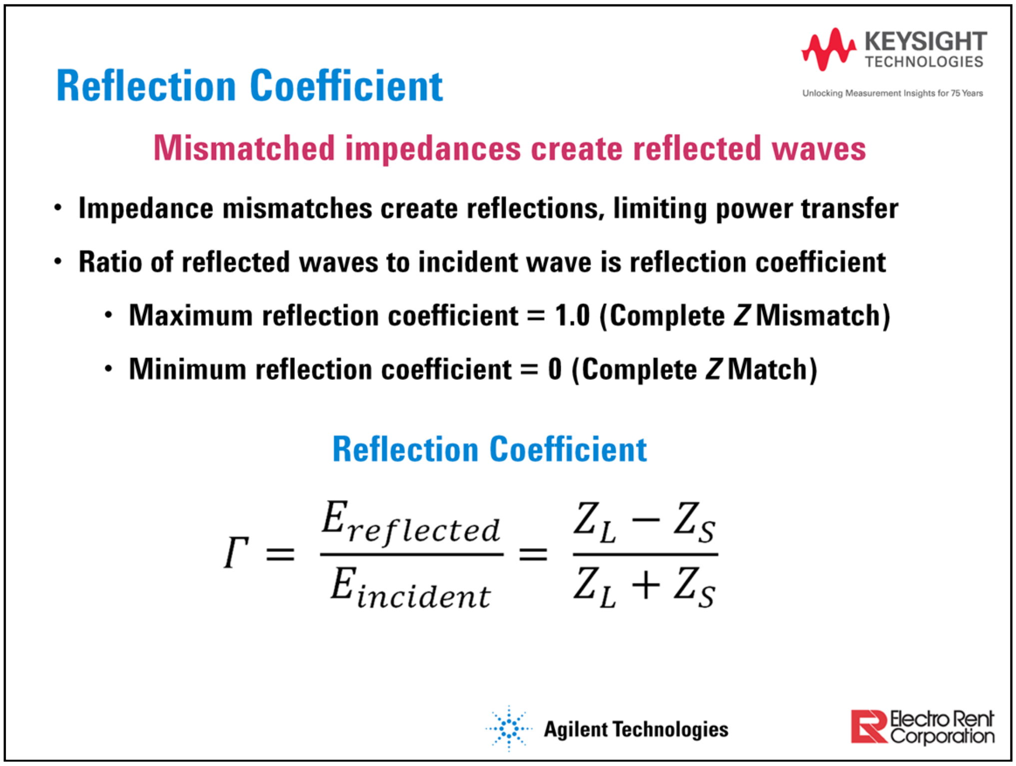


This is a simple idea, but it is an important one for the understanding of transmission lines. The imaginary infinitely long line has been cut off leaving some arbitrary length, the part we have imagined to be cut off would still be infinite in length, having a characteristic impedance of Z_0.



The length of transmission line if terminated with a lumped impedance with the same value as the characteristic impedance will appear to the generator as an infinite line. In other words the incident wave is propagating and is the only wave existing.

If the load impedance does not match the source, reflected waves or signals are created.

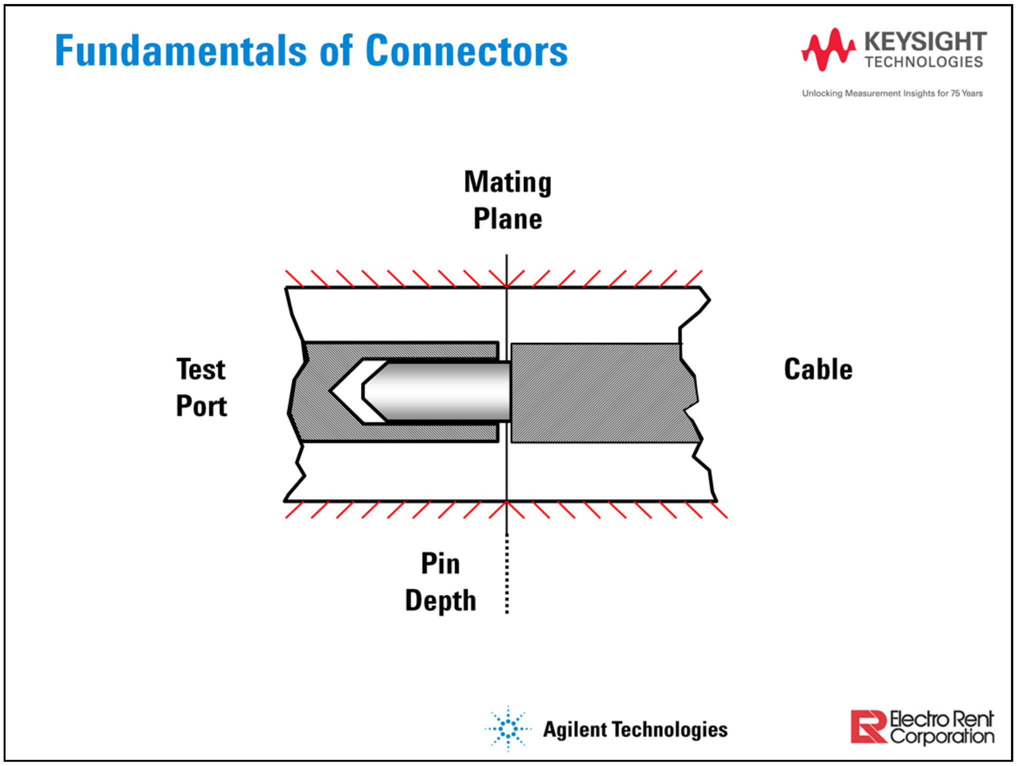


If the impedance of the load and source is not matched (the same), then reflected waves appear.

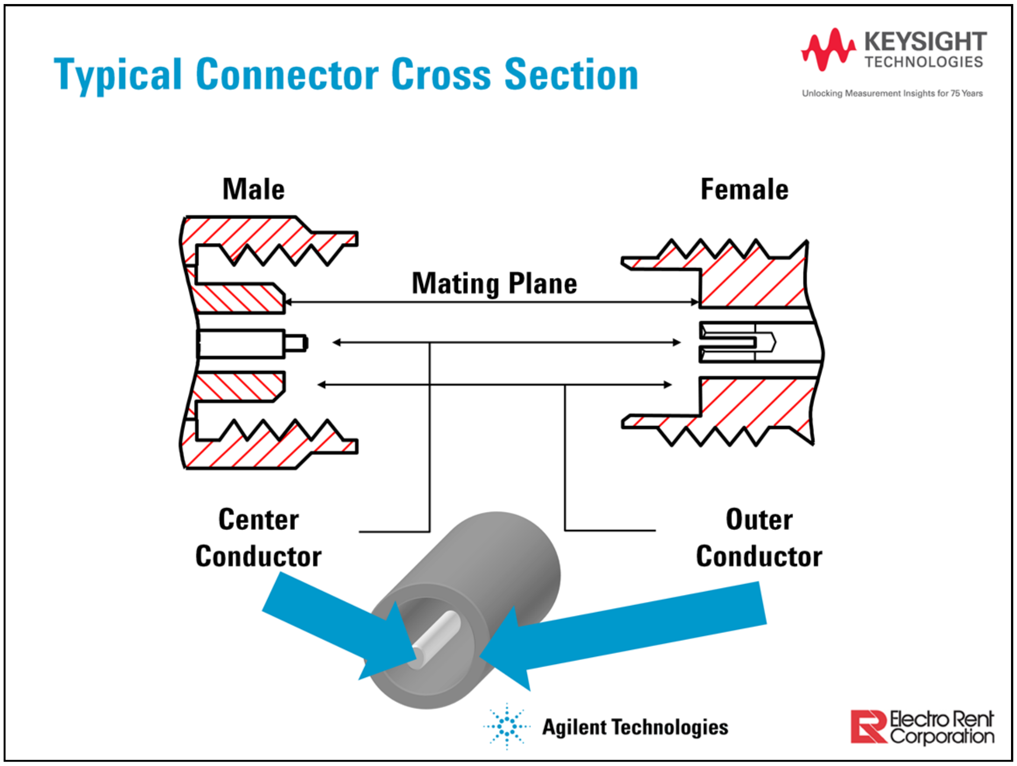
These are not desirable as maximum power transfer cannot be obtained.

(The symbol for reflection coefficient is gamma).

Reflection coefficient measures the ratio of reflected waves to incident waves, and can be calculated from the equation below.



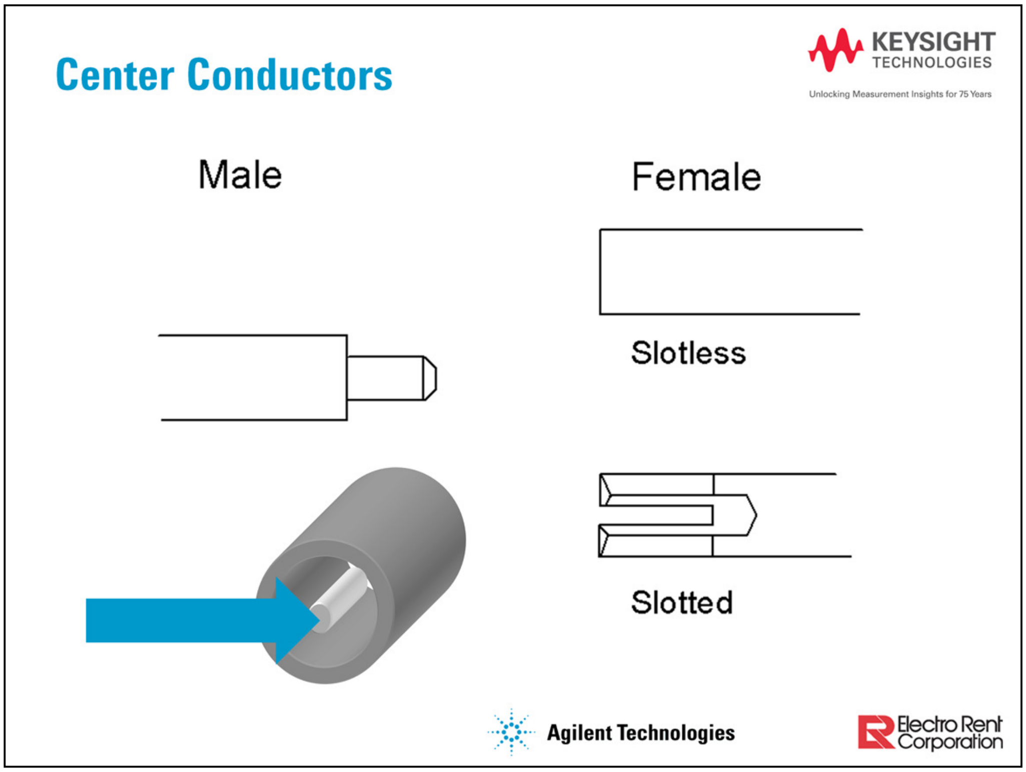
Let's begin with some fundamental aspects of connector structure which affect their use and performance. Shown is a cross-section of a female test port connector mated to a male cable connector. Important connector specifications include the mating surface, pin depth, connection torque and measurement reference plane.



This is a cross section showing the major parts of a typical sexed connector.

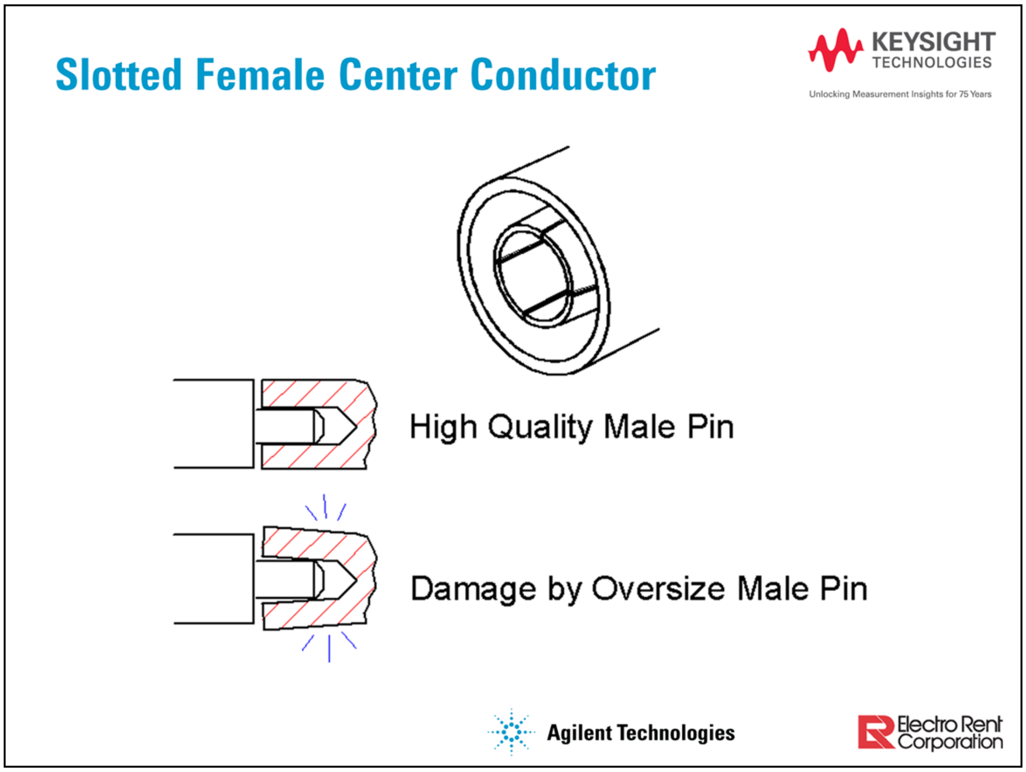
The typical connector type has a male version and a female version, depending mainly on the configuration of the center conductor. These are also called a plug and a jack, respectively. Important parts to recognize are the center conductors, the outer conductors, and the nut which tightens onto the female threads to bring the conductors into contact.

The male pin slides into the female fingers. Electrical contact is made by the internal surfaces of the tips of the female center conductor on the external surface of the male pin and clean, physical contact of the outer conductors (mating plane). It is important that only the outer nut of the male port be rotated, since rotation of the male center conductor may damage the female fingers.



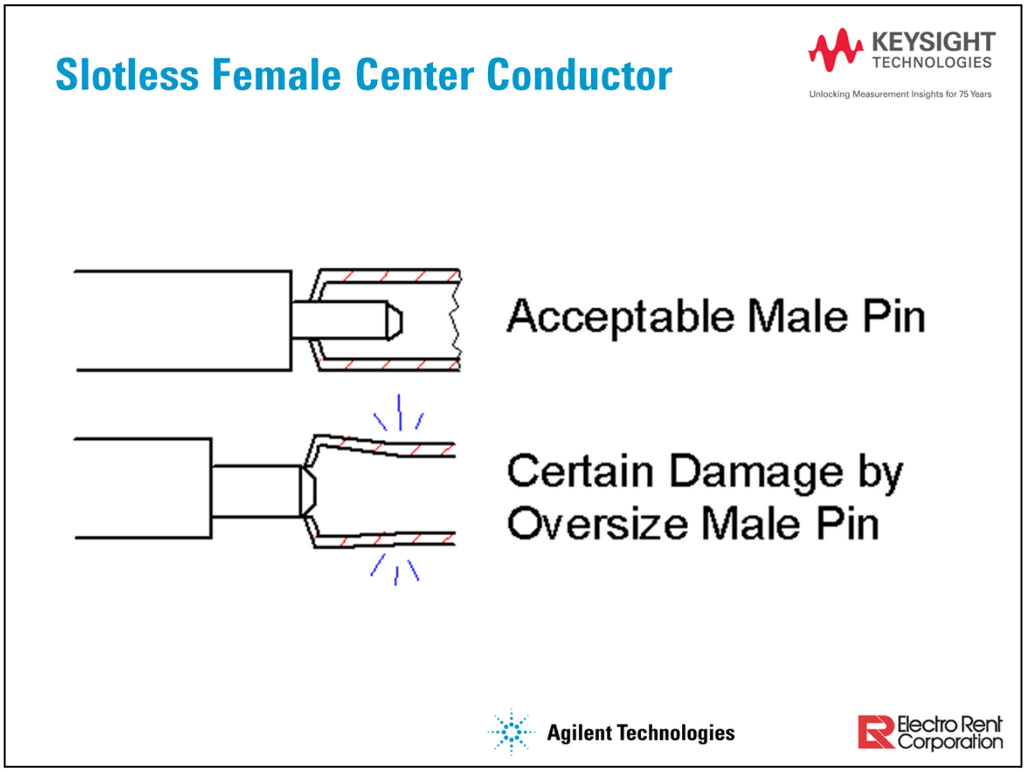
The male center conductor of high grade connectors is a precision part which fits into the female center conductor. Notice that the male center conductor is machined to form a shoulder, then the diameter of the mating portion of the pin is reduced size and it may be tapered at the end for easy insertions. For high quality male connectors, the machined diameter of the mating portion of the male pin as well as the location of the shoulder is closely controlled.

There are two types of female center conductor, either slotted or slotless.



The conventional female center conductor is slotted at the mating end. This forms a set of "fingers" that allow the female contact to expand so that the male pin can be inserted easily. For this design the fingers flex into whatever position the male pin diameter dictates.

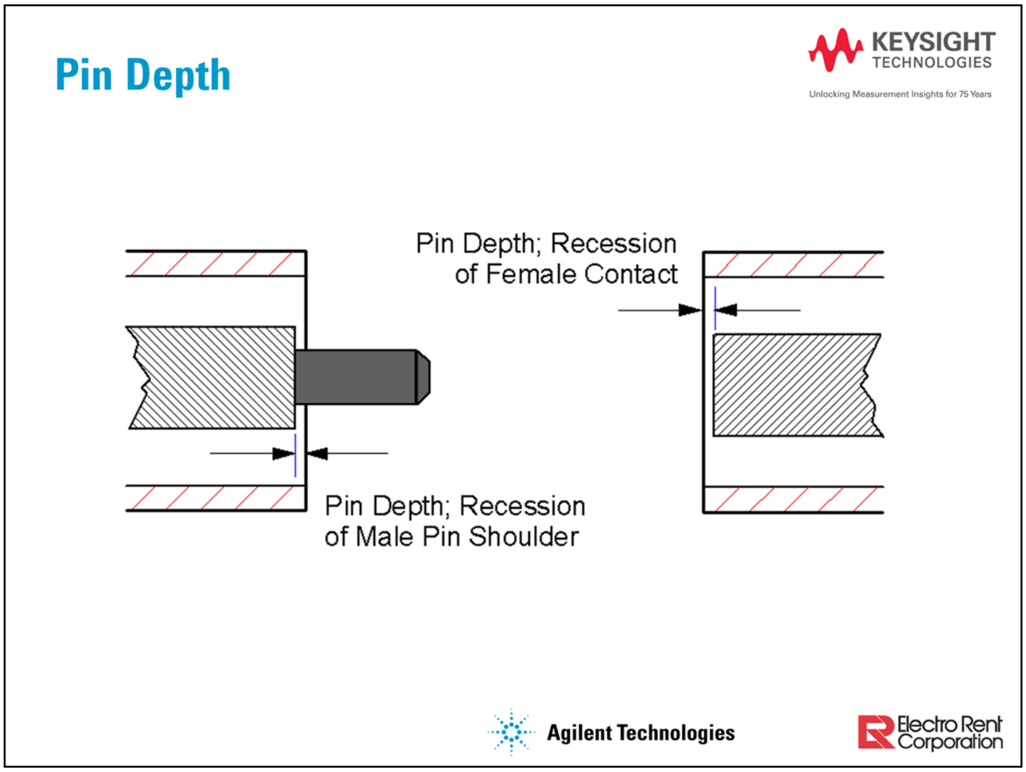
Using this type of female contact for the test port is only recommended for general use where the highest level of accuracy is not required. A fundamental problem is that the outer diameter of the female center conductor, thus, the characteristic impedance of the test port, can change depending upon the size of the male pin. For example, during calibration, when the male pin of the calibration standard is a precise size, the impedance of the connection will be exactly known; when the device under test is connected, since its male pin may not be the same size, the impedance of the connection will be different. This increases uncertainty and limits traceability of the measurement.



The slotless female center conductor consists of a precision machined outer shell which accepts the replaceable inner contact.

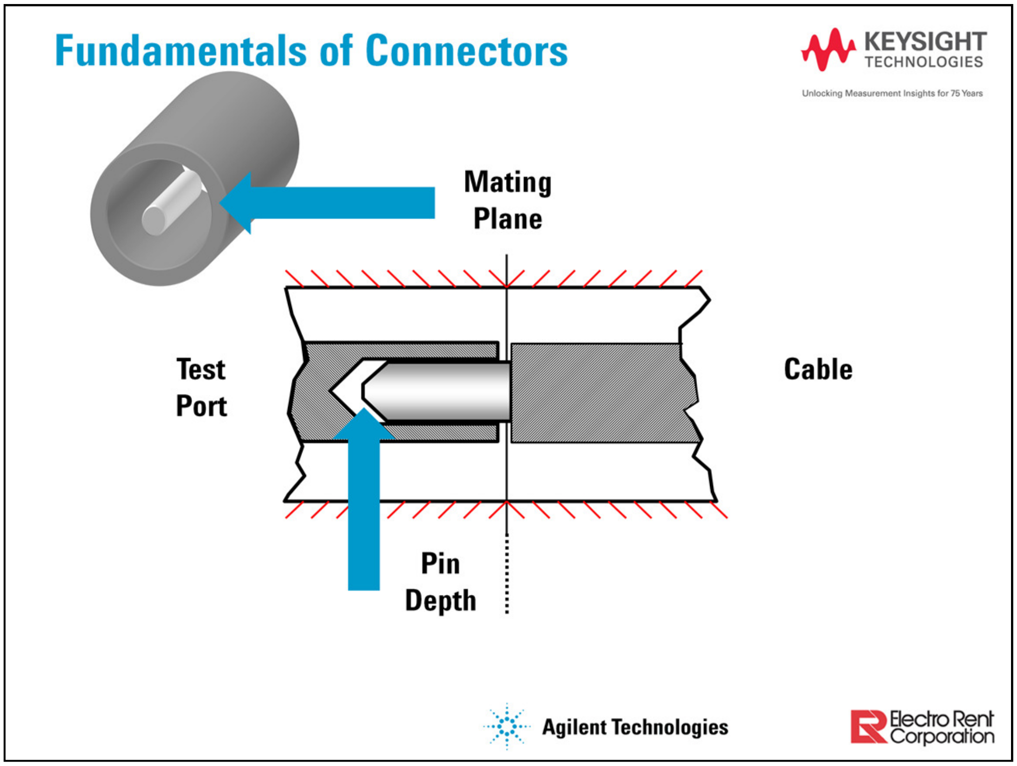
Notice how the fingers of the inner contact are constrained by the tubular inner conductor. If the male pin is of an acceptable diameter, the fingers of the inner contact can flex to make proper contact without changing the outer diameter of the female center conductor. An advantage of this design is that (within damage limits), the impedance of the connection remains constant over a wide range of male pin diameters.

Of course, using this type of center conductor for the test port may require greater care during use. It is more expensive and is intended for use only where the best accuracy and complete traceability is required. The fact that the characteristic impedance of the male contact does not depend upon the diameter of the male pin is necessary when best accuracy and traceability is required.

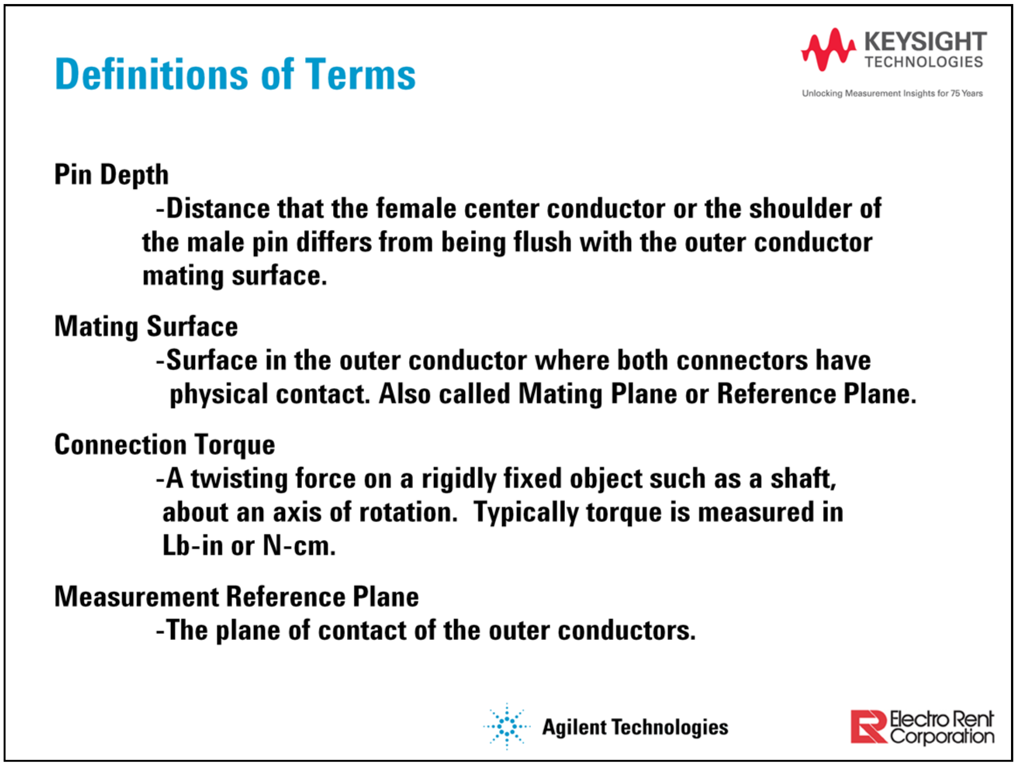


An important mechanical parameter for connectors is called Pin Depth. Pin depth is the distance the female center conductor or the shoulder of the male pin differs from being flush with the outer conductor mating plane.

If, for example, the shoulder of the male pin protrudes beyond the outer conductor mating surface, making the connection will generate force against the female contact causing damage to both the male and female parts.



Let's begin with some fundamental aspects of connector structure which affect their use and performance. Shown is a cross-section of a female test port connector mated to a male cable connector. Important connector specifications include the mating surface, pin depth, connection torque and measurement reference plane.

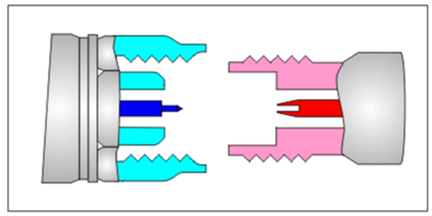


Here are some terms that will be important for you to know. We will discuss these in more depth in the next set of slides.

Making A Connection

Take electrostatic precautions

Align connectors axially



Make physical contact

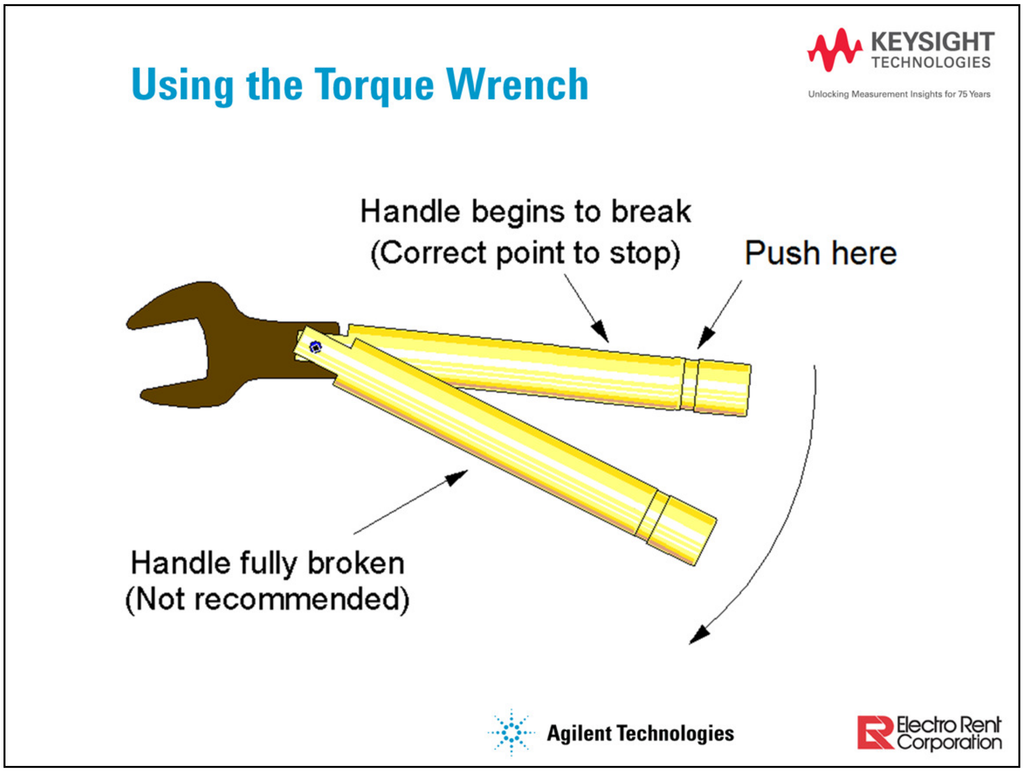
Engage connector nut

Applying even force, finger-tighten

Use correct torque wrench

Good connection techniques are <u>required</u> to produce Reliable Measurements.

Before making any type of connection, you must review and then follow these steps.

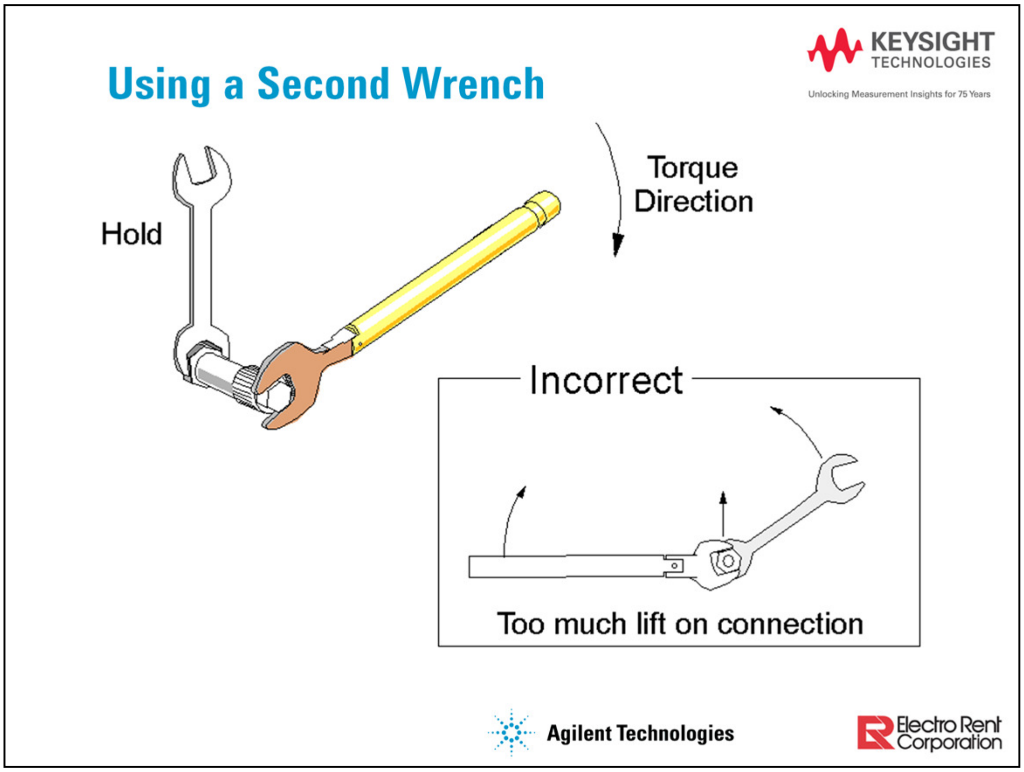


First hand tighten the connector nut so that the male and female parts are in complete contact. Then, without rotating the device body, use the appropriate torque wrench for the connector type to achieve the final torque. Each torque wrench is marked with its torque rating.

Apply force to the designated force point, in this case indicated by the line shown in the diagram.
It is vital to apply force on the designated force point, as torque is dependent upon the distance from the point of rotation.

Support the connection then apply steady force perpendicular to the wrench handle until the handle begins to give way ("breaks") at its internal pivot point. As soon as the pivot begins to operate, the torque is correct. Release the force and the wrench will spring back to its working position. This is shown in the illustration, but even less movement past the pivot will achieve the correct torque at the connection.
Try to avoid wrench backlash when releasing force on the wrench, as it sometimes reverses the amount of torque on the nut.

If you continue forcing the wrench, the handle will give way completely and snap over 90 degrees to a rest point. This helps prevent excessive torque at the connector nut. If this happens, remove the wrench from the connector, straighten the wrench, then remove and inspect both connectors before making the connection again.



Some connections may require you to hold and support one or both of the devices being connected and to prevent the rotation of anything other than the connector nut you are tightening. For example, you may use an open-end wrench to hold the body of the device with the female connector as shown here.

Position both wrenches at 90 degrees, hold the open end wrench steady, then apply force to the torque wrench to set the final torque on the connector nut.

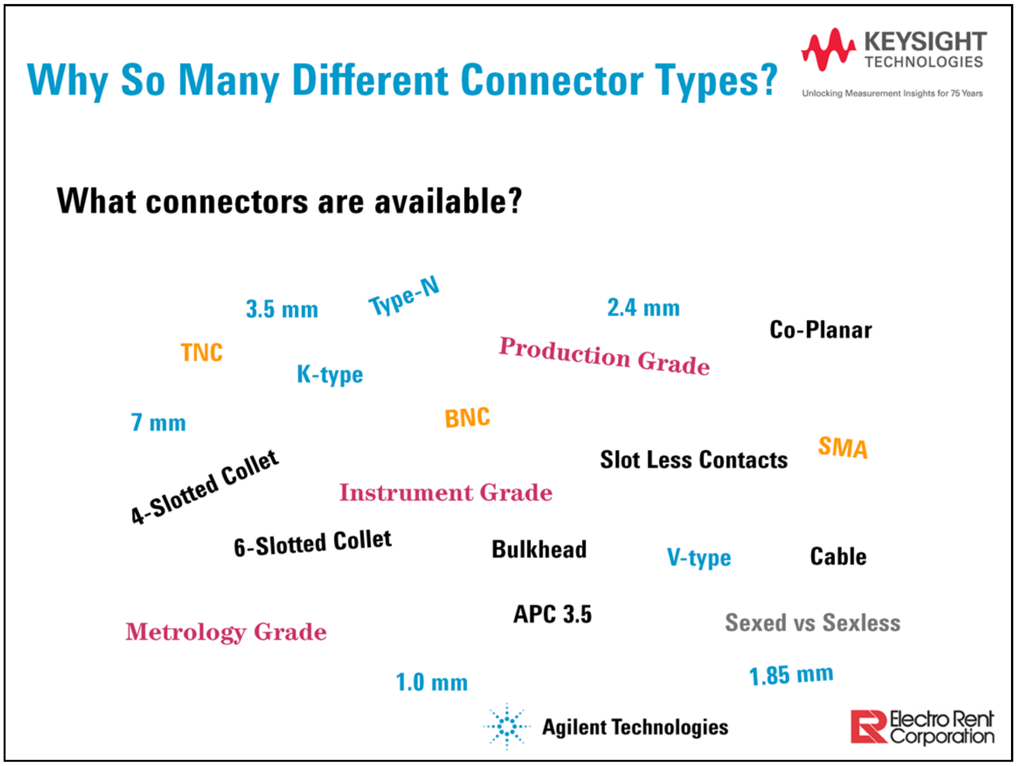
The main objective here is to relieve the torque effect on the female connector body. The final force from the torque wrench will allow the nut to bring the assembly together smoothly to complete engagement of the inner and outer conductors. If this can be done consistently, the electrical performance of the connection will also be consistent.

Recommended Torque Values for Connectors

Connector Type	Torque lb-inch (N-cm)
Precision 7 mm	12 (136)
Precision 3.5 mm	8 (90)
SMA	5 (56) Use the SMA torque value to connect male SMA connectors to female precision 3.5-mm connectors. Use the 3.5-mm torque value to connect male 3.5-mm connectors to the female SMA (8 lb-inch).
Precision 2.4 mm	8 (90)
Precision 1.85 mm	8 (90)
Type-N	Type-N connectors may be connected finger tight. If a torque wrench is used, 12 lb-inch (136 N-cm) is recommended.

While many Agilent RF/microwave connectors have been designed for rugged mechanical interfaces, the user must be aware that cleanliness of the surfaces and care in applying torque to the connector nut are crucial to long life and full signal performance. The table above shows the recommended torque for various connector types. Too much torque will result in deformation of the connector parts and probably a mismatch problem and not enough torque will yield a lousy connection with poor VSWR.

Using the correct torque also improves measurement repeatability.



Agilent designs and manufactures a wide variety of connectors to meet the needs of nearly every application. The major specifications are characteristic impedance, frequency range, and quality.

Each connector has its own unique parameters as well as its own cautions and techniques for making reliable measurements.

Three Types of Connector Specifications

KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights for 75 Years

Characteristic Impedance

Frequency Range

Quality

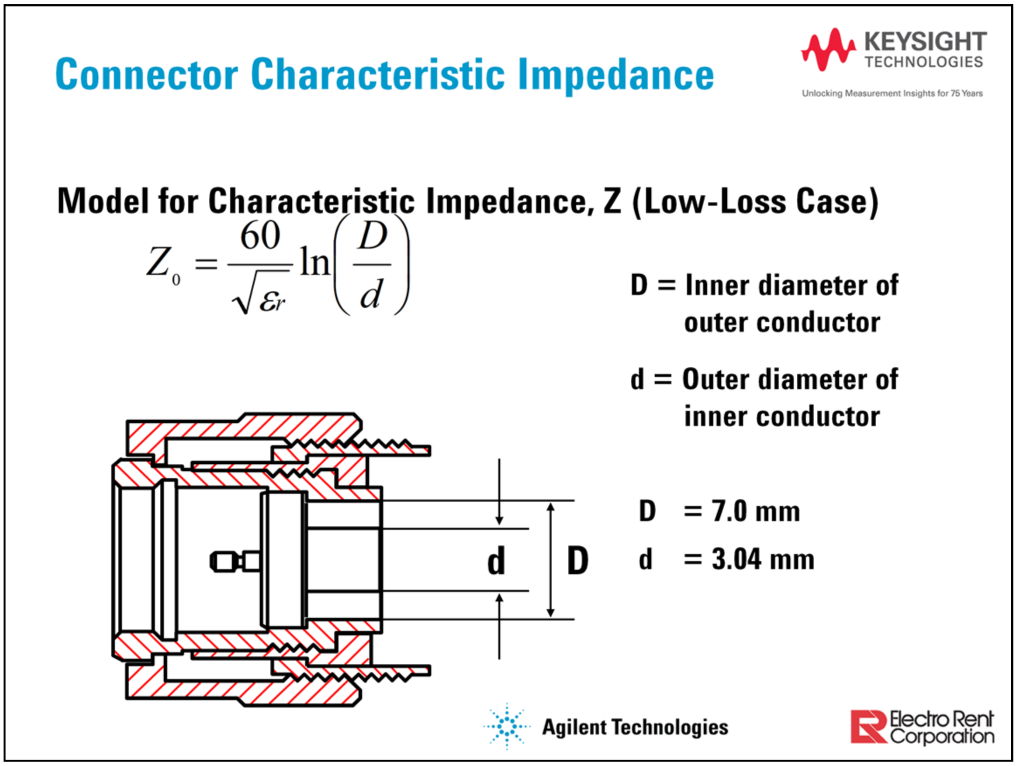
Agilent Technologies

Electro Rent Corporation

Characteristic impedance refers to the impedance of an infinitely long cable.

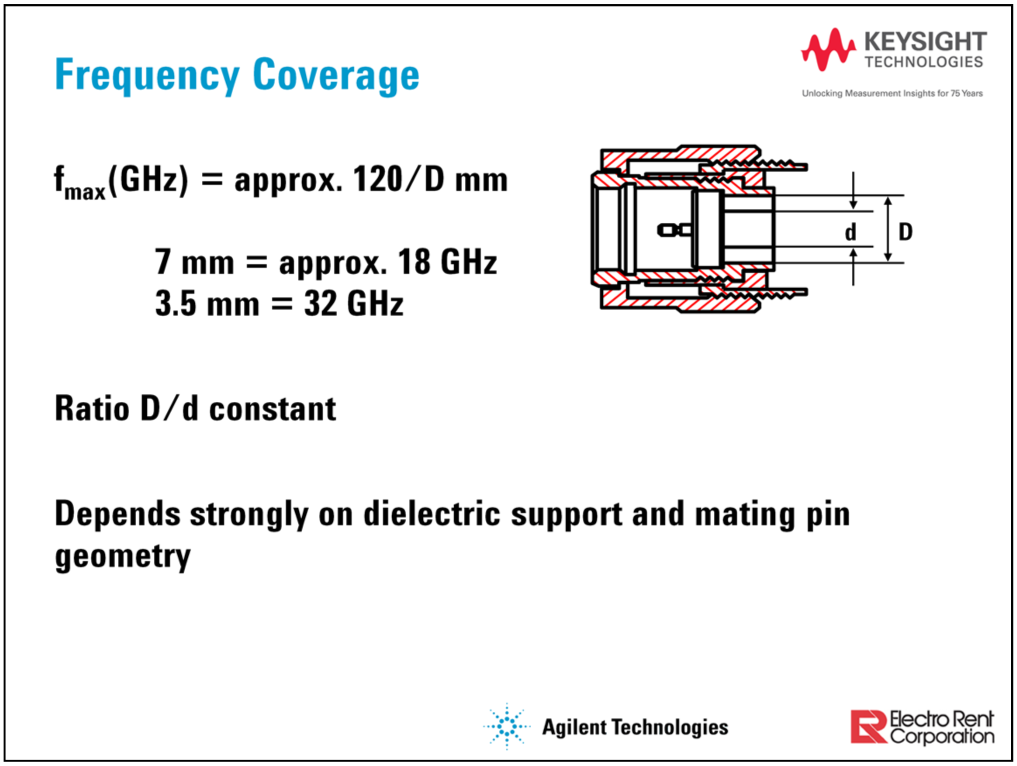
Frequency is the rate at which an electrical current alternates and is usually measured in Hertz, abbreviated upper case H and lower case z. Hertz is a measure of the number of cycles per second.

Quality refers to connector grades such as metrology, instrument, and production. The higher the quality or grade, the greater the performance of the connector.



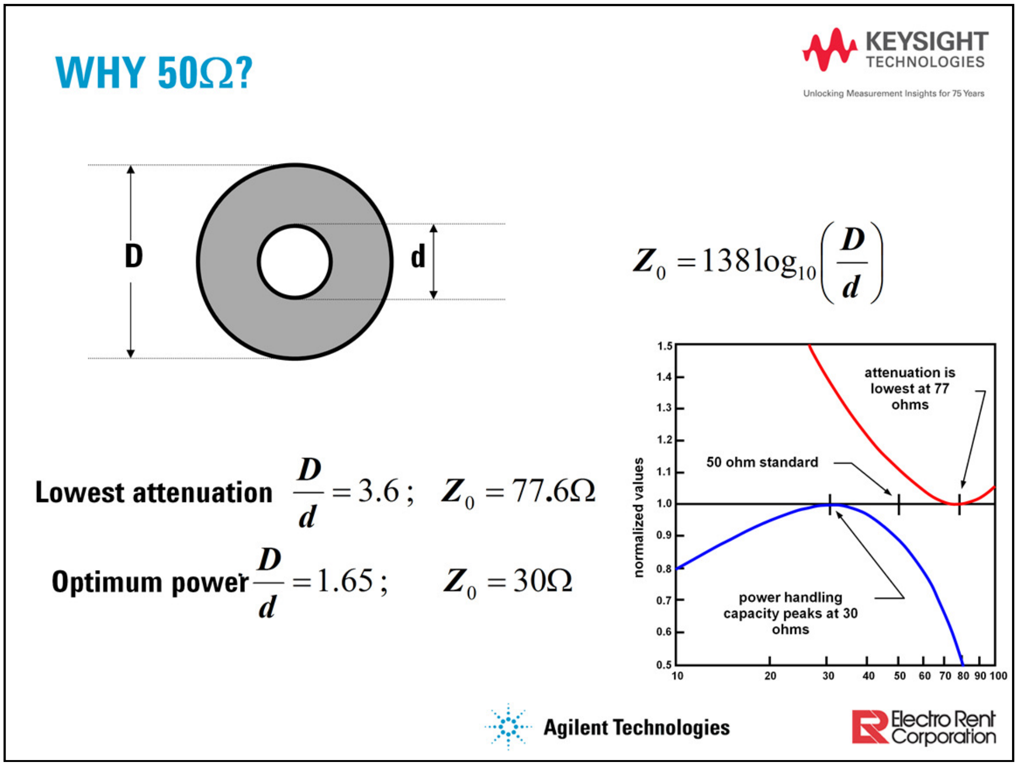
Connector dimensions determine both its characteristic impedance and frequency limits.

This is a somewhat simplified model for the characteristic impedance, Z_O, of a low loss transmission line. As an example, for a 7 mm transmission line, the inner diameter of the outer conductor, D, is 7.0 mm and the outer diameter of the inner conductor is 3.04 mm. Note that the ratio of (D/d) determines the characteristic impedance of the connection or more importantly is the only external influence on Z_O. Thus the precision of these dimensions also determines the precision of the connector's impedance.
For the materials typically used, this results in a characteristic impedance of 50 ohms. Of course the actual value of the impedance of any given transmission line at any given frequency is more complicated, but for now, accept this generalization.



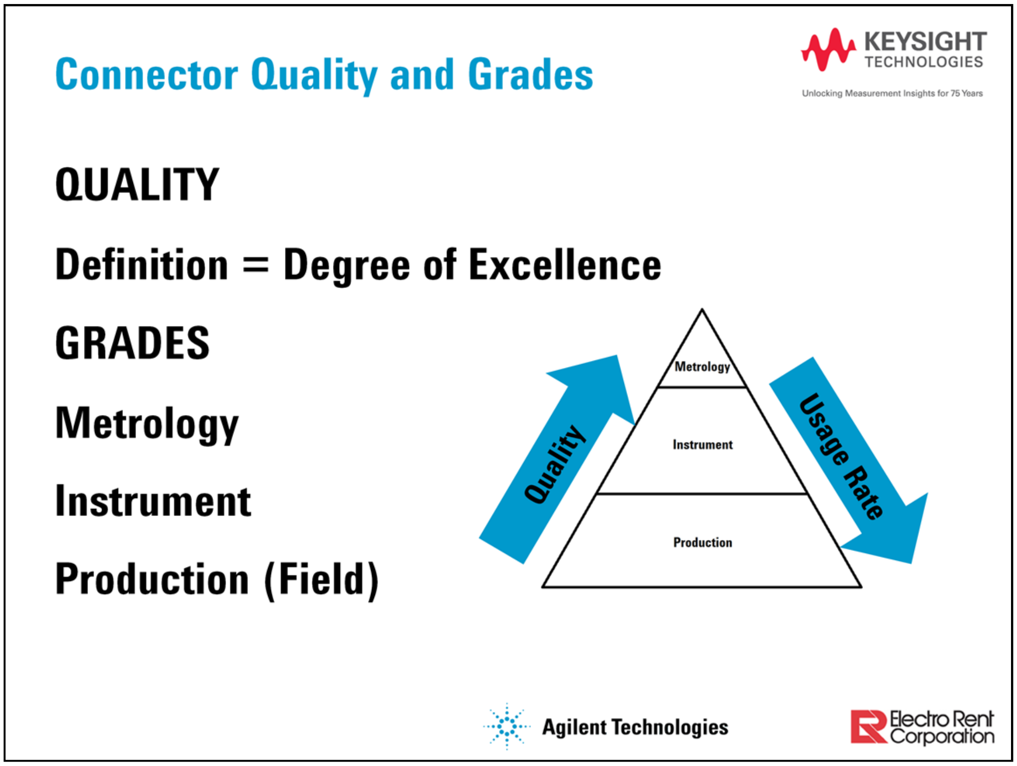
Frequency range is the next consideration. Mode-free transmission depends upon several characteristics of the line including the actual impedance of the transmission line, characteristics of the dielectric support, and the geometry of the mating pin. This can be represented in simple form as about 120 divided by the inner diameter of the outer conductor (mm). In general, the larger the conductor cross section, the more limited the frequency range.

This is why we need small geometries to cover the higher frequency ranges.



The range of impedance for reasonable mechanical ratios, for example if D/d varies from 1.5 to 10 the impedance for an air dielectric varies from 24.3 ohm to 138 ohms. So any mechanically easily made coax line is going to have a characteristic impedance around 25 to 100 ohms. For 50 ohms the ratio is 2.3.

This has not answered the question; why 50ohms? It seems to be a compromise.The lowest attenuation occurs when the inner to outer diameter ratio is 3.6 which corresponds to an impedance of 77.5 ohms. On the other hand, because the electric field strength is highest near the surface of the inner conductor this field strength could cause breakdown if too high. By calculating between the voltage breakdown in air and the transmitted power in a reflectionless line gives a diameter ratio of 1.65, corresponding to 30 ohms.



Agilent's connectors are defined by quality or degrees of excellence to which they are produced. These degrees of excellence are also known as grades. Offering up to three different grades in each connector family provides the flexibility necessary to choose the performance required for a particular application. This keeps the cost as low as possible. However, all three grades are not available in all connector families. Sometimes manufacturing processes or the basic design of the connector do not lend themselves to producing the highest grade connectors. As an example, while the SMA family may include designs of several grades and prices it can only be a Field grade connector and the 3.5 mm connector family provides the Instrument grade and Metrology grade components. For 7 mm, the connector was designed specifically for metrology type measurements and it is not desirable to design a lower grade connector. These grades are from more precise and expensive to less precise and expensive.

For the popular connector families, the device under test usually uses production grade connectors, the test set connectors and most adapters are instrument grade connectors, and most calibration kit and verification kit standards and special adapters are metrology grade. The precision of the connector dimension increases from production through metrology grades, thus cost increases correspondingly. Some specialized connector types may not have all three grades of quality.

****Draw a triangle showing the three grades inside. On the left side of the triangle, put quality with an upward arrow. As you move from production up the pyramid to metrology, the quality of the connector improves. On the right side of the triangle, put use and draw a downward arrow. In the same way, as you move down from metrology to production, the amount of use increases.**

Connector Summary

Connector	Metrology	Instrument	Production	Cutoff Freq (GHz)	Sexed	Precision Slotted Connector
Type F(75)	N	N	Y	1	Y	N
BNC (50 & 75)	N	N	Y	2	Y	Y
SMC	N	Y	N	7	Y	N
Type-N (50 & 75)	Y	Y	Y	18	Y	Y
APC-7 or 7 mm	Y	Y	Y	18	N	N
SMA (4.14mm)	N	N	Y	22	Y	N
3.55 mm	Y	Y	Y	34	Y	Y
2.92 mm or "K" [1]	N	Y	Y	44	Y	N
2.4 mm [2]	Y	Y	Y	52	Y	Y
1.85 mm [2, 3]	N	Y	Y	70	Y	N
1.0 mm	N	Y	Y	110	Y	N

1. Compatible with SMA and 3.5 mm connectors.
2. Not compatible with SMA, 3.5 or 2.92 mm connectors
3. Compatible with 2.4 mm connector

Reference: *Agilent Microwave Test Accessories Catalog* , 1992-1993 pp. 14, 15.

Agilent Technologies

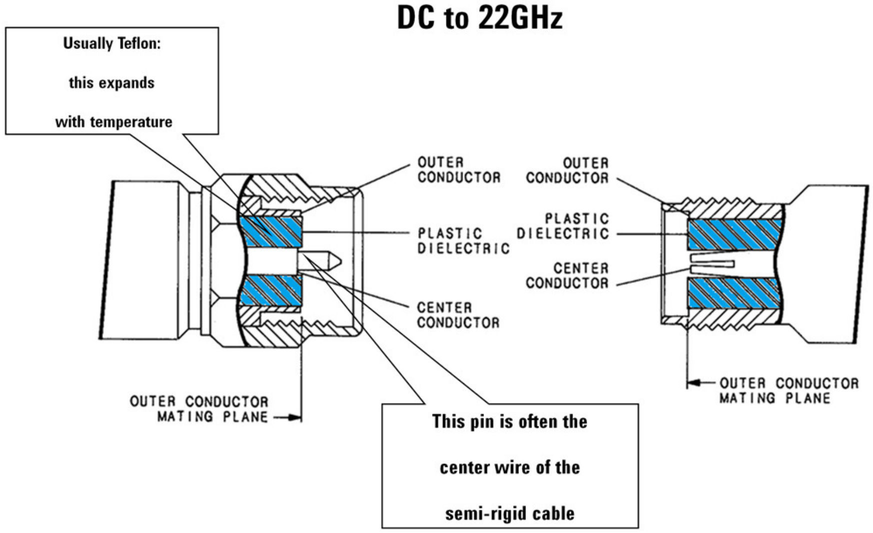
Electro Rent Corporation

The SMA Connector

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

DC to 22GHz



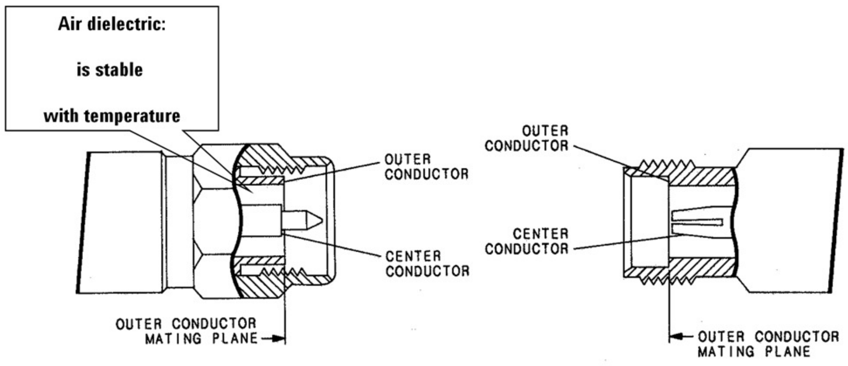
Agilent Technologies

Electro Rent Corporation

The Precision 3.5 mm Connector

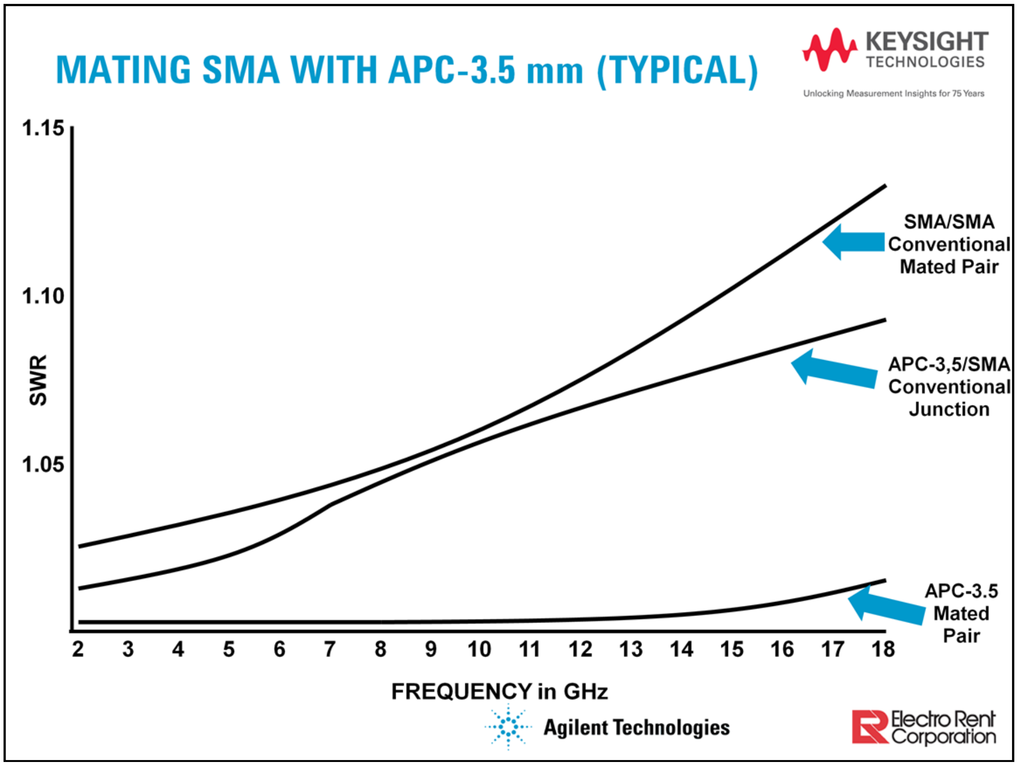
KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights for 75 Years

DC to 34GHz



Agilent Technologies

Electro Rent Corporation



Mating a Precision 3.5 mm Connector to an SMA Connector

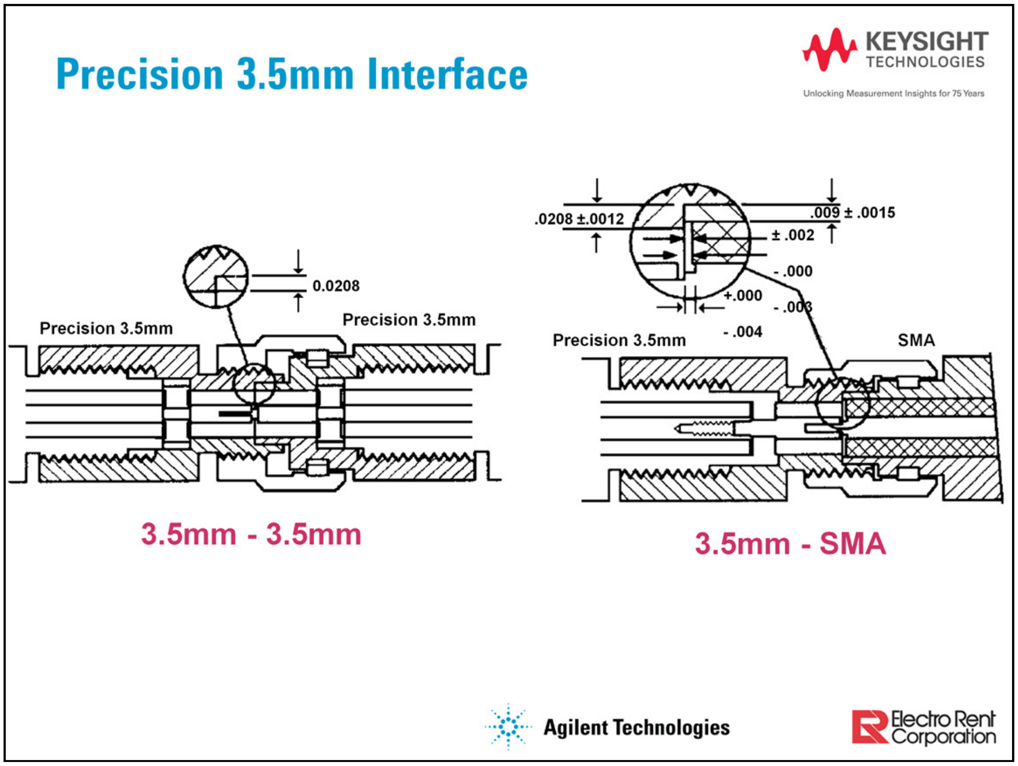
Using the following procedure very carefully, you can mate a precision 3.5 mm connector to an SMA connector. The two connectors have slightly different dimensions and mechanical characteristics. Mating a precision 3.5 mm connector to an SMA connector also affects electrical performance.

Gage both connectors. The SMA connector must meet the precision 3.5 mm connector setback specifications. If not, it will damage the 3.5 mm connector.

Carefully align the connectors and push them straight together. Do not twist either connector, just turn the male connector nut.

Use a torque wrench for the final connection (56 N-cm (5 lb-in)).

If you must make more than a few connections, use a 3.5 mm-to-3.5 mm adapter to protect the 3.5 mm connector.

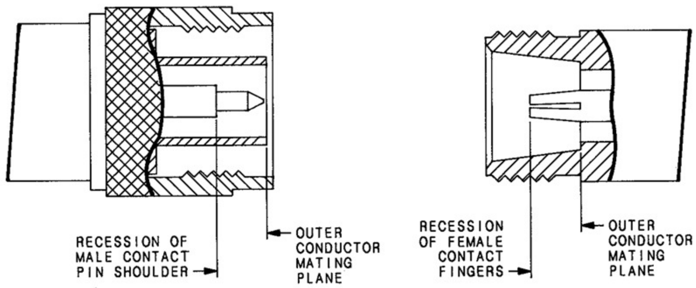


Electrical Performance

The junction of two precision 3.5 mm connectors provides superior electrical performance compared to either the junction of two SMA connectors, or an SMA connector mated to a precision 3.5 mm connector (see Figure 3-31). When you mate an SMA connector with a precision **3.5** mm connector, the connection has a typical mismatch (SWR) of 1.10 at 2 GHz (less than that of two SMA connectors, but much greater than that of two precision 3.5 mm connectors).

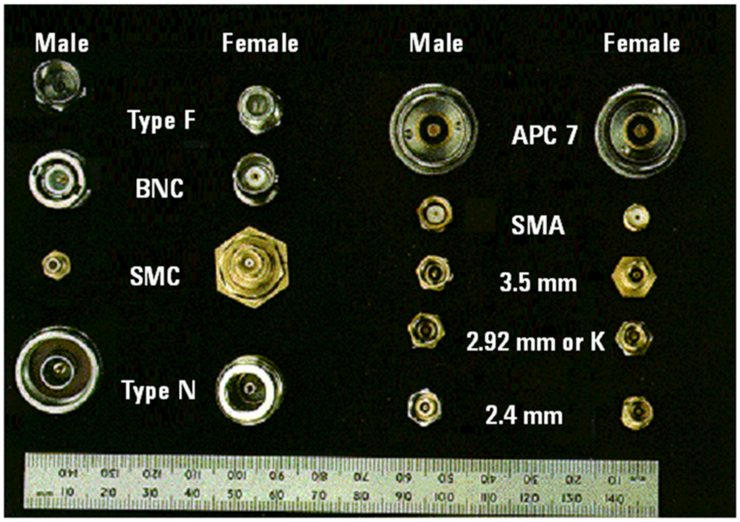
The Type N Connector

DC to 18GHz



Connector Examples

KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights for 75 Years



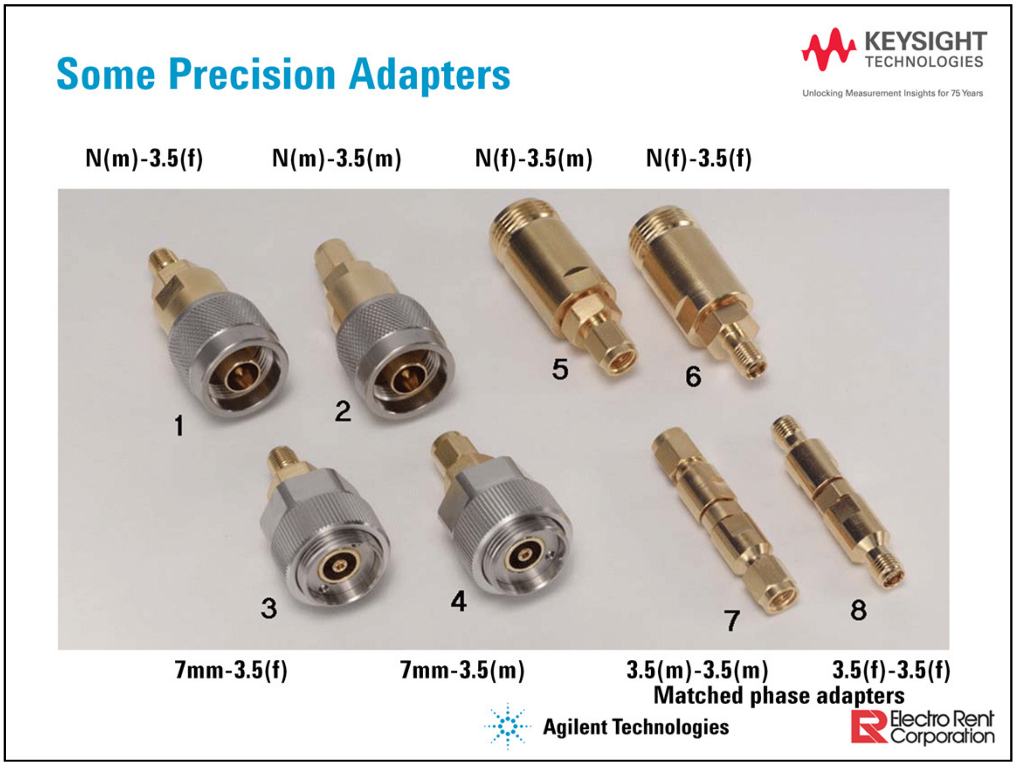
Agilent Technologies

Electro Rent Corporation

Here is a photograph of the more commonly used connector types.

Some Precision Adapters

Agilent Technologies

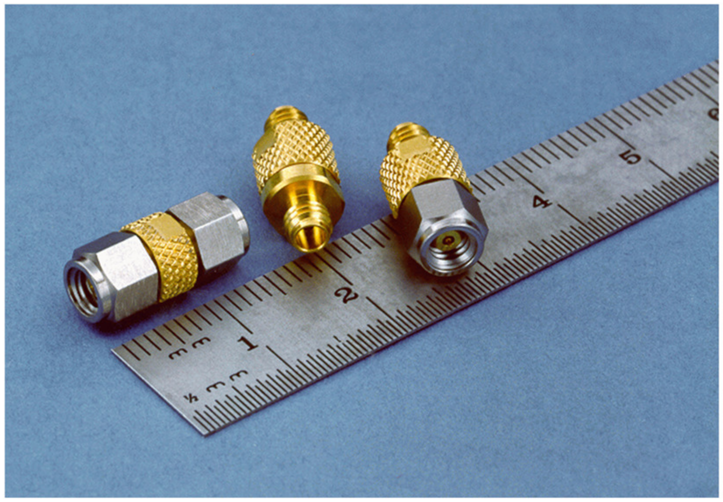


Precision adapters can have higher performing frequencies due to their tighter dimensional tolerances and higher quality machining.

That's why a 26.5 GHz N Connector can be used on some of our Spectrum Analyzers, for example.

1.0 mm Coaxial Adapters

KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights for 75 Years



Agilent Technologies

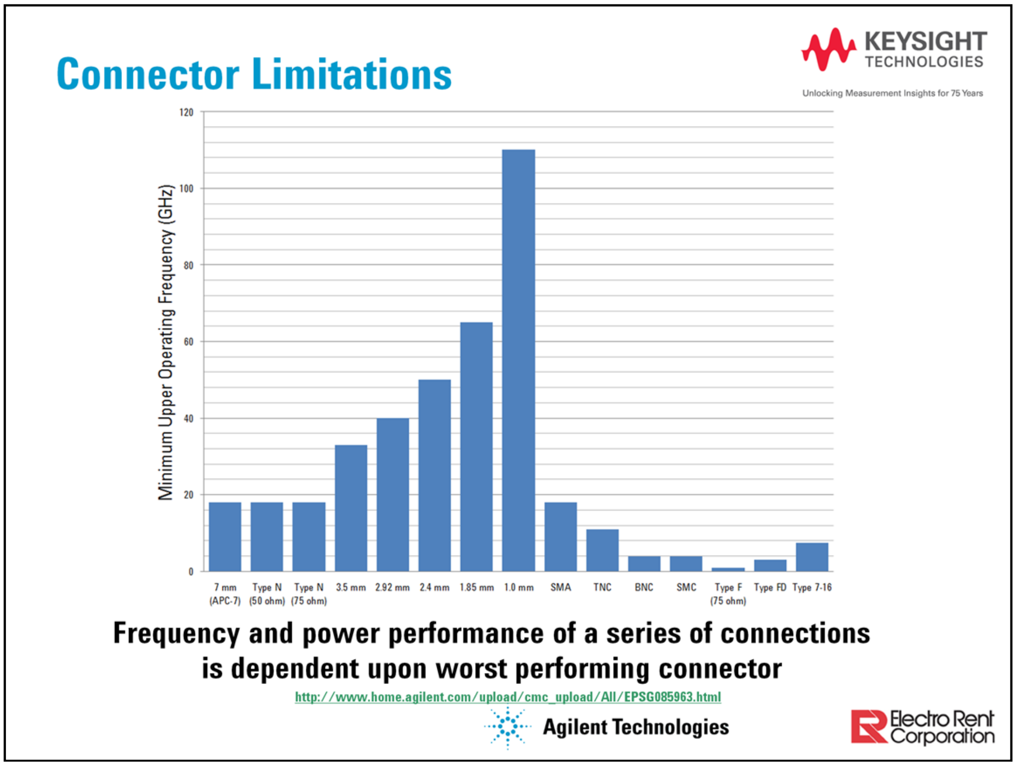
Electro Rent Corporation

The 1.0 mm series adapters are designed to be used for the measurement of components with 50 ohm 1.0 mm connectors with a frequency range from dc to 110 GHz.

The 1.0 mm connector utilizes an air dielectric interface for the highest accuracy and repeatability. The coupling diameter and thread size maximize strength, increase durability, and provide highly repeatable connections. The connectors are designed so that the outer conductors engage before the center conductors.

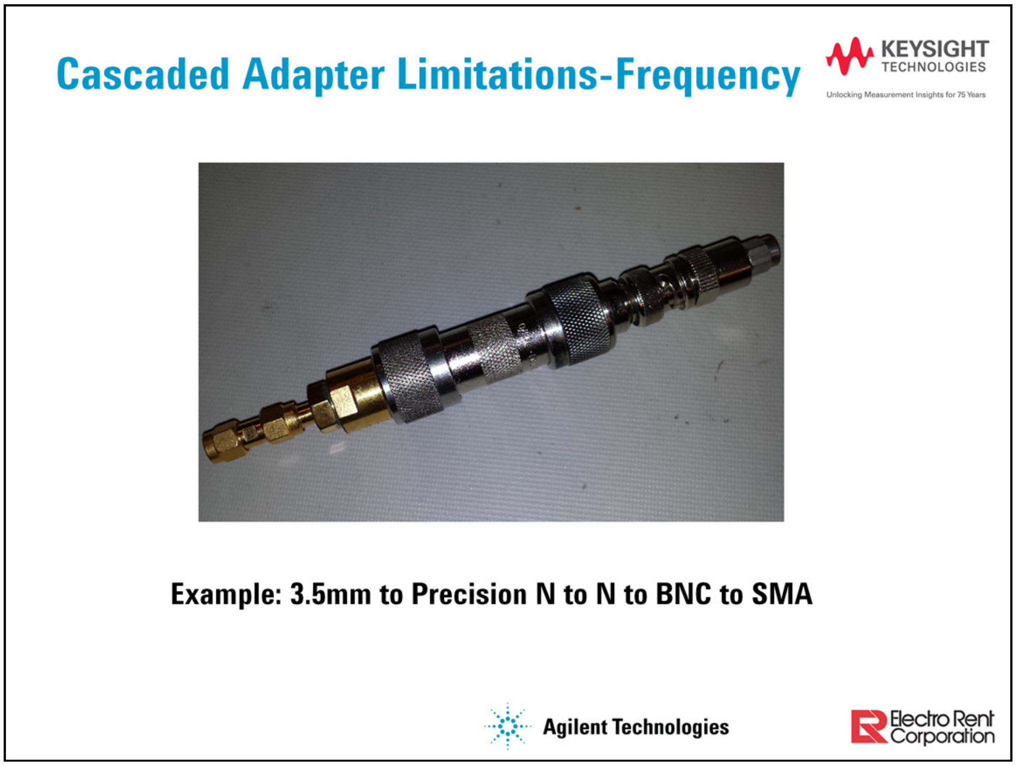
1.0 mm Launch Adapter

For Coax to Microstrip, pin diameter = 0.162 mm
11923A



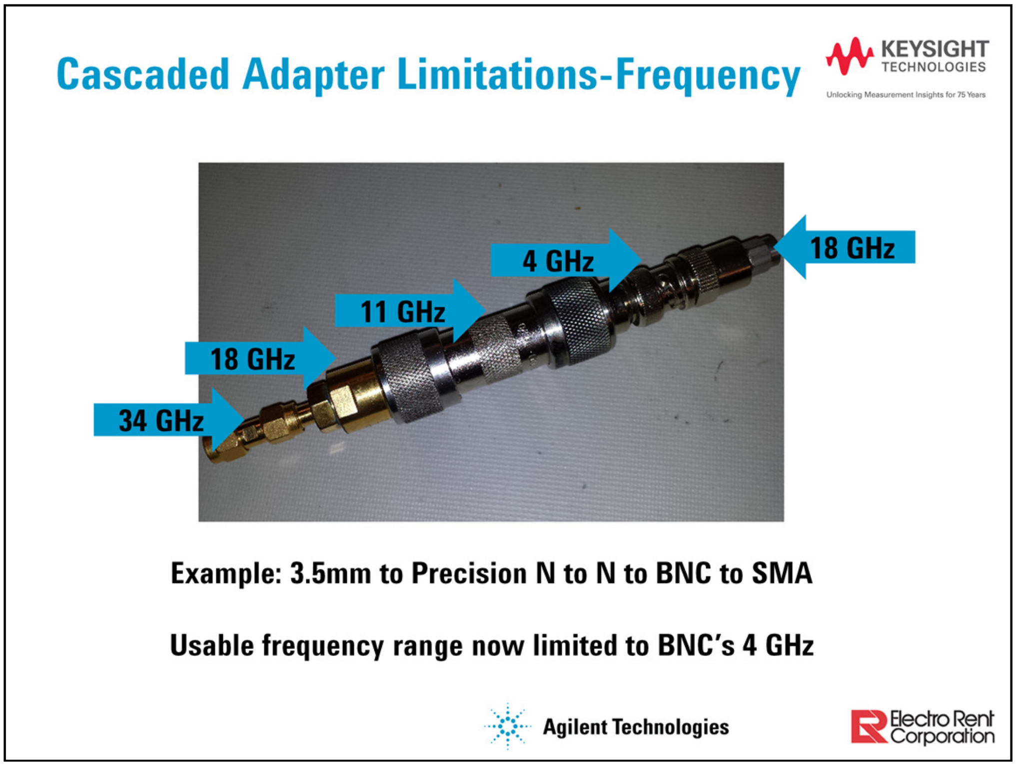
Here we have a bar graph showing the frequency ranges of various connectors, as you can see not every connector can adequately transmit at the same range.

Some connector manufacturers spec their frequency ranges to be somewhat higher or lower, but these are the minimum upper frequency ranges.



Here we have an exaggeration (we hope) of a series of connectors, a 3.5mm to Precision N to N to BNC to SMA.

From the previous graph, we know each connector does not have the same maximum operating frequency range.



Here, the 4 GHz maximum operating frequency limits my entire connection to 4 GHz.

This is because, no matter how well the other adapters operate at frequencies above 4 GHz, attenuation and reflections that will occur in at the BNC connector once the electromagnetic wave reaches it.

Cascaded Adapter Limitations-Uncertainty

KEYSIGHT TECHNOLOGIES

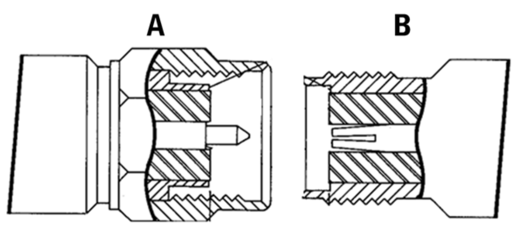
Cascading adapters increases measurement uncertainty

Connectors not perfectly matched, leading to uncertainties

- **Following the amplitude and phase uncertainty equations:**

$$\text{Amplitude Mismatch Uncertainty} = \pm 2 \ \times |\Gamma|_A \times |\Gamma|_B \times 100\%$$

$$\text{Amplitude Mismatch Uncertainty} = 20 \times \log(1 \pm |\Gamma|_A \times |\Gamma|_B \ ) \text{ dB}$$



Agilent Technologies

Electro Rent Corporation

Connectors also create measurement uncertainty, which is the range of errors from the ideal true value measurement you are trying to make.

There are multiple sources of measurement uncertainty, ranging from instrumentation errors, to sensors, to environmental factors, but connector mismatch induced uncertainties can often times be easily fixed and are large factors in total measurement uncertainty.

The basic amplitude uncertainty equations, expressed in both percentages and dB are shown, where A and B are the connectors and Γa and Γb are their corresponding reflection coefficients.

These equations are more to display the errors caused from mismatches and cascading connections (to prove minimal, high quality connections are ideal) than to have the student memorize, as this is a connector care class.

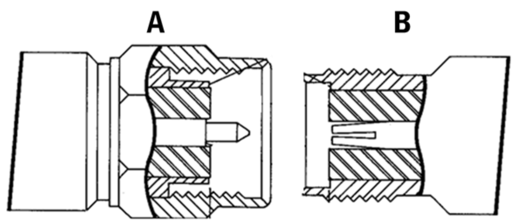
Cascaded Adapter Limitations-Uncertainty

Cascading adapters increases measurement uncertainty

Connectors not perfectly matched, leading to uncertainties

- **Following the amplitude and phase uncertainty equations:**

$$\text{Phase Mismatch Uncertainty} = \frac{180}{\pi} \times |\Gamma|_A \times |\Gamma|_B$$



Agilent Technologies

Phase mismatch uncertainty is shown here.

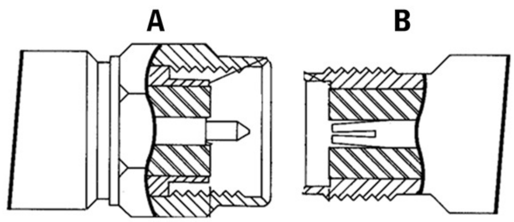
Cascaded Adapter Limitations-Uncertainty

KEYSIGHT TECHNOLOGIES

Cascading adapters increases measurement uncertainty

Example: Device Under Test connected to Test Cable

- **Device Under Test:** Return Loss = -9.5 dB → $|\Gamma|_A = 0.33$ → VSWR = 2.00
- **Test Cable:** Return Loss = -20.0 dB → $|\Gamma|_B = 0.1$ → VSWR = 1.22



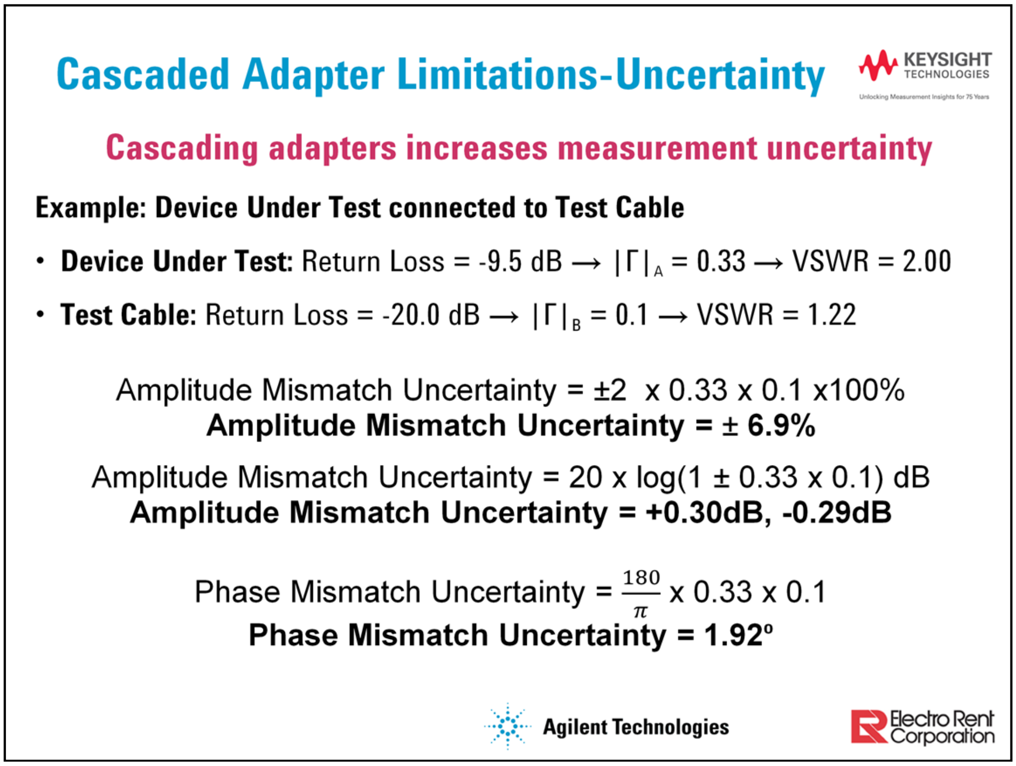
$$RL = -20\log(|\Gamma|) \qquad |\Gamma| = 10^{\frac{-RL}{20}} \qquad VSWR = \frac{1+|\Gamma|}{1-|\Gamma|}$$

Agilent Technologies

Electro Rent Corporation

In this example, we have a connection involving a Device under Test (A) and Test Cable (B) with the following characteristics.

The equations to get from return loss to reflection coefficient are also shown.



Using the previously shown equations, we calculate our measurement uncertainties.

Notice how much uncertainty a poorly matched connection can cause.

Cascaded Adapter Limitations-Uncertainty

KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights for 75 Years

Cascading adapters increases measurement uncertainty

Example: Multiple Connectors Cascaded

- **Assume for all:** Return Loss = -10.0 dB → $|\Gamma| = 0.32$ → VSWR = 1.92

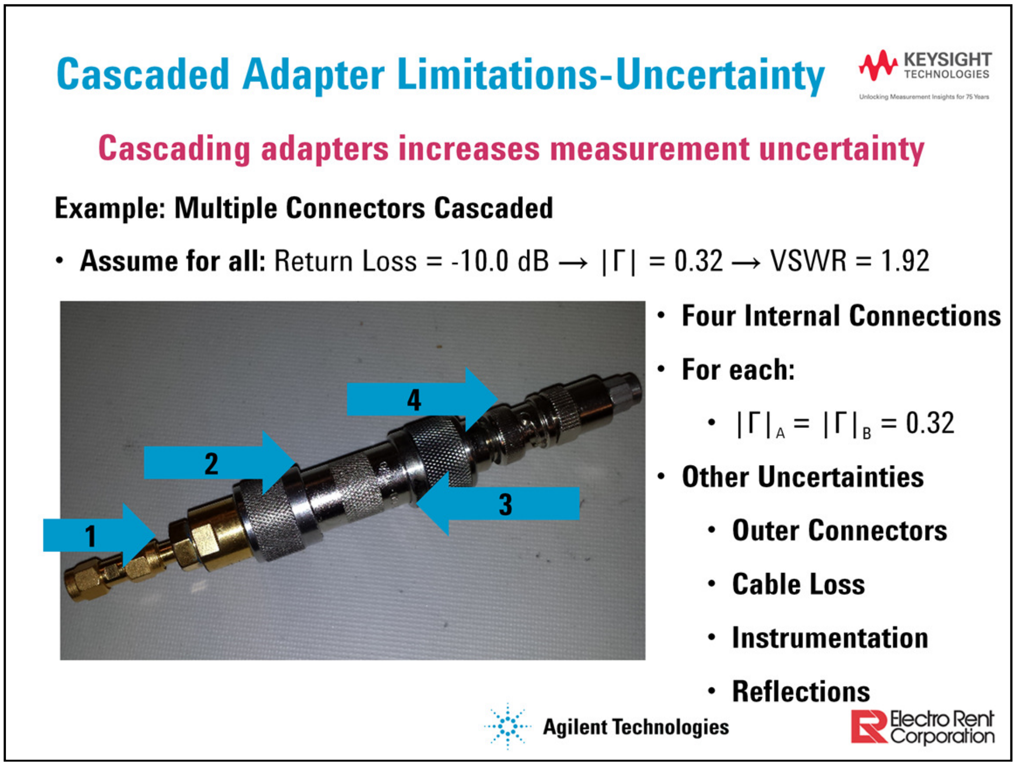
Agilent Technologies

Electro Rent Corporation

Now we will show what cascading connectors can do to measurement uncertainty.

In the chain of connections we previously discussed, assume a return loss of -10 dB for each.

(It is somewhat high but we're also excluding uncertainties that would add up)



We're only finding the uncertainties of the four inner connectors.

Each connector will have Γ's of 0.32, and Γa = Γb.

Keep in mind there are two outer connections that will add to the uncertainty of the measurement, as well as cable loss uncertainty and instrumentation uncertainty.

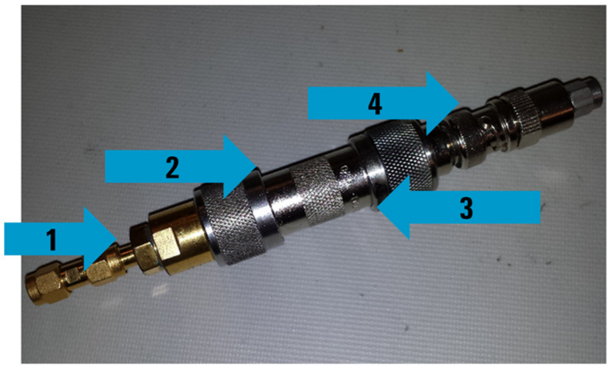
Also, there will be multiple reflections due to impedance mismatches along the path.

Cascaded Adapter Limitations-Uncertainty

Cascading adapters increases measurement uncertainty

Example: Multiple Connectors Cascaded

- **Assume for all:** Return Loss = -10.0 dB → |Γ| = 0.32 → VSWR = 1.92



- **Four Connections**
- **For each:**

Amp. Mismatch Uncertainty =

± 20.0%

Amp. Mismatch Uncertainty =

-0.83 dB to +0.92 dB

Phase Mismatch Uncertainty =

5.73°

The calculated amplitude and phase uncertainties are shown in this slide.

Cascaded Adapter Limitations-Uncertainty

KEYSIGHT TECHNOLOGIES

Cascading adapters increases measurement uncertainty

Example: Multiple Connectors Cascaded

- **Total Cascaded Worst Case Uncertainties:**

Cascaded Amplitude Mismatch Uncertainty:
4 x ± 20.0% = ± 80.0%

Cascaded Amplitude Mismatch Uncertainty:
4 x -0.83 dB to +0.92 dB = -3.31 dB to +3.66 dB

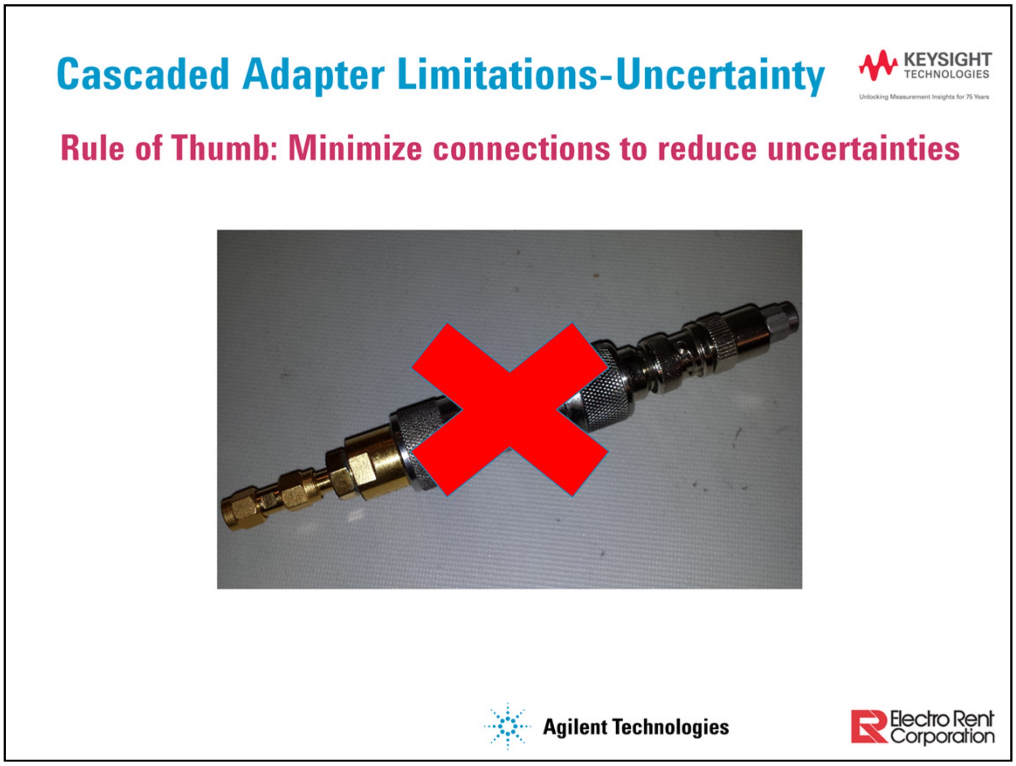
Cascaded Phase Mismatch Uncertainty:
4 x 5.73º = 22.92º

Agilent Technologies

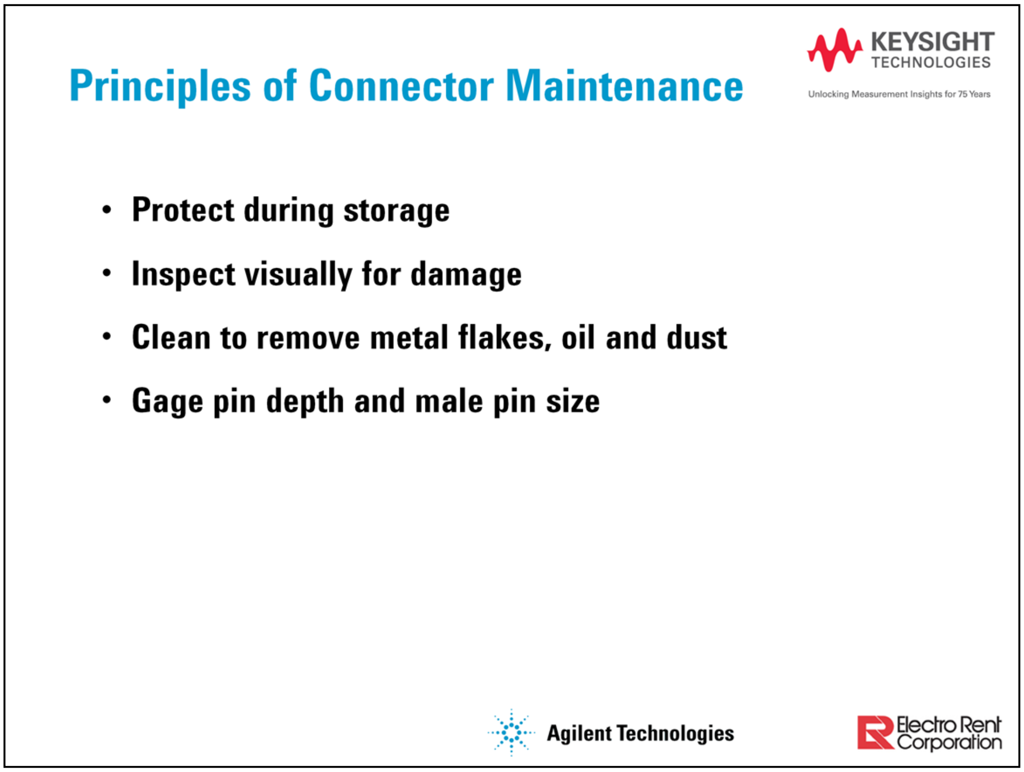
Electro Rent Corporation

The worst case measurement uncertainties for the cascaded adapters is found by adding each adapter’s uncertainty in the chain.

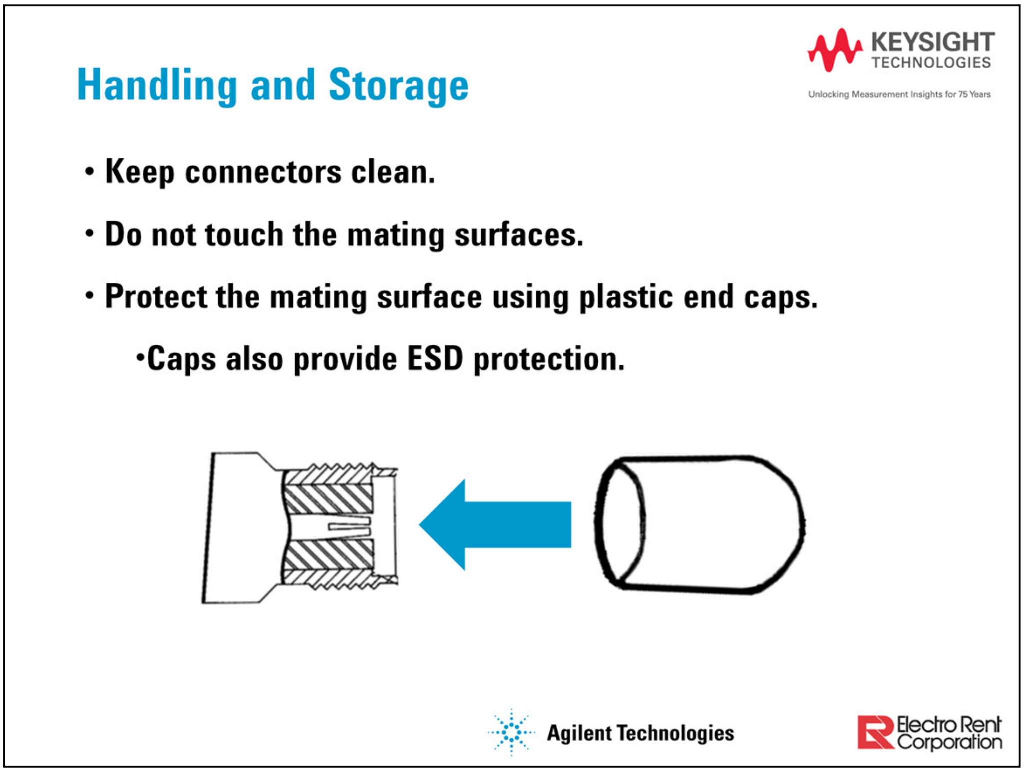
(The usual RSS method is not done here to emphasize worst case uncertainties)



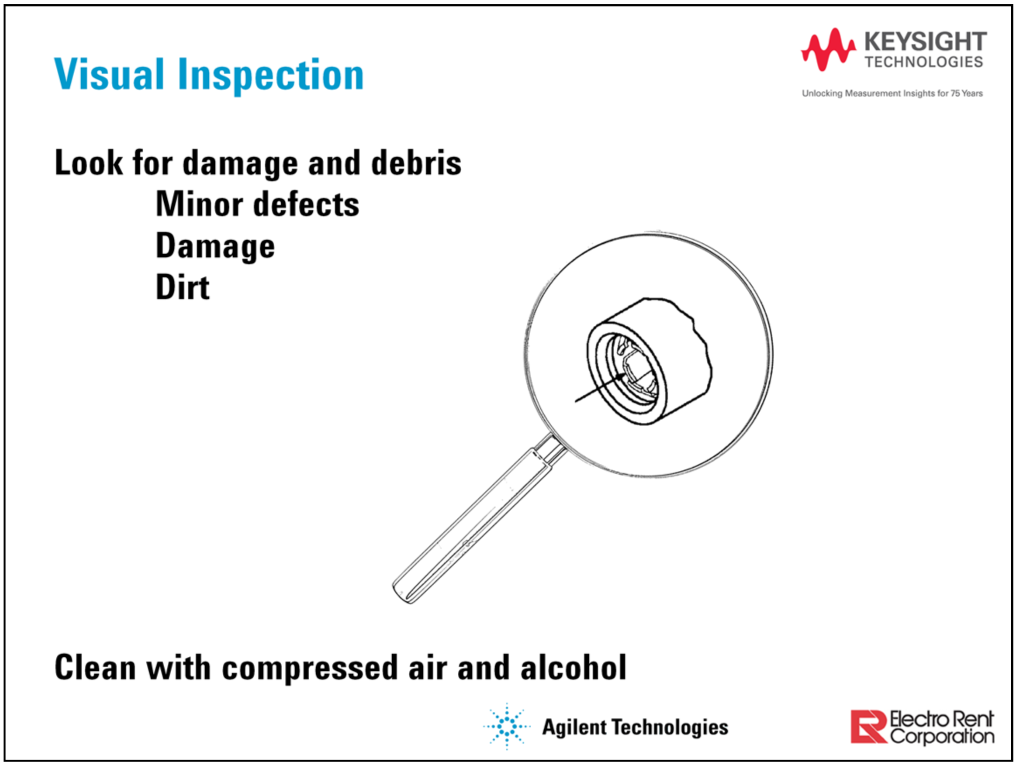
It can be concluded, based on the previous two examples, to limit the amount of adapters used in a measurement.



These are the basic recommendations for obtaining best results from your connectors. For best results you should consider these as steps to follow each time you make a connection. Inspect, clean, and Gage the test port connectors each time you change the setup, and periodically thereafter. Always check the device under test connectors before connecting it to the network analyzer.



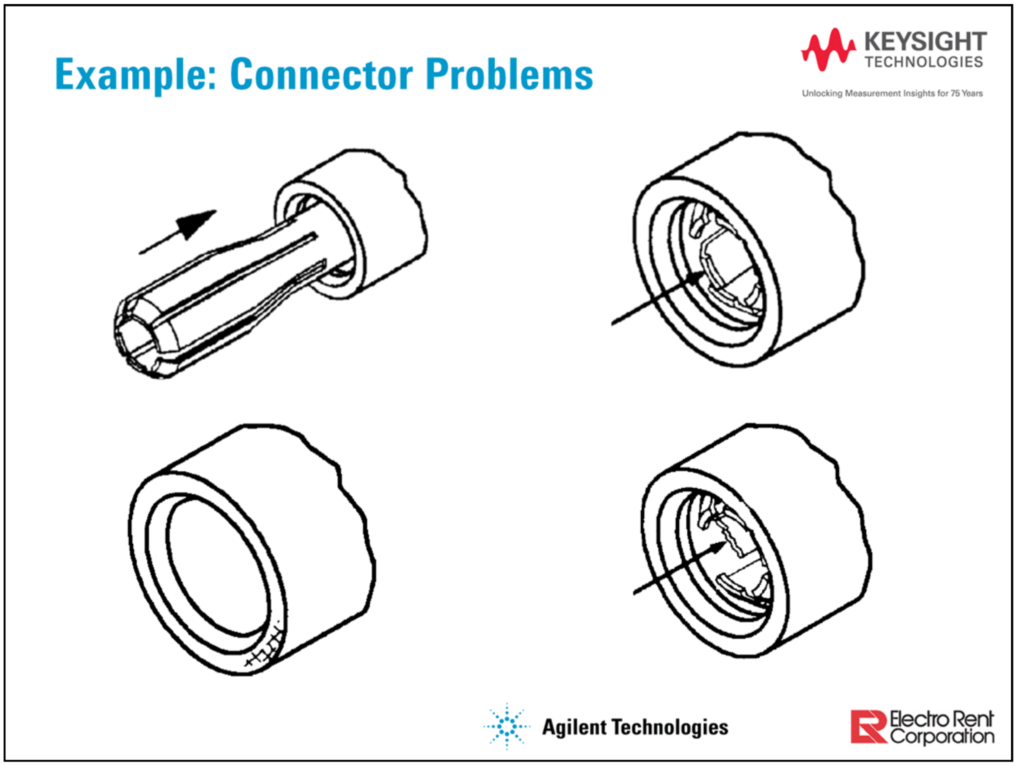
You should always store the connectors in a way that provides maximum protection, with the plastic end caps installed. Natural skin oils and microscopic particles of dirt are easily transferred to the mating surfaces and can be very difficult to remove. Never store connectors loose in a box or drawer.



It is very important to visually inspect connectors because of the small size of some coaxial connectors, and because of very precise mechanical tolerances (on the order of a few hundreds of micro inches in some cases), minor defects, damage, and dirt can significantly degrade repeatability and accuracy. In addition, a precision connector mating surface may have gold plating, making it susceptible to mechanical damage because of the softness of the metal. A dirty or damaged connector can destroy any connector mated to it.

A trained naked eye will normally notice defects in a connector but many times it is advantageous or necessary to use a magnifying glass to observe more subtle defects such as small fibers, bent pins and damaged female slotless connectors.

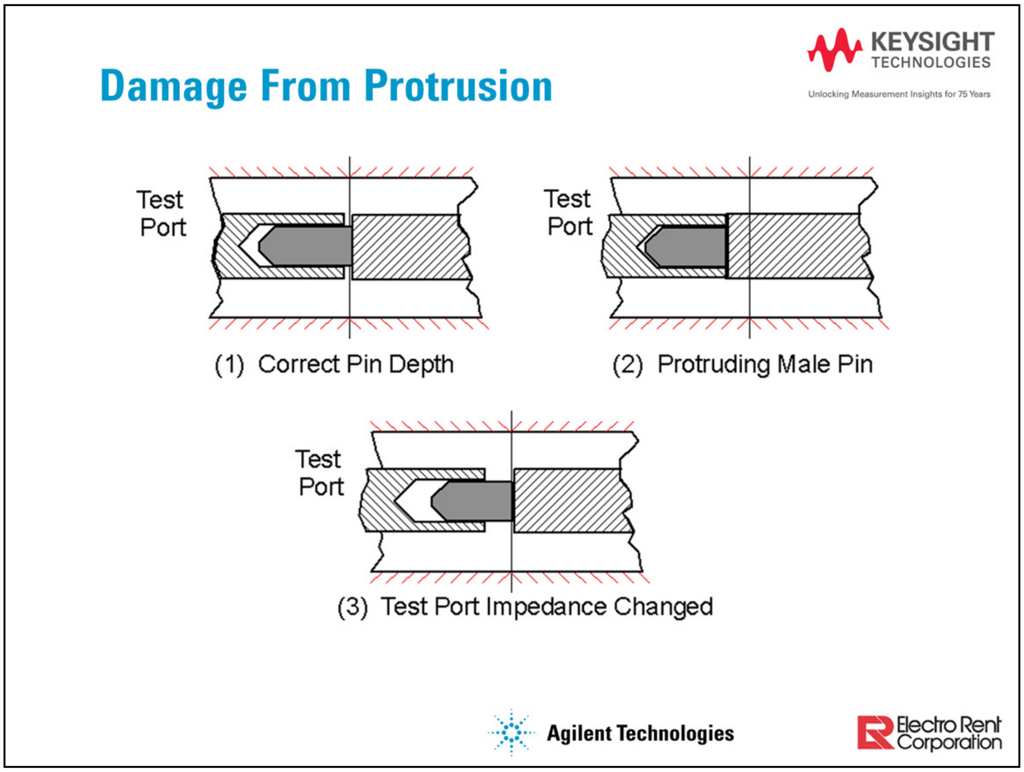
It is imperative that you NEVER use a damaged connector.



Obvious Defects

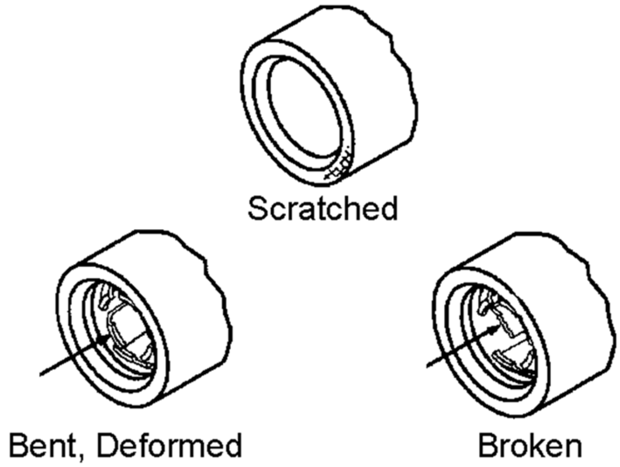
Before each connection, visually inspect all connectors. If necessary, clean the connectors each time you make a connection. Look for obvious defects or damage (badly worn plating, deformed threads, or bent, broken, or misaligned center conductors). Connector nuts should move smoothly and have no burrs, loose metal particles, or rough spots. Discard or send for repair any connector with an obvious defect.

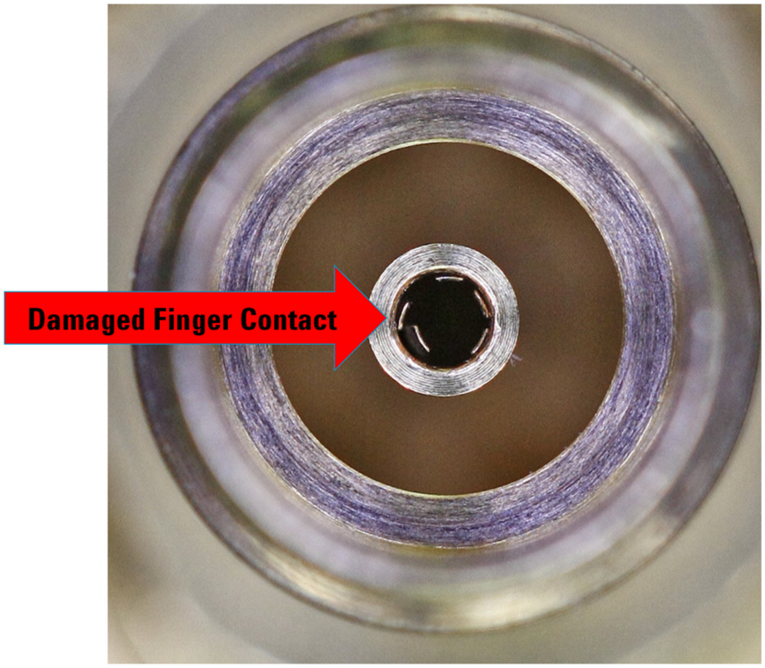
If a connector shows deep scratches or dents, particles clinging to the mating plane surfaces, or uneven wear, clean it and inspect it again. Determine the cause and extent of the damage before using a connector that has dents or scratches deep enough to displace metal on the connector mating plane surface.



If any damage is detected, DO NOT make the connection. Repair the connector, if possible, or remove it from service and get a new one. Scratches and dents on the surface of the connectors will not provide an adequate mating plane, and measurements will be degraded. Bent fingers and gouges in the center conductor are most likely caused by a misplaced male pin.

Replace Damaged Connectors

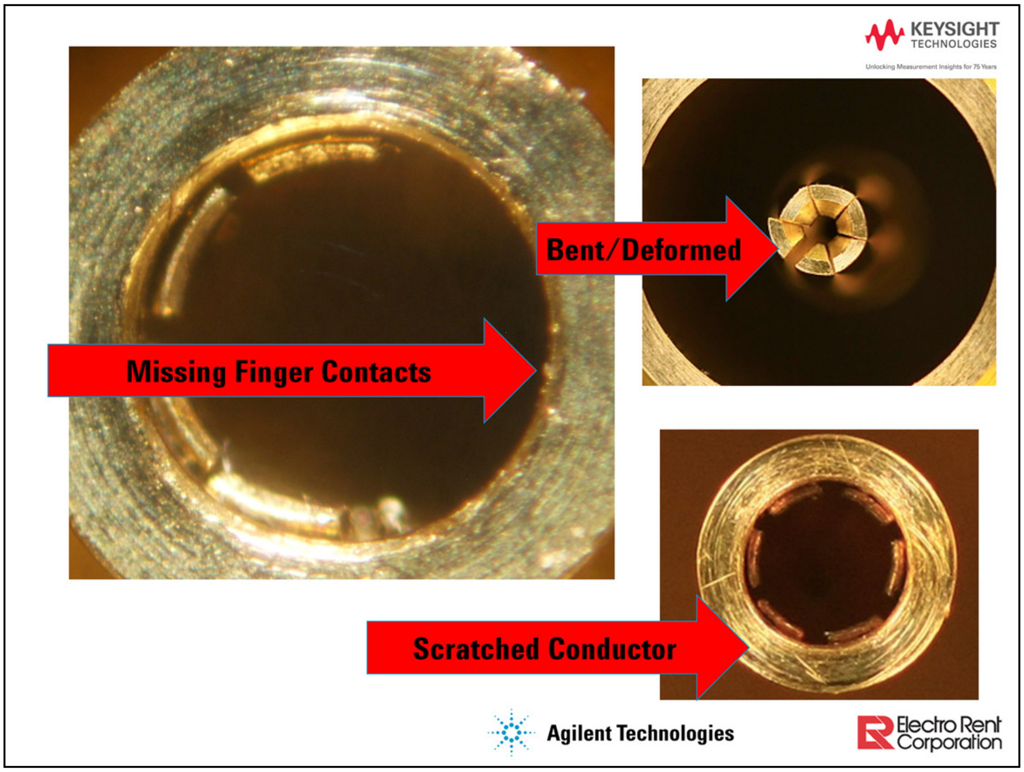


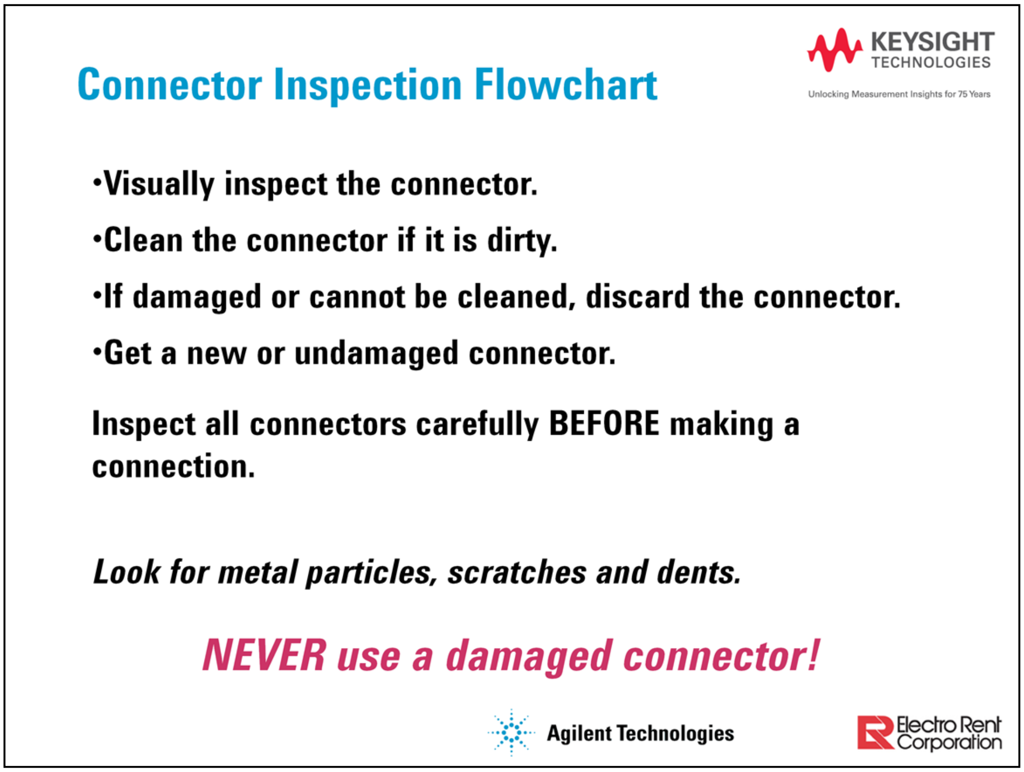


KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights for 75 Years

Agilent Technologies

Electro Rent Corporation

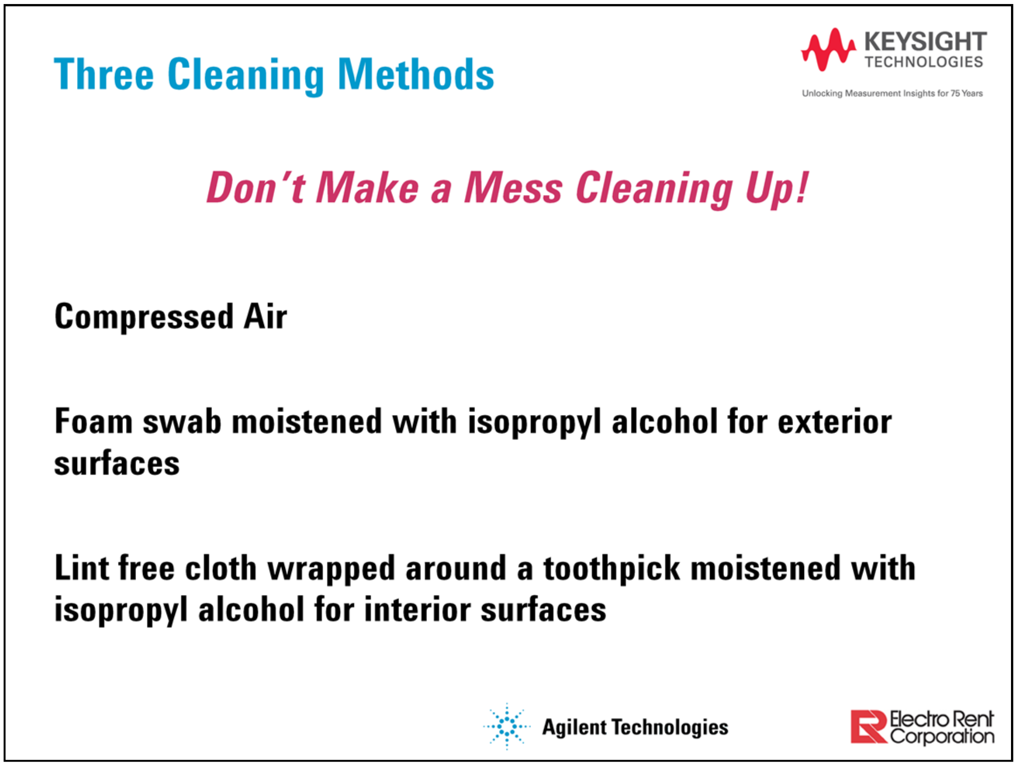

KEYSIGHT
TECHNOLOGIES
Unlocking Measurement Insights for 75 Years
Bent/Deformed
Missing Finger Contacts
Scratched Conductor
Agilent Technologies
Electro Rent
Corporation



The first step is to always visually inspect the connector. You can inspect it with the naked eye or with a magnifying glass. Next is to clean the connector if you find dents or scratches that are deep enough to displace metal on the connector mating plane surface. You should also clean the connector if it is dirty. If you decide that the connector is not dirty or that the dents and scratches are very deep, discard the connector. The dents or scratches should be deep enough to displace metal on the connector mating plane surface. Also discard it if part of the inner contact is broken, if the entire connector is broken, or if the distance between the fingers of the inner contact is too far. After discarding the connector, get a new or undamaged connector to replace it and remember to always clean a connector before reconnecting it.

Always visually inspect both connectors before making any connection. One connection made with a dirty or damaged connector can damage both connectors beyond repair.

In most cases magnification is necessary to see contamination or damage, but minor abrasions or dents not visible without magnification generally do not affect electrical performance of the connector.

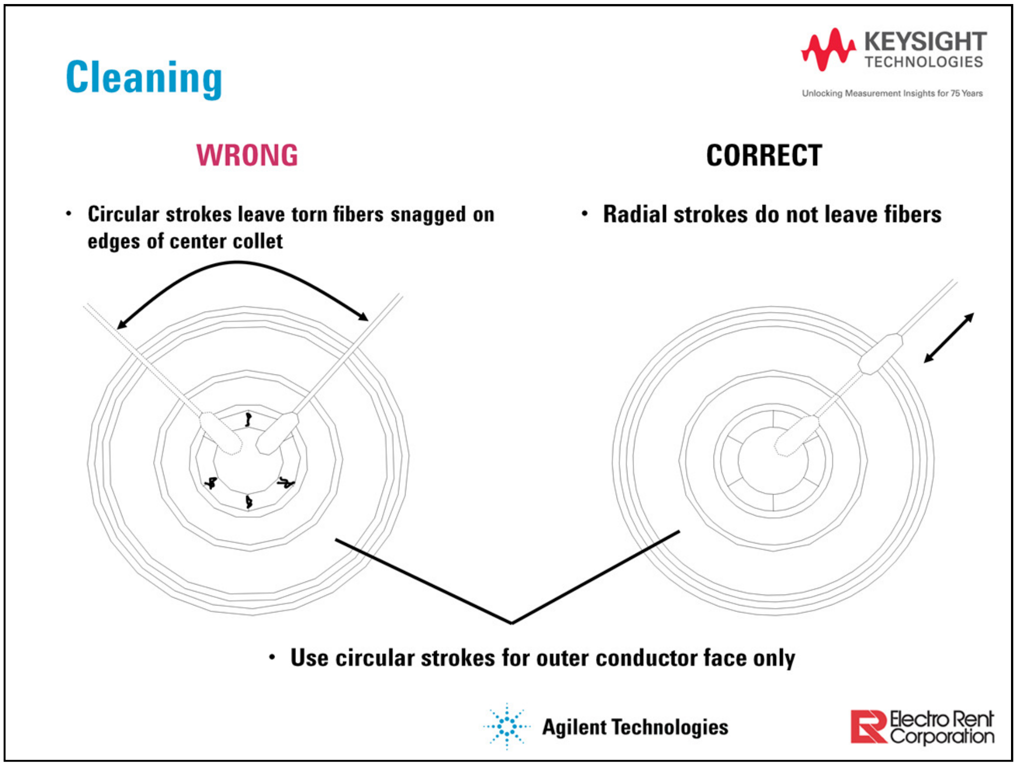


Once a connector has been visually inspected and needs cleaning, there are three cleaning methods you can choose from or you can use any combination of the three depending on the severity of the contaminants. Use compressed air to loosen particles on the connector mating plane surfaces. For dirt or stubborn contaminants you cannot remove with compressed air, try a foam swab or lint-free cleaning cloth moistened with isopropyl alcohol. Use a foam swab, not a cotton swab, moistened with isopropyl alcohol to clean exterior connector surfaces. Use a lint-free cloth wrapped around a wooden toothpick to clean interior cleaning surfaces.

We want to use cleaning materials that reduce the amounts of residue that can be left on the connector.

Always use low pressure air (5-20 psi). Always use protective eyewear when using compressed air. Flying debris may be blown into your eyes, causing damage. Also the delicate parts of the male and female center conductors may be damaged when high velocity air is blown across them.

Next, use a suitably sized lint-free swab or appropriate brush lightly moistened in pure, water-free isopropyl alcohol to remove oil from the connector mating surfaces. Always use the least amount of solvent possible, and avoid wetting any plastic parts inside the connector. Do not use acetone, methanol, or CFCs (Freon). The swab or brush must be soft so that the connector parts are not abraded during cleaning.



Cleaning the Mating Plane Surfaces

Apply a small amount of isopropyl alcohol to a new swab and clean the mating plane surfaces.If the connector has a center conductor, use very short horizontal or vertical strokes (across the connector), and the least pressure possible, especially when cleaning a female connector (to avoid snagging the cleaning swab on the center conductor contact fingers). An illuminated magnifying glass helps.

Cleaning the Interior Surfaces

In the following steps, use the proper size toothpick. The wooden handle of a foam swab, for example, is too large even if it fits into the connector.

Get a properly sized round wooden toothpick and cut off the sharp tip. Wrap the trimmed toothpick with a single layer of lint-free leaning cloth. Moisten the cloth with a small amount of isopropyl alcohol and carefully insert it into the connector. To clearly see the areas you wish to clean, use an illuminated magnifying glass. After cleaning, blow the connector dry with a gentle stream of clean compressed air or nitrogen. Always completely dry a connector before you reassemble or use it.

> For 3.5 mm connectors, use a toothpick with a diameter no greater than 1.7 mm (0.070 in).
>
> For 2.4 mm connectors, use a toothpick with a diameter no greater than 1.2 mm (0.047 in).

KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights for 75 Years

Don’ts of Connector Cleaning

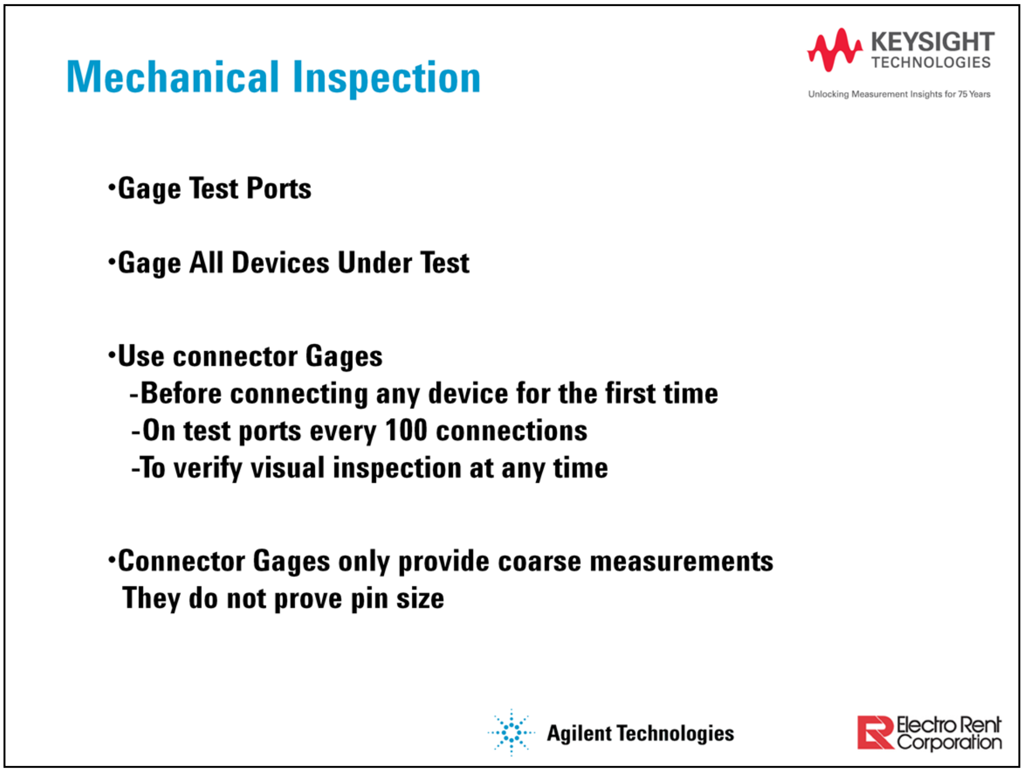
DO NOT

- Use acetone, methanol or CFCs (freon)
- Overuse the isopropyl alcohol
- Wet any plastic or dielectric parts in the connectors
- Break or bend the center conductor while cleaning
- Use a toothpick with a diameter >1.7 mm on a 3.5mm connector or one with a diameter >1.2mm on a 2.4mm connector
- Blow on the connector
- Clean with cotton swabs
- Use circular strokes when cleaning the interior of the connector

Agilent Technologies

Electro Rent Corporation

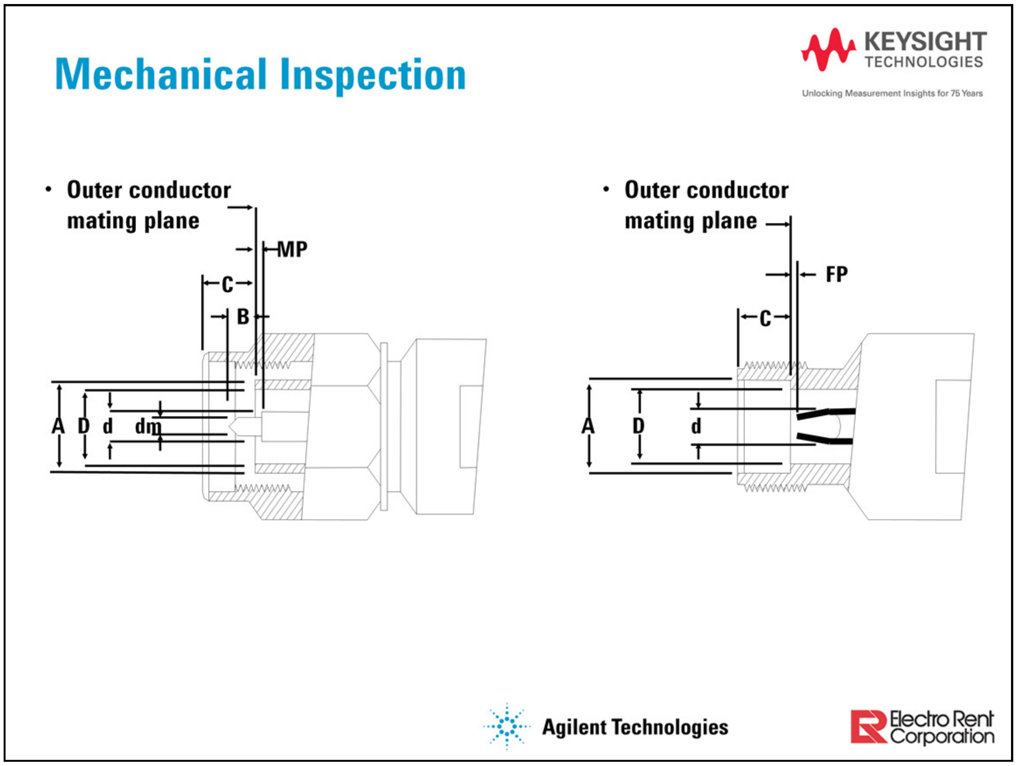
These are the cleaning don’ts to remember. The center conductor is crucial in providing a good connection so be careful not to break or bend it. If you blow on a connector, you will release contaminants from your breath and they will become embedded in the connector. You should use radial or very short horizontal strokes across the connector with the least amount of pressure possible to avoid snagging the cleaning swab on the center conductor contact fingers.



Even a perfectly clean, unused connector can cause damage if the pin depth or male pin diameter is on the order of a few ten-thousandths of an inch out of specification. Connector Gages are important tools used to verify that the connector is within mechanical specifications. Every connector should be Gaged before first use.

Assuming that the calibration standards are within specifications and that each device under test is Gaged, the test ports should require gauging only after approximately 100 connections, or if used by another operator, or used on a different test setup.

It is important to recognize that the test port connectors and calibration standards have mechanical specifications that are much too precise to be measured exactly by the type of Gages available for daily use. For this reason the Gages used in this course do not provide the accuracy or repeatability to measure the precise connector pin depths or male pin diameter. However, with proper use they serve the important function of verifying that there is not excessive protrusion or recession of the center conductor relative to the outer conductor mating plane.



Type-N

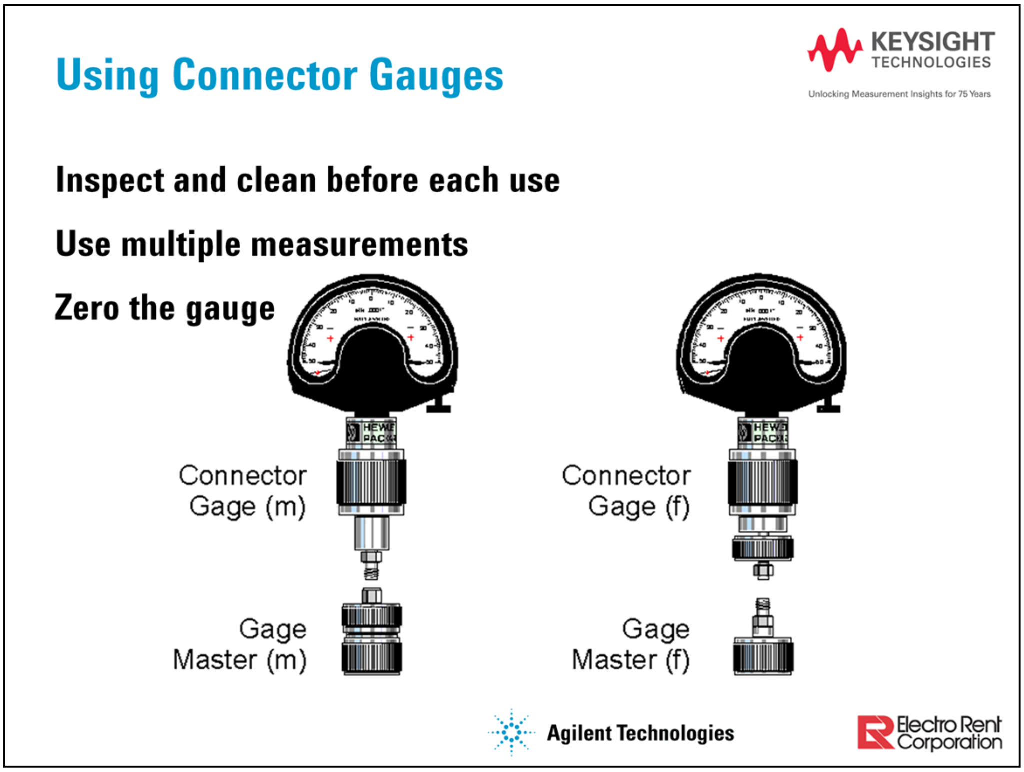
A type-N connector differs from other connector types in that its outer conductor mating plane is offset from the mating plane of the center conductor.

Specifications

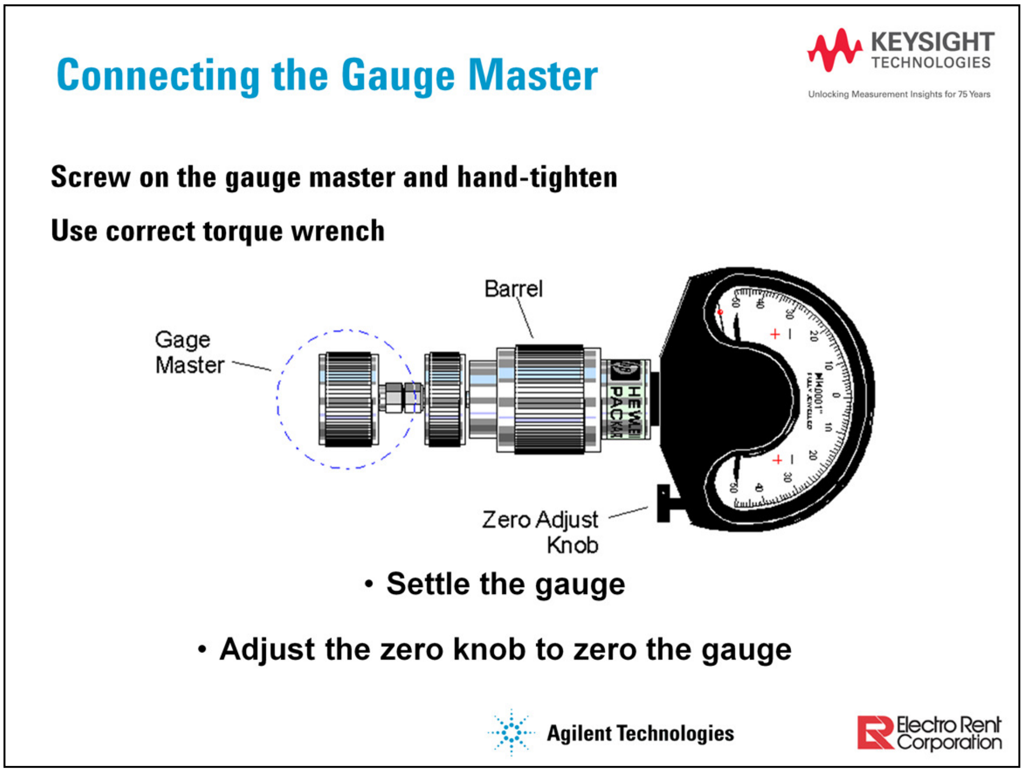
Type-N connector critical mechanical specifications:

> A maximum protrusion of the female center conductor in front of the outer conductor mating plane.
>
> A minimum recession of the shoulder of the male contact pin behind the outer conductor mating plane (0.207 inches).
>
> A maximum recession of the shoulder of the male contact pin behind the outer conductor mating plane (0.210 inches).

As type-N connectors wear, the protrusion of the female contact fingers generally increases, due to wear of the outer conductor mating plane inside the female connector. Check this periodically, because it decreases the total center conductor contact separation.

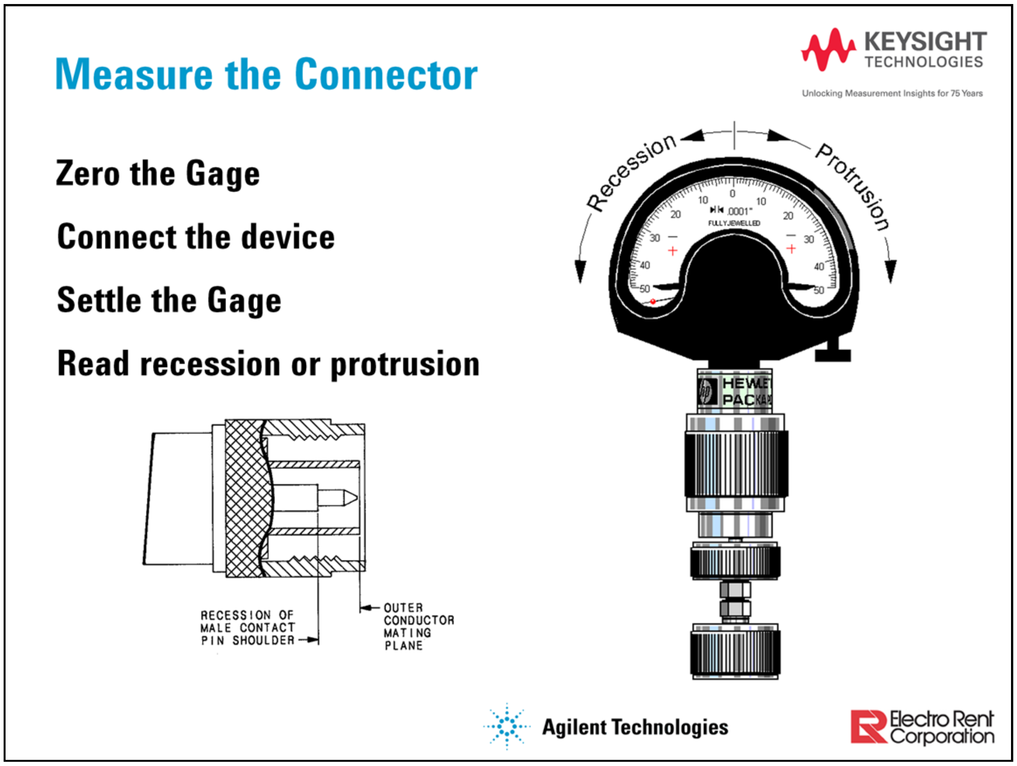


Each connector has a specific version of the gauge for measurement of the male and the female connector. Each gauge uses a special precision gage master to zero the gage. If there is doubt about the measurement, be sure the temperature of the parts have stabilized, then perform the cleaning, zeroing, and measuring procedure again.



After cleaning the gage and the gage master, hand tighten the gage master onto the gage. Then use the proper torque wrench to tighten the connecting nut.

To zero the gage, gently tap the barrel to settle the gage, then use the zero set knob so that the gage indicator reads exactly zero. Remove the gage master.

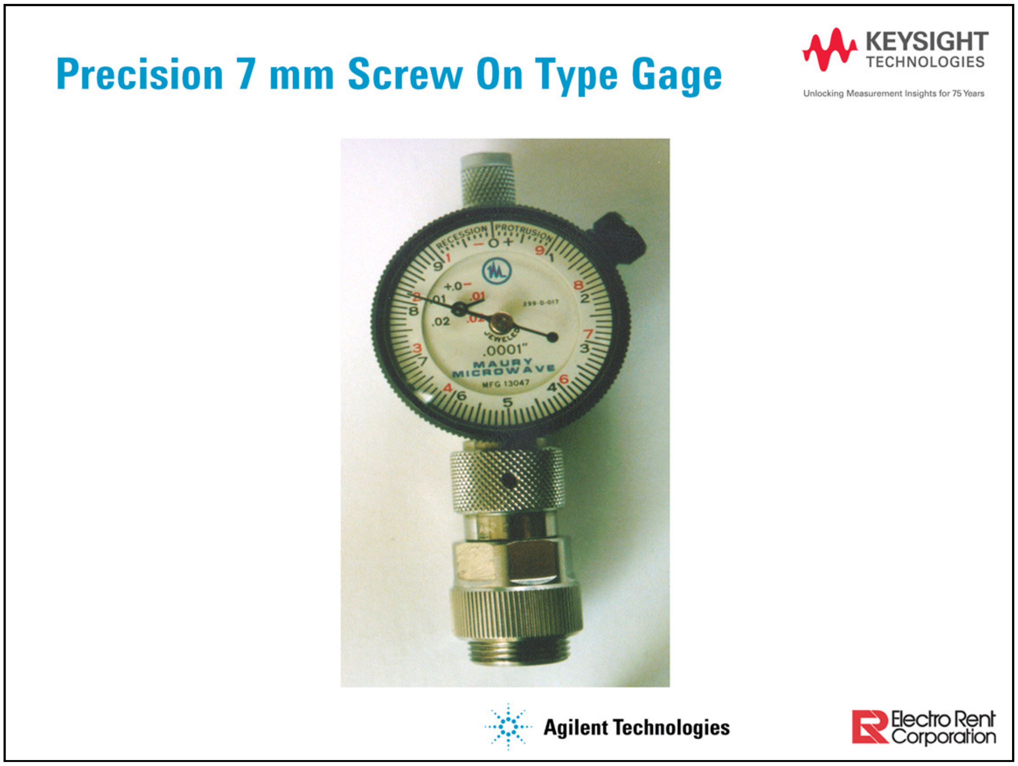


Before gaging the device, the gage must first be zeroed!

Connect the gage to the gage block.

Then zeroize the gage.

After zeroizing, hand tighten the clean, inspected device onto the Gage, then use the proper torque wrench to tighten the connecting nut. Gently tap the barrel to settle the Gage, then read the indicator. If there is any doubt about the measurement, repeat the entire zero and measurement procedure.



To gage your device it is important to recognize that there are many types of gages available, and it is very important to choose the gage with the proper type of connection to mate to your device (Connector).

Follow these steps when gaging your devices:

1. Select the proper gage for your connector.
2. Inspect and clean the gage: Inspect the connector gage and the gage calibration block carefully, exactly as you inspected the connector itself. Clean or replace the gage and the gage calibration block if necessary.
3. Zero the gage: Hold the gage by the plunger barrel (not the dial housing or cap). This prevents gage reading errors caused by stresses to the gage plunger mechanism through the dial indicator housing. If the gage pointer does not line up with the zero mark on the gage, verify the gage is clean first, then loosen the dial lock screw and turn the graduated dial until the gage pointer exactly lines up with the appropriate calibration. Then re-tighten the lock screw.
4. Measure the connector.
5. Measure the recession of the center conductor behind the outer conductor mating plane exactly the same way you zeroed the gage, but do not reset the graduated dial.
6. To monitor connector wear, record the readings for each connector over time.

Connection Techniques

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

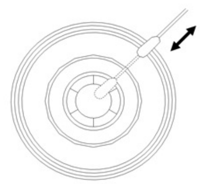
Good connection techniques are required to produce Reliable Measurements.

Before each connection:

Clean

Inspect

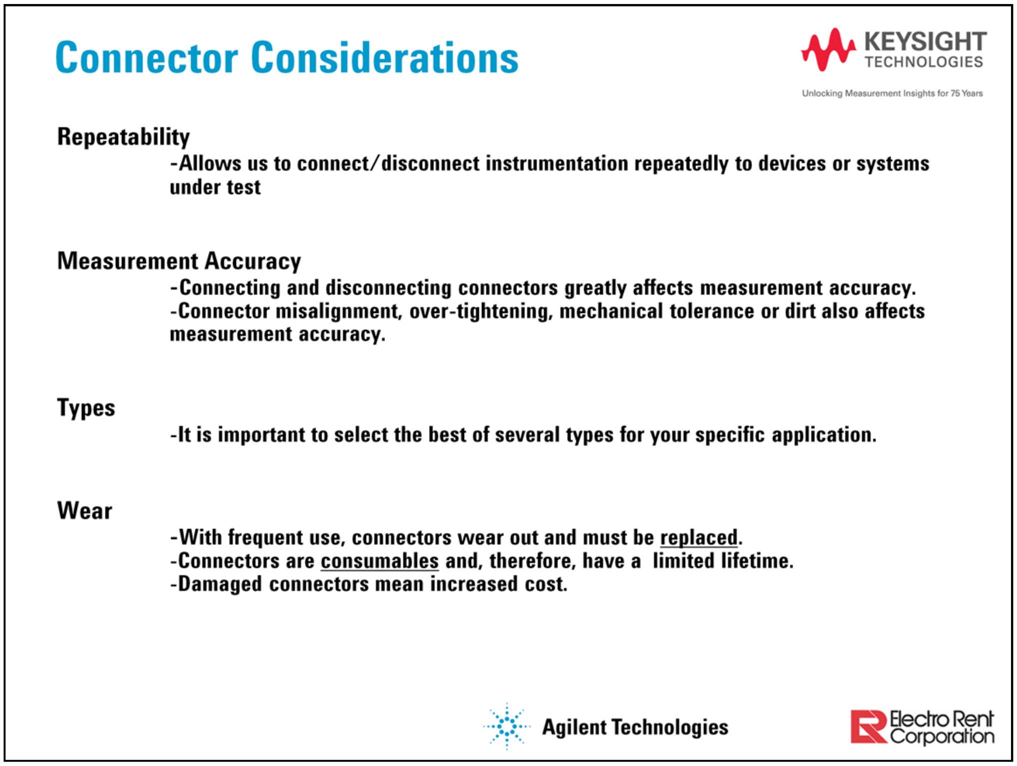
Gage



PRACTICE MAKES PERFECT.

Agilent Technologies

Electro Rent Corporation



Coaxial connectors enable us to repeatedly connect and disconnect instrumentation to devices or systems under test. For measurement purposes these connections must make as little change to the performance of the item being tested as possible and be consistent as well. Choosing which one of the several types of connectors to use depends on the measurement environment and applications, for example: production, 75 ohms, up to 1 GHz. With frequent use, connectors eventually wear and must be replaced and so must be considered as a consumable item. With care and proper technique, it is possible to maximize the useful lifetime for the more expensive measurement instrument connectors.

Bad connections result in both transmission and reflection losses at the connections which may change when the connection is removed and reconnected or may be intermittent, resulting in measurement error and repeatability problems.

Using Adapters as Connector Savers

Protect Connectors on test set or cable

Example: Becomes Port 1 and Port 2 of your VNA

Link for determining connectors for your instrumentation:

http://na.tm.agilent.com/pna/connectorcare/What_mates_with_what.htm#NMD

Agilent Technologies

There are several reasons one should use at least instrument grade adapters as the actual test ports instead of simply connecting the device under test to the test set port or to the test port extension cable. The first, and most obvious, is if the DUT doesn't use the same connector family as the test set or cable adapter. In this case, select an instrument grade between-family adapter and connect it to the test set or cable to serve as the test port. Even if the device under test has the same connector family as the test set or cable, using an adapter/connector saver protects the test port from damage and can extend the life of the connector on the test set or cable.

The adapter/test port saver must be fully inspected before connecting to the test set or cable. Because the calibration standards are connected to the adapter/connector saver, the connector saver should be instrument grade, or better.

Using Adapters as Connector Savers

KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights for 75 Years

Protect Connectors on test set or cable

Example: Becomes Port 1 and Port 2 of your VNA

Link for determining connectors for your instrumentation:

http://na.tm.agilent.com/pna/connectorcare/What_mates_with_what.htm#NMD

Make sure:

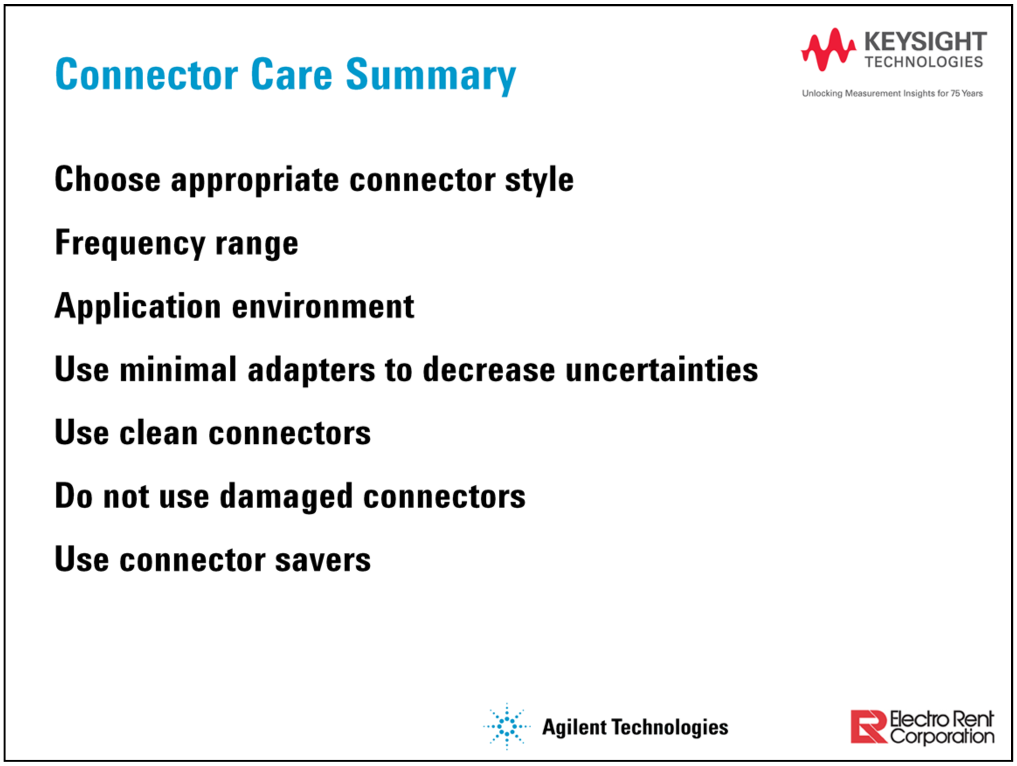
- **Connector grades adequate**
- **Connector savers calibrated out in tests**
- **Uncertainties from connector savers adequate**
- **To still check connector savers for damage!**

Agilent Technologies

Electro Rent Corporation

There are several reasons one should use at least instrument grade adapters as the actual test ports instead of simply connecting the device under test to the test set port or to the test port extension cable. The first, and most obvious, is if the DUT doesn't use the same connector family as the test set or cable adapter. In this case, select an instrument grade between-family adapter and connect it to the test set or cable to serve as the test port. Even if the device under test has the same connector family as the test set or cable, using an adapter/connector saver protects the test port from damage and can extend the life of the connector on the test set or cable.

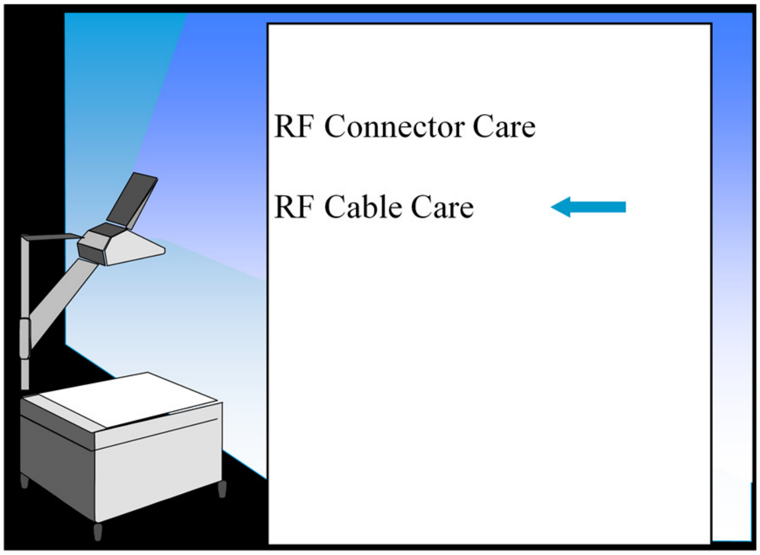
The adapter/test port saver must be fully inspected before connecting to the test set or cable. Because the calibration standards are connected to the adapter/connector saver, the connector saver should be instrument grade, or better.



The best connector for a job depends on the measurement task. When expensive connectors as part of an instrument system are used, use of adapters for multiple connections will extend the life of the main connectors and thus reduce overall cost of ownership. Use clean connectors free of dust and grit for repeatable measurements. Never use damaged connector.

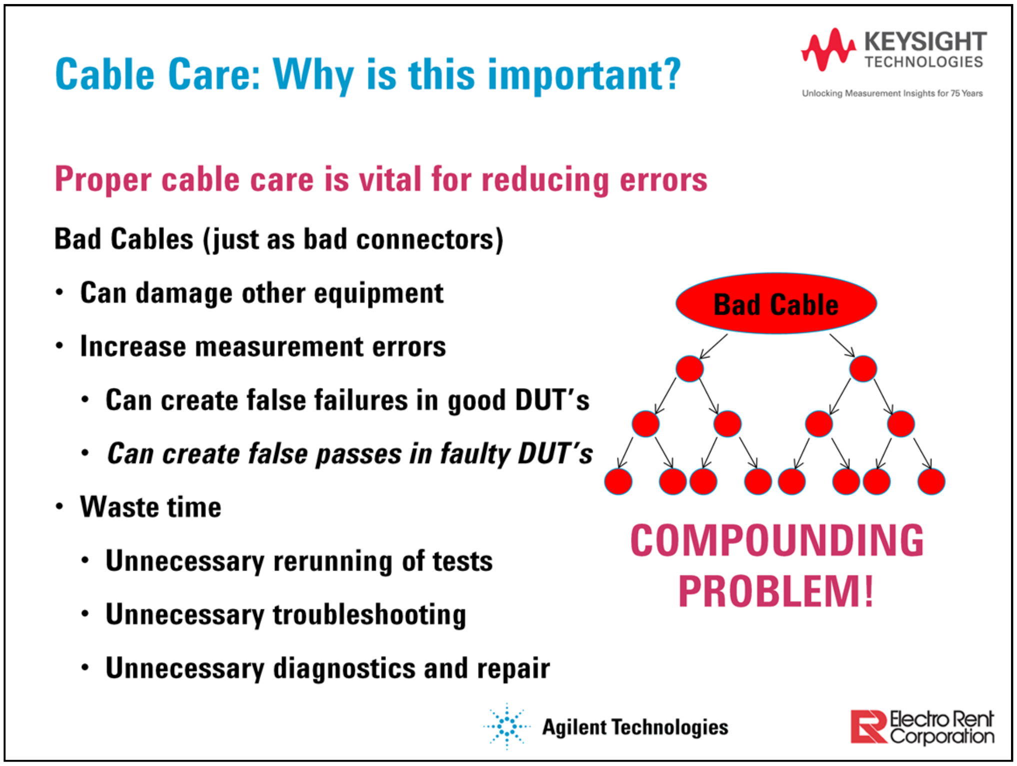
Agenda

KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights for 75 Years



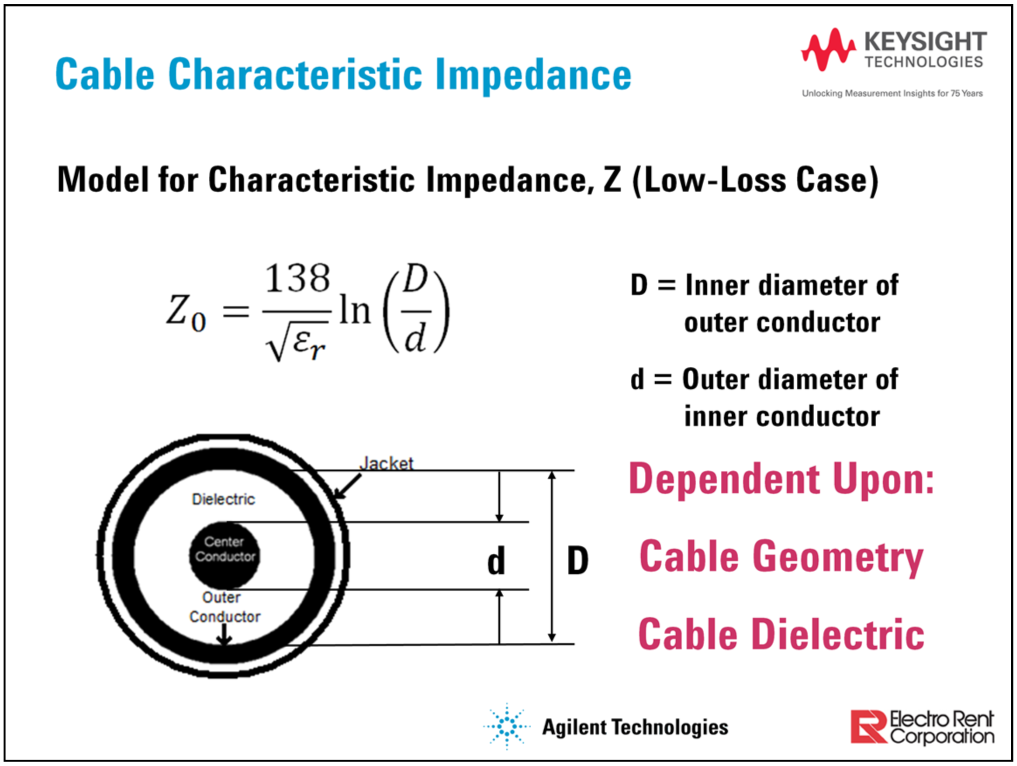
Agilent Technologies

Electro Rent Corporation



Why is cable care important in a measurement system?

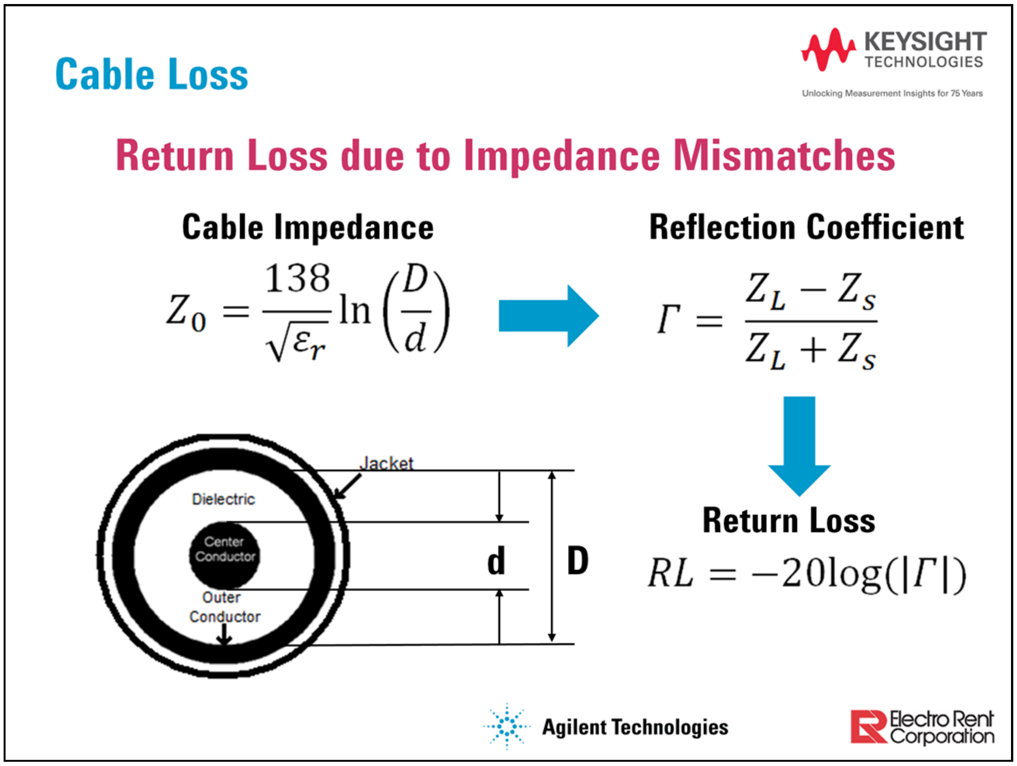
Just as faulty connectors can create compounding problems, so can faulty cables, for many of the same reasons.



Cable dimensions and dielectric properties determine both its characteristic impedance and frequency limits.

The general low loss equation for the characteristic impedance of a coaxial cable is shown.

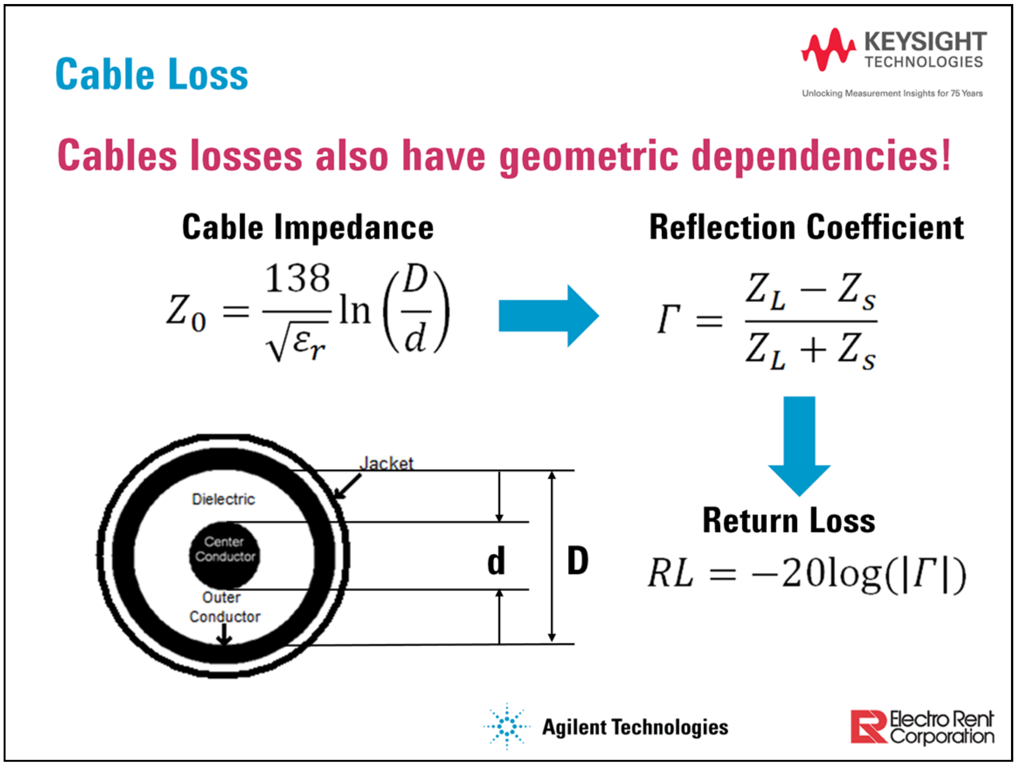
Er (Epsilon r) is the relative permittivity of the cable.



The transformation from impedance to reflection coefficient to return loss is shown. Return loss is a measurement of reflected signal power due to impedance mismatches.

The higher the return loss, the less reflected energy due to impedance mismatches exists.

As you can see, a higher impedance mismatch results in less return loss (higher insertion loss)



So, just as cable impedance is dependent upon its geometries and dielectric properties, so does its loss!

Now we will discuss why this is important.

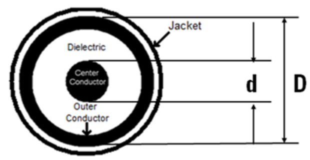
Additional Cable Loss Factors

KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights for 75 Years

Insertion loss per unit length (dB)

Skin Effect Losses-function of frequency

$$r = \sqrt{\frac{\omega\mu}{2\sigma}} \qquad \omega = 2\pi f$$



$$Loss(f) = 8.68\frac{r}{4\pi Z_0}\left(\frac{1}{D}+\frac{1}{d}\right)$$

$$= A \cdot f^{1/2}$$

Dieletric Losses-dielectric dependent

$$Loss(f) = A \cdot f^{b}$$

b is a dielectric specific factor

Agilent Technologies   Electro Rent Corporation

The loss equation of a coaxial cable can be further adjusted to factor in properties such as skin effect and dielectric properties of the cable.
These equations do not need to be memorized, they are just shown to explain other factors contributing to cable losses.

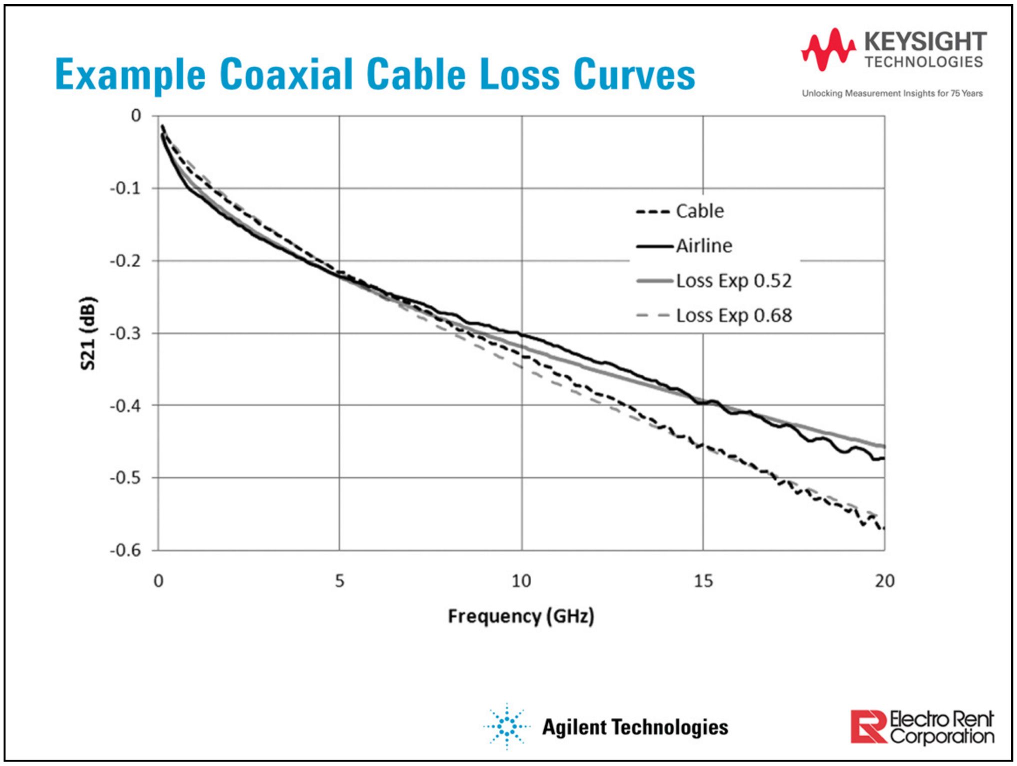
Adding in skin effect and dielectric properties can generate a better equation for the insertion loss of the cable.

In the above equation, the skin effect (tendency for high frequency signals to propagate about the outer portion of the conductor) is dependent upon the frequency, magnetic permeability μ (mu), and the conductivity σ (sigma) of the cable's conductors, as well as its geometries.
To simplify, we combined all terms and simplify to get A*f^1/2 as our insertion loss due to skin effect.

Furthermore, to factor in dielectric losses, we replace the ½ in the exponent to b which is dielectric dependent.

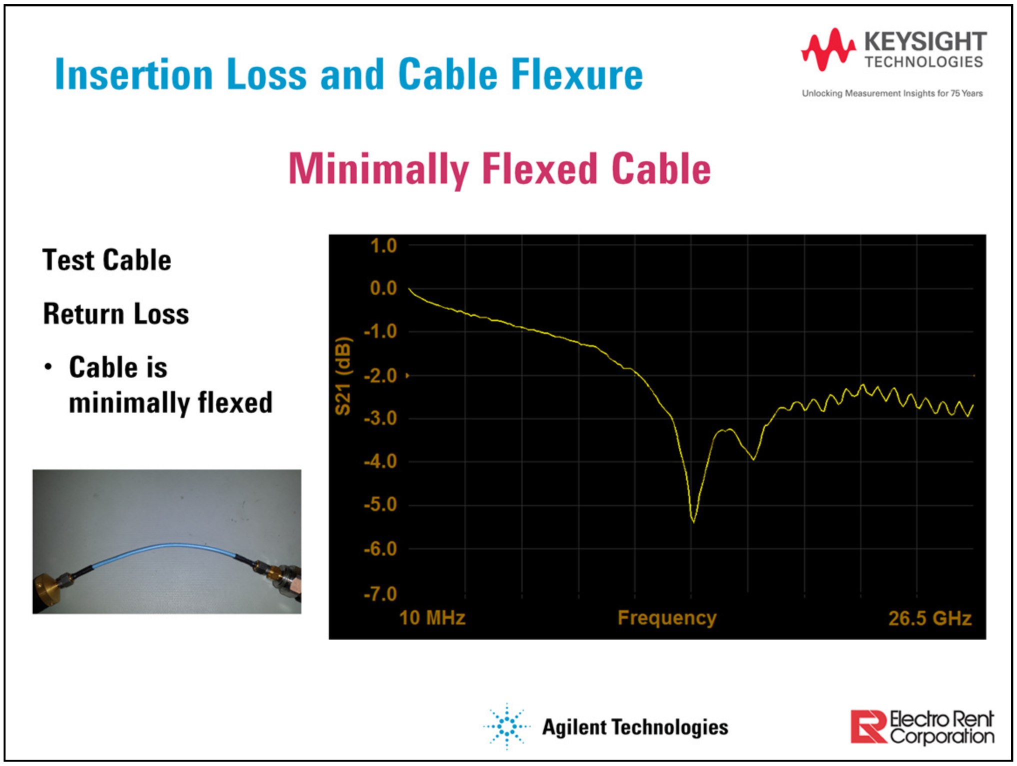
These equations are just shown to display a more accurate model of cable loss in the following slides.

They also show factors in cable loss in which the audience should be aware (geometries, eletromagnetic properties, frequency).



Shown are a few overlaid return loss curves as a function of frequency.
Notice how each dielectric possesses a different loss curve, and how frequency dependent each cable is.

Why use different dielectrics?
Different dielectrics have properties that may be more or less desirable in the given measurement environment, such as temperature stability, flexure stability, and temperature handling.

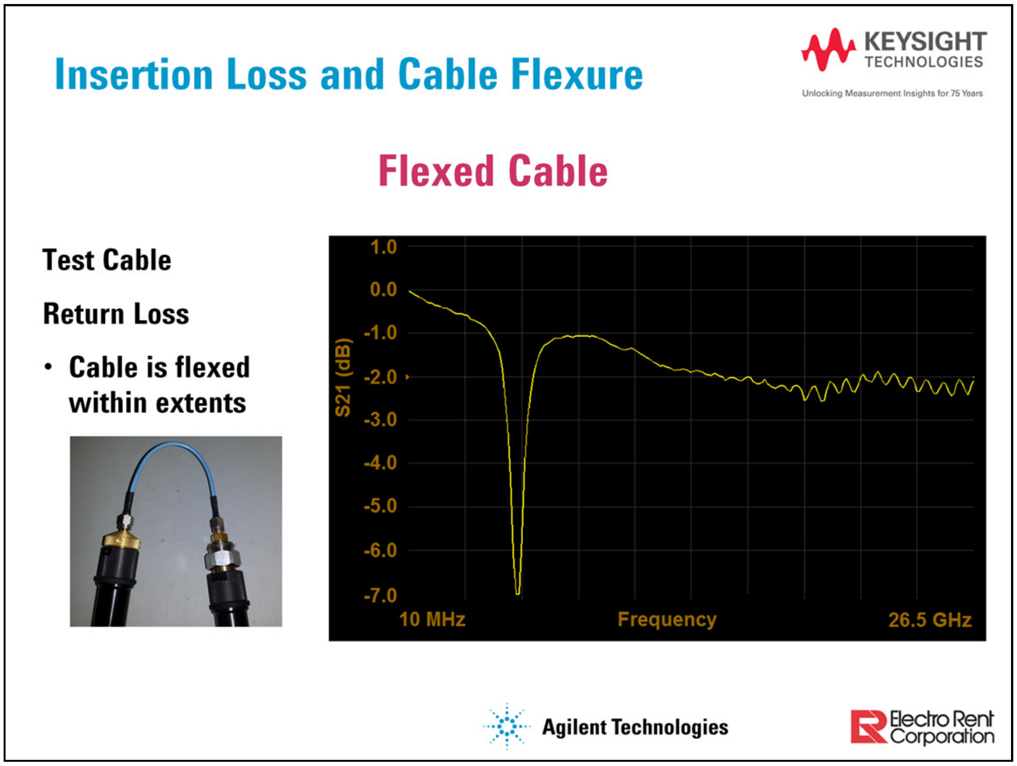


There is a reason why the dependence of cable geometries was so highly emphasized in the previous slides.

Here we are doing an S21 frequency sweep to view the insertion loss of this coaxial cable as a function of frequency.

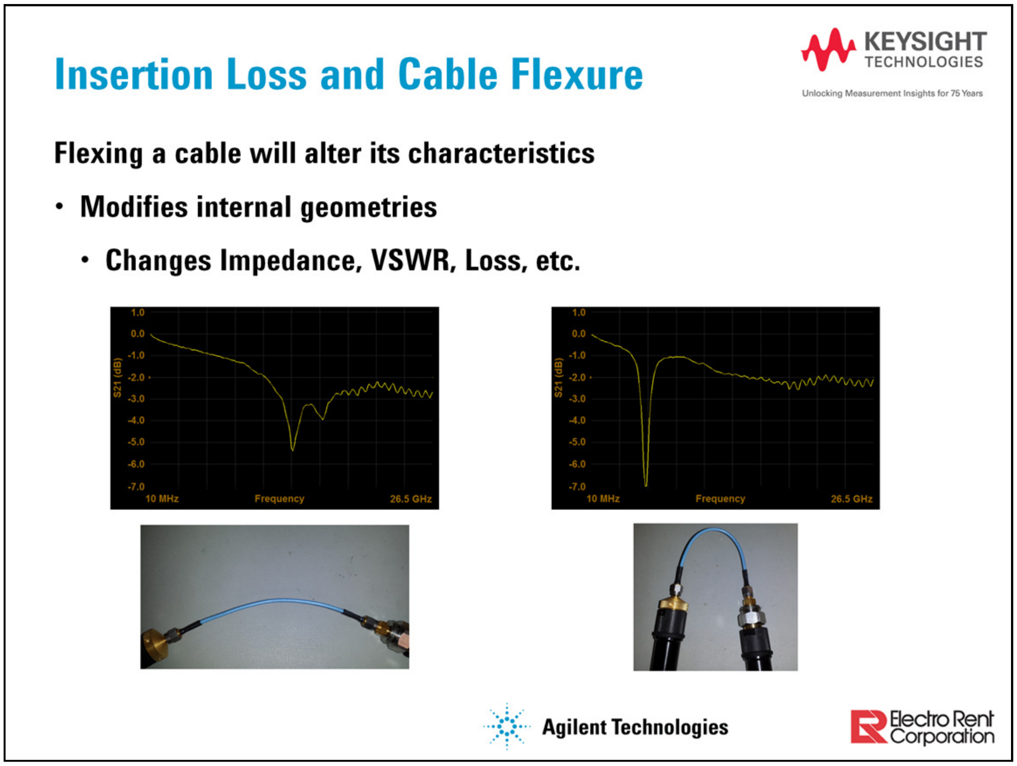
The cable is initially in the flexure position as seen in the figure.

Pay attention to the loss curve.



Now, the same cable is flexed.

Notice how much the insertion loss of the cable changes upon flexure.



As the previous slides have proven, flexing a cable will alter its electromagnetic properties, which can be a huge deal given the application.

Insertion Loss and Cable Flexure

Flexing a cable will alter its characteristics

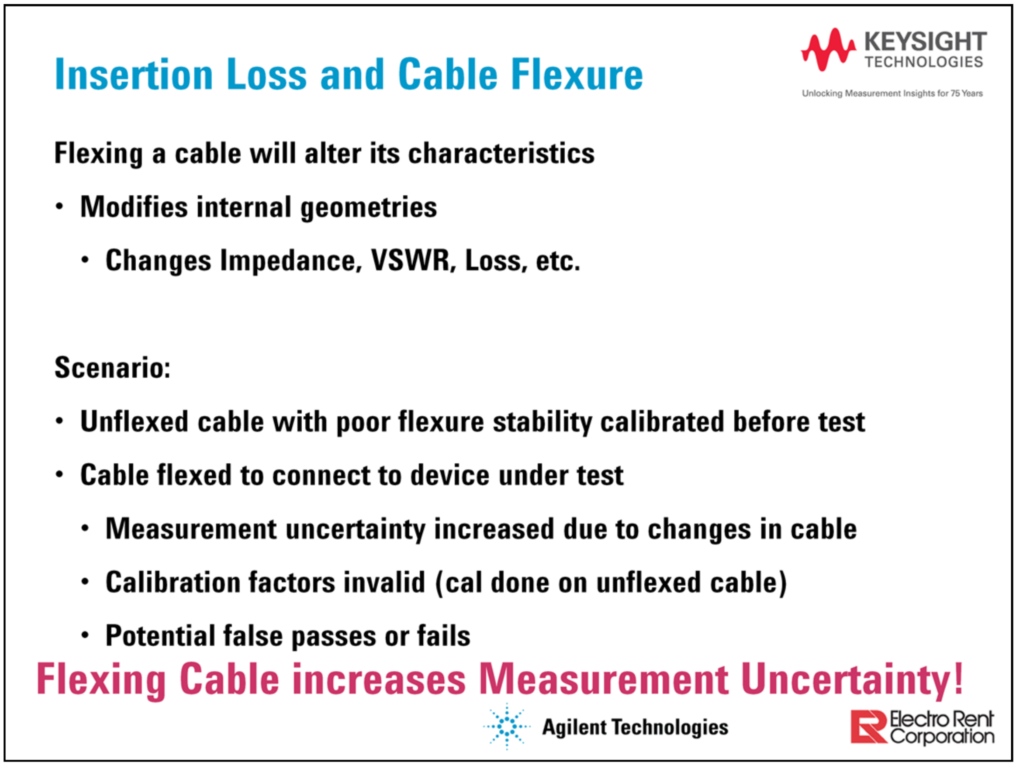
- **Modifies internal geometries**
  - **Changes Impedance, VSWR, Loss, etc.**

Scenario:

- **Unflexed cable with poor flexure stability calibrated before test**
- **Cable flexed to connect to device under test**

Here's an example that emphasizes why changes in insertion loss due to cable flexure can be problematic.

Let's say an unflexed cable with poor flexure stability was part of a calibrated path, whether it be path loss compensation or with any other types of calibration factors. The calibration factors are then stored either in the instrument or software, but it must be stressed that those calibration factors are only for the unflexed cable.



Then, the cable is flexed to connect to the device under test.
Since the cable has poor flexure stability, the loss curve of that cable will change.

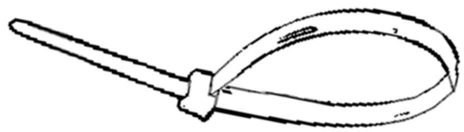
As stated in the previous slide, though, the calibration factors used will be from the unflexed cable, so any post measurement corrections done on the flexed cable will be from the unflexed cable's correction factors, therefore making the measurement uncertainty increase dramatically, and creating errors.

Insertion Loss and Cable Flexure

KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights for 75 Years

Flexing a cable will alter its characteristics

- **Modifies internal geometries**
  - **Changes Impedance, VSWR, Loss, etc.**



Additional Scenario:

- **Overtightening cables with cable or "zip" ties in systems**
  - **Overtightening cables with cable ties can affect cable geometries**
  - **Slight reflections can occur due to discontinuities**

Agilent Technologies

Electro Rent Corporation

Another potential source of error can occur from overtightening zip ties on cable. This can alter the cable geometries enough to causes unwanted reflections.

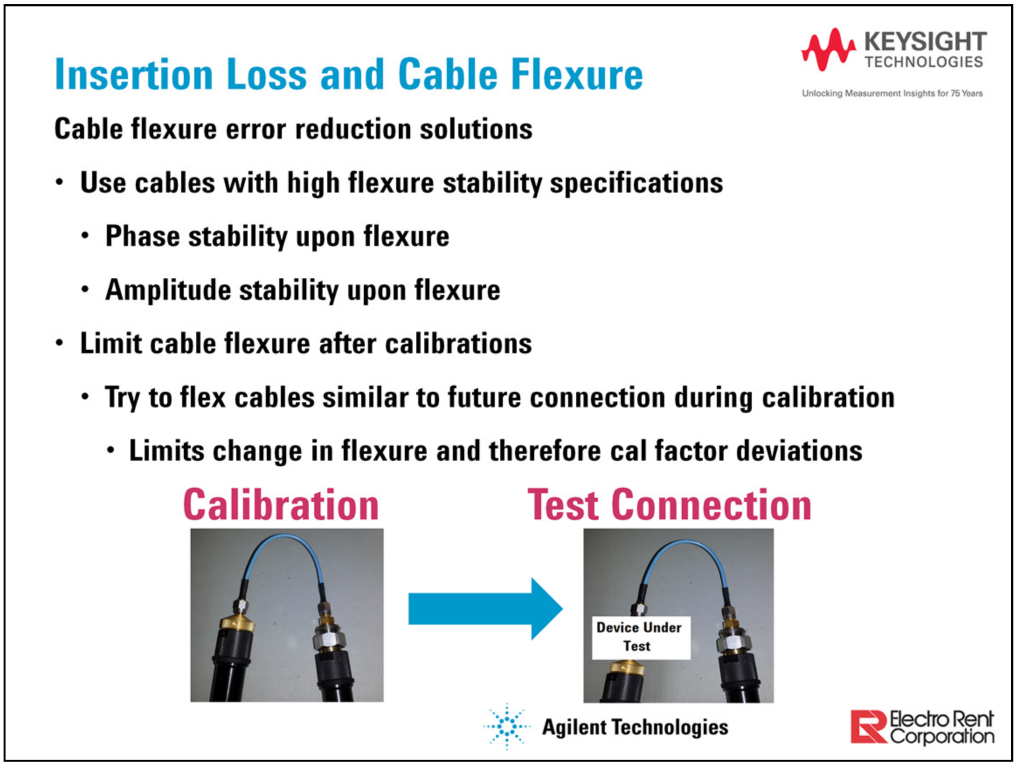
Insertion Loss and Cable Flexure

Cable flexure error reduction solutions

- Use cables with high flexure stability specifications
  - Phase stability upon flexure
  - Amplitude stability upon flexure

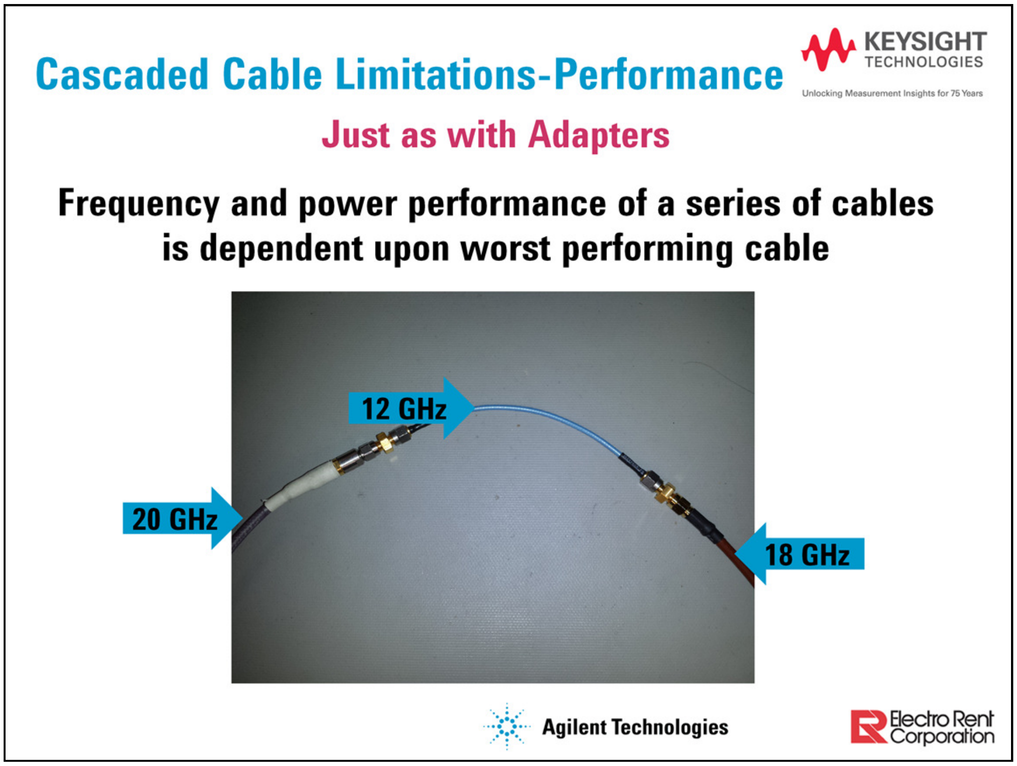
Fortunately, there are ways to decrease cable flexure errors.

You can purchase cables with high flexure stability.
They are specially designed to be flexed, and often have specifications such as amplitude and phase stability with flexure.



Another, less expensive way to reduce errors due to cable flexure is by maintaining a constant flexure during the calibration, and when making your connections to the item to be tested.

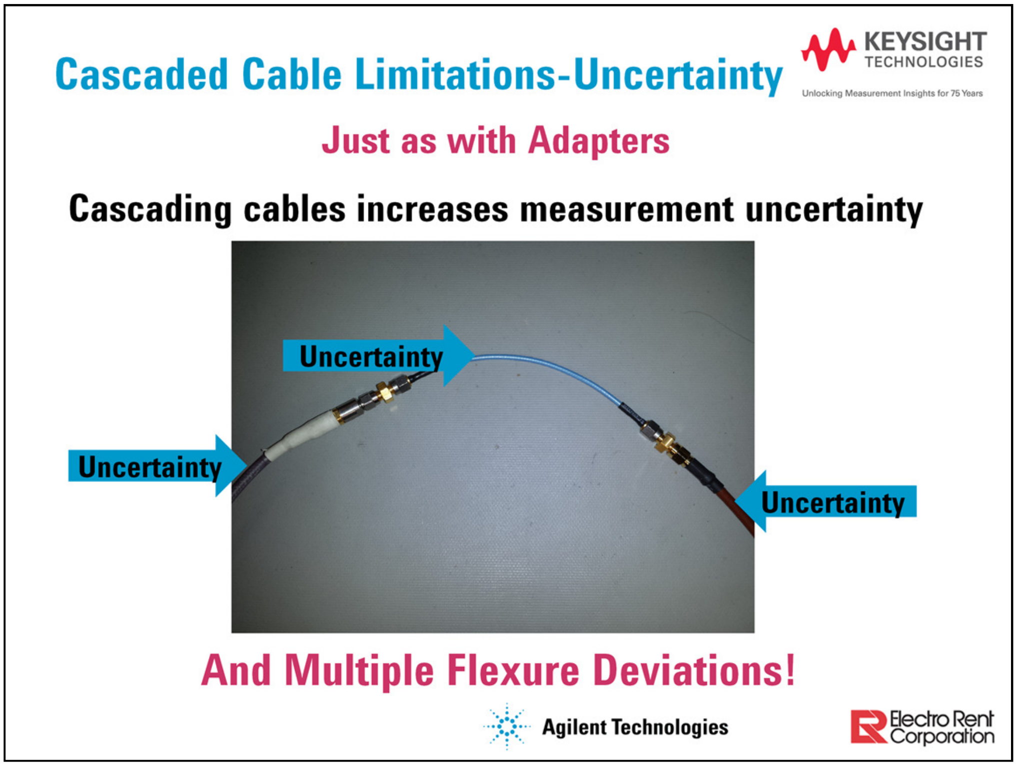
This will decreases the change in flexure of the cable, which then deceases the change in electromagnetic properties of the cable, making your calibration factors far more accurate.



Just as with cascaded adapters, adding cables to a measurement path creates problems.

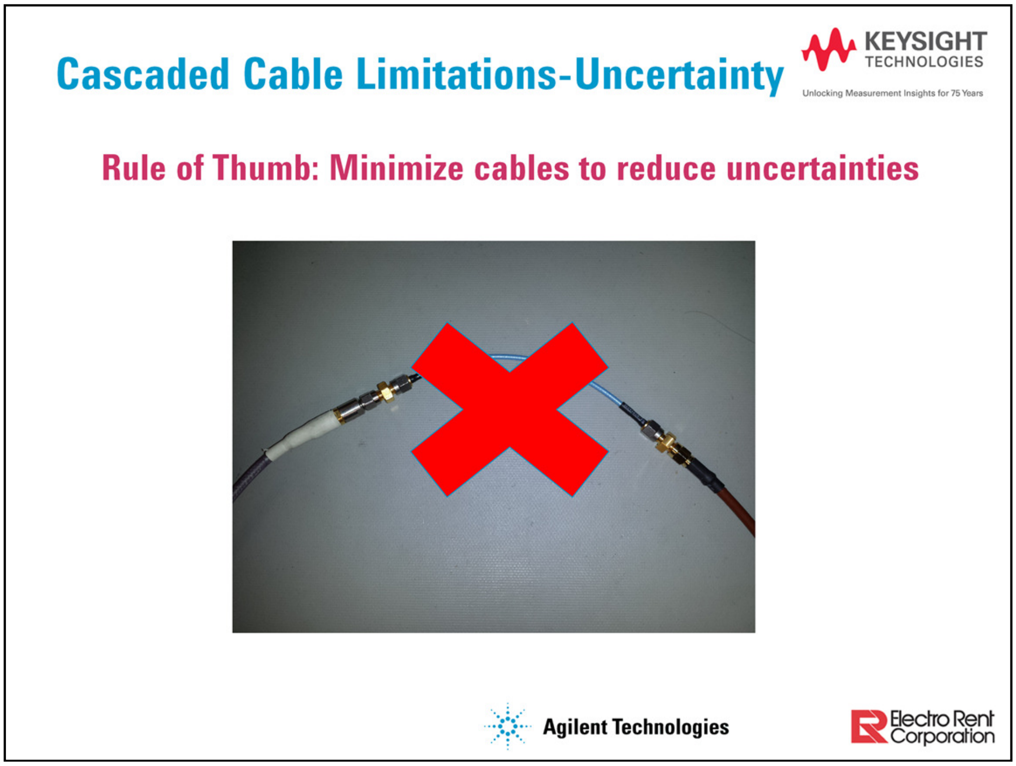
The frequency and power performance of a measurement system is limited to its worst performing component, so just like adapters, the worst performing cable in a series of cables will lower the system's power or frequency performance to that cable's specifications.

Here, the maximum frequency range of this series of cables is limited to 12 GHz.

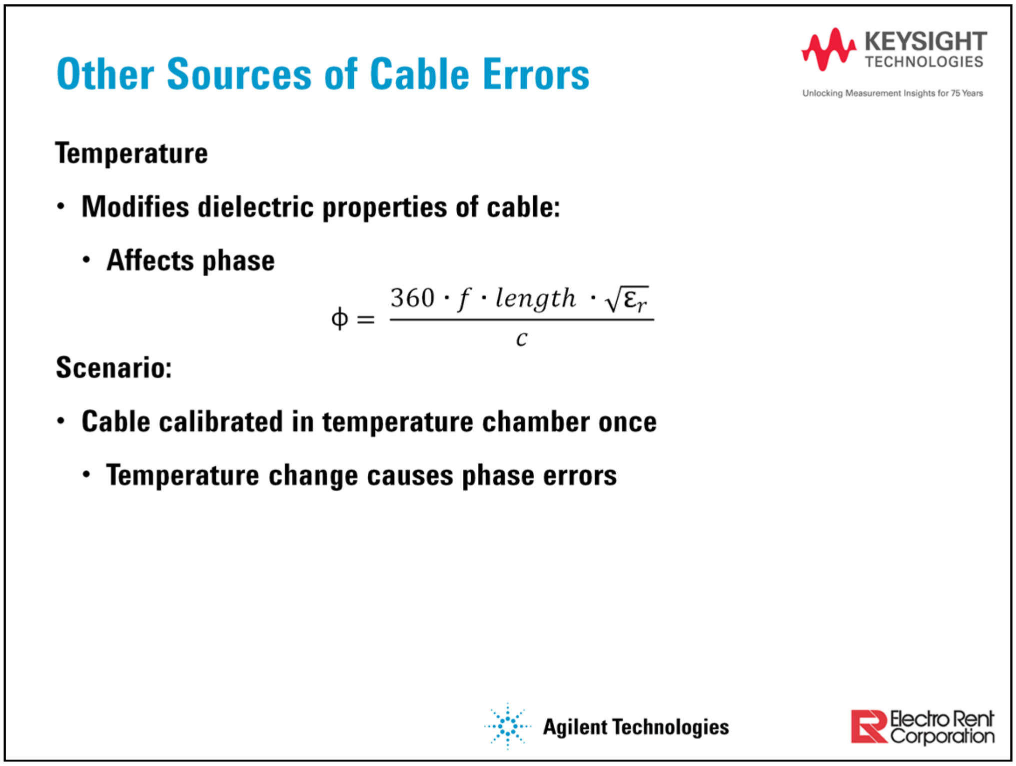


Also, just as with adapters, cascading cables will increase measurement uncertainties, as each cable has a corresponding loss uncertainty associated with it.

Not to mention, each cable will have phase and amplitude deviations due to flexure, which is a problem you should avoid.



So, just as with adapters, limiting cables in a measurement is ideal.



Another source of measurement uncertainty in coaxial cables is temperature.

This is because the dielectric (and to a point, the dimensions of the conductors) properties of the cable change due to temperature.

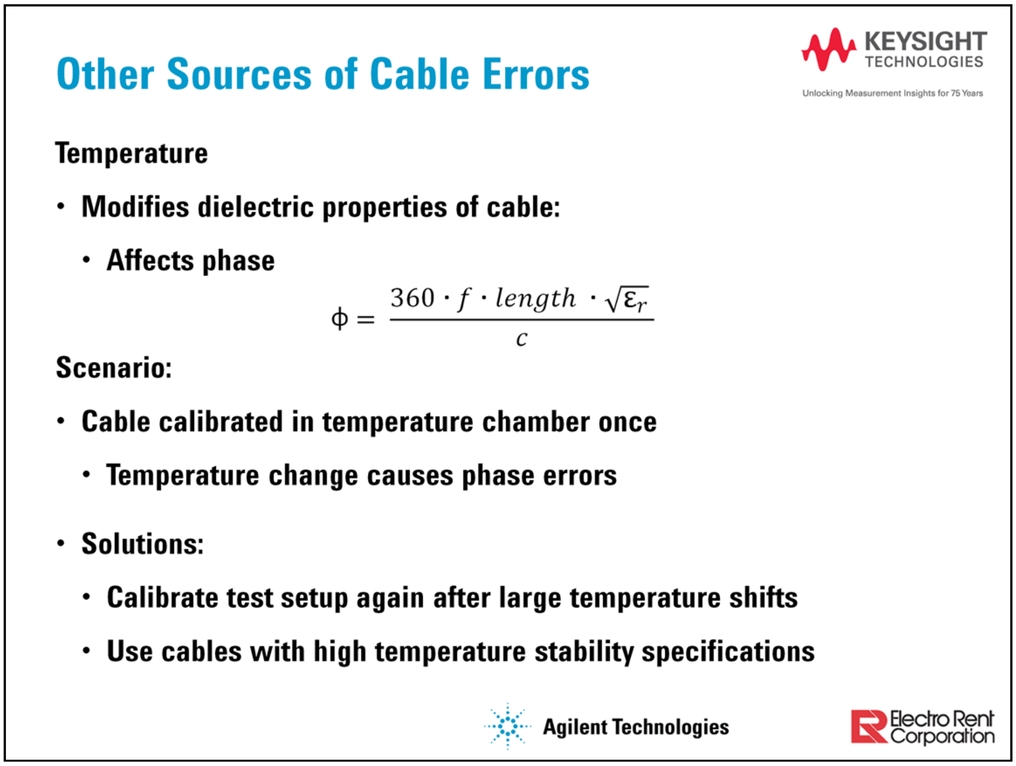
Just as the previous equations showed, many coaxial cable properties are dependent upon the dielectric.

One cable characteristic often watch carefully because of temperature is phase, which can be represented as shown in the equation, where c is the speed of light in a vacuum and length is the length of the cable.

An example of when this is important is during testing in temperature chambers.

If a cable is calibrated at one temperature, its calibration factors are saved for that temperature.

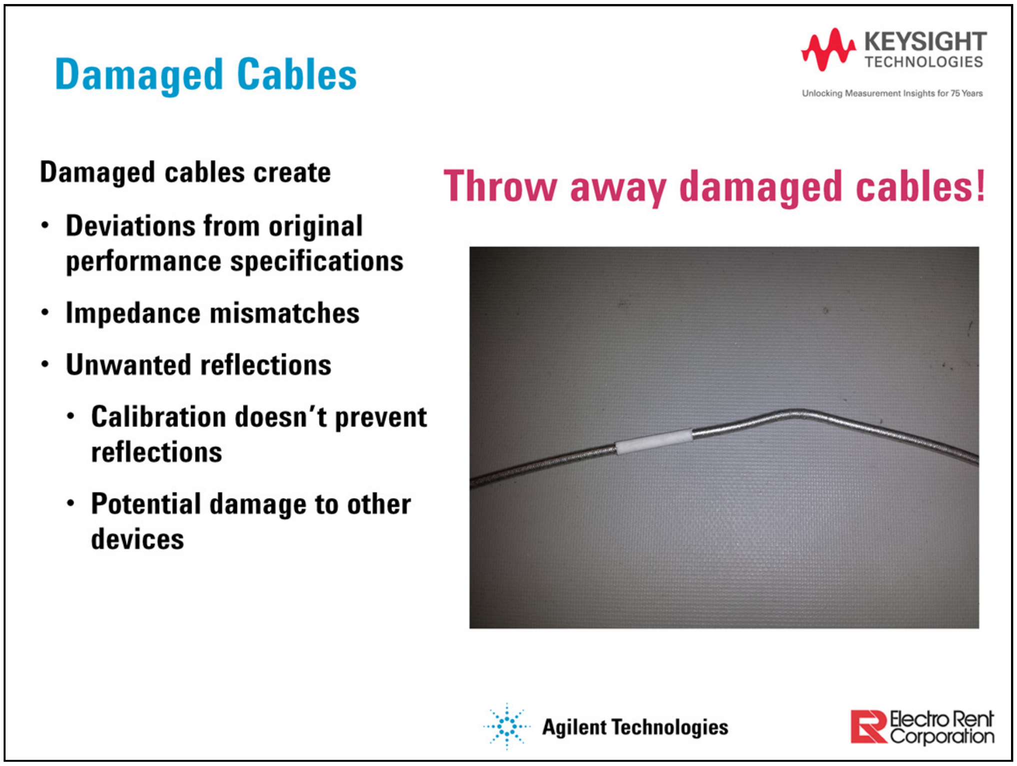
When there is a large swing of temperatures in the chamber, this could create enough of a deviation in the cable's phase (due to changes in its dielectric) that the calibration factors from the previous temperature calibration are not suffice, causing errors in the measurement.



There are two ways to deal with temperature induced cable measurement errors.

The first is to calibrate the test setup after large temperature shifts, which provides the correct calibration factors for the cable.

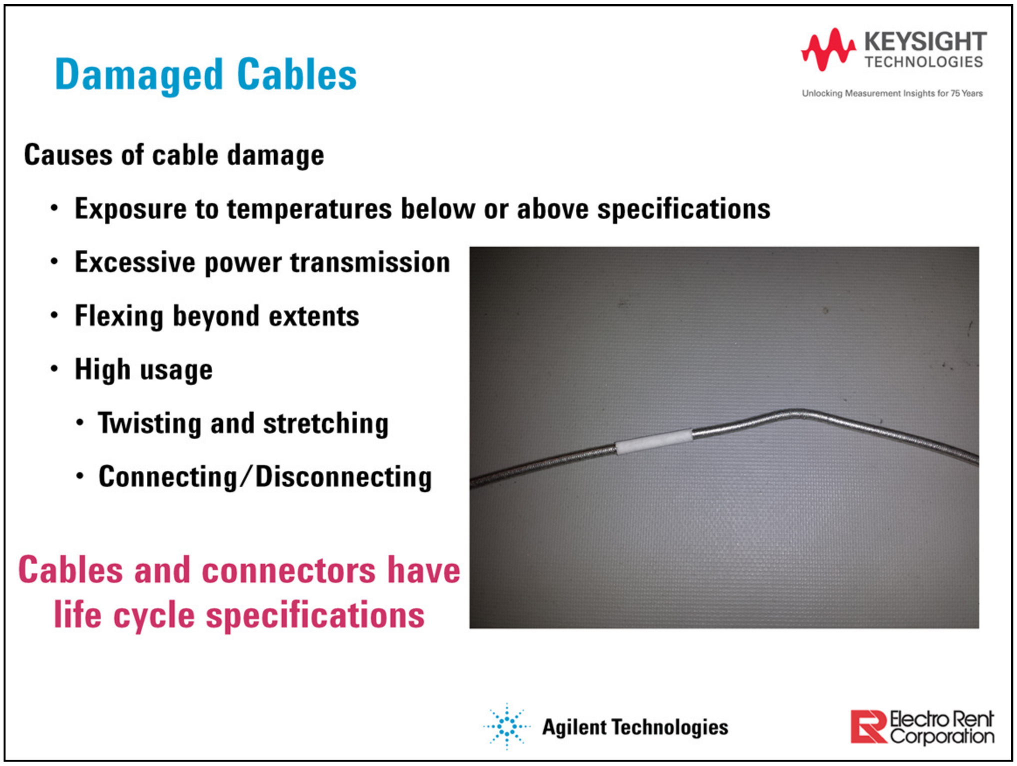
The second method is to use cables with high temperature stability specifications, which have outer jackets and dielectrics that prevent large deviations in the cable's properties.



Another similarity cables and connectors share is how costly and time wasting using a damaged one can be.

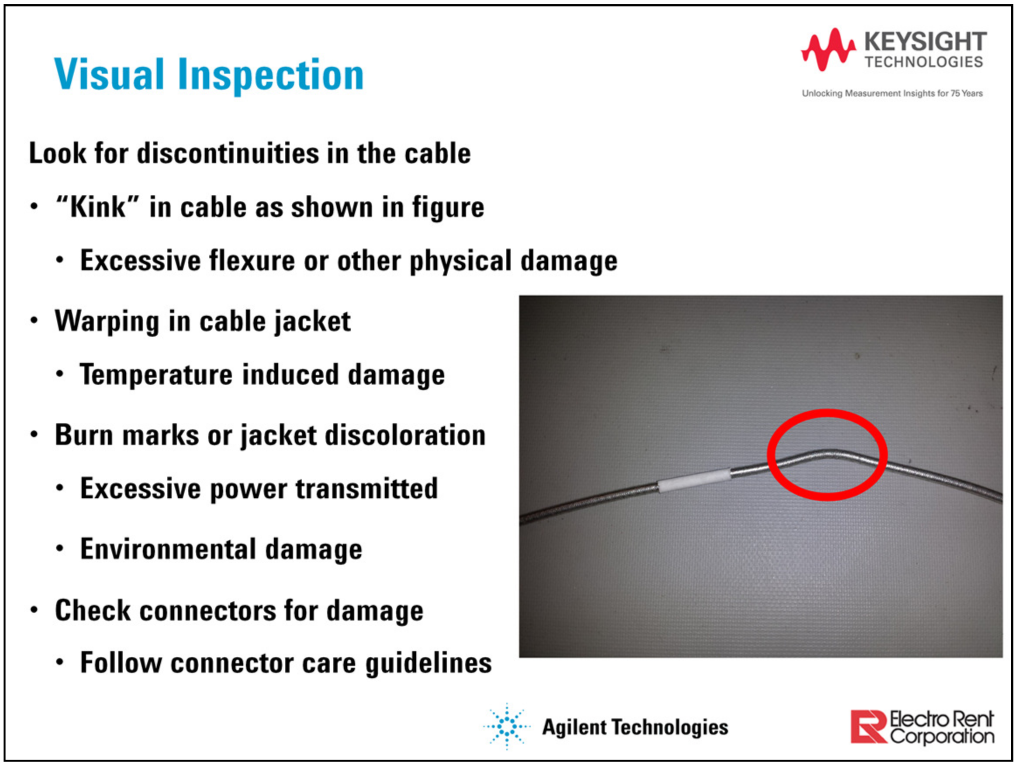
Damaged cables cannot guarantee the same performance as their initial specifications, such as frequency range and loss, so putting them in a measurement system can create such as impedance mismatches and unwanted reflections, which could damage equipment.

You should always throw away damaged cables because of this.



There are a few causes of cable damage, ranging from exposing a cable to temperature extremes beyond its specified ranges, transmitting more power than the cable is specified to tolerate, mishandling such as flexing the cable beyond its extents, and using the cable beyond its life cycle.

It should be emphasized that cables have life cycle specifications, such as maximum recommended connects/disconnects.



There are a number of visual inspections you can do to determine if a cable is damaged.

The golden rule of visually inspecting a cable is to look for discontinuities.

This includes looking for "kinks" in the cable as shown in the figure, which indicates the cable was bended beyond its extents and its geometries have been affected to a point of no return.

Warping in the cable jacket, which indicated environmental damage or other physical damage.

Burn marks on the jacket or any types of discoloration, which indicates potential excessive amounts of power transmitted through the cable or other environmental damage.

And last but not least, the connectors should be inspected as well for what should now be obvious reasons.

To make sure the broken cable will not be used again, some recommend cutting it so it isn't mistakenly deemed good because of unseen damage.

KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights for 75 Years

Further Inspection

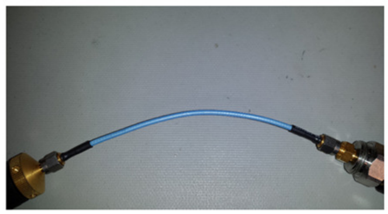
Cable damage is not always physically noticeable!

Damage may not be visible

- **Internal conductor and dielectric damage hidden by jacket**

Many application specific cable test procedures

- **Power Handling, Velocity of Propagation, Impedance, Insertion Loss**
- **Performing all would be time consuming**



Agilent Technologies

Electro Rent Corporation

Although damage can be noticed visually, it is sometimes internal and not as easy to spot.

There are many types of application specific tests which can be done to a cable, ranging from power to velocity of propagation, to loss, but doing all of them would be quite time consuming, in fact cable replacement may be more cost effective.

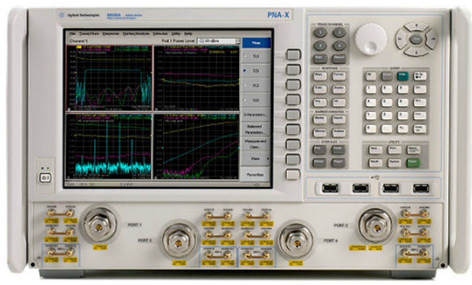
Further Inspection

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

"Quick and Easy" functional cable tests

- **Check S-Parameters along frequency range with a Network Analyzer**
  - **Reflection Coefficient**
  - **Insertion Loss**



Agilent Technologies

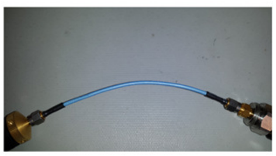
Electro Rent Corporation

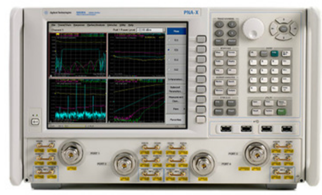
A quick and easy way to determine if a cable is functional is to use a network analyzer and find its s-parameters.
Checking for its reflection and transmission properties gives high confidence in functionality and should take a few minutes.

Further Inspection

"Quick and Easy" functional cable tests

- **Check S-Parameters along frequency range with a Network Analyzer**
  - **Reflection Coefficient**
  - **Insertion Loss**
  - **Flex cable along extents during measurements**
    - **Look for changes in performance beyond cable's specifications**
    - **Aids in spotting less noticeable cable damage**



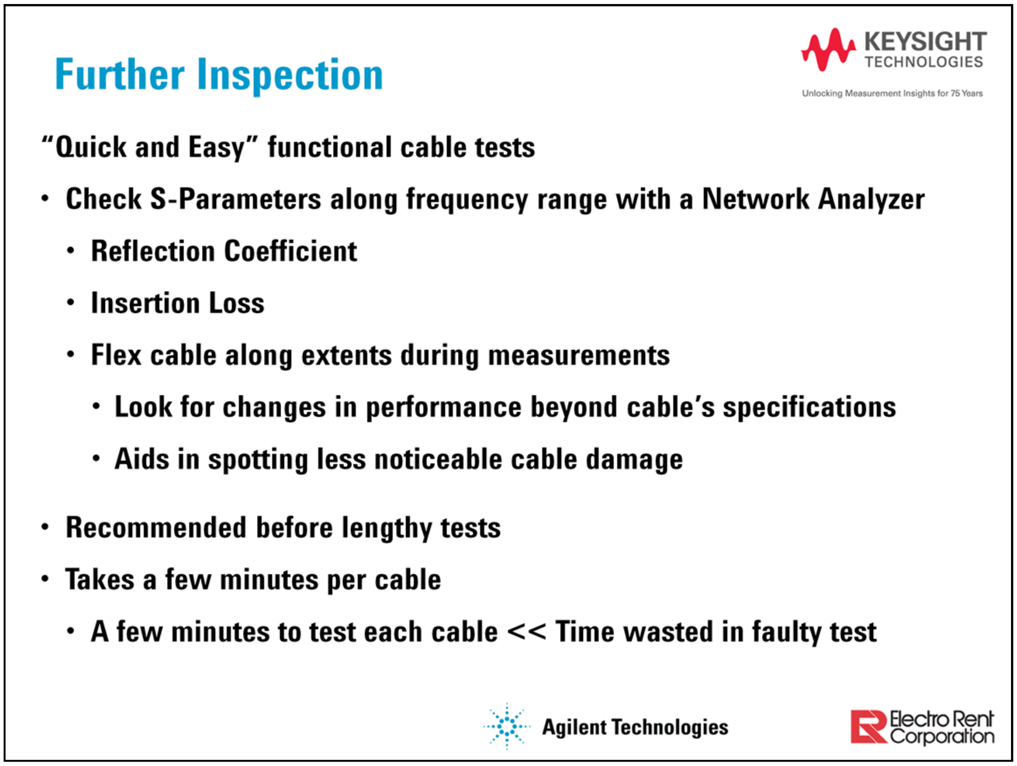


Agilent Technologies

Electro Rent Corporation

While testing the cable's transmission and reflection properties, it is recommended to flex the cable along its extents.
While doing so, monitor the measurements and look for changes in performance that go beyond the cable's specifications (such as large changes in loss).

This aids in finding less noticeable cable damage, such as slight conductor or dielectric damage that you may have missed otherwise.



This quick and easy functional test is also recommended before length tests (especially if the cable has been used a lot or is flexed) as the few minute investment can save potentially hours of time wasted from a bad cable.

Cable and Connector Care Summary

Rules of Thumb

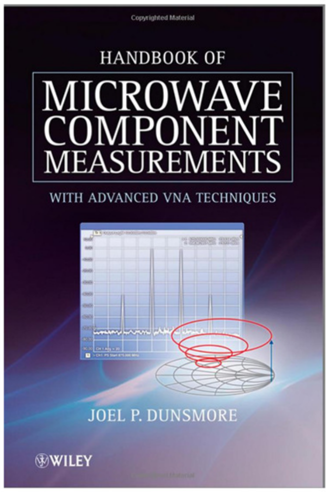
- Use appropriate grade connectors
- Use cables with specifications fit for the application and environment
- Routinely check connectors and cables for damage
- Replace damaged cables and connectors immediately
- Properly care for cables and connectors
  - Routinely clean connectors
  - Use torque wrenches when making connections
  - Don’t bend cables beyond extents or expose to damaging temperatures
- Minimize cascaded adapters and cables to reduce uncertainties

Routinely refresh cable and connector inventories!

Keysight Technologies — Unlocking Measurement Insights for 75 Years
Agilent Technologies
Electro Rent Corporation

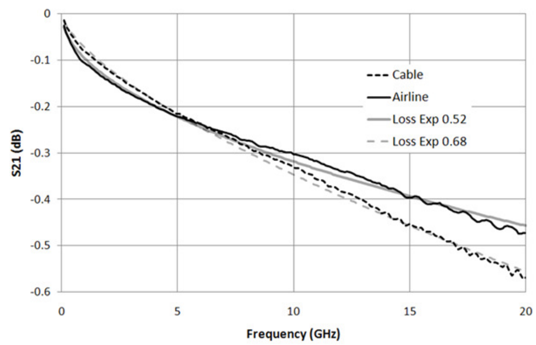
Resources

KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights for 75 Years



Handbook of Microwave Component Measurements

Joel P. Dunsmore



Agilent Technologies

Electro Rent Corporation

Resources

Literature

- Dunsmore, Joel P., *Handbook of Microwave Measurements with Advanced VNA Techniques*, Wiley, 2012.

Application Notes

- Application Note AN 1449-1, 2, 3 and 4, Fundamentals of RF and Microwave Power Measurements (Parts 1, 2, 3 and 4).
- Application Note AN 1287-3, Applying Error Correction to Network Analyzer Measurements
- Application Note AN 1287-9, Understanding the Fundamental Principles of Vector Network Analysis

Connector Compatibilities (What else can mate with what?)

Connector	Mates With
3.5 mm	SMA, 2.92 mm
2.92 mm	SMA, 3.5 mm
SMA	3.5 mm, 2.92 mm
2.4 mm	1.85 mm
1.85 mm	2.4 mm

http://na.tm.agilent.com/pna/connectorcare/What_mates_with_what.htm