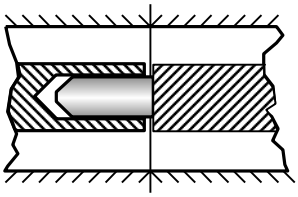
# MEAS 102: Connectors and Connector Care



Agilent Technologies


Printed on Dec. 4, 2002 5988-8492ENA

## Objectives

- **Fundamentals of Connectors**
- **Commonly Used Connectors**
- **Typical Connector Cross-Section**
- **Principles of Connector Care**
- **Visual Inspection**
- **Mechanical Inspection**
- **Connector Specifications**

By now, you've noticed that there are a variety of connectors and that we don't use the same type of connector on all of the instruments. This section will introduce you to the most commonly used coaxial connectors for Agilent products and the basic considerations that apply to their selection and proper use.

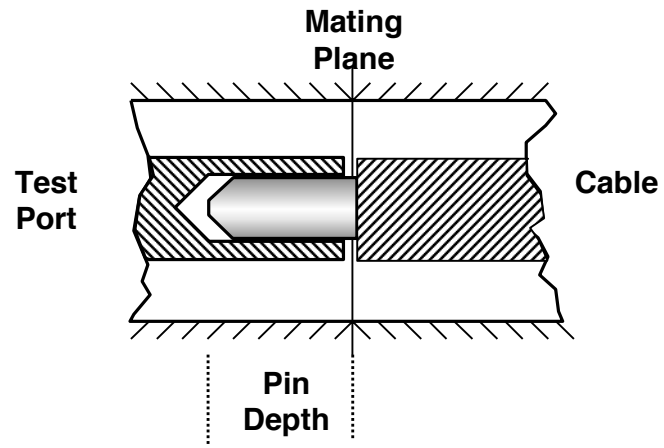
## Connector Considerations

- **A significant factor in repeatability and accuracy**
- **Selecting the best of several types for application**
- **Compatibility**
- **Connectors are consumables**
  - Limited lifetime
  - Damaged connectors are costly
  - Proper care maximizes lifetime

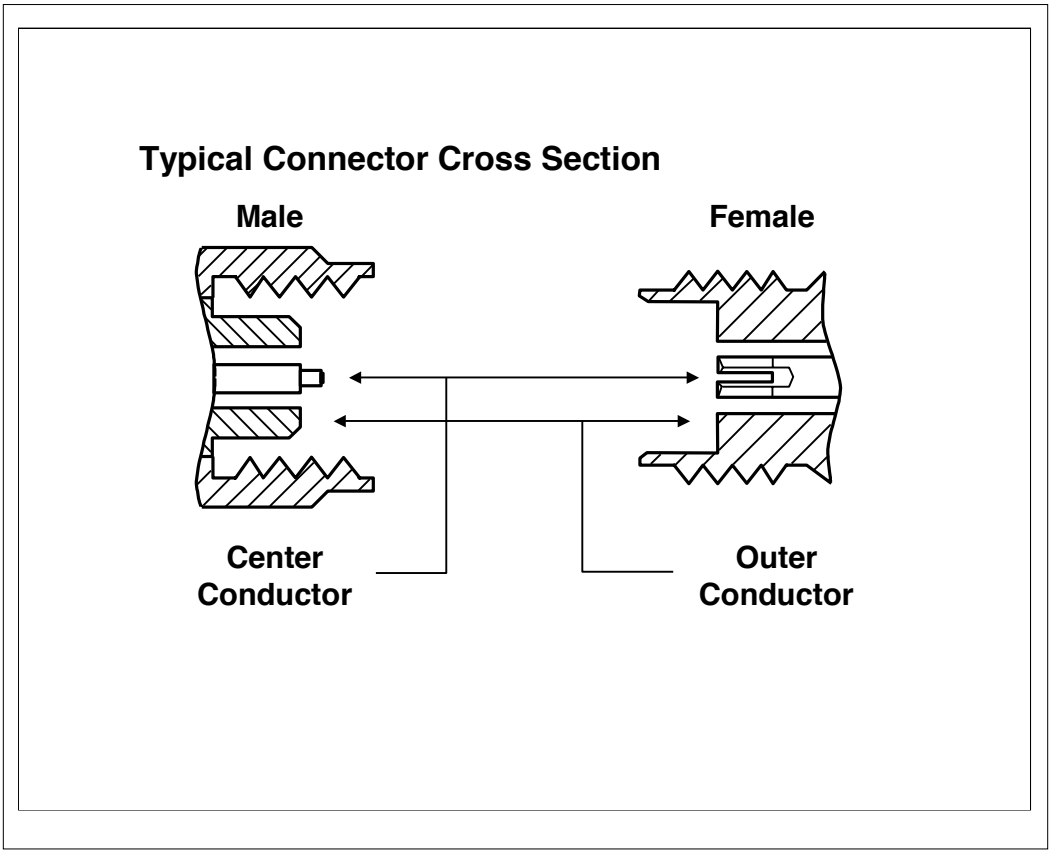
Coaxial connectors enable us to repeatedly connect and disconnect instrumentation to devices or systems under test. For measurement purposes these connections must make as little change to the *performance* (maybe better to say characteristics) of the item being tested as possible and be consistent as 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, i.e. an item with limited life-span. With care and proper technique, it is possible to both maximize the useful lifetime and minimize the degradation of performance (the accuracy and repeatability), especially 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.

## Fundamentals of Connectors




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 and connection torque.



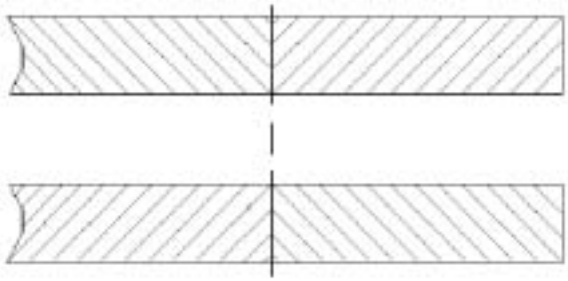

This is a cross section showing the major parts of a typical ‘gendered’ connector, i.e. male and female types.

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.

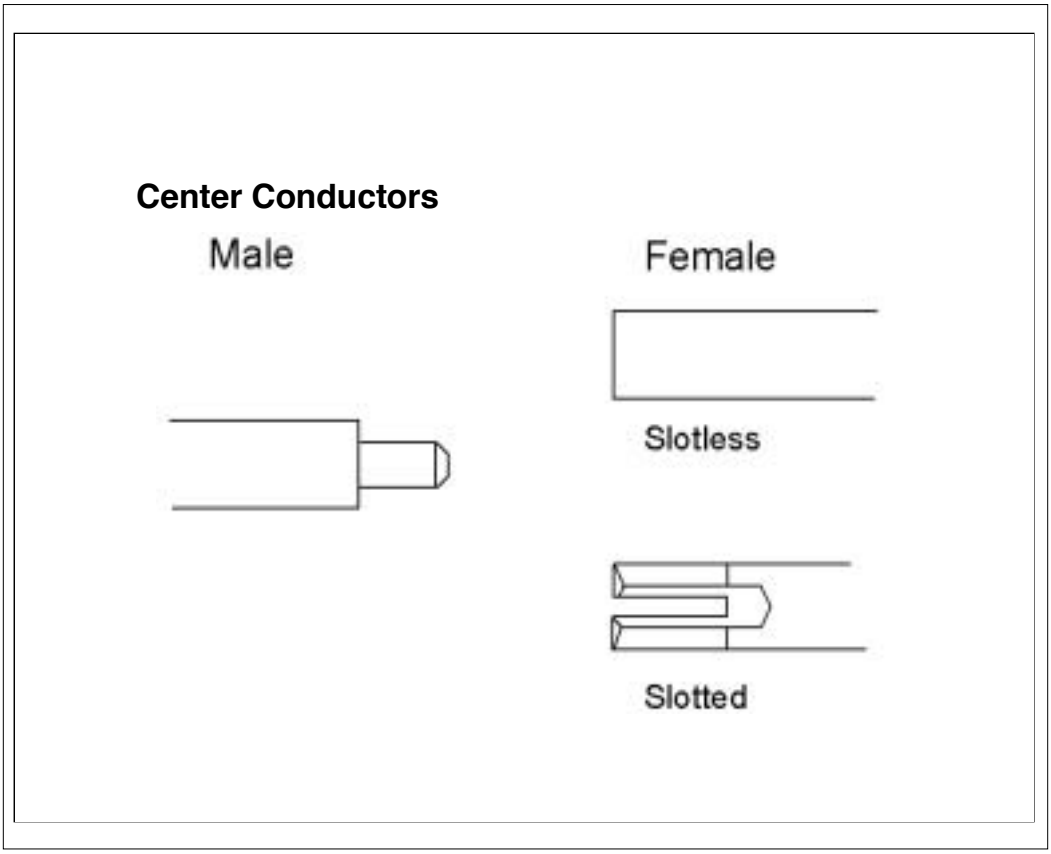
The male pin slides into the female fingers. Electrical contact is made by the internal surfaces of the tips of the female center conductor on the external surface of the male pin and clean, physical contact of the outer conductors (mating plane). It is important that only the outer nut of the male port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

## Outer Conductors

### Outer conductor mating surfaces define measurement reference plane



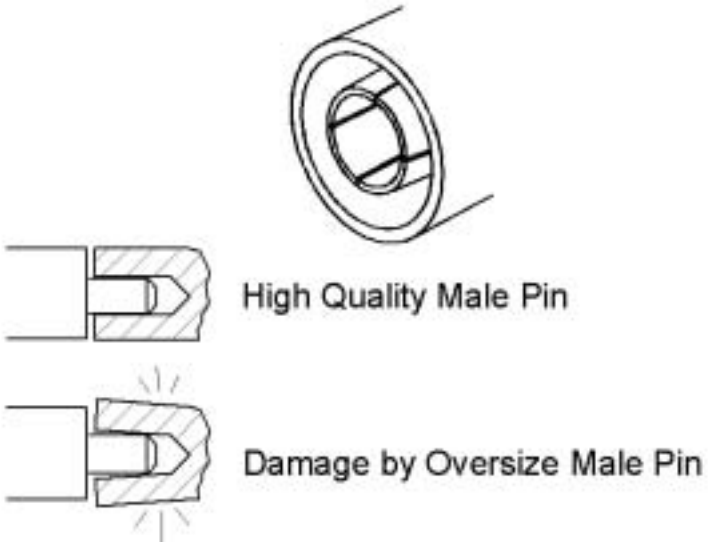
In all connector types, the measurement reference plane is defined as the plane of contact of the outer conductors.




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.

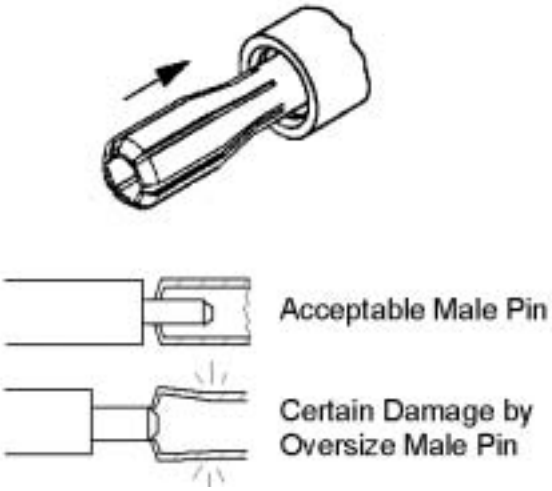
## Slotted Female Center Conductor




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 can change depending upon the size of the male pin and subsequently change the characteristic impedance of the test port. For example, when the male pin of the calibration standard is a precise size, the impedance of the connection will be exactly known. Yet, when the device under test is connected, its male pin may not be the same size as that of the standard's connector. Thus, the impedance of the connection will be different. This increases uncertainty and limits traceability of the measurement. Finally, due to the flex built into the slotted female connector, repeatability will not be as good as non-slotted types. This is because the materials used have a certain 'memory function', that is once bent, or deformed to accommodate a different size male-pin, the "fingers" will not completely return to the original diameter.

## Slotless Female Center Conductor

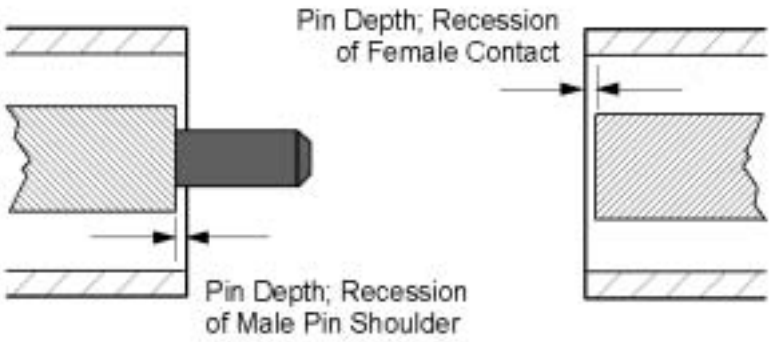



The slotless female center conductor consists of a precision machined outer shell which accepts the replaceable inner contact.

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.

## Pin Depth

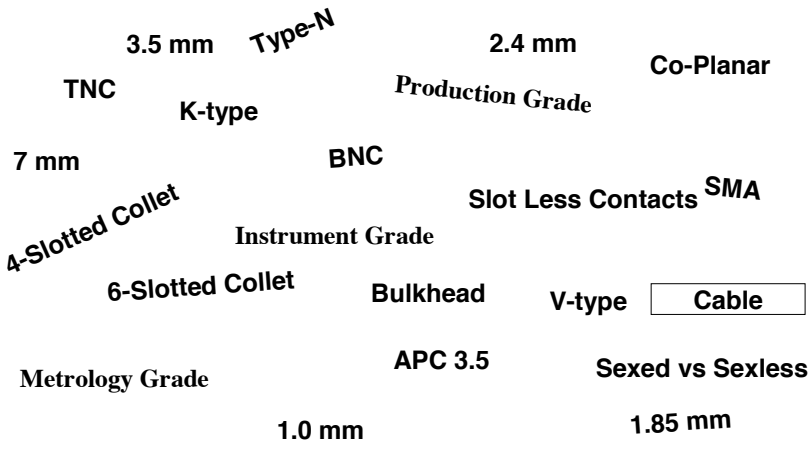



An important mechanical parameter for connectors is called Pin Depth. Pin depth is the distance the female center conductor or the shoulder of the male pin differs from being flush with the outer conductor mating plane.

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.

## Why So Many Different Connector Types?

**What connectors are available?**




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.

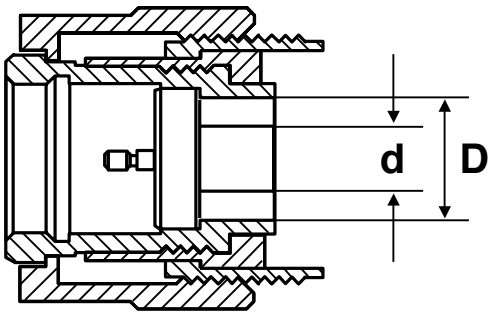
## Characteristic Impedance

**Model for Characteristic Impedance, Z (Low-Loss Case)**

$$Z_o = \frac{1}{2\pi}\sqrt{\frac{\mu}{\varepsilon}}\,\ell n\left(\frac{D}{d}\right)$$

**D = Inner diameter of outer conductor**

**d = Outer diameter of inner conductor**




**D = 7.0 mm**

**d = 3.04 mm**

**$Z_o$ = 50 ohms**

Connector dimensions determine both its characteristic impedance and frequency limits.

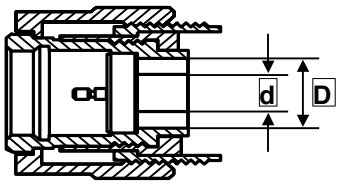
This is a somewhat simplified model for the characteristic impedance, $Z_O$, of a low loss transmission line. *Example: For* a 7 mm transmission line, the inner diameter of the outer conductor, D, is 7.0 mm and the outer diameter of the inner conductor is 3.04 mm. Note that the ratio of (D/d) determines the characteristic impedance of the connection *and* more importantly is the *single* 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 Coverage

$f_{max}$ = approx. 120/D mm

7 mm = approx. 18 GHz
3.5 mm = 32 GHz




Ratio D/d constant

Depends strongly on dielectric support and mating pin geometry

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.

## Connector Grades

**Metrology**

**Instrument**

**Production (Field)**

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:

•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.
•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.

## Metrology Grade

- **Used on calibration standards**
- **Highest performance slotless contacts**
- **Tightest tolerances**
- **Air dielectric interface**
- **Long life**
- **Highest manufacturing cost**

The metrology grade connectors have the highest performance and the highest cost of all the connector grades. This grade is used on calibration standards, verification standards, and precision adapters. Because it is a high precision connector, it can withstand many connections and disconnections, thus has the longest life of all connectors grades. This connector grade has the closest material and geometric specifications. Pin diameter and pin depths are very closely specified. Metrology grade uses an air dielectric interface and a slotless female contact, which provide the highest performance and traceability.

While precision connectors are very repeatable and provide good accuracy over many connections, this does NOT mean that, precision connectors are robust and can be treated with less care. The contrary is true: These connectors are made by highly precise machining procedures and tools, and using a precision connector with anything else than another precision connector, or introducing debris, dust, etc., will render the connector useless for any precision measurements.

*Metrology* grade connectors should not be mated with *production* grade connectors.

## Instrument Grade

- **Used for test ports**
- **Economy calibration kits**
- **Good performance**
- **Tight tolerances**
- **Dielectric supported interface**
- **Long life**

Instrument-grade connectors are considered “middle-grade,” and are mainly used in and on our instruments for most cables and adapters, and some calibration standards. It provides long life with good performance and tight tolerance. It may have a dielectric supported interface and therefore may not exhibit the excellent match of a metrology grade connector.

## Production (Field) Grade

- **Systems and device connector**
- **Low performance**
- **Loose tolerances**
- **Dielectric supported interface**
- **Limited number of connections**
- **Lowest Cost**

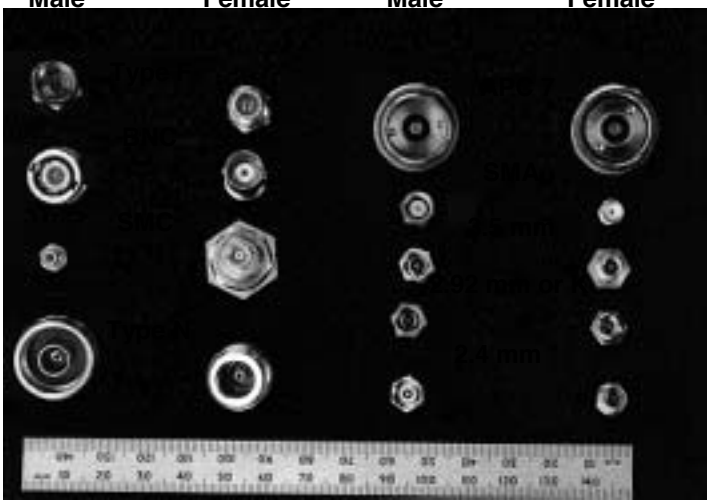
***Always Inspect Before Connecting***

This is the lowest grade connector. It is the connector most commonly used on the typical device under test. It has the lowest performance of all connectors due to the loose tolerance.

This means that this grade should always be carefully inspected before connecting it to the network analyzer. Some production grade connectors are not intended to mate with metrology grade connectors. This connector has the shortest life and also the lowest cost. Where low grade connectors are on a DUT, care must be taken to properly adapt to the test-instrument. In general, when there is a need to match different grade connectors, using suitable connectors - adapters - between DUT and test-set.

## Connector Examples

Male Female Male Female



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

## 7 mm Connector

### 3.5 mm Connectors

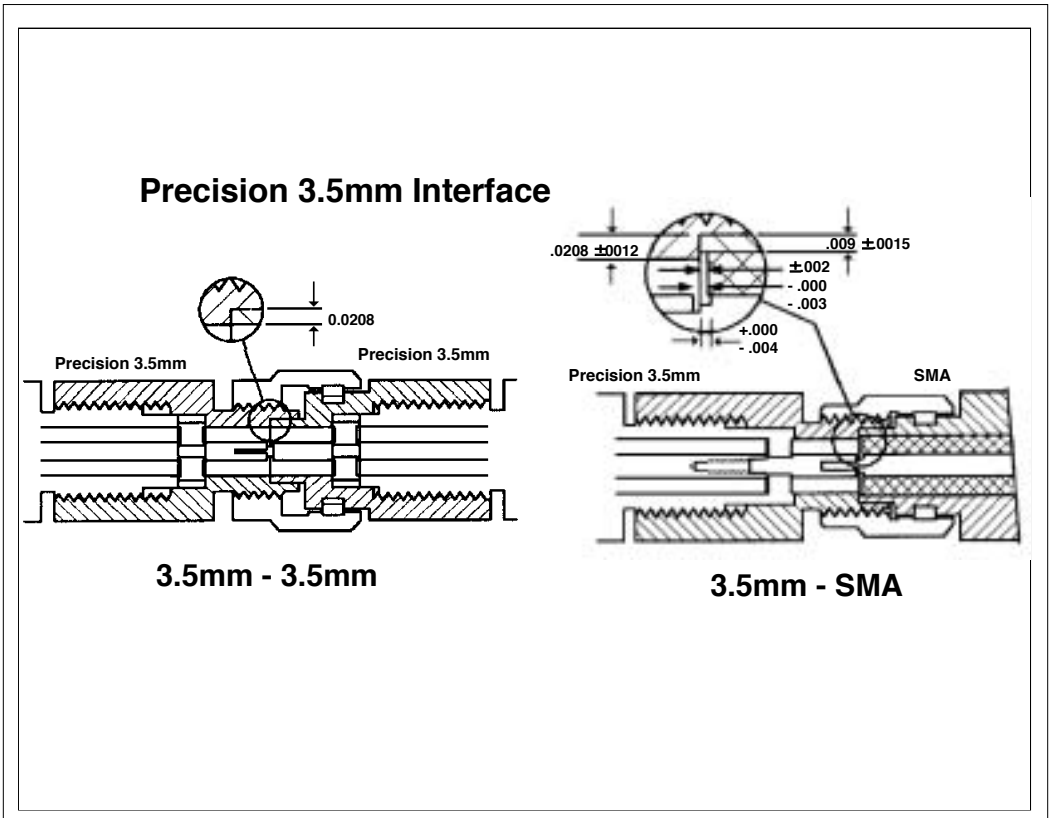
## SMA Connectors

## Recommended Torque Values for Connectors

| Connector Type | Torque<br>lb-in (N-cm) |
|---|---|
| **Precision 7 mm** | 12 (136) |
| **Precision 3.5 mm** | 8 (90) |
| **SMA** | 5 (56)<br>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-in) |
| **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-in (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.




**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).

## 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 | N |
| 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 (4.14 mm) | 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 mm, or 2.92 mm Connectors |
| 3 | 1.85 mm IS Compatible with 2.4 mm Connector |

Reference: *Agilent Microwave Test Accessories Catalog*, 1999-2000 pp. 15,16,17.

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 production grade connector and the 3.5 mm connector family provides the instrument and metrology grade components. In contrast, the APC-7 connector was designed specifically for metrology type measurements and it is not desirable to design a lower grade connector.

## Using Adapters as Connector Savers

**Protect Connectors on test set or cable**

**Become Port 1 and Port 2**

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.

## Summary

**Choose appropriate connector style**

- Frequency range
- Application environment

**Use adapters**

**Use clean connectors**

**Do not use damaged connectors**

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.

## Maintaining Connectors

### Visual Inspection

- Cleaning

### Mechanical Inspection

Before making any connection with RF and Microwave connectors, the surfaces to be mated should be carefully inspected for debris and damage. This section will go over what kinds of debris and damage to look for and how to properly clean and inspect a connector.

## Visual Inspection

**Look for damage and debris**

**Clean with compressed air and alcohol**

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.

## Connector Damage

**Badly worn plating**

**Defective threads**

**Scratched or dented outer connector**

**Bent or damaged inner conductor**

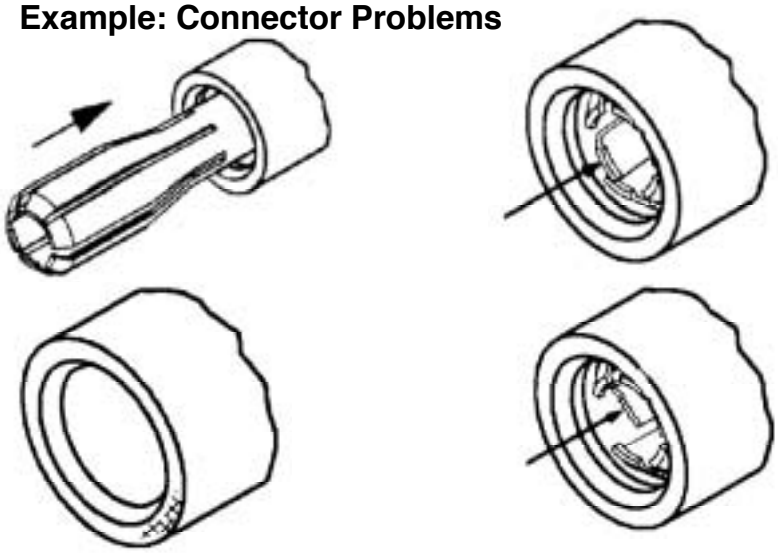
For all connectors, first look for obvious damage on the internal threads of the male nut and the external threads of the female part. The connector nuts should move smoothly and all threads should be free of burrs, loose metal particles, and rough spots. Damaged threads will usually cause metal flakes to be deposited into other parts of the connector, causing severe damage.

Next, examine the outer conductor mating surface. Flat contact is required so deep scratches, or evidence of misalignment or excess torque may make the connector useless. Light burnishing of the mating plane surface consisting of uniform, shallow concentric scratches distributed evenly over the plated surface is normal.

Deep scratches generally indicate that one or both of the mating surfaces was not clean or has a high spot or burr. Any scratch that goes through the plating should be very careful inspected under magnification to see if the scratch has left a high spot of displaced metal. This will damage other connectors.

The center conductor must be straight and centered in the outer conductor. The male pins should be shaped appropriately to engauge the female contact. No part of the female contact can be bent or out of alignment. Always carefully look at both parts before making the connection.

## Example: Connector Problems



**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.

## Cleaning

Once a connector has been visually inspected and determined to be in need of cleaning, use compressed air (not any other compressed gases) to loosen particles on the connector mating plane surfaces. Clean air cannot damage a connector, or leave particles or residues behind. You can use any source of clean, dry, low-pressure compressed air or nitrogen that has an effective oil- vapor filter and liquid condensation trap placed just before the outlet hose. Ground the hose nozzle to prevent electrostatic discharge, and set the air pressure to a very low velocity (<60 psi). High-velocity air can cause electrostatic effects when directed into a connector. For dirt or stubborn contaminants on a connector that you cannot remove with compressed air or nitrogen, try a foam swab or lint-free cleaning cloth moistened with isopropyl alcohol.

**Note**

On 3.5mm and smaller connectors, openings are very small, interior surfaces difficult to reach, and generally a plastic dielectric bead supports the center conductor only at the inner end. You can easily bend or break the center conductor if you do not use caution in cleaning.

## Cleaning

**Apply a mild blast of dry compressed air or Nitrogen**

**Use the minimum amount of pure alcohol**

**Use lint-free cleaning tools (swab or brush)**

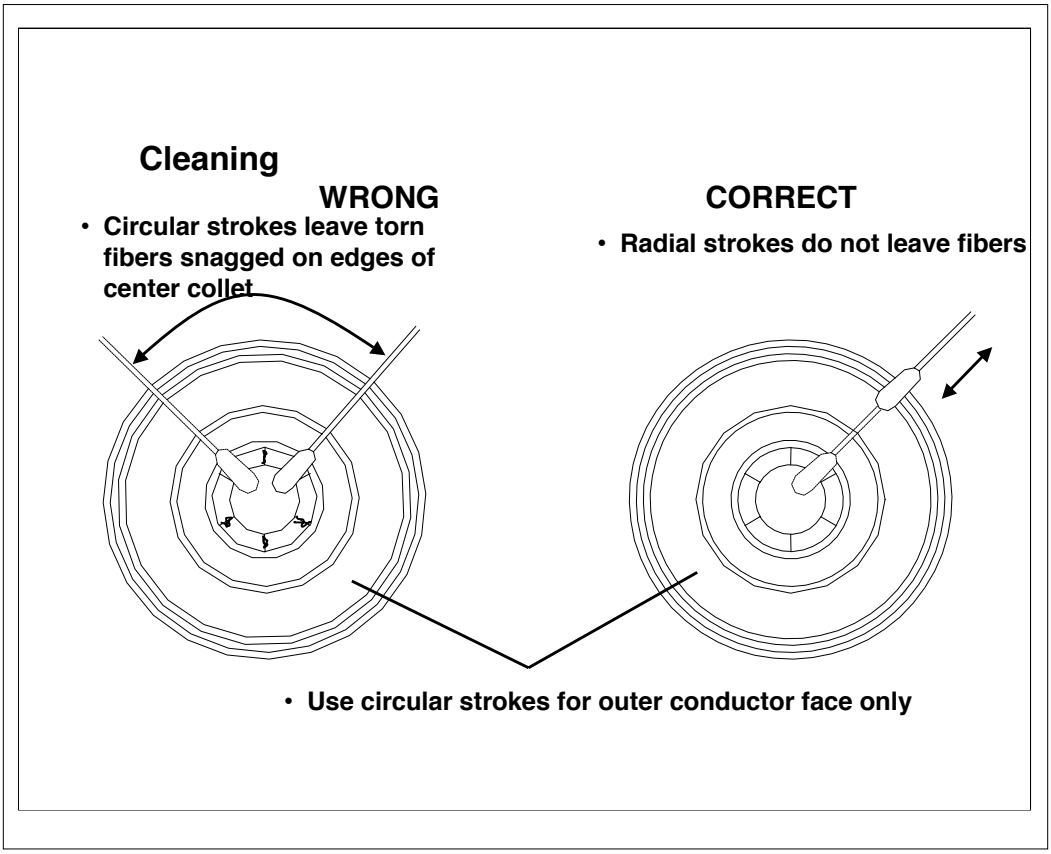
**Do not use acetone, methanol, or CFCs (Freon).**

Air blasts used to clean connectors should be from a clean dry source such as aerosol can of compressed air or from a compressor with a filter and dryer placed on the air source. Using a compressor without proper filtering and drying will result in embedding oil, water and contaminants in the connector. Also never blow the connectors with your breath since this will also result in contaminants from your breath being embedded in the connector.

Cleaning with cotton swabs will result in small fibers being left in the connector which are difficult to see. It is recommended that you use lint free swabs such as the foam tipped swab for cleaning.

## Cleaning


When it is necessary to use a solvent, use **only** pure (99,5%) isopropyl alcohol and take care to use the least amount of alcohol possible, and avoid wetting any plastic (or dielectric) parts in the connectors.




**Cleaning the Mating Plane Surfaces**

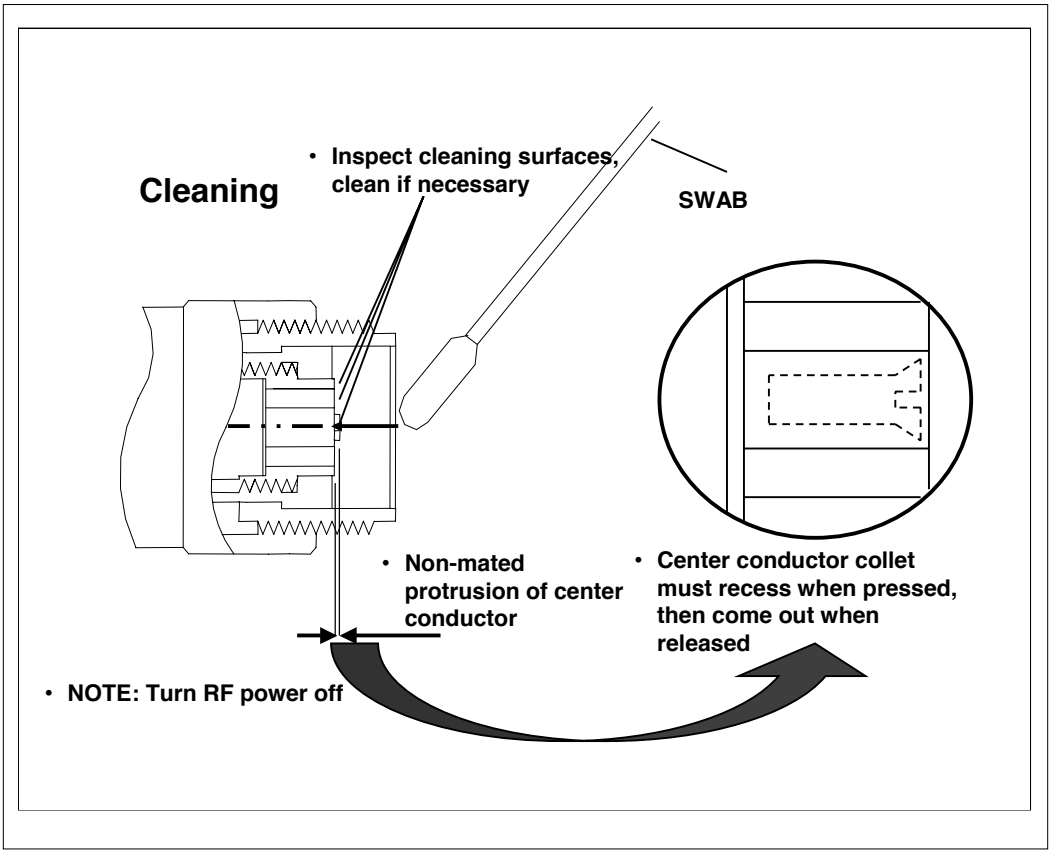
Apply a small amount of isopropyl alcohol to a new swab and clean the mating plane surfaces.If the connector has a center conductor, use very short horizontal or vertical strokes (across the connector), and the least pressure possible, especially when cleaning a female connector (to avoid snagging the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




This provides a closer look at how the Center Collet should be handled. It should be able to move in a slight amount when pressed on gently. Do not press with bare hands, use a lint free cleaning swab (swabs p/n 9301-1243).

There are 2 repair kits for the slotless connectors which are available from Agilent at this time:

- Agilent part number 85052-60049 for 3.5mm connector types.
- Agilent part number 85054-60056 for Type N connectors.

These repair kits are designed to test the grip of the female fingers in the slotless connector and includes insertion and removal tools.

We do not recommend 2.4mm and smaller connector types to be repaired in the field, therefore no repair kits are available for these connector types."

## Mechanical Inspection

**gauge Test Ports**

**gauge All  Devices Under Test**

Because coaxial connector mechanical tolerances can be very precise (on the order of a few hundreds of microinches), even a perfectly clean, unused connector can cause trouble if out of mechanical specification. Use a connector gauge to mechanically inspect coaxial connectors.

When to gauge Coaxial Connectors

**gauge a connector:**

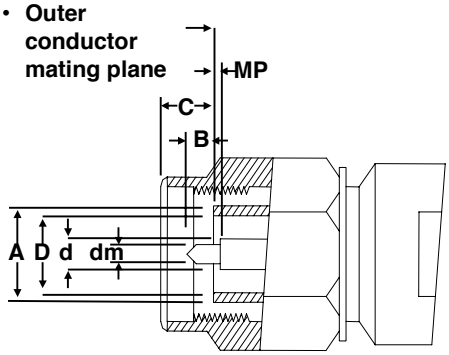
- Before you use it for the first time.
- If either visual inspection or electrical performance suggests that the connector interface may be out of specification (due to wear or damage, for example).
- If someone else uses the device.
- If you use the device on another system or piece of equipment.
- As a matter of routine: initially after every 100 connections, and after that as often as experience suggests.

**Note**

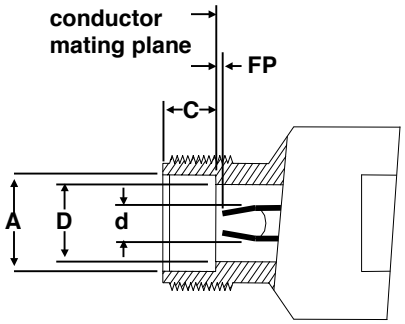
gauge 2.4 mm, 3.5 mm, and SMA connectors relatively more often than other connectors, because the center pins can pull out of specification during disconnection.

## Mechanical Inspection

- Outer conductor mating plane




- 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.

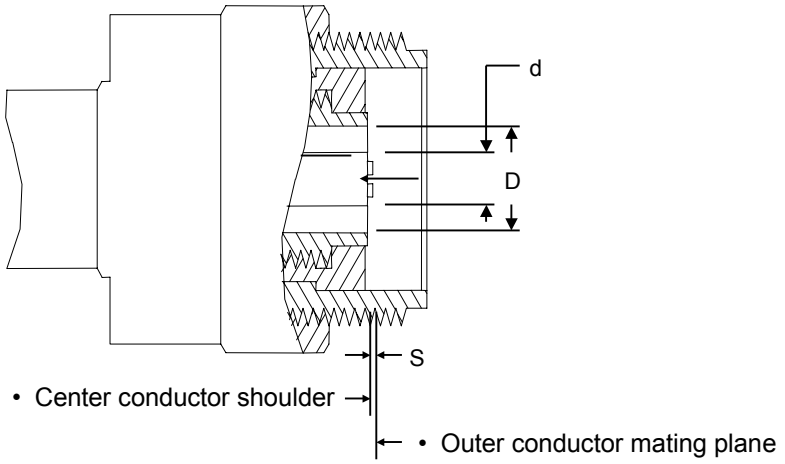
**Specifications**

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.

## Mechanical Inspection




Two mechanical specifications are generally given for precision 7 mm and 3.5mm connectors:

1. A minimum and maximum allowable protrusion of the center conductor collet in front of the outer conductor mating plane with the collet in place.
2. The maximum recession of the center conductor behind the outer conductor mating plane with the center conductor collet removed. Also, the center conductor collet should immediately spring back if you compress it fully with a blunt plastic rod.

**Caution**

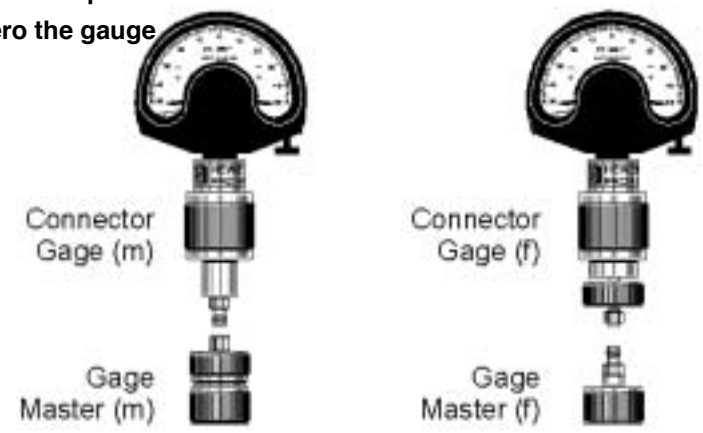
With the center conductor collet removed, the center conductor may not protrude in front of the outer conductor mating plane, and sometimes must recede minimally. Consult the mechanical specifications provided with your connector or device.

## Using Connector Gauges

**Inspect and clean before each use**

**Use multiple measurements**

**Zero the gauge**

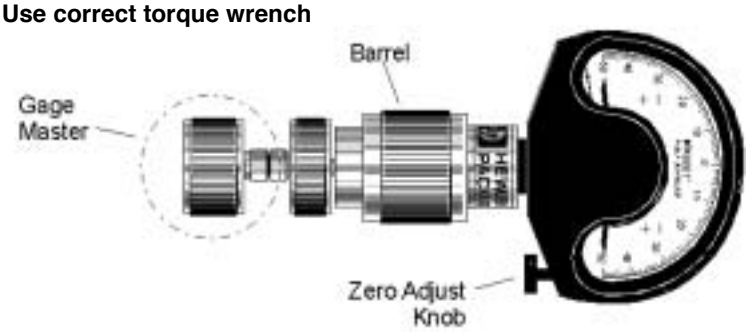



Each connector has a specific version of the gauge for measurement of the male and the female connector. Each gauge uses a special precision gauge master to zero the gauge. If there is doubt about the measurement, be sure the temperature of the parts have stabilized, then perform the cleaning, zeroing,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

## Connecting the Gauge Master

**Screw on the gauge master and hand-tighten**

**Use correct torque wrench**




**Settle the gauge**

**Adjust the zero knob to zero the gauge**

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

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

## Measure the connector

**Connect the device**

**Settle the gauge**

**Read recession or protrusion**


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

## Cost of Connector Damage

| Item | Replacement Cost ($) |
|---|---|
| 3.5 mm Sliding Load | 2,000.00 |
| 2.4 mm Sliding Load | 2,200.00 |
| 2.4 mm Flexible Cable | 1,600.00 |
| 8515A Test Port | 1,000.00 |
| 2.4 mm PSC Short | 550.00 |
| 3.5 mm PSC Short | 340.00 |

As an incentive to use test port adapters and connector savers, take a look at the cost consequences of damage a connector.

Using high quality adapters as test port or cable connector savers will significantly decrease the cost in case of damage to the damage to the relatively expensive "built-in" connectors. Using connector savers definitely makes good sense.

## Good Connector Practice

- Look
- Clean
- Gauge

## End of Module

**Thank you for attending**

**Questions, more information? Please email tm_ap@agilent.com**

**Want to learn this in greater detail? Please try www.agilent.com/find/training and look for course availability at a location near you.**