Guidance on Selecting and Handling Coaxial RF Connectors used with Rohde & Schwarz Test Equipment

Application Note

This application note describes how to handle and care for coaxial RF connectors.
This guidance should ensure good repeatable measurements with Rohde & Schwarz test equipment and extend the lifetime of connectors.

Note:

Please find the most up-to-date document on our homepage http:\\www.rohde-schwarz.com/appnote/1MA99.

Application Note
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4.2015 – 1MA99_2e

ROHDE&SCHWARZ

Table of Contents

1 Abstract

Coaxial connectors are a key component in RF and microwave applications. Their importance and contribution to overall system performance is sometimes overlooked.

This application note focuses on coaxial connectors found in RF and microwave applications, providing general information on the available types; how to take care of connectors and connector electrical properties.

This information is essential for anyone specifying and using Rohde and Schwarz test and measurement equipment and will help with:

- The selection of the correct types of coaxial connector.
- Handling connectors to obtain accurate and repeatable measurements, and to maximize the longevity and performance of coaxial connectors.

2 Simple Tips for Using Coaxial Connectors

A summarized guide on using coaxial connectors is given below. More in depth information is contained in the body of this application note.

1. Choose cables and connectors that operate below the useable upper frequency limit.
2. Use connector types compatible for interfacing to the test equipment / device under test.
3. Do not connect precision and low cost connectors together.
4. Before using, check that the connector is clean and undamaged.
5. Connectors should mate together easily using only hand tightening.
6. Do not rotate one connector against the other – only turn the nut, with fingers!
7. Use a calibrated torque wrench to complete tightening.

3 Types of Coaxial Connector

Coaxial cables are usually terminated with coaxial connectors, which retain the coaxial structure and defined impedance. More detailed information on the electrical properties of coaxial cable is given in section 5, Appendix: Coaxial Transmission Line Electrical Properties.

Generally, a coaxial connector comprises of an outer conductor contact, an inner conductor contact, and can mechanically couple to another connector. The metallic conductors are usually plated with silver or gold to obtain optimum electrical performance.

The choice of connector type is critical and will be defined by the application requirements, for example, frequency range, power handling and physical dimensions. Additionally, there are different quality grades of connector, supporting use in metrology, instrumentation and production.

Some commercially available connector types and examples of their operating frequencies are shown in Fig. 3-1. Note that smaller coaxial geometries have higher useable upper frequencies. Most connectors are named after, and referred to by the inside diameter of the outer conductor.

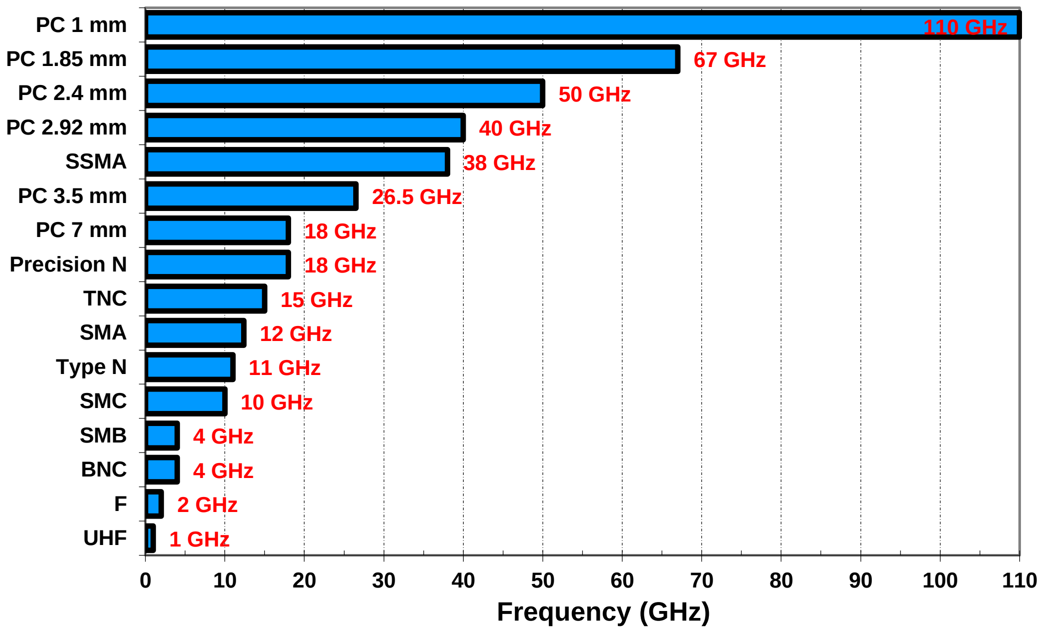


Fig. 3-1: Coaxial connectors. Operating frequencies

Care should be taken when using different connector types in a common system because the connector type having the lowest frequency range will set the frequency range of the system.

The performance of specific connector types should always be checked with the connector manufacturer.

The following sections provide more detail on the most common types of coaxial connectors used with test equipment.

3.1 Type N (*50* Ω)

Max Frequency: *11 GHz (normal), 18 GHz (precision)*
Dielectric: *PTFE*[1] *(normal), air (precision)*

The Type N (Navy) connector was developed to satisfy the need for a durable, weatherproof, medium-sized RF connector with consistent performance up to 11 GHz. Precision Type N connectors use an air dielectric and are available up to 18 GHz.

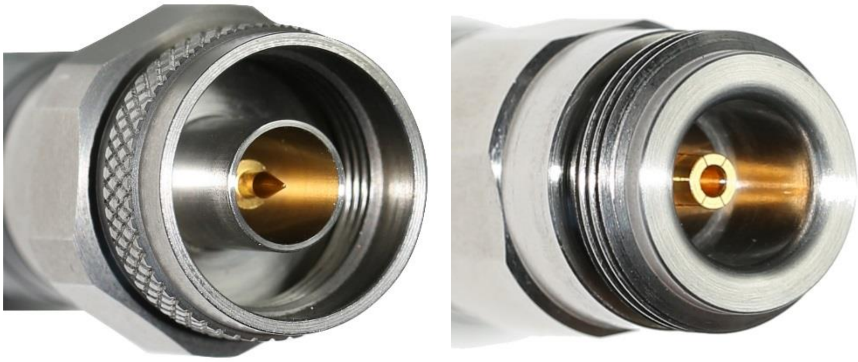


Fig. 3-2: Type N connectors. Male *(left)* and female *(right)*

Note:

1. *75 Ω and 50 Ω Type N connectors are not compatible despite sharing a common thread size. The male pin on 50 Ω Type N is larger than the female socket of 75 Ω Type N connectors, resulting in damage if connected together.*

2. *75* Ω Type N connectors have an upper frequency limit of 4 GHz.

3.2 Subminiature Version A (SMA)

Max Frequency: *12 GHz*
Dielectric: *PTFE*

Developed in the 1960's, these 50 Ω SMA connectors are semi-precision, sub miniature units that provide good electrical performance from DC to 12 GHz. Using a PTFE[1] dielectric, these general purpose connectors are compact in size and are mechanically rated for only 500 mate / de-mate operations. They are one of the most

[1] *PTFE - Polytetrafluoroethylene*

commonly used types of RF and microwave connector. Some manufacturers supply SMA connectors that operate up to 18 GHz.

The popularity of this type of connector does mean that there is considerable mechanical variance in devices from the different manufacturers. The user must take great care to check compatibility to avoid physical damage.

Fig. 3-3: SMA connectors, male *(left)* and female *(right)*

3.3 Precision 3.5 mm

Max Frequency: *26.5 GHz*
Dielectric: *Air*

A precision connector, based upon the original SMA connector. Its design strategy focused on highly-rugged physical interfaces that would allow thousands of repeatable connections and mate with popular SMA connectors.

This connector is fully compatible with cheaper SMA connectors although the larger tolerance of the center pin of some male SMAs can cause damage.

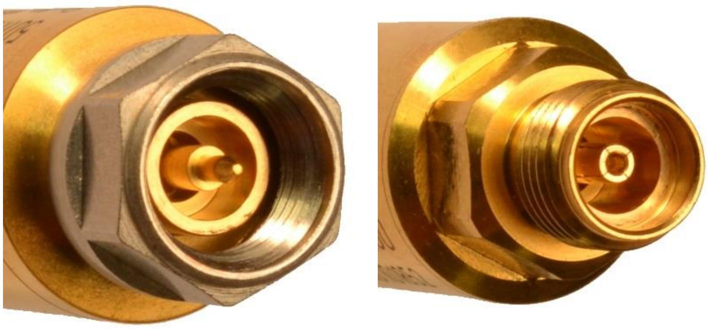


Fig. 3-4: Precision 3.5 mm connectors, male *(left)* and female *(right)*

3.4 Precision 2.92 mm.

Max Frequency: *40 GHz*
Dielectric: *Air*

This reliable connector covers the K defined frequency bands. It is used in measurement systems and applications demanding high performance and is mechanically compatible with SMA and 3.5 mm connectors.

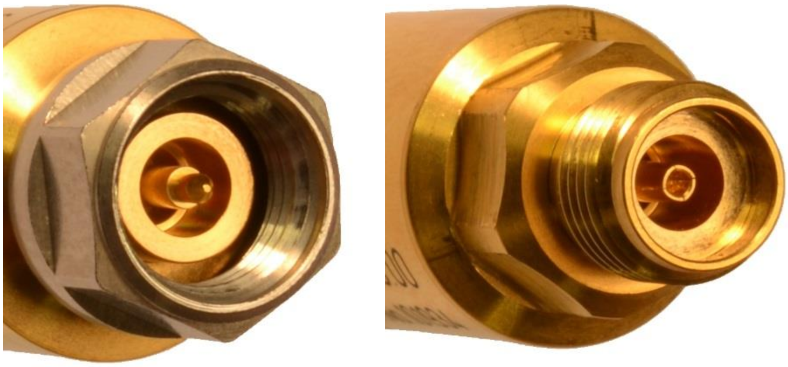


Fig. 3-5: 2.92 mm Connectors, male *(left)* and female *(right)*

3.5 Precision 2.4 mm and 1.85 mm

Max Frequency: *50 GHz (2.4 mm),*
67 GHz (1.85 mm)
Dielectric: *Air*

These two precision connector types are mechanically compatible with each other, but will not interface with SMA, 3.5 mm or 2.92 mm. The robust mechanical design ensures that the outer conductors are engaged before the inner conductors start to mate. The 2.4 mm and 1.85 mm are also known as Type Q and V respectively.

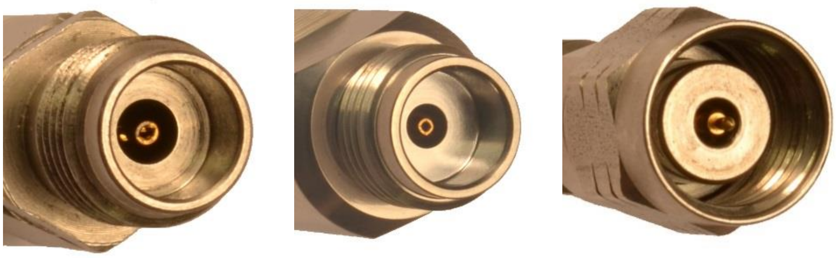


Fig. 3-6: 2.4 mm female *(left)*, 1.85 mm female *(center)*, and 1.85 mm male *(right)*

3.6 Precision 1.0 mm

Max Frequency: 110 GHz
Dielectric: Air

With this connector type the coaxial cavity has a smaller geometry to support the higher frequency. The mechanical coupling and thread sizes have been designed to maximize strength and to minimize damage to the inner conductor during the connecting process.

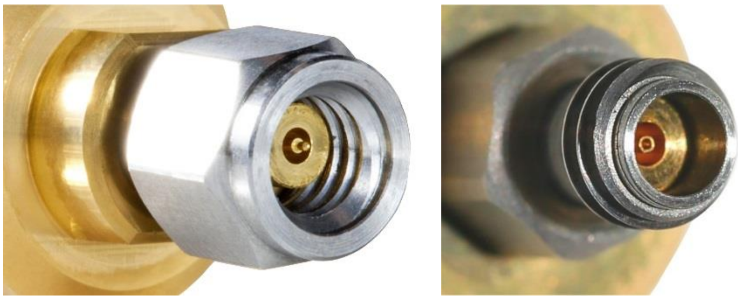


Fig. 3-7: 1 mm male *(left)* and female *(right)*

3.7 Test Equipment – 'Special Connectors'

Some test equipment uses special connectors to mechanically protect the test equipment connector interface, using either improved mechanical robustness or a sacrificial adapter.

3.7.1 Ruggedized Test Port Connector

This connector type has a large threaded body that provides a more mechanically robust interface to the test instrument. Ruggedized connectors are available that support 3.5 mm, 2.92 mm, 2.4 mm and 1.85 mm geometries. The male connector is usually fitted to the test instrument and gives the flexibility of connecting to a cable with a ruggedized connector, or to a standard female connector with the smaller mechanical dimensions. See the outer and inner threads respectively on the male connector shown in Fig. 3-8.

Fig. 3-8: Rohde & Schwarz 3.5 mm ruggedized cable

In addition to cables, there are ruggedized adapters, which convert from the ruggedized test instrument interface directly to most other coaxial connector interfaces. These adapters may also be referred to as “connector savers”, acting as sacrificial interfaces to the test instrument connector.

3.7.2 Rohde & Schwarz Test Port Adapter System

These versatile test equipment connector interfaces offer the flexibility of one test instrument providing support for different connector interfaces, and can easily and cheaply be replaced if damaged without impact to the test instrument.

Fig. 3-9: R&S Test Port Adapter. Test port interface *(left)*, N-type interface *(right)*

For more information, please refer to Rohde & Schwarz application note, “Interchangeable Port Connector System, Test Port Adapter System”, 1MA100.

4 Storage, Inspection, Cleaning and Handling

The mechanical interfaces of coaxial connectors are easily subject to damage and a damaged connector will propagate damage to other connectors with continued use.

Taking care of coaxial connectors is essential for:

- Minimum RF insertion loss and mismatch
- Good stable measurement repeatability
- Minimizing damage to expensive test equipment connectors
- Maximizing the life of the connector

4.1 Storage

Connectors must be stored in a clean and dry environment. Use the original packaging or a box partitioned with foam. Use protective plastic end caps and avoid touching the mating surfaces.

To avoid damage to mating surfaces, do not store connectors loosely together or place them face down.

Do not drop precision connectors.

4.2 Inspection

Even a well stored and handled connector will develop degraded electrical performance with use, caused by the effects of the mechanical processes involved in coupling two connectors. Therefore a visual inspection of the two connectors should always be performed before coupling. **DISCARD DAMAGED CONNECTORS**.

A visual inspection should be performed with the aid of a microscope or magnifying glass. Things to look for include:

Dirt	- Look for metal particles, fibers and other contaminants on the inner parts of the connector, the dielectric and the thread. This is particularly important for SMA connectors, since accumulated metal particles in the PTFE will have an effect on electrical performance.
Outer conductor	- Inspect the mating surface for deep scratches and associated dislodged metal, which could lead to high spots and damage to other connectors.
	- Check that the threaded body is circular and not dented.
	- Normal wear on this mating surface will show as an evenly distributed slight scouring and visual dullness.

Inner conductor

- Male pins must be straight and centered, or concentric, to ensure aligned damage-free engagement with the female socket.
- Inspect the male pin dielectric support.
- The contacts within the female socket are high precision and must be treated with great care. Check that all contacts are present, uniformly aligned and undamaged as shown in Fig. 4-1.

Fig. 4-1: Good condition 3.5 mm female

- Fig. 4-2 shows good examples of damaged centre conductors.

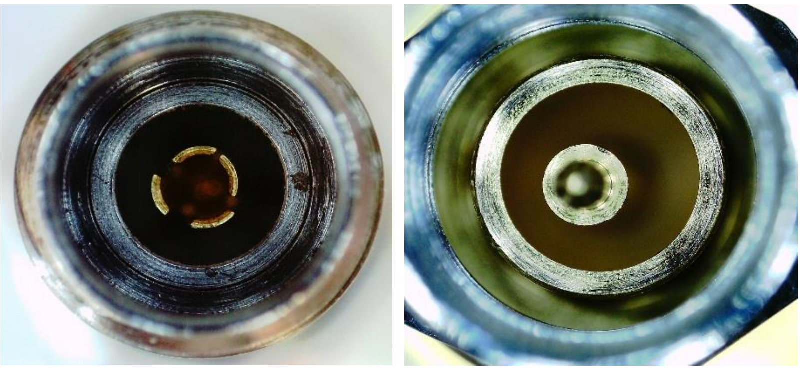


Fig. 4-2: Examples of damaged connectors: Bent fingers on female slotted connector *(left)*; non-concentric male pin *(right)*

4.3 Cleaning

If a visual inspection shows that the connector is physically good, but requires cleaning, then the following items will be required:

- Low pressure, solvent free compressed air *(use appropriate precautions).*
- Isopropanol *(use appropriate precautions).*
- Foam cleaning swabs.
- Lint free cleaning cloth.
- Wooden cocktail sticks.

Using magnification and electrostatic discharge (ESD) precautions, cleaning should proceed as follows:

1. Apply compressed air to dislodge larger debris from the thread and mating surfaces. Avoid blowing the air directly into the connector. A wooden cocktail stick can be used to carefully remove any remaining smaller particles.

2. With an isopropanol moistened swab, clean the connector thread using a circular motion around the connector, parallel to the thread (Fig. 4-3).

Fig. 4-3: Cleaning the thread

3. Cleaning the inside of the connector with an isopropanol moistened swab requires great care and minimum pressure to avoid damage. This is particularly true for air filled dielectrics which use spacers to keep the inside conductor concentric with the outer. A similar level of care should also be applied to connectors with a PTFE dielectric. Renew the swab if it becomes too dirty to be effective.

Fig. 4-4: Cleaning the inside

On female connectors, caution is required when cleaning around the contacts. For male connectors, if the region between the thread and center pin must be cleaned, wrap one coat of lint free cloth to the end of a wooden cocktail stick and proceed with extreme caution.

4. Use the compressed air to dry the connector and perform a final inspection, checking that there are no signs of debris, residues or damage.

For assistance with sourcing suitable connector cleaning materials, please contact your regional Rohde & Schwarz office.

4.4 Handling

It is strongly recommended that ESD precautions are observed, using a conductive work area and grounded wrist strap to protect test equipment and devices under test.

In most cases, an inspected, clean damage-free connector is ready for use. If the history of the connector is unknown, and in precision applications, e.g. metrology, there is a final step to measure the mechanical properties of the mating interfaces using calibrated gauges. Arguably this step should be applied to all connectors to ensure that mating tolerances are not exceeded, which could cause damage to mating connectors.

When starting to mate two connectors:

1. Carefully align the two connectors, bringing them together along a common axis.

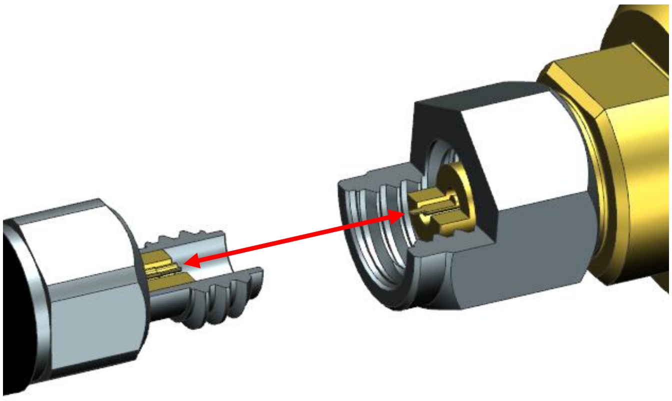


Fig. 4-5: Align and bring the connectors together along a common axis

2. Extra care must be applied on types of connector that have a protruding male pin that engages with the female socket before the outer threaded conductor has started to mesh, to avoid damage to either or both inner conductors.

3. ONLY TURN THE OUTER CONNECTOR NUT.

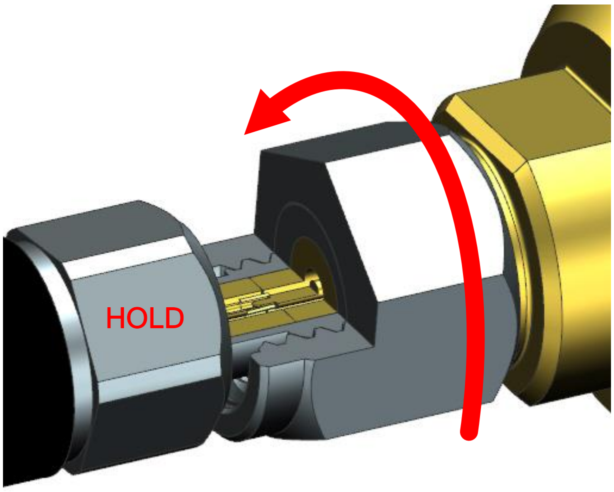


Fig. 4-6: Finger tight connection, turning the nut only

Do not turn one half of the mating assembly against the other. This causes the mating surfaces to move against each other, and in particular, the male and female inner conductors will exhibit accelerated wear and increased risk of damage.

If the connector assembly is clean and undamaged, it will be possible to finger tighten the assembly to within about half a turn of the required torque. If any resistance is experienced prior to this point, or if a spanner is required, then it is very likely that one or both of the connectors is damaged and should be taken apart and inspected immediately.

4. Once firmly coupled, the nut should be torqued to prescribed limits using a calibrated torque wrench, while holding the opposite part of the connector stationary with a spanner (Fig. 4-7).

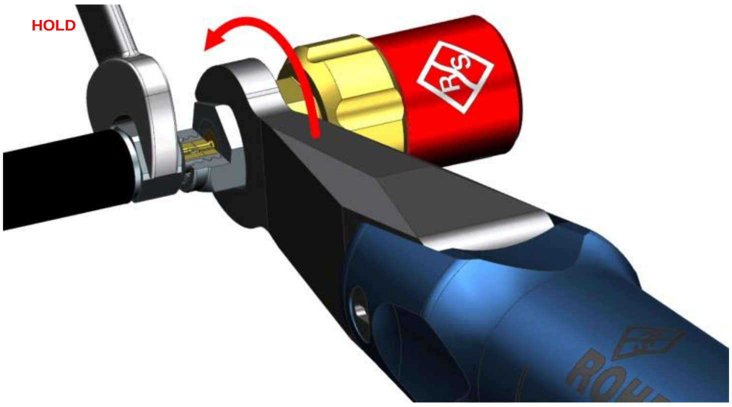


Fig. 4-7: Applying the correct torque to the connection

5. The correct torque is reached when the torque wrench "breaks" as shown in Fig. 4-8. Additional force beyond this limit should not be applied.

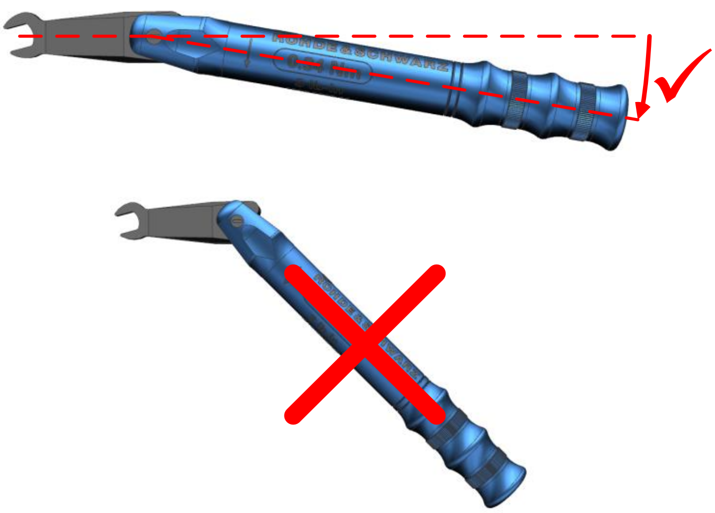


Fig. 4-8: Correct torque setting *(top)*. Too far *(bottom)*

Each connector type has its own torque limit, as shown in Table 4-1.

Connector Type	Torque Limit		Nut opening		Rohde & Schwarz Torque Wrench	
	lb-inch	Nm	Inch	mm	Part Number	Part Description
Ruggedized	13.3	1.5	3/4	20	1311.8242.03	Torque-flat wrench 1.5 Nm
N-Type	13.3	1.5	3/4	20	1311.8242.03	Torque-flat wrench 1.5 Nm
SMA	5	0.56	5/16	8	Not available	Not available
3.5 mm	8	0.9	5/16	8	1311.8213.02	Torque-flat wrench 0.9 Nm
2.92 mm	8	0.9	5/16	8	1311.8213.02	Torque-flat wrench 0.9 Nm
2.4 mm	8	0.9	5/16	8	1311.8213.02	Torque-flat wrench 0.9 Nm
1.85 mm	8	0.9	5/16	8	1311.8213.02	Torque-flat wrench 0.9 Nm
1.0 mm	3	0.34	0.236	6	1315.2803.02	Torque-flat wrench 0.34 Nm

Table 4-1: Connector torque limits

Note:

- The values given in this table are for connectors supplied by Rohde & Schwarz (except SMA). For other coaxial connectors, the correct torque limit must be obtained from the connector manufacturer to avoid damage.

- Care must be taken when mating compatible connector types. For example, mating 3.5 mm to SMA. In this situation, the lower torque limit of the two connector types should be used.

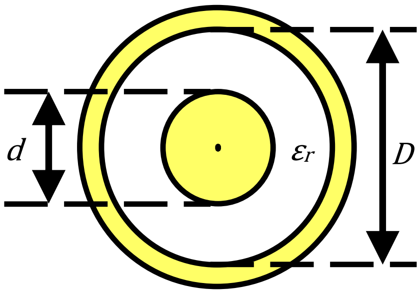
To reduce the possibility of damage to connectors on delicate and/or expensive devices, “connector savers” should be used.

5 Appendix: Coaxial Transmission Line Electrical Properties

In RF and microwave applications, unbalanced coaxial transmission line structures are used to transfer energy from a source to a load. These structures may be flexible or rigid and typically have a characteristic impedance of 50 Ω.

5.1 Characteristic Impedance

The characteristic impedance of coaxial cable (coax) is a function of its mechanical dimensions and a uniform dielectric constant. Fig. 5-1 shows a coaxial structure.



- d is the outside diameter of the inner conductor.
- D is the inside diameter of the outside conductor or shield.
- ε_r is the relative dielectric constant or permittivity.

Fig. 5-1: Coaxial cross section

Equation 5-1 gives the formula for obtaining the characteristic impedance.

$$Z_o \approx \frac{138\Omega}{\sqrt{\varepsilon_r}} log_{10} \frac{D}{d}$$

Equation 5-1: Approximate characteristic impedance of coaxial transmission line per unit length

Two important requirements of coaxial transmission lines are to have minimum insertion loss and good power handling.

In an air-filled coaxial transmission line, the minimum insertion loss per unit length occurs when the ratio of $D/d \approx$ 3.6, giving a characteristic impedance of 77 Ω.

For maximum power handling, the geometry is different, resulting in a calculated ratio of $D/d \approx$ 1.65, and a characteristic impedance of 30 Ω in air.

50 Ω is the compromise between power handling and attenuation per unit length and is the nominal characteristic impedance used in most RF and microwave applications.

5.2 Useable Upper Frequency Limit

In a coaxial transmission line, energy propagates from DC to high frequencies in a single mode called the Transverse Electromagnetic (TEM) mode, where both the electric and magnetic fields are orthogonal to the direction of energy propagation. However, at higher frequencies, the coaxial geometry can support higher order modes, which will interfere with the dominant TEM mode. Therefore it is necessary to calculate the frequency at which the first higher mode will start to propagate, so that only frequencies below this "cut off frequency", f_c, are used.

For a dielectric filled coaxial transmission line the cut-off frequency of the first higher order mode, the Transverse Electric (TE_{11}), is given by Equation 5-2:

$$f_c \approx \frac{c}{\pi \left(\frac{D+d}{2}\right)\sqrt{\varepsilon_r}}$$

Equation 5-2 - Cut-off frequency of TE_{11} mode in coaxial transmission line.

Typically the useable upper frequency limit of a coaxial cable is defined as being approximately 90-95% of the TE_{11} mode cut-off frequency. Below the cut-off frequency, only the wanted TEM mode propagates.

For example, an air filled 3.5 mm connector has the following dimensions:

- d = 1.52 mm
- D = 3.5 mm
- $\varepsilon_r \sim 1$

Therefore, the "cut off frequency", f_c, of the first higher mode is approximately 38 GHz. Some manufacturers rate 3.5 mm precision connectors up to 33GHz.

Equation 5-2 shows that the cut-off frequency of the first higher order mode can be increased through reducing the physical dimensions of the inner and outer conductors. However, when selecting a suitable cable, consideration must also be given to satisfy other requirements. For example, minimizing losses due to skin depth and having adequate power handling.

6 Literature

- Doug Skinner, "Guidance on using Precision Coaxial Connectors in Measurement", Version 3, National Physics Laboratory. 2007.
- Martin Müller, Uwe Kulms & Mark Bailey, "Interchangeable Port Connector System, Test Port Adapter System", 1MA100, Rohde & Schwarz. 2015.
- Huber & Suhner, RF Coaxial connectors, General catalogue, 2013.
- Paul Pino, "Intermateability of SMA, 3.5 mm and 2.92 mm Connectors", Microwave Journal, Cables & Connectors Supplement, 2007.
- Microwave Connectors, www.microwaves101.com.

7 Additional Information

This Application Note is updated from time to time. Please visit the website http://www.rohde-schwarz.com to download the latest versions.

Please send any comments or suggestions about this application note to TM-Applications@rohde-schwarz.com.

About Rohde & Schwarz

The Rohde & Schwarz electronics group is a leading supplier of solutions in the fields of test and measurement, broadcast and media, secure communications, cyber security, and radiomonitoring and radiolocation. Founded more than 80 years ago, this independent global company has an extensive sales network and is present in more than 70 countries. The company is headquartered in Munich, Germany.

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