How to Make Good Coaxial Connections

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1 Introduction

It seems to be very easy to make a coaxial connection. Just put the two half-connectors together and torque the nut? This just describes a very small fraction of the work and attention which is required to make repeatable and good coaxial connections.

Not observing the advice given in this guide will lead most probably to at least one damaged connector. Damaging a connector can be very costly. A simple adapter can cost more than 1000 US Dollars.

A second consequence of not observing the advice given in this guide is a waste of time. Every time a connector breaks, the S-parameters of the device connected to the bad connector will be measured wrongly. In the best case, wrong measurements are immediately detected and one has to invest time to remeasure. More often these errors are not immediately detected and complete cycles of simulation, design and production are rendered worthless.

Thus one can save considerable amounts of time and money by observing the rules for making good coaxial connections.

There are other guides to making good connections, see [1] and [2]. These guides contain more information on the dimensions of connectors. This information is nowadays contained in [3]. Although [1] is very detailed, it contains no information on connectors with frequency ratings higher than 50 GHz. Some of the procedures proposed in [1] and [2] are questionable.

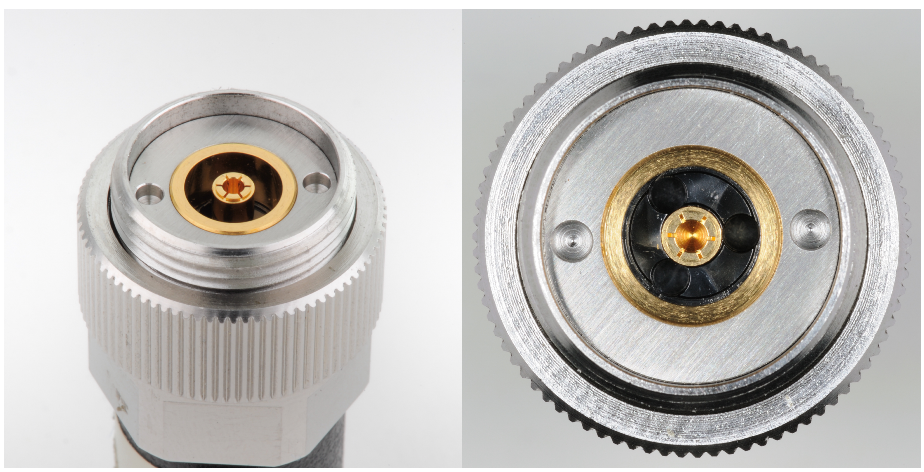
2 Types of Connectors

There exist many types of coaxial connectors. This document treats the connectors which occur most often in calibration laboratories and which need most attention. The standard [3] provides more information about the characteristics of the here treated connectors.

Basically a coaxial connector needs to press two pairs of conductors together to make contact for the outer conductor and the center conductor. There are different mechanical solutions to achieve this. The most simple solution is to just press together two metallic surfaces. This technique is applied in nearly all connectors for the outer conductor. It is problematic to employ this technique for the center conductor as well because the center conductor would need to be absolutely on the same plane as the outer conductor surface. To ease production, one bridges the last micrometers of the center conductor with small springs as in the 7 mm connector or implements a female-male connector which accepts even bigger production tolerances.

Connector names often refer to the inner diameter of the outer conductor of the coaxial line. Coaxial connectors have an upper frequency rating. If one exceeds this rating, the connector will produce higher modes which translates into nonpredictable transmission and reflection behaviour. The upper frequency rating is related to the diameter. The smaller the diameter the higher the upper frequency rating. Smaller connectors are more difficult and costly to manufacture and more fragile in their handling.

2.1 7 mm



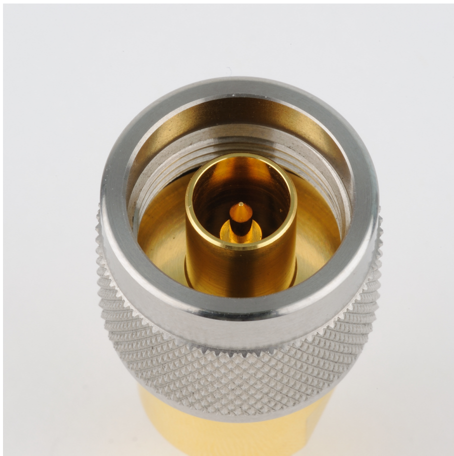
(a) (b)

Figure 1: Slanted view (a) and top view (b) of the 7 mm connector.

7 mm connectors are hermaphroditic connectors. In contrast to the other connectors presented here, they have no sex. They can be used up to 18 GHz. An example of a 7 mm connector is given in Fig. 1. Something you should not do with a 7 mm connector is to put it face down on a hard surface because this will induce scratches in the mating surface and stresses as well the collets. Another 7 mm specific advice is to retract one sleeve completely before connecting and to use only the other sleeve for the connection and torquing. Do not torque the second sleeve after the first one is torqued. This is important because this prevents the two sleeves from beeing pressed together what in turn would lower the pressure between the contact surfaces.

2.2 N-Type

N-type connectors, see Fig. 2, are very widespread. They are sexed and they can be used up to 18 GHz. They are special because the outer conductor mating plane is shifted with respect to the center conductor mating plane. There is a version with 75 Ω ,see Figs. 3a-3b, and another version with 50 Ω characteristic impedance, see Figs. 2a-2c. Although these two versions may look similar, never try to connect N-type connectors with differing characteristic impedances. Otherwise one or both connectors may be destroyed. Additionally there are female connectors which have a slotted female contact, see Fig. 2b, and others which have a slotless female contact, see Fig. 2c. Usually the slotless connectors have higher precision but they are as well more expensive.



(a)

(b)

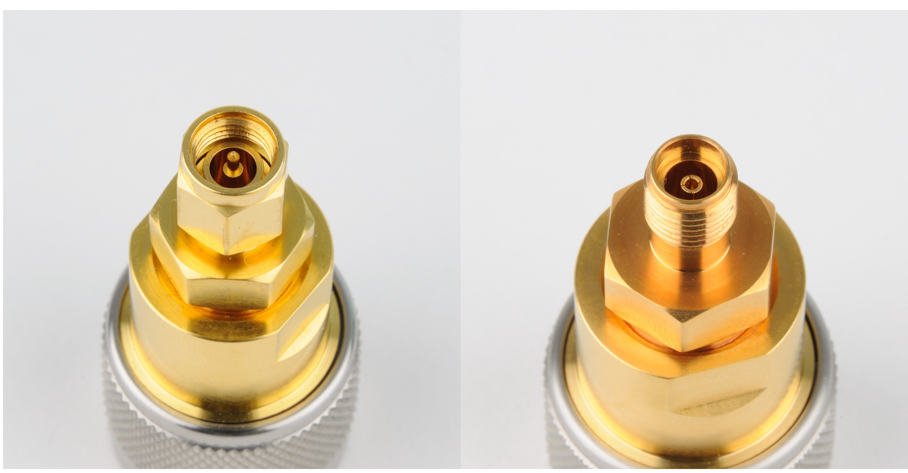
(c)

Figure 2: Male (a) and female (b) N-Type connectors with $50\,\Omega$. The slotless version of the N-Type connector is depicted in (c).

(a) (b)

Figure 3: Male (a) and female (b) N-Type connectors with $75\,\Omega$. The center conductor is thinner than for the $50\,\Omega$ version shown in Fig. 2a and 2b.

2.3 3.5 mm and SMA



(a) (b)

Figure 4: Male (a) and female (b) 3.5 mm connectors.

The 3.5 mm connector, see Fig. 4, is specified up to 33 GHz and exists with slotted and slotless female contacts, see Fig. 5. The outer and center conductor mating planes coincide. The 3.5 mm connector is mechanically compatible with

SMA connectors. The price of SMA connectors is in the 10 dollar range whereas the price of 3.5 mm connectors is in the several 100 dollar range. SMA connectors have often center conductors which are excentric and protruding. To avoid destruction of costly 3.5 mm equipment it is strongly advised to use a connector saver. This is a low grade 3.5 mm to 3.5 mm adapter with one side dedicated to SMA connections and the other side dedicated to 3.5 mm connections. The 3.5 mm connector can be mechanically mated with the 2.92 mm or K connector. This changes the electrical characteristic of the connection. Usually such connections are not specified by the manufacturers.

Figure 5: The slotless version of the 3.5 mm connector.

2.4 2.92 mm or K

The 2.92 mm and the K connector, see Fig. 6, and the 3.5 mm connector are mechanically mateable. The electric characteristics of interfamily matings are usually not specified. The difference between the K connector and the 2.92 mm connector is the male pin diameter of 0.914 mm and 0.937 mm respectively. The 2.92 mm connector is often specified with different male pin diameters in standard documents but the connectors which one can buy nowadays (year 2013) are usually labeled with 2.92 mm if they have 0.927 mm male pin diameter and K if they have 0.914 mm male pin diameter. If in doubt, ask the manufacturer. The K and the 2.92 mm connector are rated up to 40 GHz. Both types have only slotted female connectors. The outer and center conductor mating planes coincide.

(a) (b)

Figure 6: Male (a) and female (b) 2.92 mm connectors.

2.5 2.4 mm

(a) (b)

Figure 7: Male (a) and female (b) 2.4 mm connectors.

The 2.4 mm connector, see Fig. 7, is specified up to 50 GHz and exists with slotted and slotless female contacts, see Fig. 8. The outer and center conductor mating planes coincide. The 2.4 mm connector is mechanically compatible with the 1.85 mm connector. Such mixed connections have usually unspecified electical characteristics.

(a) (b)

Figure 8: The slotless version of the 2.4 mm connector.

2.6 1.85 mm

(a) (b)

Figure 9: Male (a) and female (b) 1.85 mm connectors.

The 1.85 mm or V connector, see Fig. 9, is specified up to 65 GHz. It is mechanically compatible with the 2.4 mm connector. Such mixed connections have usually unspecified electical characteristics. The center and outer conductor mating plane are the same. There exist only slotted versions of this connector.

2.7 1.00 mm

(a) (b)

Figure 10: Male (a) and female (b) 1.00 mm connectors.

The 1.00 mm connector, see Fig. 10, is specified up to 110 GHz. Its outer and center conductors mate on the same plane and there are only slotless versions available.

3 Connector Care

3.1 Inspection

All connectors which come into the laboratory should be inspected. There shouldn't be any devices with not inspected connectors within reach of the users. This is important because dirty and damaged connectors or connectors which are out of specification may damage good connectors. Dirt and damage may spread among the connectors like an infectious disease.

Inspection typically reveals dirt, scratches, defoliation, damage, staining, dents, particles, burrs, center contact protrusion, excentric center conductor and spread of female contact fingers.

Dirt comes into the connector from various sources. One important source is the human skin. Then there are sometimes lubricants from the screw threads, wear debris from the connection process and dust which falls in the connector.

Scratches are often present in new connectors. They are caused by pointy objects which touch the connector surface. Deep scratches which go through the plating have to be checked for depth. In the case of deep scratches one must decide if the connector is still mechanically acceptable and if it is still electrically acceptable. Both questions are difficult to answer and no general rules can be given. Shallow scratches on the plating surface are usually harmless.

Defoliation of the plating sometimes occurs on the male pin and on the female contact fingers. The reason is excessive stress on the plating and bad adherence of the plating. Defoliation is usually mechanically not a problem but electrically it is not acceptable unless one is willing to polish the defoliated areas before each use.

Damage occurs mostly during mating with other damaged or out of specification connectors. Typically female contact fingers are bent or broken or the male pin is bent. Damaged connectors should be discarded immediately or stored for educational purposes.

Staining of the plating occurs frequently. One has to check if the stains are removable and if they have height. If the stains are removable one should remove them. If the stains are not removable and have no height and they are not in an area which makes contact they are not important. If they are in an area which makes contact one has to check the dc contact of the connection. If the stains have height, one must decide if the connector is still mechanically acceptable and if it is still electrically acceptable. Both questions are difficult to answer and no general rules can be given.

Dents result often from connections with dirty or damaged connectors. One finds often dents at the end of scratches. Sometimes dents can be bent back to a position where they can not harm the other connectors. Otherwise one can try to cut the dent with a razor blade. Dents on surfaces which do not make contact should be left as they are.

Particles have to be removed if possible.

Burrs may falsify pin depth measurements. They can be found on the tips of female contact fingers and on the shoulders of male pins. They should be left as they are if they do not cause the pin depth gage to show protrusion. Often they can be removed with a razor blade but this should be intented only if the device is unusable otherwise. The danger of completely destroying the device with this operation is quite high.

Center contact protrusion has usually a devastating effect on the connector. If center conductor protrusion is detected the connector has to be discarded. Combining two connectors with zero pin depth or very slight recession may cause electrically unrepeatable connections.

Excentric center conductors may be a consequence of mating with another damaged connector. If the center conductor is excentric one can try to bend it back into position. The danger of completely destroying the device with this operation is quite high. Thus try to do this only if the excentricity is above the allowable limit. The amount of allowable excentricity can be deduced from the dimensions and tolerances given for every connector in [3].

Spread of female contact fingers indicate mating with a damaged or non-fitting connector. You can try to bend the fingers back to position but this can as well result in breaking the female contact fingers.

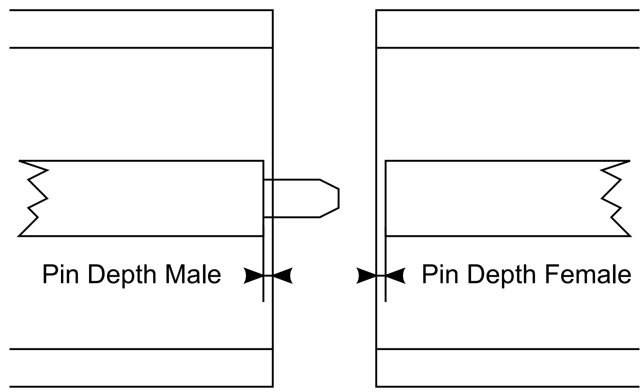


Figure 11: The recession of the center conductor is the pin depth of the individual half-connector. Note that for the N-type connector the definition is different, see [3].

For inspection one can use the following tools:

- Eyepieces or preferably stereo microscopes can be used for visual inspection. Damages and dirt are often not visible with the bare eyes.
- Sliding a toothpick over an area of interest provides information about the height profile. This gives often a better impression of the height of the defect than any image. The toothpick technique is especially important for assessing staining and scratches.
- Pin depth gauges are used to measure the pin depth, see Fig. 11, of each connector. All connectors should have negative pin depth. See [3] or the user manual of your device under test for what are admissible pin depth values.

3.2 Cleaning

Removing dirt from the connector is the most common task. There are several tools, see Fig. 12 to clean a connector:

- Dry compressed air can blow away loose dirt from the connector. The air should not contain any oil or moisture which can condense on the connector. The compressed air should be of ambient temperature because very cold or hot air thermally stresses components. Especially some types of loads suffer from extreme temperature changes. Thus it is not advisable to use cooling spray for cleaning.
- A lint-free cleaning cloth can be moistened with isopropyl alcohol. This cloth can be used to clean the threads of the connector. A new clean cloth can be used to clean the outer conductor mating surface. When cleaning the mating surface try to avoid contact with the center conductor.
- A wooden toothpick can be used to remove very resistant dirt. Wooden toothpicks can be cut to shape if necessary.
- Plastic picks can be used for cleaning the inside surfaces of female contact fingers. One has to be extremely careful not to bend the fingers in this process. For this reason one should rotate the cleaning tool only very slightly.
- Inner edges can be cleaned with a stick which is wrapped with a lint free cloth. Inner edges which have to be cleaned are present on the male center contact and on the female outer conductor.

After the cleaning procedure is completed blow away loose dirt and dry off remaining isopropyl alcohol.

3.3 Storage

Connectors should be stored in the following manner. Use a dry and well tempered place for storage. Extend the connector nut before storing the connector. Put a plastic cap over the connector to prevent dust coming in the connector. The caps protect as well the connectors from scratches. Do not store connectors loosely in a box. If you move the box the connectors will damage each other.

4 Making Connections

The working principle of the connectors described here is that the two half-connectors are pushed against each other by screw threads on both half-connectors. The screw threads have two purposes. First they convert the torque in forces which push the two halfes together and once the torquing stops they keep the forces and position.

4.1 Connecting

Making a good coaxial connection can be described as a list of actions:

Figure 12: These are accessories for cleaning connectors. In the center on can see a lint free cloth. On the right hand side of the cloth one can see a wooden toothpick and a with lint free cloth wrapped stick. On the left hand side of the cloth one can see plastic picks for cleaning female center conductors of N-Type, 3.5 mm, and 2.92 mm connectors. At the top border, one can see a plastic pick for cleaning the female center conductors of 2.4 mm and 1.85 mm connectors. In the corners one can see finger cots which are used for handling center conductors of beadless components.

1. Before the half-connectors touch each other, they should be aligned in such a way that the center axes of both halfes coincide.
2. Next the two halfes are pushed slightly together and the coupling nut is engaged in the first thread. From now on it is important not to rotate the two halfes with respect to each other. Rotating the connectors puts stress on the female contact fingers. This leads typically to defoliation of the plating on the male pin and on the female finger.
3. One torques the connector nut carefully by hand and provides a slight pulling force against the nut. Use the wrenches only for the final rotations.
4. One can feel how the female fingers engage the male pin. If one feels an unusual resistance during the mating process, one should immediately stop the mating process and examine both half-connectors for possible damage and dirt.

5. Once the two half-connectors are mated, one can start to torque the connection. During the torquing process one should take care not to rotate the half-connectors with respect to each other. Now in addition to the already mentioned damages of the center conductor, the outer conducting mating planes are stressed. Potentially present dirt will cause scratches here. For the torquing one uses the appropriate torque wrench, see Fig. 13 and 14, and additionally an usual wrench to provide counter momentum. The torque wrench and the normal wrench should be held as parallel as possible during the torquing process, see Fig. 15. The momentum exerted by both wrenches must be equal.

6. At the end of the torquing process the torque wrench starts to buckle. One can feel how the torque wrench mechanism starts to move. Completely stop torquing at the first clear sign of moving of the torque wrench mechanism. Do not seesaw the torque wrench. One movement is enough. There is one exception to this rule. The N-connector is more robust and connects better if the torquing motion is repeated three times. All other connectors require only one movement.

7. If the torque wrench buckles completely during the torquing process the connection has to be repeated because the complete buckling provides a undefined kickback.

4.2 Disconnecting

Disconnecting of coaxial connectors without damaging them can be achieved by the following list of actions.

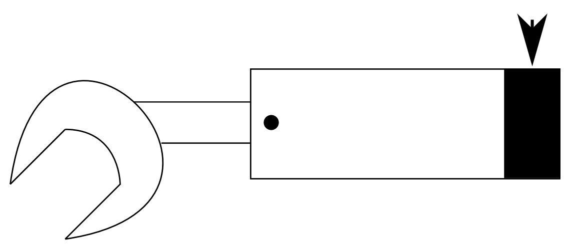


Figure 13: This is a torque wrench. Note that it can be used only in the direction indicated. Apply forces only in the black area at the end of the wrench. Do not push in the direction of the connection. This would increase the available torque. Do not pull out the handle. This would reduce the available torque.

1. First identify male and female part of the connection. For the 7 mm connector you have to find out from which side the coupling nut is used.

2. Determine if you need to rotate the coupling nut clockwise or anti-clockwise for opening the connection.

Figure 14: This are examples for torque wrenches. Note that there are different torques available for the same nut size.

3. Use two wrenches to open the connection slightly. The wrenches can be the same as were used for making the connection. The wrenches should be as parallel as possible during this operation, see Fig. 15. Do not rotate the half-connectors against each other. Apply exactly the same torque to both wrenches. Do at maximum one rotation of the nut with the wrench.
4. Remove the wrenches.
5. Completely open the nut with your hands and provide a push in force during opening. The push in force is important because the kick back which is produced during disengaging male and female center contact would otherwise hit the component. With the push in force applied it is absorbed by the thread lash. If there are lateral or bending forces on the connection you will feel that an increased torque is necessary to turn the nut. Remove these forces before opening the nut. Do not rotate the two halfes with respect to each other during this process.
6. Once the nut is open, the two half-connectors are disengaged. Make a straight continuous movement without rotation to disengage.
7. You can feel how the male pin and the female contact fingers disengage. If unusually strong or weak forces are necessary to disengage the connector you should inspect the connector before the next connection.

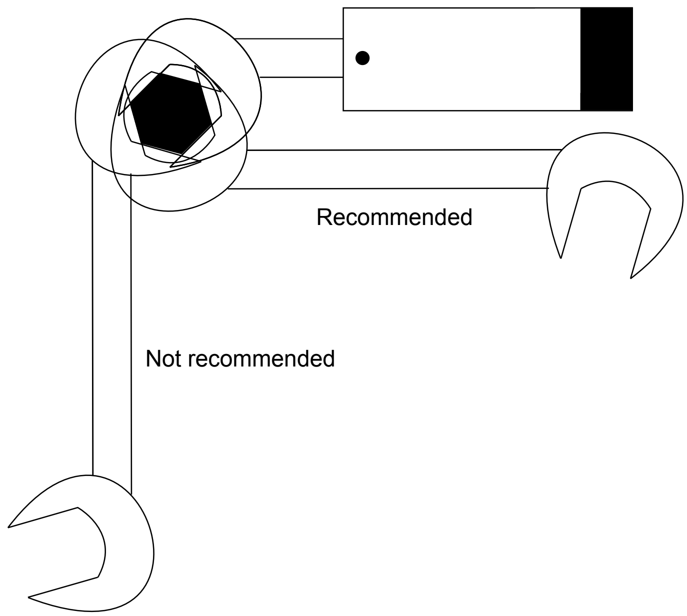


Figure 15: Position the wrenches always as parallel as possible. Do not torque in the position which is not recommended.

References

[1] Hewlett Packard. Connector care for rf & microwave coaxial connectors. Hewlett Packard Company, 1991.

[2] Doug Skinner. Anamet connector guide. National Physical Laboratory, 2001.

[3] IEEE Instrumentation and Measurement Society. *Standard for precision coaxial connectors DC to 110 GHz, IEEE P287*, Sep. 2007.