RF and Microwave Coaxial Cable and Connectors

Routing of RF and microwave signals with minimum loss and minimum reflections requires controlled impedance lines and connectors. This requires significantly more engineering effort than the simple point-to-point wiring of low frequency electronics. Once off of a printed circuit board, the most common transmission line for RF and microwave signals is the coaxial cable. These are also the standard means for getting signals into and out of various instruments and subassemblies. Connectors for coaxial cables also play a critical role, since they must maintain the controlled impedance of the transmission line while still providing connect and disconnect service.

Coaxial Cable

The most critical electrical parameters for specifying coaxial cable are: (1) the characteristic impedance $Z_0$, (2) the loss or attenuation per unit length $\alpha$, and (3) the voltage breakdown strength $BV$. In addition, there are the mechanical parameters of outside diameter $d_0$, tensile strength, and minimum bend radius.

The characteristic impedance of a coaxial cable, or any other transmission line, fundamentally gives the ratio of the electric to magnetic field strength of an electromagnetic wave propagating along the line. For a coaxial cable, the characteristic impedance is related to the inside and outside radii of the dielectric, $a$ and $b$, respectively, and the permittivity $\varepsilon$ and permeability $\mu$ of the dielectric material,

$$Z_0 = \frac{1}{2\pi} \sqrt{\frac{\mu}{\varepsilon}} \ln\left(\frac{b}{a}\right) = \frac{376.7 \Omega}{2\pi \sqrt{\varepsilon}} \ln\left(\frac{b}{a}\right).$$

The circuit parameters per unit length of the coaxial cable are

$$R' = \frac{R_s}{2\pi} \left(\frac{1}{a} + \frac{1}{b}\right) \quad \Omega/m, \quad L' = \frac{\mu}{2\pi} \ln\left(\frac{b}{a}\right) \quad H/m,$$

$$G' = \frac{2\pi \sigma}{\ln\left(\frac{b}{a}\right)} \quad S/m, \quad C' = \frac{2\pi \varepsilon}{\ln\left(\frac{b}{a}\right)} \quad F/m.$$ 

For most coaxial cable, the capacitance per unit length is around 30 pF/ft, and the inductance per unit length is around 100 nH/ft. The resistance per unit length is dominated by the smaller radius of the center conductor, but this is frequency dependent because of the skin effect which forces more of the conduction to the surface of the conductor as the frequency increases. The surface resistance for a conductor is defined from the skin effect as

$$R_s = \sqrt{\frac{\pi f \mu}{\varepsilon}} \quad \Omega.$$

Aside from the resistance per unit length which is reduced for larger diameter center conductors, the electrical transmission parameters of a coaxial cable depend only upon the ratio of the outside to inside radii of the dielectric, $\ln(b/a)$. For transmitting higher power levels, reduced series resistance is desired which dictates a larger center conductor, $a$. Increasing $a$ then demands that $b$ grow in proportion to maintain the characteristic impedance, and $b$ is what fundamentally limits the outer diameter of the coaxial cable. Higher power levels also produce larger voltages and the dielectric must be able to withstand these. Increasing the dielectric radii of $a$ and $b$ in proportion also increases the thickness of the dielectric, $b - a$, and this also motivates a larger coaxial cable diameter for handling higher power levels. The downside to larger diameter coaxial cables is of course their added bulk and limited bend radius. When used across aerial spans, the tensile strength of the coaxial cable also becomes a design issue. For
long spans where the weight of the cable might exceed its own tensile strength, a steel cable is usually included to provide the additional tensile support between towers.

Coaxial cable is available in many different standard specifications. These specifications were originally set forth in military standard MIL-HDBK-216, published in 1962, and which have now been replaced by military standard MIL-C-17. Most of these coaxial cable types carry a designation such as RG-58A/U. The RG-xx/U stands for Radio Guide / Universal. The A indicates an improved sub-type that was introduced later. There are several hundred different types described in the standard, but only a few of these are likely to be encountered in common usage. Only the most common ones are described here.

**Type RG-6/U.**

This is a 75 Ω cable that is used mainly for long runs of cable television distribution. It uses a solid #20 AWG center conductor which is compatible with type F connectors. It is double shielded and has an outside diameter of 0.275 inches. This makes it a little bit thicker and more robust than RG59/U, the other 75 Ω alternative for cable television distribution.

**Type RG-8/U.**

This is a 50 Ω cable that is generally used for higher power transmission. It is usually rated up to at least 600 V, and is capable of handling up to several kW of power. Its thicker outside diameter of 0.405 inches makes it rather bulky and only compatible with type N or C connectors. It is very robust due to its physical size, and is often used in amateur radio and higher power laboratory work. When used for 10BASE5 data communications, it is often referred to as thicknet cable.

**Types RG-58/U, RG-58A/U, and RG-58C/U.**

By far, the most commonly used coaxial cable in laboratory electronics is type RG58/U or one of its sub-types, A or C. It is a 50 Ω cable with an outside diameter of 0.195 inches. The base type RG-58/U uses a #18 AWG solid copper center conductor with a foamed polyethylene (FPE) dielectric and a tinned copper braided shield that is covered by another layer of foil. This is then enclosed in a PVC class 1 jacket. It is rated to 300 Volts, and it has a typical loss of 0.3 dB/100 ft at 1 MHz, increasing as the square root of frequency to about 10 dB/100 ft at 1 GHz.

More commonly, one of the improved sub-types, either RG-58A/U or RG-58C/U are used today. These replace the FPE dielectric with higher density polyethylene (PE), reduce the center conductor to #20 stranded tinned copper, and substitute a single braided copper shield without the additional foil wrapper. This results in much higher voltage ratings of 1400 to 1900 Volts, depending on the manufacturer, a more flexible cable, and a lower velocity factor of 0.66. These sub-types have higher loss, typically about 0.4 dB/100 ft at 1 MHz and 22 dB/100 ft at 1 GHz. As a general rule of thumb, the higher the molecular density of the dielectric material, the higher the permittivity, the lower the velocity factor, and the greater the loss per unit length.

As a caution, there are a few RG-58/U manufacturer types which are actually 52 or 53 Ω instead of the nominal 50 Ω. For low frequency electronics, this hardly makes any difference, but for 10 MHz and above, the non-50 Ω versions will produce unwanted reflections in 50 Ω systems. Simply specifying RG-58/U does not guarantee getting 50 Ω cable, so the manufacturer’s data sheet needs to be consulted. Usually, the best choice for good, but not precision RF and microwave use is RG-58C/U. This is typically the more premium version of all of the RG-58/U types.

**Type RG-59/U.**

This is the other most common 75 Ω cable which is most often seen in cable television distribution. It is slightly thinner than RG-6/U with an outside diameter of 0.242 inches, but only rated up to 300 Volts. The center conductor is #20 solid copper, making it compatible with type F connectors. It has a velocity factor of 0.66 and a loss of about 0.6 dB/100 ft at 1 MHz and 12 dB/100 ft at 1 GHz. Compared to RG-
58/U, both of the 75 Ω RG-6/U and RG-59/U cables are noticeably thicker in diameter, which is a visual clue that the cable might not be 50 Ω. But when in doubt, read the type number which is stenciled on the cable jacket.

**Type RG-174/U.**

This is a 50 Ω cable that offers a much thinner and more flexible alternative to RG-58/U with an outside diameter of only 0.110 inches. Most modern oscilloscope probes use RG-174/U for these features. There are two common manufacturer versions of this. One version uses a foamed polyethylene (FPE) dielectric which gives a velocity factor of 0.735, a voltage rating of 300 V, and a loss of 0.6 dB/100 ft at 1 MHz and 22 dB/100 ft at 1 GHz. The second version uses a higher density polyethylene (PE) dielectric which gives a velocity factor of 0.66, a voltage rating of 1100 V, and an increased loss of 1.9 dB/100 ft at 1 MHz and 34 dB/100 ft at 1 GHz.

A comparison of some typical cable and connector combinations is shown below in Fig. 1. A good summary of the coaxial cable RG-xx/U specifications can be found in the ARRL Handbook, the bible for radio amateurs, and treasure trove of other good, reliable information for everyone else.

![Figure 1. A relative comparison of coaxial cable and connector combinations. Left to right: (1) Type RG8A/U cable with a type N connector; (2) Type RG58A/U cable with a type BNC connector; (3) Type RG174A/U cable with a type BNC connector; (4) Type RG58C/U cable with a type SMA connector; (5) Type RG-142/U cable with a type SMB right angle connector.](image)

**Coaxial Connectors**

There exists an enormous variety of coaxial connectors, literally hundreds, but there are a few which are particularly common in RF and microwave use, and for which any electrical engineer should become familiar. For RF and microwave use, different connector types have limits upon the maximum frequency at which they can provide a low reflection, low attenuation connection, limits upon the maximum voltage that they can safely hold off, and limits upon the precision of their mechanical parts which impacts how electrically transparent they behave and how accurately one can define reference planes at their connection points. In all cases, these limits are guidelines.

Since electrical connectors nearly always involve some fashion of mating pin and socket to make contact, connectors have gender. Male (m) connectors have the pin, and female (f) connectors have the socket. Whether the connector insulator is an ‘innie’ or an ‘outie’ does not matter, nor does the mechanical manner of attachment, i.e. whether it screws into or screws over the mating connector. The only thing that matters for determining gender is the presence of either a center pin or a socket. In specifying
connectors, a suffix of m or f is commonly added to eliminate any confusion as to which half of the connection is being referred to. While there are some rare exceptions, instruments and larger chassis use the female connector. The interconnecting cables are nearly always terminated in the male connector.

One subtle point concerning connectors is the order in which the conductors make contact upon attachment. The strongly encouraged practice is for the outer shield conductor to be at ground or close to it, and have the higher voltage appear on the center conductor. In this manner, the shield not only electrostatically isolates the center conductor from interference, but it also shields the outside world from the possibly high voltage of the center conductor. When connecting high voltage cables, it is obviously desirable for the grounded shields to be connected first, thereby establishing the safety return paths for any faults. However, not all coaxial connectors do this. Interestingly, the extended center pin and its insulator in a type MHV connector allows the center conductor to make contact prior to the outer shield. This is one reason that type SHV connectors are preferred, since they insure that the shields are connected before the center pins connect. When working with high voltage systems, this is always a good point to check, since it not obvious from the data sheets or just inspecting the connectors.

The short summary below lists a number of common coaxial connector types. For most RF and microwave use, the three most important ones to become familiar with are the type N, type SMA, and type BNC. These three will cover at least 95 percent of the circumstances.

**Type N.**

![Type N male and female connectors.](image)

The type N connector is very widely used for RF and microwave. It was invented in the 1940s by Paul Neill of Bell Laboratories, for whom the connector is named. The type N connector is of medium size and uses a 5/8-24 thread for mechanical attachment. The connector is very robust, nearly unbreakable, and for this reason it is favored for use on most RF and microwave instruments. While the connector was originally designed only for use up to 1 GHz, modern precision manufacturing builds these to tolerances which easily extend the useful frequency range up to 10-12 GHz, and there are some proprietary designs which can go higher still. The power handling capacity of the type N connector is around 5 kW for frequencies of 20 MHz and less, with derating to about 500 W at 2 GHz to account for skin depth losses. Type N connectors come in both 50 and 75 Ω versions. While the outside bodies are identical, the inside pins are different diameters, making the two versions not quite interchangeable. The male connector has a freely spinning knurled nut that screws over the female connector. There are no flats for a wrench on the male nut; if the threads are clean it only needs to be tightened finger tight, which is typically about 10-20 inch-pounds of torque. The male type N connector contains a rubber gasket (the red material shown in Fig. 2) which seals the shell of the female connector when the two are assembled, protecting all of the
electrically contacting surfaces. The type N connector is therefore considered a weatherproof connector because of this sealing feature.

**Type C.**

The type C connector is very similar in performance to the type N. It also dates back to the 1940s, but it was invented by Carl Concelman at Amphenol, for whom the connector is named. It is also good up to about 10-12 GHz, up to about 5 kW, and comes in both 50 and 75 Ω versions. The distinguishing difference between an N and a C connector is that the C connector uses a faster-acting bayonet attachment which only requires slipping the two mating parts together and turning the male nut a quarter of a turn. Bayonet mounts can be recognized by the two small pins on the outside of the female shell, and only require a quick spin of the male nut to align its slots to the positions of these pins. Type C connectors are becoming more rare these days, but can still be found on many pieces of older RF equipment.

**Type BNC.**

![Type BNC male and female connectors.](image)

Perhaps the most ubiquitous coaxial connector in the world of electronics is the type BNC. The name stands for Bayonet-Neill-Concelman, named after the pair of Neill and Concelman who led its development back in the late 1940s. It is considered a miniature connector, so it can only be used with coaxial cable whose outside diameter is about 0.28 inches or less. Its primary attribute is its fast attachment by means of the quarter-turn, two-pin bayonet mount. Like the type N and C connectors, the BNC features a rubber gasket inside the male nut which seals the shell of the female connector, protecting the connection surfaces from weather and moisture. The type BNC connector is generally good up to about 2-4 GHz and up to 500 Volts. Type BNC connectors come in 50 and 75 Ω versions, but they are mechanically interchangeable. The two versions are only slightly different, and mismatch effects are only noticeable above 500 MHz or so.

BNC connectors are the de-facto standard for nearly all low-frequency electronic instruments and test equipment. They are used on signal generators, signal analyzers, and most notably, as the standard input connector for all oscilloscopes. There are many variations on the basic BNC connector, but the base design remains the same, which allows for wide interchangeability in cables and probes.

As a note of caution, there are a few coaxial connectors which look remarkably similar to a BNC, but which are mechanically and electrically incompatible. These include the MHV and SHV high voltage connectors and the Triax active guard coaxial connector. Each of these are readily identifiable to those who know about them, but are often mistaken for BNC connectors by novices. A good rule of thumb is that if the two connectors don’t seem fit properly, then they probably were not meant to.
connectors are manufactured to extremely tight tolerances, and it exceeding rare to get a bad one which fits poorly.

**Type TNC.**

The type TNC connector is identical in all respects to a BNC except that it uses a 7/16-28 threaded nut in place of the two-pin bayonet mount. The name stands for Threaded-Neill-Concelman, and it was developed in the late 1950s. The type TNC connector is much less commonly used than the BNC, but it provides a slightly improved mechanical attachment and better weatherproofing at the expense of more turning of the male nut to assemble and disassemble the connection. The type TNC and type BNC connectors have identical electrical specifications. Type TNC connectors also come in both 50 Ω and 75 Ω versions.

**Type UHF.**

The type UHF connector dates back to World War II, and it was developed essentially as a shielded banana plug for use in early radar systems. It is the least expensive connector type that can handle up to a few kW of power, but its less precise manufacture and electromagnetically leaky geometry generally limit its use up to around 300-400 MHz. The name stands for Ultra-High Frequency, the nomenclature of the time which meant anything above 30 MHz. Type UHF connectors remain very popular for home antennas and ham radio installations operating at 150 MHz (2 meters) and below. Type UHF connectors
use a 5/8-24 threaded nut on the male connector, and the female is connector is most recognizable by the triangular serrations on the edge of the shell which fit to a pair of triangular points inside the male connector. These serrations limit rotation of the connectors if the male nut is not fully tightened. Type UHF connectors are designed to be connected only finger tight, as evident from the knurled male nut. Unlike the type N connector, the type UHF connector does not employ any sealing gasket, so it is not classified as a weatherproof connector.

**Type mini UHF.**

![Figure 6. Type mini-UHF male and female connectors.](image)

The type mini-UHF connector is simply a down-sized version of the type UHF connector. It uses a 3/8-24 nut on the male connector, and its smaller size allows it to be used up to about 2.5 GHz.

**Type SMA.**

![Figure 7. Type SMA male and female connectors.](image)

The type SMA connector is extremely popular for RF and microwave systems, and it is also very commonly found on test equipment interfaces. The name stands for Sub-Miniature version A. It is the de-facto standard for a great deal of microwave plumbing, up to its typical frequency limit of around 18 GHz. Precision versions of the type SMA connector can operate up to 26.5 GHz. The male connector uses a 1/4-36 threaded nut which incorporates a rubber sealing gasket. The male nut has flats for a 5/16 wrench, although the torque specification is usually only 5-10 inch-pounds, which is effectively finger tight. Note that the male connector uses a female threaded nut, sometimes leading to naming confusion.
There does exist a reverse polarity SMA connector, usually denoted RP-SMA, in which the male connector has the male threads for the female nut on the female connector to thread on to. These are fairly rare, but when they do occur, they usually employ a built-in female threaded coupling nut so that a simple female-female SMA adapter barrel can be used to convert the RP-SMA male over to a more common SMAf. Such an example is shown in Fig. 8.

![Figure 8. A type RP-SMA male connector on a Hewlett-Packard 5351B microwave frequency counter.](image)

**Type SMB.**

The type SMB connector is very popular for where there is restricted space around the connector, such as on PCB board or instrument back panel. The name stands for Sub-Miniature version B. Type SMB connectors are push-on, pull-off, and they use a small detent ring on the male connector into which a spring clip inside the female shell drops to lock the pair together. The pair is disassembled by simply pulling the female connector up with a slight twist. Type SMB connectors are generally rated to about 4 GHz, and like most of the other coaxial RF and microwave connectors, they come in both 50 and 75 Ω versions. Type SMB connectors are one of the few for which the male connector, with the pin, is usually the one which is mounted to the panel of an instrument or chassis.

![Figure 9. Type SMB male connectors on a Tektronix 7D15 frequency counter plug-in module.](image)

**Type SMC.**
The type SMC is a much less common connector than the SMA or SMB, and it uses a combination of the two, both a smooth upper barrel with a #10-32 threaded lower base. The name stands for, logically enough, Sub-Miniature version C. The type SMC has nearly as compact as a type SMB, but the threaded nut on the female connector produces a more robust mechanical attachment.

**Type F.**

![Type F male and female connectors.](image1)

The type F connector is very inexpensive and used most frequently for 75 Ω cable television interconnects. It dates back to the mid-1950s. Type F connectors are generally rated up to about 1 GHz, and they can handle up to a few 100 W of RF power. Type F connectors use a 3/8-32 threaded nut on the male connector with 7/16 inch flats for a wrench. They do not provide any sealing gasket, so they are not considered weatherproof, in spite of the large number of which appear on the outside of residential homes and apartment complexes. The type F connector is unique by using the solid center conductor of the coaxial cable itself as the center pin for the male connector. This allows the male connector to be very quickly assembled onto the end of a freshly cut section of coaxial cable with only simple crimping tools, making it very efficient for use by cable TV installers. By the same token, the connection is fairly leaky for RF emissions and interference pick up. Type F connectors are nearly always used with 75 Ω type RG-6/U or RG-59/U coaxial cable because of the need for the center conductor to be solid and with a specific diameter, #20 AWG.

**Type RCA.**

![Type RCA male and female connectors.](image2)
The type RCA connector, more commonly known as a phono plug connector, is widely used in audio-video equipment. It is frequently color coded for different channels, e.g. red for right audio, white for left audio, and yellow for composite video. It was developed by the Radio Corporation of America (RCA) back in the 1940s. Its frequency range is limited to only about 100 MHz. It is a push-on, pull-off connector with the mechanical attachment simply friction between the male sleeve and the female barrel. The male pin is 1/8 inch diameter, and the female barrel is 21/64 inch diameter. Because of its limitation to rather low frequencies, it is rarely used in any RF or microwave applications.

**Type MHV.**

The type MHV connector looks very similar to a type BNC, both have identical two-pin bayonet mounts, but the interior insulators are extended further to provide better protection for high voltage use. The name stands for Miniature High Voltage connector. The type MHV is not mechanically compatible with the type BNC; however, the two are close enough that they can be forcibly mated together. This is obviously not recommended, since the type BNC is not rated to the same 5 kV and 3 A level as the type MHV connector. One of the unfortunate features of the MHV connector is that the center conductors make contact prior to the shields upon assembly. This offers the possibility of applying a high voltage on the center conductor to the equipment downstream before the return ground is established. For these reasons, the MHV connector is less preferred to the SHV connector which overcomes these problems.

**Type SHV.**

The type SHV connector also uses a two-pin bayonet mount which is identical in dimensions to the type BNC and MHV connectors. However, the interior insulators extend much farther out and eliminate any possibility of mixing a type SHV connector with any other type. The name stands for Safe High Voltage connector. The type SHV connector is usually rated to at least 5 kV and 5 A, although there exist some proprietary design variations which can handle upward of 20 kV. Type SHV connectors are most commonly found on the high voltage power supplies for gas lasers, the flyback transformers for some CRTs, and the high voltage power supply pin for photomultiplier tubes, vacuum ionization gauges, and Geiger-Muller radiation detection tubes. The type SHV and MHV connectors have the same voltage rating; the type SHV is simply the “safer” version to use, although slightly more bulky due to its length.

**Type GR874.**

![Figure 12. Three type GR874 connectors on a Tektronix type 109 transmission line pulse generator.](image)

The type GR874 connector was developed by General Radio and is found in test equipment from the 1960s and 1970s. It is rather unique connector because it is hermaphroditic or genderless – any connector can mate to any other connector – there are no male or female versions. The pin and shell of the GR874
each consist of four leaves; two which contact on the inside diameter and two which contact on the outside diameter. Two GR874 connectors, rotated 90° to each other will thus have their leaves overlap, mating the two connectors together. No tools are required; the attachment is purely a slip fit between the two connectors. The GR874 connector is quite good in terms of presenting low attenuation and minimal reflections. It is typically usable up to about 10 GHz, and can easily handle up to several kW of power. Precision metrology versions of the connector were developed, but these did not come into widespread use before other connectors were developed for the precision measurement field. The GR874 is rarely found in use today, but it is an example of some splendid engineering from a bygone era.

**Type APC-7.00mm.**

![Type APC-7.00mm connectors on an S-parameter test set.](image)

The type APC-7.00mm connector wins the award for the world's most confusing connector. It is also one of the highest performance and most beautifully engineered connectors around – once its operation is understood. The name stands for Amphenol Precision Connector – 7.00 mm. The APC-7.00mm was originally designed by Hewlett-Packard, and was then improved and manufactured by Amphenol. Type APC-7.00mm connectors are extremely high precision components; each connector typically costs $100 to $250. The APC-7.00mm connector is extremely good up to 18 GHz, offering as little as 1.025:1 VSWR and a reflection coefficient that is repeatable to within ±0.001. Type APC-7.00mm connectors have been the standard for metrology laboratories where extremely precise calibration is required.

What makes the APC-7.00mm connectors confusing is how they are mated together. The APC-7.00mm is also a hermaphroditic or genderless connector, yet it employs a threaded ring that pulls the flat faces of the connector together. Each APC-7.00mm connector contains one of these threaded rings, and the external nut can be spun down to retract the threaded ring completely into the body of the connector, or spun the other direction to extend the threaded ring completely. To mate two APC-7.00mm connectors together, the external nuts are spun to fully retract the threaded ring on one connector and to fully extend the threaded ring on the other. The two connectors can then be fitted together, and the external nut on the connector with the retracted threaded ring will engage the threaded ring on the other which is extended. Simply tightening this nut up against the nut on the other connector secures the attachment. Figure 14 shows the same APC-7.00mm connector with the threaded ring extended and retracted. The APC-7.00mm connectors do not employ any overlapping pins or sockets to make the electrical connections. The connection for both the shield and center conductor is by face-to-face contact of the two surfaces. Insuring that both of these are precisely at the proper distance is one reason for the high cost of these connectors. These connectors are usually machined to tolerances of ±0.001 inches. The fact that each connector terminates in a perfectly flat face is also one of its great advantages. This flat face perfectly defines a reference plane which would otherwise be indistinct for other connectors with
insertable pin and socket connections. In the metrology lab, this is provides an enormous advantage for calibration.

There are several common questions that get raised concerning the APC-7.00mm connectors. First, yes, they can be repaired, but it requires some special wrenches to open the body, as well as the replacement parts. Nevertheless, the parts are fairly interchangeable, even between manufacturers, due to the precision machining by which they are made. Second, yes, the APC-7.00mm connector does pass DC current. Because there is no overlapping pin and socket, only a face-to-face abutment of the contacts, concern is sometimes raised about current capacity of the center conductor. For currents of only a few mA or less, there is no issue. For those rare circumstances where higher currents must be carried with reduced resistive losses from the contact faces, it is possible to insert a small pin which will mate to the female sockets of each connector. However, at high frequencies, the current will be carried predominantly on the outside periphery of the center conductor, making this technique less effective. The type APC-7.00mm connectors are not designed for power levels much above a few hundred Watts.

Figure 14. A type APC-7.00mm connector with the threaded ring extended and retracted.

Types 3.5 mm, 2.92 mm, 2.4 mm, and 1.85 mm.

For frequencies of 18 GHz and above, there exists a continuously developing selection of different coaxial cables and connectors which are designed to provide the required low loss and minimum reflections in these millimeter wave frequencies. Some of the more popular choices include the 3.5 mm, 2.92 mm, 2.4 mm, and 1.85 mm connector families. In most cases, these physically resemble smaller versions of the type SMA connector. At these higher frequencies, the primary loss mechanism is dielectric absorption. Nearly all insulating materials present some level of dielectric absorption within the microwave to millimeter wave range, so there are no outstanding material choices to eliminate this problem, short of returning to old-fashioned air lines or metal waveguide. The general strategy for frequencies in this range is to simply minimize the amount of dielectric in the cable and connectors, which translates into smaller diameters. This is what has generally motivated the progression from 3.5 mm to 1.85 mm interconnects. It is a safe bet that future coaxial cables and connectors will become smaller still as the move toward 100 GHz and beyond continues.

Type Triax.
Figure 15. Two Triax connectors on a source-monitor unit (SMU). Paired up in this configuration, the two Triax connectors together form what is known as a Quadrax connector. A single Quadrax connector housing slips over and contacts both Triax connectors at once. The small threaded boss between the two Triax connectors mates to a long thumb screw of the Quadrax housing to secure the connection.

Triax connectors have an outer shell which is identical in dimensions to a type BNC. However, the interior is completely different by containing an active guard ring around the center conductor, in addition to the outer shield conductor. Triax and BNC connectors are completely incompatible, both mechanically and electrically. It is two versus three conductors, after all. Triax connectors and triax coaxial cable are not designed for use at frequencies higher than about 1 GHz, but are instead engineered for extremely low leakage. In typical use, the outer coaxial shield conductor of the Triax is used as an electrostatic ground while the inner coaxial guard conductor is driven by a voltage follower which brings it to the potential of the center conductor. Current only flows through the center conductor, but because the center conductor and the inner coaxial guard conductor are held to the same potential, no leakage current can flow between the center conductor and the guard. Triax connectors and cable are used mainly in semiconductor parameter analyzers, electrometers, and picoammeters where currents in the range of nanoamperes down to femtoamperes must be accurately measured.

Hewlett-Packard and now Agilent have always used a three-pin bayonet mount for the Triax connector. Keithley originally used a two-pin bayonet mount which was identical to the type BNC. This is still found on some of their older electrometers. Because of the confusion with type BNC connectors, Keithley has since switched to the three-pin bayonet mount which makes the Triax connector more obvious. There exist Triax adapters which convert the two-pin bayonet to the three-pin, and vice-versa, although they usually cost around $200 each. Triax cables and connectors are an excellent and effective solution for minimizing leakage currents. Since the market for these is small, one should expect to pay exorbitant prices for these components, though.

Rev. 0.0, R. B. Darling, 2013 Dec 7