Choosing the Right Coaxial Cable Assembly for Your Application

White Paper

Abstract

The coaxial cable is among the most commonly used transmission lines with optimal broadband performance for applications well into the W-band. The use cases for coaxial cable assemblies are numerous and varied in nature. This whitepaper dives into some of the basics of coaxial cables, their various performance parameters, and the constructional variants within the cable and connector heads.

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The Basics of Coax

Coaxial transmission

The coaxial line exhibits the desirable transverse electromagnetic (TEM) transmission where the E-field and H-field components are all transverse, or perpendicular, to the direction of wave propagation (z-direction). The characteristic impedance of a coaxial cable can be seen in **Equation 1.1**.

$$Z_0 = \frac{1}{\sqrt{\varepsilon_R}} 138 log_{10}(\frac{D}{d})$$

Equation 1.1

Where ε_r is the relative permittivity/dielectric constant of the dielectric material, D is the inner diameter of the outer conductor, and d is the outer diameter of the inner conductor. The cross sections of the coax can be seen in **Figure 1.1**. The TEM transmission of the coaxial transmission line allows for an extremely broad, mode-free bandwidth. The characteristic impedance can be adjusted by changing the cross-sectional dimensions of the coax. However, generally speaking, the higher the frequency, the smaller the cross-sectional dimension of the coax becomes to support mode-free transmission of the signal.

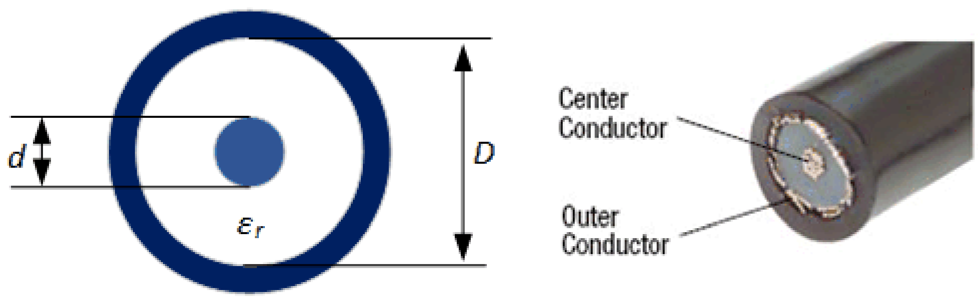

Figure 1.1

Intrinsic sources of loss

The inherent sources of loss in a coaxial cable are generally contributed by two factors:

- Dielectric losses (loss tangent and relative permittivity)
- Resistive losses in metallic conductors

The dielectric losses are expressed in **Equation 1.2** where L_d is the loss due to the dielectric, f the frequency, tanδ the loss tangent, ε_r is the relative permittivity/dielectric constant and c the speed of light[1].

$$L_d = \frac{\pi f}{c} * tan\delta\sqrt{\varepsilon_r}$$

Equation 1.2

As shown in **Table 1.1**, these losses can be minimized through the choice of the dielectric where low density, expanded, microporous, foamed, and air-spaced type dielectric materials exhibit a far lower dielectric constant and loss tangent than their high-density counterparts. The additional benefit of foamed dielectric materials is they also have an inherently better phase stability over temperature fluctuations. Velocity of Propagation (V_P) is a more common parameter found on cable datasheets and is discussed in later section.

Table 1.1 *Relative Permittivity of Dielectric Materials*		
Dielectric Material	*Relative Permittivity*	*Vp*
Air	~1	100%
High Density PE	2.34	65%
Low Density PE	2.28	66%
Foamed PE	1.6	79%
FEP	2.15	68%
Cellular FEP	1.22	91%
PTFE	2.1	69%
ePTFE	1.3	88%

Table 1.1

Losses in the inner and outer conductors can be seen in **Equation 1.3** where L_R is the resistive loss of the conductors, d and D are the diameters of the inner and outer conductors, σ_{in} and σ_{out} are the conductivity of the inner and outer conductors and µin and µout are the permeability of the inner and outer conductors. As made apparent by this equation, larger diameters limit resistive losses and also allow for a high cable power handling due to the larger surface area of the conductive materials. Low loss cables for cell tower installations or distributed antenna systems (DAS) for large indoor structures (e.g., stadium, subway, office building, etc.) are often wider in its inner and outer conductor dimensions.

$$L_R = \sqrt{\frac{f}{\pi}}\left(\frac{1}{d}\sqrt{\frac{\mu_{in}}{\sigma_{in}}} + \frac{1}{D}\sqrt{\frac{\mu_{out}}{\sigma_{out}}}\right)$$

Equation 1.3

Extrinsic sources of loss

There are a number of extrinsic sources of loss on a coaxial cable that can cause severe performance degradation including:

- Mechanical strain on cable (e.g., bending, torsion, shear forces)
- Mechanical strain on connector (e.g., improper mating, bending at joint between connector and cable)
- Environmental strain (e.g., extreme temperature fluctuations, UV radiation, etc.)

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Mechanical strains

Industrial environments or outdoor telecom coaxial installations can cause a coaxial run to experience various mechanical strains. More often than not, inconsistent performance typically occurs from frequent bends, hence the common use of the “flex cycle” measurement parameter. In reality, a dynamic loading scenario occurs on the coaxial assembly based upon the various types of bends and twists that can occur due to the handling and installation environment (See **Figure 1.2**).

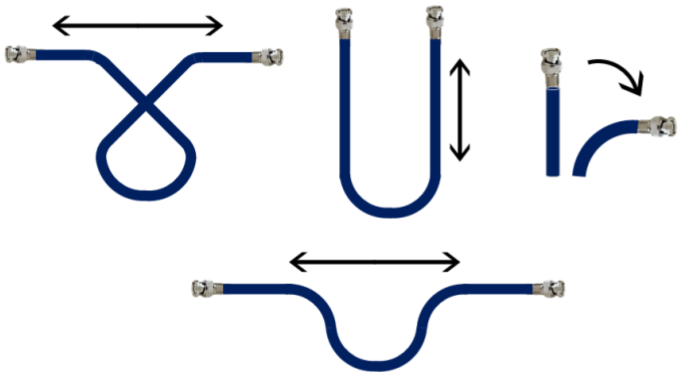

Figure 1.2:
Cables can be bent, pulled, or twisted during installation causing damage.

Outdoor coaxial installations subject to shear wind forces, cables attached to automated test equipment (ATE), the frequently leveraged test cables in an engineering lab, and cables stored in tight bends are all examples of a cable that may experience flexure and vibrational stresses. **Equation 1.4** is the bend stress equation for a cylindrical beam of homogeneous material where E is the elastic modulus, y is the distance to the neutral axis, and R is the bend radius. The neutral axis typically runs along the center of the inner conductor.

$$\sigma = E\frac{y}{R}$$

Equation 1.4

It is understood that coaxes are composed of a number of various materials so this basic equation would not take into account the interaction between the inner conductor, dielectric, shielding, and jacketing interfaces during a stress event. However, it does illuminate how the stresses tend to increase under three conditions:

- With a material with a low elastic modulus
- the further away from the neutral axis
- the tighter the bend radius

Since the inner and outer conductors have a much higher elastic modulus than the dielectric, the bend stresses would ultimately cause more strain on those materials. Moreover, the shielding is the furthest away from the neutral axis and would therefore experience the highest load in the event of a tighter bend or repeated flexures. Therefore, it follows that a thinner cable construction would yield an inherently more flexible coax. In this case, a tighter bend and more frequent bends would not alter performance as rapidly as it would for a thicker coaxial assembly. And, when combined with a phase stable low density dielectric material, there would be more inherent phase stability mitigating any losses. Some cables are available in double-shielded versions, such as RG178-DS.

Mechanical strain can also come in the form of shear (transversal) or torsional forces. This can occur from mishandling during a mate where the cable is twisted causing undue strains on the assembly. The equation for shear stress on a solid cylindrical bar is shown in **Equation 1.5**.

$$\frac{\tau}{r} = \frac{T}{J} = \frac{G\theta}{L}$$

Equation 1.5

Where τ is torsional/shear stress (MPa), r is the radius of the beam (mm), T is the torque (Nmm), J is the polar moment of inertia (mm4), G is the shearing modulus (MPa), L is the length under twist (mm), and θ is the degree of twist (rad). A mishandled coaxial cable that is subject to excessive torsional and shearing strains (e.g., rodent chewing, human step, vehicle run over, etc.) could cause a kink in the inner conductor, dielectric, and shielding. This would cause an immediate jump in attenuation and cable failure. In, for instance, a cellular installation to an antenna with a high port density where cable mating is toughest, an excessive torquing with wind forces and vibrational strain can rapidly decrease the operational lifetime of the cable.

Environmental strains

Environmental stressors can vary and include outdoor strains such as wind forces causing vibrations, UV damage to cable jacketing, water ingress in direct burial applications, salt fog/spray in marine applications and power surges caused by lightning strikes for long coaxial runs in telecom applications. Industrial environmental stressors might include exposure to damaging corrosive and non-corrosive chemicals such hydraulic fluid, brake fluid, and oils. Each of these applications has with it, its own respective constructional considerations in order to best protect the cable from damage. Damage from UV, water ingress, and chemical exposure could cause the jacketing material to swell, melt or crack, exposing the internal transmission line and subjecting it to harmful environmental agents that would lead to an eventual failure. A long coaxial run that is exposed to a lightning strike in the vicinity can act as an antenna, carrying a power surge causing EMI for sensitive nearby/connected electronic equipment. For this reason, coaxial surge protectors are typically used with outdoor installed cables, and are particularly effective in arresting the harmful effects of surges.

Basic coax parameters found on datasheets

Electrical Parameters

Typical datasheet parameters include insertion loss/attenuation and VSWR with additional parameters such as velocity of propagation, shielding effectiveness, group delay, capacitance, power handling, phase stability, mating cycles, and bend cycles (**Figure 1.3**). The use of these additional parameters depends heavily upon the application -- a low loss cable for cellular installation may specify insertion loss per unit length, or attenuation, while a precision, phase stable test cable would specify phase stability.

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Electrical Specifications

Description	Min	Typ	Max	Units
Frequency Range	DC		18	GHz
VSWR			1.25:1	
Velocity of Propagation		70		%
RF Shielding	90			dB
Capacitance		29.4 [96.46]		pF/ft [pF/m]
Phase Stability with Flexure		±2		Degrees

Performance by Frequency

Description	F1	F2	F3	F4	F5	Units
Frequency	6	12	18			GHz
Insertion Loss (Max.)	0.28 [0.92]	0.41 [1.35]	0.52 [1.71]			dB/ft [dB/m]
VSWR (Max.)	1.25:1	1.25:1	1.25:1			
Power Handling (Max.)			88			Watts

Figure 1.3:
Sample datasheet parameters

The insertion loss is a measure of the loss of signal when propagating from the input to the output of the two-port cable, this parameter translates directly to the S-parameter S_{21}. Since a coaxial cable is a passive device, the parameters S_{21} and S_{12} are ideally the same -- for this reason, the S_{12} data is typically neglected and not seen on datasheets. The two-port s-parameter data also grants information on the return loss (S_{11}, S_{22}), or the ratio of the power sent down a transmission line to the power reflected back the source. The Voltage Standing Wave Ratio (VSWR) is the ratio of the maximum to the minimum voltage of a standing wave and is correlated to the return loss via **Equation 1.6**.

$$VSWR = \frac{1+|S_{11}|}{1-|S_{11}|}$$

Equation 1.6

The VSWR is always a positive integer and is expressed in a ratio against 1 (e.g., 1.3:1) where a 1:1 ratio is considered ideal. In other words, a transmission line with a VSWR of 1:1, does not reflect any power back at the source and all of it is transmitted through, while an infinite VSWR means all the power is reflected back at the source and nothing is transmitted through the transmission line. **Figure 1.4** shows typical VNA s-parameter data for a precision coaxial cable up to 50 GHz.

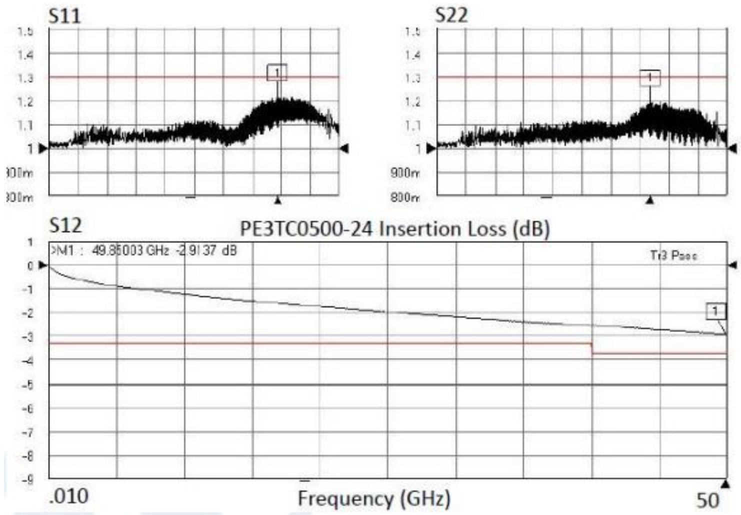

Figure 1.4:
Sample s-parameter VNA plots for a precision coaxial cable.

Group delay is the derivative of phase versus frequency or a rough estimation of the time it takes for a pulse to arrive from the source to the receiver along the length of the coax. Group delay flatness is a measure of the variation in group delay. The velocity of propagation V_P is the speed at which a signal propagates through the coaxial path and is typically expressed as a percentage of the speed of light through free space. Coaxial cables can experience phase instabilities due to bending or temperature variations. This, in effect, diminishes the integrity of a calibration over time impacting measurement accuracy of data for test applications. Therefore, a phase stable coax could extend the amount of time between calibrations. Phase stability over bending is a critical parameter for precision test cables and is often expressed in terms of degrees (See **Figure 1.3**). This whitepaper will dive more into phase stable coax in Section II.

Mechanical Parameters

Most coaxial assembly manufacturer specifications will include a bend radius, or the recommended radius at which a cable can be bent without performance degradation. Additionally, the mechanical integrity of a coax often defined by the number of flex cycles it can experience without performance degradation as well as the number of mating cycles its connector heads can go through and still function within nominal operation. Fire retardant (FR) capabilities plenum rated, low smoke (LSZH), etc. are all parameters that are listed on the datasheet for residential and in-building installations.

Types of Coax Cable

There are a variety of constructional variations found in coaxial cables based upon the required performance and application. The inner conductor, dielectric, shielding and jacketing materials can all vary to optimized mechanical, environmental, and electrical performance. Understanding these numerous options can grant a better perspective on the ideal choice of coax for a specific use case.

Flexible, Rigid, Semi-flex, Flexible

Coaxial cables come in the following variants:

- Rigid/corrugated
- Semi-rigid
- Flexible

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Rigid

Rigid coaxes often have a corrugated outer shielding where the corrugations allow for a limited bend radius. This type of solid shielding structure has an intrinsically better RF shielding performance as well as a lower PIM performance. Corrugations can vary in nature between a more basic annular construction, to a helical construction (**Figure 1.5**). For these coaxial assemblies however, being bent beyond the bend radius causes irreparable damage with a permanent deformation in the shielding, dielectric and potentially the inner conductor as well. Some iterations of rigid coaxial cables maintain the dimensions between the inner conductor and outer conductor through a plastic spiral structure that is primarily composed of an air dielectric. Many implement a foamed dielectric core in order to enhance flexibility and offer a lower attenuation while maintaining the low PIM performance.

Figure 1.5:
Example of rigid coax with solid center conductor and helically corrugated copper tube.

Semi-Rigid and Hand-formable Coax

Both the semi-rigid and hand-formable type of coax are different from the typical flexible coaxial assemblies due to their characteristic solid sheath outer conductor combined with a solid metallic inner conductor of copper or copper alloy. This allows for a degree of rigidity. The main difference between the semi-rigid and hand-formable coax is that the latter can be formed and reformed while the semi-rigid coax is generally specified to be formed in a certain shape only once. For this reason, connector heads are soldered onto semi-rigid coaxial cables only after being carefully cut and bent to the desired length and shape. The semi-rigid out conductor is generally composed of extruded metal for wideband, phase stable performance after installation. The formable coax, however, has an outer conductor made with soft (un-annealed) copper or dead soft aluminum with soldered on connector heads for reformability

Semi-flex/Flexible cables

Flexible and semi-flex coaxial assemblies are generally the most utilized type of coaxial transmission line as they are able to be installed in virtually any environment without considering the impact of bending on electrical performance. As described earlier, mechanical strain can have a significant impact on the electrical performance of a coaxial cable where both the connectors' heads and the coax can undergo a combination of tensile, compressive, bending, shear, and torsional forces. These forces are particularly troublesome in the connector-to-cable joint where the solid metal crimped ferrule of the connector can push down on the softer coaxial jacketing, thinner braided/ foil shielding and subsequently the dielectric and inner conductor. In order to avoid these pitfalls, there a number of qualities that can be found in most flexible coaxial assemblies including the following (Refer to **Figure 1.6**):

- Thinner cable for less overall bend strain
- Non-metallic layers between bonded aluminum foil, braiding and jacketing materials to lower the coefficient of friction during rubbing
- Strain relief boots or over molding at the connector ends

Figure 1.6:
Flexible coaxial cables with heavy duty boots and FEP jacket material to improve strain relief.

Inner Conductors

Coaxial inner conductors can either be stranded or solid where the stranded variants provide more flexibility but come with the trade-off of a lower frequency performance range (<1 GHz). With stranded center conductors, the stress from bends and twists are distributed between the bundle of thin wires which allow for an inherently higher flexibility than a solid center conductor. Another consideration with stranded center conductors is the potential for wires to slip from the crimped-on center pin during excessive flexure. The major source of losses from a stranded center conductor comes from the proximity effect, or the tendency for EM energy in a conductor to gather farthest away from the nearby current carrying conductors in the same direction. This can almost be seen as the multi-conductor version of the skin effect. Losses are caused by the lack of uniform current distribution across the conductors which in turn, increases the AC resistance of the conductor rapidly with frequency.

However, a solid central conductor bypasses this effect and allows for higher frequency performance and is therefore most often leveraged. Common solid inner conductor materials include bare copper, copper-covered steel, copper clad aluminum, silver-plated copper clad steel for higher frequency performance (<18 GHz), and silver-plated copper for precision assemblies.

Dielectrics

As stated earlier, the dielectric material directly contributes to the inherent loss and phase stability of the coax. **Table 1** lists several commonly used dielectric materials as well as their dielectric constants. The dielectric material essentially acts as a spacer between the inner and outer conductors in order to ensure a conformal cross section across the transmission line and therefore a consistent impedance (See **Equation 1**). However, the rate of which a signal propagates across a coax is slowed down by the use of the dielectric material. Therefore, parameters such as V_P, group delay and time delay rely on both the length of the coax and the dielectric constant of its insulator.

Outer Conductors

Shielding acts as the return path of the signal going through the inner conductor. Typically, it is either composed of thin aluminum foil tape, or braided for more flexibility (**Figure 1.7**). As stated earlier, the rigid and semi-rigid coaxial cables leverage a solid sheath outer conductor composed of soft, un-annealed copper or dead soft aluminum as well as extruded and corrugated copper. While these materials offer far less cable flexibility, they do guarantee a much higher coverage and shielding effectiveness -- a measure of a cable's ability to reject interference as well as mitigate any signal radiation from the transmission line.

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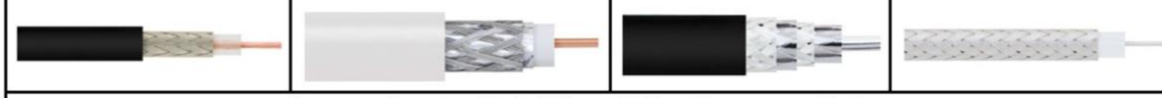
Shielding Type			
Single Braid Shield + (95% coverage)	Single Braid Shield (60%) + Foil Wraps (100%)	(2) Braids 60% + (2) Foil Wraps (100%)	Conformable Cable
			
Approximate Shielding Effectiveness Value			
-55dB	-90dB	-110dB	-150dB

Figure 1.7:
A coaxial assembly can utilize a combination of braids and foils to maintain a high degree of flexibility with 100% coverage and a high shielding effectiveness.

Typically, braided shields are composed of galvanized steel wire where the individual strands are soft or annealed. This way the loads that occur on the shield during bending are distributed between the strands of wire. Coverage is a particularly relevant parameter for braided shields as any gaps in the braid allow interference and signal degradation. To allow for both flexure and a high shield effectiveness, layers of foil and braided shields can be leveraged. Ultra flexible cables can incorporate non-metallic layers between the braided shielding and the bonded aluminum foil, this way the coefficient of friction between the two interfaces is reduced allowing for less bend stress upon the cable shielding.

Jacketing Material

Technically, the coaxial jacketing has no impact on the electrical performance of the transmission line, however it is critical in ensuring the coaxial assembly is protected from the outside environment. There are generally three types of jacketing materials including thermoplastics, thermosets, and thermoplastic elastomers (TPE). Thermoplastics generally have the benefit of easier manufacturability with an extrusion process, these materials can also easily be melted and reformed. However, this comes with the downside of a less robust material that can be susceptible to environmental strains. Thermosets such as various types of rubbers, are permanently set after a curing process where cross-linked polymers form an irreversible chemical bond. This makes them ideal for high heat applications. These materials also have an inherent mechanical durability and resistance to abrasions. TPEs consist of both thermoplastics and elastomer (rubber) materials. This way, the TPE can be molded and remolded like a thermoplastic but still maintain the benefits from structural cross-linking. **Table 1.2** lists various coaxial cable jacketing materials as well as their respective type of synthetic material. Thermoplastics can incorporate specific plasticizers in order to benefit from preferred characteristics such as fire-retardant behavior, flexibility, or high temperature resistance. This way, a thermoplastic can be used for its re-manufacturability and cost-effectiveness.

Table 1.2 *Common Cable Jacket Materials*		
Abbreviation	**Polymer Name**	**Type of Synthetic Material**
PVC	Polyvinyl Chloride	Thermoplastic
P-PVC	Plenum Polyvinyl Chloride	Thermoplastic
PE	Polyethylene	Thermoplastic
CPE	Chlorinated Polyethylene	Thermoset
XLPE	Cross-linked polyethylene	Thermoset
LLDPE	Linear Low-Density Polyethylene	Thermoplastic
FRPE	Flame Retardant Polyethylene	Thermoplastic
CSPE or Hypalon	Chlorosulfonated Polyethylene	Thermoset
EPR	Ethylene Propylene Rubber-Insulated	Thermoset
PUR	Polyurethane	Thermoset
Nylon	Polyamide	Thermoplastic
Neoprene	Neoprene	Thermoset
PTFE	Polytetrafluoroethylene (Teflon)	Thermoplastic
ETFE	Ethylene tetrafluoroethylen	Thermoplastic

Table 1.2

Thermosets can vary in their resistance to certain harsh environments. Ethylene Propylene Rubber (EPR) for instance, is especially resistant to cold temperatures. Neoprene is known for its flame retardant, self-extinguishing characteristics as well as a generalized ruggedness towards the ingress of chemicals and moisture.

Layers of jacketing can also be leveraged with cable armoring on top. A specialized interlocking occurs between a helically wrapped sheet of steel in order to yield both a flexible and crush-resistant corrugated jacket. There is also an inherent resistance to cable kinking as the cable cannot physically be bent beyond a certain bend radius (**Figure 1.8**).

Figure 1.8:
Armoring prevents the cable from being bent beyond the specified radius while also mitigating the damage that comes with shear forces and torsional strains. These can be used in precision VNA test cables to protect the thin, delicate coaxial structure beneath

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Standard Coaxial Connector Types

The types of coaxial connector vary greatly based upon their operational frequency and type of mating mechanism. The mating interfaces can include the following:

- Screw-type
- Handscrew-type
- Quick-Lock/Bayonet
- Quick-Lock/Push-Pull

Common screw-type connectors are included in **Table 1.3** as well as their respective operating frequencies and applications. Perhaps the most commonly used among these connectors are the SMA and N-type connectors, where the N-type was created in the 1940s and the SMA was developed in the 1960s. Generally, the SMA is used for semi-precision applications while the N-type connector has been leveraged in more rugged applications.

Table 1.3
Screw-on Coaxial Connectors

Screw-on Connectors	Names	Max Frequency	Applications
SMA	SubMiniature version A	25 GHz	Semi-precision applications. General purpose test.
SMC	Sub-miniature type C	10 GHz	-
SSMC	-	12.4 GHz	For semi-rigid or minature coax assemblies
UHF	-	300 MHz	Developed for use in low frequnecy systems. Can be used with impedance mate is not necessary. Replaced by BNC
Mini-UHF	-	2.5 GHz	Small version of UHF for space-savings
TNC	Thread BNC Connector	15 GHz	Reduces vibration problems in mobile military applications
N-type	-	11 GHz	General purpose test.
SC	-	11 GHz	Meets MIL-C-39012 standards

Table 1.3

The quick-lock configurations are highly utilized to simplify the mating process for mating repeatability. This has utility in applications where there is little room for a mate. For instance, the various iterations of miniature coaxial connector heads (MCX, UMCX, and MMCX) are often used in micro-coaxial assemblies to rapidly connect to test points on PCBs for production testing purposes. Where BMA and mini-SMP connectors could be used for high-frequency rack and panel applications including actively electronically scanned array antennas (AESAs), military microwave modules, radar, and telecommunications. Push-pull 4.3-10 and NEX10 connectors allow for simplified mating in base stations with passive MIMO antennas utilizing a high port density. Additionally, bayonet-type (BNC) connector configurations have often been used in military radio applications for a rapid, repeatable mate that is functional up to 4 GHz. **Table 1.4** shows the blind-mate connectors and their respective outer diameters, operating frequencies, and mating cycles.

Table 1.4 *Blind-Mate Coaxial Connectors*				
Blind-Mate Connectors	**Names**	**Diameter (straight connector)**	**Max Frequency**	**Mating Cycles**
SMP	Sub-miniature push-on	5.00mm (male)	26.5 GHz	500
Mini-SMP	-	4.06mm (male)	65 GHz	100
SMB	Sub-miniature version B	6.5mm (plug)	4 GHz	-
SSMB	Small SMB	4.7mm (plug)	12.4 GHz	-
MCX	Micro coaxial	6.22mm (plug)	6 GHz	-
UMCX	Ultra-miniature coaxial	3.1mm (jack)	3 GHz	-
MMCX	Micro-miniature coaxial	4.06mm (plug)	6 GHz	-
MMBX	-	4.7mm (male)	12.4 GHz	100
BMA	Blind-Mate Connectors	5.36 mm (male)	22 GHz	>5000
QMA	Quick disconnect version of SMA	10.49 (male)	6 GHz	100
QN	Quick disconnect version of N	19.00 (male)	11 GHz	100

Table 1.4

Precision connectors are generally defined in the IEEE standard for precision coaxial connectors (IEEE 287-2007) where all precision connectors specified to have an air dielectric in the mating space, allowing for low VSWR performance. Additionally, precision connectors are designed for thousands of mating cycles. This initially began with the 3.5 mm connector, it was originally intended to be a low loss, durable, and precise interface for calibrations with SMA-connected equipment. Later that decade, the 2.92 mm connector was released under a Department of Defense (DoD) contract -- this connector was also based upon the high utilized SMA geometry. Eventually, precision connectors reached higher frequency bands with smaller geometries. **Table 1.5** lists some common precision coaxial connectors, their mechanical compatibility with other connectors, and a general description of their performance.

Table 1.5 *Precision Coaxial Connectors*				
Precision Connectors	**Dielectric**	**Max Frequency**	**Mates with:**	**Notes**
7 mm	PTFE	18 GHz	Sexless	Very low VSWR up to 18 GHz. Often used as port connectors for VNA.
3.5 mm	Air	26.5 GHz	SMA. 2.92 mm	Developed in early 70s by HP. Allows for many repeatable connections and mates with SMA.
2.92 mm	Air	40 GHz	SMA, 3.5 mm	Developed in the mid-70s by Maury Microwave.
2.4 mm	Air	50 GHz	1.85 mm	Developed in the late-80s. Defined in IEC 61169-40
1.85mm	Air	65 GHz	2.4 mm	Developed in the late-80s by HP. Mode-free performance up to 67 GHz.
1 mm	Air	110 GHz	-	Developed in late-80s by HP. Mode-free performance up to 110 GHz.

Table 1.5

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Standard Coaxial Connector Types

Coaxial Connector Attachment Types

Another key aspect of a [coaxial cable assembly] is the method with which the coaxial connector and cable are attached. This electrical and mechanical connection is crucial to the electrical performance of the coaxial cable assembly as well as the mechanical reliability of the assembly. The most common methods of attaching a coaxial connector to a coaxial cable is by using solder, crimp, or compression. There are also twist-type coaxial connectors. However, this attachment type is generally not professionally used or only for temporary/low-performance installations in TV/broadcast applications.

Each method presents advantages and disadvantages, and some are more suitable for certain applications then others. It is often the case that coaxial connectors with specific attachment methods are chosen to meet the specifications for an installation, and each require a specific set of tools and skills to assemble to specification.

Generally, attaching a [coaxial connector] to a coaxial cable involves removing the jacketing material, shielding, and dielectric to expose the center conductor for a precise length. The inner dielectric and outer shielding also typically need to be exposed for a set length according to the specifications for the attachment method. In some cases, the outer jacket also needs to be trimmed to a precise length in respect to the end of the center conductor or shielding layer. There are often special tools available to make the trimming and exposing process of the various coaxial cable layers more precise and rpeatable.

Once exposed, the center conductor of the coaxial cable needs to be securely attached to the center conductor of the coaxial connector in such a way that ensures a quality electrical and mechanical connection. The shielding/outer conductor of the coaxial cable also needs to be securely connected to the outer conductor/shielding/housing of the coaxial connector in a way that establishes a quality electrical and mechanical connection. There are often inserts or other features or components that come with a coaxial connector attachment kit to help aid in the proper attachment of the connector and coaxial cable. In other cases, it is entirely dependent on the operator's skill and available tools to fabricate a quality attachment between the coaxial cable and connector.

Crimp Method

The crimp method may be the most common method of coaxial cable assembly fabrication. A crimp method consists of connector contacts and ferrules that must be precisely placed in respect to the center conductor and outer conductors and are then crimped with a tool that mechanically deforms the metallic conductive connector contacts and ferrules around the center conductor, outer conductor/shielding, and often jacketing material. Crimp attachment methods generally require specific crimping tools to meet the connector specifications, though some generic crimping tools with the correct crimping die can also perform the task adequately or to specification depending on the coaxial connector.

Crimp Method Advantages

Crimp type connectors are generally very easy and rapid to install. An experienced technician will often only require tens of seconds to install a crimp connector if the preparation of the coaxial cable is already done or a tool that performs this task is readily available. If a crimp connection is designed and installed properly, the deformation of the crimp connections is done to allow for secure connections even under expansion and contraction due to thermal cycling as well as shock/vibration. A proper crimp connection should also be gas tight and not allow for wicking of moisture or other fluids. Crimp connections are available that allow for solid or stranded center conductor and outer conductor designs.

Crimp Method Disadvantages

Poorly installed crimp connections can dramatically reduce the performance of a coaxial cable assembly and allow for moisture ingress and possibly even debris to enter the coaxial assembly connection area. A common way this occurs is if improper crimp dies are used, there is insufficient crimping pressure, or poor crimping techniques are employed. Mishandling and poor crimping technique can also result in damage to the wire connectors or ferrules in a way that reduces the overall performance of the connection.

Moreover, crimp connections most often need to be destructively removed, and are not generally reworkable. Under extreme stress or conditions of frequent flexure, it is possible that a crimp connection using stranded wire could allow for stranded wires to loosen from beneath the crimped ferrule.

Compression Method

Compression attachment connectors are somewhat similar to crimp method connectors except that they are typically only a single piece connector. The compression attachment method, and hence compression connectors, have historically only been common in the cable TV/broadcast industry with type-F coaxial connectors. After stripping and preparing the cable head, a compression connector can be inserted on the coaxial cable and then into a compression tool. After applying adequate force, the compression tool is designed to compress key sections of the compression connector designed to provide electrical and mechanical connection to the cable and outer shielding.

Compression Method Advantages

Most compression connectors allow for the center conductor of the coaxial cable to be exposed, instead of crimping or soldering the center conductor of a coaxial cable to the connector center contact as with crimp or solder connectors. This simplified installation generally allows compression connections to be made very rapidly. Also, the simplified approach generally requires less training and experience to successfully complete the attachment process. Moreover, a compression connector is often only a single component, which makes misplacing or attaching the wrong component impossible with this style of attachment. Many compression connectors have integrated weather seals, and the compression can sometimes enable very high pull strengths compared to crimp and solder attachments.

Compression Method Disadvantages

However, compression connectors require specialized tools and only work on very specific types of coaxial cables. There are generally only a few compression connector and coaxial cable pairings that are compatible, and few coaxial connector options. Lastly, compression connectors tend to be more expensive than both crimp and solder attachment types and are generally not reworkable. Hence, mistakes in installation can result in relatively high installation cost-per-connection for compression connector types.

Solder Method

The solder attachment method involves soldering either the center conductor or outer conductor of the coaxial cable to the coaxial connector. This can be done with braided or solid center conductors and outer conductors. Some types of connectors are hybrid and only allow for soldering of the inner conductor or outer conductor and typically require crimping of the conductor that is not soldered. Solder type connectors are specifically designed to allow for the center conductor to be soldered to the center conductor, and an outer conductor/housing of the coaxial connector to be soldered to the outer shielding/conductor. In some cases, the center conductor pin/contact is removable from the coaxial

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connector and must be inserted into the housing after soldering, in other cases the center conductor is soldered to a contact that is fixed to the coaxial connector.

Solder attachment methods are generally the most common method used for high quality connections, and there are connectors with this attachment type available for flexible, semi-rigid, and rigid coaxial cable.

Solder Method Advantages

Solder connections are often the highest performing attachment type in respect to electrical performance and reliability. Typically, all that is needed to perform a solder attachment is a soldering iron, flux, and possibly some method of holding the workpiece while soldering. Due to the limited requirements of equipment and low cost of solder connector components, soldering connections can be the most economical method of coaxial cable assembly attachment. Due to the reliability and performance of solder connections, many standards and applications require solder attachments as opposed to crimp.

Solder connectors can accept a wider range of coaxial cable sizes and types than crimp or compression attachment methods. Even very small coaxial cable types can be soldered to larger coaxial cable connectors, which is more difficult with crimp type connections.

Solder Method Disadvantages

During soldering, the thermal energy used to solder the connection to the center contact and our outer shielding/housing can result in increasing the temperature of the coaxial cable layers and coaxial connector components. If poor technique or soldering iron temperatures that are beyond the temperature ratings of the coaxial cable or connector are used, then it is possible that the coaxial cable or connector could be damaged, derated, or performance of the coaxial cable assembly can be affected. Care must also be taken by the operator to ensure that RoHS compliant applications use RoHS-compliant solder.

If a soldered connection is not installed properly, then the coaxial connection may be prone to failure from exposure to moisture and other environmental factors. A soldered connection that is not made properly may also fail to shock and vibration events far below what the connection is typically rated for. With improperly attached solder connectors, thermal cycling could result in damage to the solder material, such as cracking or pulling away from the conductor surface. Under high load conditions this poor connection could result in high levels of internal heating due to increased contact resistance that can gradually degrade or even result in destruction of the coaxial cable connection.

Soldering a coaxial connection also often takes more time and care than crimping connections. In certain installation environments it also may be dangerous to have electrically heated elements that are hot enough to solder, such as in oil & gas applications with flammability concerns. Good solder connections also generally require very clean cable conductor surface and connectors and installing solder connections in highly corrosive or dirty environments may lead to quality and reliability issues with the solder connections as well as increased fabrication difficulty.

Conclusion

There are many factors to consider when choosing a coaxial cable assembly for your specific application. Factors to consider include the environment the cable is being used in, mating and unmating cycles, cable flexure and bend radius, required frequency support, compliance with local building or fire codes etc. By looking at each type of cable characteristic, identifying the right cable to use for your application can be achieved. Knowing the exact details of your environment and electric requirements is paramount to ensuring the highest levels of performance and longevity of your cable installations.

Reference

1. https://www.microwavejournal.com/articles/33584-designing-coaxial-cable-assemblies-for-high-performance-and-reliability

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