TELECOM

BOOKLET

A
GUIDE
TO

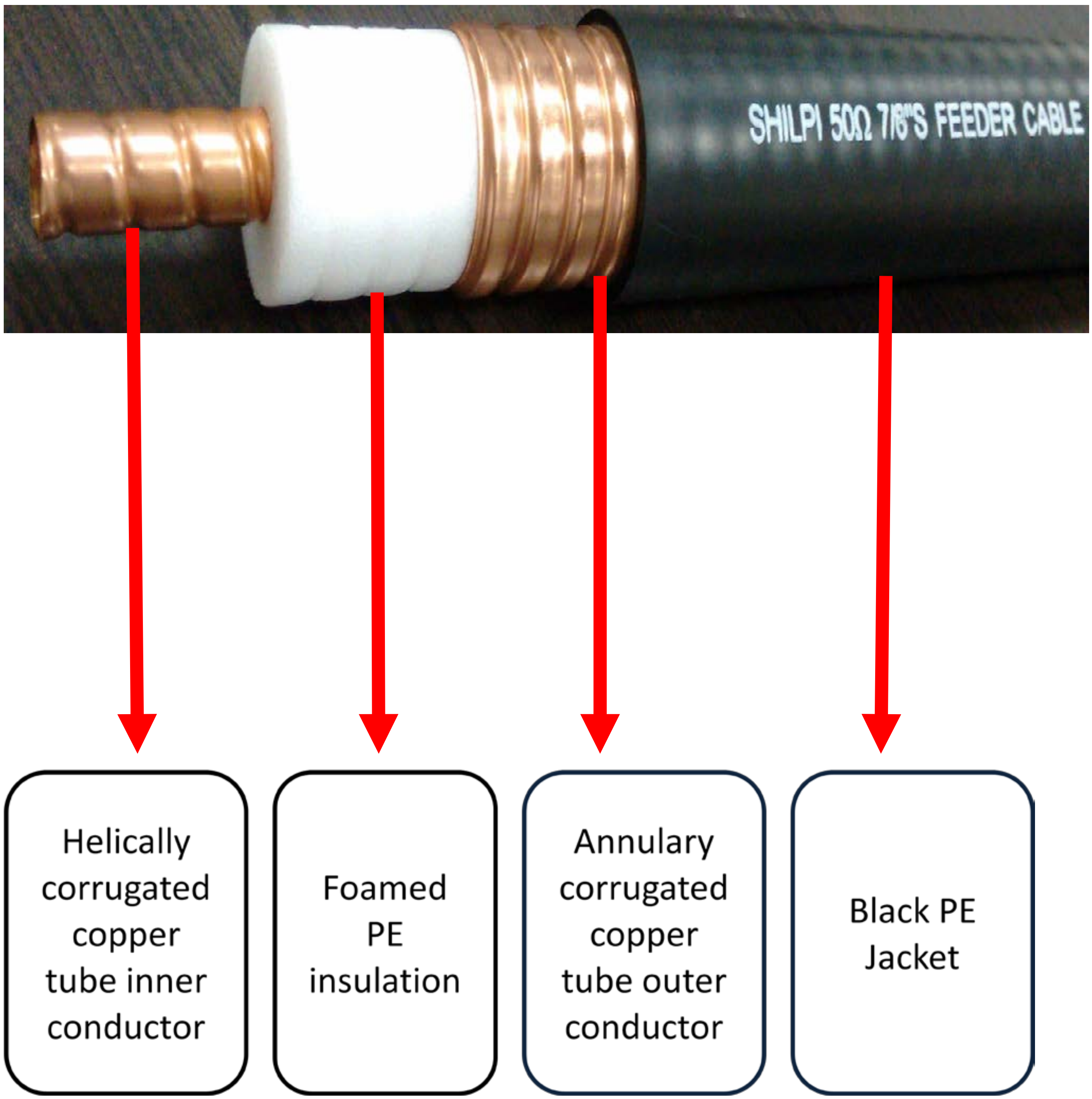
RF Coaxial Cable

——— 50 Ω ———

(CORRUGATED TYPE)

DEDICATED
TO
ALMIGHTY

Cable Construction



Radio Frequency (RF) Coaxial Cable

Cable is a system for carrying a signal from point to point. The term “Co-axial” comes from the two conductors (inner and outer) sharing common geometric axis. Coaxial cable was invented in 1929 and first used commercially in 1941.World War Two brought the use of coax into radio communications.

If an ordinary wire is used to carry high frequency currents, the wire acts as an antenna and the high frequency currents radiate off the wire as radio waves causing power losses. To prevent this, in coaxial cable, one of the conductors is formed into a tube and encloses the other conductor. This confines the radio waves from the central conductor to the space inside the tube. To prevent the outer conductor (shield) from radiating, it is connected to electrical ground, keeping it at a constant potential.

Radio Frequency coaxial cable is used as a transmission line for radio frequency signals. It is made from a number of different elements that, when together, enable the coaxial cable to carry the RF signals with a low level of loss from one location to another. At higher frequencies, wire pairs are unsuitable because they have higher electrical resistance due to skin effect and they suffer an increased loss of energy due to radiation from the wires. For higher frequencies, a coaxial cable is appropriate because it eliminates both of these problems. In addition, there is virtually no cross-talk between several coaxial cables that are bound together in one large cable. This is because the current in each coaxial cable is concentrated on the inside of the outer shell and the outside of inner conductor, creating a shielding effect. For this same reason, coaxial cables are much more immune to noise and talk.

A coaxial cable carries current in both the inner and outer conductors. These currents are equal and opposite and as a result all the fields are confined within the cable and it neither radiates nor picks up signals. This means that the cable operates by propagating an electromagnetic wave inside the cable. The transmission of energy in the line occurs totally through dielectric inside the cable between the conductors.

Applications include feed lines connecting radio transmitters and receivers with their antennae. Coaxial cable also provides protection of the signal from external electromagnetic interference.

Coaxial cable is typically classified according to its impedance or RG-type (Radio Guide- the manner that the military used to identify transmission lines).The most common coaxial cables impedances are 50,75 and 95 ohm. 50 Ω cables are used in microwave and wireless communications applications. 75 Ω cables are used in cable television (CATV) and video applications.95 Ω cables are used for data transmission applications.

RF corrugated cables(50 Ω) are available in ¼”, 1/2”,7/8”, 1-1/4” and 1-5/8” sizes in Copper & Aluminium variants. Aluminium corrugated cables having low weight, low cost by 15% but with higher attenuation up to 8%. These products are used for mobile network and telecommunication equipment.

Electrical Characteristics

1. DC Conductor resistance (CR)
2. DC breakdown voltage
3. Capacitance
4. Inductance
5. Dielectric constant
6. Velocity of propagation (VoP)
7. Skin effect
8. Characteristic Impedance
9. Attenuation
10. Return loss (RL)/Voltage standing wave ratio (VSWR)
11. Passive intermodulation (PIM)
12. Cut-off frequency
13. Maximum operation frequency
14. Peak power rating
15. RF peak voltage
16. Mean power rating
17. Jacket spark voltage (rms)
18. Insulation resistance (IR)
19. Shielding effectiveness

DC Resistance

The direct current resistance denotes the ohmic value of the inner or outer conductor based on a length of 1 Km and expressed in Ω/Km.

It is dependent on the cross section of the conductor and on the conductor materials (specific conductance).

DC Breakdown Voltage

The DC breakdown voltage is determined between the inner conductor and the outer conductor.

It is defined as the voltage at which the insulation between two conductors will fail and allow electricity to conduct or 'arc'. The DC BDV depends on the type of dielectric used and its dimensions. This value is established for each cable size and forms the basis for determining and calculating the permissible peak power rating.

Capacitance

Capacitance is the ability of cable to hold a charge. The larger the capacitance value, the longer it takes a signal to reach full amplitude within the cable. Therefore, higher capacitance is usually a bad attribute. Capacitance is length dependent. For coaxial cable, the capacitance is calculated as below -

$$C = \frac{24.15 * \varepsilon_r}{\log\left(\frac{D}{d}\right)} pF / m$$

εr - relative dielectric constant

D - electrically effective inner diameter of outer conductor(mm)

d - electrically effective outer diameter of inner conductor(mm)

Dielectric constant depends on the material used and the degree of foaming. The capacitance of RF cables is independent of frequency and is determined by the relative dielectric constant, the effective outer conductor diameter and the effective inner conductor diameter.

Inductance

For coaxial cable, the inductance is calculated as below –

$$L = 0.46 \log\left(\frac{D}{d}\right) \ \mu\text{H/m}$$

D - electrically effective inner diameter of outer conductor(mm)

d - electrically effective outer diameter of inner conductor(mm)

The inductance of RF cables is slightly frequency dependent and is determined by the effective outer and inner conductor diameter and the equivalent conducting layer due to the skin effect.

Dielectric Constant

The dielectric constant (ε_r) is the ratio of the permittivity of a substance to the permittivity of free space. It is greater than or equal to 1.Dielectric constant is also called the relative permittivity (ε_r).

It is an expression of the extent to which a material concentrates electric flux, and is the electrical equivalent of relative magnetic permeability.

Materials with high dielectric constants are useful in the manufacture of high-value capacitors. The larger the dielectric constant, the more charge can be stored.

$$\varepsilon_r = \varepsilon / \varepsilon_0$$

where ε_0 = permittivity of free space(8.85×10^{-12} F/m)

ε = permittivity of the substance

ε_r = relative permittivity

This is a property of the material itself - independent of dimensions – but is an important factor in determining VoP (Velocity of Propagation) and delay. A dielectric is a barrier – an insulator – separating positive and negative electric charges from one another, preventing direct current flow. This action is typified by a capacitor. In a cable, the dielectric is defined as the non-conducting plastic or rubber (or even air) which insulates a conductor from others.

No conductor material is perfect & the same is true of insulation materials. Making cables using a perfect vacuum as the insulation medium is impractical. So, in the real world, while we might quantify absolutes without practical access to them, we can atleast relate to them by a ratio. Thus defines dielectric constant – the ratio of a material's dielectric (charge storage) quality to that of a perfect vacuum. A perfect vacuum is valued at 1. All other materials have a greater value of dielectric constant.

The dielectric constant figures into determining characteristic impedance, loss, capacitance, cut-off frequency, VoP of coaxial cables. The lower the dielectric constant, the lower the loss, the lower the capacitance, the higher the VoP – a cable which approaches the ideal.

Velocity of Propagation

This is nothing but the velocity of propagation of a wave along the cable in relation to the speed of light in a vacuum. That is, the ratio of actual speed of electrical signal to the speed of light. This may be an important attribute if running several signals/cables in parallel, as it is important for all signals to arrive at the same time. This attribute may also be referred to as delay.

The relative velocity of propagation depends essentially on the dielectric constant (ε_r) which is derived from the type of material used and its degree of foaming. High foaming of dielectric results in 88 % of VoP. Relative propagation velocity determines the electrical length of the cable. Propagation velocity is measured at frequencies around 200 MHz as standard.

Formula-

$$VoP = \frac{100^2}{\sqrt{\varepsilon_r}}$$

The time delay from one end of a cable to the other is inversely proportional to VoP, the lower the VoP %, the longer the delay.

$$d = \frac{L}{C*VoP} = \frac{3.33}{VoP} \text{ ns/m}$$

Where,

d = Delay In nanosecond (ns)

L = Length of cable in metre,

C = Velocity of light in free space

Skin Effect

At DC, current in a conductor flows with uniform density over the cross section of the conductor. At high frequencies, the current tends to flow only in the conductor surface; the effective conductor cross section decreases and the conductor resistance increases.

At radio frequencies, current flows only in a very thin “skin”. Everywhere else the conductors are free from electromagnetic fields. Even very thin walled metal envelopes will, therefore, entirely screen the electromagnetic field within co-axial RF cables at radio frequencies.

The depth of penetration illustrates the skin effect. It is defined as the thickness of a thin surface layer (assumed to have an even distribution of current flow), having the same resistance as an actual conductor, which is undergoing to the skin effect.

Other than resistance, the skin effect also influences inductance and thereby characteristic impedance and propagation velocity.

Characteristics Impedance

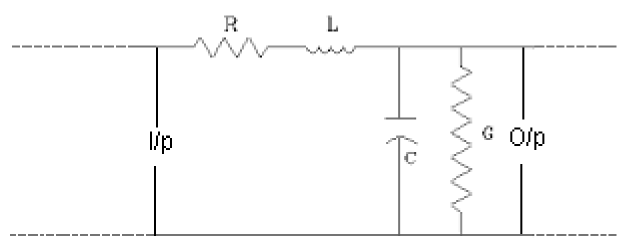
Impedance is the total opposition to the flow of electrical energy within the cable. It is not length dependent .Characteristics impedance (or simply impedance) is defined by the ratio of wave voltages to wave currents at each point along the transmission path. This ratio of voltage to current is constant for the superimposed waves (going & reflected) and thus represents a characteristic parameter of the cable. The impedance is dependent on frequency but approximates to a defined value for high frequencies. The mean value of characteristics impedance is measured at around 200 MHz. This property enables coaxial cables to be divided into defined impedance classes. Typical examples are 50 Ω cables for antenna systems and 75 Ω cables for television systems. Corrugated cables are used for antenna systems and have an impedance of 50 Ω. Tolerance is held very low at ±1 Ω for excellent adaptation (for High Power types ±2 Ω). The characteristic impedance of a coaxial cable is determined by the ratio of the diameter of the outer conductor to the inner conductor and the dielectric constant of the insulating material between the conductors. Because the RF energy in the cable travels on the surface of the conductors, the important diameters are the outside diameter of the inner/centre conductor and the inside diameter of outer conductor. Impedance is a complex value defined by cable's resistance, capacitance, Inductance and conductance and is the equivalent value of these items combined. It is selected to match the system requirements.

Formulae -

$$Z_C = 138 * VoP * \log\left(\frac{D}{d}\right) \quad \Omega$$

$$Z_C = \sqrt{\frac{R + j\omega L}{G + j\omega C}} = \sqrt{\frac{L}{C}} \quad \Omega$$

The electrical representation of Coaxial cable is as below -



R - Series resistance of the conductor in ohm per unit length (DC Resistance)

L - Series inductance in Henry per unit length

C –Shunt capacitance in Farad per unit length

G -Shunt conductance in mho per unit length

ω = 2πf, where f is frequency

Attenuation

Attenuation is one of the main criteria for selecting a suitable type of cable. Attenuation is decrease in signal level over a distance in the direction of propagation. It is the inherent signal power loss within cable & is expressed as a ratio (dB).It is dependent upon cable design and is both frequency and length dependent. It is most affected by DC resistance of inner conductor and dissipation factor of dielectric material. The higher the frequency, the greater a cable's attenuation. As the RF signal passes through the cable, a portion of the signal is converted into heat and a portion of the signal leaks out of the cable through the outer conductor. In addition to frequency, the main factors that influence attenuation are the cross section of the conductors and the dimensions and characteristics of the materials. A cable's attenuation is quoted for an ambient temperature of 20°C.The higher the ambient temperature values and the hotter the cable becomes due to the power transmitted, the higher the attenuation(α).Increase of attenuation is 0.2 % /°C.

Formulae -

$$\alpha = 10.\log\left(\frac{Pi}{Po}\right) \quad \text{dB/100m}$$

$$\alpha = \frac{1139}{Zc}\left[\frac{\sqrt{\rho ri}}{d} + \frac{\sqrt{\rho ro}}{D}\right]\sqrt{F} + 9096 * \sqrt{\varepsilon_r} * \tan\delta * F \quad \text{dB/100m}$$

F	-	Frequency (MHz),Zc-Impedance(Ω),tanδ-Dissipation factor (material purity),
ε_r	-	Dielectric constant
ρ_{ri}	-	Resistivity of inner conductor & ρ_{ro}-Resistivity of outer conductor w.r.t. copper
d	-	electrically effective outer diameter of inner conductor (mm)
D	-	electrically effective inner diameter of outer conductor (mm)
P_i	-	Input power (W),P_o–Output power(W)

Return Loss (RL)–Voltage Standing Wave Ratio (VSWR)

Return loss is defined as the ratio in decibels (dB) of the input signal power level to the reflected signal power level. Reflections of transmitted waves occur due to irregularities along the path of cable and fluctuations of impedance. The outcome can be interfering signals over the complete frequency spectrum of the transmission system. Periodic deviations will cause immense interference at a specific frequency through accumulation. The fact that all manufacturing processes are subject to certain fluctuations, means that reflections are to be found on every cable transmission path. Reflections can also arise at all cable to connector junctions. RL is a perfect indicator for the uniformity of cable.

These reflections are also defined by VSWR (voltage standing wave ratio).The incident signal mixes with the reflected signal to cause a voltage standing wave pattern on the transmission line. VSWR is a measure of the ratio of maximum voltage to minimum voltage in the standing wave. The larger the impedance mismatch (fluctuations in impedance along the path of cable system) the larger the amplitude of standing wave. When the impedances are improperly matched, reflections occur (increasing the amplitude of the standing wave) resulting in signal loss, which results in attenuation of the transmission, poor reception or both. There are three things that happen to RF energy input into a coaxial cable assembly : 1) It is transmitted to other end of cable as usually desired, 2) It is lost along the length of cable either by being transformed into heat or by leaking -out of cable & 3) It is reflected back towards the input end of cable.

Formulae –

$$RL = 10.\log\left(\frac{P_r}{P_i}\right)$$

$$RL = 20.\log\left(\frac{VSWR - 1}{VSWR + 1}\right)$$

$$RL = 20.\log\left(\frac{Z_1 - Z_2}{Z_1 + Z_2}\right)$$

Pi –Input power (W),

Pr– Reflected power (W)

Z1–Input Impedance of cable (Ω)

Z2–Impedance of reflected wave (Ω)

Passive Intermodulation (PIM)

Passive intermodulation is the production of new, unwanted signal frequency components in passive, non-linear devices commonly found in and around radio sites. These new signals can land on existing transmit or receive frequencies on the same or an adjacent site causing interference. Passive intermodulation represents a potential source of interference in the frequency range for transmission.It arises when two transmission signals form intermodulation products as the result of component non-linearities (cables & connectors).This non-linearities can be caused by oxidation of the conducting copper, bad contact between copper and connector plug (point contact and not contact over whole surface),cleanness(copper shavings and dust), scratches on the inner conductor, CCA copper layer damaged. In particular, the product of third order is critical because it lies in the transmission range and can therefore interfere with the transmission signals.

Passive intermodulation mainly depends on the characteristics of materials and the quality of contact between the cable and connector.

Resulting intermodulation products are measured by imputing two signals with defined frequencies into the transmission system.The degree of intermodulation is expressed as a signal level in either dBm or dBc(w.r.t. carrier signal).

The measurement is conducted using carrier signals at levels of 43 dBm(20 W) and a frequency based on the range of application, e.g. GSM 900 or GSM 1800.Typical measured values for coaxial cable systems are ≤ -117 dBm(-160 dBc).

Cut-off Frequency

Cut-off frequency is defined as the highest radio frequency (RF) that will pass through the cables. Above this frequency, there is a risk of undefined modes (waves) arising and exerting a negative influence (increased attenuation) on the transmission. The cut-off frequency for each cable depends on the dimensions and materials.

Formula –

$$f_c = \frac{191}{(D+d)\sqrt{\varepsilon_r}} \quad \text{GHz}$$

fc - Cut-off frequency (GHz)

εr - Dielectric constant

D - Electrically effective inner diameter of outer conductor (mm)

d - Electrically effective outer diameter of inner conductor (mm)

Maximum Operating Frequency

Maximum operating frequency is normally based on the cut-off frequency and includes a defined safety factor. Upto this frequency, the properties of the cable are within the specifications given unless otherwise stated.

Peak Power Rating

The power rating is the input power achieved when operating the coaxial cable with maximum RF operating voltage (peak value). That is, it is the input power for which the peak RF voltage rating is reached, when the cable is operating in its matched condition. The measurement is limited by the DC breakdown voltage between the cable's inner conductor and outer conductor. The peak power rating is a calculated value which is independent of frequency.

$$P = 500\left(\frac{V^2}{Zc}\right) \quad \text{KW}$$

P	=	Peak Power Rating (KW)
V	=	RF Voltage Rating (KV), Peak Value
Zc	=	Characteristics Impedance (Ohm)

RF Peak Voltage

The RF peak voltage is limited by the air gap between inner and outer conductor of a coaxial line and the voltage withstand of air. Air is also considered a dielectric for foam cables since there will always be a short section of air line at the interface between foam cable and connector. Depending on the connector used, a smaller connector mating interface can be the limiting factor.

Mean Power Rating

Mean power rating is the input power at which the inner conductor reaches a temperature agreed for a certain dielectric material. It decreases as frequency rises. Electrical losses in a coaxial cable result in the generation of heat in the center and outer conductors, as well as in the dielectric core. The power handling capability of a cable is related to the ability of cable to dissipate this heat. The ultimate limiting factor in power handling is the maximum allowable operating temperature of materials used in cable, especially the dielectric. This is because most of the heat is generated at the center conductor of cable. In general, the power handling capability of a given cable is inversely proportional to its attenuation and directly related to its size. The other factor is heat transfer properties of cable, especially the dielectric. Coaxial cables permit a continuous maximum temperature of 85°C at the inner conductor, i.e. the heat generated by the continuous power must not exceed this value. The crucial factor is the material of dielectric. The values quoted for the maximum continuous power rating are based on an ambient temperature of 40°C and VSWR of 1. The higher the ambient temperature, the lower the maximum permissible continuous power rating. Increasing the VSWR has the same effect. The continuous power rating is also affected by other ambient conditions, e.g. direct sunlight.

$$P_{max} = \frac{0.8686 * P_v}{2 * \alpha}$$

Pmax	=	Mean Power Rating (KW)
Pv	=	Maximum admissible power dissipation (W/m)
α	=	Attenuation (dB/100m)

Jacket Sparks Voltage (rms)

Within the production process, the cable jacket is tested by applying a pulsed high voltage to the jacket against the outer conductor. This is to ensure the integrity of the jacket regarding holes, inclusions and thickness.

Insulation Resistance (IR)

It is the resistance between two conductors separated by insulating material i.e. electrical property of the dielectric measured in GΩ-Km

Shielding Effectiveness

It defines the logarithmic ratio of input power (into the cable) to radiated power(from the cable).On corrugated coaxial cables, the shielding attenuation is greater than 120 dB as a result of using a solid copper tube outer conductor with an RF-tight weld. Braided coaxial cables that contain a shielding foil typically achieve shielding effectiveness values of only 90 dB.

Mechanical Characteristics

1. Inner conductor
2. Outer conductor
3. Dielectric
4. Jacket
5. Tensile strength
6. Bending radius
7. Bending moment
8. Flat plate crush strength
9. Temperature ranges
10. Recommended hanger spacing

Inner Conductor

The inner conductors of corrugated coaxial cables consist of copper wire, copper clad aluminium (CCA) wire or copper tube. For corrugated cables with small dimensions or braided cables, wires are used to guarantee sufficient flexibility. The inner conductors of corrugated coaxial cables with larger dimensions are made of copper tubes which ensures low weight as well as the necessary flexibility. Spiral (helical) corrugation of inner conductor tube lends the corrugated coaxial cable additional flexibility.

Outer Conductor

The outer conductor of corrugated coaxial cable is formed by a welded copper tube with either spiral/helical or circular/annular/ring-shaped corrugations. The welded copper tube guarantees RF shielding with screening attenuation values in excess of 120 dB. Spiral corrugations, braids and foils are used for highly flexible cable versions. The deep and tightly spaced corrugations in the outer conductor of corrugated coaxial cables result in the smallest possible bending radii and highest flexibility.

Dielectric

In all coaxial cables, highly foamed polyethylene (FPE) ensures excellent attenuation to be achieved with the smallest possible dimensions. Foam coax will have 15% less attenuation than cables with solid PE dielectric. Also, FPE cables are low weight–65% less than solid PE cables(at the same attenuation) and smaller diameter–25% smaller than solid PE cables(at the same attenuation).Foam coax can absorb moisture increasing loss. The insulation (dielectric) is used to provide separation between the conductors.

The word ‘electric’ derives from Greek ‘elektron’ which translates to ‘amber’(An insulating material known to produce an electric charge when rubbed).The prefix “di-” infers the effect of preventing flow of electrons(current).A dielectric then is a barrier-an insulator-separating positive and negative electric charges from one another, preventing direct current flow. This action is typified by a capacitor.

HDPE & LDPE are blended with a minimum amount of an endoderm nucleating agent to achieve required melt strength and viscosity for bubble growth and even cell distribution. For foaming of dielectric, preferably CO_2 is used as foaming gas due to its high solubility in polymer melts and its inertness. Foam rates up to 80% void ratio (expansion) with an uniform cell distribution providing highest quality signal transmission and minimum attenuation.

It is desirable that the dielectric has stable electrical characteristics (dielectric constant & dissipation factor) across a broad frequency range. The most common materials used are polyethylene (PE), polypropylene (PP), fluorinated ethylene propylene (FEP) and poly tetra fluoro ethylene (PTFE).PE & PP are desirable in lower cost, power and temperature range applications. A thin layer of unfoamed polyethylene is applied directly to the inner conductor so that the dielectric can be stripped with ease. A physical foaming process produces up to 80% of the polyethylene with a fine–pore, non-hygroscopic cell structure that lays the foundation for the cable’s electrical performance. High foaming means a high proportion of air in the dielectric which results in lower weight, and attenuation characteristics approaching those of air dielectric cables of similar size.

Jacket Options

Black polyethylene is the standard outer jacket for all cables. This material is suitable for indoor and outdoor use (also underground). It is UV-resistant and halogen-free, and develops no corrosive gases in case of fire. For applications which demand flame-retardant cables an outer cable jacket made of FRNC material (Flame Retardant Non Corrosive) is available. The FRNC-material is also halogen-free and enables the cable to comply with the various listed IEC, NEC and UL flame tests.

Tensile Strength

The tensile strength of a cable defines the maximum permissible tensile force which may be applied to the cable during installation or handling. The unit of measurement is Newton (N) and takes into account all the materials used in the cable. In case of corrugated conductors, tensile strength is naturally less than in the case of smooth conductors. Exceeding the quoted values may result in impairment of the cable's mechanical or electrical characteristics. The values are determined by the technical measuring instruments and include an additional safety factor. The values are based on a maximum cable elongation by 0.2%.

Bending Radius

Specific minimal bending radii are defined for all types and cable sizes. A distinction is drawn between single bending and repeated bending. In case of single bending, the cable should not be bent back again after reaching its minimal bending radius, as this could result in damage to the cable. Repeated bending allows the cable to be bent to the minimal bending radius at least 15 times. It is typical for cable to be bent between 40 and 50 times without any impairment of its transmission characteristics. A cable's behavior and stability when subjected to repeated bending is very important during installation and assembly. Repeated bending also gives an indication of the minimum admissible reel core radius. Electrical and mechanical values of coaxial cables remain stable even after repeated bending. The minimum bending radii guarantee simple and reliable installation of the cables, resulting in dependable and endurable connections. Advantage of RF cables with corrugated conductors is their flexibility.

Bending Moment

A reference value for defining the ease at which a cable can be bent. A particular advantage of RF cables with corrugated conductors is their flexibility, as expressed in the bending moment. The cable under test is fixed in a straight support and a perpendicular force is introduced at a certain distance of 1 metre away from the support. The necessary force to deflect the cable by half this distance multiplied by the distance gives the bending moment.

Flat Plate Crush Strength

A reference value for defining the load required to create some amount of deformation to a cable's outer conductor –applicable to applications where a cable is to be buried under earth or concrete.

A particular advantage of the outer conductor corrugation is the fact that it gives the cable a very high crush resistance. If the given values are not exceeded the local impedance change is less than 0.5 Ω.For instance, In order to compress a 100 mm length section of Shilpi 7/8"S cable (SCR078SC) to reduce the impedance by 0.5Ω, It is necessary to apply a force of more than 1400 N (143 Kg). Unit of crush strength is N/mm cable length.

Temperature Ranges

Temperature ranges are defined for cables in storage, during installation and operation.

Following table shows the temperature ranges which apply for cables with a standard polyethylene jacket or FRNC jacket :

	Polyethylene jacket	**FRNC jacket**
Storage :	-70 ˚C to +85 ˚C	-70˚C to +85˚C
Installation :	-40˚C to +60˚C	-40˚C to +60˚C
Operation :	-55˚C to +85˚C	-55˚C to +85˚C

Recommended Hanger Spacing

Various aspects need to be considered when fastening corrugated cables. Hangers must be spaced in accordance with specific values that are dependent on the location, the environmental conditions and the choice of installation materials. Extreme loads to the cable due to icing or strong winds must be taken into account when calculating the distance between the hangers.

The recommended maximum hanger spacing for various cable sizes are shown in the below table:

¼"S	3/8"S	½"S	½"F	5/8"F	7/8"S	7/8"F	1-1/4"F	1-5/8"F
0.6 m	0.6 m	0.8 m	0.8 m	1.0 m	1.0 m	1.0 m	1.2 m	1.5 m

Coaxial cables with corrugated outer Conductor

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