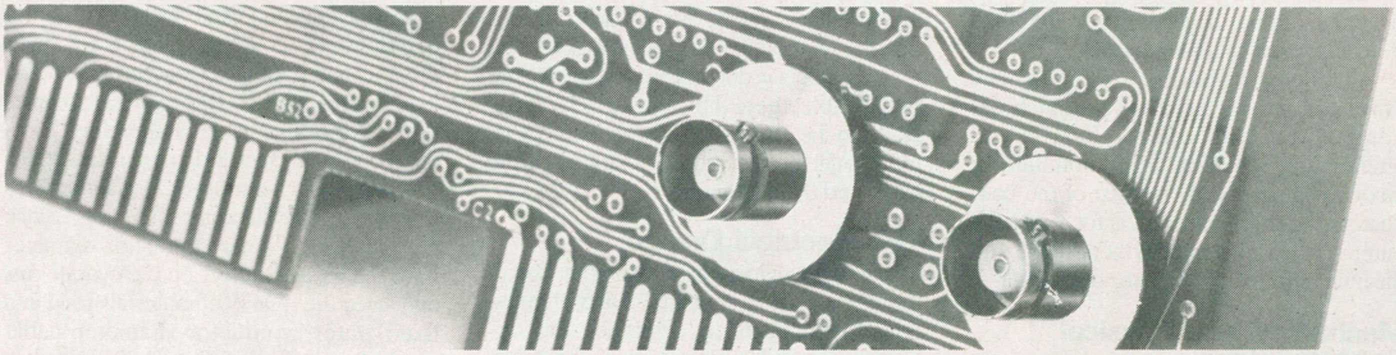
The ABCs of Coaxial Cables

Coaxial cables are the arteries of the wired city; here's how they work.

DR. H. VIRANI



The number of alternative cable constructions being placed before the system installer is vast and growing daily. This is a sign of a healthy industry, but it does not necessarily ease the pressure on the individual who has to make the final choice on the type of cable to be installed. It is however, one of the most important decision which will be taken, since the consequences of a mistake can be expensive. It is a little like the old adage that the medical profession buries its mistakes, except that in this case, the difficulty of retrieving the situation is mainly due to the fact that the mistake actually has been buried.

In this article, I hope to make that selection a little easier by examining the merits (and otherwise) of the various materials and constructions on the market, but before that can be achieved, the reader must have a basic understanding of the parameters which influence the design.

The Design Parameters

The basic requirement of the cable is that it must be capable of transmitting information in signal form from one point to another with minimum loss and distortion. There are four electrical parameters of the cable: its characteristic impedance, attenuation, return loss, and outer conductor shielding efficiency, which have a major bearing on the level to which this is achieved, while the environment through which the cable has to travel will dictate its mechanical/physical characteristics.

Electrical Considerations

The design process starts with a menu of requirements generally set by the end user. Two to these stipulated requirements must be the characteristic impedance and attenuation of the cable, since it is from a combination of these parameters that the basic design is formed.

Characteristic Impedance

The value of the system characteristic impedance is fixed to ensure that minimum mismatch between components occurs, thus ensuring maximum power transfer. For cable TV, this is now universally set at 75 ohms. The characteristic impedance does not have an influence on the overall size of the cable, but it does determine the ratio between the outer and inner conductor diameter. This ratio can be varied by employing different dielectric materials; reduction in the relative permittivity of the dielectric (a measure of storage capability) results in a corresponding reduction in the ratio.

Attenuation

The attenuation of the cable is made up of two basic components; the conductor loss which varies with the square root of frequency and the dielectric loss which varies directly with the frequency. The conductor loss can be broken down in turn into its inner conductor and outer conductor components of which the former is normally greater than 80%.

The dielectric loss is proportional to the square root of the permittivity and linearly related to the loss angle of the material. This means that there is no conflict of requirements, since again reducing the permittivity results in a lower loss. The dielectric component of attenuation is totally independent of the physical size of the cable, *ie*, for the same insulating material, it is identical for a truck and a small drop cable.

Return Loss Ratio

Return loss is the logarithmic ratio of the input voltage to the reflected voltage from the cable, and is the result of internal cable mismatch. The characteristic impedance of the cable is dependent on the permittivity of the dielectric and the diameters of the inner and outer conductors, which means that any variation in these parameters along the length of the cable will result in a corresponding variation in the characteristic impedance. Return loss is therefore not a calculated parameter but more a monitor of the competence of the manufacturer in producing the cable. It is still a characteristic however, which the design engineer must consider very carefully. The material or construction of the dielectric has to be selected such that it can either be manufactured to very fine tolerances or so that the effect of any irregularities can be minimized through subsequent processing. In the USA and Canada, for example, a variable technique is often favoured, but it can produce reading 6 db more optimistic than the major European fixed bridge method.

Shielding Efficiency

The selection of the type of shield to be employed in the cable is based on an understanding by the design engineer of the performance of the various forms of outer conductor, taking into account the environmental and installation conditions to which the cable will be subjected.

Although the shielding isolation is not a calculated parameter, it is very much dependent on skin effect. This is the phenomena resulting from nonuniform flux cutting across the surface of the conductors, where the current is forced to the outer surface of the inner conductor and the inner surface of the outer conductor.

Mechanical and Physical Considerations

The mechanical and physical properties of the cable are very dependent on the installation and environmental conditions to which it will be subjected. There are six basis parameters to consider.

1. Crush strength

This is particularly important if air is used as an integral part of the structure of the cable, *ie*, with cellular and semi-air-spaced dielectrics.

2. Longitudinal Pull Strength

The cable has to have sufficient internal mechanical strength to withstand both the longitudinal pulling forces sustained during installation and also the forces encountered *in situ*, particularly when fastened to poles above ground.

3. Flexibility

The desired level of flexibility is very much dependent on the method of installation. Rigid cables cannot be pulled, without difficulty, into conduit or ducting, but can have advantages when installed above ground.

4. Abraison resistance

The outer sheath must be capable of withstanding the abrasive effect encountered during installation into conduit, ducts or through any confined spaces. It has been the practice in a number of countries to apply an increased radial sheath, so that any external damage will still not result in failure of the cable, but the use of abrasive resistance materials is a far more successful solution.

5. Resistance to environmental conditions

After surviving the rigours of installations, the cable must also be capable of withstanding the predefined environmental conditions to which it will be subjected during its operating life. These may include high temperature, low temperature, ultra- violet light, solvents, water, abrasion, insects or rodents, to name but a few.

6. Cable weight

As a general rule, a reduction in the cable weight results in a corresponding improvements in the case of installations. A myth which is worth dispelling is that difficulties in pulling long lengths of cable through ducts is due to the physical weight of the cable; these difficulties are far more likely to be the result of frictional resistance built up between the surface of the cable and the duct lining.

The Electrical Design

The design engineer uses a combination of the characteristic impedance and attenuation requirements to determine the optimum size and construction of the cable. The formulas for the parameters are derived from long-line transmission theory, and since this is shown in a number of advanced electrical engineering text books, I will take liberty of simply discussing some of the characteristics of the final equations. These equations are for coaxial cable having a solid inner conductor, and an outer conductor construction of either a solid tube, a tape, a tape and braid, or a foil braid.

Characteristic Impedance

The characteristic impedance varies inversely with the permittivity and directly with the log of the ratio between inner and outer conductors.

If the characteristic impedance Zo if fixed and the relative permittivity of the dielectric is constant, the ratio of the outer to the inner conductor must always be the same. To give an example, for a 75 ohm solid polyethylene dielectric cable (dielectric relative permittivity Erd of 2.28) the ratio of conductors is 6.61. This is important because, although the characteristic impedance for a particular dielectric does not fix the size of the conductor, it does totally govern the ratio of the diameters of the conductors.

It can also be seen that for a specific characteristic impedance, the only way that one could practically reduce the D/d ratio would be to lower the dielectric permittivity Erd. Reducing the D/d ratio has the advantage that for a fixed overall cable diameter, the inner conductor will be increased and, this will reduce the attenuation.

Attenuation

The first term of the attenuation formula, which varies as the square root of frequency, is the conductor loss in the cable. Since the ratio of the inner and outer conductor diameters, for a specific dielectric, is fixed by the characteristic impedance value, then the ratio of the inner to outer conductor loss is also fixed at the same value as long as the conductor materials are the same, *ie*, for a 75 ohm solid polyethylene cable with D/d ratio of 6.6, the inner conductor loss is 6.6 times greater than the outer conductor loss. The lower the permittivity, the lower becomes the conductor ratio, and therefore for a fixed outer conductor diameter and hence loss, the inner conductor loss reduces as the conductor diameter increases. Since changes to the inner conductor diameter have the greatest effect on the overall loss, and since the quality of materials used in a fixed outer conductor diameter cable would be relatively constant, then an improvement in attenuation can be created without causing any significant increase in the cable cost. As one would expect, the loss is also dependent on the resistivity of the conductors, and can therefore be reduced by using the lowest possible resistivity materials. It is interesting to note, however, that the loss is proportional to the square root of the resistivity and not directly to it, as is the case with DC. This is the result of skin effect, and in practical terms means that if the cable is to operate at VHF and above, then higher resistivity conductor materials can be used without the detrimental effect normally experienced at very low frequencies.

At first sight, one would also suppose that the conductor loss could be reduced simply by increasing the characteristic impedance, but this is not in fact the case, because Zo is also dependent on the conductor ratio. This is, however, a condition for minimum attenuation which occurs when the ratio equals 3.59, and the same ratio applies whatever conductor (both conductors of the same material) or dielectric materials are used. This means that from a cable transmission point of view, for minimum attenuation the characteristic impedance should be as follows:

- For a solid polyethylene cable Zo = 50.8
- For a semi-air-spaced cable Zo = 64
- For an air-spaced cable (Erd = 1) Zo = 76.

The next term in the attenuation formula is the dielectric loss, and varies directly with frequency. In all practical cases, the dielectric loss even at high frequencies is generally small in relation to the conductor loss, *eg*, for a distribution cable such as Raydex CT1G7, at 400MHZ the dielectric loss accounts for approximately 10% of the total attenuation. It must be noted that the dielectric loss at a specific frequency is only dependent on the electrical characteristics of the dielectric being used, and is totally independent of the cable size. This means that for a constant type of insulating materials, the dielectric loss is the same for a large trunk cable and small drop cable, and the attenuation can never be reducted below this fixed dielectric loss.

If the characteristic impedance and attenuation at a specific frequency are known, then the ratio of inner to outer conductors can be calculated from the attenuation and characteristic impedance formulas respectively for various combinations of conductor and dielectric materials and hence the actual physical dimensions of the conductors can be determined. The characteristic impedance governs the relationship between the inner and outer conductor diameters, and the attenuation requirement determines the physical size.

Skin Effect

The phenomenon known as skin effect, affects the high frequency resistance of the inner and outer conductors, the attenuation and also the shielding efficiency of the outer conductor of the cable. As the frequency is increased, the current in the cable is pushed further and further to the outer surface of the inner conductor and further and further to the inner surface of the outer conductor.

If one considers the positions in the inner conductor by imagining it to be made up of an infinite number of parallel elements of equal resistance, then, as the magnetic field expands and contracts, the flux that cuts the surface elements will be only that flux which is exterior to the inner conductor at the time of maximum field expansion. The same flux cuts the inner element but, in addition, the inner element is also cut by the flux that was in the conductor itself at the time of maximum field expansion. This means that there is greater flux cutting at the centre of the conductor than at the surface which, in turn, creates a small inductance gradient is small, the inductive reactance gradient becomes large at higher frequencies, affecting the flow of current, most of which flows near the surface where the impedance is low. Since the effective area of the conductor is reduced the resistance is increased.

Summary

If I had authority to string the cable on poles above ground and the maximum required frequency at the operating level was never to rise above 300 MHz, then I would carefully consider the use of an aluminum tube/gas injected foam cable. If the frequency band above 300 MHz was required, then I would replace the foam with a semi-air spaced dielectric, but one in which the mechanical strength remained constant along its length in order that tube kinking did not become a problem. It is possible, however, that I would be looking for higher braid covers, for use in areas where there were greater levels of interference. ■