BICCCables

Electric Cables HANDBOOK

Third Edition

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Third Edition

BICCCables

Edited by

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Preface to Third Edition

The first and second editions of the *Electric Cables Handbook* were well received and there were many requests for a revised edition. The third edition provides a substantial, comprehensive and up-to-date review, reflecting the changes which have occurred in the cable industry during the last seven years. The Handbook therefore continues to be a major reference book for professional engineers and electrical contractors involved in cables.

The Handbook covers all types of energy cables, from wiring and flexible cables for general use to distribution, transmission and submarine cables. It includes information on materials, design principles, installation and standards, and the many appendices contain extensive tables of data on commonly used cable types.

Once again it has been difficult to decide which older types of cable should be excluded and which new types should be included. While the Handbook has been comprehensively revised, the main aim has been to describe adequately those new energy cables which reflect the present dynamic state of the industry. The description of cables in fires has been completely rewritten; the significant developments in high performance materials, both polymeric and paper laminate, are described in detail; the application of new materials to high voltage systems is thoroughly covered; for the first time there is an extensive description of the recent developments in high temperature superconductivity, with the emphasis on potential applications in power engineering.

The Handbook has also been significantly extended to give a broad view of communication cables for the power engineer. Recognising the increasing impact of telecommunications in the power industry, a new and substantive section describes the application of optical fibres in power transmission systems. There is also an additional section on communication cables; this includes a revision of the original chapter on electronic cables.

Reflecting the extensive revision of the text, extra material has also been added to the appendices, references and bibliography. Much of the original text has been retained in the interest of providing the necessary background to the continuing technical developments in the industry.

As in previous editions, this Handbook draws on the extensive expertise and experience of the staff of BICC Cables Ltd and the editor would like to thank the many contributors for their text, their collaboration, and many helpful suggestions.

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A particular tribute is due to the editorial committee of Dr D. G. Dalgoutte, Dr A. W. Field, and Dr K. Julian who organised the work as well as providing their own detailed technical knowledge, and to D. McAllister for his work on the first two editions and the late E. W. G. Bungay who co-edited the second edition. Finally, thanks are also due to the directors and management of BICC Cables Ltd for the provision of time and facilities for preparing the manuscript and illustrations.

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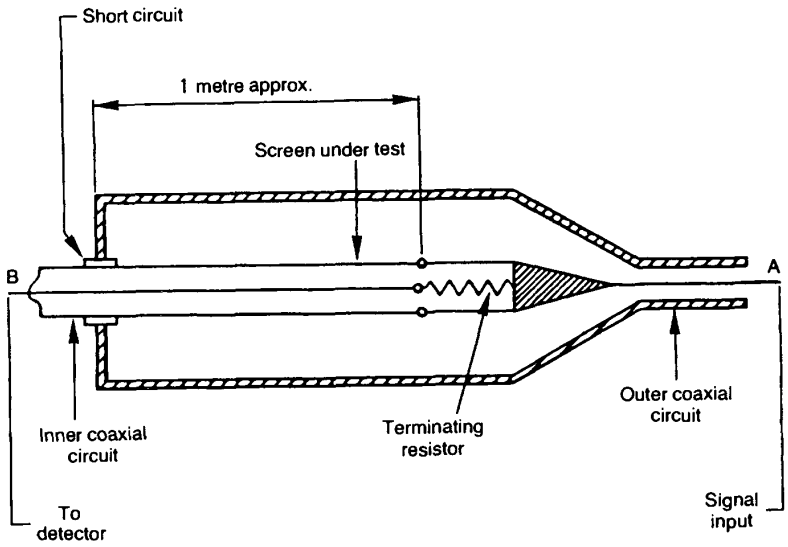

Fig. 53.13 Schematic diagram of triple coaxial apparatus

It follows that the lower the surface transfer impedance is, the better the screen is. For screens other than homogeneous tubes, the surface transfer impedance is usually measured using the triaxial arrangement shown in fig. 53.13.

Surface transfer impedances are shown in fig. 53.14 for various screen constructions at frequencies up to 30 MHz. Curves A and B show the typical drooping characteristic of the better screens. Curve C shows a popular type of screen, a single copper wire braid, which has a rising characteristic with a typical value of 200 mΩ/m at 30 MHz. To improve screening performance a second braid may be applied either directly in contact with the first (curve D) or with an intersheath (curve E).

The ratio of the resistance of a wire braid to the resistance of an equivalent tubular conductor is called the braiding factor and is given by

$$K_B = \frac{K_L}{2K_F} + \frac{\pi K_L K_F}{4} \tag{53.22}$$

where $K_L = 1 + \pi^2 D^2/L^2$ the lay factor
$K_F = mndK_L^{1/2}/2\pi D$, the filling factor
D = mean diameter of braid
m = number of spindles
n = number of wires (ends) per spindle
d = braid wire diameter
L = braid lay length

The cover provided by a braid is $100K_F(2 - K_F)\%$, and the braid angle is given by $\tan\phi = \pi D/L$.

Typical wire braid screens have a braid angle of about 40° and a cover of just over 90% which is equivalent to a filling factor of 0.7. Braids can be optimised for surface

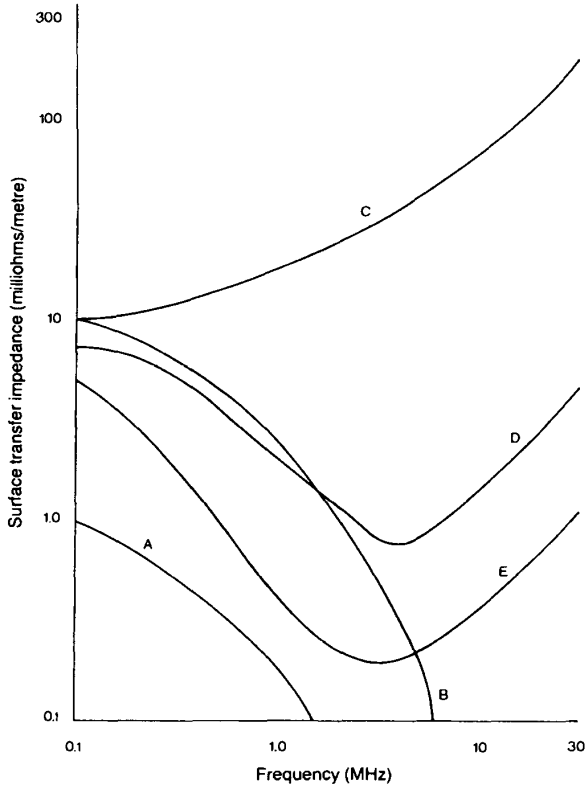

Fig. 53.14 Surface transfer impedances of various screens: curve A, seam welded copper tape 0.25 mm thick; curve B, overlapped corrugated copper tape 0.18 mm thick; curve C, single-wire braid; curve D, double-wire braids in contact; curve E, double-wire braids with intersheath

transfer impedance in terms of the numbers of spindles and ends, wire size and lay length, but generally a compromise is achieved between screening efficiency, manufacturing costs, flexibility and ease of termination.

Laminated foil tape screens provide 100% cover, and their screening efficiency is determined by the material and thickness of their metallic component. Improved efficiencies can be achieved by using double-sided foils in the form of a metal/polyester/metal sandwich, combinations of foils or combinations of foils and copper wire braids. Figure 53.15 shows the surface transfer impedance for various screens incorporating foils. Curve A is for a small coaxial cable with a single tape containing aluminium foil 0.05 mm thick. Curve B is for a multipair cable, with individual pairs screened with a single tape with an aluminium thickness of 0.025 mm, and an overall screen comprising a double-sided foil, each side 0.01 mm aluminium, and a tinned copper wire braid. Curve C shows the surface transfer impedance of the large coaxial cable illustrated in fig. 53.4 (left) which has a tape/braid/tape/braid screen, the tapes being double-sided aluminium/polyester.

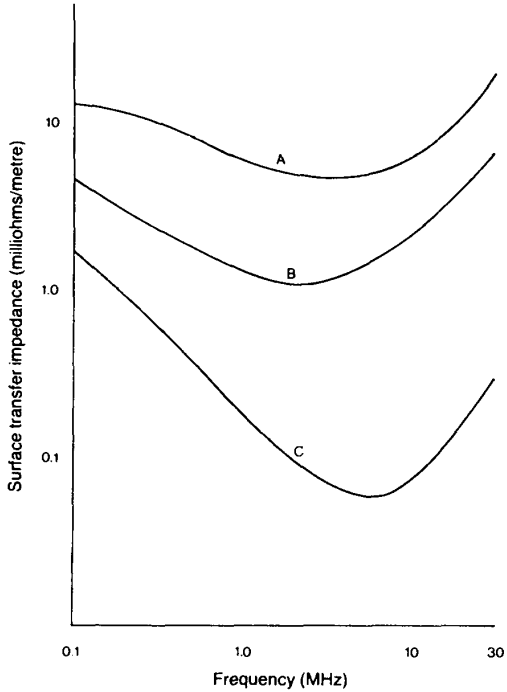

Fig. 53.15 Surface transfer impedance of cables with foil screens: curve A, single aluminium foil 0.05 mm thick; curve B, single- plus double-sided foil with copper braid; curve C, foil/braid/foil/braid

Another type of screen has been developed for applications in nuclear plant installations where very low limits are set on leakage from one control circuit to another. These 'super screened' cables have a mu-metal tape lapped between two braids and show surface transfer impedance values at 30 MHz as low as 1 μΩ/m.

COAXIAL CABLES

In general coaxial cables perform better than their pair counterparts at higher frequencies. For a given attenuation, the size and cost of a coaxial is less than that of a twin or pair cable of comparable performance. They do not display the instability of characteristic impedance, attenuation and electrical length typical of screened twins, but at lower frequencies the screening efficiency of a balanced twisted pair can be superior.

Design features

The basic coaxial cable design is an inner conductor surrounded by a dielectric and a concentric outer conductor.

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The general theory concerning transmission characteristics applies to coaxial cables, but in addition consideration should be given to particular aspects of design related to the application and methods of manufacture.

Inner conductor

The preferred form is solid plain annealed copper. For high frequency use, because of the skin effect copper-covered steel may be used, but at frequencies below 10 MHz some current will flow in the steel core. For larger cables, copper tubes or copper-covered aluminium are used.

Stranded conductors can increase the high frequency resistance by up to 25%, and the resistance of tinned copper wire is higher than that of plain copper wire at frequencies above 10 MHz.

Silver-plated conductors are used at very high frequencies because of their smoother surface finish as well as their good conductivity.

Dielectric

Insulation with low and stable permittivity and power factor is preferred. This can be solid polyethylene or cellular polyethylene.

Alternatively, a number of other methods can be employed to fabricate low permittivity dielectrics for coaxial cables by using semi-airspaced constructions with solid polyethylene as the main insulating material. In one method, discs of polyethylene spaced at intervals give an effective permittivity of about 1.07. This type can be made to very close impedance limits and is used extensively for wide band carrier telephone and video trunk routes.

Another construction is the helical membrane type. A continuous tape of polyethylene is applied in the form of a helix along the inner conductor. This gives an effective permittivity of 1.1 which, as in the case of the disc spaced cable, is approaching the lowest practical limit.

A further type shown in fig. 53.16 uses a thread and tube construction in which a thread of polyethylene is lapped round the inner conductor and a close fitting polyethylene tube is extruded over this, giving a permittivity of about 1.3.

Outer conductor

The best form of outer conductor giving low attenuation and good screening is a solid copper tube. For flexible applications copper wire braids are used or combinations of thin tapes and copper wire braids.

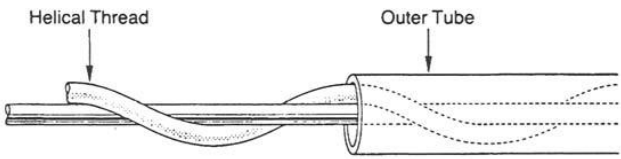

Fig. 53.16 Thread and tube dielectric construction

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Outer protection

For indoor and general applications, a PVC sheath may be applied overall. For more arduous environments or outdoor use a steel armour and further PVC sheath can be applied.

Low and high impedance coaxial cables

Some special cables have been made with a characteristic impedance as low as 14 Ω. Low impedance is obtained by the use of a relatively large inner conductor formed by a wire braid over a plastic core. The characteristics of the cable are very sensitive to small variations in conductor diameter.

High impedance cables can be made by increasing the inductance per unit length by the use of a helically wound inner conductor. The increase in inductance reduces the velocity ratio and such cables can be used as delay lines. By the use of a plastic core loaded with magnetic material as a former for winding the inner conductor, impedances as high as 4000 Ω can be achieved together with velocity ratios as low as 0.001. For this low velocity ratio it takes a signal 3.0 μs to travel 1 m of cable. The delay and high impedance are obtained only at the price of high attenuation. At high frequencies the capacitance between adjacent turns of the helix resonates with the inductance at a cut-off frequency above which there is no transmission.

Radiating cables

There is an increasing demand for rapid communication services in the interests of efficiency, safety and convenience as witnessed by the expanding use of two-way mobile radio systems, radio paging and radio control. However, there are certain situations where conventional free-space radio transmission from aerials is not practical, e.g. in mines, tunnels, power stations, industrial areas and linear situations such as railways and motorways. The range of natural radio propagation in tunnels is very poor, only a few hundred metres at the most, so that communication with a distant receiver inside a tunnel is impossible using normal techniques. One way of overcoming this problem is to use a radiating cable or leaky-feeder technique in which the required radio signals radiate from a cable rather than from a conventional aerial.

The basic principle of this technique is shown in fig. 53.17. A two-way base radio station is connected to a long radiating cable transmission line which runs throughout the area where communication is required and transfers signals to and from the mobile stations through the radiation field from the cable. The special design of cable is sometimes called a leaky feeder because when it is fed with radio signals at one end it leaks small amounts of energy all along its length to be picked up by nearby mobile aerials.

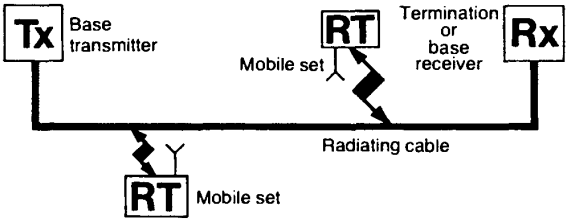

Fig. 53.17 Radiating coaxial cable system

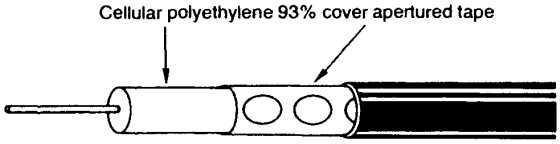

Fig. 53.18 Apertured tape screened radiating cable

The bifilar or unscreened twin cable is economic and radiates well, although the attenuation is very unstable. Even at the lower frequencies a large increase in attenuation occurs when the cable is laid on the floor or mounted close to walls. Experience in coal mines has shown that a serious increase in attenuation occurs when a layer of wet coal dust accumulates on the cable surface. However, with specially designed coaxial cables, good radiation and stable attenuation can be achieved when the cable is wet or dirty or mounted on walls. In these cables the outer screen is a corrugated copper tape perforated with a series of holes, as shown in fig. 53.18, to provide and control the radiation.

Experimental work has shown that radiation from an apertured tape cable depends on the dielectric permittivity of the insulation, and the stability of attenuation under wet and dirty conditions depends on the surface transfer impedance.

A theoretical treatment of the field leakage through a row of holes in an apertured screen has shown that at 30 MHz the surface impedance can be calculated using the formula

$$Z_T = \frac{4nd^3}{D^2} \qquad (\text{m}\Omega/\text{m}) \qquad (53.23)$$

where d = hole diameter (mm)
D = screen diameter (mm)
n = number of holes per metre

The optical coverage of apertured or braided screens is sometimes quoted as a characteristic. However, if the surface transfer impedance depends on nd^3/D^2 and the optical cover depends on nd^2/D, it can be seen that optical coverage is not a direct measure of screening efficiency.

A general purpose radiating coaxial will have a permittivity around 1.4 and a surface transfer impedance of 500 mΩ/m.

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CHAPTER 54
Datacommunication Cables

TWISTED PAIR DATA CABLES

Design features

A variety of twisted pair designs is used as shown in fig. 54.1. Conductors are generally in the range 0.2–0.8 mm^2 (24–18 AWG), solid or stranded, and tinned for ease of termination. PVC insulations are used for short distances and low speed data but for higher speeds and longer distances, polyethylene and polypropylene in solid or cellular form are used. Individual pair screens to reduce crosstalk are generally laminated foils

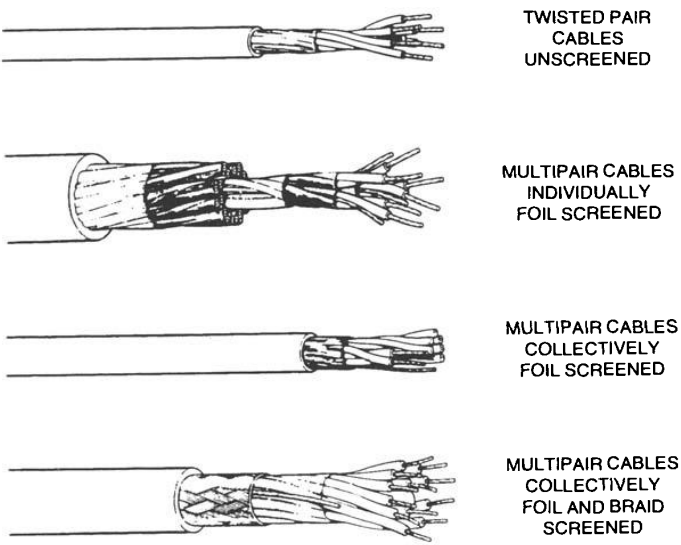

Fig. 54.1 Twisted pair cable

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and incorporate a drain wire to achieve satisfactory electrical connections. Overall screens provide protection from outside interference and can be laminated foils with or without an overall braid.

Outer sheaths are generally PVC formulated to suit the particular application, including high and low service temperatures, and to impart flame retardance. A zero halogen low smoke material is used when the emission of smoke, toxic, or acidic gases is considered a hazard in a fire.

High performance twisted pair cables

Many of the early local area network systems were introduced in the USA, and through the efforts of the American Institute of Electrical and Electronics Engineers (IEEE), and particularly Project 802, a family of standards was drawn up for local and metropolitan area networks. Having gained worldwide acceptance many of these systems standards were adopted by ISO.

The earliest standards activity for Structured Wiring was also initiated in USA in 1985 by the Electronics Industries Association (EIA) who established their Engineering Committee TR-41.8 to draw up a Commercial Building Wiring standard to provide a general purpose cabling system to accommodate all communications services. Work commenced to embrace the main features of commercially available networks and cabling schemes; particularly influential was the approval of IEEE 802.3 10 Base T, a system which promoted 10 Mbps transmission over 100 metres of a four pair unscreened cable.

After amalgamating with the Telecommunications Industries Association (TIA) the first Structured Wiring standard was published in July 1991 as EIA/TIA 568. It covered a hierarchical star network with four pair unscreened horizontal cables specified for frequencies up to 16 MHz in terms of impedance, attenuation, crosstalk, mutual capacitance, and capacitance and resistance unbalance.

As systems developed to higher data speeds, attempts were made to classify cables by performance into Levels or Categories. Five copper conductor cable categories were defined as follows.

Category 1: Basic telephone cable for voice frequencies
Category 2: Data cable for use up to 4 $Mbits^{-1}$
Category 3: LAN cables characterised up to 16 MHz. These cables will support Class C links
Category 4: LAN cables characterised up to 20 MHz
Category 5: LAN cables characterised up to 100 MHz. These cables will support Class D links

These categories were confirmed by the EIA/TIA in their Technical Systems Bulletin TSB-36, published in November 1991. Category 1 and 2 cables are not suitable for the higher performance Structured Wiring systems and Category 4 cables are becoming obsolete. Although ISO/IEC 11801 details Category 3, 4 and 5 cables, EN 50173 specifies Categories 3 and 5 only.

The requirements for balanced twisted pair cables in horizontal subsystems apply to materials, mechanical performance and dimensions, and electrical and transmission

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Table 54.1 Electrical characteristics of 100 Ω twisted pair cables to ISO/IEC 11801 and EN 50173

Cable characteristics			Cable category	
Electrical characteristics at 20°C	Units	MHz	3	5
Maximum d.c. loop resistance	Ω/100 m	d.c.	30	30
Maximum resistance unbalance	%	d.c.	3	3
Maximum capacitance unbalance	pF/km	0.0008 or 0.001	1600[a]	1600[a]
Maximum transfer impedance (for screened cables)	mΩ/m	10	100	100
Minimum insulation resistance	mΩ km	d.c.	150	150

[a] These values are specified in EN 50173. ISO/IEC allows up to 3400 pF/km.

characteristics. The physical requirements relate to the operating environment, installation practices and compatibility with connecting hardware, and ISO/IEC 11801 and EN 50173 lay down the permissible range of conductor diameters, the maximum diameter of the conductor insulation, the operational and installation temperature ranges, the minimum bending radius and pulling strength.

The electrical and transmission requirements for Category 3 and Category 5 100 Ω twisted pair cables in horizontal subsystems are shown in tables 54.1 and 54.2. When measuring impedance, structural return loss, attenuation and near end crosstalk, swept frequency techniques are used and it is a requirement that compliance is maintained at every measurement frequency as well as at the nominated frequencies.

The requirements for horizontal subsystem cables can be met by a four pair cable, either unscreened or collectively foil screened as shown in fig. 54.1. Typically these cables have a 0.5 mm (24 AWG) conductor with a polyolefin insulation, either solid or cellular. Because of the demanding performance requirements, control of materials and processing techniques must be at a significantly higher level than when manufacturing basic telephone pair cables.

Balanced cable transmission

The main parameters influencing the performance of a balanced transmission system are characteristic impedance, crosstalk, loop resistance, attenuation, velocity of propagation and the immunity to electromagnetic radiation. For some installations, electromagnetic radiation from the cable is also important.

Constructional features of the cable such as conductor size, variation in conductor diameter, insulation permittivity, variation in insulation diameter, twinning lays, cabling lays and screen foil thickness can have an effect on one or many of these parameters.

Crosstalk

Cables with twisted pairs are used where balanced signal transmission is required, together with low crosstalk. Crosstalk refers to interference on one channel caused by a signal in another channel and occurs between cable pairs carrying separate signals. This definition embraces both near end crosstalk and far end crosstalk.

Table 54.2 Transmission characteristics of 100 Ω twisted pair cables to ISO/IEC 11801 and EN 50173

Cable characteristics			Cable category	
Transmission characteristics at 20°C	Units	MHz	3	5
Velocity of propagation	–	10	0.6c	0.65c
		100	–	0.65c
Minimum longitudinal conversion loss[a]	dB	0.064	–	43
Minimum structural return loss[a]	dB @ 100 m	1–10	12	23
		10–16	10	23
		16–20	–	23
		20–100	–	[b]
Characteristic impedance	Ω	1–100	100 ± 15	100 ± 15
Maximum attenuation	dB/100 m	1	2.6	2.1
		4	5.6	4.3
		10	9.8	6.6
		16	13.1	8.2
		20	–	9.2
		31.25	–	11.8
		62.5	–	17.1
		100	–	22.0
Minimum near end crosstalk	dB @ 100 m	1	41	62
		4	32	53
		10	26	47
		16	23	44
		20	–	42
		31.25	–	40
		62.5	–	35
		100	–	32

[a] Values are not given in EN 50173.
[b] In accordance with the relationship $23 - 10\log(f/20)$ where f is the frequency in MHz.

Near end crosstalk is the crosstalk which is propagated in a disturbed channel in the opposite direction to the current in the disturbing channel, and far end crosstalk is propagated in a disturbed channel in the same direction as the current in the disturbing channel. Crosstalk is fundamentally the resultant of two factors, or couplings, capacitance unbalance and mutual inductance.

Capacitance unbalance gives rise to electrostatically induced potential differences between the wires of the disturbed pair; this coupling is important at all frequencies. When the capacitance of one conductor against the sheath and all of the other conductors combined is not the same as the capacitance of its mate (similarly measured) the pair is said to have a capacitance unbalance; this is measured by the difference between these two capacitances. When the capacitances are equal, the pair is said to be balanced.

Mutual inductance gives rise to electromagnetically induced potentials along the wires of the disturbed pair. This coupling exerts little influence at audio frequencies but becomes increasingly important as the frequency increases.

Both couplings are due to departures from balance between the circuits concerned. In design and manufacture, attempts are made to ensure that the distances between the wires of one pair and the wires of another are equal, as are the distances between each wire and earth. This is done by careful choice and control of materials, insulation thicknesses, twinning lays, and tensions, but during manufacture unavoidable small differences occur which result in residual values of the couplings.

As capacitance unbalance is an electrostatic coupling, it can be reduced by enclosing either or both of the interacting pairs in a screen. The screen need only be thin, and laminated foil screens are generally used. At higher frequencies, mutual inductance becomes important and differential twinning lays in adjacent pairs are used to minimise parallel paths and reduce the effect.

Impedance

The impedance match between a cable and its terminal equipment is important in controlling signal reflections. For twisted pair cables, random structural variations along the cable length occur in addition to periodic structural variations common to manufacturing processes involving rotating machinery. It is therefore usual to specify and measure structural return loss as well as impedance. Maintenance of machinery and control of processes are essential to meet the transmission requirements for Category 5 cables.

Attenuation to crosstalk ratio

Attenuation and crosstalk are important in determining the received signal-to-noise ratio. In ISO/IEC 11801 and EN 50173, alternative limits for attenuation and crosstalk are allowed provided the required attenuation to crosstalk ratio (ACR) is maintained. The ACR of a given length of cable is calculated as:

$$ACR = a_n - a \qquad \text{(dB)} \tag{54.1}$$

where a_n = near end crosstalk in dB between any two pairs
a = attenuation in dB

Table 54.3 shows the minimum values of ACR specified in EN 50173. The introduction of this parameter allows some flexibility in cable design, for example attenuation can be reduced by increasing the conductor size, reducing the insulation permittivity, increasing pair twinning lays and for screened cables, increasing the screen metal content to reduce its resistance. Crosstalk can be improved by optimising the pair twinning lay scheme or by introducing individual pair screens. Variation in crosstalk performance is reduced by shortening pair twinning lays.

Electromagnetic compatibility

Structured wiring systems can be subject to local regulations regarding electromagnetic emission and immunity. Although the cable as a product is considered to be a passive component of the system, and therefore is not required to be tested for electromagnetic compatibility (EMC), the operational system may be required to comply with, for example, European EMC Directive 89/336/EEC. These requirements should be taken

Table 54.3 Minimum ACR for 100 Ω Category 5 twisted pair cables to EN 50173

Frequency (MHz)	ACR (dB)
1	59.9
4	48.7
10	40.4
16	35.8
20	32.8
31.25	28.2
62.5	17.9
100	10.0

into account when designing a generic cabling system, and it may be advisable to optimise the emission and immunity characteristic of the cable, by optimising the balance of the cable and by the application of screens.

In a balanced system, the receiver responds to the differential voltage between the lines and, if the pair and cable are perfectly uniform with each leg identical, electromagnetic fields generated by the two signals flowing in the twisted pair cancel with the result that the net cable radiation is zero. If the pair is not perfectly uniform, imbalances result as the two signals do not cancel; a net current flows longitudinally which produces electromagnetic radiation. Similarly, imbalances lead to a coupling with external electromagnetic fields making the cable more sensitive to interference. Discontinuities in the cable, which may be produced during installation, can cause a part of the differential mode signals to be converted to longitudinal signals.

Two types of measurements are used to characterise the balance of a cable. These are the longitudinal conversion loss (LCL) and the longitudinal conversion transfer loss (LCTL). LCL measurements are made at the near end of the cable and identify imbalances near to a transmitter which could create radiation; LCTL measurements are made at the far end of the cable and identify the effects on the received signal of imbalances throughout the cable length.

The EMC performance of a cable can be improved by applying a collective screen, and surface transfer impedance is used as a guide to its effectiveness.

Installation

For high performance twisted pair cables operating at the higher frequencies, the cable design and installation practices must ensure that adequate cable balance is maintained after installation and termination. Both ISO/IEC 11801 and EN 50173 specify the performance of cables, connecting hardware and installed links.

Manufacturers recommendations regarding bending radii, pulling tensions and cable spacing should be observed to avoid cable stress due to sharp bends, crushing, excessive tension and tightly bunched cables. When terminating cables in connecting hardware, the untwisted length of pair and the length of removed sheath should be as short as possible.

For screened cables, earthing and bonding procedures should address the EMC performance of the link as well as electrical safety. Screens intended to improve

EMC performance are applied to both cables and connecting hardware and must be terminated in such a way that the screening effectiveness is maintained over the complete link.

OPTICAL DATA CABLES

Cable designs

Initially optical fibre cables were developed for long distance telecommunications, but as the technology advanced, numerous applications arose in data systems where the advantages of optical fibre transmission could be employed. Cables designed to meet the requirements of IEC 794 and EN 187000 will provide a satisfactory performance for the majority of data applications. The basic design principles are the same as those described in chapter 49.

For metropolitan and wide area networks where data transmission over long distances is required, cables designed for aerial, duct and buried routes on public and private telecommunications systems are used with single mode fibres (see chapter 48). For local area networks similar cable designs are used for both campus and building backbones, in some cases modified to be completely non-metallic. On the shorter route lengths, multimode fibres are often used when power budget and coupling parameters are as important as attenuation and bandwidth. IEC 793-1 (Optical Fibres) specifies a variety of step, quasi-step and graded index multimode fibres and includes a guide for fibres for short distance links, with 62.5/125 μm and 50/125 μm graded index fibres gaining popularity for local area networks.

For structured wiring, ISO/IEC 11801 and EN 50173 recommend optical fibre cables for most campus backbone cabling to overcome problems due to earth potential differences and other interfering sources as well as to provide extended route lengths up

Table 54.4 Optical fibre cable performance recommended in ISO/IEC 11801 and EN 50173

Fibre type	Multimode 50/125 or 62.5/125	Single mode
Maximum attenuation (dB/km) at:		
850 nm	3.5	–
1300 nm	1.0	–
1310–1550 nm	–	1.0
Minimum bandwidth (MHz km) at:		
850 nm	200	–
1300 nm	500	–
Maximum cut-off wavelength (nm)	–	1280

Note: Applicable standards are:
Fibre: Type A1a (50/125), A1b (62.5/125) and B1 (single mode) to IEC 793-2, EN 188201, EN 188202, EN 188100, EN 188101.
Cable: IEC 794-2, IEC 794-3, EN 187000, EN 60794-3.

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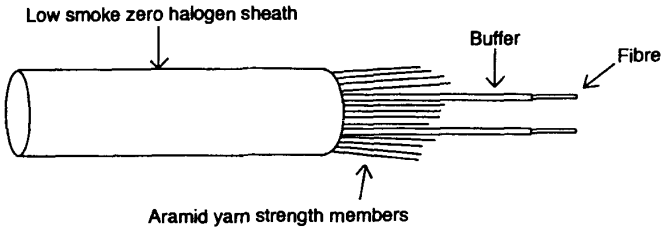

Fig. 54.2 Duplex optical cable for horizontal subsystems

to 3000 m with single mode fibres and 2000 m with multimode fibres. Optical cables are recommended for building backbones on medium to high speed data links, for horizontal data cabling with some very high bit rate systems, and where the electromagnetic environment and security considerations could cause problems with metallic conductor cables.

Table 54.4 shows the optical cable transmission requirements of ISO/IEC 11801 and EN 50173. For the horizontal cables, indoor cables are used, and preferably they should have handling characteristics similar to or better than the four pair Category 5 cables. Figure 54.2 shows a popular compact non-metallic cable featuring individually buffered fibres surrounded by a non-metallic strength member such as aramid yarn, with an overall sheath of low smoke zero halogen material.

In these tight buffered cables the fibre mechanical protection is provided by a layer of material applied directly over the coating of the fibre. This may be a dual layer, with a softer inner layer to provide a cushion against stresses which could cause an increase in attenuation, and a harder outer layer to provide mechanical protection. A typical dual layer buffer has a 140 μm thick inner layer of silicone covered by a 250 μm layer of polyamide. This form of buffer facilitates stripping, a force of only 10 N being required to strip the entire buffer over a 20 mm length.

Blown fibre systems

Of particular interest for local area networks is the development of the technique of blowing fibres into ducts or tubes. Blown fibre systems have been developed as a method of avoiding fibre overstrain for complex route installations. They allow easy upgrading and future proofing with low initial capital investment and the distribution of subsequent costs.

The network infrastructure is created by installing, using the most appropriate cabling method, one or a group of empty plastic tubes. Subsequently as and when circuit provision is required, one or more fibres can be blown by compressed air into the tubes. Individual tubes can, by means of connectors, be extended within buildings up to the fibre terminating equipment.

To enhance the blowing characteristics and to facilitate handling special coatings can be applied to the fibres. Figure 54.3 shows a typical blowable fibre construction whereby fibres can be blown singly or in groups into the same tube. Fibres with different transmission characteristics, or different types, e.g., multimode and single mode, can be blown into the same tube to accommodate particular network requirements.

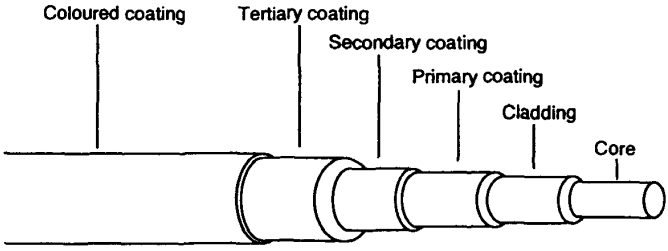

Fig. 54.3 Blowable fibre

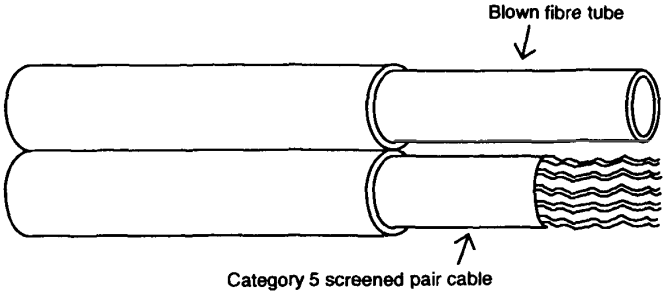

Fig. 54.4 Composite blown fibre and Category 5 pair cable

This technique can also be used to blow fibre ribbons into the tubes to take advantage of multifibre array connectors.

Another cable for local area networks combines a blown fibre tube with a Category 5 structured wiring cable, as shown in fig. 54.4. This flexible approach to the future-proofing of networks provides for immediate requirements to be met with the Category 5 four pair copper conductor cable and future optical up-grading by blowing in fibres as and when required without further cable installation costs.

Pre-connectorised cabling

To save on-site costs, loose tube, tight buffered or ribbon optical cables can be factory terminated with multifibre array connectors, and with suitable protection and end fittings, the terminated cable can be pulled-in and installed using conventional techniques.

CHAPTER 55
Twisted Pair Telecommunication Cables

SYSTEM LIMITS

To ensure satisfactory operation of a local telecommunication network the twisted pair transmission lines between the exchange and the subscriber must be planned to meet both a signal and a transmission limit. Typically the transmission limit is 10 dB (at 1600 Hz) and the signal limit is 1000 Ω. The signal limit defines the maximum loop resistance of an installed twisted pair in the local network. For a known distance between the exchange and the subscriber the maximum resistance can be used to calculate the twisted pair resistance per kilometre and hence the conductor diameter. The transmission limit defines the maximum attenuation for an installed twisted pair in the local network. For a known distance between the exchange and the subscriber (and hence a defined conductor diameter) the ideal mutual capacitance can be calculated.

In practice the twisted pair resistance and mutual capacitance are optimised[1] to:

(a) minimise cable and ducting costs;
(b) rationalise cable stock;
(c) minimise impedance mismatching at connections.

Table 55.1 summarises the conductor resistance, mutual capacitance and attenuation values of typical conductor diameters within the UK's local network.

Table 55.1 Electrical properties of local network cables

Nominal conductor diameter (mm)	Conductor resistance max. av. (Ω/km)	Mutual capacitance max. av. (nF/km)	Attenuation @ 1600 Hz (dB/km)
0.32	223	53	2.99
0.4	143	53	2.4
0.5	91	53	1.91
0.63	58	56	1.57
0.9	28	59	1.12

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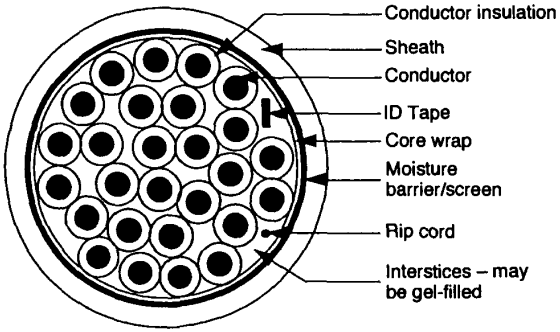

Fig. 55.1 Typical telephone cable layout

EXTERNAL TWISTED PAIR CABLES

Figure 55.1 shows a typical constructional layout for an external duct cable. In the following sections we briefly describe the main constructional elements. (See chapter 53 for a discussion of transmission theory for these cables.)

Conductor

The conductor is typically solid plain copper. In the past aluminium was considered when copper became relatively expensive, however the use of aluminium ceased when copper once again became economically viable; also corrosion problems were encountered in the field.

The gauge of conductor is dependent on the system limits, as discussed earlier. Typical rationalised gauges are 0.32 mm, 0.4 mm, 0.5 mm, 0.6 mm, 0.63 mm and 0.9 mm.

Insulation

Polyethylene has many desirable properties including high insulation resistance, low relative dielectric constant, voice frequency stability and low cost which make it especially suitable for use as the insulation material for external telecommunication cables.

Polyethylene insulation can be either solid, cellular or foam skin. The choice of insulation arises from the development of filled cables. The dielectric constant of a filled polyethylene cable is greater than that of a corresponding air core cable and therefore, for the same mutual capacitance and resistance, the solid insulation of a filled cable must be thicker than for an unfilled cable (a consequence of maintaining the $2S/d$ ratio of equation (53.19)). This disadvantage can be countered in a filled cable by introducing air into the insulation to form a cellular structure. Foam skin is an alternative to cellular structure in which an inner layer of cellular insulation is covered by a coating of solid insulation. If a cellular insulation is used in an air core cable a further reduction in insulation thickness and hence cable diameter, is possible.

Cellular insulation has allowed the introduction of filled cable without an increase in diameter compared with the solid polyethylene air core cable. Whilst cellular insulation is not as robust as solid insulation it has proven over many years to be more than adequate.

Cable assembly

Two or four insulated conductors are twisted around each other to form a twin or a quad respectively. Typically 10 pairs, 25 pairs or 5 quads are grouped together to form a unit. The colour of the insulation, and ink banding if applicable, within the unit are such that each pair can be individually identified. The units are grouped to form multiple units which can be grouped further to produce a cable core with the required number of pairs. The units and multiple units have coloured binder tapes helically applied around them which enable each unit to be individually identified.

Filling

The ingress of water into a cable can increase the mutual capacitance of affected twisted pairs by up to 125%, increasing the transmission loss, or attenuation, by up to 60%. Furthermore pin holes in the insulation can also lead to shorts between the wires under such circumstances. Filling the interstitial spaces within the cable limits both the migration of water into the cable, either through a damaged sheath or joint closure, and permeation of water through a non-hermetic sheath.

Alternatively by pressurisation the cables can be protected against the ingress of water. The cable is sealed at the far end and a constant air pressure is applied to the cable interstitial spacing at the near end. The pressure at the near end is monitored; a drop in pressure would indicate a fault in the cabling system such as damage to the sheath or closures. Pressurisation is usually confined to the primary network with the equipment being housed in the exchange.

Cables to be installed below ground in a non-pressurised network should be filled. Filling compounds are typically petroleum jelly based and are formulated to be compatible with the insulation at temperatures encountered in storage and after installation in the country of use.

Core wrap

One or more core wraps are usually applied to the cable core primarily to provide a heat barrier preventing the softening of insulation due to the heat of extrusion of the sheath. Other desirable properties of the core wraps are to provide a voltage withstand between the conductors and a metallic moisture barrier and to prevent water penetration within the region between the sheath and the cable core. The tapes can be plastic, dry paper, impregnated paper and/or water swelling material depending on the installation.

Moisture barrier/screen

The normally chosen material for external cable sheaths is polyethylene, however polyethylene alone will not block the permeation of water vapour into the cable core. Metallic moisture barriers are bonded to the inner face of the sheath and hence block the permeation of water from the sheath into the cable core. The moisture barrier is typically an aluminium tape with a polyethylene film laminated to one or both sides. The metallic moisture barrier also acts as a limited screen from external electromagnetic interference.

Within smaller cables the presence of a metallic moisture barrier can cause a small increase in the overall mutual capacitance of the cable. The pairs deviate slightly from the ideal balanced shielded pair model due to the proximity of the metallic moisture barrier.

Sheath

The grade of polyethylene used is defined by the preference of the user, the most popular grade being LDPE. Anti-oxidants are compounded into the polyethylene to prevent breakdown with age or during extrusion; also the polyethylene is impregnated with carbon black which prevents degradation due to solar radiation.

Ducted cable

External cable is most commonly installed in ducts, in which case the cable described thus far is sufficient.

Aerial cable

Aerial cable may be the same as duct cable and lashed to a pre-installed strength member (or support wire) or the cable may be self-supporting, that is the sheath will incorporate the strength member within the cable in a 'figure of eight' cross-section. The strength member must be selected to support the weight of the cable for the prescribed span and to withstand any additional loading factors such as wind, ice and perching birds.

Directly buried cable

Directly buried cable requires additional protection above that of duct cable. Depending on the level of additional protection required this can be supplied either by one or more layers of helically or longitudinally applied galvanised steel tapes with an oversheath, or by a layer of helically applied galvanised steel wire and an oversheath. The longitudinally applied galvanised steel tape is typically corrugated to give flexibility. The oversheath may be polyethylene, or PVC, or for protection against particularly voracious insects, nylon may be used.

DROPWIRE

Dropwire provides the final link, from the Distribution Point, typically a 'telegraph' pole to the individual subscriber's premises. Typically the final link is a single span but in some networks a dropwire may follow a route of several aerial spans. The length of the transmission line provided by dropwire within the local network is relatively small and hence the transmission characteristics of dropwire can be relaxed allowing more cost effective designs to be utilised.

In the more traditional double-D or figure of eight designs, as illustrated in fig. 55.2, the conductor combines both transmission performance and strength whereas in the more recent designs the conductors are conventional copper and the strength is provided by additional strength member(s).

 CommScope Exhibit 1028

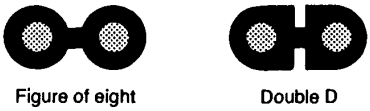

Fig. 55.2 Traditional dropwire designs

JUMPER WIRE

Jumper wire is used in cabinets to link the primary and secondary halves of the network, and for jumpering on distribution frames. The confined spaces require a tough abrasion resistant insulation for which PVC is ideally suited. Increased abrasion resistance can be achieved by irradiating the jumper wire with an electron beam, thus crosslinking the insulation.

INTERNAL CABLE

Internal, switchboard, and equipment cables are all used within buildings with typical cable lengths of 30 m. These small lengths allow the cable transmission characteristics to be less demanding. Internal cables are also likely to be subject to increased manual handling and an increased threat of fire. PVC is commonly used as the insulation and sheath material because it has good abrasion resistance and will not propagate fire.

Where it is necessary, in cases of fire, to limit the smoke emission and acid and toxic gas emission, alternative materials and cable constructions are required. Rigorous testing is required to assure, demonstrate and validate the 'Limited Fire Hazard' performance of these cables.

PVC has a tendency to stick to bare copper conductors making termination difficult, and to prevent this tinned copper conductors are typically used.

REFERENCE

(1) Spencer, H. J. C. (1970) 'A new method of local line transmission planning'. *P.O.E.E.J.* **63**, 84.