NEXANS TECHNICAL REVIEW

OCTOBER 2004

Table of Contents

Welcome to the October edition of the Nexans Technical Review
In this issue we will discuss the following topics:

The editorial team welcomes your input and feedback.
Send your comments to 'technical.info@nexans.com'.
We hope you will enjoy reading this Technical Review
and look forward to hearing from you.

DATA TRANSMISSION: 1. Data cables and the "cats"

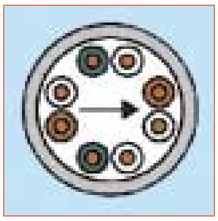
Everyone has already read information about so-called **Cat5, Cat6 or Cat7 cables.** However for those who are not entirely involved in the related domain these labels seem a little bit "esoteric".

The story began 15 years ago when Anixter launched their cabling and named them "level 3", "level 4"... The idea was to set up classes to rank the cabling according to the largest bit rate *(number of bits that are transferred between devices in one second)* they can support.

As a matter of fact, the transmission characteristics of the assembled components determine the maximum bandwidth* of the cabling.

This bandwidth is directly related to the maximum bit rate a cabling can support, thus the access speed to the information that is circulating on the cabling. The main transmission characteristics are the attenuation**, the cross-talk*** and the return loss****.

The standardisation bodies drafting standards for cabling, agreed to use labels similar to those initiated by Anixter. So, they built sets of values, **"categories"**, which a cable and connector have to meet to comply with a given ranked class; thus Cat3, Cat4, Cat5...



Moreover, they defined **"Classes"** of cabling that are built with components of a given category. Thus, Class A, Class B, and so forth up to Class F.

It should be noted that one Standardisation body (Telecommunications Industry Association: TIA) does not use the names of "classes" for "cabling", but adopted the same label "Cat3, Cat4, Cat5..." for the category of the components as well as the cabling that is built with these components.

With the rapid growing of the telecommunication market demand, it very soon became difficult to know whether the first was the egg or the chicken, the component or the cabling.

These last five years, the standardisation bodies made the choice to first define the class of the cabling, then to adapt the necessary characteristics of the components. The following relationships were established.

Cabling class	Component category	Minimum bandwidth
Class A		100 kHz
Class B		1 MHz
Class C	Cat3	16 MHz
	Cat4	
Class D	Cat5 (5^e)	100 MHz
Class E	Cat6	250 MHz
Class F	Cat7	600 MHz

Modelling and computation of "worst case" cabling configurations determine the necessary components' characteristics. Furthermore, new characteristics continuously emerge to take into account the needs of new applications.

This has resulted in lengthy discussions that have to be co-ordinated between the different standardization bodies.

* The amount of data that can be transmitted in a fixed amount of time. For digital devices, the bandwidth or bit rate is usually expressed in bits per second (bps). For analog devices, the bandwidth is expressed in cycles per second, or Hertz (Hz)

** Attenuation is a general term that refers to any reduction in the strength of a signal. Attenuation occurs with any type of signal, whether digital or analog. Sometimes called loss, attenuation is a natural consequence of signal transmission over long distances. The extent of attenuation is usually expressed in units called decibels (dB).

*** Crosstalk can be simply defined as the noise that is induced from one active cable pair to another. In it's simplest form, from the stance of testing and prevention, crosstalk is seen as Near End CrossTalk (NEXT)

**** Return loss is a measure of the ratio of signal power transmitted into a system to the power reflected (i.e. 'returned'). In simple terms, it can be thought of as an echo that is reflected back by impedance changes in the link.

1.1 Cabling standardization

The already existing standards currently define:

Cabling class	Component category	Minimum bandwidth
Class A		100 kHz
Class B		1 MHz
Class C	Cat3	16 MHz
	Cat4	
Class D	Cat5	100 MHz
Class D	Cat5 (5^e)	100 MHz
Class E	Cat6	250 MHz
Class F	Cat7	600 MHz

Note : Due to the emerging 10 Gbit application, class E and F should likely be upgraded soon. They will use upgraded Cat6 and 7 components.

1.2 Components standardization

Fortunately the standards for the components are already well advanced. Based on the current drafts of the cabling standards, the cable standards have been written and are now approved as IEC* 61156-5 and IEC 61156-6 or EN** 50288-4-1, 50288-4-2 and EN 50288-5-1, 50288-5-2. From a cable design point of view, the difference between a cable Cat5, Cat6 or Cat7 is not always obvious. As explained above, the main criteria are the attenuation, the return loss and the cross talk. Therefore, any cable manufacturer may propose Cat5^e, Cat6 or Cat7 cables that comply with these standards. The connector standards for Cat6 are, however not yet issued, while the connector standard for Cat7 (GG45) is published. The delay for the Cat6 connector standard has been troublesome for connector manufacturers, since the final compromise on the requirements has been reached only in the past few months. Construction parameters that affect these criteria are the lay length, the conductor diameter, the properties of the insulation material and the regularity of the insulation layer as well as the assembling process.
Roughly, the cross talk may be improved by shortening the lay length or using screened pairs. The return loss is linked to the regularity of the diameter of the conductor, the regularity of the lay length, and the regularity of the insulation diameter. There is a direct relationship between the diameter of the conductors and the attenuation. The larger the diameter, the smaller the attenuation. However, the quality of the insulation material (loss angle and permittivity) also affects the attenuation.

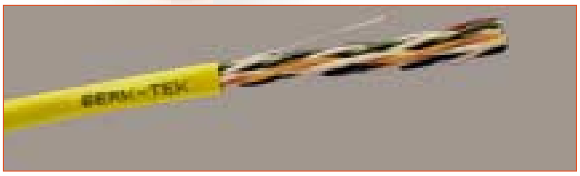
Note: Upgraded components for 10 Gbit application might be required to meet exogenous (alien) crosstalk requirements.

* IEC: International Electrotechnical Commission.
** EN: standard from CEN: European Committee for Standardization.

1.3 Nexans and the Data cables

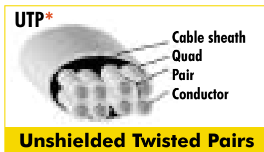
According to these explanations, the design of a Cat6 or Cat7 cable is somewhat the result of alchemy coming from the ancient ages of the cable manufacturing. Our Nexans "Nostradamus" is located in **New Holland** (Pa/USA) within the LAN Cable Competence Center and uses modelization and algorithm to find the best compromises that will result in an "optimum" cable. Thanks to them Nexans (through the plants of Abbey-Wood/UK, Fumay/F, New-Holland/USA and Kang-Hua/PRC) is one of the few cable manufacturers to put on the market, UTP*, FTP** and STP*** Cat5, 6 and 7 cables.

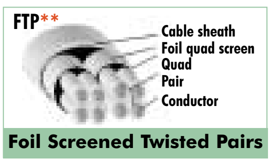
That means that we have designed:
Un-screened twisted pair cable up to cat6 (UTP): see photo below of a Cat5 LANmark cable.

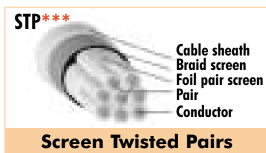


LANmark – 350 Premium Cat5^e

Foil screened cable up to Cat6 (FTP) And screened twisted pair cable up to Cat7 (STP). Our research team dreams on a Cat7 UTP, but it will be another story.







HIGH VOLTAGE CABLE: 2. Extruded High Voltage Cable

There are a variety of extruded power cables* available such as ethylene-propylene-rubber (EPR) insulated cable, polyethylene (PE)-insulated cable, and cross-linked polyethylene (XLPE)-insulated cable. They have superceded paper insulated type cable of medium-voltage and are replacing High Voltage OF (Oil-Filled) cables.

* Power cable classification:	
Low-Voltage (LV):	< 1000 V
Medium-Voltage (MV):	1 to 36 kV
High-Voltage (HV):	45 to 200 kV
Extra-High Voltage (EHV):	> 200 kV

Advantages of extruded cables:

- reduced weight versus Paper/Oil
- accessories more easily applied
- easier to repair faults
- no hydraulic pressure/pumping requirements
- reduced risk of flammability/propagation
- economics (initial and lifetime costs)

Prototype extruded cable

2.1 Insulation aspects

The two most commonly-used, polymer cable-insulation materials are Cross Linked Polyethylene (XLPE) and Ethylene Propylene Rubber (EPR).

XLPE material is based on Polyethylene (PE). EPR is based on ethylene propylene copolymer (EPM). The dielectric losses in EPR are higher than in XLPE which limits the application range to 150kV. However its good flexibility and its resistance to ozone, weather and light, have given to EPR insulated cables a widespread use in Brazil, Italy and Switzerland.
PE cables were introduced in 1945, and XLPE in the early 1960s. The low dielectric losses of PE and XLPE are an important property so that they can be used up to 500kV. Since the users of power equipment tend to proceed conservatively (with good reason), it was not until the end of the 1960s that XLPE cables began to be installed (initially LV and MV cables then HV cables).

Polyethylene

PE consists of ethylene monomers that are connected through polymerization into long molecular chains. There are several types of PE, usually classified according to their density into low (LDPE), medium (MDPE), and high-density (HDPE) PE.
PE has excellent electrical properties including high breakdown strength, and since it contains no polar groups, a low dielectric constant and very low dissipation factor but like most plastics, it is susceptible to degradation by corona discharges**. PE also may experience degradation from treeing*** when it is subjected to high electrical stress and moisture. Corona discharges and treeing may lead to premature cable failure.
The disadvantage of PE is that it starts to soften already at 80-90°C and melts at 110-115°C (120-125° in case of HDPE). This limits the maximum operating temperature of power cables insulated with LDPE to 70°C and 80°C for HDPE.

** An electrical discharge accompanied by ionization of surrounding atmosphere.

*** Treeing: Under electrical stress, a series of tiny hollow channels can develop within an insulation exposed to water. Since the resulting pattern looks like a poplar tree without leaves the name "water tree" is used to identify the pattern. The base of the tree is located at the point where the tree originated and its extremities tend to grow in a direction parallel to the direction of the electrical field. Thus, a tree originating at the stress-relieving layer at the conductor (conductor shield) of a cable grows radially until the cable fails.

Crosslinked Polyethylene

By cross-linking PE, its thermal and mechanical properties are improved, increasing the maximum working temperature to 90°C, while the electrical properties remain more or less unchanged. Cross-linking implies that the long PE molecular chains are inter-connected by bonding between the carbon atoms.

There are several methods for the cross-linking of PE. For power-cable applications, peroxide (for MV and HV cables) and silane (for LV cables) cross-linking are generally used (the peroxide method being the most common). In the peroxide method, a dicumyl-peroxide curing agent is added to the polymer compound and is activated right after the extrusion in a special tube at high temperature and high pressure. Steam was previously used for achieving both pressure and heat, and therefore often referred to as "steam curing". However it has been shown that the use of steam causes high water concentrations and voids formation in the insulation (inducing water-treeing***).

In the silane method, curing does not take place directly after extrusion, but in a separate production step. In the silane-curing process, a silane compound is grafted onto the PE chains during extrusion. After the extrusion the cable is slowly cooled. Curing takes place afterwards by putting the extruded cable on a reel in the workshop's atmosphere.

Ethylene-Propylene Rubber

Ethylene-Propylene Rubber (EPR) is a crosslinked material based on ethylene propylene copolymer (EPM) While XLPE is a mixed crystalline and amorphous material, EPR is an amorphous resin filled with mineral ingredients. The filler content that can be 50% or more. The filler is typically a treated clay or silicate. This amorphous resin accounts for EPR's flexibility when compared to XLPE.

Peroxide is the predominant crosslinking agent for EPR compounds.

EPR may be used for conductor temperatures up to 90° C continuously or 130° C during emergency conditions.

*** Treeing: Under electrical stress, a series of tiny hollow channels can develop within an insulation exposed to water. Since the resulting pattern looks like a poplar tree without leaves the name "water tree" is used to identify the pattern. The base of the tree is located at the point where the tree originated and its extremities tend to grow in a direction parallel to the direction of the electrical field. Thus, a tree originating at the stress-relieving layer at the conductor (conductor shield) of a cable grows radially until the cable fails.

2.2 Typical Cable Structure

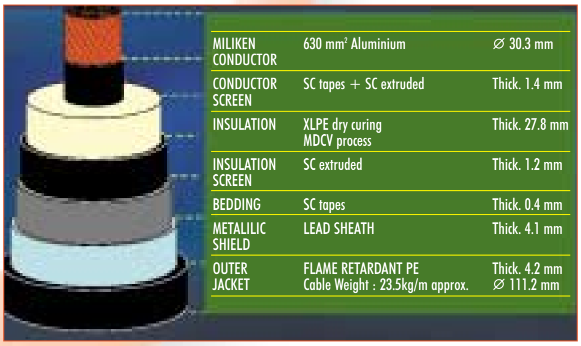
The main components of a cable are the following:

Conductor: Cu or Al, stranded or solid
Conductor screen: semi-conductor, XLPE
Insulation: EPR, XLPE
Insulation screen: semi-conducting compounds
Metallic shield: Pb, Al, Cu
Outer sheath: PE-based compounds, PVC

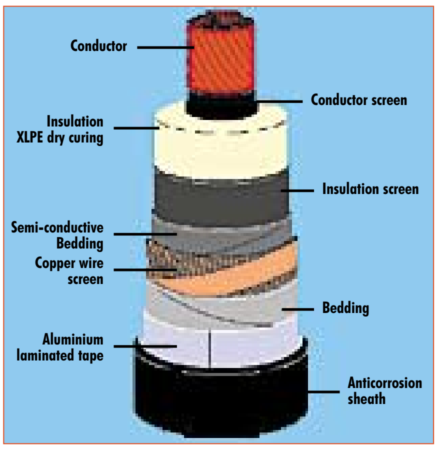
The cable structure depends on the characteristics of each project.

Two recent links carried out by Nexans will be used as illustrations:

345 kV XLPE cable manufactured in Nexans Charleroi, installed in December 2001 (with outdoor terminations), commissioned in January 2002 on the Calpine combine cycle plant at Deerpark Texas/USA.



420 kV cable installed in a tunnel for a storage station in Germany.



	Thickness (mm)	Diameter (mm)
Conductor: Cu Compact stranded		30.3
Conductor screen SC XLPE	1.2	33.7
Insulation XLPE	31.5	97.6
Insulation screen	1.1	100.3
SC swelling tape	0.3	101.3
Cu wire screen	1.38	104.1
Swelling tape	0.3	105.1
Al PE-coated tape	0.2	105.7
MDPE outer sheath	5.0	116.7

Some views from the cable manufacturing from the conductor to the outer sheath:

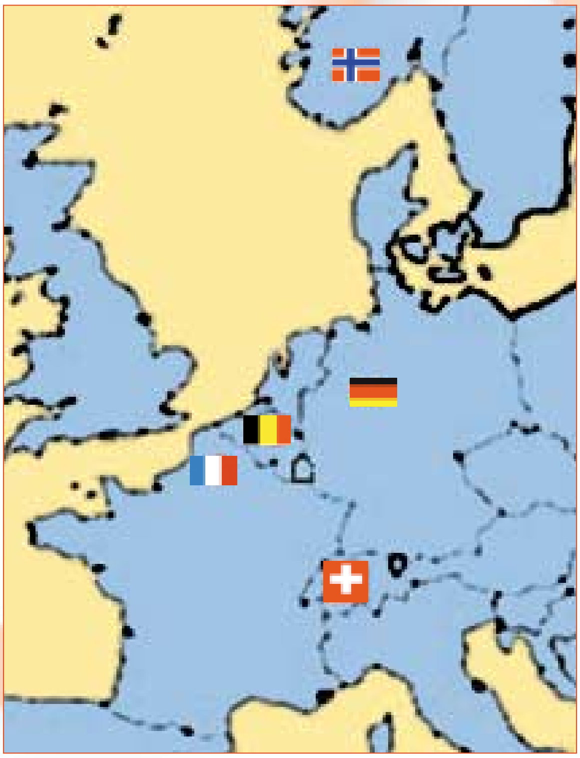
Conductor stranding

Outer protection sheath

2.3 Nexans High Voltage activities

An electrical link is not just a certain length of cable, a link needs accessories: junctions to joint the various elementary lengths and terminations (to transformer, switch, …).

These cables and accessories are manufactured within the High Voltage & Accessories Business Group with a close collaboration within 5 countries:



HV & EHV PLANTS

● CABLES
■ ACCESSORIES

Charleroi ● Erembodegem ■

Calais - R&D (HV cables)

Hannover ●

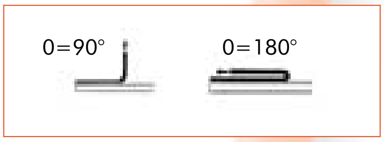
Halden ● ■

Cortaillod, Cossonay ● ■

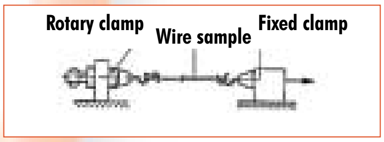
3 Competence Centers are supporting this activity: High Voltage Cable (Calais, France), Submarine HV cables (Halden, Norway) and HV accessories (Erembodegem, Belgium). The Nexans Research Center (NRC: Lyon, France and Nuernberg, Germany) is contributing to the material aspect of the HV products.

WINDING WIRES:
3. Adhesion of enamels

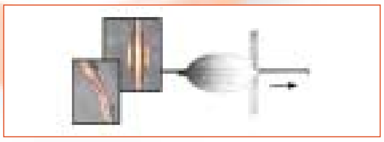
Polymer coatings on metal have come to play an important role in various technological applications including winding wires.
The enamel/copper adhesion in winding wire is assumed to be a key parameter which may influence a large set of properties as the dielectric strength, the flexibility, the windability and the chemical resistance of the wire.
Adhesion of enamel on copper depends upon a set of forces but the actual mechanism of enamel attachment is not yet fully understood.
To characterize the adhesion strength of enamel on bare copper, the most common tests used are peeling tests and pull out test:



Simple peeling tests



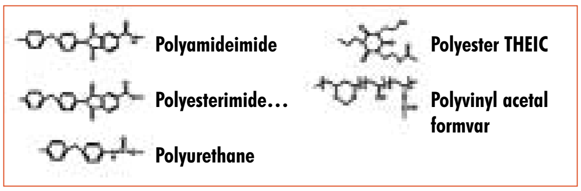
Twist peeling tests



Pull out test

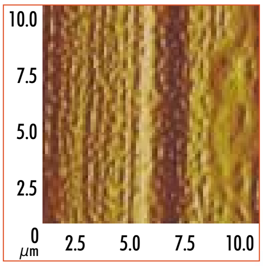
The adhesion strength must be maintained even after a thermal ageing.

The enamel used to better understand the adhesion phenomenon on copper belongs to the PVA family (Poly Vinyl Acetal), it is one example of the numerous enamel used for winding wires:



Enamel families

Several examinations (like Atomic force microscopy and scanning electron microscopy) show that the thermal ageing used (2 hours at 180°C) affects not only the coating structure (thermal degradation of the enamel) but also the copper coating interface by enhancing the oxidation process of the copper surface (formation of a porous and rough layer of cuprous oxide Cu_2O see picture, copper sample after 5 hours at 180°C in air). This kind of layer is assumed to be formed at the copper-enamel interface during the thermal ageing, this layer is characterized by a weak cohesion and would lead to a significant decrease of the adhesion strength.



It seems that the copper oxidation at the interface is the key parameter which will control the adhesion of the system. The oxidation process and the copper oxides stability at the interface are seen to depend upon the thermal ageing of the wire and the nature of the enamel including the adhesion promoters contained in it. AFM and SEM analysis have shown that adhesion promoter may play the role of oxidation inhibitor at the copper-enamel interface. At room temperature, the presence of adhesion promoter in the enamel results in a significative improvement of the adhesion strength, as measured by the peel test method. Such a result can be explained by the formation and the stabilisation of a thin cohesion Cuprous oxides layer which enhances the adhesion between the polymer and the metal thanks to chemical bonds.

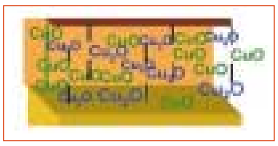
No oxide layer

Bad adhesion

CuO oxide layer

Thin layer of cuprous oxide

Large oxide layer



Bad adhesion

MATERIALS:
4. Magic Ultra-Violet

UV technology presents great advantages which are widely used for crosslinking and coating applications. UV radiations are easier to produce than X rays, less dangerous but strong enough to break chemical bonds (photoinitiators), to produce radicals and to initiate crosslinking. Hence UV radiation appears to be a promising technology offering new possibilities in the field of cable crosslinking and cables surface coating improvement.

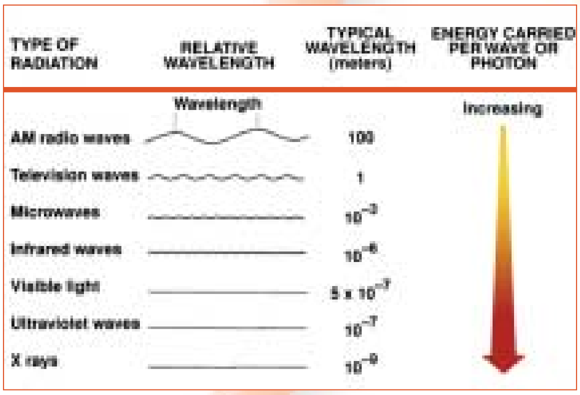


Figure 1: Wavelength of typical radiation.

4.1 UV-crosslinking of cables

The possibility to crosslink varnish, resin or colour batches via UV beam has been known for a long time. Nexans is now testing, if UV-crosslinking can also be applied for compounds used in the cable industry.

Major advantages of this technology are in-line crosslinking as well as application for thin wall products. Irradiation crosslinking, which requires high investment costs and normally an additional working step could be replaced this way. Furthermore, silane crosslinking could be partially replaced, which may show problems with pre-crosslinked silane particles at thin wall products.

First trials have been carried out with plate material in the lab, for general statements on the possibility of crosslinking. We tested different parameters, like for example wall thickness, wave length of UV-bulbs, different co-activators and different quantities of photoinitiator. These basic trials showed that both crosslinking of PVC and PE (filled and unfilled) is possible. Extrusion trials with PE and a filled PE compound for automobile applications were also very positive. However, low extrusion speed and the influence of pigments showed some problems. A large part of the UV-light is absorbed by pigments so the remaining energy is not sufficient for crosslinking.

Studies have been carried out to examine different influences and photoinitiators proposed. First photoinitiators did not bring the expected improvement of pigmented samples. However, trials will be continued intensively to overcome all present problems and to develop UV-crosslinking as a new powerful crosslinking method for wires and cables.

4.2 UV coating for wires and cables

Up to now, wire and cable manufacturers have relied on material compounding and formulating to improve the performances of their products from fire resistance, oil resistance to mechanical resistance, etc. through the development of new filler(s) / polymer(s) combinations. Curiously, the use of high performance thin surface coatings has historically not been an approach implemented in the cable business, contrary to a large number of industries such as automotive, paper, optics, etc.

Nexans research teams investigate new cable performance improvements through the use of thin-layered UV-curable coatings (in general less than 100μm). UV-curing technology has been experiencing steady growth over the past decades thanks to the major advantages it offers compared with conventional heat-based crosslinking technologies, such as:

- instantaneous cure allowing faster line speed and therefore productivity improvements
- significantly lower energy consumption, equipment cost and floor consumption
- environmental-friendly VOC*-free chemicals and processes
- access to new levels of product performance thanks to the development of new materials and additives

A cable pilot coating line has been set up at the NRC (Nexans Research center) and is now operational for trials with the following capabilities:

- Maximum line speed = 100 m/min.
- Cable diameter = 10 mm max.

Figure 2: cable pilot coating line set up in the R&D lab pay-off / take-up stations, corona treater, coating chamber and UV-curing lamp.

UV Coatings research projects being conducted in partnership with R&D teams and Units from all activities of Nexans, revolve around improvement of surface properties, such as abrasion and chemical resistance for instance.

Such projects are based upon all three following expertises:

1) **Formulation:** oligomers, reactive diluents, photoinitiators, photosensitizers, stabilizers, fillers, adhesion promoters, flowing additives, wetting agents, cure synergists, etc.

2) **Application:** thickness control, substrate wetting, adhesion improvement.

3) **Characterization:** adhesion, flexibility, hardness, abrasion resistance, fire properties, chemical resistance.

* VOC: Volatile Organic Compounds means any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions.

Nexans is the worldwide leader in the cable industry, with an industrial presence in 29 countries and commercial activities in 65. The Group employs 17,000 people. Its sales amount to 4 billion Euros. Nexans brings an extensive range of advanced copper and optical fiber cable solutions to the infrastructure, industry and building markets. Its cables and systems can be found in every area of people's lives, from telecommunications and energy networks, to aeronautics, aerospace, automobiles, railways, buildings, petrochemicals, medical applications, etc.

Nexans

Global expert in cables and cabling systems

Nexans S.A. – 16, rue de Monceau – 75008 Paris – France
Tel.: +33 (0)1 56 69 84 00 – Fax: +33 (0)1 56 69 84 84 - www.nexans.com
technical.info@nexans.com