BSc in Telecommunications Engineering

TEL3214

Computer Communication Networks

Lecture 03
Transmission Media
Copper & Fibre

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1. Understanding Transmission Medium

1.1 What is a Transmission Medium

A transmission medium is a method or material substance which can propagate waves or energy. It is the physical path between transmitter and receiver in a data transmission system.

1.1.1 Guided Medium

Waves are guided along a solid medium path (twisted pair, coaxial cable, and optical fibre).

1.1.2 Unguided medium

Waves are propagated through the atmosphere and inner/outerspace (satellite, laser, and wireless transmissions).

1.2 Examples of Transmission Media

- Conductive
    - Twisted pairs
    - Coaxial cables
- Electromagnetic
    - Microwave
- Light
    - Lasers and optical fibres (need clear line of sight)
- Wireless
    - Inner/outerspace
    - Satellite

2. Copper Transmission

2.1 Co-axial Cable

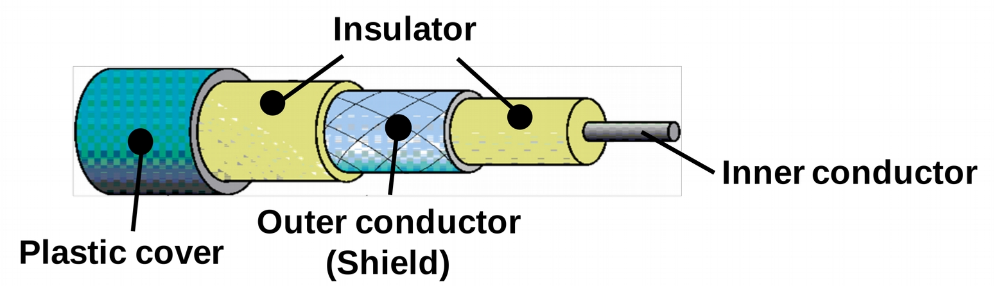


Illustration 1: Co-axial cable breakdown

Coaxial cable is an electrical cable consisting of a round conducting wire, surrounded by an insulating spacer, surrounded by a cylindrical conducting sheath, usually surrounded by a final insulating layer (jacket). It is used as a high-frequency transmission line to carry a high-frequency or broadband signal. Because the electromagnetic field carrying the signal exists (ideally) only in the space between the inner and outer conductors, it cannot interfere with or suffer interference from external electromagnetic fields.

Illustration 2: Co-axial cable

2.1.1 Transmission characteristics

- Can transmit analogue and digital signals.
- Usable spectrum for analogue signalling is about 400 MHz.
- Amplifier needed for analogue signals over 1 Km and less distance achievable for higher frequencies.
- Repeater needed for digital signals every Km or less distance achievable for higher data rates.
- Operation of 100’s Mb/s over 1 Km.

2.1.2 Applications

- TV distribution (cable tv); long distance telephone transmission; short run computer system links.
- Local area networks.

2.1.3 Thinnet – 10 Base 2

The 10Base-2 standard (also called Thinnet) uses 50Ω coaxial cable (RG-58 A/U) with maximum lengths of 185 meters. This cable is thinner and more flexible than that used for the 10Base-5 standard. The RG-58 A/U cable is both less expensive and easier to place.

Cables in the 10Base-2 system connect with BNC connectors. The Network Interface Card (NIC) in a computer requires a T-connector where you can attach two cables to adjacent computers. Any unused connection must have a 50Ω terminator.

2.1.4 Thicknet – 10 Base 5

The original cabling standard for Ethernet that uses coaxial cables. The name derives from the fact that the maximum data transfer speed is 10 Mbps, it uses baseband transmission, and the maximum length of cables is 500 meters.

10Base5 is also called thick Ethernet, ThickWire, and ThickNet.

2.2 RJ11

RJ11 is a physical interface often used for terminating telephone wires. It is probably the most familiar of the registered jacks, being used for single line Plain Old Telephone Service (POTS) telephone jacks in most homes and offices (except in the UK).

RJ14 is similar, but for a two line telephone jack, and RJ25 is for a three line jack.

RJ11, RJ14, and RJ25 all use six-position modular connectors.

An RJ11 jack uses two of the six positions, so could be wired with a 6P2C (six position, two conductor) variety of modular jack, but such jacks are quite rare. An RJ11 jack is nearly always a 6P4C jack, with four wires running to a central junction box, but unused. The extra connectors used to be used as an 'anti-tinkle' circuit to prevent a pulse-dialling phone from ringing the bell on other extensions. With tone dialling this isn't required so the connectors are used to provide flexibility so the jack can be rewired later as RJ14 or to supply additional power for special uses. Similarly, the cables used to plug telephone terminals into RJ11 jacks frequently are four-wire cables with 6P4C plugs.

In the powered variation, Pins 2 and 5 carry 24-volt, DC power. While the phone line itself supplies enough power for most telephone terminals, old telephone terminals with incandescent lights in them need more power than the phone line can supply. Typically, the power on Pins 2 and 5 comes from a transformer plugged into a wall near one jack, supplying power to all of the jacks in the house.

Pin	RJ25	RJ14	RJ11	Pair	T/R	±	Colour
1	X			3	T	+	White Green
2	X	X		2	T	+	White Orange
3	X	X	X	1	R	-	Blue White
4	X	X	X	1	T	+	White Blue
5	X	X		2	R	-	Orange White
6	X			3	R	-	Green White

Illustration 3: RJ Cable pinout chart

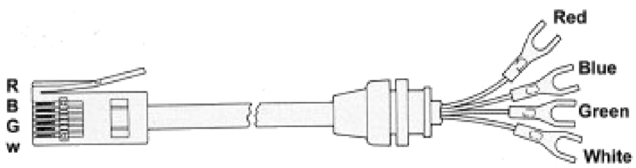
2.3 BS6312

BS6312 is the British Standard governing telephone plugs and sockets.

There are two types of modern BT plugs — 431A and 631A. 431A is 4-way and 631A 6-way. They fit a standard "type 600" telephone socket. There are also plugs with only two contacts commonly seen on modem leads.

BT Socket Wiring		
Pin		**Colour**
1	Leased Line	Green White
2	A wire	Blue White
3	Bell (to 5)	Orange White
4	Earth	White Orange
5	B wire	White Blue
6	Leased Line	White Green

Illustration 4: BS6312 pinout chart



2.4 RJ45 / 8P8C

8P8C is short for "eight positions, eight conductors", and so an 8P8C modular connector (plug or jack) is a modular connector with eight positions, all containing conductors.

The 8P8C modular plugs and jacks look very similar to the plugs and jacks used for Federal Communications Commission (FCC)'s registered jack RJ45 variants, although the true RJ45 is not really compatible with 8P8C modular connectors. It neither uses all eight conductors (but only two of them for wires plus two for shorting a programming resistor) nor does it fit into 8P8C because the true RJ45 is "keyed".

Illustration 5: RJ45 / 8P8C

Despite this, outside of the US telecommunications industry, 8P8C modular connectors are nearly always called "RJ45".

An 8P8C modular connector has two forms: the male plug and the female jack or socket. Each has eight conductors.

The 8P8C modular connector is probably most famous for its use in Ethernet. Since about 2000, it is nearly universal as the type of connector used on a cable that carries a single Ethernet network. But it is also popular for a variety of other things.

The 8P8C modular connector has replaced many older connector types because of its smaller size and relative ease of plugging and unplugging. Older connectors have also been phased out as modern electronic equipment no longer has the high current and voltage requirements for which the bulkier connectors were designed. Current technology is able to do more with a single wire than equipment of the past, and the eight conductors of an 8P8C modular connector have been sufficient for most modern applications.

The shape and dimensions of an 8P8C modular connector are specified by the standard TIA-968-A, published by the Administrative Council for Terminal Attachment (ACTA). This standard does not use the short term 8P8C and covers more than just 8P8C modular connectors, but the 8P8C modular connector type is the eight position connector type described within the standard, with eight conductors installed.

2.4.1 8P8C Applications

A very common application is in Ethernet cables, where the plug on each end is an 8P8C modular plug wired according to TIA/EIA 568-B (but with only 4 of the wires actually used). Such a cable might connect a computer to a network wall jack or connect a cable or DSL modem to a computer Ethernet network card.

Other applications include other networking services such as Integrated Services Digital Network (ISDN), E1 and T1.

The 8P8C modular connector is also used for RS-232 serial interfaces according to the EIA/TIA-561 standard.

See Registered jack for other, similar looking jacks, with which the 8P8C modular connector is likely (and often) confused, mainly because it is often falsely called "RJ45".

In floodwired environments the centre (blue) pair is often used to carry telephony signals. Where so wired, the physical layout of the 8P8C modular jack allows for the insertion of an RJ11 plug in the centre of the socket, provided the RJ11 plug is wired in true compliance with the RJ11 standard using the centre pair.

The remaining (brown) pair is increasingly used for Power over Ethernet (PoE). Legacy equipment may conflict with this use as manufacturers used to short circuit unused pairs to reduce signal crosstalk. Some routers/bridges/switches can be powered by the unused 4 lines — blue’s (+) and brown’s (-) — to carry current to the unit.

2.4.2 Ethernet LAN UTP Cabling

A Specification of ethernet copper cables can be CAT 3, 4 or CAT 5e twisted pair cable. There are stringent requirements in distance and connections in using this cabling in a LAN. Usually, the distance limitation is 205 metre's, between the most distant stations. It is important to know the wiring rules and colour codes.

- ✓ Maximum segment length is 100 metres.
- ✓ One device per segment.
- ✓ Cable is normally 4 pair, AWG 22, 24, or 26 unshielded twisted pair.
- ✓ Connectors are 8P8C (usually called RJ45) connectors.
- ✓ CAT 4 or 5e UTP wire can be substituted for best results.
- ✓ Wire is normally 4 pair (8 wire) although only 2 pair are used in transmissions.

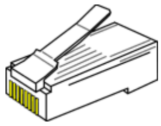


Illustration 6: RJ45 plug

Cat 5e cable is an enhanced version of Cat 5 that adds specifications for far end crosstalk. It was formally defined in 1973 in the TIA/EIA-568-B standard, which no longer recognises the original Cat 5 specification.

Although 1000BASE-T was designed for use with Cat 5 cable, the tighter specifications associated with Cat 5e cable and connectors make it an excellent choice for use with 1000BASE-T.

Category 6 (CAT6), (ANSI/TIA/EIA-568-B.2-1) is a cable standard for Gigabit Ethernet and other network protocols that is backward compatible with the Category 5/5e and Category 3 cable standards.

CAT6 features more stringent specifications for crosstalk and system noise. The cable standard is suitable for 10BASE-T / 100BASE-TX and 1000BASE-T (Gigabit Ethernet) and is expected to suit the 10000BASE-T (10Gigabit Ethernet) standards. It provides performance of up to 250 MHz.

As with all other types of twisted pair EIA/TIA cabling, CAT 6 cable runs are limited to a maximum recommended run rate of 100m.

Note:: ***TIA/EIA 568-B is one of a set of three standards that address commercial building cabling for telecommunications products and services. The TIA/EIA 568-B standards were first published in 2001 and they supersede the TIA/EIA 568-A standards set, which are now obsolete.***

TIA/EIA 568-B

Pin	Function	Colour
1	Rx Data+	White Orange
2	Rx Data-	Orange
3	Tx Data+	White Green
4	NC (normally used for telephone	Blue
5	NC (normally used for telephone	White Blue
6	Tx Data-	Green
7	Not Used	White Brown
8	Not Used	Brown

Illustration 7: TIA/EIA 568-B

2.4.3 UTP Wiring types

The typical cable is made either Straight Through or Crossover. Here is the wiring format for each of these types.

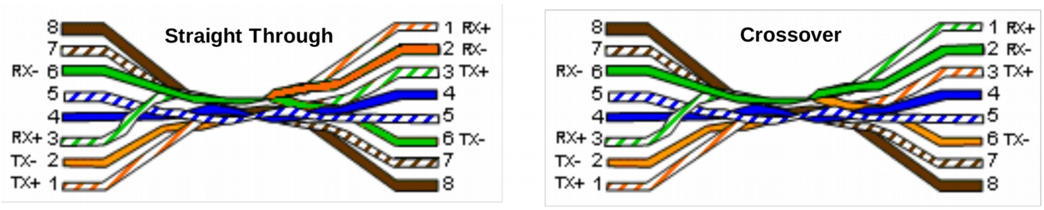


Illustration 8: UTP Wiring

2.4.3.1 Straight Through

A Straight Through cable is used to connect;

- Connecting hosts to hubs or switches.
- Connecting routers to hubs or switches.

2.4.3.2 Crossover

A Crossover cable is used to connect;

- Uplinks between switches.
- Connecting hubs to switches.
- Connecting hubs to hubs.

Illustration 9: Cable test units

2.4.4 UTP Testing

UTP Patch Leads tested using a MOD-TAP type tester. This is a 3-in-1 tester to check USOC, 568A and 568B cables although for most tests the 568B is used. A continuously-sequencing LED display provides instant identification of most wiring problems including shorts, opens, reversals and miswires. Operates on included 9V battery and features an auto-off to extend battery life. The two units conveniently snap together protecting the jacks.

2.5 RJ48

RJ48 is a registered jack. It is used for E1/T1 and ISDN termination and local area data channels/subrate digital services. It uses the 8 position modular connector.

RJ48C is commonly used for E1/T1 lines and uses pins 1, 2, 4 and 5.

RJ48X is a variation of RJ48C that contains shorting blocks in the jack so that a loopback is created for troubleshooting when unplugged by connecting pins 1 and 4, and 2 and 5.

RJ48S is typically used for local area data channels/subrate digital services, and carries one or two lines. It uses a keyed variety of the 8P8C modular connector.

RJ48 connectors are fastened to STP (Shielded Twisted Pair) cables, not the standard UTP (Unshielded Twisted Pair) CAT-(1-5).

	RJ48C and RJ48X Wiring		RJ48S Wiring	
Pin	Pair	Signal	Pair	Signal
1	R	receive ring from network	R1	transmit ring to network
2	T	receive tip from network	T1	transmit tip to network
3		reserved		(not used)
4	R1	transmit ring to network		(not used)
5	T1	transmit tip to network		(not used)
6		reserved		(not used)
7		shield	T	receive tip from network
8		shield	R	receive ring from network

Illustration 10: RJ48C and RJ48X

2.6 Insulation Displacement Connection (IDF)

Illustration 11: IDC tool

Insulation Displacement Connection (IDC). The principle of this method of wire termination is that the wire to be terminated is placed in the slot of a forked tag, pressure is applied by a spring-loaded impact tool to force the wire into the tag slot. At the end of the insertion stroke the surplus wire is cut off close to the tag. The insulation is displaced where the wire passes through the tag and the resultant contact between wire and tag makes a sound electrical and mechanical joint.

3. Lab Exercise - UTP Patch Lead Building and Testing

The Class instructor will instruct students to build either a straight through or crossover 3 M patch lead.

3.1 Objective

- Become familiar with the UTP Cabling colour code.
- Terminate UTP Cable with an RJ45 Plug.
- Build UTP Straight through and crossover patch leads.
- Test UTP Patch leads.

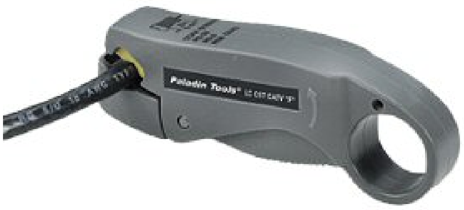
3.2 Background

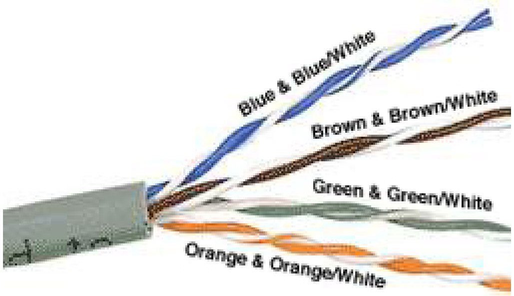
Knowing how to build a UTP Patch lead gives a greater understanding of how the computer is interfaced to networking equipment.

3.3 Lab Steps

3.3.1 Strip cable and separate pairs

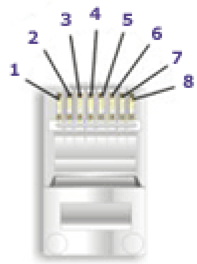
- Strip back about 4 cm of the outer protective cover and separate the four pairs contained within.



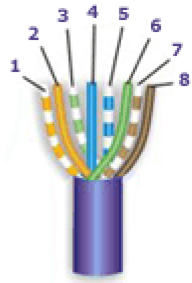


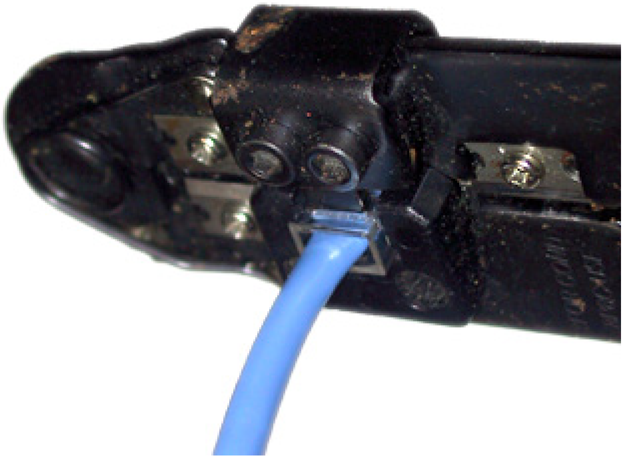
- Untwist the pairs - don't untwist them beyond what you have exposed.
- Align the coloured wires according to the cable type you are building, straight through or crossover.
- Trim all the wires to the same length, about 12 to 18 mm left exposed from the sheath.

3.3.2 Insert into RJ45 Plug



- Insert the wires into the RJ45 end - make sure each wire is fully inserted to the front of the RJ45 end and in the correct order. The sheath of the cable should extend into the RJ45 end by about 10mm and will be held in place by the crimp.
- Crimp the RJ45 end with the crimper tool. The crimper pushes two plungers down on the RJ-45 plug. One forces what amounts to a cleverly designed plastic plug/wedge onto the cable jacket and very firmly clinches it. The other seats the "pins" each with two teeth at its end, through the insulation and into the conductors of their respective wires.





3.3.3 Cable Length

- Cut the cable to the length making sure it is more than long enough for your needs. Remember, an end to end connection should not extend more than 100 M. Try to keep cables short, the longer the cable becomes the more it may affect performance, usually noticeable as a gradual decrease in speed and increase in latency.
- Repeat the above steps for the second RJ45 end.

3.4 Testing

Connect the plugs into the TIA/EIA 568B ends of the Master and Slave MOD-TAP units. The LEDs on the MOD-TAP should light in the order 1, 2, 3, 4 for a straight through lead and 1, 3, 2, 4 for a cross over lead.

4. Multicore Cable

Modern multicore cables are designed for both external plant use and specific cables for internal use. They usually consist of bare copper conductor, solid 0.5, 0.6 and 0.8 mm. They consist of a Polyvinyl chloride (PVC) core insulation with an insulation wall-thickness of 0.2 mm and 0.4 mm. The cores are twisted to pairs and pairs stranded in layers with optimal lay-length and then the Core is wrapped with plastic tape. This is surrounded with electrostatic screen (St) of plastic coated aluminium foil with drain wire and all is covered with a PVC outer sheath. The PVC self-extinguishing and flame resistant.

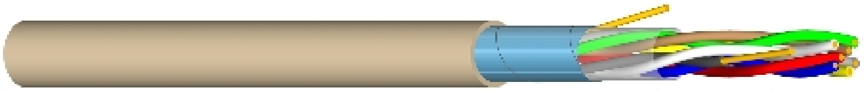


Illustration 12: Multicore cable

4.1.1 Outdoor

0.5mm tinned annealed copper conductors, PVC insulation, aluminium-polyethylene moisture barrier taped, Low Smoke Zero Halogen (LSZH) sheathed.

4.1.2 Indoor

Internal Unscreened PVC 1/0.5mm tinned annealed copper conductors, PVC insulation/polyester taped/PVC sheathed.

4.2 Poly-unit twin - Colour coding for multicore cables.

The colour code used to identify individual conductors in a kind of electrical communication wiring known as twisted pair cables. The colours are applied to the insulation that covers each conductor. The first colour is chosen from one group of five colours and the other from a second group of five colours, giving 25 combinations of two colours.

- The first group of colours is, in order: white, red, black, yellow, violet.
- The second group of colours is, in order: blue, orange, green, brown, slate.

1	White (WH)	Blue (BL)
2	Red (RD)	Orange (OR)
3	Black (BK)	Green (GN)
4	Yellow (YW)	Brown (BN)
5	Violet (VT)	Slate (Grey) (SL)

The 25 combinations are shown below. The first five combinations are very common in telecommunication and data wiring worldwide but beyond that there is considerably more variation.

The first group colours can be remembered with the mnemonic: ***W**hy **R**un **B**ackwards, **Y**ou'll **V**omit* (White, Red, Black, Yellow, Violet)

The sequence of second group colours can be remembered with the mnemonic: ***BOGBR**u**S**h* (Blue, Orange, Green, BRown, Slate).

Another mnemonic common for the second group colours is: ***B**ell **O**perators **G**ive **B**etter **S**ervice*.

(The colour violet is sometimes called purple, but in the telecommunications and electronics industry it is always referred to as violet. Similarly, slate is a particular shade of gray. The names of most of the colours were taken from the conventional colours of the rainbow or optical spectrum, and in the Electronic colour code, which uses the same 10 colours, red through violet are also in spectral order, 2-7.)

Sometimes each wire in a pair will have a coloured stripe or rings matching the colour of its paired wire. This makes it easy to identify which pair a given wire belongs to. Otherwise, to determine which pair a wire belongs to one has to note which colour codes are physically twisted together.

When used for common analogue telephone service, the first wire is known as Tip and is connected to Ground, the positive side of the direct current DC circuit, while the second wire is known as Ring and is connected to the negative side of the circuit.

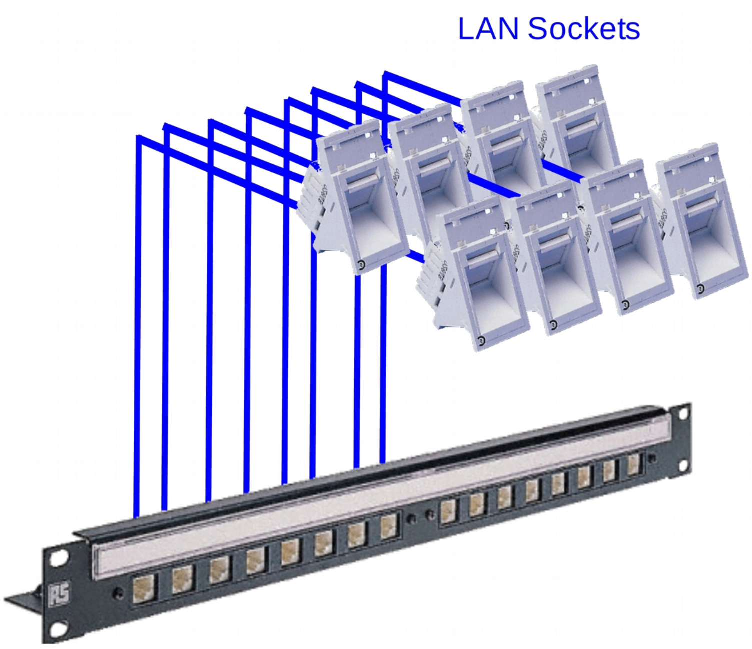
For cables with over 25 pairs, the first 10 or 25 pairs (called a binder group) are marked with a White/Blue ribbon, the second 25 pairs with a White/Orange ribbon, and so on through the 25th binder group (625 pairs), which has a Violet/Slate ribbon. The pattern then starts over with White/Blue, and continues indefinitely.

Most telephony cabling use only the first 4, 6 or 10 pairs and the basic pair sequence colours (as opposed to the tracer colour) can be remembered with the simple mnemonic: ***BOGBR**u**S**h* (Blue, Orange, Green, BRown, Slate).

Examples

	10 pair	**25 pair**	**50 pair**	
1	WH/BL- BL	WH/BL - BL	WH/BL - BL	
2	WH/OR - OR	WH/OR - OR	WH/OR - OR	
3	WH/GN - GN	WH/GN - GN	WH/GN - GN	
4	WH/BR - BR	WH/BR - BR	WH/BR - BR	
5	WH/SL - SL	WH/SL - SL	WH/SL - SL	Blue ribbon
6	RD/BL - BL	RD/BL - BL	RD/BL - BL	
7	RD/OR - OR	RD/OR - OR	RD/OR - OR	
8	RD/GN- GN	RD/GN - GN	RD/GN - GN	
9	RD/BR - BR	RD/BR - BR	RD/BR - BR	
10	RD/SL- SL	RD/SL - SL	RD/SL - SL	
11		BK/BL - BL	WH/BL – BL	Orange ribbon
12		BK/OR - OR	WH/OR – OR	
13-15		BK/- - - - -	RD/- - - - -	
16-20		YW/- - - - -	RD/- - - - -	Green ribbon
20-25		VT/- - - - -	WH/- - - - -	
26-30			RD/- - - - -	Brown ribbon
30-35			WH/- - - - -	
36-40			RD/- - - - -	
30-35			WH/- - - - -	
46-50			RD/- - - - -	Slate ribbon

5. Lab Exercise - UTP Patch Lead Building and Testing



5.1 Objective

- Become familiar with the UTP Cabling colour code.
- Terminate UTP Cable in a wall plug.
- Terminate UTP Cable in a Patch Panel.
- Test UTP Patch leads.

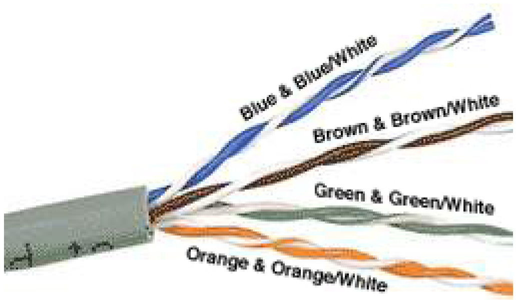
5.2 Background

Knowing how to build a UTP wiring system gives a greater understanding of how the networking equipment and computers are connected throughout a building.

5.3 Lab Steps

5.3.1 Strip cable and separate pairs

- Strip back about 4 cm of the outer protective cover and separate the four pairs contained within.

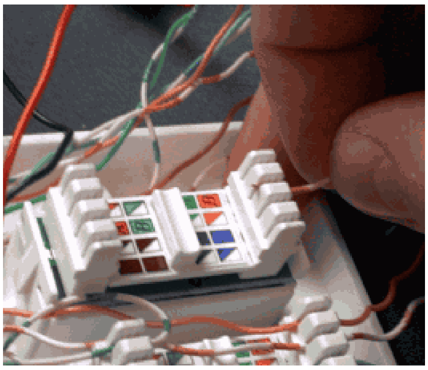
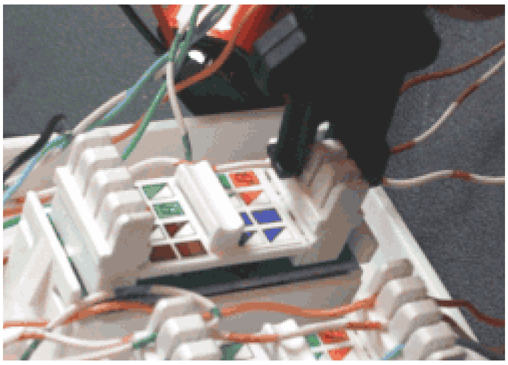



5.3.2 Inserting Cables

- Sit each of the eight cables into the slot mapping to their colour and position number. Align the IDC insertion tool on top, lining it up correctly, and then push it directly down from above. Don't push hard at first, just apply pressure gradually and sink the tool as far as it can go into the terminal, ensuring that the cable is also correctly going into the terminal.


- If you are sloppy or just unlucky, something the cable will kink as you push it in and not sit properly in the IDC terminal. In such cases, you normally have to carefully pull the cable back out, snip off the ruined bit and try again.

- After insertion. if you do not have a tool with automatic trimmer, you need to carefully cut off any excess cable sticking out of the terminals. Ideally you should trim the cable back level with the edge of the terminal block in the same fashion as the auto-trimmer would do (see below).

5.4 Testing

- Using two straight through cables tested earlier, connect each to either side of the wiring you have just done and use the Mod-Tap to confirm if it is wired correctly.

6. Fibre Interconnects

An optical fibre a small narrow tube plastic or glass which guides light along its length by total internal reflection. Optical fibres are widely used in communication particularly in high speed trunks, though nowadays they have found their way down to user PC levels as the bandwidth demands of the modern network user increases. They permit digital data transmission over longer distances and at higher data rates than other forms of electronic communication.

6.1 Light used in Fibre optics

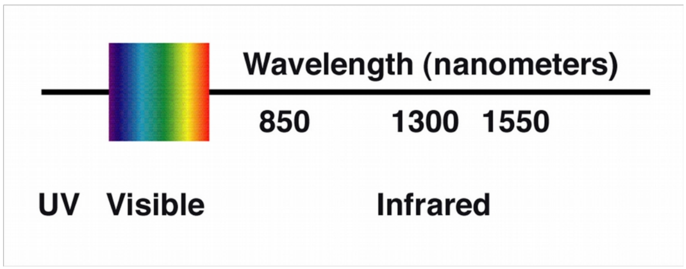


Illustration 13: Fibre frequencies

An optical fibre is a cylindrical dielectric waveguide that transmits light along its axis, by the process known as total internal reflection. The fibre consists of a core surrounded by a cladding. The ultra-pure glass used in making optical fibre has less attenuation (signal loss) at wavelengths (colours) in the infrared, beyond the limits of the sensitivity of the human eye. The fibre is designed to have the highest performance at these wavelengths.

The particular wavelengths used, 850, 1300 and 1550 nm, correspond to wavelengths where optical light sources (lasers or LEDs) are easily manufactured.

Some advanced fibre optic systems transmit light at several wavelengths at once through a single optical fibre to increase data throughput. We call this method “wavelength division multiplexing.”

6.2 Optical Transmission Systems

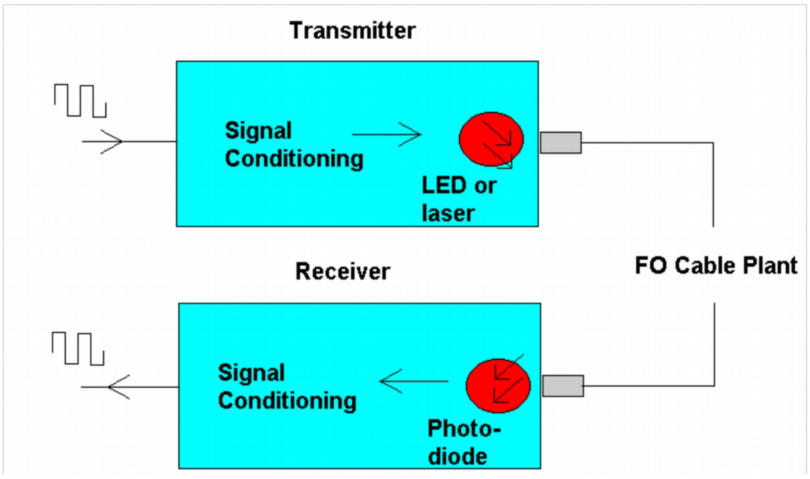


Illustration 14: Optical transmission

Fibre optic transmission systems all consist of a transmitter which takes an electrical input and converts it to an optical output from a laser diode or LED. The light from the transmitter is coupled into the fibre with a connector and is transmitted through the fibre optic cable plant.

The light is ultimately coupled to a receiver where a detector converts the light into an electrical signal which is then conditioned properly for use by the receiving equipment.

Just as with copper wire or radio transmission, the performance of the fibre optic data link can be determined by how well the reconverted electrical signal out of the receiver matches the input to the transmitter.

6.3 Multimode Fibre – Stepped Index

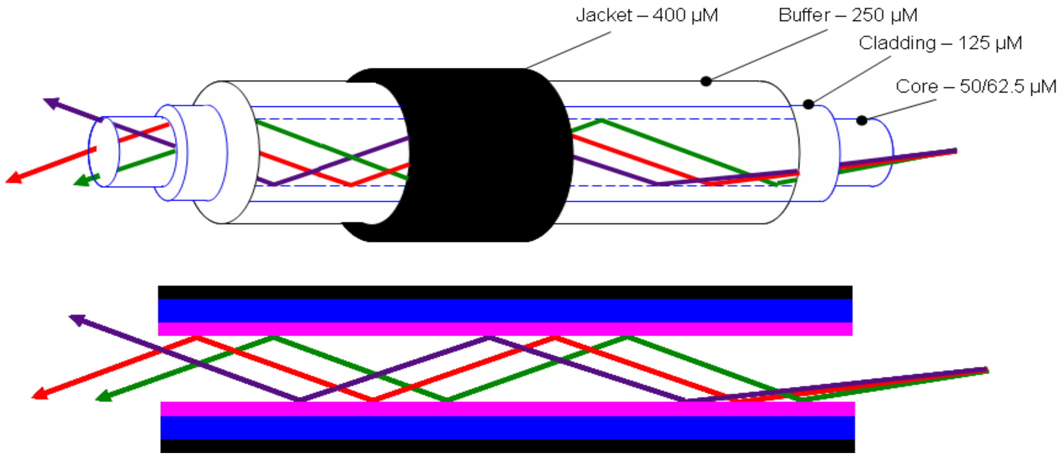


Illustration 15: Multimode fibre

The first form of multimode fibre is called Step-index. This was the first fibre design but is too slow for most uses, due to the dispersion caused by the different path lengths of the various modes.

As can be seen from the diagram above the light is reflected along the core cladding boundary, this however leads to the signal reflecting at slight different angles and over a long cable this effect causes the signal to disperse with distance.

The signal on this type of fibre-optic is sent using a Light Emitting Diode (LED).

Step-index fibre is rare today except in Plastic Optical Fibre (POF).

6.4 Multimode Fibre – Graded Index

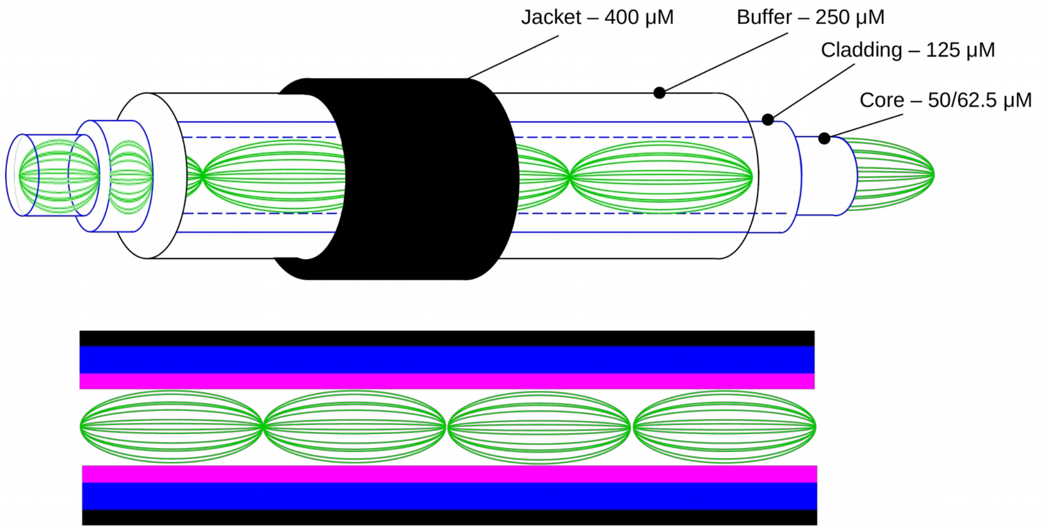


Illustration 16: Multimode - graded index fibre

An improved form of Multimode fibre is called graded-index. It uses variations in the composition of the glass in the core to compensate for the different path lengths of the modes and it offers hundreds of times more bandwidth than step index fibre - up to about 2 GHz.

The transmitter for this type of fibre uses a Vertical Cavity Surface Emitting Laser (VCSEL). It is a type of semiconductor laser diode with laser beam emission perpendicular from the top surface, contrary to conventional edge-emitting semiconductor lasers which emit from surfaces formed by cleaving the individual chip out of a wafer. VCSELs are typically based on gallium arsenide (GaAs) and are relatively cheap to manufacture.

6.5 Single mode Fibre

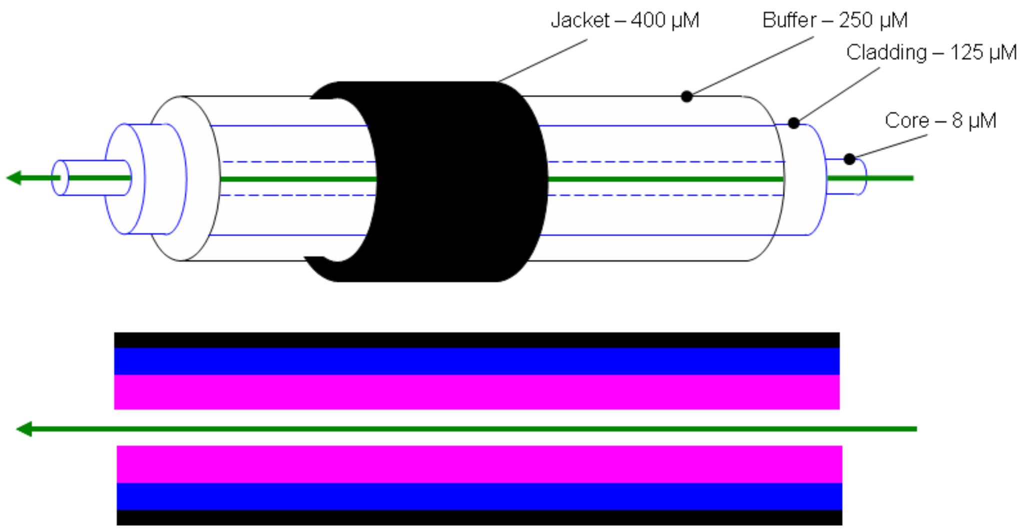


Illustration 17: Single mode fibre

Single mode fibre has a very narrow core so light can only travel in a single ray (sometimes called a single shot fibre). This increases the bandwidth to almost infinity, but it's practically limited to about 100,000 THz (terahertz) 10^{14}. Not surprisingly this is the type of fibre used by carriers for long transmission links.

6.6 Fibre Types and Specifications

Core/Cladding	Attenuation	Bandwidth	Wavelength	Applications/Notes
Multimode Graded-Index				
	850/1300 nm	850/1300 nm	850/1300 nm	
50/125 µM 3/1 dB/km	500/500 MHz-km	850/1300 nm	Laser-rated for GbE	
50/125 µM	3/1 dB/km	2000/500 MHz-km	850/1300 nm	Optimised for 850 nm - VCSELs
62.5/125 µM	3/1 dB/km	160/500 MHz-km	850/1300 nm	Most common LAN fibre - LEDs
Multimode Step-Index				
200/240 µM 4-6 dB/km	50 MHz-km	850 nm	Slow LANs & links	
Singlemode				
8-9/125 µM	0.4/0.25 dB/km	~100 Terahertz	1310/1550 nm	Carrier /CATV/Core LANs
Plastic Optical Fibre (POF)				
1mm	~ 1 dB/m	~5MHz-km	650 nm	Very short links

6.7 Fibre Connectors

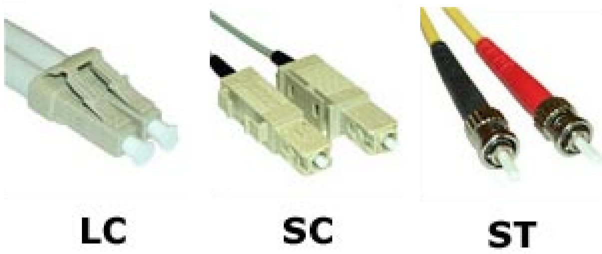


Illustration 18: Fibre connectors

An optical fibre connector constitutes a fibre-to-fibre interconnection and aligns the fibre core of two optical fibres. Due to the fast development of optical nets, a variety of optical fibre connectors are available. The main difference between connectors is in the dimensions and the mechanical grip. Standard connectors are the LC (Lucent Connector or Local Connector), FC, ST (Straight Tip) and SC (believed to be an abbreviation for Subscriber Connector, or possibly Standard Connector) connectors. If the fibre end is angled to reduce back reflections this is usually described by adding APC (Angled Physical contact Connector) to the name.

1. Standard connectors are

   - Lucent Connector/ Local Connector (LC).
   - Ferrule Connector (FC).
   - Subscriber Connector (SC).
   - Straight Tip (ST).

6.8 Fibre Colour Coding

Color coding of Premise Fibre Cable		
Fibre Type / Class	Diameter (µm)	Jacket Colour
Multimode 1a	50/125	Orange
Multimode 1a	62.5/125	Slate
Multimode 1a	85/125	Blue
Multimode 1a	100/140	Green
Singlemode IVa	All	Yellow
Singlemode IVb	All	Red

Illustration 19: Fibre colour coding

Like copper cables it makes sense to colour code fibre-optics for ease of management. The table above gives an indication of the expected colours for fibre-optics of different types.

If fibre-optics are bundled into multicores then the following EIA 598 colour codes typically apply.

EIA598 Fibre Colour Chart				
1	Blue	13	Blue	Black Tracer
2	Orange	14	Orange	Black Tracer
3	Green	15	Green	Black Tracer
4	Brown	16	Brown	Black Tracer
5	Slate	17	Slate	Black Tracer
6	White	18	White	Black Tracer
7	Red	19	Red	Black Tracer
8	Black	20	Black	Black Tracer
9	Yellow	21	Yellow	Black Tracer
10	Violet	22	Violet	Black Tracer
11	Rose	23	Rose	Black Tracer
12	Aqua	24	Aqua	Black Tracer

Illustration 20: Fibre multicore colour coding

6.9 Optical network capacity terms

Synchronous optical networking, is the method for communicating digital information using lasers or light-emitting diodes (LEDs) over optical fibres. It was developed to replace the Plesiochronous Digital Hierarchy (PDH) system for transporting large volumes of telephony and data traffic.

There are multiple, very closely related standards that describe synchronous optical networking:

- SDH or synchronous digital hierarchy standard developed by the International Telecommunication Union (ITU), documented in standard G.707 and its extension G.708.
- SONET or synchronous optical networking standard as defined by GR-253-CORE from Telcordia.

Both SDH and SONET are widely used today with SDH used across the world and SONET in the US and Canada.

Synchronous networking differs from PDH in that the exact rates that are used to transport the data are tightly synchronised across the entire network, made possible by atomic clocks. This synchronisation system allows entire inter-country networks to operate synchronously, greatly reducing the amount of buffering required between each element in the network.

Both SDH and SONET can be used to encapsulate earlier digital transmission standards, such as the PDH standard, or used directly to support either Asynchronous Transfer Mode (ATM) or Packet over SDH/SONET (POS) networking. As such SDH or SONET is a generic, all-purpose transport container for moving both voice and data.

SONET/SDH Designations and bandwidths				
SDH level & Frame Format	**SONET Optical Carrier (OC) Level**	**SONET Frame Format**	**Payload bandwidth (kbit/s)**	**Line Rate (kbit/s)**
STM-0	OC-1	STS-1	48,960	51,840
STM-1	OC-3	STS-3	150,336	155,520
STM-4	OC-12	STS-12	601,344	622,080
STM-8	OC-24	STS-24	1,202,688	1,244,160
STM-16	OC-48	STS-48	2,405,376	2,488,320
STM-32	OC-96	STS-96	4,810,752	4,976,640
STM-64	OC-192	STS-192	9,621,504	9,953,280
STM-256	OC-768	STS-768	38,486,016	39,813,120
STM-512	OC-1536	STS-1536	76,972,032	79,626,120
STM-1024	OC-3072	STS-3072	153,944,064	159,252,240

Illustration 21: SONET/SDH designations

6.10 Fibre Splicing

Fibre Optic Splicing involves joining two fibre optic cables together. The other, more common, method of joining fibres is called termination or connectorisation. Fibre splicing typically results in lower light loss and back reflection than termination making it the preferred method when the cable runs are too long for a single length of fibre or when joining two different types of cable together, such as a 48-fibre cable to four 12-fibre cables. Splicing is also used to restore fibre optic cables when a buried cable is accidentally severed.

There are two methods of fibre optic splicing, fusion splicing & mechanical splicing.

6.10.1 Mechanical Splicing

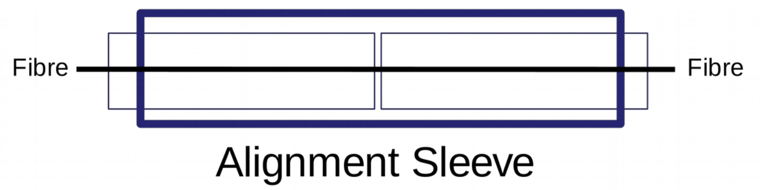


Illustration 22: Mechanical splice

Mechanical splices are simply alignment devices, designed to hold the two fibre ends in a precisely aligned position thus enabling light to pass from one fibre into the other. (Typical loss: 0.3 dB)

6.10.2 Fusion Splicing

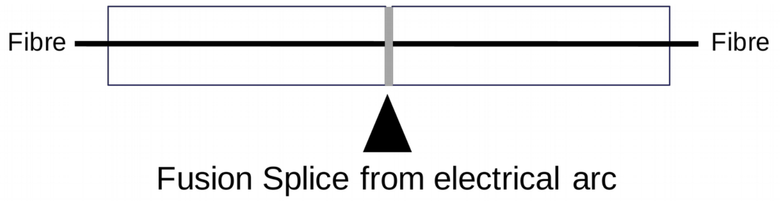


Illustration 23: Fusion splice

In fusion splicing a machine is used to precisely align the two fibre ends then the glass ends are "fused" or "welded" together using some type of heat or electric arc. This produces a continuous connection between the fibres enabling very low loss light transmission. (Typical loss: 0.1 dB)

6.10.3 Which method is better?

The typical reason for choosing one method over the other is economics. Mechanical splicing has a low initial investment (€1,000) but costs more per splice (€10-€40 each). While the cost per splice for fusion splicing is lower (€0.50 - €1.50 each), the initial investment is much higher (€20,000 - €50,000 depending on the accuracy and features of the fusion splicing machine being purchased). The more precise you need the alignment (better alignment results in lower loss) the more you pay for the machine.

Fusion splicing produces lower loss and less back reflection than mechanical splicing because the resulting fusion splice points are almost seamless. Fusion splices are used primarily with single mode fibres where as Mechanical splices work with both single and multi mode fibre.

Telecommunications and CATV companies typically invest in fusion splicing for their long haul single mode networks, but will still use mechanical splicing for shorter, local cable runs. Since analogue video signals require minimal reflection for optimal performance, fusion splicing is preferred for this application as well. The LAN industry has the choice of either method, as signal loss and reflection are minor concerns for most LAN applications.

6.11 Fusion Splicing Method

Four basic steps to completing a proper fusion splice:

- Preparing the fibre - Strip the protective coatings, jackets, tubes, strength members, etc. leaving only the bare fibre showing. The main concern here is cleanliness.

Illustration 24: Fusion splicer

- Cleave the fibre - Using a good fibre cleaver here is essential to a successful fusion splice. The cleaved end must be mirror-smooth and perpendicular to the fibre axis to obtain a proper splice. NOTE: The cleaver does not cut the fibre! It merely nicks the fibre and then pulls or flexes it to cause a clean break. The goal is to produce a cleaved end that is as perfectly perpendicular as possible. That is why a good cleaver for fusion splicing can often cost €1,000 to €3,000. These cleavers can consistently produce a cleave angle of 0.5 degree or less.

- Fuse the fibre - There are two steps within this step, alignment and heating. Alignment can be manual or automatic depending on what equipment you have. The higher priced equipment you use, the more accurate the alignment becomes. Once properly aligned the fusion splicer unit then uses an electrical arc to melt the fibres, permanently welding the two fibre ends together.

- Protect the fibre - Protecting the fibre from bending and tensile forces will ensure the splice not break during normal handling. A typical fusion splice has a tensile strength between 200 and 700 grams and will not break during normal handling but it still requires protection from excessive bending and pulling forces. Using heat shrink tubing, silicone gel and/or mechanical crimp protectors will keep the splice protected from outside elements and breakage.

6.12 Mechanical Splicing Method

Illustration 25: Mechanical splicer

Mechanical splicing is an optical junction where the fibres are precisely aligned and held in place by a self-contained assembly, not a permanent bond. This method aligns the two fibre ends to a common centreline, aligning their cores so the light can pass from one fibre to another.

Four steps to performing a mechanical splice:

1. Preparing the fibre - Strip the protective coatings, jackets, tubes, strength members, etc. leaving only the bare fibre showing. The main concern here is cleanliness.

2. Cleave the fibre - The process is identical to the cleaving for fusion splicing but the cleave precision is not as critical.

3. Mechanically join the fibres - There is no heat used in this method. Simply position the fibre ends together inside the mechanical splice unit. The index matching gel inside the mechanical splice apparatus will help couple the light from one fibre end to the other.

4. Protect the fibre - the completed mechanical splice provides its own protection for the splice.

6.13 Basic Fibre Testing

Illustration 26: Fibre tester

Basic fibre testing can be performed with a visual fault locator (VFL). This device features a universal connector accepting any optical connector style with a 2.5mm ferrule. The VFL typical output is from a 650nm laser providing visibility to 5 km.

The universal connector eliminates the inconvenience of having to use a patch cable for direct connection to fibre under test if connector styles are dissimilar.

This single basic tool is one that all installers, and maintenance technicians should have in their tool kit. It is the most economical test tool for quickly verifying continuity, checking the validity of patch cables before or after installation, test and find breaks in LANs, verifying short lengths of installed fibre, or looking for cracked fibre in splice cases, bad connectors, tight crimps in fibre cable, backbone breaks or anywhere light continuity needs checking.

6.14 Tips for Better Splices

- Thoroughly and frequently clean your splicing tools. When working with fibre, keep in mind that particles not visible to the naked eye could cause tremendous problems when working with fibre optics. "Excessive" cleaning of your fibre and tools will save you time and money down the road.

- Properly maintain and operate your cleaver. The cleaver is your most valuable tool in fibre splicing. Within mechanical splicing you need the proper angle to insure proper end faces or too much light escaping into the air gaps between the two fibres will occur. The index matching gel will eliminate most of the light escape but cannot overcome a low quality cleave. You should expect to spend around €200 to €1,000 for a good quality cleaver suitable for mechanical splicing.

- For Fusion splicing, you need an even more precise cleaver to achieve the exceptional low loss (0.05 dB and less). If you have a poor cleave the fibre ends might not melt together properly causing light loss and high reflection problems. Expect to pay €1,000 to €4,000 for a good cleaver to handle the precision required for fusion splicing. Maintaining your cleaver by following manufacturer instructions for cleaning as well as using the tool properly will provide you with a long lasting piece of equipment and ensuring the job is done right the first time.

- Fusion parameters must be adjusted minimally and methodically (fusion splicing only). If you start changing the fusion parameters on the splicer as soon as there is a hint of a problem you might lose your desired setting. Dirty equipment should be your first check and then continue with the parameters. Fusion time and fusion current are the two key factors for splicing. Different variables of these two factors can produce the same splice results. High time and low current result in the same outcome as high current and low time. Make sure to change one variable at a time and keep checking until you have found the right fusion parameters for your fibre type.

7. WAN Connections

To finish out the cabling section I will mention X.21 and V.35 which are the predominant interfaces for Leased Lines, Frame Relay connections from Customer Premises Equipment to routers.

7.1 X.21

Illustration 27: X.21 connector

X.21 is a digital signalling interface recommended by ITU-T that includes specifications for DTE/DCE. The presentation is a DB15 connector like that in the diagram. The specification covers the physical interface elements, alignment of call control characters, error checking, elements of the call control phase for circuit switching services. Data transfer at up to 2 Mbit/s. This interface standard is the most used type in Europe.

7.2 V.35

V.35 is an ITU-T physical layer standard. It maximum speed over this interface is 2 Mbit/s. V.11 specifies the physical and electrical characteristics that are used by V.35. It is used with the 37-pin ISO 4902 connector and is compatible with EIA RS-422.

Illustration 28: V.35 connector

7.3 Attributes of links

The following attributes are common for configuration of links from routers to Leased Lines or Frame Relay switches.

Interface Type	::	DTE or DCE.
Encapsulation	::	HDLC, PPP or Frame Relay.
Bandwidth	::	56 Kbit/s to 2048 Kbit/s.
Clock rate (if DCE)	::	56 Kbit/s to 2048 Kbit/s.

7.4 RJ21 (Champ)

RJ-21 (or RJ21) is a registered jack standard for a modular connector using 50 conductors, usually used to implement a 25-line (or less) telephone connection. It's also known as a 50-pin telco connector, Champ or an Amphenol connector. (After the manufacturer Amphenol who was the largest manufacturer of these connectors)

Illustration 29: RJ21 Connector

Dual RJ-21 connectors are often used on punch blocks to make a breakout box for PBX and other key telephone systems.

The same connector is used for SCSI-1 connections. Computer printers use a shorter 36-pin version known as a Centronics connector.

8. E.164 Numbering

E.164 is an ITU-T recommendation which defines the international public telecommunication numbering plan used in the PSTN and some other data networks. It also defines the format of telephone numbers. E.164 numbers can have a maximum of 15 digits and are usually written with a + prefix. To actually dial such numbers from a normal fixed line phone the appropriate international call prefix must be used.

The title of the original and revision 1 was "Numbering Plan for the ISDN era".

8.1 Addresses

E.164 addresses can be used in DNS by using Telephone Number Mapping (ENUM) which allocates a specific zone, primarily e164.arpa for use with E.164 numbers. Any phone number, such as +353 61 34 24 40 can be transformed into a hostname by reversing the numbers, separating them with dots and adding the e164.arpa suffix, like so:

0.4.4.2.4.3.1.6.3.5.3.e164.arpa

DNS can then be used to look up Internet addresses for services such as SIP IP Telephony. An alternate method is Distributed Universal Number Discovery Protocol (DUNDi), which is a P2P implementation of Electronic Numbering (ENUM), as defined in RFC 3761. DUNDi is yet to be standardised by the IETF. DUNDi is not itself an IP Telephony signalling or media protocol. Instead, it publishes routes which are in turn accessed via industry standard protocols such as Inter-Asterisk eXchange protocol (IAX), Session Initiation Protocol (SIP) and H.323. DUNDi is fully-distributed with no centralised authority whatsoever.

E.163 was the old ITU-T standard for describing telephone numbers for the public switched telephone network (PSTN). E.163 was deleted and incorporated into revision 1 of E.164 in 1997.

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