Transmission Media on Cable

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TRANSMISSION MEDIA ON CABLE

Note : This document reflects the status in year 1982, and should be read in the light of this

History in brief - Development of cable transmission media, dedicated for PCM or originally intended for analogue transmission

A few decades ago, PCM technique was not yet introduced in telecommunication networks. Some main reasons for the introduction were:

- the advent of the transistor in 1956;
- the increasing cost of cable installations, especially in cities.

PCM was introduced as a transmission system only, in order to increase the capacity of interexchange symmetric pair cables.

For this application, the nowadays classical cost relations, according to Figure 1, are valid. In many countries, a small but increasing amount of symmetric pair cables were by that time already exploited by multiplex systems of FDM type. These systems were relatively cheap, also for short haul applications. However, it was generally realized that PCM was the most future safe systems.

Today, some pair cable FDM systems are recovered and replaced by PCM since coexistence between the two systems in common pair cables is generally not advisable. Needless to say, the common bit rate used for this application was 1.5 or 2 Mbit/s.

After the standardizing during the early 70's, the next hierarchical step, 6 and 8 Mbit/s respectively, transmission media range was widened, to a considerable extent due to problems of exploitation of ordinary pair cables for PCM systems operating at substantially higher bit rates than 2 Mbit/s.

In Sweden, the introduction of systems operating at higher bit rates than 2 Mbit/s has, up to now, coincided with the introduction of digital MW systems.

Although the primary system level was also used for digital MW radio, it was obvious that the per channel cost was lower at higher bit rates.

The need for entrance links to digital MW systems operating at secondary/tertiary system level constituted in some countries the initial need for higher bit rates on cable, whereas in other countries a need arose also for pure cable plants using these bit rates. Since normally the existing cable types were technically too poor (such as normal symmetric pair cable), new cables were designed, both of pair cable type and coaxial type (such as the µcoax cable). The symmetric pair cables were used with one or two directions in one cable.

For bit rates of third/fourth order and upwards the existing small diameter, coaxial cable and normal diameter coaxial cable were found adequate, technically and economically. Optical fibre systems have reached such a degree of economy (in special applications) and technical maturity that such systems must be regarded as an established transmission medium.

Available transmission media/systems for use in a digital network or during a conversion phase from analogue to digital

A. Symmetric pair cables originally intended for voice frequency use

A.1 Technical characteristics

"Normal" symmetric pair cables are best suited for primary PCM systems. This combination of media/system is well known all over the world today. Regarding other applications, see point B.3. Most severe limiting factor for the use of normal symmetric pair cables for primary PCM system is the near-end crosstalk (NEXT). See Table 1 from GAS 3 WP C on disturbance sources affecting systems using pair cable and other media.

Table 1/B.III.4 : Disturbance Sources affecting a digital transmission system

	Disturbances Sources					
Digital Transmission System Using:	**Amplitude Distortion**	**Delay Distortion**	**Fluctuations**	**Thermal Noise**	**Impulse Noise**	**Crosstalk**
Symmetrical Pairs On Cables Originally Designed For Voice Frequency Use	**(1) Heavy**	**Negligible**	**(2) Considerable**	**Negligible**	**(3) Heavy**	**(4) Heavy**
Coaxial Cables	**(1) Heavy**	**Negligible**	**(2) Considerable**	**(5) Considerable**	**Negligible**	**Negligible**
Radio Links	**Negligible**	**Heavy**	**(6) Heavy**	**Heavy**	**Negligible**	**Negligible**
Optical Fibre Cables	**Negligible**	**Considerable**	**Negligible**	**Negligible**	**Negligible**	**Negligible**

Both junction cables and local network cables are used for PCM. Depending on cable build-up the NEXT problem is catered for by choosing different layers/units for the go-return PCM directions (if one cable operation is employed).

Vital cable parameters for the planner are NEXT attenuation and loss.

Typical NEXT values are: (in dB)

	GAS 3, typical	Swedish measurements
Non-adjacent layers	73-75	65-90
Non-adjacent units	--	80-90
Adjacent layers	62-64	60-80
Adjacent units	--	70-80
Same layer	56-58	52-70

Loss is measured at a frequency = half of the bit rate, as the PCM energy spectrum is centered around this frequency for the standardized bipolar transmission (AMI, HDB 3).

Typical loss values at 1 MHz are: (dB/km)

Wire gauge	*Paper insulation*	*Plastic insulation*
0.4 mm	24-26	19-22
0.5	19-22	15-18
0.63	15-18	12-15
0.7	13-16	11-14
0.9	11-14	8-11
1.1	9-11	

For a specific cable, e.g. paper insulation, C = 38 nF/km, diagrams like Figure 2 may be consulted.

Temperature dependence of loss amounts to roughly 2 permille per degree Centigrade.

The propagation time is sometimes of importance. For pair cables, it is negligible; around 4.3 µs/km for paper insulation and 5.8 µs/km for plastic insulated wires.

Typical impedance values are 120-130 ohms.

A.2 Standardization level

Although the pair cable medium itself is not standardized, it has been possible to develop the digital electronic equipment for cable transmission in a universal way for use in different countries, with different wire gauges, different insulation, etc. (More pertinent for variations in the electronic equipment are environmental conditions like temperature, humidity, overvoltages).

A.3 Cost structure, applications

Figure 1 shows the diagram which led to the introduction of digital technique within the field of telecommunications. It should be noted that the diagram will change for all systems concerned when digital switching is introduced.

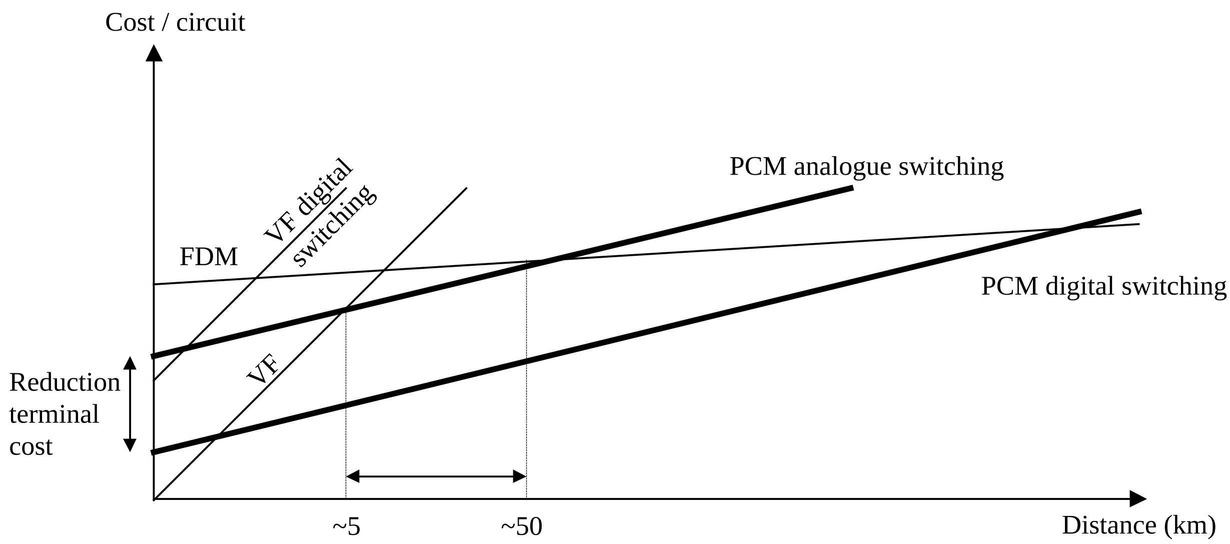


Figure 1 : Effect of Digital Switching. The economically feasible distance for PCM transmission is increased when analogue switching (short arrow) is replaced by digital

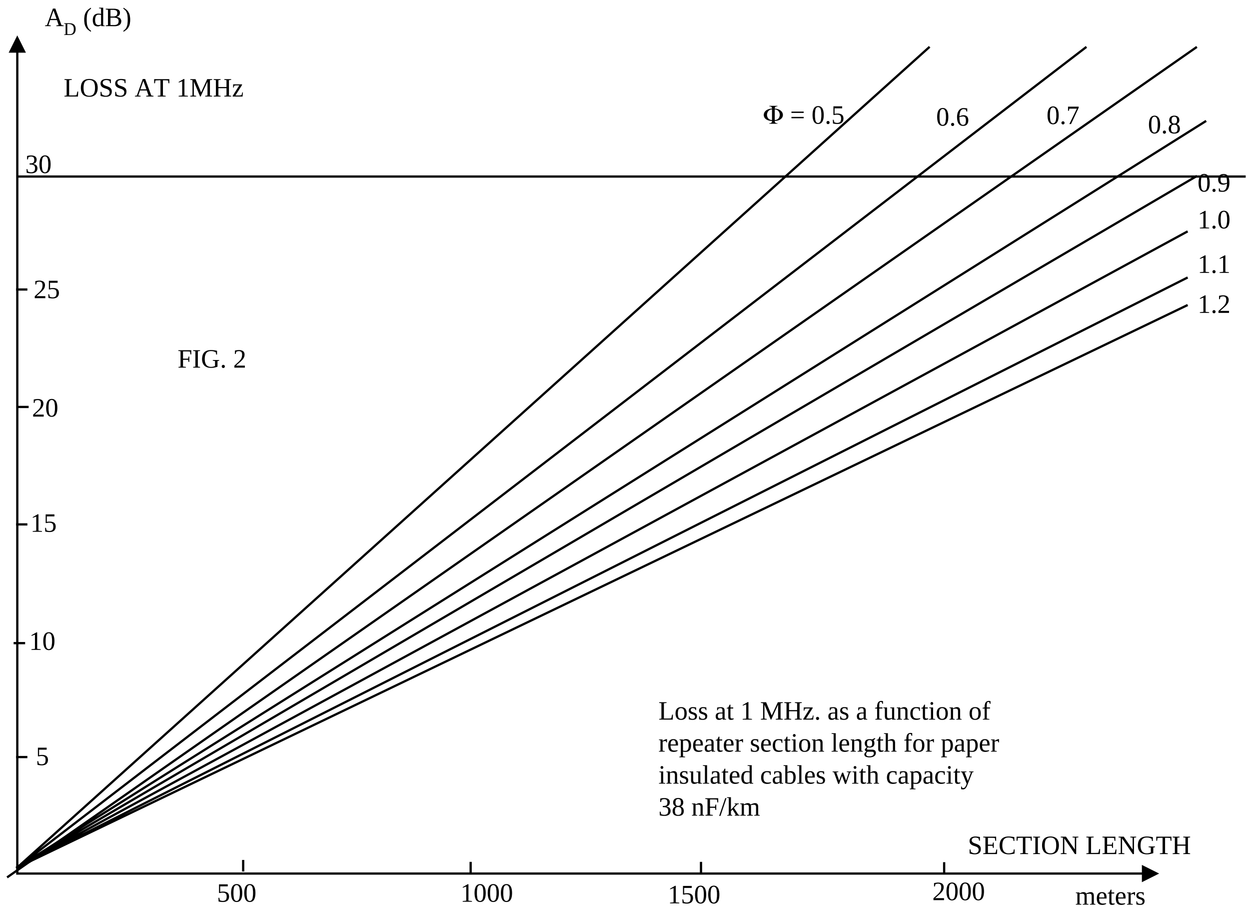


Figure 2 : Loss at 1 Mhz as a function of repeater section length

Whereas the cost of PCM transmission decreases, the opposite change is true for VF and FDM transmission. Of course, intermediate cost figures apply with analogue switching in one node and digital switching in the other node.

Generally, primary PCM systems on "normal" VF cables seem to retain a market for a very long time to come. The main applications will be:

- digital switch to RSS;
- digital junctions;
- digital PABX to analogue/digital local exchange,

provided that the distance is less than, say, 10 km in metropolitan areas and considerably more in rural areas and the circuit need for a specific route can be met by PCM on existing cables and/or possibly one new cable. For substantial capacities in the junction network, other systems will compete, like optical fibres, digital MW radio links, and possibly specially designed pair cables and micro-coaxial cables. Rural area competitors may be small digital radio links (point to point), subscriber multi-access radio systems and pole-mounted cables dedicated for PCM.

A.4 Engineering

A commonly accepted minimum target is an error rate of 10^{-8} for an individual repeater section during 90% of the time, or 10^{-7} during 99.99 % of the time. The latter figure is used in a GAS handbook.

The planner must see to it that a certain number of systems can be installed in a cable without violating the error rate targets.

For the calculation of a maximum number of PCM systems in a cable, many formulae are used. Formulae used in Sweden are:

$\overline{A_N} - A_L - A_{LR} - 1.6\sigma_N - X \cdot \log n \geq S/N\,(A_L)$ (for one-cable operation)

$\overline{A}_F - 1.6\sigma_F - 10 \cdot \log(L(n-1)) \geq S/N$ (for two-cable operation)

$\overline{A}_N$ = mean value of near end crosstalk attenuation, measured between potential pairs for send and received directions.

$\overline{A}_F$ = mean value of the effective far end crosstalk attenuation.

A_L = cable loss at 1 MHz at the actual section length.

A_{LR} = additional loss owing to change of wire gauge or insulation. It is set to different values related to the length of the inhomogeneous cable part

Length <15 m	A_{LR}	= 0
15-40 m	A_{LR}	= 0.2 dB
>40 m	A_{LR}	= 0.4 dB

σ_N = standard deviation of A_N

σ_F = standard deviation of A_F

S/N = minimum signal to noise ratio at the repeater input for obtaining an error rate = 10^{-8}.

n = number of PCM systems.

L = section length expressed in km

Regarding S/N (A_L) see Table 2

Regarding $X \log n$ see Table 3

Table 2	
A_D	S/N (A_D)
5-20	12.0
22	12.5
24	13.1
26	13.6
28	14.2
30	14.7

S/N (A_D) is increased

by 2 dB for aerial cable.

Table 3		
n	X log n	Factor (x)
2	4.2	14
3	6.2	13
4	7.2	12
5	7.7	11
6	7.8	10
7	8.4	10
8	9.1	10
9	9.5	10
10	10.0	10, etc.

Procedure with graphs (from GAS).

Given the following initial parameters:

- type of cable and conductor diameter;
- maximum number of systems envisaged;
- criterion of use,

graphs like the ones shown in Figures 3 and 4 enable determination of the repeater section lengths h in km and the line attenuation of this length αh in dB.

The length must, for safety's sake, be reduced by 10 % in the case of overhead cables which, moreover, may reach high temperatures.

Impact of Exchange Noise

This noise appears (attenuated) at the PCM pairs close to the exchange via crosstalk from neighboring pairs, for e.g. physical telephone or telex circuits or leased circuits. Terminal regeneration sections should, as a consequence, normally be shortened to a length corresponding to a loss of <20 dB, but a longer section may be possible at modern crossbar exchanges.

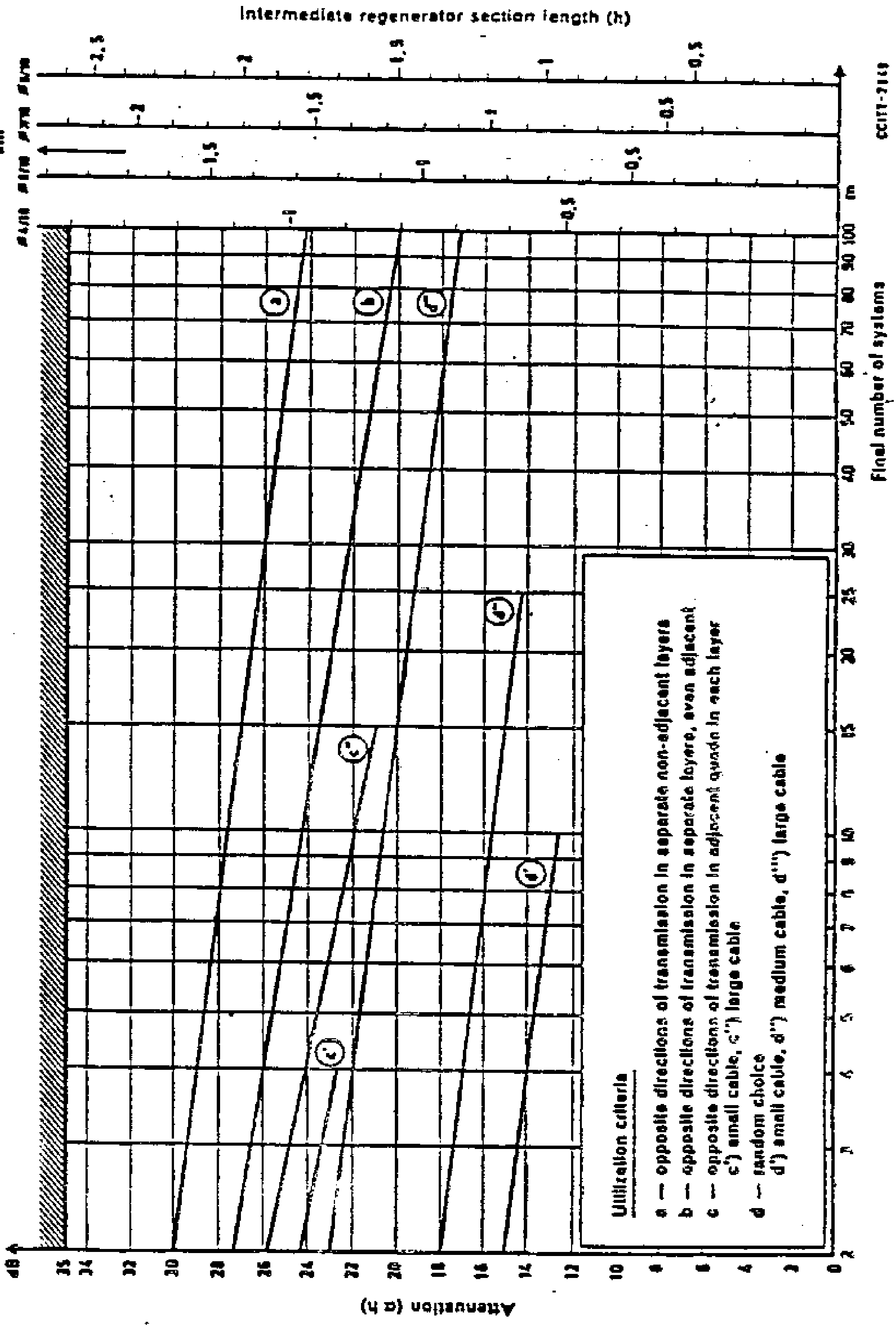


Figure 3 : Sections of regeneration for quad cables insulated by paper and air

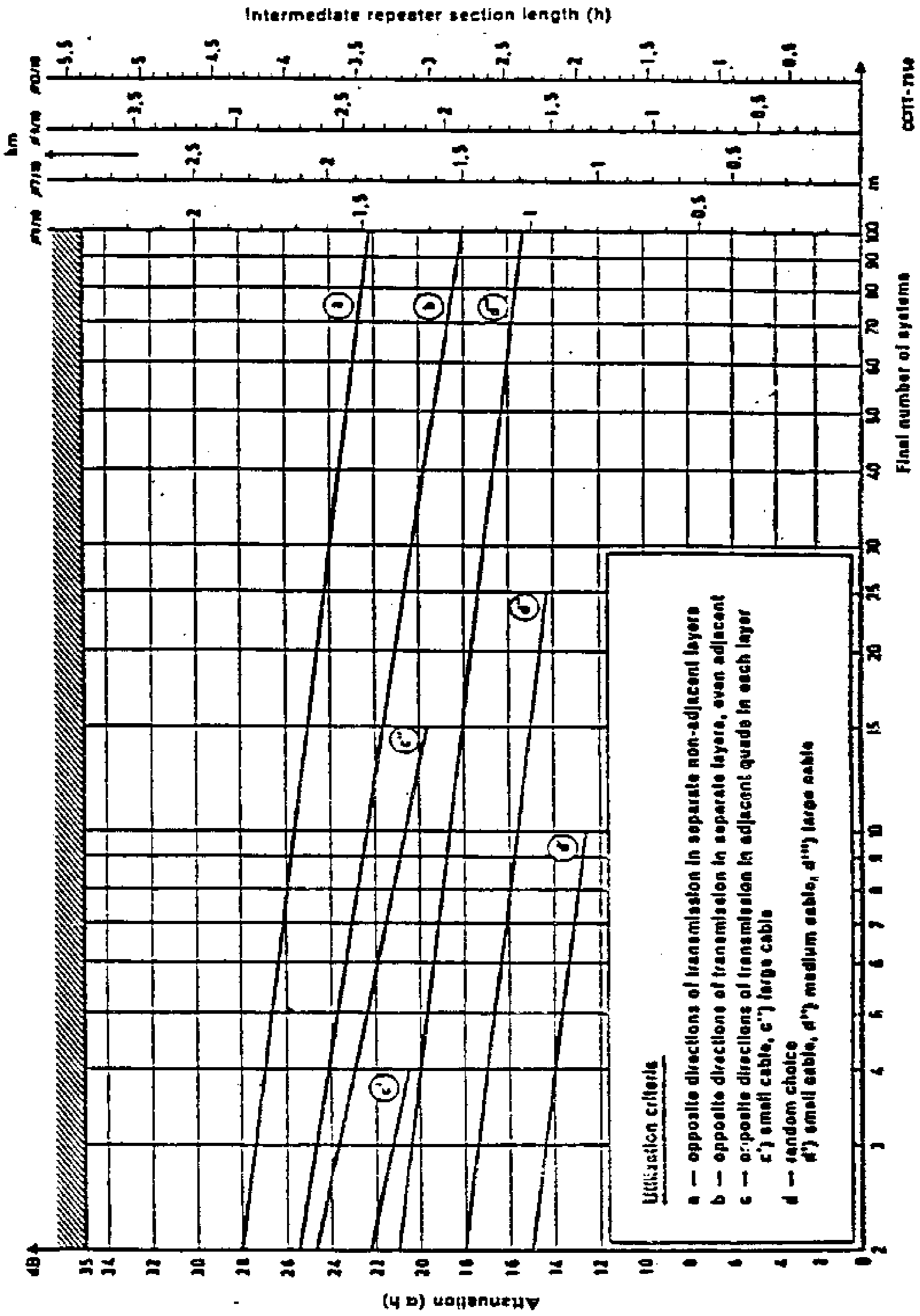


Figure 4 : Sections of regeneration for plastic quad cables

B. Some symmetric cables dedicated for transmission of PCM primary systems

B.1 Technical characteristics

Cables dedicated for PCM have been developed in order to increase the cable fill of primary PCM systems up to 100%.

Some characteristics of three Swedish cables are given below (see also Figure 5).

	Cable 1	Cable 2	Cable 3
Build-up	1 quad	10 pairs, 20 pairs in 5 pair units	Screened units 20, 40, 60, 80... pairs or screened halves 36, 68, 136... pairs
Wire diam (mm)	0.6	0.7, 1.0	0.5, 0.65, 0.7, 0.9, 1.2
Wire insulation	Polyethene thickness to be specified to meet capacity requirement		
Inner sheath (mm PE)	0.6	1.4	1.4
Screen (mm A1)	0.15	0.20	0.1
Outer sheath (mm PE)	0.7	1.4	1.4
Capacity (nF/km)	41 ± 1	39 ± 2	44 ± 2
Repeater section length (one cable operation)	2.4 km	2.2 km (0.7 mm)	different for diff. diam.
Cable fill of PCM	100 %	100 %	100 %
Cable filling	air	vaseline	water repellant compound
Moisture barrier	0.15 (same as screen)	0.20	metallic foil 0.18 Cu or 0.2 Al
NEXT	>60 db between the two pairs	>60 db between 5 pair units	>90 db between pairs on opposite side of the screen

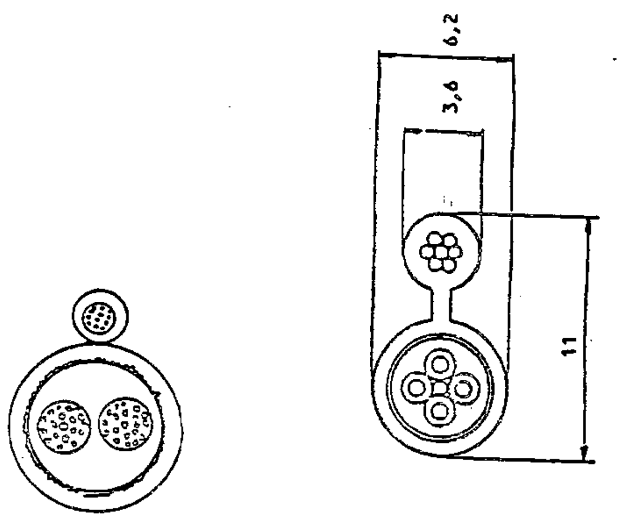


Figure 5 : Dedicated cables for PCM (small/medium capacity)

B.2 Standardization level

The above-mentioned cables dedicated for PCM are not internationally standardized.

B.3 Cost structure, applications

The cost structure is similar to the "normal” symmetric pair cables, but the cable cost must be added compared with PCM applications using existing cables (see Figure 6).

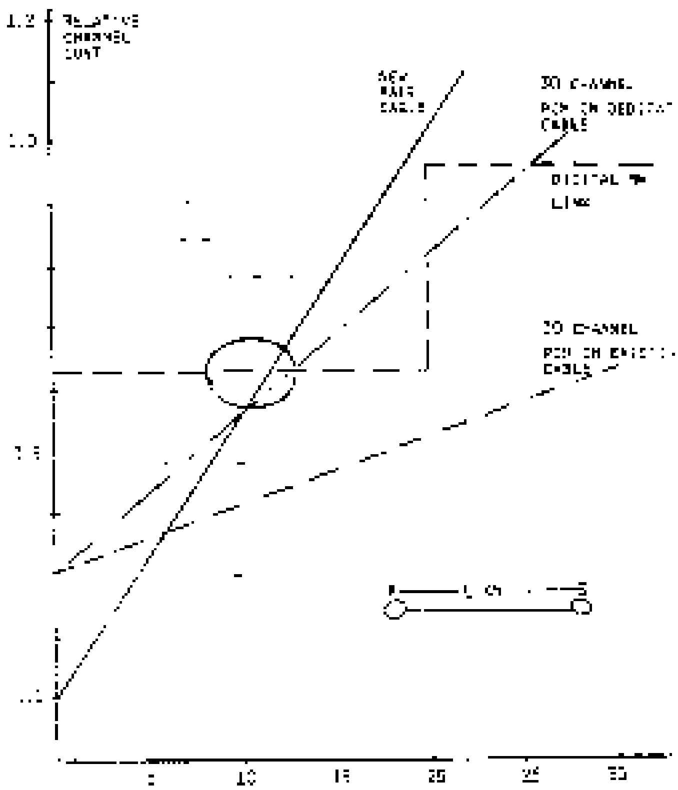


Figure 6 : Cost structures for a capacity 30 channels (example) (Analogue exchanges)

Main applications are as small capacity aerial rural routes, using existing pole routes or short/medium length medium capacity metropolitan routes where existing cables are not available. A third application might be for 8 Mbit/s entrance links to radio towers using two cable operation.

For the local network, specially designed "low cost", cables might be envisaged, for example, in order to carry primary PCM systems for connection of digital PABX:es with a minimum need of intermediate repeaters. For digital subscriber connections, operating at a lower bit rate such as 144 kbit/s, the existing types of subscriber cables will not offer specific problems. (Also intermediate bit rates, like 0.704 Mbit/s are discussed for multiplexed subscriber circuits, like 5 x 144 kbit/s, and low bit rate connections to digital PABX:es. Since this issue is under discussion, it would be premature to consider the matter of transmission media requirements at this stage, but it is quite obvious that a minimum wire diameter of 0.5 mm is preferred for this bit rate).

B.4 Engineering

If the cables are exclusively used for PCM, impact of impulse noise could be neglected, enabling full length end sections.

C. Special pair cables for 8 Mbit/s and 34 Mbit/s transmission

C.1 Technical characteristics

Below are given some data for a Danish cable which has been in use since 1977.

build-up	4 or 6 screened units, each with 5 quads
wire diameter	0.9 mm
wire insulation	0.5 mm foamed PE, same color for all pairs
screen	two Cu-screens 0.5 mm
outer screen	0.15 mm Al, part of outer sheath
NEXT	13 MHz (4B3T-kod); >139 dB 4.2 MHz >140 dB
cable fill of PCM	8 Mbit/s 100 % 34 Mbit/s 50 to possibly 100 %, depending on splicing
loss	16.4 dB/km at 4.2 MHz 31.3 dB/km at 13 MHz

C.2 Standardization level

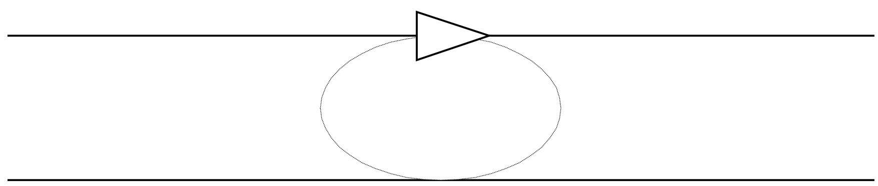
The above-mentioned special cable is not internationally recommended or standardized. Seven pair cable types and two quad cable types for two cable operation are included in CCITT Rec. G612. Thus, no uniform standard is available.

C.3 Cost structure, applications

The cost structure tends to approach, at least within a few years, the structure for optical fibres. It is also similar to cost of µcoaxial cable (see point E3). A typical application may be in the short haul trunk network.

C.4 Engineering

In addition to all aspects to cater for when planning 2 Mbit/s systems, far end crosstalk and near end crosstalk between output and input of a specific repeater, must be carefully considered. This implies restrictions in the repeater gain to reduce the so called NNEXT:



Special attention must be paid to the repeater station splicing process in order to avoid short distances between unscreened units (see Figure 7).

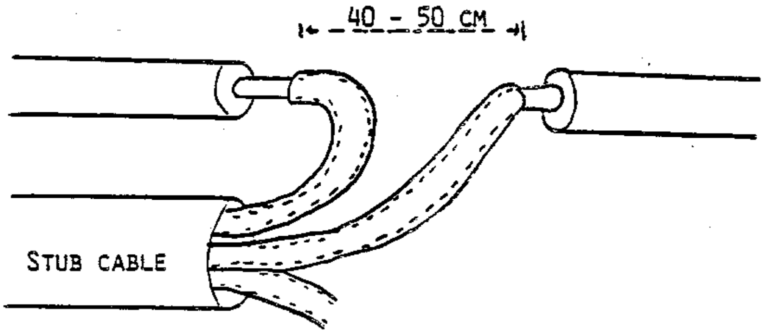


Figure 7 : Splicing

D. Coaxial cables

D.1 Technical characteristics

Coaxial cables are specified by CCITT in Rec. G621-623. For the these cables, it should not meet problems to use:

- µcoaxial cable up to 34 Mbit/s, and also possible 140 Mbit/s;
- small diameter coaxial cable up to 565 Mbit/s;
- normal diameter coaxial cable up to 565 Mbit/s or even higher bit rates.

For old non-CCITT cables, some problems may be encountered because of impedance irregulations. If the irregularities are periodical, as far as distance is concerned (e.g. splices), very sharp attenuation peaks may occur at frequencies where the reflected signal - as a forward echo (see Figure 8) and the original signal have opposite phase (see Figure 9).

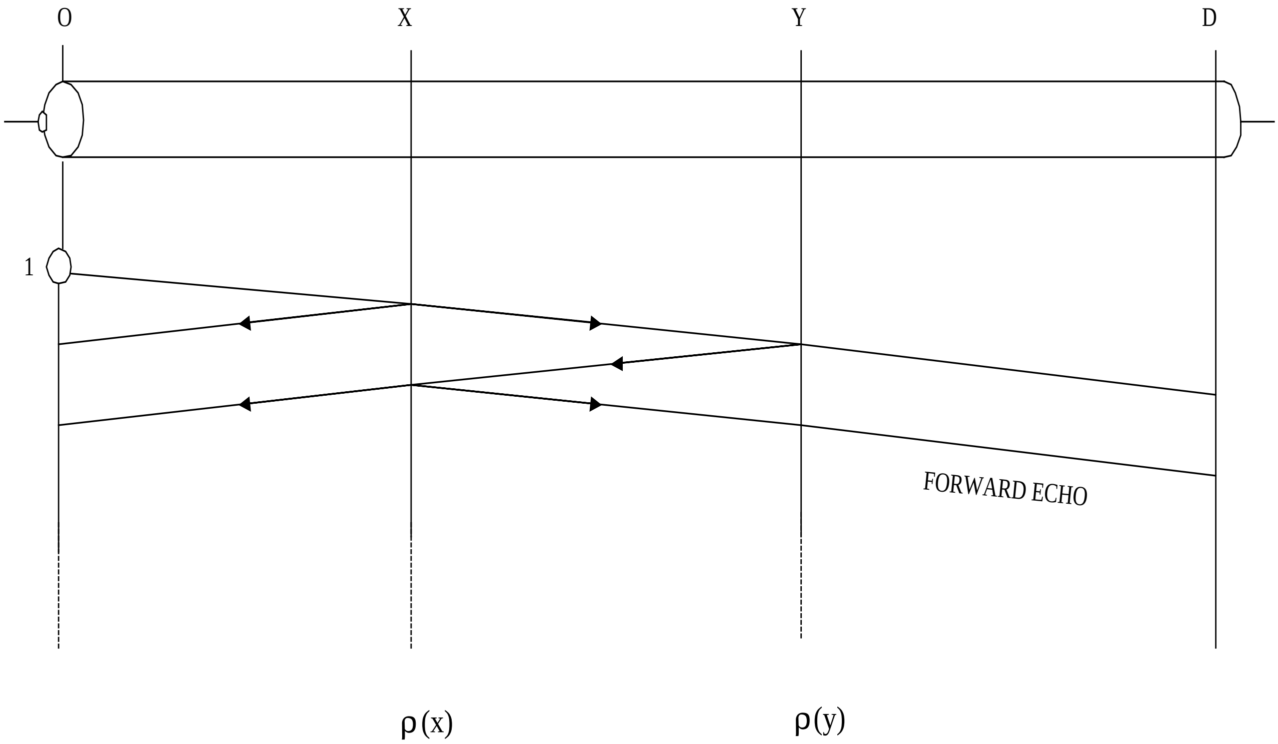


Figure 8 : Coaxial Cable - Impedance irregularities

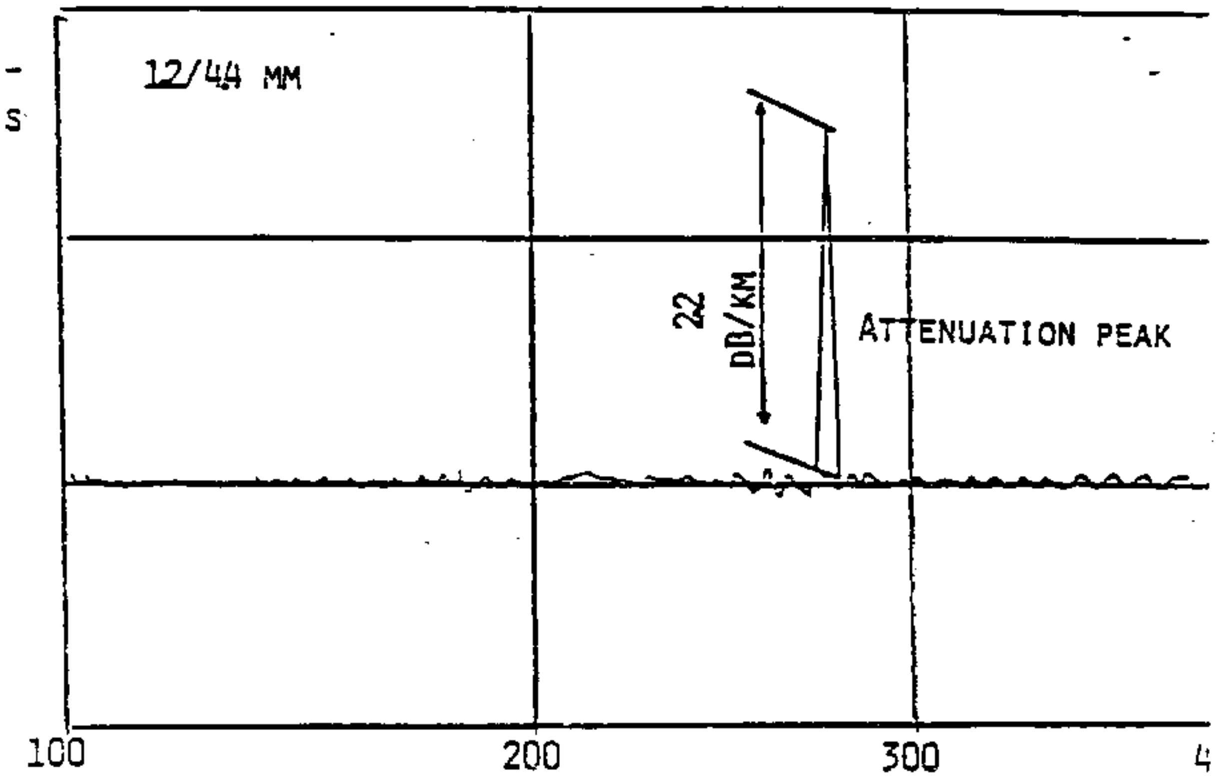


Figure 9 : Coaxial Cable - Impedance Irregularities

D.2 Standardization level

See point D.1.

D.3 Cost structure, applications

It is necessary to distinguish between the case of existing coaxial cables (fully or partly equipped with FDM systems to be converted to TDM systems) and new coaxial cable systems. If the cable is already existing, equipping with TDM systems is a very competitive alternative for LD routes and entrance links to radio stations. If a new coaxial cable is required, the coaxial cable system may be more expensive than an optical fibre system, according to Figure 10.

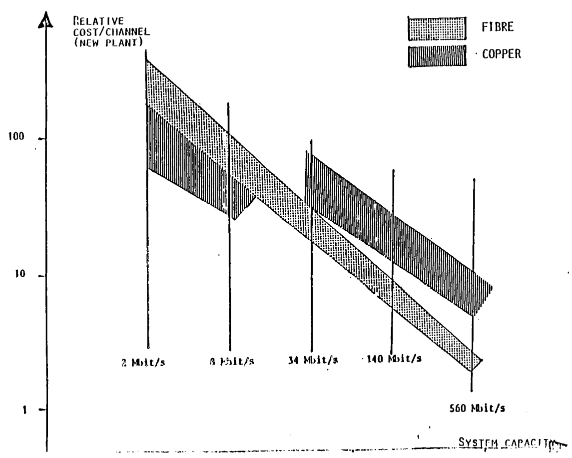


Figure 10

D.4 Engineering

See point D.1 regarding possible problems to be encountered when exploiting old type coaxial cables. Otherwise, the engineering is similar to the one for FDM systems regarding power feeding, etc. Indeed, the systems are designed to be compatible with the repeater section lengths for FDM systems with a corresponding (or slightly higher) channel capacity.

E. Optical fibre systems

E.1 Technical characteristics

Features of optical fibre systems are:

- low loss;
- wide bandwidth;
- small diameter;
- light weight;
- small bending radius;
- freedom of crosstalk;
- immunity from electromagnetic disturbances.

These properties offer a number of benefits as a transmission medium, such as:

- long repeater spacing;
- large transmission capacity;
- installation simplicity.

The optical fibre transmission system configuration is illustrated in Figure 10a and a typical cable build-up is given in Figure 11. The optical part consists of core and cladding.

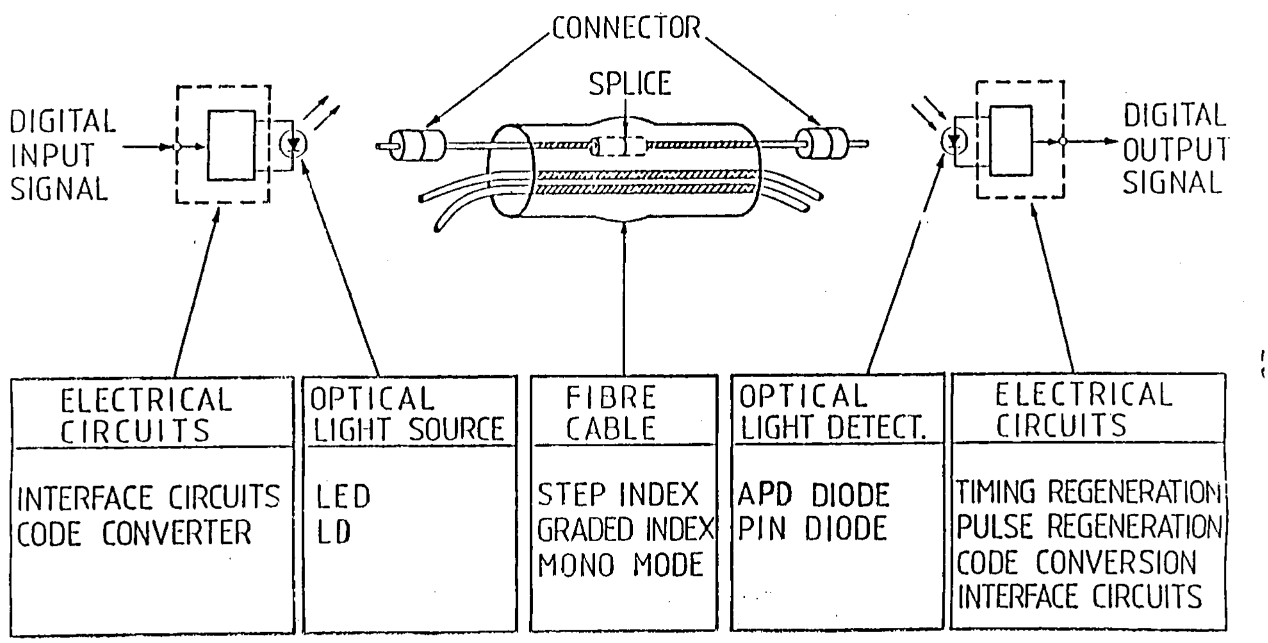


Figure 10a : First Optical System Basic Configuration

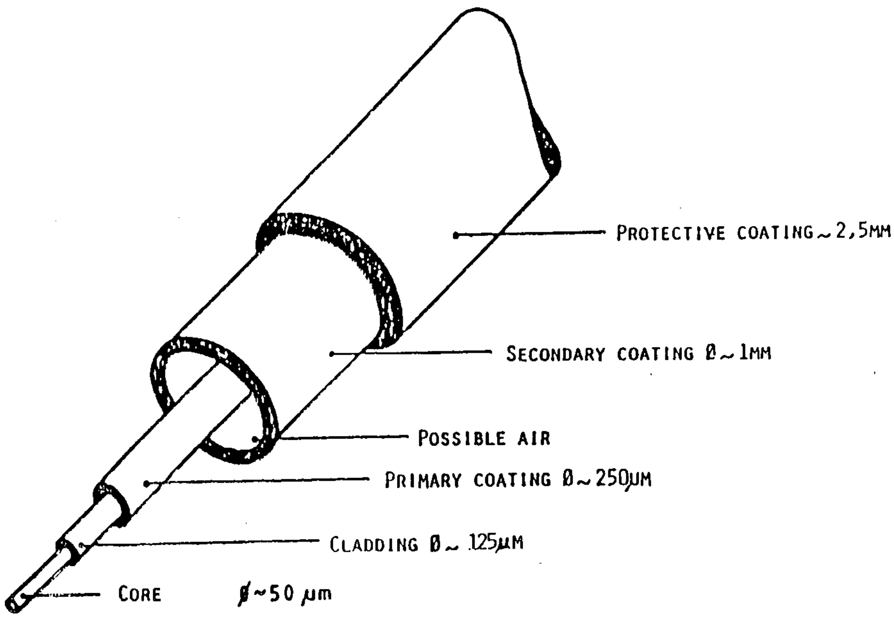


Figure 11 : Fibre cable

Optical fibres are classified by the following aspects (see, e.g., Figure 12):

- Propagation mode: a) multi-mode b) single-mode;
- Refractive index profile: a) graded index b) step-index;
- Material.

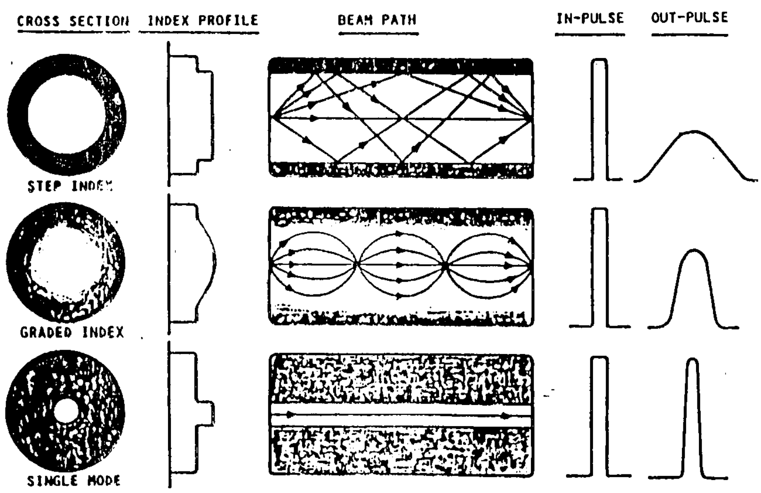


Figure 12 : Summary, Fibre Types

Regarding <u>loss</u>, the fibre attenuation varies, at present, between 0,2 and 10 dB/km in the 0,8-1,7 μm wavelength range. A main factor causing loss is <u>absorption</u> (see Figure 13).

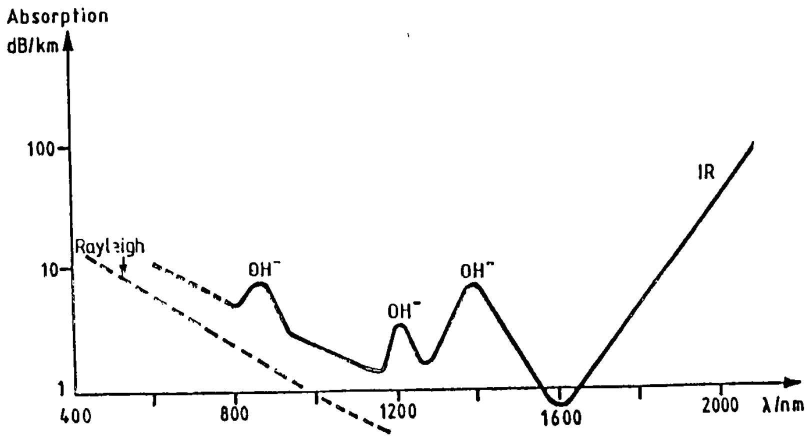


Figure 13 : Absorption

There are two or suitable light sources for transmission systems. They are the LED (light emitting diode) and the LD (laser diode) - see Figure 14.

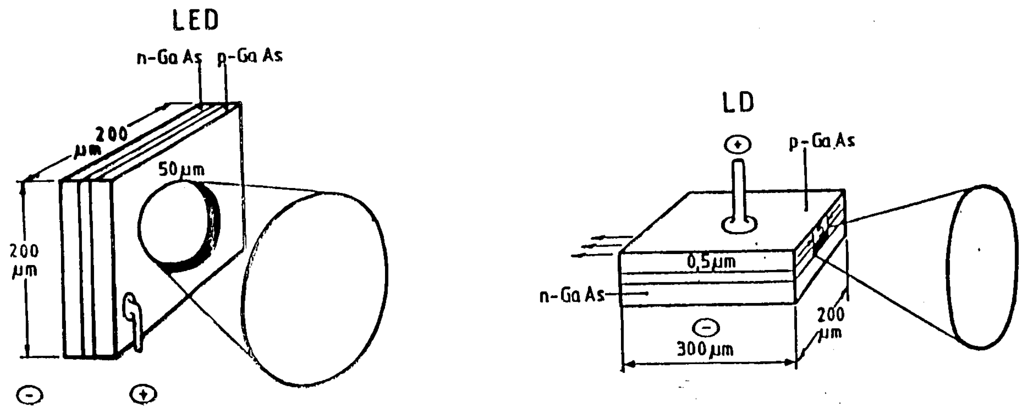


Figure 14 : Optical Transmitters

Suitable O/E (opto-electrical) converters are the PD (photo diode) and the APD (avalanche photo diode). Some typical data on optical fibre systems are given in Figure 15.

SYSTEM ➔ / PARAMETER ➔	45 Mbit / s					140 Mbit / s				
	LD / APD SW / GI			LD / PIN-FET LW / GI		LD / APD SW / GI			LD / PIN-FET LW / SM	
WAVELENGTH (nm)	830			1300		830			1300	
MEAN OUTPUT POWER [1] (dBm)	-3			-3		-3			-10	
RECEIVER SENSITIVITY [1, 2] (dBm)	-50			-41		-42			-37	
CONNECTOR LOSSES (dB)	2			2		2			2.5	
FIBRE BANDWIDTH [3] (Mhz * km$^{\gamma}$)	700	400	400	1000	700	700	600	400	>10000	>10000
FIBER ATTENUATION [4] (dB/km)	2.4	2.7	3.5	0.7	1.0	2.4	2.7	3.5	0.5	0.8
ADD. ATTEN. AT 830 nm (dB/km)	0.3			-		0.3			-	
SPLICE LOSSES (dB / km)	0.2			0.2		0.2			0.25	
REPAIR SPLICE MARGIN (dBm)	0.2			0.2		0.2			0.25	
SAFETY MARGIN (dB)	3			3		3			3	
REPEATER SPACING (km)	13.5	12.3	10.0	30.0	23.6	11.0	10.0	8.1	21.5	16.5

1) worst case figures, includes degradation margin
2) includes dispersion margin
3) γ = 0.7 - 1.0 depending on bandwidth and wavelength
4) cabled fibre at 850 nm or 1300 nm

Figure 15

E.2 Standardization level

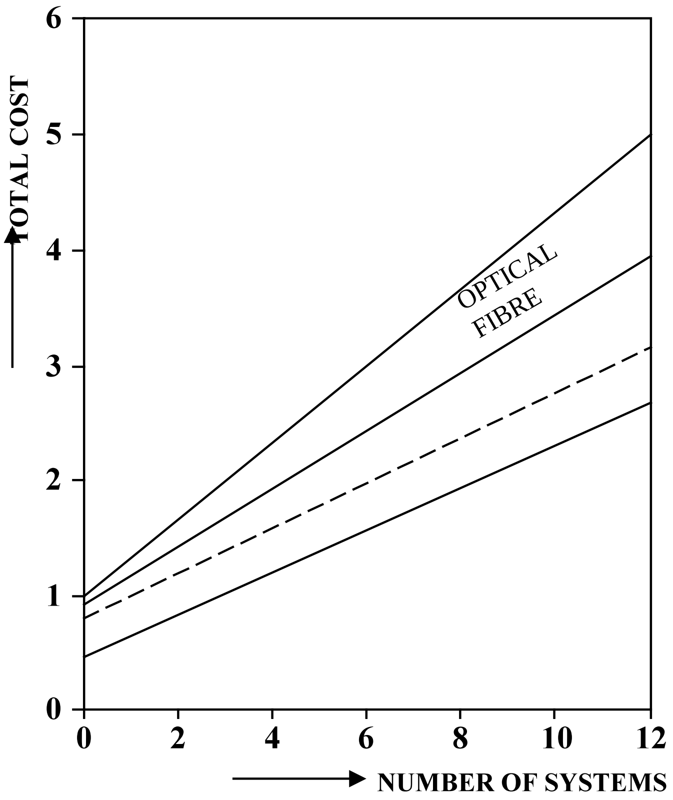
The standardization level reached up to now (1982) is low but one type of fibre whose practical use studies are most advanced can be found in Rec. G. 651 “Characteristics of 50/125 µm graded index optical fibre cables”.

E.3 Cost structure, applications

Comparisons with existing pair cable and special pair cable in Figures 16-17 tend to indicate an economy at least at the bit rate 34 Mbit/s.

Other comparisons indicate a main application area, at present in metropolitan networks.

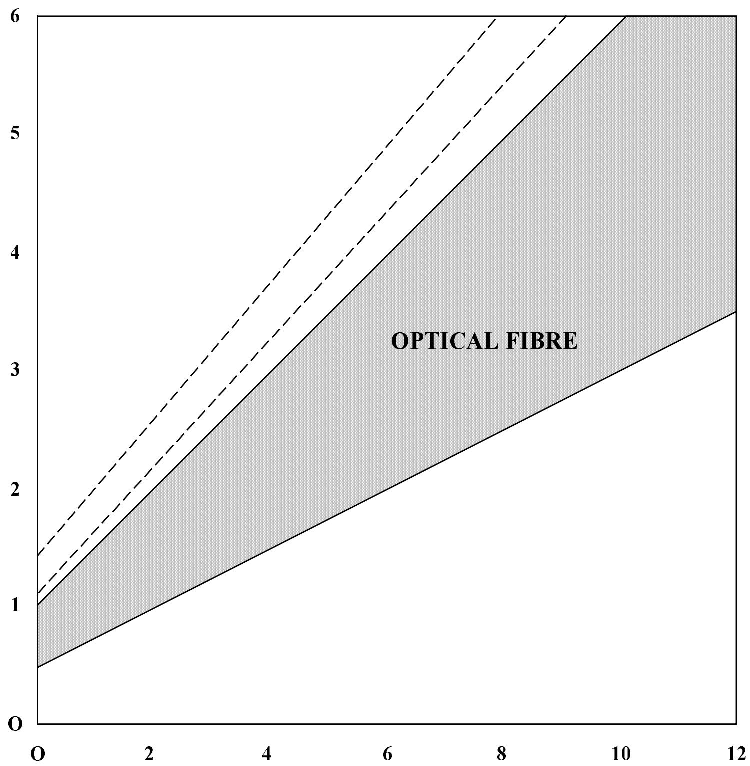
Figure 16 : 8 Mb/s - FOS vs. Special Pair Cable



FOS : LED / APD
5 dB / km optical fibre loss
8 km repeater spacing

PAIR CABLE : 4 km repeater spacing

Figure 17 : 34 Mb/s - FOS vs. Special Pair Cable



FOS : LASER / APD

5 dB / km optical fibre loss
3 ns /$\sqrt{\text{km}}$ pulse dispersion
8.2 km repeater spacing

PAIR CABLE : 2 km repeater spacing

F. Summary (CEPT hierarchy)

A summary of PCM transmission systems up to 140 Mbit/s is given in Figure 18. The corresponding summary of transmission media is found in Figure 19 and relevant repeater section lengths can be found in Figure 20.

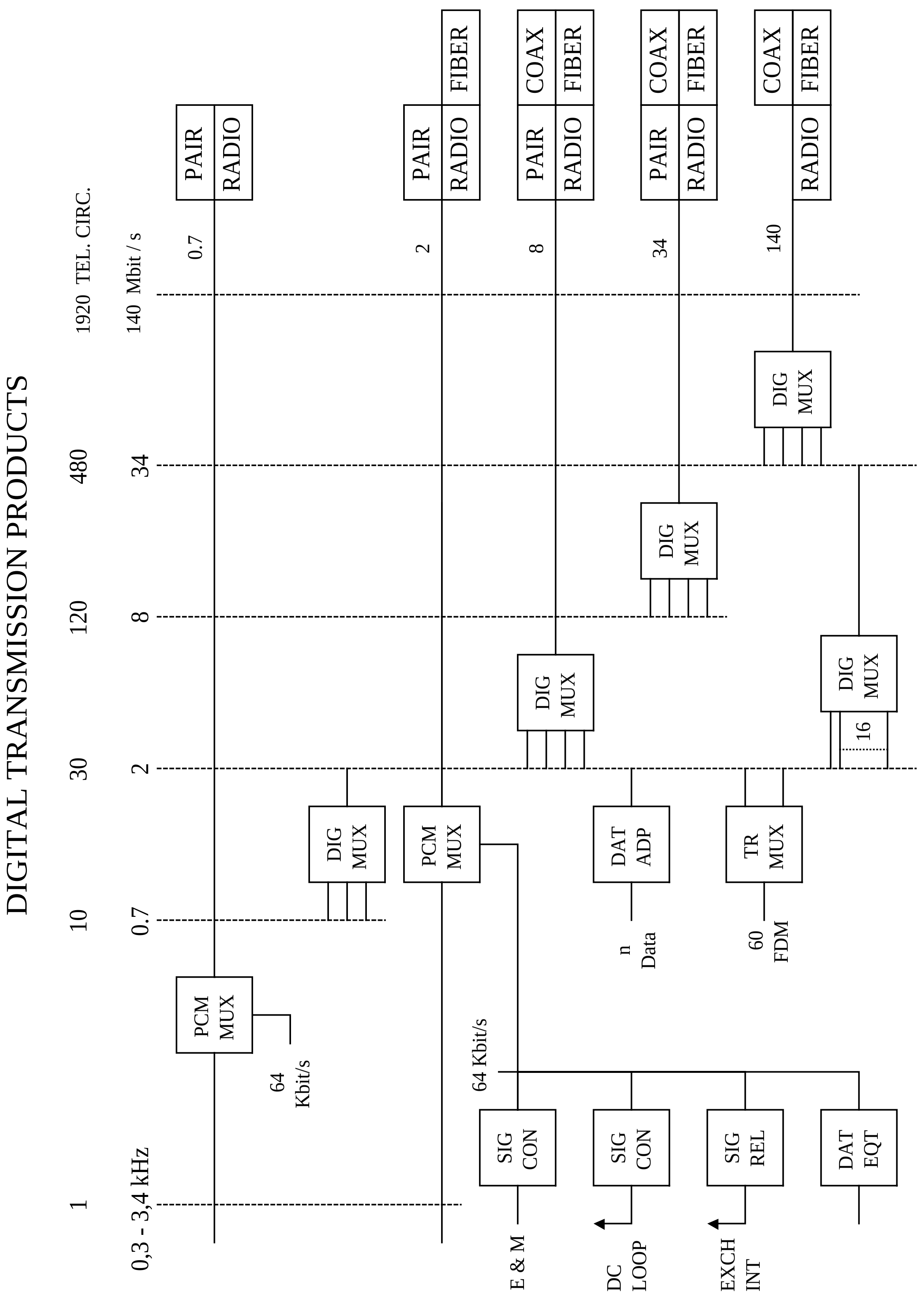


Figure 18 : Digital Transmission Products

Figure 19: Transmission Media for PCM Systems (CEPT Hierarchy)

SYSTEM		MEDIUM	SIUTABLE MEDIUM FOR ENTRANCE LINKS TO DIGITAL MW SYSTEMS
MBIT / S	CIRCUITS/SYSTEM		
2	30	normal symmetric pair cable. dedicated symmetric pair cable. digital MW. (opticat fibre)	symmetrical pair cable (normal - dedicated)
8	120	digital MW. optical fibre microcoaxial cable special symmetric pair cable	special pair cable. dedicated pair cable (two cable operation). microcoaxial cable. optical fibre.
34	480	same as for 8 Mbit / s + small diameter coaxial cable	special pair cable. microcoaxial / small diameter coaxial cable. optical fibre
140	1920	digital MW. small / normal diameter coaxial cable. optical fibre	small / normal diameter coaxial cable. optical fibre
560	7680	normal diameter coaxial cable.	

Figure 20 : Repeater Section Lengths (guidance)

PCM - SYSTEM (HIERARCHICAL) number of channels	1 30	2 120	3 480	4 1920	5 7680
"Normal"symmetrical pair cables	1.2 - 3 km (one cable operation)	1 - 2 km (two cable operation)			
Special pair cables (screened)		≤ 4 km	≤ 2 km		
Microcoaxial cables		≤ 4 km	≤ 2 km	~ 1 km	
Small diameter coaxial cables		≤ 8 km	≤ 4 km	≤ 2 km	
Normal diameter coaxial cables		~ 18,5 km	8 - 9 km	4 - 4.6 km	1.5 - 1.6 km
Optical fibre cables 4 dB / km, 850 nm	~ 10 km	~ 9 km (LED)	~ 8 km (LASER)	~ 7 km (LASER)	
Digital MW	←	5 - 50 km		→	