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INCREASING THE VALUE/COST RATIO FOR THE INTRODUCTION OF BROADBAND SERVICES

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Increasing the value/cost ratio for the introduction of broadband services

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The paper examines the architecture, system and component aspects related to the introduction of broadband services on an optical fibre distribution network, addressing in particular the cost issue.

1. Introduction

The first field trials for the use of optical fibre cables and systems in the public telecommunication network started in the second half of the '70s [1], opening the way to the commercial use of optical fibres in the junction and trunk network in the early '80s. This was eased also by the issue of international standards, in particular by CCITT. At present the commercial use of optical fibres in the junction and trunk network has achieved a consistent penetration and single-mode fibres are being more and more widely used; many operators plan to use in a near future single-mode fibres only in these areas.

The use of optical fibres in the distribution network is at present in a much less mature stage. Field trials started in the first half of the '80s in several countries, in particular in Europe [2]; at present some countries are planning a large scale introduction in the second half of the '80s — beginning of the '90s. In particular, in Europe, the Commission of European Communities has been studying the possibility of starting a cooperative R & D programme, named RACE (Research on Advanced Communication in Europe), aiming at stimulating the community-wide introduction of « Integrated Broadband Communication » (IBC) [3]. The provisional objectives are the implementation of precompetitive prototype systems around 1990 and of commercial systems aroud 1995.

Contrary to what happens in the trunk applications, in the distribution network there is generally no need of extreme performances, concerning the bit rates and repeater spacings. The problems to be solved are different but not easier: the success in this area is connected to the ability of offering services meeting the expressed or latent needs of the customers, at an acceptable price. In other words, in order to have a widespread penetration of these services, it is necessary to achieve a high value/cost ratio.

This requires the coordination of the studies in the field of network architectures, transmission, switching, terminals, optical fibres and cables, optoelectronic components, integrated circuits and optics, giving always the maximum importance to economic considerations. In particular, three areas can be considered in the distribution network: the service centre and the switching office; the subscriber loop; the customer terminals. In the first area the equipment is used by several customers and its cost is then shared among them; in the last one it is possible to rely on the economies of scale of the consumer product industry; the maximum effort must then be done in order to reduce the costs in the subscriber loop, possibly also moving them towards the two other areas.

A last fundamental consideration is that the financial aspects are probably even more important than the technological ones, as a deep penetration of the broadband distribution network requires huge investments. It is therefore very important to be able to raise funds at an acceptable cost, in order to ensure a medium term return, offering the services at market prices.

(*) Ing. Federico Tosco, CSELT, Torino. Invited paper at the IOOC-ECOC '85, Venezia, October 1985.

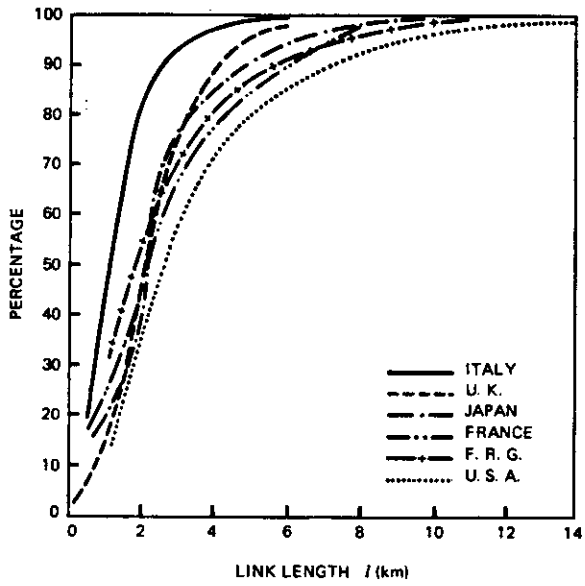

Fig. 1 - Length distributions of subscriber links in various countries.

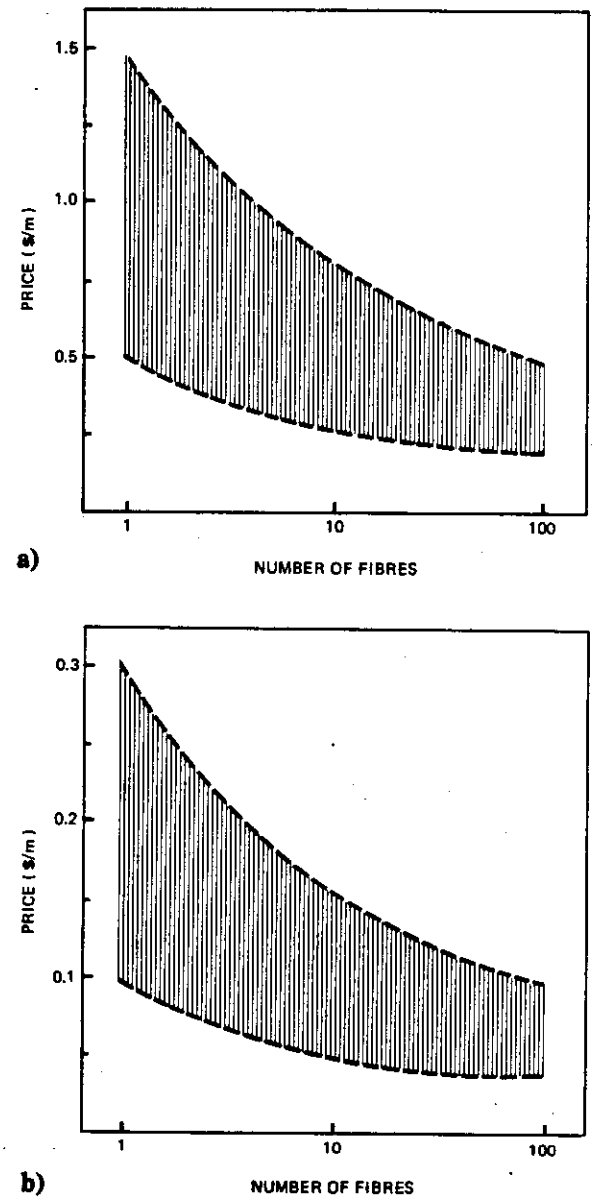

Fig. 2 - Transformation price of optical cables; *a*) present situation, *b*) forecast for large volumes of production.

2. Network considerations

In order to define the network performance, in particular concerning the bandwidth requirements, it is necessary to consider the services to be offered to the customer. These services can be grouped in telephonic — « telematic » services (telephone, data, facsimile, videotex etc., i. e. the services offered by the basic ISDN) and broadband video services (broadcast and on-demand TV, high quality videotelephone and videoconference, etc.). In the field trials and in some of the commercial applications starting now, quite often analog transmission has been used: intensity modulation or pulse modulation (PFM, PIM, etc.). For the future these is a clear and general trend to use digital transmission, which ensures a better quality, longer repeater spacings and a better overall system integration. This is also connected to the perspective of using circuits with a very large scale of integration (VLSI), that offer drastic reductions of cost, e. g. of the video coders and decoders. Using a suitable redundancy reduction, it is reasonable to consider a bit rate of 34 Mbit/s (in the European hierarchy) for the transmission of a standard TV channel (possibly 70 Mbit/s in a first phase) and a bit rate of 140 Mbit/s for a high definition TV channel (HDTV).

Looking at the architecture, only the star network is flexible enough to supply both broadcast and interactive video services to many customers; the tree network is suited only for broadcast services and the ring (or bus) network has a limited capacity and is therefore interesting mainly for LAN applications. Often a double-star (or more in general a multi-star) network is considered, with a remote switch very close to the customer (a few hundred meters). This solution can be economically attractive for long subscriber lines, in particular for broadcast services; for interactive services it introduces a certain system complexity, in particular concerning signalling. Moreover it can increase the maintenance problems.

In Italy the telephone loops are rather short: the mean length is around 1 km, nearly 95 % of the loops are shorter than 3 km and the maximum length is within 5 km (Fig. 1). In such a situation, it is envisaged in Italy to locate the wideband switching matrices in the local telephone switching centres. For the longer subscriber loops, it will be possible to share the fibre among a few customers, using TDM (or possibly WDM) multiplexers; this solution is suitable for any kind of service and does not create traffic congestion problems. The service centres, diffusing broadcast or on demand video channels, could be co-located in the switching nodes, but in general, at least in the

TABLE I

Present prices of optical sources and detectors (MM=Multimode; SM=Single-Mode)

DEVICES	PRICE (K$)
LD; 0.85 μm; MM.	0.4 - 0.8
LD; 1.3 μm; MM.	1.5 - 3.5
LD; 1.3 μm; SM.	2.5 - 6
LED; 0.85 μm; MM.	0.2 - 0.25
LED; 1.3 μm; MM.	0.4 - 1
PIN; 0.85 μm;	0.05 - 0.15
PIN; 1.3 μm;	0.55 - 1.4
APD; 0.85 μm;	0.15 - 0.2
APD; 1.3 μm;	0.4 - 0.6

initial phase in which the service penetration will be modest, each service centre will feed several switching nodes.

The considerations made in the following will be based on the network structure that has been outlined above but are in general valid (or can be easily extended) in case of other network structures.

3. Subscriber link

As said in the introduction, the subscriber link is one of the most cost-sensitive parts of the broadband network. Therefore it is very important to examine its different elements, in order to make proper and viable choices.

Starting from the optical fibre, both multimode and single-mode fibres can be candidates for use in this part of the network. Looking at the transmission performances, the single-mode fibre has a big advantage from the point of view of the bandwidth, as it is suitable for bit rates up to some Gbit/s, while the multimode fibre is in practice limited to bit rates in the order of 140 Mbit/s. The much higher capacity of the single-mode fibre can be exploited for the transmission of a higher number of video channels and/or of very wideband services, like HDTV, or for connecting several customers with one fibre, using TDM techniques.

From the economic point of view, at present single-mode fibres cost often still a little mode than multimode fibres, but this is due mainly to their lower level of technological maturity; from the technical point of view, the fabrication of single-mode fibres requires a much lower quantity of expensive dopants and the tighter requirements on dimensional tolerances are compensated by the looser requirements on the index profile. Therefore in perspective the price of single-mode fibres should be equivalent to the price of medium-quality multimode fibres, or even lower; for very high volumes of production, prices in the order of 0.04-0.1 s / m are forecast.

Single-mode fibres are more difficult to splice, but using power maximization techniques it is now possible to obtain the same splice attenuations achievable with

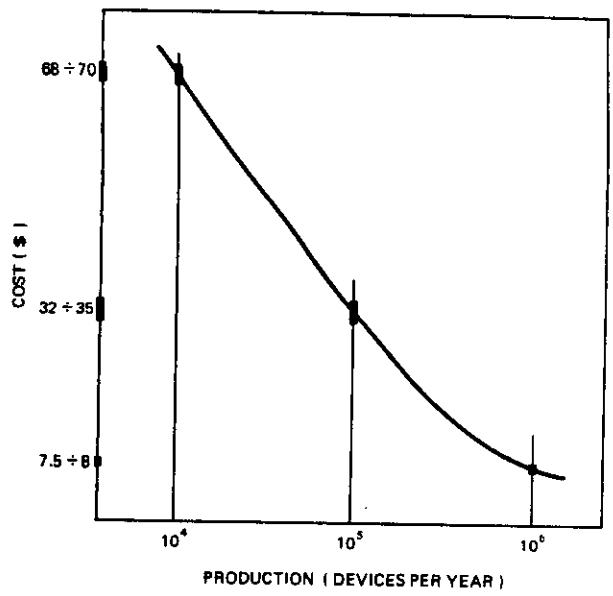

Fig. 3 - Production cost of lasers versus volume of production.

multimode fibres. The situation is less mature for the connectors, which for single-mode fibres are now less widely available on the market, with prices 2-3 times higher than the multimode fibre connectors; however, in perspective prices of 2.5-10 $ and of 2.5-5 S are forecast for single-mode and multimode connectors respectively.

WDM couplers and decouplers are at present easily available on the market only for multimode fibres, at prices in the order of 1000 $; however, using integrated optics techniques, there are good perspectives for the implementation of cheap couplers for single-mode fibres. In order to use a single-mode fibre for bidirectional transmission, in alternative to WDM couplers it is possible to use directional couplers, which are available with interesting performances.

Looking at the optical cables, there are no significant differences from the technical and economical point of view using multimode or single-mode fibres; various structures are used and the maximum densities achieved for cables with a capacity of some tens of fibres are around 1 fibre/mm². Fig. 2 shows the transformation prices, i. e. the additional price per fibre due to cabling operations, at present and forecast for large production volumes. The prices depend on the cable capacity and on the structure and degree of mechanical protection of the cables.

A key element in the optical fibre links are the sources and detectors; in this field the progress has been consistent concerning performance and reliability, but the prices are still very high (Table I), in particular for lasers for single-mode fibres. These prices however correspond to the present market situation, i.e. to small production volumes. A study has therefore been made on the fabrication cost of a laser (the most expensive and critical component) in the hypothesis of a production of one million devices per year and of

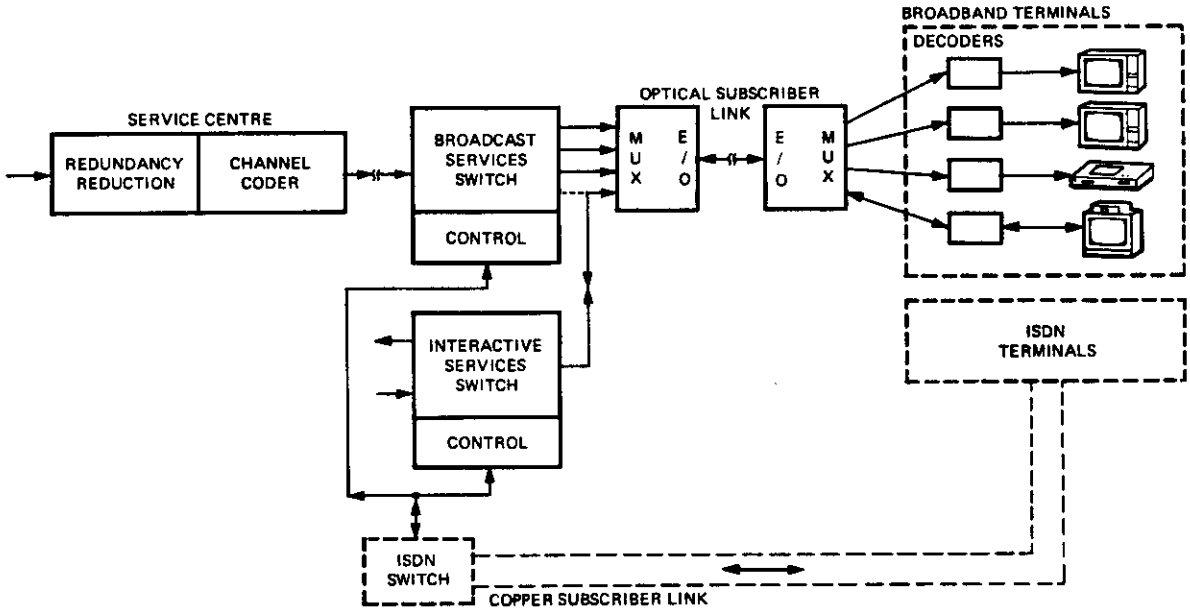

Fig. 4 - Block diagram of a broadband distribution system under study in Italy.

TABLE II

Production cost of lasers for volumes of production around 10^6 devices per year

Technology	MATERIAL		Preselection, burn-in, submount	Package & testing	Total cost ($)
	I window (GaAs)	II window (InP)			
LPE I	0.50	0.8	2.5	4.9	7.9 GaAs 8.2 InP
LPE II	0.30	0.5	2.5	4.9	7.7 GaAs 7.9 InP
MBE	0.25	0.4	2.3	4.9	7.5 GaAs 7.6 InP
MOCVD	0.25	0.4	2.3	4.9	7.5 GaAs 7.6 InP

a yield of 35 %, that seems not unrealistic for such production volumes. The results, synthesized in Table II, show that, due to the predominance of the costs of the preselection, burn-in, package and testing operations, the production costs for the different technologies would be around 7.5-8 $, both for sources for multimode and single-mode fibres; this would result in a market price around 25 $, i. e. of the same order of magnitude of the price of lasers used in the disk players. The calculations have been repeated for productions of 100.000 and 10.000 devices per year, leading to production costs of about 35 and 70 $ respectively (Fig. 3). Similar cost reductions for mass productions are foreseable for the other components.

As a conclusion of this paragraph, it can be said that, for applications in the distribution network, today the multimode fibres still present some advantages from the point of view of the costs and of the availability of some components; for this reason they are being extensively used in several field trials and early applications. However, the technology is in rapid evolution [4,5], so that looking at a perspective in the near future (end of this decade), the single-mode fibre looks much more interesting than the multimode fibre, as it will offer much higher performances at about the same cost.

4. System and cost considerations

In order to evaluate the cost of a subscriber connection, it is first of all necessary to define the system structure. In the following a structure will be outlined which is at present under study in Italy, also in view of a field trial in Rome, planned to start in 1988 (Fig. 4).

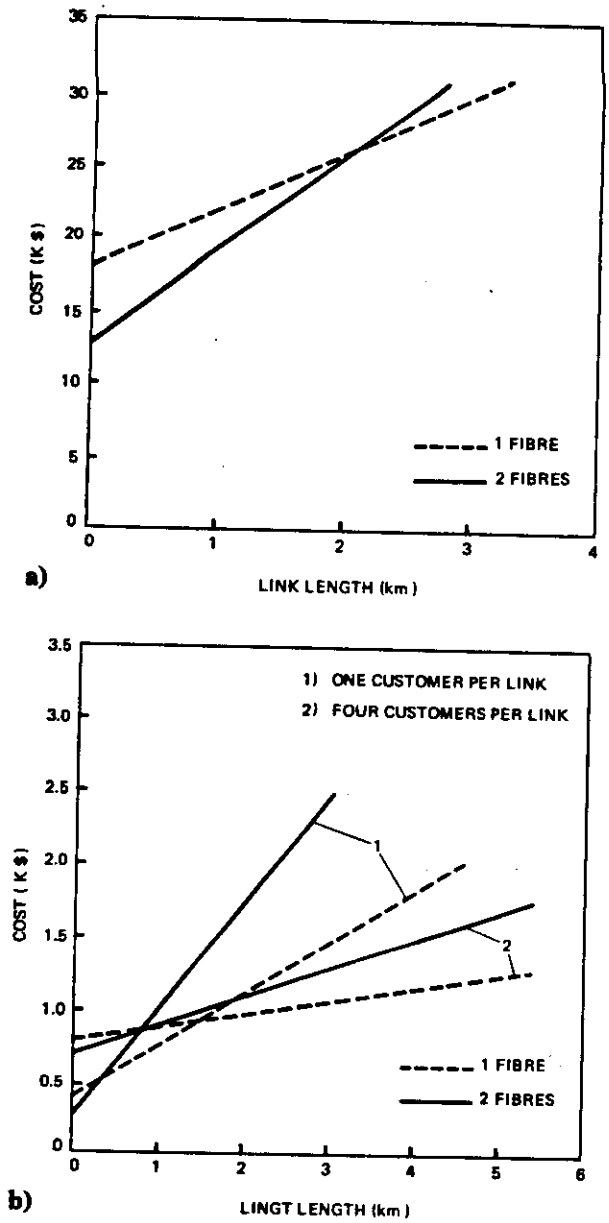

Fig. 5 - Cost of the broadband subscriber connection, as a function of the link length, for the system solution of Fig. 6. *a*) present cost; *b*) projected cost.

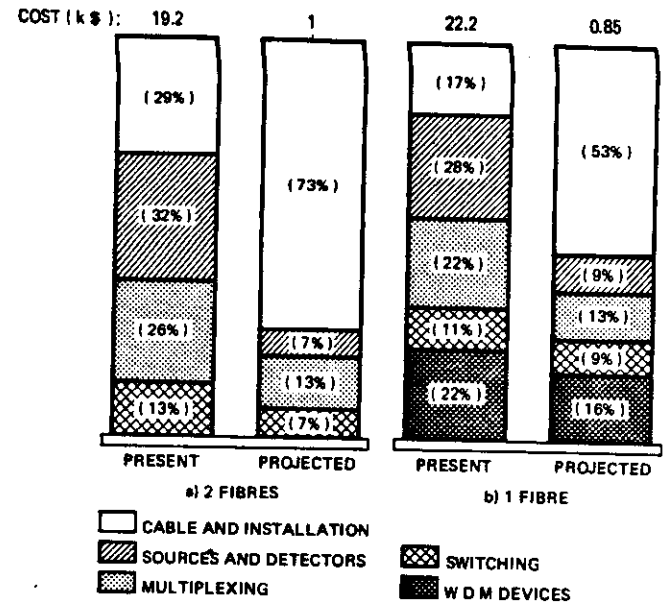

Fig. 6 - Relative apportionment of costs among system elements for a 1 km link.

In the definition of the plan for the introduction of broadband services, it is considered important to adopt an evolutionary strategy, ensuring a graceful transition from the basic ISDN (which is being implemented now) to the broadband integrated network. In this framework, it is envisaged in the first phase to continue to supply the ISDN services to the customer on his copper loop, using the optical fibre for the broadband services only. Later on, with a deeper penetration of the broadband services, it will be preferable (or even necessary, in order to avoid the congestion of the metropolitan ducts) to arrive at a full integration of all services on the optical fibre. The signalling will be in agreement with ISDN criteria and will be sent on the copper pair to the ISDN exchange, which will make a first elaboration of the lower level protocols, and then to two specialized broadband digital switches, for the undirectional (broadcast type) and bidirectional (videoconference, videotelephone) channels. The solution is open to a future evolution, unifying the ISDN and broadband subscriber accesses.

The broadband switches will have a highly modular structure, ensuring the possibility of an easy and gradual growth. Both switches will use as basic components digital, space-division crosspoints; the unidirectional matrix can have a non blocking, point-to-multipoint internal structure, while the bidirectional matrix will have a multistage, point-to-point structure. An important aspect is that the digital switches must have a « transparent » behaviour, i. e. with performances independent on the signal structure and on its path inside the matrix.

For the optical fibre subscriber-link, the solution that looks most interesting, at present and in a medium term perspective, is based on the transmission from the central-office to the customer of a 140 Mbit/s stream, obtained through a time division multiplexing of four 34 Mbit/s channels, which can carry a combination of services: TV channels, a group of HiFi stereo sound programs, and one direction of a videocommunication connection (high quality videotelephone or videoconference, partecipative TV). A bit rate of 280 Mbit/s would be required if an HDTV channel should be included in the future in the services to be supplied to the customer.

The return direction (customer - central office) of the videocommunication connection can be transmitted on a second fibre or on the same fibre, using WDM or directional couplers.

In future, if very cheap WDM couplers will be available, they could be used in alternative to the TDM so-

lution for multiplexing the various services transmitted from the central office to the customer.

As already said before, it is particularly important to limit the cost of the subscriber link; to achieve this objective, it is necessary to look at very simple system solution, tailor-made for this application and possibly different from the solutions normally adopted in the transmission systems developed for the junction and trunk network.

The structure that is at present under evaluation in Italy (Fig. 6) is based on a few unconventional solutions *.

Looking at the line coding for the broadcast-type channels, the solution that would be normally used in the trunk network would embody separate line coding-decoding for the different segments of the link from the service centre to the customer: service centre to central office and central office to customer. A consistent simplification is achievable introducing a single channel coding in the service centre, taking into account the requirements of the different link segments and transparent, as far as possible, to the multiplexing operations. In such a way it is possible to have a coder for each broadcast channel instead of a coder for each customer.

Another interesting solution seems to be the use of a synchronous TDM multiplexer, which would be much cheaper than the asynchronous multiplexers normally used in the trunk network. This solution requires a synchronization of the TV channels in the service centre or in the central office (at the input of the link from the service centre).

As already said, a further economy can be obtained, on the long subscriber loops, connecting a few subscribers (e. g. four) with a single fibre, using TDM techniques and possibly in the future WDM techniques.

Based on the system structure outlined in Fig. 4, an evaluation has been done of the cost of a broadband subscriber connection, i. e. of the additional cost for supplying to the customer the broadband services in addition to the ISDN services; the cost of the customer terminals has not been included. The evaluation has been done both in the present situation and in a future situation of a very deep penetration of the broadband network, leading to large economies of scale. For the bidirectional services two solutions have been considered, i. e. the use of two fibres or of a single fibre with WDM couplers. For the deep penetration situation an evaluation has been made also of the costs in the case of connecting four subscribers with a single fibre, using TDM techniques.

Fig. 5, shows the costs that have been obtained, as a function of the length of the subscriber link. Fig. 6 gives the relative incidence on the total cost of the various system elements, for a subscriber link having a length of 1 km (which is the average length in Italy). It can be seen that a cost reduction of more than one order of magnitude is foreseable, with a consistent variation of the relative incidence of the various cost elements.

5. Conclusions

The projected cost levels calculated in this paper for a broadband customer connection in a steady-state situation look affordable and able to ensure profitable operations. However, it has to be clearly stated that they are related to a situation of a deep penetration of the broadband network, in which the number of customers connected every year is in the order of a million. In order to achieve such a situation it is necessary to develop suitable market strategies, in particular concerning the definition of the services to be offered and of the tariff policy; this will involve also initial investments in order to « make the market » [6,7].

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(1) Patent pending.