COHERENT OPTICAL TRANSMISSION SYSTEMS

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Abstract

Coherent optical transmission, through its high sensitivity and large capacity, offers a very attractive solution for subscriber loop distribution systems.

In this paper the world's first fully-engineered coherent multi-channel (CMC) transmission system will be described. Using established technologies of semiconductor lasers and high-frequency electronics a system demonstrator has been realized, having consumer TV comparable performance. The resulting network flexibility will be discussed.

INTRODUCTION

In this paper we will try to sketch the relevant issues in the evolution of broadband networks, both for telco and for CATV applications. From the perspective of service provision various network architectures will be discussed, with an emphasis on network flexibility and evolution towards interactivity. The role of new components and technologies will be addressed, and the options for present and future networks will be outlined.

It will be shown that using different optical wavelengths for different programs or services allows for a very flexible network architecture, at the same time making optimal use of the practically infinite transmission capacity of the optical fiber. The ultimate form of wavelength multiplexing is coherent multi-channel transmission, which in principle allows for thousands of channels to be transmitted over one single optical fiber.

The main part of the paper will be devoted to the description of a coherent multi-channel system demonstrator, which has been implemented in the context of the European RACE (Research for Advanced Communication in Europe) Program. This demonstrator is the first in the world in which fully-engineered transmitter and receiver units have been built according to predetermined specifications by different parties, thus showing the maturity of the techniques employed.

In final part of the paper the expectations about future developments will be addressed, and some pertinent conclusions will be formulated.

BROADBAND SERVICES

Ever since the advent of low-attenuation glass fibers by the end of the seventies, engineers have been dreaming about fully integrated digital broadband networks. Basically they are right: the fiber, and in particular the single mode fiber, offers a transmission capacity which can be considered as infinite for all practical purposes. By deploying this "optical ether", all information streams and all communication services any individual could ever wish to have at his or her disposal, could easily be taken care of.

Reality turned out to be somewhat different: although the transmission window of the fiber is 30,000 GHz wide, thus allowing for a very low price per unit of bandwidth, the cost of the associated electronic and optoelectronic components was (and still is) prohibiting the realization of that dream. In addition, in almost all countries political issues turned out to play an important role in establishing a broadband integrated services digital network (BISDN). The basic reason for political interference is evident: for several years to come, the only real broadband service is television distribution, and the investments necessary for BISDN can only be recovered if real broadband services are supported by that network. This insight generated a controversy between the public telecom operators (PTO's) and the CATV operators.

However, there are more problems associated with an integrated digital network, such as:

- different tariffs for different services
- lack of digital consumer terminals
- lack of digital video standards
- high bitrate required for a large number of TV channels

The first issue recognizes the fact that a tariff structure simply based on kb/s or Mb/s will not be acceptable: either TV distribution would be too expensive, or telephone would be (nearly) free. Consequently, the operator will have to discriminate between different services, which means that the concept of "integration" is partly lost.

The second and third issues are strongly interrelated. In every country there is a large installed base of TV sets, VCR's, etc. which all expect analog signals at their input. Although this situation is changing (digital ATV in the USA, the acceptance of the MPEG digital coding standard, etc.), analog terminals will be around for many years to come, and future networks will have to take that into account.

Finally, there is the fact that digital transmission requires more bandwidth than its analog counterpart, unless additional measures are taken. Straightforward digitization of one PAL or NTSC channel leads to a bitrate of about 140 Mb/s. Transmission of a multitude of channels in time multiplex would require an unacceptably high bitrate on the subscriber line. Possible solutions to this problem will be discussed in the next section.

OPTIONS FOR TV DISTRIBUTION

The basic problem in providing television distribution services in an integrated digital network is due to the fact that on the one hand TV requires quite some bits/second/channel, whereas on the other hand TV distribution via the traditional CATV networks has been a cheap consumer-oriented service for decades. Various solutions to this problem are being studied, and the most important options are the following:

- fiber sharing
- analog AM or FM transmission
- optical amplification
- reduction of bitrate/channel
- wavelength multiplexing

All of the above options may be instrumental in reducing the cost per channel, and several of them are relying on sharing of resources in the network.

Fiber sharing

In many pilot projects in Europe and in the USA fiber-to-the curb or fiber-to-the-home solutions are proposed which rely on sharing the fiber and the related transmission equipment between tens of customers. The pros and cons of these solutions often depend strongly on local situations, so that it is difficult to give an assessment which has a general validity. An important issue however is the question of upgradability of such networks in future: a physical infrastructure requires high investments, and tends to have a long lifetime. Sharing the fiber inherently limits the network capacity, maybe for a long time.

Analog AM or FM transmission

By abandoning the concept of digital transmission in an integrated network, and introducing transmission in analog format, the problem indicated above could be solved in principle [ref.1.]. Several papers in this conference are devoted to this subject, so we will not address this issue further.

Optical amplification

In an optical tree-and-branch network the fiber and the transmission equipment is shared by many customers. However, the sharing factor is limited by the fact that at each branching point the optical power is distributed over the branches. The introduction of optical amplifiers at appropriate locations in the network may considerably increase the sharing factor by boosting the optical power.

There are however some disadvantages related to optical amplifiers located in the network. First of all there is active optical equipment out in the field, which will require surveillance. A second problem to be considered is that the network may lose transparency, in particular for return channels.

Reduction of bitrate per channel

A straightforward way to escape the problem of a (too) high bitrate per TV channel is the application of source coding [ref.2.]. A lot of work in this domain has been carried out worldwide, and the results seem to indicate that a bitrate of 1.5 - 2 Mb/s is the minimum required for an acceptable quality. In this domain the main trade-off is the advantage resulting from the bitrate reduction versus the increase in complexity of the decoder.

Wavelength multiplexing

One of the options for the separation of services in an optical network is to use different wavelengths for different services. Usually, a discrimanation is made between three domains in wavelength multiplexing:

- wavelength division multiplexing (WDM), with a wavelength separation of several tens of nanometers,
- high-density WDM (HDWDM) with a separation of 2-10 nanometers, and
- coherent multi-channel (CMC) multiplexing, with a separation of less than 0.1 nanometer between adjacent carriers.

In the first two cases, the optical carriers are separated by optical frequency selective devices [ref.3], in the case of coherent multiplexing the selectivity is obtained by electronic means, as will be outlined in the next section.

One of the advantages of all wavelength multiplexing schemes is that the various optical carriers are completely independent, so that different modulation schemes can be used, adapted to the particular information to be transmitted.

Furthermore, the bandwidth available in optical fiber between 1300 and 1550 nanometer is about 20,000 GHz, and this capacity can only be exploited fully by applying wavelength multiplexing techniques.

COHERENT TRANSMISSION

Coherent optical transmission is fully analogous to heterodyne or homodyne techniques applied in radio and microwave systems already for decades. The only difference is that the carrier is now an optical carrier, with a frequency of 200 THz instead of a radiowave in the MHz or GHz domain.

The basic principle of coherent transmission is outlined in fig. 1.

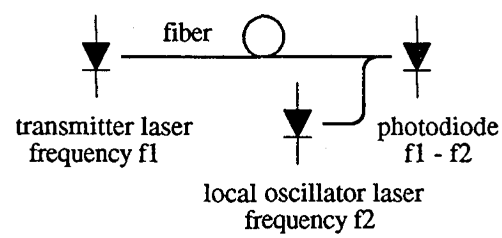

Fig. 1. Principle of coherent transmission.

The transmitter laser, which emits at a central frequency f_1, is modulated with a digital signal, either in amplitude (ASK), in frequency (FSK), or in phase (PSK). The modulated light is tranmitted via the fiber to the receiver, where it is mixed with the light of a local oscillator laser, emitting CW at a frequency f_2. One of the mixing products which are created in the photodiode is the frequency difference f_1-f_2. If $f_1 = f_2$ homodyne detection takes place, if f_1 is unequal to f_2 heterodyne detection.

The three main advantages of coherent transmission are the following:

- high sensitivity
- high selectivity
- high transmission capacity

The high sensitivity is a result of the presence of the local oscillator laser: the large optical power reaching the photodiode makes that the total receiver noise is not determined by electronics, but by shot noise from the photodiode. Depending on the modulation scheme used, the resulting sensitivity can be 10-20 dB better than that of direct detection receivers.

The high selectivity is a consequence of the fact that selection takes place electronically, not by optical means. As an example, in an FSK system with a modulation amplitude of 1 GHz and an IF frequency f_1-f_2 of 1 GHz, the signal band is in the region from 0.5 GHz to 1.5 GHz, and can easily be filtered electronically.

Evidently, for being able to detect an FSK modulation with an amplitude of 1 GHz, the inherent stability of the optical carriers must be much better than 1 GHz. Calculation shows that a laser stability of about 20 MHz is required for such systems. With today's DFB or DBR lasers this requirement can easily be fulfilled.

However, if the control over the optical spectrum on the transmission fiber is that precise, then there is no reason why one should transmit only one signal over the fiber. It is then possible to connect several transmitter lasers, with operating frequencies several GHz apart, to one and the same fiber. By changing the frequency of the local oscillator laser ("tuning"), each of the transmitted channels could be selected. If the transmitters were modulated by TV signals, such a receiver would represent an optical TV tuner.

Since adjacent channels can be separated by only a few GHz, the bandwidth of the fiber would allow for the transmission of thousands of channels. The challenge to implement such a system, in a well-engineered form and according to pre-defined specifications, has been taken up in 1988 by the RACE Project R1010 "Subscriber Coherent Multi-Channel System", consisting of a consortium formed by HHI in Berlin, GEC-Marconi in Caswell, Siemens of Munich, and IMEC of Ghent, with Philips as Prime Contractor. The results obtained will be described in the next section.

RACE DEMONSTRATOR

The fundamentals of the Demonstrator that has been implemented in the course of 1991 is shown in fig.2.

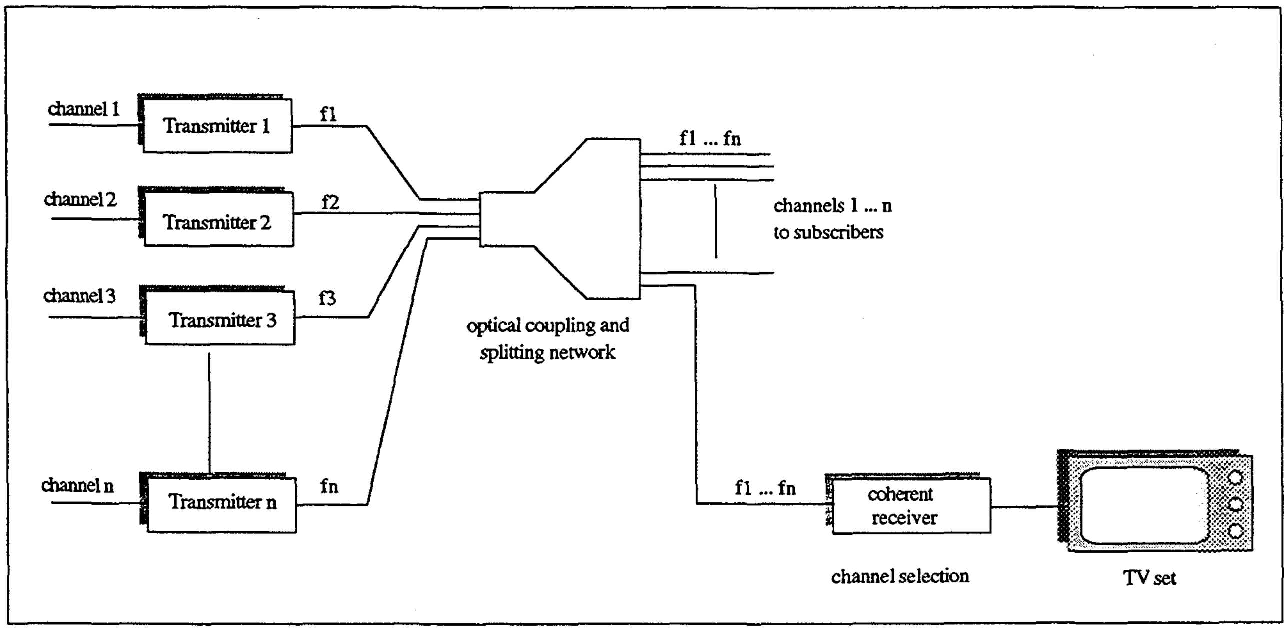

Fig. 2. Architecture of the Demonstrator.

In this Demonstrator, ten coherent FSK transmitters are modulated with a digital TV signal at 140 Mb/s. The optical outputs of the transmitters at frequencies f_1 .... f_n are combined in an optical coupling network, and subsequently split to about a thousand subscribers. Each subscriber receives all transmitted TV channels, and by tuning the local oscillator in his coherent receiver he can select any channel he wants. In the present Demonstrator only ten channels are available, but today's technology would already allow for about 50 channels at 140 Mb/s, separated by 5 GHz. Taking into consideration that with a moderate amount of compression 10 TV channels can be accomodated in one 140 Mb/s stream, it is clear that this technique makes it possible to transmit hundreds of channels. In the following sections some details on the Demonstrator will be presented.

RACE Demonstrator specifications

In the following list the relevant technical parameters of the RACE Demonstrator are presented, as they were fixed in 1989.

- Bitrate/channel 140 Mb/s
- Modulation type FSK
- Modulation amplitude 1200 MHz
- Optical output transmitter > 0.5 mW
- Receiver sensitivity < - 45 dBm
- Optical channel separation 10 GHz
- Number of channels 10
- IF frequency 1250 MHz
- Operating wavelength 1560 nm

As compared to today's state-of-the-art, these specifications are rather conservative, but in 1989 they were not, and they had to be fixed in order to allow the various partners in the project to build the transmitters and receivers according to these specifications.

But even with these conservative specifications, the capabilities of this system are impressive. With an optical output power of 0.5 mW, and a receiver sensitivity of better than -45 dBm, more than 1000 subscribers can be connected to one single transmitter. The network itself is fully transparent, and it would be easy to extend the system with ATV or HDTV transmission, just by adding transmitters for such services [ref.4.].

The fact that this Demonstrator has been built according to predefined specifications by different institutes, also shows that the technology is relatively mature. Since 1990 parts of the equipment have been moved to several locations in Europe, and switching on the mains was sufficient to put the equipment into operation. By using a normal remote control unit, any of the available channels can be selected by tuning the local oscillator laser in the receiver, within 0.2 seconds.

During 1992 the complete Demonstrator will be subjected to various tests, and the transmitters and receivers will be under continuous surveillance in order to gather information about laser stability etc. Finally, in a next phase of the RACE Programme, similar equipment will be used in field tests by European operators.

CONCLUSIONS

Various problems related to the implementation of broadband networks were addressed, and options to solve these problems were discussed. It was argued that wavelength multiplexing, and in particular coherent multichannel techniques were very attractive for the distribution of a large number of TV programs.

A demonstration system resulting from a European cooperation was described in some detail. This Demonstrator clearly shows the capabilities of coherent multi-channel systems, and the maturity of the technologies required.

In summary, it has been shown that coherent techniques are not only promising, but will be reality in the near future. The main advantages are that the network remains fully transparent and allows for flexible upgrading in the future, that the transmission capacity is practically unlimited, and that the technique can be combined with additional options like fiber sharing, optical amplification and bitrate reduction.

References

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