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Coherent Optical Techniques for Broadband ISDN [and Discussion]

C. Baack, G. Heydt and G. R. Hill

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Coherent optical techniques for broadband ISDN

By C. Baack and G. Heydt
Heinrich-Hertz-Institut für Nachrichtentechnik Berlin GmbH, Einsteinufer 37, *D-Berlin* 10, *F.R.G.*

When introducing broadband video-telephone on a large scale a considerable expansion of transmission capacity will be needed in the trunk network. This expansion might economically be achieved by the application of optical amplifiers and coherent multicarrier (CMC) techniques.

When introducing the optical fibre in the subscriber-line area the distribution of television programmes is a crucial point. In the long run, broadband distribution applying CMC techniques might be a solution. Another obstacle against the introduction of optical fibres in the subscriber loop area is the high cost of optoelectronic converters. Unless optoelectronic circuits can be made less expensive by monolithic integration an extensive application of optical fibres in the subscriber loop area cannot be expected in the long run.

The single-mode fibre is the suitable transmission medium for all network layers. When applying CMC technique crosstalk can occur caused by nonlinearities of the fibre.

According to first experiences CMC techniques seem to be applicable not only for optical transmission but also for optical switching of informations.

Introduction

Coherent optical communication techniques allow a multitude of closely adjacent optical light signals to be transmitted through a glass fibre (coherent multicarrier or CMC). The following contribution describes possible applications of this CMC technique in the trunk network of future telecommunication networks and also in the subscriber loop area of these networks, and the possibilities of optical switching by applying CMC techniques are presented. The significance of integrated optics for future telecommunication networks are also outlined.

Trunk network of future telecommunication networks

As soon as broadband video-telephone might be introduced a drastic expansion of transmission capacity will become necessary in the trunk network. This expansion would lead to extremely complex repeater stations. The application of optical amplifiers instead of electronic repeaters used at present might provide a remedy for this problem. Such a travelling-wave optical amplifier has a very high bandwidth. Thereby it becomes possible to transmit many light carriers with narrow spacing and also amplify them. The separation of closely adjacent channels is performed at the exit of the trunk network by optical superheterodyne receivers, which are extremely selective, as is well known. That means the application of optical amplifiers instead of conventional repeaters, combined with CMC techniques, might be a reasonable way to solve the problem mentioned above. In the Heinrich-Hertz-Institut (HHI), optical amplifiers with an intrinsic gain of 25 dB were realized, which means a net gain of 18 dB from fibre to fibre (figure 1).

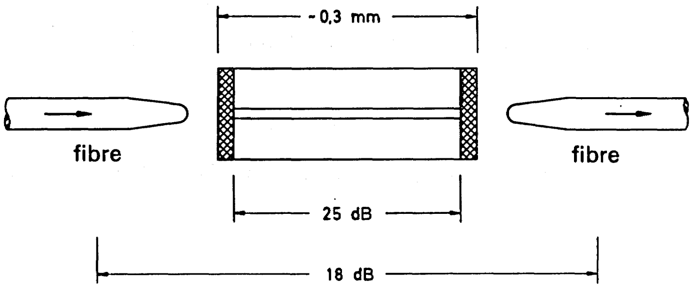

FIGURE 1. Optical amplifier, bandwith of 4 THz, $\lambda = 1.3$ μm.

With such amplifiers a transmission system was realized by transmitting two light carriers with a spacing of 10 GHz between the frequencies f_1 and f_2 (figure 2) (Grosskopf *et al.* 1988*a*). Each channel is modulated with a bit rate of 560 Mbit s^{-1}. The separation of the two channels is accomplished by two optical superheterodyne receivers at the end of the line. In this system two optical amplifiers were inserted. The system works at a light wavelength of 1.3 μm and enables a transmission span up to 110 km. It is of decisive importance that the total gain of the optical amplifier can be applied to compensate fibre attenuation.

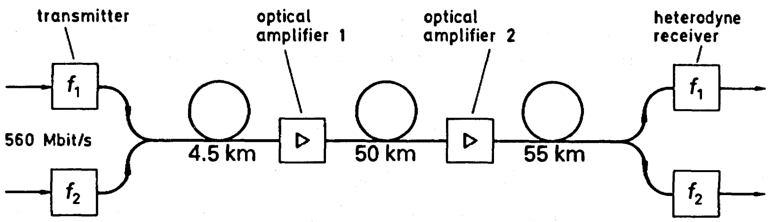

FIGURE 2. Long-haul transmission line with optical amplifiers and heterodyne receivers (two channels with a channel spacing of *ca.* 10 GHz and a bit rate of 560 Mbit s^{-1} per channel, a total transmission span of 110 km, and a wavelength of $\lambda = 1.3$ μm).

Two problems are identified when transmitting many light signals through an optical amplifier. One is that amplification is dependent on the polarization direction of the incoming light. This problem can be solved by combining two optical amplifiers connected in series or in parallel (Grosskopf *et al.* 1987). In the long run the goal must be to optimize optical amplifiers in such a way that they are no longer dependent on polarization. The second problem is crosstalk from one channel to the other caused by nonlinearities of the optical amplifier. It can be proved that this trouble can be avoided by applying phase modulation or frequency modulation to the light signals (Braun *et al.* 1986) and a channel spacing not smaller than several gigahertz, to avoid interferences caused by four-wave mixing in the amplifier (Grosskopf *et al.* 1988*b*). Our assessment is that the only motivation for the application of coherent optical communication techniques in the trunk network is the necessary utilization of frequency- or phase-modulation when applying CMC techniques and optical amplifiers. With one-channel transmission the application of coherent techniques does not seem to be necessary, because the application of optical preamplifiers in direct detection systems offers a similarly high sensitivity as coherent systems.

Subscriber loop area of future telecommunication networks

Whereas the glass fibre has proved its profitableness in the trunk network long since, such a proof is still missing for the subscriber loop area. To study the difficulties when applying optical communication in future telecommunication networks, a complex experimental model of a future broadband local network was studied (figure 3).

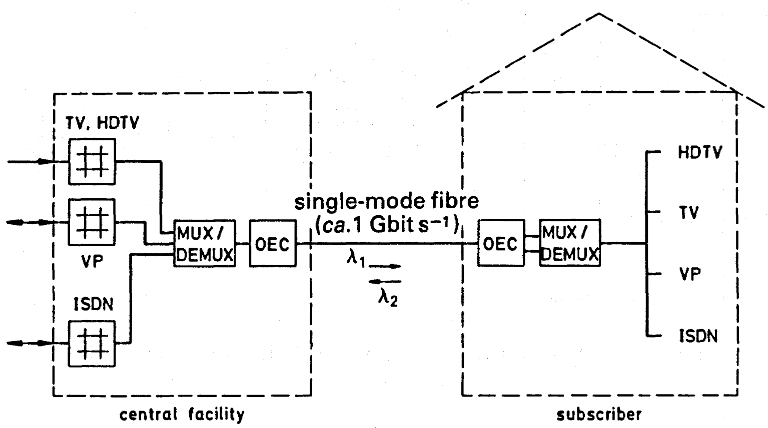

Figure 3. Experimental system of a broadband subscriber-line network. (oec, optoelectronic converter; vp, video-telephone; isdn, integrated service digital network; (de)mux, (de)multiplexer; hdtv, high-definition television.)

This system consists of a local exchange suitable for 10000 subscribers to be connected. All dialogue services and broadband services discussed at present are offered to each subscriber. The system has almost been completed and it has been proved that such a configuration can be realized by applying the present state of art (Langer *et al.* 1986). The broadband switching equipment for the video-telephone was realized in an exemplary way for 10000 subscribers, and the broadcast switch for the television services was realized as well. For the broadcast system a high-bit-rate time-division multiplex (tdm) technique was applied (*ca.* 1 Gbit s^{-1}). The problem in this configuration is not optics but electronics. Such a technical solution is not conceivable unless the necessary high-bit-rate circuits can be made available as integrated circuits. One object of the project mentioned is to stimulate the development of high-speed integrated circuits (ics) for application in telecommunications in Germany. This was obtained by a cooperation with the Ruhr-Universität in Bochum. This university realized all necessary high-speed ics based on bipolar silicon technology. Meanwhile, this group has signed contracts with many telecommunications manufacturers.

But according to our assessment the described system has two crucial disadvantages, which will be discussed in the following. A first problem is the optical subscriber loop. The cost of such a subscriber loop is too high. But the high cost is not determined by the fibre but by the optoelectronic converters that must be assembled with discrete technology in view of the present state of art. Such a technology is not at all suitable for a low-cost mass production. The glass fibre will be applied to a large extent in future subscriber loop networks only if the efforts are successful to integrate the optoelectronic components necessarily tied with the glass fibre, in the same way as we nowadays integrate the electronic circuits with the help of microelectronics. If efforts towards integration are not successful the optical communication technology will continue to be a second-class technology. That is why the integration of the optoelectronic converter is the first and the most important goal of integrated optics. To move more closely to this goal a group of 80 people was set up in HHI, aiming at a step-by-step integration of the optoelectronic converter, which is presented in figure 4.

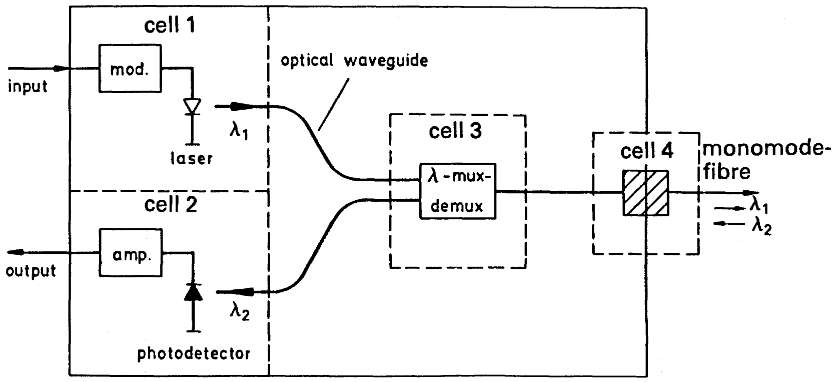

FIGURE 4. Optoelectronic converter for bidirectional transmission.

It consists of the transmitter cell (1), the receiver cell (2), the multiplexer cell (3), and the coupling cell (4). As a first step, the individual cells are planned to be integrated, but of course the goal for the remote future must be the total integration of all cells. That means that the integrated optics plays the part of a key technology for future communications. The integrated optics will play a similarly important part as microelectronics. This means also that the integrated optics must obtain a grade of maturity which has been obtained by microelectronics today. Compared with microelectronics the stage of development of integrated optics surely is 10 to 15 years behind. That means that all efforts must be focused on the goal to achieve progress in integrated optics based on InP as quickly as possible, in order to make available components for the planned broadband networks.

A second problem of the system presented in figure 3 is the kind of distributing TV programmes. The TDM technique applied there combined with a broadcast switch has, as we feel, a couple of disadvantages: the cost of the broadband switch is high, standards for TV transmission bit rates are not yet available and privacy is not granted. The narrowband upstream channel that controls the broadcast switch makes it possible to monitor the behaviour of all subscribers when watching TV programmes. As the awareness of privacy problems is growing we must take into account that, in the long run, people will not accept being monitored. An alternative system is the subcarrier multiplexing technique (Olshansky, this Symposium). If the problem is to replace present coaxial cable networks by optical distribution networks, and that seems to be the situation in U.S.A., there are two alternatives: either the TDM or subcarrier technique. Both techniques are realizable by applying the present state of the art. Our assessment is that the subcarrier technique has advantages compared with the TDM technique. If the problem is to replace coaxial cable networks by optical distribution networks in about 10 to 15 years – that might be the situation in Germany – a third technique for the distribution of TV programmes must be considered, namely the distribution technique applying the optical-frequency multiplex technique (the CMC distribution technique) (figure 5).

In such a system an optical carrier is assigned to each TV programme. All the optical light

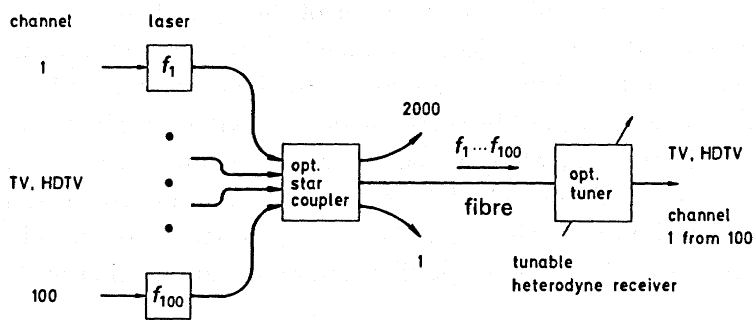

FIGURE 5. TV distribution system using optical frequency-division multiplex technique (CMC distribution technique).

signals, e.g. f_1 to f_{100}, are conveyed to a star coupler, and the star coupler feeds all subscriber loops. The selection of the TV programmes is carried out by the subscriber with the help of a tunable optical heterodyne receiver (optical tuner). This system uses the optical communication technique where it has its strength; the almost unlimited bandwidth of the glass fibre allows almost unlimited expansion of the number of channels. Moreover, the bandwidth of each channel is rather high, it is essentially determined by the modulation bandwidth of the laser. In this way it is for instance possible to transmit all TV programmes to the subscriber in digital form without data reduction. Entire studio quality can be offered to the subscriber, expensive codecs for data reduction must not be applied. This is particularly attractive for high-definition TV (HDTV) where studio bit rates of *ca.* 1 Gbit s^{-1} must be taken into account. The disadvantage of this system is, without any doubt, its extremely low stage of development. For the first time, such a system with 10 channels was realized in HHI (Foisel 1987). Meanwhile a similar one was realized by NEC in Japan (Glance *et al.* 1988). At the same time, we are going to develop this system further towards a field test. Moreover, the CMC distribution technique was presented to Research on Advanced Communication for Europe (RACE), and it is now further pursued in the RACE project R1010 with the object to establish a demonstrative system. The CMC distribution technique has no chance to be applied unless our efforts are successful to integrate the optical tuner monolithically, as this component is needed for each subscriber and therefore high numbers of them will be produced. That is why we feel that a second important object

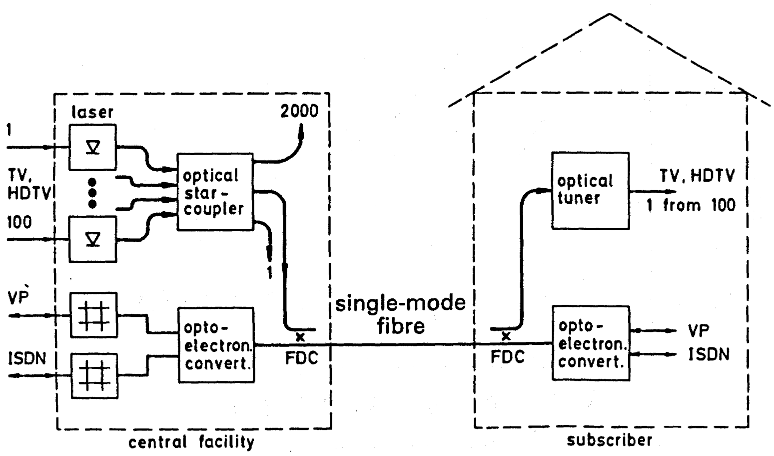

FIGURE 6. Broadband subscriber-line network with coherent multicarrier distribution technology (FDC, fibre directional coupler).

of integrated optics is the monolithic integration of the optical tuner. We pursue this goal within the framework of the RACE project mentioned above. Figure 6 presents the insertion of a CMC broadcast switch into a future broadband subscriber loop network.

Today it is generally agreed that the single-mode fibre will be applied not only in the trunk network, but also in the subscriber loop area of future telecommunication networks. The single-mode fibre allows the transmission of high bit rates and by that the application of high-bit-rate TDM-TV-distribution techniques. The single-mode fibre alone is compatible with integrated optical components. Only the single-mode fibre allows the application of the CMC technique.

Nonlinearities in single-mode fibres

The single-mode fibre will be the transmission medium for the trunk network and for the subscriber loop area of future telecommunication networks as well. As a result of the small diameter of the single-mode fibre even the low optical energy typical for optical communication leads to energy densities so high that the nonlinearities of the fibre material gain significance. There are essentially two effects to be observed: Brillouin scattering and the four-wave mixing. The Brillouin scattering is of significance when two signals are transmitted through a glass fibre in opposite directions, that is when a fibre is operated in duplex mode. These phenomena were studied in detail and it turned out that difficulties can be avoided provided that spacing between the carriers is chosen to exceed *ca.* 20–30 GHz (Brillouin frequency) (Shibata *et al.* 1987). Four-wave mixing is observed when several signals are transmitted through a glass fibre in the same direction. These phenomena were studied in detail as well (Waarts & Braun 1986). Figure 7 presents the results.

The maximum allowable light power per channel to be fed into the fibre in order not to exceed a determined level of crosstalk is displayed. On the abscissa, the number of channels to

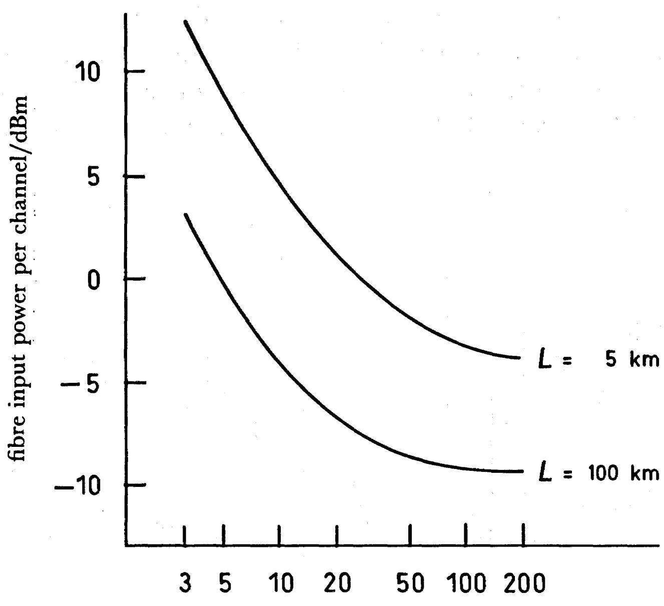

FIGURE 7. Impact of four-wave mixing on CMC systems (wavelength is 1.55 μm, channel separation is 5 GHz, crosstalk level is −20 dB).

be transmitted is presented. The curves firstly represent the results for a fibre length of 5 km (subscriber loop) and secondly for a fibre length of 100 km (trunk). If 10 channels are, say, to be transmitted through a trunk, the maximum light power must not exceed −5 dBm. For long-haul transmission this value is too low, that means when applying CMC techniques in the trunk network the nonlinear effects of the glass fibre have to be considered. On the other hand, if *ca.* 100 signals are to be transmitted by means of a subscriber loop the maximum power per channel must not exceed −10 dBm. That is a rather high value considering the star coupler according to figure 5. This means that the nonlinearities are of no importance for the CMC technique in the subscriber loop area.

Optical switching technology

If optical transmission is introduced, it is, looking with the systems engineer's eyes, extremely interesting to switch signals in the optical domain, because then it can be avoided to transfer signals from the optical to the electronic domain for being switched. To study the problems of optical switching technology a rather complex experimental model of an inhouse network with optical switching technology was established (Bünning *et al.* 1989). In this system different methods of optical switching technology were studied. The necessary optical switches and matrices were realized based on $LiNbO_3$. From this system we have learnt that it is not reasonable to copy today's electronic switching technology with optical elements on a one-to-one basis. The optical switch is on principle inferior to the electronic switch. On the other hand, optical interconnection technology is basically superior to electronic interconnection technology. The reason for that is the high interaction of electrons, which leads to the fact that switching of electronic signals is excellent, but interconnection is difficult in the electronic domain. In contrast to that, interaction of photons is rather low. This leads to the fact that switching of optical signals is difficult, but optical interconnection technology is to be preferred.

On the other hand, optical switching technology is so interesting from the systems' viewpoint that one has to look for other ways. A first step to introduce optics into electronic switching technology will surely be to replace present electronic interconnection technology by optical interconnection technology. This is carried out even nowadays in several places and is no longer a subject of research. A next step might be to replace present TDM switching techniques by future optical-frequency multiplex-switching techniques. According to figure 8*a*, the input circuits of a nowaday's TDM switch transmit the time-slots of a TDM system.

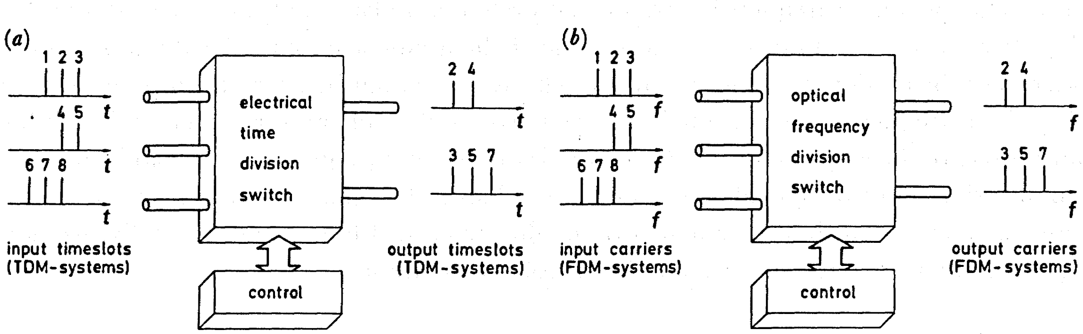

FIGURE 8. (*a*) Electrical time-division switching (space switches and time switches). (*b*) Optical frequency-division switching (space switches and frequency switches).

The TDM switching system has to switch the informations of the input time-slots to the requested output time-slots. This is obtained with space- and time-switches. According to figure 8*b*, the input circuits of a frequency multiplex switch might in future carry frequency carriers of an optical frequency-division multiplexed (FDM) system, and the FDM switch has to switch the information of the input light carriers to the requested output light carriers. Such an optical frequency multiplex switch is presented in figure 9.

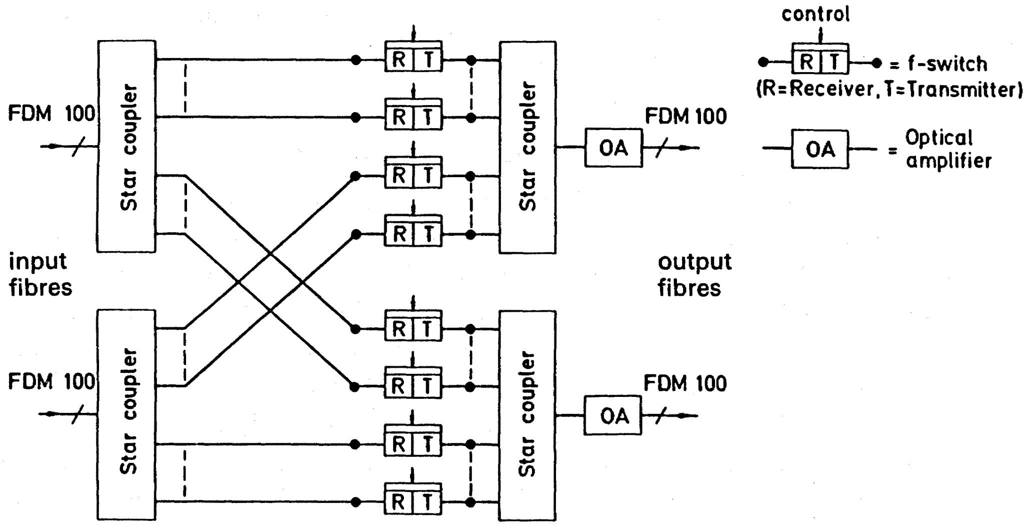

FIGURE 9. Optical frequency switching network.

The input fibres carry FDM-100 systems instead of nowaday's PCM 30, PCM 120, ... systems. The signals of the input circuits are first offered to star couplers which act as space switches. The star couplers offer all the input signals to frequency converter stages, which in this configuration each consist of a receiver and a transmitter. The frequency-converted light signals are again offered to star couplers (space switch) that feed the outgoing circuits. That means such a system is a space–frequency–space switch system.

The first system of this kind with four subscribers was realized in HHI (figure 10) (Caspar *et al.* 1987).

Each of the subscribers disposes of a transmitter and an optical superheterodyne receiver. The four transmitter frequencies are presented in the frequency scheme at the right side of the figure. The local laser frequencies are as well presented in case that the system is idle. If, say, subscriber no. 1 wants to talk to subscriber no. 4 the frequencies of the local lasers 1 and 4 are matched to the carrier frequencies 1 and 4. This is carried out by a small computer by pushing a key. The frequency conversion is realized here by a coherent receiver and a following transmitter. In the long run the goal of course is to carry out frequency conversion with the help of pumped nonlinear optical materials. To achieve this goal two ways are used: firstly, frequency conversion shall be reached by nonlinear optical fibres, and, secondly, we hope to achieve frequency conversion by nonlinear polymer materials.

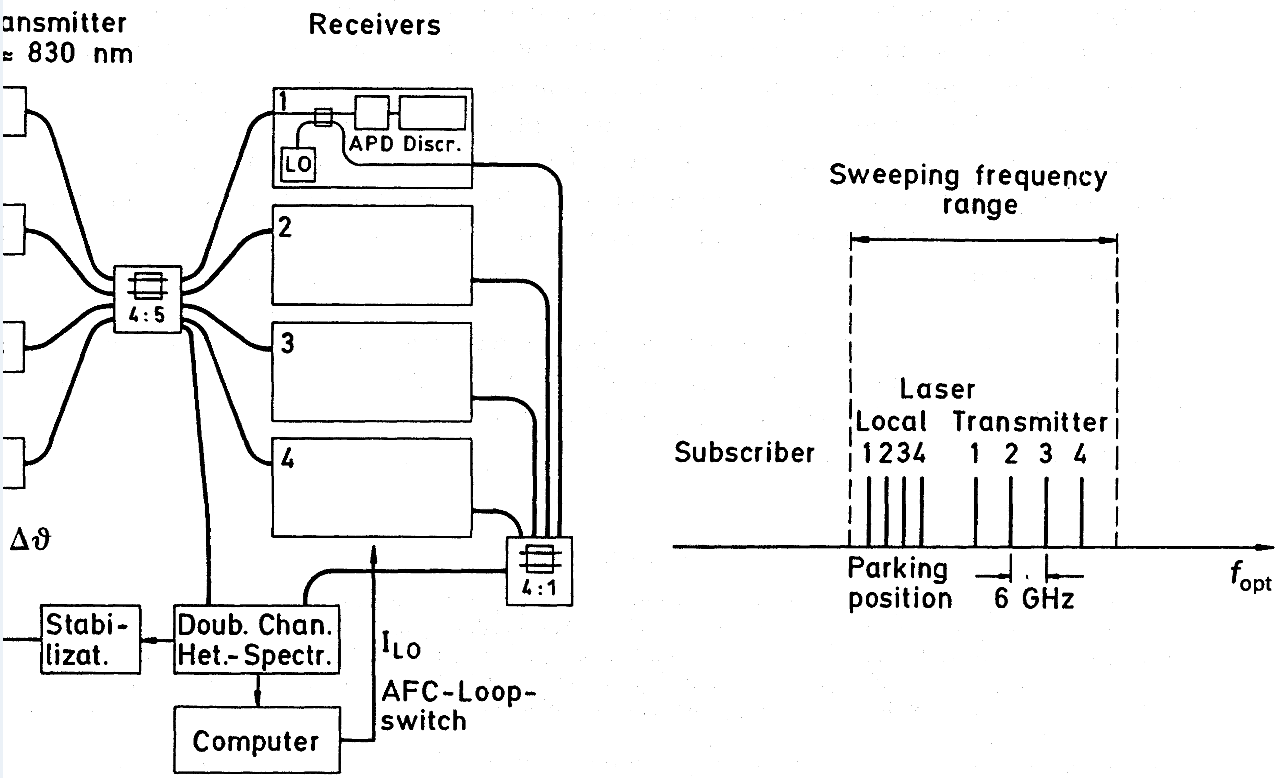

FIGURE 10. Block diagram of the switching experiment and the optical frequency scheme.

CONCLUDING REMARKS

The object of this contribution was to hint at the significance of coherent multichannel techniques combined with optical amplifiers for the trunk layers of future telecommunication networks. Coherent multichannel technique could in the long run also be an interesting method for distributing TV programmes in future subscriber loop networks. In this place the significance of integrated optics shall once more be stressed, particularly for future subscriber loop networks. The glass fibre will in the long run be introduced into the subscriber loop area on a large scale only if we succeed to integrate the optoelectronic circuits necessarily connected with the glass fibre, in the same way as we today integrate the electronic circuits with the help of microelectronics. Finally, coherent multichannel technique might in future be important not only for transmission but also for switching.

At least when applying coherent multichannel technique in the trunk network the problem of optical nonlinearities (four-wave mixing) has to be taken into account in system's design. In the subscriber loop area these effects are of no significance.

Optical communication technology has from the beginning systematically copied electrical communication technology, and it has well profited from that. We should try to systematically continue this process of copying. The first generation of optical communication technology is the so-called incoherent optical communication technology. These principles have been well known in electrical communication technology ever since. At present we are doing the step towards the second generation of optical communication technology, to the so-called coherent optical technology. These principles have been drawn from electrical communication technology as well. But there is another wide field which electrical communication technology disposes of, which has up to now not been applied by optical communication technology. These are the nonlinear phenomena, such as e.g. parametric effects, mixing effects, frequency conversion, etc. That means the third generation of optical communication technology might be called nonlinear optical communication technology. An interesting field of application for this technology might be optical switching technology based on optical frequency multiplex switching. A crucial problem in this field is the conversion of optical frequencies with the help of nonlinear techniques.

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Discussion

G. R. Hill (*British Telecom Research Labs, Ipswich, U.K.*). Professor Baack made the point that TDM distribution over a passive network led to problems over privacy in a two-way network. How is this privacy problem overcome in a coherent FDM network?

C. Baack. It is proposed that the coherent network will have one-way distribution and does not therefore create a privacy problem.