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Optical communications research in the Institute of Telecommunication of the Warsaw University of Technology

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The paper presents research areas in optical telecommunications in which the Microwave and Optoelectronics Systems Division was involved throughout last years. This division is a part of the Institute of Telecommunication of Warsaw University of Technology. The following systems and instruments developed in the division are concisely described: a coherent optical communication system, an optical WDM system, an open space optical CDMA system, a DST modification, an OTDR, and a visibility meter.

Keywords: optical communication, optical fibre, OTDR, wavelength division multiplexing.

1. Introduction

This paper presents research areas in optical telecommunications in which the Institute of Telecommunications of Warsaw University of Technology was involved throughout last years. It is worth mentioning that our Institute, and especially the Microwave and Optoelectronics Systems Division, has great traditions in fibre optics communications. The first Polish optoelectronic survey distance meter was developed in our Institute in early seventies [1,2]. Furthermore, the first Polish fibre-optics link in Lublin that operated over multimode fibre was deployed in 1979 and the transmitter and receiver electronics was designed in our Institute [3]. As it will be shown in the sequel, many trends of contemporary optical communication are followed by the research performed in the Institute. However, it is not possible to describe all topics pursued in the Institute, therefore we shall concentrate on the most important ones.

2. Coherent optical communication

Coherent optical transmission looked very attractive several years ago. When optical amplifiers and optical dispersion compensation were not available it offered higher sensitivity than direct detection systems as well as the possibility of electronic dispersion compensation. The method of detection is the most important difference between the direct detection and coherent systems. In the latter one, optical signal (homodyne or heterodyne) is added to the useful signal before detection. Since the photodiode has a square characteristics (the electrical current is proportional to the optical power) the signal and the heterodyne (homodyne) are mixing together. In this way, a beating term arises with the power proportional both to the signal and heterodyne and with the frequency equal to the difference between their optical frequencies. If this differential frequency is constant and small enough (i.e., within RF or microwave regions) this differential frequency term may be further processed by electronics.

Similar system was developed in our Institute in 1994 [4], preceded by a lot of theoretical works [5,6]. A photo of the laboratory setup is presented in Fig. 1. The 780-nm lasers were employed as transmitters due to their lower cost. The temperature and current of both, the transmitter and heterodyne lasers were stabilised to keep both wavelengths constant. The frequency shift keying (FSK) modulation was used with single filter detection scheme. The transmitter laser frequency was changed by a slight modulation of its current. Although the transmission was successful, the system showed all disadvantages of the coher-

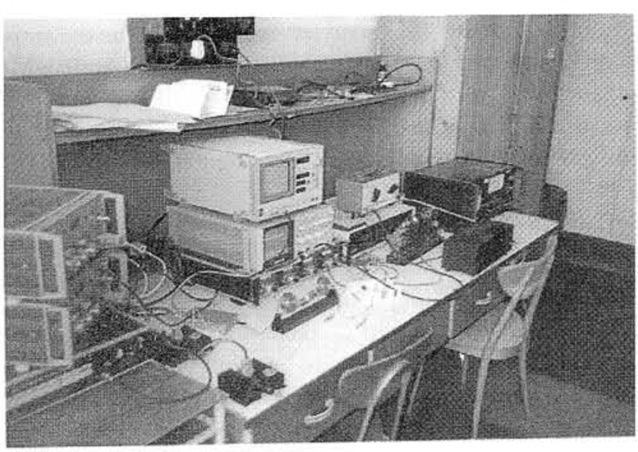

Fig. 1. Photo of the coherent system laboratory setup.

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ent detection, namely: system complexity, sensitivity to backreflections, difficult polarisation matching and laser stabilisation, need of narrow linewidth lasers, etc. Although meant as a laboratory demonstration, it was the first optical fibre coherent transmission system in Poland and therefore it is worth mentioning.

3. WDM systems

The complexity of coherent systems along with the introduction of optical amplifiers and optical dispersion compensation are behind the fact that the research trends shifted to other optical systems, among which the wavelength division multiplexing (WDM) are the most prominent. The principle of WDM transmission is straightforward. There are many (4, 8, 16, 32, 40, etc.) transmitter lasers with fixed (stabilised) but different frequencies λ_1, λ_2, ...λ_N. The light fluxes are externally modulated by interferometric or absorption modulators according to the incoming data streams. These signals are fed to a WDM multiplexer where they are combined into one output (transmission line) fibre. In this way, many signals with different wavelengths and different modulation formats are transmitted along a single fibre. At the receiver node, they are demultiplexed so that at each output port of the demultiplexer, there is only one signal with strictly defined wavelength. It may be received by a conventional photodetector. Such systems are rather costly (a 16-channel system is priced around 1 million $) since they require precise wavelength stabilisation, narrow linewidth lasers, matched (de)multiplexing as well as external modulation.

Much simpler are systems that use only two signals: one in 1310 nm window and the other in 1550 nm window. They do not require laser stabilisation and the (de)multiplexing need not be so precise. Such a system was constructed in CBR (the Central Research Laboratory of Polish Telecom) with the cooperation of the staff from our Institute [7]. There were two setups: one with counter-propagation and one with the co-propagation (see Fig. 2). The system worked over 48 km of fibre and transported two STM-4 signals. The WDM (de)multiplexers were developed by K. Jędrzejewski, PhD, of the Institute of Electronic Systems, Warsaw University of Technology. The transmission quality was assessed by an SDH analyser (Anritsu MP 1550A). The system worked perfectly well and there was no measurable influence of the wavelength multiplexing on the bit error rate (BER) in both configurations.

4. CDM systems

Another type of multiplexing is code division multiplexing (CDM). A system based on code division multiple access (CDMA) has been constructed lately in our Institute [8]. It employs infrared light and is meant for indoor applications such as laptop connection to the local network, multichannel transmission to the moving objects and remote control.

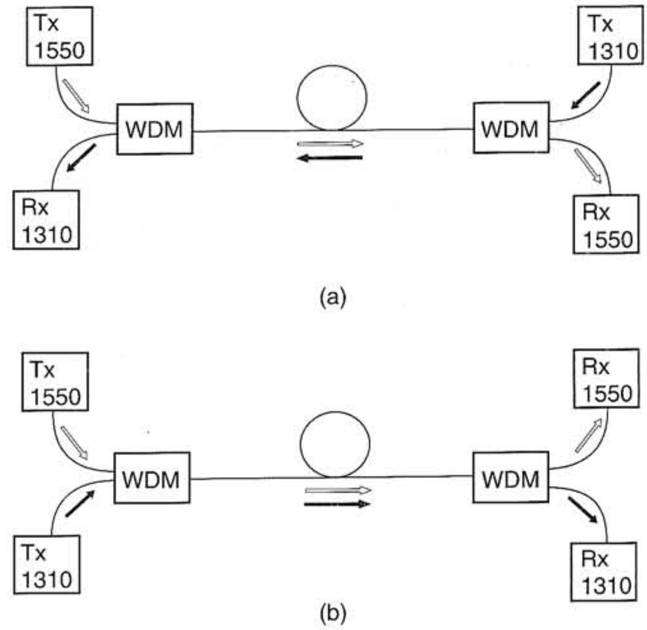

Fig. 2. Two configurations of WDM system setup: (a) counter-propagating, (b) co-propagating.

The channel properties of an indoor IR environment can be described in terms of the following factors

- attenuation caused by separation of optical transmitters and receivers,
- noise and interference produced by ambient background illumination,
- multipath signal propagation,
- near-far problem.

The simplified configuration of the link model is shown in Fig. 3. The information signals $M_i(t)$ are binary multiplied by the coding sequences $C_i(t)$ and the resulting signals from all (four) channels are then summed forming a five level signal which is used to modulate LED's in the transmitter. At the central station, the photodetected multilevel signal is fed to 3 correlators (mixers) which multiply the received signal by the appropriate replicas of the coding sequences $C_i(t)$. After filtration the output of each mixer forms the output signal. The link operation depends on the correct synchronisation of the central and terminal stations. For that purpose, a separate code of the central station is used, to which all terminals are synchronised. The automatic gain control (AGC) is applied since the levels of the receiver signals may vary considerably from terminal to terminal depending on the distance to the central station.

The code itself, its chip length, T, and the code length, N, determine the link parameters such as the acquisition time, false synchronisation probability etc. The chip length used in actual system was 1/3.75 MHz, the code length varied between 64 and 2048 whereas the maximum bit rate was 19.2 kbit/s. Two kinds of codes were tested: a maximum length sequences multiplied by the Walsh functions and the Gold codes. The synchronisation was provided by

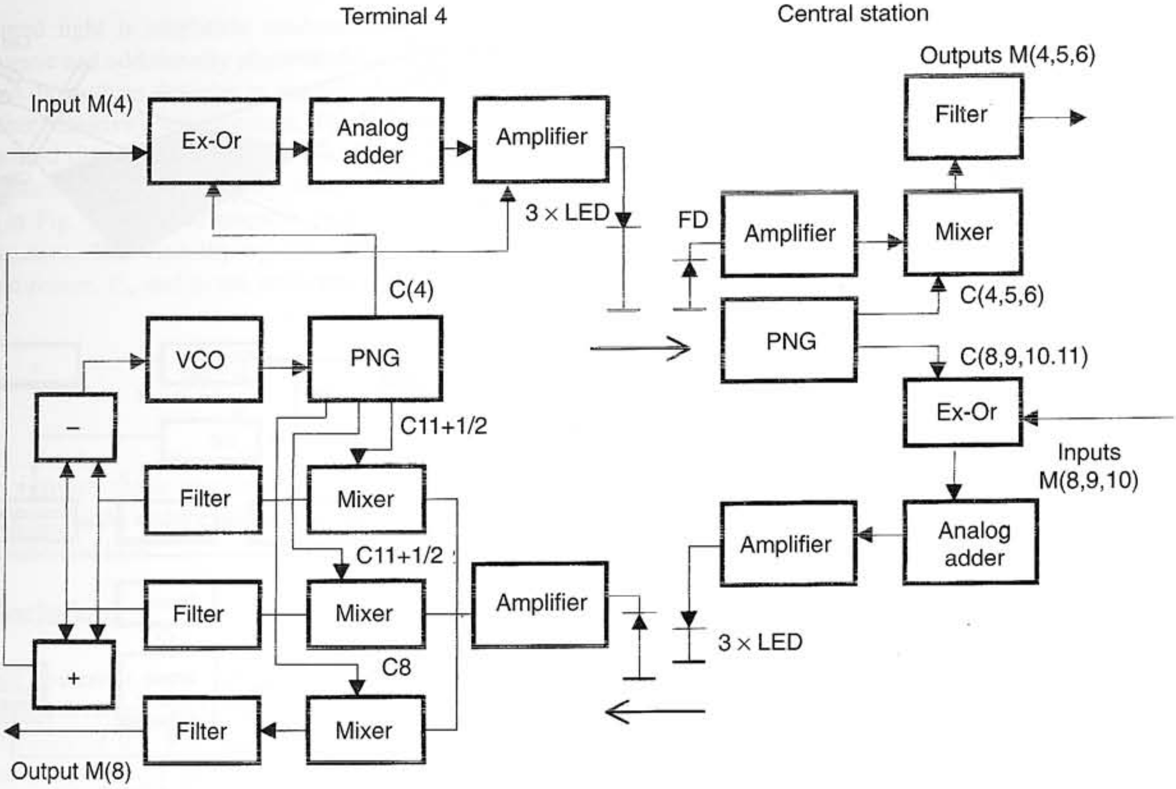

Fig. 3. Simplified configuration of CDMA system model.

a PLL. The phase detection was realised by means of the subtraction of two correlation functions shifted by a half of a bit backward and forward with respect to the synchronising code. The process of initial synchronisation was reliable since the clock signals of both stations were deliberately shifted in frequency by a small offset. The codes were then slipping in phase with respect to each other. A long initialisation time (up to 10 s) was a drawback of the system. The maximum operation range was around 18 m and it was limited by synchronisation rather than by noise.

5. DST systems

One possibility to overcome the dispersion induced limit in optical fibres is the so called dispersion supported transmission (DST). Its operating principle is based on the conversion of the transmitter laser frequency modulation (FM) to optical amplitude modulation (AM) at the receiver. The conversion is caused by the fibre chromatic dispersion. The bits "0" and "1" have different but constant frequencies at the transmitter so they travel with different group velocities and need different time periods to cover the fibre. However, even for binary modulation the optical signal at the receiver has three or four levels. This leads to the receiver complication. In our Institute, a modulation scheme was developed that produces an optical binary signal with a high extinction coefficient at the receiver. According to this proposal, a linear frequency modulation along with the differential Manchester coding is used instead of the binary frequency modulation of the transmitter [9]. For a standard

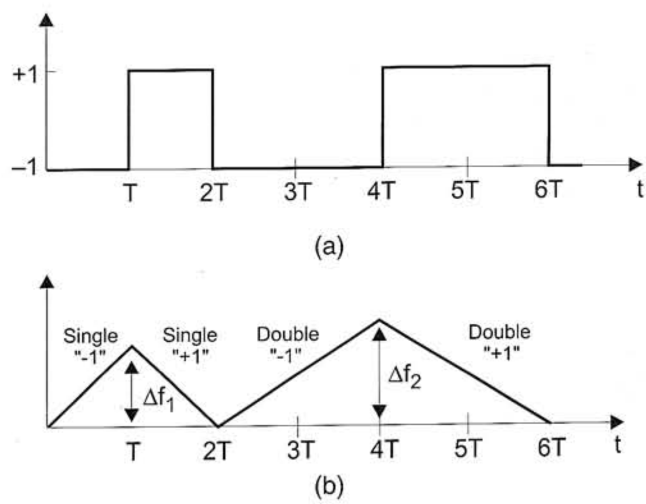

Fig. 4. Signal modulation in the modified DST scheme: (a) differential Manchester code, (b) modulation frequency.

fibre in the 1550 nm window the level "–1" corresponds to the linear frequency increase, and the level "+1" corresponds to the similar frequency decrease as shown in Fig. 4. According to the principle of the differential Manchester coding both the levels "–1" and "+1" could last only for T or 2T, where T is the bit length. The values of Δf_1, Δf_2 need not be equal. However, it was found that the signal at the receiver has the best properties (in terms of the maximum extinction coefficient) when $\Delta f_1 \approx \Delta f_2 \approx \Delta f$. The signal powers corresponding to T and 2T periods are then approximately equal. The frequency deviation Δf is related to the system parameters via

$$\Delta f = \frac{Tc}{LD\lambda^2} \tag{1}$$

where D is the dispersion coefficient, c is the light velocity, L is the fibre length, and λ is the mean laser wavelength. This modulation scheme allowed for 1 dB improvement in the extinction coefficient as compared with other research at least for the fibre length in the range of 100 km < L < 200 km. Fibre nonlinearity (the Kerr effect) improves this value by additional 0.4 ... 1 dB depending on the signal power. The method has not been realised in practice yet. However, it was extensively verified both theoretically and by computer simulation and the results are very promising. Further research is carried out at the moment.

6. Measuring equipment

There is another trend in our activity, namely the construction of optoelectronic measurement equipment. The list of these instruments is rather long. Apart from the instruments described in the sequel it includes: a laser beam diagnostics system, an optoelectronic position finder, a luminance meter, a visual target tracker, to mention only a few. Here, only two examples will be given beginning with optical time domain reflectometer (OTDR). The operating principle of OTDR is well known and it is shown in Fig. 5 [10]. Short optical impulses from a transmitter laser are sent to the fibre where they are backscattered to the transmitter/receiver. The directional coupler transfers the backscattered lightwave to the optical receiver (often an avalanche photodiode). The backscattered light power is proportional to the transmitted impulse power, the impulse length, and depends on the fibre attenuation. Unfortunately, this power is so small that special methods of reception are required such as the box car integration. A portable OTDR developed in our division [11] consists of two blocks: the transmitter/receiver and a PC board containing the integrator and control circuits. There are versions of the instrument for all transmission windows. The reflectometer works with any PC (laptop or stationary) and has the following parameters: dynamics of 25 dB, maximum range of 80 km, impulse length 15 ... 2500 ns, and resolution of 1.25 m.

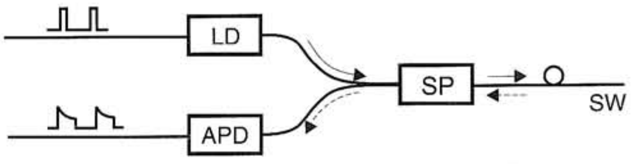

Fig. 5. Simplified block scheme of OTDR: LD- laser diode, APD is the avalanche photodiode, SP is the directional coupler, SW is the optical fibre.

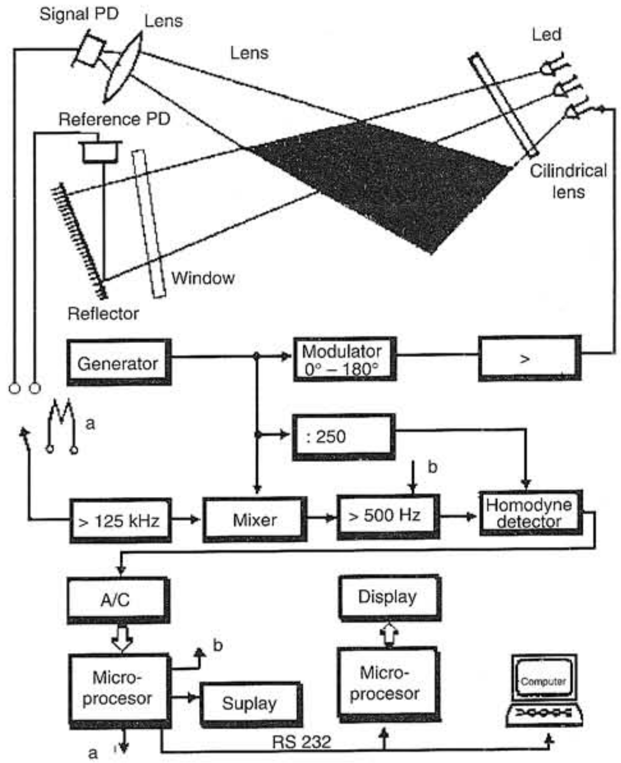

Fig. 6. Block scheme of visibility meter.

The scattering (but this time the forward scattering) is employed in another instrument [12] for fog detection and visibility measurements. Such measurements are of utmost importance at airports, for example. The optical free space transmission is used here. A block scheme of the visibility meter is shown in Fig. 6. The instrument consists of an optical transmitter and two detectors: one used as the signal power reference, and the second employed for measuring the forward scattered light power. The visibility is calculated from the ratio of the scattered light power to the reference light power. In order to improve the sensitivity the

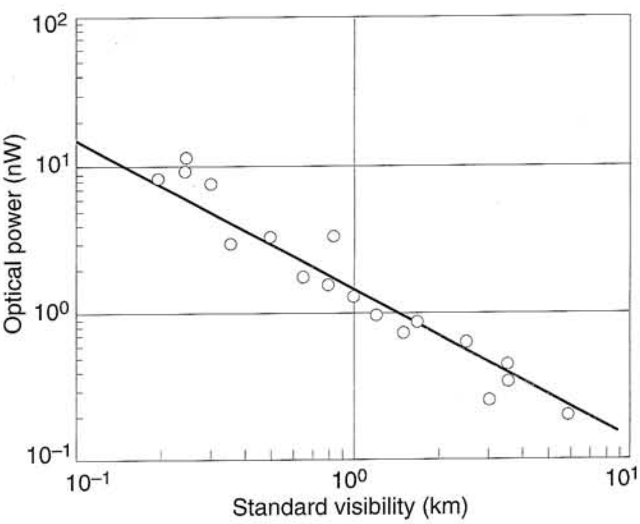

Fig. 7. Standard visibility vs. scattered light power.

transmitted light is amplitude modulated by a 125 kHz square wave and additionally phase modulated by a 500 Hz signal. A homodyne detector is employed in the receiver for further sensitivity improvement. The receiver power of the scattered signal varied between 0.3 nW and 7.5 nW for the standard visibility changing from 10 to 0.1 km as shown in Fig. 7. The instrument is controlled by two microprocessors. The visibility v_n (km) was related to the scattered power, P_s, and to the reference power, P_r, by the formula

$$v_n = 42\frac{P_r}{P_s} \quad [km] \tag{2}$$

The visibility meter was checked against similar instruments (VAISALA) and the measurement results were generally consistent [12].

7. Conclusions

We have presented some systems and instruments developed in our division (Microwave and Optoelectronic Systems Division of the Telecommunications Institute of the Warsaw University of Technology). This paper does not cover all research activities of the division; we have omitted topics related to image and signal processing as well as microwave and radio engineering. Also, the teaching and student courses were excluded from the paper. However, it may be readily seen that despite poor funding and private business competition we try to follow the international trends in modern optical communications.

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