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POLISH EXPERIMENTAL LIGHT-CONDUCTING TELETRANSMISSION SYSTEM

by

Zenon Szpigler

FOREIGN TECHNOLOGY DIVISION

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By: Zenon Szpigler

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POLISH EXPERIMENTAL LIGHT-CONDUCTING TELETRANSMISSION SYSTEM

Zenon Szpigler, Warsaw Polytechnic Telecommunications Institute

On February 13, 1979, experimental speech signals were transmitted for the first time in Poland through the experimental light-conducting teletransmission cable system in Lublin. On March 23, 1979, the Minister of Communications ceremonially made the new system available for experimental utilization.

For a number of years the Institute of Teleelectronics of the Warsaw Polytechnic Institute, lately renamed the Telecommunication Institute, has been working on establishing the most suitable transmission channels. The work was conducted within the general project 06.5.1 (the years 1971-1975) and at present within the project 06.2: "Progress of telecommunication" (the years 1976-1980).

Taking into consideration large lags in the development of the telephone network between zones and towns and an increased necessity of automating interurban traffic, special attention was directed to the problems of wide-band channels, both symmetric and coaxial. A solution was found by taking the normally used coaxial standard-size 2.6/9.5 system and introducing into it the 9 MHz and 12 MHz teletransmission systems.

A new program was initiated, using facilities of the modern Telecommunication Cable Factory in Ozarow [1]. Thanks to the application of thermoplastic materials for insulation and protective coatings, the factory was able to achieve a remarkable productivity and to eliminate the lead. However, the problem with copper remains. As is known, in the last few decades copper has become a rare product in the world. It is estimated that, at the present increased use of copper, its deposits will last for a few decades more.

For this reason, an intensive search for new transmission media has begun. At first, interest was concentrated on wave-conducting channels utilizing waves of the millimeter range. The construction of such channels has been developed and improved in several countries for a number of years producing satisfactory results, confirmed by results on experimental wave-conducting lines. However, the broader use of this system in telecommunication networks was interrupted because of the progress in studies of satellite and light-conducting systems.

At the present stage, the prevailing opinion is that the main domain of satellite systems should be primarily intercontinental communication and mobile radiocommunication on high seas and in broadcasting. And more and more often it is stressed that wave propagation is more suitable for open space and mobile and broadcast radiocommunication and not for horizontal radio lines.

Under these conditions, it was concluded that it would be most advantageous for telecommunication networks to utilize light waves in the range from 1.5 to 0.3 μm.

Also, positive results were obtained in Poland in the sphere of coherent light sources (lasers). Concepts were developed of teletransmission systems based on laser sources of light transmitted in open space. However, the experiments conducted demonstrated limited utility of these systems from the viewpoint of reliability of their action (dependence on variable weather conditions).

Only one road remained to obtain a satisfactory solution to the problem, that is, to find optimal materials and construction for production of cable channels in order to transmit light energy through them.

The Telecommunication Institute of the Warsaw Polytechnics has followed diligently the fast progress in the world of light-conducting telecommunication based on cable light-conducting channels.

The first concepts for starting work in the area of light conductors were submitted in 1971-1972, in connection with preparations for the 2nd Congress of Polish Science in June 1973 [2]. New suggestions were advanced to speed up the preliminary work. The coordination of the project was entrusted to the Telecommunication Institute (a team led by Prof. Z. Szpigler).

Another variant considered for building an experimental line was to purchase abroad a 4-channel light-conducting cable 3 km long and transmitting, receiving and auxiliary equipment, for the sum of about $100,000.

In the meantime, the work began to bring fruit. In 1975, the concept of building light-conducting channels based on glass capillary tubes was adopted. These glass capillary tubes were being constructed for gas chromatography at the Physical Chemistry Department of the University im. Maria Curie Sklodowska (UMCS) in Lublin, under direction of Prof. A. Waksmundzki. There were already well known in the world attempts to build such channels using glass tubes filled with a liquid having a light refraction coefficient higher than the coefficient of glass. However, serious difficulties of filling up longer sections of capillaries with an internal diameter 100 μm induced us to try the production of glass channels composed of a core and a coating from low-melting multi-component glass by the two-crucible method.

But really good progress was achieved when the fiber core from quartz glass was formed by the "pipe" method from the gaseous phase [3]. The first achievement was obtained in 1977 with noise suppression of about 100 dB/km. This result indicated that the direction chosen for further work was right. This work, whose aim was to build in Poland an experimental light-conducting teletransmission system by means of its own resources [4] involved:

- the choice of suitable quartz pipes for the adopted method of the production of channel core,
- improvement of facilities and technology of making preforms,
- construction of new facilities for drawing light-conducting fibers,

- facilities for fabrication of channels and light-conducting cables,

- transmitting and receiving facilities, transforming electrical signals into light signals and vice versa,

- facilities for joining channels and light-conducting cables,

- measurement methods and systems,

- building of the line and its inclusion into the existing inter-exchange network.

The following steps were taken to improve technology and facilities serving to produce preforms [5]:

- a new machine for making preforms was fabricated; it had more stable movements and more stable heating zone of the burner,

- a new type of dosimeter was applied for gaseous agents participating in the reaction,

- an optimal type of feeders was chosen for the reagents,

- a suitable method for purification of substrates was chosen, and the effect of purification on the noise suppression of fiber was examined.

As a result of this work, we obtained a multi-mode fiber with a step-wise coefficient of refraction and with noise suppression of about 15 dB/km. In spite of the lack of a suitable pyrometer, the conditions of the fiber core coating were optimized to such an extent that it was possible to obtain a numerical aperture from 0.06 to 0.14 with accuracy up to 0.01.

Further progress, both in the area of transmission characteristics and mechanical properties, was achieved by reconstruction of facilities for drawing fibers [6], namely:

- an increase of the new drawing machine height from 2.5 m to 6 m,

- stabilization of the furnace temperature with accuracy up to ± 2°C,

- stabilization of the speed of engines supplying the rod to the furnace and rotating the drum with an accuracy better than 0.2%. The drawing speed is from 30 to 60 m/min, depending on dimensions of "collapsed" rods.

The best improvement proved to be an increase of the height of the drawing machine permitting one to install between the furnace and the winding drum a setup for coating the fiber with a layer of thermosetting polyurethane resin of thickness about 3 μm. This layer formed the primary protection coating of the fiber (Figure 1).

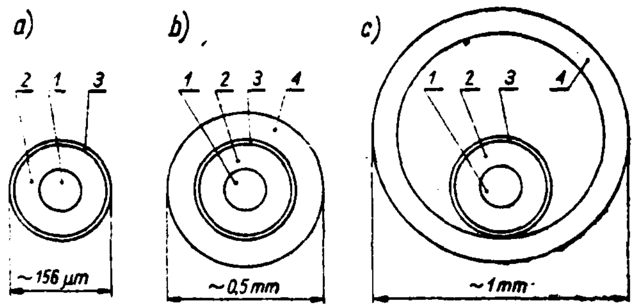

Figure 1. Construction of light-conducting (optical) fiber and of light-conducting cable channels:
a) fiber of quartz glass with primary coating; b) light-conducting cable channel; c) light-conducting cable channel with reinforced construction; 1) fiber core of diameter 50 μm; 2) fiber sheath of diameter 150 μm; 3) primary coating of thickness ∿3 μm; 4) plastic coating

Thanks to these modifications and the use of a high quality quartz tubing, we succeeded in obtaining the fiber in its primary protective coating with noise supression below 5 dB/km at a light wave of about 0.9 μm. Fibers of length 1.5 km, with high mechanical strength, were produced. The dimensions of fibers were: diameter of core about 50 μm, outer diameter (with sheath) about 150 μm.

Further work was concerned with production of light-conducting channels. According to present world practice, optical fibers have to undergo further technological treatment to improve their strength and to utilize them in the production of light-conducting cables.

Strengthening of the fibers with a primary coating is done in two ways:

- by impressing onto the fiber with the primary coating an additional layer of thermoplastic resin (Figure 1b), or

- by loose placement of the fiber with primary coating in polyethylene tubing of an internal diameter of about 0.6 mm (Figure 1c); this is the so-called "reinforced" construction.

Fibers protected in this way, forming the basic construction element, may be termed the light-conducting cable channel. To produce them, a small extrusion machine produced by the Cable Machines Shop of the Cable Factory in Cracow was installed in the Department of Physical Chemistry of UMCS (Lublin). The necessity arose to supplement the extrusion machine with the following elements:

- nozzles for covering the fibers with polyethylene coatings,
- water trough for cooling extruded channels,
- pulling arrangements for withdrawal of extruded channels,
- mechanical rewinders.

Trials to produce both types of channel construction have shown that many more studies have yet to be carried out, concerning both the materials used for protective coatings and the construction of cable machines. These needs were manifested even more clearly in the production of light-conducting cable based on the mentioned extrusion machine. It was a very difficult undertaking. Eventually, a cable was produced under laboratory conditions--a "test tube cable" [6].

After many attempts to fabricate the light-conducting cable of channel construction shown in Figure 1c, using the available materials, extrusion facility and cable "machines", it was found that the high transmission parameters of the fibers used underwent considerable deterioration. Under these circumstances, a new concept of the construction of light-conducting channels arose. The strengthening of fibers on the drawing machine was done by multiplication of layers of "primary coating". This became possible thanks to the considerable increase of the drawing machine height. Moreover, a double passage of the channel through the drawing machine was also applied to increase the strength of channels.

As a result, the construction was developed of the first experimental light-conducting cable whose profile is shown in Figure 2.

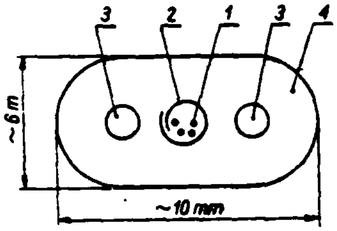

Figure 2. Profile of experimental light-conducting cable: 1) optical fiber with multiple primary coating; 2) polyurethane tubing; 3) a bunch of copper and steel wires; 4) polyethylene coating

In the core of the cable there is a tube from polyester foil, wound along as a folder inside of which there are four parallel placed light-conducting channels of new construction. On both sides of the core there are copper-steel links. Each link consists of four copper and three steel veins. In principle, these links serve to increase the strength of the cable durings its production and later during its installation when incorprated in the network. Copper veins could be used in cable channels for signalization or enhancement.

Tests to install the cable of the above construction gave satisfactory results. It was possible, therefore, to undertake the task of building a light-conducting cable teletransmission system in the interexchange network in Lublin.

The projected system was based on the light-conducting cable line, formed from light-conducting cable channels made in the Department of Physical Chemistry of UMCS, transmitting and receiving facilities developed at the Telecommunication Institute of the Warsaw Polytechnics and on terminal setups TCK 24 obtained from TELETRA Works in Poznan.

Figure 3 shows the general scheme of light-conducting channels. Systems which, in particular single cases, could be eliminated are shown within broken lines (e.g., transit systems or particular amplifiers).

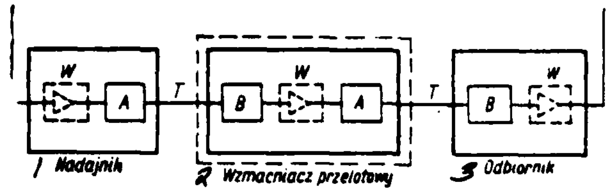

Figure 3. General scheme of light-conducting channel: A) source of light; b) detector of light; T) light conducting channel; W) amplifier; 1) transmitter; 2) transit amplifier; 3) receiver

Transmitting facilities [7]

When designing the tract, it was decided that the terminal .c-ups TCK-24 would be retained. The input and output signals of the TCK are transmitted in AMI code--a trilevel code unsuitable for transmission on light-conducting channels. The code adopted for transmission on light-conducting channels was code 1B2B because of the relatively simple construction of coder and decoder. The ideal scheme of the transmitter is shown in Figure 4.

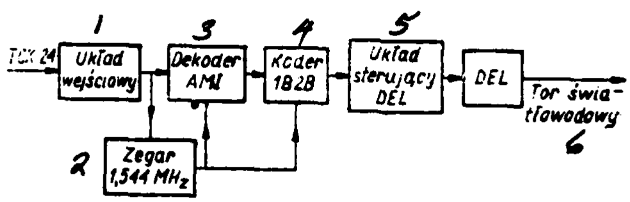

Figure 4. Block diagram of the transmitting facilities of light-conducting channel with throughput 1.544 Mbit/sec: 1) inlet system; 2) clock 1.544 MHz; 3) decoder; 4) coder; 5) controlling system; 6) light-conducting tract

The input signal from the TCK-24 terminal is sent through the inlet system to the systems of clock and AMI decoder. The clock signal controls the AMI decoder and the 1B2B coder. After the decoder system, one obtains a binary signal which in the coder 1B2B becomes transformed into an outlet signal in the 1B2B transmission code. The system controlling the DEL diode (that is, the system modulating the optical source) was made within the system of the transistor key. In the experimental line, we used the DEL Burrus type of Plessey company type HR954F.

Receiving facilities [8]

Schematics of receiving facilities are shown in Figure 5.

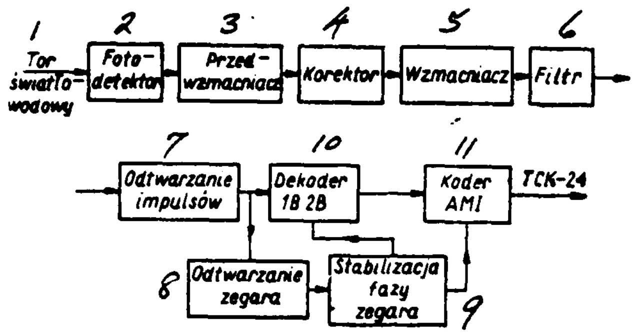

Figure 5. Block diagram of the receiving facilities of light-conducting channel with throughput 1.544 Mbit/sec: 1) light-conducting channel; 2) photodetector; 3) preamplifier; 4) corrector; 5) amplifier; 6) filter; 7) recreation of impulses; 8) recreation of a clock; 9) stabilization of clock phase; 10) decoder; 11) coder

The first part of the receiver is formed by a photodetector in the form of a Polish-produced cascade photodiode type BPYP51 with the supply system. The second part is formed by a preamplifier with large input impedance and high amplification. A further part of the system is the tract corrector whose task is to optimize the output level of errors.

After the corrector system, there is a power amplifier and low-pass filter which limits the band width to a possible minimum in order to obtain the best signal-to-noise ratio.

In a further (digital) part of the receiver, impulses of gaussian shape are transformed into the standard rectangular shape, and at the same time the clock of frequency 3.088 MHz is recreated. The clock signal, through the system stabilizing its phase, is led to the systems of decoder 1B2B and the decoder AMI to make possible its acceptance by the receiver of the terminal TCK-24.

The purchase abroad of measuring systems was not possible because of the lack of currency. The basic measuring methods were developed in the Telecommunication Institute. They concerned measurements of signal loss (noise effect) and of the numerical aperture [9]. The measurements were facilitated by obtaining in this country a radiation source of high power, in the form of a helium-neon laser of the company Spectra Physics, emitting light of wavelength 0.6328 μm and initial strength of 60 mW. Very important experiments carried out during the above measurements concerned the dependence of parameters on mechanical stresses of the fibers and on the radii of bending. The problem of dispersion at such small throughput was neglected.

A special system was developed at the Department of Physical Chemistry of UMCS for measuring distribution of the coefficients of light refraction in the core [10]. This system proved to be particuarly useful in experiments with application of variable (quasi-gradient) profile of light refraction.

<u>Installation of light-conducting cable line</u>

It was decided that the first light-conducting cable line would be built in the area of the inter-exchange network in Lublin. Many factors favored this decision. The Lublin district of PiT (Post and Telecommunication) distinguished itself with much work connected with the application of modern transmission systems, such as channels equipped with underground amplifying stations--first based on tubes then on transistors, and the use of modern information systems. Also valuable was the possibility of close cooperation with the Laboratory of Post and Telecommunication in Lublin, directed by eng. S. Zbyrad, and with the Department of Physical Chemistry of UMCS.

In order to evaluate fully the usefulness of the projected cable for mounting in the telephone network, it was decided [11] to incorporate certain obstacles in the choice of route:

- 12-times change of direction by 90°,
- change by 3 m of the level of course on 400 m section,
- passage through channels taken by one or more cable on a

length of about 860 m,

- leading the cable to terminal facilities in automatic exchanges with multiple changes of direction.

The length of line was about 2500 m. Along the line there were 49 wells of various construction, filled with existing cables. The line consisted of three sections of length 1000, 850 and 550 m. Stretching of the cable was preceded with tests on an experimental sector 100 m long. In particular, it was necessary to establish the safe force permissible in stretching the cable. This force was 800 N. Tests were made also on the pulling strength during the mounting of an especially constructed cable "stocking" joining the cable with the stretching wire.

In the period of mounting and assembling the cable in December 1978 and January 1979, under the well known atmospheric conditions ("the winter of the century"), the behavior of the light-conducting cable was tested at the temperature -12°C.

Joining of channels and light-conducting cables

Methods of joining the light-conducting cable lines are the subject of many studies and even patents in the world. One can distinguish between permanent and detachable fiber connections. In our discussed line, we used the connections developed at the Telecommunication Institute of Warsaw Polytechnics (Dr. A. Kowalski) with three-point stabilization and supplemented with immersion fluid in the space between frontal surfaces of fibers being joined. The mentioned atmospheric conditions during the assembly made it much more difficult to execute such precision tasks as light-conducting fiber connections. The transmission loss (noise) of connections having the described construction was on the average about 0.3 dB under laboratory conditions, but it increased to about 0.9 dB under field conditions (particularly in unfavorable weather).

A series of various elements for building and assembly of light-conducting cables have been developed in the Laboratory of Post and

Telecommunication. At present, two channels are active in the described cable, utilizing a multiple system with impulse-code modulation (PCM) of the TCK-24 type. Their transmission loss at the wavelength of about 0.9 μm for the whole line amounts to: 18 dB in channel 1, and 19 dB in channel 2.

The remaining two channels--after delivery to the laboratory--will serve for experimental studies or, if needed, will increase the number of connections between exchanges.

* * *

The described line has an experimental character. It enables one to collect many valuable data concerning both the design features and the assembly problems in relation to cables and line facilities. This fact permits one to outline the program for development of light-conducting technology in the telecommunication network of the country.

One has to mention also large research and didactic values obtained in the course of this work. The results of these studies will also serve as themes for doctoral dissertations and habilitation work in the Lublin and Warsaw centers.

We should point out large interest in the problems of light-condcuting technology in Poland shown by the Minister of Communication Prof. dr. E. Kowalczyk, Chancellor of the University MCS Prof. dr. W. Skrzydlo, and the Undersecretary of State in the Ministry of Higher Education, Science and Technology eng. M. Kazimierczuk.

I wish to also express my thanks to the Head Director of the Cable Factory in Ozarow eng. S. Pilarowski for enabling the workers of the University MCS to have consultations in the factory and for providing some cable materials.

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