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Nov. 27, 1934. N. R. FRENCH 1,981,999

OPTICAL TELEPHONE SYSTEM

Filed Aug. 20, 1932


Fig. 1

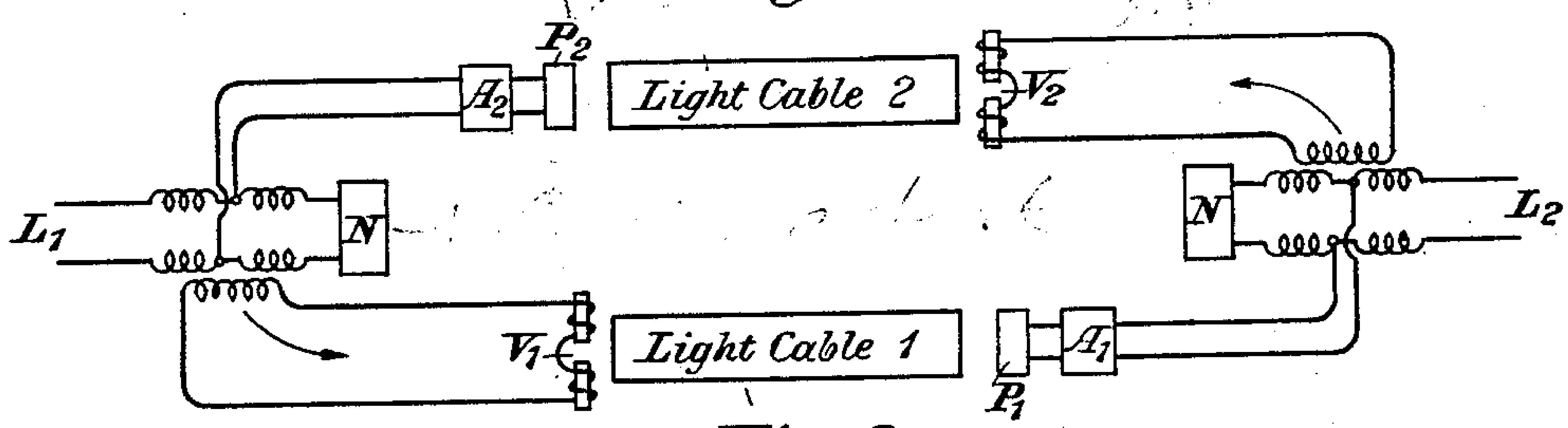


Fig. 2

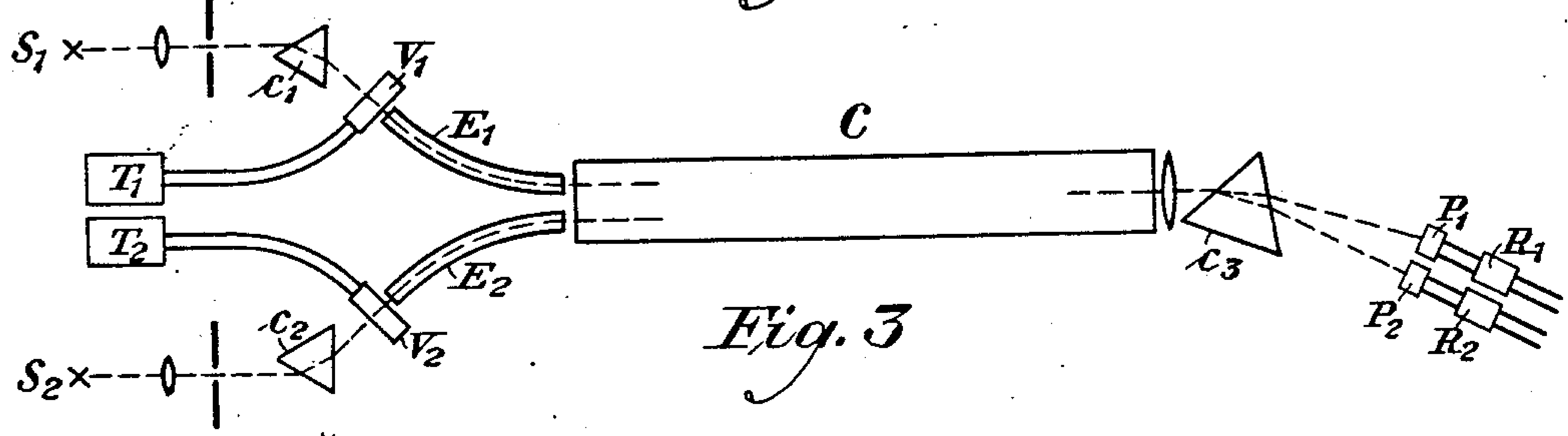


Fig. 3

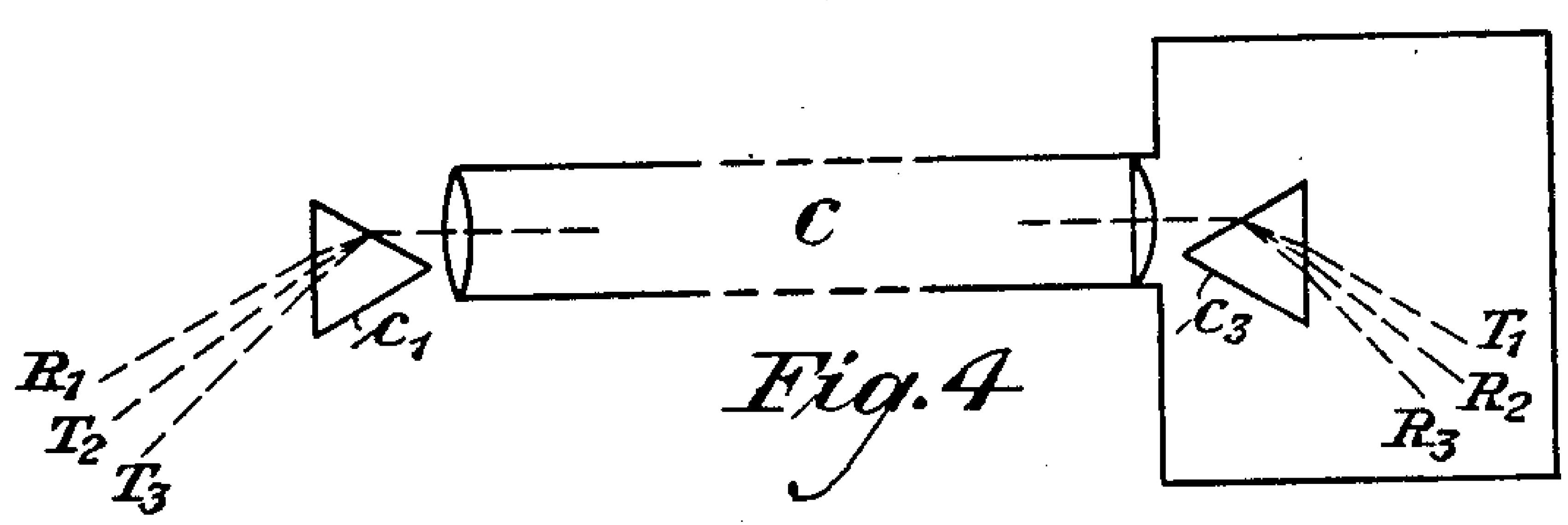


Fig. 4

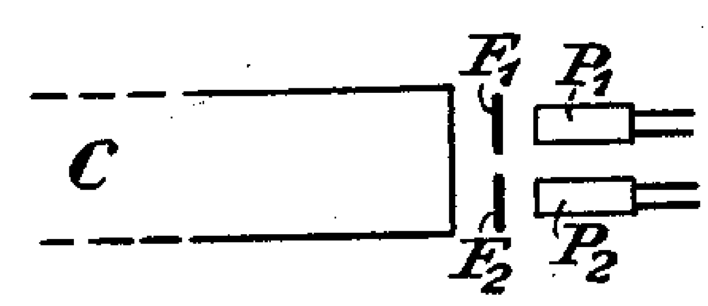


Fig. 5

Fig. 6

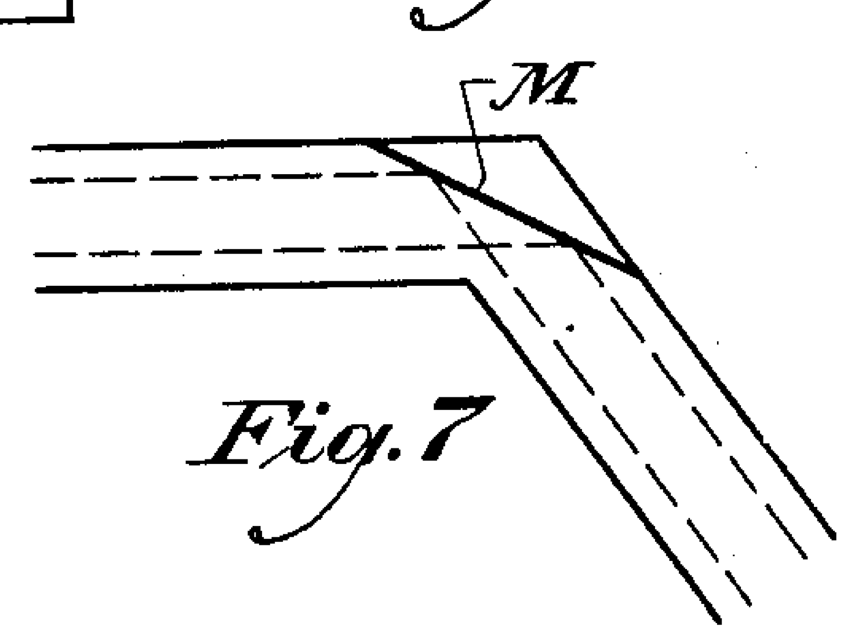


Fig. 7

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## OPTICAL TELEPHONE SYSTEM

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Application August 20, 1932, Serial No. 629,728

10 Claims. (Cl. 178—44)

This invention relates to a telephone transmission system in which an optical path constitutes a portion of the transmitting line. It is an extension of work which has been done in recent years on transmitting speech by means of a modulated light beam.

The purpose of this invention is to adapt the combination of facilities and the flexibility which are characteristic of telephone circuits, to cases in which a space is to be bridged without the use of wires, and by means other than that commonly known as radio.

Another purpose is to provide two-way transmission over an optical link.

Still another purpose is to make possible multiplex signaling over a single optical link.

The invention will be better understood by reference to the following specification and the accompanying drawing, in which Figure 1 shows a simplified telephone line of which one portion is an optical path. Fig. 2 shows the same kind of system adapted for two-way signaling. Figs. 3 and 4 show how a plurality of telephone messages may be transmitted over a single optical path, either in the same or in opposite directions. Fig. 5 shows a modified method of separating the different messages coming down an optical path. Figs. 6 and 7 are details relating to the optical path or cable.

Referring more specifically to Fig. 1, there is shown a light source S which by means of a lens 2 brings the light to a focus at a point adjacent to the lens after which the light passes into an optical path or light cable C extending between two stations more or less widely separated. Upon emerging from the light cable C the light falls upon a photoelectric cell or other suitable conversion device P, and the electric current resulting therefrom is amplified by amplifiers A and proceeds to any suitable receiver R. If now, the intensity of the light beam at the transmitting end is modulated in accordance with a speech message or other signal by any suitable means, then these modulations will appear as variations in the current in the photoelectric cell P and will be reproduced in the receiver R.

Any suitable means for modulating the light in accordance with the message to be transmitted may be used, and for purposes of illustration I have shown what may be called a light valve. This may consist of an electromagnet supplied with message current from the telephone T. The electromagnet may control a shutter to increase or decrease the amount of light passing through the opening of the shutter, or it may consist of a small mirror so mounted as to vibrate in accordance with the telephone currents through the electromagnet, thus changing the amount of light which passes through a slit and into the light cable C. Any other suitable means for a light valve may, of course, be used, and the one shown is for illustrative purposes only.

The light cable C may take on a variety of forms. It may, for example, consist of a solid rod of glass or quartz, or similar material, which has low absorption coefficient for the wave lengths to be transmitted. On the other hand, it may consist, and preferably so, of a tube which on the inside should have a reflecting surface. Since also, over such distances as 10 to 100 miles, it is important to keep the attenuation to as low a value as possible, I would prefer to have the tube evacuated, thus assuring a minimum of attenuation due to absorption, and a constancy of optical properties as weather and other conditions change. At the ends of such a tube or adjacent thereto, would be lenses 5 and 6, the first to render the light from the source S as nearly parallel as feasible, and the second to bring the light to a focus on the photoelectric cell. Even with the best optical system, however, it will be impossible to render the light strictly parallel, and furthermore, diffraction phenomena will be present so that some of the light will spread the sides of the tube. If, however, the surface is highly polished or mirrored the loss due to absorption may be kept very low and the confusion due to the fact that some of the light is not parallel to the axis of the light cable and therefore travels a longer distance will not be serious so far as it concerns the reproduction of the relatively low frequency speech signal or other modulation.

Fig. 2 shows a method of accomplishing two-way transmission, using a separate optical transmission line in each of the one-way transmission paths. Telephone currents coming in over the line $L_1$ pass through the well-known hybrid coil to the light valve $V_1$, over light cable #1 to photoelectric cell $P_1$, and amplifier $A_1$, thence to line $L_2$. Telephone currents coming in over the line $L_2$ pass to light valve $V_2$, over light cable #2 to photoelectric cell $P_2$, amplifier $A_2$, and line $L_1$. Balancing networks N are used, all in a manner now well-known in the art. In this system of Fig. 2 light of the same wave length or quality, may be used for communication in both directions.

Fig. 3 shows a method for sending two or more messages in one direction over a single optical path or light cable, but in this case it is desirable that a different wave length or color shall be set aside for each channel. Thus, in the figure there are shown two sources $S_1$ and $S_2$. Light therefrom passes through appropriate lenses and slits to a prism $C_1$ or other device by which a desired portion of the frequency spectrum may be selected for a given channel. The light selected from the source $S_1$ is then operated upon by a light valve $V_1$, in the manner previously described, and is then introduced into the light cable in any convenient manner. In the figure this is accomplished by allowing the light to pass into a quartz or similar rod $E_1$ or a hollow tube bent to any suitable form. By internal reflection the light from the valve $V_1$ will be conducted by $E_1$, whatever may be its shape, to the light cable. A similar arrangement is shown for the light from source $S_2$, it being understood that the portion of the spectrum selected by the prism $C_2$ is different from the portion selected by the prism $C_1$.

At the receiving end the two beams of light which, in general, will be completely mixed in the light cable, may be separated in a number of ways. One method which I indicate in this figure is to use a prism which will resolve the light in a well-known manner into its components, the one going to the photoelectric cell $P_1$ and the receiver $R_1$, and the other to the photoelectric cell $P_2$ and the receiver $R_2$.

A modification of this method of resolving the light beams is shown in Fig. 5, in which there is located in front of the photoelectric cells color filters $F_1$ and $F_2$, the first of which has a transmission band for the light which came down the channel $E_1$, and the second of which has a transmission band for the light which came down the channel $E_2$ of Fig. 3. While Figs. 3 and 4 have been shown with two channels only, it is understood that a much larger number of channels may be used, the limit being set only by the extent to which the various light beams may be resolved one from another. It is well known that the resolving power of optical instruments is very high so that in the visible portion of the spectrum alone, one could readily introduce several thousand channels, and still additional channels would be obtained by extension into the ultra violet and the infra red portions of the spectrum, in each case going as far into these regions as is permitted by the available optical instruments.

Fig. 4 differs from Fig. 3 more specifically at the transmitting end. The figure shows a single prism $C_1$ so adjusted that light coming from a plurality of transmitters $T_2$, $T_3$, etc., all appropriately positioned, will emerge from the prism $C_1$ parallel, or substantially parallel, to the light cable. Here, as in general, the transmitter is understood to include the light valve and, if necessary, a device for selecting a particular portion of the spectrum for itself. Also, in this figure, it is indicated that some of the channels may be used for transmission in one direction, and some for transmission in the other direction, thus the transmitter $T_1$ has been transferred to the right-hand side of the figure, and the corresponding receiver has been transferred to the left-hand side, and, although the light for the different channels may be completely intermingled in the cable each will be separated into its own proper path at the two ends. It may be convenient at one or both ends to enclose the prisms and so much of the associated apparatus as desired, in an evacuated container, and this I have shown at the one end of Fig. 4.

While it will be desirable to have the light cable a straight path extending from one end to the other, this will not always be feasible. Gradual bends in the light path are permissible, as shown in Fig. 6. This is true whether the cable be a solid conductor of quartz and similar material, or a tube mirrored on the inside. In the one case total internal reflection, in the other ordinary reflection, will keep the light within the cable. On the other hand, in case it is desired to make a sharp turn in the direction of the cable, this may be accomplished as shown in Fig. 7, in which a mirror M changes the direction of the light. Preferably, this mirror should be so located that light coming to it parallel to the axis of the first portion of the tube will be reflected in a direction parallel to the axis of the second portion of the tube. If desired the reflector M may be a curved surface, such as a spherical or parabolic mirror, and of such curvature that if the light is diverging slightly it will be again rendered parallel or substantially so. In fact it may be desirable at times to introduce two turns of the kind shown in Fig. 7 with two reflectors for the purpose of rendering the light more nearly parallel and thus reduce incidence on the tube surface with consequent absorption. Also very flat lenses may be introduced wherever desired along the light cable for this or similar purposes.

It is apparent that many variations may be introduced in such a system, and the details given are for illustrative purposes only. For example, one would wish to introduce lenses at one place or another in the system and it is to be understood that they, as well as many other optical devices, would be introduced in an obvious manner and for obvious reasons.

What is claimed is:

1. In a two-way communication system a transmission line comprising two optical paths in parallel, means for impressing on one of said paths a modulated light beam for communication in one direction, and impressing on the other a modulated light beam for communication in the other direction, terminal apparatus at the ends of said paths to connect the system for two-way communication over a pair of wires.

2. In a telephone system a transmission line a portion of which is an optical cable, means for operating said cable for a plurality of signaling channels, said means comprising a plurality of light sources and a modulating device for each, and further means for restricting the wave length of the light for the different channels to non-overlapping bands in the light spectrum.

3. The combination of claim 2 characterized by means at the receiving end for separating the light of the different channels.

4. The combination of claim 2 characterized by a prism at the receiving end to separate the light of the different channels and send each portion to means for detecting and translating the light beams to message frequency.

5. In combination, a light cable and a prism at each end, a plurality of transmitting and receiving sets at one end, corresponding receiving and transmitting sets at the other end for a plurality of signaling channels, each channel being operated over the light cable on a different light frequency.

6. In combination, a light cable and a prism at each end, a plurality of transmitting and receiving sets at one end, corresponding receiving and transmitting sets at the other end for a plurality of signaling channels, each channel being operated over the light cable on a different light

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frequency, the position of the transmitters and the prisms being so fixed that all transmitted beams are directed substantially along the axis of the light cable.

7. In combination, a light cable and a prism at each end, a plurality of transmitting and receiving sets at one end, corresponding receiving and transmitting sets at the other end for a plurality of signaling channels, each channel being operated over the light cable on a different light frequency, the position of the transmitters, the receivers and the prisms being so fixed that all transmitted beams are directed substantially along the axis of the light cable, and all received light of a given frequency is directed by the prism to the corresponding receiver.

8. In a two-way communication system a transmission line a portion thereof being an optical link, means for impressing on said optical link a modulated light beam for communication in one direction and introducing thereon a second modulated light beam for communication in the other direction, and terminal apparatus at the ends of said link to connect the system for two-way communication over a pair of wires.

9. The combination of claim 8 characterized by the fact that the second modulated beam is parallel to the first.

10. The combination of claim 8 characterized by the fact that the terminal apparatus comprises hybrid coils to connect the system for two-way communication over a pair of wires.

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