GUIDED PROPAGATION OF RADIO WAVES

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Monofilar Waveguide Cable

So far as the propagation of electromagnetic waves is concerned, an underground tunnel behaves like a pipe or hollowed waveguide. Waves propagate in this tunnel with a low attenuation only if their frequency is higher than a so-called critical frequency which depends on the shape and mostly on the cross-dimensions of the tunnel and which value is in the neighbourhood of several tenths of MHz.

However, when a metallic conductor is stretched along the gallery the electromagnetic characteristics of the latter are considerably modified and the effect of the cut-off frequency disappears; this is due to the fact that the gallery equipped with such a conductor works like a coaxial cable where the conductor serves as the outward conductor and the wall of the gallery as the return conductor. This is the principle of the monofilar waveguide cable which has been perfectly studied by Gabillard.

Two mean characteristics of the monofilar mode are as follows: first of all, when the cable is suspended in the middle of the cross section of the gallery, the electromagnetic field occupies all the space between the wire and the walls of the gallery. When the wire is close to the wall, the electromagnetic field tends to become concentrated between the wire and the wall, with the consequence that, with the given monofilar mode power, the aerial of a receiver standing somewhere in the tunnel will capture a weaker and weaker signal. Secondly, owing to the fact that the mode of monofilar propagation uses the ground as return conductor, its power of propagation is considerably diminished; the closer the wire is to the wall the higher the attenuation, for only a very small part of the wall is utilized as return conductor.

To cover great distances, everything else being equal, two or more conductors must be placed in the gallery. If the distance between two conductors of a cable is much smaller than the distance between one or other of the conductors and the walls; or again if one of the conductors surrounds the others and forms a screening, two sorts of modes appear : on the one hand the monofilar mode in which the wires or the screening serve as an outward conductor and the ground as a return conductor and, on the other hand, one or several modes in which the outward and return are effected solely by wires without intervention of the earth. This new type of mode will therefore be characterized by a relatively slight attenuation of propagation : hence, the ranges will be greater. However, the electromagnetic field of these modes is concentrated in the neighbourhood of the wires or inside the screening and it may not influence the antenna of mobile sets; only the monofilar mode possesses this property. For this system to be completed, it is therefore necessary to produce energy exchanges between these two types of mode, the monofilar mode being used in as small a quantity as possible for the link with the antenna, and the other mode for long distance propagation.

Systems Based on the Use of a Coaxial Cable

The guide-cable with the greatest range is that in which the attenuation is the slightest : it consists of a coaxial cable. For purposes of clearness we shall call the coaxial mode that which is propagated between the inner conductor and the screening and the single wire mode that which is situated outside the cable. The coaxial cable has a second advantage over cables such as the bifilar twin lead cable : the coaxial mode is entirely protected against the outer environment and does not suffer at all from a prolonged stay in a damp or dusty atmosphere or from being placed against the wall of the gallery.

The INIEX/Delogne system consists of connecting along a coaxial cable, radiating multi-purpose devices including conversion of modes.

Generally speaking, any antenna could perform these functions, but there is only one which is simple, small, economic and at the same time remarkably efficient : it consists of a cutting of the screening of the cable to which concentrated elements - coils and condensors - can always be added in order to improve the working.

Theoretical and Experimental Study

To study the INIEX/Delogne radiating devices it was necessary to solve the Maxwell equations, utilise the computer and verify the theory on the small-scale model with UHF in the laboratory. The full study has been published in a technical review (1); we give here the most important results of this study.

From the point of view of the propagation of the coaxial mode, the complete cut of the outer conductor behaves like an impedance inserted in series between the two lips in the gap of the outer conductor. This impedance is an electrical resistance and a capacity put in parallel (fig. 1). The power that should be dissipated by the electrical resistance we imagine is exactly the one which in reality goes out of the cut of the outer conductor and this power is representative of the radiation and of the monofilar mode, and this, of course, means that there is a loss of signal for the propagation in the coaxial mode.

To reduce the impedance of the cut we may add a condensor as shunt.

We may balance the effect of the condensor by inserting in series with the inner conductor a resonating spool matched with the condensor on the working frequency.

An interesting characteristic of the radiating waves is that they are concentrated in directions situated not more than about 10 degrees further away from the axis of the cable.

While systems based on coaxial cable described by others have to take into account a coupling loss of the order of 75 to 105 dB between the coaxial mode and the input of a mobile receiver, the coupling loss is only 25 dB in the INIEX/Delogne system. Therefore it allows the greatest ranges one could obtain at present without any intermediate amplification.

The system is now operating in several mines (fig. 2). A patent has been issued in several countries and is pending in the United States.

The INIEX/Deryck System

When a bifilar cable is suspended in an underground gallery, two modes of propagation appear : the parallel mode and the anti-parallel mode (fig. 3).

The way it works has been analysed intensively (2); it has been possible to provoke a controlled diaphony by inserting in the line devices called "mode converters" which are quadripoles with a transverse asymetry. Figure 4 shows two models of such a mode converter.

It happens that a bifilar transmission line equipped with the mode converters works in an entirely similar manner as the coaxial cable equipped with INIEX/Delogne radiating devices. Ranges are smaller because the attenuation of the bifilar line is higher than that of a coaxial cable. A bifilar line is less resistant to weathering than a coaxial cable, but it is cheaper.

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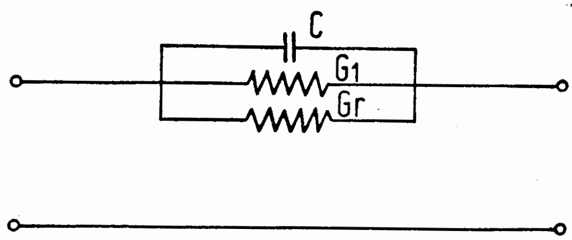

Fig. 1

Electrical model of the cut

Schéma équivalent de la coupure

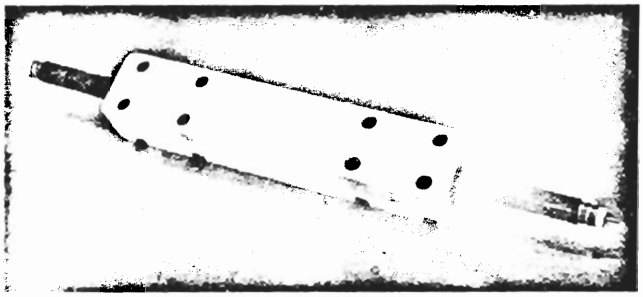

Fig. 2

Radiating device of the INIEX/Delogne system

Dispositif rayonnant du système INIEX/Delogne

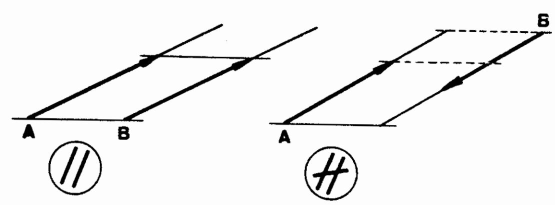

Fig. 3

"Parallel" mode, on the left; "anti-parallel" mode, on the right

Mode parallèle, à gauche; mode anti-parallèle, à droite

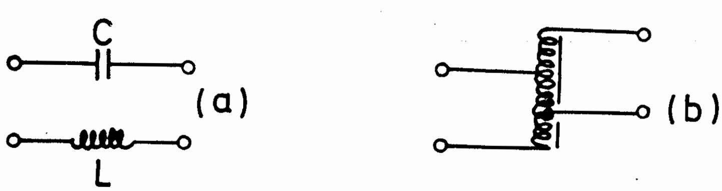

Fig. 4

Mode-converters
(a) narrow band
(b) wide band

Convertisseurs de mode sélectif (a) et à large bande (b)