

## RADIO COMMUNICATION DEVICE

The invention concerns a device for radio communication having a continuous radiating structure, a directional antenna and a means for transition of energy between the continuous radiating structure and the directional antenna.

Such a continuous radiating structure – described for example in document FR 2 608 119 – is used on certain guided urban transport sites in order to maintain continuous radio coverage between a control point on the ground and the trains, being as independent as possible of the specific propagation conditions related to the track environment (particularly in tunnels). Its functioning is very different from that of a traditional antenna since it allows, via a continuous network of slots made in a waveguide, a small part of the radiofrequency energy propagated inside the radiating structure to be brought outside in immediate proximity (a few dozen centimetres) to the antennas of trains moving along the track, being almost totally independent of the local propagation conditions. This type of structure is called “continuous” because it typically extends along a length of several hundred metres.

The known continuous radiating structure thus effectively covers an area which can be called “one-dimensional” concentrating the radiofrequency energy in immediate proximity to the track and along the length of the latter. However, this structure is not capable of effectively covering a large space such as that in a railway station, garage area or workshop. In this case it is necessary to dispose the waveguide in the form of a network of parallel guides, at regular intervals, which proves economically unrealistic. Radio coverage of a station, garage or workshop is, however, necessary or even vital.

These areas nevertheless prove less constrained from the point of view of radio propagation and are covered effectively by free radio propagation, that is, using discrete directional antennas, disposed at intervals, every few hundred metres along the track. A mixed solution which in areas of complex radio coverage uses a continuous radiating carrier giving freedom from these constraints of the propagation environment and, in areas of easier radio coverage, uses discrete antennas thus proves to be an effective combination.

In order to accommodate these constraints, the current technical solution shown in figure 1 is implemented: at the extremity 3 of the continuous radiating structure 1 (here a

waveguide) significant radiofrequency energy remains because the attenuation related to propagation and to radiation from the waveguide is of a value of less than 20 dB per kilometre and because the waveguide lengths generally used are limited to a few hundred metres, namely the inter-station distance generally found in guided urban transport systems. This energy is extracted by a waveguide/coaxial transition 4 , is transported by a coaxial cable 5, then supplies a directional antenna 6 – for example, a Yagi-type antenna –, providing radio coverage via free propagation in the space to be covered, and is relayed, if necessary, by other similar antennas carefully disposed further away and at intervals.

However, such a solution has several disadvantages: it is relatively expensive because of the waveguide/coaxial transitions, because of the cable 5 and the directional antenna 6 which have to be added to each space to be covered, it is complicated to implement and the microwave signal available at the extremity of the waveguide is rapidly attenuated as it passes through the transitions and the coaxial cable 5 towards the directional antenna 6. In addition, sudden variations in the signals transmitted are recorded when they pass between the waveguide and the directional antenna.

At present there is no known optimal solution which allows Yagi-type directional antenna technology to be combined with continuous radiating structure technology in order to reduce, in particular, the problem of signal attenuation.

Directional slotted waveguide antennas are known in the prior art. This type of conventional antenna is in general disposed high up on pylons in order to have good radio clearance and, in particular, to clear the first Fresnel zone for communication towards moving units. This type of antenna is intended to radiate directionally and with minimum congestion all the energy communicated by a transmitter. Typically, depending on the gain expected from such an antenna, its large dimension, extending along the axis of propagation, does not exceed a few wavelengths, i.e. the large dimension is less than 1 metre at 2.5 GHz. Beyond a size of a few wavelengths, the gain of such an antenna and its directivity no longer increase significantly and because of this are no longer of practical use.

However, it is not possible to combine such a directional waveguide antenna directly with a continuous radiating structure with waveguide – using, for example, waveguides of identical cross-section – because the antenna of a train suddenly moving past the radiation area of the directional antenna section would be “overwhelmed” by the very sudden transition from a reduced-power signal, the signal radiated by the continuous radiating structure, to a signal which is identical but of much greater power (typically 60 decibels more), due to the intense local radiation by this directional antenna. Because the transition is made within a very limited distance, less than a metre (length of the directional antenna) and is effected at the speed of the train, the train or ground radio equipment might then lose their synchronisation and because of this would temporarily be in a state in which they could no longer communicate with one another effectively.

*The communication device of the present invention aims to resolve the problems of devices for radio coverage of several areas whose propagation conditions differ from one another by proposing a solution which is economical, effective, simple to make and whose implementation is flexible.*

In accordance with the invention, the communication device of the type mentioned above is such that the transition means and the directional antenna consist respectively of a second and a third section of a radiating structure.

The communication device of the invention also possesses one of the following features:

- the second section of radiating structure includes a second series of slots, whose major dimension extends progressively over the length of the second section, and the third section of radiating structure includes a third series of identical slots whose major dimension is close to but less than the half-wavelength of the signal propagated in the waveguide;
- the first, second and third sections of radiating structure are adjacent and consecutive;
- the pitch between two consecutive slots is constant and identical along the length of the three sections of radiating structure;
- the length of the second section is within a range from 1 to 20 metres;

- the third series of slots includes up to 10 slots;
- the third series of slots is formed by the junction of the second series of slots with the same series of slots inverted in that the major dimension progressively reduces from the half-wavelength of the signal propagated to a size very much less than the wavelength of the signal propagated.

Other aims, features and advantages of the invention will become apparent on reading the description of the embodiments of the communication device, a description made in conjunction with the drawings in which:

- figure 1 is a diagrammatic view of the device for radio communication via a continuous radiating carrier along the length of the track then via free propagation by directional antenna of the prior art,
- figure 2 is a diagrammatic representation of a device for radio communication via a radiating carrier along the length of the track then via free propagation according to a first embodiment,
- figure 3 is a diagrammatic representation of a device for radio communication via a radiating carrier along the length of the track allowing the range of the ground-train link to be increased locally according to a second embodiment.

Figure 1 is a diagrammatic view of the device for radio communication via a continuous radiating carrier along the length of the track then via free propagation by directional antenna, and has been described above.

Figure 2 is a diagrammatic representation of a device for radio communication 10 according to a first embodiment. The communication device 10 consists of a radiating structure formed by a waveguide with a rectangular cross-section having three sections of radiating structure a, b, c pierced by slots 12, 14 and 16 respectively. The communication device 10 is disposed at height above the ground or, where necessary, is installed on the vault of a tunnel. The first radiating section a extends within an area of train movement over a distance which can be several hundred metres. The second and third sections b and c extend in an area allowing a progressive increase in the radiated power, over a distance several metres long compatible with the ability of the train and ground radio equipment to withstand

sudden variations in the incident signals, and also allowing the development of a significant directivity of the signals towards the area to be covered using free propagation, after the mechanical extremity of the structure 10 (station, workshop, garage or mixed radio coverage by continuous radiating structure and then discrete antennas). The section c specifically makes it possible to use and radiate all the residual energy at the extremity of the structure towards the space to be covered.

The communication device 10 performs two functions: the first function, maintained by the first section a of continuous radiating structure, makes it possible to communicate in one dimension of the space with an antenna of a train moving above and in proximity to the structure. The second function, maintained by the third section c, a directional antenna, makes it possible to communicate via free propagation within a space with an antenna disposed at a distance from the extremity of the communication device 10, for example on a train leaving section c. The intermediate radiating structure b makes it possible to pass progressively and effectively from one mode of functioning to the other, allowing the transition of radiofrequency energy between the continuous radiating structure a and the directional antenna c.

The slots 12 in the first section a are disposed transversely to the longitudinal direction of the waveguide and their major dimension is very much less than the wavelength of the microwave signal propagating within the waveguide. The major dimension is understood to be the dimension of the slot in the transverse direction (also called "major axis"), this dimension being clearly larger than the dimension of the slot in the longitudinal direction (also called "minor axis"). This feature makes it possible to extract only a very small amount of the energy along the length of the waveguide and thus to obtain a radiating structure with very low linear attenuation. The signal radiated is weak but continuous along the length of the structure and sufficiently powerful to provide radio communication via the train antenna moving in immediate proximity. This section a is described as "continuously radiating". Depending on the configuration of the transport network, it may extend over several hundred metres.

The slots 14 of the second section b (which corresponds to the energy transition means) are disposed transversely to the longitudinal direction of the waveguide. Their major dimension varies from the major dimension of the slots 12 of the first section a (major dimension very much less than the wavelength) up to a dimension which remains less than that of the slots 16 of the third section c (which corresponds to the directional antenna). The slots 16 of the third section c are all identical and also transverse to the longitudinal direction of the waveguide, and their major dimension is close to the half-wavelength of the signal propagated in the waveguide. For reasons of simplicity, only a few slots 12, 14 and 16 are shown in figure 2. The extraction of energy effected, and consequently the power radiated from each slot 14 increases rapidly when the size of the latter increases, the size of each slot 14 nevertheless remaining less than the half-wavelength. This energy is transferred from the inside of the waveguide to the outside. A directivity, in the direction of the waveguide towards its extremity and thus towards the space to be covered after the end of the waveguide, arises from the composition of the radiation from the different successive slots 12, 14, 16, which are regularly spaced and phase-shifted according to the principle of calculating the inter-slot distance explained below.

In section a, theory of radiation from small apertures developed by H. A. Bethe, "Theory of diffraction by small holes, Phys. Rev., vol. 66, pp. 1263, 1944" is applicable. Consequently, the radiation from a small aperture, here an elementary slot 12, can be expressed in the form of the radiation from equivalent magnetic dipoles written as  $\vec{m}$  and written in the form of a relationship between the magnetic field propagated within the waveguide, written as  $\vec{H}_0$ , and a coefficient called the "magnetic polarisability of the aperture", written as  $\alpha_m$ . At a sufficient distance from the aperture, the magnetic moment of the magnetic dipole equivalent to the radiation from this aperture is written in the form of the dyad  $\vec{m} = \alpha_m \vec{H}_0$ . The magnetic polarisability of a slot in the form of a very elongated ellipse has an analytical solution. It is written using the major axis of dimension " $2l$ " of the

aperture in the form  $\alpha_m = \frac{2\pi}{3} \frac{l^3 e^2}{E(e) - K(e)}$ , an expression in which " $e$ " is the excentricity of the ellipse-shaped aperture, " $K(e)$ " and " $E(e)$ " are the complete elliptical integrals of the

first and second kind respectively. The magnetic polarisability of a rectangular slot 12 proves to be correctly approached via that of an elliptical slot with the same major and minor axes. Consequently, disposed along the length of the continuous radiating section a are slots 12 with a major axis calculated so that the polarisability of these slots allows a reduced coupling of approximately 60 decibels between the power propagated inside the waveguide and the power radiated to the outside, enabling sufficient power to pass to maintain ground-train communication. The above expression of the magnetic polarisability of the aperture also shows that  $\alpha_m$  increases as a function of  $l^3$ .

Along the length of the transition section b, the polarisability of the apertures is increased very gradually by regularly modifying this parameter  $l$  of the slots 14 so that, from the initial -60 dB, the level of radiated power extracted from the waveguide and received by the antenna of a train moving in translation nearby is progressively increased. The change in this dimension  $l$  is calculated so that the change in the power transmitted by each slot, which varies as  $l^3$ , produces the linear variation in the power increase required along the length of this section b, whilst Bethe's hypothesis concerning small apertures remains valid. At the end of section b, the power of the radiated signal has greatly increased.

In the directional antenna formed by the section c, starting from this already high level of radiation obtained progressively along the length of the second section b, the objective is to make best possible use of all the residual energy in order to rapidly and efficiently radiate all the residual energy at the extremity of the waveguide. A slot resonating at a half-wavelength in air, correctly supplied, has a high level of radiation efficiency and has the property of radiating almost all the energy communicated to it. Consequently, if a half-wavelength slot 16 resonating at the working frequency is disposed in this third section c, this slot radiates most of the incident energy either side of its plane. Half of this energy is thus radiated into the half-space inside the waveguide (it is reinjected into the latter) and half is radiated to the exterior. In practice, there then remains in the waveguide, in the section c, after a first half-wavelength resonant slot 16, approximately half the initial power. There is then a reduced number  $n$  of successive half-wavelength resonant slots 16 ( $n < 10$ ) in this terminal part c so that it is possible to consider all the residual energy is effectively radiated,

slot 16 after slot 16. This process leads to a rapid attenuation, close to  $\left(\frac{1}{2}\right)^n$ , of the power transmitted internally to the waveguide and to the efficient radiation of all the residual energy, without additional losses (transitions, connectors, cable) and in the direction of propagation common to the three sections a, b and c. The extremity of the waveguide no longer transporting radiofrequency energy can be left open, simply protected by a dielectric cap which provides a mechanical seal.

The pitch between two consecutive slots 12, 14 and 16 is a function of the cross-section of the waveguide and the wavelength of the signals used. It is calculated in such a way as to obtain a signal of constant amplitude along the entire length of the communication device in proximity to the continuous radiating structure, in particular above a slot, or between two slots. It is obtained by taking into account the phase shifting of signals supplying the slots of the waveguide, starting from the guided wavelength – itself a function of the internal geometric dimensions of the waveguide and of its mode of propagation - and also from the phase shifting undergone in air, outside the waveguide, by all the radiation from the slots contributing to the total field received at all reception points in proximity to the waveguide. This inter-slot distance is constant and identical along the length of the sections a, b and c in order to provide a continuously increasing level of signal above the waveguide.

The radiating waveguide is installed along the length of the transport track in the form of unitary sections connected to one another electrically and mechanically. In order to ensure easy transport and fitting/removal of these sections, the length of each of these unitary sections is limited in practice to a value not exceeding 20 m. A terminal section is formed from the sections b and c shown in figure 2. The directional antenna formed by the third section c is of a short length, limited to less than ten slots, clearly less than a metre in length. The second transition section b may advantageously have a dimension at the most equal to the length of a unitary section minus the length of the section c. The first continuous radiating section a, which is very long, is made by all the other unitary sections situated upstream but may, as a variant, form part of the terminal section, depending on the dynamic variation of the signals which can be tolerated by the radio equipment and thus the effective transition distance necessary to provide sections b and c.

Beyond the directional antenna formed by the third section c, downstream radio coverage is effected by free propagation, that is, with features dependent on the radio environment particular to the propagation environment of the station, workshop, garage, or the track in the case of the mixed operating solution using a continuous radiating structure and discrete antennas.

The above explanation has been given taking into account a train moving above the communication device and leaving this area of radio coverage. The terminal radiating section formed by the second and third sections b and c provides the progressive rise in power of the signals received by the train. The problem can be reversed when a train approaches from an area not equipped with the communication device according to the invention to an equipped area, ensuring a continuous decrease in the power of the signals received from, this time, the directional antenna (third section c) as far as the continuous radiating structure (first section a). This reversible arrangement is particularly useful in the scenario where two sections of track with complex radio coverage require the use of a radiating waveguide and surround a simpler environment whose radio coverage is provided by one or more consecutive discrete antennas. At the extremity of the first waveguide area equipped with a terminal transition section according to the invention, the power of the signals transmitted will progressively increase, in accordance with the dynamic range which can be tolerated by the radio equipment used. The free propagation conditions thereafter apply in the intermediate free propagation environment for which a maximum of radiofrequency energy has nevertheless been communicated by the terminal transition section with very limited losses, thus making it possible to provide efficient free propagation. In proximity to the second area of installation of the waveguide once again covered by a radiating waveguide according to the invention, the signal will increase because of the proximity of the source of radiation then, once the beginning of the third section c has been passed and along the length of the second section b, the signal will progressively decrease over a few metres, until it returns to the base level received along the entire length of the first section a.

In this first embodiment, the first, second and third sections of the communication device are adjacent and consecutive, the second section b making it possible to pass

progressively from a continuous mode of operation with low radiation to a local mode of operation with intense radiation.

The invention thus makes it possible to produce, very simply and economically, a radio communication device which provides two types of communication in two different propagation environments.

This device permits a continuous rise in power, over an adjustable length, capable of reaching several metres and enabling the radio equipment on board the train to “follow” this rise in power progressively, without any risk of a loss of signal synchronisation.

As a variant, it is possible to locally increase the radiation by locally making slots of a larger size for a few metres, for example in the case where the waveguide is physically and locally distant from the train antenna in order to bypass a points and crossing. The additional energy radiated locally over these few metres makes it possible to compensate for the additional attenuation related to this locally increased difference in distance. Such a variant is shown in figure 3.

Over an area of the radiating structure 20 where a local increase in signal radiation is required, a first series of slots 14 (intermediate radiating area b), whose major dimension increases from a length considerably less than the wavelength of the signal propagated in the waveguide to a length less than the half-wavelength, is made between two continuous radiating sections a. A second series of slots 14' (intermediate radiating area b'), whose major dimension decreases from a length less than the half-wavelength to a length considerably less than the wavelength of the signal propagated in the waveguide, is then made. The change profile of the length of the major axes of the slots in these intermediate sections b and b' is determined in theory as described above for the second section b. The series of slots in section b, followed by the series of slots in section b', locally creates a more intense radiating section c'. In order to obtain the necessary increase in signal over the required length, the section c' can be extended over the required length by adding slots whose major dimensions are all equal to that of the last slot 14 in section b or the first slot 14' in section b'. This dimension, the upper limit of the major axis of the slots in sections b, c', and b', is calculated on the basis of the above expression  $\alpha_m$  of the magnetic polarisability of the slot in order to obtain the radiated power necessary to compensate for the additional attenuation related to

the locally increased difference in distance and then allow a return to type a operation after this area of local signal increase  $c'$ , via the section  $b'$ . Of course, the signal energy propagated after this type of area is attenuated relative to a waveguide structure which does not include the sections  $b$ ,  $c'$  and  $b'$ , which implies that, at an identical waveguide length, it is necessary to provide a greater number of repeaters.

The functioning of such a device has been described taking into account the case of ground to train communication, where the radiofrequency energy is communicated to the radiating structure intended for the trains. The general principle of antenna transmission-reception reversibility applies to the invention, i.e. in the case of train to ground communication for which the radiofrequency energy is emitted by the train antenna, received by the radiating structure and propagated within this structure to a remote receiving equipment.

### Claims

1. Radio communication device (10, 20) for maintaining a continuous radio coverage between a control point on the ground and a train moving along a track, said device having a waveguide inside which an microwave signal is injected, comprising a first section (a) pierced by a first series of slots (12), radiating part of the signal towards the moving train, a means (b) for transition of energy between the first section (a) of the waveguide, and the directional antenna (c), **characterised in that** said transition means (b) and said directional antenna (c) consist respectively of a second and a third section of the waveguide, each pierced respectively with a second and a third series of slots (14,16), said first, second and third sections of the waveguide (a, b, c) being adjacent and consecutive, **in that** the major dimension of the second series of slots (14) increases progressively along the length of the second section (b) from the major dimension of the first series of slots (12) to an dimension smaller or identical to the major dimension of the third series of slots (16), **and in that** the major dimension of the third series of slots (16) is identical along the length of the third section (c,c').
2. Radio communication device (10, 20) according to claim 1, characterised in that the major dimension of the first series of slots (12) is much smaller than the wavelength of the microwave signal propagating in said waveguide.
3. Radio communication device (10, 20) according to claim 1 or 2, characterised in that the major dimension of the third series of slots (16) of the third section (c) is superior to the major dimension of the second series of slots (14) and equal to half the wavelength of the signal propagated in the waveguide.
4. Radio communication device (10, 20) according to claim 3, characterised in that the third series of slots (16) comprises up to ten slots.
5. Radio communication device (20) according to claim 1, characterised in that the major dimension of the third series of slots (16) of the third section (c') is equal to the

major dimension of the second series of slots (14) and smaller than half the wavelength of the signal propagated in the waveguide.

6. Radio communication device (20) according to claim 5, characterized in that the third series of slots (16) is followed by a second series of slots (14') the major dimension of which decreases progressively from a length smaller than half the wavelength of the propagated signal to a dimension much smaller than the wavelength of the propagated signal.
7. Radio communication device (10,20) according to any preceding claims, characterized in that the space between two consecutive slots (12,14,14',16) is constant and identical along the length of the three sections (a,b,c) of the waveguide.
8. Radio communication device (10,20) according to any preceding claims, characterized in that the slots (12,14,14',16) are disposed transversely to the longitudinal direction of the waveguide.
9. Radio communication device (10,20) according to any preceding claims, characterized in that the length of the second section (b) is within a range from 1 to 20 meters.