

WAVEGUIDE ANTENNA EMBEDDED ON A RAILWAY VEHICLE

The invention relates to a directional transmitting/receiving device with waveguide in general, and more particularly an antenna with bi-directional and symmetrical waveguide.

5 A transmitting/receiving antenna having a bi-directional radiation pattern communicates with transmitters/receivers in two preferred spatial directions.

Such an antenna has an application for example along a road, rail, etc., transport axis. Conventionally, radio coverage is ensured by a network of transmitters located at intervals at ground level and lifted by using pylons. A mobile moves between these transmitters at
10 ground level.

When travelling along the transport axis, this mobile is in communication with the transmitter located immediately upstream. In moving away from this upstream transmitter, the signal received from this transmitter diminishes progressively until becoming unusable. Yet, simultaneously, the signal received from the downstream transmitter increases since its
15 distance from the mobile decreases. Communication transfer must be made for the mobile to transfer its communication, now inoperable, from the downstream transmitter to the upstream transmitter. This step is called « handover » in a cellular communications network.

To ensure this communication with the upstream station and, simultaneously this monitoring of the level of receiving the signal transmitted by the downstream transmitter, the
20 receiver must use two antennae pointed respectively to the front and rear pointing above the horizon in the direction of the antennae on pylons.

In the case of a railway communications system, the fixed communication device is located at ground level or in a tunnel arch along this path. The fixed communication device can be omni-directional, that is, it radiates or receives an electromagnetic signal in all spatial
25 directions. The communication device can be also directional, that is, the signals have a high gain in a spatial direction: the radiation pattern shows a main lobe of given orientation. A directional antenna having the same radiation pattern strongly optimises communication with the latter device.

In an « open » propagation medium, the communication device at ground level will
30 be for example constituted by directive transmitters/receivers. In a « closed » propagation medium such as for example in a metropolitan network, the communication device at ground level will be a waveguide for example.

A waveguide device at ground level must work at very high frequencies, above gigahertz (GHz), to result in mechanical realisation of dimensions compatible with its use on the path. Using these hyperfrequency frequencies ensures all the ground-train communications considered. These high frequencies correspond to wavelengths in the air of the order of 5 to 20 cm (1.5 GHz to 6 GHz and more). Because of this, the waveguide on the path often proves to be far - in terms of number of wavelengths - from this antenna placed on the train. This leads to electromagnetic radiation of remote field type for which radiation diagrams can be calculated theoretically and measured experimentally.

As the vehicle moves in two opposite directions along the transport axis (at 0° and at 180° , and supposing that the axis of the way is placed at 0°), the transmitting/receiving antenna must be able to communicate with the communication device on the way in both directions.

Document US 6,091,372 discloses a communications system between a transmission line on the way and a transmission line located on a railway vehicle, of radiating cable types. The principle developed in this document is connected to a coupling between radiating propagation lines, the transmission line on board of the vehicle employed as antenna being long by several metres. Communication is made essentially in the near electromagnetic field, or with a small number of wavelengths at frequencies exploited by the radiating cables (generally to 500 MHz) and for « on board radiating cable - radiating cable at ground level » distances (or in a tunnel arch) of the order of a metre.

Coupling between transmission lines oriented favourably relative to one another clearly proves more important than coupling in the opposite orientation. To receive a maximum signal and according to the orientation of the train relative to the way, it therefore proves necessary to use a switch to manually invert the relative terminal positions of the generator/receiver and loaded on this radiating cable on board of the train.

A disadvantage to this device is the length of the propagation lines necessary for this type of coupling, i.e. an antenna train of a few metres long. Another disadvantage is the necessity to switch over the orientation of the transmission lines according to the direction of travel of the vehicles to increase coupling and improve communication between the vehicle and the device on the way.

The aim of the device of the present invention is a directional receiving and/or transmitting antenna embarked on board a vehicle which can communicate reliably and

stably with a fixed directional communication device located on the way, this antenna being of simple design, not bulky and independent of the direction of travel of the vehicle.

According to the invention, the receiving and/or transmitting antenna mounted on a vehicle moving along at least one way and communicating with a fixed communication device located along at least one way by means of hyperfrequency signals of given wavelength, is constituted by a waveguide of rectangular section whereof a large face is pierced by rectangular slots whereof the large dimension is less than the half-wavelengths of said hyperfrequency signal, and in that the space between the centre of two successive slots is close to a half-wavelength of the hyperfrequency signal propagated in the waveguide.

The receiving and/or transmitting antenna can also have one or more of the characteristics below, considered individually or according to all technically possible combinations:

- the number of slots is between five and ten,
- the emissive face of the waveguide of said antenna is vertical and is located parallel to an emissive face of the fixed communication device located along the way,
- the axis of the waveguide of the antenna is parallel to the axis of the fixed communication device,
- the antenna is remote from the fixed continuous communication device by at least four wavelengths of said hyperfrequency signal propagated in the air,
- the antenna is located to one single side of the vehicle,
- the antenna is located on each side of the vehicle,
- the antenna is covered by a radome.

Due to the invention, each slot of the antenna radiates a signal exhibiting two main lobes in two symmetrical directions relative to a plane perpendicular to the plane of this slot.

The waveguide is easy to make, simple to use and reliable, and the double directivity allows to be independent from the direction of travel of the vehicle without any specific intervention. Since the propagation environment of the communication ground-trains is characterised by intense reflections on the different surrounding obstacles (trains, walls...), a directive antenna, focussing its radiation onto the waveguide on the path, limits the impact of these multiple reflections on the quality of the link and thus increases the distance « antenna embedded on the train - waveguide on the path » exploitable in practice.

Also, from the waveguide on the path and with respect to the antenna according to the invention, the amplitude of the signals proves remarkably constant and requires no particular

« smoothing » of signals. Specific focussing, symmetrical in two particular spatial orientations, and only in these directions corresponding to the maximum radiation of the waveguide on the path proves particularly favourable for optimising the balance of ground–train transmission.

5 Other aims, characteristics and advantages of the invention will emerge from the following description, a description made in reference to the attached drawings, in which:

- Figure 1 is a schematic view of the communication device of a railway network,
- Figure 2 illustrates the radiation diagram measured in azimuth of the communication device, associated with a physical representation of the waveguide,
- 10 – Figure 3 illustrates a perspective view of the waveguide antenna according to the invention,
- Figure 4 illustrates the radiation diagram belonging to the antenna according to the invention,
- Figure 5 illustrates a vehicle equipped with an antenna according to the invention,
- 15 changing direction and path by means of a loop between the two paths,
- Figure 6 illustrates a vehicle equipped with two antennae according to the invention, changing direction and way by means of a garage way.

Figure 1 is a schematic view of the communication device of a railway network, for
20 example a metropolitan line.

A directional communication device 1 enabling the control station of the line to communicate with the vehicles A, B travelling on the ways 2, 3 (and vice-versa, enabling the vehicle to communicate with the control station) is located for example between the two ways 2, 3. This information can be for example automatic control information on the
25 vehicles, information on line signalling or even video or audio information of the vehicle to the control station. It is contained in hyperfrequency signals symbolised by the full arrows S1 and S2. Alternatively, the directional communication device can be located on each side of the way.

The hyperfrequency signals are injected into the communication device 1, constituted
30 by at least one waveguide. The waveguide is in the form of a hollow tube of rectangular section comprising four faces. It is located at ground level or in a tunnel arch on a non–emissive face.

Each waveguide has two emissive vertical and opposite faces 1a and 1b, each face being pierced by a network of slots perpendicular to the axis of the guide, located on the large faces of the guide, whereof the large dimension is much smaller than the wavelength of the signals propagating in the waveguide. This characteristic draws from each slot only a very small part of the energy of the propagated signal. Consequently, since the signal is only very slightly attenuated by transmitting to the exterior of the guide via the slots, the waveguide on the path can have a length of several hundreds of metres.

The communication device is bi-directional in the direction where the slots of the two faces can also receive the hyperfrequency signals coming from the antennae 4 boarded on the vehicles A, B.

Figure 2 shows the radiation diagram measured in azimuth of the waveguide 1 of the communication device, located on the ground on a small non-emissive face. The double network waveguide 1 of slots has a directive radiation diagram in remote field which has two main and symmetrical lobes L_1 and L_2 relative to the axis of the guide (axe 0°). The orientation of each lobe describes an α -angle with the axis of the waveguide of around 30° . To communicate with such a waveguide the transmitting/receiving antenna embedded on the vehicle must also be directional. It must thus have a radiation diagram with directivity enabling the best energy transfer between the waveguide on the path and this antenna. In other terms, the radiation diagram of the antenna must have at least one main radiation lobe whereof the orientation is identical to that of one of the main lobes of the radiation diagram of the waveguide.

For example, to communicate effectively with the waveguide having a main lobe directed at 30° relative to the axis of the waveguide, the antenna embedded on the vehicle must also have a starting angle of 30° to effectively receive and transmit signals in this preferred spatial direction.

In order to be independent from the direction of travel of the vehicle on one or the other of the two ways disposed around the waveguide 1, the on board antenna 4 must be « symmetrical », i.e. each emissive slot must radiate symmetrically relative to a plane passing through its centre and perpendicular to the longitudinal axis of the guide. In other terms, and to repeat the above example, each slot must have a lobe whereof the orientation is at 30° and a lobe whereof the orientation is at 150° (180° minus 30°).

An antenna comprising these two characteristics (directional and symmetrical) is the transmitting and/or receiving antenna 4 according to the invention illustrated by Figure 3. It

is constituted by a waveguide of rectangular section whereof one of the large faces of length b is pierced by seven slots 5, located perpendicularly to the longitudinal axis of the guide. The waveguide is closed at one end by a coaxial impedance charge 7 of 50 ohms, and its other end is connected via a coaxial link 6 to a receiver (not shown). The large dimension D of the slots 5 is close to the half-wavelength of the hyperfrequency signal propagated in the waveguide, though less so as not to draw too much power from the signal propagated in the guide.

The distance E separating the centre of two successive slots 5 is close to a half-wavelength of the signal propagated in the guide. In a waveguide of rectangular section, the relation connecting the wavelength of the signal propagated in this guide noted as λ_g , the wavelength of the signal propagated in the air noted as λ and the cutting wavelength of the waveguide (above which the waveguide propagates no more power) noted as λ_c is written as:

$$\left(\frac{1}{\lambda}\right)^2 = \left(\frac{1}{\lambda_c}\right)^2 + \left(\frac{1}{\lambda_g}\right)^2.$$

In this waveguide of rectangular section, the cutting wavelength λ_c is equal to twice the large transversal internal dimension of the guide. By way of example, for a guide of 10 cm of large internal side, this gives

$$\lambda_c = 20 \text{ cm}$$

or even a low cutting frequency of 1.5 GHz. At this frequency, no signal is propagated in the guide : with the above formula λ_g tends towards the infinite. Above this frequency, signals begin to propagate in the guide with low attenuation.

In the same conditions, at 2 GHz, or a wavelength in the air λ of 15 cm, the wavelength λ_g of the signals propagated in the guide, calculated from the preceding formula will be 22.6 cm. Considering a network of a few slots spaced out evenly and fed at one end. The power communicated to this end propagate from one slot to the other with proportional phase lag to this guided wavelength λ_g . Part of this power is radiated to the exterior of the guide and propagates this time in the air with a wavelength λ . The combination of radiations in the air of these slots fed out of phase by propagation of signals in the metallic waveguide provides a radiation diagram having the required starting radiation angle, phase lag of a

guided half-wavelength $\frac{\lambda_g}{2}$ provides the necessary double radiation lobe and having

starting angles identical for orientations 0° and 180° . This phase lag is completed physically by a space E between two successive slots 5 near the guided half-wavelength.

For a more reduced space E between slots 5 there is a single radiation lobe, similar to that obtained on the waveguide 1 on the way used.

5 The obtained polarisation of the electromagnetic field is linear, the radiated electric field has a main component oriented according to the longitudinal axis of the antenna or of the guide support.

Each slot 5 made in the waveguide has a small side big enough for the metal thickness of the waveguide to be small in respect to this dimension (considering metal thickness of the
10 guide of 1 mm, slots of 3–4 mm of small side are preferred to ignore another waveguide effect introduced by propagation of signals via a very thin slot, in the metal thickness).

The antenna gain grows with the number of slots with which the radiation is combined. Under a minimum number of five slots the gain is sub-optimal, but can be sufficient if there is a severe antenna train footprint size problem. Above ten slots the gain
15 grows slightly more but the radiation lobe becomes narrow, concentrates power into a fine beam and there is a risk of leaving the adequate coverage zone in case of excessive suspension displacement of the vehicle (pitch, roll).

Figure 4 illustrates the diagram for the antenna according to the invention. The longitudinal axis of the waveguide of the antenna is the axis at 0° . Two lobes L_A and L_B
20 appear clearly at approximately 30° and approximately 150° , indicating that the wave is transmitted with equivalent gain in these two preferred directions.

The emissive face of the waveguide of the antenna is located at the vertical and parallel at an emissive face of the fixed continuous communication device located along the way. In effect, the waveguide of the communication device is located on a non-emissive
25 face, the emissive faces being located at the vertical. Polarisation of the radiation of the waveguide on the way is identical to that of the receiving/transmitting antenna.

The antenna is therefore located on the vehicle such that the longitudinal axis of the waveguide of the antenna is parallel to the longitudinal axis of the waveguide on the way so that a lobe of the radiation diagram of the antenna and a lobe of the radiation diagram of the
30 waveguide 1 on the way have an identical orientation.

The antenna is mounted either under the chassis of the vehicle if the communication device 1 is located at ground level between the two ways 2, 3, or on the roof of the vehicle if the communication device 1 is located in a tunnel arch between the two paths 2, 3. The

distance between the receiving and/or transmitting antenna and the communication device 1 is at least four wavelengths of the hyperfrequency signal propagated in the air, since radiation of the communication device towards the antenna, and vice-versa, takes place in a far field. The antenna train can be installed laterally, its waveguide volume integrated in the chassis,
 5 the plane of the slots covered by a radome flushed with the surface of the chassis.

The antenna is located either to one side of the vehicle, or on both sides of the vehicle. In effect, when the vehicle arrives at one of the terminal of the forward line, it moves on the parallel return line either via a wide-radius loop connecting the ends of both ways, or by making the return journey on a garage way located upstream of the return way.

10 Figure 5 illustrates the first figure case: the vehicle A is on the return way 3 in the same configuration as on the forward way 2, i.e. the head cabin up top. The arrow on the vehicle shows the path of the vehicle on the way. The waveguide 1 located on the way transmits out signals according to two directions shown by triangles L_1 and L_2 . By way of simplification, a signal supplied by the radiated power of a few slots of the waveguide 1 only
 15 is shown in Figure 5 but physically this signal exists all along the waveguide 1. The antenna 4 mounted on the vehicle has two lobes L_A and L_B .

On the forward path 2, the antenna 4 communicates with the waveguide 1 on the way since the transmitted (or received) signal by the waveguide 1 in the zone of the lobe L_1 has the same orientation as the zone of the receiving (or transmitting) lobe L_B of the antenna 4.
 20 On the return way 3, the antenna 4 communicates with the waveguide 1 on the way since the transmitted (or received) signal by the waveguide 1 in the zone of the lobe L_2 has the same orientation as the zone of receiving (or transmitting) the lobe L_A of the antenna 4. In this end-of-line configuration, a single antenna 4 is needed on the side of the vehicle the closest to the waveguide 1 on the way.

25 Figure 6 illustrates the second figure case: the vehicle A shifts from the forward way 2 to the return way 3 via a siding 20. It is therefore in the inverse configuration of that of the forward way 2, i.e. the head cabin at the rear of the vehicle (in this case, the vehicle generally has one cabin at each end, not featured here). Two antennae must be mounted on both sides of the vehicle, since the antenna 4, mounted on the vehicle to be closest to the waveguide 1
 30 on the way as the vehicle moves on the forward path 2, is found on the side furthest from the waveguide 1 on the way when the vehicle moves on the return way 3 while performing a forward and return journey on the siding 20.

CLAIMS

1. A receiving and/or transmitting antenna (4) mounted on a vehicle (A, B) moving along at least one way (2, 3) and communicating with a fixed communication device (1) located along at least one way (2, 3) by means of hyperfrequency signals of given wavelength, characterised in that it is constituted by a waveguide of rectangular section whereof a large face is pierced by rectangular slots (5) whereof the large dimension is less than the half-wavelengths of said hyperfrequency signal, and in that the space between the centre of two successive slots (5) is close to a half-wavelength of the hyperfrequency signal (λ_g) propagated in the waveguide.

2. The antenna according to claim 1, characterised in that the number of slots (5) is between five and ten.

3. The antenna according to claim 1, characterised in that the emissive face of the waveguide (1) of said antenna (4) is vertical and is located parallel to an emissive face of the fixed communication device (1) located along the way (2, 3).

4. The antenna according to claim 1, characterised in that the axis of the waveguide of the antenna (4) is parallel to the axis of the fixed communication device (1).

5. The antenna according to claim 1, characterised in that the antenna (4) is remote from the fixed communication device (1) by at least four wavelengths of said hyperfrequency signal propagated in air.

6. The antenna according to claim 1, characterised in that it is located to one single side of the vehicle (A, B).

7. The antenna according to claim 1, characterised in that it is located on each side of the vehicle (A, B).

8. The antenna according to claim 1, characterised in that it is covered by a radome.