United States Patent

Nakahara et al.

[15] **3,648,172**

[45] **Mar. 7, 1972**

[54] **CIRCULAR LEAKY WAVEGUIDE TRAIN COMMUNICATION SYSTEM**

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[52] **U.S. Cl.** **324/51,** 325/130, 343/717, 343/771

[51] **Int. Cl.** **H01q 13/10**

[58] **Field of Search**..................343/711, 712, 713, 717, 770, 343/771; 325/51, 130

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Primary Examiner—Eli Lieberman
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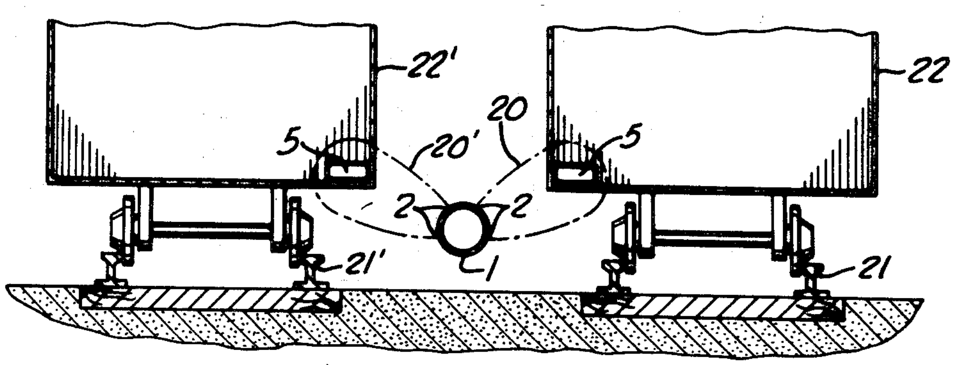
[57] **ABSTRACT**

A circular leaky waveguide comprising a metal tube or of a helix waveguide which is provided with a row or a plurality of rows of leakage apertures, each aperture having maximum diameter smaller than a half wavelength of the transmission wave, and spaced at intervals P<λoλg/λo+λg, where λ is free the space wavelength, and λg the waveguide wavelength.

3 Claims, 21 Drawing Figures



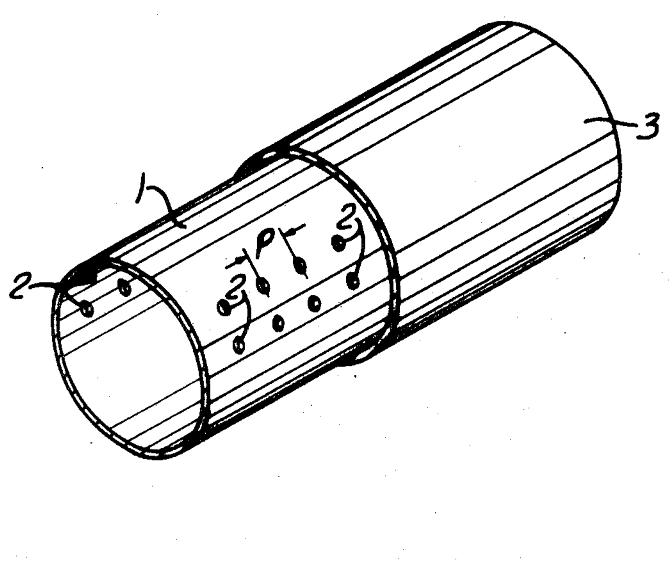


Fig. 1

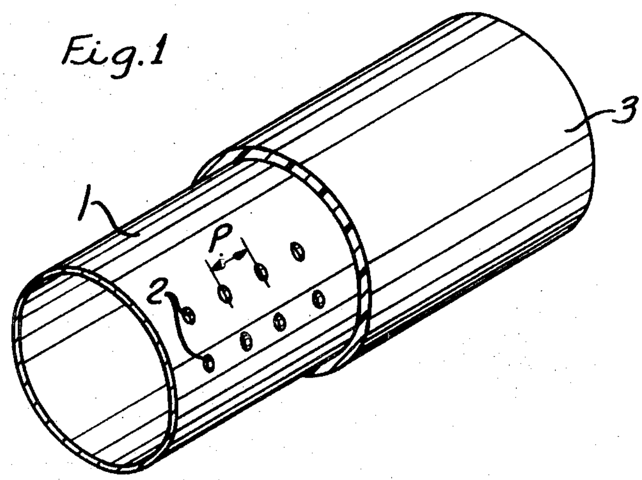


Fig. 2

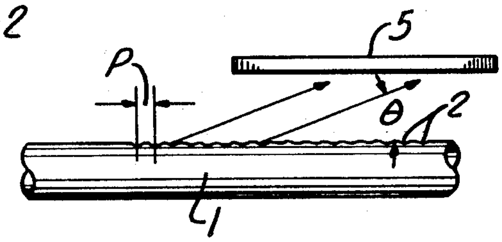


Fig. 3

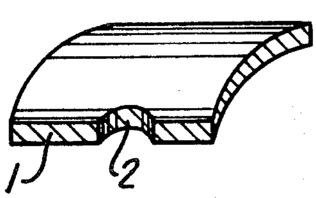


Fig. 4

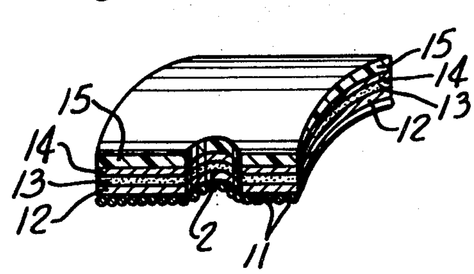


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Fig.5

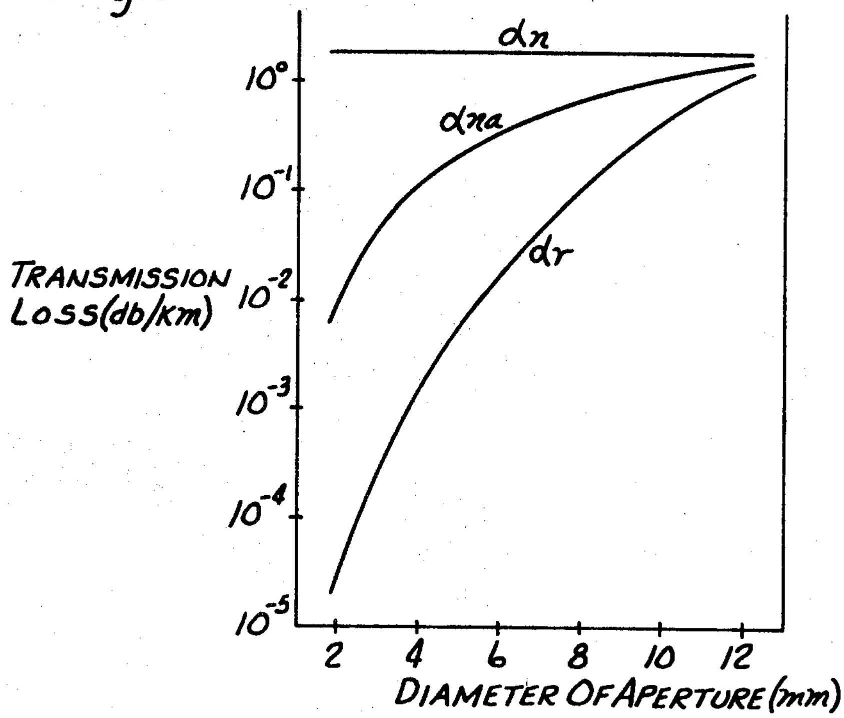

Fig.6

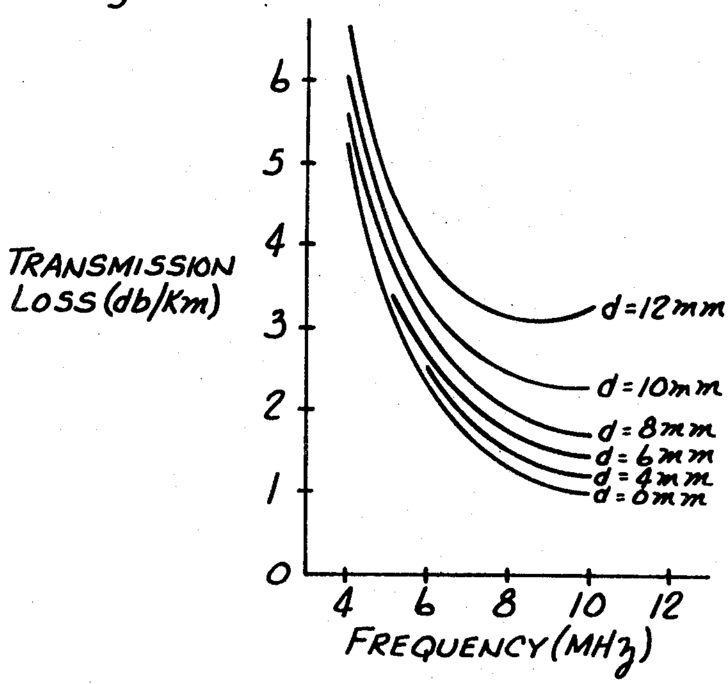

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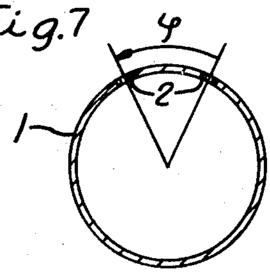
Fig. 7



TRANSVERSE RADIATION PATTERN

Fig. 7a - φ = 0°

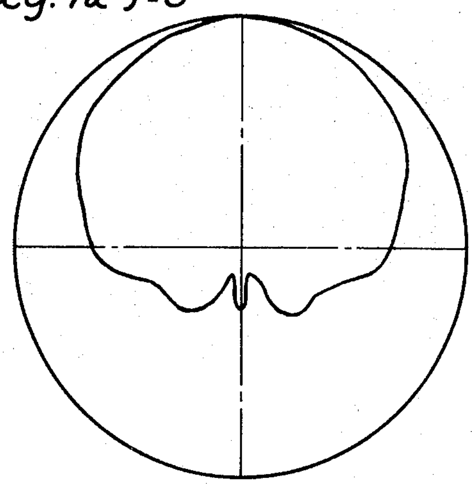


Fig. 7b - φ = 20°

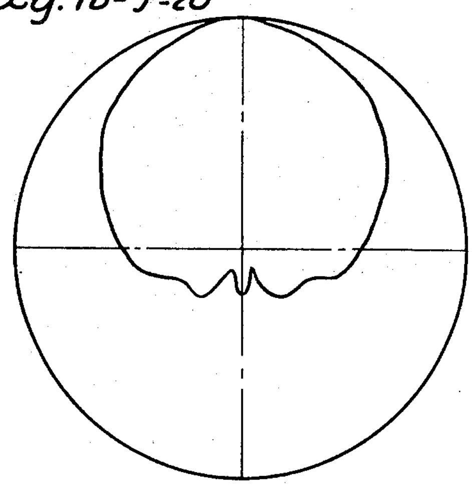


Fig. 7c - φ = 40°

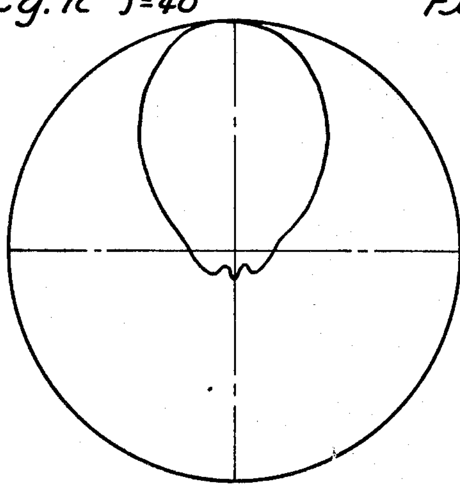


Fig. 7d - φ = 60°

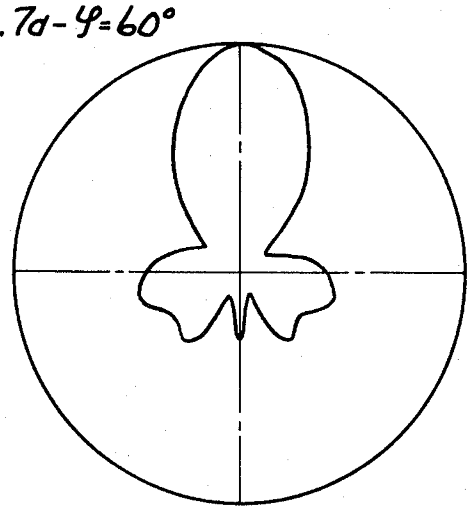


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Fig. 8

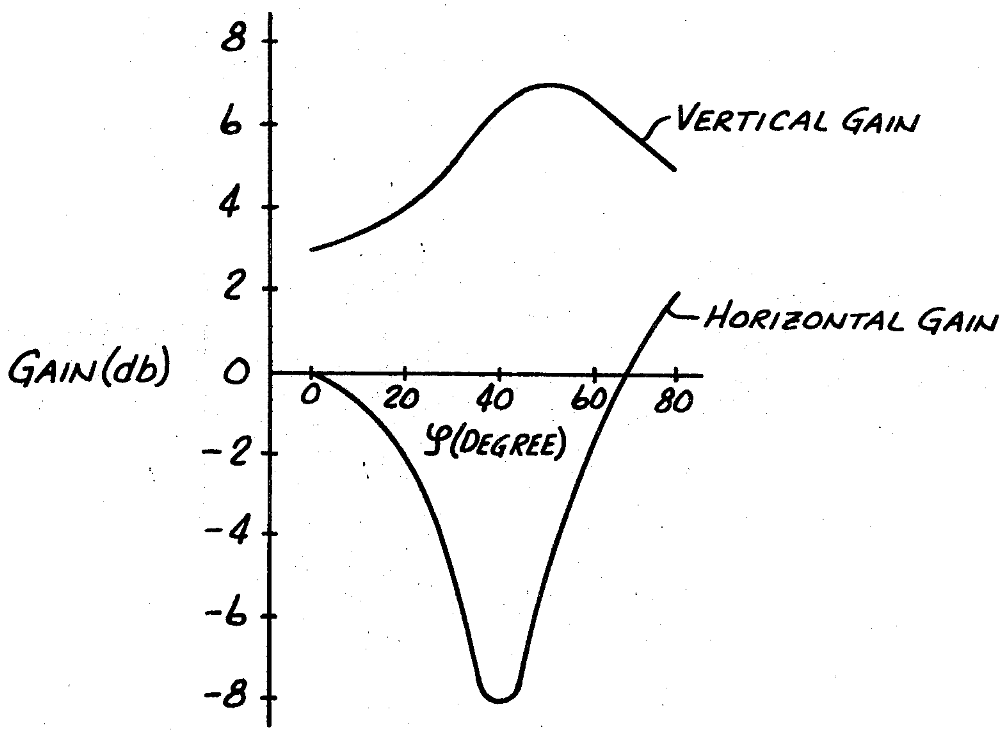

Fig. 9

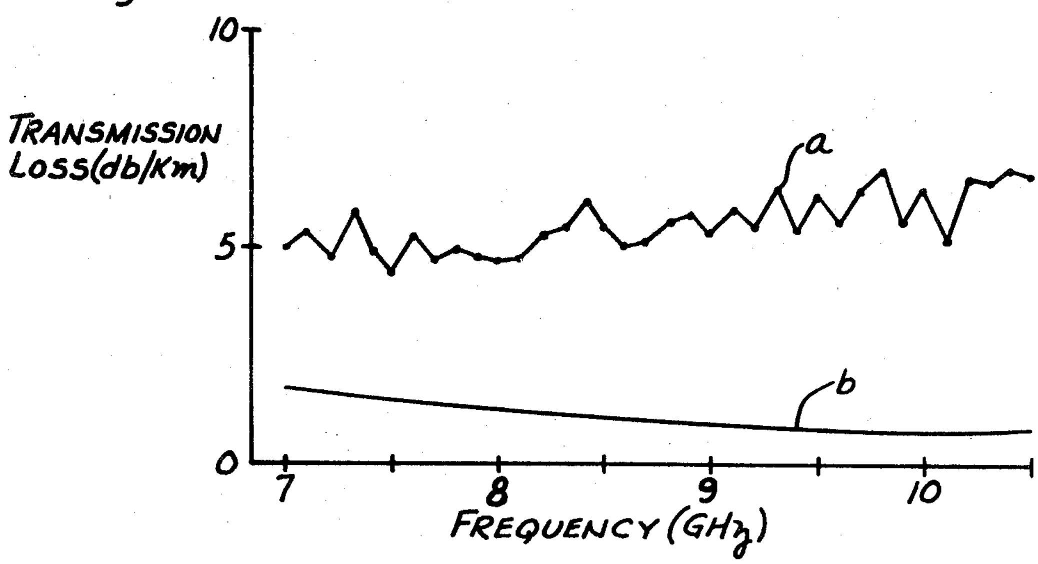

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Fig.10

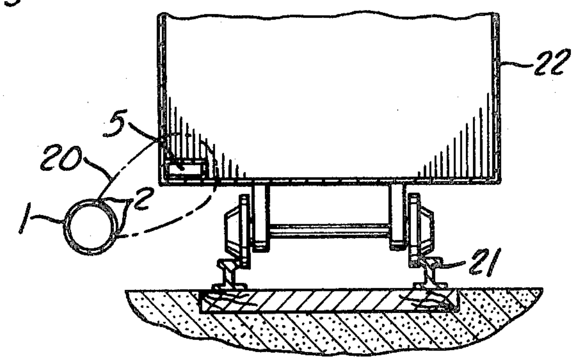

Fig.11

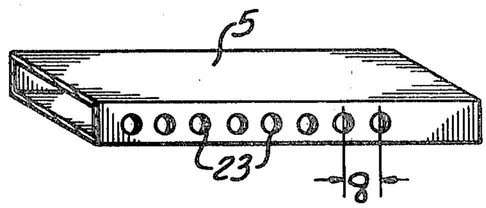

Fig.12

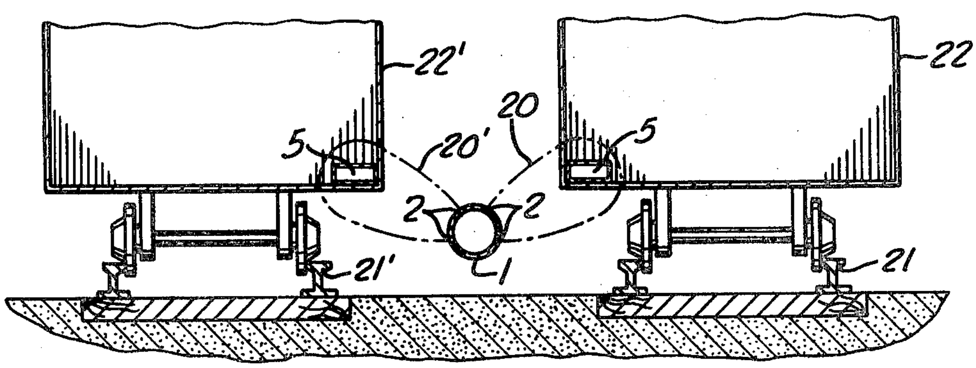

Fig.13

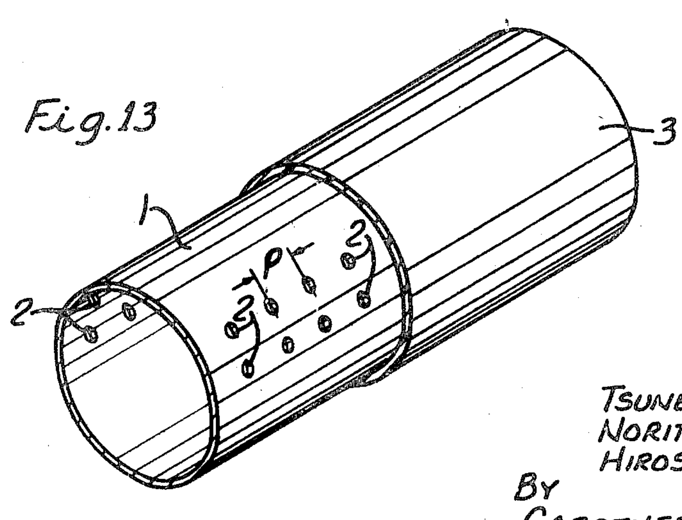

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Fig. 14a

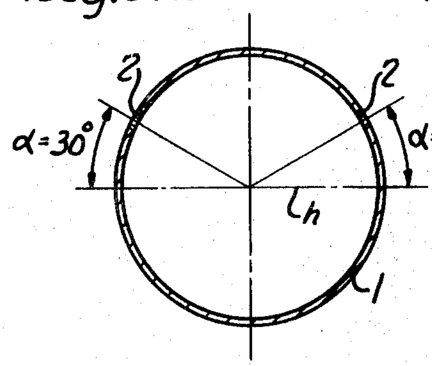


Fig. 14b

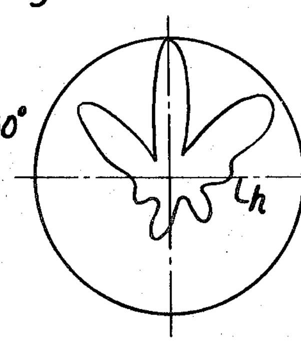


Fig. 15a

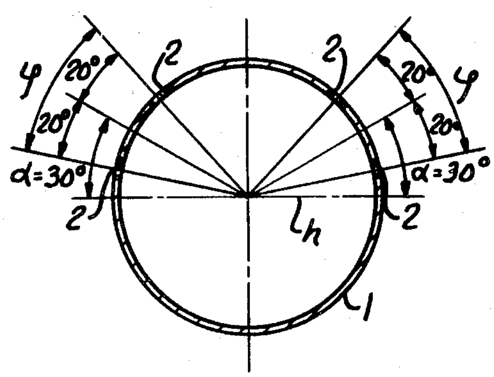
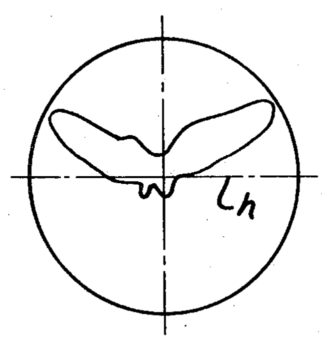


Fig. 15b



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CIRCULAR LEAKY WAVEGUIDE TRAIN COMMUNICATION SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

Train communication systems in which a leaky waveguide is installed along a railroad track and wherein a wave radiated from the leaky waveguide is received by the antenna aboard the train for transmission of signals for train telephone and signals necessary for train operation control in the frequence band from several hundred MHz. to several thousand MHz. have been under research.

The present invention relates to circular leaky waveguides.

2. Description of the Prior Art

Train communication devices have been known to employ a main circular waveguide for transmitting signal wave energy which branches off through directorial couplers at appropriate intervals into leaky waveguides of rectangular shape having leakage apertures for leaking a portion of the transmitting wave energy along a railroad track at an interval of about ½ the waveguide wavelength. The rectangular waveguide is installed in parallel to the track and an antenna aboard a train couples with the leaky wave of the leaky waveguide.

When the transmission wave is transmitted with low attenuation in the main circular waveguide, a portion of the transmission wave is divided from the main circular waveguide and directed into the branched leaky rectangular waveguide through the directional coupler to be radiated uniformly along the track and coupled with the antenna aboard the train. When the antenna aboard the train radiates radiofrequency waves, the leaky rectangular waveguide couples with the wave from the antenna and sends this wave through the main circular waveguide to fixed communication stations connected to the main circular waveguide.

Another known leaky wave communications system, in which a circular waveguide having leakage apertures on the circular waveguide at much longer intervals than the wavelength in the longitudinal direction, is installed along the track and leaky waves from said leakage apertures are coupled with the antenna aboard a train.

The former system has several draw backs which are as follows. The construction of the transmission line of this prior art system is complicated and much higher in cost and uneconomical, because this system is comprised of two types of waveguides.

The transmission loss of the leaky rectangular waveguide is very large, because the transmission mode, that is TE_{10} mode, has high heat loss characteristics. At a curved section of the track the transmission mode of the TE_{01} mode of a circular electric mode is readily converted into the unwanted TM_{11} mode, which makes it necessary to provide a film coating of polyethylene on the inner surface of the circular waveguide so as to prevent the mode conversion.

The manufacture and installation of the leaky waveguide of this system calls for a high degree of technique or skill in order to keep the uniform distribution of the leaky wave along the track, because the spacing between adjacent leakage apertures sharply effects the distribution of the leaky wave.

By the thermal expansion and contraction of the leaky waveguide, the relative distance between leakage apertures on adjacent branches of leaky rectangular waveguides changes. This causes an uneven distribution of the leaky wave which interrupts communication signals.

It is hardly possible to exclude such thermal effects.

The latter mentioned system has the following disadvantages:

Since the distance between adjacent leakage apertures in the direction of wave transmission is very long as compared with the waveguide wavelength, the leaky wave radiated to the outside from a leaky aperture is still in the state of a spherical wave in the neighborhood of the leaky waveguide and produces a standing wave between leaky waves radiated from the adjacent leakage apertures, so that when a train moves therealong the coupling level between the train antenna and leaky waveguide fluctuates greatly and produces great signal distortion in the communication.

With respect to the interior of the circular waveguide, it is observes that since the distance between adjacent leakage apertures are long as compared with the waveguide wavelength, there is no selectivity between modes which are easily excited and modes which are hard to excite in connection with the generation of unwanted modes, so that almost all unwanted modes, mainly the TE_{mn} modes (where m and n are integers, except $m = 0, n = 1$), are excited in equal amounts, with the result that a great deal of unwanted modes are generated in the waveguide. The generation of unwanted modes makes the transmission loss of the TE_{01} mode exceedingly great, and the communication distortion of the transmission due to mode conversion and reconversion is exceedingly great.

BRIEF EXPLANATION OF DRAWINGS

FIG. 1 shows a sectional perspective view of a circular leaky waveguide illustrating one embodiment of the present invention.

FIG. 2 shows a view in side elevation explaining the relation between the circular leaky waveguide and the antenna aboard a train.

FIGS. 3 and 4 show sectional perspective views of the embodiments of the present invention.

FIGS. 5 and 6 show curves of theoretical results of transmission properties of the system of the present invention.

FIG. 7 shows a transverse sectional view of the circular waveguide of the present invention for illustrating the radiation patterns of the leaky wave at different central angles.

FIGS. 7*a* through 7*d* are graphical illustrations of the transverse radiation patterns of the leaky waveguide at different central angles of the waveguide shown in FIG. 7.

FIG. 8 shows curves of the vertical and horizontal gain of the waveguide of the present invention at various central angles.

FIG. 9 graphically shows the experimental results of a transmission loss.

FIGS. 10 and 12 are sectional views in elevation illustrating embodiments of the train communication system of the present inventions.

FIG. 11 shows a sectional perspective view of an antenna used in the train communication system of the present invention.

FIG. 13 shows a sectional view of a circular leaky waveguide suited to the train communication system as shown in FIG. 12.

FIGS. 14 a and b and 15 a and b sectional views of circular leaky waveguides with their corresponding radiation patterns.

DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention provides circular leaky waveguides and a moving body communication system using said circular leaky waveguides which eliminate the drawbacks of the aforementioned two systems of the prior art.

An object of the present invention is to provide a circular leaky waveguide in which leakage apertures are placed on the wall of a circular waveguide of an electroconductive circular tube, such as an aluminum tube, copper plated steel tube or a helix waveguide at fixed intervals of $P < \lambda_o\lambda_g/\lambda_o + \lambda_g$, (where λ_o is free space wavelength and λ_g is waveguide wavelength) in one row of apertures or more than two in the longitudinal direction.

Another object of the present invention is to provide a circular leaky waveguide which has four rows of leakage apertures, two rows of the four rows of apertures being provided for the in track, and the other group of two rows being provided for the adjacent parallel out track. The central angle of each pair of aperture rows as measured from the horizontal at the central axis of the circular waveguide is from 30° to 50°, and they are placed in the wall of the circular waveguide at the fixed interval P, defined above, in the longitudinal direction.

Still another object of the present invention is to provide a moving body communication system in which the circular leaky waveguide of the present invention is installed along a railway track and antennas mounted aboard trains, couple with a leaky wave from said circular leaky waveguide.

FIG. 1 shows the perspective view of an embodiment of a circular leaky waveguide of the present invention.

In FIG. 1, 1 denotes a circular waveguide constructed of an aluminum tube, copper tube, copper plated steel pipe or a so called helix waveguide having such construction that a fine enameled copper wire is closely wound helically, this helix is surrounded by an impedance transformer jacket of dielectric material and this transformer jacket is further surround by a shielding conductive layer. 2 denotes the leakage apertures of circular, rectangular or elliptic shape having their largest measurement shorter than ½ wavelength of the transmission wave from which leaky wave radiates to the outside of the circular waveguide.

Apertures 2 are provided on the wall of the circular waveguide 1 at the interval P in the longitudinal direction in each -ow or two or more rows.

In FIG. 1, an example of the circular leaky waveguide having two rows of leakage apertures is shown. The aperture interval P determines the properties of the leaky wave radiated through the aperture of a part of the energy of the transmission wave of the TE_{01} mode of the circular electric mode. P is defined as follows:

$$P<\lambda 0\lambda g/\lambda 0+\lambda g, \text{ and}$$

where λo is free space wavelength, and λg is waveguide wavelength of circular waveguide. When the aperture interval P is kept within the range defined above, the angle θ between the axis of the waveguide and the direction of the leaky wave is determined by the following equation.

$$\theta = \cos^{-1}(\lambda o/\lambda g) = \sin^{-1}(\lambda 0/\lambda c),$$

where λ0 and λg are already explained. λc is the cutoff wavelength of the circular waveguide.

It is very important to know the fact that the radiation angle θ is not dependent on the interval P of the apertures. For example, the radiation angle θ is taken as 23° in the embodiment of the present invention where the diameter of the circular waveguide of aluminum tube is 132 mm., the frequency of the waveguide having apertures aligned at the interval $P = 14$ mm. is 7.5 GHz., and with $\lambda 0 = 40$ mm. and $\lambda g = 43$ mm.

FIG. 2 shows the radiation angle θ and the relative position between a leaky waveguide and an antenna aboard a train. In FIG. 2, 5 is the antenna equipped aboard the train which runs in parallel to the leaky waveguide, other reference numbers show the same parts as shown in FIG. 1.

FIG. 3 and FIG. 4 show sectional views of the detail of the wall structure used in the embodiments of the circular leaky waveguide.

FIG. 3 shows a wall structure of a metal pipe, such as aluminum tube, copper tube, etc., with holes properly positioned therein. In FIG. 3, 1 denotes a circular waveguide 2 denotes the leakage apertures.

When a circular waveguide transmits the wave of a TE_{01} mode, the current flow at the inner surface of the waveguide has substantially a circumferential current component alone. When a circular waveguide has apertures, the current flow at the inner surface of the waveguide has some perturbed axial current components in the neighborhood of the leakage apertures.

This axial current component is caused by the fact that the circumferential current component being disturbed by an aperture changes the direction of a part of the current flow to go round the aperture. This axial current component is apt to generate the unwanted TM mode waves which slightly increase transmission loss.

FIG. 4 shows the details of the wall structure of a helix waveguide having a leakage aperture as in the circular leaky waveguide.

In FIG. 4, 1 denotes a circular leaky waveguide, 11 is a fine insulated wire in the form of helix, 12 is an impedance matching layer of a dielectric material which is well penetrated by unwanted waves, 13 is a lossy layer for the purpose of absorbing the energy of unwanted mode waves, 14 is a conductive layer of shielding off unwanted modes, and 15 is outer protective covering made of a dielectric.

The helix waveguide as shown in FIG. 4 is disclosed in the Japanese Pat. No. 2677/1962. The helix waveguide as shown in FIG. 4 has many favorable properties in that the attenuation of the TE_{01} mode is little, the suppression of unwanted modes is very effective, the transmission loss due to mode conversion is little, and the helix waveguide serves as a filter to purify the TE_{01} mode and to remove spurious mode components, particularly those of the TE_{11} and TE_{12} modes, when used in a shorter length. If the helix waveguide having an aperture as shown in FIG. 4 transmits the wave of the TE_{01} mode, the current around the aperture does not flow to avoid the aperture because the impedance in the axial direction is very much larger than the impedance the circumferential direction, and the axial component of the current around the aperture which causes spurious modes is negligible.

The helix waveguide has more excellent properties than that shown in FIG. 3, but it is extremely expensive to manufacture.

A combined type transmission line without leaky wave apertures for the transmission of the TE_{01} mode wave, which is made of circular waveguides consisting of metal tubes and helix waveguides intermittently interposed among the circular waveguides of metal tube, has been previously known.

According to the present invention, a combined type circular leaky waveguide may be constructed by using the circular waveguides constructed of metal tube as shown in FIG. 3 and the helix waveguides as shown in FIG. 4 in combination, which not only radiates a leaky wave along the sections of the circular waveguides of metal tubing, but also radiates equally along the sections of helix waveguides.

The experimental results of an actual embodiment of the present invention will be explained as follows.

FIGS. 5 and 6 show the theoretical results of the transmission properties of the leaky waveguide of the present invention.

FIG. 5 shows the transmission loss (dB/km) of the TE_{01} mode wave versus diameter (mm.) of the leakage apertures of the circular leaky waveguide where the circular leaky waveguide is made of an aluminum tube having an inner diameter of 132 mm., a transmission wave mode which is the TE_{01} mode, frequency for the transmission wave as 8 GHz., a shape for the leakage aperture of round, and an interval P between apertures of 14 mm. aligned in the longitudinal direction. The curves αh , α_{ha} and α_r represent the substantial heat loss of the circular waveguide without leakage apertures, for the TE_{01} mode, the additional heat loss caused by the leakage aperture and the radiation loss by the leaky wave respectively.

It is noted from these curves that when the practical range of diameter of the leakage aperture lies within 4–12 mm., the additional heat loss α_{ha} by the leakage aperture is much smaller than that of the conventional leaky waveguide. For example, when the diameter of the aperture d is 4 mm., $\alpha_{ha} = 0.1$ db./km. and d is 12 mm., and $\alpha_{ha} = 1.2$ db./km.

FIG. 6 shows the curves for the total transmission loss (db./km.) of the substantial heat loss α_h, additional heat loss by leakage apertures αha and radiation loss α_r versus frequency (GHz.) by the parameter of the leakage aperture diameters of the circular waveguide.

The result is that the additional heat loss αha by the leakage apertures shown in FIG. 5 is very small and this is considered to be so as follows: The TE_{01} mode wave and other unwanted mode waves are generated progressively by the apertures aligned at intervals which are small as compared with the waveguide wavelength in the axial direction of the waveguide, and the TE_{01} mode wave newly generated reacts as a perturbed reactance to the transmission wave of the TE_{01} mode while other unwanted modes are set off and become smaller because their phases do not coincide. In consequence, the transmission wave of the TE_{01} mode is shifted slightly in its phase in the waveguide and other unwanted modes being generated contribute, to the additional heat loss by leakage apertures α_{ha}. The advantages of the leaky circular waveguide of the present invention will be explained below.

Since the radiation direction of the leaky wave having the angle θ with respect to the axis of the waveguide is determined by λo and λg as aforementioned, it is not affected by the interval P, and when the leakage apertures are provided on the wall of the circular leaky waveguide in the direction of the axis of the waveguide at the interval P. The radiation direction is not affected by a deviation of the interval of the leakage apertures when manufacturing the transmission line.

This condition is applicable also to the joints between leaky waveguides, so that the installation of the waveguide of the present invention becomes very facile. This is a remarkable advantage of the present invention.

The coupling between the antenna aboard the train and the leaky waveguide is considered in turn.

When n apertures radiating spherical waves are aligned from an original point on a straight line, the electric strength E at a point far from these wave sources in the direction of the angle θ with respect to the straight line is generally represented by following equation,

$$E=E_1e^{-j\psi_1}+E_2e^{-j\psi_2}+\ .\ .\ .\ +E_ne^{-j\psi_n}$$

where

$$\psi_n=\frac{2\pi\lambda_g}{\ln}\left(\cos\theta-\frac{\lambda_o}{\lambda_g}\right),$$

ln is the distance from the original point to the point of nth,

λo and λg in defined before,

θ is as aforementioned,

e is the base of the natural logarithm

If such wave sources are identified with the apertures of the leaky waveguide, then the radiation angle is θ, (here $\theta=\cos^{-1}($ $\lambda o/\lambda g)$ and $\Psi_n\equiv 0$.

In consequence, the electric field of the point P is given as follows:

$$E=E_1+E_2+ \cdots +E_n$$

It is noted that the maximum radiation of the leaky wave would be obtained within the radiation angle θ with respect to the waveguide axis.

In other words, the radiation in this direction has no connection with the pitch of the leakage apertures. Even if the sizes of the leakage apertures are different, they merely affect the magnitude of the aforementioned E_1, E_2 ...., E_n, so that only the intensity of the electric field of the point P changes, while the direction of radiation remains unchanged.

Moreover, since the leakage apertures are arranged at shorter intervals than the wavelength and the radiation directions of the leaky waves are uniform in the longitudinal direction, standing waves do not appear around the circular leaky waveguide so that the coupling between the antenna and the leaky wave is unfluctuable.

According to the present invention, the directivity in a plane perpendicular to the waveguide axis of the leaky waveguide is affected by the number of the rows of the apertures and distance between rows.

The beam of the leaky wave is diverged broadly when the waveguide has a single row of apertures, but concentrated more when it has double rows.

FIG. 7 shows the directivity in a plane perpendicular to the waveguide axis of the leaky wave in the situation where the central angle ϕ on the two rows of the leakage aperture changes from 0°–60°.

FIG. 8 shows two curves illustrating the gain in the vertical direction and horizontal direction when ϕ changes from 0°-80° as seen in a plane passing through centerline between the two rows of apertures and the central axis of the waveguide which is hold vertically.

It is noted from these graphs that the directivity of the leaky wave becomes sharp where ϕ is around 50° so that this is advantageous to increase the coupling between the antenna aboard the train and the leaky waveguide. The directivity of the leaky wave becomes broader where ϕ is around 20°.

This is, however, convenient for the use of a parabolic cylindrical reflector or elliptic-cylindrical reflector which reflects between the leakage aperture and the antenna. Around 40° of ϕ, the horizontal gain of the leaky waveguide becomes minimum so that this decreases the interference noise between this leaky wave system and another outside microwave communication system using the same microwave frequency, if present.

According to the present invention, since many leakage apertures are arranged along the waveguide axis, a difference appears in the transmission phase constant between the TE_{01} mode and the TM_{11} mode, so that the degeneration relation between them is released and the mode conversion from the TE_{01} mode to the TM_{11} mode and its reconversion are exceedingly reduced at a bend of the waveguide where they would inherently occur.

In consequence, the circular leaky waveguide of the present invention has little thermal loss due to mode conversion. For this reason, it makes it possible to make the distance between repeaters longer than that in the conventional system and also to intensify the coupling between the train antenna and the leaky waveguide.

It is to be especially noted that, the longer distance between repeaters makes it possible to reduce the number of repeaters required, so that the increase in thermal noise due to the additional use of repeaters may be reduced and the cost of construction may be lowered.

This has been a major cause for the lowering of the signal to noise ratio in the communication system.

The experimental results of the circular leaky waveguide of the present invention in which the transmission loss of the TE_{01} mode wave over the frequency range 7GHz. to 10GHz. is measured, was shown in **FIG. 9** in comparison with the theoretical values of thermal loss without the apertures.

In **FIG. 9**, the curve a shows these experimental results and the curve b the theoretical values.

In this experiment, a circular leaky waveguide made of an aluminum tube which has a diameter of 132 mm., has two lines of leakage apertures made at an interval of 14 mm. and has a central angle ϕ on the two alignments of the apertures of 20°.

In **FIG. 9**, the curve a shows the experimental results of the transmission loss of the circular leaky waveguide of the present invention to be nearly 4 to 6 db./km. over the frequency range of 7.5 GHz. to 10 GHz., and the curve (b) shows the theoretical values of the transmission loss of the circular waveguide without the apertures **2** to be **1** dB/Km over the same frequency range.

It is supposed that the radiation loss of the leaky wave is considered to be approximately 2–3 db./km. on this frequency range and the additional heat loss is about 1 db./km.

A train communication system according to the present invention will be explained hereinafter.

FIG. **10** shows a train communication system in which a circular leaky waveguide as shown in FIG. **1**, is connected to repeaters and other communication stations and is installed along the railroad track and the antenna aboard the train is coupled with the leaky wave from the leaky waveguide.

In FIG. **10**, **1** denotes a circular leaky waveguide, **21** is track rail, **22** is a train and **5** is the antenna aboard the train.

FIG. **11** shows an antenna which is very suitable for the train communication system as shown in FIG. **10**.

In FIG. **11**, **5** denotes an antenna of rectangular waveguide, section **23** denotes apertures provided on the narrower wall of the rectangular waveguide, and q is the interval between apertures which are sufficiently smaller than the wavelength of transmission wave.

This antenna is a type of travelling wave antenna. In the rectangular waveguide shown in FIG. **11**, if the waveguide wavelength λg is selected to be equal to the waveguide wavelength λg of the circular leaky waveguide, then the radiation directivity of the leaky wave from the apertures of the rectangular waveguide having the angle θ with respect to the axis of the waveguide would be coincident with the radiation directivity of the leaky wave from the circular leaky waveguide.

θ satisfied following relations.

$$\theta=\cos^{-1}(\lambda o/\lambda g)=\sin^{-1}(\lambda o/\lambda c),$$

where λ_c is the cutoff wavelength of the rectangular waveguide.

As a result, maximum coupling gain between the train antenna and circular leaky waveguide is obtained for transmitting and receiving.

In the train communication system as shown FIG. **10**, since the train shakes or vibrates severely in general, the mutual distance between antenna and waveguide greatly fluctuates.

This system, however, has the advantage that the variation of the coupling coefficient of this system in smaller than that of conventional systems.

It is explained as follows:

The variation of the distance between the train antenna and the leaky waveguide caused by vibration of train in a direction perpendicular to the waveguide axis is defined as *d*.

The leaky waves from the apertures radiate in the direction of the angle θ with respect to the waveguide axis by the free space wavelength λo and the transmission wave in the circular waveguide transmit in the direction of waveguide axis by the waveguide wavelength λg, so that the apparent wavelength in the direction perpendicular to the waveguide axis is equal to the cut off wavelength λ_c where $\lambda_c=\lambda o/\sin\theta$.

In consequence, the coefficient of the coupling variation *C* is obtained by the formula; $C=d/\lambda_c$, here λ_c is the cutoff wavelength of the circular waveguide which is known as $\lambda_c=90\ D/3.832$, where *D* is diameter of the circular waveguide. If $D=132$ mm., then $\lambda_c=108$ mm.

The coefficient of the coupling variation $c=d/\lambda_c$ of the system of the present invention is improved by 2.5 times in comparison with that of $C_0=d/\lambda_0$ of the conventional system which radiates the leaky wave in the direction perpendicular to waveguide axis with a free space wavelength of $\lambda_0=40$ mm. at 7.5 GHz.

Another embodiment of the train communication system of the present invention is shown in FIG. **12**. In general, in and up travelling train tracks are laid in parallel to each other, so that a circular leaky waveguide having two aperture rows for use of the in-and-out travelling train tracks respectively is installed between the two tracks and it is used at the same time for the communications of in-and-out travelling trains.

The circular leaky waveguide suitable for such train communication system is shown in FIG. **13**.

In FIG. **12**, **1** denotes a circular leaky waveguide, **20** and **20'** are leaky waves of two directions, **22** and **22'** are in-and-out travelling trains, **5** and **5'** are antennas aboard in-and-out travelling trains and **21 21'** are in-and-out railroad tracks.

In FIG. **13**, **1** denotes a circular leaky waveguide, **2** denotes leakage apertures of two rows for the in track and two rows for the out track and **3** is the outer jacket of the circular leaky waveguide.

Let us consider the relation of the leaky wave and the apertures.

FIG. **14***a* shows a sectional view of a circular leaky waveguide **1** which provides two rows of apertures **2** and **2'** for in and out tracks made at the interval P aforementioned.

Lines drawn in parallel to the in-and-out rows of apertures through each aperture center make a central angle ϕ of 30° in the circular waveguide with respect to the horizontal axis ***h***.

FIG. **14***b* shows a pattern of radiation of a leaky wave emitted from the circular leaky waveguide as shown in FIG. **14***a*. It is noted that the unwanted vertical lobe appears.

FIG. **15***a* shows the sectional view of a leaky waveguide **1** which provides four rows of apertures **2** made at the interval P, two being for the in track and two for the out track.

In FIG. **15***a* the parallel centerlines passing between the in rows of apertures and the out rows of apertures each make a central angle α of 30° with respect to the horizontal axis and the central angle ϕ between each set of two aperture rows for the in and ϕ for the out rows are both 40°.

FIG. **15***b* shows a pattern of radiation of a leaky wave emitted from the circular leaky waveguide as shown in FIG. **15***a*.

It is noted that the unwanted vertical lobe disappears, so that the radiation of the leaky wave in the direction of the angle α is made more effective.

From our experiments, it has been observed that the most suitable values for these angles for the in and out track system is obtained within the range $\phi=20°-60°$, and $\alpha=0°-40°$.

We claim:

1. A vehicle communication system comprising a metallic circular leaky waveguide positioned between inbound and outbound vehicle tracks and having two pairs of axially extending rows of leakage apertures with each pair having a circumferential spacing between row pairs determined by the central angle ϕ within the range of 20° to 80°, each of said apertures having a maximum measure smaller than half the waveguide wavelength with an interval between adjacent apertures which is less than λoλg/λo+λg , wherein λo is the free space wavelength and λg is the waveguide wavelength, one pair of said aperture rows positioned for coupling with an antenna on an outbound vehicle and the other pair positioned for coupling with an antenna on an inbound vehicle.

2. The vehicle communication system of claim **1** wherein said metallic circular leaky waveguide is a circular helix waveguide.

3. The vehicle communication system of claim **1** characterized by an antenna mounted on a vehicle on said track and coupled for leaky wave transmission or reception with said leaky waveguide, said antenna consisting of a waveguide section having a row of leakage apertures spaced at an interval sufficiently shorter than the waveguide transmission wavelength, said waveguide section having the same waveguide wavelength as that of said circular leaky waveguide.

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