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Yoshida et al.

[11] **3,781,725**

[45] **Dec. 25, 1973**

[54] **LEAKY COAXIAL CABLE**

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[73] Assignee: **Sumitomo Electric Industries, Ltd.,** Osaka, Japan

[22] Filed: **May 4, 1972**

[21] Appl. No.: **250,277**

[52] **U.S. Cl.** ..... **333/84 R,** 333/96, 343/771

[51] **Int. Cl.** **H01q 13/22,** H01p 3/06

[58] **Field of Search** ..... 333/97 R, 84 R, 96; 343/770, 771

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Primary Examiner—Rudolph V. Rolinec
Assistant Examiner—Wm. H. Punter
Attorney—Carothers et al.

[57] **ABSTRACT**

The present invention provides a leaky coaxial cable for communication with moving vehicles which comprises an inner conductor with delaying properties for an electro-magnetic wave and an outer conductor having a slot arrangement made of an oblique slot arranged repeatedly in a constant period or made of a group of oblique slots arranged repeatedly in a constant period, with said slots of each group being arranged in a different period therein. When such a leaky coaxial cable is installed along a track for a moving vehicle and fed by a communication signal of a very low frequency band as around 30 MHz, the coupling level fluctuation between the leaky coaxial cable and the antenna of a mobile unit in accordance with the movement thereof is extremely reduced even over such low frequency band and furthermore the operable frequency band width is made broader.

8 Claims, 9 Drawing Figures

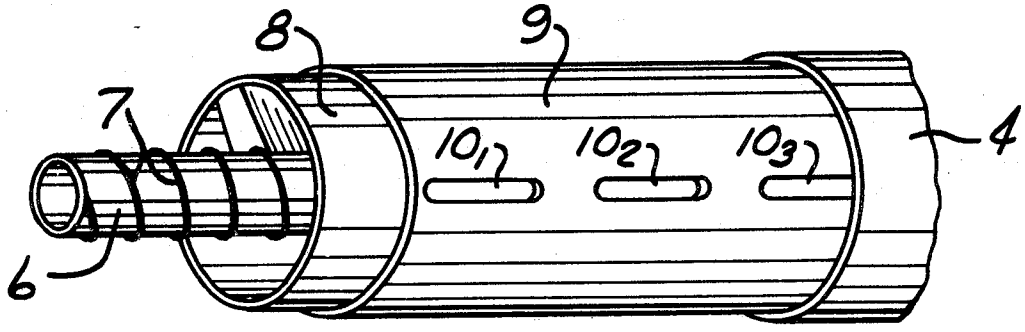


Fig. 1

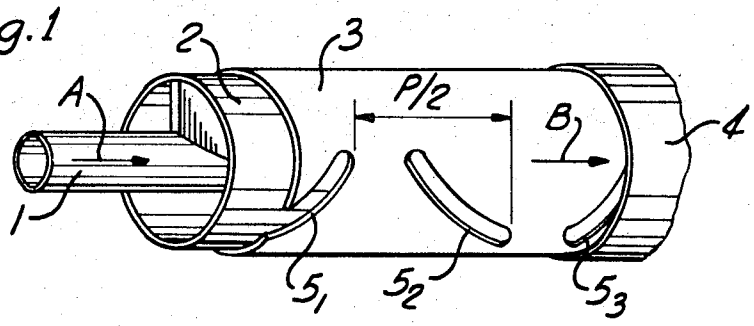


Fig. 2

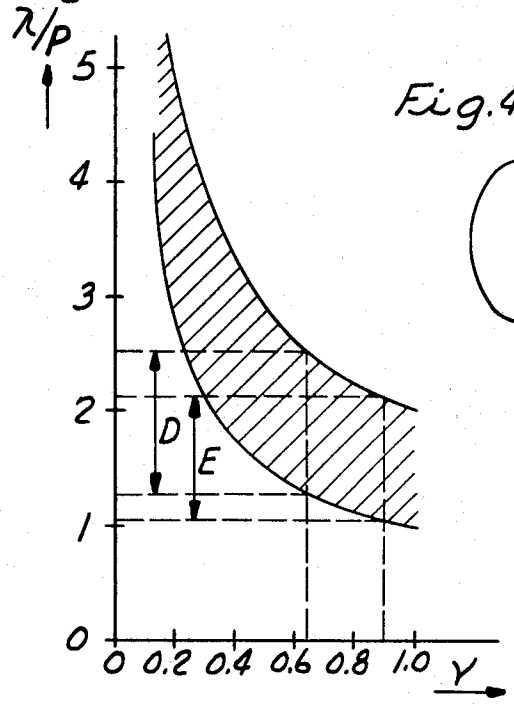


Fig. 4

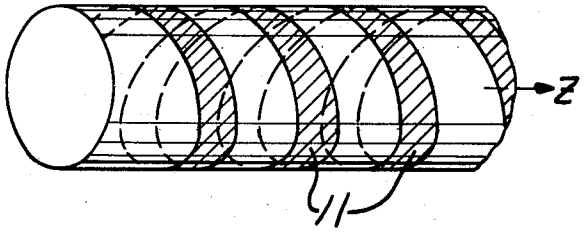


Fig. 3

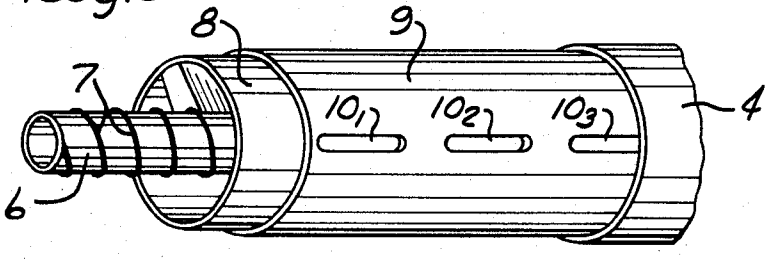


Fig. 5

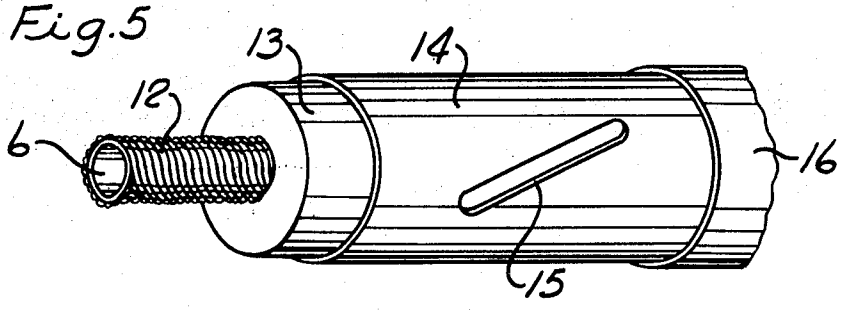


Fig. 6

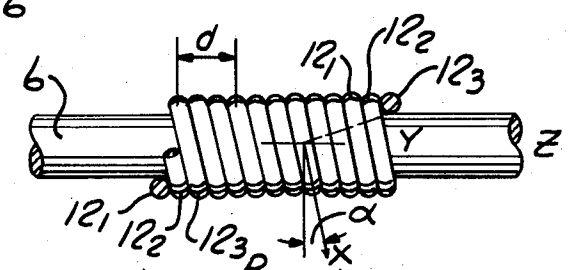


Fig. 7

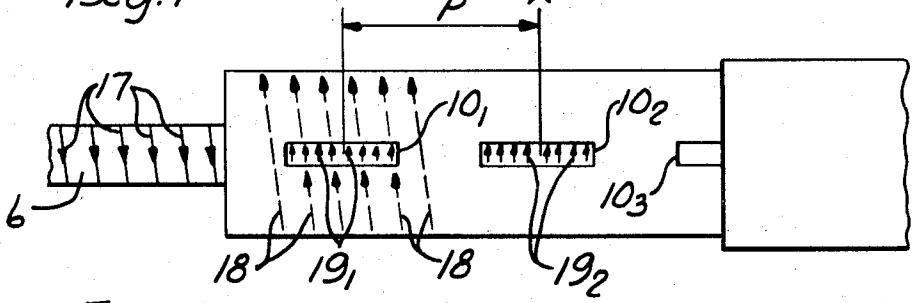


Fig. 8

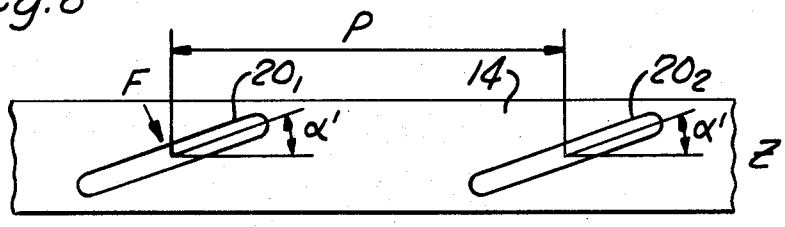
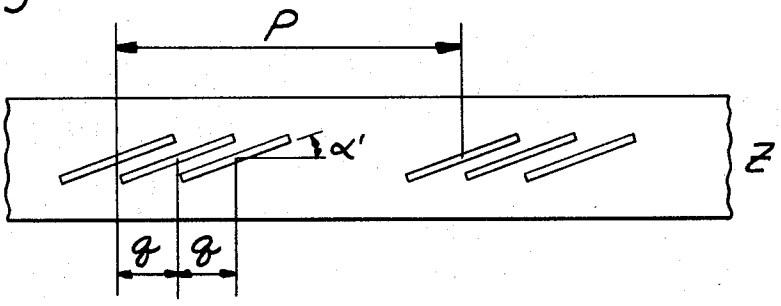


Fig. 9



LEAKY COAXIAL CABLE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to leaky coaxial cables.

2. Description of the Prior Art

A typical structure of a conventional leaky coaxial cable is shown in FIG. **1**, in which the leaky coaxial cable comprises an inner conductor designated by reference number **1**, an outer conductor **3** in which a series of slots 5_1, 5_2, . . . are provided in the axial direction with a constant period. An insulator is provided between the inner conductor **1** and the outer conductor **3** and an insulator sheath **4** protects the outer conductor **3**. The main electric characteristics of the cable, such as the uniformity of distribution of leaking wave, the stability thereof, and the frequency band width which can be used for stable leaky wave radiation, etc. are mainly determined according to the structure of the slots provided in the outer conductor, such as the shape and the period of the arrangement of the slots. As is shown in FIG. **1**, the main directions A and B of the currents flowing on the inner conductor **1** and flowing on the inner wall of the outer conductor **3** respectively are nearly parallel to the axis of the cable and are reversed alternately by the period of about one-half the wave length. Taking into consideration the distribution of the currents mentioned above, a suitable slot shape and period of arrangement must be determined for stable leaky wave radiation.

In a leaky coaxial cable as shown in FIG. **1**, the propagation phase constant γn in the radial direction of the cable is indicated, as is well known, by the following formula;

$$(\gamma n)^2 = (2\pi/\lambda)^2 - (2\pi/\lambda g + 2n\pi/p)^2, \quad (1)$$

Wherein p is the period of the slots, λ is the wave length in free space of a used frequency, λg is a propagation wave length in the cable, and n is an integer. The conditions of stable radiation is defined as $(\gamma n)^2 > 0$ in equation (1) and the number of integers which will satisfy the above conditions and provide the leaking of a single beam wave should be only one. In view of these facts, it is known that the period p of the slots is restricted by the following formula;

$$1/\nu + 1 > \lambda/p > \tfrac{1}{2}(1/\nu + 1) \quad (2)$$

wherein ν is the shortening ratio of the wave length which is defined by the ratio of the wave length in a coaxial cable to the wave length in free space.

FIG. **2** is a graph illustrating formula (2), in which by setting the abscissa for ν and the ordinate for λ/p, the area designated by the oblique lines shows a range in which the conditions of a stable radiation of a single beam wave are satisfied. When the shortening ratio ν of the wave length of the coaxial cable is given, the range of the value of λ/p is decided.

Now, one of the most important electric characteristics of the leaky coaxial cable is the uniformity of the coupling level between the cable and the antenna of a mobile unit travelling beside the cable. The uniformity of the coupling level along the axis of the cable increases in accordance with the density of the slot arrangement on the cable. Accordingly, when designing the leaky coaxial cable, the period p of the slots must

be decided so as to satisfy both the above condition of uniformity of the coupling level and the condition defined by equation **2**.

It is known that in the construction of a conventional leaky coaxial cable as shown in FIG. **1**, the value of ν is about 0.9, and even when the space between the inner conductor and the outer conductor is wholly filled with an insulator such as polyethylene, the value of the shortening ratio of the wave length of the cable reachs about 0.67 at the most. The allowable ranges of λ/p corresponding to these values of 0.67 and 0.9 of ν are designated by references D and E in FIG. **2**, respectively. Therefore, for such construction as shown in FIG. **1** of a conventional leaky coaxial cable, the preferably frequency band is about 400 MHz and is limited at the most to about 150 MHz from the viewpoint of the single wave radiation stability and uniformity of the coupling property. If a value of λ/p is selected as about 2 in the range of D or E for stable radiation restricted by formula **2** and an operation frequency is selected as 150 MHz whose wave length λ is 2 meters, the slot period p will be determined to be about 1 meter.

Such a value for p is almost the limit for keeping the uniformity of the coupling level. In the case where a lower frequency such as 30 MHz whose wave length is 10 meters is required to be used under the structure of the conventional leaky coaxial cable having the value of λ/p as 2, the slot period will be about 5 meters only because of the condition of stable radiation.

However such a long slot period causes a strong fluctuation of coupling level along the cable which is very harmful for communication with mobile units.

THE SUMMARY OF THE INVENTION

As is obvious from FIG. **2**, if the value of the shortening ratio νcan be selected to be small enough even at a low frequency band by improving the structure of the leaky coaxial cable, the value of λ/p could be very large and the range thereof could also be wide.

The object of the present invention is to provide an improved leaky coaxial cable having a novel cable structure for dissolving the defect of the conventional leaky coaxial cable as described above.

That is, the invention is characterized by employing an inner conductor having a construction for delaying the electromagnetic wave propagation so as to make a small value for the shortening ratio of the wave length of the coaxial cable. Any type of conventional delay line can be applicable for the inner conductor of the cable of the present invention. When such a leaky coaxial cable is installed along a track for mobile units and fed by a communication signal of such a very low frequency band as around 30 MHz, the coupling level fluctuation between the leaky coaxial cable and the antenna of a mobile unit in accordance with the movement thereof is extremely reduced even over such a low frequency band and furthermore the operable frequency band width is made much broader. According to the present invention, very good quality communication with mobile units is successfully obtained.

BRIEF EXPLANATION OF THE DRAWINGS

FIG. **1** is a perspective view of a conventional leaky coaxial cable partially cut away for explanation.

FIG. **2** is a graphic illustration showing the zone in which the radiation of a single wave is stable.

FIG. 3 is a perspective view of one embodiment leaky coaxial cable of the present invention partially cut away.

FIG. 4 is a perspective view showing an inner conductor of the leaky coaxial cable of the present invention.

FIG. 5 is a perspective view of another embodiment of the present invention.

FIG. 6 is a perspective view showing an inner conductor composed of a plurality of insulated wires of the embodiment which is shown in FIG. 5.

FIG. 7 is a schematic view showing an embodiment of the present invention for explaining the slot excitation.

FIGS. 8 and 9 show side views of two different embodiments of the leaky coaxial cable of the present invention.

DETAILED DESCRIPTION OF THE INVENTION:

A leaky coaxial cable has a function of leaking the part of the electromagnetic wave which propagates in the cable, along the cable axis from slots arranged in a suitable period in its outer conductor. Leaky coaxial cables have been attracting attention in recent times for use in communication controlling systems for moving vehicles.

FIG. 3 shows a typical example of the construction of the leaky coaxial cable of the present invention. Referring to FIG. 3, an inner conductor wire 7 is wound in a spiral fashion around insulator pipe 6. An insulator 8 is provided for supporting the inner conductor 7. Outer conductor 9 has slots 10_1, 10_2, . . . provided therein. An insulator sheath is provided around the outer conductor 9 for protecting it. The space between the inner and the outer conductors may be filled with a dielectric material or may be empty. Also, the spiral conductor wire 7 is not limited to the form as shown in the figure.

The propagation electromagnetic field in the leaky coaxial cable according to the invention can be analyzed by the well-known Maxwell's wave equation under the boundary conditions that the conductivity becomes infinite in a direction along the conductive wire formed in a spiral and becomes zero in a direction vertical to that direction. But, the calculation by approximation methods will be explained briefly hereinafter.

The inductance L of the leaky coaxial cable of the present invention comprising the inner conductor of a spiral conductor and the outer conductor is defined approximately as the sum of the self inductance of a solenoid of infinite length and the inductance of same rasius as coaxial cable having the inner conductor which has the same the radius as the radius of the spiral conductor and the outer conductor, and it is expressed by the following equation mathematically;

$$L \approx \mu o\, \pi\, N^2 a^2 + \mu o/2 \log b/a \qquad (3)$$

where a is the radius of th spiral conductor, b is the radius of the outer conductor, μo is the permeability, and N is the number of winding turns of the spiral conductor per unit length thereof. In regard to the capacitance, the capacitance between the inner conductor and the outer conducor is approximately defined by the following equation;

$$C \approx 2\, \pi\, \epsilon o\, \epsilon_r / \log b/a \qquad (4)$$

where ϵo and ϵr are a dielectric constant in free space and a relative dielectric constant of the insulator, respectively.

From formulae (3) and (4), the characteristic impedance Zo of the coaxial cable and the shortening ratio ν' of the wave length thereof are obtained by the following equations respectively;

$$Zo \doteqdot \frac{60}{\sqrt{\epsilon_r}} \log \left\{ \frac{b}{a} \sqrt{1 + 2\pi^2 a^2 N^2 / \log \frac{b}{a}} \right\} \qquad (5)$$

$$\nu' \doteqdot \frac{1}{\sqrt{\epsilon_r}} \times \frac{1}{1 + \log \left\{ 1 + 2\pi^2 a^2 N^2 / \log \frac{b}{a} \right\} / 2 \log \frac{b}{a}} \qquad (6)$$

From the fact that the shortening ratio of the wave length for the usual coaxial cable is provided as $\nu o = 1/\sqrt{\epsilon_r}$, the shortening ratio ν' of the wave length of the leaky coaxial cable of the present invention may be made as $\nu' < \nu o$ by selecting the suitable sectional dimensions a and b of the cable and the winding turns per unit length N of the spiral conductor. Therefore, the above two equations provide the basic equations for designing the sectional dimensions and the winding turns of the spiral conductor of the leaky coaxial cable of the present invention.

FIG. 4 shows an inner conductor formed by a spiral conductor strip 11 in place of the conductive wire of the inner conductor described above.

FIG. 5 shows another construction of the leaky coaxial cable of the present invention. Referring to FIG. 5, the insulator mandrel 6 having a circular cross section and a set of a plurality of conductive wires 12 which are coated with an insulator respectively and wound closely around the insulator mandrel 6 to form the inner conductor and it is supported coaxially along the axis of the outer conductor 14 by the insulator 13. The slots 15 are provided on the outer conductor periodically in the direction of the axis of the cable, and further, the outer surface of the outer conductor is covered with a insulator sheath 16.

FIG. 6 shows a detailed construction of the inner conductor used in the cable as shown in FIG. 5. In the figure, the three conductive wires 12_1, 12_2 and 12_3 isolated from each other are wound around the insulator 6 closely and in parallel to each other in a spiral with a winding pitch d or with winding turns of $N = 1/d$ per unit length.

Although the three isolated wires are used for the inner conductor in the above embodiment, one or a suitable number of the insulated wires can be used. When using an inner conductor composed of conductive wires which are closely wound, the distribution of current flowing in the outer conductor is uniform in correspondence to the current flowing on the inner conductor and excitation of the slots can be carried out uniformly, so that a uniform leaky electric field is generated along the leaky coaxial cable of the present invention.

As a plurality of the isolated conductive wires in the above embodiment are used, the conductivity in the winding direction X of the conductive wire shown in FIG. 6 will be made infinite and the conductivity in the vertical direction Y will be made zero.

It is obvious that the shape and the arrangement of the slots of the outer conductor of th leaky coaxial cable having an inner conductor of the spiral conductor or conductors as described above must be determined

so as to have these slots effectively cut the current flowing to the outer conductor.

FIG. 7 is a drawing explaining the relation between the shape and arrangement of the slots of the leaky coaxial cable and the current flowing therein. Referring to FIG. 7, it is understood that the current on the inner surface of the outer conductor flows to the direction of dotted arrow **18** nearly circumferentially. Corresponding to that the current flows in the direction of arrows **17** along the spiral conductor of the inner conductor. Therefore, in the case as shown in FIG. 7, the slots must be arranged in parallel to the axis of the cable and with a small slot period in order to make the slots effectively cut the current flowing to the circumferential direction on the outer conductor. The arrows 19_1, 19_2, . . . in the figure show the electric fields appearing across the slots 10_1, 10_2. . . cutting the current in the circumferential direction. According to the arrangement of the slots in the present invention, only the component of the electric field in the circumferential direction of the cable is principally radiated to the outer space. Such a leakage wave of the electric field is a vertically polarized wave, and this is very advantageous for the usual radio communication system employing the vertically polarized wave.

Further, the relation between the angle of the spiral winding of the inner conductor and the angle of the slots with respect to the cable axis Z are determined precisely in such a manner that when the inner conductor is made of a plurality of insulated wires wound spirally by a pitch angle α as shown in FIG. 6 and the currents flow along the insulated wires, while the corresponding currents on the outer conductor are flowing in the direction of the arrow F as shown in FIG. 8, the slots 20_1, 20_2 . . . should be provided in the outer conductor obliquely with an angle α' to perpendicularly cut the current flowing in the direction F so as to excite the slot with maximum strength and they should be placed with a suitable constant repeating period P which will be explained later. The oblique angle α' of the slots may be an element for controlling the leakage amount of the electromagnetic wave. Therefore, the slots of the leaky coaxial cable of the invention may be arranged in parallel to the axis Z of the cable, that is α' is zero, or may be arranged obliquely as $\Gamma' < 0$, or in some cases as $\Gamma' < 0$, for obtaining a desired amount of leakage of the wave along the cable.

In regard to the period p of the slots, it must be determined by taking into consideration the operation frequency band of the propagating wave in the leaky coaxial cable. As mentioned with respect to conventional leaky coaxial cables, the value of λ/p is also governed by the following formula;

$$1/\nu' + 1 > \lambda/p > \tfrac{1}{2}(1/\nu' + 1) \quad (7)$$

Formula (7) shows the frequency band which may be stably used in relation to the repeating period p of th slots. This is quite the same as the above equation (2) for the condition for the conventional coaxial cable, but in the case of the present invention the shortening ratio ν' of the wave length is very different from the value of ν of the conventional coaxial cable. In the case of the conventional coaxial cable, $\nu = 0.67$ is taken as the Maximum, for getting single beam wave radiation. On the contrary, in the case of the present invention, for example, the value of ν' may be taken to be a very small value such as $\nu' = 0.2$. By inserting this value into equation (7), the following relation is provided:

$$6 > \lambda/p > 3 \quad (8)$$

It is understood that when a wave length π of the leaked electromagnetic wave is given, the repeating period p of the slots of the leaky coaxial cable of the present invention can be made very short compared with that of the conventional coaxial cable. This is especially effective for a very low frequency band in which the slot period p of the conventional system could not be obtained to be a small value. The slot period p can be made very small, to one severalth of that of the conventional one according to the present invention. This is very advantageous in view of the uniformity of the coupling level obtained along the leaky coaxial cable with the mobile antenna.

FIG. 9 shows a side view of an improved leaky coaxial cable according to the teachings of the present invention. The slots are arranged in such a manner that a group of slots whose elemental slots are arranged repeatedly with a minor constant period q and with a constant oblique angle α' with respect to the axis Z of the cable on the outer conductor, are arranged repeatedly in a major constant period p so as to provide a wide range for the band width of the usable frequency and also so as to provide sufficient uniform distribution of the radiation electric field at a low frequency band. The condition of formulae (1) and (7) may also be applicable to such leaky coaxial cables as shown in FIG. 9. Accordingly, it is possible to make the usable frequency band broader and extent the distribution of the radiation electric field at the low frequency band along the leaky coaxial cable uniformly.

In all of the embodiments described hereinbefore, the slots on the outer conductor are formed as narrow and straight slots, but the present invention is not limited to these configurations and it is applicable to all of the slot shapes having a vertical component with respect to the direction F of the current flowing on the inner wall of the outer conductor of the coaxial cable.

It is easily understood that a slot of any shape having the vertical component is equivalent to the narrow and straight slot having an equivalent oblique angle with respect to the cable axis.

The leaky coaxial cable of the present invention can be very broadly applied to communication systems.

What we claim is:

1. A leaky coaxial cable comprising an inner conductor having a structure for delaying an electromagnetic wave which consists of an elongated insulator mandrel core and at least one isolated conductor wound thereon in a spiral, and an outer coaxial conductor having a slot array arranged in the axial direction, the angle of each of said slots in relation to the cable axis being selected such that the slots cut the current flowing on the inner surface of the outer conductor at an angle selected to obtain the desired amount of wave leakage, the value of the winding pitch P of said wound conductor being determined by the formula:

$$1/\nu' + 1 > \lambda/p > \tfrac{1}{2}(1/\nu' + 1)$$

wherein ν' is a wave contraction ratio and λ is the wavelength in free space of an operating wave.

2. The leaky coaxial cable of claim 1 wherein said slots are arranged in groups with a predetermined minor slot period for each group and a larger constant major slot group period between adjacent slot groups.

3. The leaky coaxial cable of claim 1 wherein a plurality of said wound conductors are employed with said wound conductors isolated from each other.

4. The leaky coaxial cable of claim 1 wherein said wound conductor is a round wire conductor.

5. The leaky coaxial cable of claim 1 wherein said wound conductor is a tape conductor.

6. The leaky coaxial cable of claim 1 wherein said slot angle is selected such that the slots are perpendicular to the winding direction of said wound conductor.

7. The leaky coaxial cable of claim 1 wherein said insulator mandrel core is circular in cross section.

8. The leaky coaxial cable of claim 1 wherein said slot angle is other than parallel to the winding direction of said wound inner conductor.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,781,725 Dated December 25, 1973

Inventor(s) KENICHI YOSHIDA and YOSHIO MIYAMOTO

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 6, line 52, cancel beginning with "1. A leaky" to and including "an operating wave." in line 67 and insert the following claim:

1. A leaky coaxial cable comprising an inner conductor having a structure for delaying an electromagnetic wave which consists of an elongated insulator mandrel core and at least one isolated conductor wound thereon in a spiral and an outer coaxial conductor having a slot array arranged with a slot period p in the axial direction, the angle of each of said slots in relation to the cable axis being selected such that the slots cut the current flowing on the inner surface of the outer conductor at an angle selected to obtain the desired amount of wave leakage, the value of the slot period p of said slot array being determined by the formula:

$$1/\nu' + 1 > \lambda/p > 1/2\ (1/\nu' + 1)$$

wherein ν' is a wave contraction ratio and λ is the wavelength in free space of an operating wave.

Signed and sealed this 22nd day of October 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

FORM PO-1050 (10-69)

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