United States Patent

[11] 3,577,197

[72] Inventor **Chester B. Watts, Jr.**
6505 Pinecrest Court, Annandale, Va. 22003

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[54] **SLOTTED CABLE LOCALIZER ANTENNA**
4 Claims, 13 Drawing Figs.

[52] **U.S. Cl.** **343/771,** 343/853, 333/98P
[51] **Int. Cl.** **H01q 13/10**
[50] **Field of Search** ..... 343/767, 768, 770, 771, 850, 853; 333/98 (P)

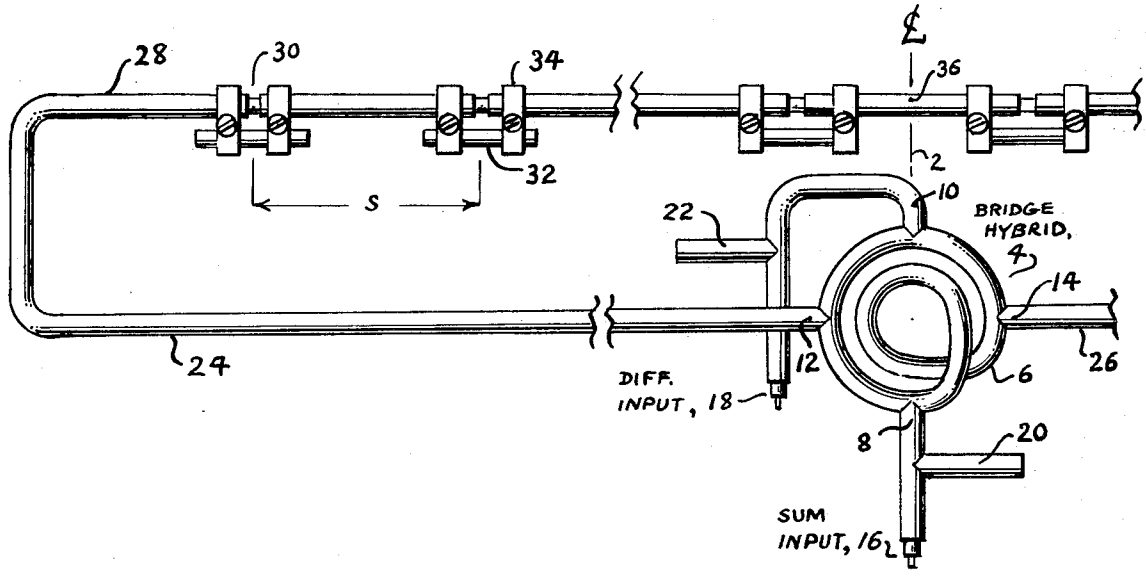
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Primary Examiner—Eli Lieberman

ABSTRACT: This invention relates to antennas for simultaneous transmission of sum and difference patterns as in a runway localizer for instrument landing of airplanes. A straight horizontal run of coaxial cable, placed centrally perpendicular to the extension of the runway centerline, is symmetrically fed from both ends by an RF bridge in sum and difference modes. The outer conductor of the cable is periodically interrupted by slots which permit currents to flow on the outside of the outer conductor. The antenna current distributions corresponding to the two modes are controlled by low-resistance shunts placed across the slots and by the relationship between the slots spacing and the internal guide-wavelength. To maintain the relationship over the 4 percent band of localizer frequencies, the guide-wavelength is adjusted always to the same value by filling the cable with the necessary quantity of a gas of relatively high-dielectric constant.



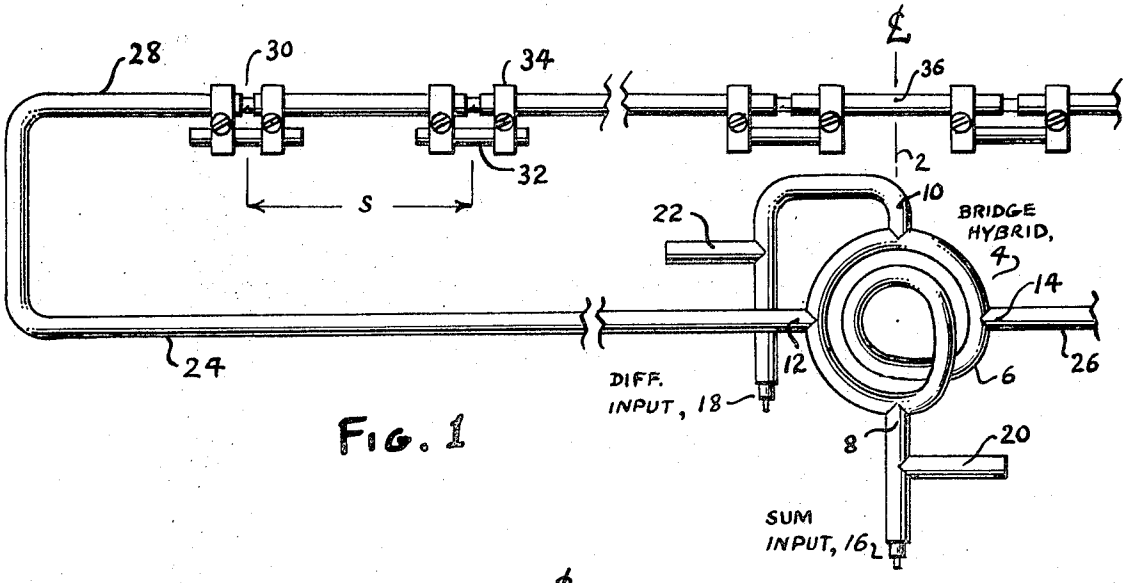


FIG. 1

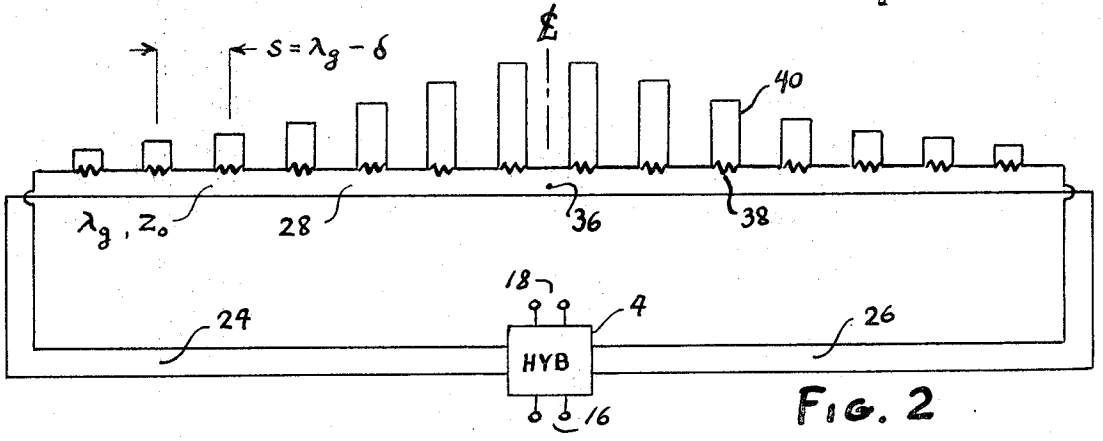


FIG. 2

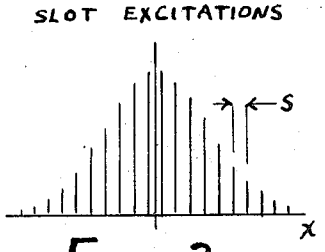


FIG. 3a

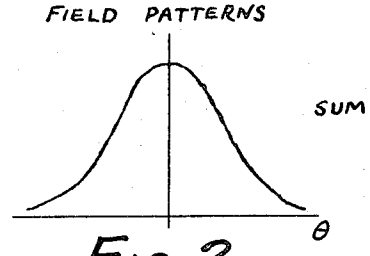


FIG. 3c

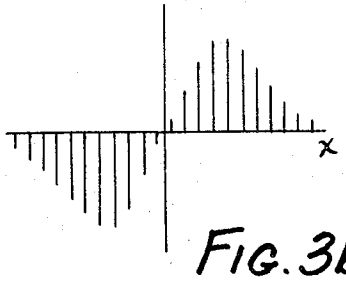


FIG. 3b

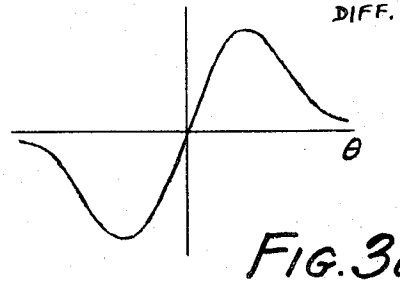


FIG. 3d

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Chester B. Watts, Jr.

FIG. 4a

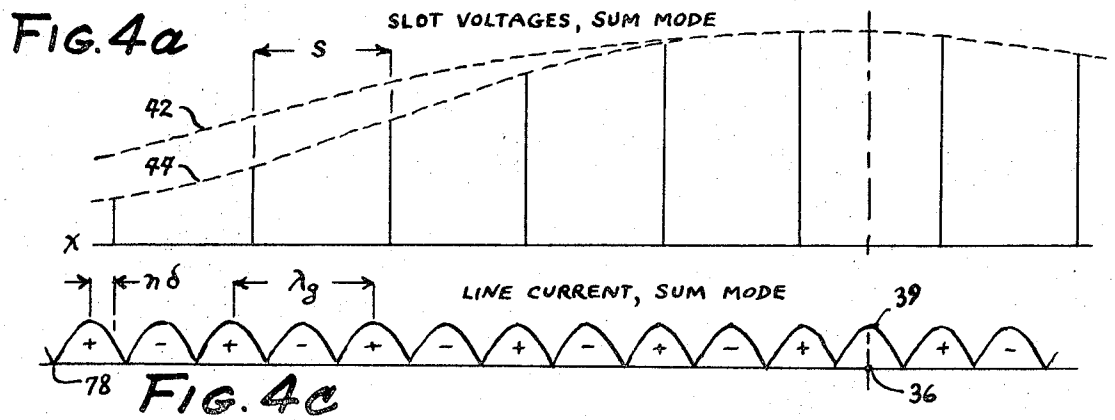


FIG. 4c

FIG. 4b

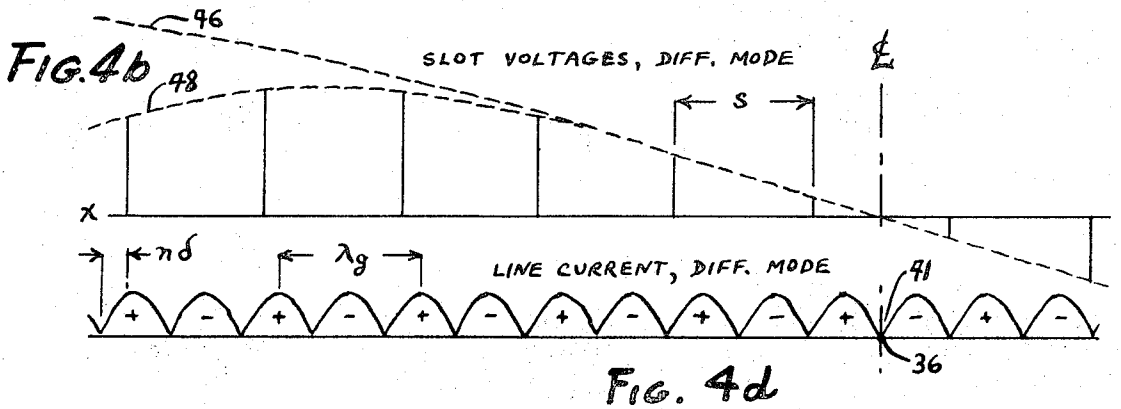


FIG. 4d

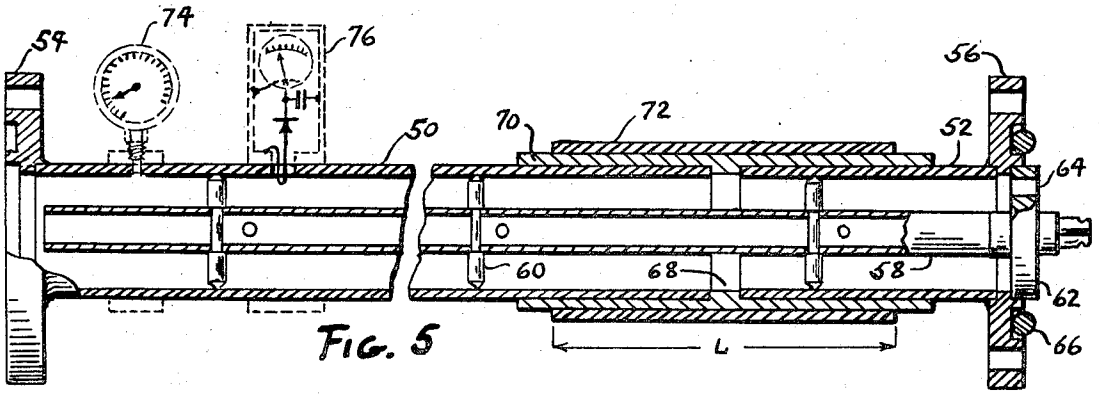


FIG. 5

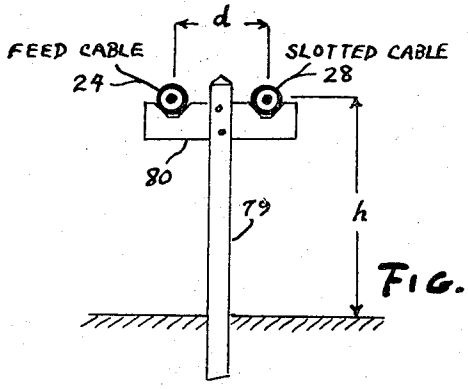


FIG. 6

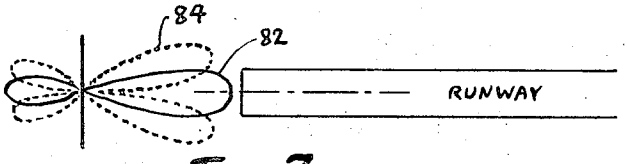


FIG. 7

INVENTOR.

Chester B. Watts, Jr.

SLOTTED CABLE LOCALIZER ANTENNA

SUMMARY

An object of the invention is to provide improvements with respect to size and performance over the slotted waveguide localizers, now in use at some airports, and which operate in the band 108—112 m.c.p.s. in accordance with the published description: C. B. Watts, Jr., "Simultaneous Radiation of Odd and Even Patterns by a Linear Array," IRE Proc., Vol. 40, pp. 1236—1239c, Oct. 1952. A drawback of the slotted waveguide localizer is the difficulty of retuning the antenna from one operating frequency to another especially in the case of the larger apertures. This is primarily due to the change with frequency of the guide-wavelength as it affects the relationship of the standing waves to the slot positions. In the present invention, a length of TEM coaxial transmission line is employed instead of TE rectangular waveguide, resulting in much smaller cross-sectional dimensions. An advantage accruing from this is the practical feasibility of filling the lines with a high-dielectric gas, and using the gas pressure to control the velocity of propagation and, hence, the guide-wavelength. With the frequency limitation thus removed, the length of the antenna can be simply extended to almost any aperture that could be reasonably used in service. With this technique, apertures of 40 wavelengths or more are considered practical.

LIST OF FIGURES

FIG. **1** is a plan view of a rudimentary model of the slotted cable localizer antenna.

FIG. **2** is an approximate equivalent circuit of the antenna.

FIG. **3** is a set of graphs representing, for sum and difference modes, the desired relative slot excitations, with the corresponding radiated field pattern shapes.

FIG. **4** is a set of graphs illustrating, for sum and difference modes, the standing waves of line current, together with resultant slot voltage distributions.

FIG. **5** is a view of one section of the antenna, indicating a practical construction which allows pressurization with a gas dielectric.

FIG. **6** is a cross-sectional view of one installation arrangement of the antenna over a ground surface, where the feed cable portion is made to serve as a reflector for the radiating slotted cable portion.

FIG. **7** is a plan view of a runway showing the antenna, with superimposed sum and difference polar patterns, not to scale.

DESCRIPTION

A rudimentary form of the slotted cable localizer antenna is shown in FIG. **1**. Construction is made as nearly symmetrical as possible, end to end, about the centerline **2**. For this reason, the view shows only a little more than half of the antenna. The coaxial transmission line bridge, or hybrid **4** may be of any suitable conventional type, the one shown being known commonly as a "rat-race," with phase-reversal provided by constructing one of the bridge arms **6** longer by a half wavelength than the other three. It is a property of the bridge that opposite ports **8** and **10** are isolated from each other if the loads presented at the other two ports **12** and **14** are equal to each other. This condition exists by virtue of the symmetry. Thus, signals can be applied independently or simultaneously to the input ports **16** and **18** without interaction. Stubs **20** and **22** are provided for separately impedance-matching each input port.

From the bridge, signals proceed outward through left and right feed cable portions **24** and **26** to the ends of slotted cable portion **28**. Here the signals turn inward toward the center, passing on the way the outer conductor slots **30**. Each slot is shunted by a relatively heavy metal strap or bar **32**, which is securely clamped and conductively connected to the cable outer conductor by clamps **34**.

Where the signals from left and right side meet in the cable at point **36** on the centerline, considerations of symmetry demand that either a virtual short circuit or a virtual open circuit exists, depending upon which input port is considered.

FIG. **2** represents an approximate equivalent electrical circuit of the antenna. Corresponding parts are labeled with the same numerals as in FIG. **1**. The cable has a characteristic impedance, Z_o, whose value is not important, as long as it is constant. It also has a velocity of propagation which, along with the operating frequency, determines the guide-wavelength, λ_g. This is quite a critical figure, as the slot spacing, S, must differ from λ_g by only a small length, δ. The accumulated difference, $n\delta$, over one entire side of the antenna should have a value preferably between 0.1 and 0.2 times the guide wavelength, where $2n$ equals the total number of slots in the antenna. FIG. **2** indicates that at each cable slot, there is an impedance effectively in series with the cable. Each impedance has two parts, the slot impedance **38**, and the shunt reactance **40**. Impedance **38**, due to the slot itself, is relatively insensitive to position in the cable if the cable is sufficiently long. It has resistive and reactive parts, the resistive part being mainly due to radiation. Shunt reactance **40**, due to bar **32** and clamps **34**, is a means of controlling the voltage drop across the slot for a given line current. As such, it has a maximum value in the center of the antenna, tapering off towards the ends. Even the maximum value of reactance **40**, however, is made to be small in comparison with both slot impedance **38** and line characteristic impedance Z_o. This means that the currents flowing in the cable are not greatly disturbed by the presence of the slots.

Nevertheless, a small fraction of the total signal does escape through each slot, causing currents to flow on the outside of the outer conductor, resulting in radiation. The polar pattern of the resultant radiation is computed by treating the problem as a long wire with multiple excitations. One tends to think of a long wire as radiating strongly off the ends. This is because a long wire, as normally fed at a single place, has a traveling wave-type current distribution with associated end-fire radiation. When, however, there are many excitation points, phased properly for broadside addition, then the various traveling waves produced add destructively to a small resultant. The overall behavior of the long wire antenna then becomes almost identical with that of a colinear broadside array of dipoles. The longer the antenna, it would seem, the more nearly so is this. Even with as few as three or four excitation points, the resemblance is quite strong. See, for example, FIGS. **3** and **4** of the article by L. C. Shen, "The field pattern of a long antenna with multiple excitations," IEEE Transactions on Antennas and Propagation, Vol. AP-16, pp. 643—646, Nov. 1968.

To a good approximation, if the number of slots is large, the field pattern may be computed, considering the slots as point sources, using standard array theory. FIG. **3** illustrates the types of slot distributions (*a*) and (*b*), with corresponding field patterns (*c*) and (*d*), desired for the localizer service. The sum and difference signals each produce their own distinctive pattern known also by the names "carrier" and "sideband" pattern, respectively. The sum pattern FIG. **3** (*c*) is an even function of azimuth angle, Θ, an ideal shape in this application being that of the Gaussian curve, $1/\exp(\Theta/k)^2$, while the difference pattern FIG. **3** (*d*) is an odd function of Θ, having the shape of the Gaussian first derivative, $\Theta/\exp(\Theta/k)^2$. The symbol, *k*, is simply a constant indicative of the beam width. These patterns are ideal in the sense that they are free of minor lobes and also that their ratio is a linear function of azimuth. In a large aperture antenna, these patterns are formed to good approximation by distributions of source amplitudes whose envelope shapes follow the same curves, FIG. **3** (*a*) and FIG. **3** (*b*): Sum mode slot voltage is proportional to $1/\exp(x/a)^2$ while difference mode slot voltage is proportional to $x/\exp(x/a)^2$, where *x* is the distance of the slot from the antenna centerline, and the constant, *a*, is indicative of the aperture size. A noteworthy point here is that the two mode distributions are in a ratio simply proportional to the distance *x* of each slot from the centerline. This fact is fundamental to the following discussion of the formation of slot excitation distributions.

FIG. **4** (*a*) and FIG. **4** (*b*) are enlargements of portions of FIG. **3** (*a*) and FIG. **3** (*b*) respectively, intended to show the

spatial relation with the standing waves of line current associated with the sum and difference modes, FIG. 4 (*c*) AND FIG. 4 (*d*), respectively. The sum mode is so-named because currents arriving at centerline point **36** via the two paths add to form a maximum **39** there, and because these currents are responsible for the formation of the sum pattern. Similarly, difference mode currents subtract there to form a null **41**, and are instrumental in forming the difference pattern. It may seem confusing that the sum mode is produced by feeding port **8** of the bridge hybrid (FIG. **1**) which is associated with the phase-reversing line section **6**. This nomenclature is convenient, however, because it is simpler to deal with standing waves of current rather than of voltage, since the slots are effectively in series rather than in shunt with the line.

Referring once more to FIG. **4** (*c*), the sum mode standing waves near the centerline have maxima which almost coincide with the slot positions. Away from the centerline, however, because the guide wavelength, λ_g, is slightly longer than the slot spacing, *s*, the slot positions appear displaced from the current maxima, more and more, the farther they are from the centerline. If all of the slots had identical shunts, and if one neglected line loss due to radiation, and other losses, this displacement effect would result in a slot voltage distribution which would follow a cosine wave envelope, indicated by the curve **42**, FIG. **4** (*a*). The slot shunts are, however, not identical, but are made to have reactances that taper down thereby reducing the slot voltages, toward the ends of the antenna. By adjustment of these reactances, then, the resultant sum mode slot voltage envelope can be made to follow a desired shape, for example, the aforementioned Gaussian $1/\exp(x/a)^2$, indicated by curve **44**, FIG. **4** (*e*). If all the shunt reactances are raised to increase the slot couplings to the point where the effects of radiation loss are no longer negligible, it will be noticed that the standing wave minima are no longer deep nulls, but become more and more filled toward the ends; the standing wave ratio is lowered, with improved efficiency. While the antenna is also operable in this manner, the detailed computation of performance is a good deal more complicated than with the simplifying assumption of loose slot-coupling. It is best then to use an iterative procedure with a digital computer to calculate line impedances as transformed through each line section in succession, starting at the centerline and working out.

Returning now to FIG. **4** (*d*), the difference mode standing waves near the centerline have minima which almost coincide with the slot positions. Away from the centerline, however, the slot positions appear displaced from the current minima, more and more, the farther they are from the centerline. If all the slots have identical shunts, this displacement effect would produce a sine wave slot distribution, curve **46**, FIG. **4** (*b*). The fact that the slot reactances taper toward the ends, however, modifies the distribution shape to something like curve **48**. If the shunt reactance taper is assumed to modify the slot couplings in the same way for both sum and difference modes, then the two distributions are distinguished from each other only by the sine and cosine factors. Since the sine/cosine ratio is the tangent function, which is fairly linear for perhaps the first one-eighth wavelength, curve **48** is simply obtained by applying a linear multiplier, proportional to *x*, to the ordinates of curve **44**. One thus reaches the conclusion, in the example cited, that curve **48** must approximate the shape of the Gaussian derivative, $x/\exp(x/a)^2$.

In order to keep the accumulated difference $n\delta$ within the preferred limits, it is necessary either to build the antenna with just about the right slot spacing, *s*, or to have some means of adjusting the guide wavelength, λ_g, to suit. A convenient way to obtain limited adjustment of λ_g is to design the antenna to be pressurized, and to fill it with a high-dielectric gas. The λ_g is proportional to $1/\sqrt{LC}$, where L and C are the line parameters, inductance and capacitance per unit length respectively. If the space between inner and outer conductors of the line could be completely filled, the λ_g would then vary inversely as the square root of the dielectric constant of the gas. For square-root localizer band, which is somewhat less than 4 percent, a gas with a dielectric constant of 1.08 will suffice. The gas sulfur hexafluoride, SF_6, which has been used commercially as an electrical insulator, has the required dielectric constant at a pressure of about 22 atmospheres. Other gases could, no doubt, be found that are suitable, such as some of the freon compounds, or other refrigerants, provided they are kept warm enough to avoid condensation in the line.

In a practical type of construction in a size suitable for use at 110 m.c.p.s., the antenna is conveniently fabricated in sections about 8 feet long, one slot in each, the sections being joined together on the site by flange connections. FIG. **5** is a view of a section designed to allow pressurization with a gas dielectric. The drawing is not to scale, diameters being considerably exaggerated relative to the length, for clarity. The transmission line is of the rigid type, standard to the radio broadcasting industry, outer conductor pieces **50** and **52** being brazed to flanges **54** and **56** at each end of the section. The inner conductor **58** is supported by dielectric pins **60** in the usual way at intermediate points along the length, and anchored longitudinally by a dielectric bead **62**, provided with ample holes **64** to allow free passage of gas from one section to the next. An O-ring **66** provides a gas seal for the flange connection. The slot **68** may be constructed by sawing a ½-inch piece out of a standard line section and cementing the pieces into the insulating sleeve **70**. As an alternative to the inductive slot shunts **32** of FIG. **1**, FIG. **4** shows a capacitive slot shunt, metal tube **72**, fitted tightly over insulating sleeve **70**. The amount of energy escaping from the slot **68** is controlled by the length of tube **72** and by the thickness of sleeve **70**. If the length L of tube **72** is very short compared to the wavelength, the shunting effect is computed as a simple capacitive reactance; if not, it is computed as a pair of transmission line transformers of length L/2 each.

Two types of indicator may be provided to assure that the guide wavelength λ_g has been properly adjusted. Indicator **74**, shown dotted, is a gas pressure gauge, mounted at any convenient point on the antenna, indicative of the quantity of gas in the line. Indicator **76**, shown dotted, is a line current probe indicator, indicative of the current flowing inside the line, and may be mounted at a place where a far-out standing wave minimum is supposed to fall. Such a place would be corresponding to point **78** in FIG. **4**. Gas pressure is then simply regulated to minimize the reading of indicator **76**.

FIG. **6** shows in cross section how the antenna may be mounted over a ground surface using a number of wooden posts **79** with notched crossarms **80**. The feed-cable portion, which could be laid on or under the ground, is shown supported at the same height, *h*, as the slotted-cable portion, separated by a distance, *d*, where it can serve as a partial reflector. FIG. **7** is a plan view, not to scale, of a runway, with the antenna located at one end. Curves **82** and **84** are indicative of the sum and difference mode polar patterns produced.

It should be recognized that the ideas just described can be used in other physical arrangements. Other types of transmission line, and other slot-shunt arrangements will work just as well. The azimuth pattern and slot excitation distributions are not limited to those shown specifically. Control of the guide wavelength can be obtained by introduction of liquid or solid materials into the line, although not as conveniently as with gases. The antenna may also be used in other orientations, such as vertically, to define a glide path.

I claim:

1. A slotted cable antenna comprising a centrally located hybrid with sum and difference input terminals, first and second transmission lines extending symmetrically outwards from the output terminals of said hybrid, a third length of coaxial transmission line connected at each end respectively to the outer ends of the said first and second transmission lines, a plurality of gaps in the outer conductor of said third transmission line, radiation control means disposed across each of said gaps, said means presenting in each case an impedance, whereby most of the line current is conveyed across

the gap, except for a portion of said current which escapes to flow on the outside of said third coaxial line, thereby producing radiation.

2. An antenna as in claim 1, with said radiation control means comprising a metallic shunt connected conductively across each of said gaps.

3. An antenna as in claim 1, with said radiation control means comprising a metal tube, surrounding each of said gaps, but insulated therefrom.

4. An antenna as in claim 3, with frequency tuning means comprising a quantity of high-dielectric gas filling the space between inner and outer conductors of said transmission lines.