

Aug. 11, 1953

J. R. FORD ET AL

2,648,839

DIRECTION FINDING ANTENNA SYSTEM

Filed Oct. 2, 1950

2 Sheets-Sheet 1

Fig. 1

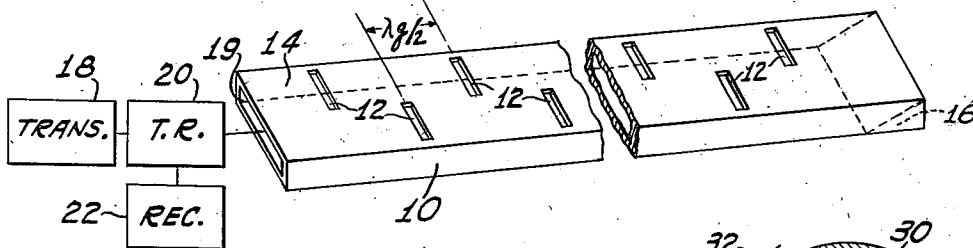


Fig. 2

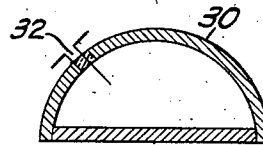
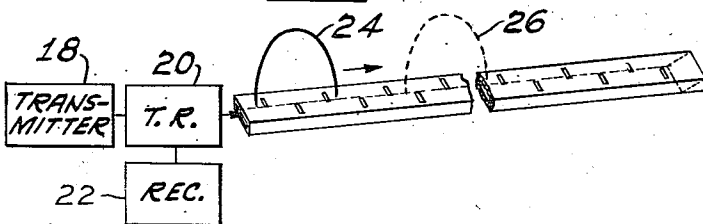


Fig. 3

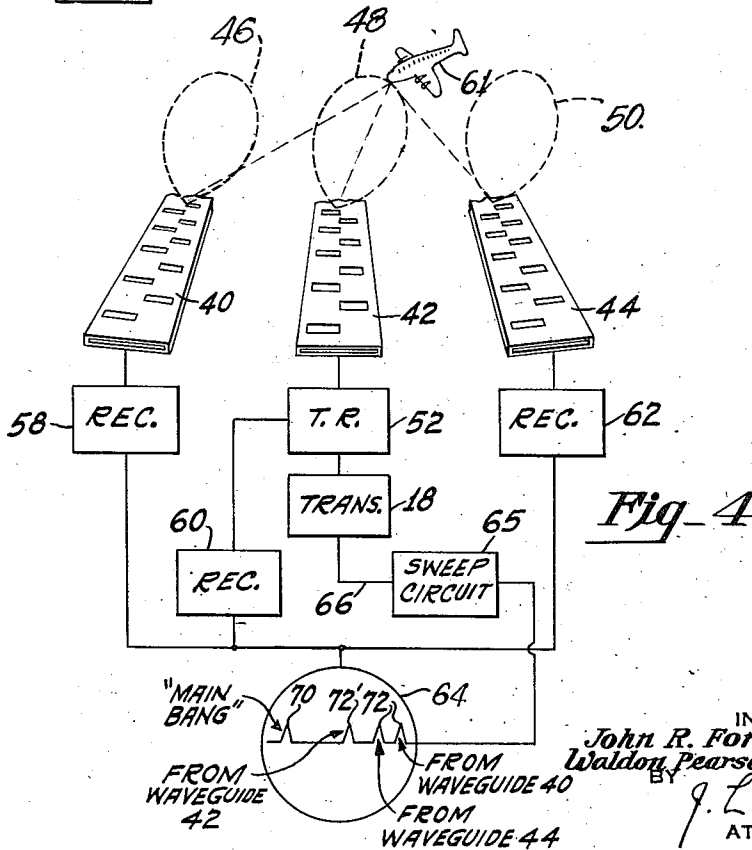


Fig. 4

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Fig-5

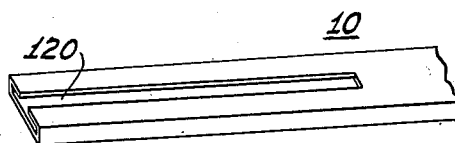
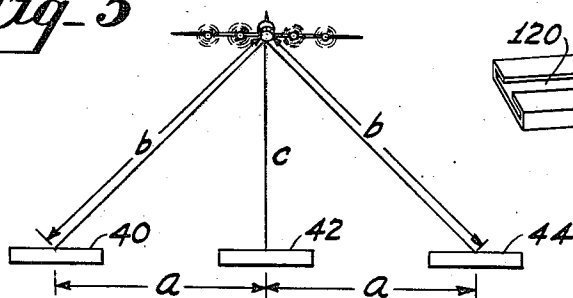


Fig-8

Fig-6

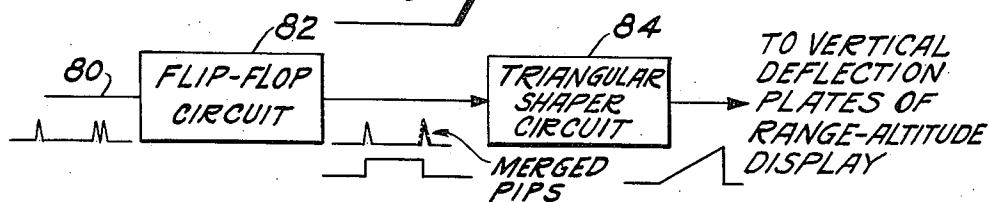
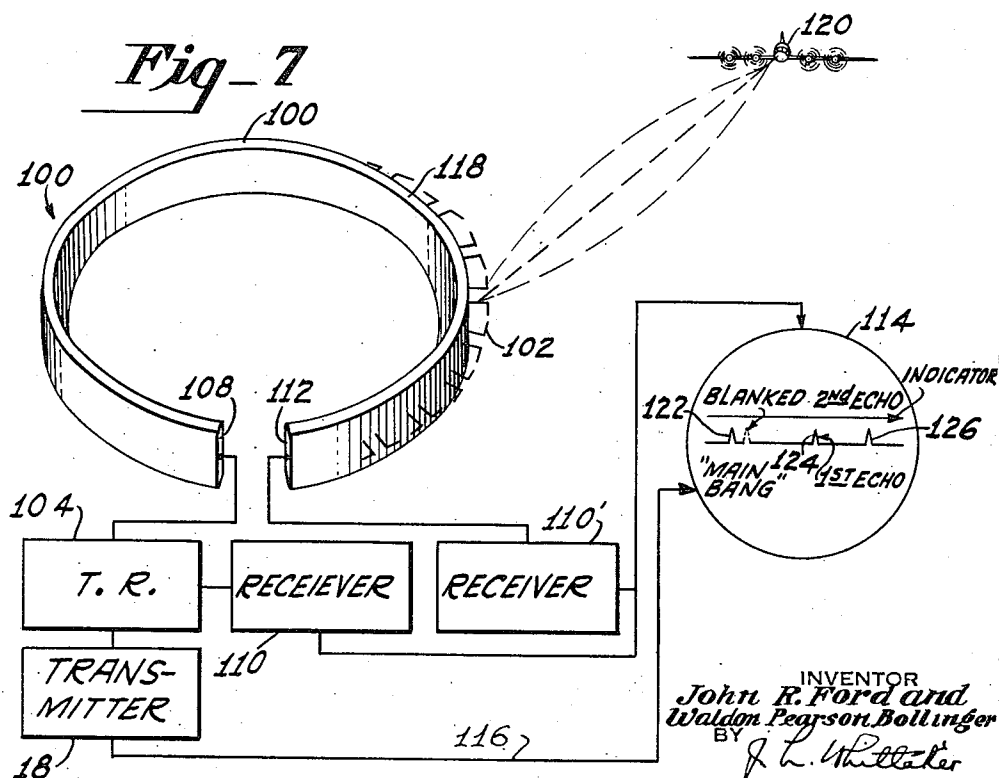


Fig-7



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DIRECTION FINDING ANTENNA SYSTEM

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Application October 2, 1950, Serial No. 187,992

3 Claims. (Cl. 343-100)

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This invention relates to radio echo detection systems and more particularly to such systems employing a wave guide feed.

A type of antenna which is now well known is that utilizing a waveguide to which is coupled a plurality of antenna elements. These antenna elements may comprise spaced slots in a hollow pipe waveguide wall through which energy within the waveguide is radiated. Again, a plurality of dipoles or the like may be suitably coupled at spaced intervals along a waveguide. The antenna slots may overlap longitudinally, thus to form a continuous staggered slot. In the past, such systems have been excited so that all of the elements radiate simultaneously during at least a major portion of the transmission or reception.

It is an object of the present invention to provide a new and novel method of operation of such an antenna.

It is another object of the invention to provide a novel combination of an antenna structure employing a plurality of such antenna elements.

A further object of the invention is to provide a novel radio echo detection system in which such an antenna is employed.

In accordance with the invention, the operation of the antenna is entirely different from the operation which has been employed heretofore. The novel operation is secured by associating with the antenna a pulsed energy generator, the pulses of energy in their travel through the waveguide being short in length with respect to the total waveguide length. Thus, an entirely novel system of operation is secured in which only a fractional portion of the antenna elements are radiating at any moment of time and at no time are all of the elements thereof simultaneously excited.

The foregoing objects, advantages and novel features of the invention will be more apparent from the following description in which like reference numerals refer to like parts and in which:

Fig. 1 is a perspective view of a slotted waveguide antenna;

Fig. 2 is another perspective view of a slotted waveguide antenna with an associated circuit schematically indicated;

Fig. 3 is a cross-sectional view of a somewhat different type of waveguide antenna which may be utilized in practicing the invention;

Fig. 4 is a schematic view of another system embodying the invention;

Fig. 5 is a sketch illustrative of the geometry of the system illustrated in Fig. 4;

Fig. 6 is illustrative in block diagram form of a circuit which may be used in connection with the system of Fig. 4.

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Fig. 7 is a perspective view of an assembly which may be used in a novel radio echo detection system embodying the invention; and

Fig. 8 is illustrative of a variation in the system of Fig. 4.

Referring now more particularly to Fig. 1, a long rectangular waveguide 10 has transverse slots 12 cut in one of the broad walls 14. These slots 12 are spaced longitudinally a half guide wavelength, the slots being successively staggered on each side of the median line of the broad wall 14, as shown, thus adjacent slots have radiation reversed in phase due to the spacing of half guide wavelengths, but also reversed due to the staggering current on opposite sides of the broad wall center line being in opposite directions. Thus adjacent slots radiate in-phase. Waveguide 10 has an absorptive matched termination 16 at one end thereof. The other end is supplied with electromagnetic energy from a transmitter 18 having a very high frequency of operation and being modulated in very short pulses. The energy is supplied to waveguide 10 from the transmitter 18 to input end 19 through a T-R arrangement 20 of any of the various well-known kinds whereby during transmission energy is supplied to waveguide 10 but upon the cessation of transmission the energy returning from waveguide 10 is switched to a receiver 22. Let the period of one of the pulses from transmitter 18 be represented by T . The energy will travel through waveguide 10 at a velocity which may be assumed to equal substantially the group velocity v . Let the length of the waveguide 10 from the input end to the termination 16 be L . Then the energy advances from the input end toward the termination 16 and the pulses are so short that the length of the pulse, in the waveguide 10 is substantially equal $v \cdot t$, and is less than L , and preferably only a small fraction, say about $\frac{1}{10}$ or less of L . Thus the length L is substantially longer than the distance traversed in the waveguide 10 by the energy in the time of a duration single pulse. Other antenna elements than the slots shown might be used. Accordingly, only a portion of the antenna elements spaced along the guide lengths are radiating energy at a time. As an example, suppose that there are a hundred apertures 12. The length of the pulse may be only ten times the spacing of the aperture, and consequently at the most ten adjacent apertures 12 are emitting energy at any instant of time. After the first ten nearest the input end 19 of the waveguide are radiating energy, a few moments in time later the first aperture is not radiating energy because the pulse

has passed it and the next ten are radiating energy. This continues until the last ten are radiating energy and thereafter as the energy strikes the matched absorbing termination 16 it is absorbed so that successively the last nine apertures, the last eight apertures, etc., near the end 16, are radiating. The effect is best seen by referring to Fig. 2. The radiation pattern from waveguide 10 may assume a shape such as that illustrated by the lobe 24 which at a later time may be in the position illustrated by the dotted line lobe 26. The waveguide 10 or apertures or both may be graduated in size in order to assure that each of the apertures 12 radiate substantially the same amount of power as every other aperture. Waveguide 10 may be of a length to extend for example, from one end of an airplane runway to the other. The energy is transmitted from transmitter 18 and the lapse in time before it is returned to receiver 22 will give information regarding the time required for the pulse to leave the transmitter, pass through the waveguide 10 to the particular position substantially directly underneath an airplane, thence to reach the airplane, and for the echo to return vertically to waveguide 10 and thence to the T-R arrangement 20 to receiver 22.

An alternative waveguide arrangement is shown in Fig. 3 in which a waveguide 30 semi-circular in cross-section feeds dipoles 32 spaced equally along the length of the waveguide 30. These are arranged to radiate in phase. The waveguide 30 may be substituted for the waveguide 10 bearing in mind again that it is to be long with respect to the length of the pulse being transmitted through it, appropriate spacing of the antenna elements 32, and appropriate orientation of the guide to direct the energy from the dipoles 32 in the vertical plane (or such other plane as may be desired).

Referring now more particularly to Fig. 4, three waveguides 40, 42, and 44 are spaced equally and laid out in parallel lines parallel to the runway of an airplane landing field. These three waveguides each may be similar to waveguide 10 having radiated elements which in the plane longitudinal thereto at the frequency of operation are quite narrow and are restricted to an area directly above the slots momentarily radiating. In the transverse plane, the waveguides 40, 42, and 44 may have respectively radiation patterns such as 46, 48, and 50. The transmitter 18, which may be the same as the transmitter of Fig. 1, feeds one end of the waveguide 42 through a T-R arrangement 52.

A receiver 60 is also connected to the T-A arrangement to receive the echo signal as from an airplane 61 from waveguide 42 and for simplicity receivers 58 and 62 are shown connected to waveguides 40 and 44 respectively to receive the signals therefrom. However, waveguides 40 and 44 could also be connected to the input of receiver 60 instead of being connected as shown. Receivers 58, 60, and 62 may be connected to an oscilloscope 64 (the face only of which is shown in the drawing) as a common element to display the signals received therein. It will be understood that the oscilloscope sweep circuit 65 may be synchronized with the transmitter by connection 66 so that the sweep starts from the left with transmission of a pulse of energy by transmitter 18 and moves uniformly with time to the right. A pip 70 will appear at the initiation of the sweep representing the "main bang," and three other pips, one 72' and two pips 72 appear at some distance

to the right (assuming the sweep to progress from left to right) representing the return of signals from waveguide 42 and waveguides 40, and 44, respectively. The velocity of the signal in the waveguides, each of which may be presumed to be constructed similarly to the others, may be known or measured. It will be assumed that an approaching plane 74 is at an altitude small compared to the slant range from the receiver ends, that is the ends of waveguides 40, 42, and 44 to which the receivers 58, 60, and 62 are connected. In order to center the plane 61 on the runway down which the waveguides are laid, it is now only necessary to direct the pilot to bring his plane toward one or the other side of the field until two of the pips 72 (from guides 40 and 44) merge into one. The distance between the pips 70 and the pip 72' on the oscilloscope screen 64 is proportional to the ground range of the aircraft plus its altitude.

The system of Fig. 4 is operative only when the plane is over the landing field, that is above the assembly of waveguides 40, 42 and 44. For ground control approach (GCA) systems, the range indicated by the distance between pips 70 and 72' approximates the true range of the aircraft, and approaches this true range more closely as the aircraft approaches touchdown over the waveguide 42. Moreover, in most cases, the error involved is small. However, if desired, the altitude of the plane may be measured by employing a slight modification of the system, whereby the error may be (in effect) subtracted from the range to indicate the true range.

Referring to Fig. 5, the applicable geometry is illustrated. When the pips 72 merge, the distance between the pip 72' and the merged pips 72 is indicative of a time of travel which in turn indicates a distance q .

Now

$$q = b - c \quad (1)$$

and

$$C^2 = b^2 - a^2 \quad (2)$$

Therefore:

$$C = \frac{1}{2} (a^2/q - q) \quad (3)$$

Therefore, the altitude C can be found by standard computer techniques. For example, a special potentiometer may be wound leaving the requisite variations with q , at least over a limited range, to give C , when motion of a pick-up arm is linear with q . On the oscilloscope 64, Fig. 4, for example, may be impressed a voltage proportional to C derived from such a computer. Fig. 6 illustrates how the voltage proportional to q may be derived. From receiver 60 a signal is supplied via a connection 68 to a flip-flop circuit 62 which is flipped in one direction by the signal indicated by pip 72' and in the other direction by merged pips 72; fed by connection 69 also. The rectangular wave output of flip-flop circuit 62 is fed to a triangular shaper 64 (or integrator). The average output voltage of the triangular shaper 64 is proportional to the distance q .

The system of Fig. 4 functions preferably when the plane 61 is somewhere over the runway, as pointed out hereinbefore. Standard known methods may be used to bring the plane in thus far, or for example, the spacing of slots 12 only at the far end of the runway, may be altered to direct the energy radiated from the end remote from the receiver to be directed longitudinally away from the waveguide. A continuous slot near the end of each of waveguides 40, 42, and 44, such as illustrated in Fig. 8, may also be used for this

purpose. Assuming, waveguides 40, 42, and 44 to be so constructed, causing a plane to move so that pips 72 coalesce lines up the course of the plane with the runway.

Referring now more particularly to Fig. 7, there is illustrated a hollow pipe waveguide 100 which is preferably substantially rectangular in cross-section to avoid moding difficulties. A series of antenna elements 102 spaced around the waveguide 100 of Fig. 5 may be excited by energy in the waveguide. Waveguide 100 is preferably bent into a substantially circular shape and the antenna elements 102 are placed on the side of the circular guide facing away from the interior of the circle. The waveguide 100 may be laid substantially in the ground plane and with the elements 102 thus facing outwardly the energy travels radially from the circle in which the waveguide 100 is shaped. A waveguide with a cross-section such as that of Fig. 3 may here be employed to advantage with antenna elements at a slight angle to the ground plane. A transmitter 18 is connected to a T-R arrangement 104 which in turn is connected to the end 108 of waveguide 100. The receiver 110 is connected through the T-R arrangement 104 to the end 108 of waveguide 100. The other end 112 of waveguide 100 is connected also to a receiver 110'. An indicator, which may be cathode ray oscilloscope 114 shown in face view in the drawing, has the signals from the receiver displayed thereon. The sweep is from left to right, linear with time and initiated to start with each pulse transmission from transmitter 18. A connection 116 is employed to synchronize the sweep. The receiver pulses are applied to the vertical plates.

In operation, the transmitter 18 feeds a pulse into the end 108 of waveguide 100. This pulse again is so short in time duration that at any moment of time only a fractional portion of the elements 102 are radiating. Accordingly the pulse travels out in a circular sweep starting at the end 108, travelling circumferentially around waveguide 100. The system is intended to give warning indications of approaching planes at a considerable distance from the waveguide 100. Accordingly, the time of travel $t_0/2$ of the signal path through waveguide 100 may be considered short and negligible compared with the time of travel through space to the object to be indicated and the return of the echo therefrom. Accordingly the distance from the "main bang" 122 of the echo pips 124 and 126 on screen of oscilloscope 114 is representative of the distance from the waveguide 100 to the plane. The angular location of the object to be indicated may be determined from the differential between the pips 124 and 126. More accurately, let t_r be the time of travel of energy radiated from a point 118 on waveguide 100 nearest some reflecting object such as an airplane. Let t_a be twice the time of travel of energy in the waveguide 100 from the point 118 to the nearest end 112. Then the elapsed time between initiation of transmission of a pulse (main bang) and the first echo is:

$$t_1 = t_a + t_r$$

Similarly, the elapsed time between the main bang and receipt of the second echo is:

$$t_2 = \frac{1}{2}t_a + t_r + \frac{1}{2}(t_0 - t_a) \\ = t_r + \frac{1}{2}t_0$$

where t_0 is twice time of travel of the pulse from one end 108 to the other end 112 of the energy in the waveguide 100. Thus t_a (proportional to

the azimuth angle) is proportional to the difference in sweep distance between the two echo pips plus a constant, and t_r (range) is proportional to the difference in sweep distance between the main bang and the second pip minus a constant. Computer circuits are well known which give a solution of these equations. Again, as a simple means, a specially wound potentiometer may be employed. To derive sensing, it may be desirable to shape the output pulses of the different receivers differently to resolve the ambiguity of whether the first pulse is received from the left or right semi-circle of the waveguide 100 as viewed in the drawing.

Referring now more particularly to Fig. 8, there is illustrated a modification of the construction of the end of waveguide 10 of Fig. 1 remote from connection to the receiver. For a short distance from this end, say a length equal to the number of simultaneously radiating elements, the waveguide is opened at the top by a continuous slot 120. From slot 120 the energy leaves substantially without reflection. However, the slot acts in this instance as an end fire array, causing the energy to be projected forwardly, instead of vertically, at an angle inclined from the horizontal to a degree determined largely by the phase velocity in this portion, that is, the portion having slot 120. Thus in a system as that of Fig. 4, there may be detected a warning signal by returned reflections of planes approaching the runway from a position well in advance of the waveguide 10. If this variation is used, one should preferably have some means for distinguishing high altitudes from a distance in advance of the end of the waveguide 10 as perhaps by another search radar. More simply, only one of the waveguides, say 42 of Fig. 4 is so made. Then the absence of an echo from the other waveguides is an indication that signal is being received from the slot portion of the one waveguide 42, and that the reflecting object or plane is an advance of the runway.

It will be apparent that there is disclosed a new and novel method of operation of a waveguide antenna, as well as new and novel combinations utilizing such a waveguide.

What we claim as our invention is:

1. In a system for radiating or receiving energy and having a long leaky waveguide, the method of operation comprising the step of exciting said waveguide with a succession of pulses of high frequency energy the time duration of each of which is substantially less than the time required for said pulse energy to traverse the length of said waveguide.

2. In a system for radiating energy, said system having a long waveguide and a substantial plurality of antenna elements equally spaced along the length of said waveguide and coupled thereto, the method of operation comprising the steps of exciting said waveguide with successive pulses of high frequency energy the time duration of each of which is substantially less than the time required for said pulse energy to traverse the length of said waveguide, and exciting each of said elements successively along the waveguide length with said pulses of energy but substantially less than all of said elements at any one time, thereby to establish an antenna pattern for said radiation which travels in space in the direction of motion of said energy through the waveguides.

3. In a system for receiving energy, said system having a long waveguide and a substantial

plurality of antenna elements equally spaced along the length of said waveguide and coupled thereto, the method of receiving pulse energy comprising the steps of energizing successively and progressively a few of the adjacent antenna elements spaced along said waveguide with each of a succession of pulses of high frequency energy the duration of each of which is substantially less than the time required for said pulse energy to traverse the length of said waveguide, and energizing said waveguide with said successive pulses of energy from the energized antennas thereby to couple energy in the waveguide

moving in the direction in which the elements are successively energized.

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