

Oct. 31, 1961

T. G. HAME
SLOT AERIAL

3,007,166

Filed May 27, 1958

2 Sheets-Sheet 1

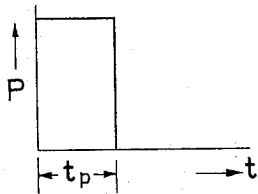


FIG. 1

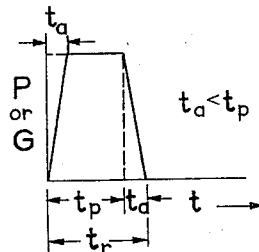


FIG. 2

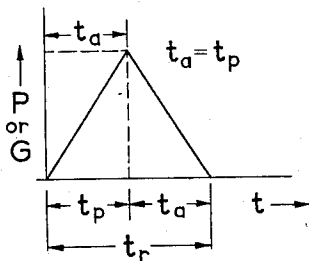


FIG. 3

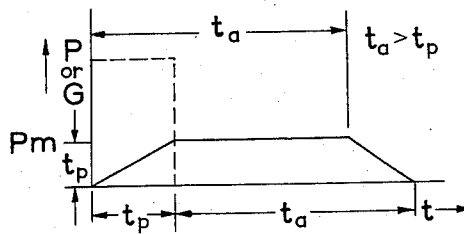


FIG. 4

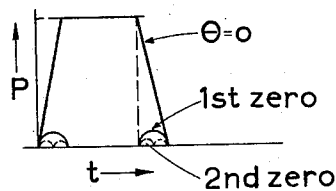


FIG. 5

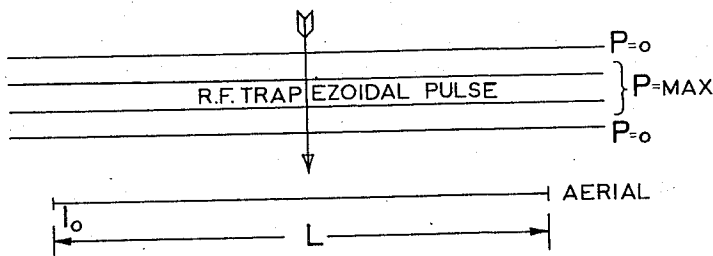


FIG. 6

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Oct. 31, 1961

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2 Sheets-Sheet 2

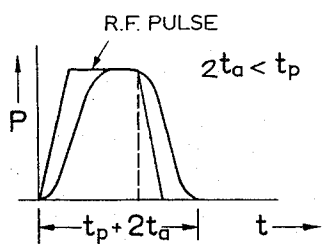


FIG. 7

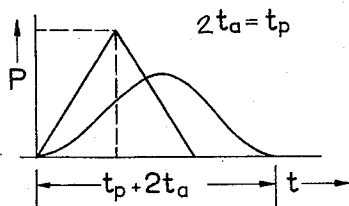


FIG. 8

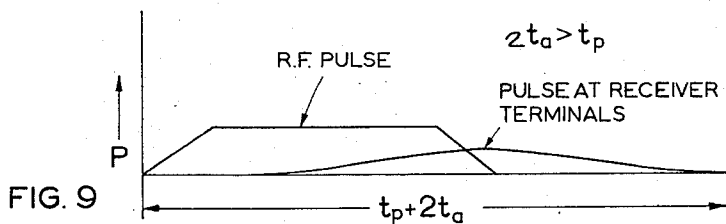


FIG. 9

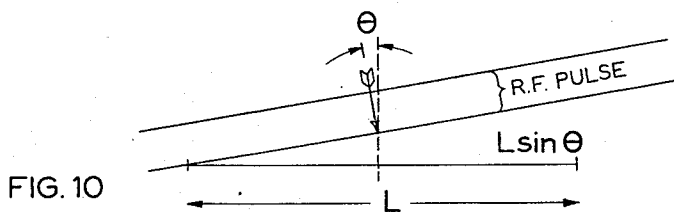


FIG. 10

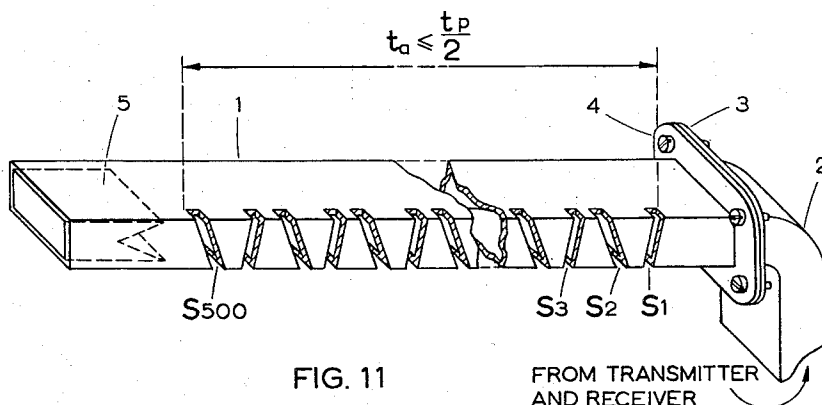


FIG. 11

FROM TRANSMITTER
AND RECEIVER

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1

3,007,166
SLOT AERIAL

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This invention relates to slot aerials and especially to transmitter-receiver aerials.

In some applications of aerials and especially in aerial arrangements operating at microwave frequencies it is required to transmit and receive pulses of energy by means of the same or similar waveguide aerials. This type of apparatus may for example be required for a transmitter which is sending out pulses, that is bursts of oscillation, to be reflected by a distant object as is so in some forms of position finding apparatus. One type of aerial which has been proposed comprises a waveguide having one or more slot like apertures which operate as the radiating elements of the aerial. Usually slots in an aerial are arranged to lie longitudinally along the aerial. The applicant has found however that in general there are certain limitations in the use of such an aerial and in particular considerable losses of signal amplitude may be produced thereby substantially reducing the usefulness of the aerial.

The object of the present invention is to substantially reduce the above mentioned limitations.

According to the present invention there is provided a slot aerial arrangement comprising a waveguide provided with a plurality of slots positioned to constitute an array and a transducer (that is a transmitter or receiver) of pulse energy coupled to said waveguide wherein the aperture of said array is so chosen as to have a predetermined relationship to the duration of pulses of said pulse energy to obtain a maximum gain from the combination of said array and said transducers.

Preferably, in a transmit-receive arrangement the aperture of the array is chosen so that the time taken for a pulse to travel across it is less than or equal to half the width in time of the pulse.

In order that the present invention may be clearly understood and readily carried into effect, the invention will be described with reference to the accompanying drawings, FIGURES 1 to 10 of which comprise graphical diagrams which illustrate the operation of the present invention and FIGURE 11 of which illustrates one example of the present invention.

The time t_a , taken for the leading edge of a pulse such as shown in FIGURE 1 to travel along an array of slots having an aperture total length L is given by

$$t_a = \frac{L}{g}$$

where g is the pulse group velocity and the duration t_r of a radiated pulse is $t_r = t_a + t_p$ where t_p is the duration of the original pulse.

FIGURES 2, 3 and 4 of the drawings illustrate the form of the radiated pulse of FIGURE 1, when $t_a < t_p$, $t_a = t_p$ and $t_a > t_p$ respectively. A picture of the variation in radiated power across the aperture of the array with respect to time is presented by these figures. In the last case, namely where $t_a > t_p$ (FIGURE 4) it is seen that the pulse duration is increased by t_a and the amplitude of the pulse is reduced so that the maximum normalised energy level is given by

$$pm = \frac{t_p}{t_a}$$

The effects on radiated pulse energy for an aperture

2

transmitting a pulse have been investigated by the applicant. The sequence of events commences with the gradual "filling" of the whole or part of the aperture, that is the progression of the leading edge of a pulse along the aerial aperture gives the effect that the aerial is gradually "filled," successive radiating elements becoming effective until the trailing edge of the pulse passes them. Thus during the "filling" period the effective radiating aperture is varying as the leading edge of the pulse proceeds along it. Similarly the effective radiating aperture is also varying as the trailing edge of a pulse passes along the aerial, the leading edge having passed the terminated end. This process can be referred to as "emptying." It can be shown that the normalised radiation pattern for a uniformly illuminated array of length L is

$$E = \frac{\sin(Ka)}{Ka}$$

where $a = \frac{1}{2}L = \frac{1}{2}tg$ and

$$K = \frac{2\pi}{\lambda} \sin \theta$$

θ being the angle of incidence to the normal of the aperture. As t , the position in time of the leading edge of the pulse increases from the zero position t_0 the effective aperture of the array increases as mentioned and the gain of the aerial increases in the same proportions.

The above equation may be rewritten

$$E = \frac{\sin \frac{Ktg}{2}}{\frac{Ktg}{2}}$$

When $t = t_0$, that is the leading edge of the pulse is just impressed on the aerial, $E = 1$ and radiation occurs equally in all directions. At all other values of t , the well known

$$\frac{\sin x}{x}$$

form of pattern is produced. The main beam is compressed and the number of side lobes increase as t increases.

As mentioned above, the effective aperture increases with t so that the radiated power pattern is given by

$$P \propto \frac{tg}{2} \left(\frac{\sin \frac{Ktg}{2}}{\frac{Ktg}{2}} \right)^2$$

or more fully

$$P \propto \frac{tg}{2} \left(\frac{\sin \left(\frac{2\pi}{\lambda} \cdot \frac{tg}{2} \sin \theta \right)}{\frac{2\pi}{\lambda} \cdot \frac{tg}{2} \sin \theta} \right)^2$$

If the broadside position of the array is considered namely in the position where $\theta = 0$ the radiated power increases linearly with t as the aerial is filled or decreases linearly when the aerial is emptied. The curves shown in FIGURES 2, 3 and 4 clearly can represent either pulse amplitude or gain as ordinates.

Considering the radiation at the zeros for the radiation pattern when the array is full, that is when $t = t_a$, then for $P = 0$,

$$\sin \left(\frac{2\pi}{\lambda} \cdot \frac{tg}{2} \sin \theta \right) = 0$$

Thus

$$\frac{2\pi}{\lambda} \cdot \frac{tg}{2} \sin \theta = n\pi (n = \pm 1, \pm 2, \pm 3 \dots)$$

Thus for $t=t_a$, the radiation is zero for values of θ given by,

$$\theta = \sin^{-1} \left(\frac{\lambda n}{lg} \right)$$

Thus the energy radiated for other values of t $t_a > t_0$, at the above angles, that is whilst the aerial is being filled say, is given by

$$P \propto \frac{g t_a^2}{2 \pi^2 n^2 t} \sin^2 \left(\frac{\pi n t}{t_a} \right)$$

For $n=1$, P is only zero when $t=t_a$.

For $n=2$, P is zero at

$$\frac{t_a}{2}, t_a, \dots$$

or in general when

$$\frac{t}{t_a} = \frac{k}{n}$$

(k an integer, $n \geq k \geq 0$)

FIGURE 5 illustrates the power radiated with respect to time for the main beam and also at the first and second zero's when $t_a < t_p$.

From the above consideration it is apparent that the duration of the pulse radiated by an aerial is increased by an amount determined by the velocity of propagation in the aerial. If $t_a < t_p$ then the forward gain and radiation pattern are determined by the length of the aperture of the array. When $t_a > t_p$ however the forward gain and the radiation pattern is determined by the pulse length. The response in this case is reduced by a factor

$$\frac{t_p}{t_a}$$

During the transient period of "filling" or "emptying" the aerial spurious side lobes can occur in the radiation pattern. These lobes however can never be greater than the normal side lobes for the aerial.

It will be thus appreciated from the above that in apparatus which is merely designed according to the invention for the transmission of pulses, in order to obtain maximum pulse amplitude, the effective aperture of the aerial is predetermined according to the duration of the intervals during which energy is emitted by a source and the velocity of propagation of the energy along the waveguide so that energy emitted at the beginning of an interval traverses the whole of said aperture prior to energy emitted at the end of the interval arriving at said aperture.

It will be assumed that it is required of the aerial to provide reception of signals transmitted by it and reflected from a distant object.

FIGURE 6 of the drawings shows a plane wave of pulse energy for which $t_a \leq t_p$ at normal incidence on a section of the aerial. The shape of the pulse is as shown in FIGURE 2. It is seen that at the beginning of the section say l_0 , a trapezoidal pulse is received and appears as such at the receiver input terminals. The contributions from other sections of the array are delayed due to the group velocity in the aerial the voltage appearing at the receiver is consequently an integration of all these contributions. The shape of the pulse at the receiver terminals as compared with the incident pulse is shown in FIGURE 7. For similar consideration the shapes of R.F. pulses appearing at the receiver terminals as compared with the incident pulses when $t_a = t_p$ and $t_a > t_p$ are as shown in FIGURES 8 and 9 respectively.

In general the duration of a received pulse is given by $t'_r = t_p + 2t_a$ where the symbols denote the quantities attached to them above and it will be appreciated from these considerations that the received signal reaches its maximum possible value only when

$$t_a < \frac{t_p}{2}$$

Considering the response of a pulse of energy at angles other than normal incidence, FIGURE 10 illustrates a plane wave incident at an angle θ to the aerial. Clearly for energy to make the transition from being radiated energy to being energy in the aerial two delays occur, firstly the delay by the finite velocity of propagation in the aerial and secondly the delay due to the varying path length $L \sin \theta$ in space. The result of these delays is that the pulse appearing at the receiver terminals is elongated as in the aforementioned examples with a further elongation, namely $L \sin \theta$.

Moreover the intensity of the incident pulse is not constant over the aerial aperture with the result that smoothing occurs of the resultant radiation pattern by effectively filling the zeros so that some energy is received for the whole range of θ . This energy, however, never exceeds the normal side lobe level so that reception in directions other than those normal to the aperture produces a low energy level for received signals. This level is, moreover, further reduced by the elongation of the pulse except for incidence in the normal direction.

In addition to the above equations therefore, on consideration of reception of the transmitted pulse by the same aerial the receiver voltage reaches a maximum value if

$$t_a < \frac{t_p}{2}$$

and by constructing the aerial according to the present invention and having the length of the transmitting or receiving element less than half the effective pulse width of the energy to be received or transmitted, maximum gain may be obtained from the aerial arrangement, whilst the spurious side lobes produced for directions other than normal are of negligible amplitude. In other words, an aerial according to the invention, adapted for transmission and reception of the same pulses with maximum amplitude therefore has an effective aperture which is predetermined according to the duration of intervals during which energy is emitted by a source and the velocity of propagation of the energy along the waveguide to cause energy emitted at the beginning of an interval applied to said aerial to traverse substantially the whole of said aperture before the whole of the energy emitted during the first half of the interval arrives at said aperture.

If for special purposes it is required to provide a minimum beam width the width of the beam may be reduced by increasing the lengths of the radiation apertures for a transmitter receiver aerial but this may be at the expense of the gain of the arrangement and with a deterioration in pulse shape.

In a typical example of an aerial according to the invention, let it be assumed that pulses of duration one fifth of a microsecond of oscillation of wavelength 3 centimeters are to be transmitted and received by the aerial. Assuming a decrease in group velocity within the aerial by a factor of 1.5 as compared with free space then the group velocity becomes 2×10^{10} cm. sec.⁻¹. According to the applicant's invention, for a transmit-receive array, $t_a \leq t_p/2$ for maximum response. So that t_a is less than or equal to one tenth of a microsecond $t_a \leq 1 \mu$ sec. But as aforementioned $t_a = L/g$ which on substitution for L and g gives

$$L \leq 2 \times 10^3 \text{ cm.}$$

Therefore one form of an aerial according to the applicant's invention with the particular conditions specified may comprise a radiating element having an aperture of 20 metres or less to give a maximum response. A typical such aerial is shown in FIGURE 11 of the drawings.

A waveguide 1 is approximately ten metres in length to enable it to carry 500 slots S1, S2, S3 to S500 mid points of which are spaced to centimetres apart. The slots are cut in the narrower face of the waveguide and

5

are tilted alternately in opposite directions to provide a correct phase relationship between the slots whilst at the same time permitting energy to be emitted from the array. It will be appreciated that although the slots are shown to be tilted at approximately equal angles on either side of the normals to the wider faces of the waveguide, the slots may progressively be tilted in known manner at larger angles to compensate for the loss of energy through the slots as a pulse progresses along the waveguide. This clearly does not detract from the invention and in the interests of simplicity mention of it has been avoided in the foregoing description and analysis. The aerial is fed in conventional manner from a source of 3 centimetre waves via the feeder guide 2 which is coupled to 1 by marrying flanges 3 and 4 bolted together. The waveguide 1 is terminated in known manner by a wooden terminating load block 5. Different forms of termination may of course be employed.

The present invention has the advantage of providing a maximum range of operation for a transmit-receive apparatus for a given power and is especially applicable to navigation equipment. If the aerial is not required to both transmit and receive the transmitted pulses but is only required for example to receive, the dimension of the aerial aperture may be chosen so that the aperture length in time is equal to or smaller than the duration of pulses to be received. No further description of such an aerial is illustrated for clearly it can merely comprise a modification with regard to longitudinal dimensions of the aerial shown in FIGURE 11. Moreover, transmit-receive apparatus, receivers and transmitters in microwave energy are certainly known so that illustration of apparatus according to the invention apart from the aerial is not shown.

What I claim is:

1. Transmission apparatus comprising a waveguide provided with a plurality of slots, arranged to operate as an aerial to transmit micro-wave energy, an energy source operative intermittently to emit energy during predetermined intervals, said energy source being connected to said waveguide, the effective aperture of said aerial being predetermined according to the duration of said intervals and the velocity of propagation thereof along said waveguide to cause energy emitted at the begin-

6

ning of an interval to traverse the whole of said aperture prior to energy emitted at the end of the interval arriving at said aperture.

2. Transmit-receive apparatus comprising a transmitter and a receiver, a waveguide provided with a plurality of slots arranged to operate as an aerial for transmitting and receiving microwave energy, means being provided for connecting said waveguide to said transmitter for transmitting energy and for connecting said waveguide to said receiver for receiving said energy, said transmitter comprising an energy source operative intermittently to emit energy during predetermined intervals, and the effective aperture of said aerial being predetermined according to the duration of said intervals and the velocity of propagation thereof along said waveguide to cause energy emitted at the beginning of an interval applied to said aerial from said transmitter to traverse substantially the whole of said aperture before the whole of the energy emitted during the first half of the interval arrives at said aperture.

3. Transmit-receive apparatus comprising an energy source operative intermittently to emit energy during predetermined intervals, a receiver, a waveguide provided with a plurality of slots and connected to said receiver to operate as a receiving aerial for said receiver to receive said energy, the effective aperture of said aerial being predetermined according to the duration of said intervals and the velocity of propagation of said micro wave energy along said waveguide, to cause energy emitted by said source at the beginning of an interval to traverse substantially the whole of said aperture before energy emitted by said source at the end of an interval arrives at said aperture.

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