United States Patent [19]

Scherer

[11] **3,775,771**

[45] **Nov. 27, 1973**

[54] **FLUSH MOUNTED BACKFIRE CIRCULARLY POLARIZED ANTENNA**

[75] Inventor: **James P. Scherer**, Sunnyvale, Calif.

[73] Assignee: **Textron Inc.**, Belmont, Calif.

[22] Filed: **Apr. 27, 1972**

[21] Appl. No.: **248,110**

[52] **U.S. Cl.** **343/770**, 343/853

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

[58] **Field of Search** 343/767, 770, 771, 343/853

[56] **References Cited**

UNITED STATES PATENTS

2,812,514	11/1957	Smith	343/767
3,680,142	7/1972	Van Atta	343/770
2,877,427	3/1959	Butler	343/770

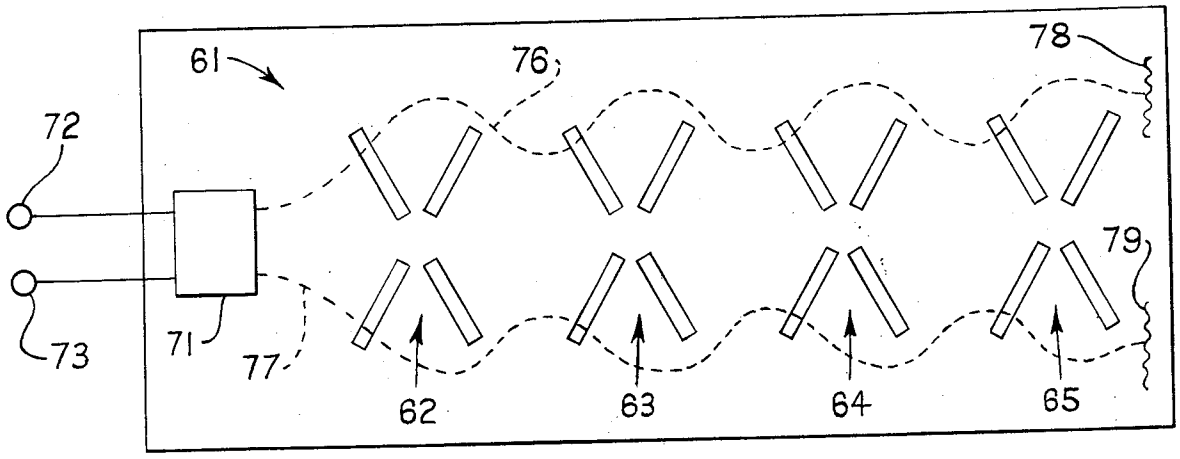
Primary Examiner—Eli Lieberman

Attorney—Alvin E. Hendricson et al.

[57] **ABSTRACT**

A flush mounted backfire antenna and array receptive to circularly polarized radiation and particularly adapted for aircraft application. Two orthogonally phased elements such as half-wave slots are arranged so that the projected angle of the E field of the elements is 90° in a backfire direction.

7 Claims, 6 Drawing Figures



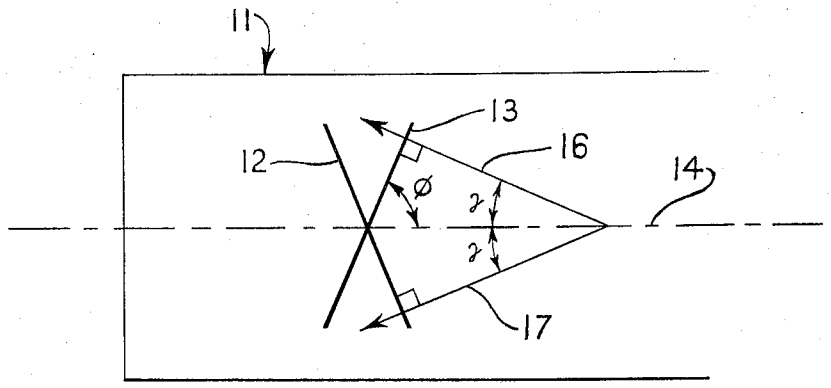


FIG. 1

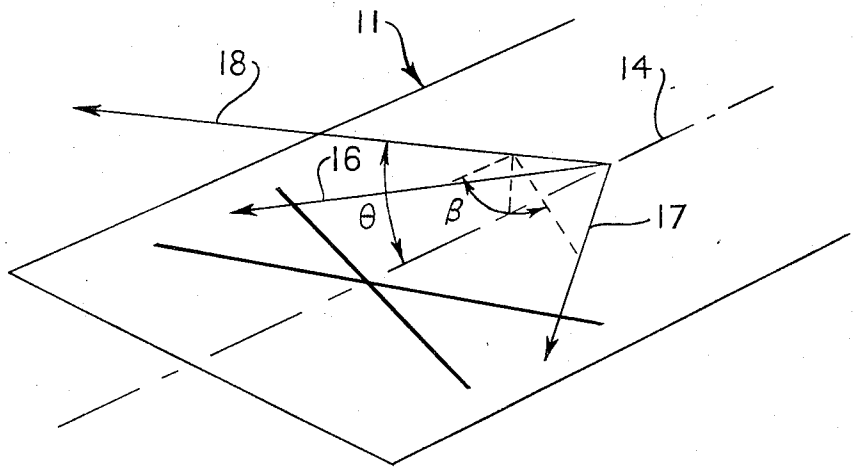


FIG. 2

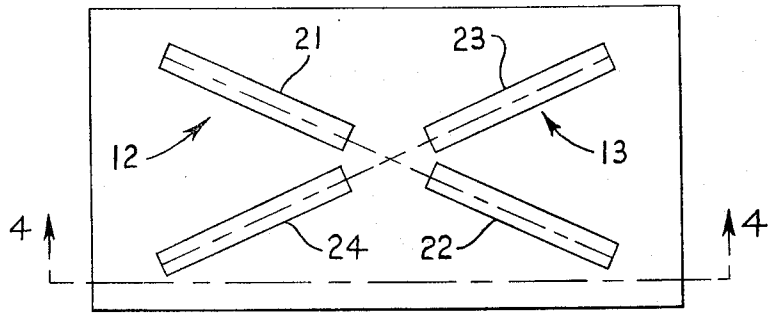


FIG. 3

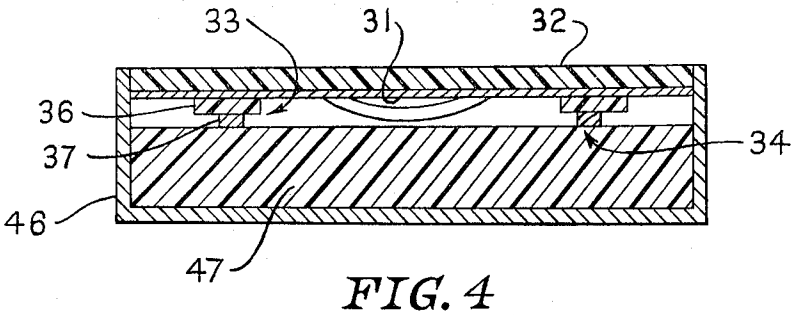


FIG. 4

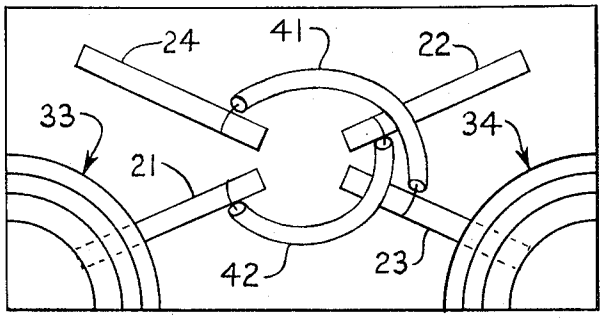


FIG. 5

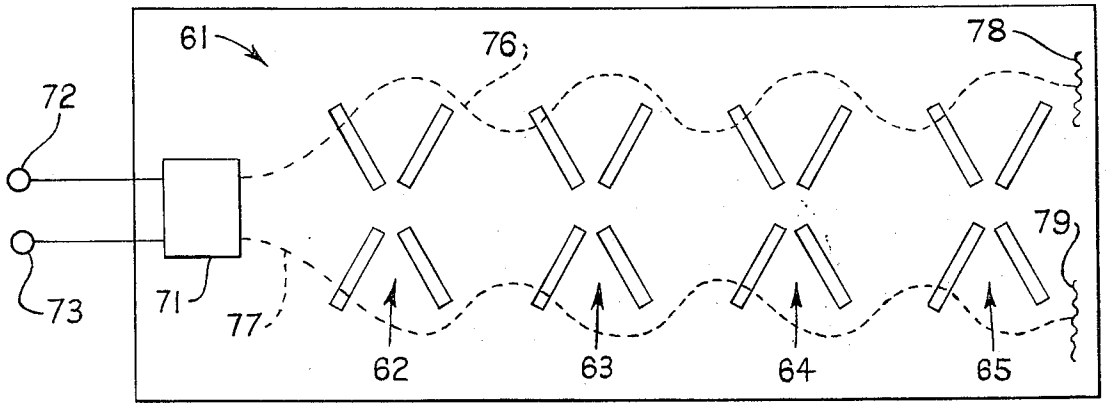


FIG. 6

FLUSH MOUNTED BACKFIRE CIRCULARLY POLARIZED ANTENNA

BACKGROUND OF INVENTION

Antennas and antenna arrays incorporating slot radiators for propagating and receiving circularly polarized radiation have long been known in the art. U.S. Pat. No. 2,767,395 discloses a beacon antenna for circularly polarized radiation and a generalized discussion of circularly polarized slot radiators is set forth in the article "Circularly Polarized Slot Radiators" by A.J. Simmons, IRE TRANSACTIONS ON ANTENNAS AND PROPAGATION, Vol. AP-5, No. 1, January, 1957, at pages 31 et seq. A further advance in this field is set forth in U.S. Pat. No. 2,982,960 wherein slot radiators are provided in a rectangular waveguide to achieve an arbitrarily polarized slot radiator.

There have also been developed a wide variety of flush mounted antennas which are paricularly adapted to aircraft use and other applications wherein space requirements may be exacting. Flush mounted antennas or radiators are commonly linearly polarized. Examples of flush mounted antennas which radiate in the backfire direction but are linearly polarized are to be found in an article entitled "A New Class of Log Periodic Antennas" by J.W. Greiser, pages 617 and 618 of May, 1964 PROCEEDINGS OF THE IEEE and an article entitled "A Log Periodic Cavity Back Slot Array" by Antoine Georges Roederer, appearing at pages 756 to 758 of the November, 1968 IEEE TRANSACTIONS ON ANTENNA AND PROPAGATION. Attempts to produce circularly polarized flush mounted antennas have been limited generally to broadside antennas and antenna arrays.

The present invention is particularly directed to the provision of a flush mounted antenna of simple and relatively inexpensive construction capable of propagating and receiving circularly polarized radiation in the backfire direction.

SUMMARY OF INVENTION

The antenna of the present invention comprises a flush mounted structure requiring only a minimal backing cavity so as to be particularly applicable to aircraft and the like. In accordance herewith a slot radiator is comprised of a pair of half-wave slots arranged so that the center lines thereof are crossed at an obtuse angle in the backfire or endfire direction of the radiator and the phase centers of the slots are coincident. The coincident phase centers produce circularly polarized radiation over a wide range of angles. The slots are energized in 90° phase relationship and in order to maintain this relationship the slots themselves do not actually cross or touch each other, but instead, each slot is formed as two slot portions. The angle between the radiating elements or slots of the present invention is set to establish the projected angle of the E field of the two elements equal to 90° along the center line of the radiator.

The antenna of the present invention may be simply constructed by etching radiation slots in a printed circuit board disposed over a small backing cavity and energizing the slots 90° out of phase with microstrip or coaxial feed lines, for example. Half-wave coaxial lines may be employed to couple opposite portions of each slot at the center of the crossed radiating elements. A total antenna depth of about 1 inch is attained hereby to thus achieve a truly flush antenna structure

It will be appreciated that antenna capabilities are in part measured by frequency sensitivity and with regard to the present invention it is also important that response be at least substantial over a wide range of angles. A single radiator in accordance with the present invention has been found to provide an axial ratio less than 3 decibels at 55° off broadside and a relatively good axial ratio at 30° off broadside in the forward fire direction while maintaining VSWR well below 2:1 at design frequency. Theoretically, a single antenna element in accordance with this invention radiates circularly polarized energy in the backfire and forward fire direction and periodic or log-periodic arrays are employed to couple the elements only to a backfire mode. Such an array is employed to maximize bandwidth and gain.

DESCRIPTION OF FIGURES

The present invention is described as to a single preferred embodiment thereof in the accompanying drawings wherein:

FIGS. **1** and **2** are diagrammatic representations of slot orientation, field vectors and relevant angles;

FIG. **3** is a plan view of an antenna formed in accordance with the present invention;

FIG. **4** is a transverse sectional view taken in the plane **4—4** of FIG. **3** and illustrating an internal arrangement of the antenna of FIG. **3**;

FIG. **5** is a sectional view taken in the plane **5—5** of FIG. **4** and illustrating electrical connection of radiating slots and portions thereof; and

FIG. **6** illustrates an antenna array and energization in accordance with the present invention.

DESCRIPTION OF PREFERRED EMBODIMENT

Reference is first made to FIGS. **1** and **2** of the drawings illustrating at **11** a ground plane having a pair of slot elements **12** and **13** disposed therein. In FIGS. **1** and **2** the numbers **12** and **13** actually represent the center lines of slot elements as further described below; however, for convenience, the term "slot element" or "element" is employed in the following theoretical discussion. The slot elements **12** and **13** will be seen to be disposed in crossing relation at the centers of each, with such centers disposed on a center line **14** of the antenna. The slot elements **12** and **13** are oriented in skew relation to each other with each of the elements making an angle ϕ with the center line **14.** The angle between the slot elements at the center line **14,** i.e., the angle 2ϕ, is greater than 90°. The direction of the E field is illustrated in FIG. **1** by the E field vectors **16** and **17.** These E field vectors will be seen to be normal to the adjacent portions of the radiators **12** and **13** and thus to each make an angle α with the center line **14.** It thus follows that $\phi + \alpha = 90°$.

FIG. **2** illustrates in perspective the ground plane **11** with the slot elements **12** and **13** thereon and E field vectors **16** and **17** being shown. The line or vector **18** is intended to represent the direction of circular polarization from the antenna. The circular polarization line **18** is shown to make an angle of θ with the ground plane **11.** There is also illustrated in FIG. **2** the angle β which is the apparent projection angle of the circularly polarized radiation and which is herein equal to 90°. From a mathematical consideration of the angles illus-

trated in FIGS. 1 and 2, it will be seen that in general sin θ = tangent α/tangent $\beta/_2$. Consequently, the angle of circularly polarized radiation from the ground plane of the radiators is, in fact, related to the slot angle ϕ and thus the present antenna does operate to radiate or receive circularly polarized radiation at a substantial angle to broadside, i.e., does comprise a backfire circularly polarized antenna.

One preferred physical configuration of the present invention is illustrated in FIGS. 3 to 5 wherein the same numerals 12 and 13 are employed to identify the radiators or slot members. In order to preclude problems arising from direct coupling between the radiators 12 and 13 that would result from actual crossing or touching of the slots, each of the radiators is formed as two longitudinally aligned slots. Thus, the radiator 12 is shown to be comprised as a pair of longitudinally aligned slots 21 and 22 of equal length, with a slight spacing between adjacent ends thereof. Similarly, the radiator or slot element 13 is comprised as a pair of longitudinally aligned slots 23 and 24 of the same length and spaced apart at the adjacent ends thereof. The slot members or, more properly, the center lines 12 and 13 thereof will be seen to intersect at the centers thereof as described above. The slots 21 and 22 are energized as described below to be in phase, and similarly, the slots 23 and 24 are energized to be in phase, so that the phase center of the slot pair 21–22 coincides with the phase center of the slot pair 23–24.

The slot radiators may be formed by etching a copper layer 31 on a dielectric plate 32 with such combination of dielectric and metal being comprised, for example, of a board for printed circuits. Energization of the radiators may be accomplished by the provision of microstrips 33 and 34 conventionally formed of a thin dielectric strip 36 having a metal conductor 37 plated on one side thereof. These microstrips may be directly connected to the metal side of the plate 32 with the strip electrode 37 separated from the copper layer 31 by the dielectric 36. Energization may be provided by a pair of microstrips, as illustrated, coupled, for example, to the slot portions 22 and 24 as shown. Placement of an energized microstrip across a slot will excite an electric field in a slot which, in turn, radiates. It is additionally noted that placement of the microstrip on a slot is such that the impedance of the microstrip matches the impedance of the slot at the crossing, so that maximum energy is transferred from the microstrip to the slot. In this respect, reference is again made to the above-identified publication of A.G. Roederer for a discussion of strip placement with respect to a slot for maximum coupling. It is also noted that the radiators may be energized from coaxial cables, and in this instance such cables might have the outer conductor connected as by soldering to the ground plane, with a gap in the outer conductor where the inner conductor thereof crosses the slot to be energized. Maximum coupling for coaxial energization is also attained by appropriate placement of the coax with respect to the slot in the same manner as microstrip coupling.

Coupling of the energized slot portions to the other portions of the respective slot pairs may be accomplished by the provision of coaxial connectors 41 and 42, as illustrated in FIG. 5. Each of the coaxial connectors is formed as a conventional cable of one-half wavelength at the operating or nominal frequency of the antenna. Considering the connector 42, for example, it will be seen that the central conductor thereof is coupled across the slot portions 21 and 22 of the radiation element 12. Thus the two slot portions 21 and 22 are electrically coupled together in phase for energization from the microstrip 33. Similarly, the slot portions 23 and 24 of radiator 13 are coupled together in phase by the coaxial line 41 for energization from the microstrip 34. Maximum coupling is provided by appropriate location of cable ends and slots in the same manner as discussed in the Roederer reference.

Each of the slot portions is formed as one-half wavelength slots at the operating or nominal frequency of the antenna and the two radiators 12 and 13 are energized 90° out-of-phase. This energization may be accomplished, for example, by providing a simple T-power splitter and an extra one-quarter wavelength in one of the microstrip lines or, alternatively, as described in connection with FIG. 6 below. This 90° energization or phase difference between radiator energization is accomplished in order to provide for the radiation of a rotating vector to thus establish the circular polarization of radiation from the radiators. The sense or direction of the circular polarization may be determined by inserting the extra one-quarter wavelength in the appropriate line.

The antenna structure may be completed by the provision of a shallow rectangular metal housing 46 having an open top into which there fits the dielectric plate 32 and elements carried thereby. This housing 46 has an open top to receive the upper portion of the antenna and may be substantially filled with an absorbent material 47, as illustrated.

It will be appreciated that the slots of the present antenna radiate when the electric field thereof is perpendicular to the slot length and thus it will be seen that the E field vector is, in fact, normal to the slot length to establish the E field vector directions as indicated in FIG. 1. It will be appreciated that the dielectric plate 32 and metallic ground plane 31 may be sealed to the open topped receptacle 46 to thus form a shallow sealed unit comprising a flush mounted circularly polarized backfire antenna. As previously noted the total depth of this antenna need only be about 1 inch for radiation in the microwave range. It is to be further appreciated that the above brief discussion of antenna radiation properties is equally applicable to antenna reception properties and thus the antenna of the present invention is particularly adapted to receive circularly polarized radiation from the back end of the antenna without undue attenuation thereof.

It is further noted that the antenna of the present invention may be provided in a periodic array or log-periodic array. In FIG. 6 there is generally illustrated a periodic array 61 of antenna elements 62–65 in accordance with the present invention. Another manner of energizing the antennas is illustrated in FIG. 6 as including a 90° hybrid 71 having ports 72 and 73 and providing not only a power split between the outputs but also a 90° phase difference therebetween. Microstrip or coaxial lines 76 and 77 are illustrated to extend from the hybrid 71 into coupling relationship with radiators of the antennas, and the lines 76 and 77 being terminated by matching loads 78 and 79, respectively. In order for the projected angle of the E fields from the successive pairs of radiating elements to attain space orthogonally, there is to be provided a slight phase difference between the energization of successive pairs of

elements. This phase difference may be provided by the length of microstrip or coaxial line between successive radiators to which it is coupled. The degree or amount of phase difference depends upon the physical spacing of the successive pairs and in this respect reference is made to the publication "Directive Frequency Independent Arrays," by K.K. Mei et al., appearing in the September, 1965 IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION regarding calculation of phase delay for coupling to the backward wave mode.

There will be seen to have been described above a simple flush antenna structure capable of radiating or receiving circularly polarized radiation in the backfire direction. It is furthermore noted that the dimensional tolerances of the elements of the invention are not critical. There is provided hereby a truly practical advance in the art. It is not intended to limit this invention to the precise terms of description or details of illustration for it will be apparent to those skilled in the art that numerous modifications and variations may be made.

What is claimed is:

1. An antenna structure comprising

electrically conducting means defining a ground plane having a center line longitudinally thereof,

said means having a pair of crossed slot radiators therein with the center lines of said slots crossing each other at said center line and symmetrically disposed with an angle greater than 90° therebetween at said center line, and

means electrically energizing said slots ninety degrees out-of-phase to thus radiate from the slots circularly polarized radiation at an angle to broadside from said ground plane.

2. The antenna of claim 1 further defined by each of said slots making an angle of ϕ with the center line of said ground plane, the E field vectors of said slots making an angle $\alpha = 90°-\phi$ with the center line of said ground plane and the center of said circularly polarized radiation making an angle with the ground plane of θ wherein $\sin\theta = \tan\alpha/\tan 45°$.

3. The antenna of claim 1 further defined by said ground plane being comprised as a metal layer on a dielectric plate and the means energizing said slots including microwave transmission lines coupled to separate slots.

4. The antenna of claim 1 further defined by means defining a shallow cavity disposed behind said ground plane.

5. The antenna of claim 1 further defined by each of said slots being comprised of two longitudinally aligned half-wave slot portions slightly separated at adjacent ends, and a half-wave transmission line coupling the portions of each slot.

6. An antenna structure comprising

an electrically conducting ground plane having at least two slot radiators therein,

said slot radiators having the center lines thereof crossing at the centers of the radiators and having an angle between the center lines greater than ninety degrees,

each of said slot radiators comprising a pair of longitudinal aligned slots spaced apart at adjacent ends with the phase centers of the two radiators coincident, and

means electrically energizing said slot radiators ninety degrees out of phase for propagating circularly polarized radiation from the antenna structure.

7. The antenna of claim 6 further defined by a plurality of pairs of said slot radiators aligned on said ground plane to radiate in the backfire mode.

* * * * *