June 30, 1953 A. DORNE 2,644,090

RECESSED SLOT ANTENNA

Filed March 5, 1948 4 Sheets-Sheet 1

Fig. 1.

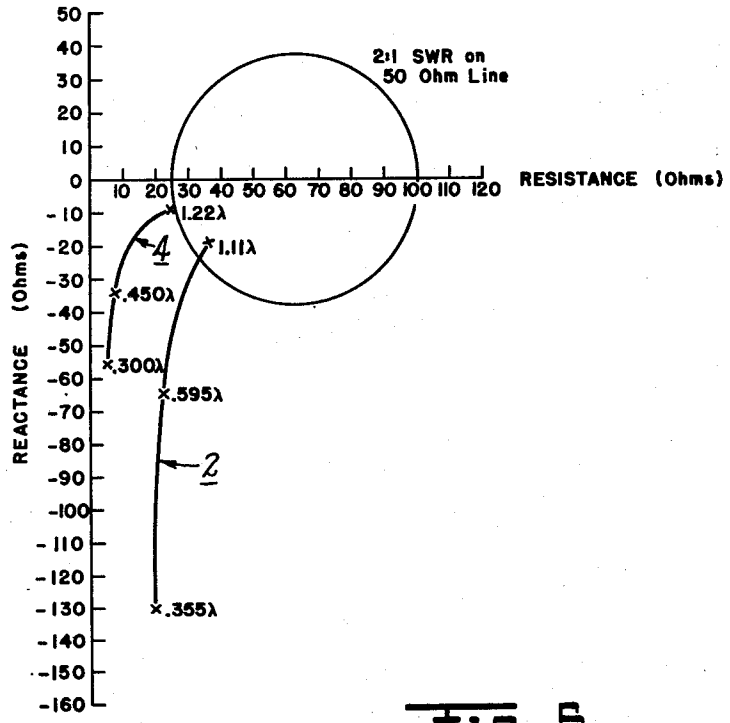


Fig. 6.

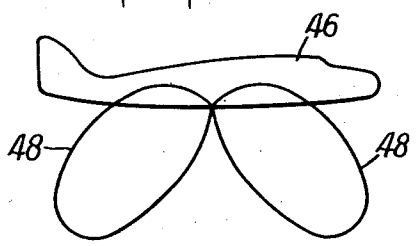
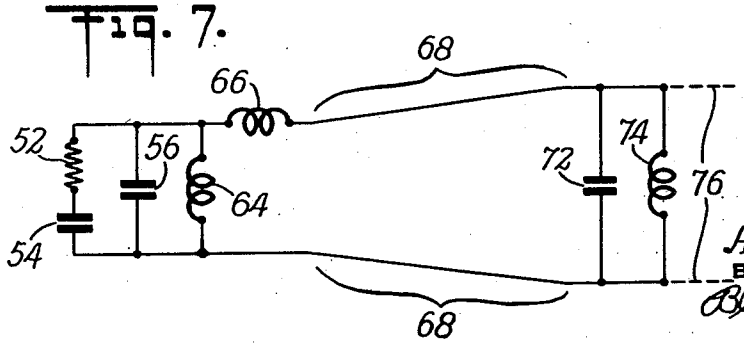


Fig. 7.



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June 30, 1953 A. DORNE 2,644,090

RECESSED SLOT ANTENNA

Filed March 5, 1948 4 Sheets-Sheet 2

Fig. 2.

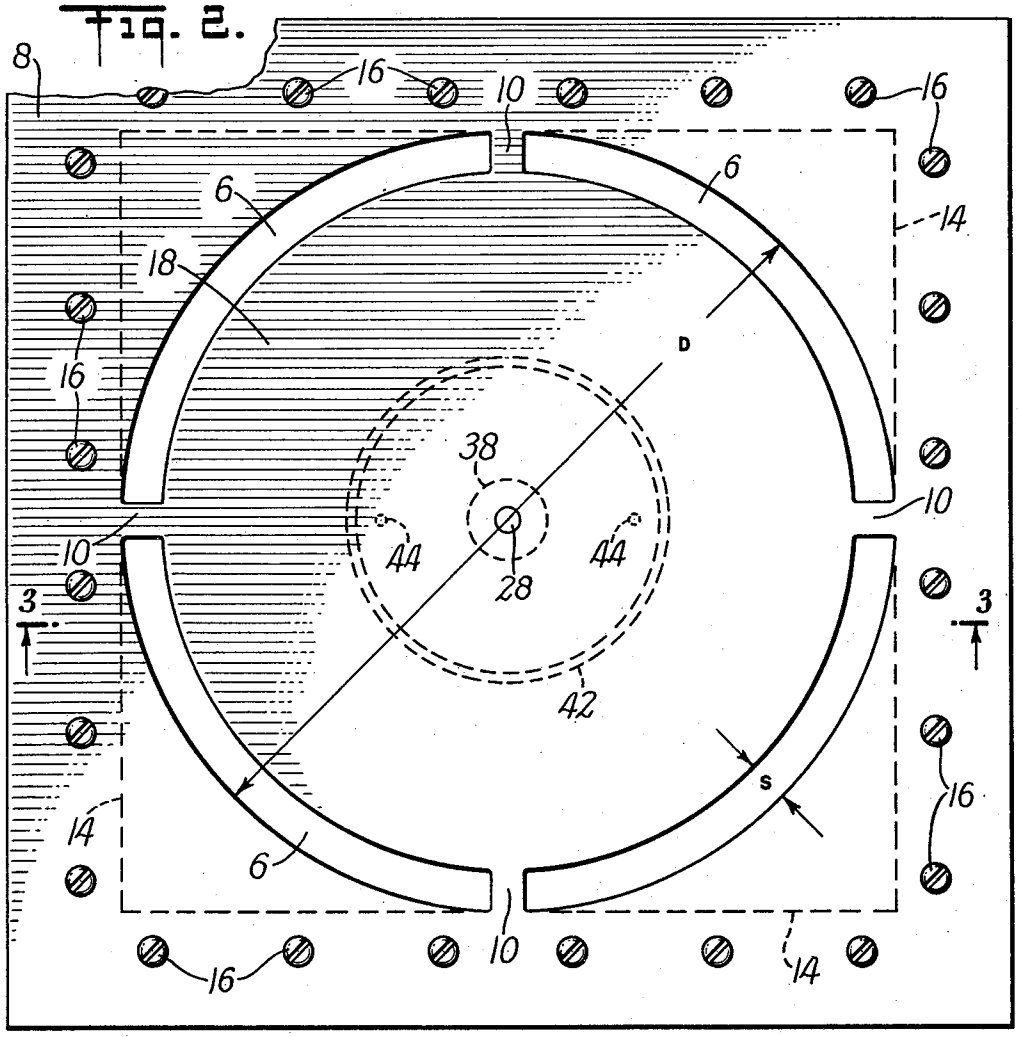


Fig. 3

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June 30, 1953 A. DORNE 2,644,090

RECESSED SLOT ANTENNA

Filed March 5, 1948 4 Sheets-Sheet 3

Fig. 4.

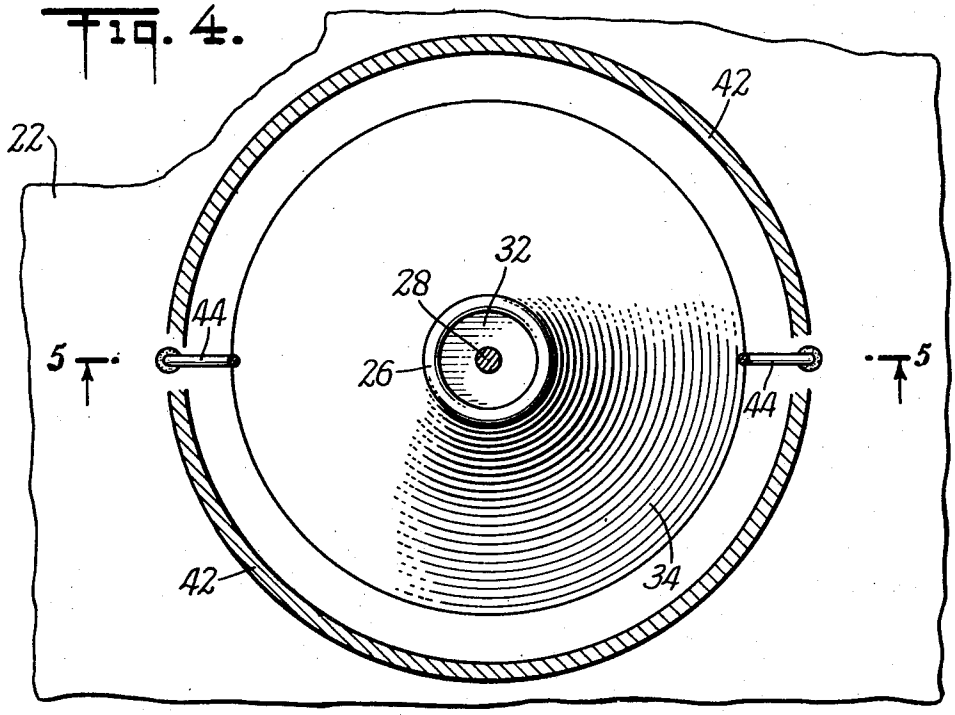
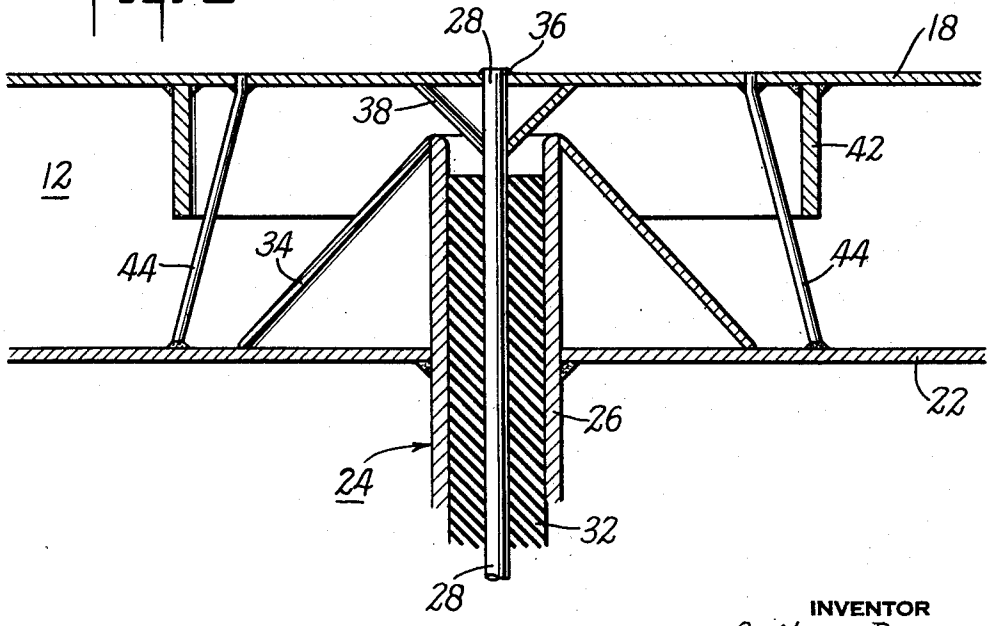


Fig. 5



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June 30, 1953 A. DORNE 2,644,090

RECESSED SLOT ANTENNA

Filed March 5, 1948 4 Sheets-Sheet 4

Fig. 8.

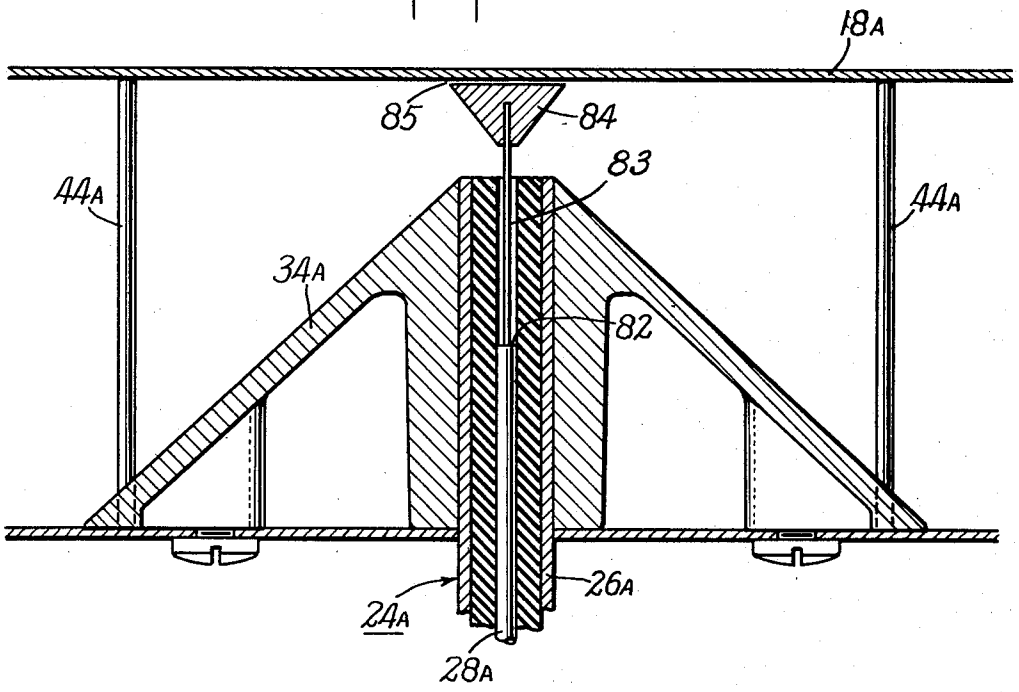


Fig. 9.

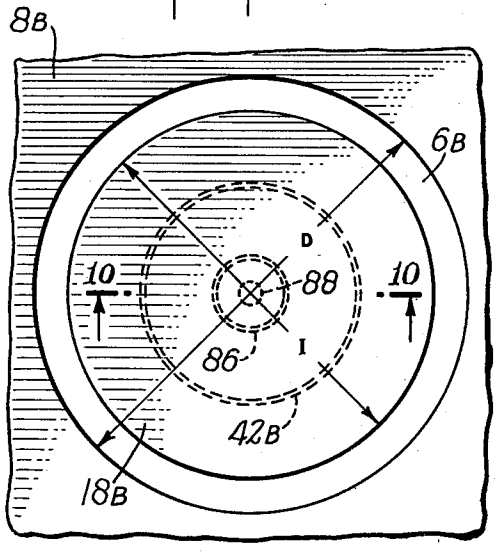
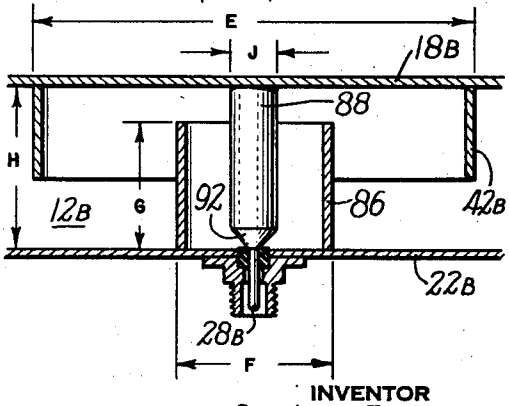


Fig. 10.



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Patented June 30, 1953 2,644,090

UNITED STATES PATENT OFFICE

2,644,090

RECESSED SLOT ANTENNA

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Application March 5, 1948, Serial No. 13,280

12 Claims. (Cl. 250—33.63)

1

This invention relates to antennas for the transmission or reception of radio signals. More particularly it relates to aperture type antennas that are recessed in the structure supporting the antenna, and which are suitable particularly for use on aircraft.

The continued rapid development of aircraft, with continual demands for higher speed and greater safety, has caused the transmission of radio signals to and from the aircraft to assume ever increasing importance. Such signals are utilized for the purpose of communication, but also have become essential in the performance of many other useful functions, for example, in navigation systems, radio altimeters, and in conjunction with radar and beacon systems and the like. This increase in the utilization of radio waves for such varied purposes has caused a corresponding increase in the number of antennas which are carried by a modern aircraft.

Accordingly, it has become of the utmost importance to minimize the number of antennas required to perform these necessary functions. Thus, the need is increasing for antennas capable of operation over extremely wide ranges of frequency so that in many cases a single antenna can be used in the performance of two or more separate functions.

Concurrently with this general trend, the flight speed of aircraft has been increased steadily. Structures which project from the fuselage, for example, stub antennas which protrude at an angle from the surface of the aircraft, have become more and more undesirable. The wind drag caused by such antennas, even when they are highly streamlined, is a serious factor in reducing the top speed and consequently reducing the range of high speed aircraft. In addition, the vibration of such protruding structures and the possibility of ice formation on them are further reasons why their elimination is important. Thus, it is desirable that the antennas be recessed into the surface of the aircraft so that no portion of the antenna protrudes therefrom. With many of the higher speed aircraft, where external dimensions have been reduced, space within the aircraft becomes very precious and, accordingly, it is desirable that these "faired-in" antennas and their associated equipments occupy the smallest possible space within the aircraft.

One approach that has proven useful at the higher frequencies is to utilize a slot-like aperture in the outer conductive surface of the aircraft, and to excite this slot electrically so that it is effective to radiate or receive the desired radio waves.

2

In general, such slots have comprised narrow rectangular apertures cut in the conductive surface of the aircraft. This asymmetrical construction of the antenna produces an asymmetrical field pattern, that is, the radio waves are not radiated uniformly in all directions and, therefore, the intensity of the radio signal, at a particular receiving station, depends both upon the position and upon the orientation of the aircraft. For many applications, such directional radiation is undesirable; for example, in communication systems where it is necessary to transmit and receive radio signals between ground stations and the aircraft. Such linear slot antennas are unsuitable for this purpose because they will not provide the necessary all-around coverage. Vertical stub antennas, which extend at an angle from the conductive surface of the aircraft have a field pattern that does provide the desired all-around coverage. In general, it is desirable that the omnidirectional radiation characteristics of an antenna, which is to be used for this purpose, be such that a certain proportion of the energy is radiated in the plane of the conductive surface of the aircraft on which the antenna is mounted, that the maximum radiation be in the region of 20 or 30 degrees from horizontal, and that the intensity of the radiation be uniform throughout 360 degrees, so that the strength of the signal received on the ground is independent of the heading of the aircraft.

In accordance with the present invention, a faired-in antenna is provided which utilizes a non-linear slot, for example, circular, and which meets the requirements for a vertically polarized microwave antenna suitable for replacing an exterior stub type antenna on aircraft.

Accordingly, it is an object of this invention to provide an improved faired-in antenna particularly suitable for use on aircraft but having characteristics which render it useful for other applications.

Another object of this invention is to provide an antenna which utilizes a crooked slot as the radiating element.

Another object is to provide an antenna system in which the radiating and receiving aperture is in the form of a substantially annular slot.

Still another object is to provide an improved recessed antenna having radiation characteristics similar to those of a stub antenna.

Another object is to provide a crooked-slot antenna in combination with a cavity so that the antenna structure occupies minimum space.

Another object is to provide an impedance

matching structure for use with such a crooked-slot antenna.

A further object of this invention is to provide an aperture type antenna in which a series of arcuate slots are separated by conducting material which serve as inductive elements to compensate the capacitive reactance of the radiating aperture.

Other objects and advantages will be apparent from the consideration of the following detailed description taken in conjunction with the accompanying drawings in which similar numbers refer to similar parts throughout the several views, and in which:

Fig. 1 is a graphical representation of the impedance of a wide and of a narrow slot in a conductive surface;

Fig. 2 is a plan view of an antenna constructed in accordance with the present invention and showing the configuration of the radiating aperture;

Fig. 3 is a sectional view taken on line 3—3 of Fig. 2;

Fig. 4 is an enlarged sectional view taken on line 4—4 of Fig. 3;

Fig. 5 is a sectional view taken on line 5—5 of Fig. 4;

Fig. 6 is a representation of the field patterns of the antenna shown in Figs, 2, 3, 4, and 5;

Fig. 7 is a circuit diagram for the purpose of explaining one theory of operation of the antenna;

Fig. 8 is a sectional view of an alternative impedance matching arrangement;

Fig. 9 is a plan view of still another antenna arrangement; and

Fig. 10 is an enlarged partial cross-section of the same antenna taken on line 10—10 of Fig. 9.

The antenna shown in the drawings are described with respect to the transmission of radio frequency energy, but because the characteristics of a given antenna are the same, if properly interpreted, whether the antenna is used for transmission or reception, the invention is not to be limited to transmitting antennas; and such terms as "radiation," "transmission" and so forth, are to be interpreted to cover both transmitting and receiving or the transmission of energy either toward or away from the antenna.

In accordance with the invention a circular slot in a conducting surface is excited symmetrically, in order to produce a radially symmetrical field pattern. However, in order to excite such a slot efficiently, it is necessary that the impedance of the slot be approximately the same as the impedance of the transmission line which feeds energy to the slot, or that matching networks be provided which accomplish the necessary impedance transformation. If the antenna is to be broadband, that is, useful over a wide range of frequencies, the impedance of the aperture must be made to match the transmission line impedance throughout the operating range of frequencies. Such a circular slot has capacitive reactance as may be seen by examination of Fig. 1, in which reactance and resistance are plotted as functions of frequency for two particular slots. Curve 2 represents the impedance of a slot as the frequency varies so that the diameter of the circular slot (measured from the outside edges) varies from approximately 0.3 to 1.0 wavelength along the length of the curve. Curve 4 shows the impedance values obtained with a wider slot over substantially the same frequency range.

In order to compensate partially for the capacitive impedance of the circular slot, the radiating aperture of the antenna shown in Figs. 2, 3, 4, and 5, and which comprises a substantially annular slot, is arranged in the form of four arcuate slots 6 (Fig. 2) in a conducting surface 8, and which are separated by conducting strips 10. Thus, the slot aperture is substantially annular in shape with spaced conducting strips 10 extending transversely across the slot. The strips 10 provide the effect of an inductive reactance in shunt with the capacitive reactance of the radiating slots.

In order to produce symmetrical excitation of the arcuate slot portions 6, and to minimize space requirements, a shallow cavity 12 (Fig. 3) is formed in conjunction with surface 8, by outwardly extending cavity walls 14 of conducting material, which are secured to the conducting surface 8 by screws 16, and a back plate 22 parallel to surface 8 and formed integrally with walls 14. Thus, cavity 12 is formed between a disc 18, which is defined by the arcuate slot portions 6, and the back plate 22. Plate 22 and disc 18 may be regarded as forming a parallel-plate transmission line having a characteristic impedance which varies throughout its length, that is, from the center of disc 18 outwardly to the slots 6.

In order to feed electrical energy into cavity 12, a coaxial transmission line 24, having an outer conductor 26 (Fig. 5), an inner conductor 28, and insulating material 32, is connected from a suitable transmitter or other source of radio frequency energy (not shown), to the center of cavity 12. The outer conductor 26 of the transmission line 24 is in electrical contact with and extends through the back plate 22 and transversely across the cavity toward, but not touching, the inner surface of disc 18. The inner end of conductor 26 is connected to the smaller end of cone 34, the larger end of which is secured to the inner surface of back plate 22. Inner conductor 28 of cable 24 extends beyond the end of outer conductor 26 and is secured to the center of disc 18, as at 36. The portion of the inner conductor 28, near disc 18, is surrounded by a conductive cone 38, the smaller end of which is joined to conductor 28 substantially at the end of cable 24 and the larger end of which is joined to the inner surface of disc 18.

Thus, radio frequency energy is fed to the cavity through the conical transmission line formed by cones 34 and 38 and disc 18, and which has a characteristic impedance, in this example, of approximately 50 ohms. This conical transmission line extends outwardly from the center of the cavity about one-third of the distance to the outer edges of slots 6. The energy from the conical transmission line travels outwardly, that is, radially, through the parallel-plate transmission line formed by disc 18 and plate 22, to the slots 6.

The impedance measured at the junction of the parallel-plate transmission line with the conical transmission line, looking toward the slot aperture, is such that on a 50-ohm transmission line it would produce a maximum standing wave ratio of 3.5 to 1 within the frequency range in which the diameter D of the radiating aperture (measured from the outside edges of the slots) is between 0.55 and 1.0 wavelength.

In order to reduce the standing wave ratio to a maximum value of approximately 2 to 1 over this

frequency range, a parallel resonant circuit is incorporated in the antenna structure. Compensation in this manner is possible because the impedance of the slot portions 6 together with the strips 10, which is inductive at the low frequency end of this range, and capacitive at the high end, is so transformed by the parallel-plate transmission line that the compensation is effective at the location of the resonant circuit. The resonant circuit is constructed by means of a ring 42 (Fig. 5), one edge of which is secured to the inner surface of disc 18, and which acts as a capacitive element; the inductive portion of the resonant circuit being provided by two wires 44 which are connected directly across the cavity from disc 18 to the inner surface of plate 22.

With this arrangement of matching elements, the antenna operates with high efficiency over the frequency range in which the diameter D of the radiating aperture is between 0.55 and 1.0 wavelength.

However, because of the addition of the matching elements, the antenna structure is not perfectly symmetrical and, therefore, the symmetry of the field pattern is distorted. For frequencies at which the slot diameter D is less than approximately 0.8 wavelength, the asymmetrical antenna construction produces very little change in the radial symmetry of the radiated energy; the asymmetrical effect becoming more pronounced as the frequency increases so that the slot diameter D approaches one wavelength.

The approximate field pattern of this antenna installed on the underside of an airplane 46, so that the radiation is generally downward, is shown in Fig. 6. The curves 48 indicate the relative field strength of the radiated signals in various angular directions in a plane which extends vertically through the axis of symmetry.

It is to be understood that the field pattern will be affected by the configuration and size of the ground plane or conductive surface 8 in which the slot 6 is cut; this effect being substantially similar to the effect of the adjacent ground surface on a stub type antenna. For example, the slot may be formed in a curved surface and the antenna constructed in accordance with the general principles exemplified herein. However, with sharply curved ground surfaces, modification of the matching networks may be necessary and the field pattern may be changed to considerable extent. This change in field pattern may be advantageous or disadvantageous depending upon the particular requirements of the antenna installation.

The operation of the antenna may be clarified by considering the lumped constant circuit shown in Fig. 7. The impedance of an annular slot is represented by a resistance 52 in series with a capacitance 54. A capacitance 56, in parallel with this series combination, represents the capacity between the disc 18 and the inner surfaces of cavity walls 14 (Fig. 3). The presence of the shunt capacitance 56 reduces the bandwidth over which the antenna can be matched to the transmission line 24 and, accordingly, this capacitance should be made as small as possible within the space limitations of the particular installation. In this example, the horizontal cross-section of the cavity 12 is square so that the average distance between the annular aperture and the walls 14 is increased. An inductance 64 is in shunt with capacitance 56 and is produced, in this antenna, by the strips 10. The inductance 64 and the capacitances 54 and 56 form a parallel circuit which is resonant within the operating range of the antenna. A series inductance 66 represents the inductive reactance of the cavity walls and, for most considerations, is a negligible quantity. The radial transmission line, formed by the back wall 22 and disc 18 of cavity 12, with its varying characteristic impedance, is represented at 68 in Fig. 7. In this example the impedance varies from about 20 ohms at the slot to about 50 ohms at the junction with the conical transmission line. A shunt capacitance 72, produced by the ring 42, is in parallel with an inductance 74, formed by the wires 44. In this example, capacitance 72 and inductance 74 form a circuit resonant substantially at the center of the frequency range of the antenna and transform the impedance so that the antenna operates efficiently over a wider range of frequencies. The broken line 76 correspond to the transmission line 24 by which electrical energy is fed to or from the antenna structure.

For one particular application, the antenna described above was built in accordance with the following dimensions. The slot diameter D (Fig. 2) is the radial distance between the outside edges of the slot portions 6. In terms of this dimension, the slot width S is approximately 0.052D and the cavity depth C (Fig. 3) is about 0.16D.

In those cases where a series resonant circuit should be associated with the input circuit of the antenna to achieve the most desirable operating characteristics, the circuit may be constructed as shown in Fig. 8. In this example, the center conductor 28A of the coaxial transmission line, starting at point 82, contains a short circuited section of coaxial transmission line, having an inner conductor, generally indicated at 83, and length such that it produces a series inductive reactance. The series capacitance is provided by cone 84 which is secured to the end of inner conductor 83 and which is adjusted to provide a small airgap 85 between the base of cone 84 and the inner surface of disc 18A. The value of the capacitance may be adjusted by varying the airgap 85 between the end of inner conductor 83 and the surface of disc 18A.

Figs. 9 and 10 show another antenna construction, the basic operation of which is similar to that already described but which differs in details of the matching structure. The radiating aperture is a circular slot 6B in the conductive surface 8B. Cavity 12B, in this example, has a circular cross-section, the inner diameter of which corresponds to the dimension D shown in Fig. 9. The matching structure includes ring 42B, which extends inwardly from disc 18B, and a ring 86, of smaller diameter, which extends inwardly from the back wall 22B of the cavity 12B. Inner conductor 28B is provided with an enlarged end portion 88 which is joined to the center of the inner surface of disc 18B. Near the back wall 22B of the cavity, enlarged section 88 is reduced in diameter, by a tapered portion 92, to form the inner conductor 28B of the coaxial transmission line.

This antenna has been found to give good performance over a relatively wide frequency range, for example, through the frequency range where diameter D is between approximately 0.68 and 1.0 wavelength. Suitable dimensions for

the antenna in terms of diameter D are given in the following table:

Dimension	Value
E	0.51D
F	0.17D
G	0.149D
H	0.192D
I	0.745D
J	0.074D

It is understood that the radiating apertures of antennas described herein are intended to be covered with suitable dielectric material when installed on aircraft, to provide thereby a smooth continuous exterior surface.

If wide band operation is not required for particular applications, the diameter of the slot may be smaller than those of the antennas described; satisfactory operation with about twenty per cent bandwidth has been obtained with antennas approximately one-half the size of those described. The radiation pattern of the smaller antennas has substantially the same characteristics as those of the antennas described above.

Many modifications are possible, for example, the aperture may comprise a square, rectangular, or other polygonal shaped slot, and may have either a uniform or non-uniform width along its length, for example, the outside of the slot may be square and the inside circular.

It is to be distinctly understood that the examples and the dimensions given herein are provided for the purposes of exemplifying a working embodiment of the invention; the theories of operation are provided to assist in explaining the embodiment of the invention and are not to be regarded as rigorous or classical theories which determine the ultimate limitations of antennas constructed in accordance with this invention or their suitability for specific applications.

I claim:

1. In an antenna, the combination comprising a member having a conductive surface with a curved slot in said surface, a box having opposed conductive side walls defining a radially-conductive wave-transmitting cavity, wave-transmission means, and coupling means connected to said wave-transmission means and extending transversely across said cavity substantially at its center and electrically coupled thereto, said slot being coupled to said cavity near the outer limits of said cavity whereby electromagnetic energy fed into said cavity by said wave-transmission means is conducted radially therein and radiated by said slot.

2. The combination as described in claim 1 including an impedance compensating element comprising an inductive strap of conductive material extending across said slot and arranged to compensate for the capacitive reactance of said slot.

3. The combination as described in claim 1 wherein the slot is substantially annular.

4. In an aperture type antenna comprising a member having a conductive surface with a radiating aperture including at least one arcuate slot portion in said surface, said surface being continuous within the sector defined by said arcuate slot portion, a conductive enclosure electrically connected to said surface and defining a cavity coupled near its outer edge to said slot, a radio frequency transmission channel, and coupling means connected to said transmission channel and extending transversely across said cavity substantially at the center of curvature of said arcuate slot portion whereby energy is transferred from said channel through said cavity to said slot.

5. A high frequency antenna comprising a member having a conductive surface with a plurality of spaced arcuate slots therein, a radial transmission line coupled to said slots and having opposed parallel conductive surfaces one of which is formed by the conductive surface of said member, a transmission channel for carrying radio frequency energy, and coupling means connected to said channel and extending between said parallel conductive surfaces substantially at the center of curvature of said arcuate slots, whereby energy is coupled from said transmission channel through said cavity and radiated by said slot.

6. An antenna as described in claim 4 wherein the radius of curvature of the outer edge of said slot portion is less than one-half wavelength at the lowest frequency of operation.

7. An antenna structure comprising a member having a conductive surface with an arcuate slot therein, a transmission line for conducting radio frequency energy, and means for coupling said energy between said transmission line and said slot, said means comprising a parallel-plate radial transmission line electrically coupled to said slot, one surface of said radial transmission line being formed by the conductive surface of said member, and excitation means connected to said transmission line and extending transversely across said radial transmission line substantially at the center thereof, whereby energy is coupled into said radial transmission line in such manner as to be transmitted radially therethrough to said slot.

8. A high frequency antenna system comprising a member having a conductive surface, a disc having a substantially continuous conductive surface spaced from and surrounded by said member so as to form a substantially annular slot in the conductive surface of said member, the conductive surfaces of said member and said disc lying substantially in the same plane, a conductive enclosure defining a cavity formed in part by said member and said disc and having a transverse dimension in a direction radially of the disc larger than the maximum diameter of said slot and adapted to energize said slot for the radiation of electromagnetic energy, and a transmission line extending across and coupled to said cavity substantially at the center of curvature of said annular slot.

9. An antenna system as described in claim 8 and including a plurality of spaced conductive strips extending across said slot said strips being inductive and so positioned and dimensioned as to substantially compensate the capacity reactance of said slot at the frequency of operation.

10. An aperture type antenna system adapted for operation over a predetermined range of frequencies, comprising a source of electromagnetic energy, a first transmission line coupled to said source, a parallel circuit resonant within the range of frequencies of operation of said antenna and coupled to said first transmission line substantially at the termination thereof, and a parallel-plate radial transmission line connected substantially at its center to said first transmission line and including a member having a conductive surface with a substantially circular slot therein.

11. In a faired-in aperture-type antenna, the combination comprising a member having a conductive exterior surface with a slot therein for radiating electromagnetic energy from said surface, a first parallel-plate radial transmission line coupling energy to said slot, a second transmission line for feeding energy to said first transmission line and coupling means extending between said second transmission line and the center of said radial transmission line.

12. A faired-in antenna for use in aircraft comprising a first coaxial transmission line for feeding energy to said antenna, a second transmission line coupled to said coaxial line and including a conical member, a third parallel-plate radial transmission line coupled to said second line, a member having a conductive surface forming a portion of one surface of said radial transmission line and having a substantially annular slot therein coupled to said radial transmission line, a plurality of conductive straps extending across said slot for compensating the capacitive reactance of said slot, and a parallel resonant circuit for further compensating the reactance of said slot and including a metallic ring connected to said surface for providing a capacitive reactance and a plurality of conductors extending across said second transmission line for providing an inductive reactance.

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