April 24, 1962 J. L. BUTLER 3,031,666

THREE CONDUCTOR PLANAR ANTENNA

Original Filed June 6, 1955 2 Sheets-Sheet 1

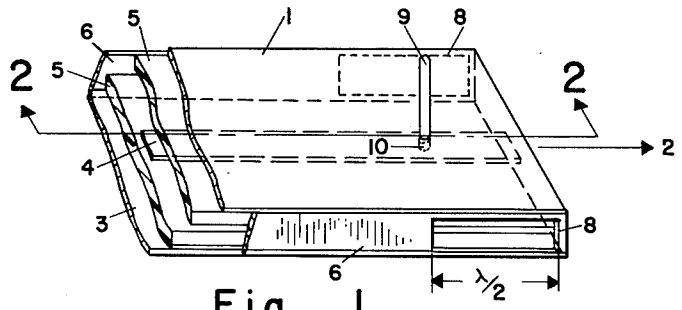



Fig. 1

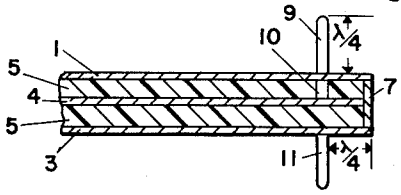



Fig. 2

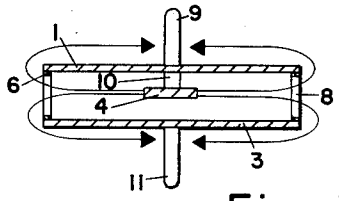



Fig. 3

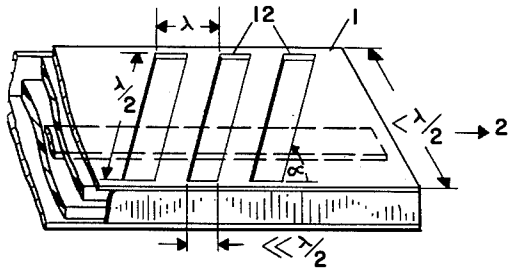



Fig. 4

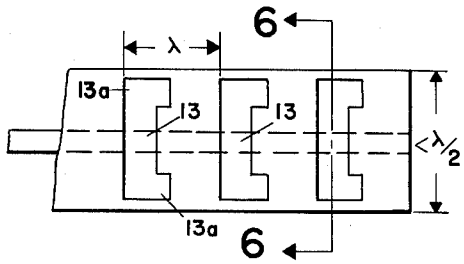



Fig. 5

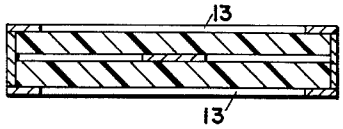



Fig. 6

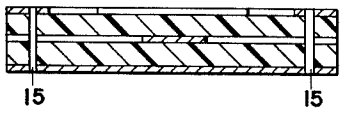



Fig. 8

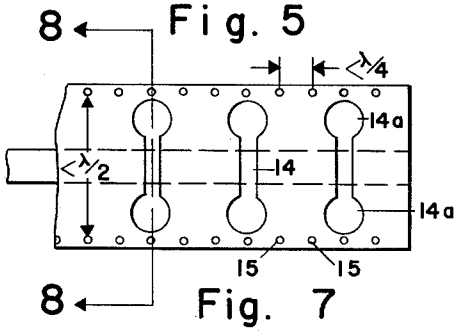



Fig. 7

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THREE CONDUCTOR PLANAR ANTENNA

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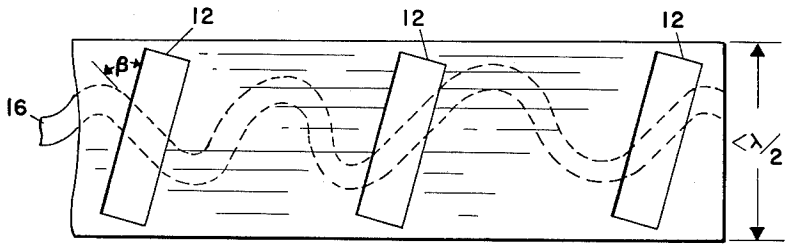



Fig. 9

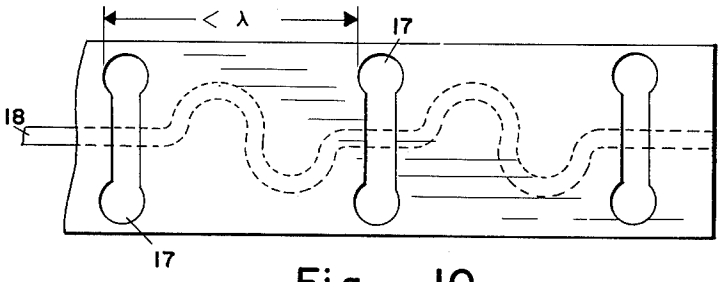



Fig. 10

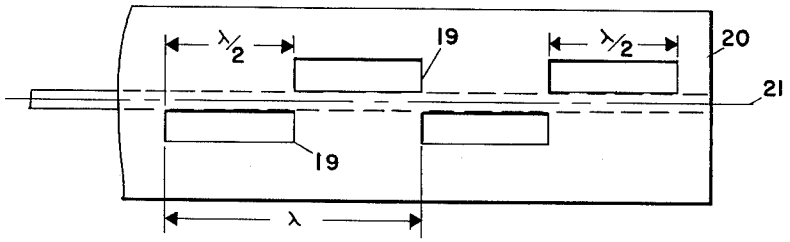



Fig. 11

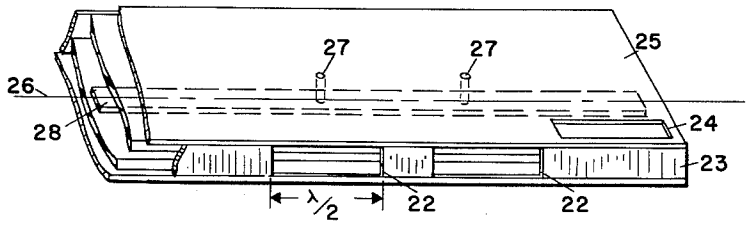



Fig. 12

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United States Patent Office 3,031,666
Patented Apr. 24, 1962



3,031,666

# THREE CONDUCTOR PLANAR ANTENNA

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Original application June 6, 1955, Ser. No. 513,223, now Patent No. 2,914,766, dated Nov. 24, 1959. Divided and this application Nov. 18, 1959, Ser. No. 853,838
2 Claims. (Cl. 343—771)

The present invention relates to antennas. More particularly, the invention relates to microwave antennas utilizing a double ground plane, three conductor circuit. This is a division of my co-pending application, Serial Number 513,223, now Patent Number 2,914,766, filed June 6, 1955.

In the prior art, coaxial transmission lines and waveguide transmission lines have been structurally so modified as to become radiators of microwave energy. These prior art devices are not readily adaptable to modern printed circuit configurations and are, moreover, bulky, expensive and inflexible in relation to the needs of modern microwave engineering.

It is therefore an object of the invention to provide an improved microwave antenna utilizing configurations readily adaptable to printed circuit techniques.

A further object of the invention is to provide an improved antenna of the type described employing resonant dipole radiators.

A still further object of the invention is to provide an improved antenna of the type described utilizing a plurality of resonant slot radiators.

It is a further object of the invention to provide an improved antenna of the type described including means for phasing resonant radiating elements.

It is a still further object of the invention to provide an improved antenna of the type described including means for varying the degree of excitation of resonant, radiating elements.

A still further object of the invention is to provide an improved antenna of the type described including means for suppressing extraneous propagation modes.

Other and further objects of the invention will be apparent from the following description of preferred embodiments, taken in connection with the accompanying drawings.

In accordance with the present invention there is provided an antenna which comprises the combination of a first elongated outer conductor providing a ground plane and a second elongated outer conductor providing a second ground plane. An elongated inner conductor of lesser width than the outer conductors is centrally disposed in insulated spaced relation between the outer conductors. A resonant radiating element is disposed in the path of propagation. Discontinuity means are disposed in the path of propagation to excite the radiating element. Side conductive means disposed less than a half wavelength apart $\lambda/2$ at the operating frequency connect the sides of the outer conductors together adjacent their opposite edges to suppress extraneous modes of propagation.

In the preferred embodiment there is provided an antenna which comprises the combination of a first elongated, planar, outer conductor providing a first ground plane along an axis, and a second elongated, planar, outer conductor providing a second ground plane, parallel and in register with the first ground plane. The conductors are less than one-half of one wavelength wide at the operating frequency and so thin as to be incapable of self-maintaining their configuration. An elongated, planar, inner conductor of lesser width than the outer conductors is centrally disposed in parallel with and in spaced relation between the outer conductors. Elongated dielectric insulating



members support the conductors in spaced relation. Side conductive members connect the edges of the outer conductors together to provide boundaries for suppressing the extraneous modes of propagation. An end conductive member connects the side conductive members and the outer conductors together enclosing an end thereof. A pair of elongated slots are formed in the side conductive members and are axially disposed adjacent the end. The slots are one-half of one wavelength long at the operating frequency. A resonant dipole element is connected to and extends from the center of the first outer conductor a distance of one-quarter of one wavelength from the end. A discontinuity conductive member is co-linear with the dipole element and connects the first outer conductor and the inner conductor together. A second dipole element is co-linear with the first dipole element and is connected to and extends from the center of the second outer conductor.

In a modification of the invention a plurality of elongated, resonant radiating slots are formed in the outer conductors and angularly disposed relative to the direction of propagation. The slots in a given outer conductor are separated by an integral number of wavelengths at the operating frequency. The slots are one-half of one wavelength long at the operating frequency.

In a further embodiment of the invention the slots have enlarged end portions to cause their effective length to be one-half of one wavelength long at the operating frequency and are disposed perpendicular to the direction of propagation. In one aspect of the invention the enlarged end portions have substantially a rectangular configuration. In another aspect of the invention, the enlarged end portions have substantially a circular configuration.

In a further modification of the invention the configuration of the inner conductor is so chosen as to increase the propagation path between slots and cause slots which are physically separated by less than an integral number of wavelengths at the operating frequency to be effectively, electrically separated by substantially an integral number of wavelengths.

In another embodiment of the invention shunt slots are formed in the outer conductors and are longitudinally disposed alternately on opposite sides of the center line of the outer conductors. The slots on the same side of the center of the outer conductors are separated by one wavelength at the operating frequency. Successive slots disposed on either side of the center of the outer conductors are disposed one-half of one wavelength apart at the operating frequency.

In still another embodiment of the invention a discontinuity is introduced between the first outer conductor and the inner conductor to excite resonant shunt slots which are formed in the side conductive members adjacent an end thereof.

In another modification of the invention conductive rods connect the outer conductors together with the inner conductor disposed between them. The conductive rods are transversely spaced less than one-half of one wavelength at the operating frequency to provide boundaries for suppressing extraneous modes of propagation. The rods are separated in the direction of propagation by less than one-quarter of one wavelength at the operating frequency to provide conductive boundaries.

In the accompanying drawings:

FIG. 1 is an isometric view, partially fragmentary, of an antenna embodying the present invention;

FIG. 2 is a sectional view, partially fragmentary, of the antenna in FIG. 1 taken along the lines 2—2;

FIG. 3 is a cross-section, partially schematic, view of the antenna in FIG. 1;

FIG. 4 is an isometric view, partially fragmentary, of an antenna embodying a modification of the invention;

FIG. 5 is a plan view, partially fragmentary, of an antenna embodying a further modification of the invention;

FIG. 6 is a sectional view of the embodiment in FIG. 5 taken along the lines 6—6;

FIG. 7 is a plan view, partially fragmentary, of still another embodiment of the invention;

FIG. 8 is a sectional view of the embodiment in FIG. 7 taken along the lines 8—8;

FIG. 9 is a plan view, partially fragmentary, of a modification of the embodiment of FIG. 4;

FIG. 10 is a plan view, partially fragmentary, of a modification of the embodiment of FIG. 7;

FIG. 11 is a plan view, partially fragmentary, of another embodiment of the invention; and

FIG. 12 is an isometric view, partially fragmentary of still another embodiment of the invention.

In each of the above figures except the cross-sectional views, microwave energy is assumed to be introduced from the left as shown.

Referring now to the drawings, and with particular reference to FIGS. 1, 2, and 3, a first, elongated, planar, outer conductor **1** formed, for example, of copper foil .001 of an inch thick, provides a first ground plane along an axis in the direction of propagation of the energy within the antenna as indicated at **2**. A second, elongated, planar, outer conductor **3** provides a second ground plane parallel and in register with the first ground plane as shown. The outer conductors, as shown, are less than onehalf of one wavelength wide $\lambda/2$ at the operating frequency. Here, $\lambda/2$ refers to the wavelength of propagated energy within the antenna as determined by the dielectric constant of the insulators which support the conductors in spaced relation as is well-known in the art. An elongated, planar, inner conductor **4** is narrower than the outer conductors and centrally disposed in parallel with and in spaced relation between the outer conductors **1** and **3**. A pair of elongated, dielectric insulating members **5** formed, for example, from polytetrafluoro-ethylene impregnated fibreglass, support the conductors **1**, **3**, and **4** in the above-mentioned spaced relation.

The conductors and insulating members are laminated together, for example, by suitable processes involving the use of a cupric coated conductor as disclosed in a copending application, Serial No. 459,841, filed October 1, 1954, by Victor F. Dahlgren entitled, "Method of Bonding Copper to Tri-fluoro-chloro-ethylene." A pair of longitudinally disposed side conductive members **6** connect the edges of the outer conductors **1** and **3** together, as shown, to provide boundaries for suppressing extraneous modes of propagation. An end conductive member **7** connects the side conductive members and the conductors **1**, **3**, and **4** together enclosing an end thereof as shown. A pair of elongated slots **8** are formed in the side conductive members **6** and are axially disposed adjacent the end of the conductors as shown. The slots are resonant and are electrically one-half of one wavelength $\lambda/2$ long at the operating frequency. The exact length for resonance is determined experimentally and is somewhat less than the physical one-half of one wavelength $\lambda/2$ in free space due to the shunt capacity effect of the dielectric members **5**. A resonant dipole element **9** is connected to and extends from the center of the first outer conductor **1** and is disposed one-quarter of a wavelength from the end of the conductor **1** as shown. A discontinuity conductive member **10** is disposed co-linear with the dipole element **9** and connects the first outer conductor **1** and inner conductor **4** together. A second dipole element **11**, disposed co-linear with the first dipole element **9**, is connected to and extends from the center of the second outer conductor **3** as shown. The dipole elements **9** and **11** are substantially one-quarter of a wavelength long $\lambda/4$.



A modification of the invention in which resonant slot radiators are utilized is illustrated in FIG. 4. Resonant radiating slots **12** are formed in the uppermost outer conductor and angularly disposed at an angle $\alpha$ relative to the direction of propagation **2**, as shown. Since the outer conductor **1** as shown is less than one-half of one wavelength wide at the operating frequency, the slot **12** must be angularly disposed to obtain an effective, electrical length one-half of one wavelength $\lambda/2$ long at the operating frequency. The slots **12** are longitudinally disposed a wavelength $\lambda$ apart at the operating frequency, where $\lambda$ is taken to be the propagation wavelength within the antenna.

In FIG. 5 and the sectional view of FIG. 6, the slots are shown with enlarged end portions **13***a* to cause the slots to be effectively, electrically one-half of one wavelength long at the operating frequency even though the physical length is less as shown.

In the embodiment of FIG. 7 and sectional view of FIG. 8, the enlarged end portions have a circular configuration **14***a* as shown. The boundary defining side conductive members here comprise conductive rods **15** spaced transversely less than one-half of one wavelength apart at the operating frequency and longitudinally less than one-quarter of one wavelength apart as shown.

In the embodiment of FIG. 9 the inner conductor **16** has a curved configuration as shown, to increase the length of the propagation path within the antenna and cause the slots **12** to be separated electrically a full wavelength $\lambda$ apart at the operating frequency, even though physically they are disposed less than a wavelength apart.

In FIG. 10 an antenna of the type described utilizing circularly enlarged slots **17** physically disposed less than a wavelength apart are shown as used with a curved planar inner conductor **18** parallel to the outer conductors. The curved conductor **18** extends the propagation path within the antenna and effectively, electrically separates the slots **17** by one wavelength $\lambda$.

In FIG. 11 an embodiment of the invention is illustrated in which resonant slots **19** are disposed successively on alternate sides of a center line **21** of the outer conductor **20**. The slots are electrically a half wavelength $\lambda/2$ long at the operating frequency and successive slots are displaced one-half of a propagation wavelength apart as shown.

In the embodiment of FIG. 12 a pair of slots **22** are shown disposed in the side conductive member **23**. Another slot **24** is longitudinally disposed off the center line **26** of the outer conductor **25**. A pair of conductive, discontinuity members **27** short circuit the outer conductor **25** to the inner conductor **28** to excite the slots **22**. The slots **22** and **24** are each electrically one-half of a wavelength $\lambda/2$ long at the operating frequency. The slot **24** provides its own discontinuity by virtue of its position relative to the electric field in the typical TEM mode of propagation of the line. Relative to the direction of propagation of the energy within the antenna, the slots **22** and **24** radiate broadside, the principal axis of radiation of the slots **22** being perpendicular to that of the slot **24** when the slots **22** are separated by an integral number of wavelengths.

The dipole elements **9** and **11** in the embodiment of FIG. 1 are symmetrically excited by microwave energy which travels through the slots **8** as shown in FIG. 3. The slots are formed in both side members **6** to balance the impedances between the dipoles and ground as well as to provide maximum excitation to the radiating dipoles. The slots **8** are on the order of one-eighth wavelength $\lambda/8$ wide, which varies with the impedance of the antenna; hence, the slot width is a function of the impedance required for proper termination of an input transmission line. The slots **8** are preferably centrally disposed relative to the discontinuity member **10** but may be varied in position to vary the degree of excitation of the resonant dipole radiating elements **9** and **11**. Energy radiated by

the slots 8 is plane-polarized perpendicular to the principal direction of propagation within the antenna. The dipoles radiate omnidirectionally in free space in a principal plane parallel to the outer conductors 1 and 3.

The conductors 1, 3 and 4 comprise a double ground plane transmission line which characteristically propagates microwave energy in the TEM mode; i.e., the electric field distribution between the conductors 1 and 4 is symmetric and 180 degrees out of phase with the field between the conductors 3 and 4. Such a transmission line does not radiate without the introduction of a discontinuity to disturb the symmetry of the electric fields. The conductive discontinuity member 10 connects the outer conductor 1 to the inner conductor 4 to short circuit the electric field therebetween at the point of highest intensity. Such a discontinuity sets up a difference of potential between the conductors 1 and 3 which tends to initiate propagation in a different mode; e.g., parallel plate or $TE_{0,1}$. A discontinuity may also be effected by inserting material between the conductors which is characterized by a dielectric constant differing from the insulating members 5. The side members 6 are separated less than one-half wavelength $\lambda/2$ apart at the operating frequency to provide boundaries below cut-off to suppress extraneous propagation modes within the antenna.

In the embodiment of FIG. 4 a plurality of resonant, radiating slots 12 are shown disposed within the outer conductor 1 at an angle $\alpha$ relative to the principal direction of propagation of microwave energy within the antenna. Since the conductor 1 is less than one-half wavelength $\lambda/2$ wide and the slots 12 must be one-half wavelength $\lambda/2$ long to be resonant, the slots are angularly disposed as shown. The angle $\alpha$ may be varied for each slot to vary the degree of excitation in accordance with the expression:

$$E=A \sin \alpha \tag{1}$$

where $E$=degree of excitation and $A$=maximum energy available to each slot.

For broadside radiation, along an axis perpendicular to the conductor 1, the slots 12 are separated one wavelength in the direction of propagation. For end fire radiation, that is, in a direction parallel with the principal direction of propagation within the antenna, the slots are separated one-half wavelength apart. Since the wavelength in the antenna is a function of the propagation constant and, hence, the dielectric constant of the insulators, the phase of the slots may be varied to vary the principal direction of radiation in free space by introducing dielectric materials with differing dielectric constants.

Slots may be formed in the outer conductor 3 corresponding to and in register with the slots 12. In this case, the propagation fields within the antenna are symmetric, the slots introducing no discontinuity to disturb the TEM mode symmetry. The side members 6 may then be eliminated.

The slots may be oriented perpendicular to the principal direction of propagation within the antenna by enlarging the end portions as in FIGS. 5 and 7 to cause the slots to be effectively, electrically one-half wavelength long $\lambda/2$.

Slots asymmetrical with the slots 12 may be formed in the conductor 3. Since the side members 6 suppress extraneous modes of propagation which may tend to arise, the radiation relative to the conductor 1 is substantially independent of the radiation relative to the conductor 3. Thus, radiation at a principal angle of 45 degrees may take place relative to the conductor 3, while radiation at 90 degrees is effected relative to the conductor 1. As is well-known in the art, increased directivity of radiation is provided proportional to the number of slots.

The angularly disposed slots are termed "hybrid" in the art as distinguished from being in series or perpendicular and in shunt or parallel relative to the principal direction of propagation within the antenna. Where slots are formed in both outer conductors 1 and 3, dielectric materials of different constants may be used to effect the phasing. Thus, an insulating member with a dielectric constant of 2.5 may be used between the conductors 1 and 4 while an insulating member having a dielectric constant of 2.0 may be used between the conductors 3 and 4.

For maxium excitation, the slots are perpendicularly disposed as in FIGS. 5 and 7. If a rectangular slot less than one-half wavelength long $\lambda/2$ is used, an insert of insulating material beneath the slot characterized by a higher dielectric constant relative to the insulating members 5 may be utilized to effectively increase its electrical length to one-half wavelength. Similarly, the slots 13 and 14 may have enlarged, substantially rectangular, end portions 13*a* as in FIG. 5 or substantially circular end portions 14*a* as in FIG. 7.

As a practical matter, conductive rods 15 as shown in FIGS. 7 and 8 are used to provide mode suppression. The rods 15 are longitudinally disposed less than one-quarter wavelength apart and transversely disposed less than one-half wavelength apart as shown.

The configuration of the inner conductor may be so chosen as to vary the degree of excitation of the resonant slots, the phasing therebetween, or both. Thus, in FIG. 9, the inner conductor is curved as shown to extend the propagation path between the slots 12. The angle $\beta$ between the inner conductor 16 and the slots 12 as shown determines the degree of excitation of the slots.

Varying the configuration of the inner conductor of prior art coaxial transmission line to vary the path of propagation has been unsuccessfully attempted. Excessive capacitive coupling between adjacent loops defeats the purpose of providing a longer path by short circuiting the loops. Here substantially no capacitive coupling is encountered within the inner conductor 16, since its edges present a negligible surface area and the conductor is planar.

In the embodiment of FIG. 10, the configuration of the inner conductor 16 is so chosen as to extend the propagation path between the slots 17 without changing the excitation to each slot. Here the conductor 18 is perpendicular to the slots 17 at intersections therebetween as shown. Conversely, the configuration of the conductor 18 may be modified to vary the excitation to each slot without substantially extending the propagation path between the slots.

In the embodiment of FIG. 11 the slots 19 are successively alternately disposed on either side of the center line 21 of the conductor 20 as shown. The field distribution within the antenna decreases exponentially from the center (as illustrated by R. M. Barrett in his article entitled, "Etched Sheets Serve As Microwave Components," Electronics, June 1952, page 115, Figures 1 and 2). In prior art, conventional, waveguides, the electric field intensity decreases sinusoidally. Here the slots are located closer together relative to the center line 21 than is possible in such prior waveguides for a given degree of excitation. Prior art coaxial line is incapable of this type of slot excitation since the transverse equipotential electric intensity distribution is circularly symmetric.

In the antenna of FIG. 1, for operation, for example, at 10,000 megacycles, X-band, the conductors 1 and 3 are 5/16 of an inch wide by .001 of an inch thick; the conductor 4 is 1/8 of an inch wide by .001 of an inch thick; the insulators 5 are 1/16 of an inch thick; the dipole elements .26 of an inch long by .020 of an inch in diameter; and the slots 8 are .57 of an inch long by .1 of an inch wide.

The antenna of the present invention combines the advantages of prior art coaxial and waveguide transmission line devices in a configuration readily adaptable to printed circuit techniques. The present invention is broadly applicable to every area of radio signaling.

While there has been hereinbefore described what are at present considered preferred embodiments of the invention, it will be apparent that many and various changes and modifications may be made with respect to the embodiments illustrated, without departing from the spirit of the invention. It will be understood, therefore, that all such changes and modifications as fall fairly within the scope of the present invention, as defined in the appended claims, are to be considered as a part of the present invention.

What is claimed is:

1. An antenna operating in the TEM mode comprising the combination of a first elongated, outer conductor providing a ground plane; a second elongated, outer conductor providing a second ground plane, said conductors being less than one-half of a wavelength wide at the operating frequency; an elongated inner conductor extending throughout the length of and of lesser width than said outer conductors, centrally disposed by dielectric members in insulated spaced relation between said outer conductors; side conductive means less than one-half wavelength wide connecting the sides of said outer conductors together at their opposite edges to suppress extraneous modes of propagation; and a plurality of elongated, resonant, radiating slots formed in said first outer conductor, said slots being one-half of a wavelength long at said operating frequency and successively axially disposed substantially in rows on alternate sides of the center of said first outer conductor and successive slots, at their midpoints, being separated along the length of the antenna, one-half of a wavelength at the operating frequency.

2. An antenna comprising the combination of a first flat, elongated outer conductor providing a ground plane along an axis; a second flat, elongated outer conductor providing a second ground plane parallel and in register with said first ground plane, said conductors being less than one-half of one wavelength wide at the operating frequency and so thin as to be incapable of self-maintaining their configuration; a flat elongated inner conductor of lesser width than said outer conductors and centrally disposed in parallel with and in spaced relation between said outer conductors; elongated dielectric insulating members supporting said conductors in said spaced relation; a pair of longitudinally disposed side conductive members connecting the edges of said outer conductors together to provide boundaries for suppressing extraneous modes of propagation; and a plurality of elongated slots formed in said side conductive members and axially disposed, said slots being one-half of one wavelength long at the operating frequency and adapted to radiate along an axis perpendicular to said side members.

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