

Nov. 22, 1955

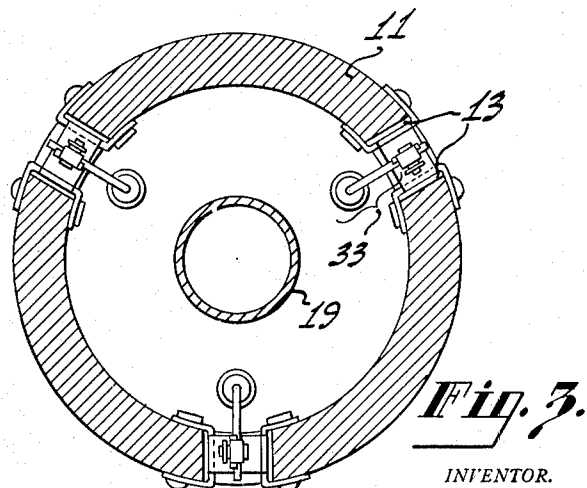
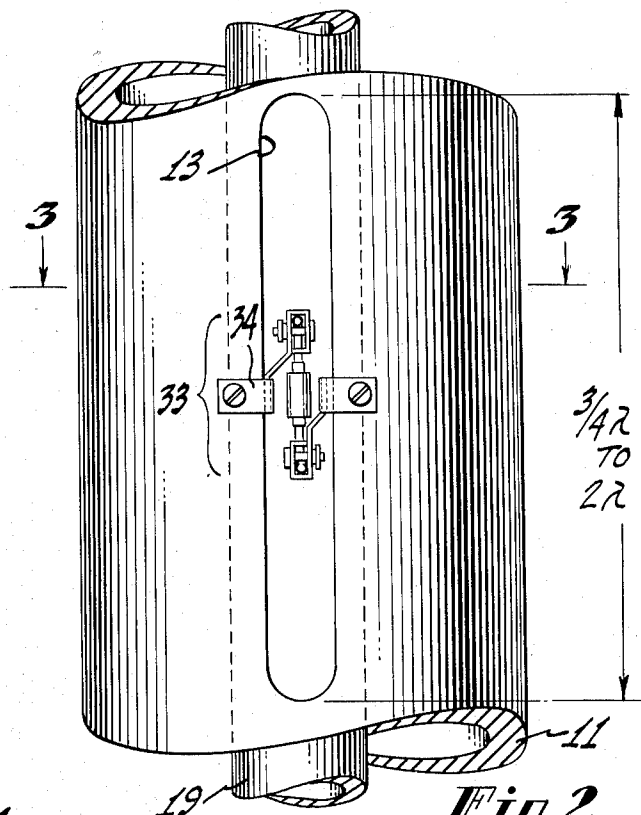
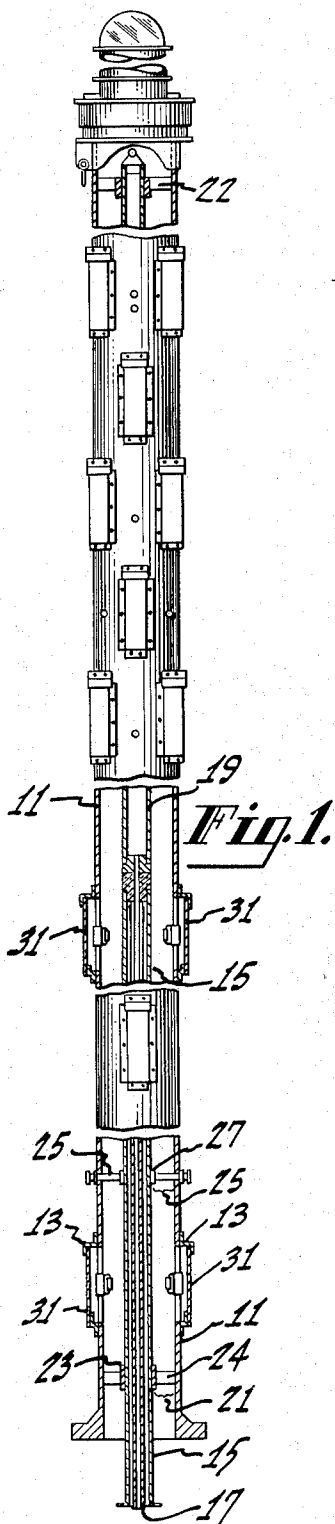
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2,724,774

SLOTTED CYLINDER ANTENNA

Filed June 3, 1952

4 Sheets-Sheet 1



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SLOTTED CYLINDER ANTENNA

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4 Sheets-Sheet 2

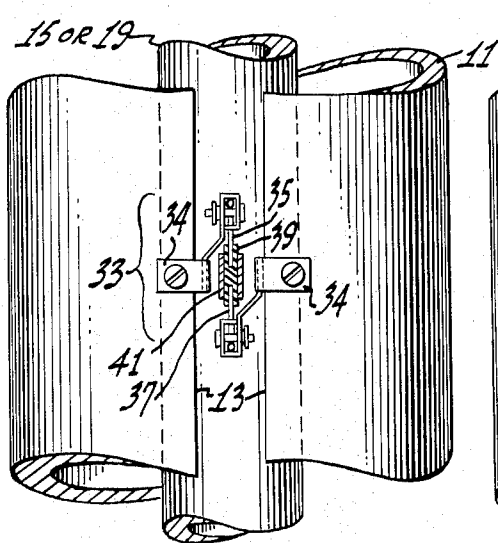


Fig. 4.

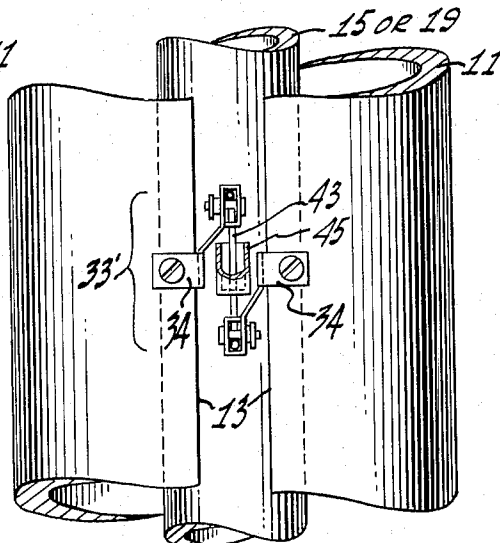


Fig. 5.

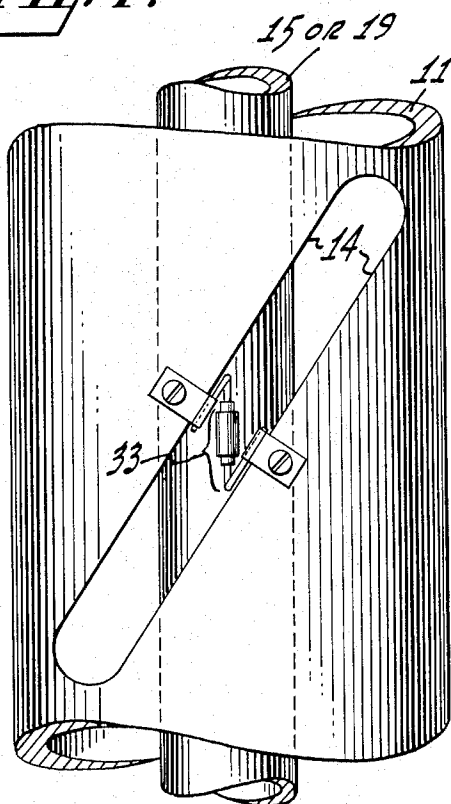


Fig. 6.

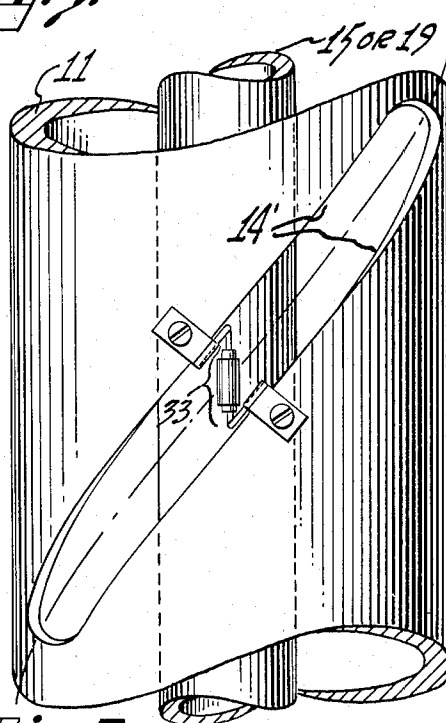


Fig. 7.

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4 Sheets-Sheet 3

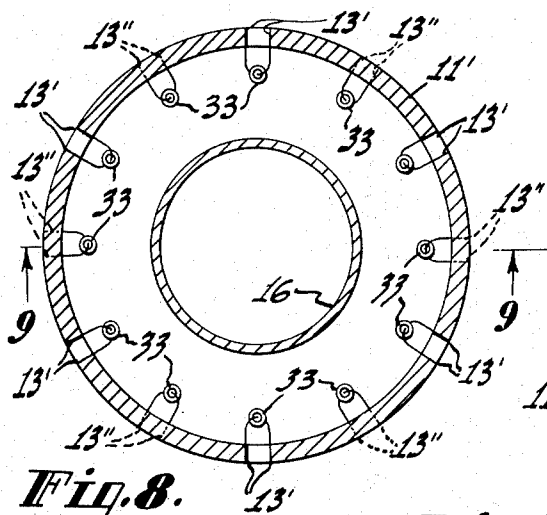


Fig. 8.

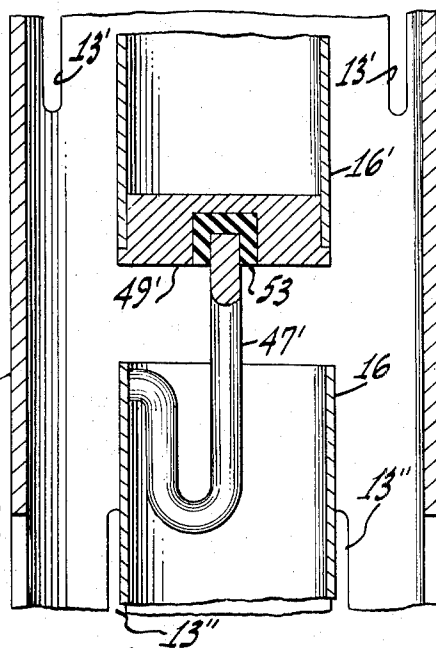


Fig. 10.

Fig. 9.

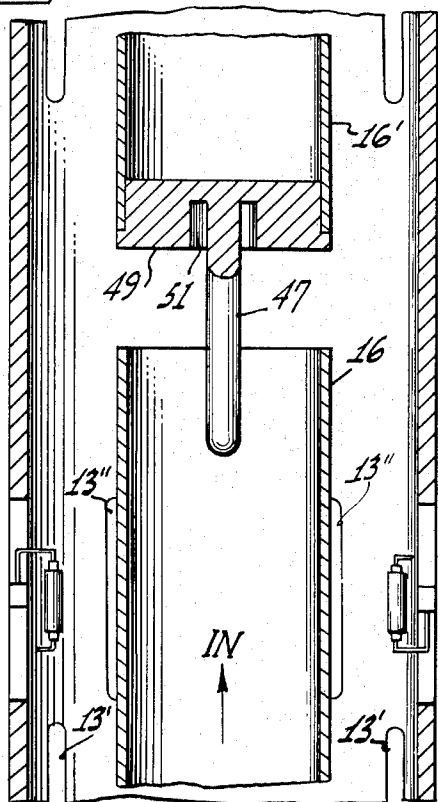
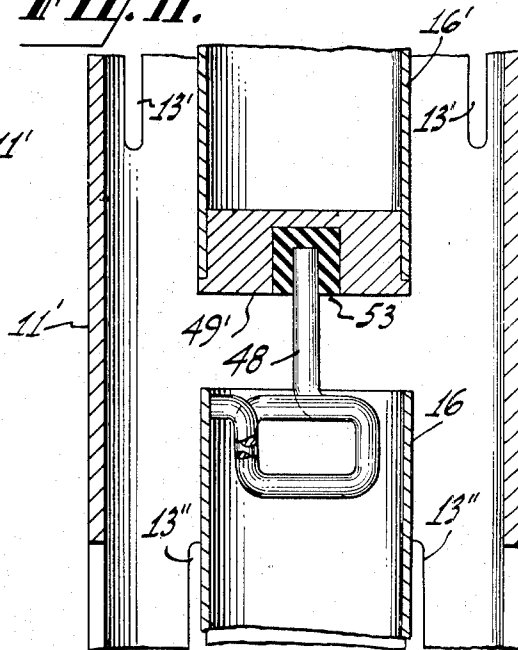


Fig. 11.



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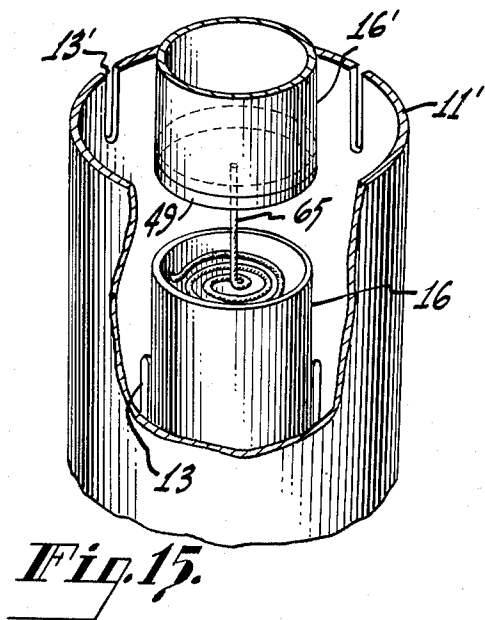
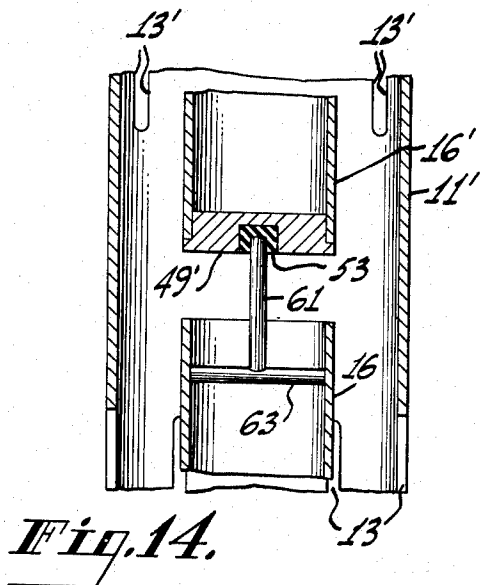
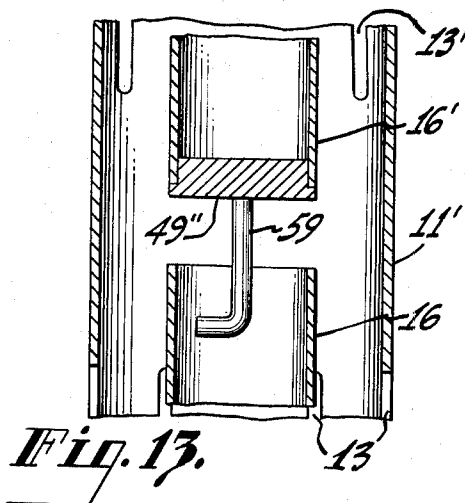
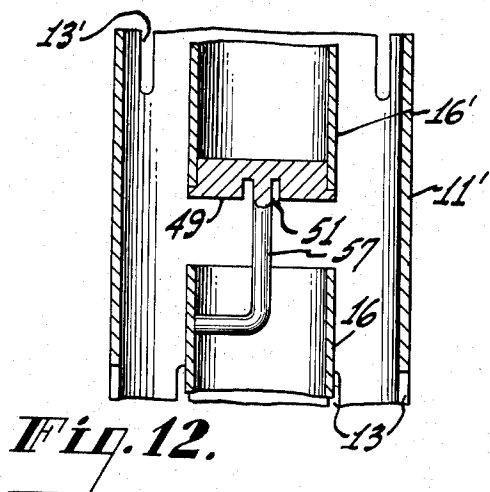
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SLOTTED CYLINDER ANTENNA

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4 Sheets-Sheet 4



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2,724,774

SLOTTED CYLINDER ANTENNA

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Application June 3, 1952, Serial No. 291,524

22 Claims. (Cl. 250—33)

This invention relates to slot antennas and particularly pertains to an ultrahigh frequency slotted cylinder antenna array.

This application is a continuation-in-part of the joint application of O. O. Fiet and R. M. Scudder, Serial No. 150,078 filed March 16, 1950, now Patent No. 2,658,143, issued on November 3, 1953, and assigned to the same assignee.

Broadcasting of television program service in the ultrahigh frequency band between 470 and 890 megacycles has imposed severe requirements for the necessary antenna systems. Effective radiated powers of 100 to 200 kilowatts are necessary, and power handling capability up to 1000 kilowatts of effective radiated power are desirable. The effect of wind deflection of the antenna and its supporting tower must not seriously affect the signal strength at any receiver within the intended service area. Antenna power gains to obtain up to 200 kilowatts of effective radiated power must be of the order of 20 to 30 times that of a simple tuned dipole to permit these high values of effective radiated power to be obtained with transmitter equipment of good efficiency and nominal power output.

It has been found from propagation measurements that interfering signals beyond the useful service area of an ultrahigh frequency broadcasting station can be greatly reduced by tilting the vertical pattern of a high-gain antenna downward a suitable amount. This feature of beam tilting enables a high-gain tilted beam antenna to give greater effective radiated power within its service area than at the horizon or boundary of the service area. A consequent better coverage efficiency of the broadcast transmitter power can be gained in many instances by utilizing a tilted beam.

It is an object of this invention to provide an improved ultrahigh frequency, omnidirectional, high power antenna system of simple construction for operation over a relatively wide frequency band.

It is another object of this invention to provide a slot antenna system of highly stable mechanical construction which is utilizable even in heavy storm-loading areas.

It is a further object of this invention to provide a slotted cylinder antenna in which the electrical beam tilting of the vertical pattern can be changed by a simple mechanical adjustment.

It is still another object of the invention to provide a slotted cylinder antenna which can be fed in the center and wherein means are provided to match each half of the antenna to the transmission line.

Yet another object of this invention is to provide a multilayer slotted cylinder antenna wherein the tuning and degree of coupling of each layer of slots can be adjusted to present a load of a predetermined magnitude and phase to the transmission line feeder system.

These and other objects are achieved, in accordance with the present invention, by providing an antenna system comprising a hollow tubular conductive member hav-

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ing a plurality of elongated slots arranged along the length thereof in groups or layers of slots spaced about the periphery. Each of the slots is coupled to the interior of the tubular conductive member by means of a coupling device having a lumped reactance as an integral part thereof. A coupling loop individual to each slot is provided, and the loop associated with each slot is conductively connected to opposite sides of the slot with which it is associated. Radio frequency energy is distributed to the plurality of layers of slots from a centrally located feedpoint. This distribution of energy is performed by a transmission line which utilizes the slotted cylinder as its outer conductor and a cylindrical conductor coaxial therewith as the inner conductor. The term "cylinder" as used herein is considered to be the surface traced by any straight line, called generatrix or element, moving parallel to a fixed straight line, according to Webster's unabridged dictionary, 1934 edition. Visualized from the feedpoint, the energy distribution transmission line may be considered as two lengths of coaxial transmission line extending in opposite directions, short-circuited at the far end.

Two arrangements are shown for bringing the radio frequency energy to the feedpoint near the longitudinal center of the slotted cylinder (or extracting the energy therefrom for reception). The first feeder transmission line described is of the coaxial type. In this embodiment, the inner conductor of the energy distribution transmission line serves as the outer conductor of the energy feed transmission line.

The second feeder system to bring the energy to the centrally located feedpoint utilizes one half of the inner cylindrical conductor of the energy distribution transmission line as a waveguide transmission line. In this second arrangement, certain desirable higher order modes may be utilized, and at the same time non-circular higher order coaxial modes may be suppressed.

In one embodiment of the invention, the slots are longitudinal of the hollow tubular conductive member. If the tubular conductive member is used in a vertical position and the slots are parallel to the axis thereof, horizontally polarized radiation results.

The elongated slots may also be skewed with respect to the axis of the hollow tubular conductive member, in which case elliptical or circularly polarized waves result. The skewed slots may have a helical configuration or assume the form of the intersection of a plane with a cylinder. The hollow tubular conductive member may have a cross-section which is circular, elliptical, polygonal or irregular, depending upon the particular application of the antenna system.

Although the antenna of this invention is described with reference to use as a transmitting antenna, it will be understood by those skilled in the art that it is equally utilizable for reception.

A more detailed description follows in conjunction with the drawings, wherein:

Fig. 1 is an elevation, partly in section, of one form of the slotted cylinder antenna of this invention;

Fig. 2 is a view in elevation of a single slot in a layer of slots of the slotted cylinder antenna of this invention;

Fig. 3 is an end view in section through a layer of slots taken along the line 3 of Fig. 2;

Fig. 4 is a view, partly in section, of a slotted cylinder antenna coupling device utilized in the present invention;

Fig. 5 is a view, partly in section, of another coupling device utilized in the present invention;

Fig. 6 is a view of a skew slot arrangement in accordance with the present invention;

Fig. 7 is a view of a helical slot utilizing the principles of the present invention;

Fig. 8 is a cross sectional view of a modified form of the arrangement shown in Figs. 1, 2 and 3; and

Figs. 9, 10, 11, 12, 13, 14 and 15 show arrangements for coupling a slotted cylinder antenna to a waveguide transmission line at the feedpoint of the antenna.

Referring now to Fig. 1, there is shown a slotted cylinder antenna in accordance with the present invention having an outer conductive cylinder 11 with a plurality of slots 13 arranged in layers around the periphery thereof. The outer cylinder 11 may be a circular, elliptical, polygonal or other cylinder. In the arrangement shown in Fig. 1, there are three slots 13 in each layer equally spaced around the conductive tubular member 11. Each layer of slots is staggered 60° with respect to the next adjacent layer. The number of layers of slots is dependent upon the required power gain of the antenna commensurate with the resultant narrowing of the vertical radiation pattern characteristic.

For gains of the order of 20 to 30 times that available from a tuned half-wave dipole, 14 to 18 such layers of slots are required where the slot length is between 1 and 1½ wavelengths, and the center-to-center slot separation is approximately 1½ or 2 wavelengths.

Radio frequency energy is distributed to the plurality of layers of slots by a center feed system within the slotted cylinder radiator. For such a center feed system, the outer conductive tubular member 11 serves as the outer conductor of a coaxial line. An intermediate conductive tubular member 15 within and coaxial with the outer conductive tubular member 11 serves as the inner conductor of the coaxial line for feeding one-half (the lower half) of the antenna. This intermediate conductive tubular member 15 also serves as the outer conductor of another transmission line for feeding energy (or extracting energy, for reception) to the center of the radiating system. The inner conductor 17 of this energy feed transmission line is surrounded by and is coaxial with the intermediate tubular member 15.

The transmission line for coupling to the slots in the other half (the upper half) of the antenna is formed by the outer slotted cylinder 11 as the outer conductor and a tube 19 coaxial therewith as the inner conductor. According to the arrangement shown in Fig. 1, coupling of the two halves of the antenna to the transmission line 15, 17 is accomplished by connecting the inner conductor 17 of the feeder transmission line 15, 17 to the tubular inner conductor 19 of the upper one half of the antenna. Since the intermediate tubular member 15 forms the other conductor of the energy feed transmission line 15, 17, wave energy is introduced or taken from the adjacent ends of the intermediate tubular member 15 and the tube 19. The structure may, therefore, be considered as two lengths of energy distribution transmission line 11, 19 and 11, 15 connected in series with respect to the feedpoint. This center feed system avoids dissymmetry in the vertical pattern with changes in frequency which would be characteristic of end-fed broadside arrays. The feedpoint formed between the two ends of the tubular conductors 15, 19 may be shifted from the exact electrical center of the array, if desired, to produce a phase difference of the currents in the two halves of the antenna. This phase difference is accompanied by a corresponding tilt in the vertical radiation pattern characteristic.

The two tubular members 15 and 19 forming the inner conductors of the energy distribution transmission lines 11, 19 and 11, 15 are held in place at each end of the outer conductive tubular member 11 by means of shorting blocks 21, 22. While these shorting blocks 21, 22 may be in the form of angular discs or the like, they preferably comprise a collar member 23 split transversely at one point of the circumference to permit clamping, and a plurality of spoke members 24 integrally fastened to the collar 23. The use of spoke members 24 also provides an advantageous feature in that the antenna of this invention may be prevented from icing and the like by

blowing hot air in between the outer tubular member 11 and the coaxial conductors 15, 19 by a heater-blower combination (not shown) located at the base of the outer conductive cylinder 11. For high power and high temperature operation of the slotted cylinder antenna, cooling air may be blown between the outer tubular member 11 and the coaxial conductors 15, 19.

Since the length of the outer conductive cylinder 11 may be from 20 to more than 40 feet for ultrahigh frequency television broadcasting service depending upon the gain required, it was found desirable to employ several sets of centering spacers 25. Three or four such spacers are used at each of several layers along the length of the outer conductive cylinder 11 to maintain the energy distribution transmission line 11, 19 and 11, 15 in perfectly coaxial relation. Each spacer 25 has a nose member 27 of insulating material. It has been found that a polytetrafluoroethylene material marketed under the trade name "Teflon" has highly desirable mechanical properties which combine a high insulation resistance, low dielectric loss, and low friction coefficient with respect to the conductive tubular members 19, 15. The nose members 27 are given a high polish so that the entire inner assembly of the energy feed transmission line 15, 17 and the energy distribution transmission line inner conductors 15 and 19 can be drawn easily into and out of the antenna.

Each of the slots 13 is covered by a slot covering 31 of insulating material. The covers 31 are held in place by end and side clamping fixtures. The use of covers 31 over the slots prevents rain and ice from entering the interior of the antenna and providing undesired leakage paths, and further obviates difficulties which might arise by high wind velocities setting up sound vibrations in the antenna structure.

Referring now also to Figs. 2 and 3, as well as to Fig. 1, the slots 13 are coupled to the interior of the energy distribution transmission line 11, 15 and 11, 19 by means of coupling loops 33 having a reactance as an integral part thereof. Such coupling loops for coupling radio frequency energy from a transmission line to a load are described and claimed in an application of Owen O. Fiet and Charles Polk, Serial No. 279,138, filed March 28, 1952. One such loop may include a capacitance arranged in series therewith. Another such loop may include an inductive metallic sleeve.

A coupling loop 33 having a capacitive reactance as an integral part thereof may be used to tune the coupling loop 33 and slot 13 combination to appear as a pure reactance as seen from the transmission line 11, 15 or 11, 19. A coupling device suitable to tune out the reactance of a slot which is capacitive in character at a particular frequency is described below with reference to Fig. 5. The coupling loop 33 may also be used to make the entire coupling device and slot to which it is coupled appear as a complex impedance of a desired magnitude and phase as seen from the transmission line 11, 15 or 11, 19.

When the slotted cylinder antenna of this invention is utilized with the coaxial transmission line feeding system 17, 15 shown in Fig. 1, the energy introduced across the adjacent ends of the tubular members 15, 19 which form the feedpoint is propagated in the energy distribution transmission line 11, 19 and 11, 15 in the TEM, or transmission line mode. Each slot 13 has a coupling loop 33 connected across the opposite sides of the slot near the longitudinal center thereof. Each coupling loop 33 is suspended in the proper spatial relation to the slot 13 with which it is associated by means of a pair of brackets 34. If the slots 13 are spaced center-to-center along the axis of the outer tubular member 11 an odd multiple of one-half wavelength, the coupling loop 33 in one layer of slots will have its terminals reversely connected to the edges of its slot relative to the terminals of the coupling loop in a slot in a next adjacent layer along the length of the cylinder. This achieves an in-phase voltage applied

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across the slots of different layers by the respective coupling loops. If the slots are spaced center-to-center a multiple of one wavelength in the axial direction, the terminals of the coupling loop in the separate layers will be connected in the same sense to produce an in-phase voltage across the slots of the different layers.

The length of the slots 13 which can be coupled efficiently by the type of coupling loops shown in Figs. 2 and 3, and to be further described below, may vary between limits of $\frac{3}{4}$ of a wavelength to 2 wavelengths at the operating frequency. For an efficient use of the available aperture in a slotted cylinder antenna for broadcast purposes, it has been found that a slot length between 1.15λ and 1.45λ offers numerous advantages. With a length of slot in this range, the spacing between adjacent layers of slots may conveniently be made 1.5λ and the slots in one layer will not overlap in their length with the slots of an adjacent layer. This feature makes the antenna of this invention a mechanically strong and stable structure.

A second advantage of utilizing a length of slot in the range from 1.15λ to 1.45λ is that such slots offer impedances which are of such value that the individual slots may be tuned to appear as a resistive load to the transmission line by utilizing a coupling loop in accordance with the application of O. O. Fiet and C. Polk referred to above. Extending the length of the individual slots to $1\frac{1}{2}$ or 2 wavelengths at the operating frequency makes it possible to arrive at the same value of gain in a given aperture that would be enjoyed with a much larger number of slots. Decreasing the number of layers of slots also decreases the number of tuning operations necessary to adjust a slotted cylinder antenna for optimum operation.

A practical compromise of these factors may be found in the discussion which follows of a slotted cylinder antenna built in accordance with the present invention.

The antenna had eighteen layers of slots, each layer consisting of three slots symmetrically spaced 120° apart around the cylinder. Adjacent layers of slots were staggered or rotated 60° relative to each other to obtain maximum mechanical strength and a circular horizontal pattern. The slotted outer tubular member 11 was of galvanized steel tubing $\frac{6}{8}$ inches in diameter and 34 feet long. The individual slots were 1 inch wide and approximately 1.3 wavelengths long parallel to the axis of the outer tubular member 11.

Radio frequency energy in the band from 842 megacycles to 848 megacycles was distributed to the eighteen layers of slots by means of a single coaxial line feeder system having a $1\frac{1}{8}$ inch diameter copper tube as the inner conductor 15, and the slotted steel cylinder 11 as the outer conductor. Each of the slots 13 was 18.1 inches long. The center of each layer was spaced 1.5 wavelengths, 20.9 inches at this frequency, from the center of the next adjacent layer.

A slot length of 1.3λ presents an antenna impedance of each layer which is slightly inductive in character, allowing the slot to be adjusted to present a resistive load with a coupling loop having a capacitance as an integral part thereof. The length of slots in each layer was made tunable by providing adjustable shorting blocks to close the ends of the slot. The individual slots in each layer could therefore be adjusted in length to present the proper tuning and reactance to the internal transmission line.

With the above-described antenna, a power gain of approximately 27 times that of a tuned half-wave dipole was obtained. This specific embodiment of the antenna is capable of transmitting more than 200 kilowatts of effective radiated power. The horizontal field pattern was circular within $\pm 0.232\%$.

Electrical pattern tilt of the vertical pattern characteristic was provided by arranging the inner conductors 15 and 19 of the energy distribution transmission line so that it could be shifted axially with respect to the electrical center of the slotted cylinder. This shifting of the feedpoint produces a phase difference of the currents in the two

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halves of the antenna. The layers of slots immediately adjacent the electrical center of the antenna may have any desired amount of additional spacing. This additional spacing enables the vertical radiation pattern to be tilted over wide limits without affecting the feedpoint impedance.

Referring now to Fig. 4, there is shown a cross-sectional view of a loop type coupling device 33 having a capacitive reactance as an integral part thereof in association with a slot radiator. This coupling device consists of a split metallic loop having two L-shaped members 35 and 37 maintained in insulated spaced relationship by a sleeve of insulation 39. The sleeve of insulation 39 is surrounded over a portion of its length by a metallic sleeve 41. The metallic sleeve 41 is capacitively coupled to the spaced but adjacent ends of members 35, 37 which it surrounds. The insulated sleeve 39 is provided with two spaced holes at opposite ends and in the same straight line into which the adjacent ends of the L-shaped members 35 and 37 are inserted for the desired distance. This coupling loop 33 is electrically connected across the sides of the slot 13 by a pair of metal brackets 34 near the electrical center of the slot 13.

In Fig. 5 there is shown another radio frequency coupling device 33', partly in cross section, which may be utilized to energize the slotted cylinder antenna of this invention. This coupling device 33' consists of a U-shaped loop member 43 having an inductive metallic sleeve 45 intermediate the ends thereof. The inductive metallic sleeve 45 is coaxial with the straight portion of the loop 43, and is conductively connected to the U-shaped loop 43 at one end of the metallic sleeve 45. Suspension brackets 34 are also utilized with the arrangement shown in Fig. 5. The coupling loop shown in Fig. 5 is especially adapted to tune out the reactance of a slot antenna which is capacitive in character.

In Fig. 6 there is shown a modification of a slotted cylinder antenna according to the present invention in which a radiating slot 14 is inclined at a skew angle with respect to the longitudinal axis of the outer conductive tubular member 11. In this figure, the slot has a semi-elliptical shape, being formed by the intersections of planes with the cylinder 11. The type of slot shown may be most easily made by two parallel saw cuts at an angle with respect to the longitudinal axis of the outer tubular member 11. The total end-to-end length of the slot will then be in the same range as that described above for slots parallel to the longitudinal axis of the cylinder, and the effective electrical length of the slot is measured along its axis. It will be noted that the skew slot 14 is excited by a coupling loop 33 coupled thereacross, as described above in connection with Figs. 1 through 5. For maximum coupling, the plane of the coupling loop 33 will not be parallel to the axis of the skewed slot, but instead will be transverse to a magnetic field in the energy distribution transmission line 11, 15 or 11, 19. The position of the coupling loop 33 shown in this figure will be used for coupling to the TEM mode and to transverse magnetic fields, that is, TM modes of propagation.

Fig. 7 is another modification showing a skewed slot 14' which is of helical configuration. The effective slot length in wavelengths is measured along the axis of the slot in this instance also as was set out above in connection with Fig. 6. It will be noted that for coupling to the TEM and TM modes, the coupling loop 33, which is coupled across the slot 14' at or near the center thereof, will have its plane parallel to the axis of the cylindrical members forming the distribution transmission line 11, 15 or 11, 19.

The polarization from skew and spiral slots in a slotted cylinder antenna will be elliptical or circular, depending on the configuration of the slot and the angle at which it is inclined to the longitudinal axis of the cylinder. Circular polarization results when there

is an equal amount of energy coupled into both the horizontal and vertical components of field, and these components of field are in phase quadrature. Other conditions result in elliptical polarization.

Fig. 8 shows a cross-section of a modification of the slotted cylinder antenna of the present invention which utilizes a cylindrical waveguide 16 for feeding energy to the center of the radiating system. A cylinder 11' surrounding the waveguide 16 and having a plurality of slots 13' arranged around the periphery thereof forms the radiating structure. In this arrangement, the cylindrical waveguide 16, in addition to serving as the input transmission line, also serves as the inner conductor of the energy distribution transmission line 11', 16. In the view shown in this figure, six equally-spaced longitudinal slots 13' per layer are the radiating elements. Also shown by dotted lines are the slots 13'' constituting the next adjacent layer. For the reasons set forth above in the description of Fig. 1, the slots 13'' in the next adjacent layer are staggered for improved structural strength and improved pattern circularity.

When the input transmission line is a waveguide 16 having sufficient diameter that propagation in one or more modes is possible at the operating frequency, a coaxial transmission line 11', 16 formed by the waveguide 16 as its inner conductor and a surrounding cylinder as its outer conductor is capable of propagating energy in other than the TEM mode. The coupling loops 33 used in conjunction with the present slotted cylinder antenna couple to any transverse magnetic field and are therefore operative to couple if propagation in the energy distribution transmission line 11', 16 is in the TEM mode of any TM mode. By proper orientation of the coupling loops 33, the slots may be coupled to TE modes of transmission.

In some applications of the invention, where the input waveguide 16 has a diameter large enough that more than one mode of propagation is possible therein, it may be desirable to include a mode filter in the input waveguide 16 just ahead of the coupling from the input waveguide 16 to the coaxial guide 11', 16 and 11', 16'. The use of mode filters is well known and understood, and their utilization in the present invention is to insure purity of the desired transmission mode at the coupling point.

This mode purity is preferred because of the deleterious effects of variation in velocity of phase propagation of the several modes of transmission, which results in a spurious, phase-delayed signal being coupled between the waveguide and the slotted cylinder antenna. An improvement in transmission efficiency may be realized by employing mode filters, since the waveguide couplings can be made most efficient for a single mode, and power is not wasted in modes which are inefficiently coupled.

Referring now to Fig. 9, there is shown a center feed arrangement for a slotted cylinder antenna using a waveguide input. A cylindrical waveguide 16 is shown concentric with the slotted outer conductive cylinder 11'. The cylindrical waveguide 16, as described above in connection with Fig. 8, forms a coaxial energy distribution line with the slotted cylinder 11' for the plurality of slots 13' and 13'' in one-half of the slotted cylinder antenna. The energy distribution transmission line for the other one-half of the slotted cylinder antenna is formed by a like coaxial line having an inner tubular conductor 16' which is preferably of the same outer diameter as the input waveguide 16. Energy is coupled, according to this arrangement, from the input waveguide 16 to the coaxial energy distribution line 11', 16 and 11', 16' by means of a conductive probe 47 extending into the input waveguide 16 along the longitudinal axis thereof. The probe 47 may be mounted in, or an integral part of, a metallic closing plug 49 which is con-

ductively connected to the tubular inner conductor 16' of one energy distribution line 11', 16'.

An under-cut portion 51 around the base of the probe 47 introduces a series reactance useful for aiding in matching the characteristic impedance of the coaxial transmission lines 11', 16 and 11', 16' to that of the waveguide 16. The reactance of the undercut portion 51 depends upon the width and depth of the undercut at the operating frequency of the radio energy applied. With a certain set of dimensions, the reactance of such an undercut portion 51 around the base of the probe 47 will be inductive in character, while at a higher frequency the reactance of the undercut portion will be capacitive.

The probe 47 extending along or parallel to the longitudinal axis of the input waveguide 16 will couple to transverse magnetic fields, that is to TM modes of propagation.

In Fig. 10 there is shown another center feed arrangement for a slotted cylinder antenna using a waveguide input. A cylindrical waveguide 16, concentric with the slotted outer conductive cylinder 11', forms a coaxial energy distribution line with the slotted cylinder 11' for one-half of the antenna. The energy distribution line for the other half of the antenna is formed by a like coaxial line having an inner tubular conductor 16' as described above in connection with Fig. 9. A conductive probe 47' is utilized to couple the energy from the input waveguide 16 to the two halves of the energy distribution line 11', 16 and 11', 16'. The probe 47' has one end conductively connected to the cylindrical input waveguide 16 at a point on the inner periphery of the waveguide 16. A plug 49' closes the end of the inner tubular conductor 16'. The other end of the coupling probe 47' is positioned in spaced relation to the closing plug 49'. The spacing between the probe 47' and the closing plug 49' may be maintained by a block of dielectric material 53 seated within a recess in the shorting block 49'.

The structure described, with the probe 47' in spaced relation to the closing plug 49', forms a series reactance between the input waveguide 16 and the energy distribution transmission line 11', 16'. The series reactance thus formed is utilizable as an aid in impedance matching between the waveguide 16 and the energy distribution transmission line, in the same manner as the undercut portion 51 described in conjunction with Fig. 9.

The main axis of the longer portion of the probe 47' coincides with or is parallel to the axis of the input waveguide 16. The main coupling of this type of probe will be to the transverse magnetic field, as described with respect to the structure of Fig. 9. This type of coupling, by proper dimensioning and proper orientation, may be made to couple strongly to TE modes of propagation.

Fig. 11 shows an arrangement similar in some respects to that just described for Fig. 10, with the exception that a coupling device has been provided which couples with transverse electric fields and at least certain transverse magnetic fields propagated in the input waveguide 16. Like reference numerals refer to corresponding parts in Fig. 11 already described in connection with Figs. 9 and 10.

The coupling arrangement in this case is formed by a coupling loop 48 which preferably has one end conductively connected to a point on the periphery of the input waveguide 16. The loop portion of the coupling loop 48 will have its major axis transverse to the longitudinal axis of the input waveguide 16. Such a loop 48 may consist of a fraction of a turn or more than one turn, or enclose less or greater area in the loop, depending upon the total amount of coupling necessary, and the reactance of the coupling loop 48 at the frequency to be fed to the slotted cylinder. The amount of capacitive reactance between the end of the coupling loop 48 in spaced relation to the closing plug 49' will also be a determining factor in the total number of

turns utilized. In the arrangement shown in Fig. 11, $1\frac{7}{8}$ turns of the loop 48 are shown.

Referring now to Fig. 12, there is shown another coupling device for coupling the energy in the input waveguide 16 into the coaxial lines 11', 16 and 11', 16'. An L-shaped coupling loop 57 is shown which has one end conductively connected to a closing plug 49. An undercut portion 51 around the point of connection of the coupling loop 57 to the closing plug 49 forms a series reactance like that described in connection with Fig. 9.

The coupling loop 57 extending transversely to the axis of the waveguide 16 and conductively connected to the periphery of the waveguide 16 will couple to transverse magnetic fields, that is, TM modes of propagation within the waveguide 16.

In Fig. 13, there is shown another coupling arrangement which utilizes an L-shaped probe 59 conductively connected to a closing block 49' and which extends for a short distance inside the input waveguide 16. The L-shaped probe 59 is bent transverse to the axis of the input waveguide, but is not conductively connected to the periphery of the input waveguide 16. With the physical structure shown in Fig. 13 of the drawing, the L-shaped probe 59 couples to transverse electric fields in the input waveguide 16. As the portion of the probe 59 which is transverse to the axis of the input waveguide 16 is brought into closer proximity to the periphery of the waveguide 16, there will be a greater coupling to transverse magnetic fields because of the capacitance between the end of the probe 59 and the wall of the waveguide 16. The limiting case, where the end of the probe 59 is very close to the wall of the waveguide 16, is like the configuration shown in Fig. 12 with a capacitive reactance between the end of the probe 59 and the wall of the waveguide 16.

A further configuration for coupling energy from a waveguide to a surrounding coaxial waveguide line is shown in Fig. 14. A T-bar coupler 61 is utilized in which the crosspiece 63 is conductively connected to opposite sides of the wall of the waveguide 16. A closing plug 49', which has a dielectric material 53 between the end of the T-bar 61 and the closing plug 49', may be used in connection with this coupler. The T-bar coupler 61 couples to transverse magnetic fields in a manner similar to that explained in connection with Fig. 9. The T-bar configuration has an advantage in that increased mechanical stability is obtained than with the probe coupler of Fig. 9.

Fig. 15 illustrates a further coupling arrangement which utilizes a flat metallic spiral 65 in a plane substantially transverse to the axis of the input waveguide 16. The outer turn of the spiral 65 is conductively connected to the wall of the input waveguide 16, and the inner end of the spiral 65 is connected to a closing plug 49, as described above in connection with Figs. 12, 13 or 14.

The spiral 65 couples to transverse electric fields in the input waveguide 16.

Other coil configurations having the main axis coaxial with the axis of the input waveguide 16 may be directly substituted for the spiral 65 in Fig. 15. For example, a solenoid helix having a uniform diameter throughout, or one which is tapered along its length may be used.

Although the types of devices shown for coupling energy from a waveguide to a surrounding coaxial guide have been described as having their primary or more efficient coupling to certain modes of propagation, it is possible to make them couple efficiently to modes other than those cited as examples. By altering the coupler dimensions or its orientation with respect to the incident wave, certain of the probes and loops will couple with good efficiency to TE rather than TM modes, or vice versa, or to two or more modes simultaneously. The choice of coupling device depends upon the mode of propagation in a waveguide and impedance matching

considerations between the input waveguide 16 and the surrounding coaxial guide 11', 16 and 11', 16'.

Matching between the input waveguide 16 and the coaxial waveguide lines 11', 16 and 11', 16' is accomplished by adjusting several parameters of the coupling arrangements. The lumped reactance offered by the undercut portion 51 in Figs. 9 and 12, or the spaced relation between the couplers and the closing block 49' in Figs. 10, 11 and 14, may be varied to affect the impedance seen by the waveguide 16. The degree of penetration of the probe or loop into the interior of the input waveguide 16 also affects the impedance matching. The separation between the ends of the input waveguide 16 and the inner tubular conductor 16' is a further determining factor in correctly terminating the input waveguide 16. The size of the conductors used for the loops or probes 47, 47', 48, 57, 59, 61 and 65 may be selected to aid in obtaining a proper impedance match. A further factor is the characteristic impedance between the surrounding cylinder 11' and the inner conductors 16 and 16' of the coaxial waveguide into which the energy is to be coupled.

What is claimed is:

1. A slotted cylinder antenna comprising a hollow tubular conductive member, a plurality of elongated slots in said tubular member arranged in layers along the length thereof, each of said slots having a length of from $\frac{3}{4}\lambda$ to 2λ at the operating frequency, each slot of said plurality of slots having associated therewith a coupling device including a lumped reactance as an integral part thereof, said coupling device comprising a loop conductively connected to points on opposite sides and intermediate the ends of the slot with which it is associated.

2. A slot antenna comprising an enclosing hollow side wall adapted to carry high frequency currents, said side wall having a plurality of slots therein serving as radiating elements, said slots being arranged in layers of slots spaced about the periphery of said side wall, each of said slots having a length of from 1.15λ to 1.45λ at the operating frequency, each slot having a coupling element associated therewith, said coupling element for each slot comprising a loop positioned within the hollow interior of said side wall and conductively connected to opposite sides of said slot at points intermediate the ends thereof, said loop having a lumped reactance intermediate the ends of said loop.

3. A slotted cylinder antenna comprising a hollow tubular conductive member, a plurality of elongated slots in said tubular member arranged in layers of slots spaced about the periphery of said tubular member along the length thereof, each of said slots inclined at an angle to the axis of said tubular member and having a length of from 1.15λ to 1.45λ at the operating frequency, each slot of said plurality of slots having associated therewith a coupling device including a lumped reactance as an integral part thereof, said coupling device comprising a loop conductively connected to opposite sides and intermediate the ends of the slot with which it is associated, the center-to-center spacing of adjacent layers of said slots having a value of an integral multiple of one-half wavelength at the operating frequency.

4. A slotted cylinder antenna comprising a hollow tubular conductive member, a plurality of elongated slots in said tubular member arranged in layers of slots equally spaced about the periphery of said tubular member along the length thereof, each of said slots having a length of from 1.15λ to 1.45λ at the operating frequency, each slot of said plurality of slots having associated therewith a coupling device comprising a loop conductively connected to opposite sides and intermediate the ends of the slot with which it is associated, and loop including a lumped reactance as an integral part thereof, the center-to-center spacing of adjacent layers of said slots having a value of $3/2\lambda$ at the operating frequency.

5. A slot antenna comprising a hollow tubular conductive member having a plurality of elongated slots therein, each of said slots having a length of 1.15λ to 1.45λ at the operating frequency, said plurality of slots being arranged in layers having a center-to-center spacing of 1.5λ from the next adjacent layer, a conductor concentrically disposed within said conductive tubular member and conductively connected to said tubular member at the ends thereof, said conductor having an interruption near the center thereof and being hollow for at least the length of one of the portions formed by said interruption to effect an enclosing side wall of a transmission line, each slot having a coupling element associated therewith comprising a loop conductively joined to opposite sides of said slot and having a lumped reactance intermediate the ends of said loop.

6. A slot antenna comprising a hollow tubular conductive member having a plurality of elongated slots therein, each of said slots having a length of 1.15λ to 1.45λ at the operating frequency, said plurality of slots being arranged in layers having a center-to-center spacing of 1.5λ from the next adjacent layer, a conductor concentrically disposed within said conductive tubular member and conductively connected to said tubular member at the ends thereof, said conductor having an interruption near the center thereof and being hollow for at least the length of one of the portions formed by said interruption to effect an enclosing side wall of a transmission line, a further conductor coaxial within and extending entirely through the hollow portion of said conductor, said further conductor having one end connected to the other of the portions formed by said interruption, each slot having a coupling element associated therewith comprising a loop conductively joined to opposite sides of said slot and having a lumped reactance intermediate the ends of said loop.

7. A slot antenna comprising a hollow tubular conductive member having a plurality of elongated slots therein, each of said slots having a length of 1.15 to 1.45λ at the operating frequency, said plurality of slots being arranged in layers having a center-to-center spacing of 1.5λ from the next adjacent layer, a conductor concentrically disposed within said conductive tubular member and conductively connected to said tubular member at the ends thereof, said conductor having an interruption near the center thereof and being hollow for at least the length of one of the portions formed by said interruption to effect an enclosing side wall of a transmission line, energy coupling means at said interruption cooperating with said hollow portion and the other portion of said conductor to couple energy between said transmission line and the concentric structure of said conductor and said conductive tubular member, each slot having a coupling element associated therewith comprising a loop conductively joined to opposite sides of said slot and having a lumped reactance intermediate the ends of said loop.

8. An antenna system comprising a conductive tubular member having a number of elongated slots therein, said slots each having a length of 1.15 to 1.45λ at the operating frequency, said number of slots being divided into groups of slots spaced at intervals of one and one-half wavelengths at said frequency, the slots of each group being spaced about the periphery of said tubular member, the slots of each group being staggered with respect to the slots of a next adjacent group, a conductor concentrically arranged within said tubular member having each end connected to said tubular member, said conductor having an interruption therein near the center thereof and being hollow for at least the length of one of the portions formed by said interruption to effect an enclosing side wall of a transmission line, loop coupling elements connected to said conductive tubular member on opposite sides of said slots at the center thereof and disposed in the space between said conductive tubular member and said conductor, said loop having a lumped reactance intermediate the ends of said loop.

9. An antenna system comprising a conductive tubular member having a number of elongated slots therein, said slots each having a length of 1.15 to 1.45λ at the operating frequency, said number of slots being divided into groups of slots spaced at intervals of one and one-half wavelengths at said frequency, the slots of each group being spaced about the periphery of said tubular member, the slots of each group being staggered with respect to the slots of a next adjacent group, a conductor concentrically arranged within said tubular member having each end connected to said tubular member, said conductor having an interruption therein near the center thereof and being hollow for at least the length of one of the portions formed by said interruption to effect an enclosing side wall of a transmission line, a further conductor coaxial within and extending entirely through the hollow portion of said conductor, said further conductor having one end connected to the other of the portions formed by said interruption, loop coupling elements connected to said conductive tubular member on opposite sides of said slots at the center thereof and disposed in the space between said conductive tubular member and said conductor, said loop having a lumped reactance intermediate the ends of said loop.

10. An antenna system comprising a conductive tubular member having a number of elongated slots therein, said slots each having a length of 1.15 to 1.45λ at the operating frequency, said number of slots being divided into groups of slots spaced at intervals of one and one-half wavelengths at said frequency, the slots of each group being spaced about the periphery of said tubular member, the slots of each group being staggered with respect to the slots of a next adjacent group, a conductor concentrically arranged within said tubular member having each end connected to said tubular member, said conductor having an interruption therein near the center thereof and being hollow for at least the length of one of the portions formed by said interruption to effect an enclosing side wall of a transmission line, energy coupling means at said interruption cooperating with said hollow portion and the other portion of said conductor to couple energy between said transmission line and the concentric structure of said conductor and said conductive tubular member, loop coupling elements connected to said conductive tubular member on opposite sides of said slots at the center thereof and disposed in the space between said conductive tubular member and said conductor, said loop having a lumped reactance intermediate the ends of said loop.

11. An antenna system comprising a conductive tubular member having a number of elongated slots therein, said slots each having a length of 1.15 to 1.45λ at the operating frequency, said number of slots being divided into groups of slots spaced at intervals of one and one-half wavelengths at said frequency, the slots of each group being spaced about the periphery of said tubular member, the slots of each group being staggered with respect to the slots of a next adjacent group, a conductor concentrically arranged within said tubular member having each end connected to said tubular member, said conductor having an interruption therein near the center thereof and being hollow for at least the length of one of the portions formed by said interruption to effect an enclosing side wall of a waveguide transmission line, energy coupling means at said interruption cooperating with said hollow portion and the other portion of said conductor to couple energy between said transmission line and the concentric structure of said conductor and said conductive tubular member.

12. The combination as defined in claim 7 wherein said energy coupling means comprises a probe coaxial with and extending into said transmission line and connected to the other portion formed by said interruption.

13. The combination as defined in claim 10 wherein said energy coupling means at said interruption comprises a probe having one end extending into said hollow portion

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formed by said interruption and coupled through a lumped reactance to the other portion formed by said interruption.

14. The combination as defined in claim 11 wherein said energy coupling means at said interruption comprises a probe having one end extending into said hollow portion formed by said interruption and conductively connected to the periphery of said hollow conductor, the other end of said probe being coupled through a lumped reactance to the other portion formed by said interruption.

15. The combination as defined in claim 7 wherein said energy coupling means at said interruption comprises a coupling loop positioned within the hollow portion adjacent said interruption and having one end conductively connected to said conductor and the other end coupled to the other portion of said conductor formed by said interruption.

16. The combination as defined in claim 10 wherein said energy coupling means at said interruption comprises an L-shaped probe having one end extending into said hollow portion formed by said interruption, the other end of said probe being coupled through a lumped reactance to the other portion formed by said interruption.

17. The combination as defined in claim 11 wherein said energy coupling means at said interruption comprises an L-shaped probe having one end extending into said hollow portion formed by said interruption and conductively connected to said hollow conductor, the other end of said probe being coupled through a lumped reactance to the other portion formed by said interruption.

18. The combination as defined in claim 7 wherein said energy coupling means at said interruption comprises a T-bar having a cross-piece and a central member, said cross-piece being within and connected to opposite sides of said hollow portion formed by said interruption, said central member coupled to the other portion of said conductor formed by said interruption.

19. The combination as defined in claim 10 wherein said energy coupling means at said interruption comprises

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a helical spiral lying in a plane transverse to the axis of said conductor and within said hollow portion of said conductor and having one end coupled to the other portion formed by said interruption.

20. A slot antenna comprising a hollow tubular conductive member having a plurality of elongated slots therein, each of said slots having a length of $\frac{3}{4}\lambda$ to 2λ at the operating frequency, a conductor concentrically disposed within said conductive tubular member, and a loop coupling element having a lumped reactance intermediate the ends thereof associated with each of said slots.

21. A slot antenna comprising, a hollow tubular conductive member having a plurality of longitudinally extending slots therein, each of said slots having a length of $\frac{3}{4}\lambda$ to 2λ at the operating frequency, a conductor concentrically disposed within said conductive tubular member, and a loop coupling element having a lumped reactance intermediate the ends thereof associated with each of said slots.

22. A slot antenna comprising, a hollow tubular conductive member having a plurality of longitudinally extending slots therein, each of said slots having a length of $\frac{3}{4}\lambda$ to 2λ at the operating frequency, and a loop coupling element having a lumped reactance intermediate the ends thereof associated with each of said slots.

References Cited in the file of this patent

UNITED STATES PATENTS

2,129,852	Lieb	Sept. 13, 1938
2,349,942	Dallenbach	May 30, 1944
2,414,266	Lindenblad	Jan. 14, 1947
2,423,416	Sontheimer et al.	July 1, 1947
2,496,242	Bradley	Jan. 31, 1950
2,574,433	Clapp	Nov. 6, 1951

OTHER REFERENCES

Proc. of the IRE, pages 474-478, May 1947.