ULTRAHIGH-FREQUENCY BROADCAST ANTENNA SYSTEM

Owen Orlando Fiet, Oaklyn, and Robert Marion Scudder, Westmont, N. J., assignors to Radio Corporation of America, a corporation of Delaware

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11 Claims. (Cl. 250—33)

1. This invention relates to antennas and in particular pertains to ultra-high frequency slot radiator arrays and transmission line assemblies therefor.

Broadcasting of radio and television programs in the frequency band lying between 500 and 890 megacycles has imposed stringent requirements for the necessary antenna systems. Effective powers of 10 to 20 kilowatts are desirable. The bandwidth requirement is no less serious than for similar lower frequency services. The effect of deflection of the antenna and the supporting tower in high winds must not seriously affect the signal strength at any receiver located within the intended service area. Antenna power gains of the order of 20 to 25 times that obtained with a simple dipole tuned to the frequency of measurement are likewise desirable.

Another factor to be considered in the ultra-high frequency bands is that the dimensions of the radiation system being much smaller, there is less than sufficient room for the prior art type of transmission line assemblies.

It is an object of the invention to provide an ultra-high frequency, omnidirectional, high power antenna system of simple construction for operation over a relatively wide frequency band. It is another object of the invention to provide a slotted antenna system in which beam tilting with frequency change is reduced or eliminated.

It is a further object of the invention to provide a slotted antenna system in which energy in the TEM mode is utilized and effects of TE_{11} and other non-cylindrical modes are suppressed.

It is still another object of the invention to provide means to obtain maximum efficiency from each of the several layers of a multi-layer slotted antenna.

It is yet another object to provide a slot antenna constructed in accordance with the foregoing objects having a simple, single-element centrally-located transmission line.

These and other objects of the invention which will appear as the specification progresses are attained by means of a transmitting or receiving antenna system comprising a hollow tubular conductive member having a plurality of elongated longitudinal 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 conductive member by means of an adjustable probe member attached to the hollow tubular conductive member at an edge of each slot. Additional probe members placed between layers of slots may be used advantageously to vary the impedance of the network between the layers of slots to match the respective slots to the portions of the transmission line to which they are coupled. Wave energy is introduced into the interior of said member in the transmission line or TEM mode by means of a centrally-located conductor assembly having an interruption at or near the center thereof effecting two lengths of coaxial transmission line in conjunction with the slotted radiator or receptor member. The ends of the hollow conductive member may be electrically connected to the centrally-located conductor, and if so, the means for such connections also preferably serve as a means of mechanical support. Preferably at least a part of the centrally-located conductor is hollow from the point of interruption to one end and contains a further conductor thus forming a further section of coaxial transmission line to which a transducer is coupled. Preferably the transducer is coupled to the last-mentioned transmission line by means of a waveguide though it may be coupled directly with only small loss in efficiency.

The invention will be described with reference to the accompanying drawing forming a part of the specification and in which:

Fig. 1 is an elevation view of an antenna system according to the invention;

Fig. 2 is an enlarged cross-section view of a portion of the antenna shown in Fig. 1 illustrating essential details of an antenna system according to the invention;

Fig. 3 is an end view of the radiator of the antenna according to the invention;

Figs. 4–6 are cross-section views of the arrangement of Fig. 2 taken along lines 4–4, 5–5, and 6–6;

Fig. 7 is a schematic diagram of the feed system of the antenna according to the invention;

Fig. 8 is an illustration of details of construction of the probe member employed with the antenna according to the invention; and

Fig. 9 is an illustration of an alternative coupling arrangement.

Referring to Fig. 1, there is shown an elevation view of an antenna installation according to the invention. The antenna as designed for operation at 590 megacycles consists of a galvanized steel tube 23 having a 9/16 inch inside diameter and an outside diameter of 10 3/4 inches, with a half-inch wall. Tube 20 may be made in two lengths, each approximately 20 ft. long,
joined by means of flanges at the radiation center of the antenna for ready access to the interior at that point as shown in Fig. 1, although it is contemplated that a simple length of tubing will be preferred in commercial practice.

The basic radiating system consists of four half-wave slots 22 equally spaced around the circumference of tube 26. There are 22 layers of these half-wave slots, making 88 individual slots in the tube 26. The slots are driven by radially projecting probes 24 shown in Fig. 2 and more completely described hereinafter.

The antenna is broken into two electrically identical groups of half-wave slots, the slots being spaced approximately one-half wavelength between ends. Each successive layer of slots is preferably rotated 45°, with respect to the preceding layer to suppress transmission of the TEM modes and other non-cylindrical modes within cylinder 26. This construction also inherently provides increased mechanical strength. The modes which do not have cylindrical symmetry would cause unequal excitation of individual slots in a layer resulting in a non-circular horizontal pattern. Other modes need not be suppressed if a dispersed directional pattern is produced as a result. Horizontal patterns deviating considerably from a circular configuration observed during development work were found to be corrected by staggering the layers. The use of matching probes, later to be described, also aids in correcting the field pattern.

A 3/8 in. outside diameter tube assembly 26 installed within tube 22 acts in conjunction therewith as a transmission line to transfer wave energy to and from the interior of tube 20 and to distribute the energy to slots 22. The cut-off frequency of the TEM 01 mode in the transmission line thus formed is approximately 500 megacycles.

A tube assembly 26 within the antenna has an inner conductor 40 within the lower half 26B to effect a further transmission line to convey wave energy to the center of the antenna feed system. This is accomplished by dividing conductor 26 into two lengths, 26A and 26B, separated by an insulator member 56 located at the center conductor 40 and conductor 26B. At this point inner conductor 40 is connected to the adjacent end of conductor 26A. Thus wave energy is introduced or taken from the center of the transmission line formed by conductor 20 and tube assembly 26. Or the structure may be considered as two lengths of transmission line 26A and 26B connected in series with respect to the feed point. This center feed avoids any vertical pattern tilt or other disymmetry in vertical pattern with changes in frequency which would be characteristic of end fed broadside arrays. Also, the effect of antenna and lower swny is reduced. The feed point may be shifted off center of the array if desired to produce a phase difference of the currents in the two halves of the antenna which is accomplished by a corresponding tilt in the vertical pattern. If desired desirable, this adjustable tilt in vertical pattern may be used to advantage in any particular installation to adjust for particular terrain conditions or cover densely populated valleys, and the like.

The tube assembly 26 is held in place at each end of tube 20 by means of shorting members 30. While these members may be in the form of annular discs and the like, they preferably comprise a collar member 32 split transversely at one point of the circumference to permit clamping, and a plurality of spoke members 34 integrally fastened to collar 32. Spokes 34 are a little longer than the distance between the collar 32 and the tube 20 and are cramped as shown at 34a. Spokes 34 are also quite wide in the axial direction of the antenna and relatively thin in the remaining dimension. Due to this construction ordinary manufacturing tolerances are necessarily observed but an exceedingly strong and well fitting structure is obtained. Bolts 36 are used to fasten members 30 in place and in the tightening process will draw spokes 34 out, reducing the degree of crimp 34a. The drawing out of spokes 34 will also tend to spring collar 32 when screw 35 is loosened, thus facilitating removal of tube assembly 26 whenever desired. Tube assembly 26 is fitted with a draw ring 48 having a frusto-conical base 45 which serves to center the tube assembly as it is drawn into or out of tube 20. The use of spoke members 34 also provides another advantageous feature in that the antenna according to the invention may be prevented from icing and the like by blowing hot air in between tubes 20 and 22 from a blower combination 23 located at the base of tube 20. The circulation of air will also tend to dissipated heat generated in tube 26 due to high current flow and provide free interior ventilation on hot sunny days to prevent excessive interior operating temperature.

Tube assembly 26 is preferably made of copper, and due to the fact that copper and steel have rather widely differing coefficients of expansion, the top shorting member 30 is not clamped tightly about tube 26a, but the latter is allowed to expand and contract freely. A pair of coil spring contact members 33 are employed to provide electrical contact between collar 32 and tube 26a.

The length of tube assembly 26 being about forty feet in the described embodiment, it was found desirable to employ several sets of spacing members 55. Three or four such spacers are used at each of several levels along assembly 26. Referring to Fig. 6, there is shown an example of four spacers 55 adjustedly positioned on wall member 20 and held by a collar member 56 locked by a jam nut 51. Each spacer 55 has a nose member 58 of teflon insulating material which prevents damage to tube 26. Nose members 58 are preferably given a high polish so that tube assembly 26 can be readily drawn into and out of the antenna.

Slots 22 are covered by polyethylene slot covers 22. Covers 22 are held in place by end and side clamping fixtures. The convex construction of covers 22 is preferably employed to reduce the area of the slots in which high frequency currents flow. The use of the protruding slot covers 22 also prevents deleterious effects of certain wind velocities on the tube 20 which may set up a harmonic vortex wave. As herebefore indicated, slots 22 are coupled to the interior of the coaxial transmission line formed by conductors 20 and 26 by means of coupling probes 24. The energy introduced therebetween is preferably of the TEM, or transmission line, mode. Each slot 22 has one such probe 24 connected near the center of the slot at one edge. If slots 22 are spaced center-to-center at an odd multiple of a half-wave apart in the axial direction, the probes 24 are all connected to opposite edges of slots 22. If the slots are spaced center-to-center a multiple of a wavelength in
the axial direction, the probes 24 are placed on corresponding edges of the slots.

When one layer only is driven the pattern is closely circular and in agreement with theoretical calculations. Energy of modes other than TEM, notably TE_{m1}, may be present, and steps are taken according to an aspect of the invention to eliminate the effect of these other modes. One such step is the 45° staggering of successive slots along the axis of conductor 20. Another step is the use of four matching probes 44. A multiple layer array using a cylinder having a smaller diameter/wavelength ratio than that thus far suggested will give a circular horizontal pattern without staggering successive layers because the TE_{m1} and other non-cylindrical modes introduced on the coaxial line within the antenna cylinder by the slot feed probes and matching probes are rapidly attenuated.

The upper and lower groups of slots in the present antenna consist of 11 layers each, with a space of about 3 wavelengths between the two groups. The current passing through the probe capacity also passes through the driving point impedance of each radiating slot. It was observed that the system input bandwidth becomes progressively narrower as the number of layers, and consequently the gain, is increased. Therefore to maintain the original bandwidth, sets of radial matching probes 44 are used between each layer of slots to obtain an impedance bandwidth at the input of each succeeding layer of the antenna which is approximately equal to the bandwidth of the end of the antenna. In some instances two layers of four probes 44 each are used between layers as shown. In other cases one layer will suffice. The vertical location of these probes is not critical. As to horizontal location, it is considered best to place the probes equidistantly between the nearest slots. In the present case that would be 22 45° from each of the nearest slots.

Referring to Fig. 8, there is shown a detailed drawing of the construction of a probe 24. The outer end is threaded into member 20 and has a frusto-conical bore 61 and intersecting radial saw slots 63 in the threaded end. A frusto-conical member 62 is drawn into bore 61 by means of a screw 65. The action of screw 65 is to expand the portions of probe 24 between slots 63 against the threaded surface of wall member 70 and thus hold probe 24 rigidly in place. Probes 24 and 40 are similarly constructed.

While shorting members 30 may be adjustably positioned at points permitting a low impedance to be placed across the transmission line sections formed between conductors 26A and 26, and 25B and 29, it is obvious that a more rigid construction is desirable. By means of further sets of adjustable tuning probes 54, similar in construction to probes 24 and 44, arranged between the end slots and shorting members 30, the advantages of fixed shorting members are obtained without incurring the disadvantages thereof. Probes 54 will be most effective if located a quarter-wavelength from shorting members 30. However, the probes are actually placed at a distance less than a quarter-wavelength from members 30 to provide better trimmer action.

Referring to Fig. 7, there is shown a schematic diagram illustrating the electrical operation of the feed system used in the antenna. The tuning and feed probe settings for successive layers usually differ. The resistor symbols correspond to the radiation resistances of each layer of slots from the outermost ends of the antenna toward the center. The capacity of tuning probes 54 is shown by the symbol C1; that of the matching probes 44 by symbols C_{a} to C_{c}; and the capacity of the coupling probes 24 by symbols A_{1} to A_{11}. The probes settings required for matched impedances in the corresponding layers of the top and bottom half of the antenna will usually be different due to small mechanical variations in the antenna structure.

The characteristics of the antenna were determined experimentally. In the determination the antenna was excited as a transmitting antenna but it must be understood that reverse operation as a receiving antenna will be equally efficiently obtained. A matched load was inserted in the end of the antenna tube 23 and the relative magnitude and phase of the voltage across the load was made with one layer of the antenna matched by means of the tuning probes. Various settings of the slot coupling probes gave a curve of additional phase retardation vs. relative power absorbed by the radiating layer. This curve is useful to determine the proper spacing between layers to compensate for the additional phase shift introduced by the tuning probes. The proper amount of power absorbed by each layer of slots relative to that power transmitted to the layers nearer the end was determined for the eleven layers in each of the top and bottom halves of the antenna. The end layers, bottom and top extremity of the complete 22-layer antenna, have no succeeding layers to which power must be transmitted. Consequently, they must utilize or absorb all of the power which is contained in the incident wave. This is accomplished by adjusting the four-slot coupling probes 24 and the shorting member 30, or the tuning probes 54 at the end of the antenna, until this layer matches the characteristic impedance of the concentric line within the antenna, which is approximately 68 ohms. The second layer from each end must utilize one-half of the power and transmit one-half of the power to the end layers. A combination of settings for coupling probes 24 and tuning probes 44 is then found to provide this power distribution, that is, to reduce the voltage on the matched load in the end of the antenna to 0.707 of the value obtained when no tuning or coupling probes are inserted. The tuning probes 44 must be adjusted for an impedance match each time coupling probes 24 are changed. The setting of the coupling probe for the third layer transmits two-thirds of the incident power and utilizes one-third, the fourth layer utilizes one-fourth and transmits three-fourths of the power, and so on, to the eleventh or innermost layer which utilizes one-eleventh of the power and transmits ten-eighths.

Each layer of the described antenna was adjusted to obtain an impedance match at 550 mc/s. Difficulty in adjustment of the entire antenna by doing each successive layer from each end simultaneously led to the discovery that the tuning probe settings for corresponding layers from each end were not the same if the input impedance was matched. The proper reference conditions on the slotted measuring line for each half of the antenna were obtained by shorting out one-half of the antenna at a point one wavelength from the feed point and substituting a matched load in the unshorted half of the an-
tenna after all feed probes and tuning screws had been removed. The matched load may be constructed of four radial fins of phenolic laminate about 10 feet long mounted on a sleeve of inside diameter permitting the assembly to slide freely on conductor 25. The fins should be of maximum width just clearing the inside surface of outer steel tube 20. The fins are covered on both sides with 377 ohms per square space cloth and have a linear taper on the input end about three wavelengths long. With the load adjusted for match, the input impedance to the antenna feeder system will not change when the load is moved on conductor 26. After the reference conditions are obtained with the matched load, it will be possible to cut each half of the antenna, either by using the matched load in one half and tuning the other half or shorting out the one half with a shorting disc installed an integral number of half waves from the feed point.

While probes 24 have been shown and described for coupling slots 22 to the interior of the antenna, a loop arrangement may also be used. Such an arrangement is shown in Fig. 9, wherein a loop 42 of wire is connected across a slot 22 at the edges thereof. The plane of loop 42 is in the direction of the longitudinal axis of slot 22. Such an arrangement can be poled, just as were the probes, by reversing the terminals of the loop to the edges of the slots while maintaining the same direction of the winding. The loops in the upper half of the antenna are poled oppositely to those of the lower half, just as the probes of one half are on opposite sides of the associated slots, than the probes of the other half of the antenna. Coupling loops 42 are useful at low impedance points whereas the probe is useful at high impedance points. Consequently when slots 22 have a length of approximately a wavelength, loops 42 would be preferred to probes 24. The length L of slots equipped with loops 42 may be three quarters to one and one half wavelengths long. If desired, however, such longer slots 22 can be coupled to the interior of members 25 by using two probes 64 and 64' spaced a half wave apart and located on alternate edges of the slot.

The transmission line effected by conductors 25E and 40 may be extended to the transducer apparatus if desired and may be constructed along known principles of this art. However, the commercially available air dielectric concentric transmission line has a uniform tubular inner conductor with supporting ceramic disc insulators clamped to it at one-foot intervals.

This type of line is satisfactory for V. H. F. service where the characteristic impedance is practically constant. However, the uncompensated bands at periodic intervals make the line behave like a low pass filter with attenuating bands in the U. H. F. region. The characteristic impedance fluctuates rapidly with frequency and is imaginary over much of the U. H. F. band. A line of this type is clearly not suitable for the stringent standing wave requirements of TV transmitting antenna systems in the U. H. F. band where a nearly constant resistance load must be used. Therefore, the transmission line employed in practice of the invention was constructed according to a method developed by D. W. Peterson, wherein the insulator supports on the transmission line were mounted in undercut spaces on the inner conductor 40. Small series inductances were cut in the faces of the undercut to compensate for the step capacity. The transmission line in the described installation changed the standing wave characteristic of the antenna very little, when measurements were made on the antenna mounted on the tower through 200 ft. of transmission line.

As shown in Fig. 2, a short transmission line transformer section is employed to provide wider band characteristics than would otherwise be provided. In one embodiment of the invention two such sections were employed. An alternative construction providing wider band width is that of continuing conductor 40 on into conductive tube 25A and connecting the same at a point above the lower end of the tube at which the proper impedance value is obtained.

Thus far the antenna according to the invention has been described as having four slots spaced about the periphery of the outer tube 10. Almost any number of slots may be used to good advantage, however. If but one slot is used a field pattern of cardional shape, similar to that obtained with the pylon antenna, will result. A bidirectional figure 8 pattern will be produced with two opposing slots. Three or more slots will provide a circular pattern, the circle in general being closer to theoretical as the number of slots is increased. An antenna with three slots appears to be the best solution when all factors are considered.

The number of slots in the vertical direction will be determined by the gain and directivity required.

The dimensions given above relate only to the description of one model taken as an example, it being understood that obvious modifications in the arrangement will be suggested to those skilled in the art without departing from the spirit and scope of the invention. For example, rotation of slots may be at an angle other than 45° to suppress the non-circular modes. Slots 22 need not be oriented as shown but may be inclined at an angle to the axis of the antenna. Slots 22 may also be of spiral configuration. No coupling probes or loops are needed for the latter arrangements. Skew and spiral slots will not provide horizontal polarization, however. The polarization will be elliptical, circular, etc., depending on the exact configuration of the coupling loops for skew slots will have the plane of the loop parallel to the axis of the cylindrical members and not the axis of the skewed slot. Also, if a multiple of probes are used the probe spacing will be a half wavelength or a multiple thereof along the axis of the tubular members.

The invention claimed is:

1. An antenna system comprising a conductive tubular member having a number of slots longitudinally arranged therein, said slots each being substantially a half-wave long at the operating frequency, said number of slots being divided into groups of slots spaced at intervals of a half-wavelength at said frequency, there being a plurality of slots in each of said groups of slots equidistantly spaced about the periphery of said tubular member, said conductive tubular member being suitably arranged within said tubular member, each end of said conductive member being electrically connected to said tubular member to form a length of concentric transmission line short-circuited at the ends thereof, probe elements connected to said conductive tubular member at an edge of each of said slots and projecting inwardly toward but spaced from said conductor to couple said slots to said concentric transmission line, and means to couple transducer apparatus between said conductor and said hollow conductive tubular member.
2. An antenna system comprising a conductive tubular member having a number of slots longitudinally arranged therein, said slots each being substantially a half-wave long at the operating frequency, said number of slots being divided into groups of slots spaced at intervals of a half-wavelength at said frequency, there being a plurality of slots in each of said groups of slots equidistantly spaced about the periphery of said tubular member, a conductor concentrically arranged within said tubular member, each end of said conductor being electrically connected to said tubular member to form a length of concentric transmission line short-circuited at the ends thereof, probe elements connected to said conductive tubular member at an edge of each of said slots and projecting inwardly toward but spaced from said conductor to couple said slots to said concentric transmission line, further probe elements arranged at each end of said tubular member effective to adjust the electrical length of said length of concentric transmission line, and means to couple transducer apparatus between said conductor and said hollow conductive tubular member.

3. An antenna system comprising a conductive tubular member having a number of slots longitudinally arranged therein, said slots each being substantially a half-wave long at the operating frequency, said number of slots being divided into groups of slots spaced at intervals of a half-wavelength at said frequency, there being a plurality of slots in each of said groups of slots equidistantly spaced about the periphery of said tubular member, a conductor concentrically arranged within said tubular member, each end of said conductor being electrically connected to said tubular member to form a length of concentric transmission line short-circuited at the ends thereof, probe elements connected to said conductive tubular member at an edge of each of said slots and projecting inwardly toward but spaced from said conductor to couple said slots to said concentric transmission line, further probe elements arranged at each end of said tubular member effective to adjust the electrical length of said length of concentric transmission line, and means to couple transducer apparatus between said conductor and said hollow conductive tubular member.

4. An antenna system comprising a tubular conductor having a number of radiant energy transferring slots longitudinally arranged there-in, said slots each being substantially a half-wave long at the operating frequency, said number of slots being divided into groups of slots spaced at intervals of a half-wavelength at said frequency, there being a plurality of slots in each of said groups of slots equidistantly spaced about the periphery of said tubular member, a conductive tube assembly comprising two elongated conductive elements arranged in end-to-end relationship, one of said conductive elements being hollow, a further conductor within said hollow conductive element to form a coaxial transmission line therewith and in insulating member interposed between said conductive elements to constitute an end-sealing member for said coaxial transmission line, said further conductor extending through said insulating member and being connected to the other elongated conductive element, and means to couple transducer apparatus between said further tubular conductor and said hollow conductive element.

5. An antenna system comprising a conductive tubular member having a number of slots longitudinally arranged therein, said slots each being substantially a half-wave long at the operating frequency, said number of slots being divided into groups of slots spaced at intervals of a half-wavelength at said frequency, there being a plurality of slots in each of said groups of slots equidistantly spaced about the periphery of said tubular member, a conductive tube assembly comprising two elongated conductive elements arranged in end-to-end relationship, one of said conductive elements being hollow, a further conductor within said hollow conductive element to form a coaxial transmission line therewith and in insulating member interposed between said conductive elements to constitute an end-sealing member for said coaxial transmission line, said further conductor extending through said insulating member and being connected to the other elongated conductive element, and means to couple transducer apparatus between said further tubular conductor and said hollow conductive element.

6. An antenna system comprising a conductive tubular member having a number of radiant energy transferring slots longitudinally arranged there-in, said slots each being substantially a half-wave long at the operating frequency, said number of slots being divided into groups of slots spaced at intervals of a half-wavelength at said frequency, there being a plurality of slots in each of said groups of slots equidistantly spaced about the periphery of said tubular member, a conductive tube assembly comprising two elongated conductive elements arranged in end-to-end relationship, one of said conductive elements being hollow, a further conductor within said hollow conductive element to form a coaxial transmission line therewith and in insulating member interposed between said conductive elements to constitute an end-sealing member for said coaxial transmission line, said further conductor extending through said insulating member and being connected to the other elongated conductive element, and means to couple transducer apparatus between said further tubular conductor and said hollow conductive element.
of the concentric transmission line, additional probe elements arranged at each end of said tubular member to adjust the electrical length of said length of concentric transmission line, and means to couple transducer apparatus between said further conductor and the hollow portion of said conductor.

7. An antenna system comprising a conductive tubular member having a number of slots longitudinally arranged therein, said slots each being substantially a half-wavelength long at the operating frequency, said number of slots being divided into groups of slots spaced at intervals of a half-wavelength at said frequency, their being four slots in each of said groups of slots spaced at ninety degree intervals, about the periphery of said tubular member, the slots of alternate groups being shifted forty-five degrees about the periphery of said conductive member with respect to the slots of the other groups, a conductor concentrically arranged within said tubular member, each end of said conductor being connected to said tubular member, and means to couple transducer apparatus between said further conductor and the hollow portion of said conductor by crimped members of conducting material, one of said crimping members being only loosely clamped to permit relative movement between said tubular conductor and said cylindrical conductive member, one component of said cylindrical conductive member being hollow, a further conductor within said hollow component forming a transmission line therewith, and an insulator member serving both as an end seal for said transmission line and to mechanically couple said components together.

10. An antenna system including a length of concentric transmission line comprising an outer conductor and a central conductor arranged within said outer conductor, connections short-circuiting said outer and central conductors near the ends thereof, said outer conductor having a plurality of elongated radiant energy transferring slots therein, an interruption in said central conductor near the center thereof, means to couple transducer apparatus near the center of said length of concentric transmission line at said interruption to excite said transmission line in the TEM mode, and coupling elements connected to said outer conductor at the edges of said slots and substantially to each of said slots, said coupling elements projecting inwardly into the space between said outer and central conductors but being spaced from said central conductor.

11. An antenna system comprising a conductive tubular member having a number of slots thereof, said slots each being substantially a multiple including unity of a half-wavelength long at the operating frequency, said number of slots being divided into groups of slots spaced at intervals, there being a plurality of slots in each of said groups of slots spaced symmetrically about the periphery of said tubular member, the slots of alternate groups being circumferentially shifted with respect to the slots of the other groups, a conductor concentrically arranged within said tubular member, each end of said conductor being connected to said tubular member, said conductor having an interruption thereon substantially at the center thereof and being hollow for at least the length of one of the portions formed by said interruption, a further conductor arranged in said hollow portion to effect a length of coaxial transmission line, said further conductor being connected to the other portion of said conductor at said interruption, coupling probe elements connected to said conductive tubular member at an edge of each of said slots and projecting inwardly, impedance matching probe elements arranged between said groups of slots to vary the impedance of said transmission lines, tuning probe elements arranged at each end of said tubular member effective to adjust the electrical length of said length of concentric transmission line, and means to couple transducer apparatus between said further conductor and the hollow portion of said conductor.
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further conductor and the hollow portion of said conductor.

OWEN ORLANDO FLET.
ROBERT MARION SCUDDER.

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