Feb. 7, 1961 M. S. O. SIUKOLA 2,971,193

MULTIPLE SLOT ANTENNA HAVING RADIATING TERMINATION

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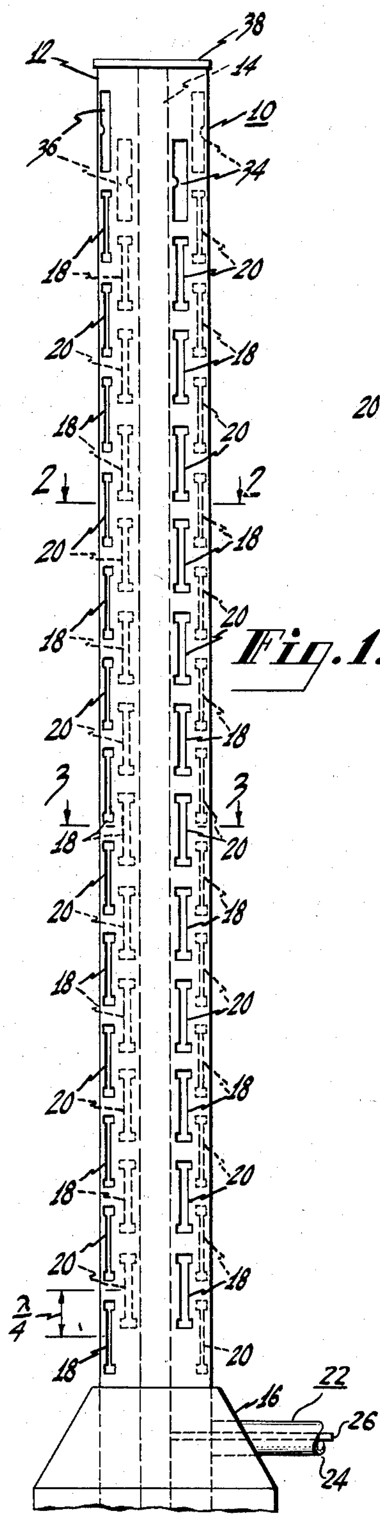

Fig. 1.

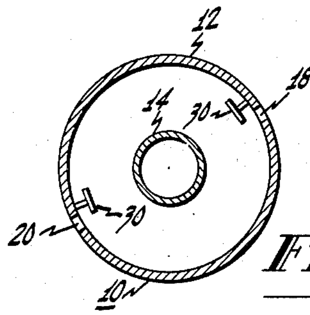

Fig. 2.

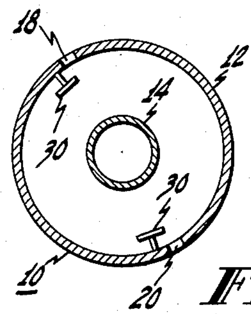

Fig. 3.

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MULTIPLE SLOT ANTENNA HAVING RADIATING TERMINATION

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8 Claims. (Cl. 343—770)

The invention relates to a radiating termination, and particularly to a radiating termination for reducing the reflection of waves in a traveling wave antenna.

An object of the invention is to provide an improved traveling wave antenna.

Another object is to load the top of a vertically arranged traveling wave antenna in such manner as to reduce the antenna height, maintain a good impedance match, obtain satisfactory pattern circularity, and increase the antenna gain by utilizing the remaining power which would otherwise be lost or dissipated in the loading.

Briefly, the traveling wave antenna of the invention comprises a hollow, cylindrical outer conductor, and a cylindrical inner conductor concentrically positioned within the outer conductor. The outer conductor has a plurality of elongated, relatively high Q slots therein. These slots are positioned around the periphery of and along the length of the outer conductor in a spiral. Means are coupled to one end of the traveling wave antenna for applying radio frequency energy thereto, and means are coupled between the outer conductor and the inner conductor to cause each of the high Q slots to radiate a small amount of the radio frequency energy applied to the antenna in a predetermined pattern of directivity. In addition to the high Q slots which appear in the main aperture of the antenna, the outer conductor also has a plurality of elongated, relatively low Q slots positioned in the spiral at the other end remote from the one end to which the radio frequency energy is applied. Coupling means are coupled between the inner conductor and the low Q slots so as to cause the low Q slots to radiate substantially all of the remaining radio frequency energy in the antenna. The low Q slots can be designed to radiate the remaining radio frequency energy in a useful manner so as to aid the radiation characteristic of the high Q slots, in addition to reducing the reflected waves in the antenna. Thus, the invention provides a traveling wave antenna that has the advantages of providing a decrease in reflected waves and an increase in radiation. This arrangement permits the main aperture to operate more efficiently.

The invention is explained in detail in connection with the accompanying drawing, in which:

Fig. 1 shows an elevation of a traveling wave antenna utilizing the radiating termination of the invention; and

Figs. 2 and 3 enlarged show cross-sectional views of the traveling wave antenna taken along the lines 2—2 and 3—3 respectively.

Referring to the drawing, Fig. 1 shows a traveling wave antenna 10 which includes a hollow, cylindrical outer conductor 12, and a cylindrical inner conductor 14 concentrically positioned within the outer conductor 12. Or, a plurality of inner conductors may be used. The traveling wave antenna 10 is designed to radiate radio frequency signals in the television band, and is preferably mounted in a vertical position on some high structure, such as a building or a tower. In Fig. 1, the anntena 10 is shown mounted in or supported by a suitable pedestal 16, which may house or contain suitable means for applying radio frequency energy to the lower end of the antenna 10. The outer conductor 12 of the antenna 10 extends above the pedestal 16, and is provided with a plurality of elongated slots 18, 20 each positioned with its long dimension (about one-third wavelength at the operating frequency) substantially parallel to the longitudinal axis of the anntena 10. These slots 18, 20 are designed to have a relatively high Q, the value depending on the gain and bandwidth to be provided by the antenna 10. It has been found that a slot having an enlarged width at the ends provides a higher Q than a slot having a uniform width throughout. The configuration of such a slot can be seen in Fig. 1, and is similar to a dumbbell. The slots are arranged in a spiral about the outer conductor 12 of the traveling wave antenna 10. There is one pair of slots 18, 20 positioned at the same horizontal level at every quarter wavelength at the operating frequency up the vertical height of the antenna 10, the slots 18, 20 of each pair being diametrically opposite each other. Each successive or higher pair of slots 18, 20 lies in a vertical diametrical plane that forms an angle of substantially 90° with the plane in which the adjacent lower pair of slots 18, 20 lies. Thus, it will be seen that one group of slots 18 forms one spiral along the outer conductor 12, each of the slots 18 in the one group being positioned 90° from the adjacent slots 18 in the one group as measured in a horizontal plane, and each being higher than the adjacent lower slot 18 by substantially a quarter wavelength at the operating frequency. Likewise, the same is true of the other group of slots 20. Thus, in effect, there are two groups of slots 18, 20, each group being arranged in a spiral that is positioned around the periphery of and along the length of the outer conductor 12. By way of example, there are twenty-five slots shown in the drawing for each of the groups of slots 18, 20, thus making a total of fifty high Q slots 18, 20 to provide a gain of about six. The number of these slots may be varied according to the gain desired from the antenna.

Radio frequency energy may be applied to the traveling wave antenna 10 by any suitable means, such as a coaxial transmission line 22 whose outer conductor 24 is connected to the outer conductor 12 of the antenna 10, and whose inner conductor 26 is connected to the inner conductor 14 of the traveling wave antenna 10. The inner conductor 14 and the outer conductor 12 of the antenna 10 may be supported by a plate within the pedestal 16 that is positioned substantially a quarter wavelength at the operating frequency below the point of attachment of the transmission line 22 to the traveling wave antenna 10. It is preferred that this radio frequency energy, when excited in the traveling wave antenna 10, be in the TEM mode. This energy is applied at the base, or pedestal 16, of the antenna 10 and travels upward thru the antenna 10 toward the top. Equal amounts of this radio frequency energy are coupled to each of the slots 18, 20 by any suitable means. One suitable means, shown in Figs. 2 and 3, comprises a capacitive coupler 30. The coupler 30 includes a conductive rod-like element which extends radially from the outer conductor 12 at a point adjacent a slot toward the inner conductor 14. The element does not touch the inner conductor 14. A conductive plate is fastened to the unattached end of the element to provide a capacitor that couples a portion of the radio frequency energy being propagated thru the antenna 10 to the slot adjacent to which the coupler 30 is positioned or fastened. The couplers 30 for each diametrical set of slots 18, 20 are positioned on adjacent sides of their respective slots 18, 20, that is on one side of a diametrical plane passing thru the centers of the slots 18, 20, so that the slots 18, 20 of any diametrical pair of slots 18, 20 are 180° out of phase with one another. And since successively higher slots 18, 20 lie in a diametrical plane that forms an angle of substantially 90° with the diametrical plane in which the adjacent lower pair of slots 18, 20 lies, successively higher slots are excited at 90° out of phase with the adjacent lower pair of slots 18, 20. Thus, an omnidirectional radiation pattern can be obtained if each of these slots 18, 20 radiates a small, substantially equal amount of the energy in the antenna 10.

Such an arrangement provides uniform attenuation of the traveling wave in the antenna 10, but does not ensure that all of the energy of the wave will be radiated or that there will be no reflected energy. In order to reduce the amount of energy that is reflected from the top of the antenna 10 back toward the pedestal 16, terminating slots 34, 36 are added. Two terminating slots 34 are provided for the one group of high Q slots 18, and two terminating slots 36 are provided for the other group of high Q slots 20. These terminating slots 34, 36 are spaced vertically a quarter wavelength at the operating frequency and spaced horizontally at an angle of substantially 90° so that the terminating slots 34 form a continuation of the spiral of one group of high Q slots 18, and so that the other terminating slots 36 form a continuation of the spiral of the other group of high Q slots 20. The terminating slots 34, 36 are positioned with their long dimension (about one-half wavelength at the operating frequency) substantially parallel to the longitudinal axis of the antenna 10. The terminating slots 34, 36 have a substantially uniform width throughout and substantially rectangular configuration so as to provide a relatively low Q slot instead of a high Q slot. The terminating slots 34, 36 have a Q that is theoretically as low as possible. The terminating slots 34, 36 may also be excited in the same manner as the high Q slots 18, 20, namely by the couplers 30, so that substantially all of the remaining energy in the traveling wave antenna 10 is radiated by the terminating slots 34, 36. However, the degree of coupling is different. To provide a complete termination, the inner and outer conductors 14, 12 are short-circuited at a proper place at the top of the antenna 10 by some suitable means, such as the plate 38, so as to minimize reflections in the antenna 10. While the short-circuiting plate 38 is preferred, the same effect may be gotten by using an open-circuited antenna, with the open circuit being properly positioned.

One definition of Q in relation to a pair of slots on the same level on opposite sides of the outer hollow conductor 12 may be given by the relation

$$Q=\frac{R}{\omega_0 L}=R\omega_0(C+C_m)$$

$$\left(\omega_0^2=\frac{1}{L(C+C_m)}\right)$$

wherein ω_0 (at resonance frequency) equals $2\pi f$, R is the parallel loss resistance in an equivalent tuned circuit due to the radiation impedance of the slots, L and C are, respectively, the inductance and capacitance indicated in an equivalent circuit which represents the pair of slots within a narrow range of frequencies close to the resonant frequency of the slots, and C_m is the sum of the two series capacitances at the edge of the slots. The equivalent network of a pair of such slots on the same level, referred to above, across a transmission line includes the capacitance C_m in series with a parallel tuned circuit (C and L and R in parallel to one another).

The terminating slots 34, 36 not only radiate substantially all of the remaining radio frequency energy in the antenna 10, but they also reduce the reflected waves in the antenna 10 to substantially zero. Thus, the terminating slots 34, 36 provide two advantages, namely useful radiation of radio frequency energy and reduction of reflected waves. Since the terminating slots 34, 36 radiate substantially all of the remaining energy in the antenna 10, the height of the antenna 10 is approximately 30% less and the cost of the antenna 10 is approximately 50% less than if high Q slots, similar to slots 18, 20, are used to radiate the remaining radio frequency energy from the upper portion of the antenna 10. The terminating slots 34, 36 provide, in effect, a matched, broadband, termination for the antenna 10, thus reducing reflections back into the traveling wave antenna 10, a feature which improves the operation of the antenna 10. And finally, the terminating slots 34, 36 also contribute to the omnidirectional radiation pattern of the antenna 10, thus increasing its usefulness, economy, and efficiency.

What is claimed is:

1. In combination, a traveling wave antenna comprising a hollow outer conductor, an inner conductor concentrically positioned within said outer conductor, said outer conductor having a plurality of elongated, relatively high Q slots therein positioned around the periphery of and along the length of said outer conductor in a spiral, means coupled to one end of said traveling wave antenna for applying radio frequency energy thereto, coupling means positioned between said outer conductor and said inner conductor for causing each of said high Q slots to radiate a portion of said radio frequency energy applied to said traveling wave antenna, said outer conductor further having an elongated, relatively low Q slot positioned at the other end thereof in said spiral, and coupling means positioned between said outer conductor and said inner conductor for causing said low Q slot to radiate substantially all of the remaining radio frequency energy in said antenna, wherein Q is measured for parallel resonance.

2. In combination, a traveling wave antenna comprising a hollow, cylindrical outer conductor, a cylindrical inner conductor concentrically positioned within said outer conductor, said outer conductor having a plurality of elongated, relatively high Q slots therein positioned around the periphery of and along the length of said outer conductor in a spiral with the long dimension of each of said high Q slots positioned substantially parallel to the longitudinal axis of said traveling wave antenna, means coupled to one end of said traveling wave antenna for applying radio frequency energy thereto, coupling means positioned between said inner conductor and said outer conductor adjacent each of said high Q slots for coupling a portion of said radio frequency energy applied to said traveling wave antenna to each of said high Q slots for radiation to the surrounding space, said outer conductor further having a plurality of elongated, relatively low Q slots positioned at the other end of, around the periphery of, and along the length of said outer conductor in said spiral with the long dimension of each of said low Q slots positioned substantially parallel to said longitudinal axis of said traveling wave antenna, and coupling means positioned between said inner conductor and said outer conductor adjacent each of said low Q slots for coupling substantially all of the remaining radio frequency energy in said traveling wave antenna to said low Q slots for radiation to the surrounding space, wherein Q is measured for parallel resonance.

3. In combination, a traveling wave antenna comprising a hollow, cylindrical outer conductor, a cylindrical inner conductor concentrically positioned within said outer conductor, said outer conductor having a first group of slots comprising a plurality of elongated, relatively high Q slots therein positioned around the periphery of and along the length of said outer conductor to form a first spiral, the long dimension of each of said high Q slots being positioned substantially parallel to

the longitudinal axis of said traveling wave antenna, and having a second group of slots comprising a plurality of elongated, relatively high Q slots therein positioned diametrically opposite corresponding slots of said first group to form a second spiral, the long dimension of each of said high Q slots of said second group being positioned substantially parallel to said longitudinal axis of said traveling wave antenna, means coupled to one end of said traveling wave antenna for applying radio frequency energy thereto, coupling means positioned between said inner conductor and said outer conductor adjacent each of said high Q slots of said first and second groups for coupling a portion of said radio frequency energy applied to said traveling wave antenna to each of said high Q slots for radiation to the surrounding space, said outer conductor further having two elongated, relatively low Q slots positioned at the other end of, around the periphery of, and along the length of said outer conductor in each of said spirals with the long dimension of each of said low Q slots positioned substantially parallel to said longitudinal axis of said traveling wave antenna, coupling means positioned between said inner conductor and said outer conductor adjacent each of said low Q slots for coupling substantially all of the remaining radio frequency energy in said traveling wave antenna to said low Q slots for radiation to the surrounding space, and short-circuiting means coupled between said inner conductor, wherein Q is measured for parallel resonance, and said outer conductor near the end of said traveling wave antenna remote from said one end to which said radio frequency energy is applied.

4. In combination, a traveling wave antenna comprising a hollow outer conductor, an inner conductor concentrically positioned within said outer conductor, said outer conductor having a plurality of elongated, relatively high Q slots therein positioned around the periphery of and along the length of said outer conductor in a spiral, means coupled to one end of said traveling wave antenna for applying radio frequency energy thereto, coupling means positioned between said outer conductor and said inner conductor for causing each of said high Q slots to radiate a portion of said radio frequency energy applied to said traveling wave antenna, said outer conductor further having an elongated, relatively low Q slot positioned at the other end thereof in said spiral, coupling means positioned between said outer conductor and said inner conductor for causing said low Q slot to radiate substantially all of the remaining radio frequency energy in said antenna, wherein Q is measured for parallel resonance, and a short-circuiting plate coupled between said inner and said outer conductors at said other end of said traveling wave antenna to short-circuit said inner and outer conductors.

5. In combination, a traveling wave antenna comprising a hollow outer conductor having a plurality of elongated, relatively high Q slots therein positioned around the periphery of and along the length of said hollow conductor in a spiral, means coupled to one end of said traveling wave antenna for applying radio frequency energy thereto, coupling means positioned within said outer conductor for causing each of said high Q slots to radiate a portion of said radio frequency energy applied

to said traveling wave antenna, said hollow conductor further having an elongated, relatively low Q slot positioned at the other end thereof in said spiral, and coupling means positioned within said outer conductor for causing said low Q slot to radiate substantially all of the remaining radio frequency energy in said antenna, wherein Q is measured for parallel resonance.

6. In combination, a traveling wave antenna comprising a hollow conductor having a plurality of elongated, relatively high Q slots therein positioned around the periphery of and along the length of said hollow conductor in a spiral, means coupled to one end of said traveling wave antenna for applying radio frequency energy thereto, coupling means positioned within said outer conductor for causing each of said high Q slots to radiate a portion of said radio frequency energy applied to said traveling wave antenna, said hollow conductor further having an elongated relatively low Q slot positioned at the other end thereof in said spiral, coupling means positioned within said outer conductor for causing said low Q slot to radiate substantially all of the remaining radio frequency energy in said antenna, wherein Q is measured for parallel resonance, and a short-circuiting plate coupled between said inner and outer conductors at said other end of said traveling wave antenna to short circuit said inner and outer conductors.

7. A transmitting traveling wave antenna comprising a hollow conductor having a plurality of elongated relatively high Q slots therein positioned around the periphery of and along the length of said hollow conductor in a spiral, means coupled to one end of said antenna for applying radio frequency energy thereto, said hollow conductor further having an elongated relatively low Q slot positioned at that end of said spiral which is remote from said means, wherein Q is measured for parallel resonance.

8. An antenna comprising a hollow conductor having a plurality of elongated relatively narrow slots therein positioned around the periphery of and along the length of said hollow conductor in a spiral, means coupled to one end of said antenna for applying radio frequency energy thereto, said hollow conductor further having a plurality of relatively wider slots positioned at that end of said spiral which is remote from said means.

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