Jan. 26, 1965 R. GUERTLER 3,167,775

MULTI-BAND ANTENNA FORMED OF CLOSELY SPACED FOLDED DIPOLES OF INCREASING LENGTH

Filed Sept. 29, 1960 2 Sheets-Sheet 1

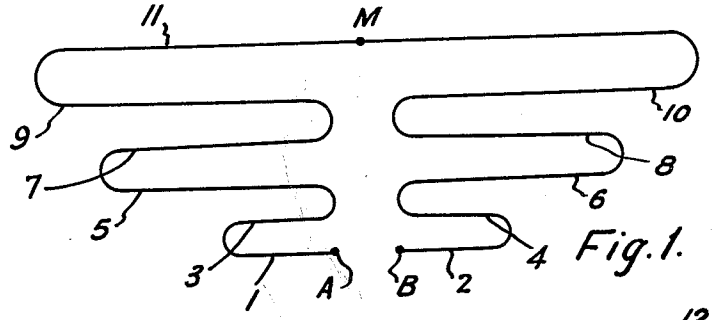


Fig. 1.

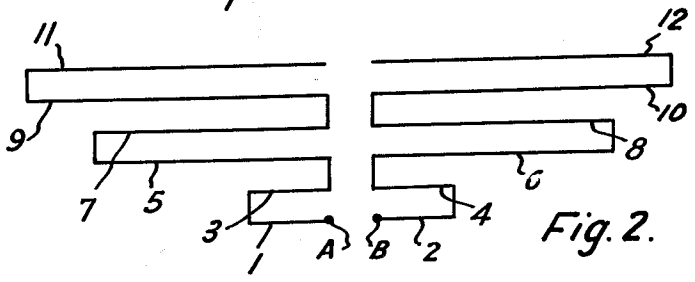


Fig. 2.

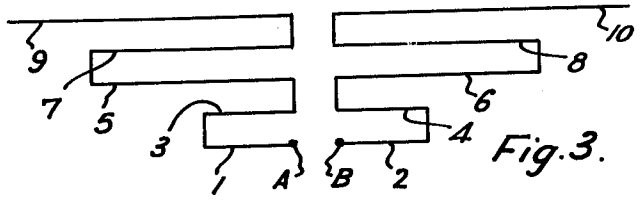


Fig. 3.

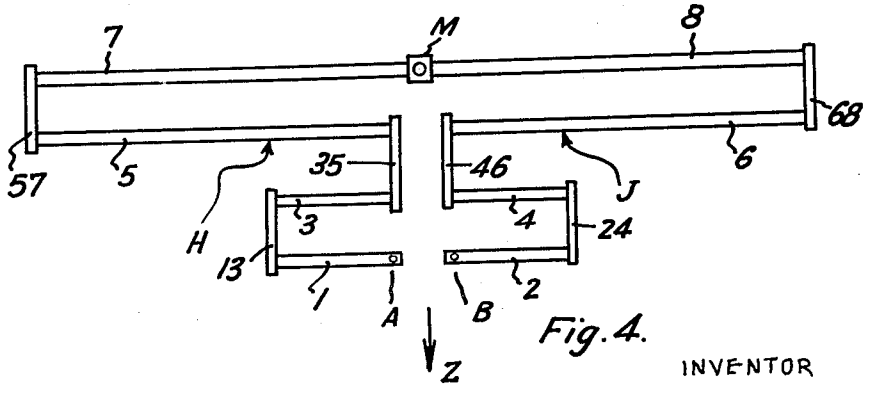


Fig. 4.

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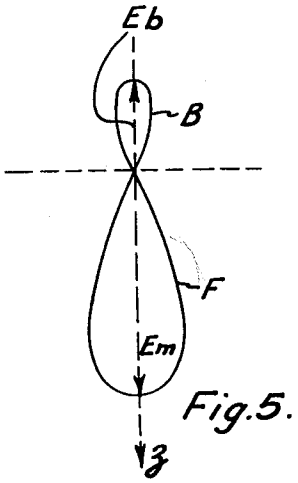


Fig.5.

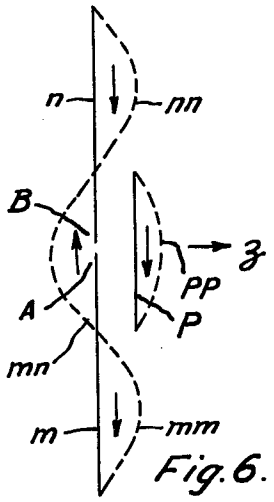


Fig.6.

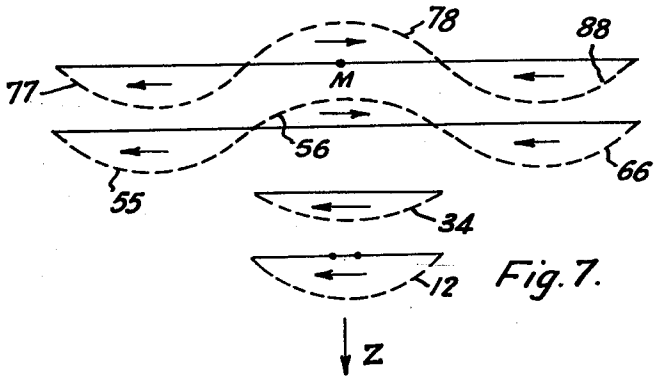


Fig.7.

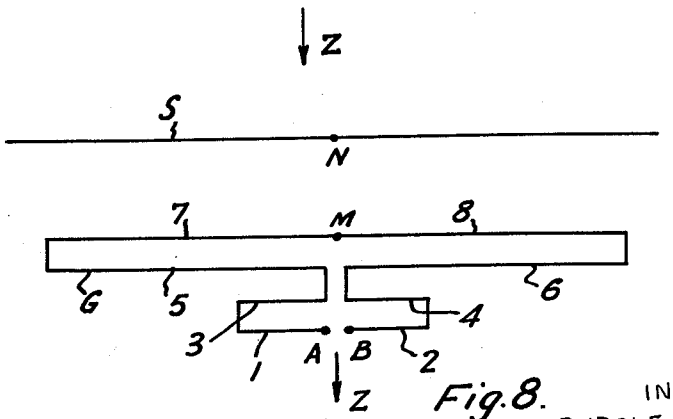


Fig.8.

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MULTI-BAND ANTENNA FORMED OF CLOSELY SPACED FOLDED DIPOLES OF INCREASING LENGTH

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3 Claims. (Cl. 343—806)

This invention relates to antennas, and particularly it relates to antennas with high directivity and high gain over a wide frequency range or over several distince frequency bands.

The object of the invention is to provide an improved antenna for use over a wide frequency range and/or for use over two or more distinct frequency bands, for instance for reception of several television channels in the lower and higher V.H.F. range.

A further object of the invention is to provide an improved antenna with high gain, high directivity, and a feed point impedance which does not cause high standing waves on the feeder.

A still further object of the invention is to provide an antenna of sturdy construction, low wind resistance and easy mounting.

The invention provides an antenna consisting of a plurality of dipoles having parallel axes disposed in a common plane with the centers of the dipoles defining a straight line, the spacing between adjacent dipoles being less than one-tenth of a wavelength at the highest operating frequency, the length of the dipoles increasing from pair to pair, and all dipole elements on one side of said straight line being serially connected thus forming a meandering conducting path, the dipole elements on the other side of said straight line being similarly connected and the terminals of the last longest dipole being short circuited whereby a single continuous conducting path is formed leading from one input terminal of the antenna through all dipole elements to the other input terminal of the antenna. The series connection of all dipole elements on each side enables the elements to operate simultaneously in two electromagnetic modes—firstly in a radiating or antenna mode, and—secondly in an essentially non-radiating transmission line mode. The combination and control of the radiating mode and the transmission line mode on the serially connected dipole elements make it possible to obtain high directivity, high gain, favourable radiation patterns and a useful feed point impedance over a wide frequency range or over several distinct frequency bands. The objective of obtaining high directivity, high gain and a useful feed point impedance requires that the length of the shortest dipoles be approximately equal to a half-wavelength at the highest operating frequency, so that the transmission line stub consisting of adjacent elements of the shortest dipole pair is about a quarter-wave long and has a high input impedance.

An antenna according to the invention may mechanically consist of several parts connected conductively to form a meandering conductive path, or may consist of a single wire or rod bent to form a meandering path in accordance with the invention. The principle of the invention, its operation and advantages will best be understood by reference to the following description taken in connection with the accompanying drawings, in which FIG. 1 shows schematically the fundamental type of an antenna acording to the invention.

FIGS. 2 and 3 show derivatives of the antenna of FIG. 1, when the last longest dipole is open circuited at the center or removed.

FIGURE 4 shows an antenna consisting of two pairs of

dipoles serially connected according to the invention, suitable for two distinct frequency ranges of about 1:3 ratio of centre frequencies.

FIGURE 5 shows a graph of the radiation pattern in the plane of the antenna in the higher frequency range.

FIGURE 6 is an explanatory diagram of a conventional active three-half-wave dipole combined with a passive half-wave dipole.

FIGURE 7 is an explanatory diagram for explaining the improvements of the present invention.

FIGURE 8 shows an antenna similar to FIGURE 4 combined with a screen or reflectors.

FIG. 1 shows the fundamental type of antenna according to the invention. It consists of three pairs of dipoles with elements connected serially so that a continuous meandering conductive path is obtained between the terminals A and B, namely, A–1–3–5–7–9–11–10–8–6–4–2–B, the length of the dipoles increasing from pair to pair, 1, 2, 3, 4 being the shortest elements, 9, 10, and halves of 11 being the longest elements. M is the neutral-potential point of the antenna and may be grounded. All said dipole elements perform a double operation—as radiators, and as conductors of transmission line stubs. Elements on opposite sides of the straight line connecting centers of the dipoles, as for instance 1 and 2, or 3 and 4, or 9 and 10, or 11, act as dipoles. Adjacent elements as, for instance, 1–3, or 3–5, or 9 and part of 11 on the left side of M, act as transmission line stubs. Straight elements inside the antenna belong substantially to three circuits; for instance, element 3 is part of the dipole 3–4, part of the stub 1–3, and part of the stub 3–5. The multiple operation of the antenna elements represents a multitude of adjustable antenna parameters. The frequency range, particularly, is determined by the length of dipole elements. Variation in the spacing of adjacent elements and variation of element diameters have only a small influence on the antenna mode and a limited influence on the transmission line mode.

The antenna, FIGURE 2 is derived from FIG. 1 by leaving the terminals of the last longest dipole 11, open-circuited at the center M. This variant, FIG. 2, comprises the same transmission line stubs as the fundamental antenna form of FIG. 1 from which it is obtained by opening the last longest dipole at the center M. An antenna according to FIG. 2 has the same radiating elements and the same transmission line stubs as an antenna of the same geometry but with short-circuited terminals M of the last longest dipole of FIG. 1. It has similar qualities to the fundamental antenna with some quantitative variations as, e.g., changed frequency bands.

The antenna, FIG. 3, can be derived from FIGURE 1 by removing element 11. The variant of FIG. 3 has one radiating dipole and two transmission line stubs less than the corresponding fundamental antenna of FIG. 1, from which it is derived. Due to the remaining configuration similar in principle to FIG. 1, the variant of FIG. 3 exhibits similar qualities to the fundamental antenna, FIG. 1.

FIGURE 4 shows an example of an antenna of type FIGURE 1. The antenna consists of straight tubular conductors, 1, 2, 3, 4, 5, 6 and 7–8, joined by coupling members such as conductive strips 13, 35, 57, 68, 46, and 24, so that a meandering conductive path in accordance with the invention is obtained. The antenna can be used in two distinct frequency ranges. Excellent performance is obtained when the longer folded dipole 5–7–8–6 represents a three-half-wave dipole at frequencies where 1–2 and 3–4 operate as half-wave dipoles. At about one-third of this frequency 5–7–8–6 operates as folded half-wave dipole.

In an actual television receiving antenna for the fre-

quency bands 63 to 70 megacycles and 181 to 202 megacycles of a construction similar to FIGURE 4, according to the invention, the following dimensions were used:

	Inches
Length of sections 1, 2, 3, 4	13½
Length of sections 5 and 6	40½
Length of section 7–8	82
Axial separation between adjacent sections, that is between 1 and 3, between 3 and 5, and between 5 and 7	2½
Total width of antenna, that is separation between axes of sections 1 and 7	7½

All the sections 1 to 7–8 are of aluminum tubing of ½ inch or ⅝ inch outer diameter. The antenna can be built also of a single rod or tubular conductor bent to the meandering form indicated by A–1–3–5–7–8–6–4–2–B. In the lower frequency band, part 5–7–8–6 operates like a folded half wave dipole; part 1–3–4–2 acts like inductive loading of the antenna at the feed point. The currents in sections 1–2 provide at the lower frequencies some increased radiation in the direction indicated by arrow z; the radiation diagram in the plane through the dipole elements is substantially a figure-eight pattern with a front-to-back ratio of about 1.1 to 1.2.

In the higher frequency band (181 to 202 megacycles) the part 5–7–8–6 operates as a folded three-half-wave dipole, and the part 1–3–4–2 as a folded half-wave dipole. The radiation pattern in the plane of the antenna, measured at frequencies near the centre of the higher frequency range consists substantially of two narrow lobes, as indicated in diagram, FIGURE 5. The forward-lobe F has a field intensity maximum, E*m*, in the *z* direction. The backward-lobe, B in FIGURE 5, has a maximum of F*b*, in direction opposite to *z*. The forward-maximum, E*m*, is greater than the backward-maximum, E*b*. The front-to-back ratio, E*m*/E*b*, for an actual antenna as described above in connection with FIGURE 4, is about 2 or more. At frequencies near the lowest and highest frequency of the higher frequency range (181 to 202 megacycles), some small side-lobes will appear in the radiation pattern, FIGURE 5.

To appreciate fully the merits of an antenna incorporating the invention, the properties of a known antenna type indicated in FIGURE 6, may be described. This conventional type consists of a three-half-wave dipole *n*—*n*, and an adjacent passive half-wave element *p*, as described by F. A. Kolster, "Antenna Design for Television and F.M. Reception," Proceedings of the Institute of Radio Engineers, volume 36, pages 1242–1248, October 1948. The current distribution indicated by *mm*, *mn*, *nn*, and *pp*, shows that the currents *mm*, *nn*, and *pp* have the same direction, but current *mn* has the opposite direction; its unfavourable radiation can be neutralized to a certain degree by the current distribution *pp*. This antenna acts almost like two co-linear half-wave dipoles with current distributions *mm* and *nn*, respectively. The radiation pattern of this antenna has the same forward-lobe and backward-lobe. The operation of the passive element *p*, FIGURE 6, can be controlled only to a certain degree; higher gain in a single direction *z* is not obtainable without additional elements as, for instance, reflectors and/or directors.

The operation of an antenna, FIGURE 4, incorporating the invention, is considerably more involved. In the higher frequency range, the part 1–3–4–2 represents a folded half-wave dipole with element 3–4 loaded at the centre with a folded three-half-wave dipole 5–7–8–6. The quarter-wave stubs 1–3 and 2–4, and the three-quarter-wave stubs 5–7 and 6–8 have a broadbanding effect encountered in folded dipoles. Section 3 together with the adjacent part of section 5 operate as a phase-reversing quarter-wave stub, that is phase reversal takes place between strip 13—the end of section 3—and point H on section 5, FIGURE 4. Similarly, phase reversal is obtained between strip 24 and point J on section 6. The quarter-wave stubs 1–3 and 2–4 have also to secure a phase reversal with respect to the driving voltage across A–B as at the input of the folded three-quarter-wave dipole 5–7–8–6 driving voltage of opposite polarity as required.

The theory of antennas consisting of serially connected dipole elements in accordance with the invention has not yet been fully developed. However, it is believed that distribution of radiating or antenna currents takes place approximately as indicated in FIGURE 7. Currents 12 and 34 in dipoles 1–2 and 3–4 respectively, have the same direction as currents 55, 77, 66 and 88, in the outer thirds of dipoles 5–6 and 7–8; currents 56 and 78 in the middle thirds of the dipoles 5–6 and 7–8 have the opposite direction. Current 34 neutralizes current 56, and current 78 acts like current in a reflector with respect to dipole 1–2, that is the central part of the antenna acts like an endfire array, and this accounts for directivity in direction z as expressed in the radiation pattern, FIGURE 5. The relative narrowness of the forward-lobe and backward-lobe and the higher gain are due to the co-linear arrangement of current distributions 55 and 66, 77 and 88, and the nearly co-linear end-fire arrangement of currents 12 and 78, FIGURE 7.

The input impedance of an antenna as represented in FIGURE 4 matches satisfactorily to a feeder of 300 ohm characteristic impedance. It is quite obvious that at lower frequencies the feed point impedance will match the feeder because the antenna operates substantially as a folded half-wave dipole with a moderate inductive loading at the feed point.

Satisfactory matching is obtainable also in the higher frequency range. Experiments with an antenna whose dimensions have been given above in connection with FIGURE 4, showed a voltage standing-wave ratio of about 1.5 at the lowest and highest frequency of the higher frequency range; at these boundary frequencies of the range the antenna impedance had only a small reactive component. The matching is noticeably better than with a conventionally tolerated standing-wave ratio of 2 for good television reception. If an antenna is required for three frequency bands, three pairs of dipoles should be used, that is, a configuration similar to FIG. 1.

Directivity and gain of an antenna incorporating the invention can be improved by adding one or several known types of passive elements as reflectors and/or directors. FIGURE 8 shows schematically the plan projection of an antenna according to the invention, with a reflector S comprising a single long element or colinear shorter elements or a suitable screen. All known methods of combining a plurality of similar antennas into an array (for instance cophased arrays, colinear arrays, broadside arrays, end-fire arrays) can be applied to antennas according to the invention.

Similar antennas as, for instance, FIGURE 4 or FIGURE 8, may be stacked vertically to increase gain and to reduce the vertical acceptance angle.

There are many other types of antennas feasible in accordance with the invention, and many kinds of arrays employing antennas incorporating the invention.

I claim:

1. An antenna consisting of a plurality of pairs of dipoles having parallel axes disposed in a common plane with the centers of said dipoles defining a straight line, the spacing between adjacent dipoles being less than one-tenth of a wavelength at the highest frequency of operation, the length of the dipoles increasing from pair to pair, all dipole elements on one side of said straight line being connected serially, the terminals of the last longest dipole being short-circuited, and all dipole elements on the other side of said straight line being connected serially, so that a continuous meandering conducting path is provided starting from one terminal of the first shortest

dipole and continuing serially through all dipole elements on one side of said straight line, thence through all dipole elements on the other side of said straight line and finishing at the other terminal of the first shortest dipole, thus enabling each element to act as a radiating element in cooperation with the element opposite with reference to said straight line and to take part in transmission line stub operation with an adjacent element, the entire antenna so formed exhibiting highest sensitivity along said straight line, and being capable of operating over a wide range of frequencies.

2. An antenna consisting of first and second pairs of dipoles, the dipoles of the second pair being longer than the dipoles of the first pair, all dipoles having parallel axes disposed in a common plane with the centers of said dipoles defining a straight line, the spacing between adjacent dipoles being less than one-tenth of a wavelength at the highest frequency of operation, all dipole elements on one side of said straight line being connected serially, the terminals of the last longer dipole being short-circuited, and all dipole elements on the other side of said straight line being connected serially, so that a continuous meandering conducting path is obtained starting at one terminal of the first shorter dipole in said first pair, passing serially through all dipole elements on one side of said straight line, thence through all dipole elements on the other side of said straight line and finishing at the other terminal of said first shorter dipole, thus enabling each element to act as a radiating element in

cooperation with the element opposite with reference to said straight line and to take part in transmission line stub operation with an adjacent element, the entire antenna so formed exhibiting highest sensitivity along said straight line, and being capable of operating in two frequency bands.

3. An antenna according to claim 2 wherein the length of the dipoles in said second pair is approximately three times the length of the dipoles in said first pair, the dipoles operating in two distinct frequency ranges whereof the ratio of the range center frequencies is approximately 1:3 whereby the wavelength at the center frequency of the higher frequency range is about twice the length of a dipole in said first pair and significant sensitivity at frequencies of the higher frequency range being exhibited along said straight line in the direction from the longer to the shorter dipoles.

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