Nov. 3, 1964 A. F. WICKERSHAM, JR., ET AL 3,155,976

BROADBAND STRAIGHT LADDER ANTENNA WITH TWIN WIRE BALANCED FEED SUPPLIED VIA INTEGRAL UNBALANCED LINE

Filed Aug. 31, 1959 3 Sheets-Sheet 1

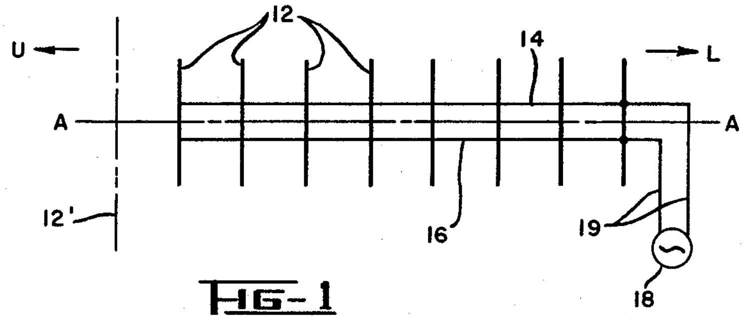

FIG-1

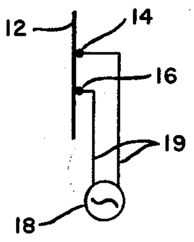

FIG-1-A

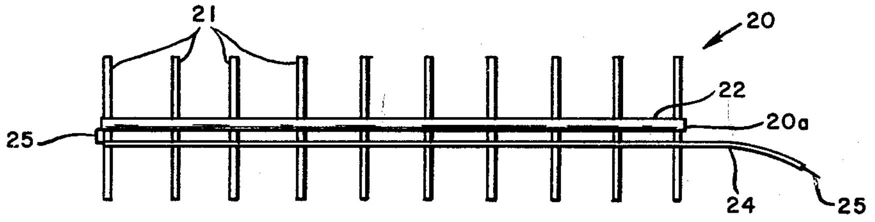

FIG-2

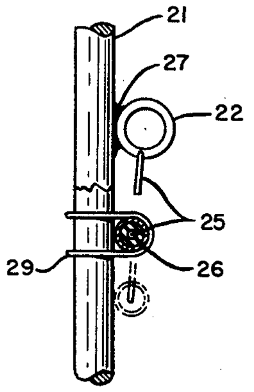

FIG-4

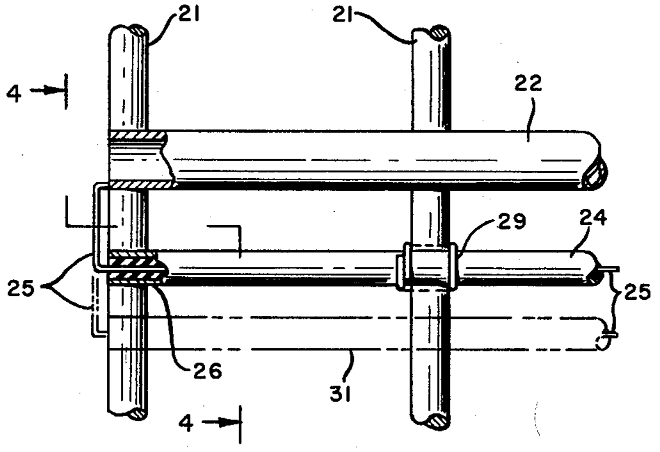

FIG-3

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Filed Aug. 31, 1959 3 Sheets-Sheet 2

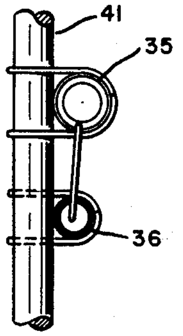

FIG-6

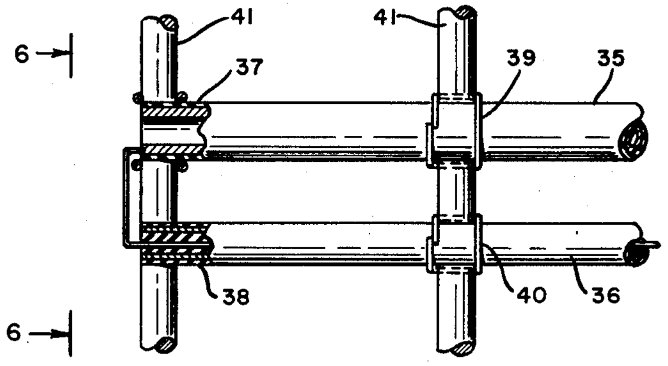

FIG-5

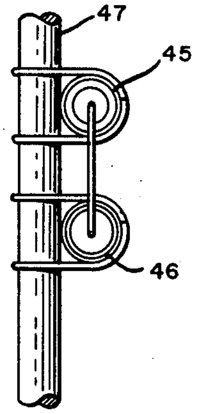

FIG-8

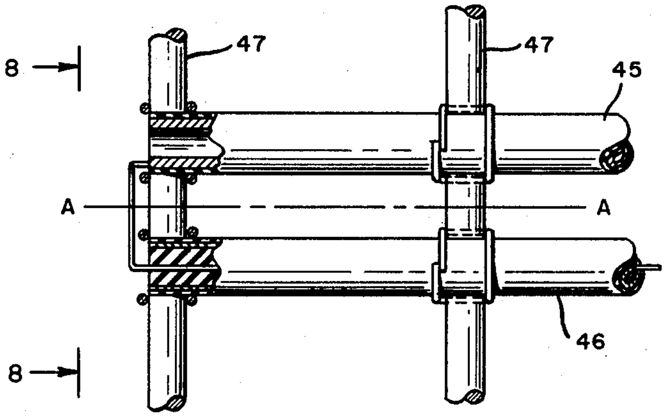

FIG-7

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Filed Aug. 31, 1959 3 Sheets-Sheet 3

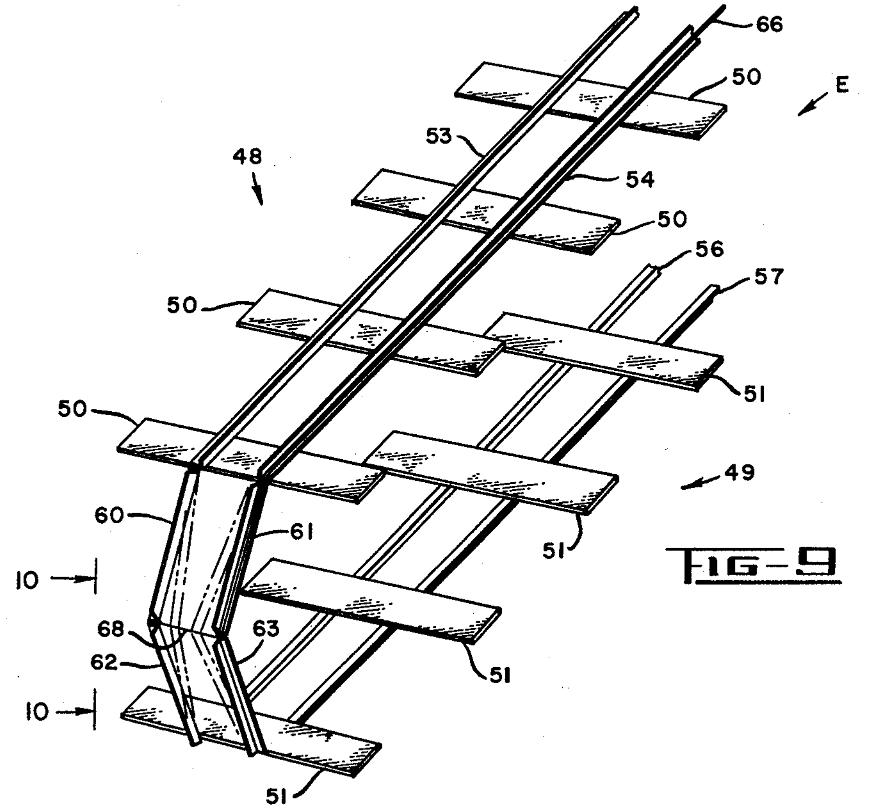

FIG-9

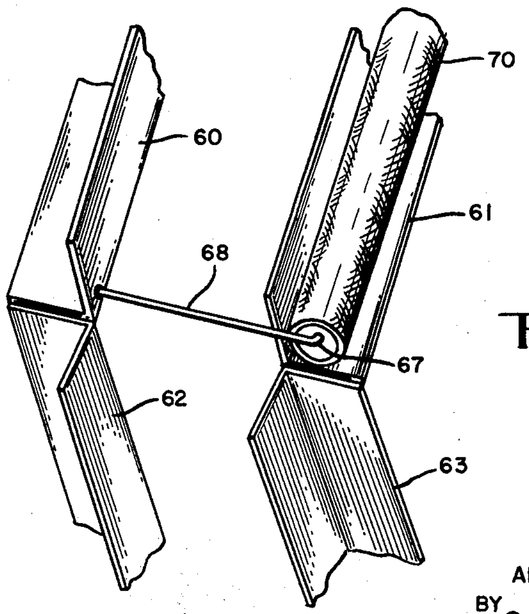

FIG-10

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BROADBAND STRAIGHT LADDER ANTENNA WITH TWIN WIRE BALANCED FEED SUPPLIED VIA INTEGRAL UNBALANCED LINE

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5 Claims. (Cl. 343—814)

This invention relates to antennas, and in particular to a broadband end-fire antenna resembling the Yagi-Uda type.

The well-known Yagi-Uda antenna, called a "Yagi," is one of the simplest and most compact high-gain antennas known in the art. However, it has a high gain only over a very narrow band of frequencies, in the order of plus or minus 1½% of the operating frequency for a 1 db drop from maximum gain. The usefulness of the antenna is therefore limited to narrow band applications.

The present invention is concerned with improvement of the operating bandwidth of the Yagi-type antenna while preserving its compactness and structural simplicity. Briefly, we have provided an antenna comprising several parallel radiating elements aligned in a row and equally spaced apart, and a twin wire feed line which traverses these several elements for the length of the row. The array is descriptively called a straight-ladder antenna. The length and spacing of the radiating elements may be the same as used in conventional Yagi designs. The twin wire feed line may be electromagnetically coupled to the radiating elements and in one embodiment of the invention comprises the antenna backbone members, called the "booms." A coaxial line extends alongside or inside one of the booms for the full length of the antenna. The center conductor of the coaxial line is connected to the end of the opposite boom which, in effect, becomes an extension of the center conductor. In one embodiment the outer conductor of the coaxial cable may of itself be, physically and electrically, one of the booms. The booms, then, constitute a twin wire feed.

In another embodiment, two such ladder antennas are stacked and joined at one end and are fed in parallel by a single coaxial line. The gain for this two-bay array is greater than that of the single-bay configuration. In both the single and two-bay arrays, the operating bandwidth is about four times that of the conventional Yagi antenna.

A primary object of our invention is the provision of a compact broadband end-fire antenna.

Another object is the provision of a modified Yagi-type antenna having an operating bandwidth substantially greater than that of the conventional Yagi antenna.

A further object is the provision of a broadband end-fire antenna which can be directly fed from an unbalanced line.

Another object is the provision of a straight-ladder type antenna having an input impedance which is readily and conveniently adjustable.

These and other objects of our invention will become apparent from the following description of preferred embodiment thereof, reference being had to the accompanying drawings in which:

FIGURES 1 and 1–A are schematic plan and end views, respectively, of a straight-ladder antenna and twin wire feed system embodying our invention.

FIGURE 2 is a plan view of a straight-ladder antenna in which the twin wire feed lines comprise the antenna boom and a juxtaposed coaxial cable.

FIGURE 3 is the enlarged partially cut-away end portion of the antenna of FIGURE 2 showing the connection of the center conductor of the coaxial line to the boom.

FIGURE 4 is a section taken along line 4—4 of FIGURE 3.

FIGURES 5 and 6 are views similar to FIGURES 3 and 4, respectively, showing a modified form of the antenna feed.

FIGURES 7 and 8 are plan and end views, respectively, of another form of antenna feed.

FIGURE 9 is a perspective view of a modified form of the invention comprising a two-bay array of the straight-ladder type antenna.

FIGURE 10 is an enlarged view of a portion of FIGURE 9 showing the junction of the two bays and connection between the coaxial line to the boom.

Referring now to the drawings, an antenna embodying our invention is shown schematically in FIGURE 1 and comprises an array of elements 12 which are substantially identical in size and length, and which are equally spaced apart, parallel to each other, and perpendicular to and symmetrical about the antenna axis A—A. In accordance with our invention, electromagnetic energy is fed to the antenna by means of a twin wire transmission line comprising laterally spaced conducting lines 14 and 16 which extend across the elements 12 parallel to the antenna axis for the full length of the antenna. Conductors 14 and 16 may be intertwined about the radiating elements, so as to be in contact with opposite sides of adjacent elements, or may extend along the same side of the elements as shown in FIGURES 1 and 1–A. One or both of conductors 14 and 16 may be insulated from the radiating elements 12, but satisfactory results also have been obtained when both conductors 14 and 16 are in direct electrical contact with each element 12. When the antenna is used for transmitting, it is energized by a source 18 of high frequency having output lines 19 connected in parallel to lines 14 and 16. If the antenna is used in a receiving system, a receiver replaces the source 18. It will be understood, therefore, that the term "feed lines" as applied to conductors 14 and 16 comprehends the function of receiving energy from as well as delivering energy to the elements 12, which elements either intercept or radiate the energy depending upon the use.

The general antenna configuration and feed system therefor shown in FIGURE 1 differs from the conventional Yagi antenna in that the former omits the exciter element and may omit the reflector element of the Yagi and has instead an array of elements that are essentially director elements. The distributed feed afforded by the twin wire transmission line operates in two ways to broaden the operating frequency of the antenna. First, the input impedance of the antenna, as seen at the terminals of lines 19, remains uniform over the wider frequency band so that the problem of matching the antenna to the line is solved without resorting to line balancing devices (baluns) which are frequency sensitive. Secondly, the distributed feed, as opposed to excitation of one element as in the Yagi design, has the effect of producing a stable uniform radiation pattern over the wider frequency range. The directivity and gain of the straight-ladder antenna are about the same as that of the Yagi.

It should be noted that the direction of radiation of the straight-ladder antenna undergoes a sharp reversal as the frequency of the electromagnetic energy is swept over the operating range. (This is a reversal within as little as 0.12% change in frequency and without deterioration of the quality of the beam.) At the lower end of the operating range, the radiation is in the direction of the arrow L in FIGURE 1 and as the frequency is increased, energy radiates in the direction of the arrow U. If unidirectional radiation over the band is desired, one or more end elements 12′ having an increased length indicated by the broken lines may be added to the array so as to function as a reflector.

A preferred embodiment of the twin wire feed line for the straight-ladder antenna is shown in FIGURE 2 wherein the antenna **20** has radiating elements **21** supported on a central boom **22** and energy is transmitted to the antenna (when used as a transmitter) by means of a coaxial line **24** juxtaposed to the boom and extending parallel thereto across the radiating elements for the length of the antenna. The coaxial line **24** joins the antenna assembly at the input end **20***a* and its center conductor **25** is connected directly to the end of boom **22** opposite from the input end. Either the boom or the outer conductor of the coaxial line may be insulated from the radiating elements, although substantially the same operating characteristics are attainable when both the boom and the coaxial outer conductor are directly electrically connected to the elements **21**. The outer conductor **26** of cable **24** forms one of the twin wire feed lines, and the boom, which is essentially an extension of the coaxial inner conductor, is the other feed line. The input impedance of the antenna as seen at the input end of the coaxial line is determined in part by the lateral spacing between the boom and the coaxial line, and conveniently may be matched to the feed line by adjustment of that spacing as suggested in FIGURES 3 and 4 in phantom lines.

Boom **22** is a rigid member made of conducting material, may be tubular as shown, and is the common support for the several radiating elements **21** which are secured to it as by welding **27**, see FIGURE 4. The coaxial cable **24** may be intertwined on opposite sides of successive radiating elements or may extend along one side of the elements, as shown. Spring wire clamps, one of which is shown at **29**, may be used to hold the cable in position. This clamp also permits adjustment of the spacing between the coaxial line and the boom for impedance matching purposes, as described above. In the embodiment shown in FIGURES 3 and 4, outer conductor **26** of the coaxial cable is directly connected to each of the radiating elements **21**. It is not necessary to insulate elements **21** from either the outer conductor or the boom since this direct electrical connection does not cause a short at radio frequencies.

The straight-ladder antenna described above has an efficiency (ratio of realized gain to observed directivity) which is identical to that of the conventional Yagi antenna but has a bandwidth at least four times as great as the Yagi. While the impedance of the straight-ladder antenna does vary with large excursions in frequency, nevertheless, the voltage standing wave ratio is 1.1 or less over the frequency range for units which have been built and tested.

FIGURES 5 and 6 illustrate a modification of former arrangement wherein both the boom **35** and the coaxial cable **36** are insulated from radiating elements **41**. The boom has external insulation **37** and, similarly, cable **36** is insulated by rubber-like sheath **38**. Spring clamps **39** and **40** hold the radiating elements **41** to the boom and cable, respectively. Energy is derived from both sections of the twin line by electromagnetic coupling. The overall input impedance of the antenna can be controlled by varying the thickness of the dielectric insulation between the elements **41** and boom **35** and between elements **41** and cable **36**, as well as by varying the distance of separation of boom **35** and cable **36** from one another.

In another form of the invention shown in FIGURES 7 and 8, the boom **45** and cable **46** are insulated from the radiating elements **47**, as in FIGURES 5 and 6, but here the boom and cable are the same diameter. Also, these two parts of the twin feed line are symmetrically disposed about the center line A—A of the antenna. This configuration has the advantage that the radiated beam is more nearly colinear with the center line of the antenna. In other respects, performance is substantially the same as with the antennas of FIGURES 3 and 5.

Another form of our invention shown in FIGURES 9 and 10 wherein two straight-ladder type antennas **48** and **49** are stacked with their respective longitudinal axes parallel and spaced apart and with their respective transversely disposed radiating elements **50** and **51** having axes lying in successive equally spaced planes substantially perpendicular to the longitudinal axes. In the embodiment shown in the drawings, antenna **48** has a pair of structural members **53** and **54**, such as angle iron strips, extending parallel to and spaced from each other and to which the several radiating elements **50** are secured. Similarly, co-extensive laterally spaced structural parallel members **56** and **57** provide support for the radiating elements **51** of antenna **49**. Members **53** and **54** are mechanically and electrically connected and secured at one end to members **56** and **57**, respectively, by means of interconnecting members **60**, **61**, **62** and **63**. The radiating elements **50** and **51** take the form of rectangular plates made of conducting material, secured as by welding to the structural members.

The two antenna bays are fed from the open end E, to the right as viewed in FIGURE 9, by a coaxial line **66** which extends along structural members **54** and **61** to the junction of the latter with member **63**, see FIGURE 10. At this point, the coaxial line terminates but its center conductor **67** is connected by conductor **68** to the opposite member **60**. The outer conductor **70** of the cable is in direct electrical contact with members **54** and **61**, and since members **61**, **63** and **57** are electrically connected, the effect is that members **56** and **57** of the lower bay are parallel fed twin wire feed lines. In order to improve the match of the antenna to the line, members **60**, **61**, **62** and **63** may be disposed to converge toward the centered feed point as indicated in broken lines in FIGURE 9. This in effect functions as a transformer and holds the voltage standing wave ratio to a minimum. The two-bay array of FIGURE 9 provides in the order of 3 db additional gain over that of a single array and has an end-fire radiation pattern that is substantially uniform over a wide frequency range.

Dimensions and characteristics of antennas of the type described above which have been successfully tested and operated are:

	Figure 2	Figure 9
Elements 21	Rods	Plates.
Number	13 Directors, 2 Reflectors.	4 in each Bay, Total 8.
Length	Dir.—3.31″, Ref.—3.94″.	10.25″.
Diameter or Thickness	0.125″	0.1875″.
Width		0.875″.
Spacing	2.5″	5″.
Length of Boom 22	36.8″	22″.
Spacing of Antenna Axes		10.25″.
Design Frequency	1,450 mc.	468 mc.
Operating Bandwidth (1 db down from max. gain).	Approx. ±7%	Approx. ±8%.
VSWR (max. over bandwidth)	1.1	2.0.

Modifications and changes may be made to the above described embodiments of our invention without departing from spirit and scope of the invention. The appended claims define the elements of novelty of the invention.

We claim:

1. A high frequency end-fire antenna having an axis and comprising a plurality of conducting elements arranged in a common plane and extending parallel to each other, said elements being axially spaced from each other, and means for feeding electromagnetic wave energy to said conducting elements comprising a coaxial cable and a conducting member, both extending axially and being electromagnetically coupled to said elements for the full length of the antenna, said cable having an outer conductor and an inner conductor, said inner conductor being directly electrically connected to said conducting member at one end of the antenna, and energy input means coupled to said coaxial line at the opposite end of the antenna for transmitting energy to said elements.

2. A high frequency end-fire antenna having an axis and comprising a plurality of straight conducting elements arranged in a row in a common plane and extending parallel to each other transversely of and generally symmetrically about said axis, said elements being axially spaced from each other, and transmission line means for feeding electromagnetic wave energy to said conducting elements comprising an axially extending conducting member traversing said elements for the full length of the row, a coaxial cable having a length thereof juxtaposed to and coextensive with said member and terminating at one end of said row, said cable having an inner conductor and an outer conductor, said member and the outer conductor of said cable being electromagnetically coupled to said elements, means connecting said inner conductor at said one end of the cable to the adjacent end of said member, said cable and said member being laterally spaced apart, and electromagnetic apparatus connected to the other end of said coaxial cable for feeding energy to said elements.

3. A high frequency end-fire antenna having an axis and comprising a plurality of straight conducting elements of equal length arranged in a row and in a common plane parallel to each other and extending transversely of and generally symmetrically about said axis, said elements being equally axially spaced from each other, and transmission line means electromagnetically coupled to said conducting elements comprising an axially extending conducting member traversing said elements for the full length of the row, a coaxial cable having a length thereof juxtaposed to and coextensive with said member and terminating at one end of said row, said cable having an inner conductor and an outer conductor, means connecting said inner conductor at said one end of the cable to the adjacent end of said member, said cable and said member being laterally spaced apart, and electromagnetic apparatus connected to the other end of said coaxial cable for feeding energy to said elements.

4. An antenna having an axis and comprising an array of axially spaced continuous transverse elements in a common plane containing said axis, and a pair if juxtaposed axially extending feed lines coextensive with said array and disposed immediately adjacent to and coupled to said elements, one of said feed lines comprising an unbalanced transmission line.

5. An antenna having an axis comprising an array of axially spaced continuous transverse elements in a common plane containing said axis, and a pair of juxtaposed axially extending feed lines coextensive with said array and disposed immediately adjacent to and coupled to said elements, one of said feed lines comprising a coaxial cable.

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