Dec. 17, 1957 J. SCHWARTZ ET AL 2,817,085

BROAD-BAND END-FIRE TELEVISION ANTENNA

Filed Nov. 14, 1956 3 Sheets-Sheet 1

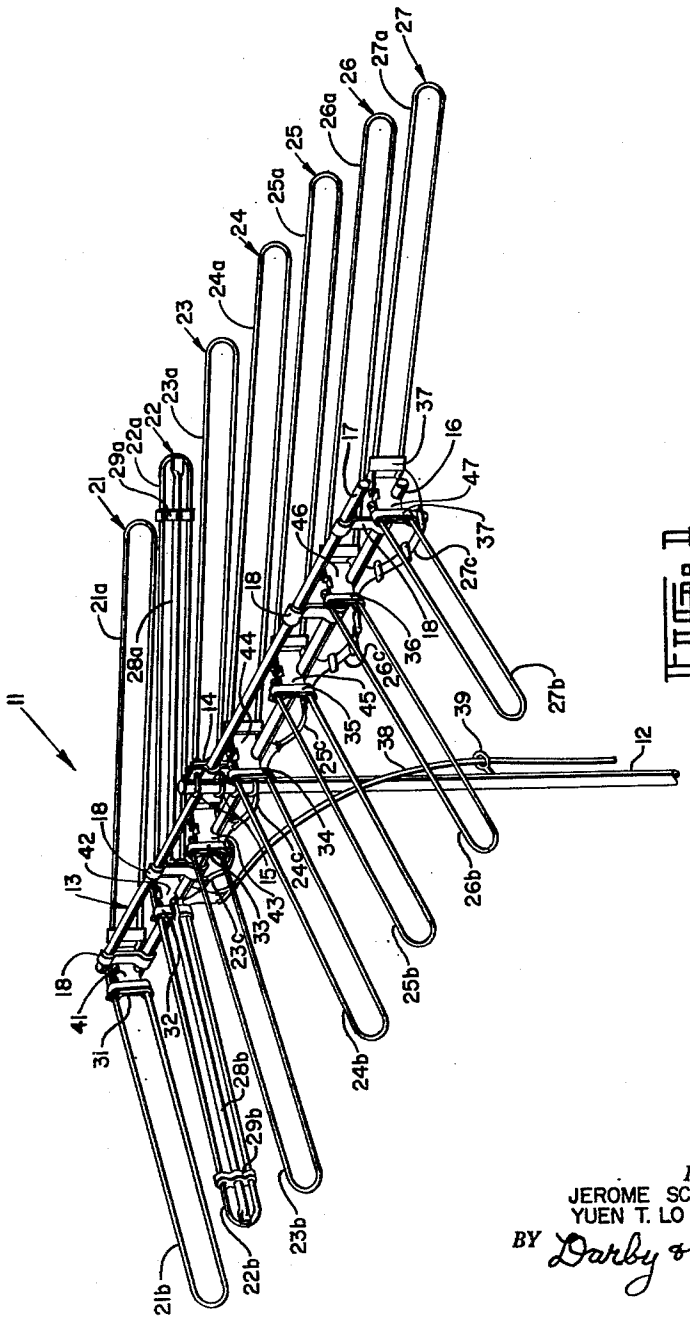


FIG. 1

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Filed Nov. 14, 1956 3 Sheets-Sheet 2

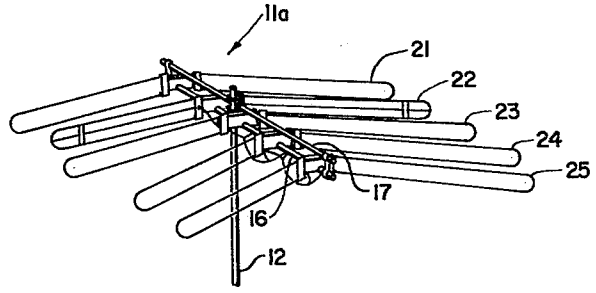


FIG. 2

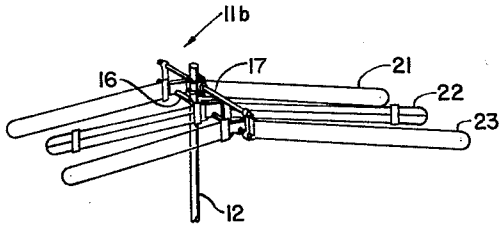


FIG. 3

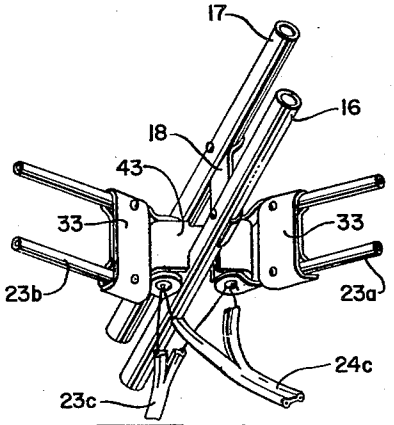


FIG. 4

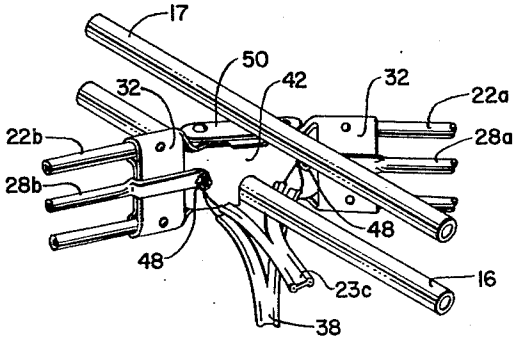


FIG. 5

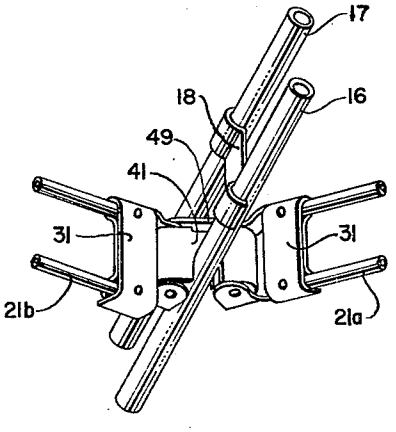


FIG. 6

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BROAD-BAND END-FIRE TELEVISION ANTENNA

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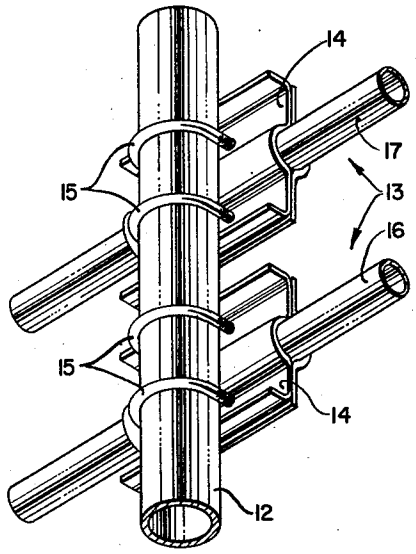


FIG. 7

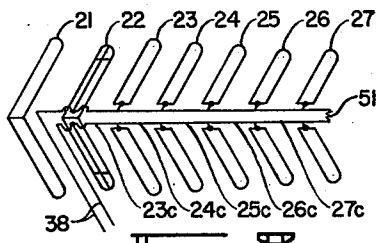


FIG. 8

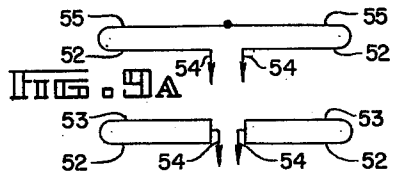


FIG. 9A

FIG. 9

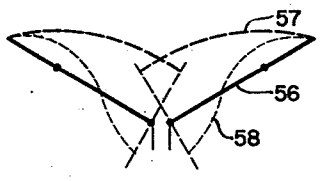


FIG. 10

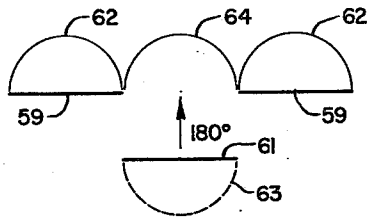


FIG. 11

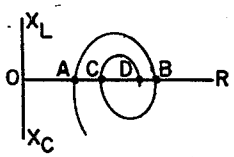


FIG. 13

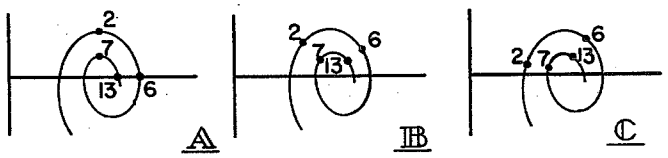


FIG. 14

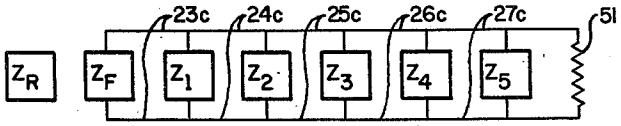


FIG. 12

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United States Patent Office 2,817,085 Patented Dec. 17, 1957

2,817,085

BROAD-BAND END-FIRE TELEVISION ANTENNA

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Application November 14, 1956, Serial No. 622,073

26 Claims. (Cl. 343—814)

The present invention relates to high-gain broad-band television antennas with multiple in-line active elements, and more particularly to such antennas in which the active elements are constructed so that the amount of radio frequency current produced by each in response to excitation by radiated radio frequency energy is substantially the same.

A particularly effective television antenna is most necessary in so-called fringe areas, which because of their great distance from the television transmitter, or for other reasons, receive a very weak television signal. In such areas an antenna having considerable gain is required (gain being the antenna's signal gathering ability compared to a standard dipole antenna). It is normally not sufficient that an antenna in such areas have a high gain for only a few of the channels in the band which it is designed to cover. On the contrary, it is desired that an antenna for such an area have a high gain at each channel to be received and that the gain across the complete band or bands formed by all the various channels be substantially constant or "flat."

A further feature of increasing importance in television antennas is the so-called "front-to-back-ratio." High gain antennas are highly directive, so that signals from a particular direction are received with a gain many times as great as the gain for signals from other directions from the antenna. The direction from which signals are best received is designated the "front" of the antenna. Most antennas are also somewhat sensitive in other directions and particularly to the direction opposite to the "front," namely the "back" of the antenna. In fact, for most antennas, the second most sensitive direction is the "back" of the antenna, which in some cases may have a gain equal to the "front" gain unless special provision is made, as by use of a reflector.

As the number of television stations has increased and television stations have increased their power, the problem of interference between stations has increased. Interference may occur between two television stations on the same channel or on adjacent channels. An interfering station is seldom located in the same direction as the desired station, and thus an antenna with a high degree of directivity is very effective in eliminating this interference except from the "back" direction. The degree of directivity of antennas as to the "back" direction is frequently defined in terms of relative sensitivity in the forward and reverse directions, called "front-to-back ratio." An antenna with a high front-to-back-ratio is therefore very desirable, particularly in fringe areas where problems of co-channel and adjacent channel interference arise most often.

The basic type of antenna previously considered to be most effective in overcoming the problems described above is the so-called "broad-band" Yagi antenna. Many variations of this type of antenna exist, but it may be identified generally by several parallel parasitic dipole elements (directors) arranged in-line in front of an active element, usually with a single parasitic reflector element behind the active element. (By "in-line" is meant in a common horizontal plane with elements spaced in the front-to-back direction.)

In spite of its superiority in some respects over many other types of antennas, the broad-band Yagi is still subject to many limitations. A basic theoretical condition for maximum receiving antenna performance in a multi-element antenna is that every element should produce an equal amount of current in the proper phase relationship. The broad-band Yagi antenna cannot fulfill this condition on more than one or two channels because the current and phase relationships do not hold constant across the V. H. F. band. Since it cannot make full use of the transmitted energy at all frequencies, this atnenna type cannot realize uniform gain on every channel and is not properly called "broad-band."

The ability of the Yagi antenna to produce a high front-to-back-ratio on all channels is also inherently limited. The impedance of each parasitic element and the physical spacing between them, determine both the phase and the amplitude of the current flowing in the parasitic elements since no electrical connection is provided to them.

Ideally, automatic compensation should be provided to maintain substantially equal current in the proper phase for changes in frequency. However, the physical character of the parasitic element is fixed and therefore changes in current magnitude and phase must invariably occur with changes in frequency.

Antennas according to the present invention are not subject to the inherent limitations of the broad band Yagi antenna due to the fact that the present antenna does not rely on forward parasitic elements (directors) to increase the antenna gain. On the contrary, all the elements of the antenna are active with the exception of a single rear parasitic element (reflector). Since the forward elements of the antenna are all thus connected by an electrical transmisson line, the current and phase relationships of each element are not determined solely by its physical dimensions but also by the current flowing in the transmission line. Proper design of the present antenna can therefore provide an antenna in which every element provides a substantially equal amount of current for all channels in the band.

It is accordingly an object of the present invention to provide a television antenna having multiple in-line active elements wherein each element produces substantially an equal amount of current in the proper phase relationship at every channel in the band.

It is a further object of the present invention to provide a television antenna having a number of in-line dipole elements wherein all of the elements except a reflector element are active elements connected to a transmission line.

It is still another object of the present invention to provide a television antenna having several in-line active dipole elements wherein the impedances of the active elements are different, with the rear active element having the highest impedance and each successive element in front of the rear element having a successively lower impedance with this relationship maintained over the entire operating range.

It is still another object of the present invention to provide an antenna of the above type wherein the transmission line connecting the active elements is of different characteristic impedance at different points along its length to better balance the active elements of different impedance.

It is a further object of the present invention to provide a television antenna having several in-line active dipole elements of the V-type wherein the impedances of the active elements are different, with the rear active

element having the highest impedance and each successive element in front of the rear element having a successively lower impedance at all operating frequencies.

It is a further object of the present invention to provide a television antenna of the above type wherein the forward elements are constructed with a smaller included V angle and the rear elements are constructed with a larger V angle so that the currents in the elements are maintained more nearly equal throughout the band and the proper phase relationship is better maintained throughout the band.

It is a still further object of the present invention to provide a television antenna having several in-line active elements with the rear active element having the greatest impedance and the impedances of the remaining elements being graduated toward the front of the antenna at all operating frequencies, and further having a terminating resistor at the forward end of the antenna for eliminating reflection and improving the front-to-back-ratio of the antenna.

It is a still further object of the present invention to provide a television antenna wherein all of the elements of the antenna are physically folded elements in a vertical plane so that each of the elements is in effect a truss-like member having a greater resistance to downward bending.

Further objects and advantages of the present invention will be apparent from a consideration of the following description in conjunction with the appended drawings, in which:

Fig. 1 is a perspective downward view of a 7-element television antenna according to the present invention;

Fig. 2 is a perspective partly schematic view of a 5-element television antenna according to the present invention;

Fig. 3 is a perspective partly schematic view of a 3-element television antenna according to the present invention;

Fig. 4 is an enlarged fragmentary perspective view of the mounting structure of the hairpin dipole elements of the antennas shown in Figs. 1, 2 and 3;

Fig. 5 is an enlarged fragmentary perspective view showing the mounting structure for the three-conductor dipole element of the antennas in Figs. 1, 2 and 3;

Fig. 6 is an enlarged fragmentary perspective view of the mounting structure for the reflector element of the antennas in Figs. 1, 2 and 3;

Fig. 7 is an enlarged fragmentary perspective view of the U-bolt and cross-arm mounting clamps of the antennas of Figs. 1, 2 and 3;

Fig. 8 is a schematic diagram of a 7-element antenna according to the present invention useful in explaining the theory of operation of the antenna;

Fig. 9 is a schematic diagram of the hairpin-type dipoles used in the present invention;

Fig. 9*a* is a schematic diagram of a conventional folded dipole;

Fig. 10 is a schematic diagram of a V-type dipole antenna showing the current distribution for the antenna;

Fig. 11 is a diagram of the current distribution in a circuit equivalent to the V-type dipole presented to demonstrate the theory of operation of the V-type dipole;

Fig. 12 is a schematic circuit diagram of a substantially equivalent electrical circuit for a 7-element antenna according to the present invention;

Fig. 13 is an impedance curve of a typical dipole antenna presented to aid in the explanation of the theory of operation of the present antenna;

Figs. 14*a*, 14*b* and 14*c* are impedance curves of respective ones of the dipoles of an antenna according to the present invention presented to explain the theory of operation of the antenna.

Referring now to Fig. 1 and to Fig. 7, a 7-element antenna according to the present invention is shown at **11**. The antenna **11** is supported by a mast **12**; a double cross-boom **13** is connected to the mast **12** by means of a cross-arm clamp **14** and U-bolts **15**. The cross-boom **13** is constructed of a lower cross-arm **16** and a similar upper support-arm **17**. The cross-arm **16** and the support-arm **17** are rigidly secured together in spaced relationship by a number of truss members **18**.

The provision for two structural arm members, namely the cross-arm member **16** and the support-arm member **17** renders the structure of antenna unusually sturdy by utilizing the truss principle of construction.

The electrically operative portion of the antenna consists of seven V-type reflector and dipole elements **21**, **22**, **23**, **24**, **25**, **26** and **27**. The V-type reflector **21** is composed of two arms **21***a* and **21***b* located at an obtuse angle to one another and forming the arms of the V. The dipole elements **22**, **23**, **24**, **25**, **26** and **27** are similarly composed of two arms **22***a* and **22***b*, **23***a* and **23***b*, **24***a* and **24***b*, **25***a* and **25***b*, **26***a* and **26***b*, and **27***a* and **27***b*, respectively. Each of the arms of elements **21** and **23—27** is formed of a single conductor doubled back on itself to form a fold or "hairpin."

The manner in which the antenna elements are secured and connected may best be seen by reference to Figs. 4, 5 and 6. Each of the arms **21***a* and **21***b* is secured to a respective mounting strap **31**, and the mounting strap **31** is further secured to a mounting block **41** secured to the cross-arm **16** of the antenna **11**. The other pairs of arms are similarly secured to respective mounting blocks **42**, **43**, **44**, **45**, **46** and **47** by means of respective mounting straps **32**, **33**, **34**, **35**, **36** and **37**. The mounting blocks **42—47** are formed of a dielectric insulating material. The arms **21***a* and **21***b*, the straps **31** and the blocks **41** may be connected together by riveting, bolting or any other suitable means. The mounting block **41** is also connected to the cross-arm **16** by riveting, bolting or other suitable means. The other elements **22—27** are assembled and secured to the crossarm **16** in a similar manner. The straps **31—37** are of conductive material and serve the purpose of providing an electrical connection to complete a closed electrical loop for each of the dipole arms.

Dipoles **21** and **22** are provided with connecting bars **49** and **50** respectively for electrically connecting the arms of the dipoles at their centers. The bars **49** and **50** are fastened between straps **31** and between straps **32** respectively so that the reflector arms **21***a* and **21***b* and the dipole arms **22***a* and **22***b* are each electrically connected at their centers. The other five elements are center-fed hairpin dipoles and are therefore not provided with connecting bars.

The dipole **22** differs from the other elements in that it is provided with center conductors **28***a* and **28***b*. The center conductors **28***a* and **28***b* are conductively connected at their outer ends to the respective outer bends of the dipole arms **22***a* and **22***b*. In addition a shorting bar **29***a* of conductive material interconnects the two outer conductors of dipole arm **22***a* and its center conductor **28***a* at a point near the end of the dipole arm **22***a*. A similar shorting bar **29***b* is similarly connected across the dipole arm **22***b* and the center conductor **28***b*. The inner ends of the center conductors **28***a* and **28***b* are not electrically connected to the straps **32** as may be seen in Fig. 5. Electrical terminals **48** are provided at the inner ends of the center conductors **28***a* and **28***b* for connecting an electrical transmission line **38** to the dipole **22**. The significance of this particular construction of the dipole element **22** will be explained in connection with the explanation of the electrical theory of operation of the antenna below.

The transmission line **38** provided for connecting the antenna **11** to a television receiver is connected to the antenna at terminals **48** of the 3-conductor dipole **22**. A second electrical transmission line section **23***c* is electrically connected between the terminals **48** of the 3-conductor dipole **22** and respective straps **33** of the dipole

element 23. A third transmission line section 24c connects the straps 33 of the dipole 23 to the straps 34 of the dipole 24. A transmission line section 25c similarly connects the dipole 24 to the dipole 25, another transmission line section 26c connects the dipole 25 to the dipole 26, and still another transmission line section 27 connects the dipole 26 to the dipole 27 in a similar manner.

As seen in Fig. 1, 6 of the 7 elements of the antenna are connected by means of successive transmission line sections to the television receiver. The transmission line harness sections 26c and 27c leading to the front two dipoles 26 and 27 are preferably constructed with a wider conductor spacing and thus have a higher characteristic impedance than do other sections of the transmission line. Although this construction utilizing different types of transmission line is preferred, all the transmission line sections may be made of the same type line.

As seen in Fig. 1, the front dipole 27 has arms 27a and 27b which are shorter than the arms of any of the other dipoles. The arms of the various dipole elements are progressively longer for dipoles 26, 25, 24 and 23. This is a significant feature of the invention and will be explained in detail in connection with the explanation of the theory of operation of the antenna.

In addition, the four front dipole elements 24, 25, 26 and 27 have a smaller V-angle than do the three rear elements 21, 22 and 23. This feature further improves the operation of the antenna, as will be explained below.

Fig. 2 shows an antenna 11a according to the present invention having only 5-elements rather than the 7-elements of the antenna shown in Fig. 1. The antenna of Fig. 2 naturally has less gain than the more elaborate antenna of Fig. 1. However, in some instances a smaller amount of gain is required, and in the development of the very high-gain 7-element antenna desirable attributes were developed which are also useful in antennas of lower gain.

In the 5-element antenna 11a, the element 21 is a reflector element as before, the element 22 is a 3-conductor folded dipole element as before, and the elements 23, 24 and 25 are center-fed hairpin dipoles, all as in antenna 11 of Fig. 1. The major change in the antenna 11a is the elimination of the front two elements of antenna 11, namely, the dipoles 26 and 27. The V-angle of the dipoles 24 and 25 is somewhat less than the V-angle of the rear elements 21, 22, and 23 as was the case with the 7-element antenna 11 in Fig. 1. The length of each of dipole elements 23, 24 and 25 is successively less than that of the preceding one to provide elements of diminishing impedance progressing toward the front of the antenna. The transmission line sections between various antenna elements may be selected to have different impedances to improve the antenna characteristics. The dimensions and characteristics of a particular preferred embodiment of the 5-element antenna is provided in the table below.

Fig. 3 shows a further simplified version of an antenna according to the present invention. A 3-element antenna 11b is shown having only a reflector element 21, a 3-conductor folded dipole element 22 and a hairpin dipole element 23. The 3-element antenna 11b will, of course, have still less gain than the 5-element antenna 11a. The antenna 11b is therefore particularly adapted for situations in which high gain is not required and where the broad-band, flat response and other desirable features of the present antenna will be particularly useful.

Any of the present antennas and particularly the 7-element antenna may be modified to have a higher front-to-back-ratio by providing a terminating resistor connected in parallel with the front element of the antenna. In the 7-element antenna 11, for example, a terminating resistor 51 may be electrically connected between the straps 37 of the forward element 27. The terminating resistor reduces reflection from the forward end of the transmission line by providing an impedance which is more nearly matched to the transmission line at this point. The terminating resistor may of course, be omitted, and it normally would not be used with the 3-element and 5-element antennas which do not require as high front-to-back ratio in any case.

In view of the fact that the proper operation of any antenna depends to some extent upon the physical dimensions and upon the electrical characteristics of its various elements, three particularly preferred representative constructions for antennas according to the present invention are described in the tables below.

Table I.—7-element antenna

element	length-center to tip, inches	forward tilt of arms, degrees	impedance of transmission line to element	spacing from adjacent element (rear), inches	transmission line length from adjacent element (rear), inches
1 (refl.)	54	30			
2 (3-conductor)	[1] 50	30	300	25	
3 (hairpin)	52	30	300	18½	20 11/16
4 (hairpin)	50	40	300	18½	20⅜
5 (hairpin)	48	40	300	18½	20⅜
6 (hairpin)	46	40	425	18½	19⅜
7 (hairpin)	42	40	425	15	19⅜

[1] Shorting bars 7¼" from ends of dipole arms.

Terminating resistor, if used, should preferably have a value of approximately 500 ohms.

Table II.—5-element antenna

element	length-center to tip, inches	forward tilt of arms, degrees	impedance of transmission line to element	spacing from adjacent element (rear), inches	transmission line length from adjacent element (rear), inches
1 (refl.)	54	30			
2 (3-conductor)	[1] 50	30	300	25	
3 (hairpin)	52	30	300	18½	22⅞
4 (hairpin)	48	40	300	18½	20⅜
5 (hairpin)	48	40	425	18½	20

[1] Shorting bars 8½" from ends of dipole arms.

Table III.—3-element antenna

element	length-center to tip, inches	forward tilt of arms, degrees	impedance of transmission line to element	spacing from adjacent element (rear), inches	transmission line length from adjacent element (rear), inches
1 (refl.)	54	30			
2 (3-conductor)	[1] 49	30	300	25	
3 (hairpin)	50	40	425	20	24 11/16

[1] Shorting bars 6¼" from ends of dipole arms.

Tubing for antenna elements is preferably 7/16" O. D. except for the center conductor of the 3-conductor element which is ⅝" O. D.

Distance between conductors of folded dipoles (outside conductors of 3-conductor dipoles) is preferably 2½" center to center.

A theory of operation of the present antenna will now be explained by reference to Figs. 8 through 12. Fig. 8 shows schematically the approximate equivalent electrical circuit of the 7-element antenna 11 shown in Fig. 1. In Fig. 8 it may be seen that the reflector element 21 is not electrically connected to the other antenna elements but has its arms connected together. The element 22 is a 3-conductor folded dipole in which the center conductors are connected by means of a transmission line to the other active antenna elements. The element 22 is the main element of the antenna, or in other words, the element connected by the transmission line 38 to the television receiver. The antenna elements 23, 24, 25, 26 and 27 are all hairpin dipole elements and are all electrically connected by means of transmission line segments 23c to 27c to the main element 22 and from there to the television receiver. A terminating resistor

51 is connected across the terminals of the forward antenna element 27.

As previously explained, the dipoles 23 to 27 in the preferred embodiments of the antenna are hairpin-type dipoles. The manner in which hairpin dipoles differ from ordinary folded dipoles is shown in Figs. 9 and 9a. As shown in Fig. 9 the hairpin dipole has both conductors 52 and 53 of each arm connected together at both ends, and connected at the inner ends to a respective conductor of a transmission line 54. On the other hand, as shown in Fig. 9a, an ordinary folded dipole has only one conductor 52 of each arm connected to a respective conductor of a transmission line 54. The outer ends of conductors 52 are joined by a separate single long conductor 55 parallel to conductors 52 to form a single elongated loop from one terminal of the line to the other. The hairpin conductor of Fig. 9 has more desirable impedance characteristics in the present arrangement and it is therefore preferred that such dipoles be utilized in the construction of the present antenna.

In explaining the operation of the antenna it is desirable to first explain the operation of a single one of the V-dipole elements. It is an important feature of the present invention, where the antenna is to be used as a dual-band V. H. F. television antenna, to construct each of the dipole elements with its arms tilted slightly forward toward the source of received signals. V. H. F. television signals are broadcast in two separate bands with channels 2 through 6 being in the lower band between 54 and 88 megacycles per second and channels 7 through 13 in the upper band between 174 and 216 megacycles per second. Approximately half of the television channels therefore have frequencies which are roughly three times the frequencies of the other half of the television channels. It has been found by early workers in the television antenna art that the frequency response curve of a dipole antenna for dual-band V. H. F. television signals can be improved by tilting the arms of the dipole forward at an angle of 30° to 40° or so.

One general theoretical explanation of this phenomenon may be explained by reference to Figs. 10 and 11. A dipole which is one-half wavelength long in the lower band will be three half-wavelengths long in the upper band. A dipole 56 is shown in Fig. 10 with dashed lines 57 indicating current distribution for low band signals and dotted lines 58 indicating current distribution for high-band signals. In a straight dipole anti-phase high band operation would result but in the V-dipole such anti-phase high band operation is made harmless because the center section of the V-antenna is located approximately 180° in space behind the two outer sections. The approximate equivalent of this situation is shown in Fig. 11 where the outer dipole arm sections are shown at 59 and the center section at 61. The current distribution of the outer sections 59 is indicated generally by the solid lines 62. The current distribution of the central section 61 in absence of the space phase difference is indicated by the dotted line 63. The space phase difference of 180° converts the current distribution of 63 into the reverse distribution 64 so that the current of all three sections is in phase and the effect of anti-phase high band operation is avoided. The V-dipole thus operates well on both low and high bands.

All of the dipole elements of the antenna are of the V-type and hence utilize the principles explained above. The V-type dipole cannot be advantageously adapted for use with the Yagi antenna due to the fact that the inter-element spacing of the parasitic elements of the Yagi antenna produces a substantial effect on antenna characteristics. The Yagi antenna can therefore not be designed to operate well on both high and low bands simply by providing V-type elements, since the Yagi is seriously limited by the fact that the proper low-band inter-element spacings will be too great for high-band V. H. F. television signals by a factor of about three.

In order to explain the combined operation of the multiple V-type hairpin dipoles connected as shown in Fig. 8, it is useful to consider for a moment a circuit in which the dipole elements are replaced by their respective impedances at a given frequency. Such a circuit is shown in Fig. 12 where the various antenna elements equivalent impedances are represented schematically. The impedance of the reflector element 21 is represented at Z_R, and it may be noted that the reflector element is not physically connected in the transmission line circuit. The three-conductor dipole 22 is represented by the impedance Z_F. The impedances of the remaining dipole elements are represented by the impedances Z_1, Z_2, Z_3, Z_4 and Z_5. The terminating resistor 51 is shown connected across the terminals of the impedance Z_5.

The basic directivity patterns (and thus the gain) of an antenna are determined by the phases and amplitudes of the currents in the dipoles of the antenna as well as by the position of the dipoles in respect to each other. It has previously been explained that the current in each of the active dipoles of the present antenna is controlled in part by the current flowing in the transmission line sections between the elements of the antenna.

As seen in Figs. 1, 2 and 3, and described above, the transmission line harness length between each pair of adjacent dipoles is greater than the free space distance between the same two dipoles which increases the directivity over a conventional end-fire antenna.

For maximum antenna performance each dipole of the antenna should also have an equal amount of current induced in it. It is therefore desirable to select the impedances shown in Fig. 12 so that this result is obtained. It would at first appear that the current in each of the impedances shown in Fig. 12 (that is, in Z_F, Z_1, Z_2, Z_3, Z_4 and Z_5) would be equal if each of the foregoing impedances were equal. This is not the case, however, due to the fact that the signals involved have wavelengths not substantially different from the spacings of the antenna elements, and thus low-frequency alternating current theory is not applicable.

The proper selection of the impedances in Fig. 12 may be understood by utilizing the concept of reciprocity and considering the 7-element antenna in question as a transmitting antenna for the moment. Considering the antenna as a transmitting antenna, the feed element impedance Z_F should be relatively large so that the major portion of the signal sent into the antenna will not be absorbed and transmitted by the first or feed element Z_F. It is rather desired that only approximately one-sixth of an input signal be absorbed or radiated by the impedance Z_F, and that the remainder be transmitted about the transmission line. As the signal continues down the harness 23c it is desired that a greater portion, namely, about one-fifth of the remaining signal be absorbed by the impedance Z_1. Therefore, in order to accomplish the desired result, the impedance Z_1 should be less than the impedance Z_F. At the impedance Z_2 it is desired that approximately one-fourth of the remaining signal be diverted, and so on to the end of the transmission line, so that each impedance Z_F through Z_5 will have received substantially an equal current from the transmission line.

It is impracticable, of course, to arrange that all of the remaining signals be absorbed by the last impedance Z_5 and thus the terminating resistor 51 may be provided to absorb substantially all of the remaining signal and prevent reflections from the end of the transmission line harness which would tend to cause undesirable back-lobes in the antenna pattern which would impair the desired high front-to-back-ratio.

Correlating the principles explained in connection with Fig. 12 with the physical construction of the antenna schematically represented in Fig. 8, the main dipole 22 is a three-conductor dipole and thus has a substantially higher impedance than does a hairpin dipole of the same length. Although the three-conductor dipole 22 is physically some-

what shorter than the longest hairpin dipole 23, the three-conductor dipole 22 has the highest impedance of any of the active dipole elements of the antenna. The rear active hairpin dipole 23 is the longest of any of the hairpin dipole elements and thus has the greatest impedance among them. Each of the dipoles 24, 25, 26 and 27 is successively shorter than its preceding dipole, and hence each has somewhat lower impedance than the dipole immediately to its rear.

Therefore, by comparing the physical structure of the antenna with the theoretical optimum situation explained with reference to Fig. 12, it will be seen that the present antenna is constructed to create a condition where each dipole receives substantially the same current and thus substantially optimum antenna performance may be realized. Although the principle of operation has been explained in terms of transmission, it will be understood that an antenna designed for maximum transmission efficiency will likewise provide maximum reception efficiency in accordance with the principle of reciprocity in antenna design.

It is not sufficient for the equal current conditions discussed above to exist only for a limited frequency range within the frequency band sought to be recovered. Other antennas are able to realize these conditions for limited frequency ranges. The most outstanding advantage of the present antenna resides in the fact that it can maintain substantially equal current in the antenna elements throughout a substantial range of frequencies such as over both the V. H. F. television bands. The manner in which these conditions are thus maintained is explained by reference to Figs. 13 and 14.

Referring first to Fig. 13, there is shown a typical spiral curve of the impedance of a dipole. The line OR represents resistances from zero toward infinity. Inductive reactances X_L, are indicated by distances above the line OR. Capacitive reactances X_C are indicated by distances below the line OR.

It will be observed that the impedance spiral crosses the horizontal line OR at a number of points A, B, C and D and thus the impedances at the given points are effectively resistive and the dipole is resonant.

It may be assumed that the points A, B, C, and D represent the first, second, third and fourth harmonics or in other words, points where a dipole is ½, 1, 1½ and 2 wave-lengths long. It will be seen that the dipole characteristics are about the same between points A and B between points C and D; that is, the total impedance (which is the distance from a point in the curve to point O) diminishes as frequency is decreased, from B to A or D to C. The present antenna takes advantage of this fact in order to provide superior performance over both the low V. H. F. band and the high V. H. F. band, where the two bands have a frequency ratio of approximately 3 to 1.

As previously indicated it is necessary that the decreasing relationship of the impedances of the successive antenna elements must be maintained for all frequencies in the band to be covered. The manner in which the present antenna construction accomplishes this will be understood by reference to Figs. 14*a*, 14*b* and 14*c* which show impedance diagrams with reference to a 5-element antenna, but the same principle would apply to antennas having a greater or lesser number of elements. The feed element 22 represented by the impedance Z_F is constructed as a three-conductor dipole to assure that the feed element 22 will always have a higher impedance than any of the other antenna elements. The particular impedances desired for the three-conductor dipole is attained by suitably positioning the shorting bar 29*b* across the three-conductor dipole.

The remaining problem then is to assure that the proper impedance relationships are maintained in the three remaining hairpin dipoles, and it is the solution to this problem which is explained by reference to Figs. 14*a*, 14*b* and 14*c*. Fig. 14*a* represents the impedance spiral of the first hairpin dipole 23. Fig. 14*b* represents the impedance spiral of the second hairpin dipole 24. Fig. 14*c* represents the impedance spiral of a third or front harpin dipole 25. In Fig. 14*a*, four points are represented having reference numerals 2, 6, 7 and 13. These numerals correspond to channel numbers in the V. H. F. television band, channels 2 and 6 being respectively the lowest and highest frequency channels in the low V. H. F. television band, and channels 7 and 13 being respectively the lowest and highest frequency channels in the upper V. H. F. band.

As seen in Fig. 14*a* the first hairpin dipole element has a length such that a maximum resonant impedance for the element results at a frequency approximately corresponding to channel 6 of the V. H. F. television band. This element is thus "cut" to channel 6. The impedance for lower frequency channel-2 signals is less than that for channel-6 signals, but the impedance for channel-2 signals is more than the impedance minimum corresponding to point A in Fig. 13. The physical configuration of the dipole is such that the channel-13 and of the channel-7 points fall in positions on the inner loop of the impedance spiral generally corresponding to the location of the channel-6 point and the channel-2 point on the outer loop of the impedance spiral.

The second driven hairpin dipole 24 has a physical length somewhat shorter than that of the dipole 23 and the impedance spiral of that dipole is represented in Fig. 14*b*. Since the dipole 24 has a length which is a somewhat smaller fraction of a wavelength than was the dipole 23, the channel-6 point is moved clockwise around the impedance spiral relative to its location in Fig. 14*a*. All the other impedance points for the other channels are moved a corresponding distance around the spiral in a counter clockwise direction. In Fig. 14*c* the impedance spiral of the still shorter element 25 is shown and thus the impedance points for the various corresponding channels are moved still farther in a counterclockwise direction around the impedance spiral of Fig. 14*c*.

By comparing the relative location of the channel-6 impedance points in Figs. 14*a*, 14*b* and 14*c*, it will be observed that the impedance of the second hairpin dipole as shown in Fig. 14*b* is less than that of the first hairpin dipole shown in Fig. 14*a* for channel-6 frequencies. The impedance at channel-6 frequencies of the third hairpin dipole as shown in Fig. 14*c* is still less than that for the preceding dipoles.

Comparing the impedances of each of the three dipoles at frequencies corresponding to other V. H. F. television channels, it will be seen that regardless of the received frequency (within the V. H. F. television bands) the impedance of the dipole 24 for that particular frequency is less than the impedance of the dipole 23 and the impedance of the dipole 25 is still less than that of the dipole 24. Therefore the present antenna construction utilizes these various principles to achieve an antenna construction wherein the current received in each of the television antenna elements tends to be substantially equal not only for a portion of the V. H. F. television band, but for each channel in both the upper and lower V. H. F. television bands. The present antenna therefore achieves a result which was impossible of accomplishment with previous high-gain antennas such as the Yagi and its variations.

The invention is not limited to the particular means for providing elements of progressively diminishing impedance described above. In addition to varying the length and configuration of the antenna elements in the manner described, other schemes for providing elements of different impedances might be used. The invention is not limited to the use of particular types or numbers of dipole or other elements for the antenna. However, the three-conductor folded dipole 22 with shorting bars 29*a*, 29*b* is particularly adapted for use with the present antenna. The three-conductor dipole is a high impedance element and by incorporating shorting bars which

may be located at various points near the ends of the dipole, an antenna element of relatively high, adjustable impedance is provided. The shorting bar for the three-conductor dipole is located at slightly different positions in the 3-, 5- and 7-element antennas in order to provide slightly different impedances for the element and thereby obtain optimum antenna characteristics in the respective antenna configurations.

It will also be observed that the use of double- or triple-rod construction for all antenna elements provides an antenna structure of superior physical strength.

The particular embodiments of the antenna described above are designed to operate in conjunction with a 300-ohm transmission line to the television receiver. Antennas utilizing the same principle may of course be designed to have a lower or higher impedance suitable for use in conjunction with transmission lines of lower or higher impedances.

In the foregoing explanation it was shown that the characteristics of the antenna could be improved by utilizing transmission line harness of different characteristic impedances for connecting certain of the antenna elements. Table I, for example, shows that a preferred embodiment of the 7-element antenna utilizes 300-ohm transmission line for the main transmission line harness sections to the third, fourth and fifth elements of the antenna. The sixth and seventh elements at the front antenna are connected, however, by means of higher impedance transmission line, for example of 425-ohms. By utilizing a high impedance harness for the front two antenna elements, these elements absorb the proper amount of power so that the equalized power absorption previously explained is attained.

As also described above, the front elements in the preferred embodiments of the present antenna are tilted forward at a sharper angle. This feature, though not essential for the practice of the invention, does however produce further improvements in the antenna characteristics. Rather than using the two particular angles of 30° and 40° as described in the preferred embodiments above, the antenna elements could be set at more than two different angles, differing more or less from 30° and 40°. The important characteristic of the tilt angles of the antenna elements is that at least one of the forward elements be tilted forward at a sharper angle than other elements to the rear of the forward element or elements. It is thought that the improvement brought about by the difference in tilt angles is due to rather complex interaction between the forward and rear antenna elements. No entirely satisfactory theoretical basis for the improved characteristics afforded by this construction is available.

Although preferred embodiments of antennas according to the present invention have been shown and described in great detail, it should be understood that the invention is not limited to the details described. For example, the specific manner in which the antenna elements are supported in position is obviously not important with respect to their electrical functioning. It is also obvious to those having a knowledge of the antenna art that other types of dipole antenna elements could be substituted for the particular type of elements shown in the preferred embodiment of the present invention. The present invention could be practiced with a greater or lesser degree of success with any of these other type of antenna elements by selecting active elements constructed to have progressively increasing impedances as you approach the rear active element.

It is equally obvious that although the reflector element 21 in the various preferred embodiments of the present antenna is a hairpin dipole type reflector element, other equivalent reflector elements, dipole or otherwise, could also be used in an antenna according to the present invention.

The particular embodiments of the antenna described were designed for use as television receiving antennas primarily. The invention is not limited to antennas for such use, however, and may be used for other purposes including transmission as well as reception.

While the theory of operation of the present antenna has been explained in accordance with the best knowledge available, and the foregoing theory of operation is believed to be correct, the present invention is not to be limited by the theory of operation advanced above.

Thus an antenna is provided according to the present invention which possesses high gain and high front-to-back-ratio as well as other desirable characteristics which are exhibited throughout a wide-band of frequencies such as the V. H. F. television band.

Although particular preferred embodiments of the present invention have been described in detail it will be understood that many modifications could be made by those skilled in the art within the scope of the present invention, and accordingly the present invention is not to be limited by the particular embodiment shown and described. Rather the present invention is to be limited solely by the appended claims.

What is claimed is:

1. A broad-band directive antenna array comprising a plurality of V-shaped dipole elements arrayed in file in horizontally spaced relation with corresponding arms of said dipole elements disposed in a common plane, the included V-angle of at least one of said V-shaped dipole elements being less than that of others of said elements, said dipole elements having progressively increasing impedance from front to back of said antenna array at all frequencies in the operating band, signal transmission means connected to at least two of said dipole elements to receive a signal therefrom and a parasitic reflector antenna element horizontally displaced from an end one of said dipole elements.

2. A broad-band directive anenna array comprising a plurality of V-shaped dipole elements arrayed in file in horizontally spaced relation with corresponding arms of said dipole elements disposed in a common plane, the included V-angle of at least one of said V-shaped dipole elements being less than that of others of said elements, said dipole elements having progressively increasing impedance from front to back of said antenna array at all frequencies in the operating band, signal transmission means connected to at least two of said dipole elements to receive the signal therefrom and a parasitic reflector antenna element horizontally displaced from an end one of said dipole elements, said reflector element having arms respectively parallel to the arms of said end dipole element.

3. A broad-band directive antenna array comprising a plurality of V-shaped dipole elements arrayed in file in horizontally spaced relation with corresponding arms of said dipole elements disposed in a common plane, the included V-angle of at least one of said V-shaped dipole elements being less than that of others of said elements, said dipole elements having progressively increasing impedance from front to back of said antenna array at all frequencies in the operating band, signal transmission means connected to at least two of said dipole elements to receive signals therefrom, said signal transmission means comprising a transmission line connected to a first of said dipole elements and a further transmission line section connecting at least one other of said dipole elements to said first of said dipole elements, said further transmission line section between said elements having a length greater than the physical spacing between said elements, and a parasitic reflector antenna element horizontally displaced from an end one of said dipole elements.

4. A broad-band directive antenna array comprising a plurality of V-shaped dipole elements arrayed in file in horizontally spaced relation with corresponding arms in said dipole elements disposed in a common plane, the included V-angle of at least one of said V-shaped dipole elements being less than that of others of said elements, and at least one of said elements being a high impedance

type dipole having a higher resonance impedance than others of said dipole elements and said other dipoles having progressively varying impedance from front to back of said antenna at all operating frequencies, signal transmission means connected to at least two of said dipole elements to receive a signal therefrom, and a parasitic reflector antenna element horizontally displaced from an end one of said dipole elements.

5. A broad-band directive television antenna array for both the high and low frequency portions of the V. H. F. television band comprising a plurality of V-shaped dipole elements arrayed in file in horizontally spaced relation with corresponding arms of said dipole elements disposed in a common plane, the impedances of said dipole elements being different at each antenna frequency within said V. H. F. television band and arranged with increasing element impedance from the front to the rear of the antenna for all frequencies in both said portions.

6. An antenna array as claimed in claim 5 wherein the impedance of each of said dipole elements is selected to maintain substantially equal signal currents in said elements.

7. A broad-band directive antenna array comprising at least three coplanar V-shaped dipole elements arranged in substantially parallel spaced relationship with the bisectors of the V-angles of said elements colinear and the vertex of the V of each element pointed toward the rear of said antenna, a parasitic reflector element in spaced relation with and to the rear of the rear one of said dipole elements, a first transmission line connected to the rear one of said dipole elements, and further transmission line sections electrically connecting each of said dipole elements to the dipole element to its rear, said further transmission line sections between said elements having lengths respectively greater than the corresponding physical spacings between said elements, said dipole elements having progressively increasing impedance from front to back of said antenna array at all frequencies in the operating band.

8. An antenna array as claimed in claim 7 wherein at least one of said further transmission line sections has a characteristic impedance different from said transmission line characteristic impedance.

9. An antenna array as claimed in claim 7 wherein at least one of the rear-most ones of said dipole elements is constructed with an included V-angle greater than the included V-angle of the front one of said dipole elements.

10. An antenna array as claimed in claim 7 further including a terminating resistance element electrically connected between the terminals of the front one of said dipole elements.

11. A broad-band directive antenna array comprising a plurality of dipole elements, each element comprising a pair of outwardly extending arms each formed of elongated loops of conductive material, the loops of each pair of arms being relatively disposed at an angle to provide a V-shaped dipole element, said V-shaped dipole elements being arranged in substantially spaced coplanar relation with the bisectors of the V-angles thereof in colinear relation and with the vertex of the V of each element pointed toward the rear of said antenna array, said dipole elements further having different impedances at all frequencies in the operating band and being arranged in order of increasing impedance toward the rear of said antenna array for all said frequencies, a parasitic reflector element having a pair of extending arms formed of elongated loops of conductive material, said loops being electrically connected at their inner ends and disposed at an angle to provide a V-shaped reflector element, said reflector element being disposed in coplanar parallel spaced relation with, and to the rear of, the rear one of said dipole elements, a first transmission line connected to the rear one of said dipole elements, and further transmission line sections electrically connecting each of said dipole elements to the dipole element to its immediate rear, said further transmission line sections between said elements having respective lengths greater than the corresponding physical spacings between said elements.

12. A broad-band directive antenna array comprising a plurality of dipole elements, each element comprising a pair of outwardly extending arms each formed of elongated loops of conductive material, the loops of each pair of arms being relatively disposed at an angle to provide a V-shaped dipole element, said V-shaped dipole elements being arranged in substantially spaced coplanar relation with the bisectors of the V-angles thereof in colinear relation and with the vertex of the V of each element pointed toward the rear of said antenna array, said dipole elements further having different impedances at all frequencies in the operating band and being arranged in order of increasing impedance toward the rear of said antenna array for all said frequencies, a parasitic reflector element having a pair of extending arms formed of elongated loops of conductive material, said loops being electrically connected at their inner ends and disposed at an angle to provide a V-shaped reflector element, said reflector element being disposed in coplanar parallel spaced relation with, and to the rear of, the rear one of said dipole elements, a first transmission line connected to the rear one of said dipole elements, and further transmission line sections electrically connecting each of said dipole elements to the dipole element to its immediate rear, said further transmission line sections between said elements having respective lengths greater than the corresponding physical spacings between said elements, the rear one of said dipole elements having its elongated loops conductively connected together at their inner ends and further including a conductor rod for each of its arms extending substantially the length of the arm adjacent its corresponding elongated loops and conductively connected near the outer end to said corresponding elongated loop and electrically connected near the inner end to a corresponding terminal of said transmission line.

13. An antenna array as claimed in claim 12 wherein at least the one of said further transmission line sections connected to the front one of said dipole elements has a characteristic impedance higher than the characteristic impedance of said first transmission line.

14. An antenna array as claimed in claim 11 wherein at least one of the rear ones of said dipole elements is constructed with an included V-angle greater than the included V-angle of the front one of said dipole elements.

15. An antenna array as claimed in claim 11 further including a terminating resistance element electrically connected between the terminals of the front one of said dipole elements.

16. A broad-band directive antenna array comprising a plurality of dipole elements, each element comprising outwardly extending arms formed of elongated loops of conductive material disposed at an angle to provide a V-shaped dipole element, said dipole elements being arranged in coplanar spaced relation with the bisectors of the V-angles thereof colinear, with the vertex of the V of each element pointed toward the rear of said antenna array, the included V-angle of at least the front one of said elements being less than the included V-angle of the rear one of said antenna elements, said dipole elements further having different impedances at all frequencies in the operating band and being arranged in order of increasing impedance toward the rear of said antenna array for all said frequencies, a reflector element having extending arms formed of elongated loops of conductive material, said loops being electrically connected at their inner ends and disposed at an angle to provide a V-shaped reflector element, said reflector element being disposed in spaced relation with, and to the rear of, the rear one of said dipole elements, a first transmission line connected to the rear one of said dipole elements for coupling to other apparatus, further transmission line sections electrically inter-connecting each pair of adjacent dipole elements to complete an electrical path from each of said

dipole elements to said first transmission line, said further transmission line sections between said elements having respective lengths greater than the corresponding physical spacings between said elements, and at least the front one of said transmission line sections having a higher characteristic impedance than that of said first transmission line, and a terminating resistor electrically connected between the terminals of the front one of said dipole elements.

17. A broad-band directive television antenna array for both the high and low frequency portions of the V. H. F. television band comprising a plurality of V-shaped dipole elements arrayed in file in horizontally spaced relation with corresponding arms of said dipole elements disposed in a common plane, the included V-angle of at least one of the rearmost ones of said dipole elements being greater than the included V-angle of the front one of said dipole elements, the impedances of said dipole elements being different and arranged with increasing impedance from the front to the rear of the antenna at all antenna frequencies within said V. H. F. television band.

18. A broad-band directive antenna array comprising at least three coplanar V-shaped dipole elements arranged in spaced relationship with the bisectors of the V-angle of said elements colinear and vertex of the V of each element pointed toward the rear of said antenna, at least one of the rearmost ones of said dipole elements having an included V-angle greater than the included V-angle of the front one of said dipole elements, said dipole elements having progressively increasing impedance from front to back of said antenna array at all frequencies in the operating band, a parasitic reflector element in spaced relation with and to the rear of the rear one of said dipole elements, a first transmission line connected to the rear one of said dipole elements, and further transmission line sections electrically connecting each of the others of said dipole elements to the dipole element to its rear, said further transmission line sections having lengths between said elements respectively greater than the corresponding physical spacings between said elements.

19. A broad-band antenna array for operation in a given frequency band comprising a plurality of active elements arrayed in file in horizontally spaced coplanar relation, said active antenna elements having different impedances at every antenna frequency in said band and being arranged in order of increasing impedance toward the rear of said antenna array for every frequency in said band, the impedances of said active antenna elements being further selected to maintain substantially equal signal currents in said elements throughout the antenna frequency band, a reflector element horizontally displaced to the rear of the rear one of said active antenna element, and signal transmission means electrically connected to at least two of said dipole elements for coupling said array to other apparatus.

20. A broad-band antenna array comprising a plurality of active elements arrayed in file in horizontally spaced coplanar relation, said active antenna elements having different impedances at all operating frequencies and being arranged in order of increasing impedance toward the rear of said antenna array for all said frequencies, the impedances of said active antenna elements being further selected to maintain substantially equal signal currents in said elements throughout the antenna frequency band, a reflector element horizontally displaced to the rear of the rear one of said active antenna elements, signal transmission means electrically connected to at least two of said dipole elements for coupling said array to other apparatus, said signal transmission means comprising a first transmission line connected to a first of said antenna elements and a further transmission line section connected to at least one other of said active elements, said further transmission line section having a length between said elements greater than the physical spacing between said active elements, and said further transmission line section having a characteristic impedance higher than the characteristic impedance of said first transmission line.

21. A broad-band directive antenna array comprising at least three coplanar V-shaped dipole elements arranged in spaced relationship with the bisectors of the V-angle of said elements colinear and the vertex of the V of each element pointed toward the rear of said antenna, at least one of the rearmost ones of said dipole elements having an included V-angle greater than the included V-angle of the front one of said dipole elements said dipole elements having progressively increasing impedance from front to back of said antenna array at all frequencies in the operating band, a parasitic reflector element in spaced relation with and to the rear of the rear one of said dipole elements, a first transmission line connected to the rear one of said dipole elements, and further transmission line sections electrically connecting each of said dipole elements to the dipole element to its rear, said further transmission line sections between said elements having lengths respectively greater than the corresponding physical spacings between said dipole elements and at least one of said further transmission line sections having a characteristic impedance different from said transmission line characteristic impedance.

22. A broad-line directive antenna array comprising a plurality of dipole elements, each element comprising a pair of outwardly extending arms each formed of an elongated loop of conductive material with said arms being disposed at an angle to provide a V-shaped dipole element, said dipole elements being arranged in coplanar spaced relation with the bisectors of the V-angles thereof colinear and with the vertex of the V of each element pointed toward the rear of said antenna array, the included V-angle of at least the front one of said elements being less than the included V-angle of the rear one of said elements, said dipole elements further having different impedances at all operating frequencies and being arranged in order of increasing impedance toward the rear of said antenna array at all said frequencies, a reflector element having a pair of extending arms each formed of an elongated loop of conductive material electrically connected at their inner ends and said arms being disposed at an angle to provide a V-shaped reflector element, said reflector element being disposed in spaced relation with, and to the rear of, the rear one of said dipole elements, a first transmission line connected to the rear one of said dipole elements for coupling to other apparatus, further transmission line sections electrically interconnecting each pair of adjacent dipole elements to complete an electrical path from each of said dipole elements to said first transmission line, said further transmission line sections between said elements having respective lengths greater than the corresponding physical spacings between said elements.

23. A multi-band antenna for a high frequency band and a low frequency band, the frequencies of said high frequency band being approximately triple the frequencies of said low frequency band, comprising a plurality of active dipole elements arranged in line, each of said elements having respective half-wavelength, full-wavelength, three-halves wavelength and two-wavelength resonant frequencies, said low frequency band being between said half-wavelength and full wavelength resonant frequencies of all said elements, and said high frequency band being entirely between said three-halves wavelength and two-wavelength resonant frequencies, and said elements being arranged in descending order of resonant frequency from front to back of said antenna, whereby said elements offer progressively increasing impedance from front to back of said antenna at all frequencies of said low and high bands.

24. An antenna as in claim 23 further including an additional active dipole element in back of said plurality of elements and having a higher impedance than all said plurality of elements for all frequencies in both said bands.

25. A wide-band antenna for operation over a given band of frequencies comprising a plurality of active dipole elements arranged in line, all of said elements having resonant frequencies at or outside the extreme edge of said given band, and said resonant frequencies being progressively smaller from front to back of said antenna, whereby said elements offer progressively increasing impedances from front to back at all frequencies of said given band.

26. A wide-band antenna for operation over a given band of frequencies comprising a pair of active dipole elements arranged in line and spaced from the front to back of said antenna, said elements both having resonant frequencies at or outside the extreme edge of said given band, the resonant frequency of said front element being

higher than that of said back element, and a third active dipole element arranged in line with said first two elements and spaced rearwardly of said first two elements, said third element having an impedance at all frequencies of said band greater than the impedances of said first two elements whereby said three elements offer progressively increasing impedances from front to back of said antenna at all frequencies of said given band.

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