

July 30, 1963

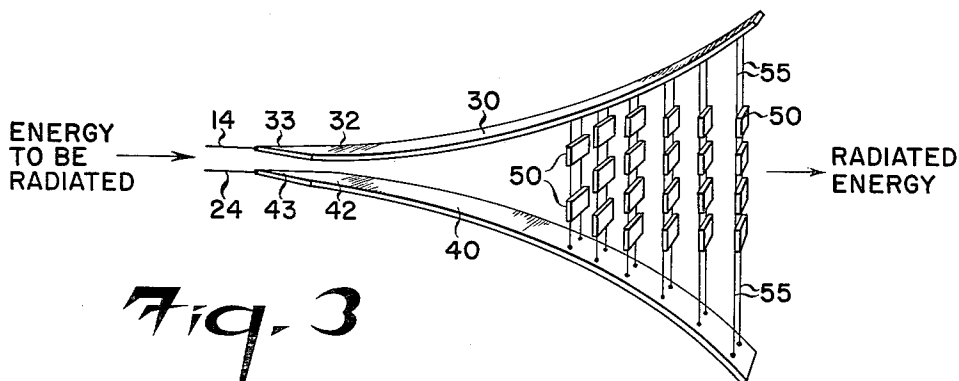
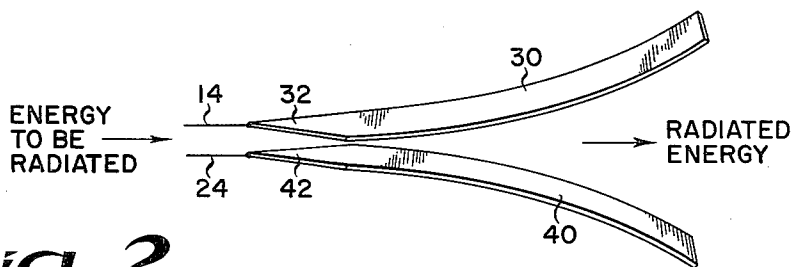
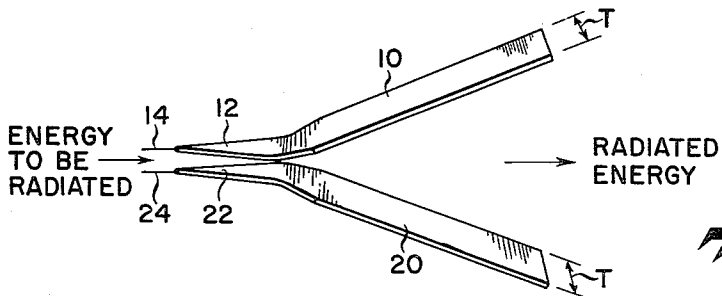
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3,099,836

V-STRIP ANTENNA WITH ARTIFICIAL DIELECTRIC LENS

Filed May 16, 1960

4 Sheets-Sheet 1



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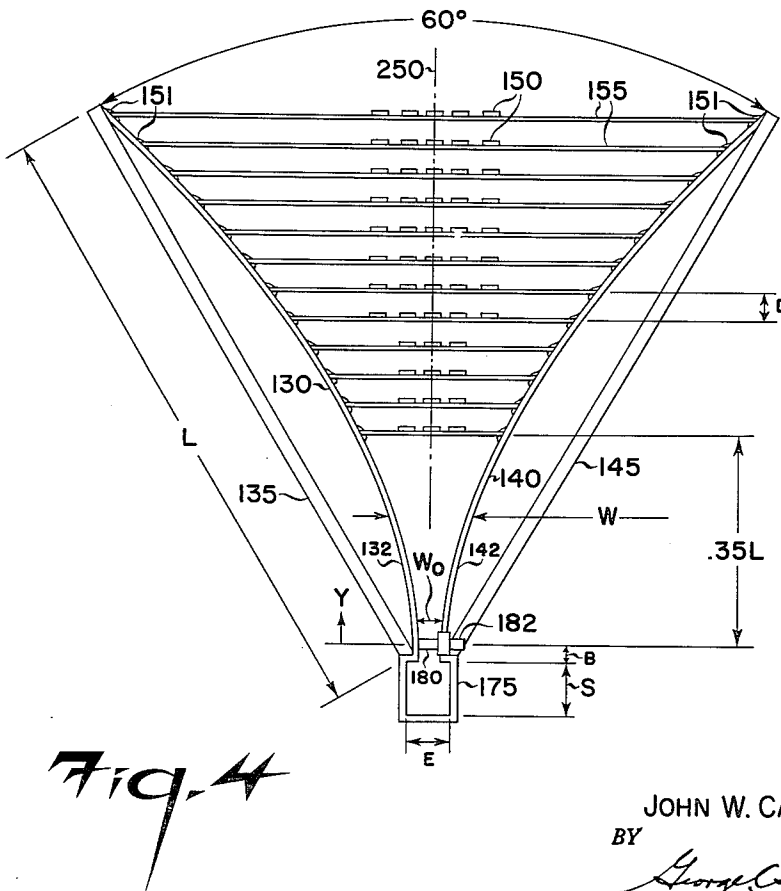
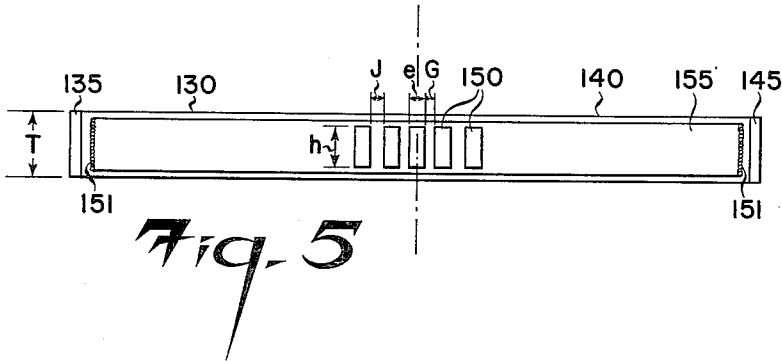
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4 Sheets-Sheet 2



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4 Sheets-Sheet 3

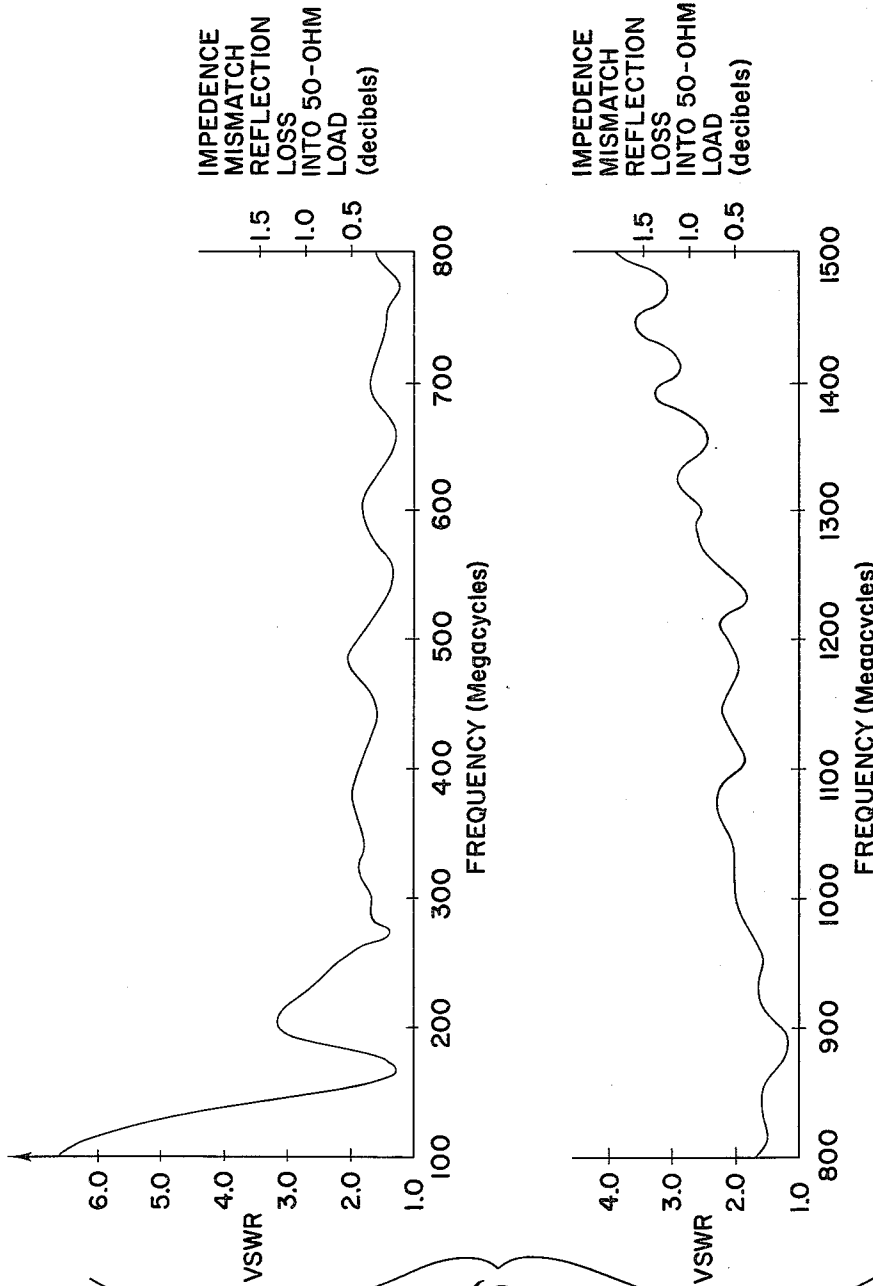


Fig. 6

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4 Sheets-Sheet 4

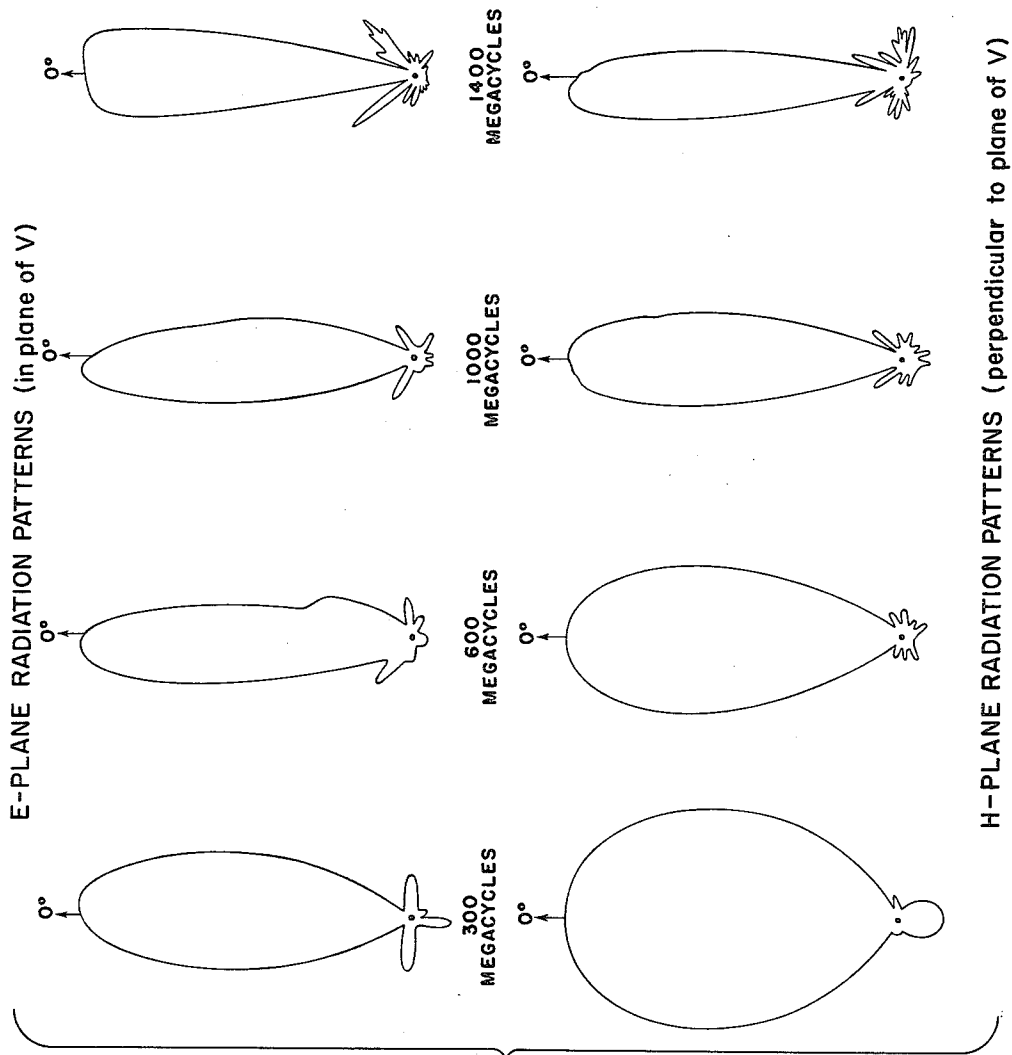


Fig. 7

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3,099,836 V-STRIP ANTENNA WITH ARTIFICIAL DIELECTRIC LENS

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This invention relates generally to antenna systems for electromagnetic radiation and reception, and more particularly to a simple V-strip high gain antenna system which provides a unidirectional radiation pattern and is operable over a very wide frequency band.

The advantages to be derived from a high gain unidirectional antenna system which is capable of operation over a wide frequency band are well recognized in the art. However, heretofore the achieving of such an antenna system required considerable complexity, expense and critical adjustment which severely restricted the use to which the system could be put. Consequently, there has been an extensive search for simplified antenna systems which will exhibit the desired characteristics of unidirectional high gain operation over a wide frequency band.

In the search for simplified antenna systems the V-type of antenna has received considerable attention, mainly because of its ease of construction. However, in order to achieve unidirectional operation it has been found necessary to introduce additional structures such as multiple V's, reflectors, loops, stubs, parasitic elements and the like into the basic V structure, and even then the bandwidth obtained is quite limited. Also, the resulting structure is usually critical and much more complicated than the basic V structure.

Accordingly, it is the broad object of this invention to provide an improved antenna system of the V-type.

A more specific object of this invention is to provide a simple V-type antenna structure having a unidirectional radiation pattern which is operable over a wide frequency band, and is capable of exhibiting high gain at the high frequency end of the band.

Another object of this invention is to provide improved means and methods for broad-banding a V-type antenna.

Still another object of this invention is to provide a high gain unidirectional V-type antenna which is operable over a frequency bandwidth of 10 to one.

A further object of this invention is to provide a wide-band, high gain unidirectional V-type antenna whose input impedance can be non-critically controlled down to small values.

A still further object is to provide the antennas of the above mentioned objects in simple and inexpensive form.

In accordance with the present invention it has been found that, contrary to present thinking with regard to antenna systems of the V-type, it is possible to achieve a high gain antenna system which is basically not significantly more complex than the basic V structure and yet, is capable of providing a unidirectional radiation pattern and is operable over a remarkably wide frequency band.

The present invention is based upon my discovery that if metal strips are employed as the radiating elements of a V antenna of sufficient width as compared to their length, and these strips are excited so that the currents developed are concentrated on the inside surfaces thereof, then the radiated electromagnetic field will be substantially concentrated in the region between the flat strips making up the arms of the V. The antenna, therefore, will be unidirectional in a direction in the plane of the V along the line bisecting the two arms thereof. If the strips of the V are curved, such as in the form of a parabola it has been found that the resulting bandwidth and impedance characteristics are very much improved. In addition,

because the field is concentrated in the region between the strips making up the arms of the V, dielectric loading may be employed in this region to correct the phase front of the radiation fields within the V, thereby permitting operation to be obtained over a very large frequency band which may be made greater than 10 to 1.

The specific nature of the invention as well as other objects, uses and advantages thereof will clearly appear from the following description and the accompanying drawing in which:

FIG. 1 is a perspective view of an embodiment of a basic V-strip antenna in accordance with the invention.

FIG. 2 is a perspective view of an improved embodiment of a V-strip antenna in accordance with the invention.

FIG. 3 is a perspective view of an embodiment of the V-strip antenna of FIG. 2 in which artificial dielectric loading is incorporated for phase correction, in accordance with the invention.

FIGS. 4 and 5 are respectively top and front views of a specific embodiment of the V-strip antenna system of FIG. 3.

FIG. 6 comprises two graphs illustrating the variation of the voltage-standing-wave-ratio (VSWR) and the impedance mismatch reflection loss into a 50-ohm load over a frequency range from 100 to 1500 megacycles.

FIG. 7 illustrates the E and H plane radiation patterns obtained for the specific embodiment of the V-strip antenna illustrated in FIGS. 4 and 5 at frequencies of 300, 600, 1,000 and 1,400 megacycles.

Like numerals refer to like elements throughout the figures of the drawing.

As mentioned previously, the present invention is based on the realization that a single V element may be employed to provide a unidirectional antenna radiation pattern by using metal strips as the radiating elements which make up the arms of the V and exciting these strips so that the currents developed are concentrated on the inside surfaces thereof. A basic V-strip structure in accordance with the invention is illustrated in FIG. 1.

In FIG. 1, the V antenna comprises thin metal strips 10 and 20 forming the arms of the V which are bent at the apex of the V to form adjacent parallel flat portions 12 and 22. The antenna is fed from a balanced two-wire line indicated by the wires 14 and 24. In order to provide a smooth transition from the two-wire line 14 and 24 to the metal strips 10 and 20, the width of the metal strips 10 and 20 is tapered to the two-wire line 14 and 24 as shown.

As is conventional practice, the characteristic impedance of the two-wire line should match the input impedance of the antenna as well as possible over the frequency band of operation. Since the ratio of the distance between the flat portions 12 and 22 to the thickness T of the metal strips 10 and 20 controls the antenna input impedance, the input impedance can conveniently and non-critically be controlled down to small values.

By employing the metal strips 10 and 20 as the radiating elements of the V of sufficient width T as compared to their length and exciting these strips as shown in FIG. 1, it has been found that the energy radiated from the V will be substantially contained within the region between the metal strips 10 and 20. The important feature in maintaining unidirectional radiations is that the width T of the strips 10 and 20 be sufficient as compared to their length to maintain a large radiating-surface-to-length ratio; that is, the width T over the length of the metal strips 10 and 20 for a given length controls the Q obtained, and these should be made sufficiently wide to provide an unidirectional antenna pattern.

Variation of the width T of the metal strips 10 and 20 will show that once the radiating element takes on the

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form of a strip as contrasted with the rod-type shape of a conventional thin wire antenna, the Q drops rapidly to a relatively small value and unidirectional operation is thereby achieved. Making the strip width T larger does not achieve any appreciable change in overall performance unless it becomes of the order of a wavelength.

The unidirectional operation obtained by the use of the metal strips 10 and 20 as radiating elements is believed to result because of the restricted type of current flow developed in each of the metal strip radiators and the low Q condition thereby obtained which causes most of the radiated energy to travel outward without being reflected from the antenna aperture-to-free-space transition back into the antenna feed line.

The V-strip antenna shown in FIG. 1 is able to provide a usable unidirectional radiation pattern over a range of frequencies of about 4 to 1 with a respectable gain which increases with increasing frequency, the length of the metal strips 10 and 20 preferably ranging from about $\frac{1}{2}$ wavelength to 2 wavelengths over the operating band.

In order to obtain a smoother impedance characteristic over the operating frequency band, I have found it advantageous to provide a curvature for the metal strips as shown in FIG. 2. While various types of curvatures are possible, I prefer to use a curvature of parabolic form. The provision of curvature in the metal strips 30 and 40 in FIG. 2 has been found to reduce the peak values of voltage-standing-wave-ratio (VSWR) obtained, especially in the low frequency region where the metal strips are about one-half to one wavelength long. The flat portions 32 and 42 in FIG. 2 respectively correspond to the like portions 12 and 22 in FIG. 1. Preferably, the metal strips are of the order of one-half wavelength long at the low frequency end of the operating band.

Because the energy radiated from a V-strip antenna, such as shown in FIGS. 1 and 2 is substantially confined to the region between the arms of the V, it now becomes possible to employ some type of phase correction technique to extend the bandwidth to higher frequencies. FIG. 3, shows one type of artificial dielectric loading which may be incorporated in the basic antenna system of FIG. 2. The artificial dielectric loading comprises a number of rows of thin metal elements 50, parallel to the transverse plane, suspended between the curved metal strips 30 and 40 making up the arms of the V by means of non-conductive cords 55, which may be of nylon. These thin metal strips 50 act to correct the phase of the wave-front leaving the antenna. By suitable design of the artificial dielectric loading provided, the frequency of an antenna such as shown in FIG. 3 may be made operable over a frequency range of greater than 10 to 1.

The array of metal elements 50 between the arms of the V may be considered as an electromagnetic lens which corrects for electromagnetic aberration in the same way as an optical lens may be used to correct for defects of the eye. The design of electromagnetic lens systems for various types of applications are well known in the art and such techniques may be employed for designing a suitable electromagnetic lens system for the antenna of FIG. 3. The width of the metal elements in the E and H plane, their longitudinal and lateral separation, and their overall longitudinal and lateral distribution and total number are functional parameters.

It will be noted in connection with the embodiments of FIGS. 1-3 that supporting structures for the antenna elements have not been shown. Since the provision of such supporting structures is well within the skill of those in the art, these structures have been omitted in order not to confuse the figures. However, it will be understood that any of a number of readily providable structural arrangements can be employed in the antennas of FIGS. 1-3.

In order to show how the present invention may be practically employed, a specific embodiment of the antenna system of FIG. 3 will now be described. Top and front views of this specific embodiment are illustrated in

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FIGS. 4 and 5, respectively. It is to be understood that the presentation of this specific embodiment is no way intended to limit the present invention and is included only for illustrative purposes.

In FIG. 4, curved metal strips 130 and 140 serve as the arms of the V and have a width T as shown in FIG. 5. These curved metal strips 130 and 140 are supported in a desired curvature by rigid supporting members 135 and 145, respectively, suitably attached to the ends thereof. These rigid supporting members 135 and 145 may be either conductive or non-conductive, since substantially no radiated energy exists outside the region between the strips 130 and 140.

As in the antennas of FIGS. 1-3, the metal strips 130 and 140 become parallel flat portions 132 and 142 at the apex of the V. The distance between these portions 132 and 142 is indicated at W_0 . However, unlike the antenna systems of FIGS. 1-3 which employ a balanced two-wire feed line, the specific embodiment of FIGS. 4 and 5 employs a coaxial feed instead. A coaxial input connector is shown at 182 having its outer conductor making electrical contact with the metal strip portion 142 and its center conductor 180 insulated therefrom and passing between the parallel portions 132 and 142 to make electrical contact with the metal strip portion 132.

Since the V-strip antenna requires a balanced feed arrangement, a balun, indicated at 175 in FIG. 4, is employed to convert the unbalanced coaxial feed into an effective balanced feeding arrangement. The use of a balun for converting an unbalanced feed into a balanced one is well known in the art and its design for use in FIG. 4 will be clearly understood. The impedance of the balun 175 is chosen in conjunction with the input impedance of the V-strip antenna and the characteristic impedance of the coaxial line (not shown) to be connected to the connector 182 so that the voltage-standing-wave-ratio (VSWR) is made as small as possible over the operating frequency band.

In obtaining satisfactory operation of the balun 175 over the large frequency bandwidth of the antenna of FIGS. 4 and 5, it has been found useful to choose the width E of the balun 175 relatively wide of the order of 0.2 of a wavelength at the high frequency end of the band. Also, the characteristic impedance of the balun 175 is chosen of the order of 3 or 4 times the characteristic impedance of the coaxial feed line. With the balun chosen in this manner it will be able to radiate, so that its input impedance which is in parallel with the coaxial feed line, never becomes small enough to have any appreciable shorting effect. The balun 175, therefore, will be able to operate satisfactorily over the necessary frequency range.

Structurally, the balun 175 could be provided integrally with the metal strip portions 132 and 142, or could be provided separately and suitably mounted to the supporting members 135 and 145 in any convenient manner. Also, it is to be understood that if desired, a balanced two-wave feed line could be employed in place of the coaxial feed line and balun in the same manner as shown in FIGS. 1-3.

The electromagnetic lens in the specific embodiment of FIGS. 4 and 5 comprises an arrangement of thin metal elements 150 similar to that shown in FIG. 3 and supported on nylon cords 55. In the embodiment of FIGS. 4 and 5, however, the metal elements 150 are conductive metal portions coated at appropriate spacings on thin strips 155 of insulative material such as mylar. These thin strips 155 are stretched between the metal strips 130 and 140 and are bonded thereto by a suitable adhesive indicated at 151. In the particular embodiment shown, the metal strips 150 are all the same size having an E-plane width e and an H-plane width h , and the strips 155 are set at equal distances D from one another, the first eight strips having five symmetrically located metal elements 150 coated thereon, while the remaining four strips

155 near the apex have three metal elements 150 coated thereon. The spacing between the center metal element 150 and the adjacent metal elements 150 on both sides thereof is indicated as G, while the spacing between each end metal element 150 and the adjacent metal element 150 is indicated as J (see FIG. 5). The first strip 155 from the apex is spaced from the center portion 180 by an amount approximately equal to .35L, where L is the length of the supporting members 135 and 145.

For illustrative purposes, specific dimensions will now be given for an antenna constructed in accordance with the embodiment of FIGS. 4 and 5 for the frequency range of 150 to 1500 megacycles having wave lengths of 79 inches to 7.9 inches. Letter dimensions correspond to similarly designated dimensions in FIGS. 4 and 5.

Length L of members 135 and 145	48 inches.
Width T of metal strips 130 and 140	3.0 inches.
Spacing W_0 of metal strip portions 132 and 142	0.5 inch.
Width E of balun 175	1.6 inches.
Length S of balun 175	4.4 inches.
Distance b between center portion 180 of coaxial connector 182 and beginning of balun 175	0.38 inch.
Spacing D between mylar strips 155	2.3 inches.
E-plane width e of metal elements 150	1.5 inches.
H-plane width h of metal elements 150	4.0 inches.
Separation G between metal elements 150	0.37 inch.
Separation J between metal elements 150	1.0 inch.
Equation of curved metal strips 130 and 140	$Y^2=36(W-W_0)$
Characteristic impedance of coaxial feed line	50 ohms.

From the above and from the 60 degree aperture angle of FIGURE 4 it can be seen that the projected length along the bisecting axis between metal strips 130 and 140 is equal to approximately 50 percent of the maximum wavelength. That is, $\cos 60^\circ (48'') = 53\% (79'')$. The width of the strips is equal to approximately 3.8% of the maximum wavelength of the signal. These dimensions are critical because they provide an antenna which has the minimum possible length of about one-half wavelength and the maximum possible waveband.

In an antenna constructed with the above listed dimensions, the curves shown in FIG. 6 were obtained over the frequency range from 100 to 1500 megacycles. It will be seen from FIG. 6 that less than 1.5 decibels reflection loss (due to impedance mismatch) is obtained over the total 150 to 1500 decade bandwidth, and for most of the band is less than 0.5 decibel. Also, it can be seen that the voltage-standing-wave-ratio (VSWR) is quite good over the entire frequency band and can be reduced further by more careful design, such as by tapering the center conductor 180 of the coaxial connector 182 to a diameter of $\frac{1}{2}$ inch so as to limit the series inductance at the feed.

In FIG. 7 the E and H plane radiation patterns which have been obtained for the embodiment of FIGS. 4 and 5 with the above listed dimensions are shown for frequencies of 300, 600, 1,000 and 1,400 megacycles. These radiation patterns clearly demonstrate the broad band unidirectional operation achieved in accordance with this invention. The gain over the band can be derived by realizing that the gain is proportional to the inverse of the product of the E and H plane beamwidths. By so doing, it will be seen that the gain of the antenna ranges from about 7 decibels at the low frequency end to about 17 decibels at the high frequency end.

It will be understood that the metal strips making up

the arms of the V and the metal elements of the lens may be made up of a metal mesh instead of being solid as illustrated in the drawing, the electrical characteristics being substantially identical. Where the antenna is to be used outdoors and/or rotated, the use of such metal mesh will significantly cut down wind resistance. Also, considerable savings in weight may be possible. The terms metal strip and metal elements, therefore, are intended to include the use of a metal mesh or any other type of metal strip or element structure which is substantially equivalent electrically.

It will be apparent that the embodiments of the invention described herein are subject to many possible modifications and variations in construction and arrangement without departing from the spirit of this invention. The invention, therefore, is to be considered as including all such modifications and variations coming within the scope of the invention as defined in the appended claims.

I claim as my invention:

1. A unidirectional broad band antenna system comprising a generally V-shaped antenna having angularly disposed metal strips as radiating elements, the angle between said metal strips being about 60 degrees, the flat portions of said strips substantially facing one another, the width of said strips being substantially constant throughout their lengths and being sufficient to achieve unidirectional operation, and dielectric phase correction means disposed in the region between said metal strips.
2. The invention in accordance with claim 1 wherein said phase correction means comprises a plurality of metal elements having a predetermined arrangement in the region between said strips.
3. The invention in accordance with claim 2 wherein each of said metal strips has a parabolic curvature.
4. The invention in accordance with claim 3 wherein said metal strips are of the order of one-half wavelength at the low frequency end of the operating band.
5. A unidirectional broad band antenna system comprising a generally V-shaped antenna having angularly disposed metal strips as radiating elements, the angle between said metal strips being about 60 degrees, the flat portions of said strips substantially facing one another, the width of said strips being substantially constant throughout their lengths and being sufficient to achieve unidirectional operation, means exciting the V-shaped antenna at its apex so that the currents developed in the metal strips are concentrated on the inside surfaces thereof and phase correction means operatively connected to and disposed between said metal strips.
6. The invention in accordance with claim 5 wherein said means exciting the V-shaped antenna comprises coaxial feed means at the apex of the V-shaped antenna and a balun cooperating therewith to convert the coaxial feed to a balanced feed for the antenna.
7. A unidirectional broad band antenna system comprising a generally V-shaped antenna having curved angularly disposed metal strips as radiating elements, the flat portions of said metal strips substantially facing one another, said metal strips having a generally parabolic curvature and a length of the order of one-half wavelength at the low frequency end of the operating frequency band, the width of said strips being substantially constant throughout their lengths and being sufficient to achieve unidirectional operation, the angle between said metal strips being about 60 degrees, means exciting the V-shaped antenna at its apex so that the currents developed in the metal strips are concentrated on the inside surfaces thereof, and dielectric phase correction means disposed in the region between said metal strips so as to extend the range of operation at the high frequency end of the operating frequency band, said phase correction means comprising a plurality of metal elements in a predetermined arrangement in said region.

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