May 26, 1964 R. L. BELL **3,134,979**

TAPERED LADDER LOG PERIODIC ANTENNA

Filed Jan. 27, 1961 3 Sheets-Sheet 1

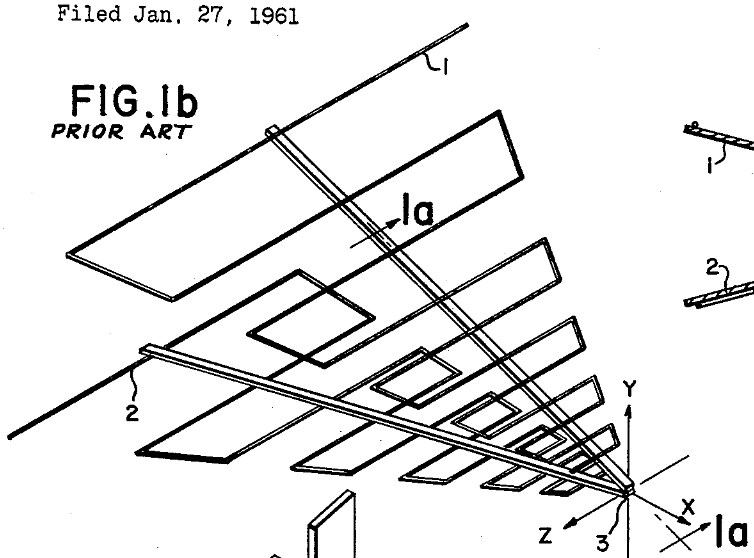

FIG. 1b
PRIOR ART

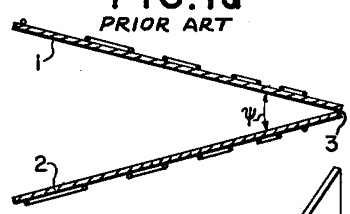

FIG. 1a
PRIOR ART

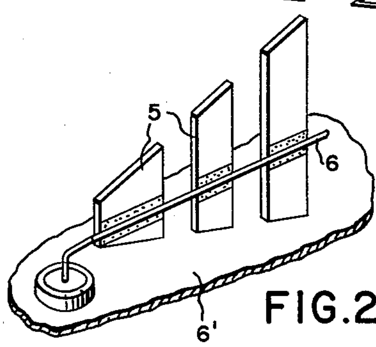

FIG. 2a

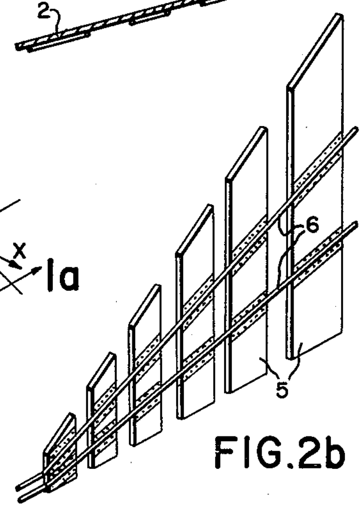

FIG. 2b

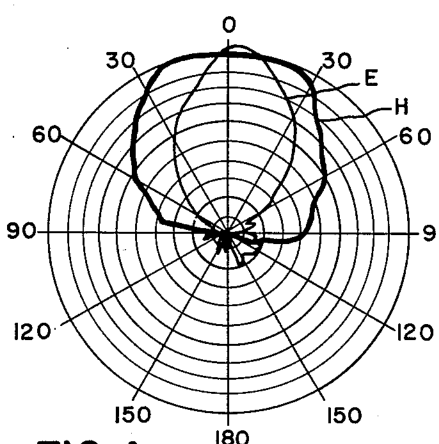

FIG. 4

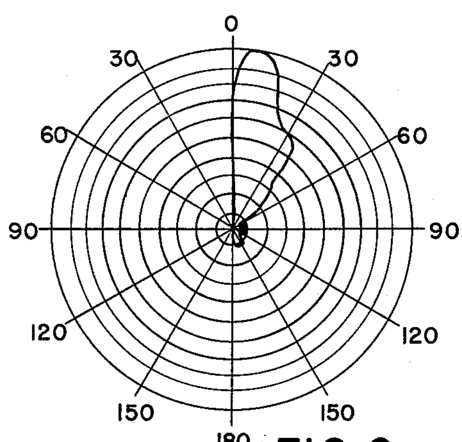

FIG. 6

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TAPERED LADDER LOG PERIODIC ANTENNA

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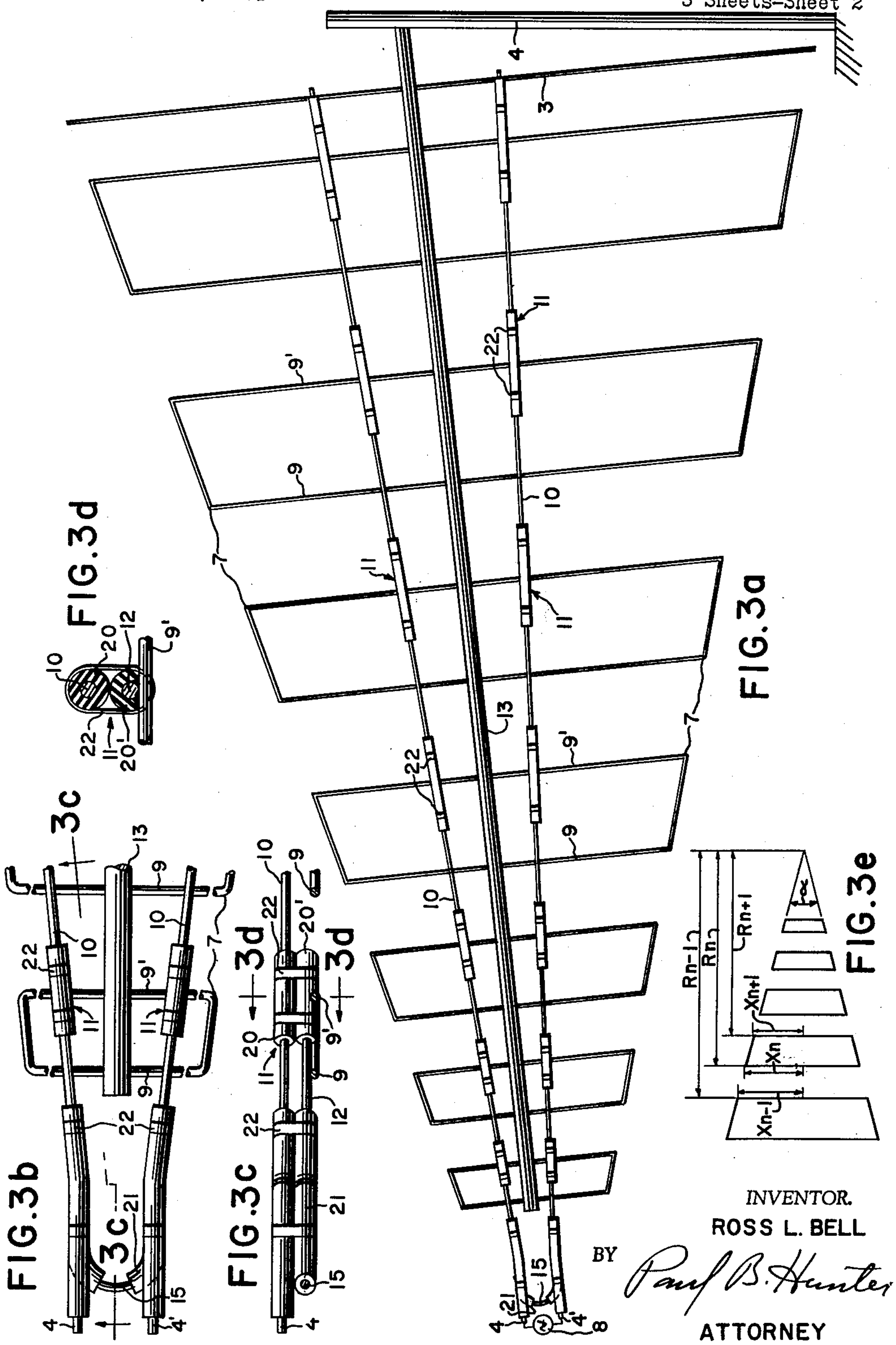

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TAPERED LADDER LOG PERIODIC ANTENNA

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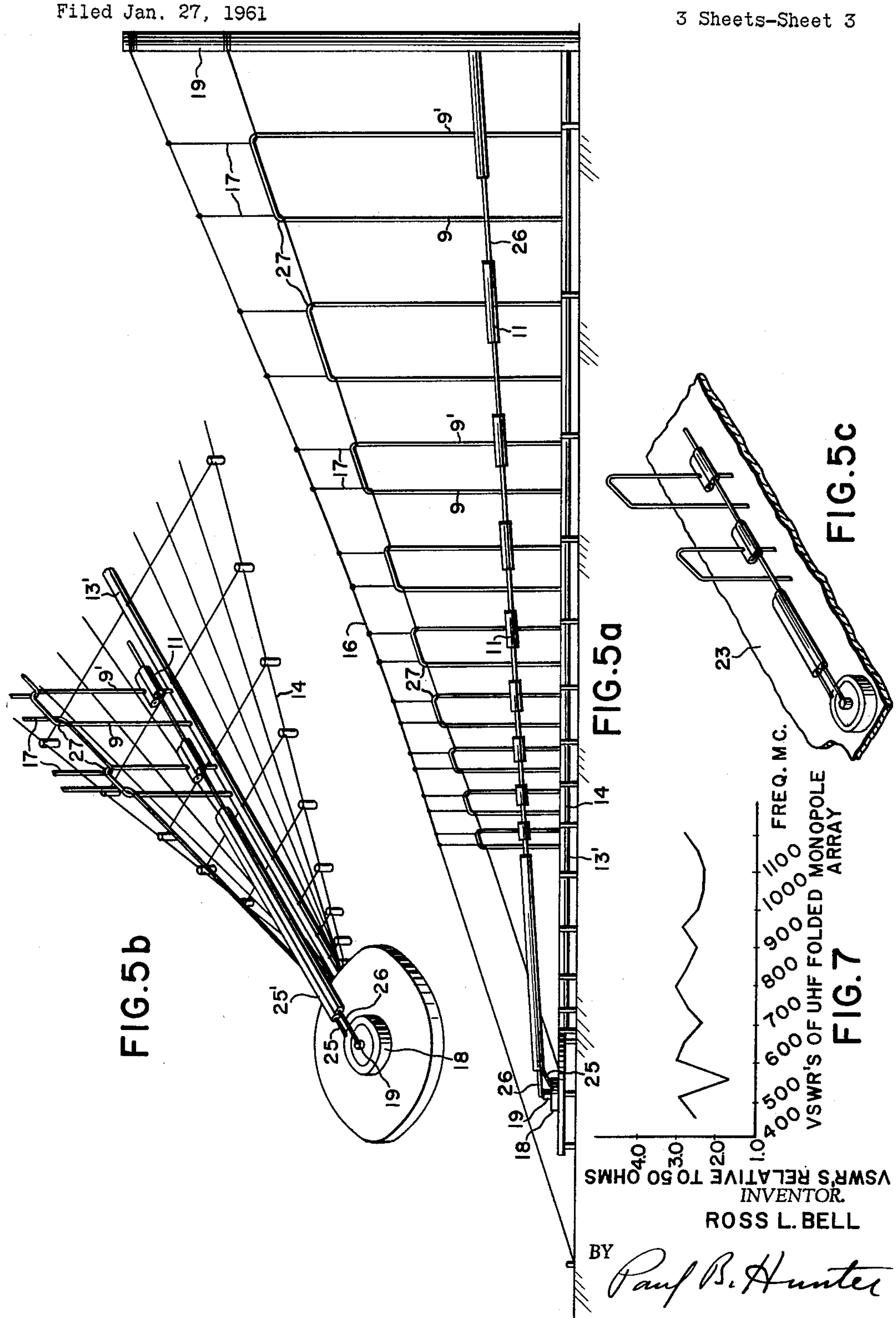

FIG.5a

FIG.5b

FIG.5c

VSWR'S OF UHF FOLDED MONOPOLE ARRAY

FIG.7

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TAPERED LADDER LOG PERIODIC ANTENNA

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4 Claims. (Cl. 343—792.5)

This invention relates generally to antenna structures, and the invention relates more particularly to a novel symmetrical antenna of the log-periodic type.

Log-periodic antennae have been developed within the last few years which have the desirable properties of maintaining relatively constant radiation patterns and impedances over relatively large frequency bands of the order of 10:1 or even greater. While these antennae perform satisfactorily for many applications they are not compatible with systems operating in the high frequency range that require vertical polarization. In addition, the physical configuration of these log-periodic antennae as heretofore constructed leave much to be desired, both from the structural and fabrication points of view.

The early unidirectional log-periodic antennae usually consisted of two separate planar antennae that diverged from the apex or feedpoint with repetitious antenna elements whose dimensions increase with increasing distance from the apex of the array. These antennae occupied a considerable volume, thereby producing complex structural problems which are magnified when the antennae are to be operated in environments which have even moderate wind and icing conditions. In addition, the structures are asymmetrical, that is, the portion above the X—Z plane is not a mirror image of the portion below this plane, and this makes it impossible for imaging these antennae as over the ground or over a counterpoise. Thus, for vertical polarized applications these prior art antennae have been restricted to optimum performance only in a free space environment. Furthermore, the asymmetrical structure makes these antennae in use difficult to maintain due to differential wind pressures on the two planar members or arms of the antenna.

More recently a balanced or symmetrical form of log-periodic antenna, known as the "tapered ladder" has been developed jointly by the applicant hereof and Arthur F. Wickersham, Jr. consisting of tapered plates of progressively larger dimension as measured from the apex and are shunt-excited as by leads. While the radiation patterns and impedances of the tapered ladder antenna are very satisfactory, in practice, however, its usefulness is limited to frequencies of relative short wavelengths due to the fact that the radiating elements are solid plates which render the "tapered ladder" extremely vulnerable to wind loading as well as extremely expensive at lower frequencies.

It is a principal object of the present invention to provide a novel antenna of the log-periodic type which is of simple construction and has highly desirable structural features, i.e., which is of relative light weight, rugged, and can withstand large wind loading, and which may be used for space radiation or may be imaged over the ground or counterpoise, resulting in such case in a substantial reduction in the antenna height for the same range of operating frequency.

A feature of the present invention is to provide a novel, simply constructed symmetrical log-periodic antenna that comprises, in effect, a series of folded dipole radiators that diverge from an apex and in which the pertinent dimensions of the radiators increase uniformly and proportionally with an increase in distance from the apex of the structure.

Still another feature of the present invention is to provide a novel symmetrical broadband antenna employing

rod or wire antenna elements in trapezoidal form and which is capable of having an exceptionally wide frequency band and wherein the dipole elements are shunt excited.

Another feature of the present invention is to provide an antenna of the above character wherein energy from the antenna terminals when acting as a transmitter travels along a balanced two-wire transmission line toward the rear or large end of the structure until it reaches the active region, that being the one in which the folded dipole elements are near resonance wavelength at the operating frequency.

Still another feature of the present invention is to provide a novel antenna that is well adapted to be used as a folded monopole array operating in conjunction with the ground or counterpoise.

These and other features and advantages of the present invention will be more apparent after a perusal of the following specification taken in connection with the accompanying drawings wherein:

FIG. 1*a* shows a sectional view through a prior art asymmetrical log-periodic antenna,

FIG. 1*b* is a perspective view which shows the antenna of FIG. 1*a* with the planar members **1** and **2** extending above and below the X—Z plane,

FIG. 2*a* is a perspective view which shows a tapered ladder antenna suitable for being mirrored or vertically imaged,

FIG. 2*b* is a perspective view which shows a tapered ladder antenna useful for free space environment,

FIG. 3*a* is a perspective view of the novel folded dipole antenna of this invention suitable for free space environment,

FIG. 3*b* is an enlarged fragmentary view of a portion of the structure shown in FIG. 3*a*,

FIG. 3*c* is an enlarged sectional view taken along line *c—c* of FIG. 3*b* looking in the direction of the arrows,

FIG. 3*d* is an enlarged sectional view taken along the line *d—d* of FIG. 3*c* looking in the direction of the arrows,

FIG. 3*e* illustrates the geometry of the structure of FIG. 3*a* in plan,

FIG. 4 is a typical E- and H-plane pattern of the novel antenna structure of FIG. 3*a*,

FIG. 5*a* shows in elevation an imaged, folded monopole array embodying the present invention,

FIG. 5*b* is a perspective view of a portion of the structure shown in FIG. 5*a*,

FIG. 5*c* is a perspective fragmentary view of a monopole array employing a ground plane,

FIG. 6 illustrates a typical elevational pattern for the folded monoplane antenna of FIG. 5*a*; and

FIG. 7 shows the VSWR's of the antenna structure of FIGS. 5*a* and 5*b* with respect to a nominal impedance of 50 ohms.

Referring now to the drawings, FIGS. 1*a* and 1*b* show an early form of periodic antenna having two asymmetrical periodic plane members **1** and **2** that diverge from the apex or feedpoint **3**, the said planar members being separated by an angle ψ as shown in FIG. 1*a*. Antennae of this nature occupy considerable volume, producing complex structural problems which are magnified when the antennae are operated in environments having even moderate wind and icing conditions, and since the antenna is asymmetrical, as shown in FIG. 1*b*, that is, the planar members **1** and **2** are not identical, it is impossible to image one-half of this antenna above ground or a counterpoise.

The structures shown in FIGS. 2*a* and 2*b* are of the tapered ladder type, wherein tapered plates **5** are shunt excited by leads **6** or by a lead **6** and a counterpoise or ground plane **6'**. The radiation patterns and impedance structures of the antenna are quite satisfactory; however, in practice its usefulness is limited to short wavelengths due to cost of the plates used and to the fact that for the longer wavelengths the solid plates **5** offer too much wind resistance and are subject to ice loading. For example, at 4 mc./s. this antenna would have solid plate radiating elements that are about 100 feet high and 35 feet wide, which not only would be highly expensive but the solid plate construction produces enormous amounts of wind drag and ice loading even at designs of much shorter wavelength.

FIG. 3*a* shows one form of the novel periodic antenna of this invention which is suitable for free space environment. Physically this antenna consists of a series of folded dipole radiators **7** each folded dipole consisting of spaced parallel dipole antennas connected together at their ends successively arranged in a plane and mutually spaced apart and in which the dimensions of the radiators and their spacing increases uniformly and proportionally with the increase in distance from the vertex of the structure. Each of the folded dipole radiators **7** consists of two rod or wire parallel dipoles, that is, two parallel wires or rods **9** and **9'** which are connected together at their extremities by oppositely tapered portions. The dipole elements **7** are shunt excited from a balanced two-wire transmission line **10** by means of couplers or connections connected to wires **9'** only of the folded dipoles. Each of the two wires of transmission line **10**, as shown in FIGS. 3*b*, 3*c*, and 3*d*, is surrounded in the region of each of the dipole wires **9'** with insulating sleeves or members **20**, as of Teflon, or other low-loss dielectric material. Similar insulating members **20'** surround relatively short conducting wires **12** extending parallel to the leads of line **10**, which wires may have an electrical length of the order of two-tenths of an electrical wavelength though they may be lumped capacitors if desired. The insulators **20'** are cut away substantially midway of their lengths to permit the dipole wires **9'** to be soldered or welded to the short wires **12**, as especially shown in FIG. 3*d*. In this way the wires **9'** are electrically capacity coupled to the leads of transmission line **10** due to the capacity coupling between the leads of transmission line **10** and the short wires **12** and the direct connection of wires **12** to wires **9'**. The insulating members **20** and **20'** may be held in assembled relation upon wires **10** and **12**, as by Teflon or other insulating bands **22**. No connection is made between the leads of transmission line **10** and the wires **9** of the dipole **7** so that these dipole elements are shunt excited through the balanced line through use of the couplers. It will be noted that two couplers are required for each folded dipole, that is, a coupler is in proximity to each of the transmission line wires. Energy supplied, as from a source **8** when the antenna is being used as a radiator, is extracted from the transmission line to the folded dipole elements where it is radiated toward the vertex of the structure and on into the space beyond.

Electrically, energy from the antenna terminals **4—4'** travels along the balanced line **10** toward the rear or large end of the structure until it reaches the active region of the antenna, the active region being the portion of the antenna in which the folded dipole elements are near resonant wavelength at the operating frequency. In practice, approximately three folded dipole elements are active at any particular frequency. In the active region the energy is coupled from the transmission line to the folded dipole elements and then radiated into space.

Since the couplers are attached to the rear or longer segment of wire **9'** of each dipole radiator, energy in the shorter or forward element **9** lags in time phase from that in the longer element **9'**, thereby yielding a resonant phase progression in the direction toward the apex of the structure. Since the energy lags in time in the direction toward the apex or vertex of the structure, the net radiation occurs in that direction. The sharpness of the radiated beam, that is, the directivity, depends on the precise amplitudes and phases of the currents in the radiators and the electrical distance separating the individual radiating elements.

Preferably a matching capacitor **15** comprising a substantially U-shaped wire having insulated legs **21** extending along the two transmission lines **10** adjacent the apex of the structure is employed to prevent reflections where the parallel wires of the line join divergent portions of wires **10** of the antenna structure. This type of antenna produces a directive gain of approximately 7.5 decibels over an isotropic radiator.

In the geometry of this radiating structure as shown in FIG. 3*e*, the angle α defines the extremities of the folded dipole elements and their distances from the vertex of the structure may be designated as R. The subscripts $n-1$, n, $n+1$, etc., denote particular radiating elements, while X denotes the half lengths of these elements. The geometry is such that the pertinent dimensions, R and X, pertaining to an individual element are the geometric mean of respective adjacent element, dimensions, or

$$X_n=\sqrt{X_{n-1}X_{n+1}}$$
$$R_n=\sqrt{R_{n-1}R_{n+1}}$$

or

$$\frac{R_{n+1}}{R_n}=\frac{R_n}{R_{n-1}}=\sigma$$
$$\frac{X_{n+1}}{X_n}=\frac{X_n}{X_{n-1}}=\sigma$$

The parameter σ in the above equations is a constant for a given antenna. This means that the folded dipole radiators differ from each other only by the scale factor, σ^2. The range of frequencies over which the structure will operate is determined by the size of the antenna, that is, by the number of radiators in the structure. Various combinations of design perameters will work satisfactorily, for example, with $\sigma=0.90$, $R_n=0.90R_{n+1}$ and $X_n=0.90X_{n+1}$. If an α of 40° is used, then the active portion of the antenna is approximately two-thirds of a wavelength from the apex or feedpoint of the antenna.

The radiation patterns and impedances of this novel antenna remain essentially constant over the operating frequency band. In FIG. 4 there is shown typical E and H plane patterns, the E pattern being shown in light line and the H pattern being shown in heavy line. In a typical antenna such as that shown in FIG. 3*a*, the values of the design parameters may be, for example, $\alpha=40°$, $\sigma=0.875$, and $R_1=33$ inches. Such an antenna would operate from 300 mc. to 1500 mc. Since the antenna is a balanced symmetrical structure, a central longeron **13** may be used to which each of the folded dipoles is secured to support the antenna as shown in FIG. 3*a*. This longeron is shown carried by a post **4**. Also, a reflector **3** is shown at the end of the transmission line **10** and is also carried by the longeron **13**.

Since the novel antenna of this invention is symmetrical it can be used as a folded monopole array, resulting in a substantial reduction in size. Such an arrangement is shown in FIGS. 5*a*, 5*b*, and 5*c*, wherein parts that are similar to FIG. 3*a* are similarly numbered, and consists of half of the folded dipole array shown in FIG. 3*a*. The antenna of FIG. 5*a* can be imaged over either the ground or a counterpoise, a counterpoise **14** being shown in FIGS. 5*a* and 5*b* and its equivalent a ground plane **23** as of sheet metal in FIG. 5*c*. It will be noted that the folded dipoles of FIG. 5*a* are carried by a catenary cable **16** suspended from a rear post support **19** through insulating U-shaped supports **17**, as of Teflon or other insulating material, which are shown extending down from the cable **16** and under adjacent dipoles. Since the structure is imaged, its feed is unbalanced and is shown excited by means of a coaxial line with its outer conductor **18** being connected to the ground system and its inner conductor **19** being coupled to wires **9'** through a feed line **26** and couplers **11**, as in FIG. 3*a*. Assuming a perfect ground system, the operation of this folded monopole array is identical to the folded dipole array of FIG. 3*a*. This array produces a radiation pattern that is substantially constant with frequency and as shown in FIG. 6 produces a lobe that has a maximum radiation very near the ground and is highly directive. In a typical instance a folded monopole array, such as that shown in FIG. 5*a*, may have the following values: $\sigma=0.875$ and $\alpha/2$ is 20°, where α is the vertical angle of the antenna. The distance R_1 in the VHF model is of the order of 40 feet and the R_1 in the HF model is 220 feet. An insulated matching capacitor shown consisting of a wire **25** connected to the outer conductor **18** and insulated at **25'** extends along an insulated portion of the feed line conductor **19** adjacent the apex of the structure to match the concentric line to the antenna. The folded monopoles **27** of this structure are shown secured at their lower ends to a central longeron **13'**, which longeron is conductively connected to the counterpoise **14**.

In FIG. 5*c* a ground or ground plane **23** as of sheet metal is used as a counterpoise.

FIG. 7 shows the VSWR's of said monopole folded antenna structure with respect to a nominal impedance of 50 ohms. The VSWR's are less than 3:1 over the operating band.

Thus it will be seen that both the novel monopole array as well as the dipole array of this invention are of extremely simple, rugged design and suitable for fabrication of large as well as small antennae, which is not true of the prior art. The dipole array being symmetrical is easily supported and can be made readily resistant to wind pressures without undue whipping whereas the monopole array is extremely simple and can be made in large sizes without undue wind pressures, which is not true of prior art antennae. Since these antennae can be fabricated from wires, fabrication costs are comparatively lower. Also, higher frequency or smaller antennae can be made rigid by fabricating the radiators from tubes which are supported by a central longeron. It is evident that wind drag and icing conditions for these antennae are much less severe than for either the non-planar log-periodic or the tapered ladder antenna.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A broadband antenna comprising a structure diverging from a vertex having a plurality of mutually spaced similar folded radiators, each such radiator consisting of a pair of spaced parallel antenna wires and conducting means electrically interconnecting the ends of said wires, the said radiators being successively arranged in a plane such that the dimensions of the radiators and their spacings increase uniformly and proportionally with increase in distance from the vertex, a feed line and capacity coupling members interconnecting one antenna wire only of each of said folded radiators to said feed line for passing alternating currents therebetween.

2. An antenna as defined in claim 1 wherein each folded radiator has its parallel antenna wires extending orthogonally with respect to the bisector of the vertex angle of said antenna, said conducting means including at least one outer connecting wire extending along a line leading to such vertex, said feed line being capacity coupled by said coupling members to the parallel wire of each radiator that is more removed from such vertex.

3. An antenna as defined in claim 2 wherein a longeron extending centrally of and along the length of said antenna is used to support said folded radiators substantially midway of the lengths of their parallel wires, said conducting means comprising connecting wires extending along lines leading to said vertex, the outer ends of the parallel antenna wires of each radiator being interconnected by said connecting wires.

4. An antenna as defined in claim 3 wherein said feed line comprises divergent leads, said capacity couplers being connected between said feed lines and the parallel wire of each folded radiator more removed from the antenna vertex.

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