Dec. 22, 1970 R. D. GRANT 3,550,143

MULTIPLE TOOTH LOG-PERIODIC TRAPEZOIDAL ARRAY

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FIG. 1.

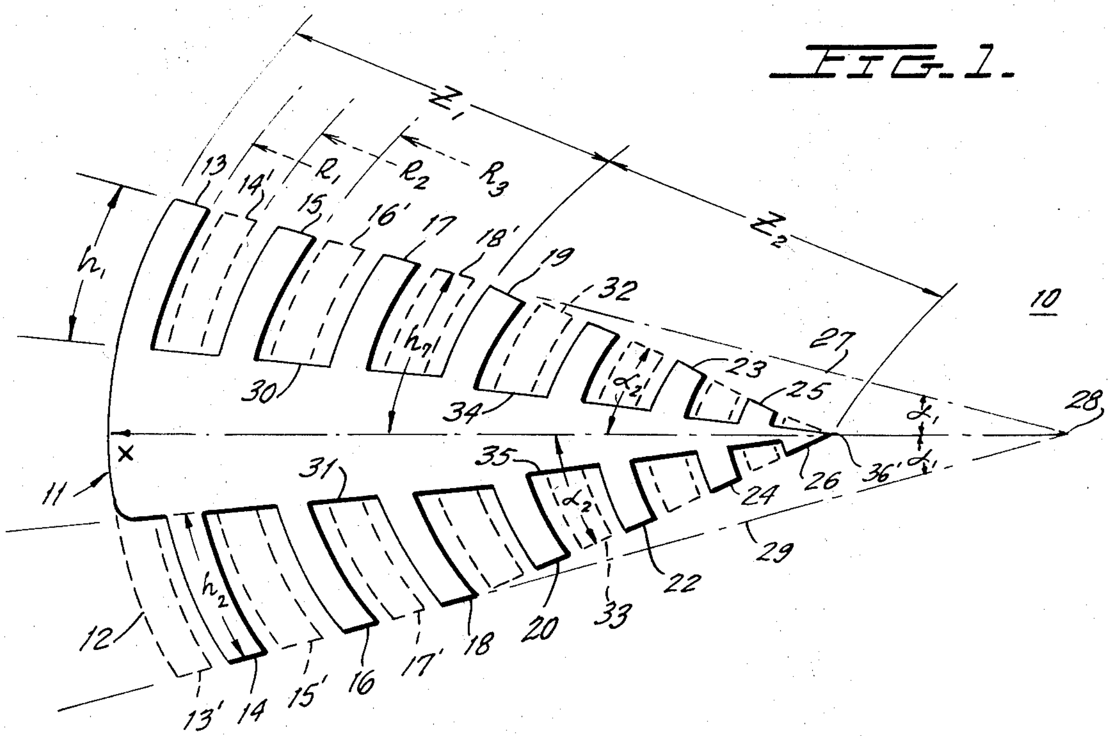


FIG. 1a.

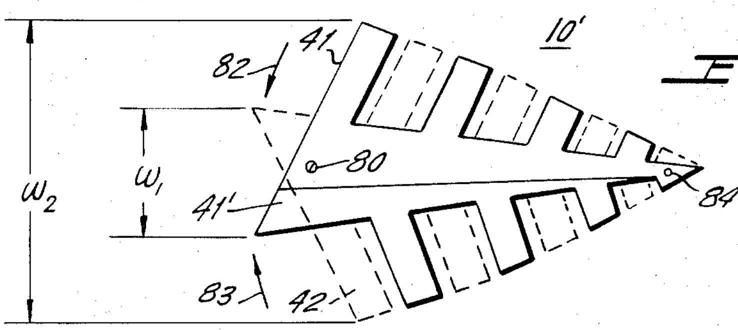


FIG. 5.

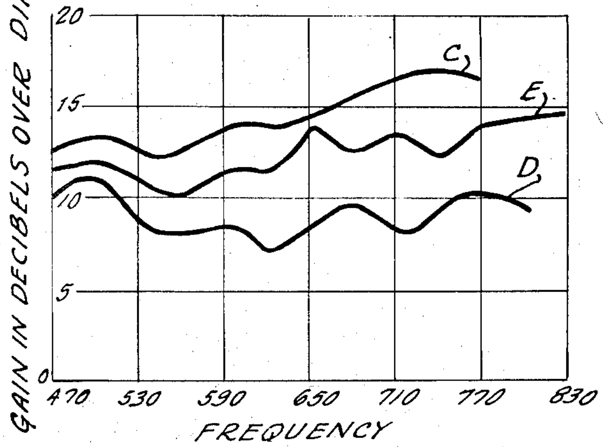
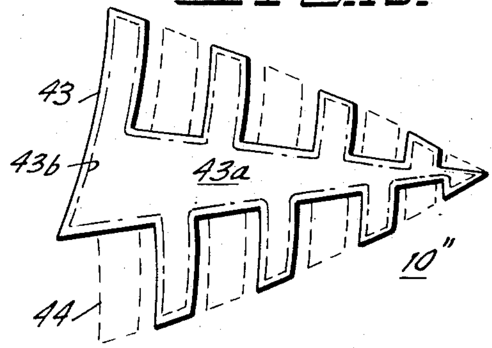


FIG. 1b.



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MULTIPLE TOOTH LOG-PERIODIC TRAPEZOIDAL ARRAY

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FIG. 2.

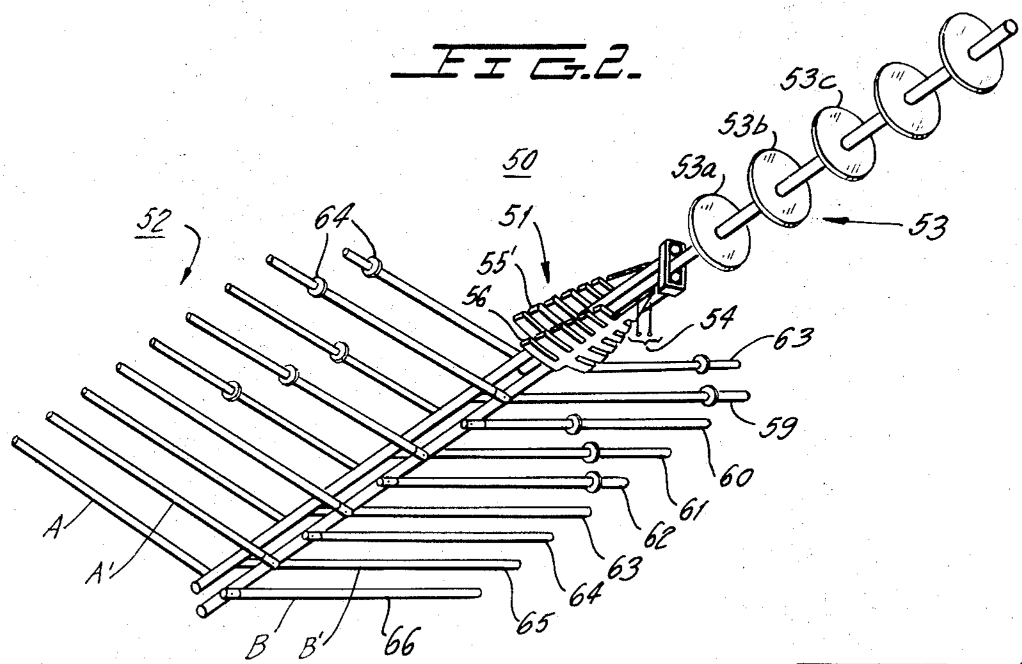


FIG. 4.

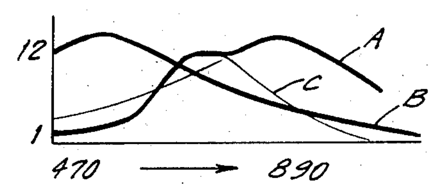


FIG. 3a.

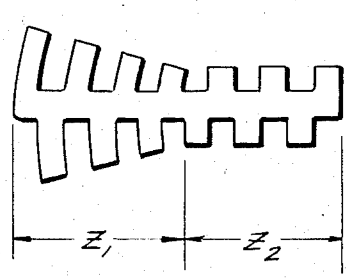
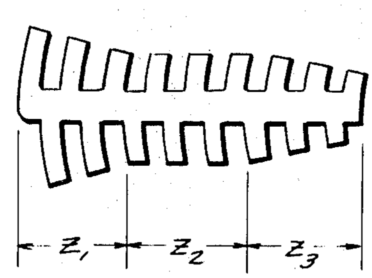


FIG. 3c.



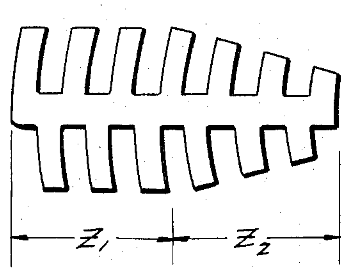


FIG. 3b.

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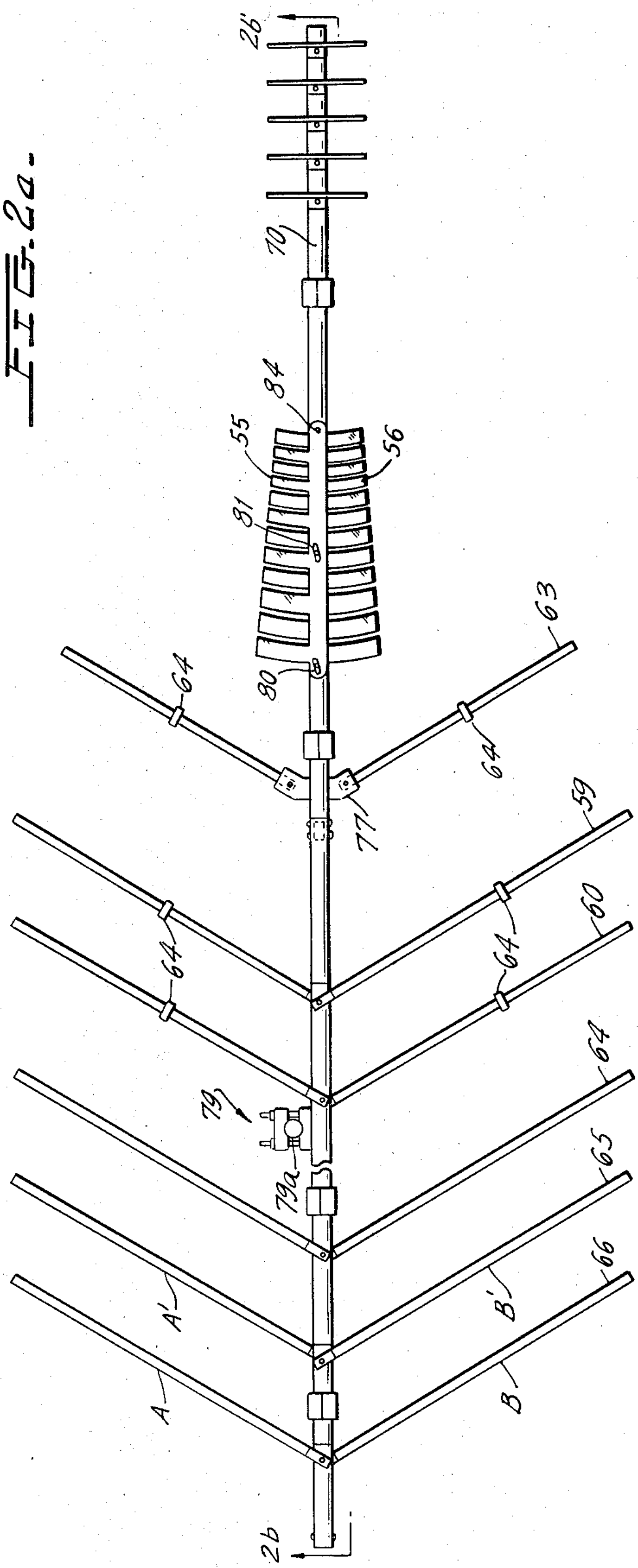
FIG. 2a.



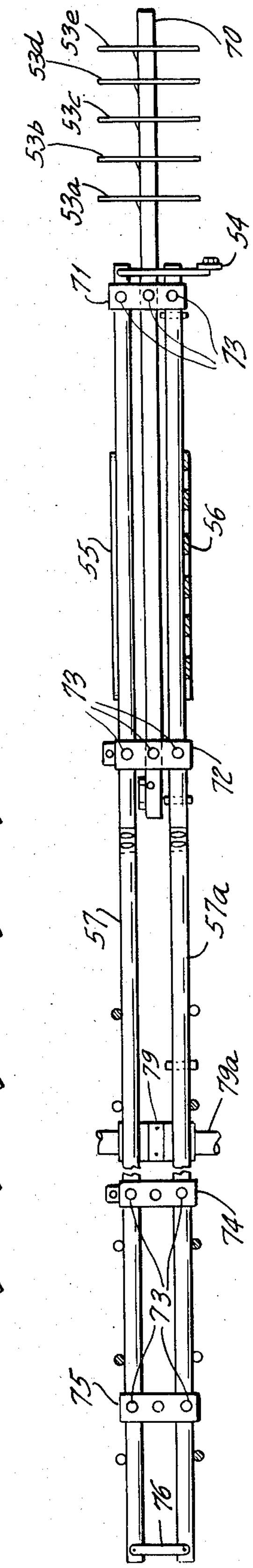


FIG. 2b.

MULTIPLE TOOTH LOG-PERIODIC TRAPEZOIDAL ARRAY

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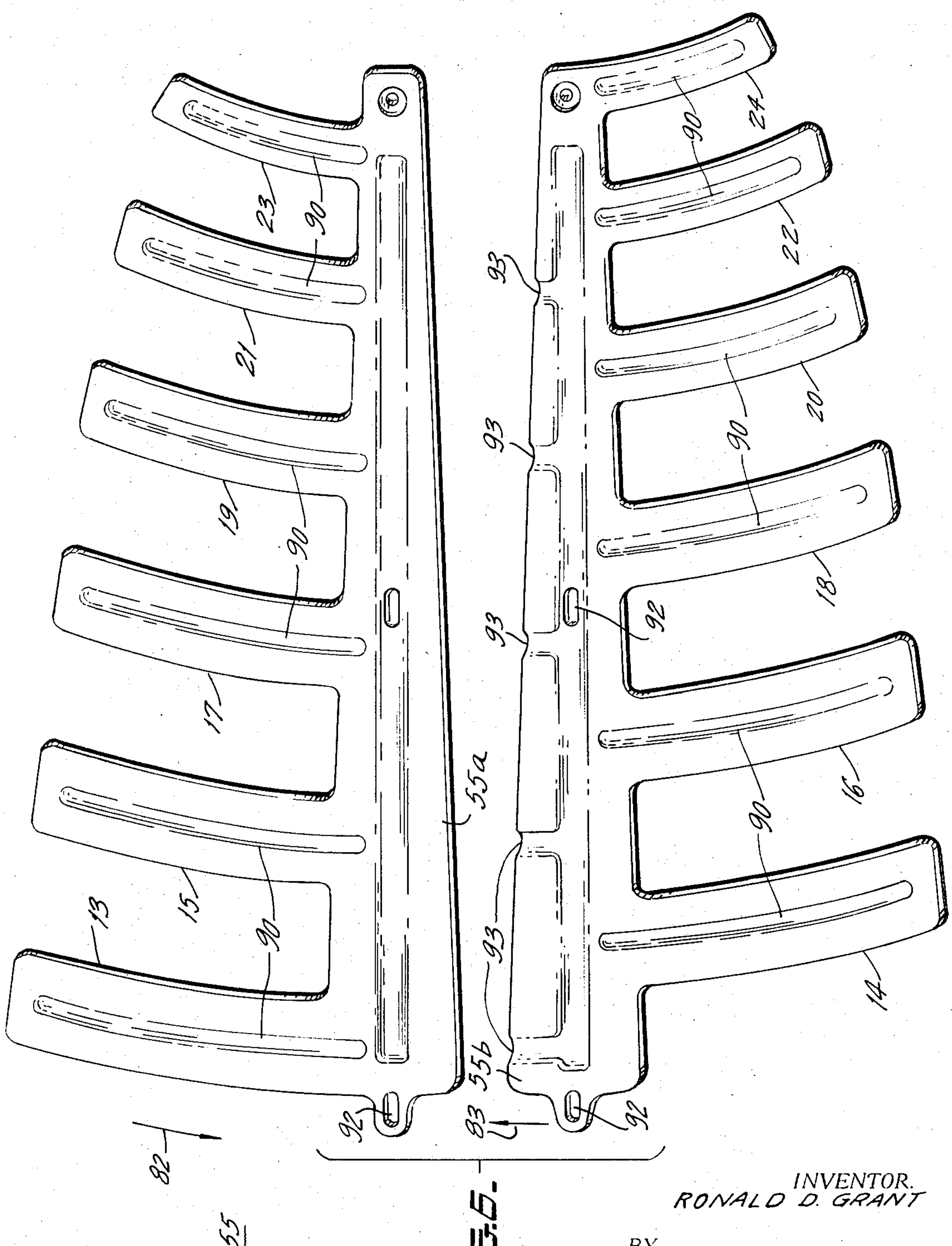

FIG.6.

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United States Patent Office

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3,550,143

MULTIPLE TOOTH LOG-PERIODIC TRAPEZOIDAL ARRAY

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Filed Mar. 21, 1967, Ser. No. 624,765
Int. Cl. H01q *11/10*
U.S. Cl. 343—792.5 5 Claims

ABSTRACT OF THE DISCLOSURE

This invention teaches a multiple tooth trapezoidal antenna array comprised of first and second multiple tooth trapezoidal plates forming a driver which provides extremely high gain over a wide operating radio frequency band. The length, spacing and taper of the tooth in the array may be varied in a variety of different ways to adjust the gain-frequency response characteristic so as to yield antenna gain which increases with frequency so as to maintain constant signal at the receiver input.

The instant invention relates to antennas, and more particularly to antenna arrays for use in transmission or reception wherein a novel multiple tooth trapezoidal array having multiple tapered zones is arranged in such a manner as to obtain high impedance, low capacitive coupling and unidirectional radiation patterns exhibiting higher gain and broad band response as compared with conventional techniques.

It is conventional in the prior art to employ log-periodic antennas in order to obtain unidirectional radiation patterns while maintaining broad bandwidth. One very suitable conventional design is described in detail in U.S. Pat. 3,011,168 wherein a pair of identical substantially V-shaped electrical conducting elements, each having a plurality of similar slots and teeth bounded by straight lines are arranged relative to one another so that the planes passing through each tooth intersect at an angle ψ, where ψ is normally in the range from 30° to 100°. The slots and teeth of each V-shaped conductive sheet are bounded by straight lines and arcs of concentric circles having a common center. The antenna feed points are located at the truncated end of the structure near the common center. The radii measured from the center are related to one another by a constant τ which usually lies in the range from 0.60 to .99, and in any case, is normally less than 1.0.

Antenna structures of this general type, when energized at their feed point, are found to display performance characteristics which repeat at all frequencies in the ratio given by τ^n where n is any real integer within a range of integers which depends upon the number of teeth on the structure. The factor τ determines what may be considered the bandwidth of a period of operation, that is, τ is equal to f_2/f_1 where f_1 and f_2 are two frequencies exactly one period apart, and where f_1 is greater than f_2.

The lower and upper limits of the frequency band in which the radiation patterns are independent of frequency are determined by the longest and shortest teeth, respectively, in the antenna. The low frequency limit is that value for which the longest teeth have an electrical length of approximately one-quarter wavelength $\lambda_1/4$ where λ_1 is the wavelength of the lowest operating frequency. Likewise, the high frequency limit is that value for which the shortest teeth have an electric length of somewhat less than one quarter wavelength. $\lambda_2/4$ where λ_2 is the wavelength for the highest operating frequency. The bandwidth of the antenna can, therefore, be adjusted as desired

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by making the shortest and longest teeth in the antenna correspond to the desired dimension as determined by frequency limits.

The antennas of the above described category have the disadvantages for television receiving of having a low antenna impedance due to high capacitive coupling between the elements. Also, as the angle ψ is reduced, the impedance variation with frequency increases to an unacceptable degree. When such antennas are designed to operate in the UHF band, it becomes extremely difficult and often impossible to combine such arrays with conventional VHF arrays to form a single composite antenna array, since the required supporting brackets and connecting linkages create effective "dipoles" significantly disturbing the resultant pattern and contributing to response to undesired polarizations of the incident field. Furthermore, the gain of log-periodic antennas is conventionally uniform over extremely wide bands which may not be the most desirable condition, particularly in the UHF television band.

Whereas conventional log-periodic antennas provide the rather remarkable result of yielding constant gain over the operating frequency range, this characteristic does not always provide the optimum design. To maintain constant signal at the receiver input, the gain should increase with frequency. The trapezoidal log-periodic driver of the instant invention is designed to include a plurality of zones wherein the scale factors for each zone are selected so as to compress the overall dimensions of the trapezoidal array, as well as being further adjustable for the purpose of cooperating with a parasitic array so that the composite result of the parasitic array and the trapezoidal array yields the desired gain-frequency response curve.

The instant invention overcomes the disadvantages of such conventional arrays and is characterized by being comprised of a pair of spaced, substantially planar conductive plates having a generally trapezoidal configuration with each of the plates being provided with a plurality of teeth and notches, with the outer edges of the teeth being tapered from the rear toward the front in each of the plates, the front end being the feed point for the antenna. The taper of the plates is irregular in the sense that a selected number of teeth of each plate constitutes a zone having a predetermined taper, and adjacent zones are provided with differing tapers so as to affect antenna performance individually for each zone, each zone of the antenna corresponding to the operating region for a certain frequency band.

The teeth of each plate are arranged in a staggered fashion relative to a center line so that a tooth on one side of the center line is defined along its curved edges by two radii which fall between two additional radii defining a slot positioned between the adjacent edges of two teeth positioned on the opposite side of the center line. The pattern is repeated substantially along the entire length of each conductive plate. The conductive plates are mounted in a spaced substantially parallel fashion so that the teeth on one side of the center line of the lower conductive plate lie between the teeth of the upper conductive plate on the same side of the center line. The teeth are cut so that the notches therebetween are substantially wider than the teeth so that no teeth from either conductive plate overlie any portion of the teeth from the other conductive plate. With this unique arrangement, the capacitive coupling between plates, even when arranged in closely spaced parallel fashion, is so small as to have no deleterious effect upon the operation of the antenna. In particular, the variations of impedance with frequency are reduced as compared to the so-called self-complementary designs where slot and tooth are equal widths. The use of substantially narrow teeth further serves to raise the antenna impedance so as to make it relatively simple to achieve a desired impedance of 300 ohms, for example. The fact that the conductive plates of the antenna are arranged in a spaced parallel fashion to one another makes it quite simple to combine such an antenna designed for UHF operation with a conventional VHF section without in any way affecting the resulting pattern, as well as being inexpensive.

It is, therefore, one object of the instant invention to provide a novel multiple tooth trapezoidal antenna array which exhibits a unidirectional radiation pattern of high gain over a substantially broad range of operating frequencies.

Another object of the instant invention is to provide a novel circular tooth trapezoidal antenna array comprised of a plurality of substantially planar conductive plates having a plurality of teeth and notches arranged along two tapered edges of each plate wherein selected groups of teeth form associated zones, with each zone having a different taper in such a manner as to effectively control the gain in each of several adjacent frequency bands.

Still another object of the instant invention is to provide a novel multiple tooth trapezoidal antenna array comprised of a plurality of substantially planar conductive plates having a plurality of teeth and notches arranged along two tapered edges of each plate wherein selected groups of teeth form associated zones, with each zone having a different taper in such a manner as to effectively control the gain in each of several adjacent frequency bands, and wherein the teeth of each of the plates do not overlie one another, when operatively assembled, so as to increase the impedance of the antenna while reducing the capacitive coupling between the plates to a level that does not adversely affect operation.

These and other objects of the instant invention will become apparent when reading the accompanying description and drawings in which:

FIG. 1 is a plan view of the conductive plates forming the antenna array of the instant invention.

FIGS. 1*a* and 1*b* are plan views showing alternative arrangements for the conductive plates of FIG. 1.

FIG. 2 is a perspective view showing a composite antenna array comprised of active and parasitic elements and embodying the principles of the instant invention.

FIGS. 2*a* and 2*b* are top and side views, respectively, of the composite array of FIG. 2.

FIGS. 3*a*, 3*b*, and 3*c* show a variety of different tapered arrangements which may be employed in the instant invention.

FIG. 4 is a plot of curves showing the relationship of gain versus frequency for the tapered arrays of FIGS. 3*a*–3*c*, respectively.

FIG. 5 is a plot of gain versus frequency for a particular tapered array when combined with various parasitic arrays.

FIG. 6 is a perspective view of one trapezoidal array which may be used in the composite array of FIGS. 2–2*b*.

Referring to the drawings, FIG. 1 shows a circular tooth trapezoidal array **10** designed in accordance with the principles of the instant invention, and which is comprised of a pair of substantially planar conductive plates **11** and **12**, with plate **11** being shown in solid fashion and plate **12** being shown in dotted fashion for purposes of facilitating the understanding of the invention.

Considering first conductive plate **11**, this plate is formed of a suitable conductive material such as the light gauge copper sheet approximately 1/32 inch thick. Other suitable materials are aluminum and brass, to name just a few. Conductive member **11** has a generally trapezoidal shaped configuration. The tapered edges are provided with discontinuities in the form of alternating teeth and slots. The teeth **13**, **15** and **17**, for example, are bounded by the straight line **27** along their outer edges and by the arcs of concentric circles having their common center at point **28** and having radii X, R_1, $R_2 \ldots R_n$.

The teeth **13**, **15** and **17** which lie on one side of the radius X, which is also the center line, together with teeth **14**, **16** and **18**, lying to the opposite side of center line X, form a first zone Z_1. The prime characteristic of the zone is such that all scaling factors, to be subsequently described, are peculiar to their associated zone, and usually, but not absolutely, have differing values when compared with the scaling factors of other zones in the array. For example, arcuate shaped tooth **13** is bounded by line **27** and curves having radii X and R_1. The radii are approximately mathematically related to one another by a proportionality factor τ_1 wherein:

$$R_1=\tau_1\times(X+\alpha)$$
$$R_2=\tau_1\times R_1=\tau_1^2X$$
$$R_3=\tau_1^3X=\tau_1^2R_1=\tau_1R_2$$

The constant τ_1 holds throughout the zone Z_1. The distance $X+a$ represents that distance measured from point **28** to the front or forward edge of the next largest tooth in the array which would be generally to the left of tooth **13** relative to FIG. 1 but which tooth has been omitted due to the rear truncation of the antenna which is carried out to enable a practical antenna of reasonable dimensions to be achieved.

The length h_1 of the longest tooth **13** which is measured along the backward edge of the tooth is selected to have an electrical wavelength of approximately $\lambda_1/4$ where λ_1 is equal to the wavelength for the lowest operating frequency f_1 of the circular tooth trapezoidal array. The lengths of the rear edges of teeth **13–18** are related to one another through the τ^1 factor such that:

$$h_1\approx\lambda_1/4 \text{ at frequency } f_1$$
$$h_2=\tau^1\times h_1$$
$$h_3=h_1\times(\tau^1)^2$$

where τ'_1 is not necessarily equal to τ_1.

From the expressions, the generalized equation is:

$$h^n=h_1\times\tau_1^{1(n-1)}$$

The τ_1 and τ'_1 factors remain substantially fixed throughout the zone Z_1. τ_1 and τ'_1 have values normally lying within the range from 0.60 to 0.99, and, in any case, assumes a value less than or equal to 1.0. Although not essential, a preferred arrangement is for $\tau_1=\tau'_1$. Whereas the embodiment of FIG. 1 shows the zone Z_1 to consist of the teeth **13–18**, it should be understood that the number of teeth per zone is dependent only upon the needs of the particular application and that a greater or lesser number of teeth may comprise each zone. The rearward electrical lengths h_1–h_6 taper in such a manner so as to cause the outer edges of teeth **13**, **15** and **17** to be approximately colinear with line **27** and likewise causes the outer edges of teeth **14**, **16** and **18** to be approximately colinear with line **29**. The taper of the teeth in zone Z_1 may thereby be simply identified by a taper angle, to be more fully described. As can clearly be seen from FIG. 1, the slots between adjacent teeth do not extend inwardly to the center line X of the antenna but their inward edges are seen to lie along a radial line **30** whose center lies at the point **28** so as to form an angle $\beta_1/2$ with the radial line X. Thus the portion of the conductive sheet **11** lying between radial line X and **30** can be seen to be substantially continuous. Further examination of FIG. 1 also shows the region of the conductive plate **11** defined by the center lines X and **31** to be likewise continuous. The lines X and **31** embrace an interior angle equal to $\beta_1/2$ such that the total continuous surface area of conductive sheet **11**, in zone Z_1, is defined by a taper angle β_1. Thus the taper angle of the teeth **13**, **15**, **17** (as well as the teeth **14**, **16** and **18**) is defined by the taper angle $\beta_1/2+\alpha_1$.

The array **10** of FIG. 1 is further comprised of a second zone Z_2 lying to the right of zone Z_1 and having teeth **19–26**. The scaling factors for zone Z_2 are τ_2 and τ'_2. In the case shown $\tau_2=\tau'_2$ is less than $\tau_1=\tau'_1$.

Returning to a consideration of zone Z_1, the tooth **18** which has the smallest electrical length, determines the upper operating frequency for the operating frequency range of zone Z_1 such that the upper operating frequency f_2 is that frequency for which the electrical length h_6 is somewhat less than $\lambda_2/4$ where λ_2 is the wavelength of the upper operating frequency f_2.

In the same manner as that previously described, the lower operating frequency f_3 for zone Z_2 is that frequency having a wavelength λ which is about four times as great as the electrical length h_7. The electrical length h_7 is determined by the equation:

$$h_7=\tau_2 h_6$$

The remaining teeth in zone Z_2 are then defined by the equations:

$$h_8=\tau_2 h_7$$

$$h_9=\tau_2 h_8$$

and so forth.

Whereas the embodiment of FIG. 1 shows the array as being comprised of only two zones, it should be understood that more (or less) than two zones may be provided in an array, depending only upon the particular application.

A very small region near the forward tip of the antenna is left as a solid conductor since continuation of the teeth in the direction toward the forward tip of the antenna requires an infinite number of teeth of zero width in the limit.

The outer edges of teeth **19–25** (and also of teeth **20–26**) lie approximately along a straight line **32** (and **33**, respectively) which determines the taper angle for teeth in zone Z_2, which taper angle is equal to

$$\frac{\beta_2}{2}+\alpha_2$$

where angles β_2 and α_2 are determined in the same manner as was previously described with reference to the angles β_1 and α_1 of zone Z_1. It can clearly be seen that the radial lines **32** and **33** defining the outer edges of teeth **19–25** and **20–26**, respectively, as well as the radial lines **34** and **35** defining the interior edges of the slots lying upon opposite sides of center line X, all originate from a second apex **36** somewhat removed from the first apex **28** previously described. Examination of FIG. 1 clearly shows the tapers of zones Z_1 and Z_2 as being different from one another. Control of the taper for each zone affects the gain of the antenna, enabling the gain to be controlled for each zone so as to improve the frequency response considerably over a wide range of frequencies, with each zone being peaked for its own particular operating frequency range in a manner to be more fully described.

As was previously described, the solid-line tapered conductive member **11** forms only one-half of the trapezoidal array with the other half **12** being shown in dotted line fashion for purposes of facilitating an understanding of FIG. 1. The conductive member **12** is substantially a mirror image of the conductive member **11** (with the mirror considered as lying along center line OX and perpendicular to the plane of the figure) with the teeth **13′**, **15′** and **17′** being defined by substantially the identical radii and taper angles as the teeth **13**, **15** and **17** of conductive member **11**, with the exception that the teeth **13′**, **15′** and **17′** lie to the opposite side of the center line X relative to teeth **13**, **15** and **17**, respectively. The zone Z_1 is determined in the same manner for conductive member **12** as was the zone Z_1 for conductive member **11**. Likewise, zone Z_2 is defined in a substantially identical manner, with the only proviso being that of the substantially mirror image arrangement. It should be understood further, for example, that the teeth **14**, **16** and **18** of conductive member **11** have their mirror image counterparts as defined by the teeth **14′**, **16′** and **18′**, respectively. One significant feature of the conductive plates **11** and **12** is such that, when operatively positioned in spaced parallel fashion, the distance between adjacent teeth is substantially greater than the width of the tooth positioned within the associated gap. For example, it can clearly be seen that the tooth **15′** of conductive plate **12** is substantially narrower than the distance separating the adjacent edges of teeth **14** and **16** of conductive plate **11**. Also, it can clearly be seen that the tooth **15′** lies intermediate the facing edges of teeth **14** and **16** so that its left-hand edge lies a first spaced distance from the right-hand edge of tooth **14** and its right-hand edge lies a second spaced distance from the left-hand edge of tooth **16** where the first and second spaced distances are not necessarily equal. All of the other teeth of the conductive plates **11** and **12** are arranged in a like manner.

Whereas the embodiment of FIG. 1 has been described as being comprised of first and second zones Z_1 and Z_2, respectively, it should be understood that a greater or lesser number of zones may be employed, depending upon the particular result which is to be achieved.

FIG. 1*a* shows an alternative embodiment **10′** for the trapezoidal array wherein substantially similar design criteria are employed (i.e., taper angles, multiple zones and τ factors).

FIG. 1*a* shows an alternative embodiment **10′** which may be used in place of the embodiment **10** of FIG. 1. In this embodiment, the conductive plates **41** and **42** have configurations employing similar design criteria to those employed in FIG. 1, namely, multiple zones each having a different τ factor and each having a different taper angle. The major distinction between the embodiments **10** and **10′** is that the arrangement of FIG. 1*a* employs straight teeth and hence is provided with substantially straight slots between adjacent teeth. The conductive plates **41** and **42** are shown in solid line and dotted fashion, respectively, to facilitate an understanding of this embodiment.

FIG. 1*b* is still another alternative embodiment **10″** wherein the conductive teeth of the plates **43** and **44** are curved rearwardly as opposed to being curved in the forward direction in the manner shown in FIG. 1. It should be obvious that the embodiment of FIG. 1*b* may be modified so as to have straight teeth aligned in the rearward direction so that its modification would be likened to FIG. 1*b* as the modification of FIG. 1*a* is likened to the embodiment of FIG. 1.

FIG. 2 shows a perspective view and FIGS. 2*a* and 2*b* show top and side views respectively, of a composite antenna array **50** which is comprised of a trapezoidal array **51** designed for operation in a UHF range and a periodic dipole array **52** whose dipole arms are V'd forward and which is designed for operation in both the lower band and upper band VHF. A parasitic array **53** is positioned in front of the trapezoidal array **51**. For purposes of clarity, FIG. 2*a* shows a sectional view of the array taken along line **2*b*–2*b*′**, which is offset by a spaced distance from the longitudinal axis of the array.

A pair of feed terminals **54** are each coupled to the forward tips of the conductive plates **55** and **56** which comprise the trapezoidal array **51**. Plates **55** and **56** are secured by suitable conductive fastening (not shown) along upper and lower sides of the square shaped conductive crossarms **57** and **57*a***, respectively. The conductive plates **55** and **56** are provided with multiple zones, each having different taper angles and τ factors, depending upon the specific frequency response curve desired. As was previously mentioned, the trapezoidal arrangement **51** may be comprised of more or less than two zones, depending upon the particular application.

The rearward edges of conductive plates **55** and **56** are electrically coupled through the cross-arms **57** and **57*a*** to the inboard ends of the arms of dipoles **59–66** which comprise the log-periodic array **52**. The design criteria of the log-periodic array **52** may be determined in accordance with prior art teachings such as, for example, those teachings set forth in issued Pats. 3,011,168; 3,210,767 and 3,276,028, and copending application Ser. No. 414,-975. For example, the dipoles **59–61** and the parasitic element **67** employ capacitive coupling elements **64** in accordance with the copending application Ser. No. 414,-975 filed Dec. 1, 1964. The trapezoidal array **51** is designed to be operative within the UHF range and the log-periodic array **52** is operative in the VHF range (both low-band and high-band VHF).

The parasitic elements **53*a*–53*e*** comprising the parasitic array **53** are substantially disc-shaped conductive members which are insulated from the active elements in arrays **51** and **52**. The conductive members are secured to a square shaped center cross-arm **70** held in spaced parallel fashion relative to and between cross-arms **57** and **57*a*** by means of triple boom insulator supporting brackets **71** and **72** which electrically insulate the parasitic elements **53*a*–53*e*** and **63** from the active elements **59–66**. Each of the members **57**, **57*a*** and **70** are secured to brackets **71** and **72** by fastening means **73**. Similar supporting brackets **74** and **75**, secured to cross-arms **57** and **57*a*** by fastening means **73**, maintain the left-hand ends of the crossarms in spaced parallel fashion.

A 180° phase shift between adjacent dipoles is obtained with the twin cross-arms (in lieu of a transposed feeder harness) by alternating the electrical connections of the dipole arms to the twin cross-arms. For example, arms A and B of dipole **66** are connected respectively to cross-arms **57** and **57*a***, whereas arms A′ and B′ of dipole **65** are connected respectively to cross-arms **57*a*** and **57**. The remaining dipoles **64–59** are connected to the cross-arms **57** and **57*a*** in a similar manner to obtain the desired phase shift which, in turn, markedly improves the antenna front-to-back ratio. A shorting strap **76** is coupled across the left-hand ends of cross-arms **57** and **57*a***.

Whereas a twin cross-arm arrangement has been described herein, it should be understood that a transposed feeder harness arrangement may be substituted for the twin cross-arm arrangement described herein without departing from the scope of the instant invention.

The parasitic element **63** is secured to center cross-arm **70** by means of a mounting bracket **77**. A clamp **79** secured to cross-arms **57** and **57*a*** is provided for mounting the array to a mast **79*a***.

The parasitic array **53** comprised of elements **53*a*–53*e*** are designed in accordance with the principles set forth in U.S. Pats. 2,955,287 and 3,015,821. Basically, the disc-shaped conductive elements are of selected dimensions and are selectively spaced along the central cross-arm **70** so that the spacing and sizes of the discs in the parasitic array act to increase bandwidth and capture area; boost gain over the UHF range over that obtainable through the use of conventional thin linear directors; and produce a narrower beamwidth. The discs are omnipolarized to intercept UHF signals that often depart from horizontal polarization.

Whereas the embodiment **50** of FIG. 2 teaches the use of the trapezoidal array **51** in combination with a particular type of antenna designed for VHF operation, it should be understood that other types of antennas may be employed for the VHF band. The conductive plates **55** and **56** comprising the trapezoidal array **51**, being arranged in closely spaced parallel fashion, do not in any way disrupt the radiation pattern and frequency response of the VHF antenna array **52** which is located rearwardly of the trapezoidal array **51**. In prior art composite antenna arrays employing the conductive plates the plates are neither arranged in closely spaced fashion nor in spaced parallel fashion, but are aligned at angles to one another usually of the order of 30°–100°. See U.S. Pat. No. 3,011,168 for example. Placement of an array taught by this patent in front of the array **52** of FIG. 2, for example, substantially affects the radiation pattern and frequency response characteristic of the rearwardly positioned array **52**. Also, the angular orientation of the conductive plates requires suitable metallic structural supporting means as well as suitable conductive means for connecting the rear of the UHF zoned trapezoidal section to the small elements of the VHF section. These means create effective "dipoles" which significantly disrupt the resulting antenna pattern and increase the response to undesirable cross-polarized fields. By closing in the UHF section comprised of plates **55** and **56** so as to be arranged in substantially closely spaced parallel alignment, attachment to the VHF section becomes quite simple and the effective dipoles produced by the conducting means employed in arrays with angularly displaced members are totally eliminated. With the thickness of each tooth of the conductive members **55** and **56** being substantially less than the width of each slot between adjacent teeth, the impedance of the array **51** is significantly raised making it quite simple to achieve a 300 ohm impedance which is highly desirable for coupling with a TV receiver, for example. The closely spaced parallel alignment of the plates has a direct effect upon capacitive coupling between the plates. However, since the teeth of the lower plate, for example, are substantially thinner than the overlying slot of the upper plate, the capacitive coupling is significantly reduced so as to produce no deleterious effect upon the antenna operation. In prior art structures such as, for example, those described in Nos. 2,985,879 and 3,011,-168, the teeth of the pair of plates have complementary symmetry such that the width of each tooth of a first plate is exactly equal to the corresponding width of a slot provided in the other plate. Through a significant reduction in the width of each tooth relative to a corresponding slot, this enables the conductive plates to be arranged in closely spaced parallel fashion without any significant effect upon capacitive coupling therebetween as well as producing a marked increase in antenna impedance and an extremely advantageous gain characteristic. Experimentation has shown that antennas designed in accordance with the principles of the instant invention provide more gain than wire-formed or stem arrays of the type similar to the array **52** of FIG. 2, as well as providing an antenna which is quite rugged, can be mounted with relative ease, and results in a significant reduction in cost when compared with wire or stem-formed arrays of the type similar to the array **52**.

FIGS. 3*a*–3*c* show in schematic fashion a variety of multi-zoned trapezoidal arrays, while FIG. 4 shows the gain versus frequency response curves for the three different arrays. Considering FIG. 3*a*, the trapezoidal array is comprised of first (Z_1) and second (Z_2) zones having τ constants τ_1 and τ_2, respectively. It can clearly be seen that zone Z_1 has a decided taper angle whereas zone Z_2 has almost no taper angle, or at best a very small taper angle. A trapezoidal array of the type of FIG. 3*a* has a gain versus frequency curve A, as shown in FIG. 4, wherein gain relative to a tuned half-wave dipole is relatively low (but greater than 1) at the lower end of the UHF band and increases by a significant amount toward the upper end of the UHF band.

FIG. 3*b* shows a multi-zoned trapezoidal array comprised of zones Z_1 and Z_2 having τ factors τ_1 and τ_2, respectively. In the arrangement of FIG. 3*b*, zone Z_1 has no taper angle or at best a very slight taper angle, whereas zone Z_2 has a very significant taper angle. In the multi-zoned array of this type, the resulting gain versus frequency response is given by curve B in FIG. 4. It can clearly be seen that the gain is quite high at the lower end of the UHF band and tapers almost linearly toward the upper end of the UHF band.

FIG. 3*c* shows the trapezoidal array comprised of zones Z_1–Z_3 having τ factors τ_1–τ_3, respectively. The taper angles at zones Z_1 and Z_3 are quite substantial, while the zone Z_2 has no taper angle, or at best a very small taper angle. The trapezoidal array of the type shown in FIG. 3*c* yields a gain versus frequency response curve C, shown in FIG. 4, wherein gain is maximum in the intermediate frequencies between the upper and lower ends of the UHF range. From these differing embodiments, it can clearly be seen that it is possible to provide a good gain pattern over the entire UHF range, and at the same time to peak the gain of the antenna within any desired region over the UHF band.

Considering FIG. 5, curves D, E and F represent the gain versus frequency curves for an antenna of the type shown in FIG. 3*a*, for example, employing one, seven and fourteen director elements, respectively. Through the use of a parasitic array, such as the array **53** shown in FIG. 2, the resultant improvement in gain over a wider frequency range, as compared with the gain of the antenna shown in FIG. 3*a* in the absence of a parasitic array, can clearly be seen. Thus, a variety of antenna array design combinations are possible, namely employment of a single zoned trapezoidal array; a multiple zone trapezoidal array; a single or multiple zone trapezoidal array in combination with a conventional antenna array such as that shown in FIG. 2, for example; and a single or multi-zoned trapezoidal array in combination with a parasitic array and/or a conventional array.

From the viewpoint of facilitating handling, packaging and shipping of the trapezoidal array, it is preferred that each conductive plate such as, for example, the conductive plate assembly **55** of FIG. 1*a* (or FIG. 6) has two separate plates **41** and **41'** which are securely fastened to one another at two points by removable fastening means **80** and **84** (see FIG. 2*a*) when in the fully assembled position. For handling, packaging and transportation purposes, the fastening means **80** and **84** (or fastening means **80** alone) may be removed and the plate halves **41** and **41'** may be pivoted about pin (i.e., rivet) **84** which is preferably installed in a permanent manner so as to be moved toward one another in the directions shown by arrows **82** and **83**, respectively, yielding disassembled width W_1 which is substantially less than the assembled width W_2 (i.e., the operating position), thereby greatly facilitating the packaging, handling and shipping problems encountered with such antenna arrays. Whereas only two removable fastening means (i.e., wingnuts) are shown, it should be understood that additional fastening means may be arranged at spaced intervals along the plate. Also, it should be understood that both plates, such as, for example, plates **55** and **56** of FIGS. 2–2*b* may be comprised of plate halves which may be folded in toward one another in the manner previously described to facilitate the packaging, handling and shipping activities.

FIG. 6 shows a perspective view of the preferred multiple toothed trapezoidal array for use in the composite array of FIGS. 2–2*b*. The plate halves **55***a* and **55***b* are reinforced against bending due to wind, rain, snow, sleet, etcetera, by providing a plurality of depressions **90**, one in each tooth, and **91** along each lengthwise portion. Slots **92** are adapted to receive the fastening means **80**, **81** and **84** referred to previously. The fastening means **80**, **81** and **84** serve to provide good electrical contact between plate halves **55***a* and **55***b* when properly tightened. Depressions **93** extending transversely from depression **91** in plate half **55***b* assures good electrical contact between cross-arms **57** and **57***a* and (upper and lower) trapezoidal arrays **55** and **56** respectively.

It can, therefore, be seen that the instant invention provides an antenna of novel design which can be cheaply produced, cheaply and easily mounted, and which provides high antenna impedance, low capacitive coupling and high gain over a large operating frequency range through the employment of a pair of closely spaced parallel plates having teeth along the tapered edges of the plates which are substantially thinner than the slots of the antenna.

Although this invention has been described with respect to its preferred embodiments, it should be understood that many variations and modifications will now be obvious to those skilled in the art, and it is preferred, therefore, that the scope of the invention be limited not by the specific disclosure herewith, but only by the appended claims.

One design modification which may be employed consists of use of a perforated sheet or a sheet formed of a rigid metallic screen as the sheets for the trapezoidal array. Appropriate adjustment of the design parameters (i.e., τ, α, β, etc.) to compensate for the perforated or screen materials employed are well within the purview of those possessing ordinary skill in the art. If desired the conductive sheets may be formed using silk-screening or printed circuit techniques without departing from the spirit of the invention.

In addition to employing perforated conductive sheets substantially the entire interior sections of the teeth may be removed if desired for purposes of weight reduction and wind resistance reduction. Considering the conductive plate **43** shown in solid line fashion in FIG. 1*b*, the interior region **43***a* which is embraced by phantom line **43***b* may be removed so that merely an outline or marginal portion of the plate remains. Plate **44** (shown in dotted line fashion) may likewise be formed in a similar cut-out manner. Carrying this arrangement one step further, each plate may be substituted by a conductive wire bent in a configuration which generally follows the outline of each conductive plate. Appropriate adjustment of the design parameters due to the substitution of wire (or a cut-out arrangement) for the flat solid conductive plate is well within the skill of the ordinary artisan in the antenna art. Suggested modifications are set forth in U.S. Pat. No. 2,985,879 showing a slot antenna cut into a conductive plate in FIG. 2 of the patents.

The zones described in detail above are primarily presented as consisting of a plurality of teeth. It should be understood, however, that each zone may have as few as a single tooth causing τ for lengths and τ' for spacing to vary continuously along the length of the array rather than remaining constant across each one of the several.

The embodiments of the invention in which an exclusive privilege or property is claimed are defined as follows:

1. An antenna array being comprised of first and second substantially thin planar conductive plates, said first plate being positioned above an imaginary horizontal plane and said second plate being positioned below said first plate and said imaginary horizontal plane;

said first plate having a substantially pie-shaped periphery;

the tapered sides of said first plate being provided with alternating teeth and slots;

the length of said teeth being greater at the wide end of said first plate and substantially diminishing in length toward the tip of said first plate;

said second plate having substantially the same pie-shaped configuration as said first plate and having alternating teeth and slots;

the teeth of said second plate each being positioned to overlie a corresponding slot of said first plate;

each slot of said first plate having a width substantially greater than the width of the corresponding overlying tooth of said second plate;

the teeth arranged on one tapering side of said first and second plates occupying a position corresponding to a slot on the other tapering side of the plate;

a pair of balanced feed terminals being coupled to the forward tips of said first and second plates;

said first and second plates each being divided into a plurality of zones arranged in tandem fashion;

each of said zones encompassing at least one tooth lying along at least one tapering side of said plates;

the outer edge of the tooth on one tapering side of each zone lying substantially along a first straight line;

the outer edges of the teeth on the other tapering side of each zone lying substantially along a second straight line intersecting said first straight line at a common point and thereby defining a taper angle;

the taper angle of each zone being different from the taper angle of its adjacent zones.

2. The antenna array of claim **1** wherein the sides of each tooth within a zone are located at distances from their corresponding common point, which distances are related to one another by a factor τ, wherein τ is a constant less than 1.

3. The antenna array of claim **2** wherein the teeth of each plate are curved;

the sides of each tooth in a zone being defined by concentric circles having radii extending from the common point corresponding to the zone;

the radii being related to one another by the equation

$$R_n+1=\tau^{-Rn}$$

wherein

R_n=the longer radial distance

R_n+1=the next shorter radial distance

0.7<=constant <1

the value of the constant τ for each zone being different from the value of the constant τ in each adjacent zone.

4. The antenna array of claim **1** wherein the inboard ends of the teeth arranged on the tapering sides of each of said first and second plates are separated by and extend from a substantially continuous conductive central portion;

the inboard ends of the teeth on said opposite tapering sides defining a pair of intersecting straight lines which form a second angle defining the taper of said central portion;

the taper angle of said central portion differing for each zone.

5. An antenna array being comprised of first and second substantially thin planar conductive plates, said first plate being positioned above an imaginary horizontal plane and said second plate being positioned below said first plate and said imaginary horizontal plane;

said first plate having a substantially pie-shaped periphery;

the tapered sides of said first plate being provided with alternating teeth and slots;

the length of said teeth being greater at the wide end of said first plate and substantially diminishing in length toward the tip of said first plate;

said second plate having substantially the same pie-shaped configuration as said first plate and having alternating teeth and slots;

the teeth of said second plate each being positioned to overlie a corresponding slot of said first plate;

each slot of said first plate having a width substantially greater than the width of the corresponding overlying tooth of said second plate;

the teeth arranged on one tapering side of said first and second plates occupying a position corresponding to a slot on the other tapering side of the plate;

a pair of balanced feed terminals being coupled to the forward tips of said first and second plates;

said first and second planar conductive plates are each comprised of first and second plate halves;

fastening means for joining the associated first and second plate halves at least at their forward and rearward ends;

at least the said fastening means at the rearward end being removable to permit the plate halves to be pivoted toward one another about the fastening means joining their forward ends to permit the plate halves to overlie one another and thereby facilitate packaging and handling of the antenna.

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