# United States Patent [19]

**Tiuri et al.**

[11] **3,806,946**

[45] **Apr. 23, 1974**


[54] **TRAVELLING WAVE CHAIN ANTENNA**


[76] Inventors: **Martti Eelis Tiuri,** Takojantie 1F, Tapiola; **Seppo Ilmari Urpo,** Kalasaaskentie 3B22, Karakallio; **Henry Stefan Tallqvist,** Lastenlinnantie 96 C15, Helsinki, all of Finland



[22] Filed: **Sept. 28, 1972**

[21] Appl. No.: **294,448**

[52] **U.S. Cl.** ..... **343/731,** 343/846, 343/853

[51] **Int. Cl.** ..... **H01q 11/02**

[58] **Field of Search** ..... 343/792.5, 846, 897, 908, 343/731, 853



[56] **References Cited**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 3,290,688 | 12/1966 | Kraus | 343/897 |
| 3,123,827 | 3/1964 | Arnold et al. | 343/792.5 |



*Primary Examiner*—Eli Lieberman

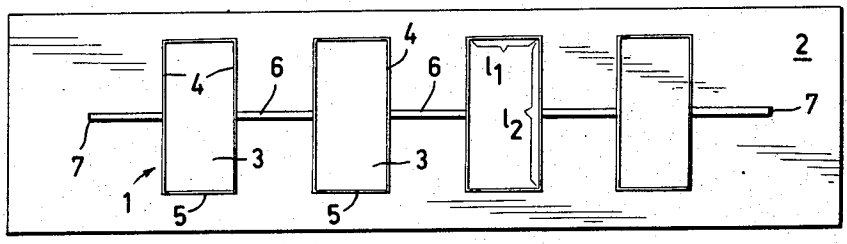
*Attorney, Agent, or Firm*—Eric H. Waters



[57] **ABSTRACT**

A travelling wave chain antenna including a ground plane, having a radiation beam, the direction of which can be varied by altering the frequency, wherein the antenna consists of four-sided links made of conducting material and of connection parts between the links, these being located one after another, either in a straight row, in such a manner that the connection parts are at right angles to the longer sides of the links, or in an oblique row, in such a manner that the connection parts are at an angle to the longer sides of the links, the center points of the longer sides of the links being electrically connected to the center point of the longer side of the following link by means of the connection parts which are parallel to the shorter sides of the links, and the antenna being fed from either end by means of a cable, in such a manner that one conductor is connected to one end of the chain structure of the antenna and the other conductor is connected to the ground plane, the end of the antenna opposite the feed point being either open or loaded with a load impedance connected between the end of the antenna and the ground plane.


**17 Claims, 9 Drawing Figures**



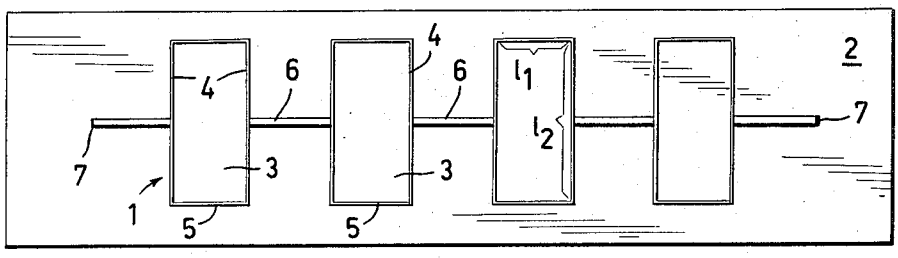



FIG. 1

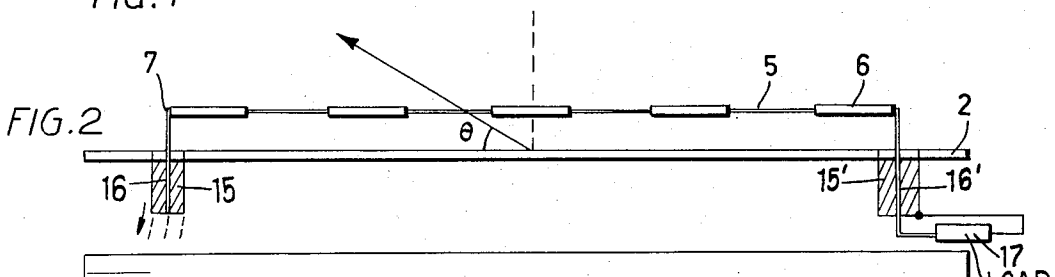



FIG. 2

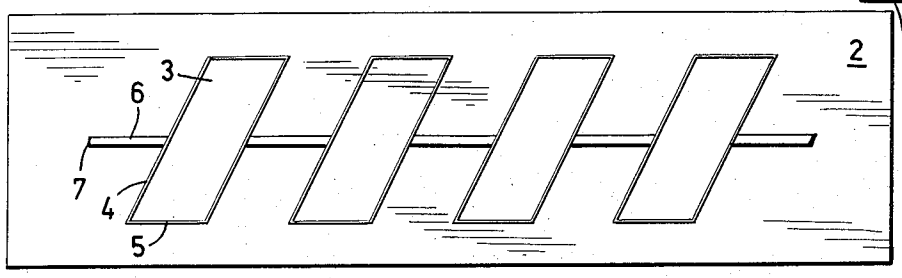



FIG. 3

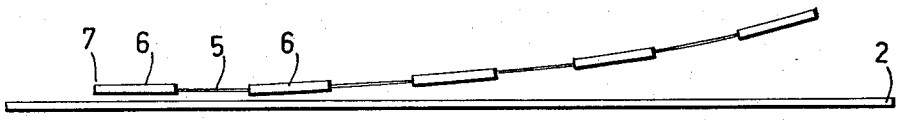



FIG. 4

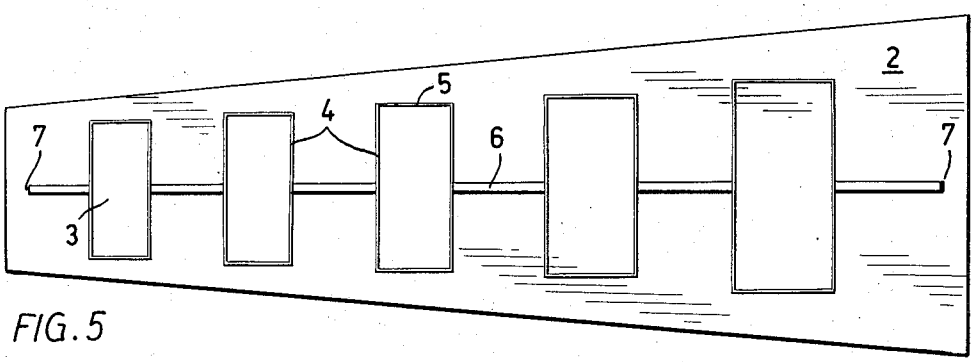



FIG. 5

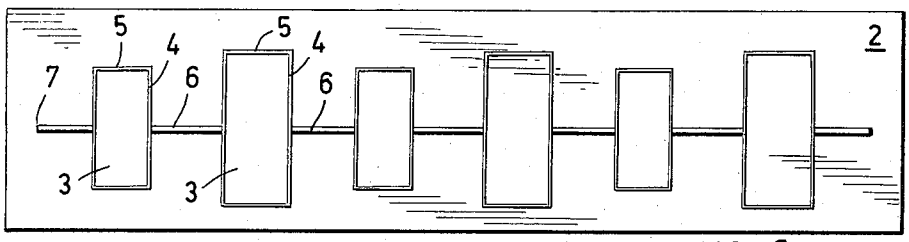



FIG. 6

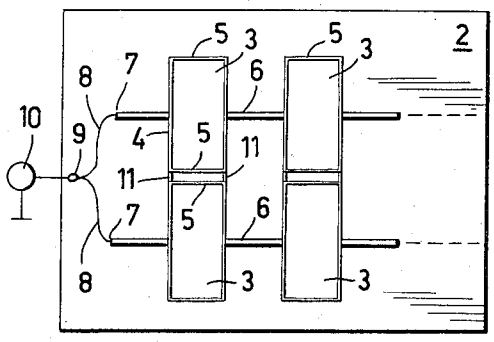



FIG. 7

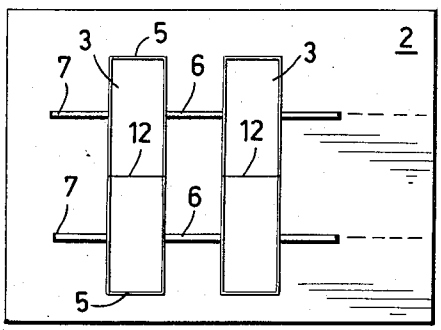



FIG. 8

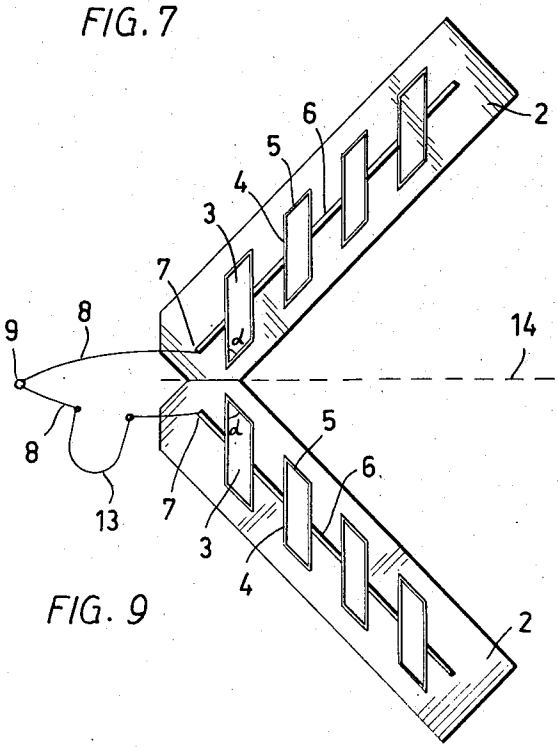



FIG. 9

# TRAVELLING WAVE CHAIN ANTENNA

This invention relates to high gain travelling wave antennas having a ground plane and in which the direction of the radiation beam generally depends on the frequency.

When a high gain antenna is required, especially in the HF, VHF, UHF and SHF ranges, dipole arrays are generally used. When the number of dipoles is large, however, the feed system for the antenna array becomes extremely complicated and expensive. Also the band width of the assembly is in general seriously limited by the feed system. The travelling wave antenna has the advantage of a simple feed system. One disadvantage of previous antennas of this type, such as the long-wire antenna, V-antenna and rhombic antenna, is that the direction of the radiation beam is determined by the length of the antenna, and therefore the beam from the antenna cannot be freely directed in the desired direction. Also, in order to achieve a narrow beam, the length of a long-wire antenna, for example, must be several wavelengths. The resulting radiation pattern is finger shaped, or in other words, has several side lobes in addition to the main beam.

Some of the earlier resonant-type antennas used especially in the short wave range can be fed at a single point. These include the Franklin antenna, the Sterba array and the Bruce array (Jasik: Antenna Engineering Handbook, Chapters 4 and 21). As these antennas are of the resonant type, they operate efficiently only at one frequency, and generally only as broadside arrays. Because of the difficulties in controlling the radiation properties of these antennas, their length is limited, in practice, to a few wave lengths, and the beam width cannot be greatly reduced.

The wire mesh antenna described by J.D. Kraus (U.S. Pat. No. 3,290,688) consists of a wide network made up of rectangular wire meshes and fed at a single point. A disadvantage of this antenna is that it is not power matched. This causes a decrease in gain and an increase in the back beam due to reflections. The distribution of the current at the feed in end of the antenna is only good when operating at the middle frequency, and, in addition, the antenna cannot be used with circular polarization.

An object of the antenna provided in accordance with the invention is to eliminate the aforementioned disadvantages. it is characteristic to the invention that the antenna is a travelling wave, chain shaped antenna located above a ground plate, the radiation properties of which can easily be controlled. The structure of the antenna is simple and it requires only one feed point. By varying the frequency, the radiation beam of the antenna can be rotated over a large area. A high gain can be achieved with this antenna if required, and also a narrow beam, without the occurrence of strong, interfering side lobes. The antenna can easily be used as an element in large antenna arrays, and can be used both for the transmission and reception of linear or circular polarization.

The invention is described in detail in the following with reference to the attached drawing in which:

FIG. 1 shows a plan view of the basic arrangement of the antenna;

FIG. 2 shows a side view of the basic arrangement of the antenna;



FIG. 3 shows an antenna having parallel-sided links;

FIG. 4 shows an antenna in which the distance from the ground plane varies continuously;

FIG. 5 shows an antenna having a radiation structure of increasing dimensions;

FIG. 6 shows an antenna in which alternate links are of equal size;

FIG. 7 shows a parallel connection of two chain antennas;

FIG. 8 shows a parallel connection of two chain antennas; and

FIG. 9 shows a parallel connection of two chain antennas, to obtain circularly polarized radiation.

As shown in FIGS. 1, 2 and 3, the basic arrangement of the antenna consists of a chain shaped structure 1 made of electrically conductive material, located above a ground plane 2 made of electrically conductive material. The chain is made up of links 3 and connection parts 6 electrically connected to them. The four-sided links 3, which are rectangular as in FIG. 1 or parallelograms as in FIG. 3, are arranged in a row in such a manner that the longer sides 4 of the links are parallel to each other and the midpoints of all the longer sides lie on the same line. The midpoints of the longer sides of adjacent links are connected to each other by means of connection parts 6. Ground 2 is, for example, a solid metal sheet, a perforated metal sheet, a wire net having a mesh size of 0.1 wavelengths or a grid made up of wires located side by side and parallel to parts 5 and 6. Typical dimensions for the antenna, in wavelengths corresponding to the middle frequency of the operating range, are as follows: the shorter sides 5 of the links and the connection parts 6 between the links, 0.4 wavelengths, the longer sides 4 of the links, one wavelength, the distance from the ground plane, 0.1 wavelengths and the total length of the antenna, for example, 10 wavelengths. The antenna is fed at one end 7 of the chain by means of a coaxial cable, for example, in such a manner that the center conductor 16 (16') is connected to the chain structure 1 and the outer conductor 15 (15') to the ground plane 2. Feeding can also be effected by means of a twin conductor structure.

The antenna can also be fed at both ends. Several receivers or transmitters operating at different frequencies can be connected simultaneously to the antenna.

Measurements have shown that an antenna constructed in accordance with the dimensions given above radiates in such a manner that the maximum beam is directed at a backward elevation angle of $\theta = 75°$ at the middle frequency. Alteration of the frequency by $\pm 10$ percent causes the rotation of the beam over the range $\theta = 45° - 85°$ without the gain of the antenna changing considerably.

It is essential to the operation of the antenna that there exist a power wave moving away from the feed point of the antenna. For this reason, in an ideally constructed antenna, the characteristic impedance of the transmission line made up of parts 6 and the ground plane must be half the characteristic impedance of the transmission line made up of parts 4 and 6 and the ground plane. This condition can be fulfilled in a manner of ways such as, for example, by making parts 6 of considerably thicker sections than parts 4 and 5, by making parts 6 of broad flat sections or of two or more adjacent wires, by decreasing the distance between the

ground plane and parts **6** or in some other way in which the inductance of parts **6** is decreased or the capacitance between parts **6** and the ground plane is increased. Tests with various antennas have shown that the fulfillment of the above-mentioned impedance condition within an accuracy of approximately 10 percent is sufficient for the more usual antenna applications. In an antenna of middle frequency 3 GHz, having parts **4** and **5** made of 0.5 mm diameter round wire and parts **6** made of 0.5 × 10 mm flat section, a power wave, ideal within the limits of measurement accuracy, moving away from the feed point has been measured.

When the above-mentioned impedance condition is fulfilled the whole antenna can be represented as a transmission line with losses, having a constant impedance and with the size of the losses depending on the radiation power per unit length of the antenna. If the impedance condition is not fulfilled, power reflections occur in the transmission line and the power wave reflected backwards causes a back beam in the radiation pattern and a decrease in the main beam. The back beam, caused by the power wave reflected from the end opposite to the feed end of the antenna can be eliminated by loading the further end of the antenna. This can be done, for example, using a termination **17** equal to the characteristic impedance of the antenna, by placing absorbing material between the far end of the antenna and the ground plane or by making the antenna sufficiently long.

The radiation properties of the antenna can be controlled by varying the distance to the ground plane. An increased distance gives greater radiation power per unit length of the antenna, and a smaller distance to the ground plane means lower radiation power per unit length of the antenna. A chain antenna which is long in comparison to the wavelength is located near the ground plane such as, for example, at a distance of 0.05 wavelengths from it, and thus a high gain and a narrow beam is achieved. A shorter antenna having a smaller gain and a wider beam is located further away from the ground plane, for example at a distance of 0.15 wavelengths. The radiation power per unit length can also be increased by bending parts **5** and **6** into upward curved shapes in such a fashion that the middle sections of the parts are further away from the ground plane than their ends, or by otherwise arranging that parts **5** and **6** are further away from the ground plane than parts **4**, over their whole or partial length.

The distribution of the current in the antenna can be improved, at the same time increasing the efficiency of the antenna, by increasing the distance from the ground plane either in steps or continuously when moving away from the feed point of the antenna. A side view of such a chain antenna is shown in FIG. **4**. The shortest distance from the ground plane can be approximately 0.05 wavelengths and the maximum distance approximately 0.25 wavelengths. The total length of this type of antenna can be approximately 20 wavelengths.

The current distribution and the radiation properties of the antenna can be altered by making the ground plane or the radiating antenna structure itself, or both of them curved. If, for example, the ground plane and the antenna are both curved in the same direction in the plane parallel to the longitudinal axis of the antenna, and the antenna is on the concave side of the ground, the beam from the antenna can be angled at the same direction over the whole range of operating frequency and, if the antenna is on the convex side of the ground, a circular radiating antenna of large angular range is achieved.

The geometrical shape of the antenna has proved to be such that the longer parts **4** of the links cancel each other out almost completely, and the shorter parts **5** and connection parts **6** function as efficient radiation elements. From a functional point of view, parts **4** of the antenna are transmission lines which cause additional phase shift when moving to the next radiation element.

The direction of the main beam can be set at the desired angle at the middle frequency by dimensioning the parts so that parts **4** have a length of one wavelength and parts **5** and **6** are 0.25 – 0.75 wavelengths. The elevation angle $\theta$ of the radiation beam, measured as shown in FIG. **2**, is small when the length of radiation elements **5** and **6** is small, and large when the elements are long. When parts **5** and **6** have a length of 0.3 wavelengths, for example, the angle of elevation $\theta$ is approximately 48°, and when they are 0.4 wavelengths long the angle is 75°. The mathematical formula which gives the approximate direction of the beam is

$$\theta = \arccos\left[(n \cdot \lambda - 0.5 \cdot l_2)/l_1\right]$$

where $n$ is an integer, $\lambda$ is the wavelength, $l_1$ is the length of parts **5** and **6** and $l_2$ is the lengths of parts **4**.

A certain phase shift takes place between two adjacent radiating elements **5** and **6** due to the physical dimensions of the antenna. The electrical length between the beginning point of part **5** and the beginning part of the following part **6** can be increased or decreased artifically, thus altering the direction of the main beam at a certain frequency. Conventional electrotechnical methods of altering the phase shift can be used, such as using a variable series inductance or a shunt capacitance. The additional phase shift can also be made adjustable so that the direction of the beam can be remotely controlled without altering the frequency.

The frequency band of the antenna or, in other words, the frequency range over which the gain of the antenna is at its maximum can be increased by increasing the dimensions of links **3** and connection parts **6** continuously, so that the dimensions at one end of the antenna are smallest and they increase by approximately 2 percent in each link and in each intermediate element when moving towards the other end. Such a structure is shown in FIG. **5**.

The range of operating frequencies can also be increased by using the design shown in FIG. **6**. In every second link **3** and intermediate element **6** the lengths of the parts are 10 percent larger than in the adjacent links.

The width of the beam of the antenna, in the plane of the longitudinal antenna axis, can be adjusted by altering the total length of the antenna. A longer antenna gives a narrower beam than a short one. The width of the radiation beam in the direction perpendicular to the longitudinal axis can be narrowed conventionally, by connecting antennas in parallel to give an antenna array. The feed points of the various antenna elements are connected to each other using conventional parallel connecting methods for loads, for example with cables of equal length. Parallel antenna elements can also be located quite close to each other and interconnected

electrically as shown in FIG. 7. In this figure, the elements are connected by means of cables 8 of equal length to connection point 9, to which point generator 10 or the receiver is also connected. The parallel links 3 are connected to each other at points 11 in such a way that the distances between the parallel parts 5 are such that the characteristic impedance of the transmission line 12 made up of the parallel parts 5 and the ground plane 2 is half the characteristic impedance of the transmission line made up of parts 4 and the ground plane. The connections and the impedance requirements can also be achieved by the method shown in FIG. 8, in which the connections are made using parts 12 which have the same physical shape and dimensions as the connection parts 6 between the adjacent links.

The antennas shown in FIGS. 1 and 3 operate with linear polarization. Using two antennas in accordance with FIG. 3, in which the links 3 are parallelograms, elliptical polarization can be achieved, and two types of circular polarization as limit cases, as shown in FIG. 9. With two chain antennas in which the links 3 are parallelograms of similar shape but are inclined in opposing directions, the feeding points 7 are connected to connection point 9 by means of connection transmission lines 8 so that there is an additional phase shift element 13 in one of them. Measurements have shown that the radiation pattern of the antenna array shown in FIG. 9 is in the plane through the mirror image axis 14 of the antenna and, in general, is elliptically polarized. In the case where the acute angle $\alpha$ of the parallelograms is 45° and the additional phase shift is 13° ± 90°, the radiation is circularly polarized. For other values of $\alpha$ and additional phase shift, the radiation is elliptically or linearly polarized. Both of the oblique chains shown in FIG. 9 can also be replaced by antenna arrays formed, by means of parallel connections, of corresponding chain antennas.

When pure circular polarization is required, the direction of the radiation beam must also be taken into account. In general, the acute angle $\alpha$ of the parallelograms can be computed from the formula $\cot \alpha = \sin \theta$, where $\theta$ is the angle of elevation of the main radiation beam. For the antenna shown in FIG. 9, for example, the radiating elements 5 and 6 have a length of 0.4 wavelengths, parts 4 have a length of one wavelength, the angle of elevation $\theta$ is approximately 70° and the angle of inclination $\alpha$ is approximately 47°

According to FIG. 7, the parts 5 are interconnected at the end points 11 thereof whereas, according to FIG. 8, said parts 5 are interconnected along their entire length 12.

What I claim is:

1. A travelling wave chain antenna having a radiation beam, the direction of hwich can be varied by altering frequency, comprising:

a. a ground plane;

b. a plurality of four-sided links made of conducting material and being located in sequence to form a part of a chain structure, said links including longer and shorter sides;

c. a cable for feeding the antenna from one end, and including a first conductor connected to one end of the chain structure and a second conductor connected to the ground plane; and

d. connection parts arranged between the links and electrically connecting the center points of the longer side of each adjacent link, said connection parts being parallel to the shorter sides of the links and arranged in a common plane at least substantially orthogonal to the ground plane.

2. A chain antenna in accordance with claim 1 wherein the end of the antenna opposite said one end is open.

3. A chain antenna in accordance with claim 1 comprising a load impedance and wherein the end of the antenna opposite said one end is loaded with said load impedance which is connected between the end of the antenna and the ground plane.

4. A chain antenna in accordance with claim 1 wherein the links are arranged in a straight row, such that the connection parts are at right angles to the longer sides of the links.

5. A chain antenna in accordance with claim 1 wherein the links are arranged in an oblique row such that the connection parts are at an angle to the longer sides of the links.

6. A chain antenna in accordance with claim 1 wherein the connection parts are so constructed that the characteristic impedance of the transmission line formed by the connection parts and the ground plane is considerably smaller than the characteristic impedance of the transmission line formed by the sides of the links and the ground plane.

7. A chain antenna in accordance with claim 1 wherein, at the middle frequency of the operating range, the electrical length of the longer sides of the links is approximately one wavelength and the electrical length of the shorter sides and the connection parts between the links is approximately 0.25 to 0.75 wavelengths, and the distance of the chain structure from the ground plane is constant and approximately 0.1 wavelengths.

8. A chain antenna in accordance with claim 1 wherein the characteristic impedance of the transmission line formed by the connection parts between the links and the ground plane is half the characteristic impedance of the transmission line formed by the sides of the links and the ground plane.

9. A chain antenna in accordance with claim 1 wherein the radiating structure, consisting of the links and connection parts between the links and the ground plane are curved in relation to each other.

10. A wide band chain antenna in accordance with claim 1 wherein the lengths of the sides of the four-sided links and of the connection parts between the links increase sequentially so that each change in length is approximately 2 percent.

11. A wide band chain antenna in accordance with claim 1 wherein the shorter sides of the links in the antenna chain and the connection parts between the links are of length $l + l_1$ in every alternate link or link connection, and of length $l - l_1$ in the other alternate links or link connections, and wherein, at the middle frequency of the operating range, the longer parts of the links have a length of approximately 1 wavelength, $l$ having a length of approximately half a wavelength and $l_1$ generally having a length of between 0.05 and 0.40 wavelengths, the larger value of $l_1$ giving an antenna of wide bandwidth and the smaller value giving an antenna of narrower bandwidth.

12. A chain antenna in accordance with claim 1 wherein the links are parallelograms.

13. A chain antenna in accordance with claim 1 wherein the distance of the ground plane from the radiating structure increases in such a manner that the distance is at its smallest at said one end and at its greatest at the opposite end of the antenna, so that the distance of the ground plane from the radiating structure can vary from 0.05 wavelengths to 0.30 wavelengths depending on the total length of the chain.

14. An antenna array comprising a plurality of chain antennas in accordance with claim 1 wherein the adjacent antenna chains are electrically connected to each other at the shorter sides of the adjacent links so that the characteristic impedance of the transmission line formed by the common sides of the links and the ground plane is approximately half the characteristic impedance of the transmission line formed by the longer sides of the links and the ground plane and that the said one ends of the parallel chains are connected to the generator when transmitting or to the receiver for reception by means of conventional parallel coupling methods for loads.

15. An antenna array in accordance with claim 14 wherein the connection parts between the successive and adjacent links are similar.

16. An antenna array consisting of chain antennas in accordance with claim 12 wherein elliptical polarization, and its limit cases, both circular polarization and linear polarization, are achieved using two said antennas consisting of links of parallelogram shape, in which the parallelograms are identical and the longer sides of the parallelograms are parallel to each other, the shorter sides being approximately perpendicular to each other and the antennas being mirror images of each other in relation to an axis which is perpendicular to the longer sides of the parallelograms, these being parallel to each other, and in which the said one ends of the antennas are connected to the connection point by means of transmission lines, one of which includes a phase shift element which causes a fixed or adjustable phase shift between the parts in the antenna array having different directions.

17. An antenna array consisting of chain antennas in accordance with claim 13 wherein elliptical polarization, and its limit cases, both circular polarizations and linear polarization, are achieved using two said antennas consisting of links of parallelogram shape, in which the parallelograms are identical and the longer sides of the parallelograms are parallel to each other, the shorter sides being approximately perpendicular to each other and the antennas being mirror images of each other in relation to an axis which is perpendicular to the longer sides of the parallelograms, these being parallel to each other, and in which the said one ends of the antennas are connected to the connection point by means of transmission lines, one of which includes a phase shift element which causes a fixed or adjustable phase shift between the parts in the antenna array having different directions.

* * * * *