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(71) Applicant: **MASSACHUSETTS INSTITUTE OF TECHNOLOGY** [US/US]; 77 Massachusetts Avenue, Cambridge, MA 02139 (US).

(72) Inventor: **FENN, Alan, J.**; 4 Sherman Bridge Road, Wayland, MA 01778 (US).

(74) Agents: **CONNORS, Matthew, E.** et al.; Samuels, Gauthier & Stevens, LLP, 225 Franklin Street, Suite 3300, Boston, MA 02110 (US).

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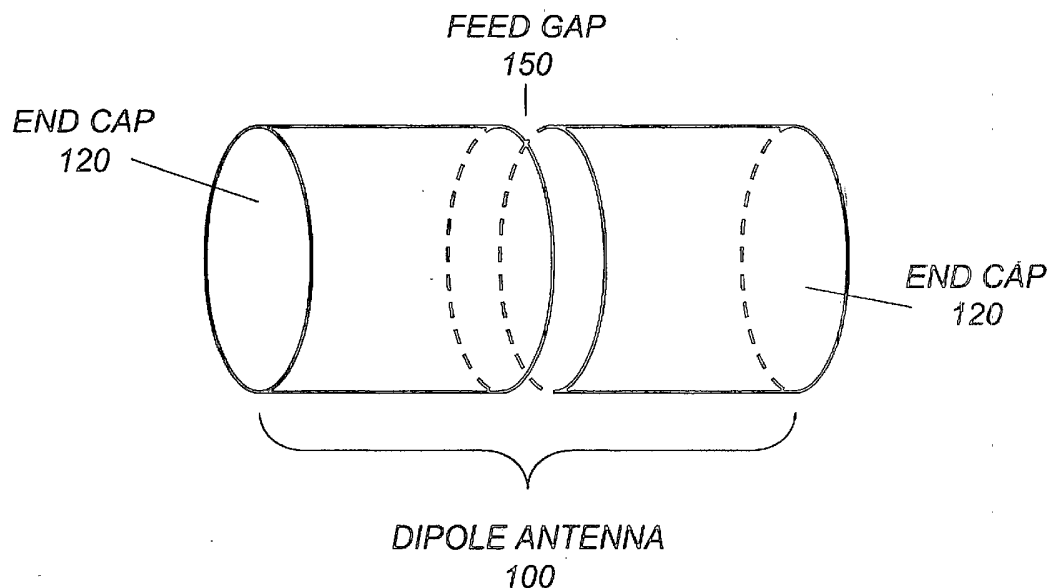
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(54) Title: **WIDEBAND DIPOLE ARRAY ANTENNA ELEMENT**



(57) Abstract: A linearly polarized wideband dipole array antenna element capable of operating up to approximately 5:1 to 10:1 or more in bandwidth for receive and/or transmit wireless communications applications is provided. The antenna element includes multiple large-diameter cylindrical tubular dipole elements that are very closely spaced. The internally fed dipoles have flat end caps and the close spacing increases the mutual coupling between dipoles to improve the low frequency performance.

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WIDEBAND DIPOLE ARRAY ANTENNA ELEMENT

SPONSORSHIP INFORMATION

This invention was made with government support under Grant No. F19628-00-
5 C-0002 awarded by the U.S. Air Force. The government has certain rights in the invention.

PRIORITY INFORMATION

This application claims priority from provisional application Ser. No.
10 60/396,427 filed July 17, 2002, which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

The invention generally relates to a wideband dipole array antenna to be used in
15 wideband wireless communications applications.

Little published information exists for wideband phased array antennas covering greater than an octave (2:1) bandwidth. A recent paper by Hansen [R.C. Hansen, Dipole array scan performance over a wide-band, IEEE Transactions on Antennas and Propagation, vol. 47, no. 5, 1999, pp. 956-957] has a theoretical analysis of short thin
20 dipole elements in a 5:1 bandwidth array. However, no experimental designs or data on practical wideband phased arrays covering 5:1 or greater bandwidth has been published, and there appear to be no references for fat tubular dipole elements with internal feeding in a wideband array as provided by the invention. The terms wideband, very wideband, and ultrawideband (as commonly used in the literature) are
25 understood to be equivalent in this invention.

SUMMARY OF THE INVENTION

A new design for a linearly polarized wideband dipole array antenna element capable of operating up to approximately 5:1 to 10:1 or more in bandwidth for receive
30 and/or transmit wireless communications applications is provided. The design makes use of multiple large-diameter cylindrical tubular dipole elements that are very closely spaced. The internally fed dipoles have flat end caps and the close spacing increases

the mutual coupling between dipoles to improve the low frequency performance.

Applications of the invention include wideband reception and/or transmission of microwave signals such as those approximately in the 400 to 2000 MHz frequency range for wireless telecommunications. Applications include mobile telephone (453 to 468 MHz), analog cellular telephone (824 to 960 MHz), digital cellular telephone (824 to 1880 MHz), and personal communications systems (1850 to 1990 MHz). These frequencies span 453 to 1990 MHz or a frequency ratio of 4.4:1, possibly requiring multiple antennas. The wideband dipole array design introduced here is capable of covering this large bandwidth in a single antenna. The design is compatible with field deployment for example on a cell tower, over a ground plane, or within a non-conducting fiberglass or plastic pole or rail.

A dipole array antenna provides wideband wireless radiofrequency (RF) communications capability. The dipole antenna elements can be connected to a module and transmission line via a coaxial connector internal to one half of the dipole element.

The dipole antenna elements are tubular and are fabricated from a conducting material such as brass or aluminum with a diameter sufficient to contain the module, transmission line, and coaxial connector as well as achieve the desired bandwidth. The modules can contain electronic components, suitable for transmitting or receiving microwave communications signals, such as low noise amplifiers, power amplifiers, filters, phase shifters, switches, and resistive or reactive loads for impedance matching.

The dipole phased array antenna can be linear or planar and can be operated either horizontal or vertical to a conducting ground plane or without a ground plane. The dipoles can be bent as in the case of a v-shaped dipole with or without a ground plane. The communications signals can be transmitted or received from a single dipole element of the array or from multiple dipole elements of the array either coherently or non-coherently.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of a single dipole antenna for wideband phased array applications;

Figure 2 is a block diagram of a single dipole antenna with a slot in one half of the tubular dipole section to provide an entry or exit point for a transmission line;

Figure 3 is a block diagram of a single dipole antenna with a hole in one half of the tubular dipole section to provide an entry or exit point for a transmission line;

Figure 4 is a block diagram view of a single dipole antenna with a hole in one end cap of the dipole to provide an entry or exit point for a transmission line;

5 Figure 5 is a schematic diagram of a single dipole antenna with a coaxial connector, module, and transmission line passing through the tubular surface of the dipole;

Figure 6 is a schematic diagram of a single dipole antenna with a coaxial connector, module, and transmission line passing through the end cap of the dipole;

10 Figure 7 is a schematic diagram of a wideband array in a linear configuration in which the dipole elements are closely spaced such that they are nearly touching one another;

Figure 8 is a schematic diagram of a wideband array in a planar configuration in which the dipole elements are closely spaced in the x dimension (such that they are nearly touching one another) and the elements are spaced approximately one-half wavelength at the maximum frequency in the y dimension;

15 Figure 9 is a schematic diagram of a wideband array in a linear configuration in which the dipole elements are parallel to a conducting ground plane, wherein the spacing H between the dipoles and the ground plane is approximately one-quarter wavelength at the maximum operating frequency;

Figure 10 is a schematic diagram of a wideband array in a linear configuration in which the dipole elements are perpendicular to a conducting ground plane, wherein the minimum spacing V between the first dipole in the array and the ground plane is approximately one-quarter wavelength at the maximum operating frequency;

25 Figure 11 is a schematic diagram of a wideband array in a linear configuration in which the dipole elements are perpendicular to a conducting ground plane, but with the first dipole being approximated by a half dipole or monopole;

Figure 12 is a block diagram of a cell tower containing a number of communications antennas including wideband dipole arrays;

30 Figure 13 is a schematic diagram of a wideband dipole array element designed to operate from UHF to S-band frequencies;

Figure 14 is a schematic diagram of a seven-element wideband dipole array

designed to operate from UHF to S-band frequencies over an approximate 5:1 bandwidth (500 MHz to 2500 MHz);

Figure 15 is a graph of the measured voltage standing wave ratio (VSWR) for a single isolated fat tubular dipole antenna over the band 200 MHz to 2500 MHz. The 3 dB bandwidth is approximately 1 GHz;

Figure 16 is a graph of the measured voltage standing wave ratio (VSWR) for the center fat tubular dipole antenna in a seven-element dipole array over the band 200 MHz to 2500 MHz, wherein the 3 dB bandwidth is approximately 2 GHz, or double that of a single isolated fat dipole element;

Figure 17 is a Smith Chart graph of the measured input impedance for a single isolated fat tubular dipole antenna;

Figure 18 is a Smith Chart graph of the measured input impedance for the center fat tubular dipole antenna in a seven-element dipole array, wherein the input impedance data are pulled in towards the center of the Smith Chart indicating an improvement in impedance match compared to the data in Figure 17;

Figure 19 is a graph of the radiation pattern for the center dipole antenna in the seven-element dipole array at 500 MHz;

Figure 20 is a graph of the radiation pattern for the center dipole antenna in the seven-element dipole array at 1 GHz;

Figure 21 is a graph of the radiation pattern for the center dipole antenna in the seven-element dipole array at 2.5 GHz;

Figure 22 is a graph of the theoretical and measured peak gain for the center dipole antenna in the seven-element dipole array over the frequency band 500 MHz to 2500 MHz, wherein the measured data are in good agreement with the theory;

Figure 23 is a graph of the measured mutual coupling amplitude from the center element to an adjacent element and an element next to the adjacent element, wherein from 500 MHz to 2500 MHz the mutual coupling is fairly constant indicating broadband behavior;

Figure 24 is a schematic diagram of a wideband array of dipoles contained within a fiberglass or plastic tube;

Figure 25 is a schematic diagram of a dipole element with a tapered feed region;

Figure 26 is a block diagram of a v-shaped dipole element;

Figure 27 is a block diagram of an alternate wideband dipole array configuration in which the tips of v-shaped dipoles are nearly touching;

Figure 28 is a block diagram of a wideband v-dipole array over a conducting ground plane;

5 Figure 29 is a block diagram of a single wideband tubular monopole element with a conducting ground plane; and

Figure 30 is a block diagram of a single wideband tapered monopole element with a conducting ground plane.

10 DETAILED DESCRIPTION OF THE INVENTION

Figure 1 is a block diagram of a large diameter (fat) tubular dipole antenna element **100**. In the context of this invention, the terms “large diameter” and “fat” refer to an antenna element with diameter equal to or greater than approximately one-tenth of a wavelength at the highest electromagnetic frequency of operation. Each half of the dipole is a conducting tube with flat end caps **120** and a feed gap region **150**.
15 The preferred cross section of the individual dipoles is circular to achieve omnidirectional coverage, but the dipole cross-section may also be square or rectangular. A continuous wave (CW) or other time-varying signal voltage is applied across the feed gap region, inducing a time-varying current that gives rise to
20 electromagnetic radiation for wireless transmission. For wireless reception, an incident time-varying electromagnetic wave signal induces a time-varying electric current on the dipole and a time-varying voltage across the feed gap.

In order to transfer microwave signals to or from a module located internal to one dipole half, a slot **130** as in Figure 2 or a hole **140** in the side of the dipole as in
25 Figure 3 is located in the side of the dipole near the end cap. Figure 2 is a block diagram of a single dipole antenna with a slot in one half of the tubular dipole section to provide an entry or exit point for a transmission line, and Figure 3 is a block diagram of a single dipole antenna with a hole in one half of the tubular dipole section to provide an entry or exit point for a transmission line.

30 Alternately, microwave signals can be transferred to or from the dipole through a hole **145** in the end cap as in Figure 4. Figure 4 is a block diagram view of a single dipole antenna with a hole in one end cap of the dipole to provide an entry or exit point

for a transmission line.

Figure 5 is a schematic diagram of a single dipole antenna with a coaxial connector, module, and transmission line passing through the tubular surface of the dipole. In Figure 5, a microwave coaxial connector **300** flange is grounded to one of the feed gap **150** poles and the center pin is attached to the pole of the other half of the dipole – the center pin **301** may be soldered to the dipole half or it may be threaded and the dipole half screwed onto the center pin. Module **500** contains electronic components that may include low-noise amplifiers, power amplifiers, filters, phase shifters, and switches. Feedline **310** extends through the sidewall of the dipole antenna **100**. The feed gap poles are separated by the distance g . The dipole diameter is denoted d and the length L . Figure 6 is a schematic diagram of a single dipole antenna with a coaxial connector, module, and transmission line passing through the end cap of the dipole. Figure 6 is similar to Figure 5, except that the feedline **310** extends through the end cap.

Figure 7 is a schematic diagram of a wideband array in a linear configuration in which the dipole elements are closely spaced such that they are nearly touching one another. The N -element wideband dipole array antenna as shown schematically in Figure 7 uses a segmented approach with closely-spaced fat tubular dipole antenna elements with flat end caps as in Figure 5 and Figure 6 to achieve the desired wideband receive antenna gain. Each dipole has length L , diameter d , and feed region gap spacing denoted as g . A receiver or transmitter can be connected to the coaxial feedline attached to the center gap poles. The communications signals can be transmitted or received from a single dipole element of the array or from multiple dipole elements of the array either coherently as a phased array or non-coherently as a switched array.

In a wideband array, the spacing between the tips of adjacent dipoles (denoted as t) is very small, that is, t is a very small fraction of a wavelength. The center-to-center spacing between the dipoles is denoted s . The dipole segments form one-half wavelength dipoles at the high frequency edge of the band. At the low frequency of the band, the dipoles are electrically short in proportion to the change in frequency. At low frequency with close element spacing the mutual coupling (defined as the ratio of received to transmitted signal) between the dipole segments is strong, which makes the center (or embedded) element effectively longer – current does not go to zero at the

ends of the dipole as normally is the case for an isolated dipole. The wideband dipole array antenna is arranged in a co-linear array that can be extended to an arbitrary length.

Adjacent collinear arrays can be used to form a two-dimensional aperture of M rows and N columns with element spacings s_x and s_y as depicted in Figure 8. Figure 8 is a schematic diagram of a wideband array in a planar configuration in which the dipole elements are closely spaced in the x dimension (such that they are nearly touching one another) and the elements are spaced approximately one-half wavelength at the maximum frequency in the y dimension.

The dipole array can be placed parallel to a conducting ground plane **400** at a distance h over the ground plane, as shown in Figure 9. Figure 9 is a schematic diagram of a wideband array in a linear configuration in which the dipole elements are parallel to a conducting ground plane, wherein the spacing H between the dipoles and the ground plane is approximately one-quarter wavelength at the maximum operating frequency. The ground plane **400** in Figure 9 is depicted flat and the shape can either be circular, elliptical, square, or rectangular; however, the ground plane can also be concave or convex. If the ground plane is curved into a parabolic cylinder a two dimensional aperture with a directional radiation pattern can be formed using a co-linear array or planar array as a wideband feed at the focal point of the parabolic cylinder.

The dipole array can also be placed perpendicular to a conducting ground plane, in which the first element of the array is positioned a distance v over the ground plane as shown in Figure 10. Figure 10 is a schematic diagram for a wideband array in a linear configuration in which the dipole elements are perpendicular to a conducting ground plane, wherein the minimum spacing v between the first dipole in the array and the ground plane is approximately one-quarter wavelength at the maximum operating frequency.

Alternately, the first element of the dipole array can be one-half of a dipole (referred to as a monopole **501**) with its feed gap at the ground plane as shown in Figure 11. Figure 11 is a schematic diagram for a wideband array in a linear configuration in which the dipole elements are perpendicular to a conducting ground plane, but with the first dipole being approximated by a half dipole or monopole. In this case the

microwave connector **300** and module **500** for the first element are located behind the ground plane.

Figure 12 is a block diagram of a cell tower containing a number of communications antennas including wideband dipole arrays. The wireless communications example includes one or more wideband dipole arrays **200** are located on a cell tower **600**. Wireless applications include wideband reception and/or transmission of microwave signals such as those in the 400 to 2000 MHz frequency range for wireless telecommunications. Applications include mobile telephone (453 to 468 MHz), analog cellular telephone (824 to 960 MHz), digital cellular telephone (824 to 1880 MHz), and personal communications systems (1850 to 1990 MHz). These frequencies span 453 to 1990 MHz or a frequency ratio of 4.4:1, often requiring multiple antennas to fully cover the band. The wideband dipole array concept disclosed here is capable of covering this large bandwidth in a single antenna. Other applications include those described in Federal Communications Commission document FCC 02-48, First Report and Order, Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems, Adopted February 14, 2002, Release date April 22, 2002. The term wideband in this invention is used equivalently with the FCC's term ultra-wideband.

For example, in an array operating over 5:1 in bandwidth, the individual fat dipoles of this invention are approximately one-half wavelength long at the high frequency and only about one-tenth of a wavelength at the low frequency. A typical high microwave frequency would be on the order of 2.5 GHz, and the corresponding 5:1 low frequency would then be 500 MHz. The dipoles have flat end caps and are spaced very close in order to increase the mutual coupling between dipoles, which enhances the effective length and gain of the dipoles over the low frequency in particular as well as over the entire operating bandwidth.

In this 5:1 wideband array element example, there are 5 dipoles and all 5 dipoles are used to receive microwave energy over the operating bandwidth 500 MHz to 2.5 GHz. The electrical length of each dipole element is one-half wavelength at 2.5 GHz, and the total length of 5 dipoles at 500 MHz is also approximately one-half wavelength. The dipole antenna element peak gain of each of the 5 dipoles is approximately 1.5 to 2.0 dBi at 2.5 GHz taking account of mutual coupling effects in

the small 5-element array. Without mutual coupling, the theoretical peak gain of a one-half wavelength dipole is 2.1 dBi. As the dipole length decreases below one-half wavelength, the effective gain or efficiency of the dipole antenna will decrease.

In theory the effective gain of an isolated dipole antenna with 2 dBi gain at 2.5
 5 GHz would be significantly lower at 500 MHz due to the decrease in antenna electrical length and very low value of input resistance. However, with mutual coupling in a closely spaced array, the gain (efficiency) will increase significantly. This wideband dipole array antenna offers significant improvement in radiation pattern gain over existing dipole antenna designs. The wideband dipole array antenna is compact in
 10 terms of the radius of each tubular antenna element. Doubling the number of dipoles in the array would, in theory, double the antenna bandwidth.

From basic antenna theory, for an electrically short thin dipole antenna the maximum effective aperture is equal to $0.119 \lambda^2$ [see J.D. Kraus, *Antennas, 2nd Edition*, 1988, McGraw-Hill, p. 44]. Similarly a one-half wavelength thin dipole has a
 15 maximum effective aperture equal to $0.13 \lambda^2$. Thus, the maximum effective aperture of a short dipole (rounded off to $0.12 \lambda^2$) and a one-half wavelength dipole (rounded to $0.13 \lambda^2$) are within 10% of each other and can be neglected for a first-order analysis. The so-called effective height of a short dipole is approximately equal to the electrical length of the short dipole. The power received by an antenna is proportional to the
 20 effective aperture of the antenna. The antenna gain G is equal to the product of the antenna efficiency η and directivity D . The effective antenna gain is reduced by any mismatch loss in the feedline to antenna terminals connection. The antenna effective aperture is equal to the antenna efficiency η times the maximum effective aperture A_{em} .
 Thus, the power received by an antenna is proportional to the antenna efficiency times
 25 the maximum effective aperture.

The antenna efficiency takes account of the losses in the antenna. The antenna efficiency can be calculated from the ratio of the antenna radiation resistance to the total input resistance [see W.L. Weeks, *Antenna Engineering*, McGraw-Hill, 1968, p. 31]. The total input resistance is the sum of the radiation resistance plus all the resistance
 30 associated with dissipative losses. The gain of an antenna can be expressed as

$$G = 4\pi A_{em} \eta / \lambda^2 \quad (1)$$

Since the maximum effective aperture of a dipole in square wavelengths does

not vary significantly, the maximum effective aperture of the dipole can be approximated as $0.125 \lambda^2$. Thus, the gain relation for a dipole antenna is given approximately as

$$G = \pi \eta / 2 \quad (2)$$

5 which simplifies to

$$G = 1.57 \eta \quad (3)$$

where the efficiency η depends on the dipole electrical length.

An electrically short dipole antenna in free space has poor efficiency and low effective gain. The efficiency is expected to be reduced linearly as the frequency
10 decreases from the one-half wavelength resonance frequency of the dipole antenna. The efficiency and gain of an electrically short linear antenna can be improved by surrounding the antenna with an array of antennas, which effectively increases the length of the antenna. For a dipole array in free space, it has been pointed out by Hansen that the input resistance of an isolated dipole is close to 2 ohms, whereas the
15 resistance for broadside scan for close dipole spacing (0.1 wavelengths) is 76 ohms.

The efficiency of an isolated dipole antenna can be calculated as follows [see W.L. Stutzman and G.A. Thiele, Antenna Theory and Design, Second Edition, John Wiley, New York, 1998, pp. 43-48.]. The radiation efficiency of an antenna is expressed as

$$20 \quad e = R_r / R_A \quad (4)$$

where R_r is the radiation resistance and

$$R_A = R_r + R_{ohmic} \quad (5)$$

is the total input resistance of the antenna.

The ohmic resistance for a dipole of length L and diameter D is given by

$$25 \quad R_{ohmic} = L R_s / (3 \pi D) \quad (6)$$

where $R_s = \sqrt{\pi f \mu / \sigma}$ is the surface resistance of the dipole which depends on the frequency f , permeability μ , and electrical conductivity σ of the dipole material.

Thus, since the ohmic resistance is inversely proportional to the dipole diameter, to reduce the ohmic resistance and increase the efficiency a larger diameter
30 dipole can be used.

Further, the reactive part of the input impedance of an electrically short antenna can be large, which leads to stored energy in the near field region surrounding the

antenna and reduces the overall efficiency. A tuning circuit is often used in reducing the reactive component of the input impedance.

Figure 13 is a schematic diagram of a prototype wideband dipole array antenna element designed to operate from UHF to S-band frequencies to cover the 500 to 2500
5 MHz band (5:1 bandwidth) when embedded in an array of like dipoles. The wideband dipole element has a 1.905 cm outer diameter and 5.59 cm length including an air gap feed region. Each dipole segment consists of two monopole conducting segments fabricated using brass tubing. Seven of these dipole antenna segments were assembled into a seven-element antenna array as depicted in Figure 14. Figure 14 is a schematic
10 diagram of a seven-element wideband dipole array designed to operate from UHF to S-band frequencies over an approximate 5:1 bandwidth (500 MHz to 2500 MHz).

A Teflon dielectric spacer 0.127 cm in thickness separated each of the dipole elements. A 0.254 cm air gap was used in the dipole feed region. A standard SMA coaxial connector with the center pin extended across the air gap and soldered to the
15 dipole segment was used to feed the dipole in a concentric coaxial balanced mode. Since the total length of the seven-element dipole array antenna is 39.88 cm (15.7 inches), then at 500 MHz (wavelength is 60 cm) the effective electrical length with strong mutual coupling is $39.88/60=0.66$ wavelengths. A short slot approximately 0.254 cm wide was cut at the edge of the center dipole and a right-angle coaxial cable
20 (RG-085) was used to attach to the dipole element microwave SMA connector. The antenna array was supported horizontally by a styrofoam cradle for testing purposes with the antenna elements and dielectric spacers pressed tightly together. Swept-frequency return loss (reflection) and input impedance measurements over the 200 to 2500 MHz band and pattern gain measurements over the 500 to 2500 MHz band were
25 conducted in an anechoic chamber at Lincoln Laboratory.

For purposes of comparing the bandwidth performance of a single dipole and the center element of the 7-element array, let the bandwidth be defined by a maximum voltage-standing-wave ratio $VSWR = 6:1$, which corresponds to approximately a -3 dB return loss (20 times $\log_{10}$ of the reflection coefficient) or a 3 dB mismatch loss. Under
30 this 3 dB mismatch loss condition, 50% of the power is transmitted and 50% is reflected.

Measured results for the VSWR and input impedance for a single dipole and the

center dipole element of the 7-element array are shown in Figures 15 to 18. Figure 15 is a graph of the measured voltage standing wave ratio (VSWR) for a single isolated fat tubular dipole antenna over the band 200 MHz to 2500 MHz. The 3 dB bandwidth is approximately 1 GHz. Figure 16 is a graph of the measured voltage standing wave ratio (VSWR) for the center fat tubular dipole antenna in a seven-element dipole array over the band 200 MHz to 2500 MHz, wherein the 3 dB bandwidth is approximately 2 GHz, or double that of a single isolated fat dipole element. Figure 17 is a Smith Chart graph of the measured input impedance for a single isolated fat tubular dipole antenna. Figure 18 is a Smith Chart graph of the measured input impedance for the center fat tubular dipole antenna in a seven-element dipole array, wherein the input impedance data are pulled in towards the center of the Smith Chart indicating an improvement in impedance match compared to the data in Figure 17.

For the center element of the 7-element array, VSWR measurements (Figure 16) show a $VSWR < 6:1$ over the band 550 to 2500 MHz, with reduced performance below 550 MHz for this design. Thus the VSWR bandwidth of the embedded dipole in a 7-element array is about 4.5:1. In contrast, the isolated dipole bandwidth in Figure 15 is only 1.4 to 2.5 GHz or 1.8:1. The input impedance measurements for the center element of the 7-element array shown Figure 18 will be useful in improving the impedance match and bandwidth by tuning.

Radiation patterns normalized to 0 dB at the peak for the center embedded dipole element are shown in Figures 19 to 21. Figure 19 is a graph of the radiation pattern for the center dipole antenna in the seven-element dipole array at 500 MHz. Figure 20 is a graph of the radiation pattern for the center dipole antenna in the seven-element dipole array at 1 GHz. Figure 21 is a graph of the radiation pattern for the center dipole antenna in the seven-element dipole array at 2.5 GHz.

The absolute peak gain (in dBi) for the center embedded dipole element versus frequency is summarized in Figure 22. Figure 22 is a graph of the theoretical and measured peak gain for the center dipole antenna in the seven-element dipole array over the frequency band 500 MHz to 2500 MHz, wherein the measured data are in good agreement with the theory. The measured peak gain is approximately -4 dBi at 500 MHz and increases nearly linearly (as indicated by the solid line curve fit) to about 1.7 dBi at 2500 MHz, close to the theoretical peak gain of 2.1 dBi for an isolated dipole.

For the 7-element array with element number 1, 2, 3, 4, 5, 6, 7, the mutual coupling between the center dipole (dipole 4) and one (dipole 3) and two (dipole 2) elements away is shown in Figure 23. Figure 23 is a graph of the measured mutual coupling amplitude from the center element to an adjacent element and an element next to the adjacent element, wherein from 500 MHz to 2500 MHz the mutual coupling is fairly constant indicating broadband behavior. The amplitude of the mutual coupling is flat (within about plus or minus 2 dB) over the band 500 MHz to 2500 MHz, indicating wideband behavior is achieved.

The preliminary measurements indicate that enhanced dipole bandwidth can be achieved by arraying collinear fat dipole antennas with very close tip-to-tip spacing, compared to the bandwidth of an isolated fat dipole. The experimental prototype element exhibits an impedance and pattern gain bandwidth of 4.5:1. An even closer tip-to-tip spacing could help increase the bandwidth for a given number of dipole elements. Additional dipole elements, fatter dipoles, shaping of the feed region, and dielectric loading of the outer diameter of the dipoles also could help increase the bandwidth and lower the operating frequency for a given diameter. Further enhancement of the dipole bandwidth can be achieved by impedance matching techniques [see, for example, R.L. Thomas, *A practical introduction to impedance matching*, Artech House, Dedham, Massachusetts, 1976]. The preliminary results suggest that a bandwidth of about 5:1 may be approached in a closely spaced array with approximately 7 dipole elements. Mutual coupling measurements between dipoles will also be useful in analyzing the effects of close dipole spacing on the bandwidth.

Figure 24 is a schematic diagram of a wideband array of dipoles contained within a fiberglass or plastic tube. In field deployment, the wideband dipole array could be mounted within a fiberglass or plastic tube **900** with a means such as fiberglass or plastic end caps **910** for holding the antenna elements together closely spaced as depicted in Figure 24. The antennas and dielectric spacers may be attached together using adhesive materials and foam **920** to fill the tube.

Figure 25 is a schematic diagram of a dipole element with a tapered feed region. In this embodiment, the feed region of the dipoles **102** can have a shaped or tapered gap **151** described by the parameters g_1 , g_2 , and d_1 in order to improve the VSWR - the taper can be linear or curved in general.

Figure 26 is a block diagram of a v-shaped dipole element. In this embodiment, the arms of the dipole can be bent into the shape of a V, known as a v-dipole antenna 101. Bending the arms can broaden the antenna radiation pattern.

A wideband array of v-dipoles, as shown in Figure 27, will have a very small gap 250 between the ends of the v-dipoles. Figure 27 is a block diagram of an alternate wideband dipole array configuration in which the tips of v-shaped dipoles are nearly touching.

The v-dipole array can be placed a distance h over a conducting ground plane 400 as shown in Figure 28. Figure 28 is a block diagram of a wideband v-dipole array over a conducting ground plane.

In another embodiment, for some applications such as a handset antenna 700 in Figure 12 a single tubular monopole over a ground plane may be suitable as a wideband antenna element as depicted in Figure 29. The wideband monopole element may be tapered as shown in Figure 30. Tapered or conical shaped monopoles have been used in the transmission and reception of wideband signals [R.H.T. Bates and G.A. Burrell, Towards faithful radio transmission of very wide bandwidth signals, IEEE Transactions on Antennas and Propagation, vol. AP-20, no. 6, November 1972, pp. 684-690. J.G. Maloney and B.L. Shirley, Physical description for the reception of short pulses by antennas, IEEE Antennas and Propagation International Symposium Digest, Volume: 3, 20-24 June 1994, pp. 1790-1793.]

While the invention has been particularly shown and described with references to illustrated embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. For instance, the apparatus described herein is applicable from low RF frequencies (approximately 10 MHz) to high microwave frequencies (approximately 10 GHz). Further, the invention is applicable to medical applications such as microwave thermotherapy and imaging.

Although the present invention has been shown and described with respect to several preferred embodiments thereof, various changes, omissions and additions to the form and detail thereof, may be made therein, without departing from the spirit and scope of the invention.

What is claimed is:

CLAIMS

- 1 1. A wideband antenna system comprising an array of closely spaced large-diameter
2 tubular dipole antenna elements with flat end caps, wherein said large-diameter tubular
3 dipole antenna elements have a diameter greater than approximately one-tenth of a
4 wavelength at the highest operating frequency.
- 1 2. The system of claim 1, wherein said dipole antenna elements are approximately one-
2 half wavelength long at the highest operating frequency and one-twentieth of a
3 wavelength at the lowest operating frequency.
- 1 3. The system of claim 1, wherein said dipole antenna elements have a diameter
2 approximately 0.15 wavelengths at the highest operating frequency and 0.015
3 wavelengths at the lowest operating frequency.
- 1 4. The system of claim 1, wherein said operating frequency range is from
2 approximately 250 MHz to 2.5 GHz.
- 1 5. The system of claim 1, wherein said dipole antenna elements are approximately
2 circular or square in cross section.
- 1 6. The system of claim 1, wherein said dipole antenna elements are elliptical or
2 rectangular in cross section.
- 1 7. The system of claim 1, wherein said dipole antenna elements are hollow and the
2 dipole feedline connection is with a standard sub-miniature coaxial connector located
3 within the hollow portion of the dipole.
- 1 8. The system of claim 1, wherein said dipole antenna elements comprise a metallic
2 electrical conducting material.
- 1 9. The system of claim 1, wherein said dipole antenna elements form a linear array.
- 1 10. The system of claim 1, wherein said dipole antenna elements are 5.59 cm long for
2 operating in an array over the frequency band 250 MHz to 2500 MHz.
- 1 11. The system of claim 1, wherein said dipole antenna elements have a center feed

- 2 gap distance of in the range of 0.1 to 0.3 cm.
- 1 12. The system of claim 1, wherein said dipole antenna elements have a center feed
2 gap distance of 0.254 cm.
- 1 13. The system of claim 1, wherein said dipole antenna elements have a center feed
2 gap region filled with air or dielectric material.
- 1 14. The system of claim 1, wherein the center feed gap region dielectric material is
2 Teflon or an acrylic.
- 1 15. The system of claim 1, wherein said dipole antenna elements have flat conducting
2 end caps attached to the ends of the dipoles.
- 1 16. The system of claim 1, wherein the ends of adjacent dipoles are separated by an air
2 or dielectric-filled gap region in the range of 0.01 to 0.5 cm.
- 1 17. The system of claim 1, wherein the dielectric material separating adjacent dipoles
2 is Teflon, acrylic, or polystyrene foam.
- 1 18. The system of claim 1, wherein a coaxial cable connects to the module or coaxial
2 connector feeding the dipole element.
- 1 19. The system of claim 18, wherein the coaxial cable passes through an opening
2 proximate to the end of the dipole.
- 1 20. The system of claim 1, wherein a receiver module is coupled to the coaxial
2 connector feeding the dipole.
- 1 21. The system of claim 20, wherein the receiver module comprises components
2 including power amplifiers, low noise amplifiers, filters, switches, phase shifters, and
3 resistive or reactive loads for impedance matching.
- 1 22. The system of claim 1, wherein said dipole antenna elements form a planar array.
- 1 23. The system of claim 1, wherein said dipole antenna elements form a planar array
2 parallel to a conducting ground plane.

- 1 24. The system of claim 1, wherein the dipole antenna elements are parallel to a
2 conducting ground plane.
- 1 25. The system of claim 1, wherein the dipole antenna elements are perpendicular to a
2 conducting ground plane.
- 1 26. The system of claim 1, wherein the wideband dipole array is used for wireless
2 telecommunications.
- 1 27. The system of claim 1, wherein the wideband dipole array antenna is mounted
2 within a dielectric tube or pole fabricated from fiberglass or plastic.
- 1 28. The system of claim 1, wherein the wideband dipole array elements are tapered
2 instead of tubular.
- 1 29. The system of claim 1, wherein the wideband dipole array elements are located at
2 the focus of a parabolic cylinder to form a directional radiation pattern.
- 1 30. The system of claim 1, wherein the wideband array element is a monopole with a
2 conducting ground plane.

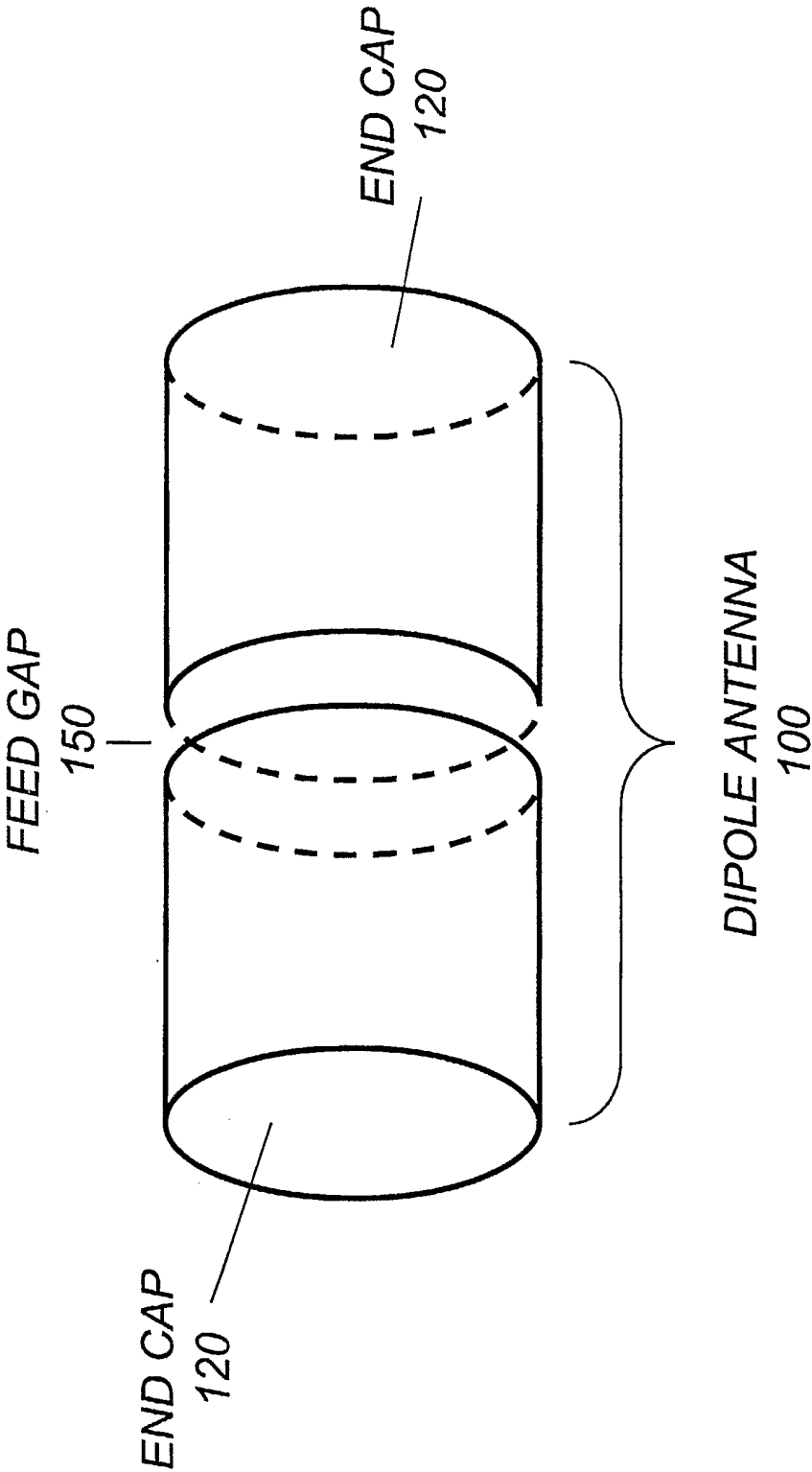


Figure 1

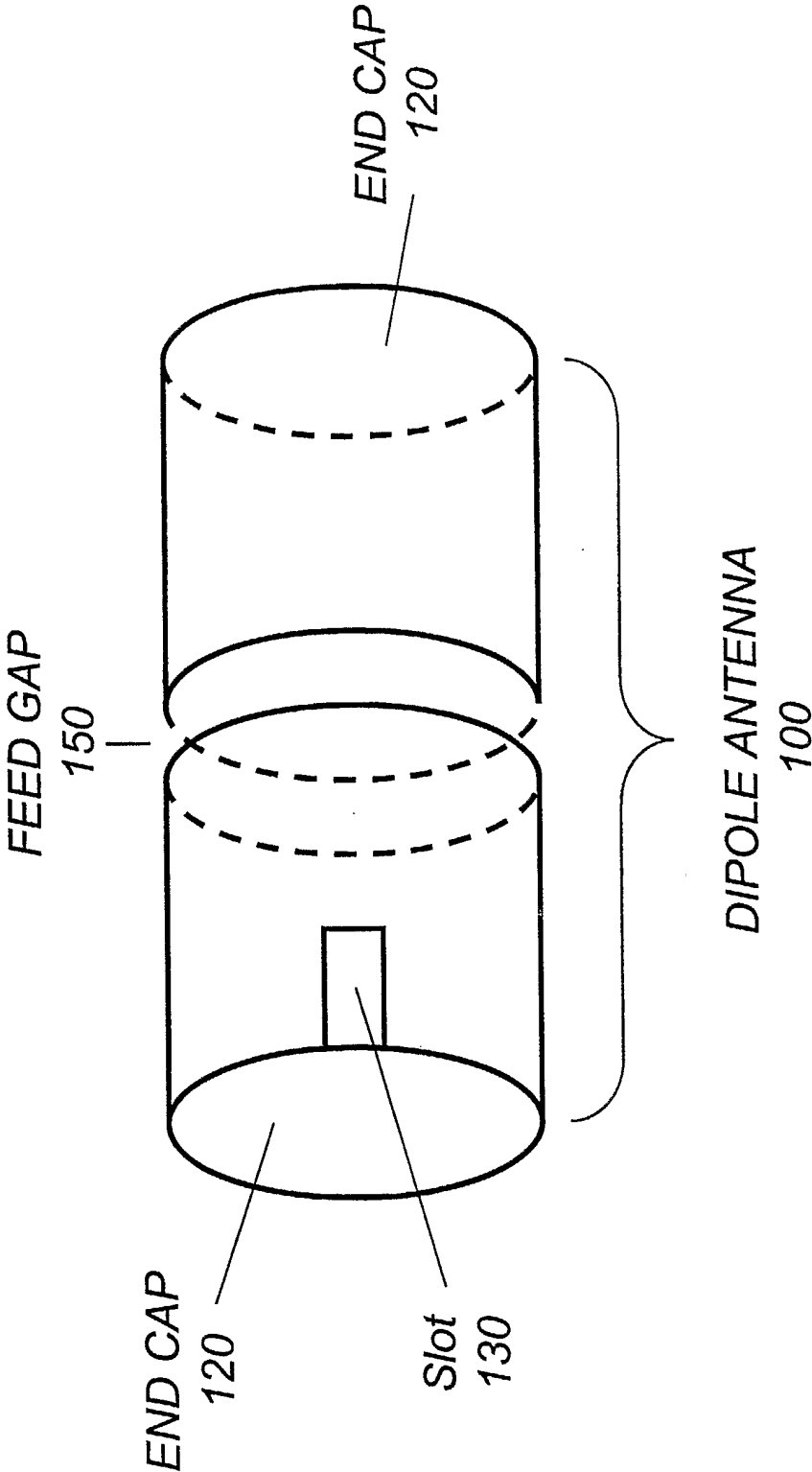


Figure 2

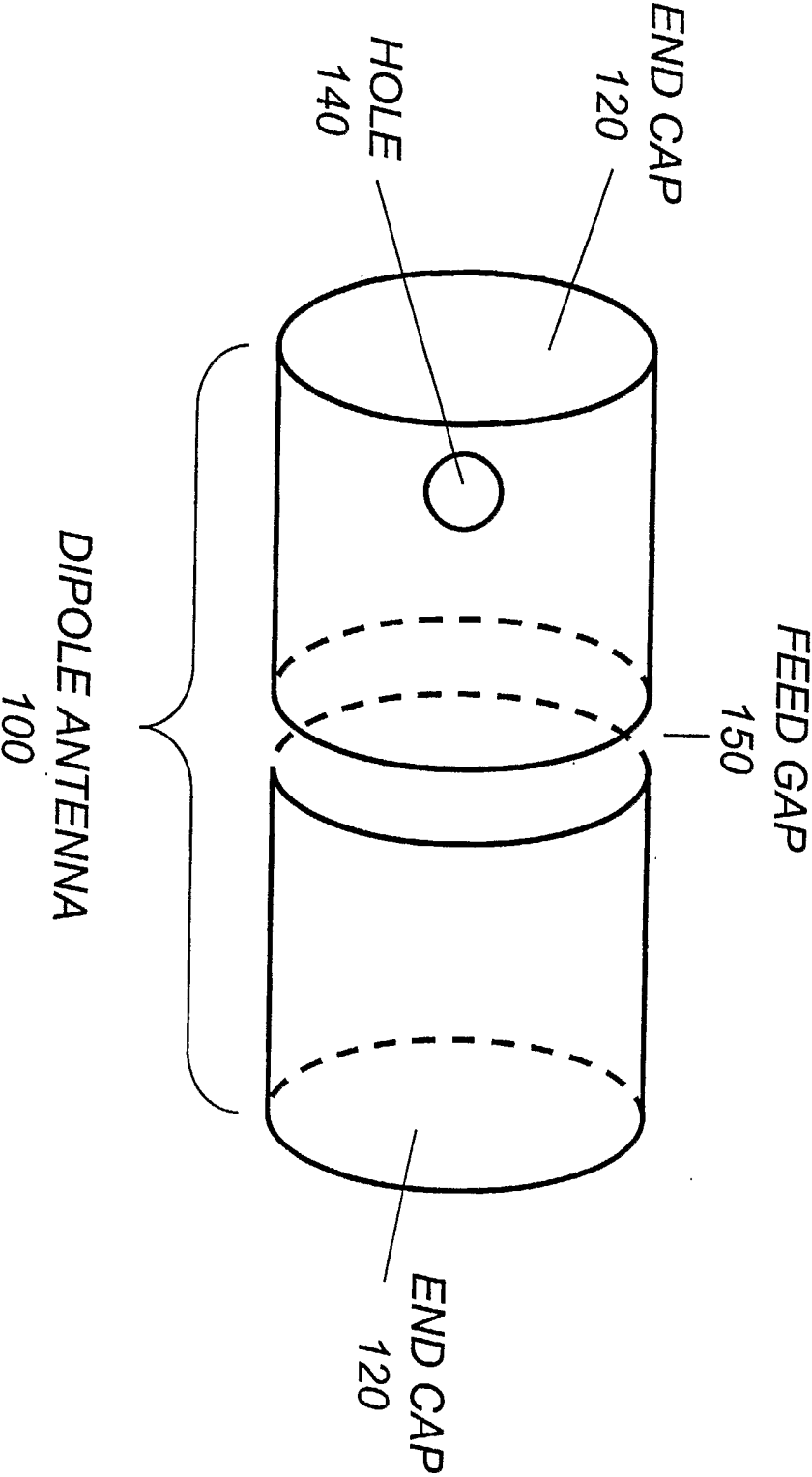


Figure 3

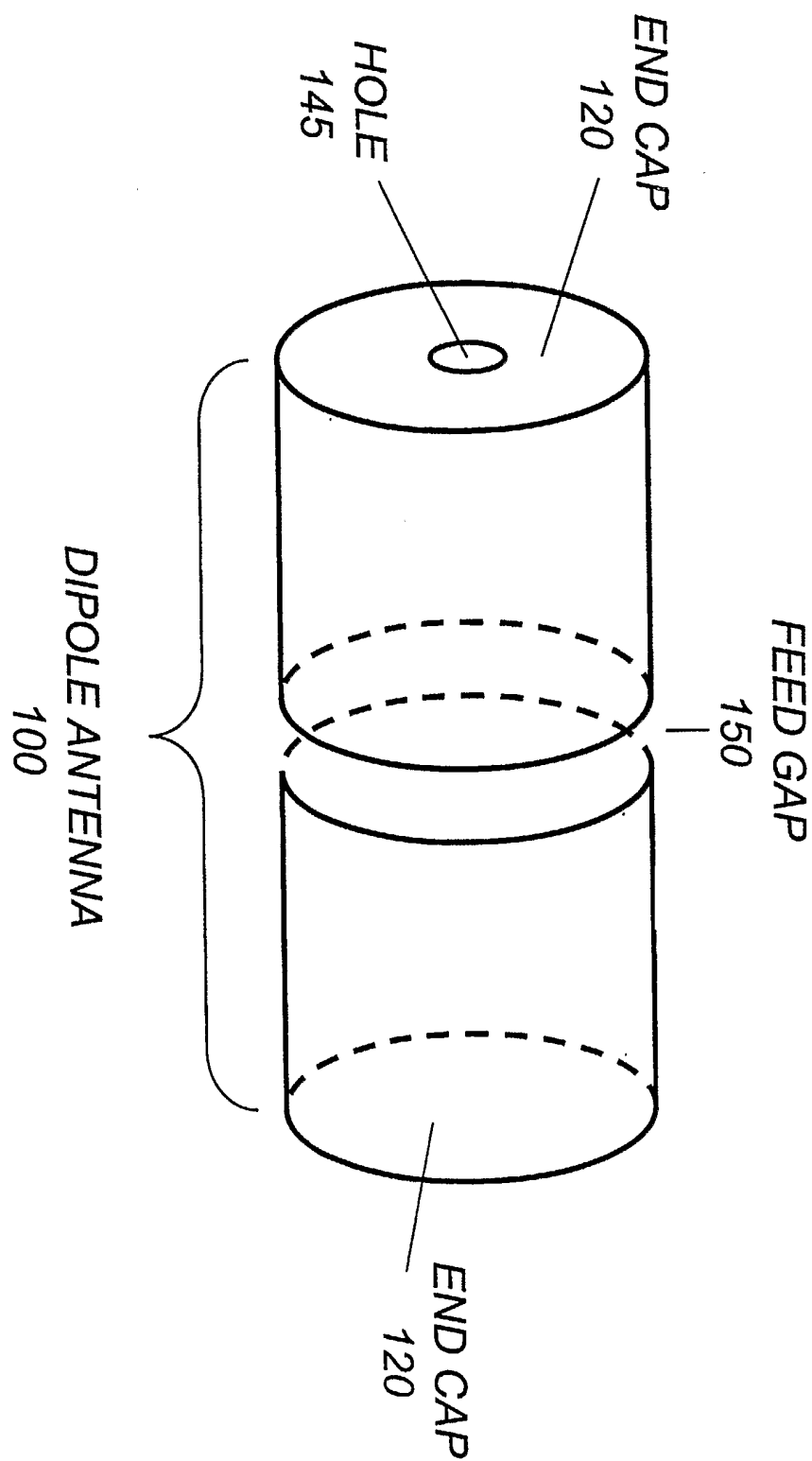


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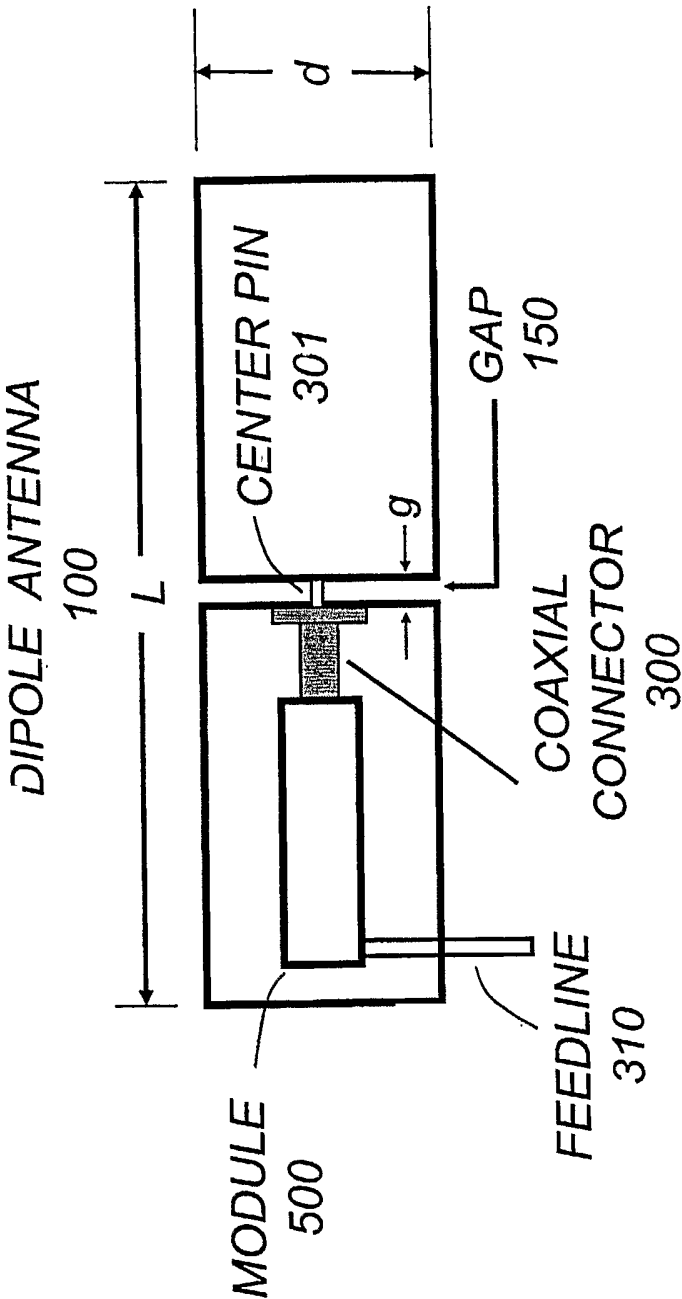


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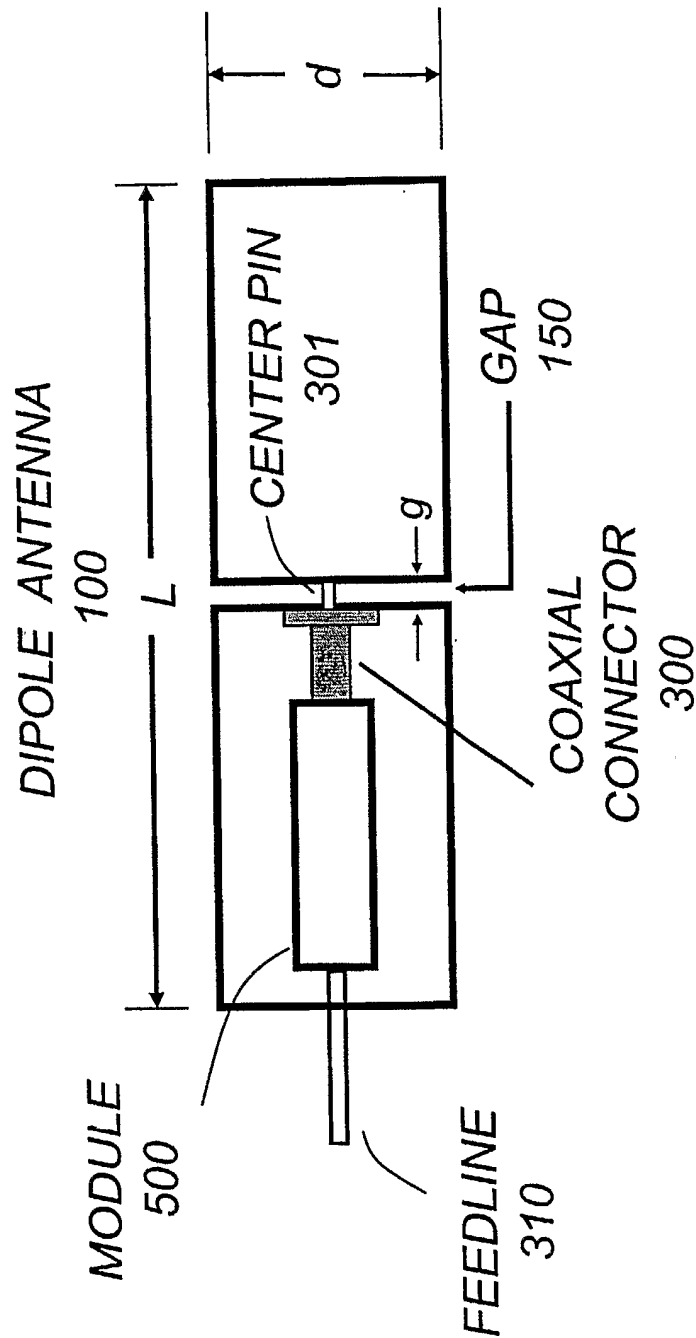


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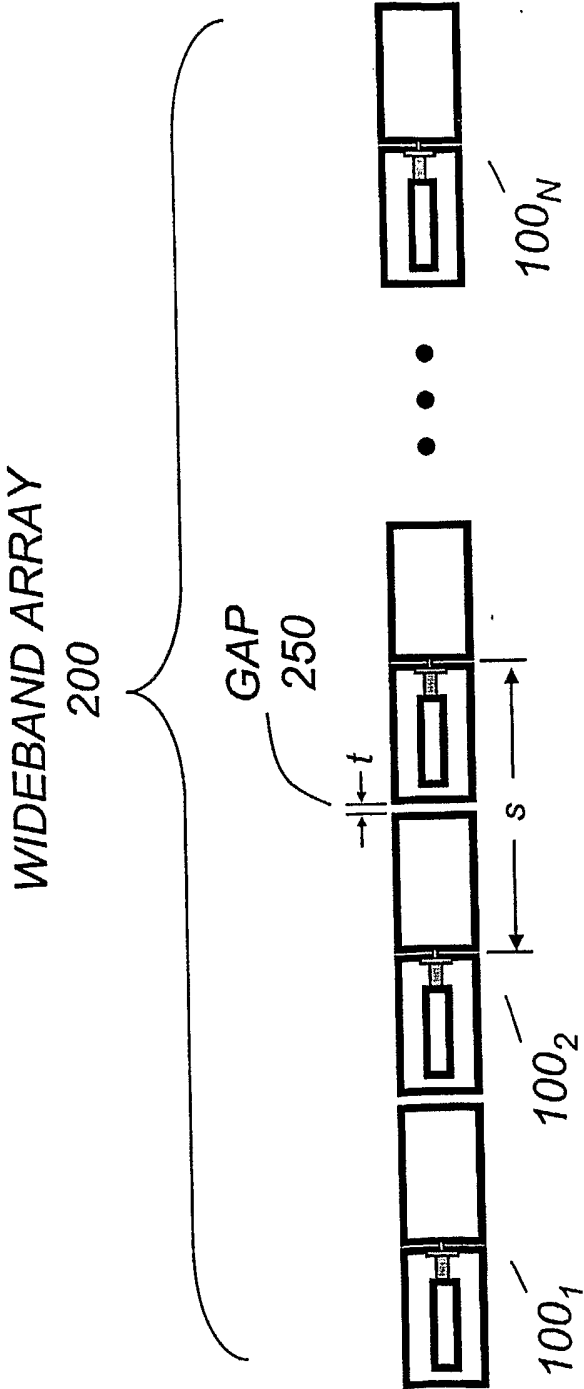


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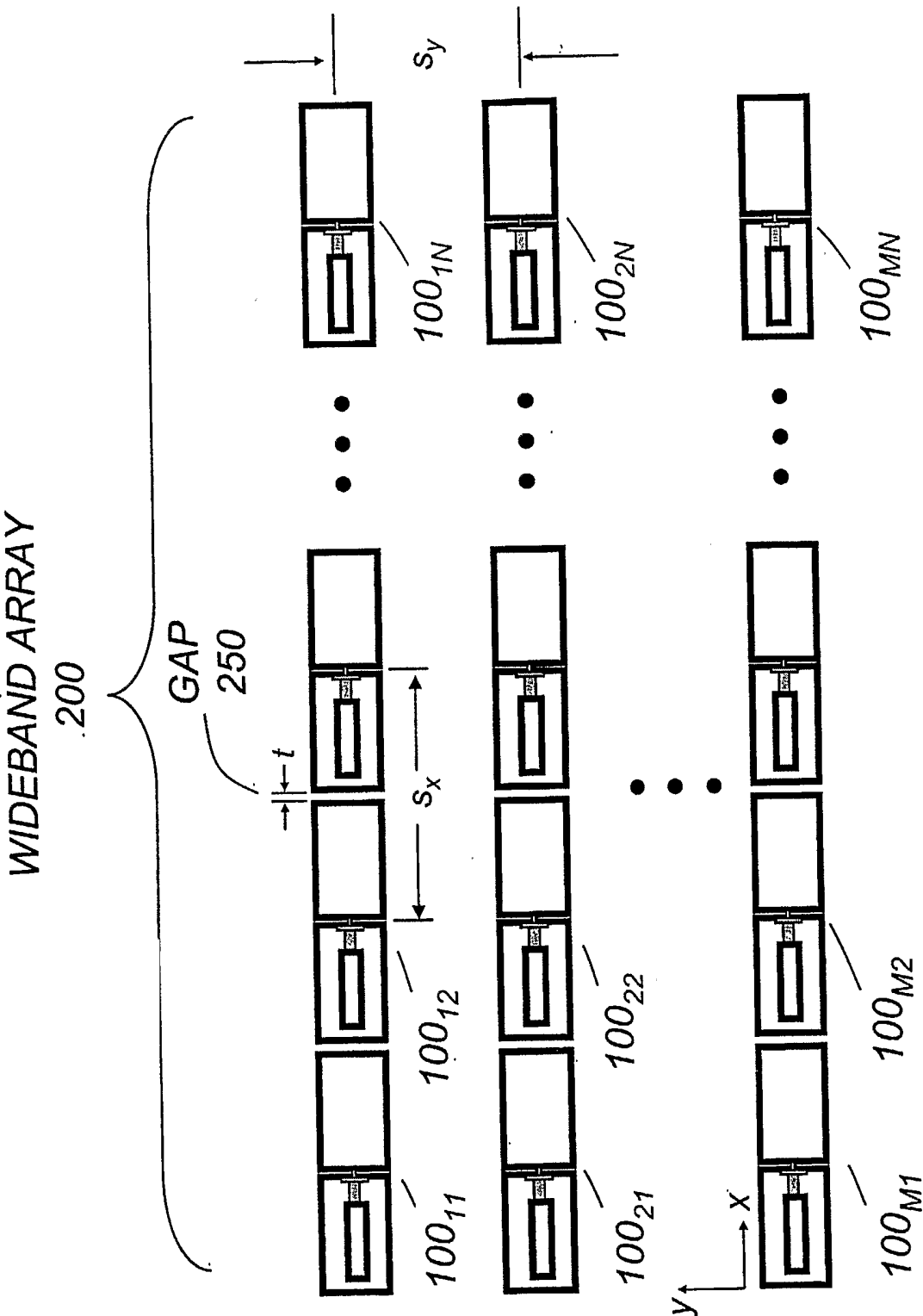


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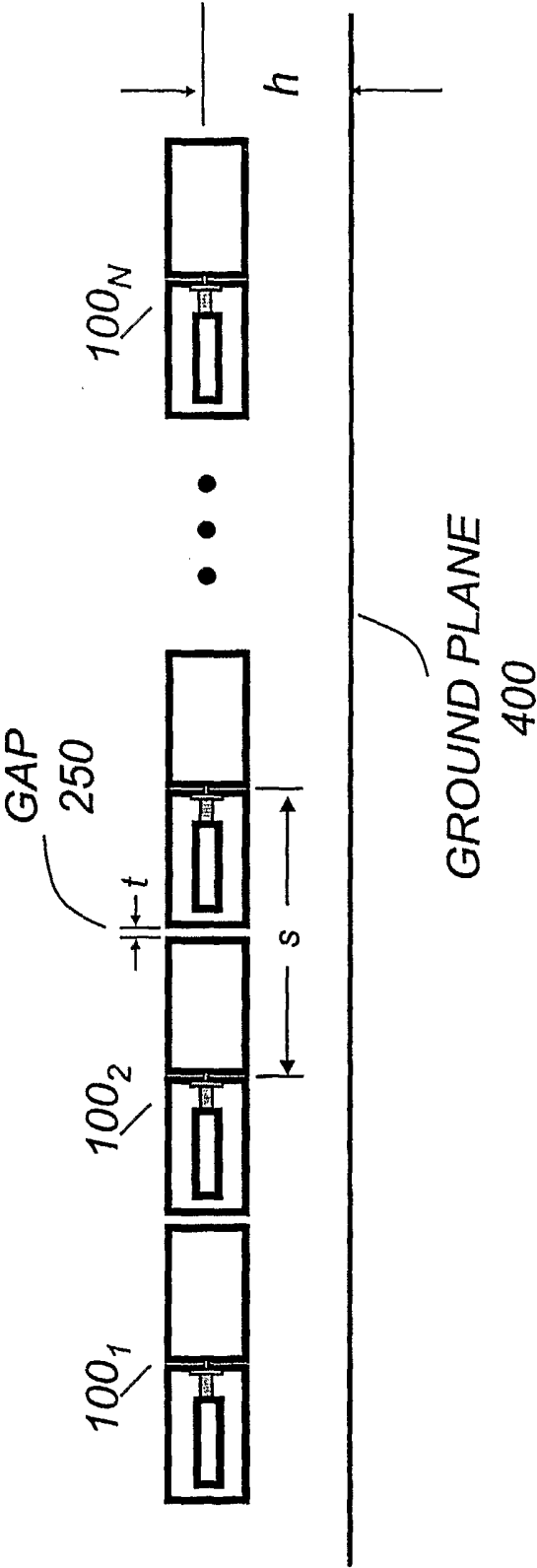


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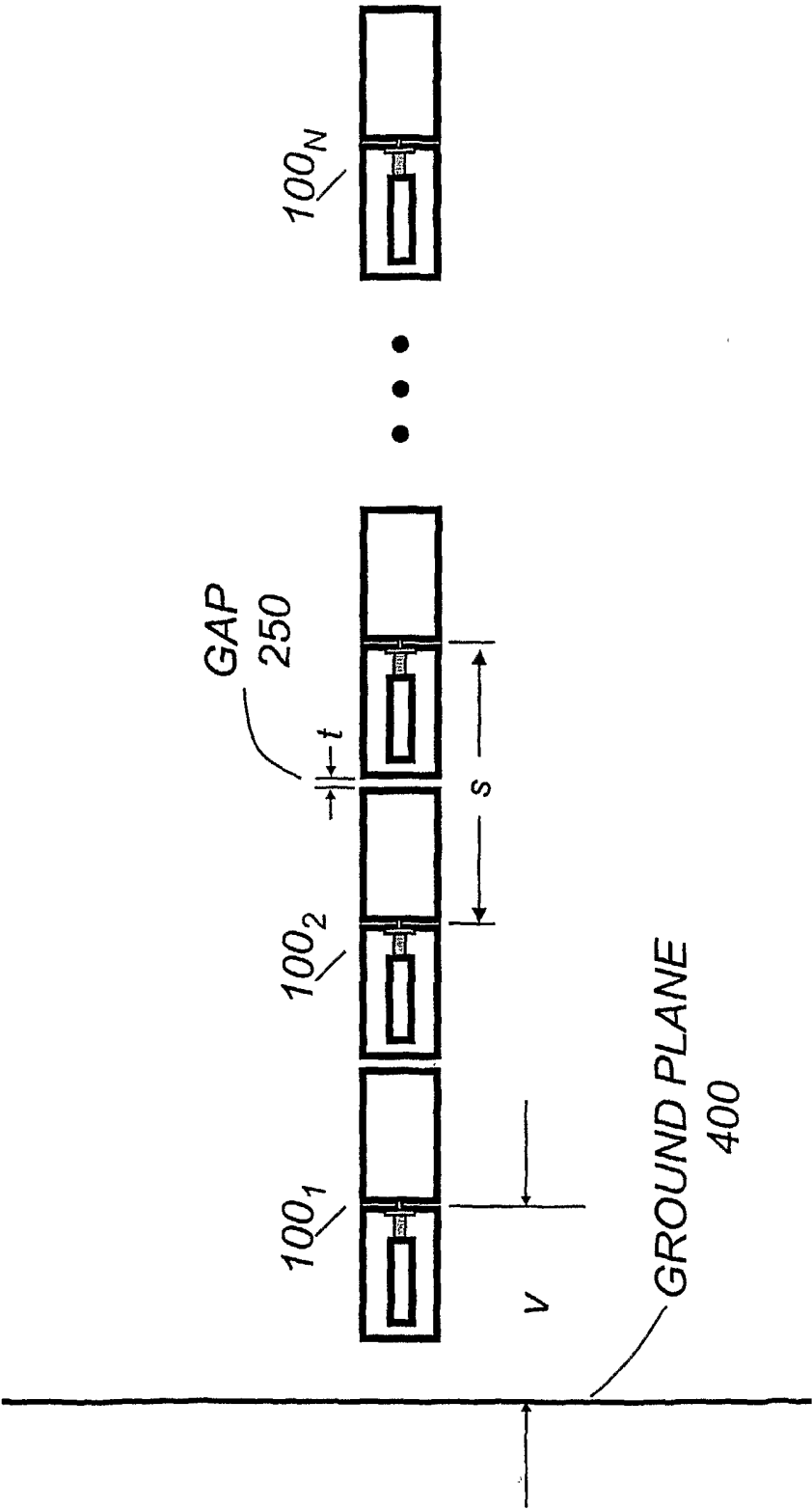


Figure 10

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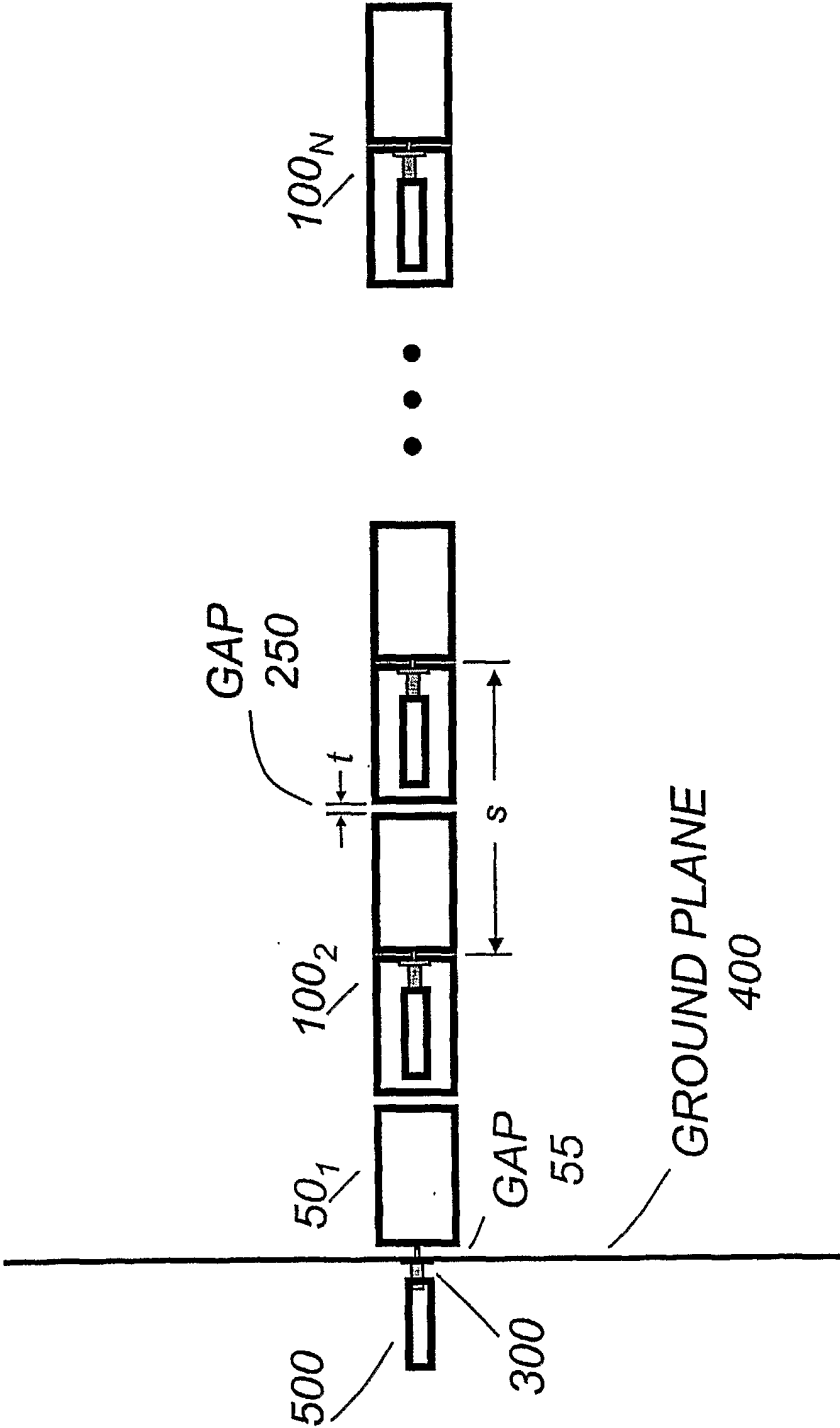


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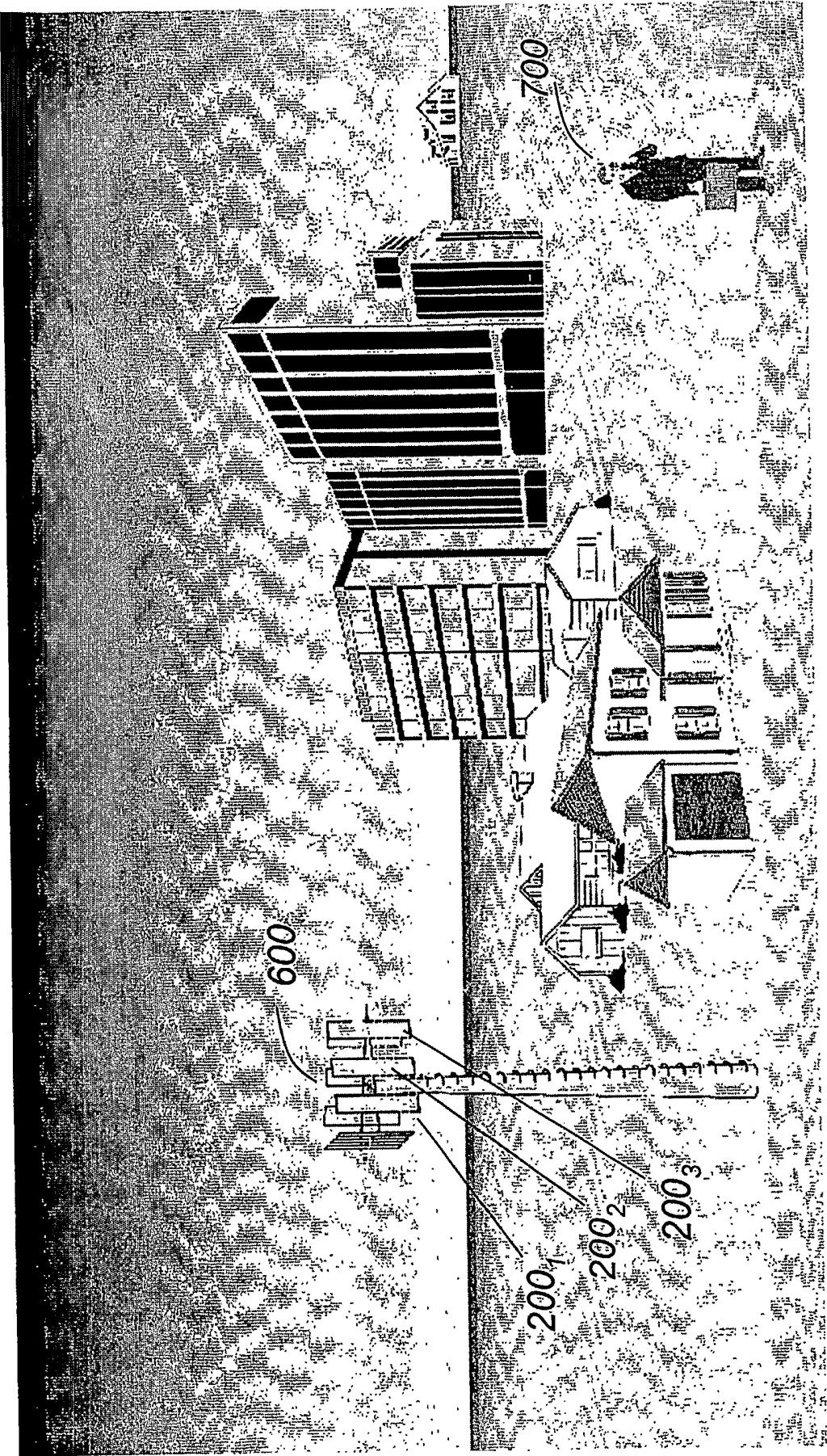


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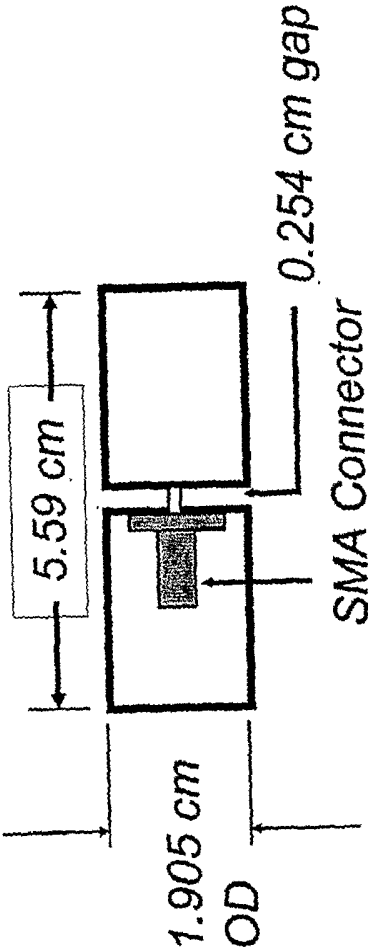


Figure 13

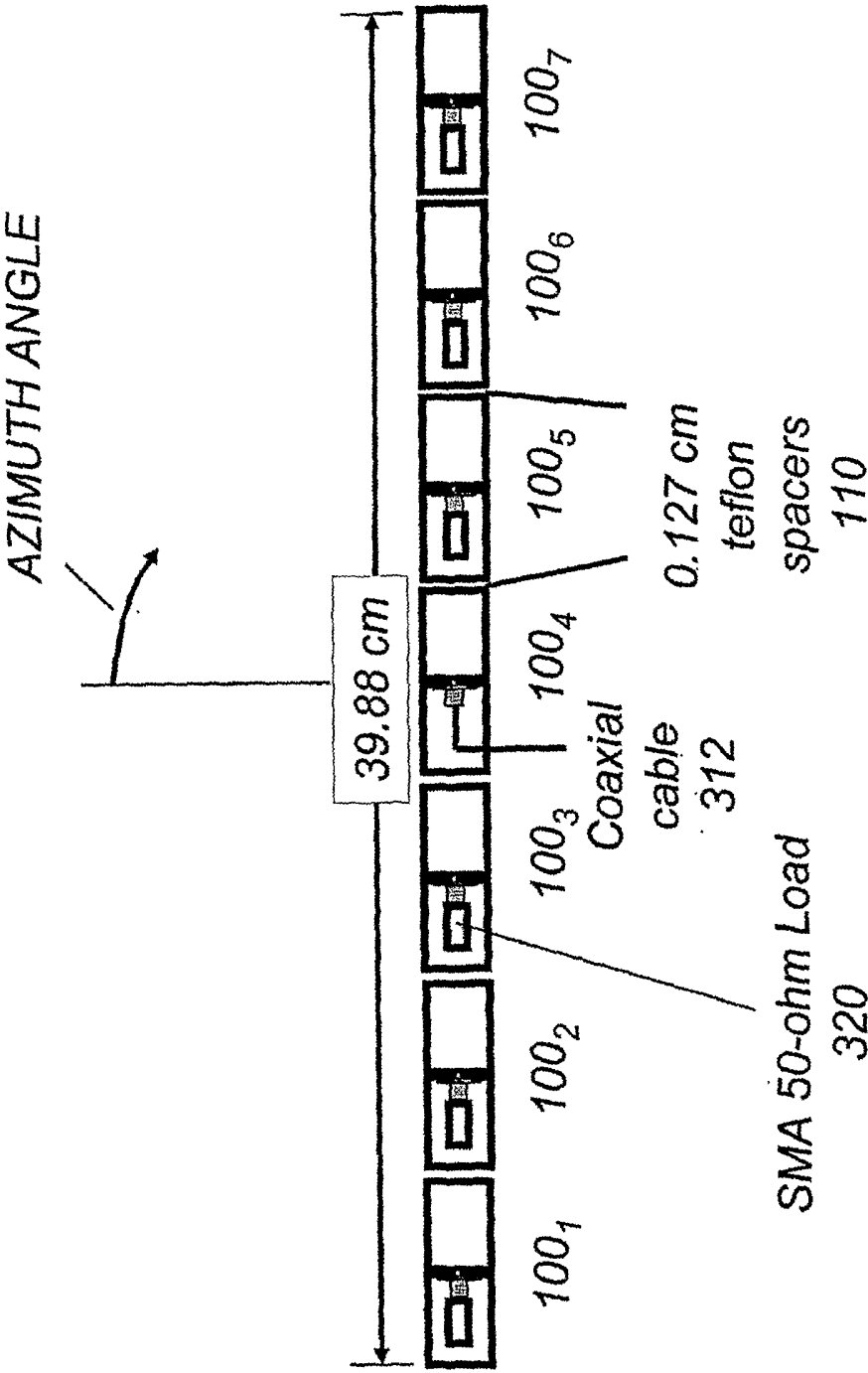


Figure 14

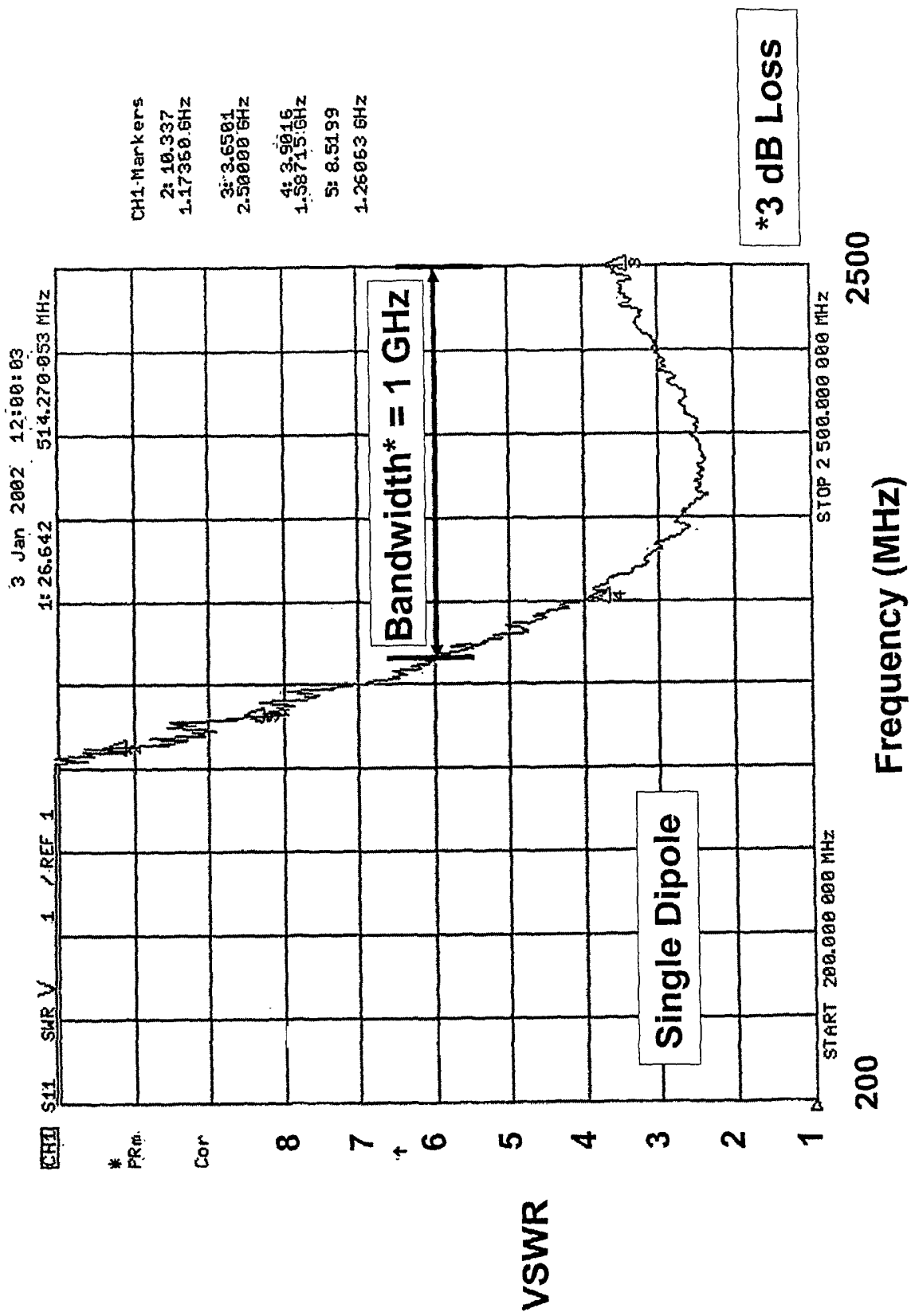


Figure 15

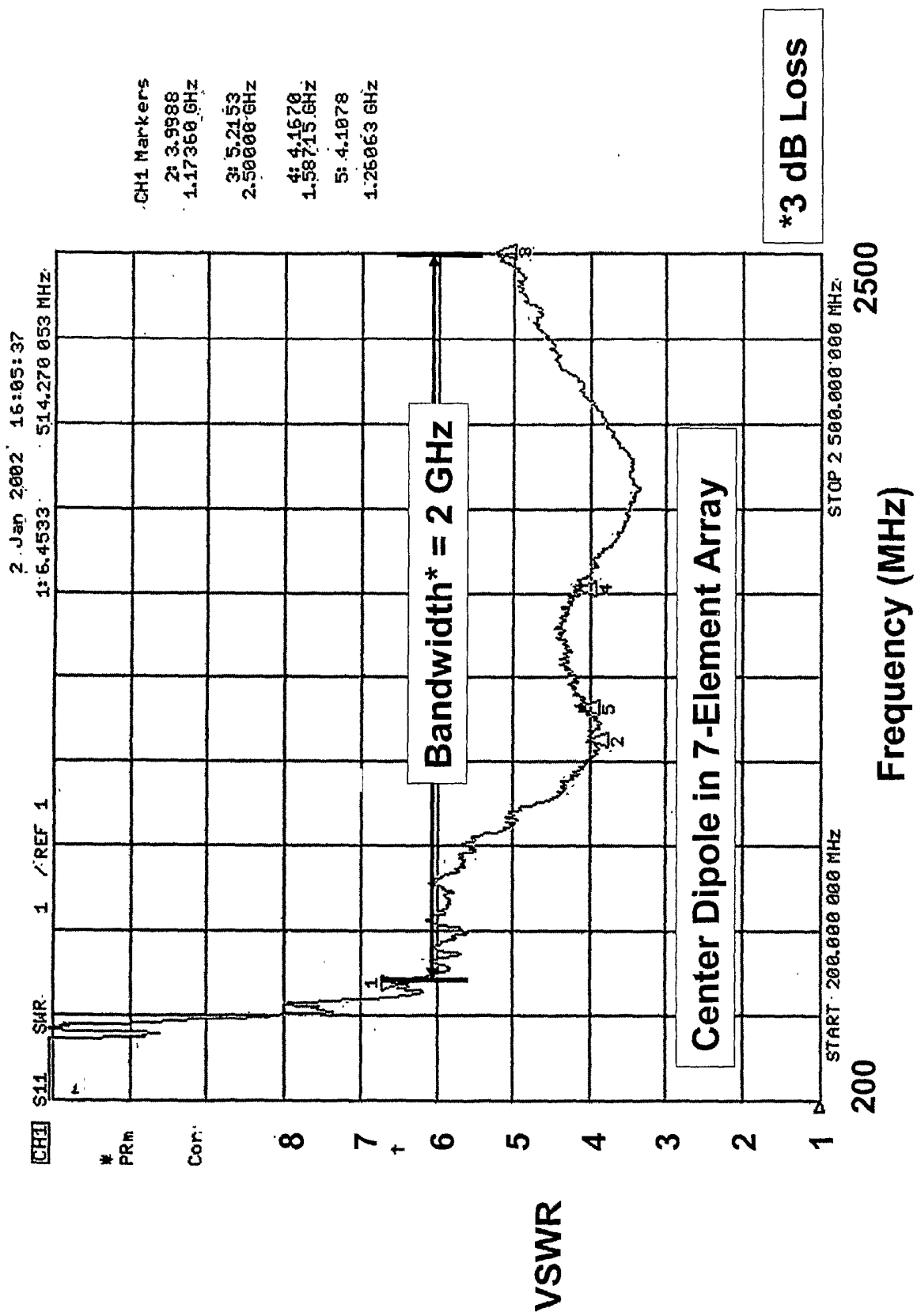


Figure 16

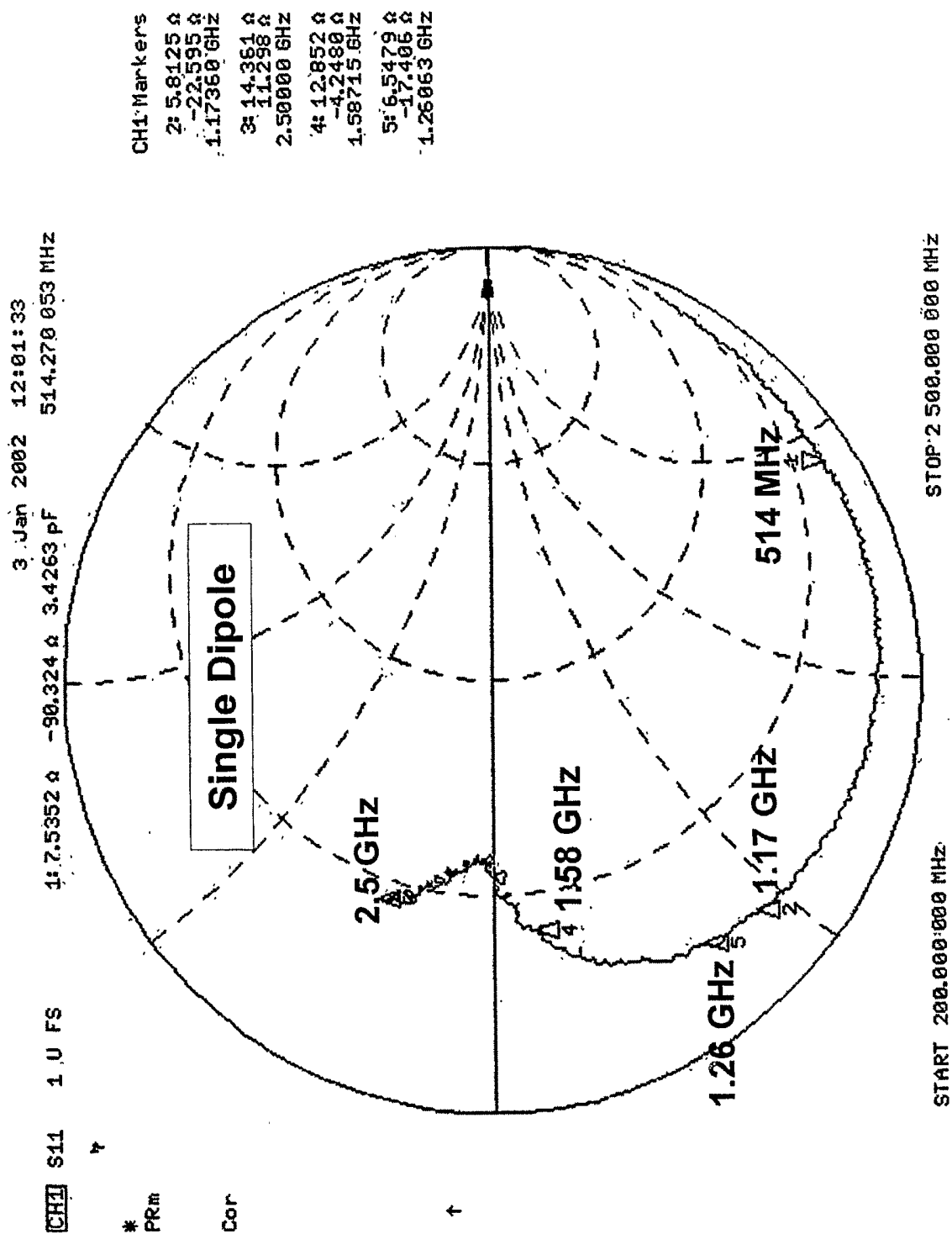


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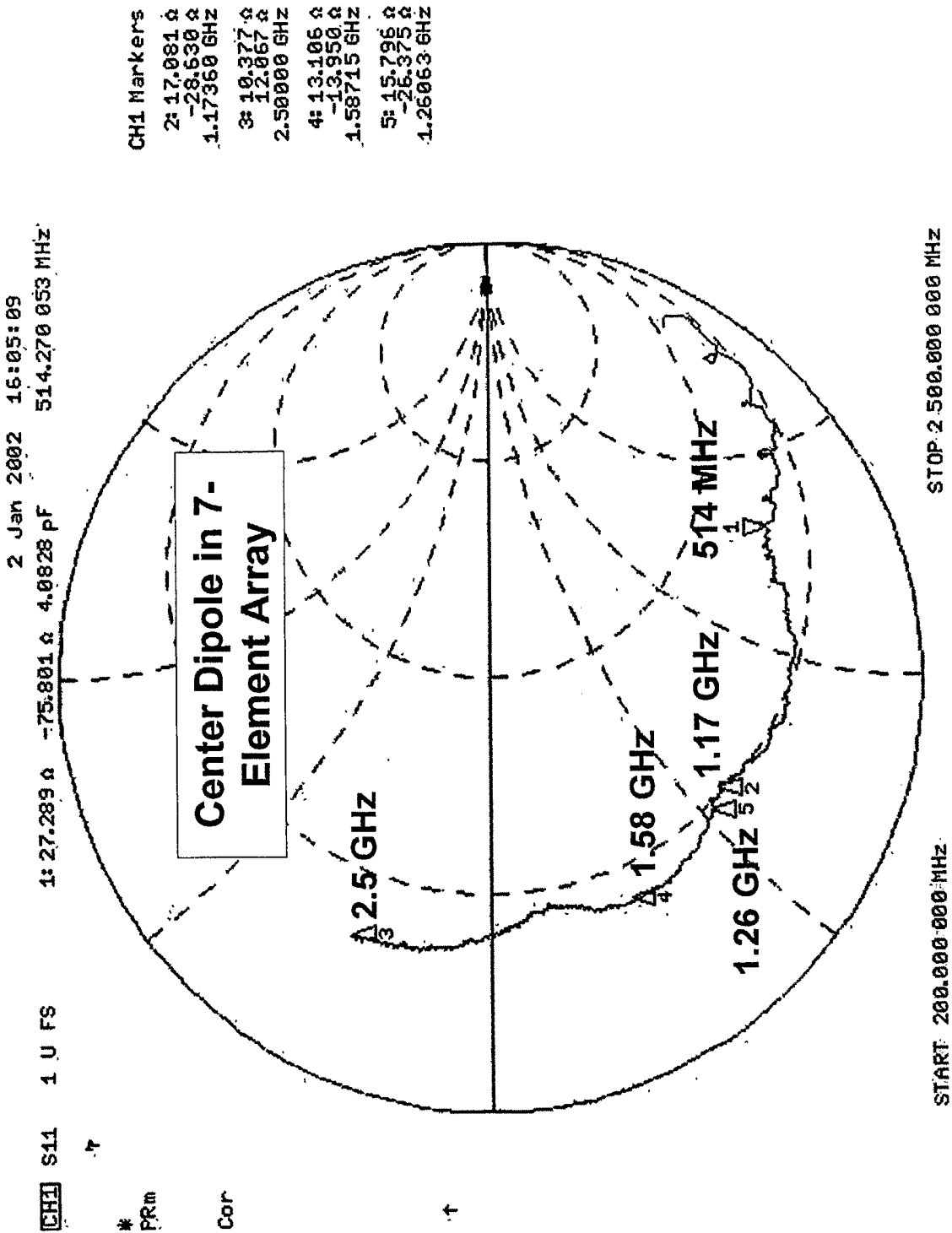


Figure 18

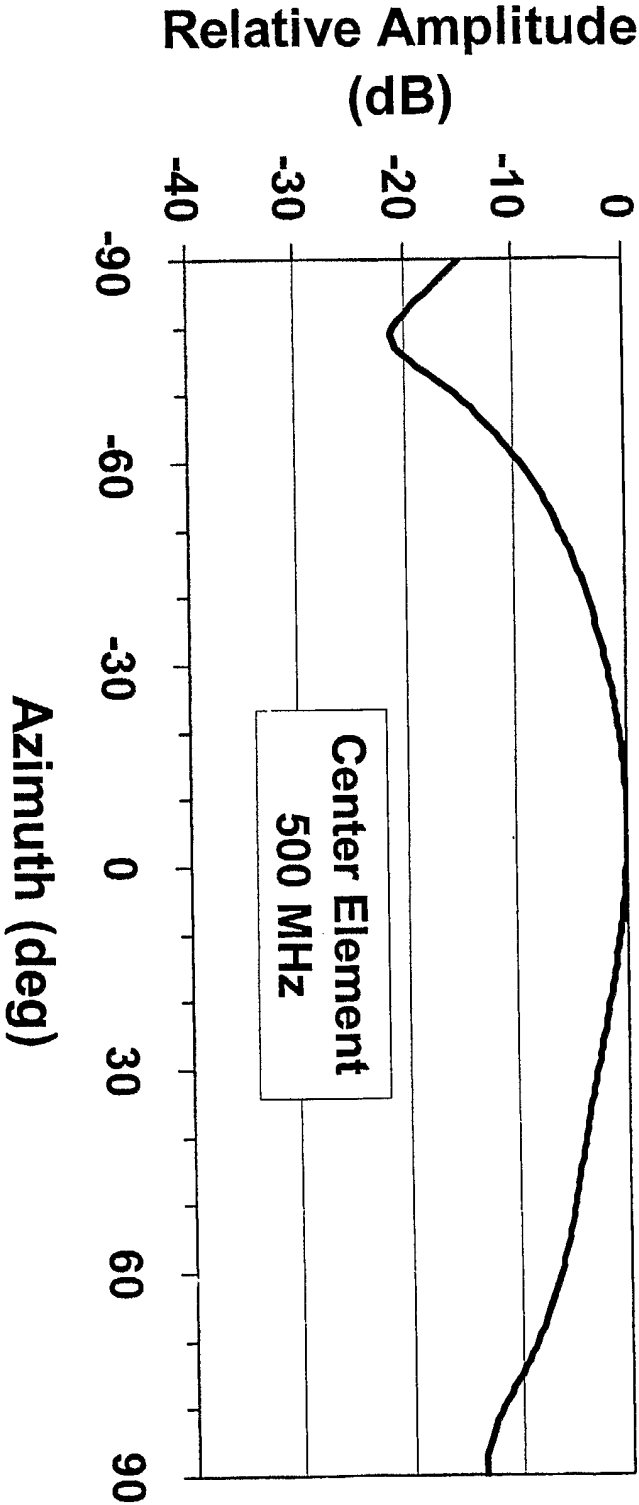


Figure 19

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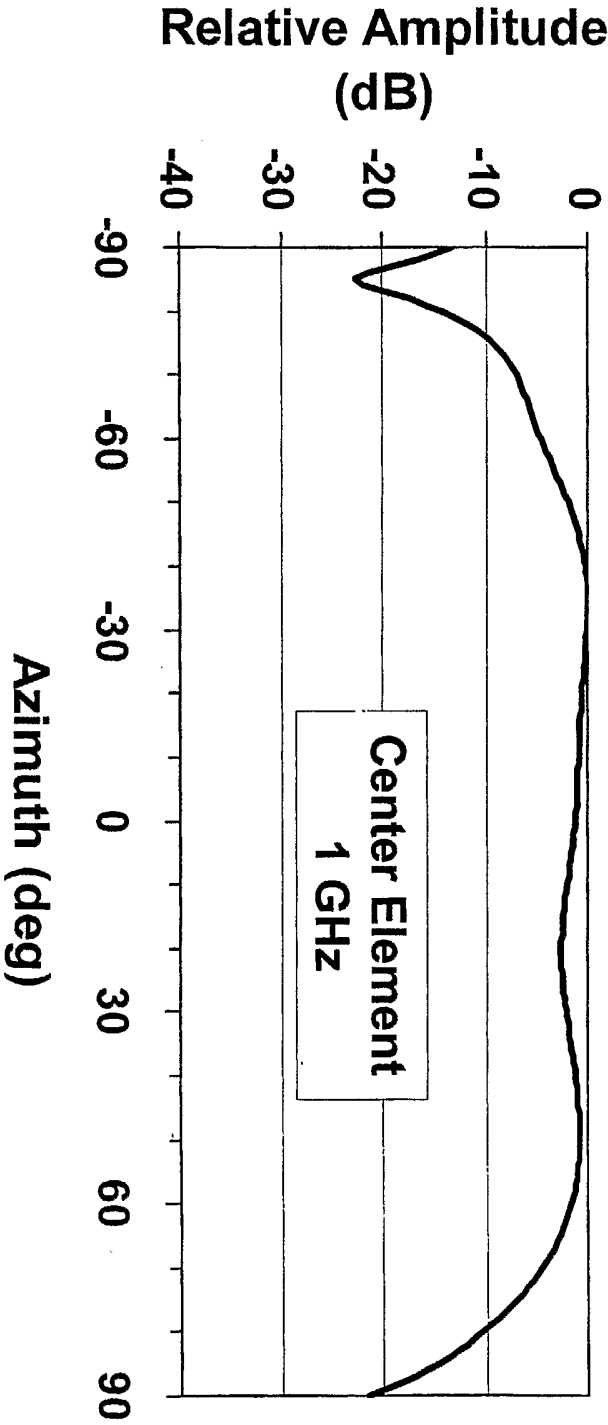


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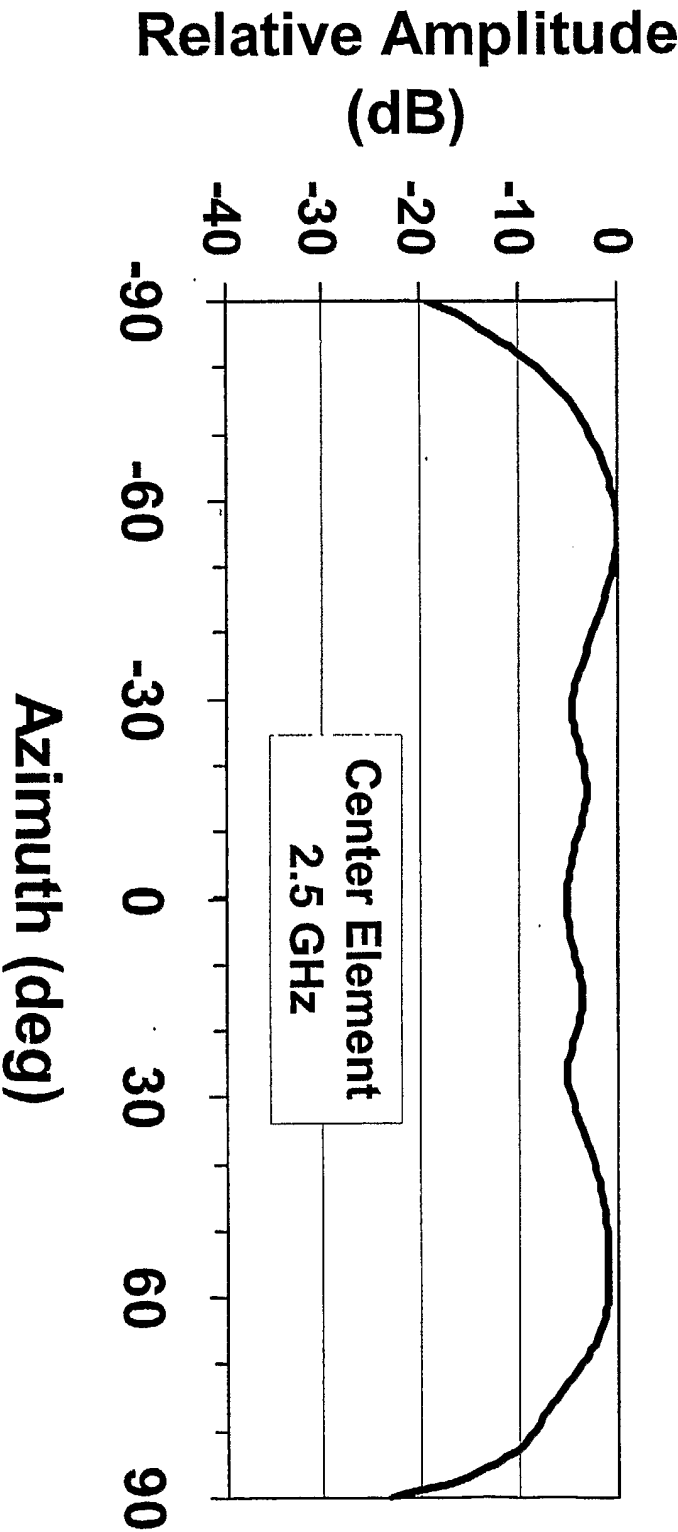


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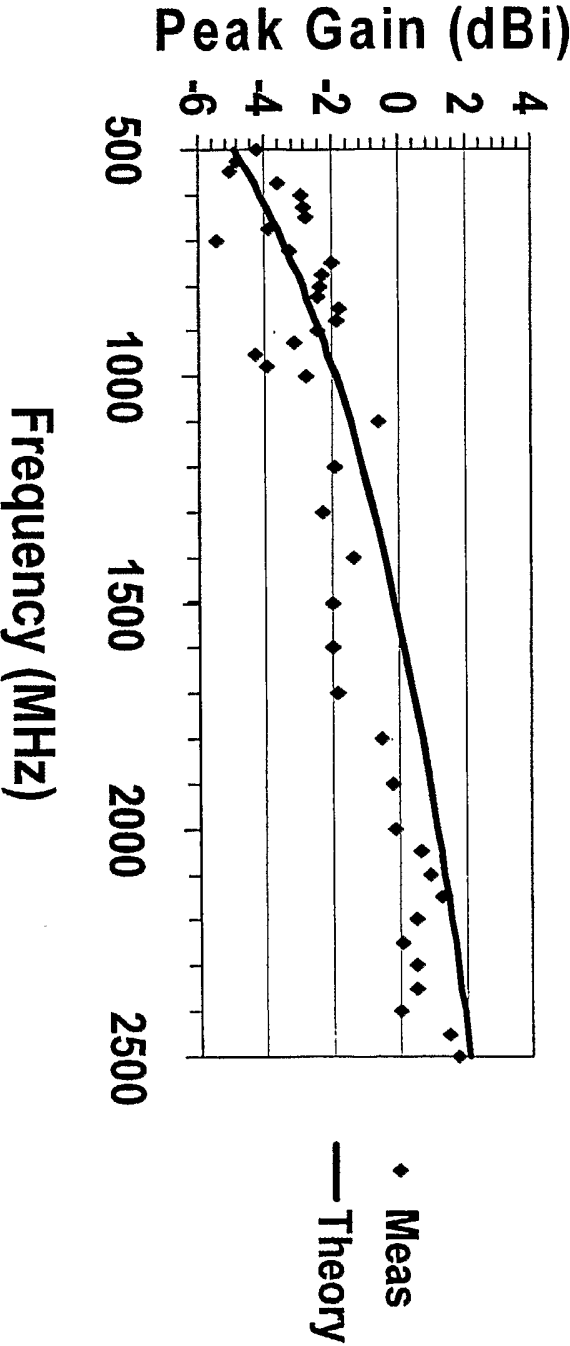


Figure 22

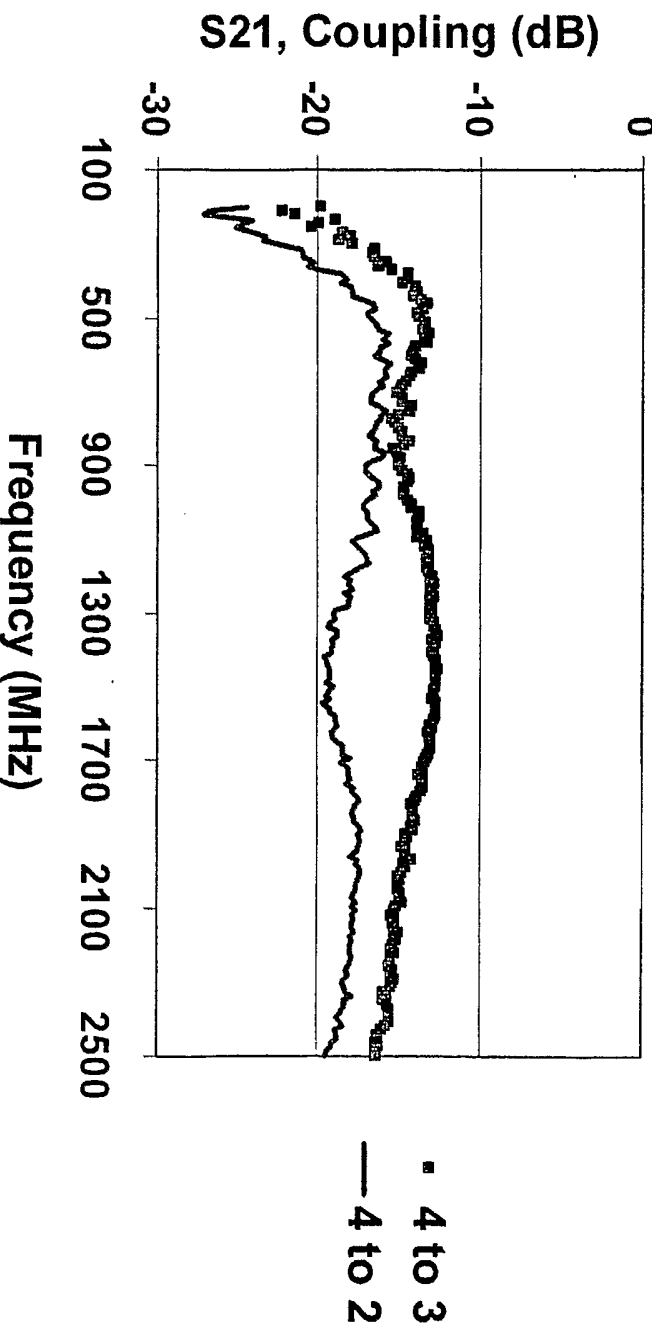


Figure 23

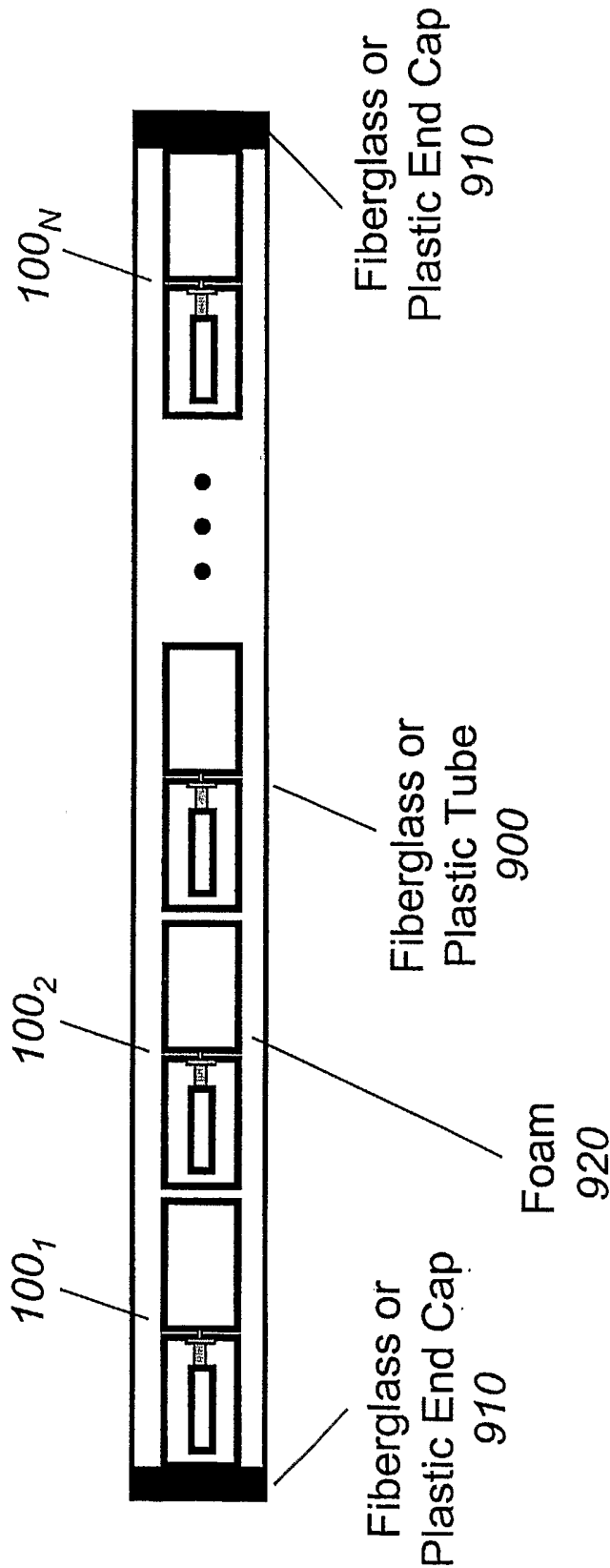


Figure 24

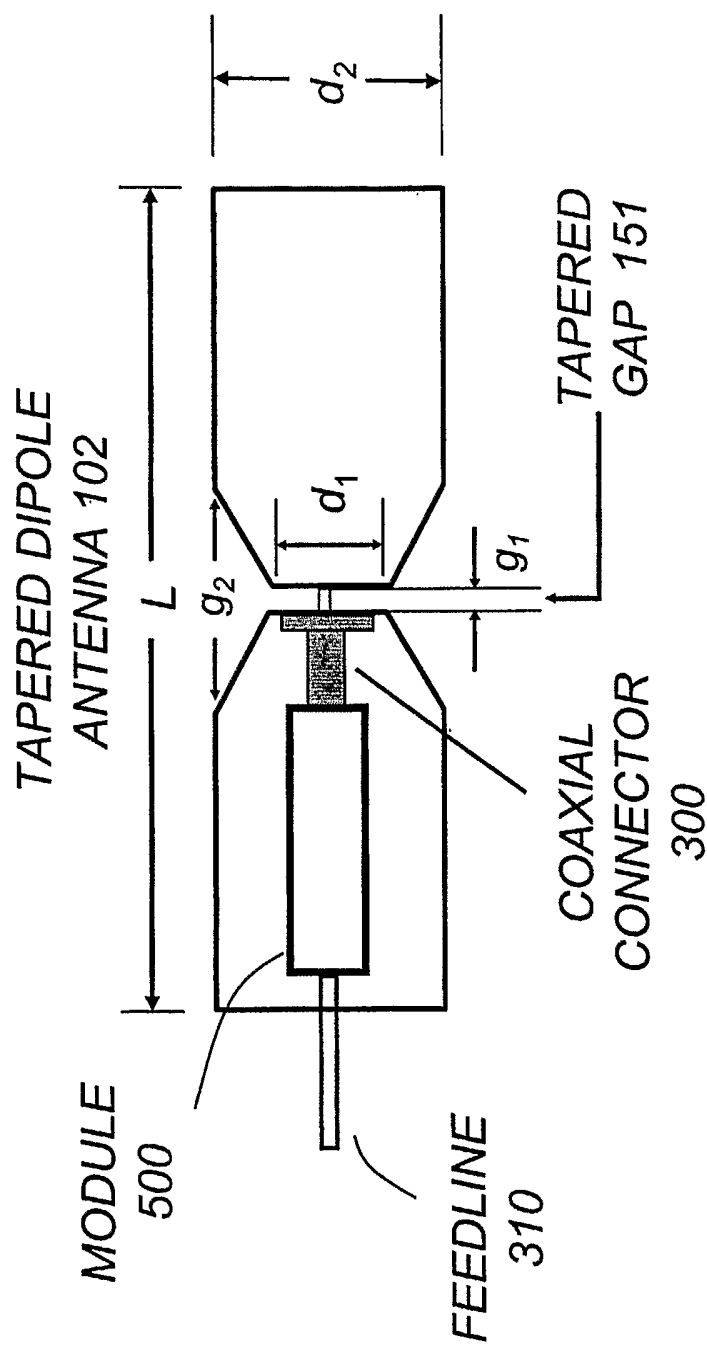


Figure 25

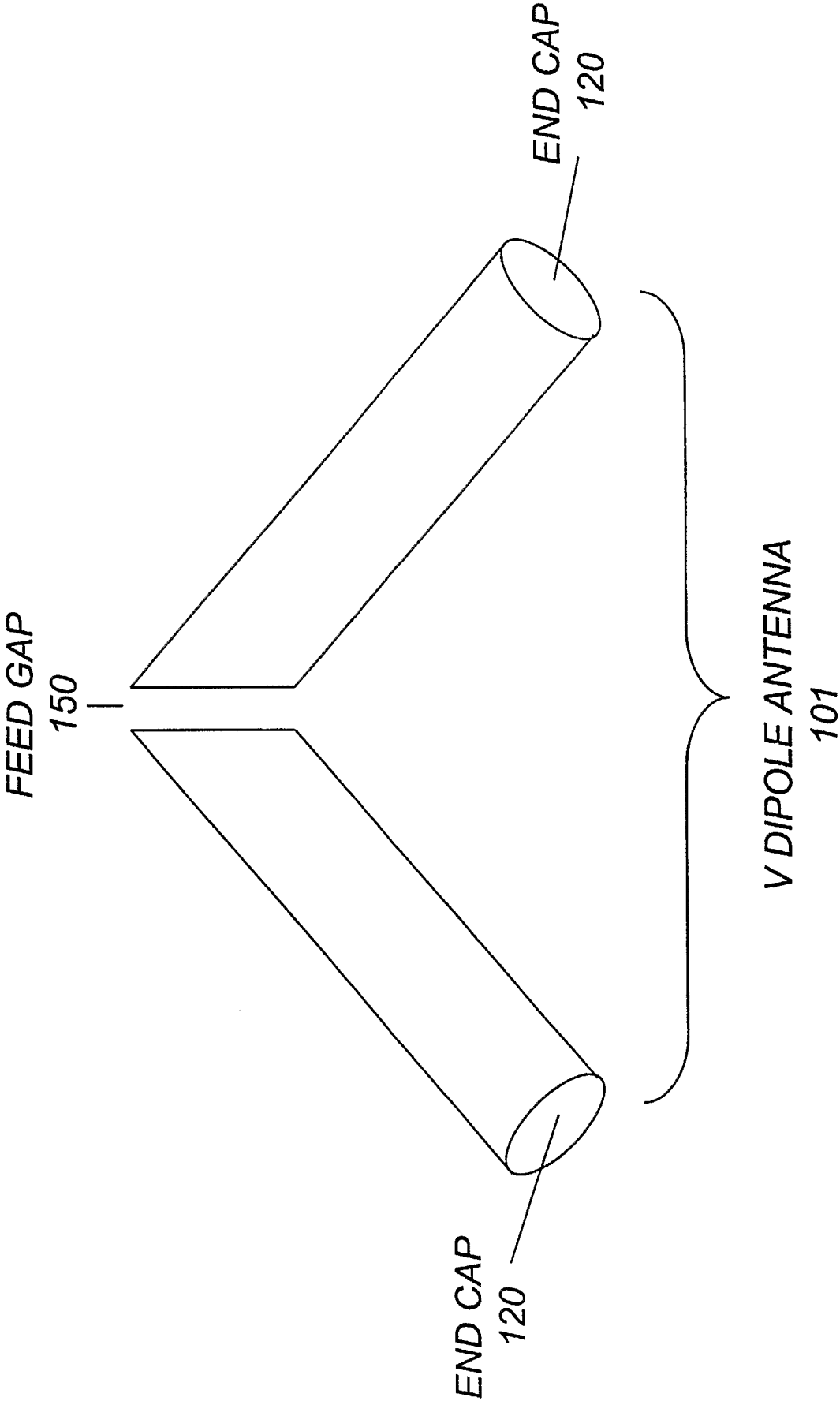


Figure 26

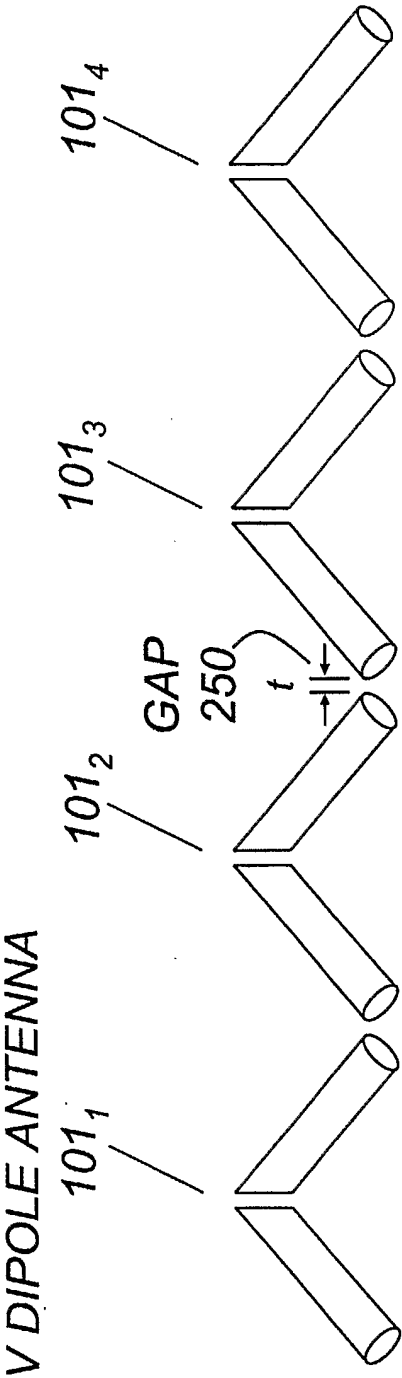


Figure 27

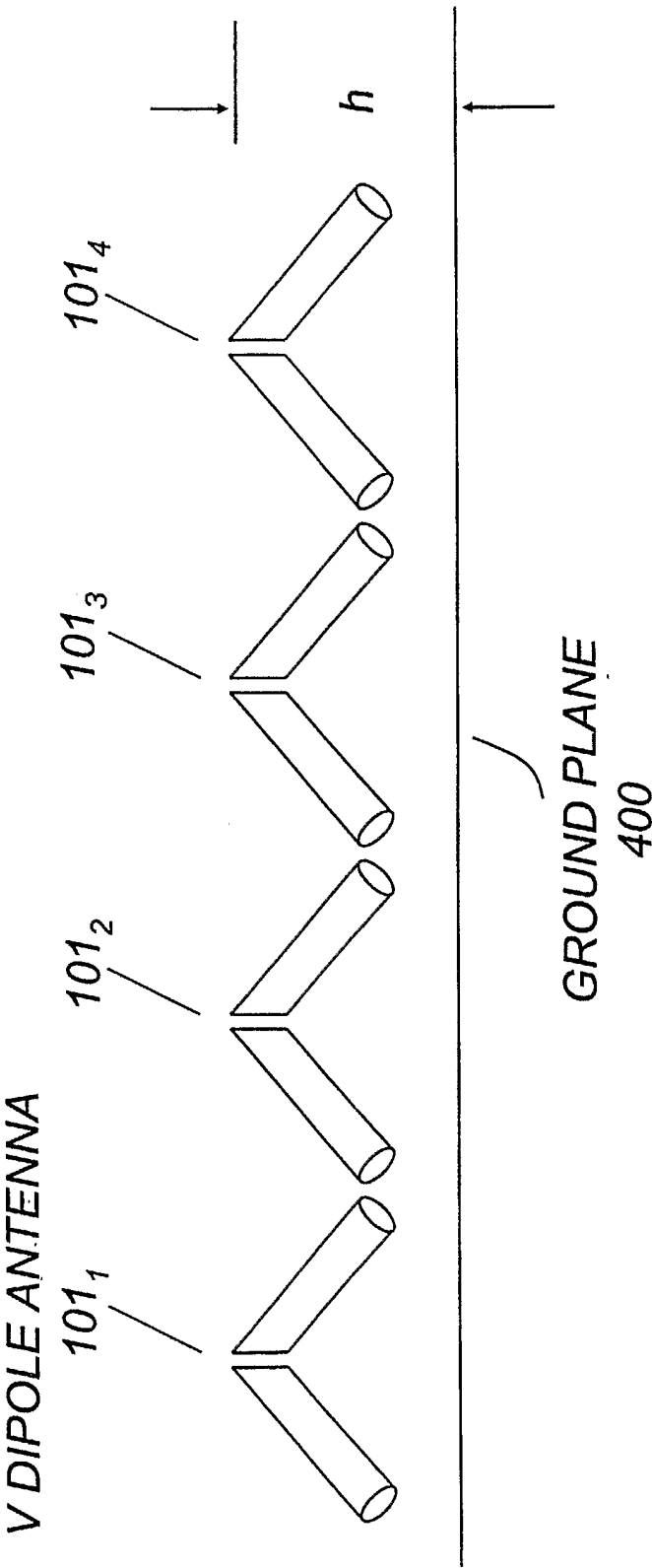


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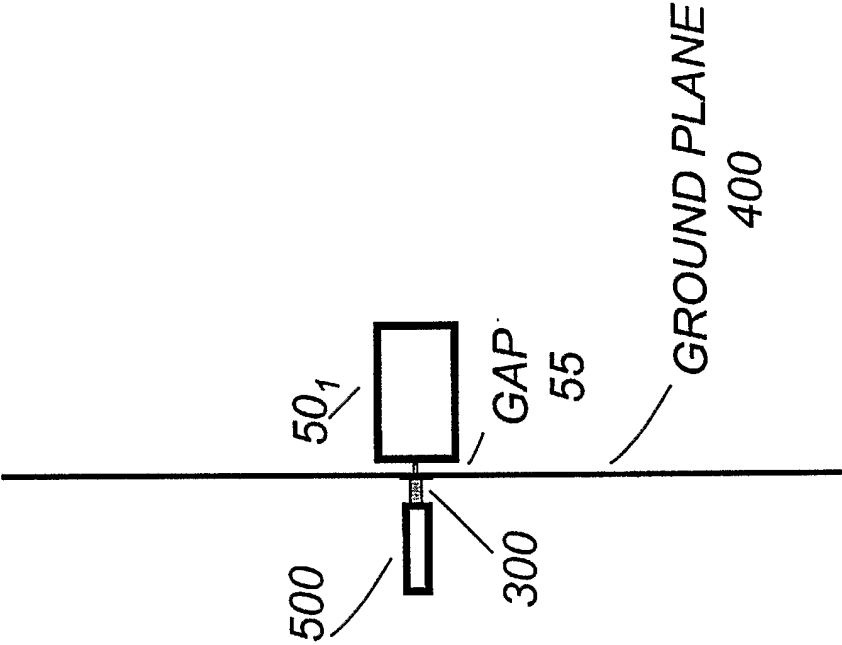


Figure 29

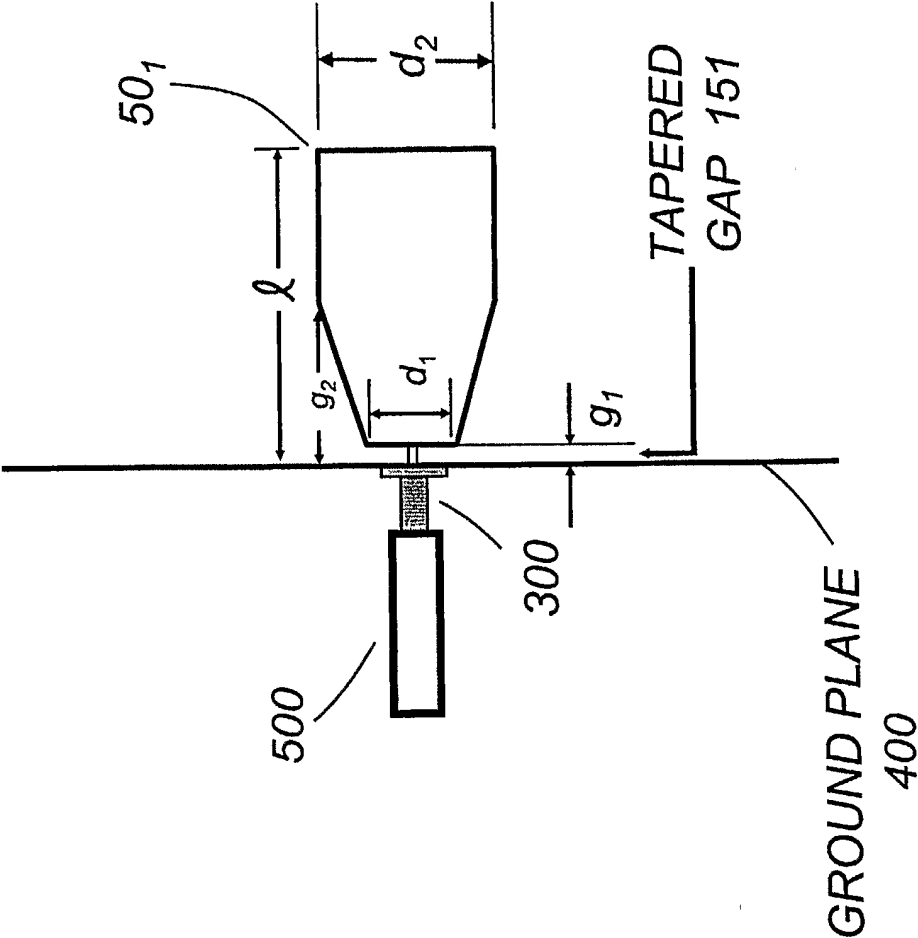


Figure 30