



(51) International Patent Classification:

H01Q 21/29 (2006.01) H01Q 21/20 (2006.01)

H01Q 1/38 (2006.01) H01Q 9/26 (2006.01)

H01Q 13/16 (2006.01) H04B 1/38 (2015.01)

(21) International Application Number:

PCT/CA2019/000124

(22) International Filing Date:

30 August 2019 (30.08.2019)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

3016167 30 August 2018 (30.08.2018) CA

(71) Applicant: LOEN ENGINEERING, INC. [CA/CA]; 846 Carrie Street, Victoria, British Columbia V9A 5R4 (CA).

(72) Inventor: LOEN, Andrew; 846 Carrie Street, Victoria, British Columbia V9A 5R4 (CA).

(74) Agent: URBANEK, Ted B.; Urbanek Intellectual Property Law, 2300 - 1066 West Hastings Street, Vancouver, British Columbia V6E 3X2 (CA).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: ANTENNA ARRAY FOR RADIO DIRECTION FINDING AND RADIO LOCATING UNIT UTILIZING SAME

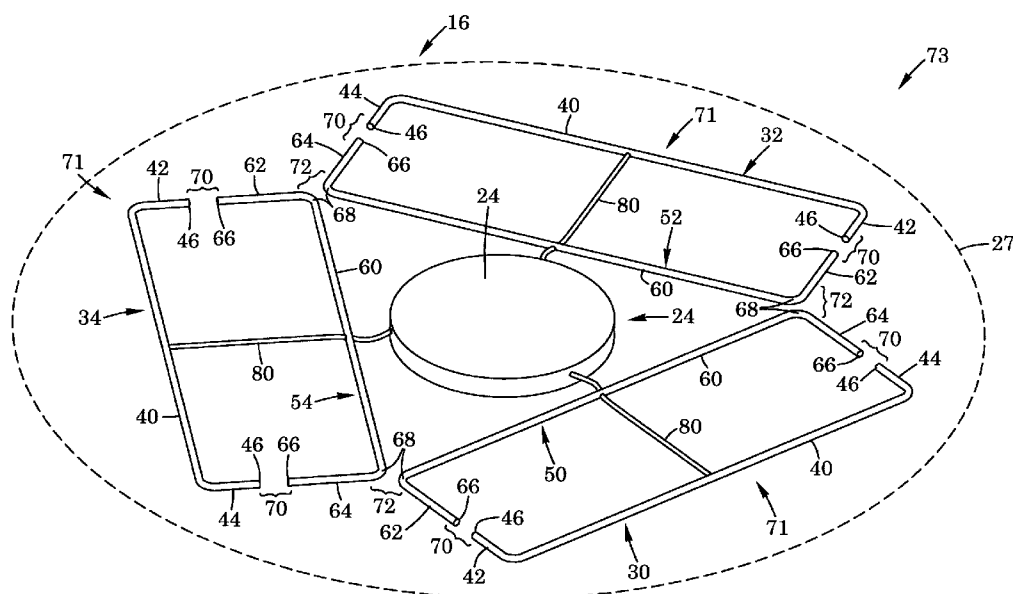


FIG. 2

(57) Abstract: A fixed, radial array of antennas for use with a transceiver radio and electronics module for radio direction tracking is provided. The array comprises a plurality of co-planar, rectangular antennas and a radio frequency coupling calibrated space between each adjacent pair of antennas.



ANTENNA ARRAY FOR RADIO DIRECTION FINDING AND RADIO LOCATING UNIT UTILIZING SAME FIELD

This invention relates to an antenna array for radio direction finding and an improved locating system using such an antenna array.

BACKGROUND

Radio signal tracking is used to determine the location of tagged assets and to locate missing people who have wandered. Current systems are often large and unwieldy, or difficult to use, requiring training, or lacking sensitivity and tracking range. It is difficult to design a system that has excellent tracking range, is simple to use, and is compact and portable.

Directional radio signal detectors rely on phase measurement, signal strength measurement, or Doppler frequency shifts in received signals. The signal strength approach relies on the characteristic of an antenna or antennas where the signal strength varies depending on the incident angle on the antenna or antennas. Some examples of directional antennas include loops, Yagi, and quad antennas.

Loop antennas are often used because they are easy to build and can have deep signal strength nulls resulting in good directional accuracy. A loop antenna has a symmetric response so the direction of the signal has an ambiguity of 180 degrees.

Yagis are multi-element antennas with reflector and director elements arranged along a boom. Yagi antennas have good directionality but are relatively large because of the multiple elements required to form the beam pattern. The distance between the elements is typically $1/4$ of a wavelength and the element lengths are approximately $1/2$ of a wavelength. The antenna must be swept slowly over the whole horizon, effectively pointing the directional "beam" of reception at all the points of the compass.

Quad antenna systems often use sophisticated electronic switching circuits to create a pseudo-Doppler frequency shift in the received radio signal. While these systems are simple to use and provide a bearing to the radio source, the antenna array does not typically have any gain. This results in poor sensitivity and tracking range.

United States Patent 4121216 discloses the use of an energy receiving antenna having two orthogonally mounted vertically oriented, loop antennas, a monopole antenna and a horizontally oriented loop antenna. Signals from the two orthogonally mounted loop antennas contain bearing information for

processing in a phase comparison system. The monopole antenna signal provides for elimination of any ambiguity in the bearing information signal as received from the two orthogonally mounted loop antennas. Sensing the polarization of the energy waves at the receiving antennas is provided by comparison of the horizontal loop antenna signal with the resultant signal obtained by the quadrature summation of the signal from the two vertical loop antennas. A bearing indication from the two orthogonally mounted loop antennas is generated by phase shifting one of the antenna signals. This phase shifted signal is combined with the second loop antenna signal in both a summing network and a difference network. A phase detector coupled to the summing network and the difference network provides a signal representing a multiple of the bearing angle between the emitting source and the receiving antenna. The ambiguity in this multiple of the bearing angle is removed by coupling a phase detector to the summing network and the monopole antenna. The output of this second phase detector is combined with the output of the first phase detector in an ambiguity resolver to produce a true bearing angle. This is a bulky three-dimensional antenna system. Further, it has no inherent gain. It is also impossible to determine the direction of a signal based on the two loops alone. A third antenna is needed to determine whether the signal is coming from the front or back of a particular loop.

United States Patent 6,088,002 discloses an antenna system including a support structure and an antenna assembly having an open grid reflector structure in a closed ring and dipole elements. The antenna assembly includes a number of antenna panels, each including a number of the dipole elements, the closed ring is self-supporting and connected to the support structure by radial beams and struts, and the antenna panels are interconnected by a variable angle connection.

United States Patent Application 20140049428 discloses an apparatus for direction finding a received radio signal. The receiving apparatus selectively receives on a predetermined frequency to match the transmitter frequency. The receiving apparatus is comprised of one non directional antenna and two or more loop antennas. The loop antennas modify the field of the incident radio signal by absorbing the incident radio frequency energy to create a non-ambiguous gain pattern on the sense antenna that can be used to determine the direction of the incident RF signal.

United States Patent Application 20140002306 discloses an apparatus for direction-finding a received radio signal. The receiving apparatus selectively receives on a predetermined frequency to match the transmitter frequency. The receiving apparatus comprises of two or three antennas, including one or two loop antennas that work in conjunction with a third reference antenna (whose phase does not vary when its orientation changes relative to the transmitter) such as a dipole, monopole or helical antenna. By

comparing the phase between the antennas the direction of the incoming radio frequency signal can be determined. In some embodiments, the windings of the two loop antennas are wound in reverse with respect to each other in order to substantially double the sensitivity of the signal-detection capabilities. It is a phase comparison system, hence it does not have the range afforded by the signal strength system.

What is needed is an antenna array for radio direction finding that has good sensitivity and high gain. The system should be compact, light-weight, and sealed to the environment, to permit portable hand held operation. The antenna would preferably have excellent impedance matching to the radio equipment. It would be easy to operate and provide full coverage over all directions of the compass. It would be of further advantage if it had a small bandwidth for selective reception and minimal interference.

SUMMARY

In accordance with various aspects of the subject invention in at least one embodiment the invention presents an improved antenna array for radio direction finding and an improved locating system utilizing such an antenna array in which a compact, lightweight, and portable unit enables determining the location of radio tags connected to assets or people.

The subject invention results from the realization that, in part, an improved antenna array for radio direction finding can be achieved through radio frequency coupling of adjacent antennas in a radial arrangement of antennas. The performance of each of the antennas in the antenna array was improved through this coupling mechanism. In particular, the standing wave ratio (SWR), the return loss (RL), and the impedance match of each antenna was improved by this coupling mechanism. In addition, the radiation pattern of each of the antennas in the array was improved through the coupling mechanism.

The preferred embodiments of the antenna array may include three identical antennas. Each of the antennas is rectangular in shape, comprising a bent dipole element on the outer part of the rectangle and a bent reflector element on the inner part of the rectangle. A calibrated gap is situated between the bent dipole element and the bent reflector element. This Moxon style antenna has excellent gain in the forward direction and minimal signal from the back side. The radiation pattern for this antenna is perfectly suited for this radial arrangement of antennas, with the beam pattern sufficiently wide to provide balanced coverage over all points of the compass.

The antenna array is arranged in one plane. This co-planar array permits setting the radio frequency coupling between adjacent reflector elements in each of the antennas. The geometry of the co-planar antenna array permits simple mechanical support and sealing cover for portable hand-held operation.

The angles and distances of the elements of the receiver array are fixed and non-adjustable in a given embodiment.

In one embodiment, a fixed, radial array of antennas for use with a transceiver radio and electronics module for radio direction tracking is provided, the array comprising a plurality of co-planar, rectangular antennas and a radio frequency coupling calibrated space between each adjacent pair of antennas, the radial array defining a periphery and a central zone, each antenna forming a rectangle comprising: a bent dipole element at the periphery of the array, the bent dipole element including a pair of legs and a dipole length terminating in a pair of ends, each leg extending orthogonally from the dipole length at the ends and each terminating in a leg end; a reflector, which includes a pair of legs and a reflector length terminating in a pair of ends, each leg extending orthogonally from the reflector length to define a corner and terminating in a leg end; and a gap between the ends of the legs of the bent dipole element and the ends of the legs of the reflector.

The fixed, radial array may further comprise a substrate, the substrate located in the radio frequency coupling calibrated space.

In the fixed, radial array the corners of the reflectors of each adjacent pair of antenna may define the radio frequency coupling calibrated space.

The fixed, radial array may further comprise a plurality of bent coupling wires, each coupling wire including a length and a pair of bent ends, the coupling wires extending between each adjacent pair of antennas, each bent end and each leg of the reflector defining the radio frequency coupling calibrated space.

The fixed, radial array may further comprise a support, which has a planar surface, the array mounted on the planar surface.

The fixed, radial array may comprise three antennas.

The fixed, radial array may include the transceiver radio and electronics module which is in electronic communication with each antenna.

In the fixed, radial array the transceiver radio and electronics module may be located in the central zone of the array and is co-planar with the array.

In another embodiment, an antenna system for radio direction finding is provided, the system including a housing, a transceiver radio and electronics module retained in the housing and a fixed, radial array of antennas retained in the housing, the array comprising a plurality of co-planar, rectangular antennas and a radio frequency coupling calibrated space between each adjacent pair of antennas, the radial array defining a periphery and a central zone, each antenna in electronic communication with the transceiver radio and electronics module and each antenna forming a rectangle comprising: a bent dipole element at the periphery of the array, the bent dipole element including a pair of legs and a dipole length terminating in a pair of ends, each leg extending orthogonally from the dipole length at the ends and each terminating in a leg end; a reflector, which includes a pair of legs and a reflector length terminating in a pair of ends, each leg extending orthogonally from the reflector length to define a corner and terminating in a leg end; and a gap between the ends of the legs of the bent dipole element and the ends of the legs of the reflector.

The antenna system may further comprise a substrate, the substrate located in the radio frequency coupling calibrated space.

In the antenna system the corners of the reflectors of each adjacent pair of antenna may define the radio frequency coupling calibrated space.

The antenna system may further comprise a plurality of bent coupling wires, each coupling wire including a pair of bent ends and a length therebetween, the coupling wires extending between each adjacent pair of antennas, each bent end and each leg of the reflector defining the radio frequency coupling calibrated space.

The antenna system may comprise three antennas.

In the antenna system the transceiver radio and electronics module may be located in the central zone of the array and is co-planar with the array.

The antenna system may further comprise a direction indicator which is retained by the housing.

The antenna system may further comprise an electronic display which is in electronic communication with the transceiver radio and electronics module and is either retained by the housing or is remote to the housing.

In another embodiment, a radio tracking system is provided, the tracking system comprising a radio transmitter and an antenna system in radio communication with the radio transmitter, the antenna system including a housing, a transceiver radio and electronics module retained in the housing and a fixed, radial array of antennas retained in the housing, the array comprising a plurality of co-planar, rectangular antennas and a radio frequency coupling calibrated space between each adjacent pair of antennas, the radial array defining a periphery and a central zone, each antenna in electronic communication with the transceiver radio and electronics module and each antenna forming a rectangle comprising: a bent dipole element at the periphery of the array, the bent dipole element including a pair of legs and a dipole length terminating in a pair of ends, each leg extending orthogonally from the dipole length at the ends and each terminating in a leg end; a reflector, which includes a pair of legs and a reflector length terminating in a pair of ends, each leg extending orthogonally from the reflector length to define a corner and terminating in a leg end; and a gap between the ends of the legs of the bent dipole element and the ends of the legs of the reflector.

In the radio tracking system the corners of the reflectors of each adjacent pair of antenna may define the radio frequency coupling calibrated space.

The radio tracking system may further comprise a plurality of bent coupling wires, each coupling wire including a pair of bent ends and a length therebetween, the coupling wires extending between each adjacent pair of antennas, each bent end and each leg of the reflector defining the radio frequency coupling calibrated space.

The radio tracking system may comprise three antennas.

FIGURES

Figure 1 is a schematic of a locator system for radio direction finding.

Figure 2 is an isometric view of the multi-antenna system with radio coupling between reflector elements achieved by close physical proximity of the corners of adjacent reflector elements.

Figure 3 is an isometric view of the multi-antenna system with radio coupling between reflector elements achieved with coupling elements added between reflector elements.

Figure 4 is an isometric view of the multi-antenna system with radio coupling between reflector elements achieved with the radio properties of the mechanical support structure.

Figure 5 is an isometric view of an alternate embodiment of Figure 2, with a four antenna system.

Figure 6A is an alternative embodiment with a five antenna system; and Figure 6B is an alternative embodiment with coupling wires and material in the calibrated space.

Figure 7 is a polar log antenna pattern for the transceiver array of Figure 2.

Figure 8 is vector network analysis showing Smith diagram of an uncoupled transceiver array.

Figure 9 is vector network analysis showing Smith diagram for the transceiver array of Figure 2.

Figure 10 is a vector network analysis showing Standing Wave Ratio (SWR) and Return Loss (RL) of an uncoupled transceiver array.

Figure 11 is a vector network analysis showing Standing Wave Ratio (SWR) and Return Loss (RL) for the transceiver array of Figure 2.

DESCRIPTION

Definitions:

Plurality – in the context of the present technology, plurality refers to three or more.

Co-planar – in the context of the present technology, co-planar refers to approximately the same plane, and preferably the same plane.

Rectangular – in the context of the present technology, rectangular refers to the overall shape of the antenna and does not refer to a closed structure, but rather one that has a gap between the ends of the reflector legs and the ends of the dipole element legs.

Detailed Description:

Except as otherwise expressly provided, the following rules of interpretation apply to this specification (written description and claims): (a) all words used herein shall be construed to be of such gender or number (singular or plural) as the circumstances require; (b) the singular terms "a", "an", and "the", as used in the specification and the appended claims include plural references unless the context clearly dictates otherwise; (c) the antecedent term "about" applied to a recited range or value denotes an approximation within the deviation in the range or value known or expected in the art from the measurements method; (d) the words "herein", "hereby", "hereof", "hereto", "hereinbefore", and "hereinafter", and words of similar import, refer to this specification in its entirety and not to any particular paragraph, claim or other subdivision, unless otherwise specified; (e) descriptive headings are for convenience only and shall not control or affect the meaning or construction of any part of the specification; and (f) "or" and "any" are not exclusive and "include" and "including" are not limiting. Further, the terms "comprising," "having," "including," and "containing" are to be construed as open ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted.

Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. Where a specific range of values is provided, it is understood that each intervening value, to the tenth of the unit of the lower limit unless the context clearly dictates otherwise, between the upper and lower limit of that range and any other stated or intervening value in that stated range, is included therein. All smaller sub ranges are also included. The upper and lower limits of these smaller ranges are also included therein, subject to any specifically excluded limit in the stated range.

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the relevant art. Although any methods and materials similar or equivalent to those described herein can also be used, the acceptable methods and materials are now described.

Radio apparatus design requires careful consideration to the performance of the antenna. A properly matched antenna is required to efficiently convert electrical signals to electromagnetic waves, and vice versa. The designer must balance trade-offs of efficiency, bandwidth, radiation pattern, gain, frequency, and antenna matching, with available size and housing constraints. It is almost impossible to achieve the desired antenna without compromising some element of performance.

Through numerous experiments with several types of antenna patterns, it was discovered that an improved antenna array for direction finding could be realized. It was found that the standard bent dipole and reflector arrangement of a Moxon style antenna could be combined into a multi-antenna array that achieved superior performance, when compared to the properties of a single antenna.

Many antennas require a sizeable ground plane to achieve acceptable performance. This is particularly true of small patch antennas, trace antennas printed on circuit boards, and short whip antennas. The bent dipole antennas with matching reflector elements used in this multi-antenna array do not require a ground plane to function, as the ground return path is part of the dipole element. This provides excellent performance without the need of large and heavy grounding components.

The mechanism for the improved antenna performance when using these combined antennas in the array was not initially clear. Tests eventually showed that radio frequency coupling between adjacent reflector elements in the antenna array was responsible for the improvements. Furthermore, it was found that there are several means of achieving this coupling. Some of the methods of coupling that were tested included: direct coupling through close proximity of the reflector elements, coupling through the radio frequency properties of the supporting mechanical structure, and coupling through the addition of a parasitic coupling elements.

A locator system for radio direction finding, generally referred to as 10 is shown in Figure 1. It includes an electronic display 12, which may be remote, a hand-held antenna system 16, and a radio transceiver 18. The radio transceiver 18 is attached to an asset, a person, or wildlife and is remote to the hand-held antenna system 16. The hand-held antenna system 16 has a housing 22, which has an outer edge 26 and a central zone 28, and a handle 29. The central zone 28 of the antenna system 16 may include electronics for radio transceivers, control, communications, and compass direction 14.

As shown in Figure 2, the antenna system 16 includes three bent dipole elements - a first dipole element 30, a second dipole element 32, and a third dipole element 34. The dipole elements 30, 32, 34 are identical and are co-planar to one another. Each element 30, 32, 34 includes an element length 40, a first element

leg 42 and a second element leg 44. The element legs 42, 44 are orthogonal and co-planar to the element length 40, parallel with one another and extend inward to the middle of the system. There are three reflectors, a first reflector 50, a second reflector 52 and a third reflector 54. The reflectors 50, 52, 54 are identical, co-planar with one another and co-planar with the bent dipoles 30, 32, 34. Each reflector 50, 52, 54 has a reflector length 60, a first reflector leg 62 and a second reflector leg 64. The reflector legs 62, 64 are orthogonal and co-planar to the reflector lengths 60, parallel with one another and extend outward towards the outer edge 28 of the hand-held antenna system 16. The reflector legs 62, 64 oppose the dipole element legs 42, 44 of the corresponding element – the first reflector 50 is aligned with the first dipole element 30, the second reflector 52 is aligned with the second dipole element 32 and the third reflector 54 is aligned with the third dipole element 34. A space 70 is defined between the ends 66 of the reflector legs 62, 64 and the ends 46 of the dipole element legs 42, 44. Each dipole element 30, 32, 34 and its corresponding reflector 50, 52, 54 are an antenna 71.

Radio frequency coupling between adjacent reflectors is provided by a calibrated space 72 between adjacent reflector corners 68. Specifically, the calibrated space 72 provides radio frequency coupling between the first reflector 50 and the second reflector 52, between the second reflector 52 and the third reflector 54 and between the third reflector 54 and the first reflector 50.

A transceiver radio and electronics module 24 is located in the central zone 28 of the system 16. A wire 80 extends between each dipole element 30, 32, 34 and the module 24 for bi-directional communication of the radio signal. The module 24 is co-planar or approximately co-planar to the dipole elements 30, 32, 34, and the reflectors 50, 52, 54. The radial array 73 of antennas defines a periphery 27.

The specific dimensions for one fixed, radial array 73 are as follows: the length of the dipole element of each antenna is about 245 mm to about 253 mm, more preferably about 249 mm; the width is about 91 to about 95 mm, more preferably about 93 mm, the gap is about 12 to about 16 mm, preferably about 14 mm, the wire rod for the antenna is about 2 to about 4 mm, preferably about 3 mm in diameter; the distance between the centre of the array and the periphery is about 160 to about 172 mm, preferably about 166 mm; the radius of the corners is about 7 to about 9 mm, preferably about 8 mm and the diameter of the transceiver radio and electronics module is about 100 to about 116 mm, preferably about 108 mm.

As shown in Figure 3, an alternate embodiment of the multi-antenna, co-planar system includes bent coupling wires 90. The co-planar arrangement of bent dipole elements, 30, 32, 34 and reflectors, 50, 52,

54 are similar to those in Figure 2. The coupling between adjacent reflectors 50, 52, 54 is achieved with the coupling wires 90, as opposed to the close physical proximity of the corners 68 of the reflectors 50, 52, 54, and the calibrated space 72. The coupling wires 90 have bent ends 92. The calibrated space 74 is defined between the bent ends 92 and the reflector legs 62, 64. The calibrated space 74 provides radio frequency coupling between the first reflector 50 and the second reflector 52, between the second reflector 52 and the third reflector 54 and between the third reflector 54 and the first reflector 50.

As shown in Figure 4, an alternate embodiment of the multi-antenna, co-planar system includes a supporting material 100, which has a planar surface 94 over much of the surface and which fills the calibrated space 76. The preferred support is polyvinyl chloride expanded foam. The co-planar arrangement of bent dipole elements, 30, 32, 34 and reflectors, 50, 52, 54 are similar to those in Figure 2. The coupling between adjacent reflectors is achieved through the radio frequency properties of the mechanical support 100. The nature and quantity of the supporting material 75 in the calibrated space 76 between the corners 68 of the reflectors 50, 52, 54, is carefully chosen to provide the correct coupling between the reflectors 50, 52, 54. The calibrated space 76 provides radio frequency coupling between the first reflector 50 and the second reflector 52, between the second reflector 52 and the third reflector 54 and between the third reflector 54 and the first reflector 50. This may include bent coupling wires 90.

In an alternative embodiment, the material in the calibrated space 76 is different to the material of the supporting material 100.

Figure 5 shows an alternate embodiment of the multi-antenna, co-planar array 73 with four antennas 71. Each of the antennas 71 include the bent dipole elements 30, 32, 34, 36, reflectors 50, 52, 54, 56, and connecting wires 80. This figure shows the antenna calibrated space 72 between reflector elements 50, 52, 54, 56. The calibrated space 72 provides radio frequency coupling between the first reflector 50 and the second reflector 52, between the second reflector 52 and the third reflector 54, between the third reflector 54 and the fourth reflector 56 and between the fourth reflector 56 and the first reflector 50.

Other alternative embodiments include a multi-antenna, co-planar array 73 with more than four antennas 71, for example, but not limited to, five antennas 71 or six antennas 71. A five antenna array is shown in Figure 6A. In Figure 6B, it is shown that these may include bent coupling wires 90 and may also include the supporting material 75 in the calibrated space 74. In all embodiments, the antenna 71 are arranged in a fixed, radial array 73.

Figure 7 shows a polar log radiation pattern for the multi-antenna, co-planar array. Measurements of radiation pattern for each of the antennas in the multi-antenna array showed improvements to the pattern over a single antenna. The front to back ratio showed a measured improvement with the coupled reflector elements altering the radiation pattern. The front lobe was slightly broader, which helped to improve the omni-directional coverage of the antenna array. In addition, the forward gain of the antennas was slightly larger than for the stand alone antennas.

Figure 8 shows a vector network analysis showing Smith diagram for an uncoupled multi-antenna, co-planar array.

Figure 9 shows a vector network analysis showing Smith diagram for the radio frequency coupled multi-antenna, co-planar array. Measurements using a vector network analyzer showed the impedance match of each antenna in the multi-antenna array, over a range of frequencies. These were plotted on a Smith Chart to assist in visualizing the real and imaginary components of impedance. The Smith Chart showed the ideal 50 ohm impedance match at the desired frequency. The impedance change with frequency also indicated the good match over the desired bandwidth of the antenna. These results show that the system is superior to that of the prior art and to the uncoupled array of Figure 8.

Figure 10 shows a vector network analysis showing Standing Wave Ratio (SWR) and Return Loss (RL) for an uncoupled multi-antenna, co-planar array.

Figure 11 shows a vector network analysis showing Standing Wave Ratio (SWR) and Return Loss (RL) for the radio frequency coupled multi-antenna, co-planar array. Measurements using a vector network analyzer showed the standing wave ratio of each of the antennas in the array was improved to the ideal 1.0 : 1. The standing wave ratio, SWR, indicates the amount of electrical energy from a radio that is converted into electromagnetic radiation. Typically a fraction of the energy is bounced back from an antenna and appears as a mismatched antenna load. Commercial antennas typically have an SWR of 2 : 1 to 1.5 : 1. These results show that the system is superior to that of the prior art and to the uncoupled array of Figure 10.

Another aspect of antenna design for radio apparatus is how the antenna behaves with external loading on the antenna. When antennas are deployed in real world applications the housing and support structures for the antenna will alter the antenna frequency response, the standing wave ratio, and the antenna match to the transceiver circuit. Often antennas designed to be embedded in housings are purposely designed to be out-of-band, or tuned to a different frequency than desired. This allows the

antenna to be loaded by the housing and pulled into the correct frequency. The nature of the coupling between the reflector elements in the multi-antenna array ensures that the effects of the housing and support structure is incorporated into the design and nature of the system.

While example embodiments have been described in connection with what is presently considered to be an example of a possible most practical and/or suitable embodiment, it is to be understood that the descriptions are not to be limited to the disclosed embodiments, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the example embodiment. Those skilled in the art will recognize or be able to ascertain using no more than routine experimentation, many equivalents to the specific example embodiments specifically described herein. Such equivalents are intended to be encompassed in the scope of the claims, if appended hereto or subsequently filed.

CLAIMS

1. A fixed, radial array of antennas for use with a transceiver radio and electronics module for radio direction tracking, the array comprising a plurality of co-planar, rectangular antennas and a radio frequency coupling calibrated space between each adjacent pair of antennas, the radial array defining a periphery and a central zone, each antenna forming a rectangle comprising: a bent dipole element at the periphery of the array, the bent dipole element including a pair of legs and a dipole length terminating in a pair of ends, each leg extending orthogonally from the dipole length at the ends and each terminating in a leg end; a reflector, which includes a pair of legs and a reflector length terminating in a pair of ends, each leg extending orthogonally from the reflector length to define a corner and terminating in a leg end; and a gap between the ends of the legs of the bent dipole element and the ends of the legs of the reflector.
2. The fixed, radial array of claim 1 further comprising a substrate, the substrate located in the radio frequency coupling calibrated space.
3. The fixed, radial array of claim 1 or 2, wherein the corners of the reflectors of each adjacent pair of antenna define the radio frequency coupling calibrated space.
4. The fixed, radial array of claim 1 or 2, further comprising a plurality of bent coupling wires, each coupling wire including a length and a pair of bent ends, the coupling wires extending between each adjacent pair of antennas, each bent end and each leg of the reflector defining the radio frequency coupling calibrated space.
5. The fixed, radial array of any one of claims 1 to 4, further comprising a support, which has a planar surface, the array mounted on the planar surface.
6. The fixed, radial array of any one of claims 1 to 5 comprising three antennas.
7. The fixed, radial array of any one of claims 1 to 6, including the transceiver radio and electronics module which is in electronic communication with each antenna.

8. The fixed, radial array of claim 7, wherein the transceiver radio and electronics module is located in the central zone of the array and is co-planar with the array.

9. An antenna system for radio direction finding, the system including a housing, a transceiver radio and electronics module retained in the housing and a fixed, radial array of antennas retained in the housing, the array comprising a plurality of co-planar, rectangular antennas and a radio frequency coupling calibrated space between each adjacent pair of antennas, the radial array defining a periphery and a central zone, each antenna in electronic communication with the transceiver radio and electronics module and each antenna forming a rectangle comprising: a bent dipole element at the periphery of the array, the bent dipole element including a pair of legs and a dipole length terminating in a pair of ends, each leg extending orthogonally from the dipole length at the ends and each terminating in a leg end; a reflector, which includes a pair of legs and a reflector length terminating in a pair of ends, each leg extending orthogonally from the reflector length to define a corner and terminating in a leg end; and a gap between the ends of the legs of the bent dipole element and the ends of the legs of the reflector.

10. The antenna system of claim 9, further comprising a substrate, the substrate located in the radio frequency coupling calibrated space.

11. The antenna system of claim 10 or 11, wherein the corners of the reflectors of each adjacent pair of antenna define the radio frequency coupling calibrated space.

12. The antenna system of claim 10 or 11, further comprising a plurality of bent coupling wires, each coupling wire including a pair of bent ends and a length therebetween, the coupling wires extending between each adjacent pair of antennas, each bent end and each leg of the reflector defining the radio frequency coupling calibrated space.

13. The antenna system of any one of claims 10 to 12, comprising three antennas.

14. The antenna system of any one of claims 10 to 13, wherein the transceiver radio and electronics module is located in the central zone of the array and is co-planar with the array.

15. The antenna system of any one of claims 10 to 14 further comprising a direction indicator which is retained by the housing.

16. The antenna system of any one of claims 10 to 15 further comprising an electronic display which is in electronic communication with the transceiver radio and electronics module and is either retained by the housing or is remote to the housing.

17. A radio tracking system, the tracking system comprising a radio transmitter and an antenna system in radio communication with the radio transmitter, the antenna system including a housing, a transceiver radio and electronics module retained in the housing and a fixed, radial array of antennas retained in the housing, the array comprising a plurality of co-planar, rectangular antennas and a radio frequency coupling calibrated space between each adjacent pair of antennas, the radial array defining a periphery and a central zone, each antenna in electronic communication with the transceiver radio and electronics module and each antenna forming a rectangle comprising: a bent dipole element at the periphery of the array, the bent dipole element including a pair of legs and a dipole length terminating in a pair of ends, each leg extending orthogonally from the dipole length at the ends and each terminating in a leg end; a reflector, which includes a pair of legs and a reflector length terminating in a pair of ends, each leg extending orthogonally from the reflector length to define a corner and terminating in a leg end; and a gap between the ends of the legs of the bent dipole element and the ends of the legs of the reflector.

18. The radio tracking system of claim 17, wherein the corners of the reflectors of each adjacent pair of antenna define the radio frequency coupling calibrated space.

19. The radio tracking system of claim 17, further comprising a plurality of bent coupling wires, each coupling wire including a pair of bent ends and a length therebetween, the coupling wires extending between each adjacent pair of antennas, each bent end and each leg of the reflector defining the radio frequency coupling calibrated space.

20. The radio tracking system of any one of claims 17 to 19, comprising three antennas.

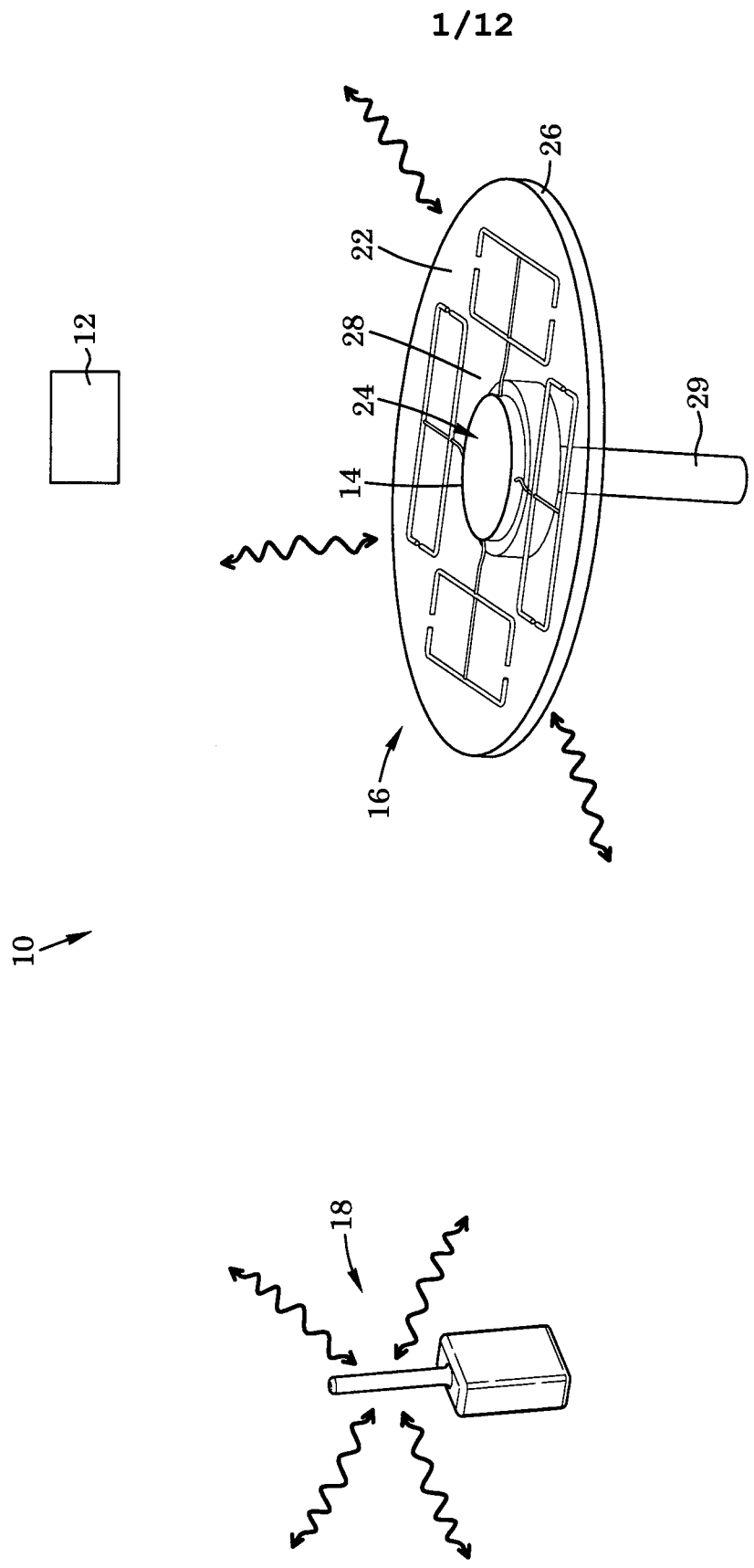


FIG. 1

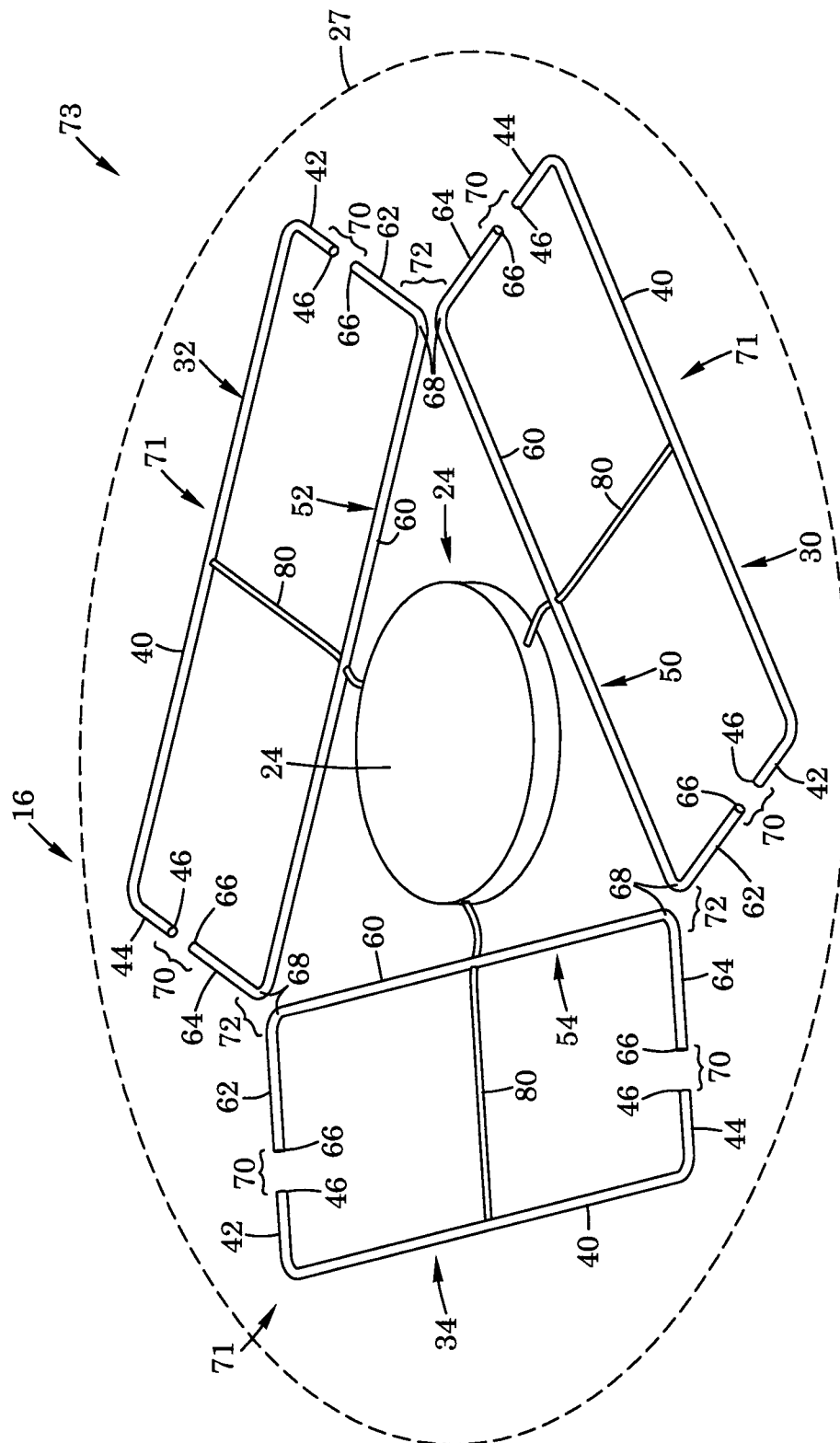


FIG. 2

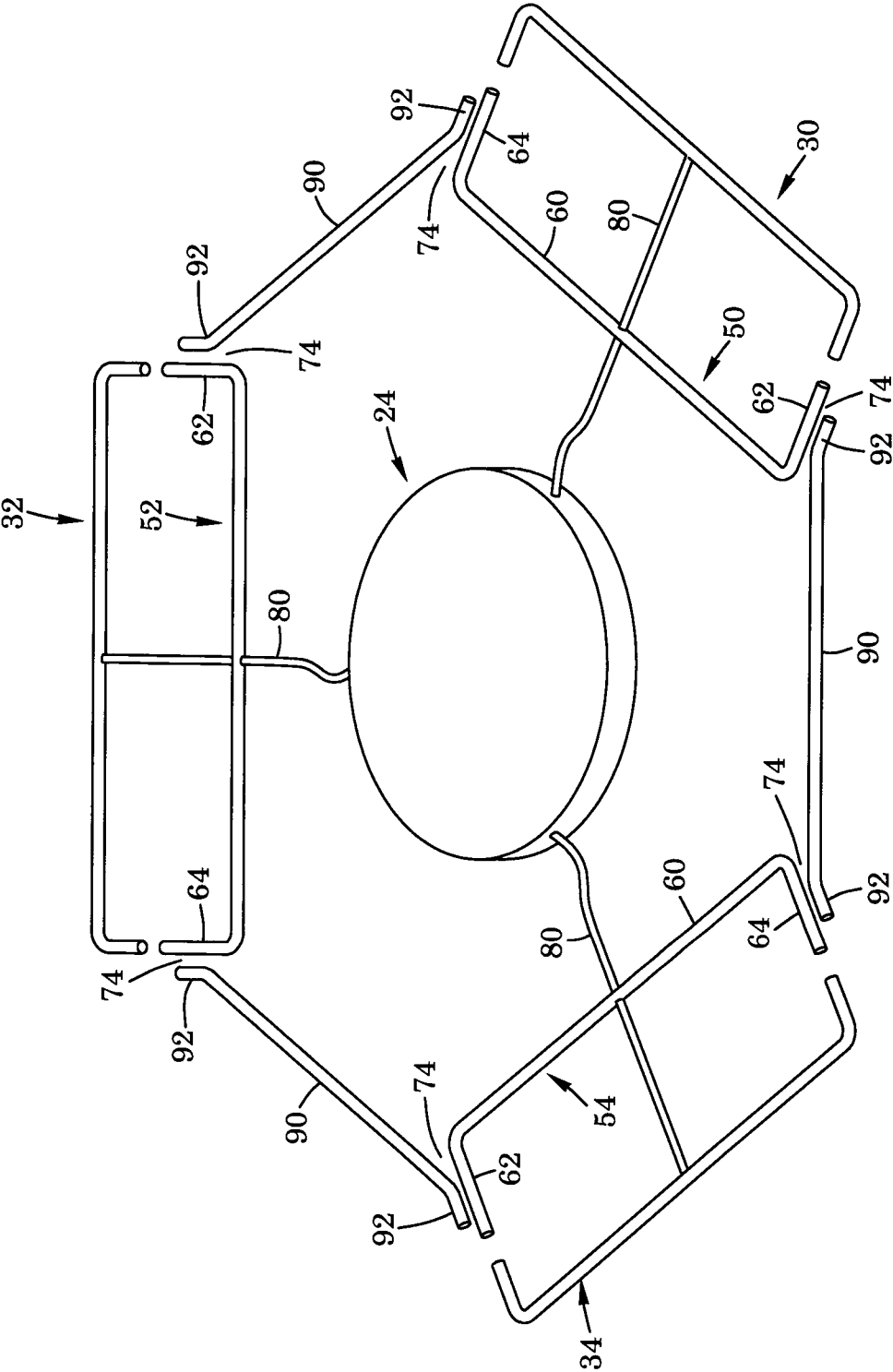


FIG. 3

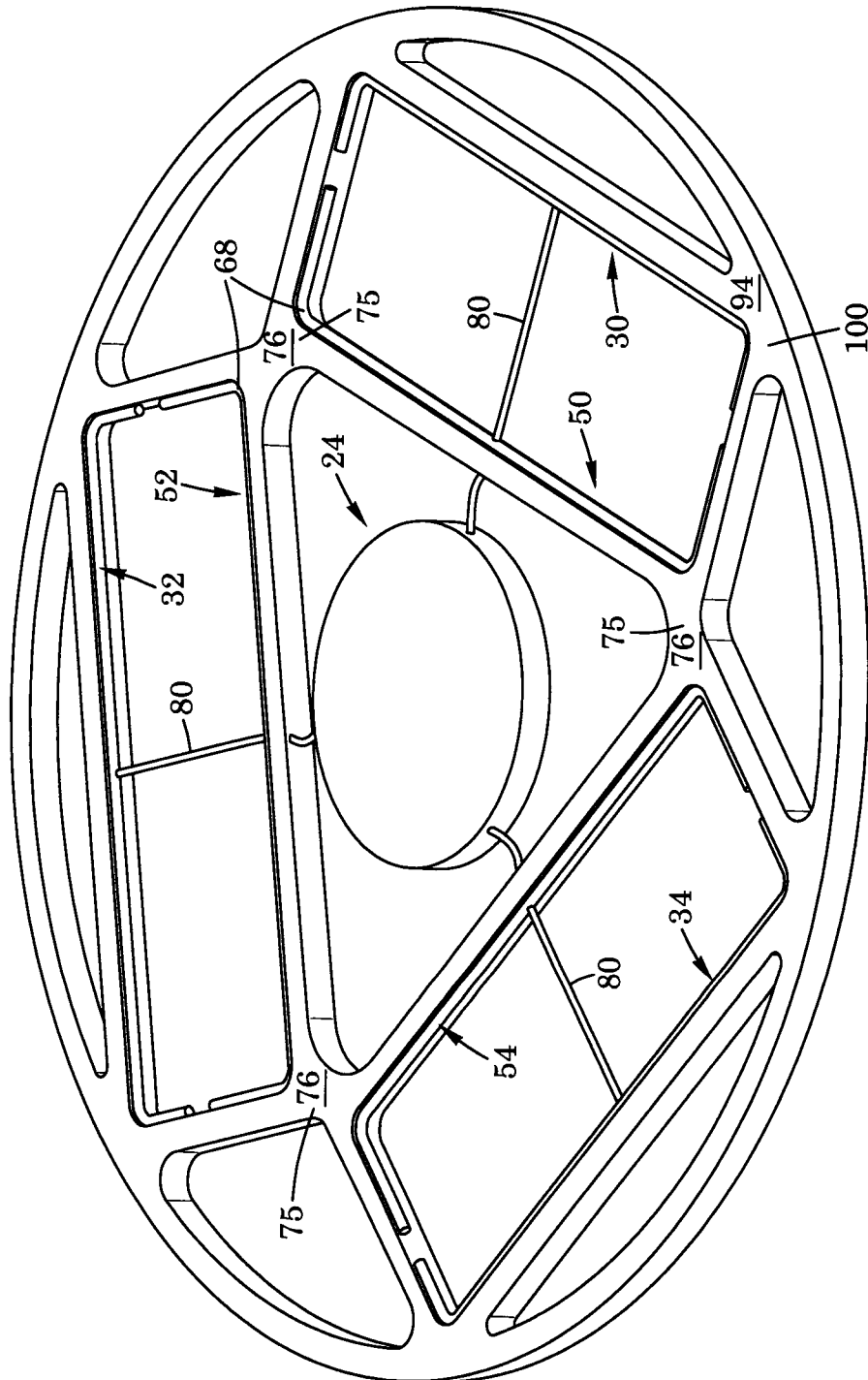


FIG. 4

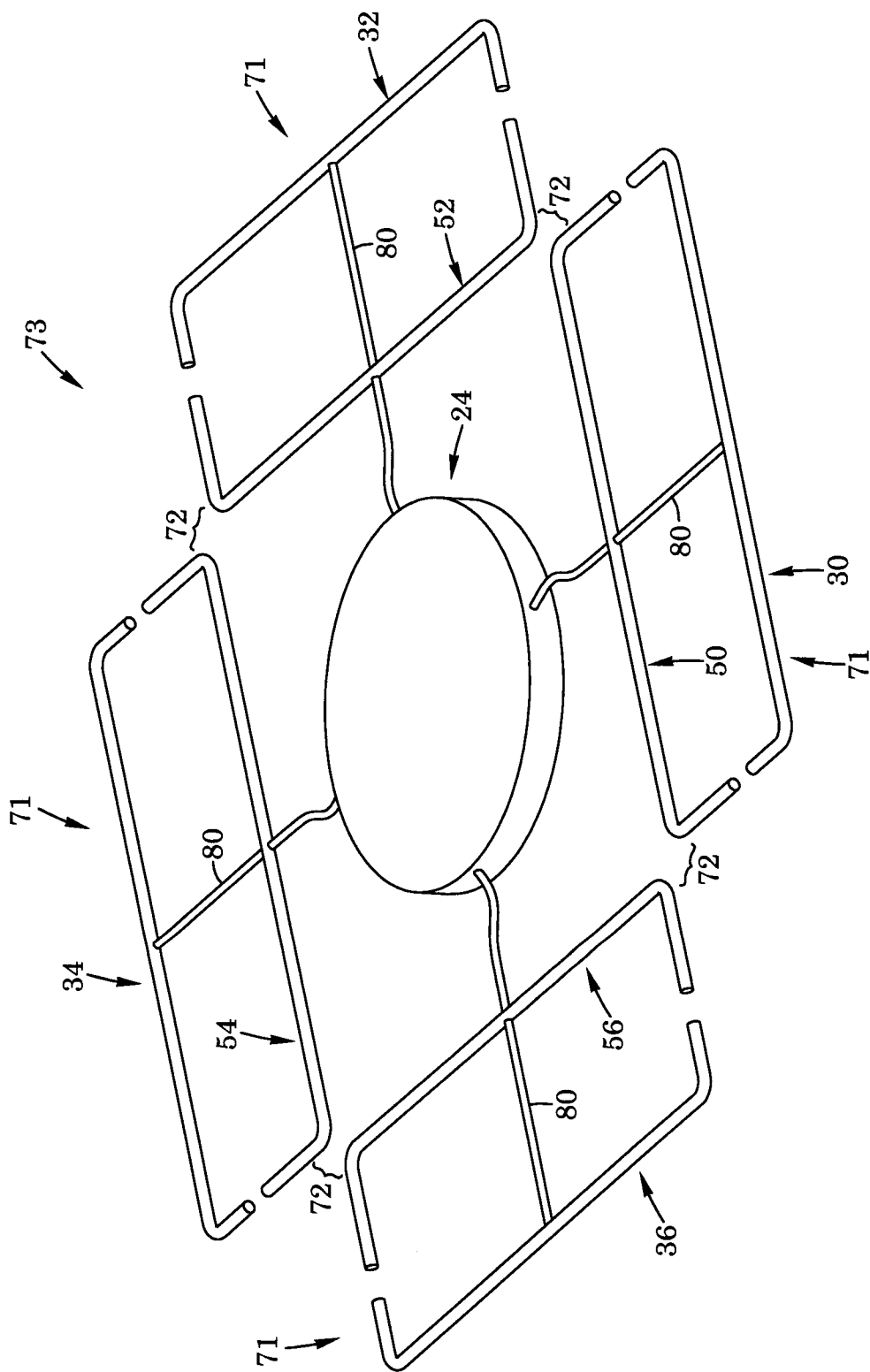


FIG. 5

6/12

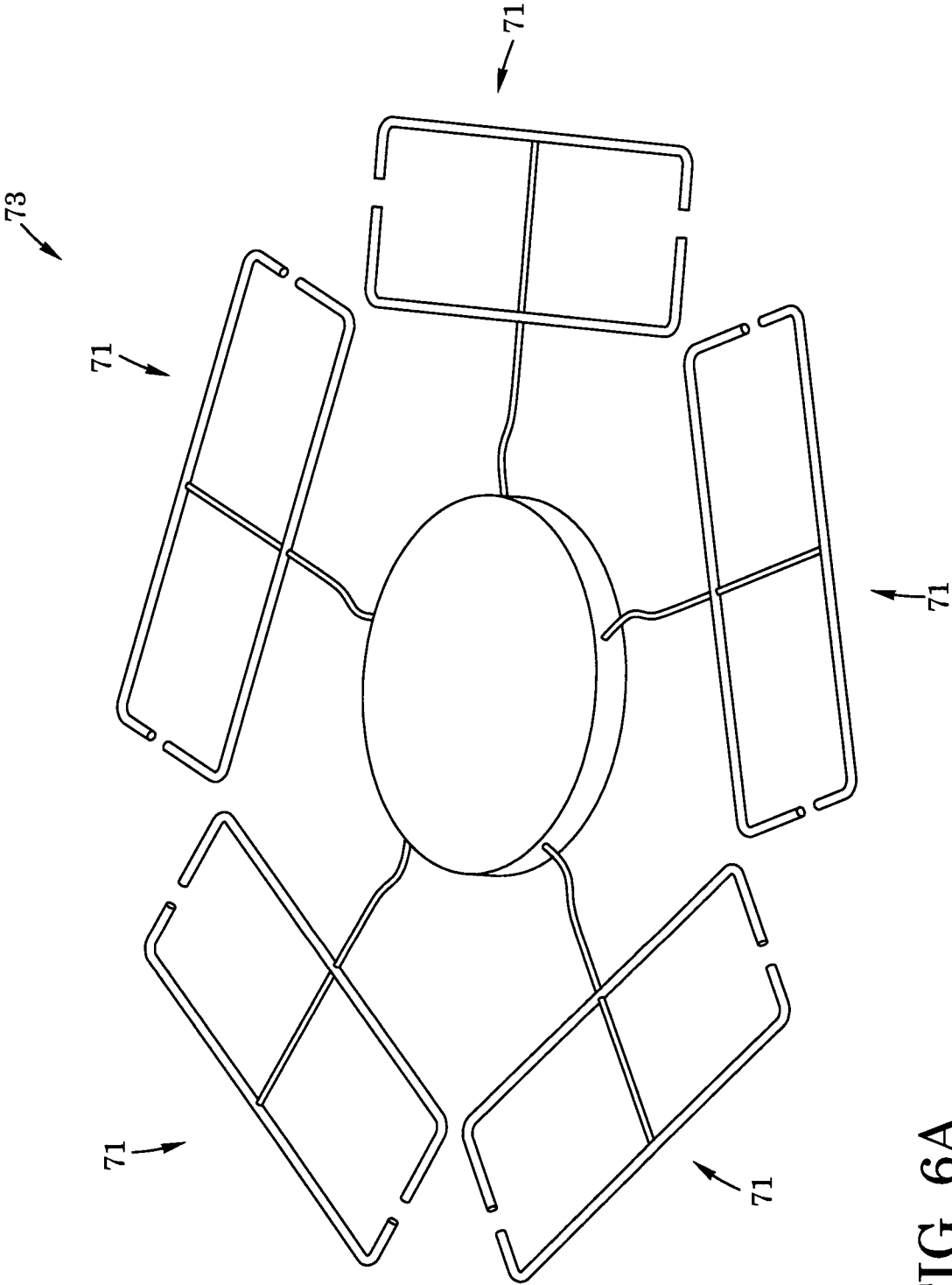


FIG. 6A

7/12

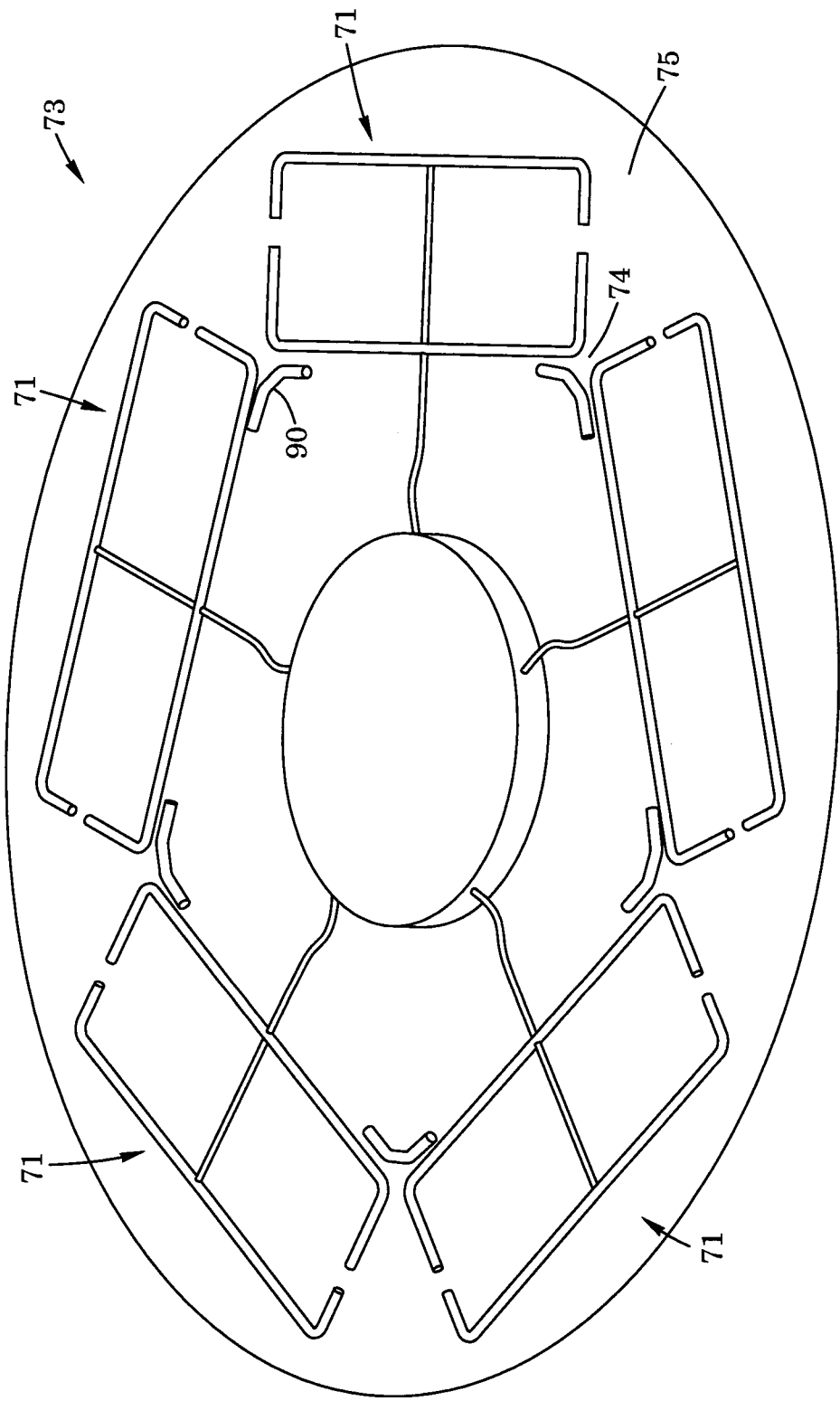


FIG. 6B

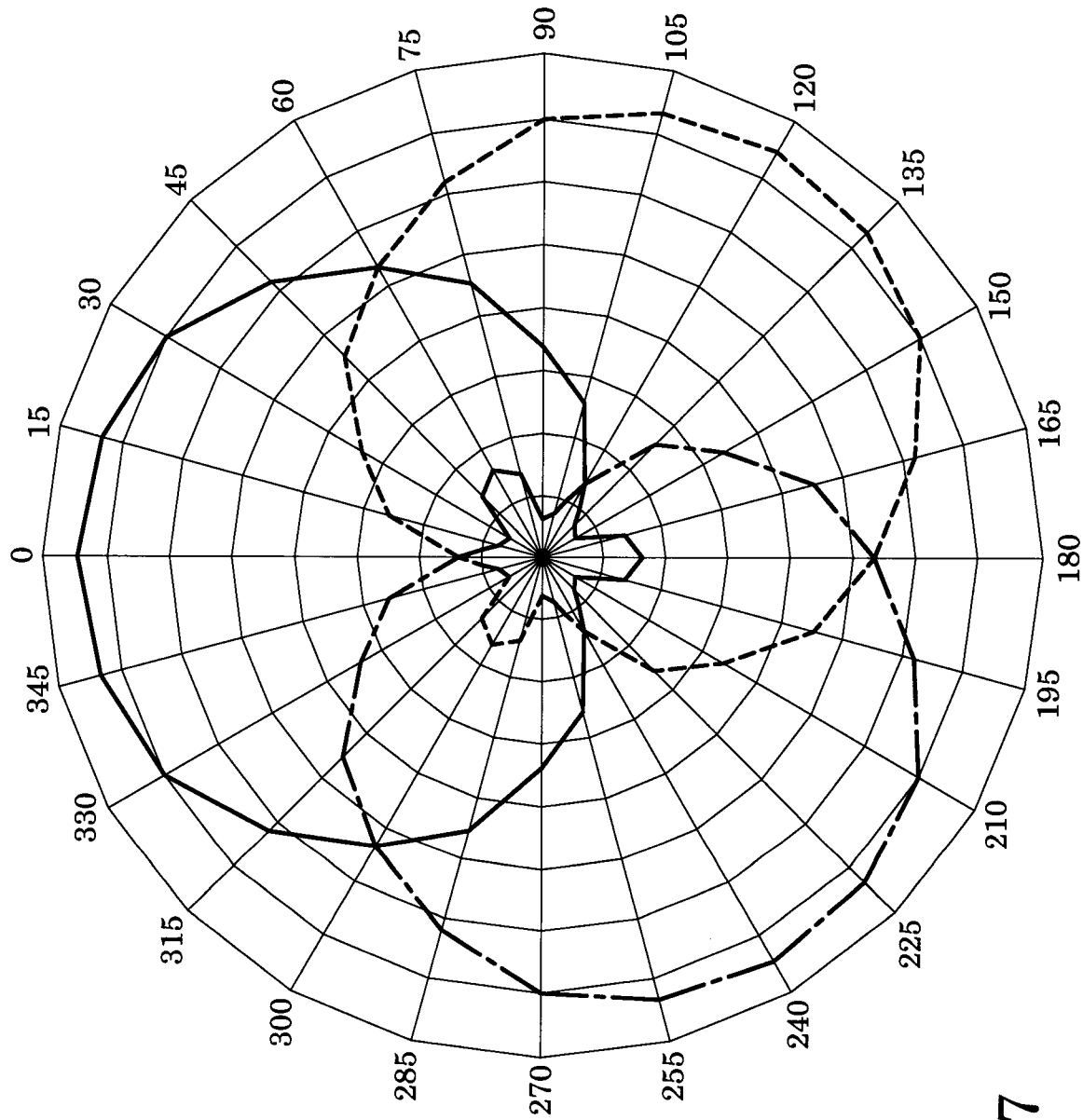


FIG. 7

1: 429,684,717H:
RL -11.11dB
RP -29.88°
Z 81.0Ω
Rs 77.5Ω
Xs -23.3Ω
Swr 1.8:1
Mag 0.278

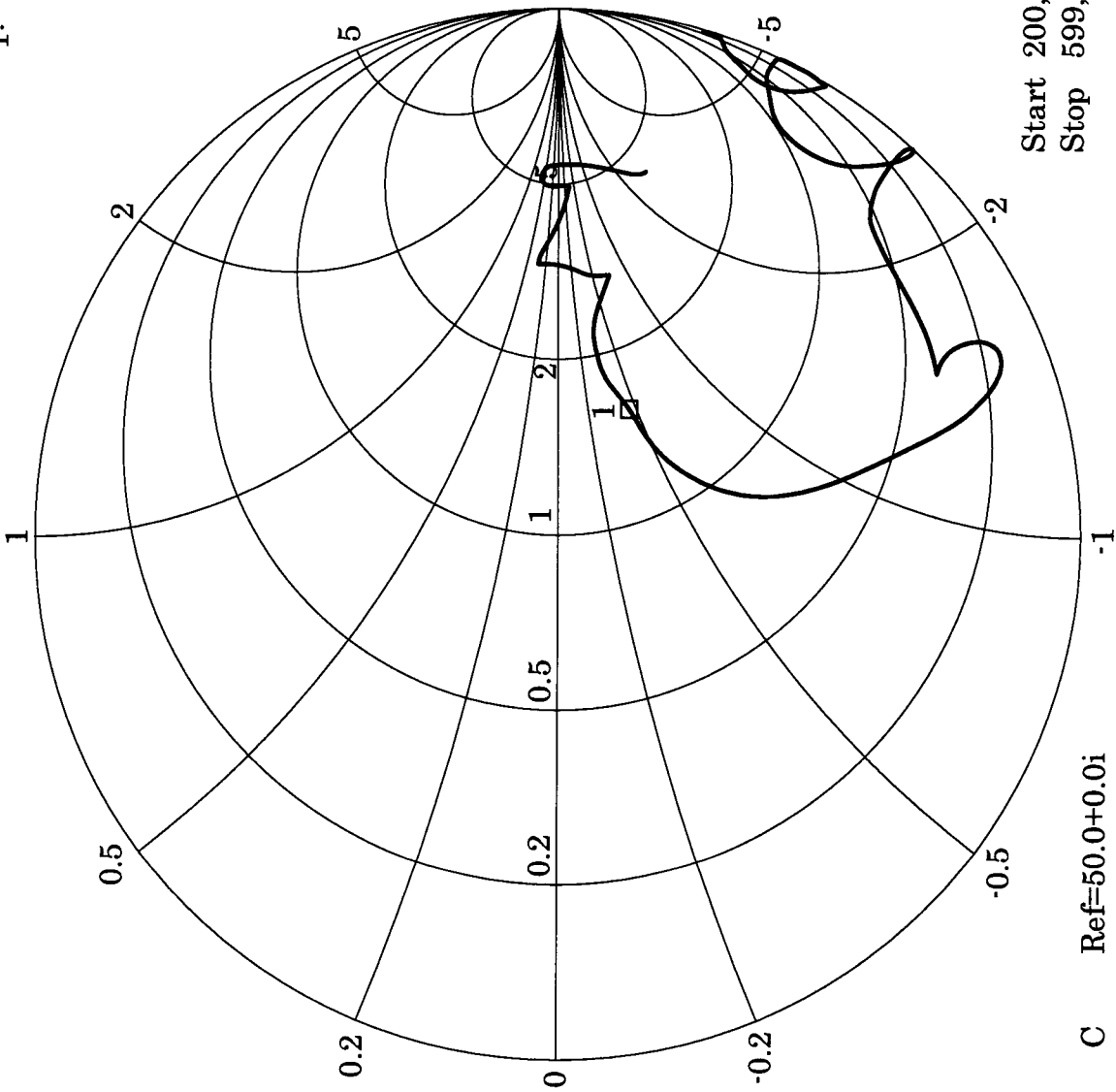


FIG. 8

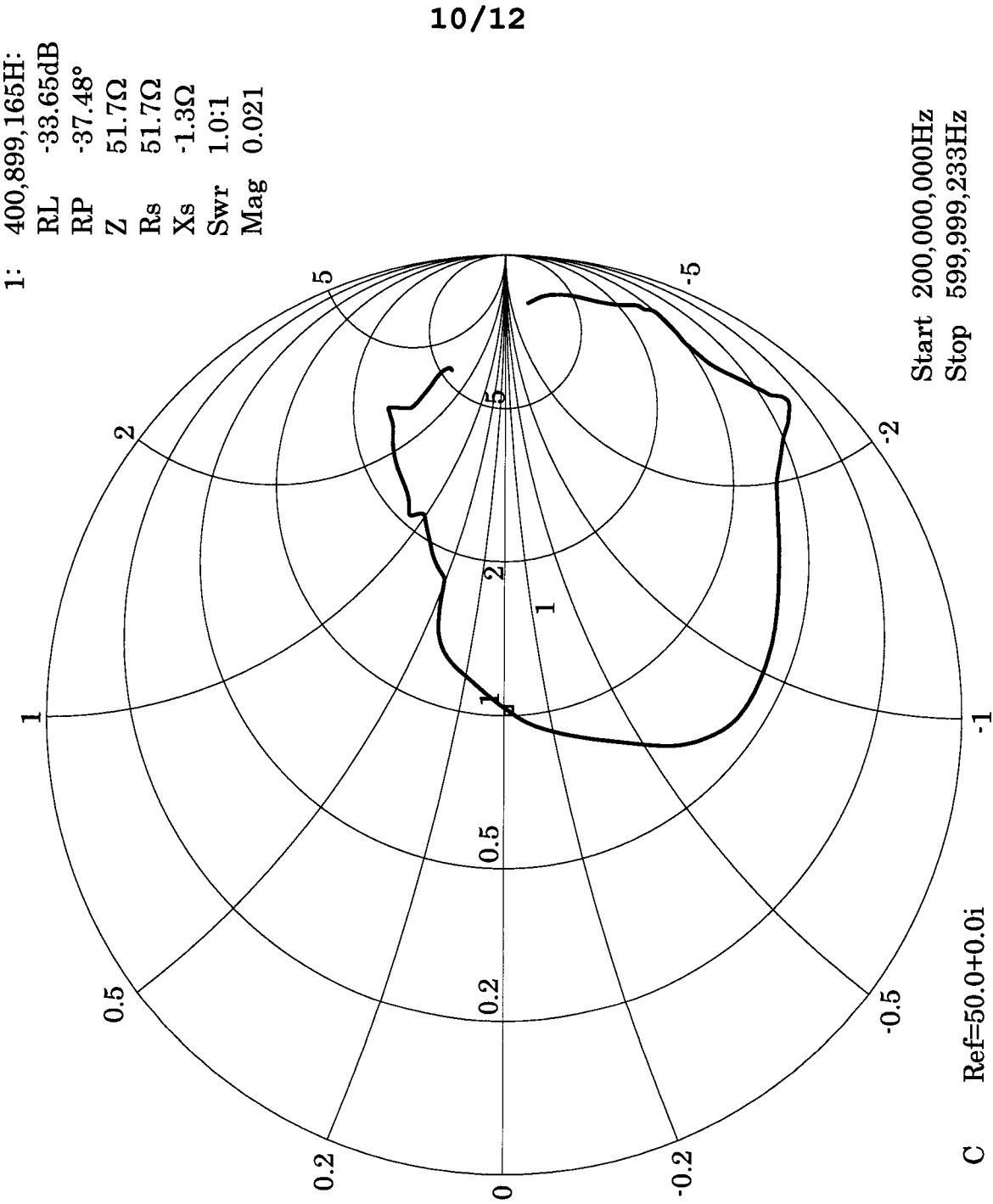


FIG. 9

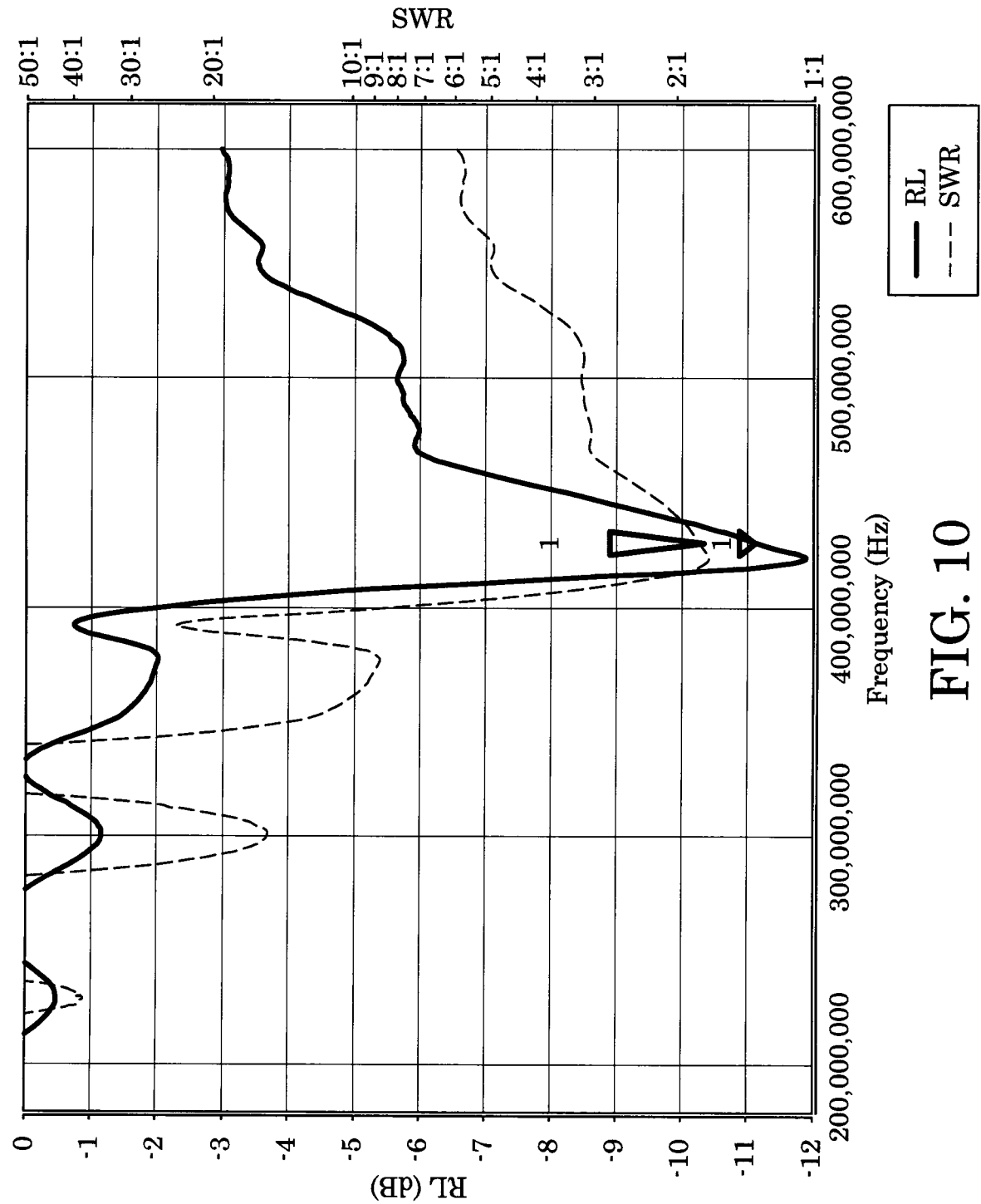


FIG. 10

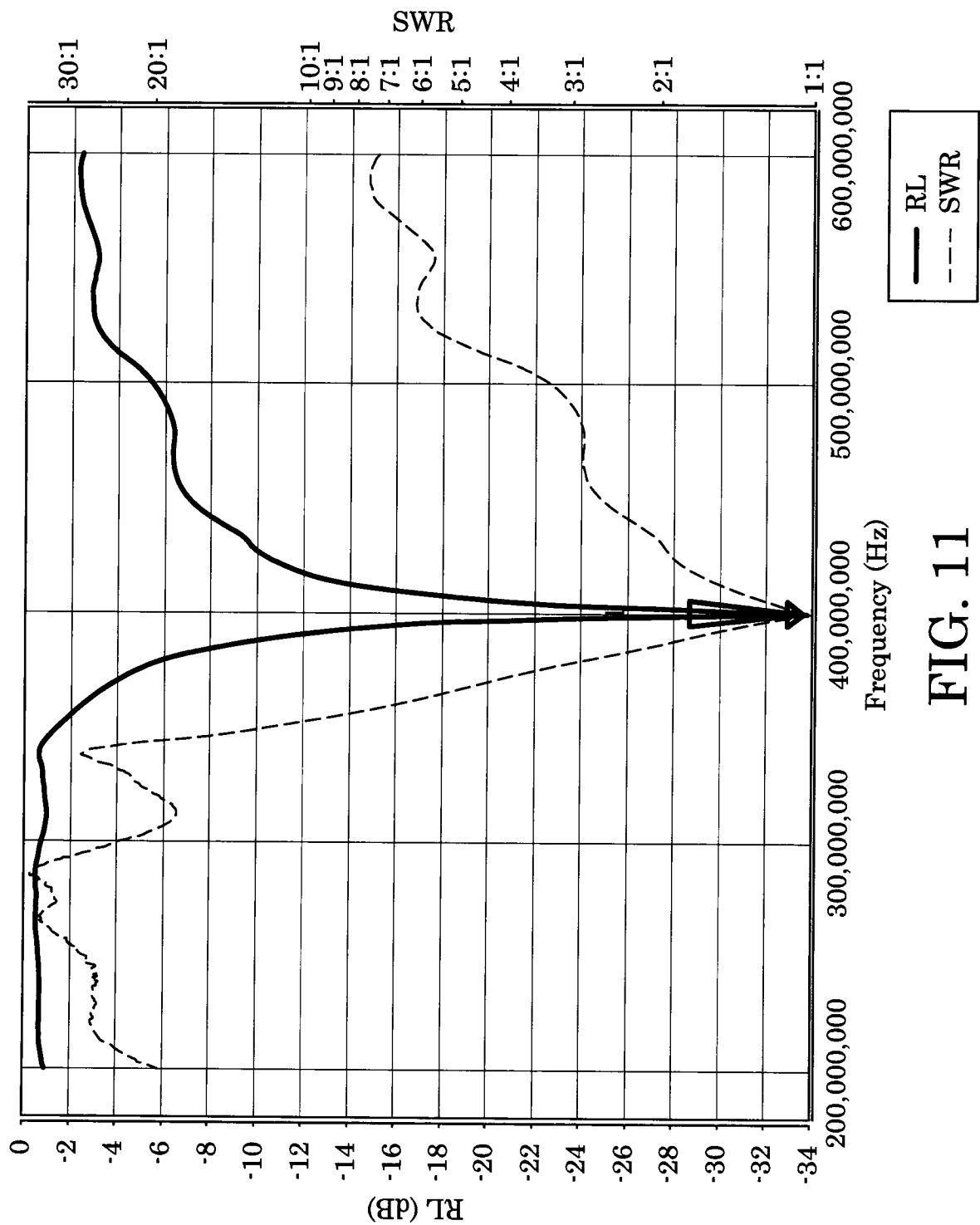


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2019/000124

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **H01Q 21/29** (2006.01), **H01Q 1/38** (2006.01), **H01Q 13/16** (2006.01), **H01Q 21/20** (2006.01), **H01Q 9/26** (2006.01), **H04B 1/38** (2015.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: H01Q 21/29 (2006.01), H01Q 1/38 (2006.01), H01Q 13/16 (2006.01), H01Q 21/20 (2006.01), H01Q 9/26 (2006.01), H04B 1/38 (2015.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)

Questel and Canadian Patents Database.

Keywords: antenna, dipole, reflector, track, direction, location, radial, array

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	CN1591976 A A1 09 March 2005 (09-03-2005) * figures 3, 6, 9a and Technical field paragraph*	1-20
Y	US 2016/0141765 A1 Moon et al. 19 May 2016 (19-05-2016) * paragraph 0041, figure 7*	1-20

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"D" document cited by the applicant in the international application	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"E" earlier application or patent but published on or after the international filing date	"&" document member of the same patent family
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
19 November 2019 (19-11-2019)

Date of mailing of the international search report
19 November 2019 (19-11-2019)

Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 819-953-2476

Authorized officer

Tariq Khader (819) 639-7977

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2019/000124

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
CN1591976	09-03-2005	None	
US20160141765A1	19-05-2016	WO2014185709A1 US10224643B2 EP299050A4 KR10-2001519B1 JP6282726B2	20-11-2014 05-03-2019 04-01-2017 18-07-2019 21-02-2018