

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
19 January 2006 (19.01.2006)

PCT

(10) International Publication Number  
**WO 2006/007004 A2**

(51) International Patent Classification:  
**G01R 1/00** (2006.01)

(74) Agents: **KINNEAR, Brian** et al.; 555 17th Street, Suite 3200, Denver, Colorado 80201 (US).

(21) International Application Number:  
PCT/US2005/013790

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(22) International Filing Date: 21 April 2005 (21.04.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
10/871,207 18 June 2004 (18.06.2004) US

(71) Applicant (*for all designated States except US*): **CENTURION WIRELESS TECHNOLOGIES, INC.** [US/US]; 3425 N. 44th Street, Lincoln, Nebraska 68504 (US).

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): **KADAMBI, Govind, R.** [IN/US]; 1925 Greenway Drive, Apt. No. I-4, Melbourne, Florida 32901 (US). **NARAYANAN, Ram, N** [US/US]; 575 Cricklewood Drive, State College, Pennsylvania 16803 (US). **HUANG, Yeqin** [CN/US]; 2101 Manhattan Blvd., B103, Harvey, Louisiana 70058 (US). **EVERT, Gordon** [US/US]; 7405 Rokeby Road, Lincoln, Nebraska 68517 (US). **WINTER, James, Blake** [US/US]; 1530 E. Manor Drive, Lincoln, Nebraska 68506 (US).

**Published:**

— *without international search report and to be republished upon receipt of that report*

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*



**WO 2006/007004 A2**

(54) Title: METHOD AND APPARATUS TO CONTROL AN ANTENNA EFFICIENCY TEST DEVICE

(57) Abstract: The present invention provides a method to measure antenna efficiency using the cavity method. In particular, the present invention provides a tunable cavity that can be tuned to avoid the anti resonance and antenna-cavity coupling problems. In particular, tuning probes and/or variable volumetric sizing of the cavity are used to tune the cavity to avoid the anti resonance and antenna-cavity coupling.

## METHOD AND APPARATUS TO CONTROL AN ANTENNA EFFICIENCY TEST DEVICE

This application is related to co-pending application filed herewith under attorney docket number 38105.830084.US0.

5

### FIELD OF THE INVENTION

The present invention relates to antenna testing devices and, more particularly, to a cavity test device capable of measuring antenna efficiency.

### BACKGROUND OF THE INVENTION

One important performance attribute of an antenna is the antenna's radiation efficiency. One way to define or identify an antenna's radiation efficiency is as a ratio of the power radiated from the antenna to the power input to the antenna. The ratio indicates losses in the antenna system. Formula (1), below, defines radiation efficiency  $\eta$  of an antenna as:

$$\eta = \frac{P_R}{P_R + P_L} \quad (1)$$

where  $P_R$  is the radiated power, and  $P_L$  is the power loss of the antenna. The quantity  $P_R + P_L$  is the power input to the antenna. Because power input to the antenna is known, and power radiated from the antenna is measurable, power loss is derivable.

An equivalent definition of efficiency is through a ratio of radiation resistance and loss resistance. In this case, formula (2) measures antenna efficiency  $\eta$  as:

$$\eta = \frac{R_R}{R_R + R_L} \quad (2)$$

where  $R_R$  is the radiation resistance, and  $R_L$  the loss resistance. The quantity  $R_R + R_L$  is the input resistance of the antenna and it constitutes the real part of the antenna input impedance.

As is commonly understood in the art, the radiation resistance of an antenna is equivalent to the resistance of an equivalent ideal resistor which when replaced would deliver the same power as that of the antenna.

Conventionally, a 3D-Pattern Integration Method is used to determine the radiation efficiency of the antenna. The 3D-Pattern Integration Method of efficiency measurement is based on power, see formula (1), and involves measuring the radiation pattern over a sphere that encloses the test antenna.

While the conventional and accepted method of determining radiation efficiency, the 3D-Pattern Integration Method has several drawbacks. Some of the drawbacks are that the test is relatively expensive and time consuming. The 3D-Pattern Integration Method computes the efficiency of the antenna based on the gain computations, which in turn are determined through volumetric or 3D patterns of the test antenna.

An alternative to the 3D-Pattern Integration Method above involves a process conventionally known as the Cavity Method of Efficiency. The Cavity Method of Efficiency is also known as the Wheeler Method. This method originally proposed by Wheeler [H.A. Wheeler, "The Radiansphere around a Small Antenna", Proceedings of the IRE, August, 1959, pp. 1325-1331] enables the determination of the antenna efficiency defined in terms of radiation and loss resistance, see formula (2) above. The Cavity Method of Efficiency assumes radiation resistance gets shorted when an antenna under test is enclosed by a conducting cavity. In other words, the antenna will not radiate when a conducting cavity encompasses, bounds, or shields the antenna. Under this assumption, the input resistance of the test antenna placed inside a shielded cavity is a direct measure of the loss resistance of the antenna. Thus by making two impedance measurements of the test antenna, one when the test antenna is in free space (to measure  $R_R + R_L$ ) and the other when the test antenna is inside the shielded cavity (to measure  $R_L$ ), the radiation resistance  $R_R$  can be determined because  $R_R = (R_R + R_L) - R_L$ . Once

the radiation resistance  $R_r$  and the loss resistance  $R_L$  of the antenna are known, one can determine the antenna efficiency using formula (2).

When compared to the 3D-Pattern Integration Method, the Cavity Method of Efficiency is considered simpler, less time consuming and less tedious. However, it has its own drawbacks despite all these novel features. In particular, the Cavity Method of Efficiency has constraints on the bandwidth of the measurement. This means, depending upon the size of the cavity or shielding, the antenna may encounter an anti resonance of the cavity.

The term anti resonance defines that resonant frequency of the cavity which overlaps the measurement frequency of the test antenna. The measurement cavity has inherent different resonant frequencies depending upon the dimensions of the cavity.

The anti resonance of the cavity results in the measurement of loss resistance  $R_L$  whose magnitude is higher or much higher than the input resistance ( $R_r + R_L$ ) of the test antenna in free space. This in turn leads to a case of negative radiation resistance  $R_r$  and therefore negative efficiency of the antenna. Both the negative radiation resistance  $R_r$  and negative efficiency  $\eta$  of the antenna are unrealistic and defy the physical significance or meaning of the underlying antenna parameters.

In the past, the only recourse to overcome the anti resonance of the cavity was to use cavities of different sizes for different test antennas. Even for the same test antenna, there may be need to use separate cavities of varying sizes for different frequency bands of interest. The above-cited limitations have restricted the practical utility of Cavity Method of Efficiency. Thus, it would be desirable to develop a cavity that addressed the drawbacks of the existing Cavity Method of Efficiency.

## SUMMARY OF THE INVENTION

To attain the advantages and in accordance with the purpose of the invention, as embodied and broadly described herein, method for determining

the efficiency of a test antenna is provided. The method comprises measuring an input resistance of an antenna to be tested. Once the input resistance is determined, the antenna is positioned in the test cavity. Next, the input resistance at a given frequency is determined. A rectangular plot of the  
5 frequency and input resistance is displayed. Next, the tuning parameters are changed to obtain the minimum input resistance and the antenna efficiency is calculated.

The foregoing and other features, utilities and advantages of the invention will be apparent from the following more particular description of a  
10 preferred embodiment of the invention as illustrated in the accompanying drawings.

### BRIEF DESCRIPTION OF THE DRAWING

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the present invention,  
15 and together with the description, serve to explain the principles thereof. Like items in the drawings are referred to using the same numerical reference.

FIG. 1 is a perspective view of a test cavity constructed in accordance with the present invention;

FIG. 2 is a perspective view of the test cavity of FIG. 1 with a side  
20 removed to view the interior of the cavity;

FIG. 3 is a perspective view of another embodiment of a test cavity constructed in accordance with the present invention;

FIG. 4 is a functional diagram of a measurement set up in accordance with an embodiment of the present invention;

FIG. 5 is a flowchart illustrative of a conversion consistent with the  
25 present invention;

FIG. 6 is a flowchart regarding plotting information relating to antenna efficiency consistent with the present invention;

FIG. 7 is a Smith chart of a typical test antenna; and

FIG. 8 is a rectangular plot of the input resistance vs. frequency of the  
30 same test antenna.

## DETAILED DESCRIPTION

This invention provides, among other things, a novel test cavity design for the Cavity Method of Efficiency. This novel test cavity enhances the scope of applicability of Cavity Method of Efficiency and improves the accuracy of the measurement. Further, the novel test cavity increases the bandwidth of the measurement range. This invention also proposes and demonstrates that it is possible to use the novel test cavity to carry out the measurement with different types of antennas across many frequency bands of interest. One particular and significant improvement of the novel test cavity of the present invention involves avoidance of the anti resonance and associated negative values of efficiency that result from attempting to take measurements in the anti resonance bandwidth. As will be described, this technical advantage is achieved by the novel test cavity of the present invention in part by minimizing the coupling between the test antenna and the measurement cavity.

The present invention will be described with reference to Figs. 1-6. Referring first to Fig. 1, a test cavity 100 is shown. As shown, test cavity 100 is cubic in shape having six generally equal sides 102 surrounding a volumetric space 104 (see Fig. 2). Sides 102 may be referred to as a front side, a back side, a left side, a right side, a top side and a bottom side, but the designations are relative in nature. The sides 102 are fixed, so volumetric space 104 is similarly fixed in size. While shown as a cube, test cavity 100 could have other geometric, irregular, or random shapes. While a cubic test cavity 100 has been shown to be satisfactory, it is believed a spherical, cylindrical, or conical shape test cavity would be equally useful. One of the sides 102, in this case topside 102t, contains one or more ports 106 to accommodate one or more tuning probes 108. Fig. 2 shows two ports 106 and two tuning probes 108<sub>1</sub> and 108<sub>2</sub>, but more or less could be used as desired. Further, the tuning probes 108<sub>1</sub> and 108<sub>2</sub> each have a cross-sectional area  $c_1$  and  $c_2$  and extend a length  $L_1$  and  $L_2$  into space 104, respectively (see Fig. 2). While the cross-sectional areas and the lengths of the two probes 108 are shown as different, they could be identical. While shown as cylindrical probes, the probes could have numerous cross-sections, such as, polygonal,

elliptical, oval, triangular, irregular, or the like. Also, ports 106 and probes 108 are shown as residing on topside 102t. Ports 106 and probes 108 could reside on multiple sides of test cavity 100. Located on one or the other sides 102 is a power port 110. Power port 110 is generally located on the same side  
5 as port 106 but could be located on the side opposite port 106. In this example, power port 110 is located generally at the center of side 102t equidistant from ports 106, but other locations are equally possible. Further, the test antenna (not shown) would be removably coupled to power port 110 when being tested. Thus, side 102t should be removable to facilitate insertion  
10 of the test antenna.

Referring now to Fig. 2, test cavity 100 is shown with one of the sides 102 removed showing volumetric space 104. Probes 108 extend into volumetric space 104. In this embodiment, tuning probes 108 provide a way to tune the resonant frequency of test cavity 100. Tuning test cavity 100  
15 provides a means to avoid the anti resonance phenomenon. Tuning probes 108 can be arranged orthogonally to assist in operation, but can be arranged other than orthogonally as well.

Tuning probes 108 are means to avoid the anti resonance phenomenon in cavity measurement but it has been discovered that the Cavity Method of  
20 Efficiency has another drawback also. In particular, the antenna under test couples to test cavity 100 causing erroneous results. This coupling seems to occur at or around the anti resonance bandwidth. Tuning probes 108 also assist in minimizing the coupling between the antenna (not shown) and test cavity 100.

Using the Cavity Method of Efficiency to accurately measure  
25 efficiency requires removal of the anti resonance phenomenon and the inhibition of coupling between the test antenna and test cavity 100. Tuning probes 108 minimize both effects.

As shown in Figs 1 and 2, each tuning probe 108 extends a length  $l$   
30 into test cavity 104. Further, tuning probes 108 have a cross-sectional area  $c$ . A distance  $d$  separates tuning probes 108. Altering one or more of lengths  $l$ , cross sectional areas  $c$  or distance  $d$ , as well as the placement of power port

110 provides a means to control or vary the resonant frequency of test cavity 100.

Referring now to Fig. 3, a test cavity 300 is shown. Test cavity 300 as shown has four generally equal elongated sides 302 and two generally square sides 304. Of course, as explained above, test cavity 300 could be, for  
5 example, cylindrical in shape. In this case, instead of four elongated sides 302, cavity 300 would have a single curved elongated side. Also, generally square side 304 would be circular. Other shapes are, of course, possible. Further, as shown, test cavity has sharp edges 302e where sides 302 and 304  
10 abut. These edges 302e could be beveled as desired. One side 302t (or a removable section of side 302t, which is shown in phantom as 302s) of test cavity 300 could have ports 106, tuning probes 108, and power feed 110 similar to test cavity 100 above, which operate as explained above and will not be re-explained herein. Ports 106, probes 108, and power feed 110 could  
15 be located on removable portion 302s on side 302t.

Sides 304 are movably coupled to sides 302 using, for example, an arm 306 such that the relative position of sides 304 can be varied by sliding the sides using arm 306. While both sides 304 are shown as slidably coupled to sides 302, only one side needs to move or both the sides can move. If only  
20 one side 304 is slidably coupled, portion 302s should be movably coupled as well such that the test antenna remains approximate the center of the test cavity space. Positioning of sides 304 could be by manual placement or movement of arms 306 or automatic by a motor 308, servo or the like.

Being able to vary the volume of the test cavity through movably  
25 coupled side 304 facilitates the resonant tuning of the cavity. Further, varying the volume facilitates the very wide bandwidth of the measurement range without encountering the negative efficiency either via the anti resonance or coupling. In addition to the dual tuning probes 108, cavity 300 includes at least one movable side 304 to vary the volume of the cavity. The  
30 moving walls of the cavity should be on either sides of the feed/input point of the cavity, such that the tuning probes and power port remain relatively equidistant from each side. However, the tuning probes and power port do not need to remain equidistant, for example, if only one side 304 is movable.



Although, as explained above, it would be possible to have a single moving side with moving tuning probes/power ports.

As shown, the walls 304 are designed to increase or decrease the length of the cavity thereby altering the volume of the cavity. With the changes in the positions of the sliding walls, the resonant frequencies of the cavity can be varied to avoid the cavity anti resonance within the measurement range. The placement of the anti resonance outside the operating frequency band also minimizes the antenna – cavity coupling. Because changing the positions of the sliding walls can vary the length of the cavity, the separation between the anti resonance and the operating frequency of the test antenna can also be increased. The larger separation between the anti resonance and the operating frequency also ensures greater suppression of the antenna-cavity coupling thereby resulting in improved accuracy.

To retain the repeatability and the stability of the results of the measurement, at least one conductive gasket 310 is placed around the edge of sides 304 to inhibit RF leakage out of the cavity. It has been found using two gaskets placed in annular grooves 312 about the perimeter 314 of sides 304 works well. Alternatively, gaskets could be placed in sides 302. Gaskets 310 should form an air tight seal between sides 302 and 304. The conductive gasket on the perimeter wall of the sliding wall provides an easy motion of the sliding wall without causing an abrasion on the respective inner walls of the cavity.

Because moving sidewall 304 facilitates rapid changes in the resonant frequency of the cavity, tuning probes 108 are optional in this embodiment.

Referring to FIG. 4, a measurement set up 400 is shown using test cavity 300. In this case, measurement set up 400 includes an analyzer 402, such as a network analyzer commonly available in the art, having a display 404. Analyzer may be connected to a computer 406 (such as a personal computer or other processors) having a display 408. Measurement set up 400 is coupled to test cavity 300 using a communication link 410. In this example, a cable serves as a RF link but communication link 410 could be a cable, fiber optic, wireless, or the like. In the Cavity Method for Efficiency measurement, the presence of the anti resonance and the minimization of the

antenna –cavity coupling can be ascertained through the measured value of the input resistance (loss resistance) of the antenna placed inside a cavity. The measurement set up 400 has a display of polar plot 412 indicating both the measured input resistance as well as the reactance on display 404. On  
5 reviewing the plots, whether the test antenna placed inside the measurement cavity is approaching the anti resonance or is already in the anti resonance of the cavity is determined through the measurement of the antenna input resistance  $R_i$  (inside the cavity). As already stated, the measured antenna input resistance  $R_i$  (inside the cavity) is the loss resistance of the subject  
10 antenna.

Before placement of the antenna into the cavity, the input resistance of the test antenna is measured in free space to get  $R_i$  (free space).  $R_i$  (free space) is a combination of radiation resistance  $R_R$  and loss resistance of the antenna  $R_L$ .

15 For a realistic antenna,  $(R_R + R_L) > R_L$  and  $R_R \gg R_L$ .

In addition, the radiation resistance of an antenna  $R_R$  can never be negative. When  $R_L = 0$ ,  $\eta = 100\%$ ,  $R_R = 0$ ,  $\eta = 0\%$

Any sudden and sharp spike in the plot of antenna input resistance  $R_i$  (inside the cavity) vs. frequency is an indication of the presence of the anti  
20 resonance. If the magnitude of the above spike is greater than the corresponding value of  $R_i$  (free space), then it is a confirmation of the presence of the anti resonance as well as the coupling between the cavity and the antenna.

When the test antenna is not in the anti resonance region and if the  
25 coupling between the antenna and the cavity is minimal, then antenna input resistance  $R_i$  (inside cavity) is always less or far less than the antenna input resistance of the test antenna  $R_i$  (free space) implying positive efficiency.

However, if the antenna input resistance  $R_i$  (inside cavity) shows a spike or peak at a measurement frequency such that such a peak is greater or  
30 far greater in magnitude compared to that of  $R_i$  (free space), implies that the test antenna is in anti resonance region and or there exists a strong coupling between the antenna and the cavity. When the calculation  $R_R = R_i$  (free

space)-  $R_i$  (inside cavity) is made to determine the radiation resistance, we get negative value of  $R_r$  (and therefore negative efficiency according to formula (2)) implying the measurement frequency is in the anti resonance region of the cavity. At the anti resonance of the cavity, the antenna input resistance  $R_i$  (inside cavity) can be 3 or 4 magnitude higher than that of the antenna input resistance  $R_i$  (free space).

To ensure the desired absence of the anti resonance and the minimization of the antenna-cavity coupling in the operating frequency band, it is more convenient to have a display of rectangular plot with the two axes representing the frequency and the measured input resistance only. Referring to Fig. 5, a flowchart 500 shows a method by which the processor of measurement set up 400 may convert polar plot 412 a rectangular plot displayable on display 408 of computer 406, for example. First, the processor receives conventional polar plot input from test cavity 300, step 502. The polar plot input includes the real and imaginary components of the reflection coefficient. The processor converts the polar plot inputs to rectangular plot inputs that displays resistance vs. Frequency.], step 504. The conversion algorithm is generally known in the art and will not be further explained herein. Finally, the rectangular plot is displayed, step 506, on, for example, processor display 408. A typical Smith chart (Polar Plot) of an antenna and a desirable rectangular plot showing the input resistance vs. Frequency of the same antenna are shown in Figs. 7 and 8, respectively. Figs. 7 and 8 are only for the purpose of illustration and should not be considered limiting.

One factor that makes the display unique is the ability to observe changes in the resistance that occur because of the cavity losses. The display shows the resistance vs. frequency at the present moment and may display the minimum resistance vs. frequency - in a different color - since the measurement interval began. The operator then changes the cavity dimensions as well as other tuning parameters to move the cavity loss peaks (loss resistance peaks) out of measurement frequency band. Changes in the minimum resistance of the test antenna are updated. The operator is confident the adjustments are complete when the minimum resistance display ceases to change.

Once displayed, the rectangular plot on the monitor indicates the instantaneous values of the measured input resistance of the test antenna for that particular instant combination of the positions of the two sliding walls as well as the depth and positions of the two tuning probes. For a particular  
5 frequency, the measurement of the input resistance (loss resistance) of the antenna placed inside a cavity under the realizable condition of zero antenna-cavity coupling (ideal case) or non zero and yet maximally reduced antenna-cavity coupling (near ideal case) is indicated by the attainable lowest value of the input resistance (loss resistance) through any combination of variations  
10 involving the positions of the two sliding walls as well as the positions, size and the inserted depth of the tuning probes.

The Cavity Method of Efficiency uses the minimum cavity size so as to not to disturb the near fields of the test antenna. In the design, care should be taken to see that even when the two sliding walls of the cavity are in the  
15 closest positions with respect to each other, the size of the cavity is large enough to satisfy the minimum cavity size requirement. Once this criterion is met, the minimum attained value of the measured loss resistance with the above mentioned condition of either ideal or near ideal condition of maximally reduced antenna-cavity coupling could be relied upon to determine  
20 the efficiency of the antenna.

When the efficiency measurement over a relatively wider frequency band is of interest, it is possible that one particular combination of tuning parameters involving the positions of the sliding walls and the tuning probes may not lead to the ideal or near ideal condition of zero or maximally reduced  
25 antenna cavity coupling across the entire frequency band of interest. Under such a scenario, there may be a need to arrive at separate and different combination of tuning parameters to realize the required near ideal condition of maximally reduced antenna cavity coupling for individual frequencies. However for ease of experiment over a frequency band, it is desirable to view  
30 and retain a plot of measured lowest possible loss resistance at each individual frequency of the desired band arrived after trying all possible permutations and combinations of the tuning parameters. Such a methodology is shown by flowchart 600 (see FIG. 6). First, the processor

displays two plots, step 602. The first plot is instantaneous value of measured loss resistance at individual frequencies for that instant combination of tuning parameters. The other (or second) plot is termed the minimum loss resistance curve, which shows the lowest value of the loss resistance at the individual  
5 frequencies measured during the elapsed measurement period including all the previous iterations. Initially, the plots are developed using a predetermined combination of tuning parameters, which will be largely dictated by the antenna being tested and the cavity parameters. Initially, the plots coincide with each other. Next, the tuning parameters are changed, step 604. In  
10 particular, the variable tuning parameters may be changed by the positions of the sliding walls, the positions as well as depth of the tuning probes inside the cavity, or the like. While all the parameters can be changed simultaneously, generally only one parameter is varied at a time so that optimization of that parameter can be fully carried out in a straight forward manner.

15 The positions of the each of the sliding walls 304 may be varied separately. The movement of a sliding wall in a particular direction is continued if there is a steady and continuous decrease in the magnitude of the loss resistance curve with respect to any frequency within a specified band. This is continued until the limiting positions of that particular sliding wall is  
20 reached. Then the above procedure is repeated with the other sliding wall. With these positions of the sliding walls, the positions and the depth of insertion of a tuning probe are varied to get the minimization of the loss resistance curve across the frequency band. The same sequence is repeated with the other tuning probe. In a further refinement of the procedure, the  
25 positions of the movable sliding walls can be incrementally and discretely varied and at each of these incrementally varied positions, the positions as well as depth of insertion of the tuning probes can be altered to achieve the minimum loss resistance of the test antenna across the band. Once that instant combination is changed, the measured loss resistance at individual  
30 frequencies is measured, step 606. Next, the processor compares the instantaneous (new) value of the measured loss resistance with the previous lowest value of the loss resistance for each individual frequency, step 608. If the instant measured loss resistance at a particular frequency is lower than the

previously lowest loss resistance, then the data of the minimum loss resistance curve (plot) will be updated and displayed with the updated data and the new minimum is stored for further comparison, step 610. Next, the processor determines whether there is noticeable or significant change in the  
5 minimum loss resistance, step 612. If there is noticeable or significant change, the system determines whether further combinations of tuning parameters exists, step 614. If there is no noticeable or significant change or there are no further combinations, then the process ceases, step 616. The  
10 minimum loss resistance curve at the end of the experiment yields the measured loss resistance data of the antenna across the frequency band of interest.

While the invention has been particularly shown and described with reference to an embodiment thereof, it will be understood by those skilled in the art that various other changes in the form and details may be made  
15 without departing from the spirit and scope of the invention.

We claim:

1. A method for testing the efficiency of an antenna, the method comprising the steps of:
  - measuring free space resistance of an antenna to be tested;
  - positioning the antenna in a test cavity;
  - measuring an input resistance of the antenna at a frequency;
  - displaying a plot representative of the frequency v. input resistance of the antenna;
  - changing tuning parameters of the test cavity to obtain the minimum input resistance for the frequency;
  - calculating a measured loss resistance for the antenna for at least one frequency; and
  - determining an antenna efficiency the antenna.
2. The method according to claim 1, wherein the step of changing tuning parameters includes the step of varying a volumetric space of the test cavity.
3. The method according to claim 2, wherein the step of varying the volumetric space comprises moving at least one sidewall of the test cavity.
4. The method according to claim 1, wherein the step of changing tuning parameters includes using at least one tuning probe.
5. The method according to claim 4, wherein the step of using the at least one tuning probe further comprises altering at least one dimension of the tuning probe, the at least one dimension selected from the group consisting of: a length, a width, a radius, a cross-section, or a diameter.
6. The method according to claim 4, wherein the step of using at least one tuning probe includes using a plurality of tuning probes and the step of further comprises altering the position of the plurality of tuning probes.
7. The method according to claim 3, wherein the step of changing tuning parameters includes using at least one tuning probe.

8. The method according to claim 1, wherein the step of displaying a plot further comprises the step of displaying a polar plot.

9. The method according to claim 1, wherein the step of displaying a plot further comprises the step of displaying a rectangular plot.

10. The method according to claim 9, wherein the measuring step measures frequency and input resistance in polar coordinates and further comprising the step of converting the polar coordinates to rectangular coordinates.

11. The method according to claim 10, further comprising the step of displaying the rectangular coordinates.

12. The method according to claim 1, wherein the changing the tuning parameters includes manually changing the parameters.

13. A method of testing an antenna preformed on a processor, the method comprising the steps of:

- (a) establishing initial preset conditions;
- (b) plotting an instantaneous value of measured loss resistance for a test antenna at individual frequencies associated with initial preset conditions;
- (c) plotting a minimum loss resistance value at the individual frequencies over a measurement period;
- (d) storing a lowest measured loss resistance as the stored loss resistance;
- (e) adjusting the preset conditions by a predetermined amount;
- (f) measuring a new minimum loss resistance value;
- (g) compare the new minimum loss resistance value with the stored loss resistance value;
- (h) if the new minimum loss resistance value is less than the stored loss resistance value, replace the stored loss resistance value with the new minimum loss resistance value and update the plots of steps (b) and (c);
- (i) determine whether the difference between the replaced stored loss resistance and the previous stored loss resistance is greater than a predetermined amount;



(h) if it is determined that the change is greater than the predetermined amount, determine whether additional adjustments can be made to the present conditions;

(i) if additional adjustments can be made, repeat steps (e) to (i); and

(j) finalize the plots of steps (b) and (c).

14. The method according to claim 13, wherein the preset conditions comprise tuning parameters.

15. The method according to claim 14, wherein the step of adjusting the preset conditions comprises altering positions of tuning probes.

16. The method according to claim 13, wherein the step of adjusting the present conditions comprises altering the size of a test device.

17. The method according to claim 13, wherein the step of adjusting the present conditions comprises altering at least one dimension of the tuning probes, the at least one dimension selected from the group consisting of a length, a width, a radius, a cross-section, or a diameter.

18. The method according to claim 13, wherein the step of adjusting the preset conditions comprises manually adjusting the preset conditions.

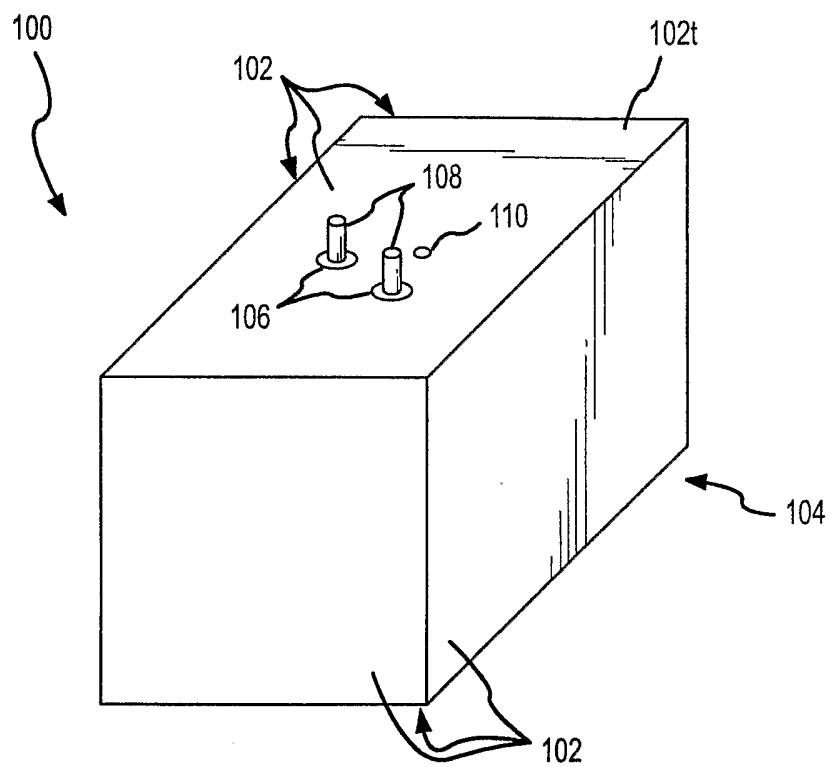


FIG.1

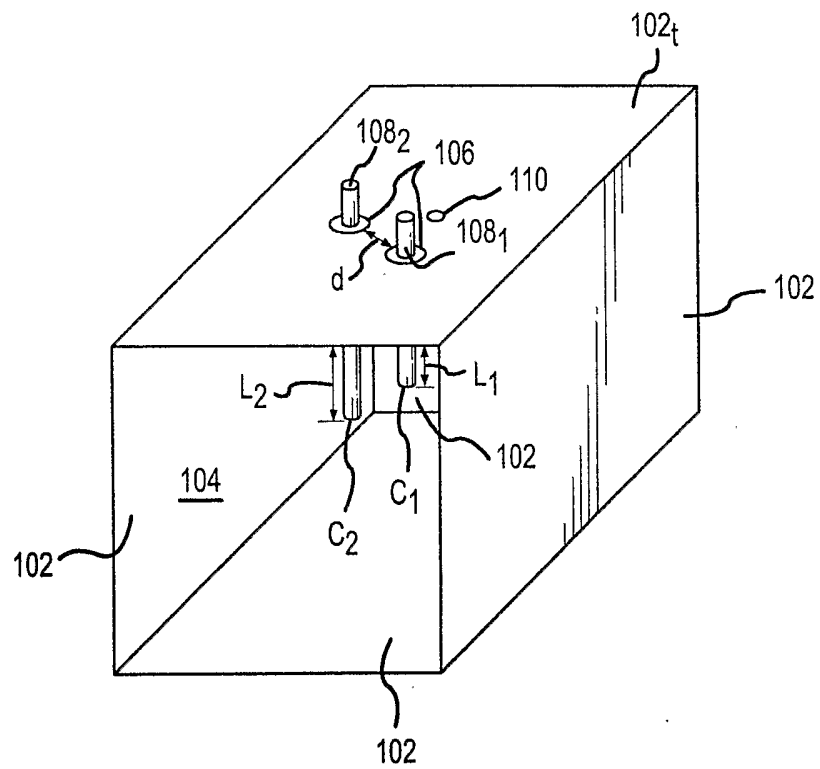


FIG.2

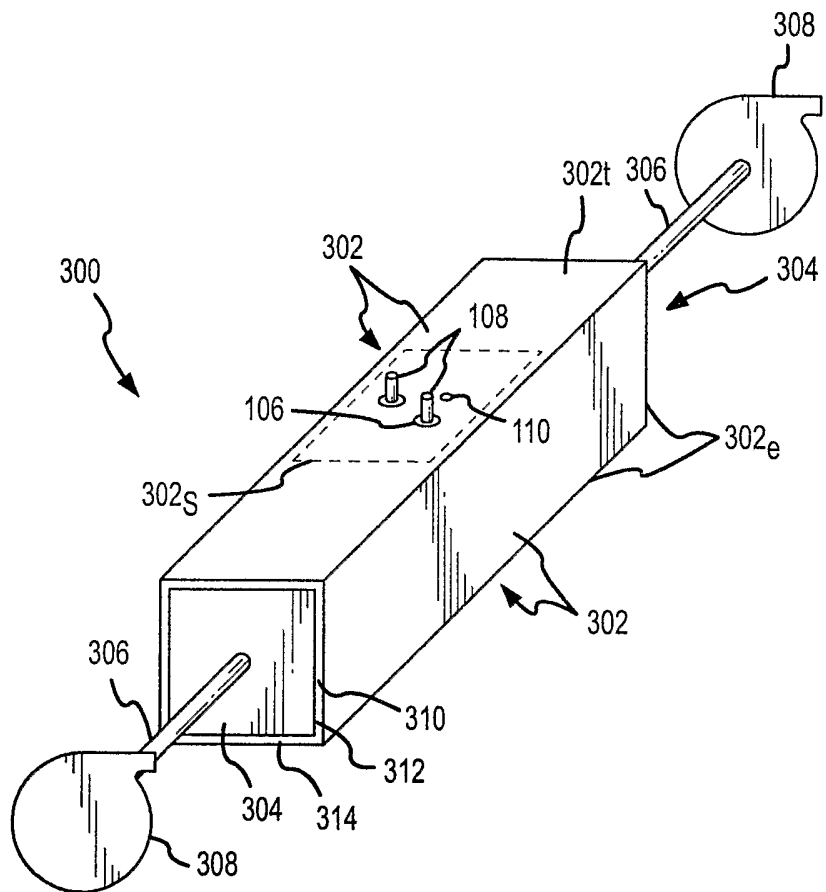


FIG.3

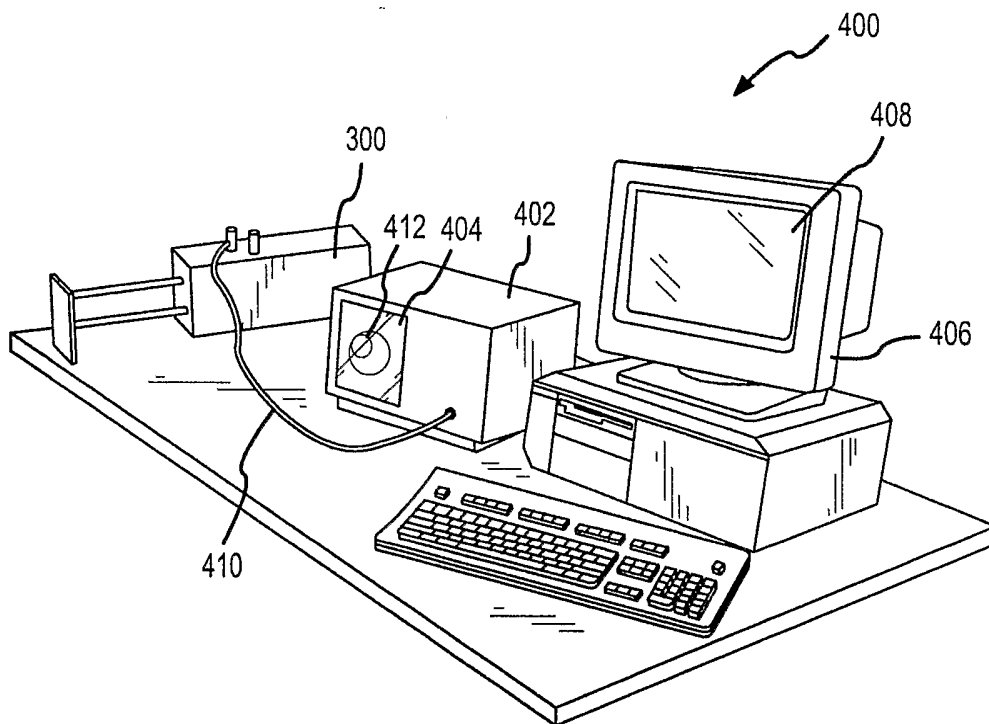


FIG.4

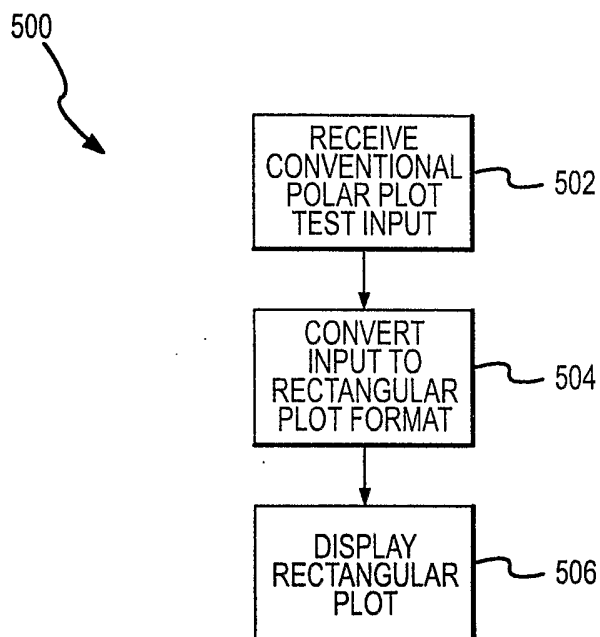


FIG.5

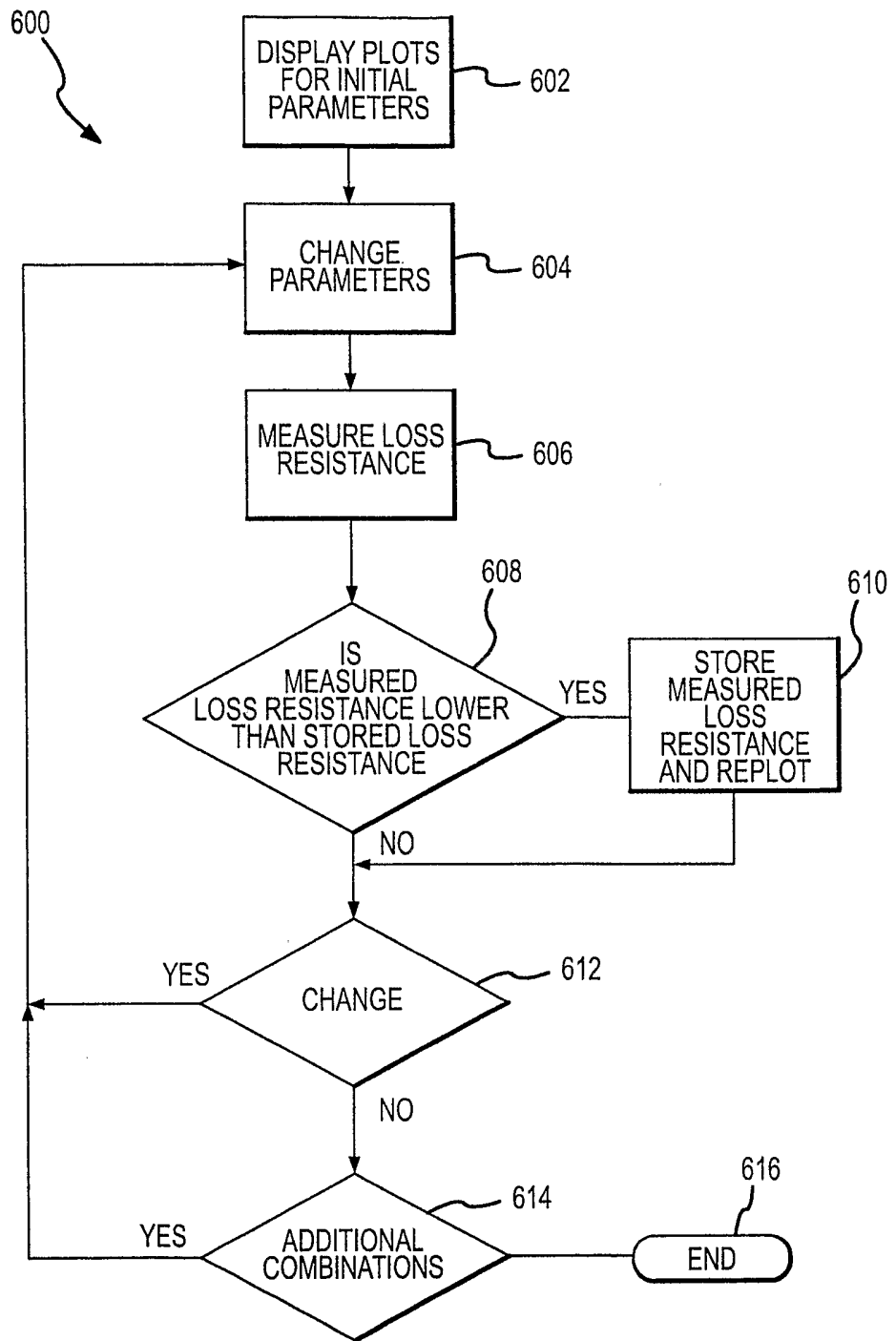


FIG.6



Smith Chart (Polar Plot ) of a Planar Antenna in Free Space

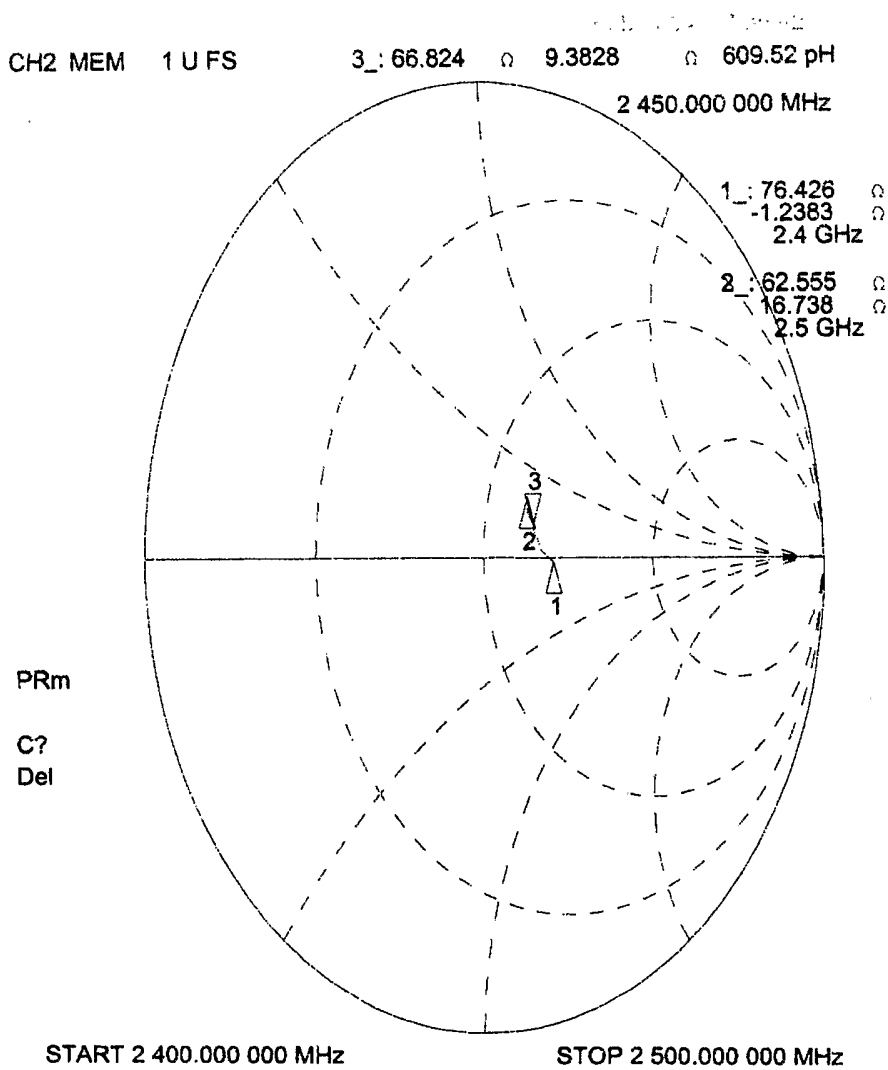


Fig. 7

Rectangular Plot of Free Space Input Resistance of a Planar Antenna

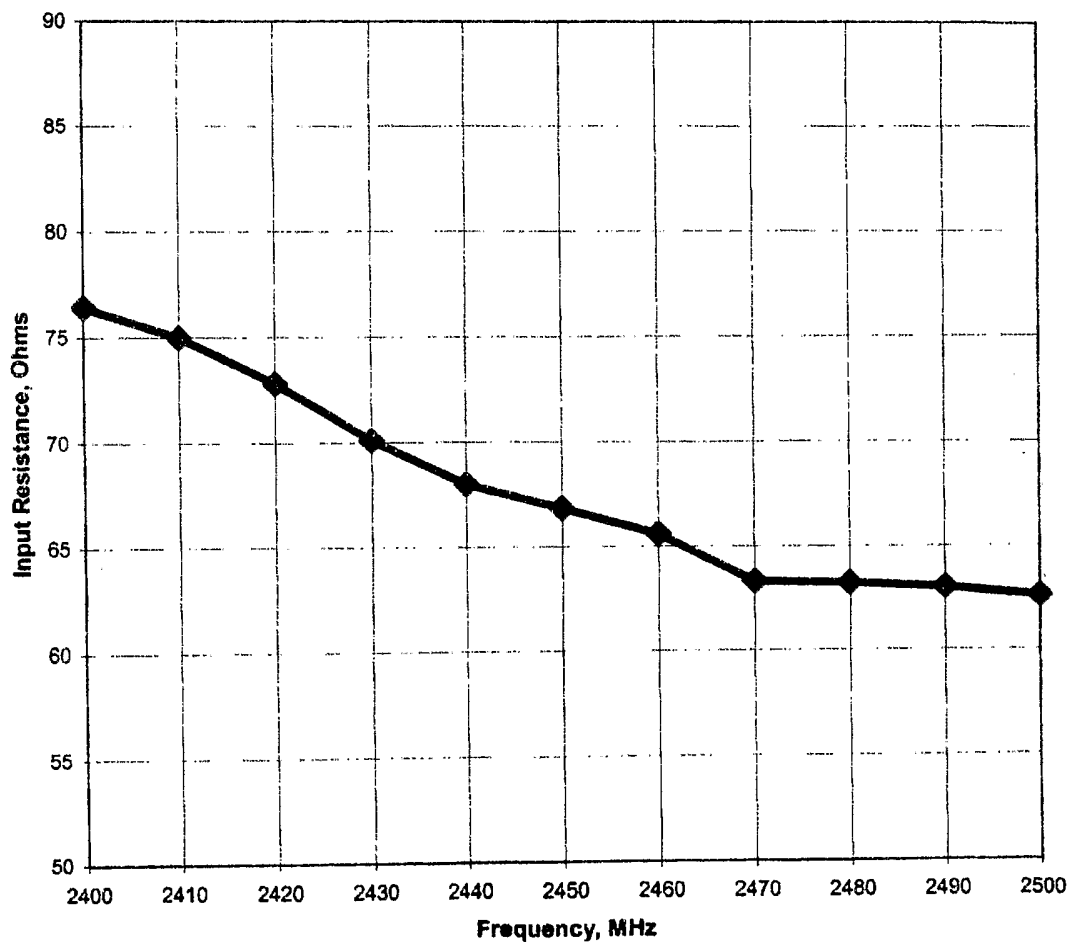


Fig. 8