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(54) Antenna for multi mode mimo communication in handheld devices

Antenne für eine Multimodus-MIMO-Kommunikation in tragbaren Vorrichtungen

Antenne pour communication mimo multimodale dans des dispositifs portables

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(56) References cited:
EP-A1- 1 298 760
DE-A1- 10 049 845
JP-A- 2002 158 529
JP-A- 2005 210 523
US-A1- 2003 001 781
US-A1- 2004 125 030
US-A1- 2004 130 495

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Description

FIELD OF THE DISCLOSURE

[0001] The present invention relates to the field of communications systems, and, more particularly, to antennas for mobile wireless communications devices and related methods.

BACKGROUND

[0002] Mobile devices are being required to support multiple applications, such as GSM, PSC, UMTS, WLAN, Wibro (Wireless broadband), and Bluetooth, and LTE, which in turn require multiple antennas, since one antenna cannot typically cover the bandwidth requirements of the multiple applications due to the physical limitations of an antenna described in "Physical Limitations of Antennas," IEEE Transactions on Antennas and Propagation, vol. 51, no. 8, pgs. 2116-2123, 2003. As a result, multiple antennas must now share the already limited space within the mobile device.

[0003] Furthermore, techniques such as multiple-input multiple-out (MIMO) have emerged, which significantly increase the performance of HSPA (high speed packet access) and LTE (long term evaluation) networks. This is usually accomplished by using multiple antennas arranged to have low correlation between two or more unique radio signals. In large devices, where space is less limited, this is easily accomplished by using spatial diversity (distance between antennas), or somehow by pattern diversity (difference between antenna aiming directions), and polarization diversity together. Unfortunately, the size of mobile wireless communications devices (e.g., cellular devices) continue to decrease and so too does the allowable space for the device antenna. As a result, having multiple antennas in a close proximity poses significant coupling and mode isolation problems; furthermore, the signals received by each of the antennas may be undesirably correlated. This noticeably disrupts MIMO performance.

[0004] Thus it can be seen that designers of antennas for mobile devices face significant challenges, particularly wherein the antennas may be capable of covering as many bands as possible while being small in size and still having a high performance.

[0005] One form of antenna commonly used in mobile devices is the monopole antenna. Compared to PIFA or IFA, a monopole can easier achieve large bandwidth because they may be arranged to radiate at two or more resonant frequencies (from its fundamental mode, second order and higher modes) Since a monopoles inherent dual mode characteristic makes it easy to achieve a frequency ratio of two-to-one of its upper and lower frequency band.

[0006] JP2005210523 describes a multi-frequency surface mounted antenna comprising a radiation electrode which is formed to cover two surfaces or more of a base, to have one end connected to a power supply electrode terminal and the other open end, to have an inner radius formed in an eddy pattern when viewed in an plane angle, and to have a frequency adjustment unit which has a line width thicker than that of other parts; and at least one sub-radiation electrode formed to externally direct from the radiation electrode. The multifrequency surface mounted antenna is mounted on a mounting substrate which is formed with a power supply electrode and a ground conductor layer thereon.

[0007] JP2002158529 describes a loop-shaped radiation electrode, an opening terminal 3a of this radiation electrode is arranged opposite to a power feeding terminal side electrode portion via a gap, and a capacitor is formed between the opening torminal and the power feed terminal side electrode portion. Since the interval between the resonance frequency of a fundamental mode and the resonance frequencies of a higher-order mode can be controlled variably by varying this capacitor, without markedly changing the resonance frequency in the fundamental mode of the radiating electrode, it is easy to design the respective resonance frequencies of the fundamental mode and the higher-order mode, as demanded. Both the fundamental mode and the higher-order mode of the radiating electrode can be utilized and multi-banding can be attained. Furthermore, an antenna is mounted on a non-grounded area of a mount board. Thus, both the widening of frequency band and miniaturizing of the antenna can be attained.

[0008] However using a single radiator for multi-order modes poses a difficulty, particularly if specific frequency bands are to be adjusted independently. Additionally, in a single radiator if one of the operating bands is required to be relatively wide the monopole may not cover all bands, such as GSM 900 (880 to 960 MHz) at a lower band and GSM1880/1900 and UMTS2100 (1710 to 2170 MHz) together at an upper band, unless additional parasitic branches are used to enhance the bandwidth and adjust the frequency ratio. However this introduces additional volume and potential higher-mode coupling among radiation elements.

[0009] Another disadvantage is that since a monopole is typically a quarter-wavelength of the fundamental mode, the size of the antenna is increased when it is designed to operate at lower resonant frequency bands.

[0010] Accordingly, it is desirable to have a monopole that may be arranged in a limited space.

SUMMARY

[0011] Accordingly there is provided an antenna as detailed in claim 1. Advantageous features are provided in the dependent claims. A wireless device as detailed in claims 3 to 6 is also provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The present disclosure will be better understood with reference to drawings in which:

FIG. 1 shows a schematic block diagram of a mobile wireless communications device in accordance with an exemplary embodiment including a monopole antenna;

FIGs. 2a-e show schematic diagrams of various aspects of an implementation of a multi-band three-dimensional (3D) folded monopole antenna assembly, according to an embodiment of the present matter;

FIG. 3 shows an unfolded two-dimensional (2D) view of the antenna of FIG. 2;

FIG. 4 shows a graph of a comparison of simulated reflection coefficients for the antenna of FIG. 2;

FIG. 5 shows a graph of reflection coefficients for the antenna of FIG. 2 for different patch widths;

FIG. 6 shows a graph of measured and simulated reflection coefficients for the antenna of FIG. 2;

FIGs. 7a-7d shows graphs of measured far-field radiation patterns at respective resonant frequencies of 900 MHz, 1800 MHz, 2.5 GHz and 5.5 GHz for the antenna of FIG.2;

FIGs. 8a-b show schematic diagrams of respective top and bottom perspective views of an antenna according to another embodiment of the present matter;

FIGs. 9a-c show schematic diagrams of multi-port antenna configurations according to further embodiments of the present matter;

FIG. 10 shows graphs of measured S parameters, for the two-port antenna of FIG. 9a;

FIGs. 11a-b show schematic diagrams of various ground plane stub sizes for the two-port antenna of FIG.9a;

FIGs. 12a-c show plots of measured S parameters, for the antenna configuration of FIG. 11 a;

FIGs. 13a-c show plots of measured S parameters, for the antenna configuration of FIG. 11 b;

FIGs. 14a-c show plots of measured S parameters, for the antenna configuration of FIG. 11c; and

FIG. 15 is a schematic diagram of components of a hand-held mobile wireless communications device.

DETAILED DESCRIPTION

[0013] In the following description like numerals refer to like structures illustrated in the drawings. For clarity a set of orthogonal axes **x-y-z** are shown in the drawings, where appropriate, to provide a frame of reference for describing the relative arrangement of the structures in the various drawings. The terms horizontal and vertical where used are for convenience of describing structures oriented with respect to the **x-y** plane and the **y-z** plane respectively, and are not meant to be limiting.

[0014] The present matter describes multi-band three-dimensional (3D) folded monopole antennas for use in mobile devices. More particularly the present matter describes a small compact multi-radiation element antenna that exhibits high mode isolation allowing it to cover several communication application frequency bands such as GSM 1900, UMTS2100, GPS, WALN in the 2GHz and higher range and the lower bands such as 1 GHz and wherein the operational frequency bands of antenna elements can be adjusted independently i.e. the upper bands can be adjusted independently of the lower bands. In other words the high mode isolation allows the antenna to function at different operation frequencies.

[0015] Furthermore, the multi-radiation element antenna also exhibits high isolation between the radiation elements. In other words there are low couplings (or power transferred from one element to another) at the operation frequencies of the antenna.

[0016] Furthermore the present matter describes a multi antenna array comprised of two or more of the multi-radiation element antennas, wherein the antennas of the array also exhibit high isolation.

[0017] Referring to **FIG. 1** there is shown a mobile wireless communications device **100** including a housing **102**, a substrate **104** carried within the housing, the substrate **104** having a ground plane (not shown) on one side thereof, wireless communications circuitry **106** carried within the housing **102** and located over the substrate **104** and a multi-band folded monopole antenna assembly **108** coupled to the wireless communications circuitry **106**. By way of example, the wireless communications circuitry **106** may comprise cellular communications circuitry, e.g., a cellular transceiver. Other wireless communications circuitry, such as wireless local area network (WLAN) and satellite positioning (e.g., GPS) communications circuitry, may also be used.

[0018] Referring to **FIGs. 2a-e** there is shown various aspects of an implementation the multi-band three-dimensional (3D) folded monopole antenna assembly **108** according to an embodiment of the present matter. In these views it is assumed that major surfaces **105, 107** of the substrate **104** lie in the **x-y** plane. The antenna assembly **108** comprises a radiation part comprised of pair of monopoles formed of conductive metallic strips **110** folded into a **3D** rectangular structure and located substantially on a top surface **105** and to one corner of the substrate **104**, as shown in **FIG. 2a**, a feed section **112** also located on the top surface **105** of the substrate connects the monopoles to a feed point **114** for coupling RF signals to and from the monopoles via a 50Ω connector (not shown). Furthermore, as more clearly shown in the bottom perspective view of **FIG. 2b** a ground plane **116** is located on a bottom surface **107** in a first area **109** of the dielectric substrate **104**. As may be further seen from the figure, the radiation part is arranged in a second area **115** of the dielectric substrate where the ground plane is not formed. In an exemplary implementation the ground plane **116** is comprised of a metallic layer of polygonal shape having one edge delineating a boundary between the first area **109** and the second area **115**. In an exemplary implementation the ground plane is rectangular, having a width (w) of 55mm and length (l) of 90mm and the substrate **104** is comprised of a 1.5 mm thick FR4 material with a dielectric constant of 4.4, having a width (W) of 55mm and length (L) of 105mm. The dimension of the substrate is usually constrained by the size of the mobile device housing.

[0019] The 3D geometrical configuration of the pair of folded monopoles is shown more clearly in **FIG. 2c** and **FIG. 2d**, and an unfolded two-dimensional (2D) view is shown in **FIG. 3**. The pair of folded monopoles comprise a first and second monopole antenna elements **monopole-1 202** and **monople-2 204** formed of conductive metallic traces **110**, extending at right angles to each other, from the feed section **112**, the first monopole **monopole-1 202** for radiating at a first resonant frequency, and the second monopole **monople-2 204** for radiating at a second resonant frequency higher than the first frequency, and a patch element **120** coupled to the second monopole for determining the resonant frequency of the second monopole antenna element **monople-2 204.** In **FIGs**. **2c** and **2d** the continuous metallic trace **110** is folded to take a generally rectangular shape and in an exemplary implementation is supported by a rectangular shaped dielectric shell **122** as shown more clearly in **FIG. 2e**. The dielectric shell **122** is mounted on a surface of the substrate **104** opposing the surface of the ground plane, referred to as the top surface **105 in FIG. 2a**. For the purpose of the description following the faces of the dielectric are referred to as opposing top **124** and bottom **125** faces in an **x-y** plane, opposing first **126** and second **127** end faces in an **x-z** plane, and opposing first **128** and second **129** side faces in the **y-z** plane. It is to be noted that the bottom face **125** is formed by the substrate **104**.

[0020] As shown in **FIG. 3** the folds of the metallic trace are made along the dashed lines, representing fold lines. In an exemplary implementation the metallic trace **113** has a uniform width of 2mm and is folded such that first monopole antenna element **monopole-1 202** includes a continuous metallic trace comprised of the feed section **S0 112** extending from the feed point **114** to a first horizontal section **S1h** arranged along a lower portion of the first end face **126** of the dielectric shell **122** to form a first L shaped section comprising **S0** and **S1h** a first U-shaped section **S2** on the first side face **128**, a second U-shaped section including a horizontal section **S3** extending along a lower portion of the second end face **127**, a third U-shaped section **S4** on the second side face **129** and ending in a second L-shaped section **S5** on the bottom face **125**. The second monopole **monopole-2 204** is composed of the feed section **S0**, a vertical section **S1v** extending vertically along the first end face **126** and the patch **P 120** formed on the top face **124**. It may be seen that the antenna is composed of three U- shaped sections formed generally of strips **S2, S3**, and **S4** and two L-shaped section formed of strips **S1** and **S5**.

[0021] As the total length and layout of each monopole antenna element determines the antenna's performance, the total length may be optimized taking into account the constraints on the volume for the antenna and the desired resonant frequency. The total length controls the fundamental resonating mode of the monopole elements, as will be appreciated by those skilled in the art. The modes at higher frequencies are generated at various portions of this length.

[0022] The 3D wrapping of the antenna controls the current distribution along the monopole length, and thus controls the electrical length(s) for the higher resonant frequency band(s) as well as antenna bandwidth, as will also be appreciated by those skilled in the art.

[0023] The initial electrical length of the first and second monopoles is set to a quarter of the wavelength of respective first and second resonant frequencies for the chosen fundamental modes. In an implementation the fundamental mode is set at 1 GHz for the first monopole and 2 GHz for the second monopole. The geometric parameters may be optimized by using electromagnetic simulators such as those based on Finite-difference time-domain (FDTD) computational electrodynamics modeling techniques, as is known in the art. An example of which is a commercially available program by CST.

[0024] The width **d** of the patch **120** varies the bandwidth and performance of the antenna. In an exemplary implementation the width **d** of the patch **120** is set to 2mm, identical to the width of the other strips. The dielectric shell has dimensions of 14mm in length (**l1**), 7mm in width (**w2**) and 7.5mm in height (**h**). It is to be noted that the dielectric shell is mounted to the top surface of the substrate and thus the height of the dielectric shell is increased by 1.5 mm, the thickness of the substrate **104**. The lengths of the sections of metallic strips for the first monopole are as follows: **S0** = 3mm, **S1h** = 7mm, **S2** = [s21 =4mm, s22= 2.5mm, s23 =10mm, s24 =2.5mm, s25 =4mm], **S3** = 7mm, **S4** = [s41=40mm, s42= 2.5mm, s43= 12m, s44= 6mm], **S5**= [s51=5.5mm, s52=11mm]. The lengths of the sections of metallic strips for the second monopole are as follows: **S0** = 3mm, S1v = 7.5mm (the vertical section) and **P**=14mm. The above dimensions are for an exemplary embodiment; however, it will be appreciated by those skilled in the art that other dimensions and/or materials may be used in different embodiments.

[0025] Referring to **FIG. 4** there is shown a comparison of simulated reflection coefficients for the antenna, having dimensions as above, when **monopole-1 202** is excited on its own **402**; **monopole-2 204** is excited alone **404**, and the combined reflection coefficients when **monopole-1 202** and **monopole-2 204** are excited simultaneously **406**. As may be seen, when the two monopoles are excited at the same time, the antenna exhibits four resonant frequencies of 0.95 GHz (**408**), 2 GHz (**410**), 2.5 GHz (**412**) and 5.4 GHz (**414**). When compared to the reflection coefficients for the separately excited monopoles, the bandwidths and impedance matching at the frequencies of 0.95 GHz, 2 GHz and 5.4 GHz for the simultaneously excited monopoles are not significantly different. However at 2.5 GHz the bandwidth is significantly enhanced. Thus, it may be seen that one of the monopoles, in this case the first monopole **monopole-1 202,** determines the bandwidths and resonant frequencies at 0.95 GHz, 2 GHz and 5.4 GHz bands, whereas the other monopole, in this case the second monopole **monopole-2 204**, determines the bandwidth at the 2.5 GHz band.

[0026] Furthermore, by simulating surface current distributions (not shown) for the antenna, having dimensions as above, it was demonstrated that the first monopole **monopole-1 202** operates at its fundamental mode and the total length of the first monopole **monopole-1 202** is approximately a quarter wavelength. As operation frequency is increased to 2 GHz, it was verified that the first monopole **monopole-1 202** operates at the second-order mode of 2 GHz. At this frequency, the electrical length of the first monopole **monopole-1 202** is a half wavelength. Furthermore, as the operation frequency is increased to 5.2 GHz, multiple nil points appear for the current distributions on the first monopole **monopole-1 202.** Hence, the antenna works at the higher order mode and its electrical length is more than one wavelength. In the case of the second monopole **monopole-2** when it is excited alone at 2 GHz the currents also flow in a continuous direction, which means that the second monopole **monopole-2** operates at the fundamental mode and its length is a quarter wavelength. Finally, when the two monopoles were simultaneously excited at several frequencies the frequency bands of 1 GHz, 2 GHz and 5.5 GHz, the first monopole **monopole-1 202** had strong surface currents while the second monopole **monopole-2 204** exhibited weak surface currents. Accordingly, it can be inferred that the two monopoles have high-mode isolation, and that the first monopole **monopole-1 202** primarily determines these resonant frequencies. However, when the antenna operates at the 2.5 GHz band, the two monopoles exhibit strong surface currents, so they both have an influence in this band.

[0027] As mentioned earlier, the width **d** of the patch **120** changes the resonant frequency and bandwidth of the antenna. Accordingly, referring now to **FIG. 5** there is shown the reflection coefficients for the pair of monopole antennas 108 for different patch widths **d** i.e. d = 2mm (**502**), d= 4mm (**504**) and d= 6mm (**506**). It may be seen that in the frequency range from 2.2 to 4 GHz the plots of the reflection coefficients for the different widths **d** show changes in the resonant frequency and bandwidth, but for frequencies below 2 GHz there is little difference in the plots except for a slight adjustment in impedance matching. This is further evidence that the monopoles have high mode-isolation. This high mode-isolation, allows the lower and the upper bands of the antenna to be easily set by changing the geometric parameters of the first and second monopoles independently.

[0028] Another characteristic shown in **FIG. 5** is that even by changing the patch width **d** and thereby varying a resonant frequency range, the antenna continues to be useful in a number of applicable frequency bands. In the exemplary implementation this ranges from 2 GHz to 4 GHz, which covers frequency bands applicable to GSM 1800/1900, UMTS2100, Blue-tooth 2.4 GHz, WiFi/LTE 2.6 GHz, WiMAX 3.3 to 3.8 GHz.

[0029] In applications requiring frequency agility RF-switches, such as RF-MEMS (Radio-Frequency Micro-Electro-Mechanical System), may be used to dynamically increase or decrease the patch **P** width **d** so that the antenna provides greater flexibility.

[0030] Referring to **FIG. 6** there is shown a comparison of a measured **602** and simulated **604** reflection coefficient **S11** for an exemplary implementation, where the patch width d is 2 mm. It may be noted that for a 6 dB return loss the frequency range for the antenna is from 880 to 1000 MHz, which is within the frequency range for GSM 900 applications. Furthermore as shown in **FIG. 6** the impedance bandwidth of 10 dB return loss is from 1700 MHz to 2820 MHz, which covers multiple applications at GSM /1800/1900 and UMTS 2100, long term evolution (LTE) 2.1 and 2.6 GHz bands.

[0031] Referring, additionally to **FIGs. 7a-7d** there is shown a logarithmic polar plot of measured far-field radiation patterns at resonant frequencies of 900 MHz (**FIG. 7a**), 1800 MHz (**FIG. 7b**), 2.5 GHz (**FIG. 7c**) and 5.5 GHz (**FIG. 7d**) of the exemplary implementation at the three planes of XOZ, YOZ and XOY, where the values are in units of dBi of gain. The orientation of the antenna for these measurements are the same as that of **FIGs. 2a-d** As may be seen from the radiation patterns the antenna peak gain ranges from -2 dBi to - 0.5 dBi at **900** MHz band, from 1.5 to 2.9 dBi at the middle frequency bands (1.7 to 2.17 GHz) and from 4 to 6 dBi at the high frequency band (4.9 to 6 GHz). These radiation patterns are omnidirectional and dipole-like at 900 MHz (**FIG. 7a**), but the patterns are directive at 1800 MHz (**FIG. 7b**), 2.5 GHz (**FIG. 7c**) and 5.5 GHz (**FIG. 7d**). Moreover, the total antenna efficiency was measured, which is defined as the ratio of the radiated power to the total power delivered to the input terminal of the antenna, i.e. the efficiency includes the impacts from mismatching loss, dielectric loss, and conductor loss. The antenna **108** achieved an efficiency of 50-75 % from 824 MHz to 960MHz, an efficiency of 58-85% from 1.6 GHz to 2.2 GHz and an efficiency of 50-75% from 4.9 to 6 GHz.

[0032] Referring now to **FIG. 8a and 8b** there is shown respective top and bottom perspective views of the 3D geometrical configuration of a multi-band 3D folded monopole antenna **808** according to another embodiment of the present matter. As described earlier with respect to the antenna **108** shown in **FIGs. 2**, the antenna **808** is also located at a top of a PCB, having a feed point and feed section similar to antenna **108**. The antenna is positioned on the PCB and formed, in an exemplary embodiment, on a dielectric body **128** in a manner as previously described.

[0033] The antenna **808** also comprises two monopole antenna elements, **810** and **812** formed on the dielectric shell illustrated in **FIG 2e**. In the embodiment illustrated, the first monopole **810** is composed of a first folded monopole comprising a continuous metallic trace of uniform width comprising a feed section **S0'** extending from the feed point **114** to a vertical section and two roughly U-shaped sections **S1', S2**' formed on a first side face of the dielectric body. The U-shaped sections **S1', S2**' form a loop back to the feed section **S0'**. A second monopole **812** is composed of the feed section **S0'**, a section **S4'** extending vertically along the first end face, the top face, the second end face opposite the first end face of the dielectric body and ending in a patch **P'** formed on the bottom face of the substrate under the dielectric body. An L-shaped section **S5**' extends from the second end face section of the second monopole and is formed on the second side face opposite the first side face of the dielectric body. Also as described with the antenna **108** earlier, the patch **P'** in this embodiment is also spaced at distance h (the height of the dielectric body) from the first monopole. In this embodiment however one of the L-shaped sections (as described with respect to the embodiment of **FIG. 2)** is formed with the second monopole. The antenna response and performance are similar to the antenna **108** described earlier.

[0034] It may be seen from the above that there is described herein a compact 3D folded multi-band high mode-isolation, monopole antenna for handheld devices. The antenna has a simple structure and a small size combined with high-efficiency. As shown in the exemplary implementations, in addition to the two bands at 900 MHz and 5.5 GHz, the exemplary antennas provide a number of resonant frequencies within a desirable bandwidth in the frequency range of 2 GHz to 4 GHz by adjusting the patch width. This is useful when finalizing antenna designs because antenna adjustments are generally required at a late stage of product development. Typically large adjustments in the antennas dimensions are not feasible since the antenna's overall size has been fixed at the production stage.

[0035] Furthermore the antenna of the present matter can be easily adapted for used in mobile devices for reception of two or more unique radio signals, which require relatively low correlation between each of the received signals.

[0036] Accordingly, referring now to **FIG. 9a** there is shown two-port antenna configurations **900**, as an example of a multi-port antenna, using a pair of folded monopole antennas **108** of the present matter. For simplicity and illustrative purposes the configuration of the antenna in **FIG. 9a** is shown with the ground plane and antenna elements and without the substrate and dielectric. The antenna arrangement **900** includes a rectangular ground plane **901** as described earlier and a first 3D folded monopole antenna **902** and second 3D folded monopole antenna **904.** The antennas are spaced apart and oriented 90 degrees with respect to each other in the second area 107 of the dielectric substrate where the ground plane **901** is not formed. A feed point **906** (port1) of the first antenna **902** is at one edge **905** of the ground plane **901** and a feed point **908** (port2) of the second antenna **904** is at a section of the ground plane **901**, which includes a section of metal that extends the ground plane, herein referred to as a stub **903**. In the illustrated implementation the stub **903** extends from the edge **905** of the ground plane into the second area **107** and between the spaced apart antennas to end in proximity to the feed point **908** of the second antenna **904**. In An exemplary implementation the stub **903** has a length of 17mm and a width of 10mm.

[0037] In **FIG. 9b**, there is shown the two-port configuration comprised of antennas **808** and in **FIG 9c** there is shown the two-port configuration comprised of antennas **808** and **108** for the respective ports. Multi-port configurations can thus be built using one or more of the different pairs of monopole antennas described herein.

[0038] Referring to **FIG. 10** there is shown plots of measured S parameters (S11, S21 and S22), for the dual port antennas, where S11 and S22 are reflection parameters and S21 is an isolation or coupling parameter. It can be seen that the dual-port antenna operates over multiple application bands, such as GSM/900/1800/1900, UMTS 2100 MHz bands, LTE 2.1/2.6 bands and WLAN 2.45/5 GHz bands, and the isolation between the two ports are better than - 13 dB across all bands from 500 MHz to 6 GHz.

[0039] The isolation may be attributed to the two antennas having well implemented antenna diversities such as spatial, polarization and pattern diversity. Thus it may be seen that the diversity techniques applied to the pair of antennas result in high isolation (low coupling) between the two ports. For example, whereas the two monopole antenna elements of each antenna are arranged vertically with respect to each other for polarization and pattern diversities, each of the dual antennas are separated for spatial diversity.

[0040] Varying a size and arrangement of stub sections, such as stub section 903, may change the response of the two-port antenna arrangement shown in **FIGs. 9a-c**. Referring to **FIGs. 11a-b** there is shown various stub sizes and arrangements for the two-port antenna **900**. For example, as shown in **FIG. 11a**, a section **1102** is added along the edge **905** of the ground plane 901, to extend the ground plane under the second antenna **904**. In an exemplary embodiment the section **1102** has a width of 5 mm and length of 17mm and **FIGs. 12a-c** shown corresponding plots of measured S parameters (S11, S21 and S22, respectively), for the dual port antennas.

[0041] Similarly, **FIG. 11b** shows a further section **1104** added alongside one edge of the section **903** to extend the ground plane **901** between the antennas **902, 904.** In an exemplary embodiment the section **1104** has a width of 10 mm and length of 17mm and **FIGs. 13a-c** show corresponding plots of measured S parameters (S11, S21 and S22, respectively).

[0042] Still further, in **FIG. 11c** there is shown a section **1106** added alongside the section **1104** to extend the ground plane **901** further between the antennas **902, 904**. In an exemplary embodiment the section **1106** has a width of 10 mm and length of 17mm, adding a width of 20 mm to the section **903** and **FIGs. 14a-c** show corresponding plots of measured S parameters (S11, S21 and S22, respectively).

[0043] It may be seen from the S parameter plots in **FIGs. 12-14** that the size of the stub, such as stub **903** affects the operating frequency and isolation of the antennas **902, 904**. Thus the size of the stub may be varied in order to change the overall operating frequency of the dual antenna arrangement. Furthermore, this may be combined with varying the patch width **d** of each multiband antenna to provide a greater degree of flexibility in the operating range of the dual antenna. Still further, because of the high mode isolation and low coupling between the antennas each antenna may be adjusted to operate in a particular frequency range without greatly affecting the other antenna. While the above embodiments have been described with respect to a dual antenna arrangement, arrangements with more than two antennas may also be implemented without departing from the scope of the present matter.

[0044] Exemplary components of a hand-held mobile wireless communications device **2200** in which one or more of the above-described folded monopole antennas 108 may be used are now described with reference to **FIG. 15**.

[0045] The mobile device of **FIG. 15** is not meant to be limiting, but merely provides an example of a mobile device that could be used in association with the present method and apparatus.

[0046] Mobile device **2200** is preferably a two-way wireless communication device having at least voice and data communication capabilities. Mobile device **2200** preferably has the capability to communicate with other computer systems on the Internet. Depending on the exact functionality provided, the mobile device may be referred to as a data messaging device, a two-way pager, a wireless e-mail device, a cellular telephone with data messaging capabilities, a wireless Internet appliance, or a data communication device, as examples.

[0047] Where mobile device **2200** is enabled for two-way communication, it will incorporate a communication subsystem **2211**, including a receiver **2212** and a transmitter **2214**, as well as associated components such as one or more, preferably embedded or internal, antenna elements **2216** and **2218**, local oscillators (LOs) **2213**, and a processing module such as a digital signal processor (DSP) **2220.** As will be apparent to those skilled in the field of communications, the particular design of the communication subsystem **2211** will be dependent upon the communication network in which the device is intended to operate.

[0048] Network access requirements will also vary depending upon the type of network **2219**. A GSM/UMTS device typically has a subscriber identity module (SIM) in order to get full service from the network. A cdma2000 device typically has such access credentials stored in it non-volatile memory or may use a removable user identity module (RUIM) in order to operate on a CDMA network. The SIM/RUIM interface **2244** is normally similar to a card-slot into which a SIM/RUIM card can be inserted and ejected like a diskette or PCMCIA card. The SIM/RUIM card can have approximately 64K of memory and hold many key configurations **2251**, and other information **2253** such as identification, and subscriber related information.

[0049] When required network registration or activation procedures have been completed, mobile device **2200** may send and receive communication signals over the network **2219**. As illustrated in **FIG. 15**, network **2219** can consist of multiple base stations communicating with the mobile device.

[0050] Signals received by antenna **2216** through communication network **2219** are input to receiver **2212,** which may perform such common receiver functions as signal amplification, frequency down conversion, filtering, channel selection and the like, and in the example system shown in **FIG. 15,** analog to digital (A/D) conversion. A/D conversion of a received signal allows more complex communication functions such as demodulation and decoding to be performed in the DSP **2220**. In a similar manner, signals to be transmitted are processed, including modulation and encoding for example, by the DSP **2220** and input to transmitter **2214** for digital to analog conversion, frequency up conversion, filtering, amplification and transmission over the communication network **2219** via antenna **2218**. The DSP **2220** not only processes communication signals, but also provides for receiver and transmitter control. For example, the gains applied to communication signals in receiver **2212** and transmitter **2214** may be adaptively controlled through automatic gain control algorithms implemented in the DSP **2220**.

[0051] Mobile device **2200** preferably includes a microprocessor **2238** which controls the overall operation of the device. Communication functions, including at least data and voice communications, are performed through communication subsystem **2211**. Microprocessor **2238** also interacts with further device subsystems such as the display **2222**, flash memory **2224**, random access memory (RAM) **2226**, auxiliary input/output (I/O) subsystems **2228**, serial port **2230,** two or more keyboards or keypads **2232**, speaker **2234,** microphone **2236,** other communication subsystem **2240** such as a short-range communications subsystem and any other device subsystems generally designated as **2242** Serial port **2230** could include a USB port or other port known to those in the art.

[0052] Some of the subsystems shown in **FIG. 15** perform communication-related functions, whereas other subsystems may provide "resident" or on-device functions. Notably, some subsystems, such as keyboard **2232** and display **2222**, for example, may be used for both communication-related functions, such as entering a text message for transmission over a communication network, and device-resident functions such as a calculator or task list.

[0053] Operating system software used by the microprocessor **2238** is preferably stored in a persistent store such as flash memory **2224**, which may instead be a read-only memory (ROM) or similar storage element (not shown). Those skilled in the art will appreciate that the operating system, specific device applications, or parts thereof, may be temporarily loaded into a volatile memory such as RAM 2226. Received communication signals may also be stored in **RAM 2226**.

[0054] As shown, flash memory **2224** can be segregated into different areas for both computer programs **2258** and program data storage **2250, 2252, 2254** and 2256. These different storage types indicate that each program can allocate a portion of flash memory **2224** for their own data storage requirements. Microprocessor **2238**, in addition to its operating system functions, preferably enables execution of software applications on the mobile device. A predetermined set of applications that control basic operations, including at least data and voice communication applications for example, will normally be installed on mobile device **2200** during manufacturing. Other applications could be installed subsequently or dynamically.

[0055] A preferred software application may be a personal information manager (PIM) application having the ability to organize and manage data items relating to the user of the mobile device such as, but not limited to, e-mail, calendar events, voice mails, appointments, and task items. Naturally, one or more memory stores would be available on the mobile device to facilitate storage of PIM data items. Such PIM application would preferably have the ability to send and receive data items, via the wireless network **2219**. In a preferred embodiment, the PIM data items are seamlessly integrated, synchronized and updated, via the wireless network **2219**, with the mobile device user's corresponding data items stored or associated with a host computer system. Further applications may also be loaded onto the mobile device **2200** through the network **2219**, an auxiliary I/O subsystem **2228,** serial port **2230**, short-range communications subsystem **2240** or any other suitable subsystem **2242**, and installed by a user in the RAM **2226** or preferably a non-volatile store (not shown) for execution by the microprocessor **2238**. Such flexibility in application installation increases the functionality of the device and may provide enhanced on-device functions, communication-related functions, or both. For example, secure communication applications may enable electronic commerce functions and other such financial transactions to be performed using the mobile device **2200**.

[0056] In a data communication mode, a received signal such as a text message or web page download will be processed by the communication subsystem **2211** and input to the microprocessor **2238**, which preferably further processes the received signal for output to the display **2222**, or alternatively to an auxiliary I/O device **2228**.

[0057] A user of mobile device **2200** may also compose data items such as email messages for example, using the keyboard **2232**, which is preferably a complete alphanumeric keyboard or telephone-type keypad, in conjunction with the display **2222** and possibly an auxiliary I/O device **2228**. Such composed items may then be transmitted over a communication network through the communication subsystem **2211**.

[0058] For voice communications, overall operation of mobile device **2200** is similar, except that received signals would preferably be output to a speaker **2234** and a microphone **2236** would generate signals for transmission. Alternative voice or audio I/O subsystems, such as a voice message recording subsystem, may also be implemented on mobile device **2200**. Although voice or audio signal output is preferably accomplished primarily through the speaker **2234**, display **2222** may also be used to provide an indication of the identity of a calling party, the duration of a voice call, or other voice call related information for example.

[0059] Serial port **2230** in **FIG**. **15** would normally be implemented in a personal digital assistant (PDA)-type mobile device for which synchronization with a user's desktop computer (not shown) may be desirable, but is an optional device component. Such a port **2230** would enable a user to set preferences through an external device or software application and would extend the capabilities of mobile device **2200** by providing for information or software downloads to mobile device **2200** other than through a wireless communication network. The alternate download path may for example be used to load an encryption key onto the device through a direct and thus reliable and trusted connection to thereby enable secure device communication. As will be appreciated by those skilled in the art, serial port **2230** can further be used to connect the mobile device to a computer to act as a modem.

[0060] Other communications subsystems **2240**, such as a short-range communications subsystem, is a further optional component which may provide for communication between mobile device **2200** and different systems or devices, which need not necessarily be similar devices. For example, the subsystem **2240** may include an infrared device and associated circuits and components or a Bluetooth™ communication module to provide for communication with similarly enabled systems and devices.

Claims

1. A multi-band antenna (108) comprising:

   a dielectric substrate (104);
   a ground plane (116) formed on a first area (109) of the dielectric substrate (104);

a radiation part arranged in a second area (115) of the dielectric substrate (104) where the ground surface is not formed,
a feed section (112) formed of a metallic trace (113) and having one end connected to the radiation part and an opposite end disposed near an edge of the ground plane forming a feed point (114);
the radiation part having a pair of monopole antenna elements (202, 204) formed of conductive metallic traces (113); a first monopole antenna element (202) for radiating at a first resonant frequency, and a second monopole antenna element (204) for radiating at a second resonant frequency and the conductive metallic traces being folded to form a three dimensional structure, with at least a portion of said first monopole spaced from a plane of the substrate and said second monopole;
a patch element (120) coupled to said second monopole (204) and arranged in a spaced relationship to the first monopole (202), a width of said patch element (120) for determining the resonant frequency of the second monopole (204) antenna element, independently of the resonant frequency of the first monopole (202);
a dielectric shell (122) defining a generally rectangular shape having opposing top (124) and bottom faces (125), opposing first (126) and second (127) end faces and opposing first (128) and second (129) side faces, the bottom face (125) of said dielectric shell positioned in said second area of said substrate and said three dimensional structure of said metallic trace (113) being formed around said dielectric shell, wherein
the metallic trace (113) has a uniform width, wherein:

> the first monopole antenna element (202) includes a continuous metallic trace comprised of the feed section (112) extending from the feed point (114) to a first horizontal section (S1h) arranged along a lower portion of a first end face (126) of the dielectric shell (122) to form a first L shaped section and a first U-shaped section (S2) on a first side face (128), a second U-shaped section including a horizontal section (S3) extending along a lower portion of a second end face (127), a third U-shaped section (S4) on a second side face (129) and ending in a second L-shaped section (S5) on a bottom face (125)
> the second monopole (204) is composed of the feed section (S0), a vertical section (S1v) extending vertically along the first end face (126), and
> the patch element (120) formed on the top face (124).

2. The antenna as defined in claim 1, a width of said patch element (120) for setting the resonant frequency of the second monopole antenna element.

3. A mobile wireless communication device comprising:

> a housing;
> a dielectric substrate carried within said housing;
> wireless communication circuitry carried by said substrate within said housing; and
> a multi-band antenna as claimed in any preceding claim coupled to said wireless communication circuitry.

4. The mobile wireless communication device of claim 3, said wireless communication circuitry comprises a cellular transceiver.

5. A mobile wireless communication device comprising:

> a housing;
> a dielectric substrate carried within said housing;
> wireless communication circuitry carried by said substrate;
> a ground plane formed on a first area of the dielectric substrate;
> a plurality of multi-band antennas as claimed in any one of claims 1 to 2, the multi-band antennas arranged in a second area of the dielectric substrate.

6. The mobile wireless communication device of claim 5, including a stub section coupled to said ground plane and extending into said second area for determining an operating frequency of said multi-band antenna arrangement.

Patentansprüche

1. Eine Mehrbandantenne (108), die aufweist:

> ein dielektrisches Substrat (104);
> eine Masseebene (116), die auf einem ersten Bereich (109) des dielektrischen Substrats (104) gebildet ist;
> einen Strahlungsteil, der in einem zweiten Bereich (115) des dielektrischen Substrats (104) ausgebildet ist, wo nicht die Massefläche gebildet ist,
> einen Zufuhrabschnitt (112), der aus einer metallischen Bahn (113) gebildet ist und dessen

eines Ende mit dem Strahlungsteil verbunden ist und ein entgegengesetztes Ende in der Nähe einer Kante der Masseebene angeordnet ist, einen Zufuhrpunkt (114) bildend;
wobei der Strahlungsteil ein Paar von Monopolantennenelementen (202, 204) hat, die aus leitenden metallischen Bahnen (113) gebildet sind; wobei ein erstes Monopolantennenelement (202) zum Ausstrahlen an einer ersten Resonanzfrequenz vorgesehen ist und ein zweites Monopolantennenelement (204) zum Ausstrahlen an einer zweiten Resonanzfrequenz vorgesehen ist und die leitenden metallischen Bahnen gefaltet sind, um eine dreidimensionale Struktur zu bilden, wobei zumindest ein Teil des ersten Monopols beabstandet ist von einer Ebene des Substrats und dem zweiten Monopol;
ein Patch-Element (120), das mit dem zweiten Monopol (204) gekoppelt ist und in einer beabstandeten Beziehung zu dem ersten Monopol (202) angeordnet ist, wobei eine Breite des Patch-Elements (120) zum Bestimmen der Resonanzfrequenz des zweiten Monopolantennenelements (204) vorgesehen ist, unabhängig von der Resonanzfrequenz des ersten Monopols (202);
eine dielektrische Hülle (122), die eine allgemein rechteckige Form mit einander gegenüberliegenden oberen (124) und unteren (125) Flächen, gegenüberliegenden ersten (126) und zweiten (127) Endflächen und gegenüberliegenden ersten (128) und zweiten (129) Seitenflächen definiert, wobei die untere Fläche (125) der dielektrischen Hülle in dem zweiten Bereich des Substrats positioniert ist und die dreidimensionale Struktur der metallischen Bahn (113) um die dielektrische Hülle gebildet ist, wobei
die metallische Bahn (113) eine einheitliche Breite hat, wobei:

> das erste Monopolantennenelement (202) eine kontinuierliche metallische Bahn umfasst, die besteht aus dem Zufuhrabschnitt (112), der sich von dem Zufuhrpunkt (114) zu einem ersten horizontalen Abschnitt (S1h) erstreckt, angeordnet entlang eines unteren Teils einer ersten Endfläche (126) der dielektrischen Hülle (122), um einen ersten L-förmigen Abschnitt und einen ersten U-förmigen Abschnitt (S2) auf einer ersten Seitenfläche (128) zu bilden, einen zweiten U-förmigen Abschnitt mit einem horizontalen Abschnitt (S3), der sich entlang eines unteren Teils einer zweiten Endfläche (127) erstreckt, einen dritten U-förmigen Abschnitt (S4) auf einer zweiten Seitenfläche (129) und endend in einem zweiten L-förmigen Abschnitt (S5) auf einer unteren Fläche (125),
> wobei der zweite Monopol (204) aus dem Zufuhrabschnitt (S0), einem vertikalen Abschnitt (S1v), der sich vertikal entlang der ersten Endfläche (126) erstreckt, und
> dem Patch-Element (120) besteht, das auf der oberen Fläche (124) gebildet ist.

2. Die Antenne gemäß Anspruch 1, wobei eine Breite des Patch-Elements (120) zum Setzen der Resonanzfrequenz des zweiten Monopolantennenelements vorgesehen ist.

3. Mobile drahtlose Kommunikationsvorrichtung, die aufweist:

   ein Gehäuse;
   ein dielektrisches Substrat, das in dem Gehäuse getragen wird;
   drahtlose Kommunikationsschaltungen, die von dem Substrat in dem Gehäuse getragen werden; und
   eine Mehrbandantenne gemäß einem vorhergehenden Anspruch, die mit den drahtlosen Kommunikationsschaltungen gekoppelt ist.

4. Die mobile drahtlose Kommunikationsvorrichtung gemäß Anspruch 3, wobei die drahtlosen Kommunikationsschaltungen einen zellularen Transceiver aufweisen.

5. Eine mobile drahtlose Kommunikationsvorrichtung, die aufweist:

   ein Gehäuse;
   ein dielektrisches Substrat, das in dem Gehäuse getragen wird;
   drahtlose Kommunikationsschaltungen, die von dem Substrat getragen werden;
   eine Masseebene, die auf einem ersten Bereich des dielektrischen Substrats gebildet ist;
   eine Vielzahl von Mehrbandantennen gemäß einem der Ansprüche 1 bis 2,
   wobei die Mehrbandantennen in einem zweiten Bereich des dielektrischen Substrats angeordnet sind.

6. Die mobile drahtlose Kommunikationsvorrichtung gemäß Anspruch 5, mit einem Stummelabschnitt, der mit der Masseebene gekoppelt ist und sich in den zweiten Bereich erstreckt, zum Bestimmen einer Betriebsfrequenz der Mehrbandantenne-Anordnung.

Revendications

1. Antenne multi-bande (108), comprenant :

un substrat diélectrique (104) ;
un plan de masse (116) formé sur une première zone (109) du substrat diélectrique (104) ;
une partie de rayonnement disposée dans une deuxième zone (115) du substrat diélectrique (104) où la surface de masse n'est pas formée ;
une section d'alimentation (112) constituée par une piste métallique (113), et comportant une extrémité connectée à la partie de rayonnement et une extrémité opposée disposée près d'un bord du plan de masse, formant un point d'alimentation (114) ;
la partie de rayonnement comportant une paire d'éléments d'antenne monopôle (202, 204) constitués par des pistes métalliques conductrices (113) ; un premier élément d'antenne monopôle (202) pour rayonner à une première fréquence de résonance, et un deuxième élément d'antenne monopôle (204) pour rayonner à une deuxième fréquence de résonance, et les pistes métalliques conductrices étant pliées de façon à former une structure en trois dimensions, avec au moins une partie dudit premier monopôle espacée d'un plan du substrat et dudit deuxième monopôle ;
un élément de plaque (120) couplé audit deuxième monopôle (204) et disposé selon une relation espacée par rapport au premier monopôle (202), une largeur dudit élément de plaque (120) servant à déterminer la fréquence de résonance du deuxième élément d'antenne monopôle (204), indépendamment de la fréquence de résonance du premier monopôle (202) ;
une enceinte diélectrique (122) définissant une forme globalement rectangulaire comportant des faces supérieure (124) et inférieure (125) opposées, des première (126) et deuxième (127) faces d'extrémité opposées et des première (128) et deuxième (129) faces latérales opposées, la face inférieure (125) de ladite enceinte diélectrique étant positionnée dans ladite deuxième zone dudit substrat et ladite structure en trois dimensions de ladite piste métallique (113) étant formée autour de ladite enceinte diélectrique, dans laquelle :

> la piste métallique (113) a une largeur uniforme, dans laquelle :
>
> > le premier élément d'antenne monopôle (202) comprend une piste métallique continue constituée par la section d'alimentation (112) s'étendant du point d'alimentation (114) à une première section horizontale (S1h) disposée le long d'une partie inférieure d'une première face d'extrémité (126) de l'enceinte diélectrique (122) de façon à former une première section en forme de L et une première section en forme de U (S2) sur une première face latérale (128), une deuxième section en forme de U comprenant une section horizontale (S3) s'étendant le long d'une partie inférieure d'une deuxième face d'extrémité (127), une troisième section en forme de U (S4) sur une deuxième face latérale (129), et s'achevant en une deuxième section en forme de L (S5) sur une face inférieure (125),
> > le deuxième monopôle (204) est constitué par la section d'alimentation (S0), une section verticale (S1v) s'étendant verticalement le long de la première face d'extrémité (126), et
> > l'élément de plaque (120) formé sur la face supérieure (124).

2. Antenne selon la revendication 1, dans laquelle une largeur dudit élément de plaque (120) sert à établir la fréquence de résonance du deuxième élément d'antenne monopôle.

3. Dispositif de communication sans fil mobile, comprenant :

> un boîtier ;
> un substrat diélectrique porté à l'intérieur dudit boîtier ;
> des circuits de communication sans fil portés par ledit substrat à l'intérieur dudit boîtier ; et
> une antenne multi-bande selon l'une quelconque des revendications précédentes couplée auxdits circuits de communication sans fil.

4. Dispositif de communication sans fil mobile selon la revendication 3, lesdits circuits de communication sans fil comprenant un émetteur/récepteur cellulaire.

5. Dispositif de communication sans fil mobile, comprenant :

> un boîtier ;
> un substrat diélectrique porté à l'intérieur dudit boîtier ;
> des circuits de communication sans fil portés par ledit substrat ;
> un plan de masse formé sur une première zone du substrat diélectrique ;
> une pluralité d'antennes multi-bande selon l'une quelconque des revendications 1 à 2, les antennes multi-bande étant disposées dans une deuxième zone du substrat diélectrique.

6. Dispositif de communication sans fil mobile selon la revendication 5, comprenant une section d'adaptateur à ligne couplée audit plan de masse et s'étendant dans ladite deuxième zone pour déterminer une fréquence de fonctionnement dudit agencement d'antennes multi-bande.

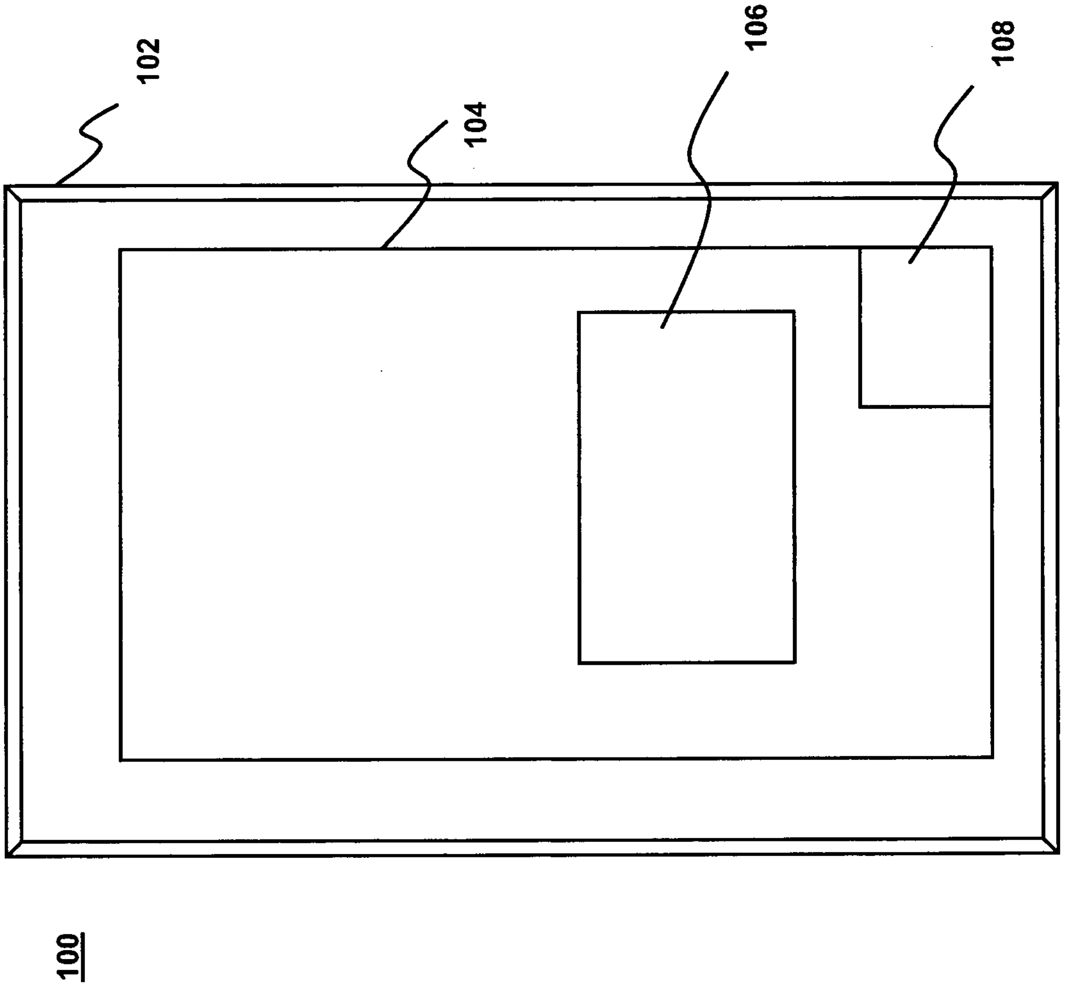

FIG. 1

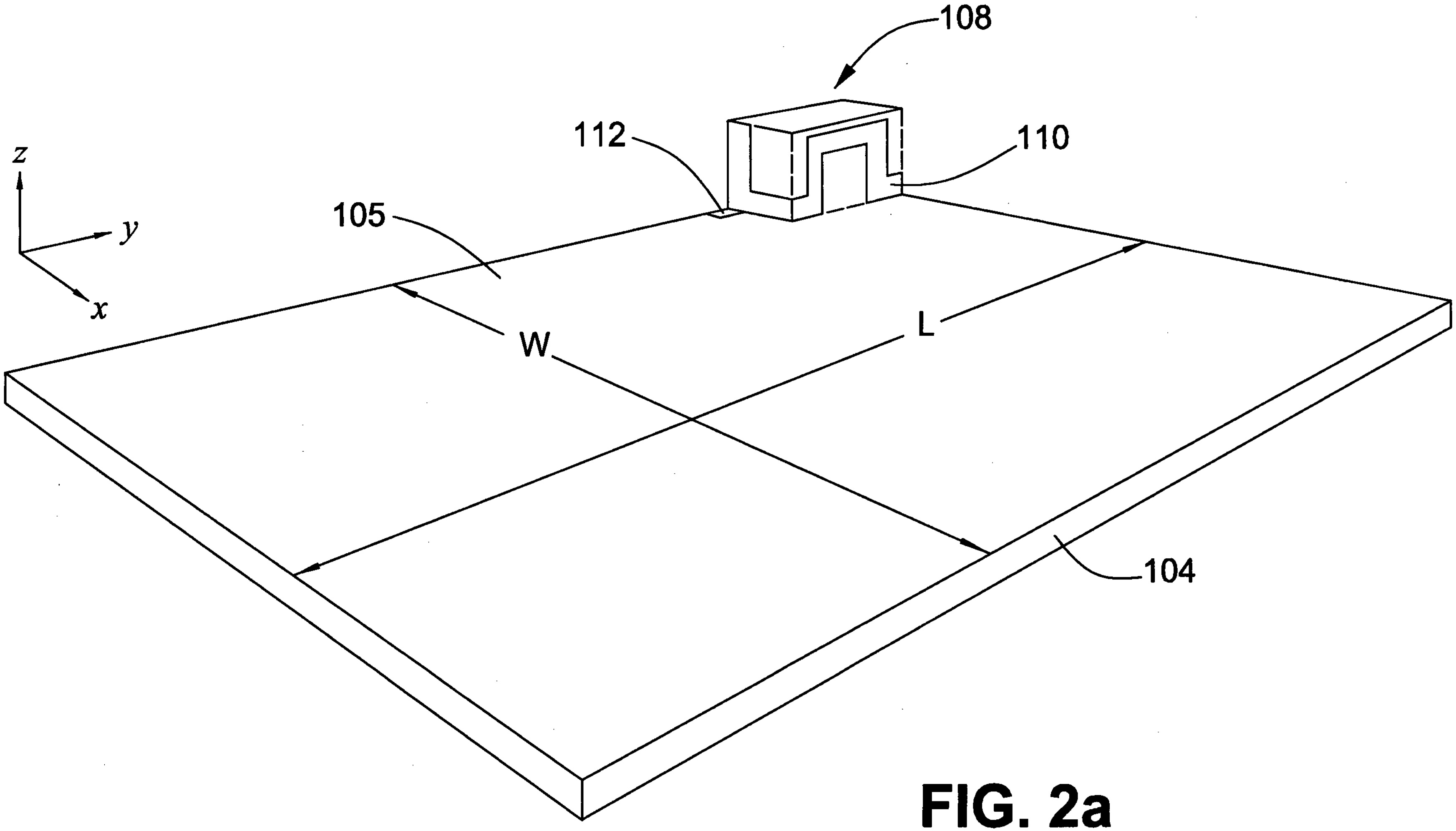

FIG. 2a

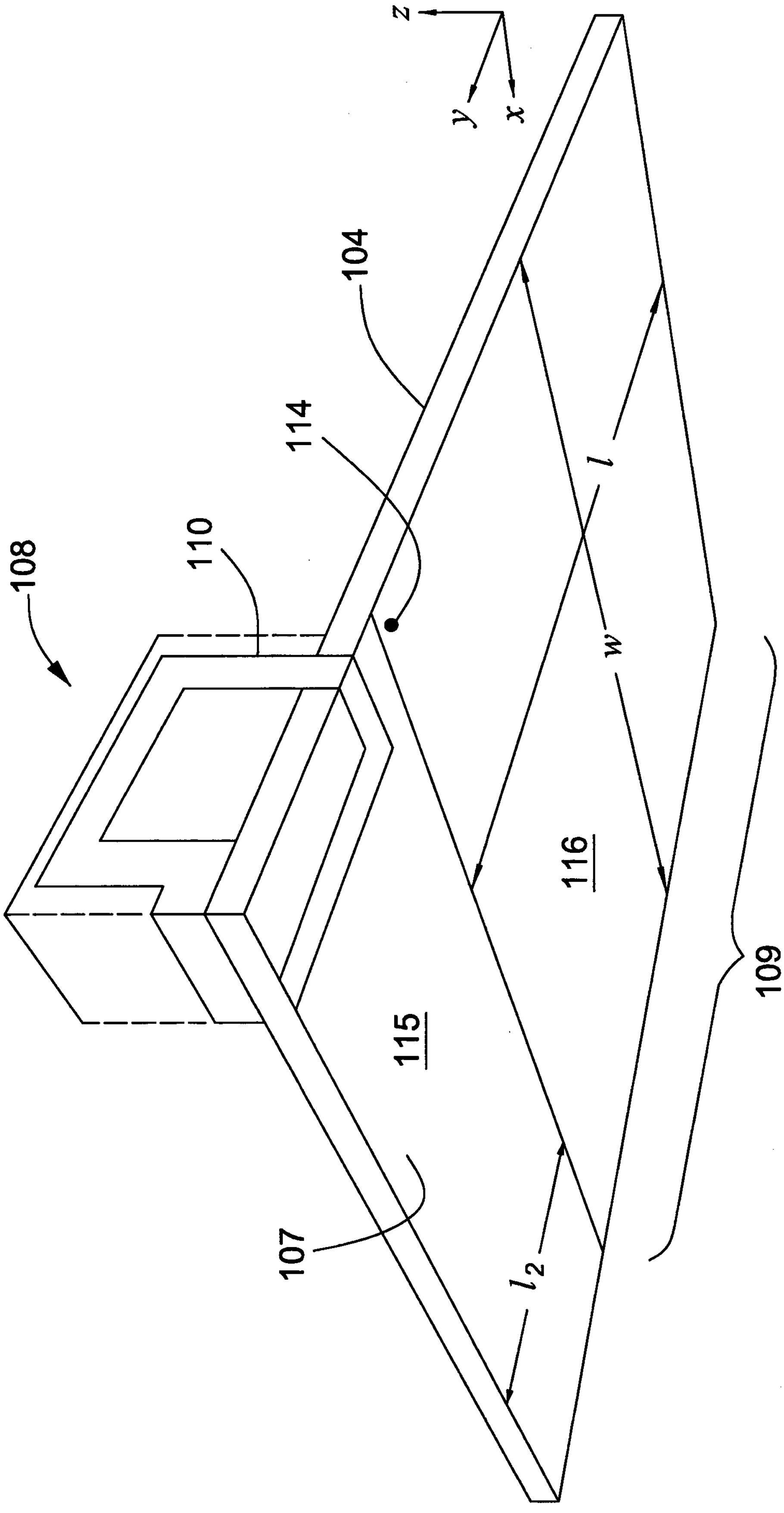

FIG. 2b

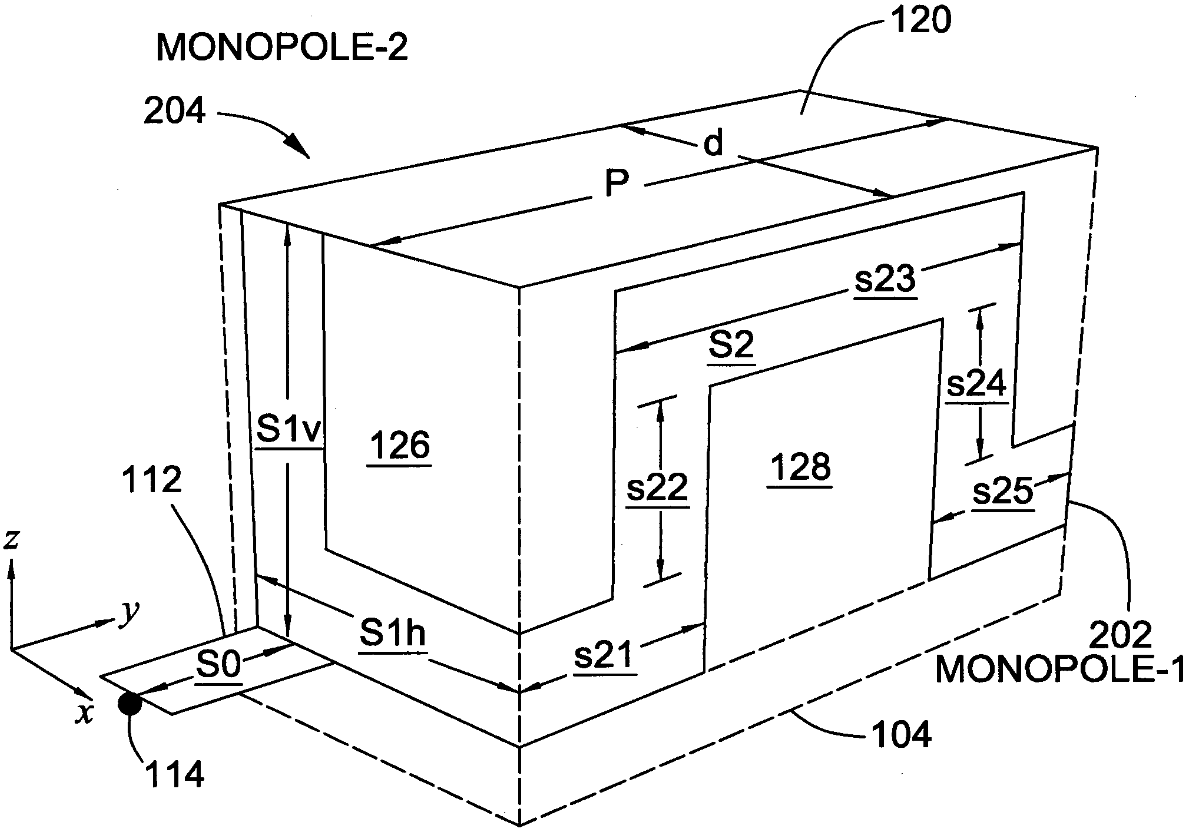
MONOPOLE-2
204
120
d
P
s23
S2
s24
S1v
126
128
s22
s25
112
z
y
x
S1h
s21
202
MONOPOLE-1
S0
114
104

FIG. 2c

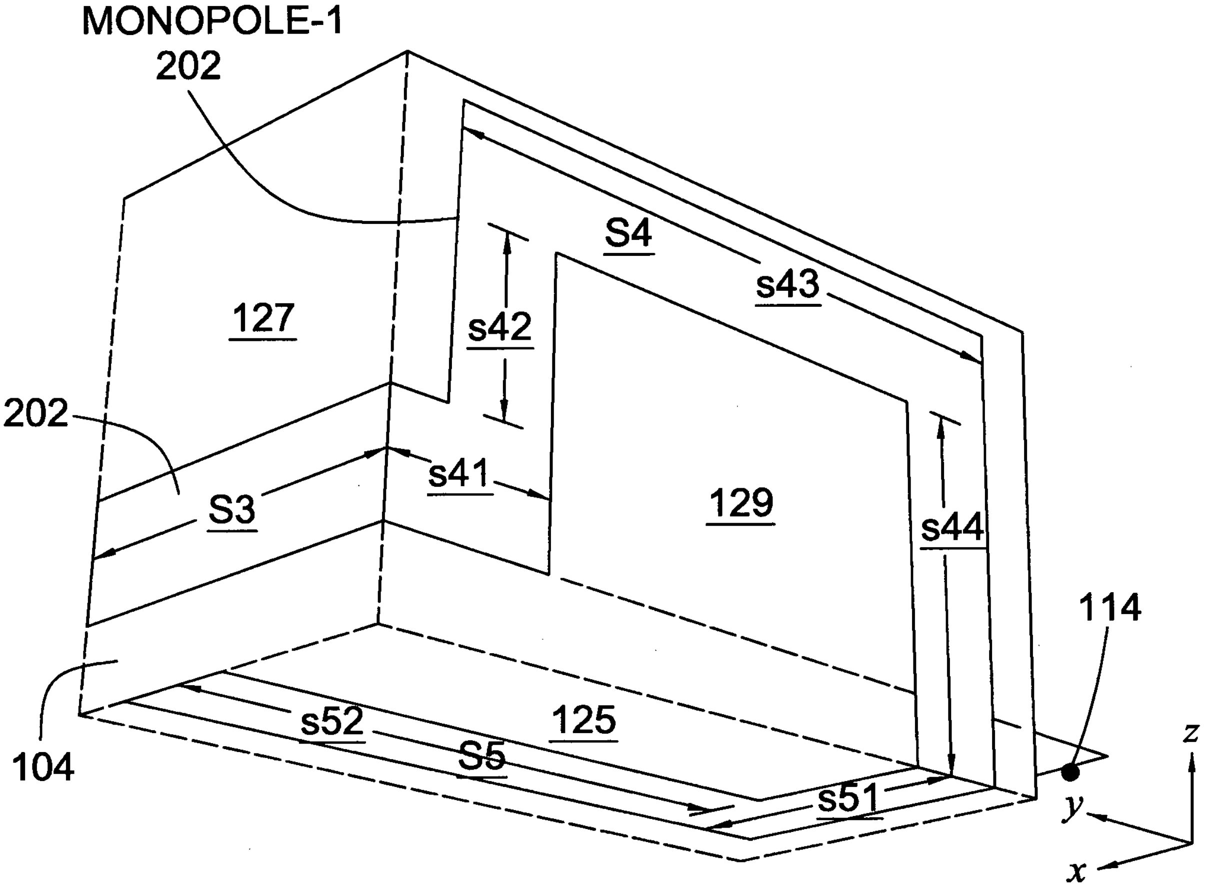
MONOPOLE-1
202
127
202
S3
s41
s42
S4
s43
129
s44
114
104
s52
125
S5
s51
z
y
x

FIG. 2d

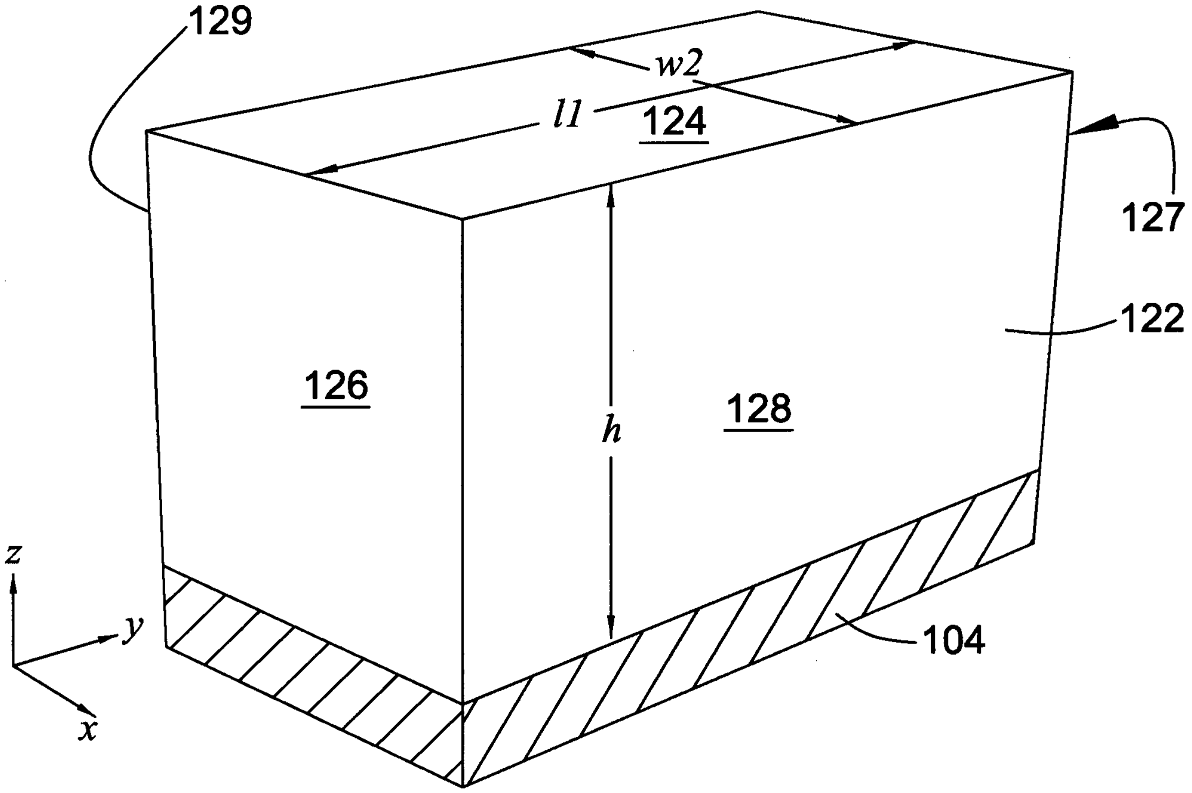

FIG. 2e

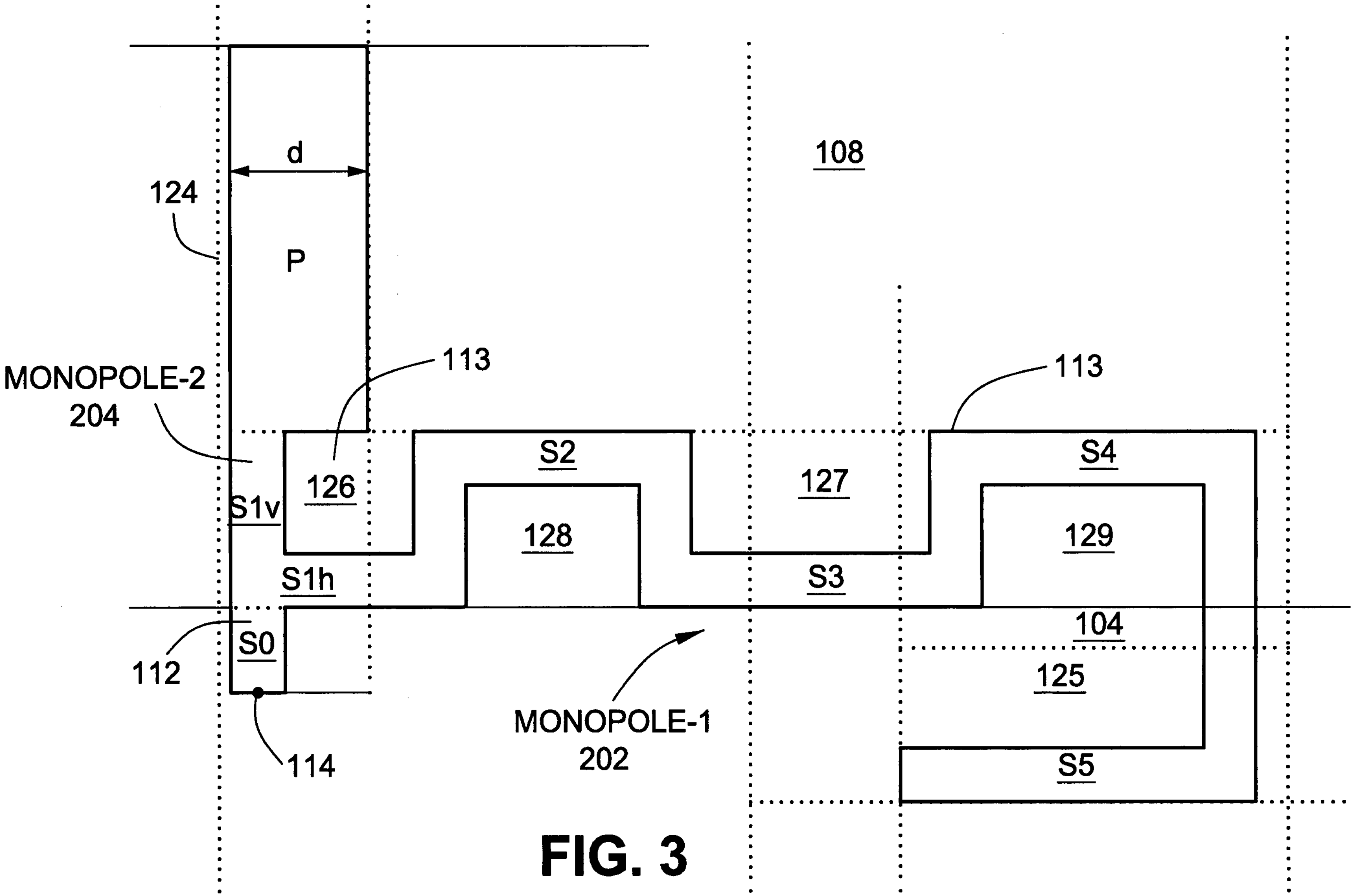
108
d
124
P
113
MONOPOLE-2
204
113
S2
S4
126
127
S1v
128
129
S1h
S3
104
112
S0
125
MONOPOLE-1
202
114
S5

FIG. 3

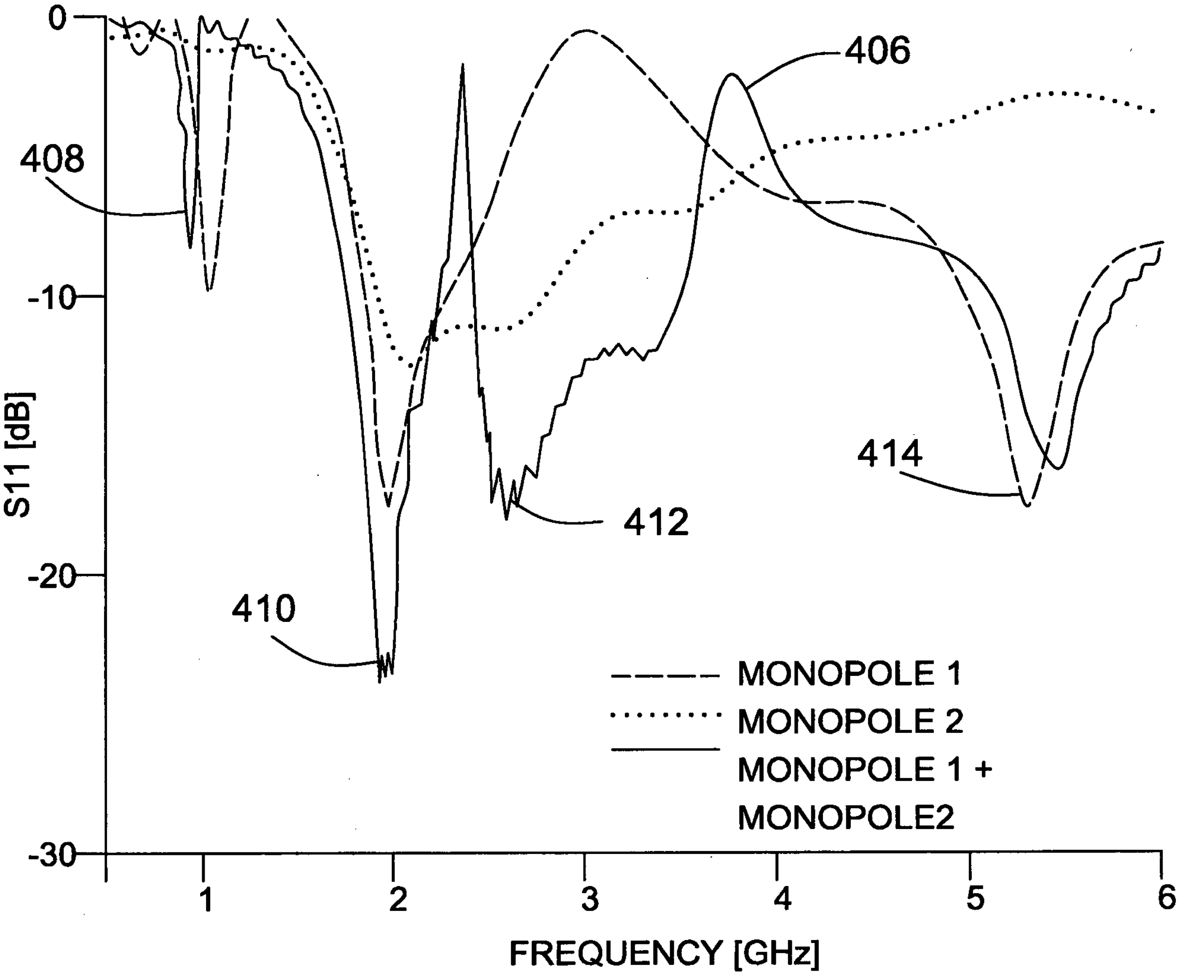
0
-10
-20
-30
S11 [dB]
1
2
3
4
5
6
FREQUENCY [GHz]
406
408
410
412
414
MONOPOLE 1
MONOPOLE 2
MONOPOLE 1 +
MONOPOLE2

FIG. 4

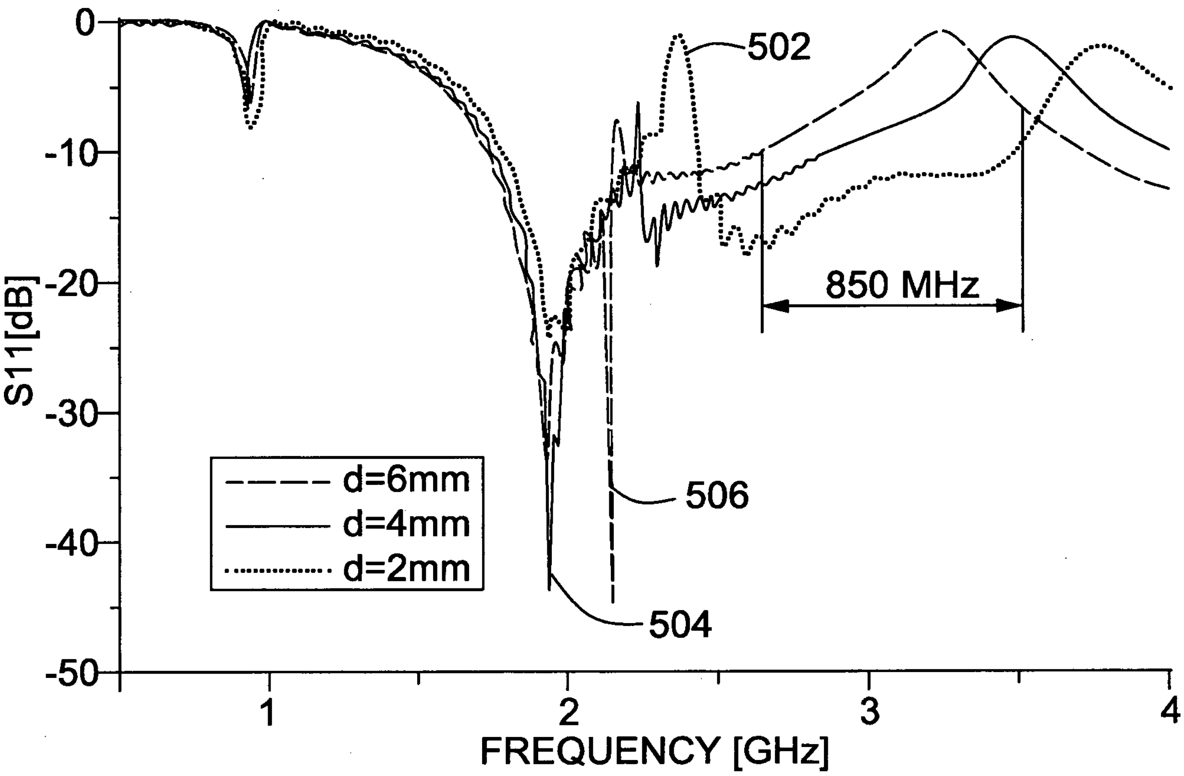
0
-10
-20
-30
-40
-50
S11[dB]
1
2
3
4
FREQUENCY [GHz]
d=6mm
d=4mm
d=2mm
502
504
506
850 MHz

FIG. 5

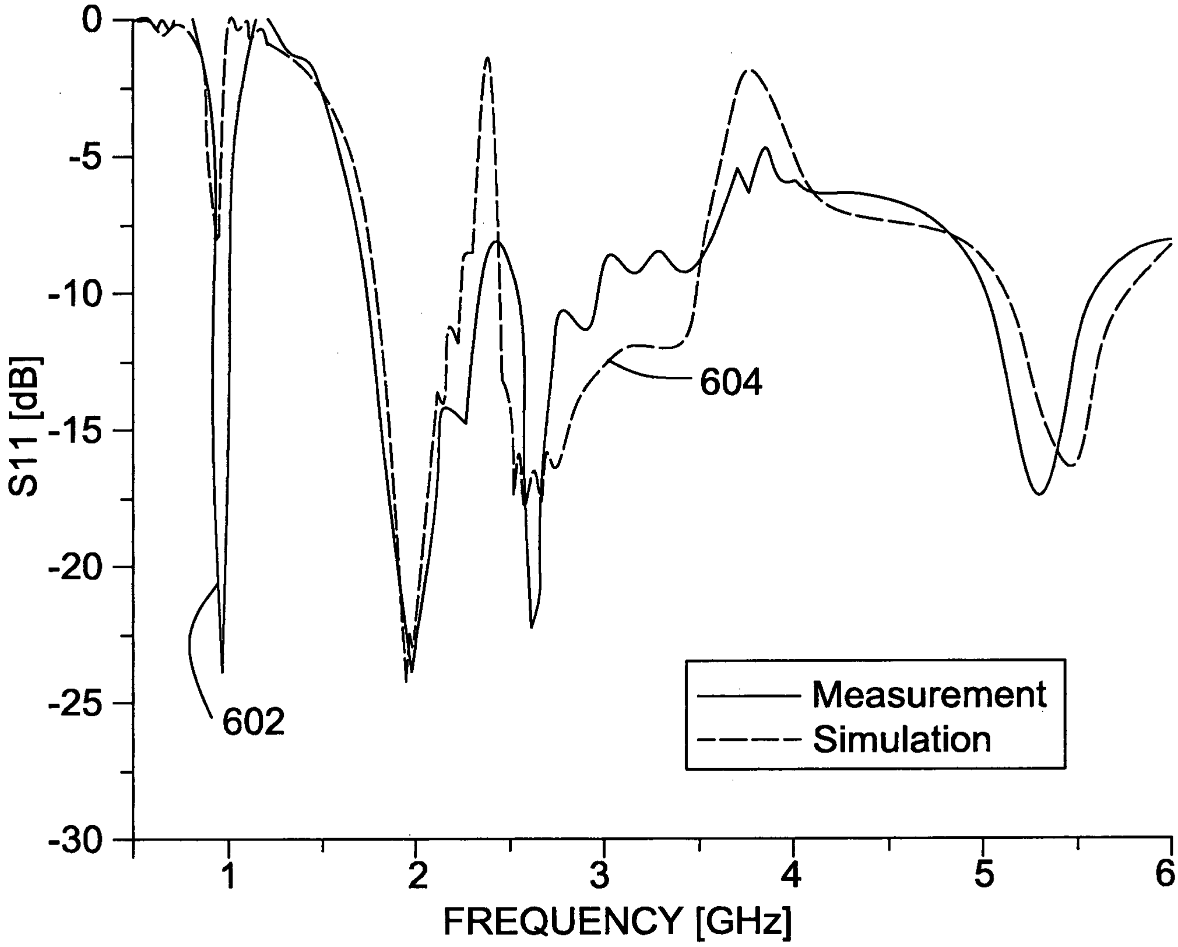
0
-5
-10
-15
-20
-25
-30
S11 [dB]
1
2
3
4
5
6
FREQUENCY [GHz]
602
604
Measurement
Simulation

FIG. 6

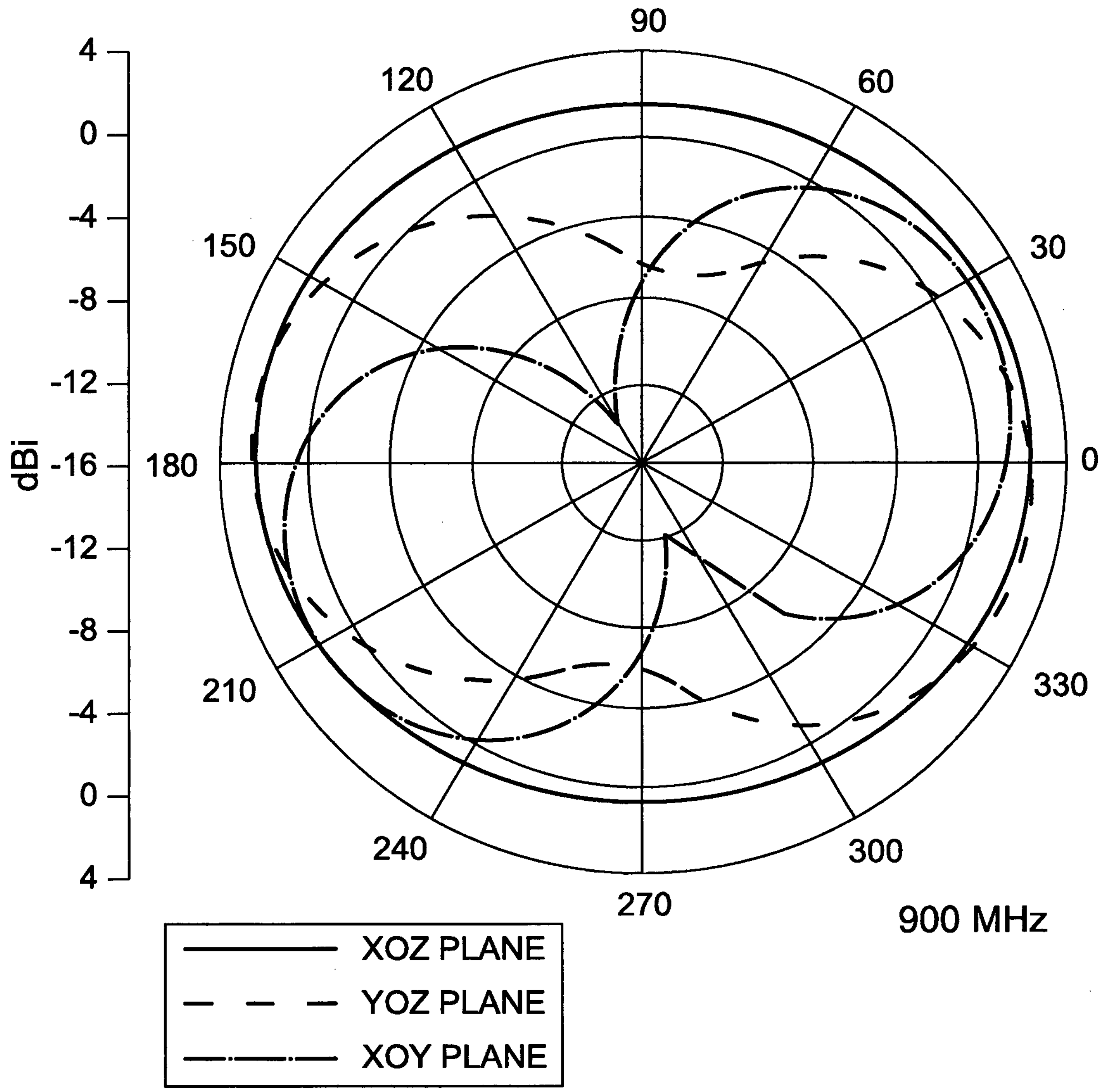
90
120
60
150
30
180
0
210
330
240
300
270
4
0
-4
-8
-12
-16
-12
-8
-4
0
4
dBi
900 MHz
XOZ PLANE
YOZ PLANE
XOY PLANE

FIG. 7a

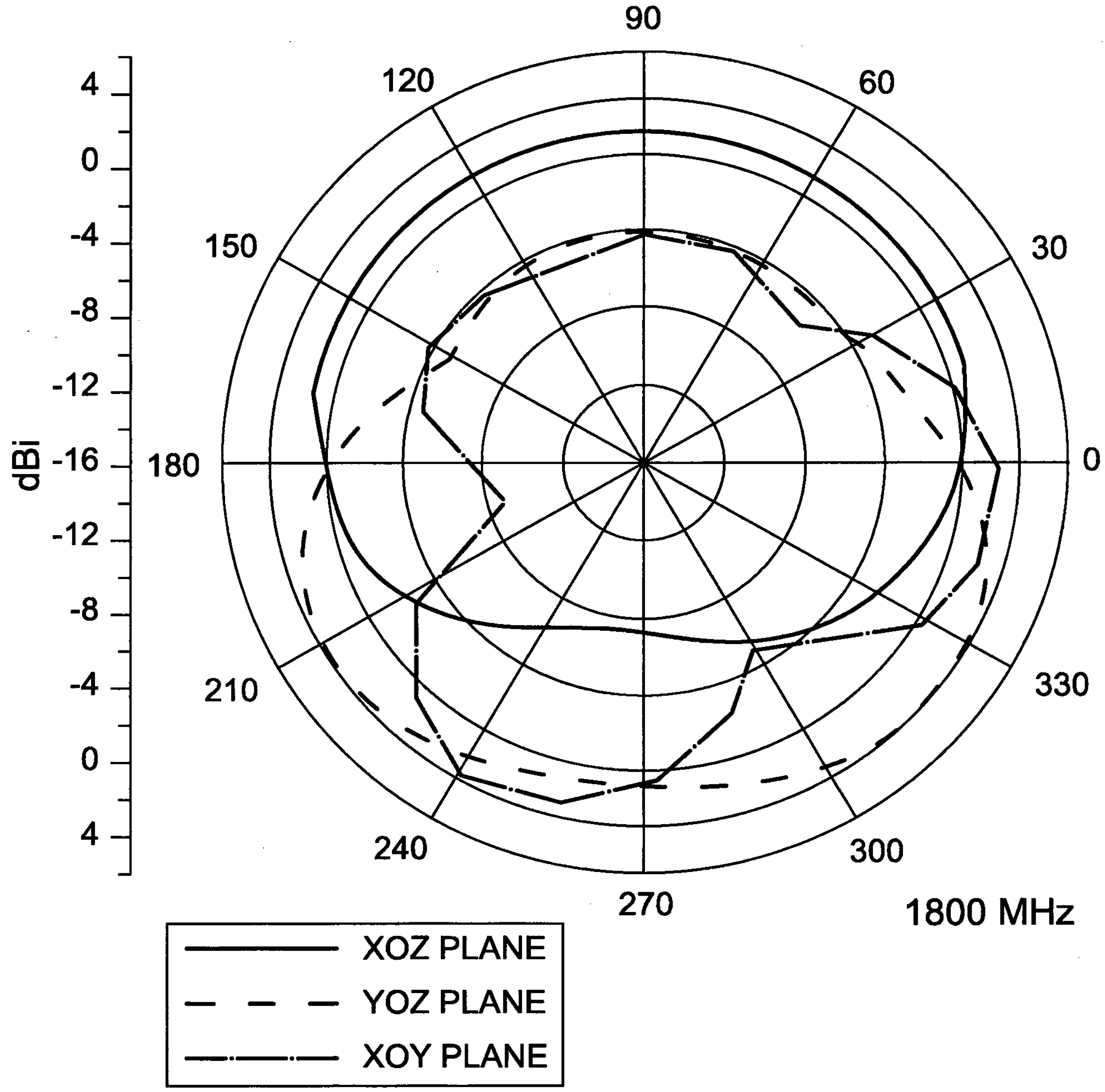
90
120
60
150
30
180
0
210
330
240
300
270
dBi
4
0
-4
-8
-12
-16
-12
-8
-4
0
4
1800 MHz
XOZ PLANE
YOZ PLANE
XOY PLANE

FIG. 7b

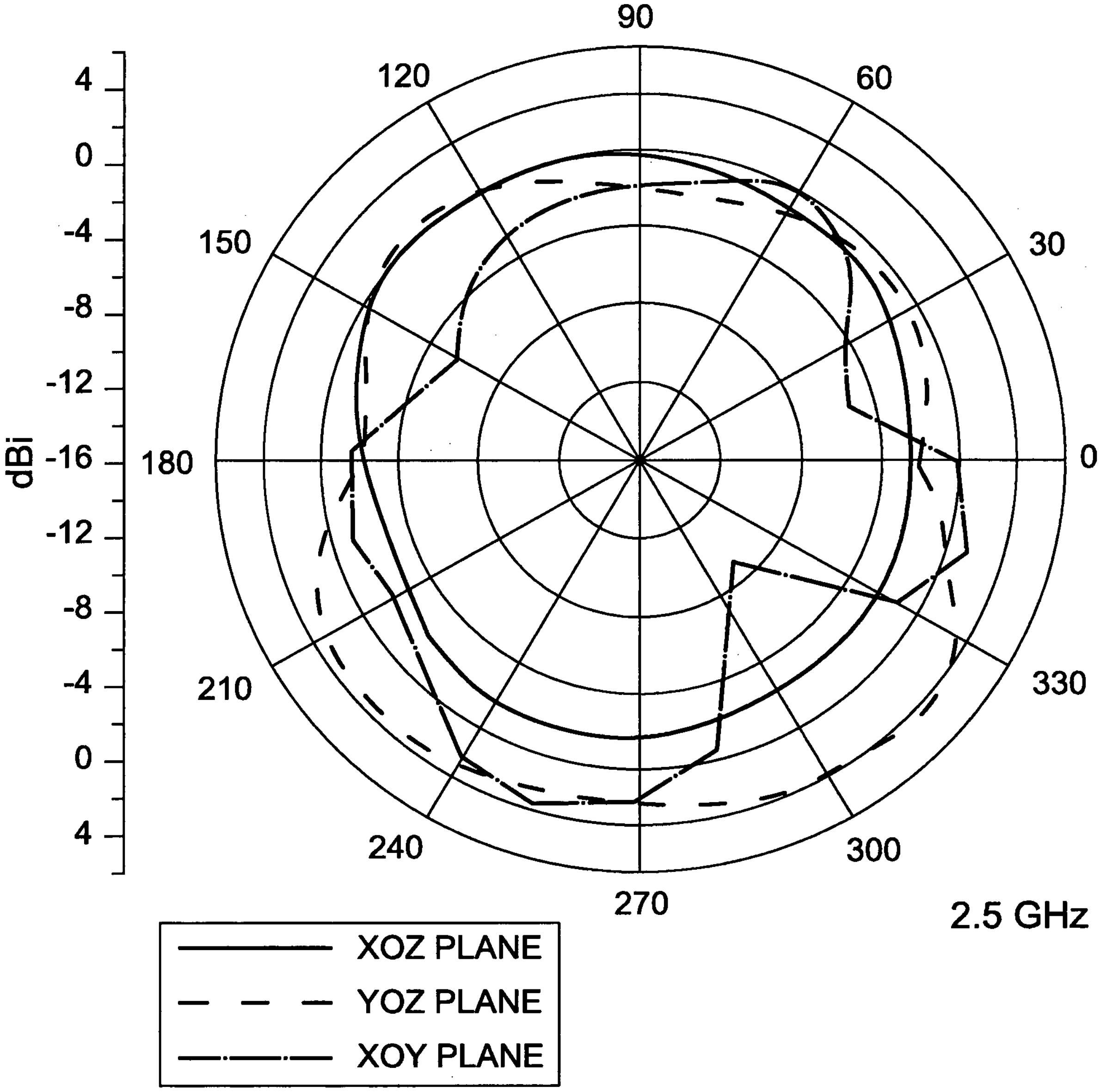
90
120
60
150
30
180
0
210
330
240
300
270
dBi
4
0
-4
-8
-12
-16
-12
-8
-4
0
4
2.5 GHz
XOZ PLANE
YOZ PLANE
XOY PLANE

FIG. 7c

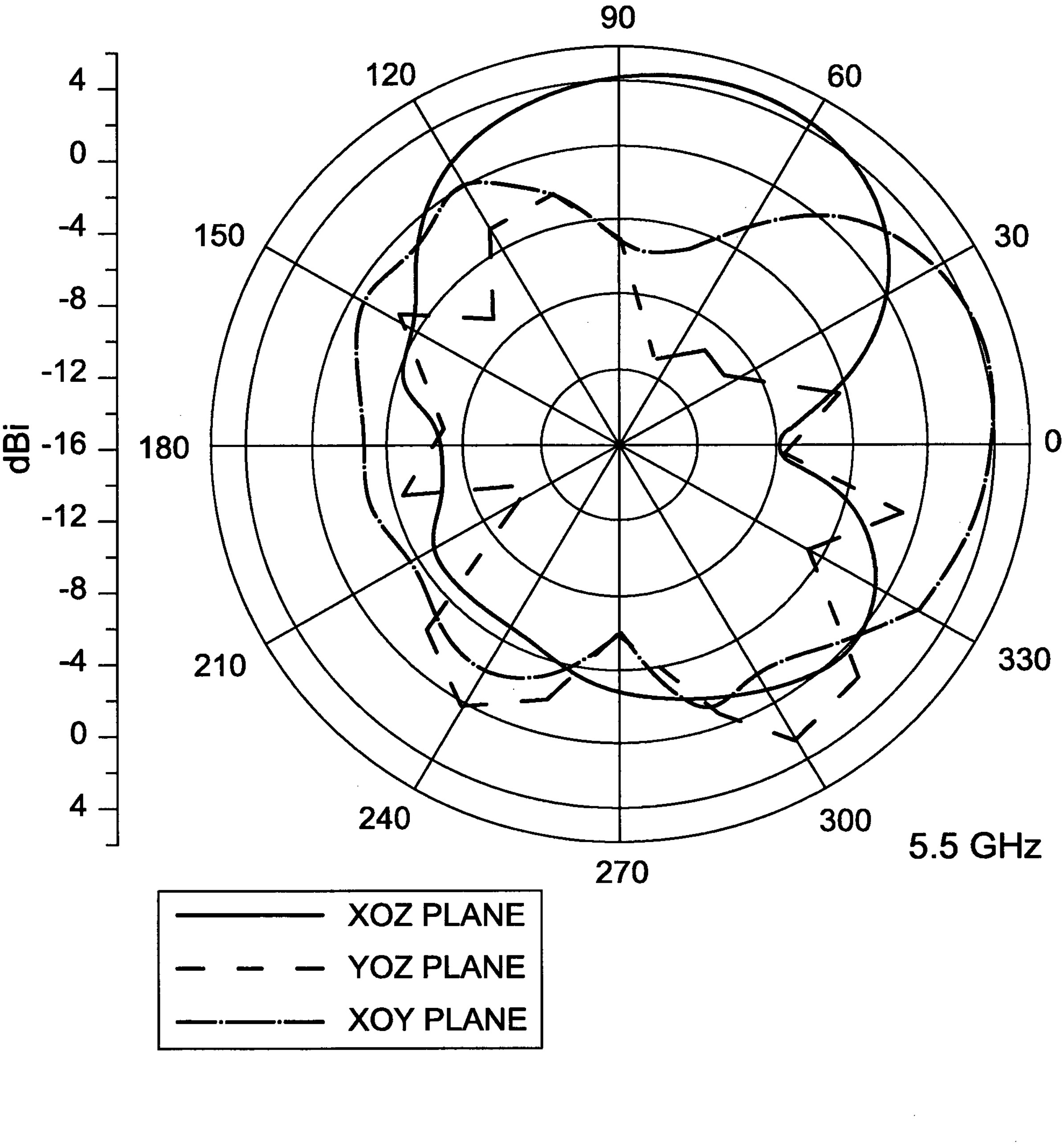
90
120
60
150
30
180
0
210
330
240
300
270
5.5 GHz
dBi
4
0
-4
-8
-12
-16
-12
-8
-4
0
4
XOZ PLANE
YOZ PLANE
XOY PLANE

FIG. 7d

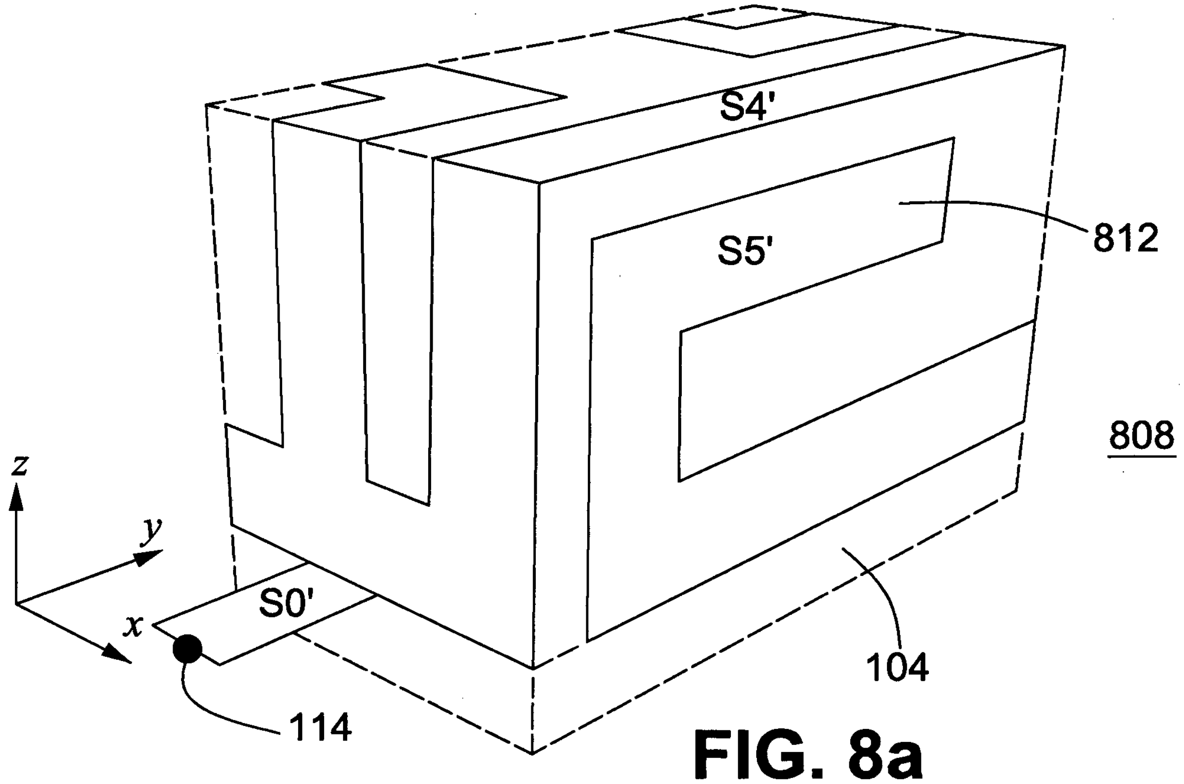

FIG. 8a

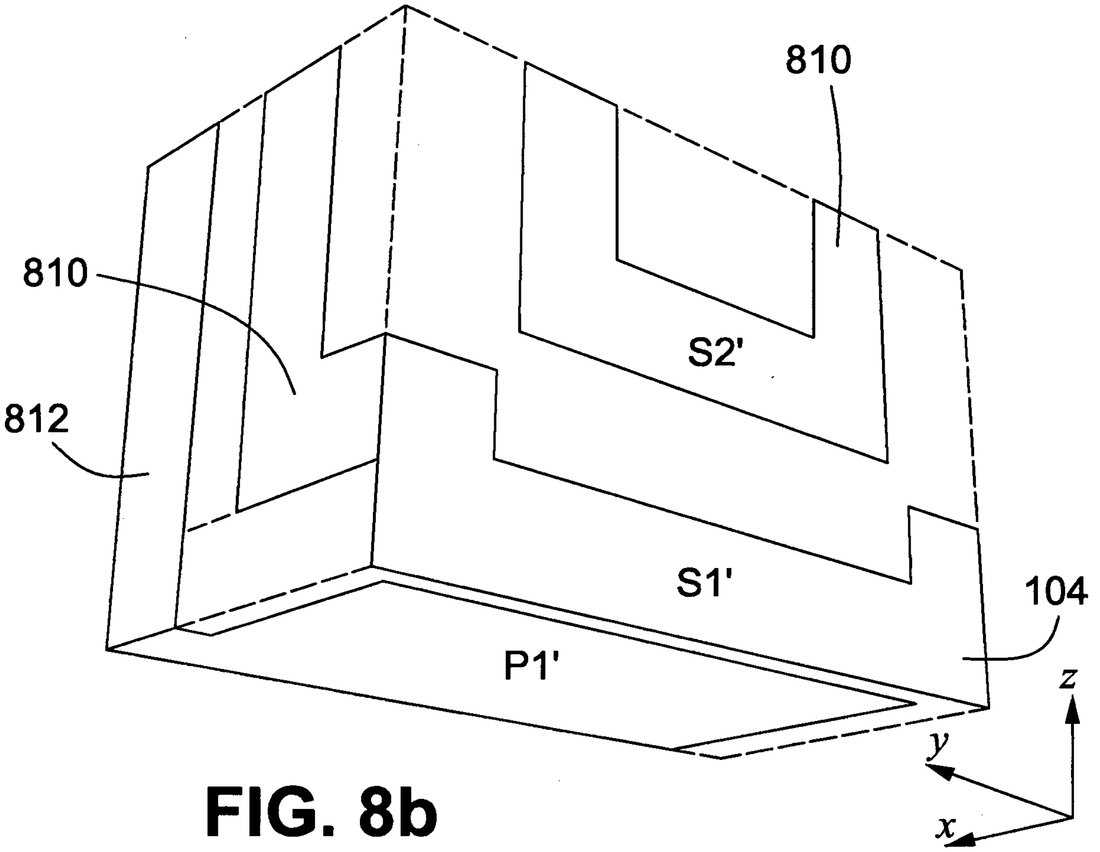

FIG. 8b

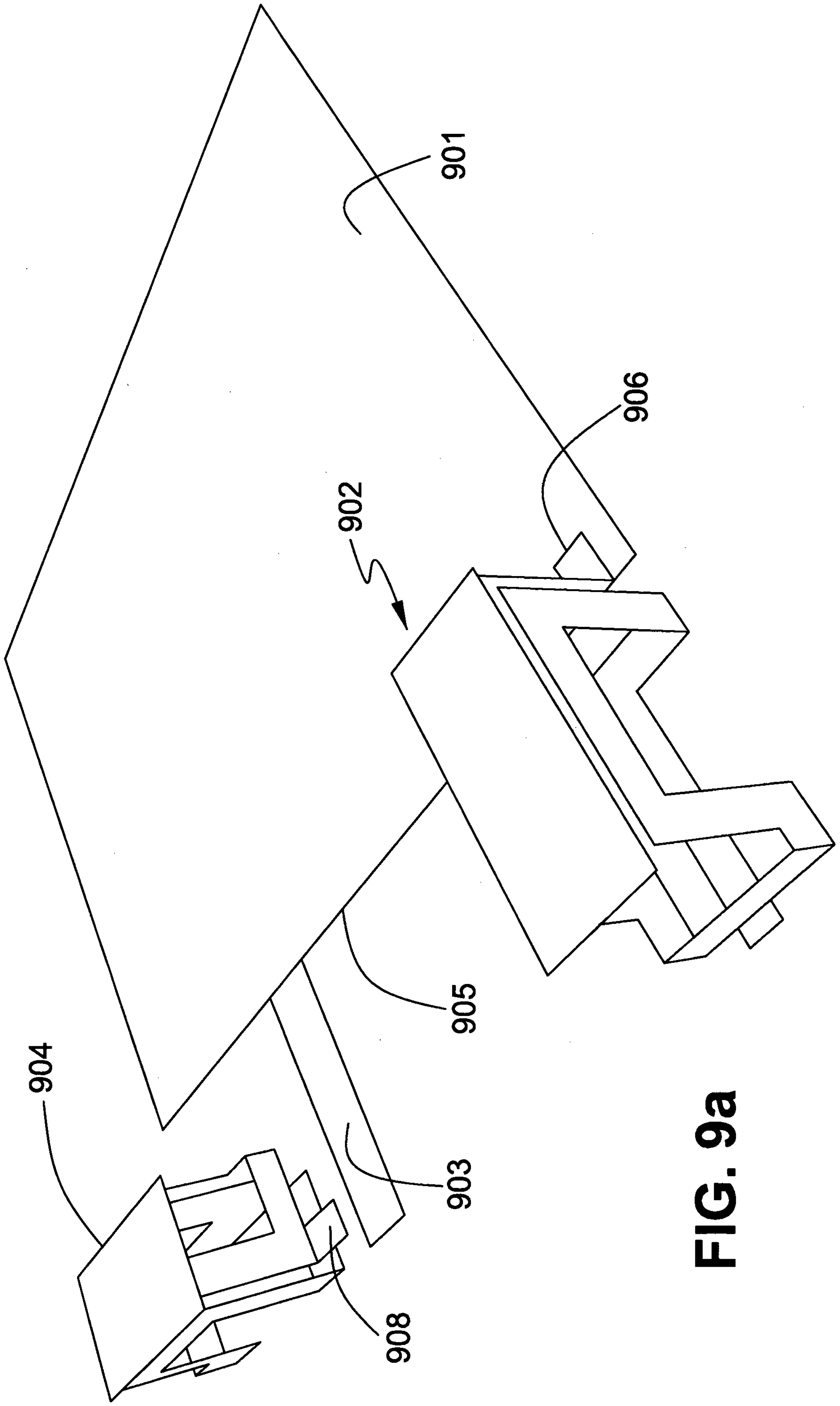

FIG. 9a

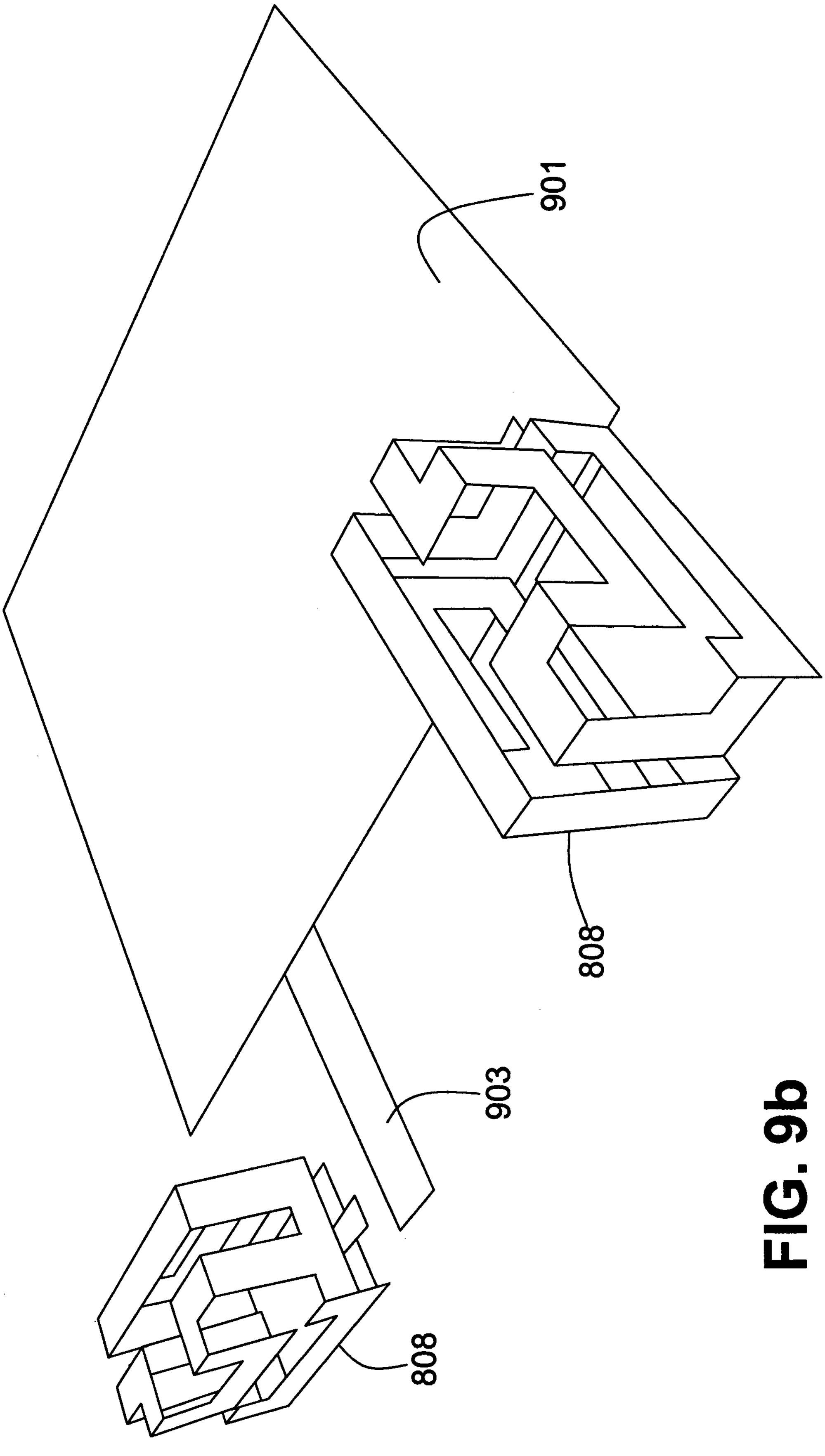

FIG. 9b

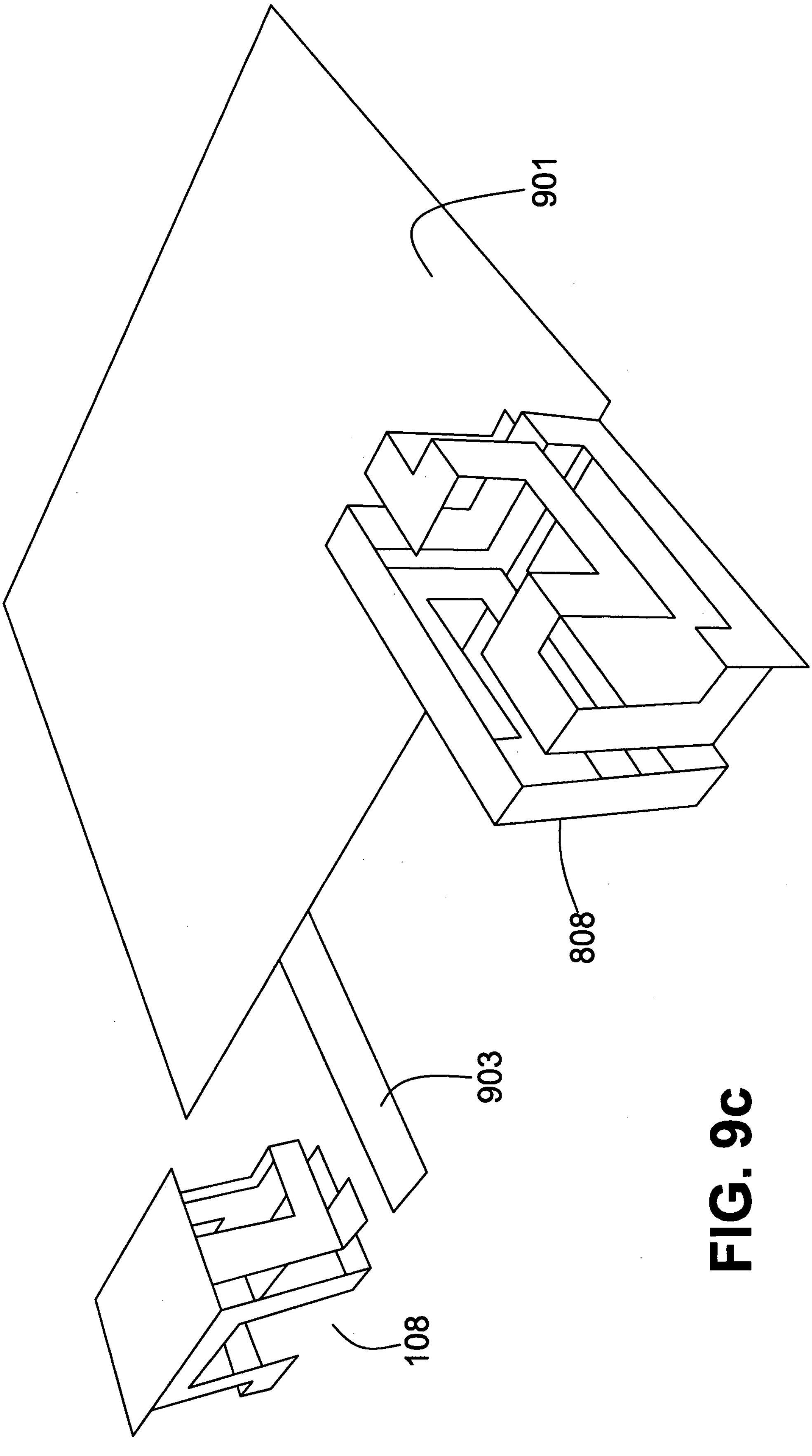

FIG. 9c

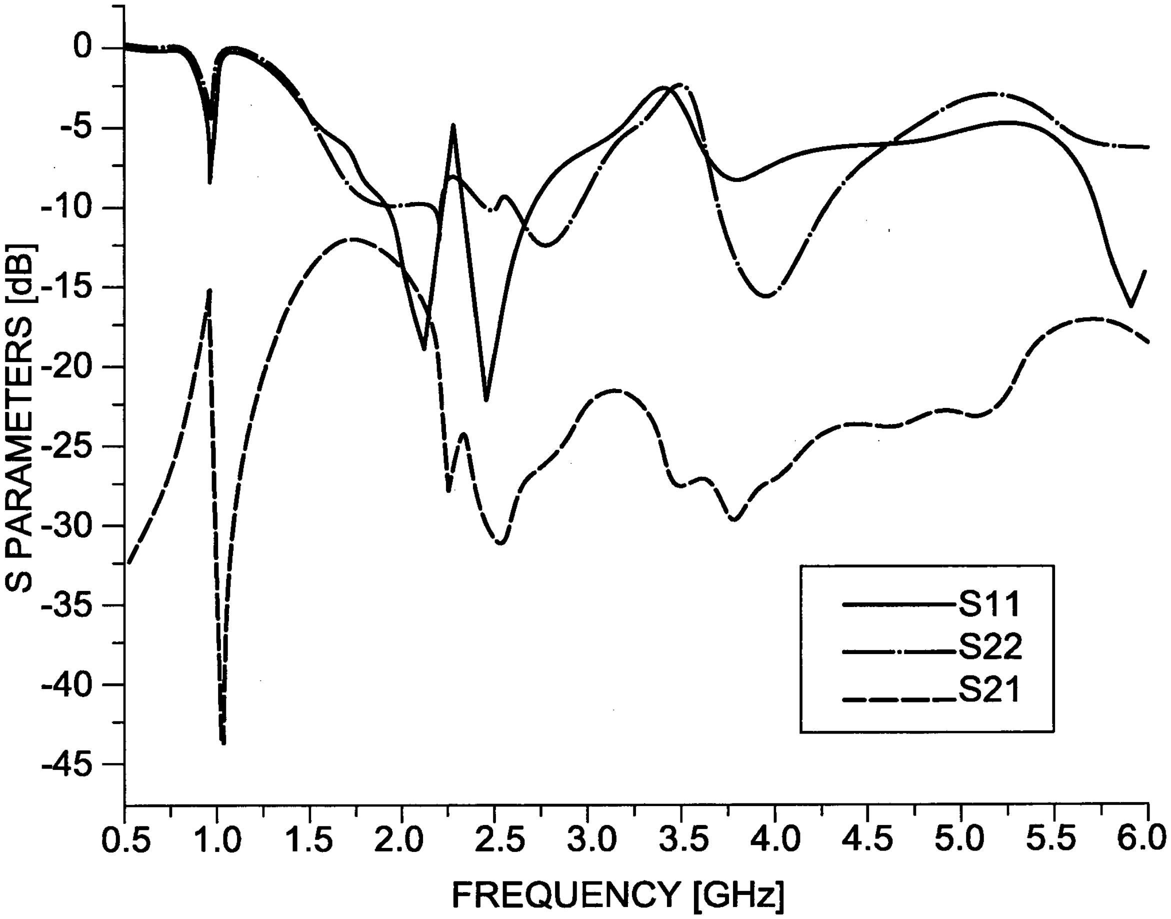
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
S PARAMETERS [dB]
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
FREQUENCY [GHz]
S11
S22
S21

FIG. 10

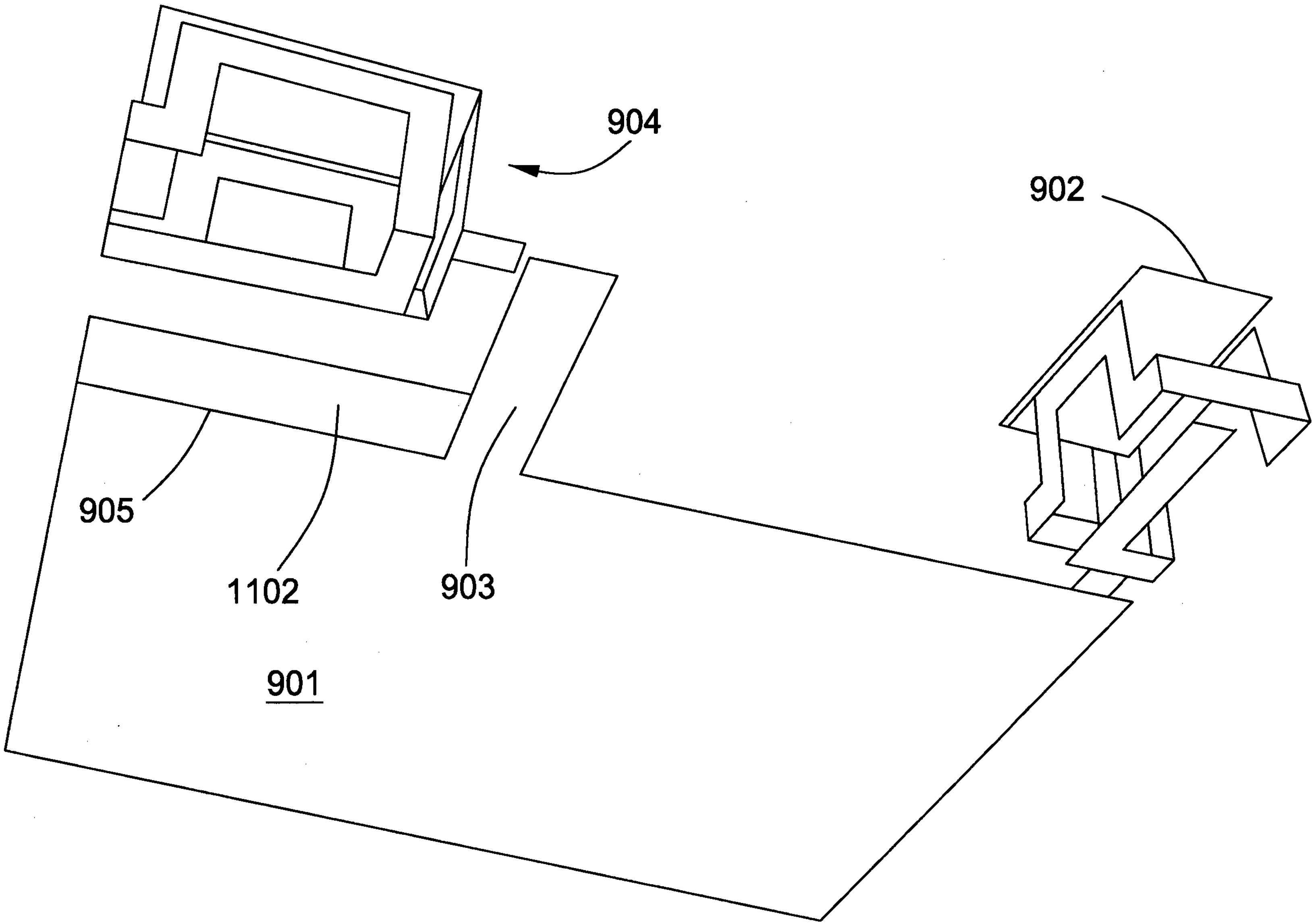

FIG. 11a

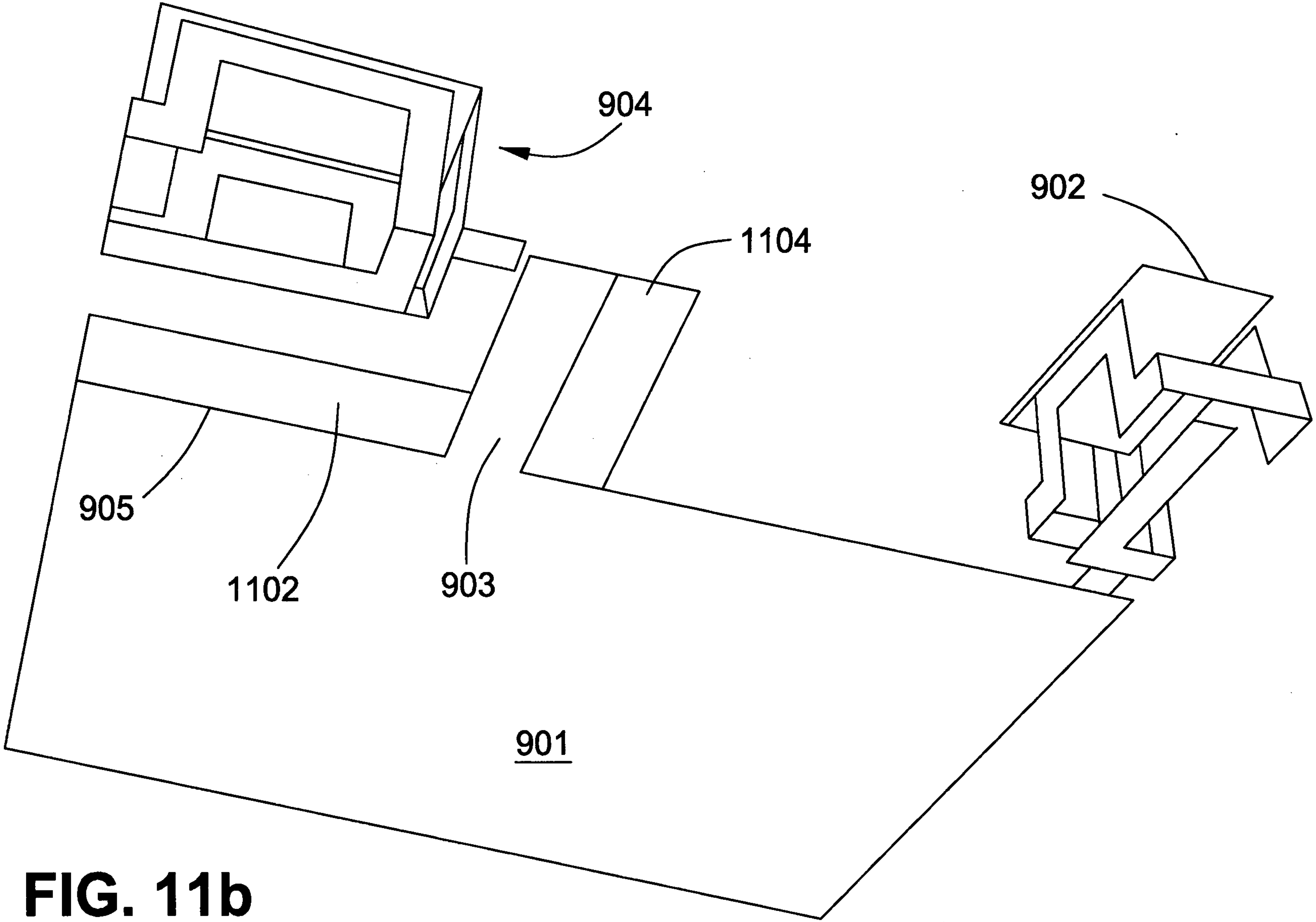

FIG. 11b

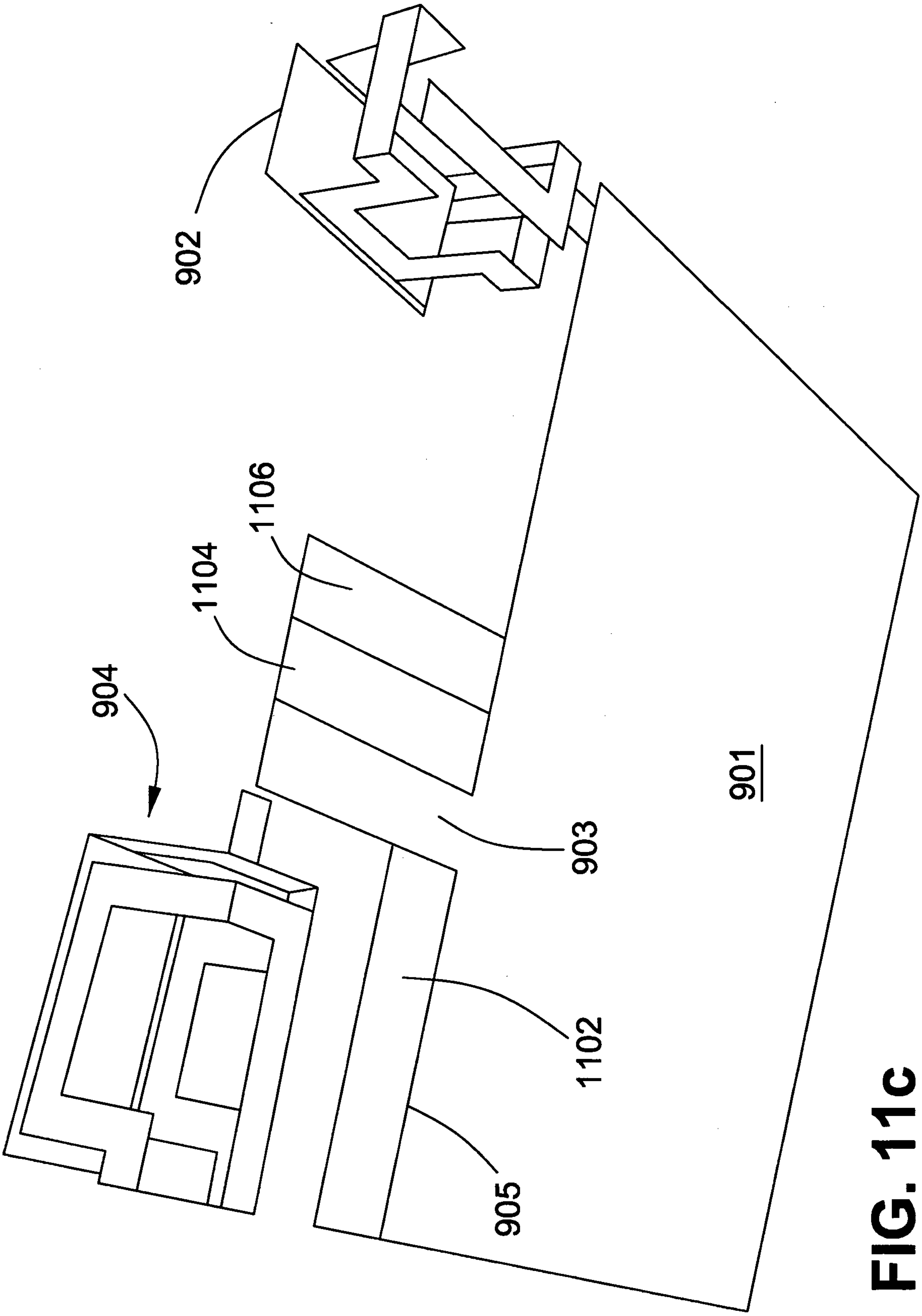

FIG. 11c

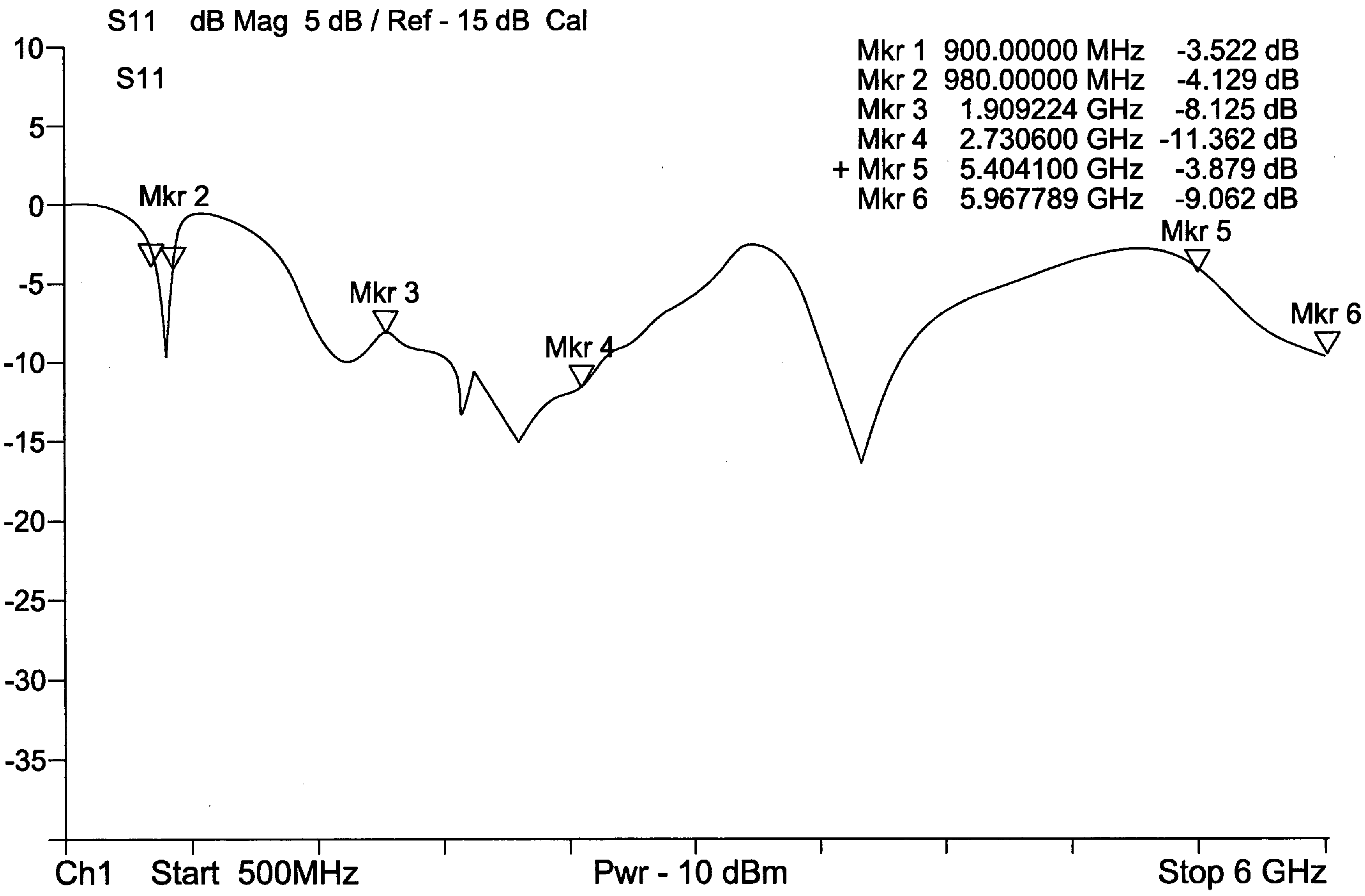
S11 dB Mag 5 dB / Ref - 15 dB Cal
S11
Mkr 1 900.00000 MHz -3.522 dB
Mkr 2 980.00000 MHz -4.129 dB
Mkr 3 1.909224 GHz -8.125 dB
Mkr 4 2.730600 GHz -11.362 dB
+ Mkr 5 5.404100 GHz -3.879 dB
Mkr 6 5.967789 GHz -9.062 dB
10
5
0
-5
-10
-15
-20
-25
-30
-35
Mkr 2
Mkr 3
Mkr 4
Mkr 5
Mkr 6
Ch1
Start 500MHz
Pwr - 10 dBm
Stop 6 GHz

FIG. 12a

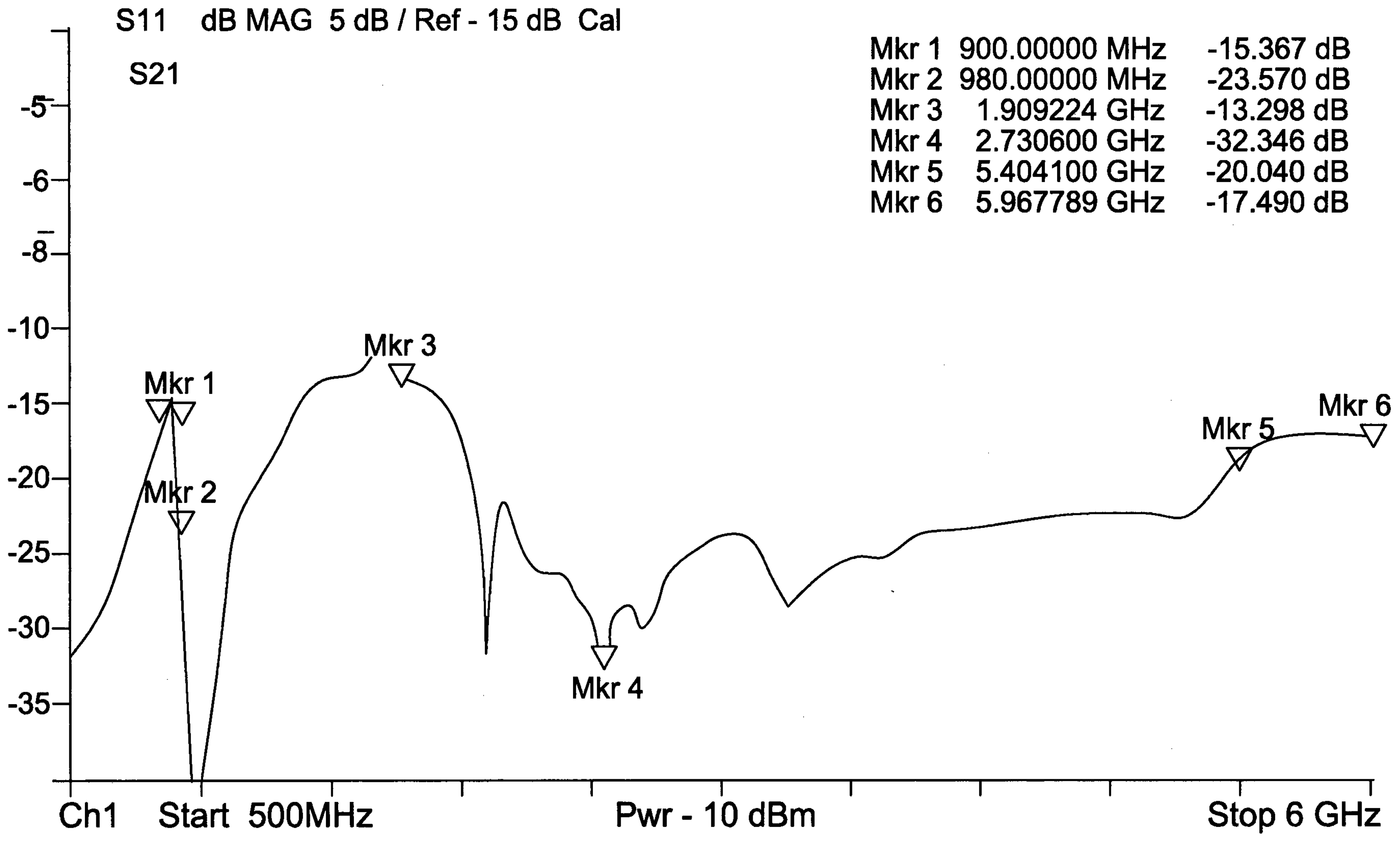
S11 dB MAG 5 dB / Ref - 15 dB Cal
S21
Mkr 1 900.00000 MHz -15.367 dB
Mkr 2 980.00000 MHz -23.570 dB
Mkr 3 1.909224 GHz -13.298 dB
Mkr 4 2.730600 GHz -32.346 dB
Mkr 5 5.404100 GHz -20.040 dB
Mkr 6 5.967789 GHz -17.490 dB
-5
-6
-8
-10
-15
-20
-25
-30
-35
Mkr 1
Mkr 2
Mkr 3
Mkr 4
Mkr 5
Mkr 6
Ch1
Start 500MHz
Pwr - 10 dBm
Stop 6 GHz

FIG. 12b

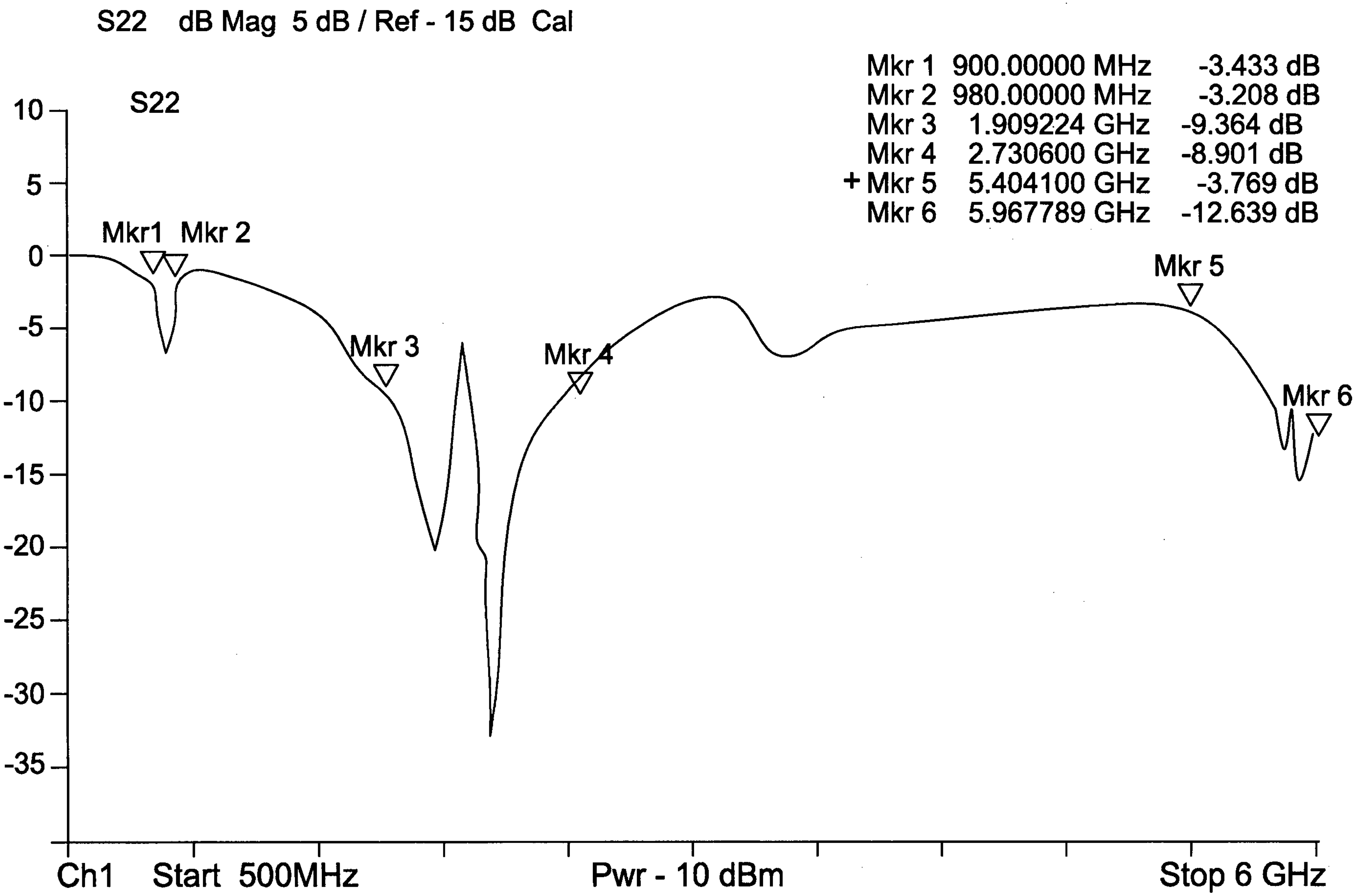
S22 dB Mag 5 dB / Ref - 15 dB Cal
S22
Mkr 1 900.00000 MHz -3.433 dB
Mkr 2 980.00000 MHz -3.208 dB
Mkr 3 1.909224 GHz -9.364 dB
Mkr 4 2.730600 GHz -8.901 dB
+ Mkr 5 5.404100 GHz -3.769 dB
Mkr 6 5.967789 GHz -12.639 dB
10
5
0
-5
-10
-15
-20
-25
-30
-35
Mkr1
Mkr 2
Mkr 3
Mkr 4
Mkr 5
Mkr 6
Ch1
Start 500MHz
Pwr - 10 dBm
Stop 6 GHz

FIG. 12c

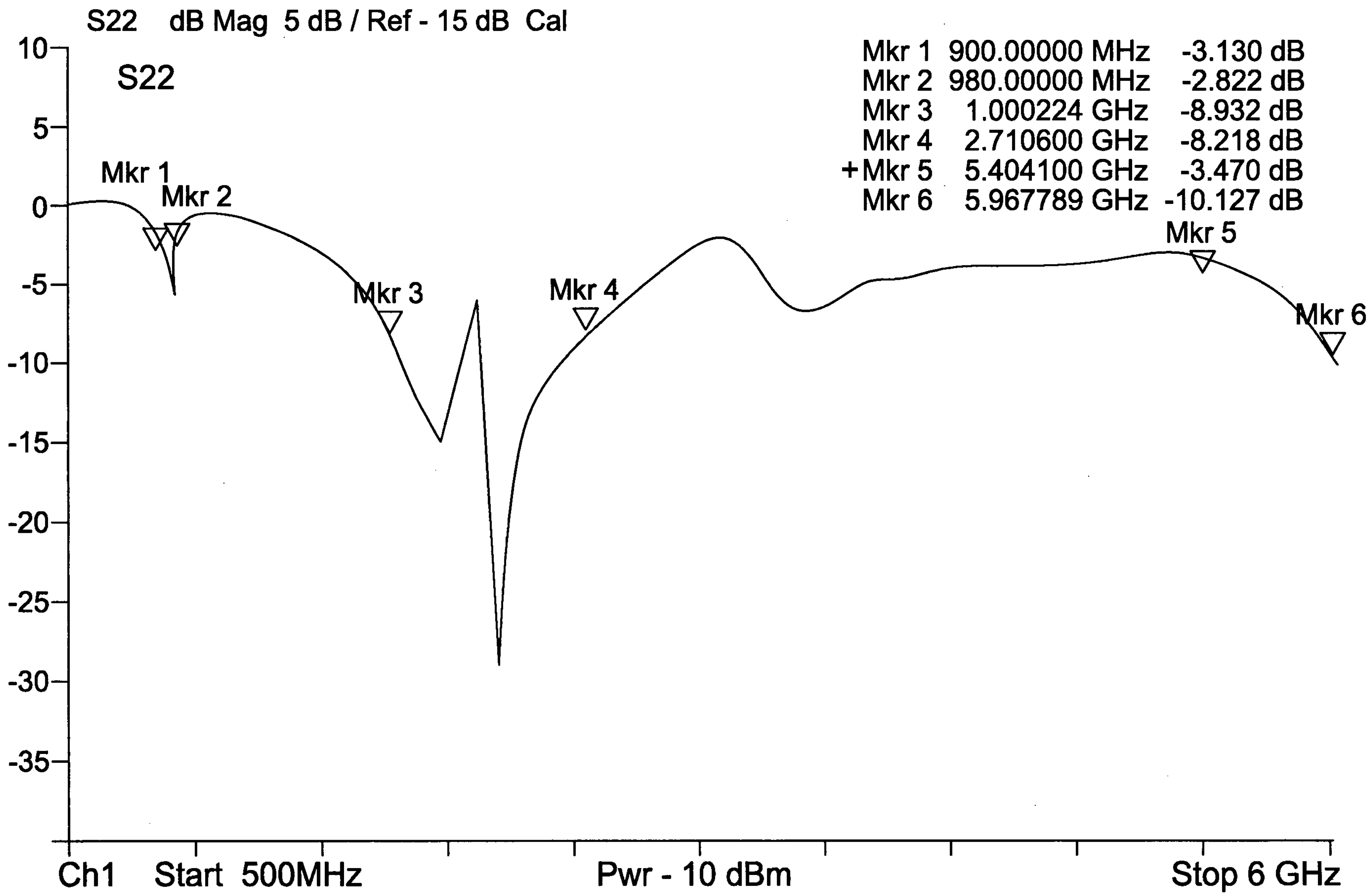
S22 dB Mag 5 dB / Ref - 15 dB Cal
S22
Mkr 1 900.00000 MHz -3.130 dB
Mkr 2 980.00000 MHz -2.822 dB
Mkr 3 1.000224 GHz -8.932 dB
Mkr 4 2.710600 GHz -8.218 dB
+Mkr 5 5.404100 GHz -3.470 dB
Mkr 6 5.967789 GHz -10.127 dB
10
5
0
-5
-10
-15
-20
-25
-30
-35
Mkr 1
Mkr 2
Mkr 3
Mkr 4
Mkr 5
Mkr 6
Ch1
Start 500MHz
Pwr - 10 dBm
Stop 6 GHz

FIG. 13a

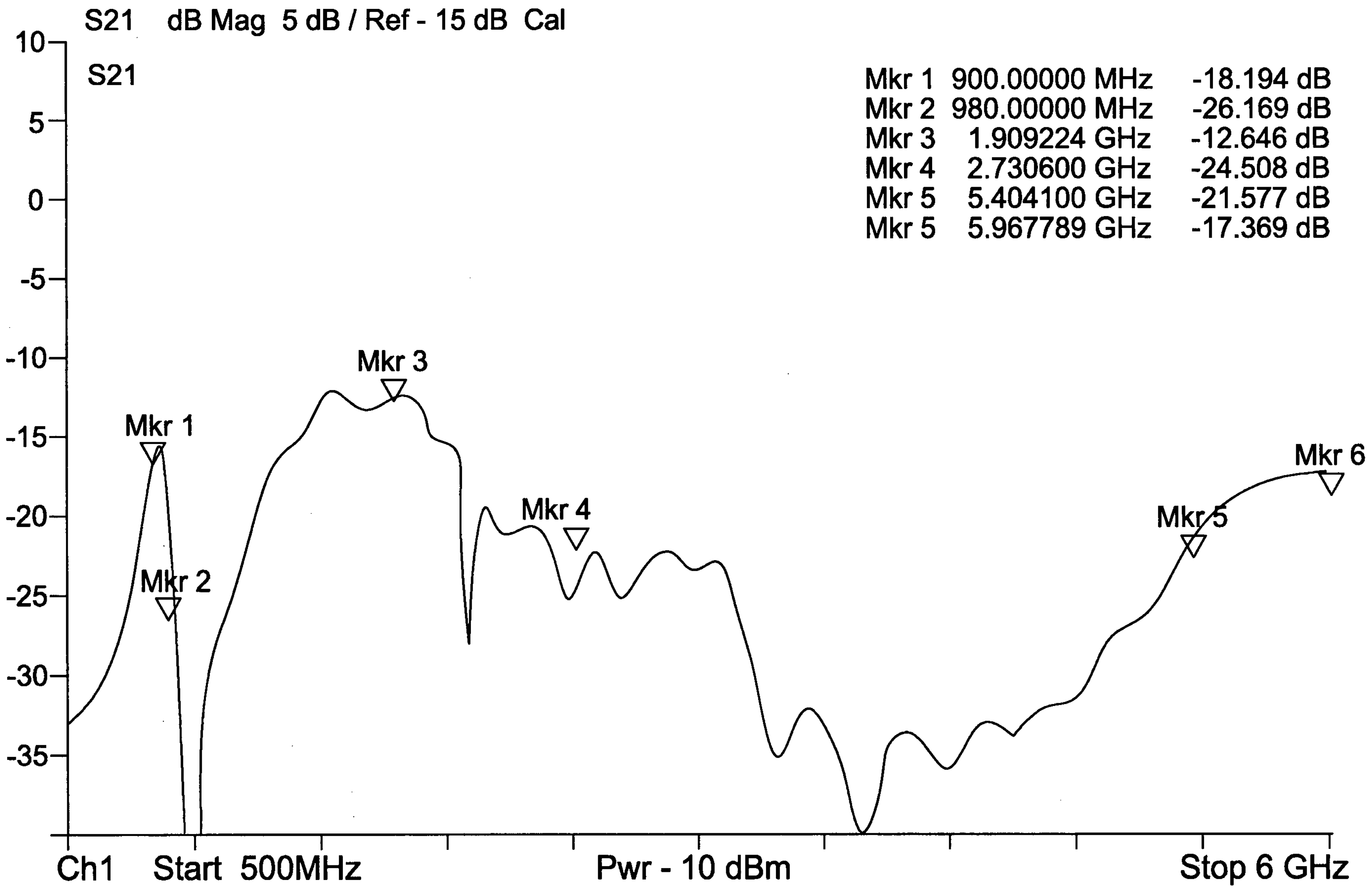
S21 dB Mag 5 dB / Ref - 15 dB Cal
S21
Mkr 1 900.00000 MHz -18.194 dB
Mkr 2 980.00000 MHz -26.169 dB
Mkr 3 1.909224 GHz -12.646 dB
Mkr 4 2.730600 GHz -24.508 dB
Mkr 5 5.404100 GHz -21.577 dB
Mkr 5 5.967789 GHz -17.369 dB
10
5
0
-5
-10
-15
-20
-25
-30
-35
Mkr 1
Mkr 2
Mkr 3
Mkr 4
Mkr 5
Mkr 6
Ch1
Start 500MHz
Pwr - 10 dBm
Stop 6 GHz

FIG. 13b

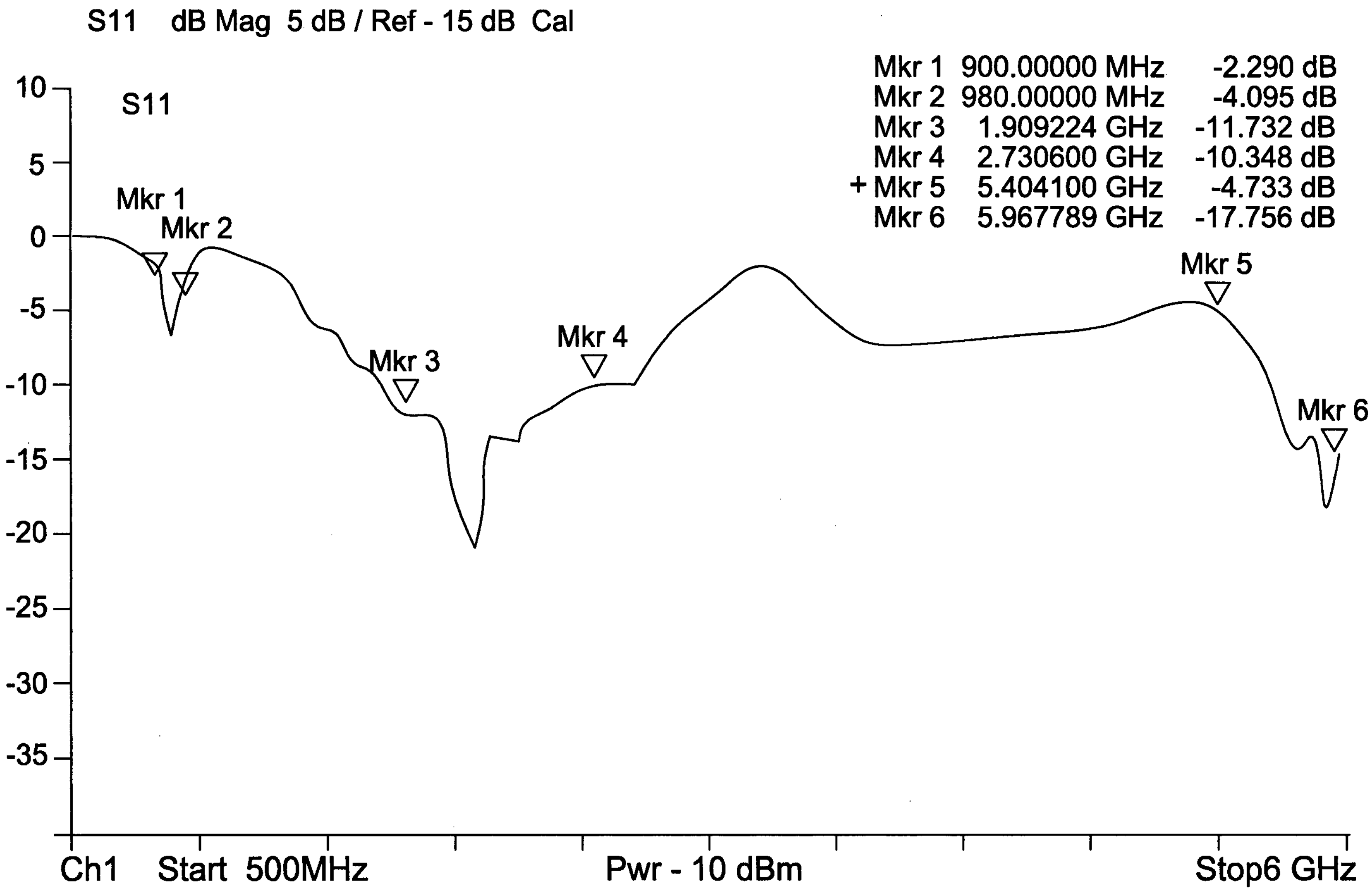
S11 dB Mag 5 dB / Ref - 15 dB Cal
S11
10
5
0
-5
-10
-15
-20
-25
-30
-35
Mkr 1
Mkr 2
Mkr 3
Mkr 4
Mkr 5
Mkr 6
Mkr 1 900.00000 MHz -2.290 dB
Mkr 2 980.00000 MHz -4.095 dB
Mkr 3 1.909224 GHz -11.732 dB
Mkr 4 2.730600 GHz -10.348 dB
+ Mkr 5 5.404100 GHz -4.733 dB
Mkr 6 5.967789 GHz -17.756 dB
Ch1
Start 500MHz
Pwr - 10 dBm
Stop6 GHz

FIG. 13c

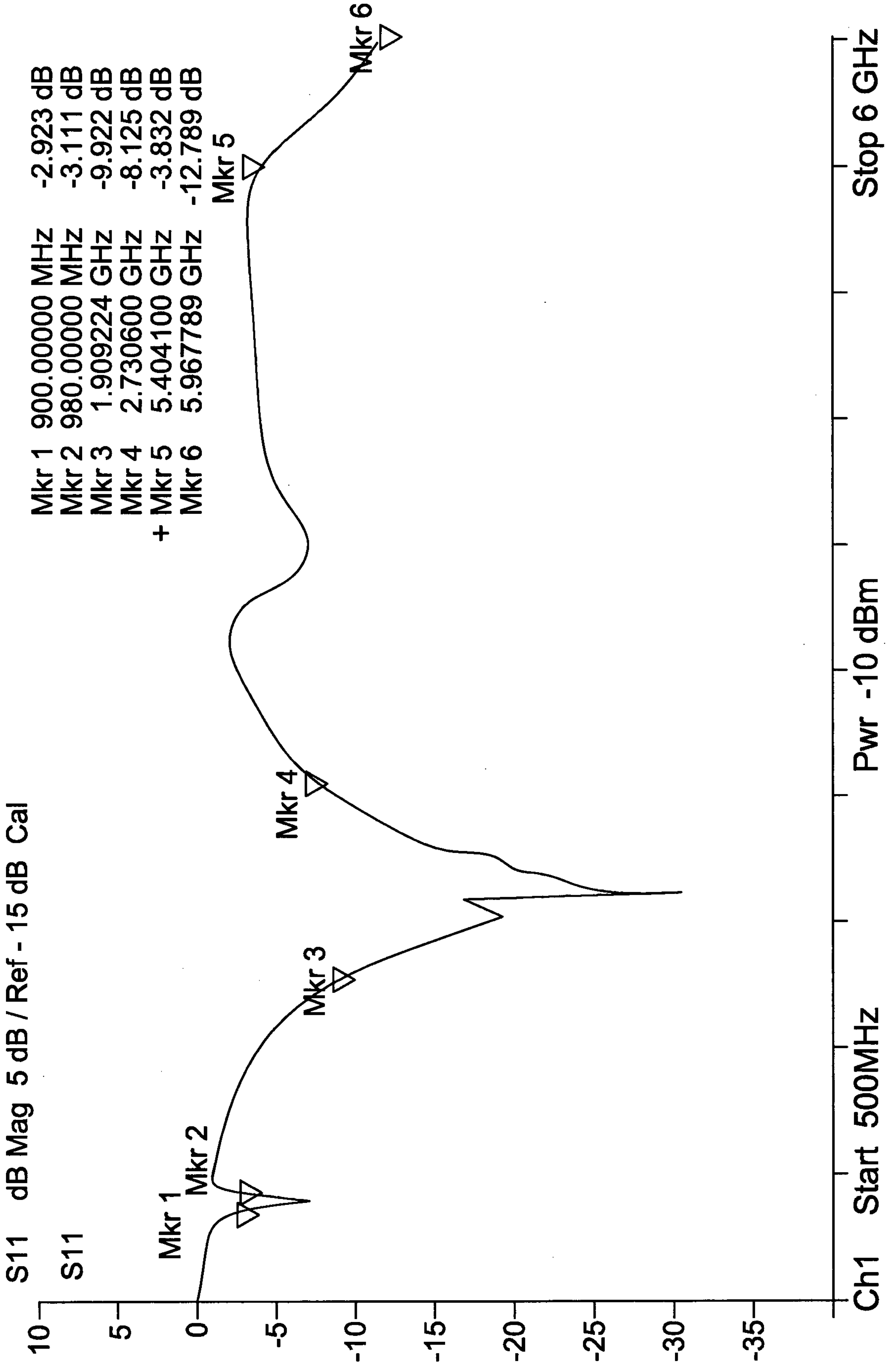
S11 dB Mag 5 dB / Ref - 15 dB Cal
S11
Mkr 1 900.000000 MHz -2.923 dB
Mkr 2 980.000000 MHz -3.111 dB
Mkr 3 1.909224 GHz -9.922 dB
Mkr 4 2.730600 GHz -8.125 dB
+ Mkr 5 5.404100 GHz -3.832 dB
Mkr 6 5.967789 GHz -12.789 dB
Mkr 1
Mkr 2
Mkr 3
Mkr 4
Mkr 5
Mkr 6
10
5
0
-5
-10
-15
-20
-25
-30
-35
Ch1 Start 500MHz
Pwr -10 dBm
Stop 6 GHz

FIG. 14a

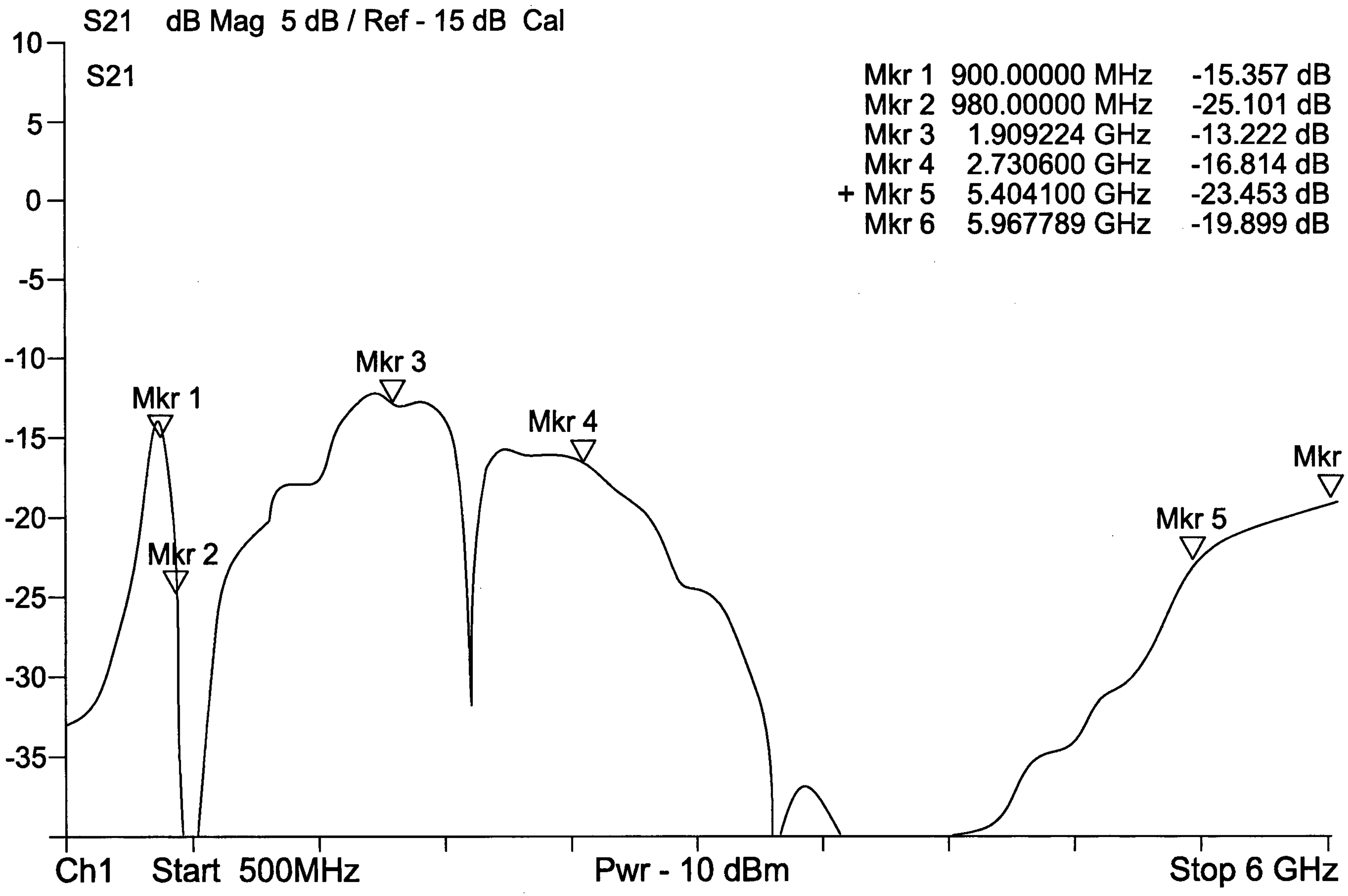
S21 dB Mag 5 dB / Ref - 15 dB Cal
S21
Mkr 1 900.00000 MHz -15.357 dB
Mkr 2 980.00000 MHz -25.101 dB
Mkr 3 1.909224 GHz -13.222 dB
Mkr 4 2.730600 GHz -16.814 dB
+ Mkr 5 5.404100 GHz -23.453 dB
Mkr 6 5.967789 GHz -19.899 dB
10
5
0
-5
-10
-15
-20
-25
-30
-35
Mkr 1
Mkr 2
Mkr 3
Mkr 4
Mkr 5
Mkr 6
Ch1
Start 500MHz
Pwr - 10 dBm
Stop 6 GHz

FIG. 14b

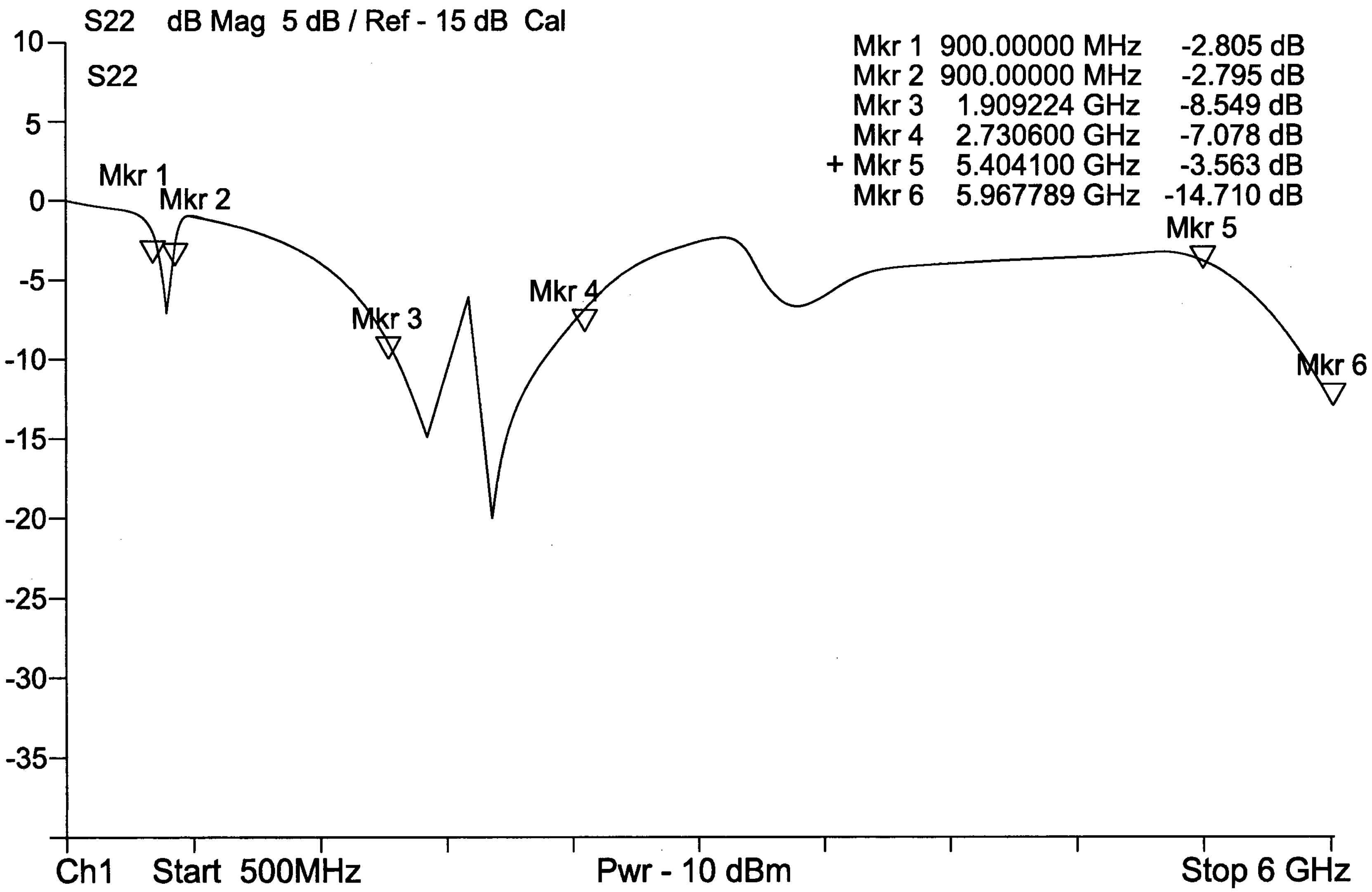
S22 dB Mag 5 dB / Ref - 15 dB Cal
S22
Mkr 1 900.00000 MHz -2.805 dB
Mkr 2 900.00000 MHz -2.795 dB
Mkr 3 1.909224 GHz -8.549 dB
Mkr 4 2.730600 GHz -7.078 dB
+ Mkr 5 5.404100 GHz -3.563 dB
Mkr 6 5.967789 GHz -14.710 dB
10
5
0
-5
-10
-15
-20
-25
-30
-35
Mkr 1
Mkr 2
Mkr 3
Mkr 4
Mkr 5
Mkr 6
Ch1
Start 500MHz
Pwr - 10 dBm
Stop 6 GHz

FIG. 14c

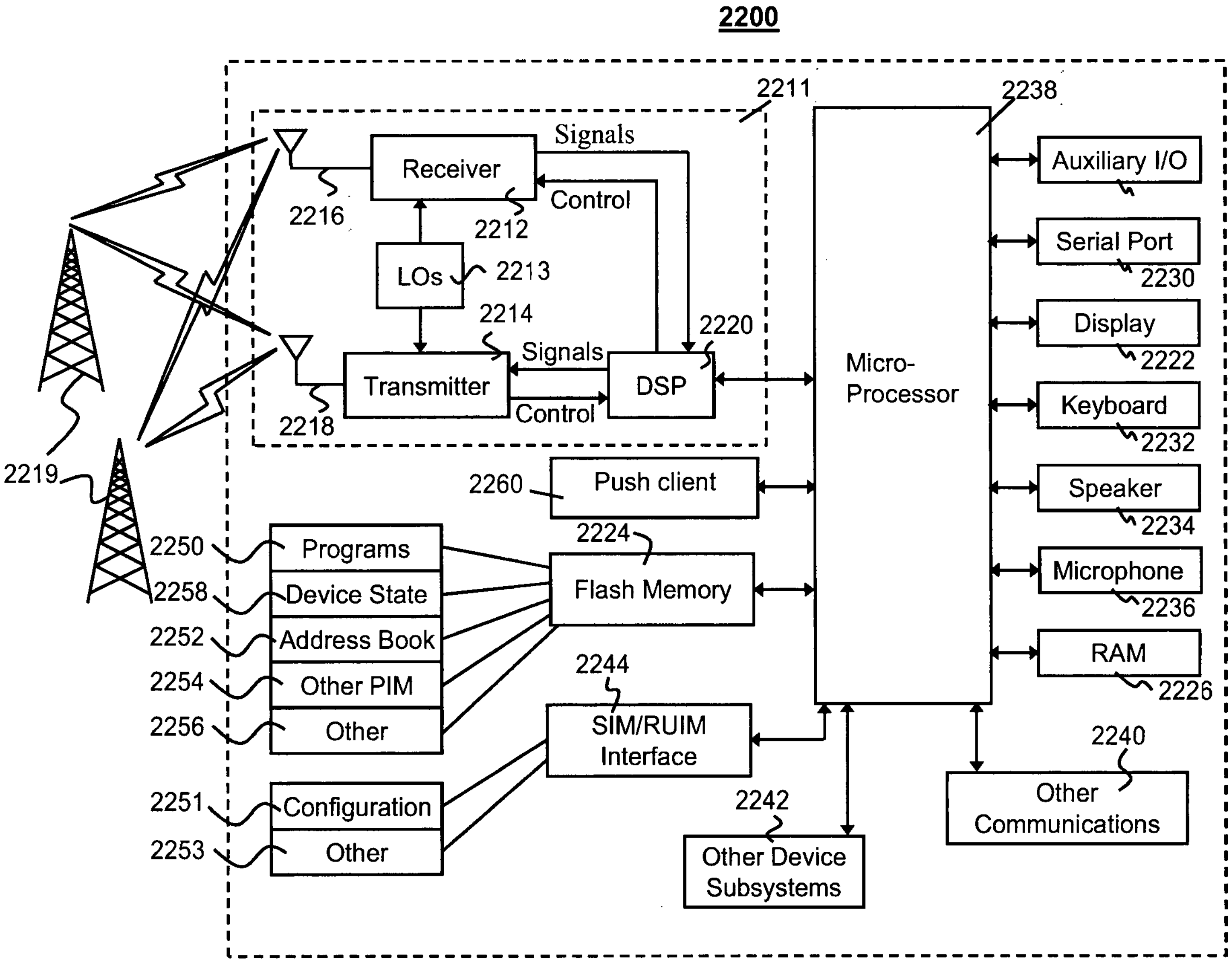
2200
2211
2238
Signals
Receiver
Control
2216
2212
LOs
2213
2214
Signals
2220
Transmitter
DSP
Control
2218
Micro-
Processor
Auxiliary I/O
Serial Port
2230
Display
2222
Keyboard
2232
Speaker
2234
Microphone
2236
RAM
2226
2219
Push client
2260
2224
Flash Memory
Programs
2250
Device State
2258
Address Book
2252
Other PIM
2254
Other
2256
2244
SIM/RUIM
Interface
Configuration
2251
Other
2253
2242
Other Device
Subsystems
2240
Other
Communications

FIG. 15

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2005210523 B **[0006]**
- JP 2002158529 B **[0007]**

Non-patent literature cited in the description

- Physical Limitations of Antennas. *IEEE Transactions on Antennas and Propagation,* 2003, vol. 51 (8), 2116-2123 **[0002]**