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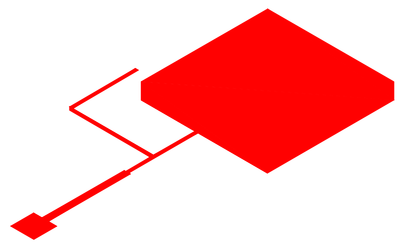

Microwave Planar Antenna Design

Group #4

ELE 791 Project Report
Spring 2002

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Design of a 1.575 GHz GPS Receiver Antenna Design

Abstract

This report presents a design of a corners-truncated rectangular microstrip patch antenna operates at 1.575 GHz. Predicted data is shown for input impedance and radiation patterns. The art work is included at the end of the report. The tools used were Ansoft Ensemble, HFSS and HP Momentum

Introduction

Microstrip antennas have been used for many years since they have a lot of advantages such as low-cost, conformability and easy manufacturing though they also have disadvantages such as narrow bandwidth and low power capacity.

This report presents the design of a 1.575 GHz GPS Receiver Antenna. Duroid is employed as the dielectric giving 3.8% bandwidth.

Design of the patch

Microstrip antenna patch elements are the most common form of printed antenna. They are popular for their low profile, geometry and low cost. A microstrip device in its simplest form is layered structure with two parallel conductors separated by a thin dielectric substrate and the lower conductor acting as a ground plane. If the upper conductor is patch that is an appreciable fraction of a wavelength, then the device becomes a radiating microstrip antenna (Fig. 1). Conventional patch designs yield bandwidths as low as a few percent.

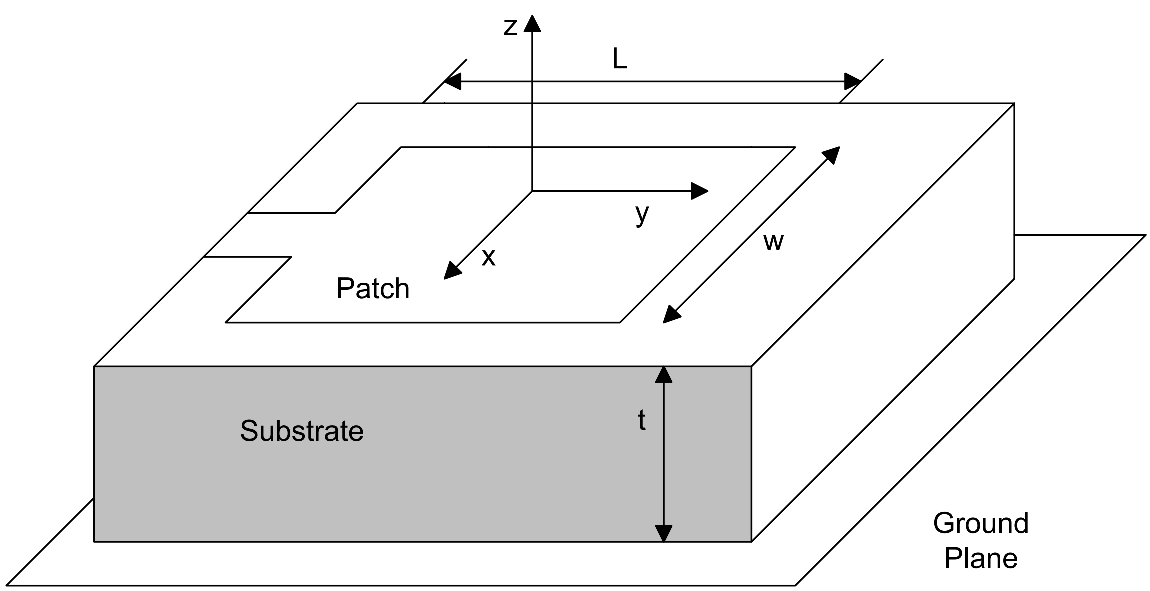


Figure 1 A sample edge-fed microstrip patch antenna.

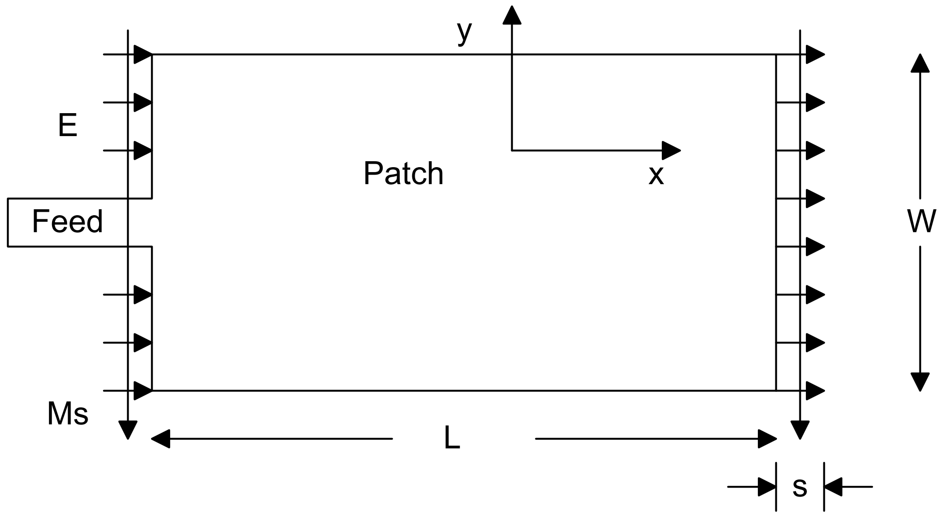


Figure 2 Fringing electric fields that are responsible for radiation. The equivalent magnetic surface currents M_s are also shown.

This had been the one of the main drawback of microstrip antennas. Recently, some approaches have been developed for the bandwidth enhancement [1], [2]. One way to enlarge it is to increase the height of the dielectric and decrease the dielectric constant. However, the latter will make the matching circuit more difficult since line widths will be wider. Since for this project, square patch is used, the equations related to rectangular (a more general case) patch will be presented.

The Corners Truncated Rectangular Patch

The rectangular patch is usually designed so that it can operate near resonance frequency in order to get rid off complex impedance. Some models are developed to accurately determine the resonant frequency. Among them the most accurate one is cavity model [3]. The fringing fields acts as an additional length to the patch. Thus, the length of a half-wave patch is slightly less than a half wavelength in order to compensate for the length introduced by the fringing fields. The amount of length introduced depends on the substrate media, its height and width of the patch. In the literature, there are couples of formulas available for the calculation of the resonant length [4], [5]. An approximate formula given by [6] is,

$$L \approx 0.49\lambda_d = 0.49\frac{\lambda_d}{\sqrt{\varepsilon_r}} \qquad \text{Half-wave patch} \qquad (1)$$

Where
λ is the free-space wavelength, λ_d the wavelength in the dielectric, and ε_r the substrate dielectric constant. This project uses half-wave patches.

The fringing field (Fig. 2) can be represented by an equivalent magnetic surface current. Both are in the same direction but have a distance of half-wavelength. Therefore, the total fringing fields at the edges are 180^0 out of phase and equal in magnitude. When viewed from the top, the x-components of the fringing fields are actually in-phase. Leading to a broadside radiation pattern; that is, the peak radiation is in the +z-direction.

The pattern of a rectangular patch antenna is rather broad with a maximum direction normal to the plane of the antenna. Pattern computation for the rectangular patch is easily performed by first representing fringe electric fields using $M_s = 2E_a \times \hat{n}$, where **E**$_a$ is the fringe electric field. The factor of 2 comes from the image of the magnetic current in the electric ground plane if assume t is small. The far field components follow as [7],

$$\begin{aligned} E_\theta &= E_o \cos\phi . f(\theta,\phi) \\ E_\phi &= -E_o \cos\theta \sin\phi . f(\theta,\phi) \end{aligned} \tag{2}$$

Where

$$f(\theta,\phi) = \frac{\sin\left[\frac{\beta W}{2}\sin\theta\sin\phi\right]}{\frac{\beta W}{2}\sin\theta\sin\phi}\cos\left(\frac{\beta L}{2}\sin\theta\cos\phi\right) \tag{3}$$

and β is the usual free-space phase constant. The first factor is the pattern factor for a uniform line source of width W in the y-direction. The second factor is array factor for a two-element array along the x-axis corresponding tot he edge slots. Detail explanation will be given for array factor in the next sections

Typical impedance of a rectangular patch antenna varies from 100 to 400 Ω. At the resonance the approximate input impedance of a patch is given by [4],

$$Z_A = 90\frac{\varepsilon_r}{\varepsilon_r - 1}\left(\frac{L}{W}\right)^2 \Omega \qquad \text{for half wave patch} \tag{4}$$

Thus, the input impedance (resistance) is reduced by widening the patch.

There are different kinds of techniques for feeding patches, namely, probe fed, microstrip edge feed with quarter wave transformation, microstrip edge feed with gap, two layer feed. A general understanding of feeding can be realized by Schaubert's study [8].

Design Method in Project

In the design of antenna to meet the design requirements, we followed some procedures as follows,

a) First of all, I have chosen the ε (dielectric permittivity) of the dielectric to give maximum bandwidth. I have chosen the dielectric from Rogers corp. as RT/Duroid5880.
b) From Eqn. 1 or using Estimate module of Ensemble obtain the rough dimensions of resonant length.
c) I simulated 32 mils thickness substrate and then increased to 125 mils to get 60 MHz impedance bandwidth. 125 mil thicknesses is the maximum height of the substrate which is available at Rogers. The height can be increased further and further but then the efficiency and the gain of the antenna will be reduced accordingly [7]. Once the height is found, the patch size is made optimum in order to resonate at 1.575 GHz.
d) If the resonance frequency is smaller than 1.575 GHz, decrease patch size, otherwise increase it and follow step 2. Otherwise, terminate the simulation.
e) To satisfy the requirements, we added tuning stub to get input impedance real and also this stub increased the bandwidth about 5 MHz.
f) After getting real impedance, we transformed this value to 50 ohms using quarter wave transformer.
g) After done with Ensemble, I used HFSS to simulate the circuit. I scaled down the patch to get the right resonance frequency.

Feeding Techniques Review

There are three common structures that are used to feed planar printed antennas. These are coaxial probe feeds, microstrip line feeds, and aperture coupled feeds. The coaxial –fed structure is often used because of ease of matching its characteristic impedance to that of the antenna; and as well as the parasitic radiation from the feed network tends to be insignificant. Compared to probe feeds, microstrip line-fed structures are more suitable due to ease of fabrication and lower costs, but serious drawback of this feed structure is the strong parasitic radiation. The aperture-coupled structure has all of the advantages of the former two structures, and isolates the radiation from the feed network, thereby leaving the main antenna radiation uncontaminated.

We selected microstrip line feed technique due to ease of fabrication.

Input Impedance

Input impedance can be changed changing the length of tuning stub. At the attached presentation file, you can see the comparison table of Ensemble simulations for various tuning stub lengths.

Measurement Results

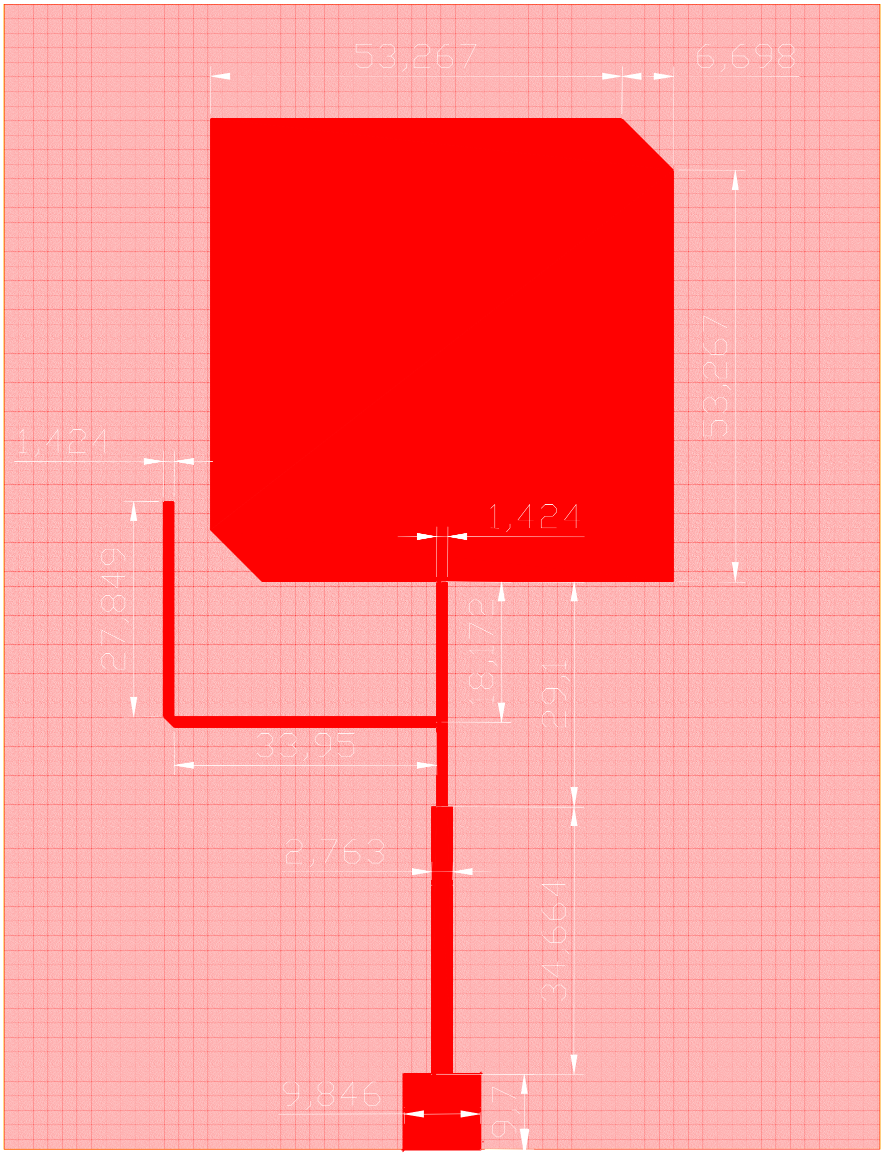
Measured results agree fairly well with the simulated values. Especially HFSS gives more accurate values. We got 60 MHz as VSWR bandwidth (known as impedance bandwidth), 55.5 Ohms+ j2.7 Ohms input impedance and -24 dB S11 at our operating frequency. We also measured our antenna at Anaren Microwave Company for pattern and gain. We got 5.5 dB gain.

Conclusion

In this project we designed and tested patch antenna. The design steps have been presented. It is expected that, because of their small size and low mass, the demand for microstrip antennas in commercial, military and space areas will continue to increase. We have discussed two methods of widening the bandwidth. We have seen that HFSS gives more accurate results. In ADS, it is really hard to draw antenna and in Sonnet and Microwave Office, you can give some discrete values for dimensions. For Sonnet and MW Office, this characteristic seems to be a drawback, in fact designing the antenna in Sonnet, will be the best way. This is because, sometimes, it is impossible to build antennas which have fractional values as dimensions.

Artwork

(Figure not to scale. Dimensions are given in mm.)



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[3] K. R. Carver and J. W. Mink, "Microstrip Antenna Technology," *IEEE Trans. Antennas & Propagation*, Vol. AP-29, pp. 2-24, Jan. 1981.

[4] D. R. Jackson and N. G. Alexopoulos, "Simple Approximate Formulas for Input Resistance, Bandwidth, and Efficiency of a Resonant Rectangular Patch*," IEEE Trans. Antennas & Propagation,* Vol. 3, pp. 407-410, March 1991.

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[6] R. E. Munson, "Conformal Microstrip Antennas and Microstrip Phased Arrays," *IEEE Trans. Antennas & Propagation*, Vol. AP-22, pp. 74-78, Jan. 1974.

[7] W. L. Stutzman, G. A. Thiele, "Antenna Theory and Design," pp. 212-213, John Wiley & Sons, Inc., New York, 1998.

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Antenna Terminology

The definitions in quotation marks are taken from **IEEE Standard Definitions of Terms for Antennas, IEEE Std 145-1983**.

Antenna: "That part of a transmitting or receiving system which is designed to radiate or to receive electromagnetic waves". An antenna can also be viewed as a transitional structure (transducer) between free-space and a transmission line (such as a coaxial line). An important property of an antenna is the ability to focus and shape the radiated power in space e.g.: it enhances the power in some wanted directions and suppresses the power in other directions.

Frequency bandwidth: "The range of frequencies within which the performance of the antenna, with respect to some characteristics, conforms to a specified standard". VSWR of an antenna is the main bandwidth limiting factor.

Input impedance: "The impedance presented by an antenna at its terminals". The input impedance is a complex function of frequency with real and imaginary parts. The input impedance is graphically displayed using a Smith chart.

Reflection coefficient: The ratio of the voltages corresponding to the reflected and incident waves at the antenna's input terminal (normalized to some impedance Z0). The return loss is related to the input impedance Zin and the characteristic impedance Z0 of the connecting feed line by: Gin = (Zin - Z0) / (Zin+Z0).

Voltage standing wave ratio (VSWR): The ratio of the maximum/minimum values of standing wave pattern along a transmission line to which a load is connected. VSWR value ranges from 1 (matched load) to infinity for a short or an open load. For most base station antennas the maximum acceptable value of VSWR is 1.5. VSWR is related to the reflection coefficient Gin by: VSWR= (1+|Gin|)/(1-|Gin |).

Isolation: "A measure of power transfer from one antenna to another". This is also the ratio of the power input to one antenna to the power received by the other antenna, expressed in decibel (dB). The same definition is applicable to two-port antennas such as dual-polarization antennas.

Far-field region: "That region of the field of an antenna where the angular field distribution is essentially independent of the distance from a specified point in the antenna region". The radiation pattern is measured in the far field.

Antenna polarization: "In a specified direction from an antenna and at a point in its far field, is the polarization of the (locally) plane wave which is used to represent the radiated wave at that point". "At any point in the far-field of an antenna the radiated wave can be represented by a plane wave whose electric field strength is the same as that of the wave and whose direction of propagation is in the radial direction from the antenna. As the radial distance approaches infinity, the radius of curvature of the radiated wave's phase front also approaches infinity and thus in any specified direction the wave appears locally a plane wave". In practice, polarization of the radiated energy varies with the direction from the center of the antenna so that different parts of the pattern and different side lobes sometimes have different polarization. The polarization of a radiated wave can be linear or elliptical (with circular being a special case).

Co-polarization: "That polarization which the antenna is intended to radiate".

Cross-polarization: "In a specified plane containing the reference polarization ellipse, the polarization orthogonal to a specified reference polarization". The reference polarization is usually the co-polarization.

Antenna pattern: The antenna pattern is a graphical representation in three dimensions of the radiation of the antenna as a function of angular direction. Antenna radiation performance is usually measured and recorded in two orthogonal principal planes (such as E-Plane and H-plane or vertical and horizontal planes). The pattern is usually plotted either in polar or rectangular coordinates. The pattern of most base station antennas contains a main lobe and several minor lobes, termed side lobes. A side lobe occurring in space in the direction opposite to the main lobe is called back lobe.

Normalized pattern: Normalizing the power/field with respect to its maximum value yields a normalized power/field pattern with a maximum value of unity (or 0 dB).

Gain pattern: Normalizing the power/field to that of a reference antenna yields a gain pattern. When the reference is an isotropic antenna, the gain is expressed in dBi. When the reference is a half-wave dipole in free space, the gain is expressed in dBd.

Radiation efficiency: "The ratio of the total power radiated by an antenna to the net power accepted by the antenna from the connected transmitter".

E-plane: "For a linearly polarized antenna, the plane containing the electric field vector and the direction of maximum radiation". For base station antenna, the E-plane usually coincides with the vertical plane.

H-plane: "For a linearly polarized antenna, the plane containing the magnetic field vector and the direction of maximum radiation". For base station antenna, the H-plane usually coincides with the horizontal plane.

Front-to-back ratio: "The ratio of the maximum directivity of an antenna to its directivity in a specified rearward direction". Sometimes the directivity in the rearward direction is taken as the average over an angular region.

Major/main lobe: "The radiation lobe containing the direction of maximum radiation". For most practical antenna there is only one main beam.

Side lobe level: Is the ratio, in decibels (dB), of the amplitude at the peak of the main lobe to the amplitude at the peak of a side lobe.

Half-power beamwidth: "In a radiation pattern cut containing the direction of the maximum of a lobe, the angle between the two directions in which the radiation intensity is one-half the maximum value". The Half-power beamwidth is also commonly referred to as the 3-dB beamwidth.

Antenna directivity: The directivity of an antenna is given by the ratio of the maximum radiation intensity (power per unit solid angle) to the average radiation intensity (averaged over a sphere). The directivity of any source, other than isotropic, is always greater than unity.

Antenna gain: The maximum gain of an antenna is simply defined as the product of the directivity by efficiency. If the efficiency is not 100 percent, the gain is less than the directivity. When the reference is a loss less isotropic antenna, the gain is expressed in dBi. When the reference is a half wave dipole antenna, the gain is expressed in dBd (1 dBd = 2.15 dBi).

Antenna efficiency: The total antenna efficiency accounts for the following losses: (1) reflection because of mismatch between the feeding transmission line and the antenna and (2) the conductor and dielectric losses.

Effective radiated power (ERP): "In a given direction, the relative gain of a transmitting antenna with respect to the maximum directivity of a half-wave dipole multiplied by the net power accepted by the antenna from the connected transmitter".

Power handling: Is the ability of an antenna to handle high power without failure. High power in antenna can cause voltage breakdown and excessive heat (due to conductor and dielectric antenna losses) which would results in an antenna failure.

Passive intermodulation (PIM): As in active devices, passive intermodulation occurs when signals at two or more frequencies mix with each other in a non-linear manner to produce spurious signals. PIM is caused by a multitude of factors present in the RF signal path. These include poor mechanical contact, presence of ferrous contents in connectors and metals, and contact between two galvanically unmatched metals. PIM spurious signal, which falls in the up link band, can degrade call quality and reduce the capacity of a wireless system.

Side lobe suppression: "Any process, action or adjustment to reduce the level of the side lobes or to reduce the degradation of the intended antenna system performance resulting from the presence of side lobes". For base station antenna, the first side lobe above the horizon is preferred to be low in order to reduce interference to adjacent cell sites. At the other hand, the side lobes below the horizon are preferred to be high for better coverage.

Null filling: Is the process to fill the null in the antenna radiation pattern to avoid blind spots in cell site coverage.

Isotropic radiator: "A hypothetical, loss less antenna having equal radiation intensity in all direction". For based station antenna, the gain in dBi is referenced to that of an isotropic antenna (which is 0 dB).

Omnidirectional antenna: "An antenna having an essentially non-directional pattern in a given plane of the antenna and a directional pattern in any orthogonal plane". For base station antennas, the omnidirectional plane is the horizontal plane.

Directional antenna: "An antenna having the property of radiating or receiving electromagnetic waves more effectively in some directions than others".

Half-wave dipole: "A wire antenna consisting of two straight collinear conductors of equal length, separated by a small feeding gap, with each conductor approximately a quarter-wave length long".

Log-periodic antenna: "Any one of a class of antennas having a structural geometry such that its impedance and radiation characteristics repeat periodically as the logarithm of frequency".

Microstrip antenna: "An antenna which consists of a thin metallic conductor bonded to a thin grounded dielectric substrate". An example of such antennas is the microstrip patch.

Linear array: A set of radiating elements (e.g. dipole or patch) arranged along a line. Radiating elements such as dipole and patch have dimensions comparable to a wavelength. A linear array has a higher gain, than a single radiator, and its radiation pattern can be synthesized to meet various antenna performance requirements such as upper side lobe suppression and null fill. It should be noted that the gain of any antenna is proportional to its size.

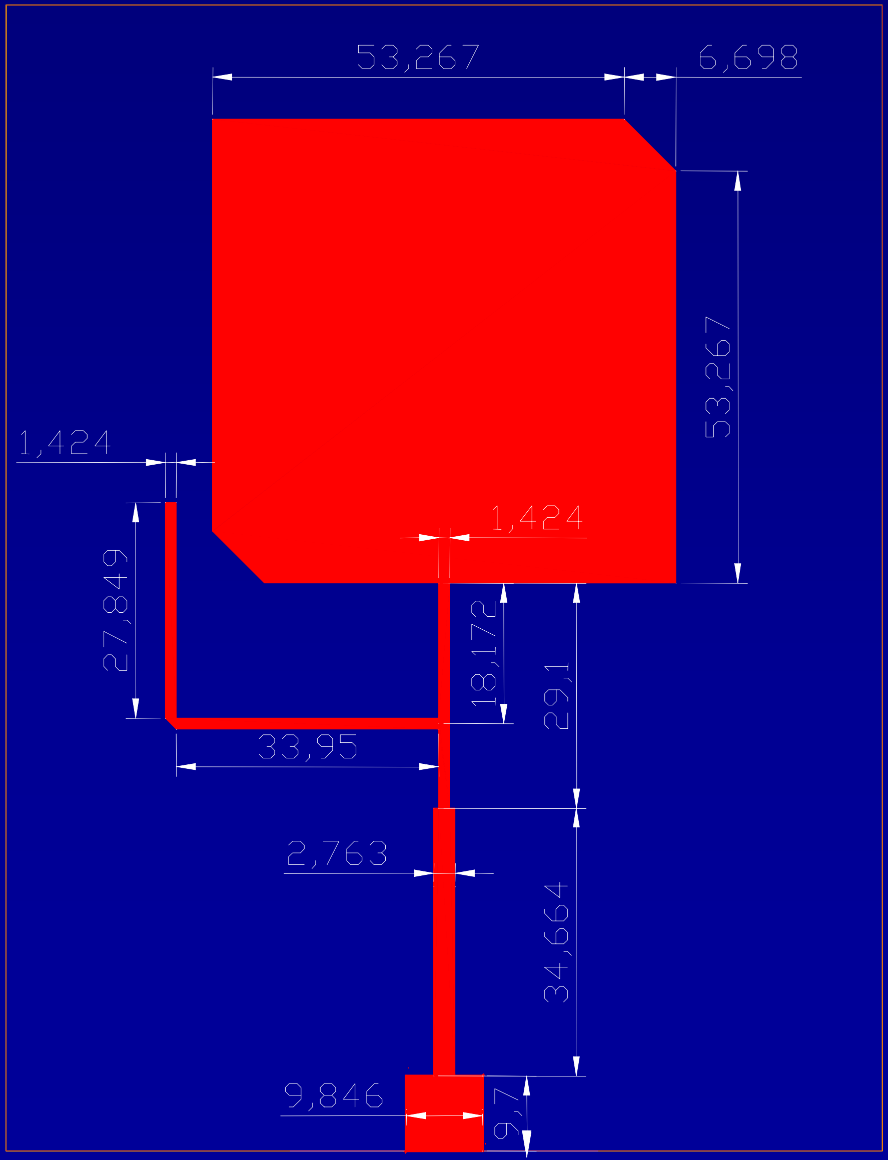
Coaxial antenna: "An antenna comprised of a extension to the inner conductor of a coaxial line and a radiating sleeve which in effect is formed by folding back the outer conductor of the coaxial line".

Collinear array antenna: "A linear array of radiating elements, usually dipoles, with their axes lying in a straight line".

Adaptive (smart) antenna: "An antenna system having circuit elements associated with its radiating elements such that one or more of the antenna properties are controlled by the received signal".

HFSS

Dimensions



ELE 791
Planar Microwave Antenna Project

Group# 4

- Lokman Kuzu
- Erdoğan Alkan

GPS Receiver Antenna

Project Specs

- Operating Frequency : 1.575 GHz
- Input Impedance: 50 Ohm
- VSWR: 2:1 @ 1.575 GHz
- Polarization: RHCP
- Bandwidth: 3.8% (~60 MHz)

Substrate

- RT/Duroid (Rogers Corp.)
- ε= 2.22
- h= 125 mils
- tanδ = 0.001

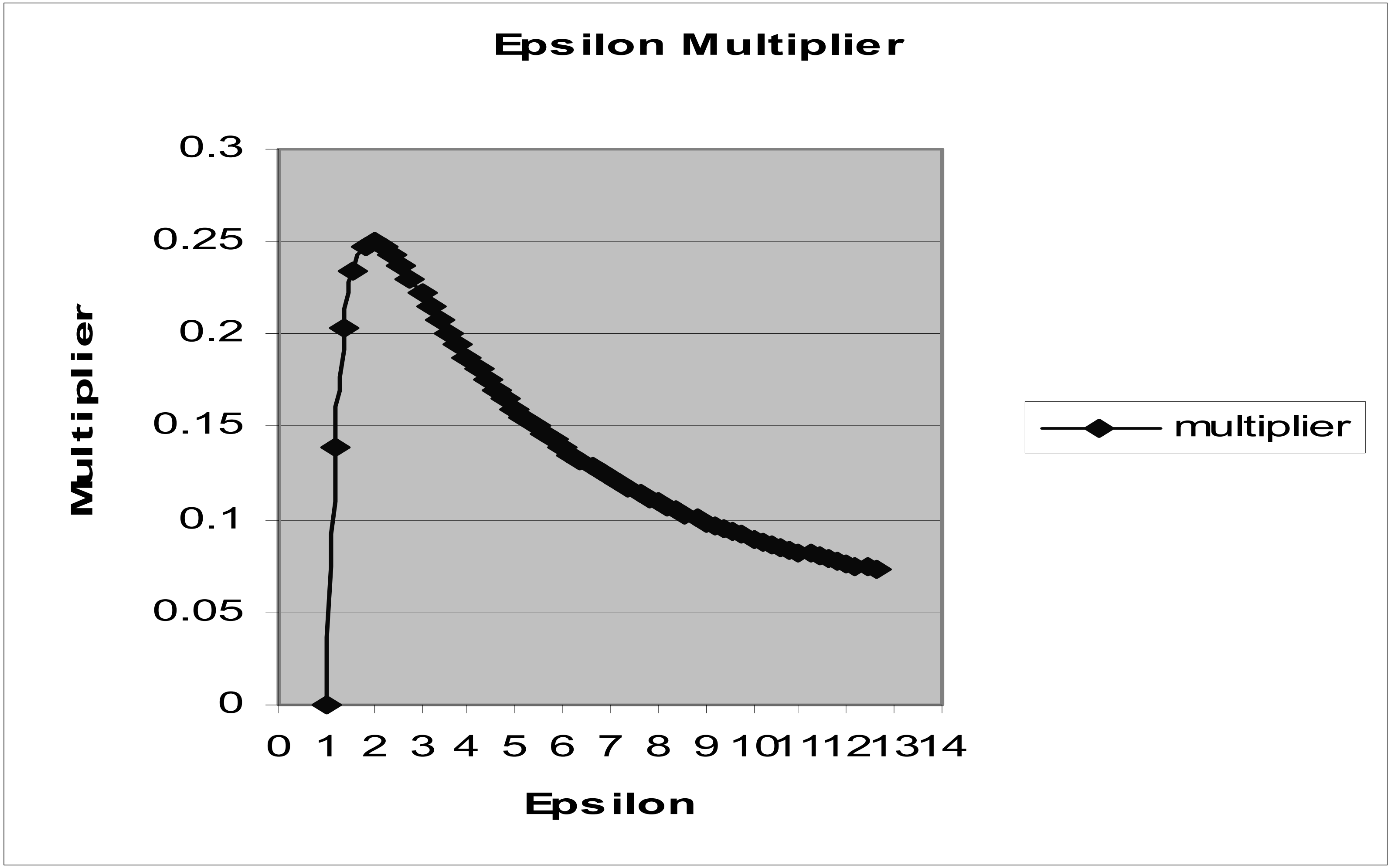
Bandwidth Enhancement

- Decreasing Epsilon (ε).
- Increasing thickness (t).
- Feeding technique
  - Edge Feeding
  - Probe Feeding
  - Aperture Coupling to a microstrip feed line

$$BW = 3.77 \times \frac{\varepsilon - 1}{\varepsilon^2} \times \frac{W}{L} \times \frac{t}{\lambda} \qquad t << \lambda$$

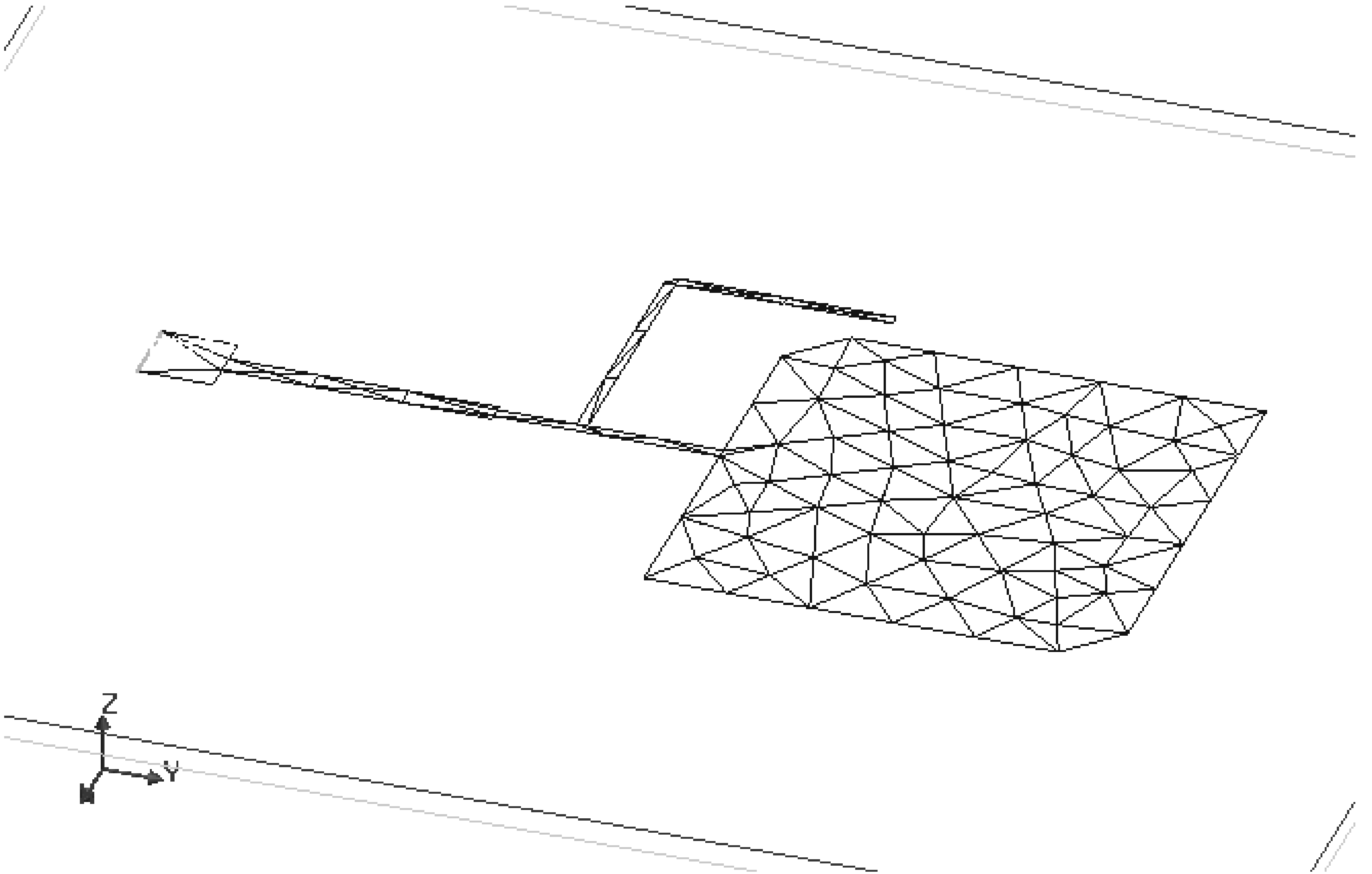
Bandwidth Enhancement

- Optimum Epsilon (ε) value =2.



Ensemble Simulation Results

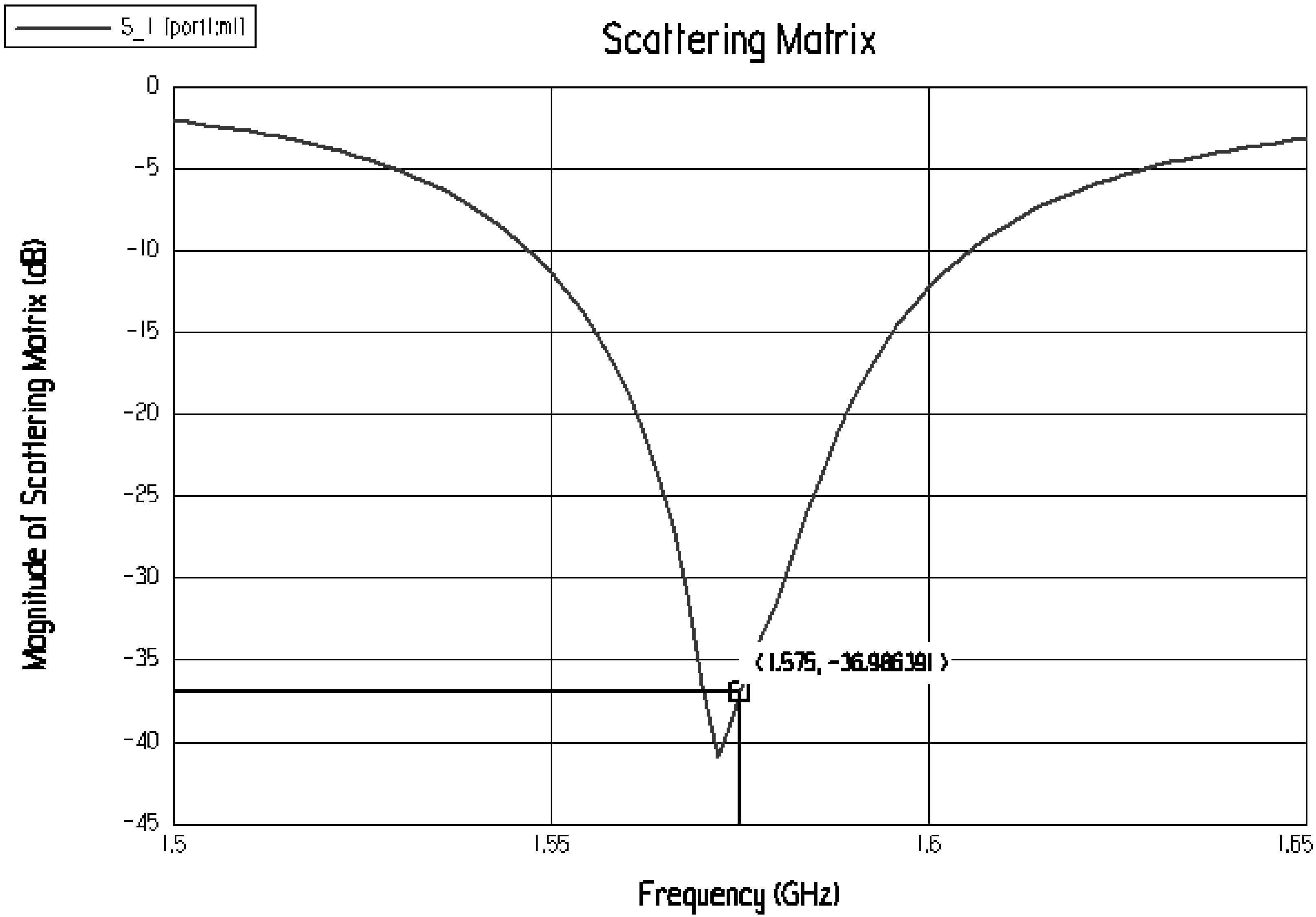
2D View



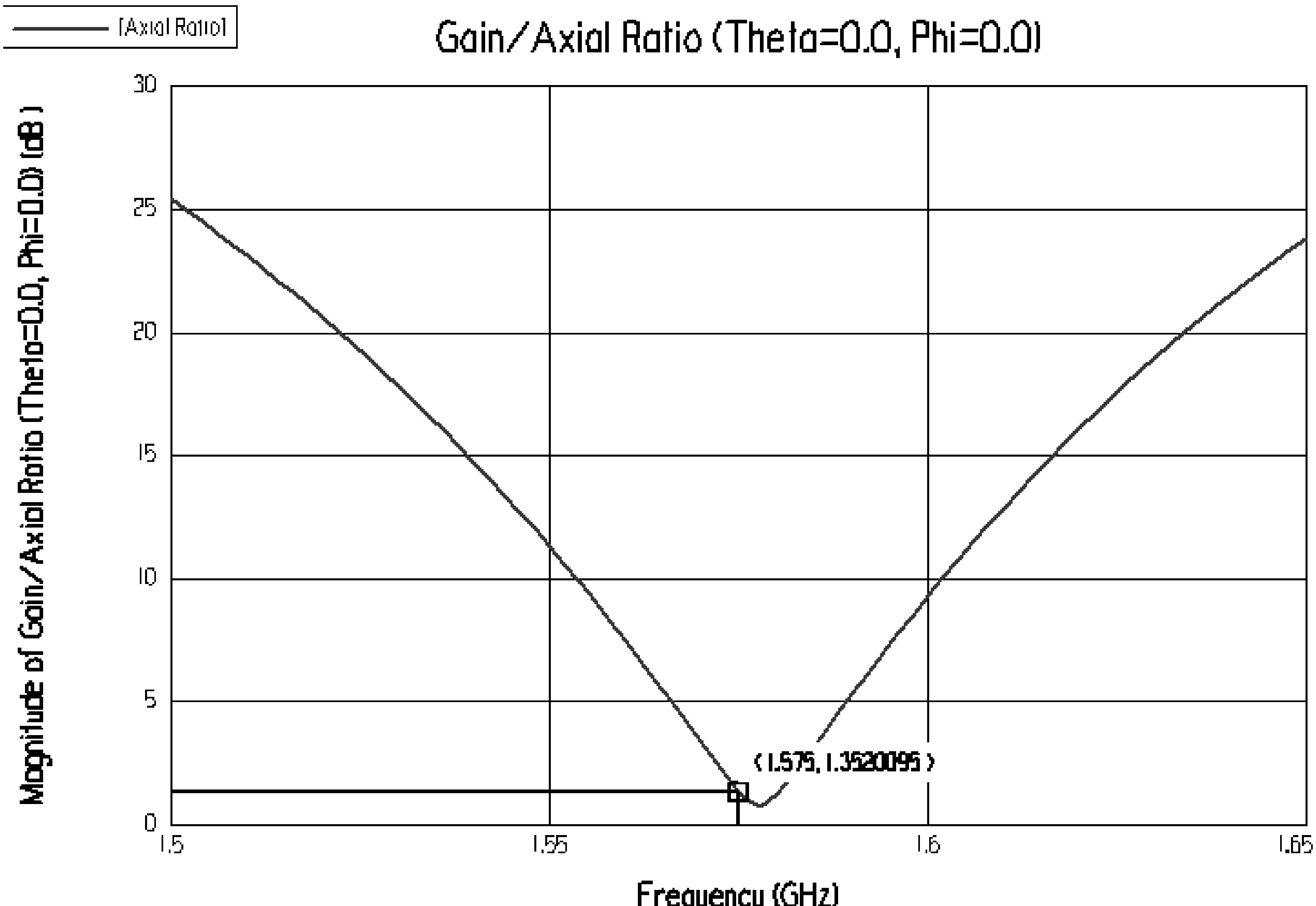
Ensemble

HFSS ADS Measured

S11 in dB

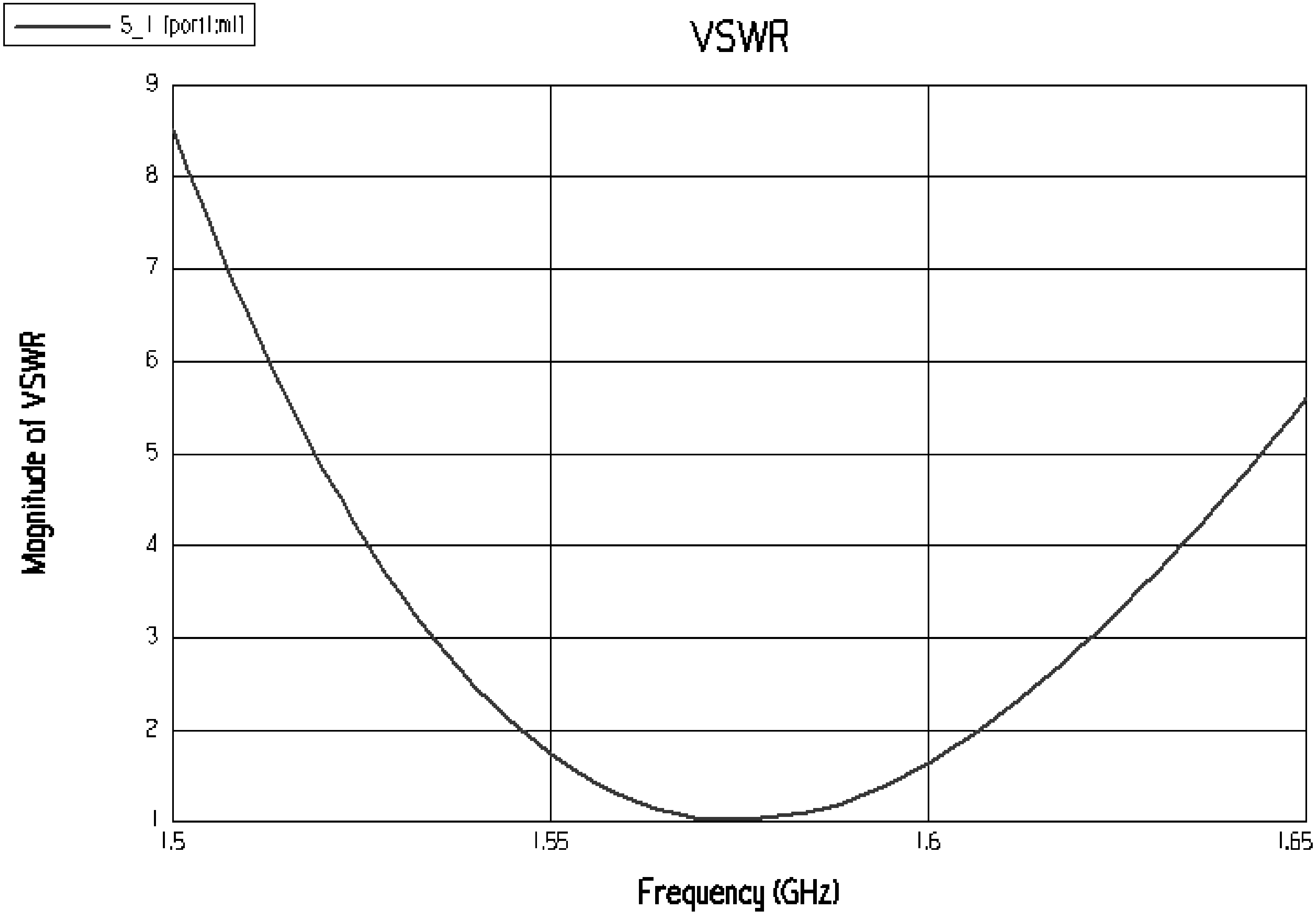


Axial Ratio


[Axial Ratio]
Gain/Axial Ratio (Theta=0.0, Phi=0.0)
Magnitude of Gain/Axial Ratio (Theta=0.0, Phi=0.0) (dB)
30
25
20
15
10
5
0
1.5
1.55
1.6
1.65
Frequency (GHz)
(1.575, 1.3520095)

Ensemble

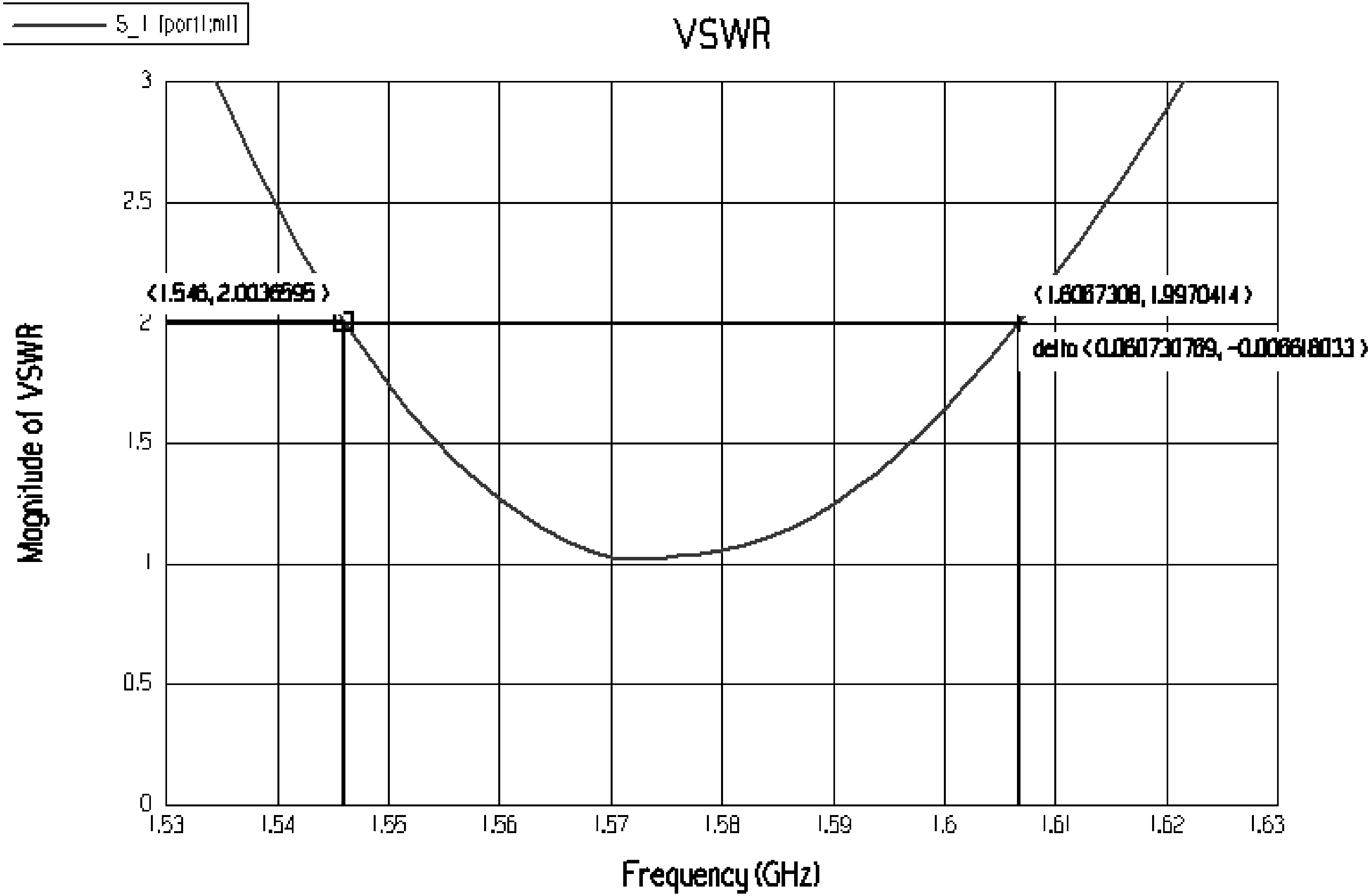
VSWR



Ensemble

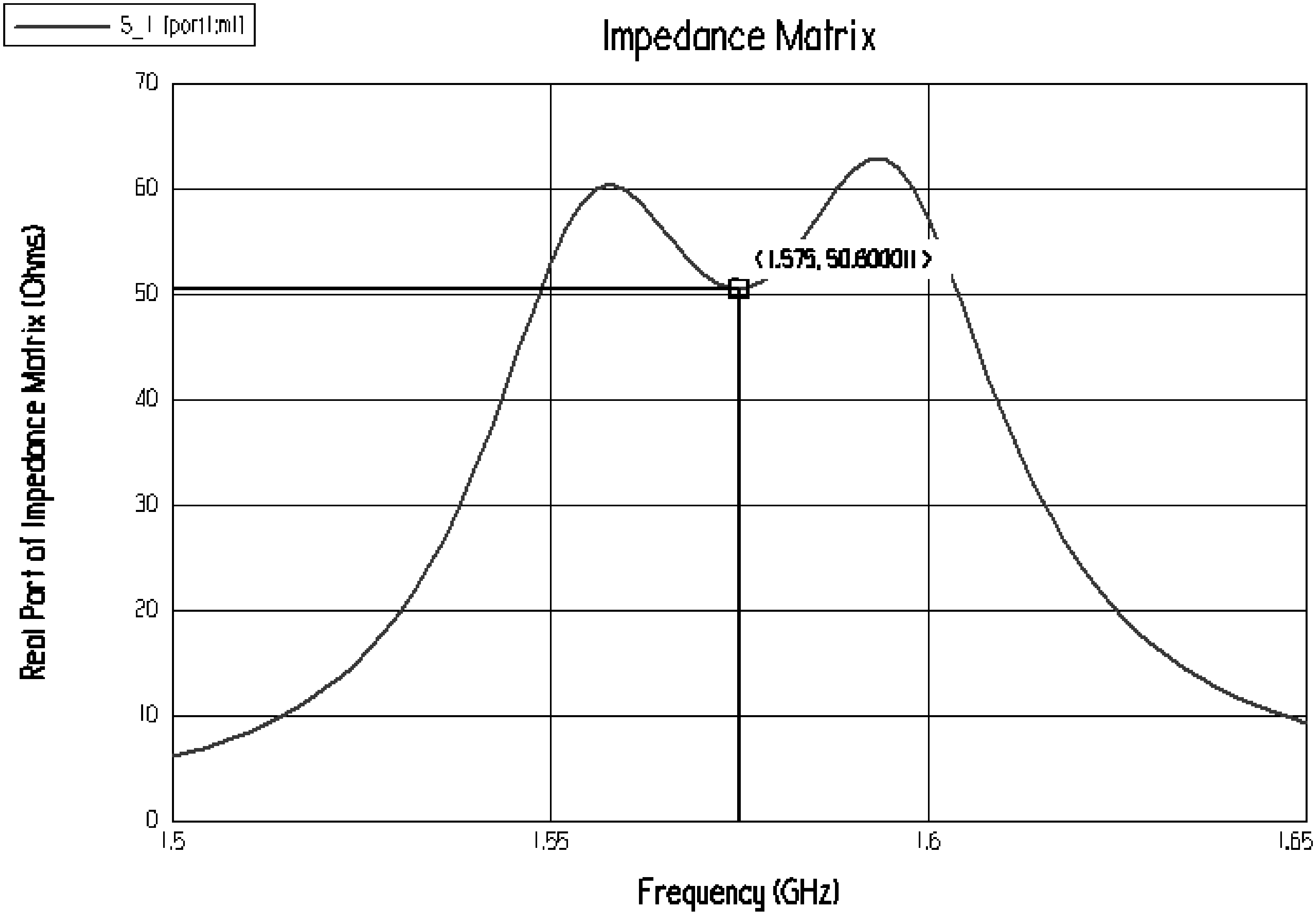
HFSS ADS Measured

VSWR : Close Up

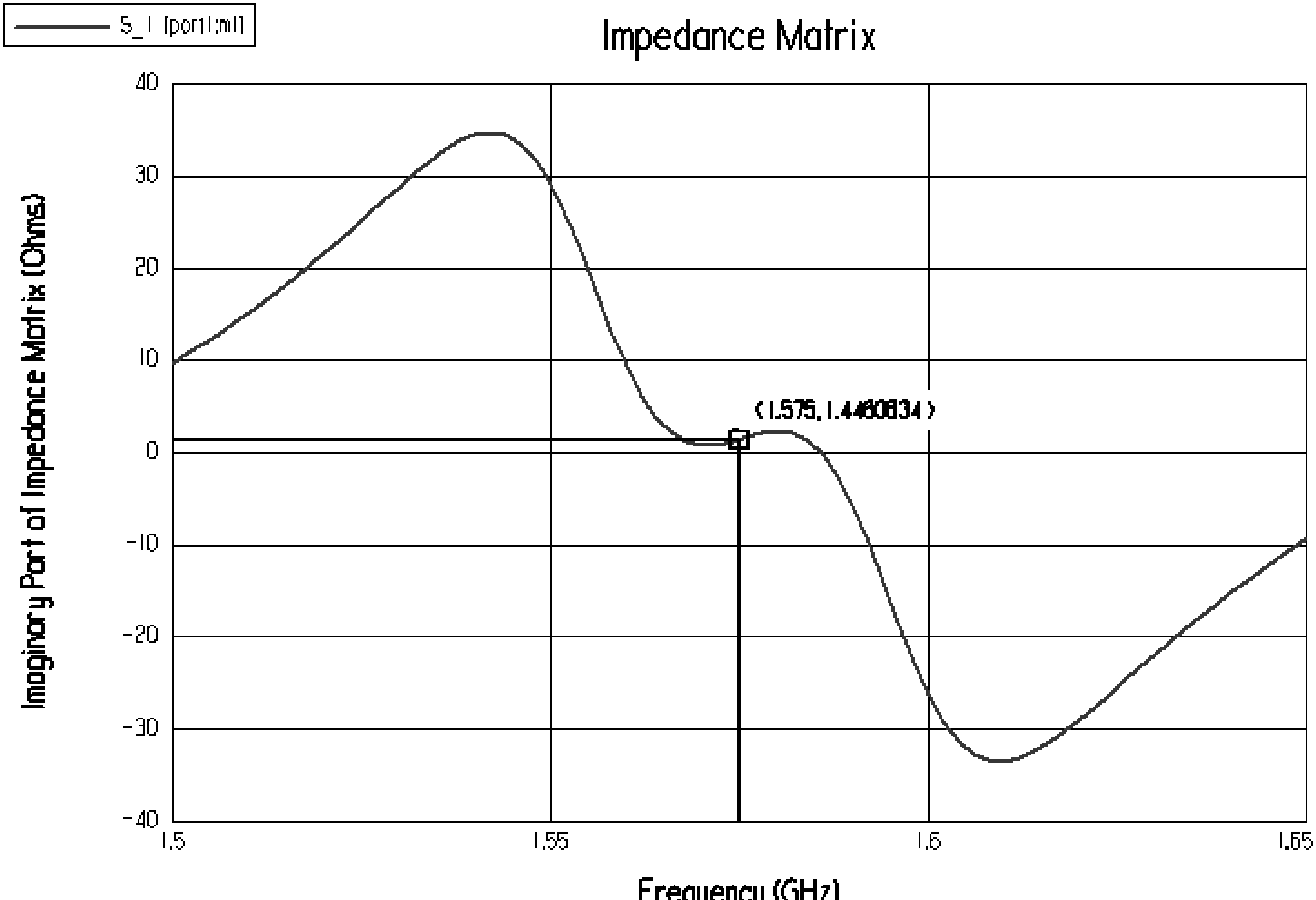


Ensemble

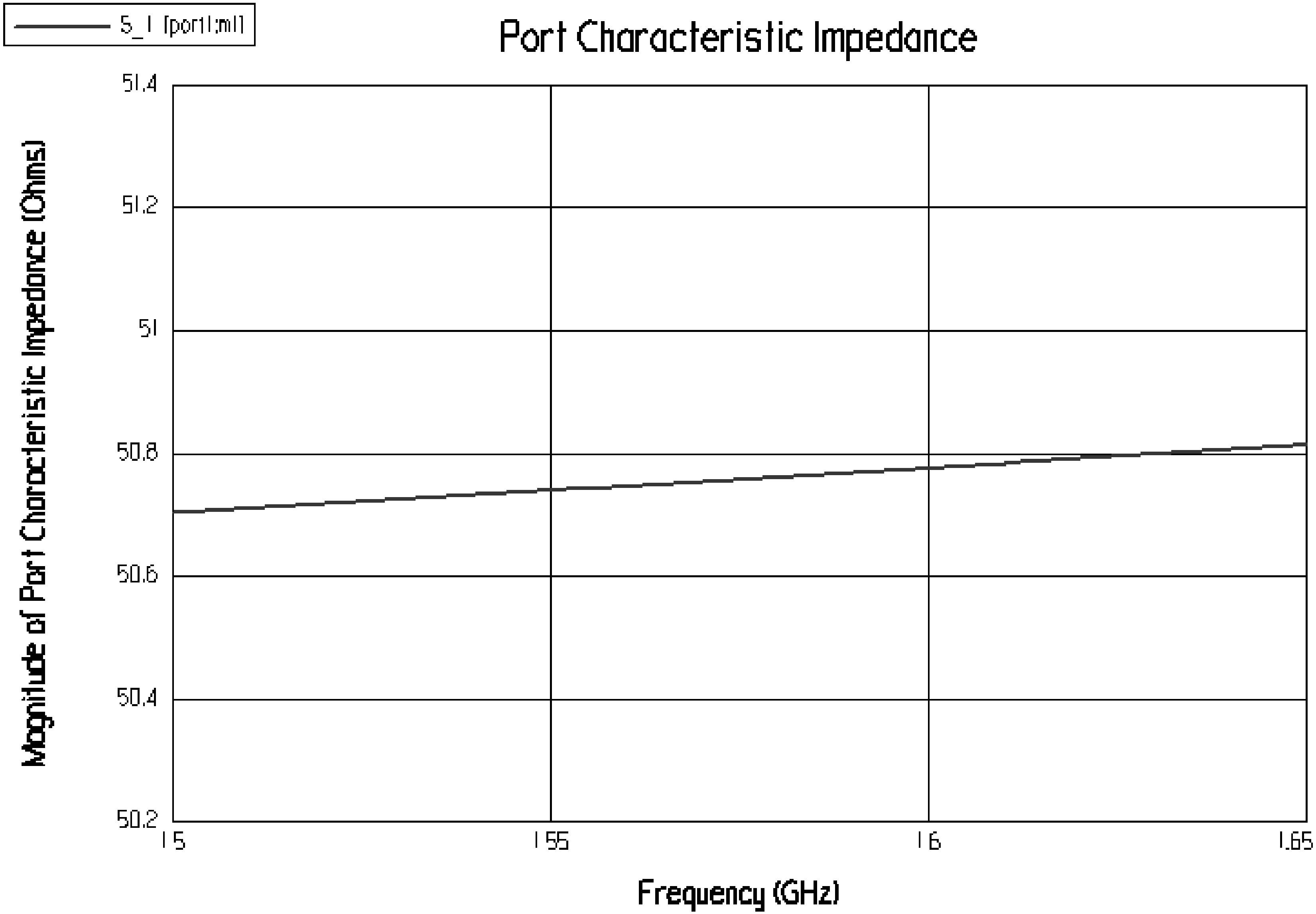
Re(Z)



Im(Z)


5_1 [port1;m1]
Impedance Matrix
40
30
20
10
0
-10
-20
-30
-40
(1.575, 1.4480834)
1.5
1.55
1.6
1.65
Imaginary Part of Impedance Matrix (Ohms)
Frequency (GHz)

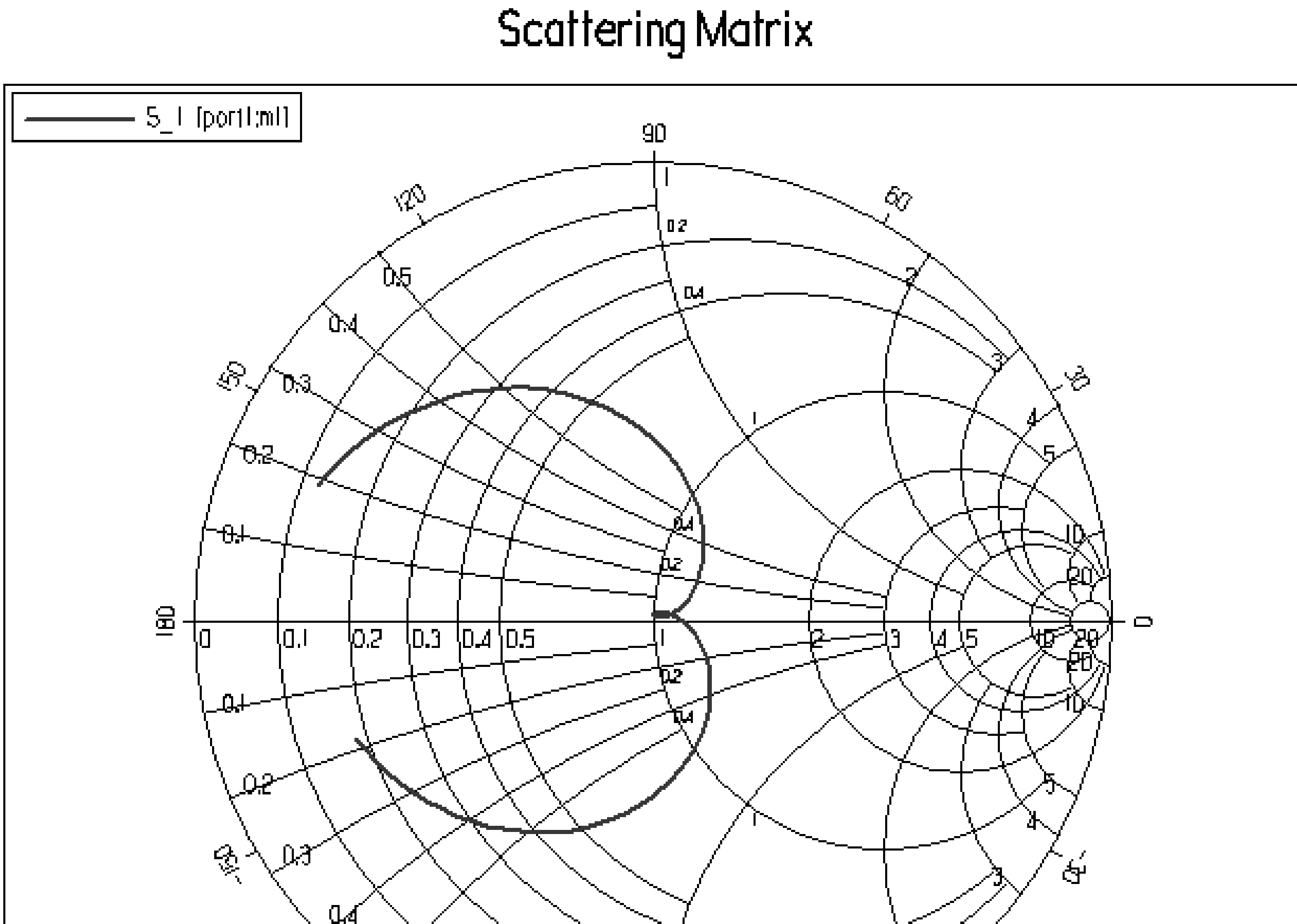
Port Z_o


S_1 [port1:m1]
Port Characteristic Impedance
Magnitude of Port Characteristic Impedance (Ohms)
51.4
51.2
51
50.8
50.6
50.4
50.2
1.5
1.55
1.6
1.65
Frequency (GHz)

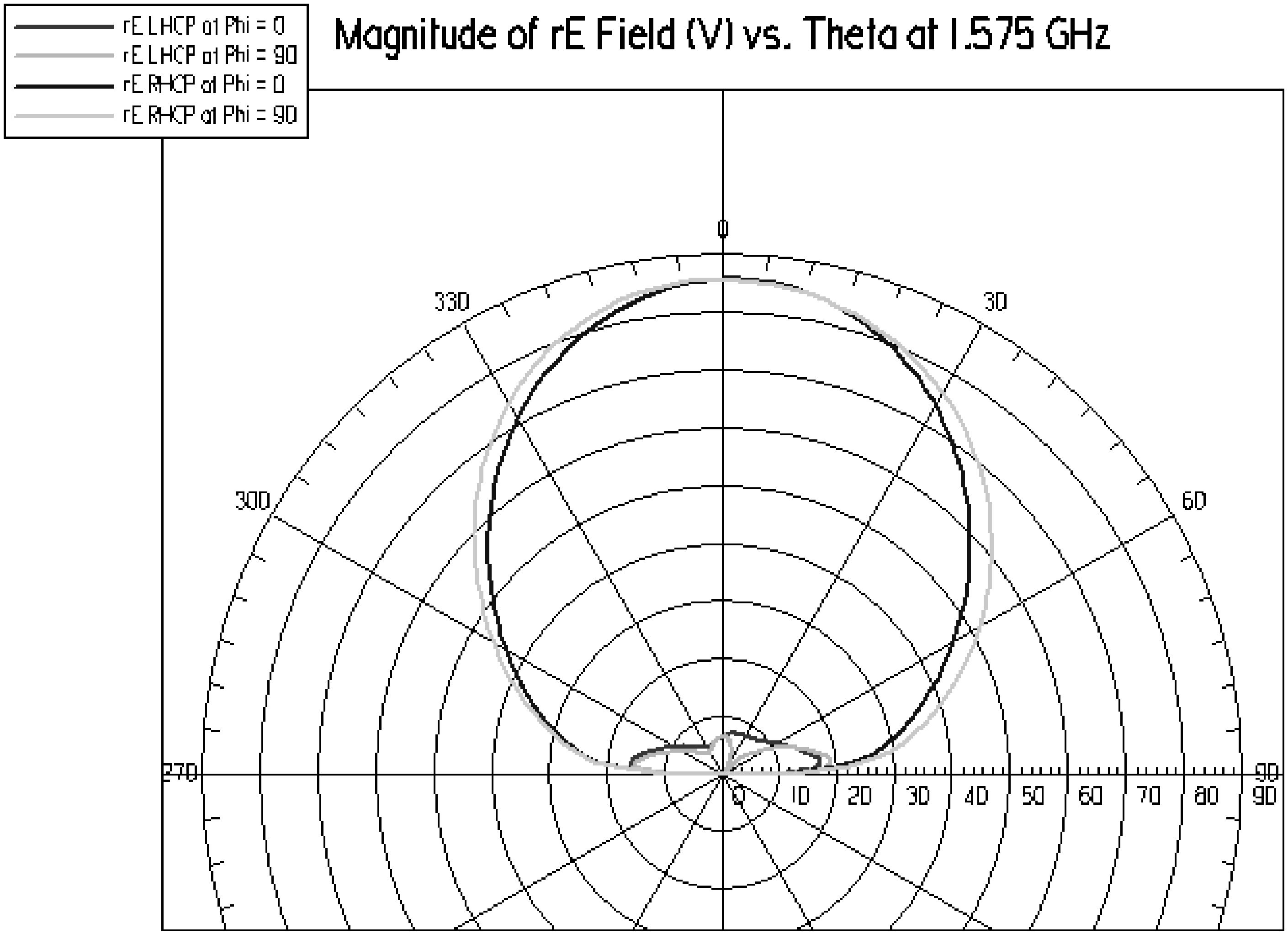
Ensemble

HFSS ADS Measured

S11 on Smith Chart



Far Field

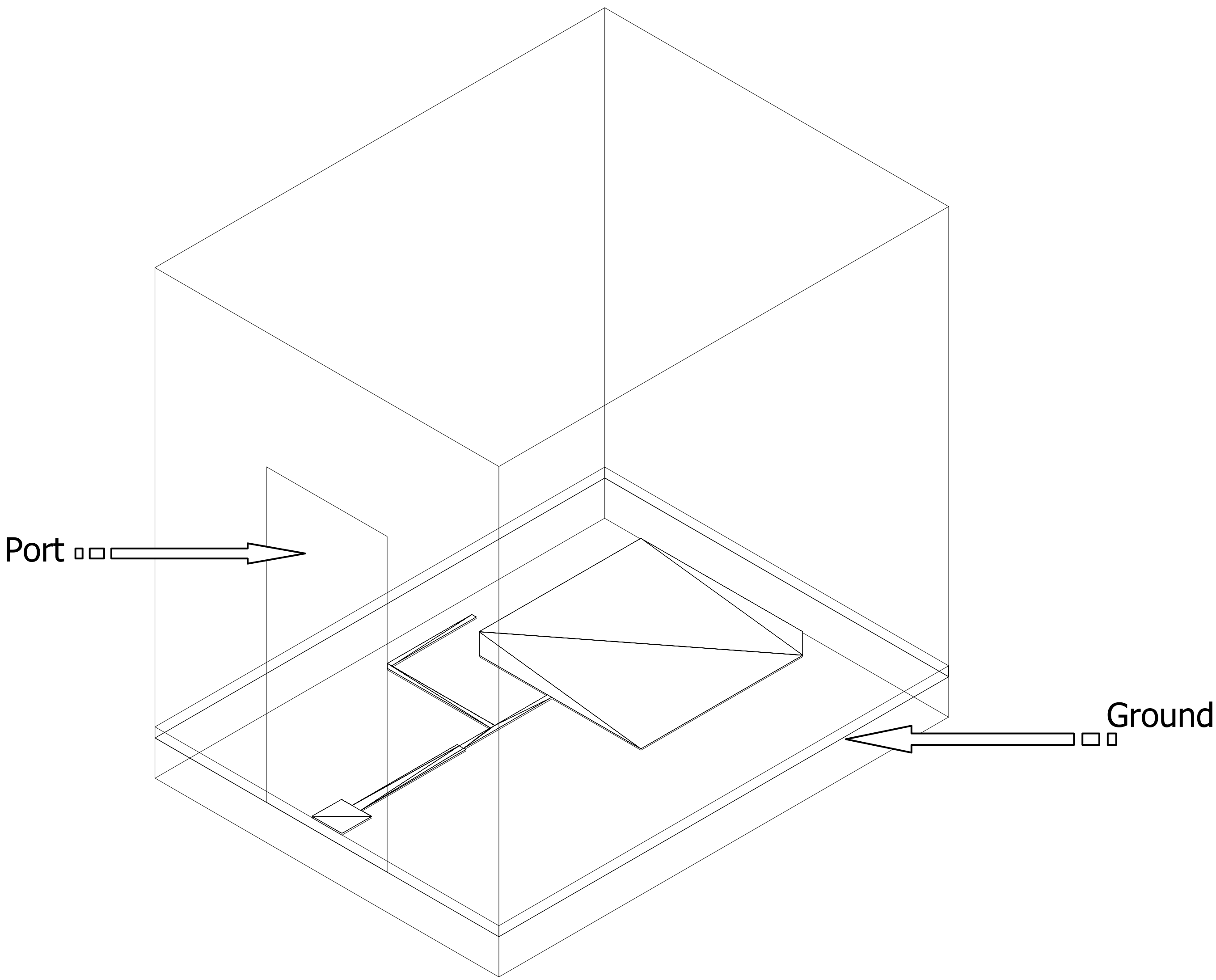

rE LHCP at Phi = 0
rE LHCP at Phi = 90
rE RHCP at Phi = 0
rE RHCP at Phi = 90
Magnitude of rE Field (V) vs. Theta at 1.575 GHz
0
30
60
90
330
300
270
0
10
20
30
40
50
60
70
80
90

Effect of Tuning Stub Length

Stub Length	S11	ReZ	ImZ	Axial Ratio	VSWR BW
mm	dB	Ohm	Ohm	dB	MHz
28.71	-24	57.36	-0.055	1.19	56
26.94	-38	51.37	1.32	1.33	60
26.72	-36.9	50.57	1.44	1.35	60.5
25.44	-24	45.37	1.83	1.51	62

HFSS Simulation Results

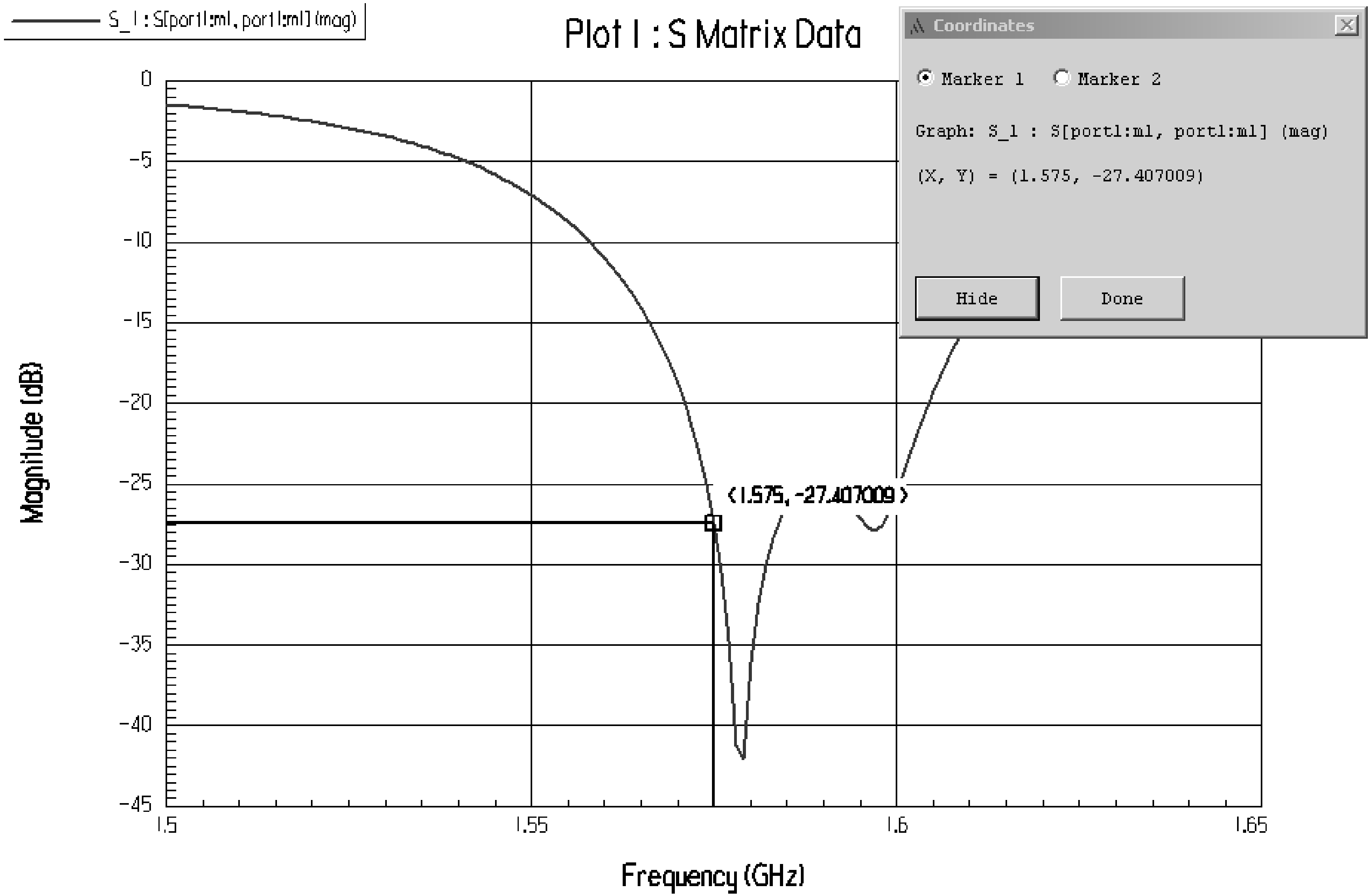
3D View



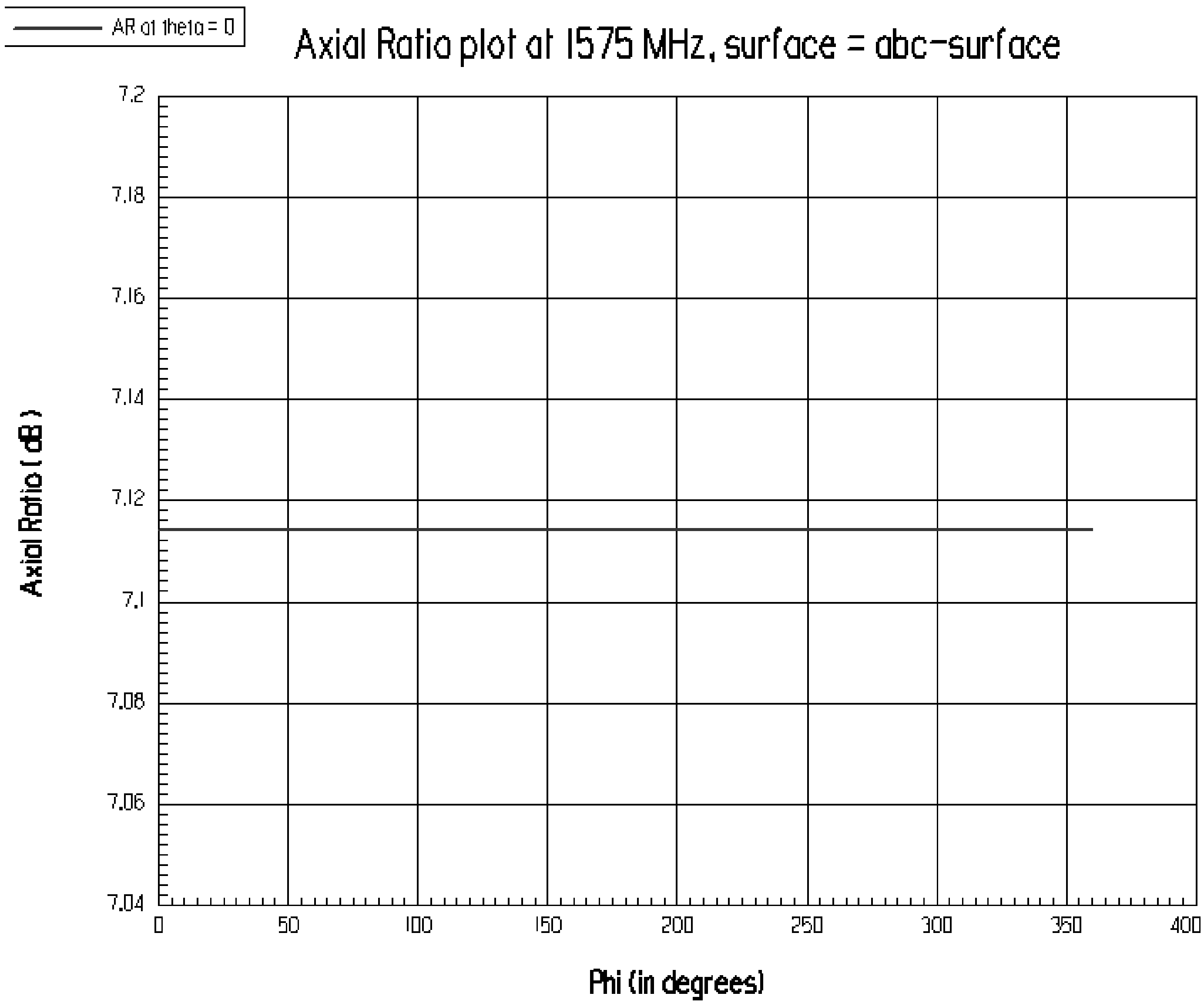
HFSS

Ensemble ADS Measured

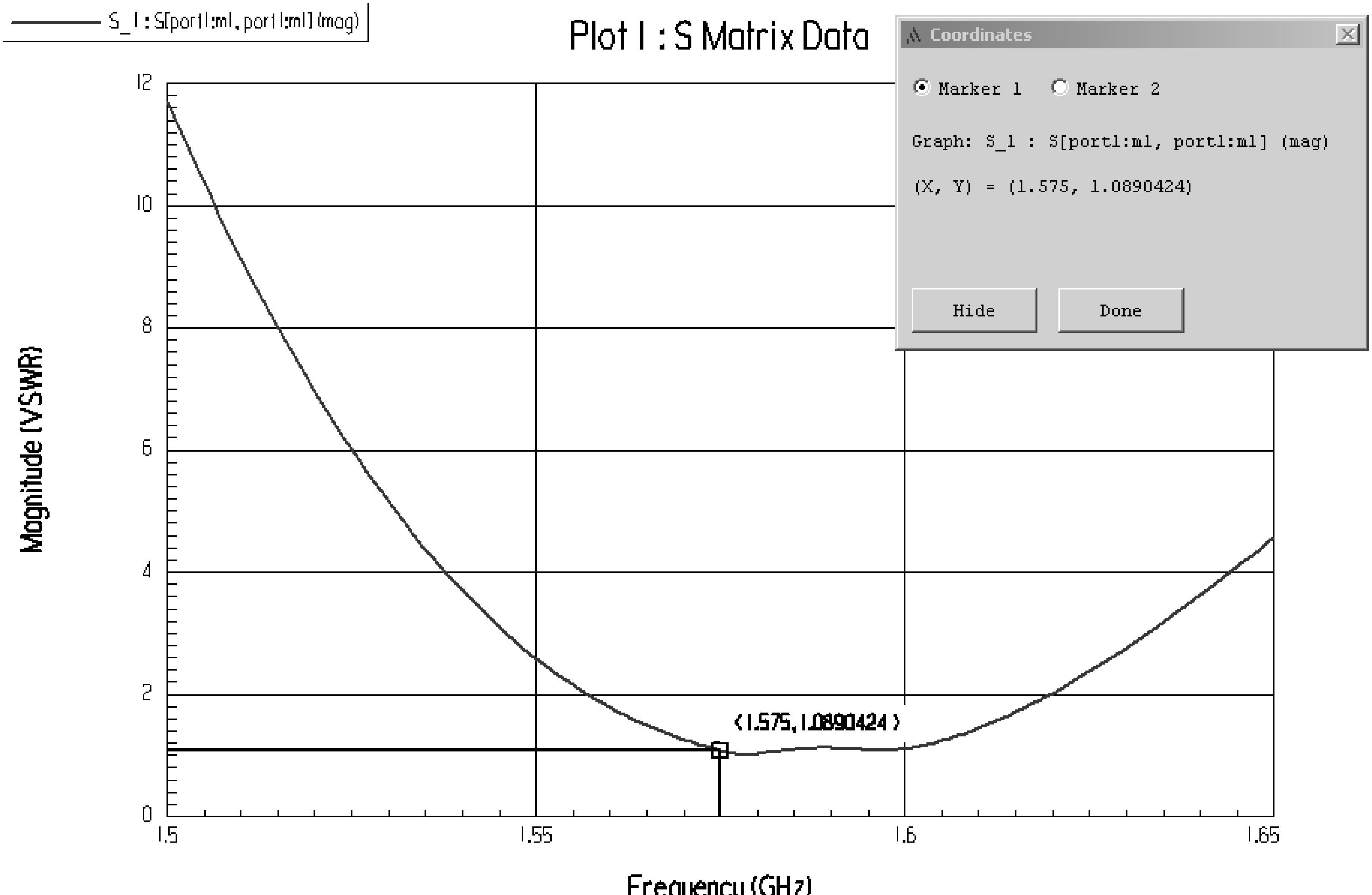
S11 in dB



Axial Ratio in dB



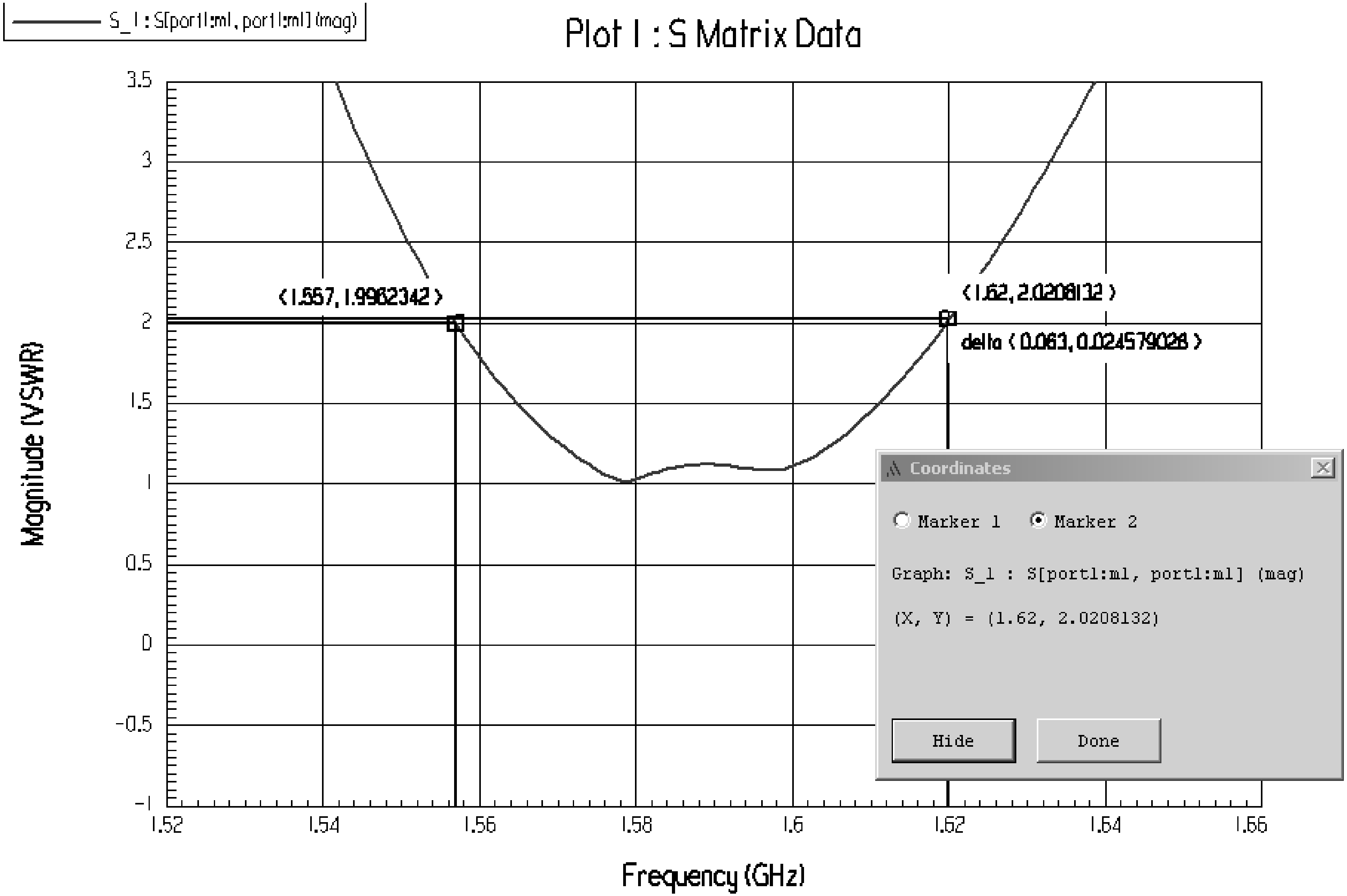
VSWR


S_1 : S[port1:m1, port1:m1] (mag)
Plot 1 : S Matrix Data
Coordinates
Marker 1
Marker 2
Graph: S_1 : S[port1:m1, port1:m1] (mag)
(X, Y) = (1.575, 1.0890424)
Hide
Done
12
10
8
6
4
2
0
1.5
1.55
1.6
1.65
Magnitude (VSWR)
Frequency (GHz)
(1.575, 1.0890424)

HFSS

Ensemble ADS Measured

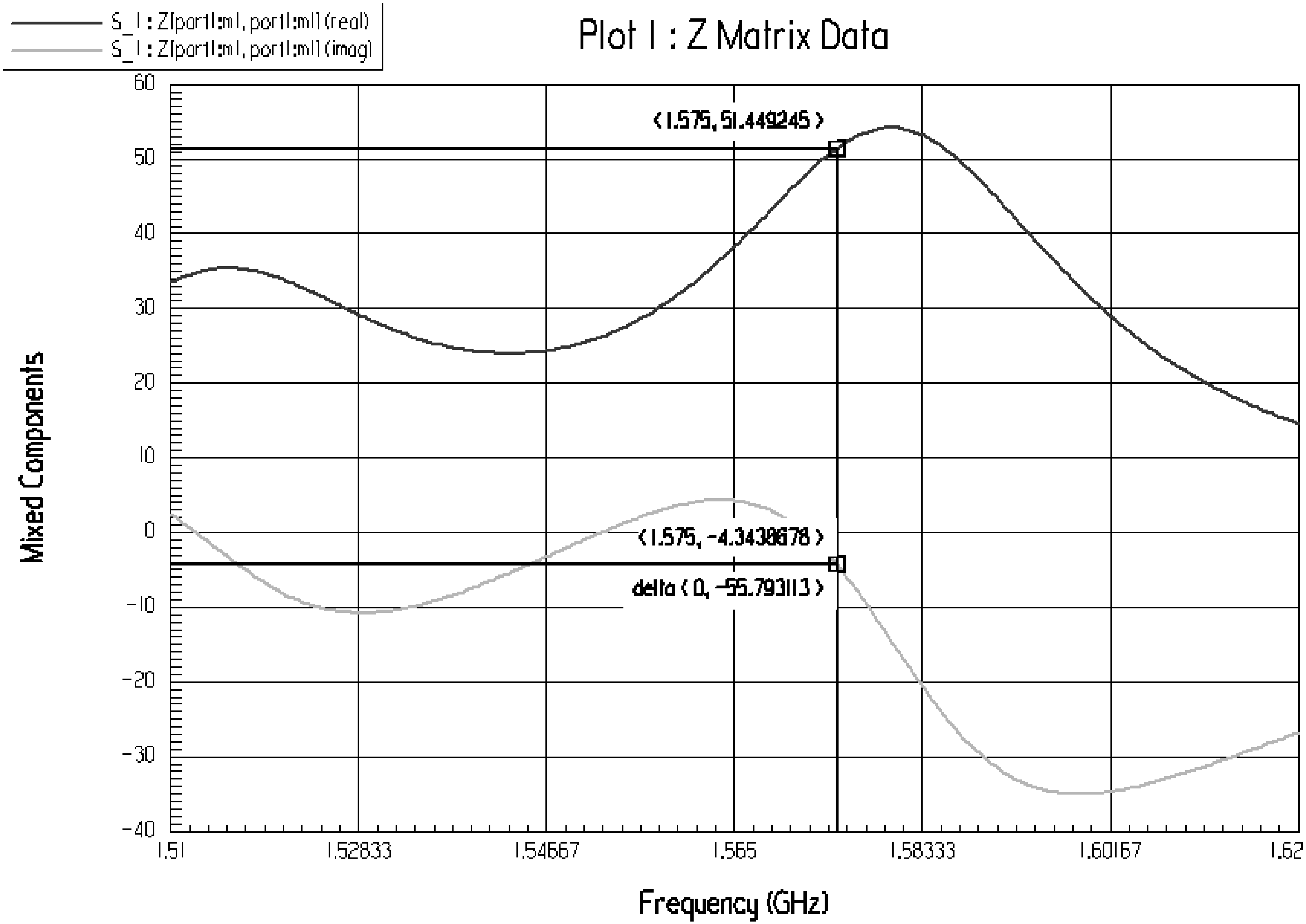
VSWR: close up



HFSS

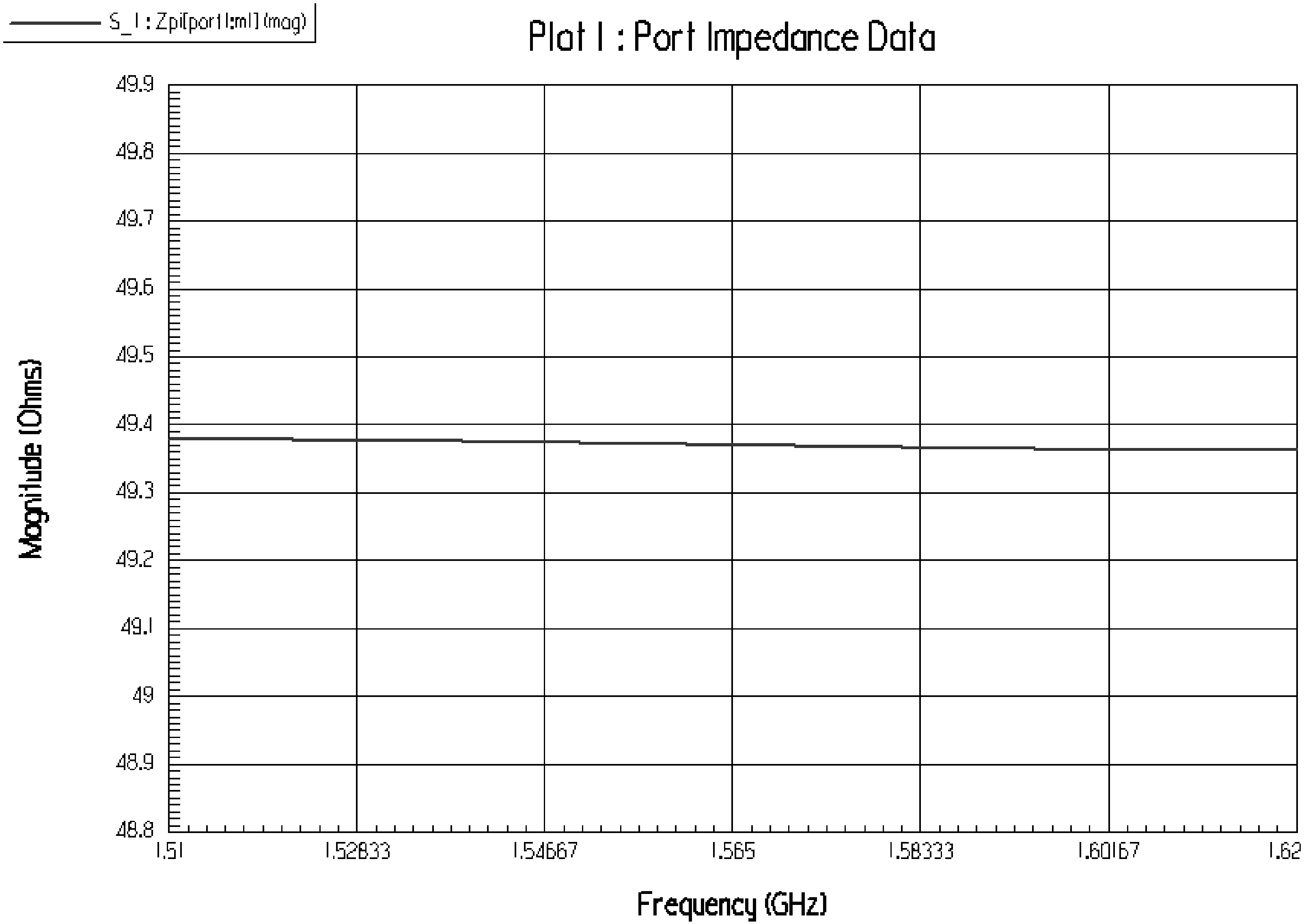
Ensemble ADS Measured

Re(Z) and Im(Z)



HFSS

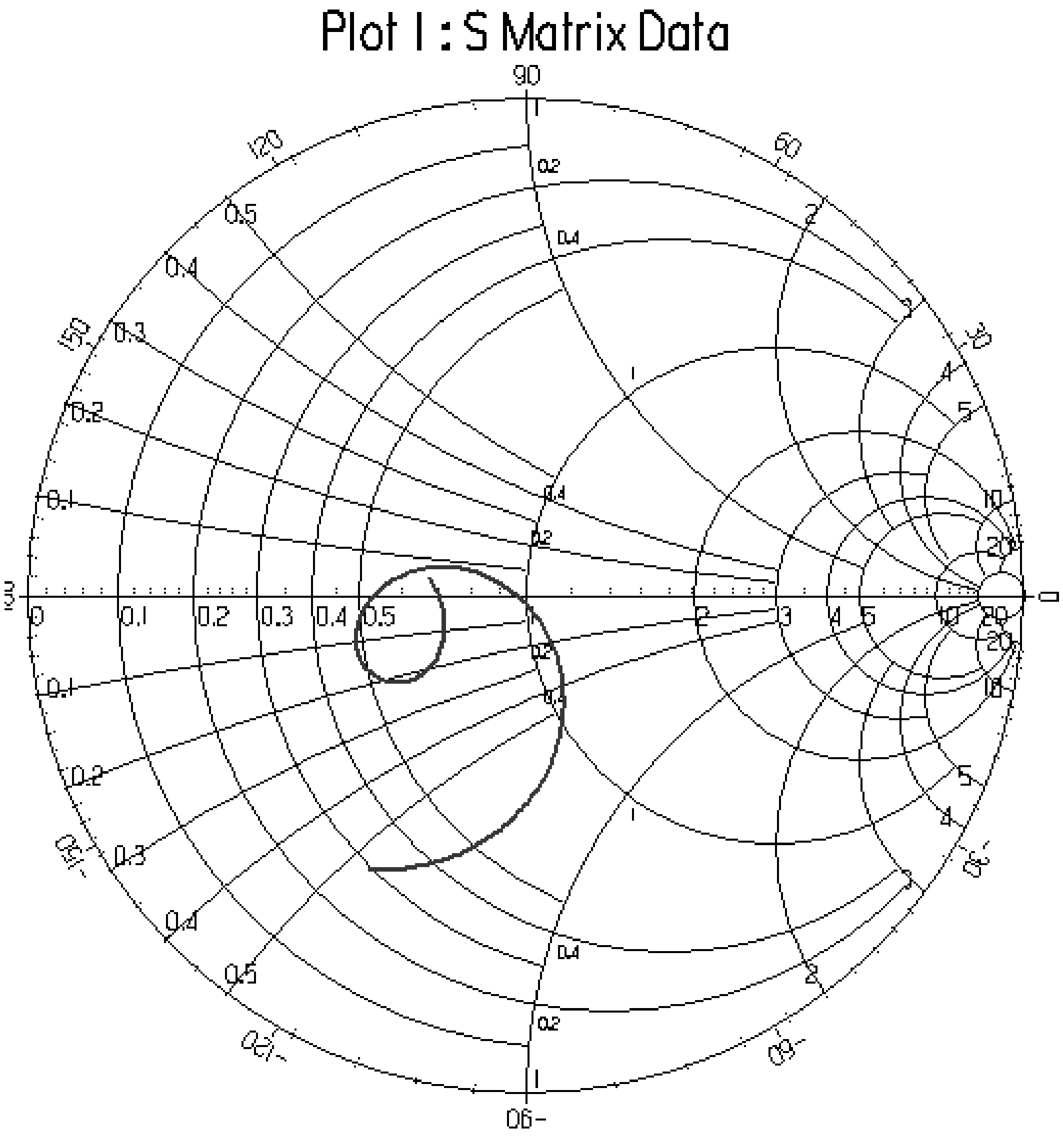
Port Z_o


S_1 : Zpi[port1:m1] (mag)
Plot 1 : Port Impedance Data
49.9
49.8
49.7
49.6
49.5
49.4
49.3
49.2
49.1
49
48.9
48.8
Magnitude (Ohms)
1.51
1.52833
1.54667
1.565
1.58333
1.60167
1.62
Frequency (GHz)

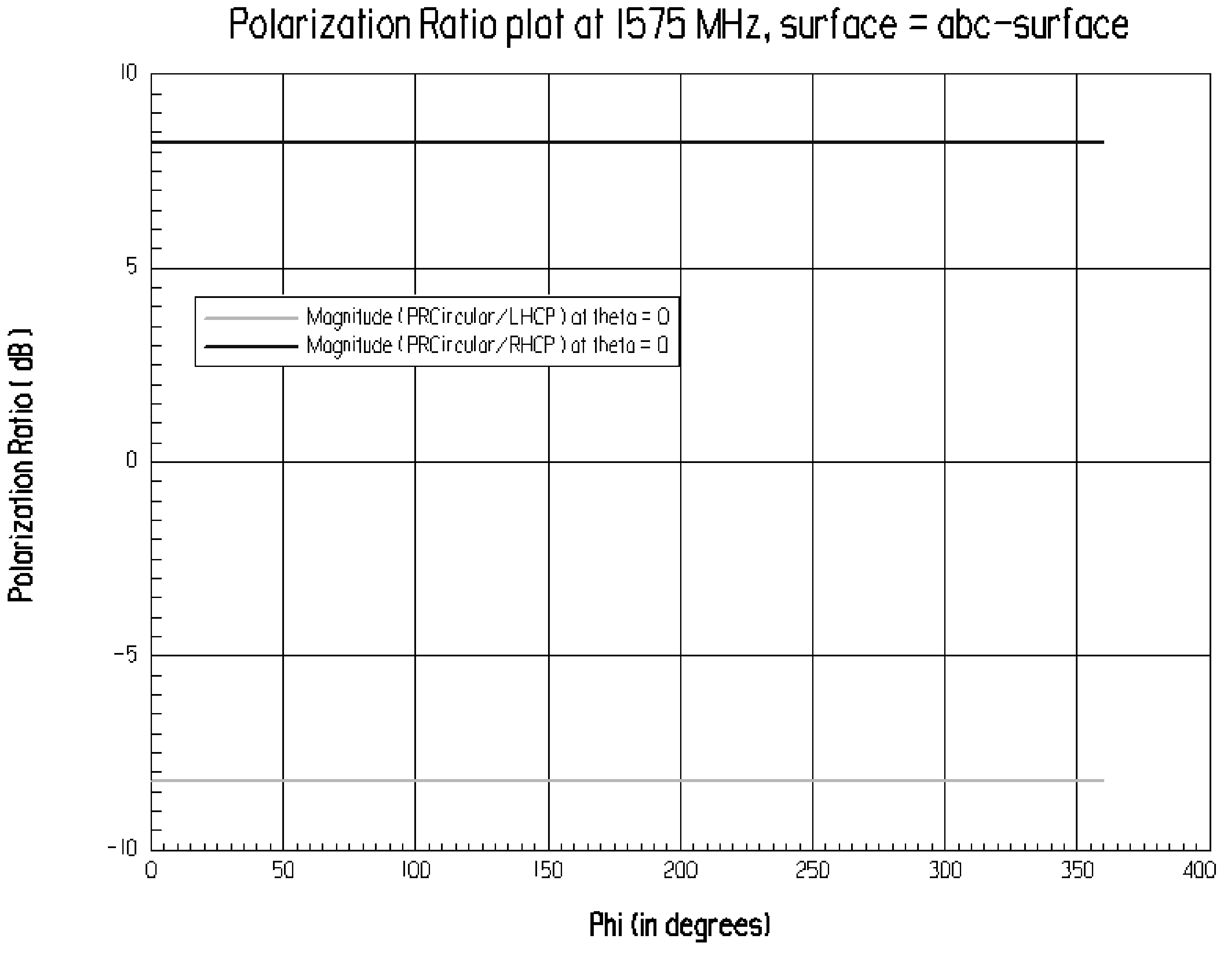
HFSS

Ensemble ADS Measured

Smith Chart

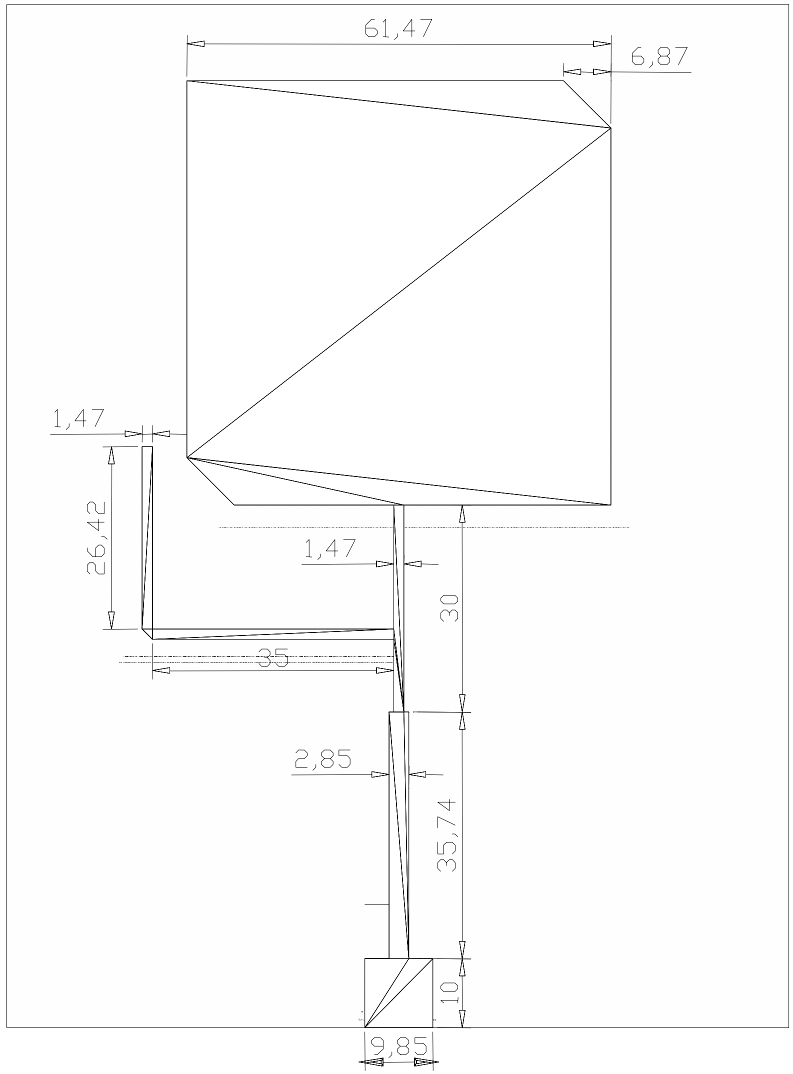


Polarization Ratio



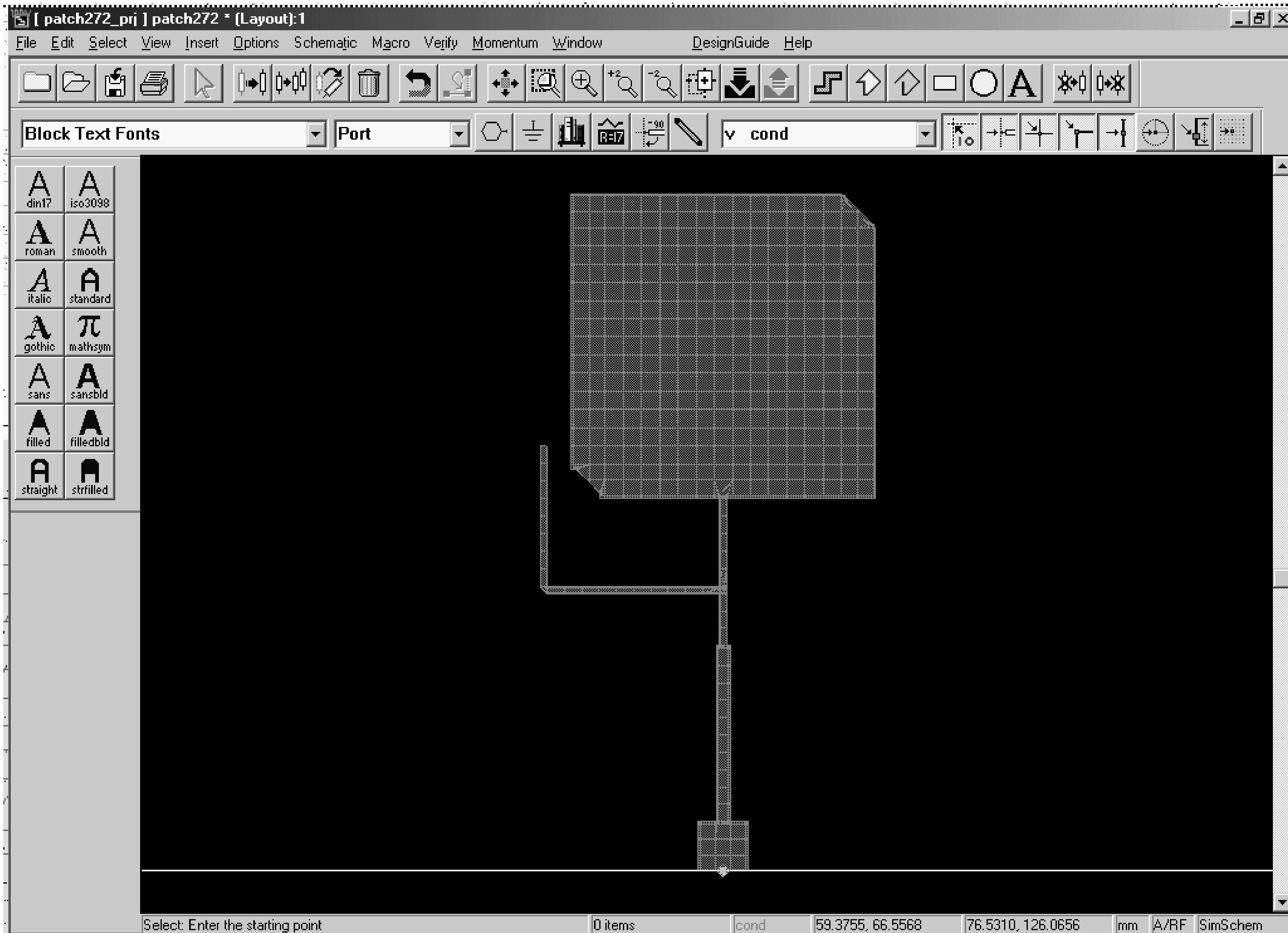
HFSS

Dimensions (mm)



Agilent ADS Simulation Results

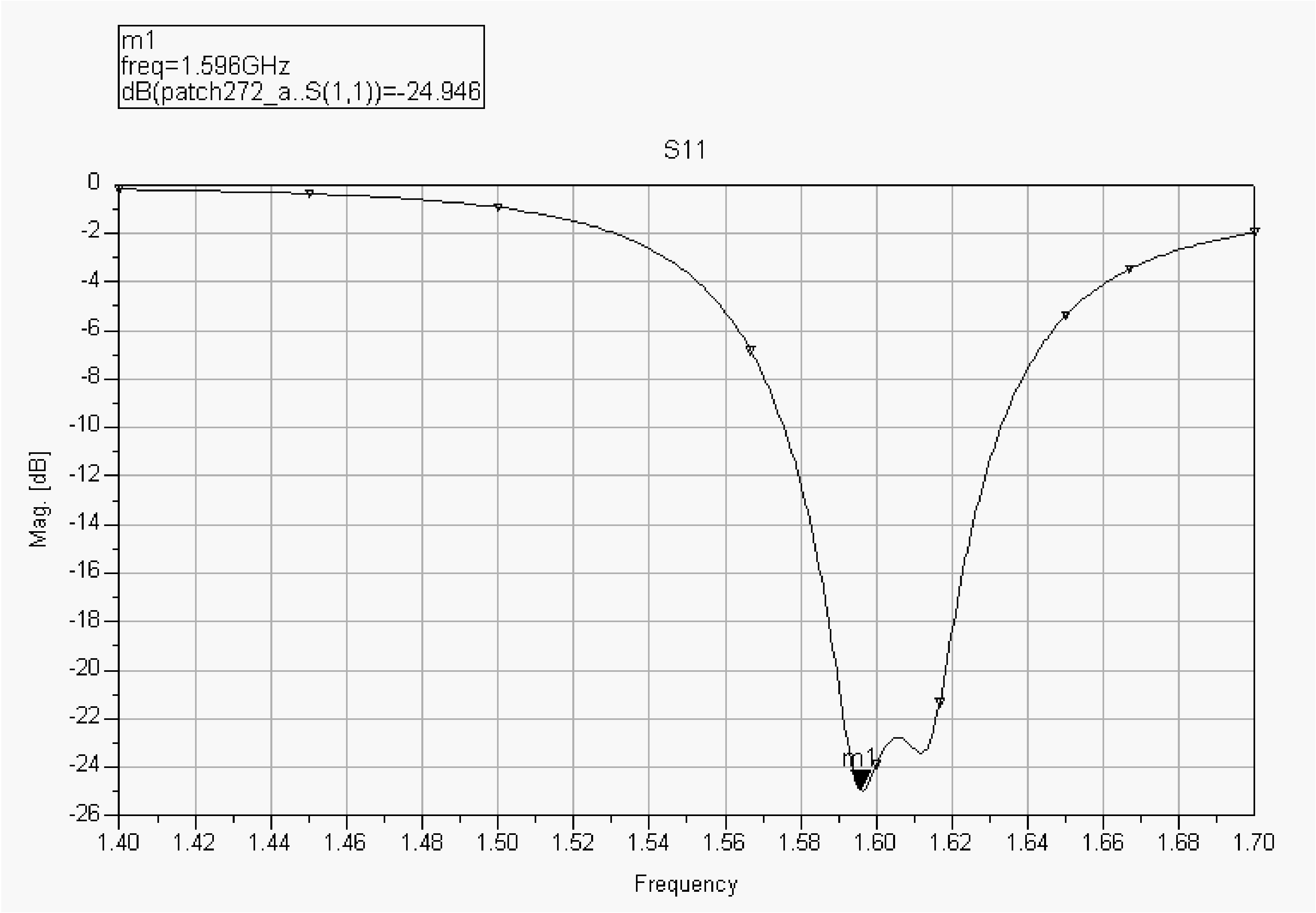
ADS View


[patch272_prj] patch272 * (Layout):1
File Edit Select View Insert Options Schematic Macro Verify Momentum Window DesignGuide Help
Block Text Fonts
Port
cond
din17
iso3098
roman
smooth
italic
standard
gothic
mathsym
sans
sansbld
filled
filledbld
straight
strfilled
Select: Enter the starting point
0 items
cond
59.3755, 66.5568
76.5310, 126.0656
mm
A/RF
SimSchem

Agilent ADS

HFSS Ensemble Measured

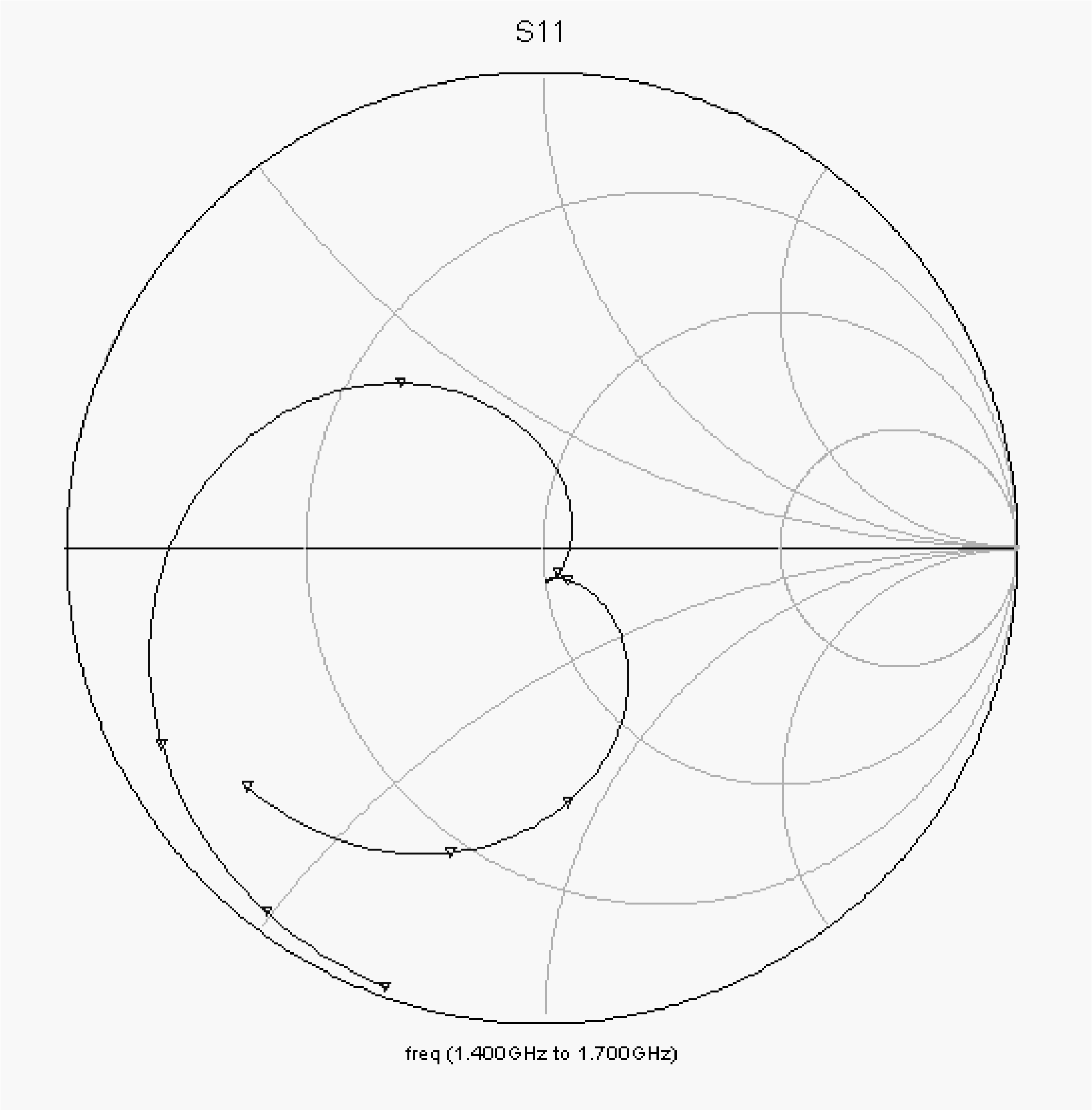
S11 in dB



Agilent ADS

Ensemble HFSS Measured

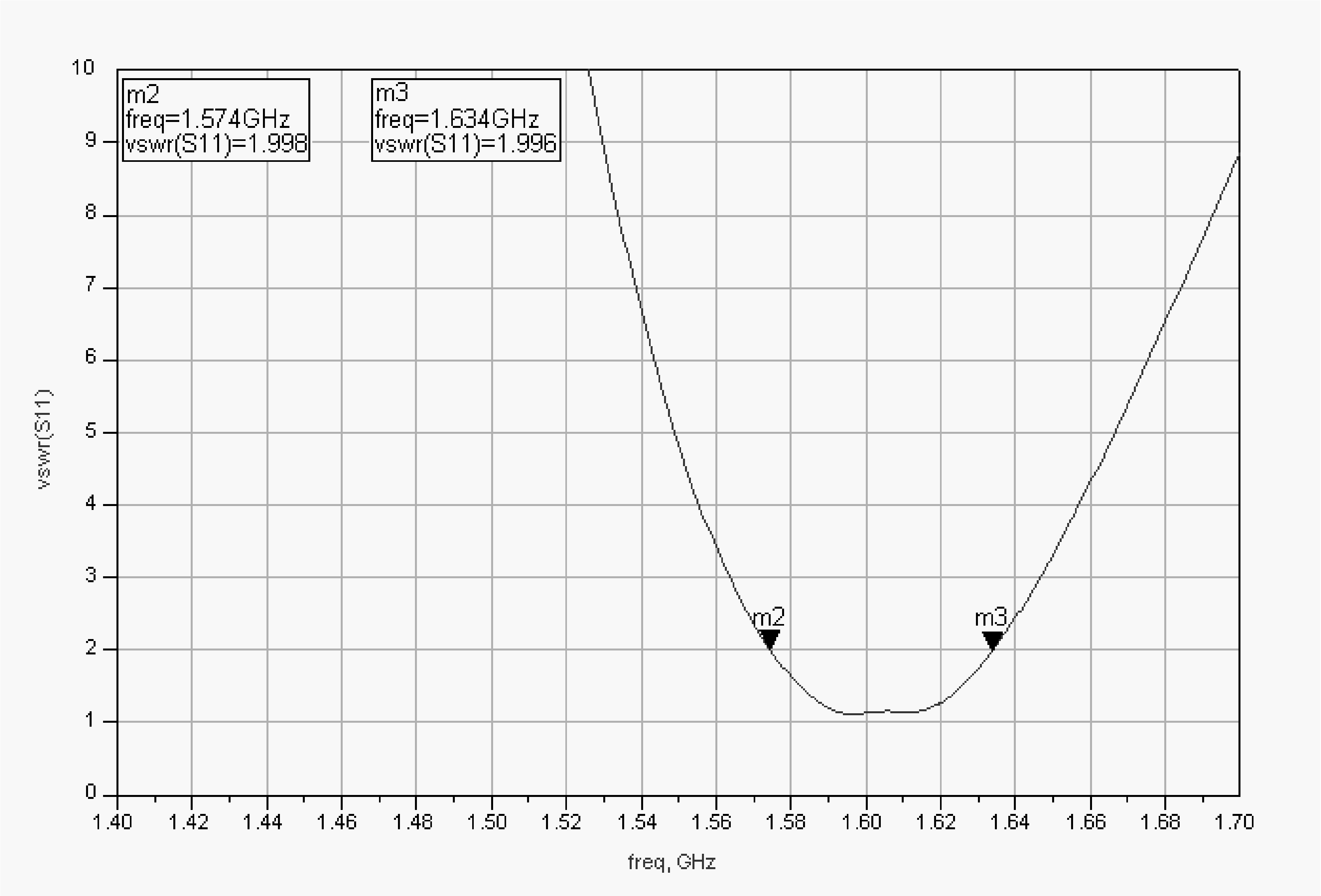
Smith Chart



Agilent ADS

Ensemble HFSS Measured

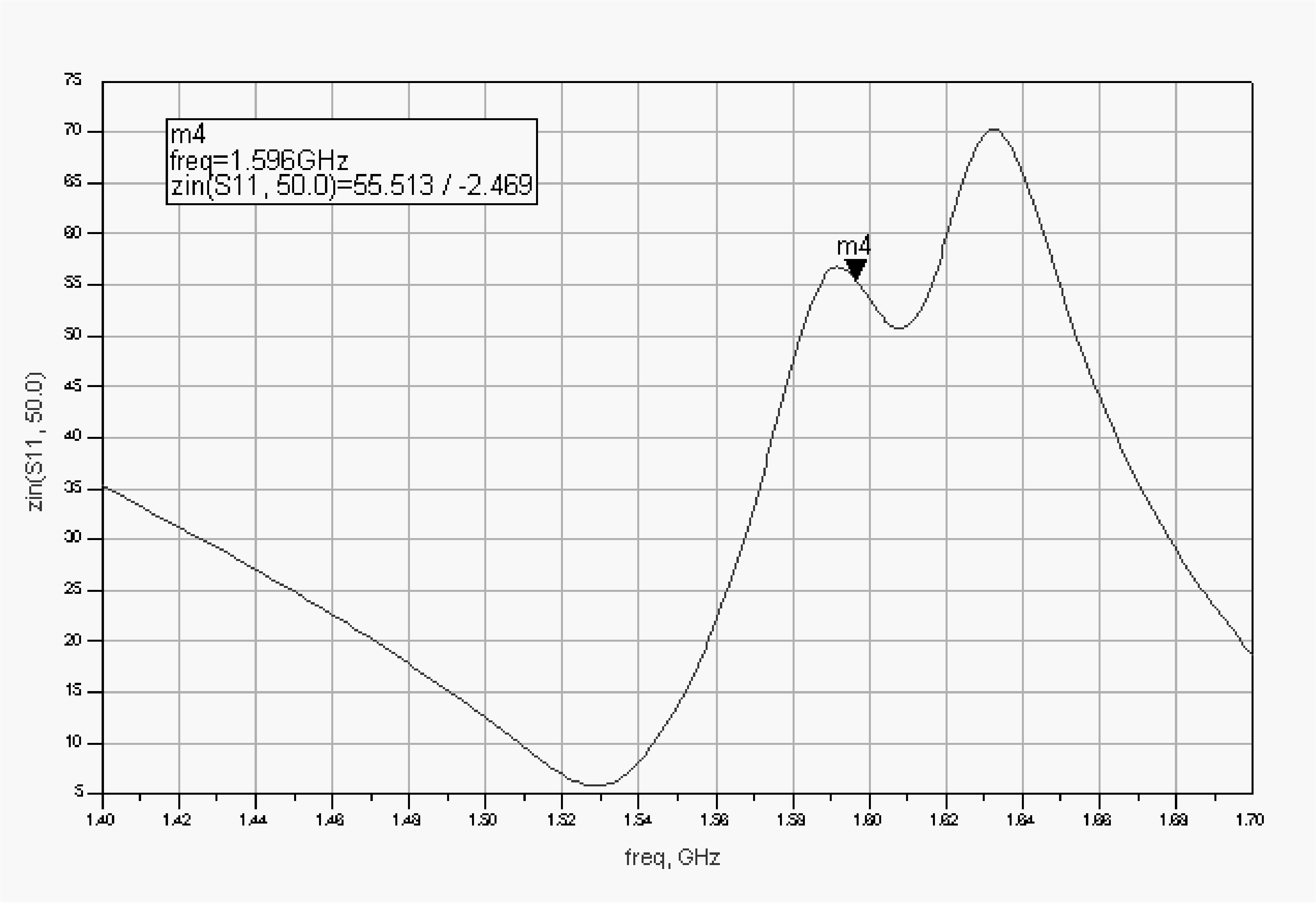
VSWR



Agilent ADS

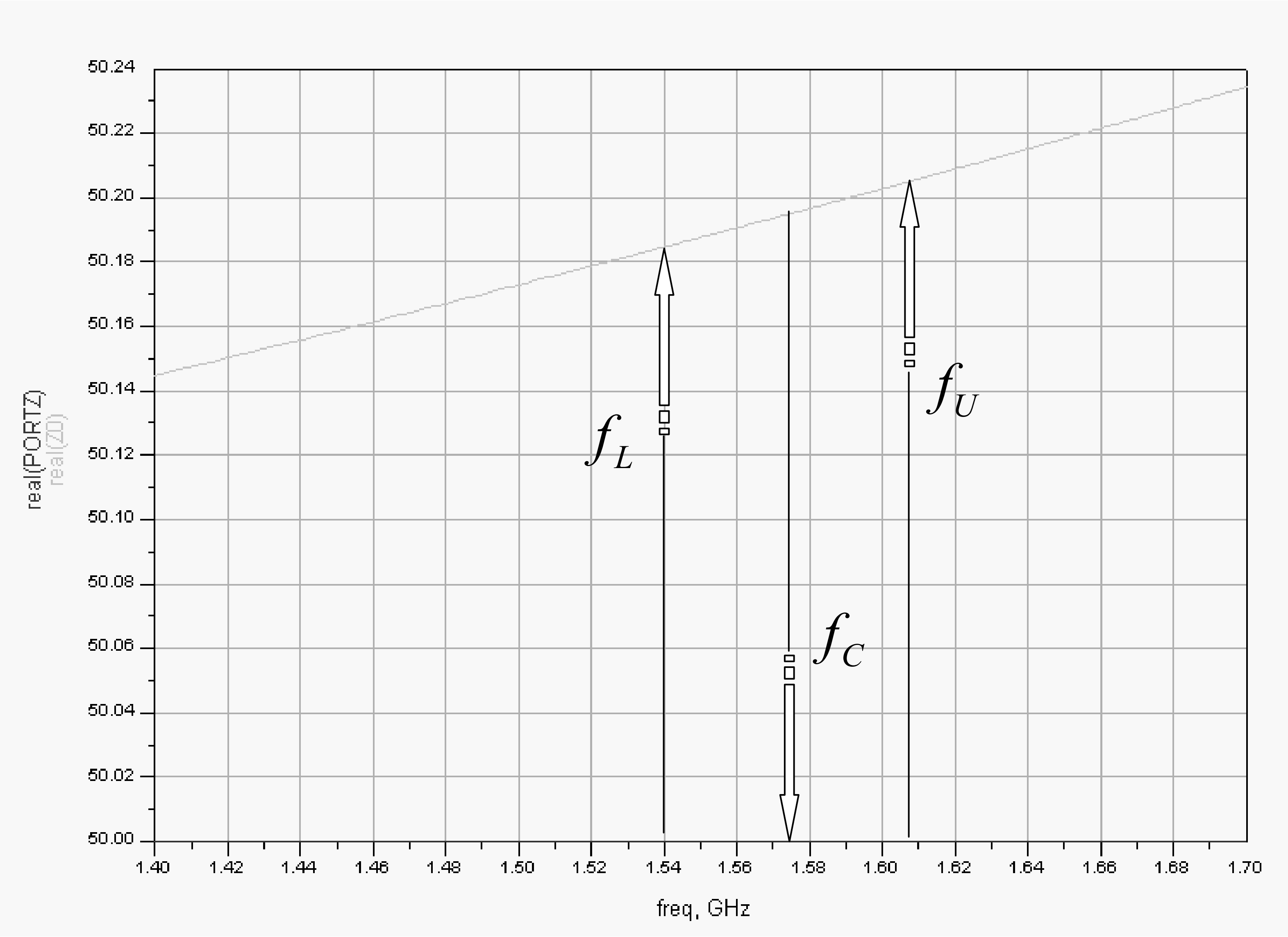
Ensemble HFSS Measured

Z matrix

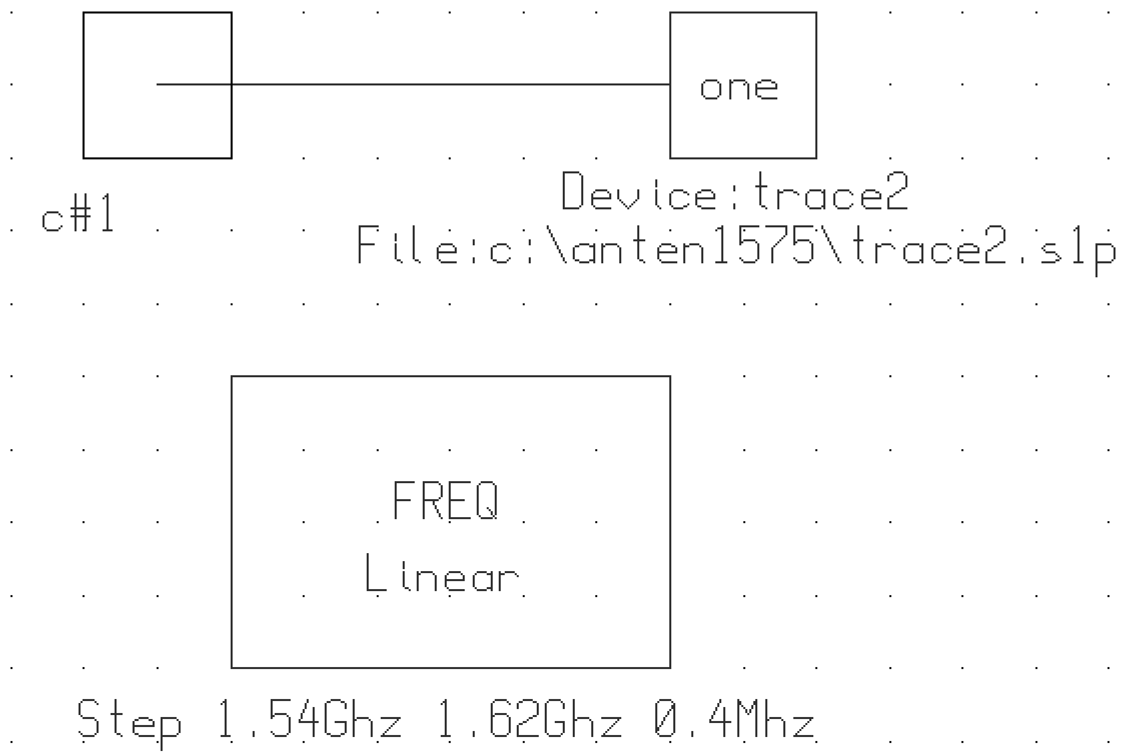


Agilent ADS

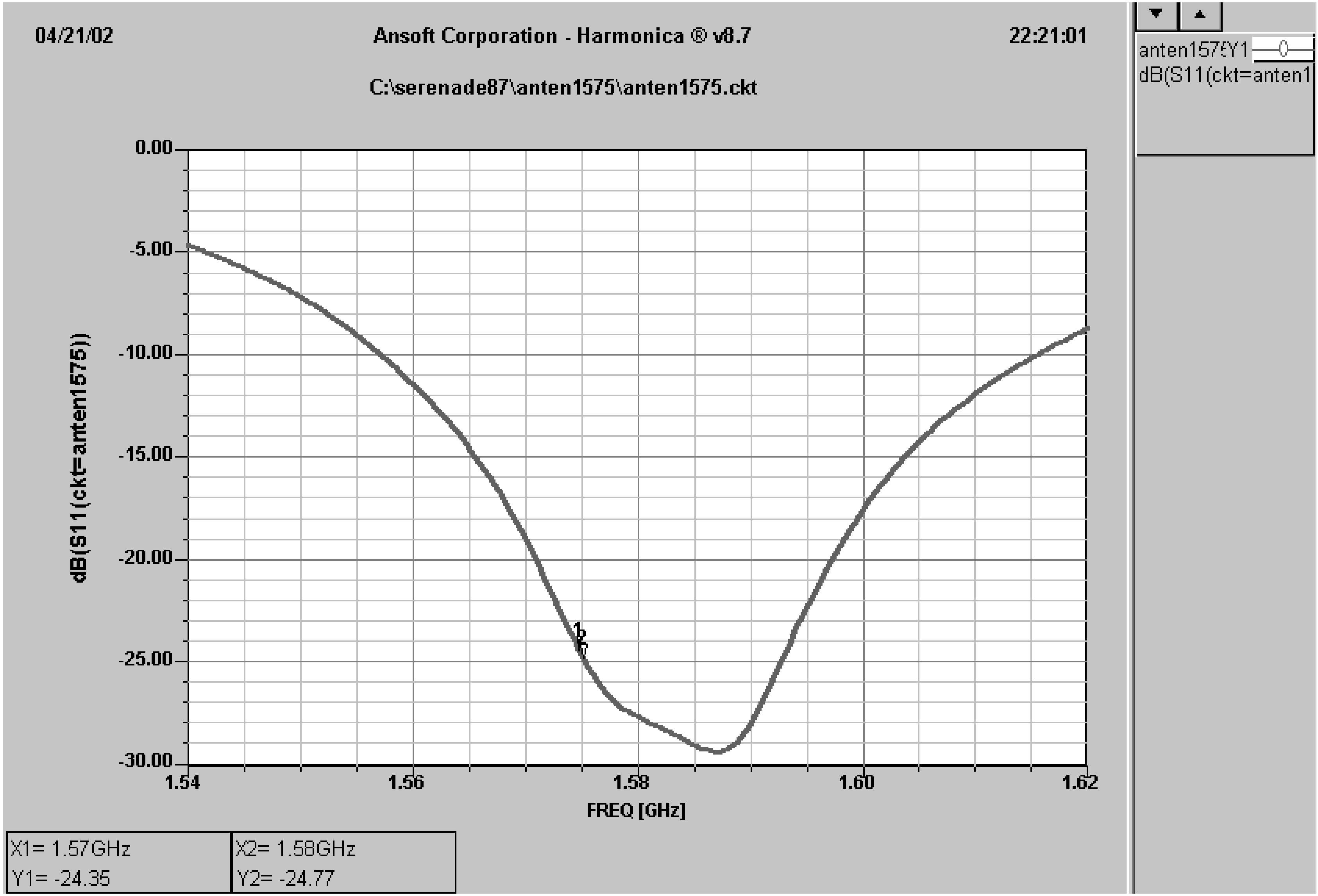
Port Z_o



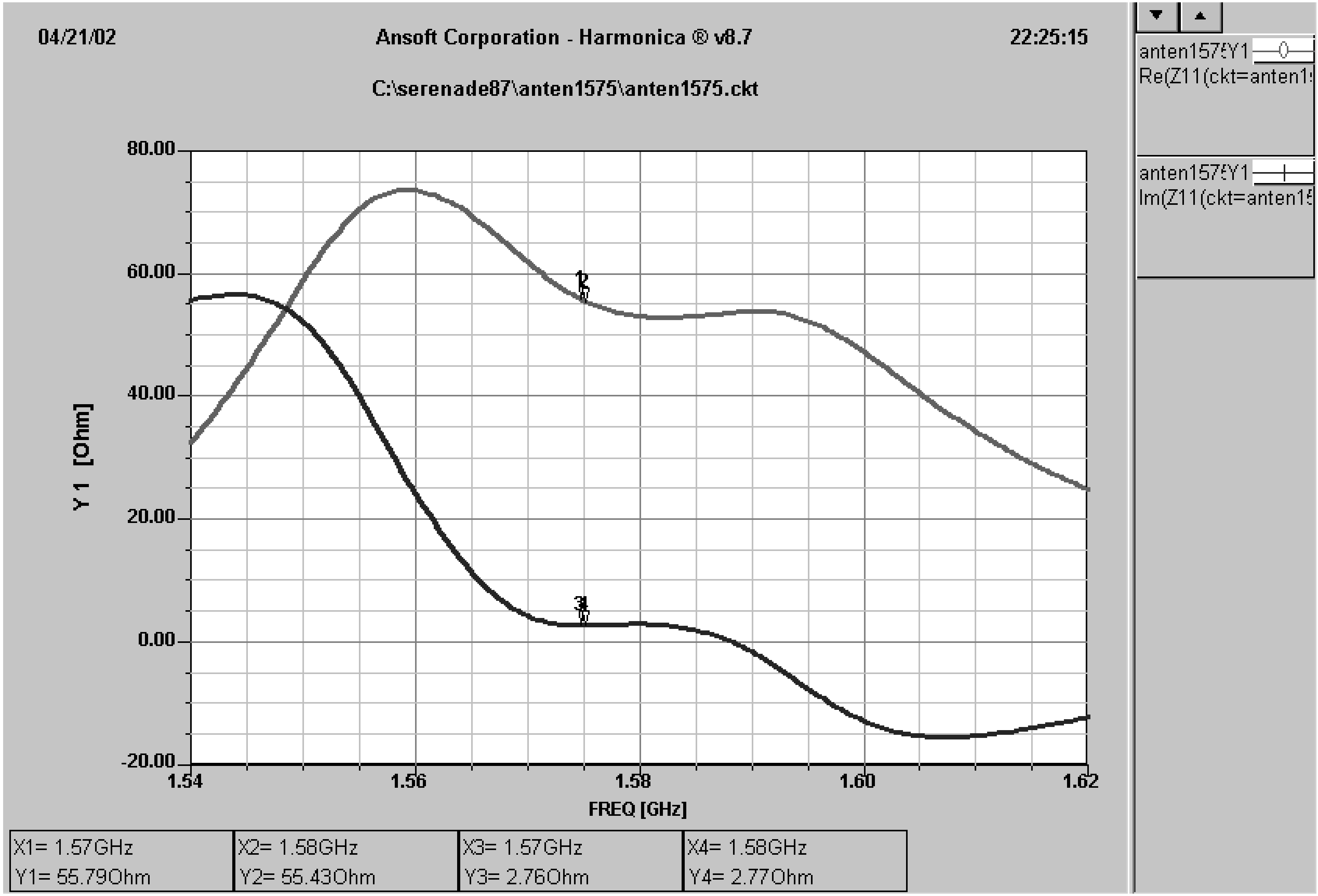
Measurement Results



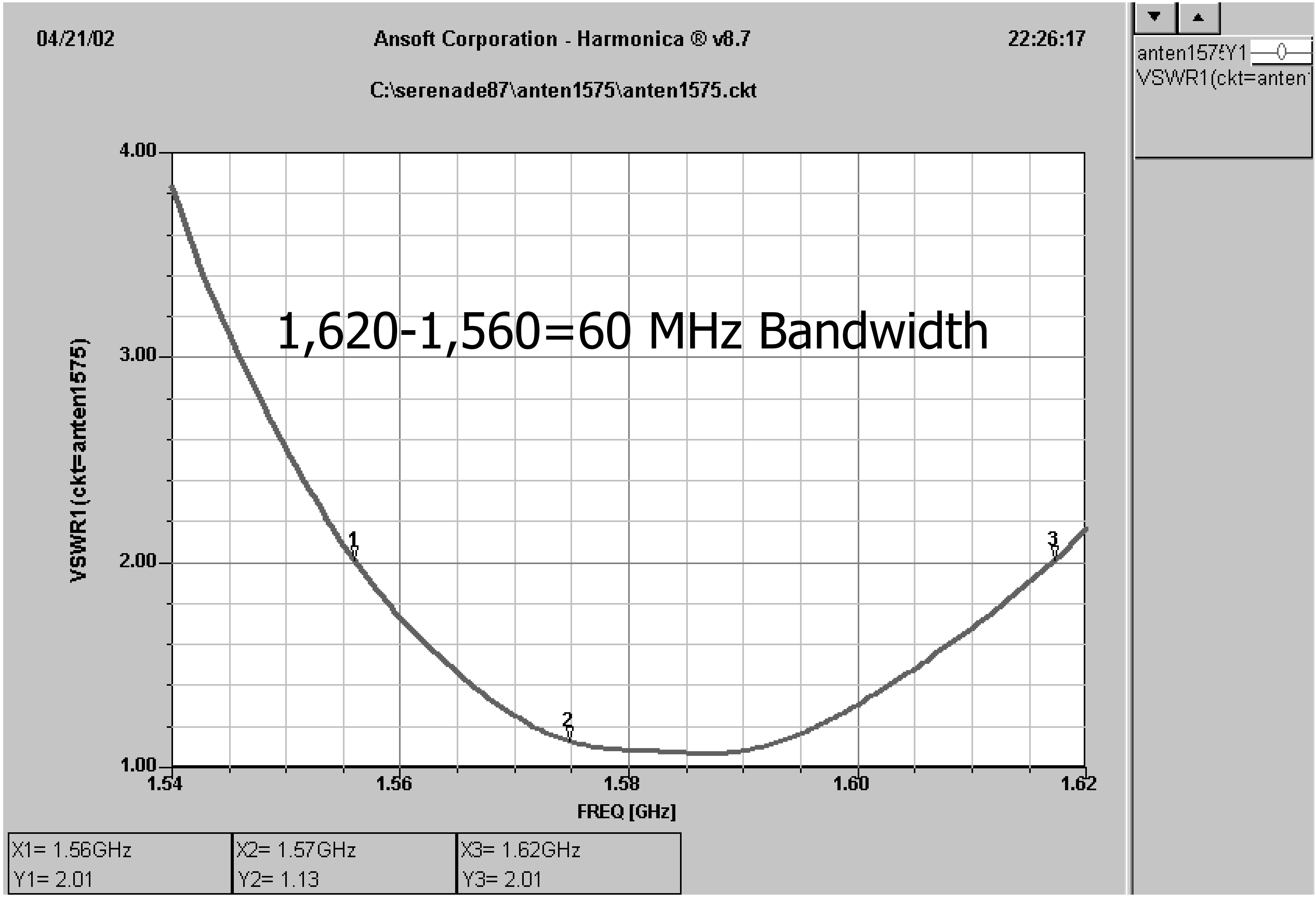
S11 in dB


04/21/02
Ansoft Corporation - Harmonica ® v8.7
22:21:01
C:\serenade87\anten1575\anten1575.ckt
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
dB(S11(ckt=anten1575))
1.54
1.56
1.58
1.60
1.62
FREQ [GHz]
X1= 1.57GHz
Y1= -24.35
X2= 1.58GHz
Y2= -24.77
dB(S11(ckt=anten1

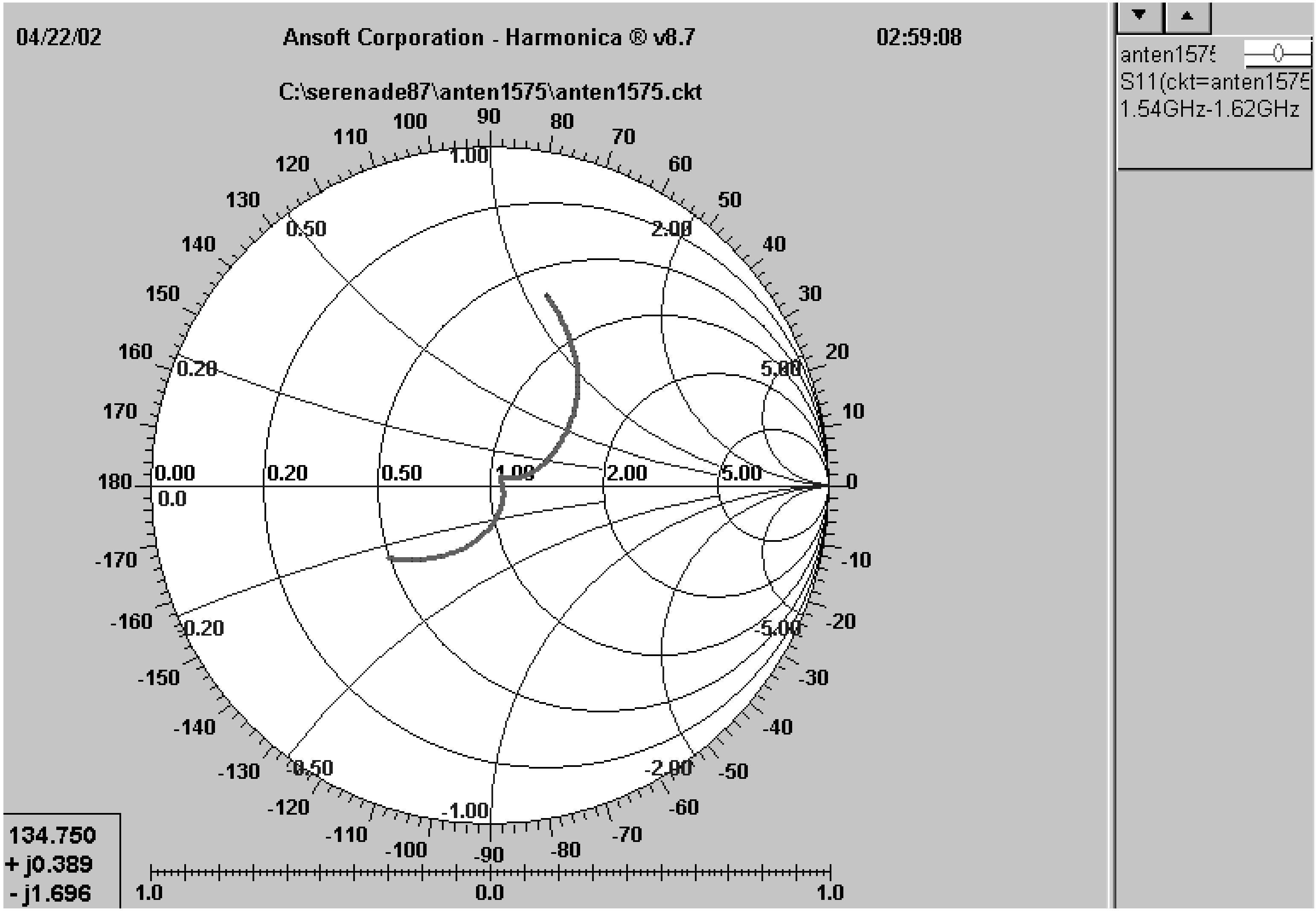
Input Impedance



VSWR


04/21/02
Ansoft Corporation - Harmonica ® v8.7
22:26:17
C:\serenade87\anten1575\anten1575.ckt
1,620-1,560=60 MHz Bandwidth
VSWR1 (ckt=anten1575)
4.00
3.00
2.00
1.00
1.54
1.56
1.58
1.60
1.62
FREQ [GHz]
1
2
3
X1= 1.56GHz
Y1= 2.01
X2= 1.57GHz
Y2= 1.13
X3= 1.62GHz
Y3= 2.01
VSWR1(ckt=anten

Smith Chart


04/22/02
Ansoft Corporation - Harmonica ® v8.7
02:59:08
C:\serenade87\anten1575\anten1575.ckt
anten1575
S11(ckt=anten1575
1.54GHz-1.62GHz
134.750
+ j0.389
- j1.696

Q & A

Thanks !...