UNIVERSITÄT DUISBURG ESSEN

HFT

Master Thesis

Modeling of a Patch-Antenna

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Introduction

The history of microstrip antennas has about 57 years old. The idea of this kind of antenna dates back to the 1950’s, but it was not until the 1970’s that serious attention was given to this element. As shown in the following figure the basic configuration of a microstrip antenna is a metallic patch printed on a grounded dielectric substrate. One is fed by a coaxial line through the bottom of the substrate; another is fed by a coplanar microstrip line.

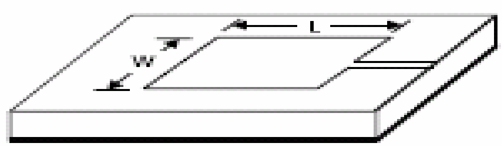


Fig. 4.1

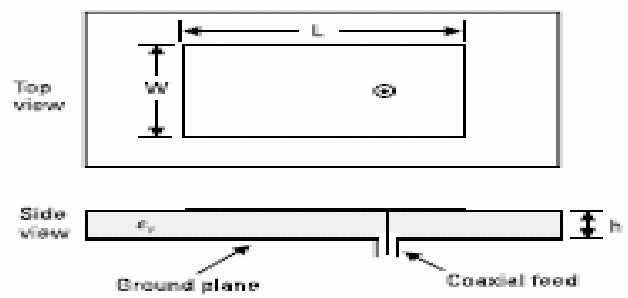


Fig. 4.2

Fig. 4.1 and Fig. 4.2 the basic configuration of microstrip patcha antennas

Introduction

Microstrip patch antennas have been very widely used today in various application fields such as satellites, radars, mobilephones, car and sensors due to the advantages of fabrication and mechanism. In addition, because of its inherent advantages the works on improving the electrical characteristics have been performed by researchers throughout the world.

Introduction

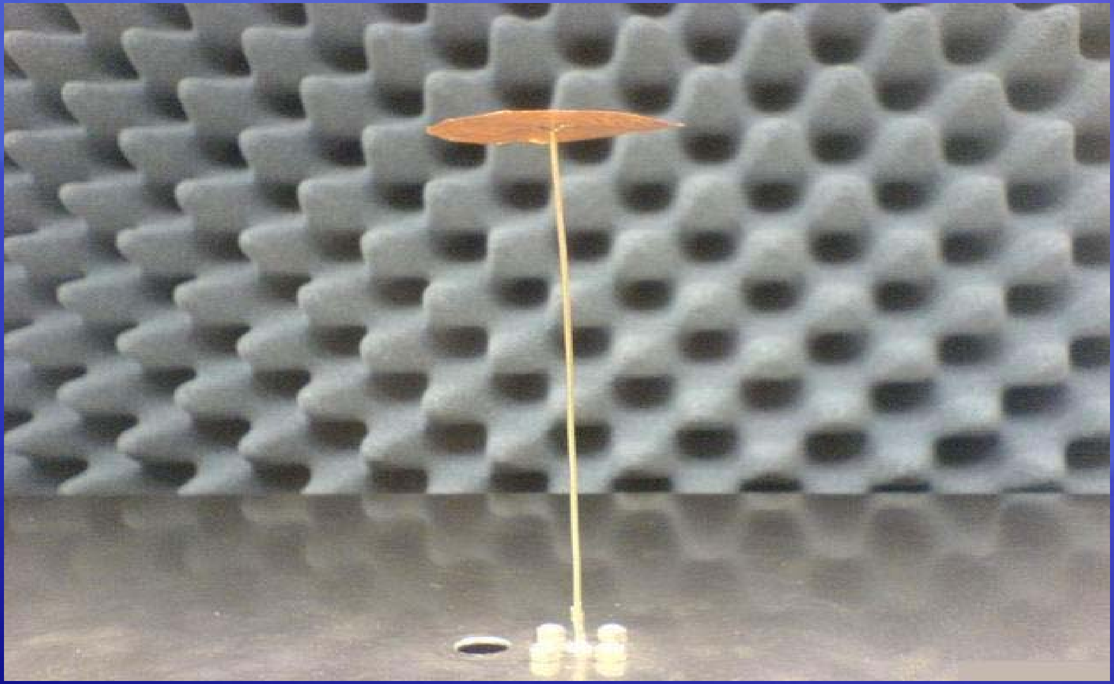
Objective:

In this thesis we analyze and model a probe-fed patch antenna, with length less than half wavelength and width less than quarter wavelength at the resonant frequency around 1 GHz. Also we model and analyze the feeding probe with variable heights.

Meanwhile, asymmetric E-plane pattern is analyzed and the efficiency of the antenna is measured by adaption of the Wheeler Cap method.

Modeling of disk-loaded monopoles

For this thesis, the patch antenna is fed by a short probe. As we knew, the current distribution is uniform along the probe. The short probe is like a disk-loaded monopole. Thus it is necessary to analyze this situation and the circuit network model built in this thesis. The following figure shows one of disk-loaded monopoles we measured.



Modeling of disk-loaded monopoles

For the approximate uniform current distribution, we get the radiation resistance of disk-loaded monopoles based on the equation:

$$R_r = 395 L_\lambda^2$$

$$L_\lambda = \frac{L}{\lambda} = \frac{2h}{\lambda}$$

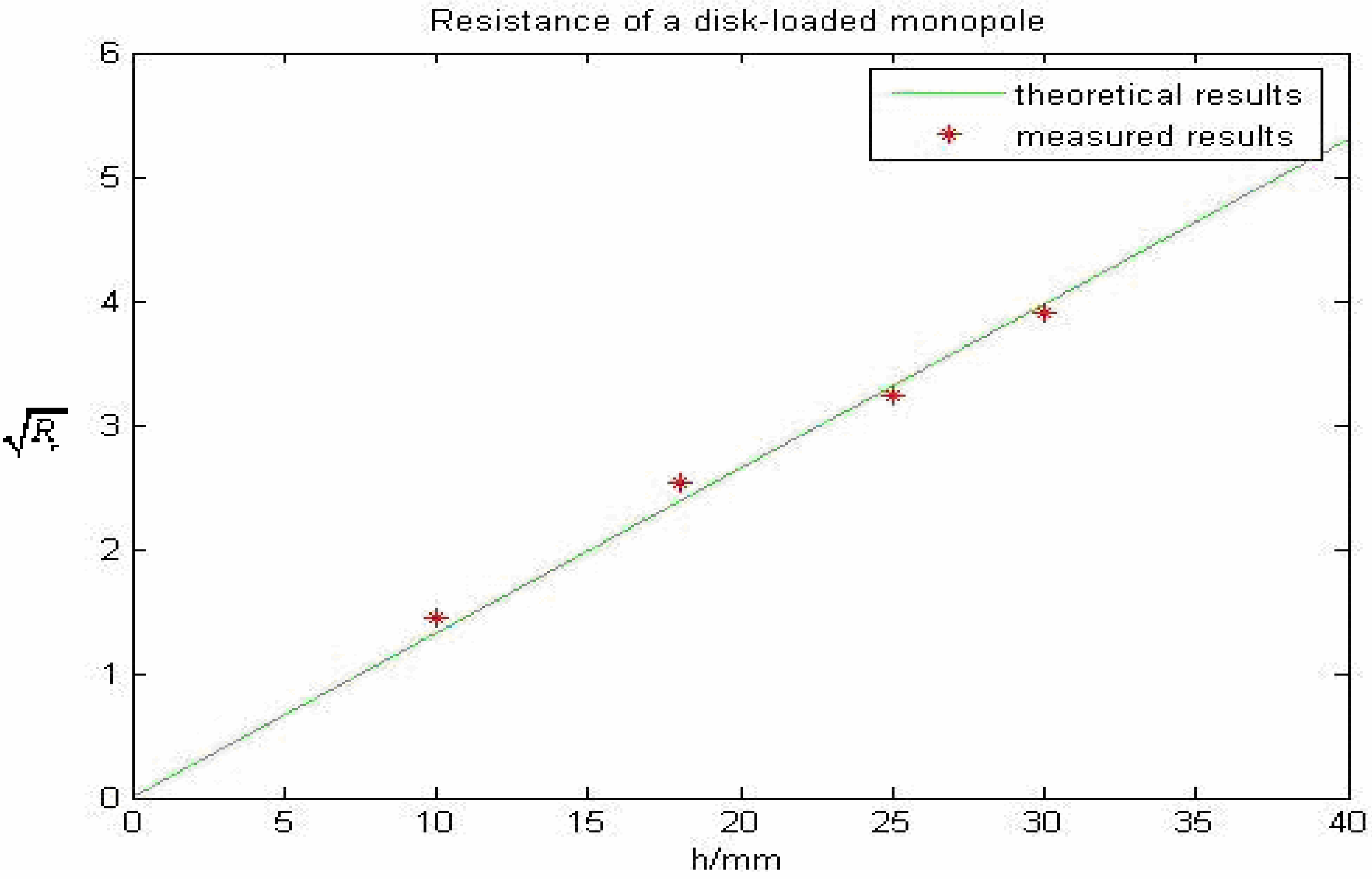
Modeling of disk-loaded monopoles

The heights of monopoles are 10 mm, 18 mm, 25 mm and 30 mm. The diameter of the loading disk is 25 mm. The substrate is air.

The relation between radiation resistance and the monopole height at the same frequency is shown in the following figure.

In the figure the green line is the radiation resistance of a Hertzian monopole, at the frequency 1 GHz. The red star points are the results we measured.

Modeling of disk-loaded monopoles

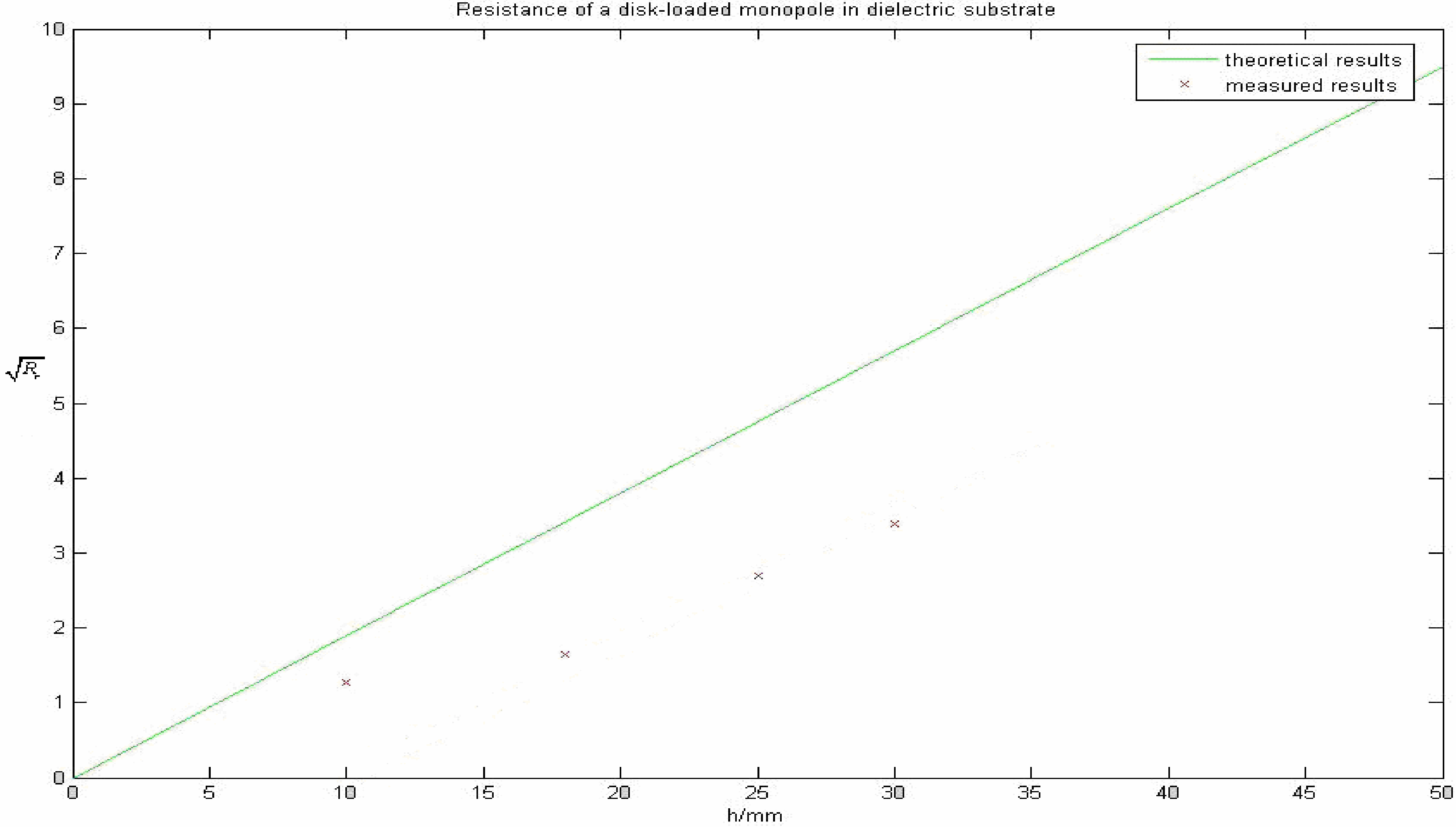


Modeling of disk-loaded monopoles

From the above graphic, we see a good close agreement between theoretical results and measured results that proves the current distribution is uniform along the disk-loaded monopole.

Meanwhile, we measured the radiation resistances of disk-loaded monopoles in dielectric substrate (dielectric constant =2.1). The heights of monopoles are 10 mm, 18 mm, 25 mm and 30 mm and the diameter of the loading disk is 25 mm. And the size of the dielectric substrate is 225 mm (length) and 160 mm (width).

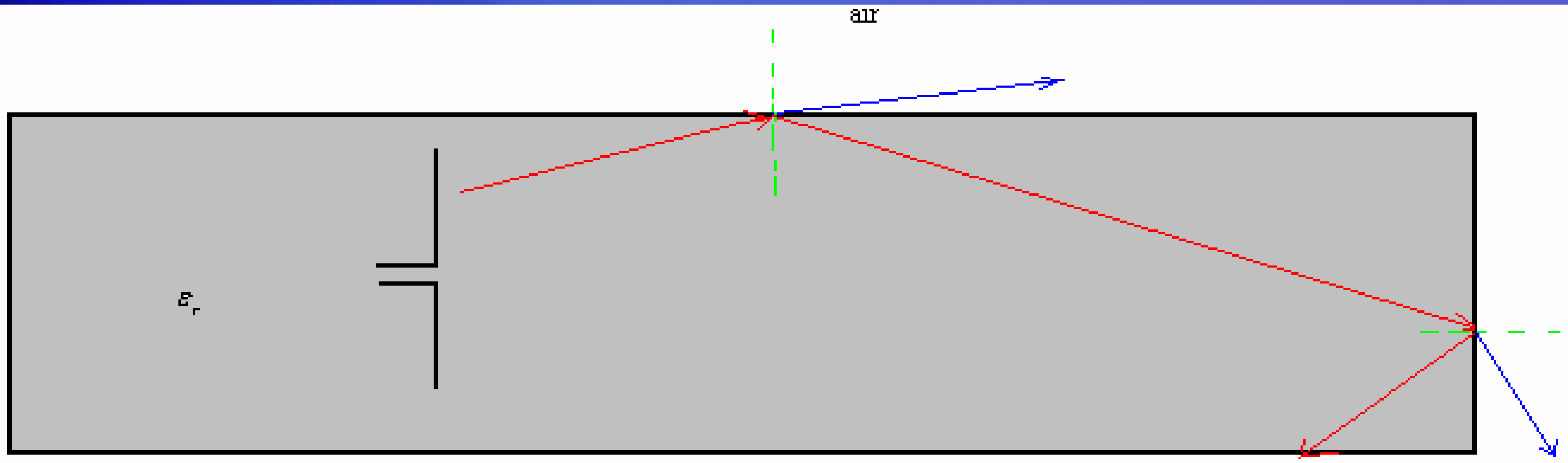
Modeling of disk-loaded monopoles



Modeling of disk-loaded monopoles

From the above figure, there is much difference between theoretical results and measured results. I think there has much dielectric loss due to dielectric substrate. Thus the loss may include dielectric loss , surface wave loss, conductor loss.

We may present it based on the propagation of radiated waves.



Modeling of disk-loaded monopoles

In above graphic we see the situation of wave propagation in dielectric materials. Some waves are reflected and some refracted into air. The reflected waves cause standing waves in dielectric materials that store some energies.

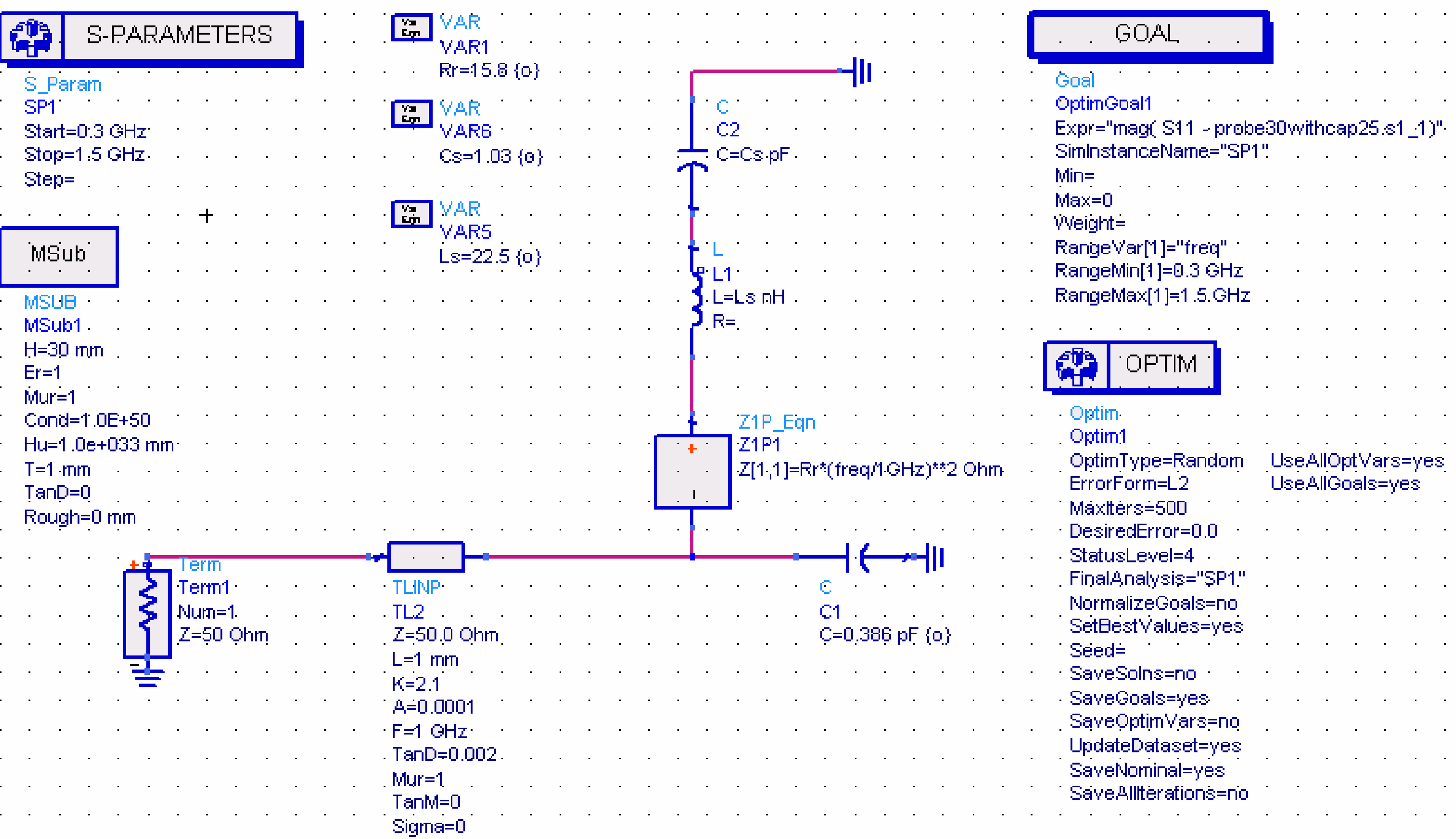
We may find the resistance point at 10 mm is closer to theoretical resistance than other points. That is because the height of substrate is small and most of waves are radiated into air, and only few are reflected.

Modeling of disk-loaded monopoles

As well known, arbitrary electrically small antennas can be presented in R-L-C circuit. For this thesis, the monopole is short that is much smaller than wavelength. Thus we may express the equivalent circuit of disk-loaded monopoles by using ADS.

In the following figure, the first part of the equivalent network is the capacitor is consisted by two elements: loading disk’s capacitance and vertical monopole’s capacitance. The second part is the vertical monopole’s inductance and the third part is the radiation resistance, dependent on the measured frequencies.

Modeling of disk-loaded monopoles



Modeling of disk-loaded monopoles

We use the above equivalent circuit network to fit the measured curves by optimizing the element parameters' values.

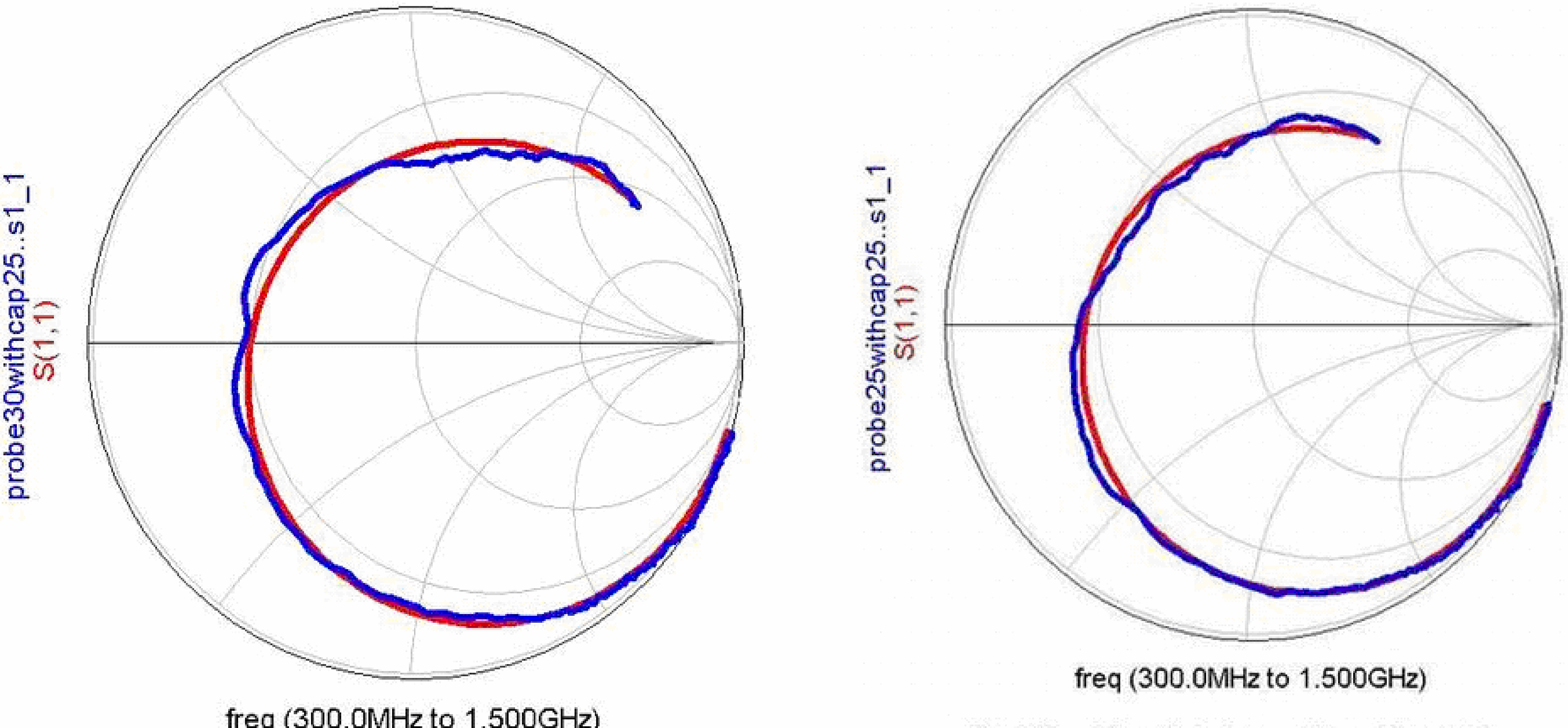


Fig. 3.38 The optimized comparison of S-parameter

Modeling of disk-loaded monopoles

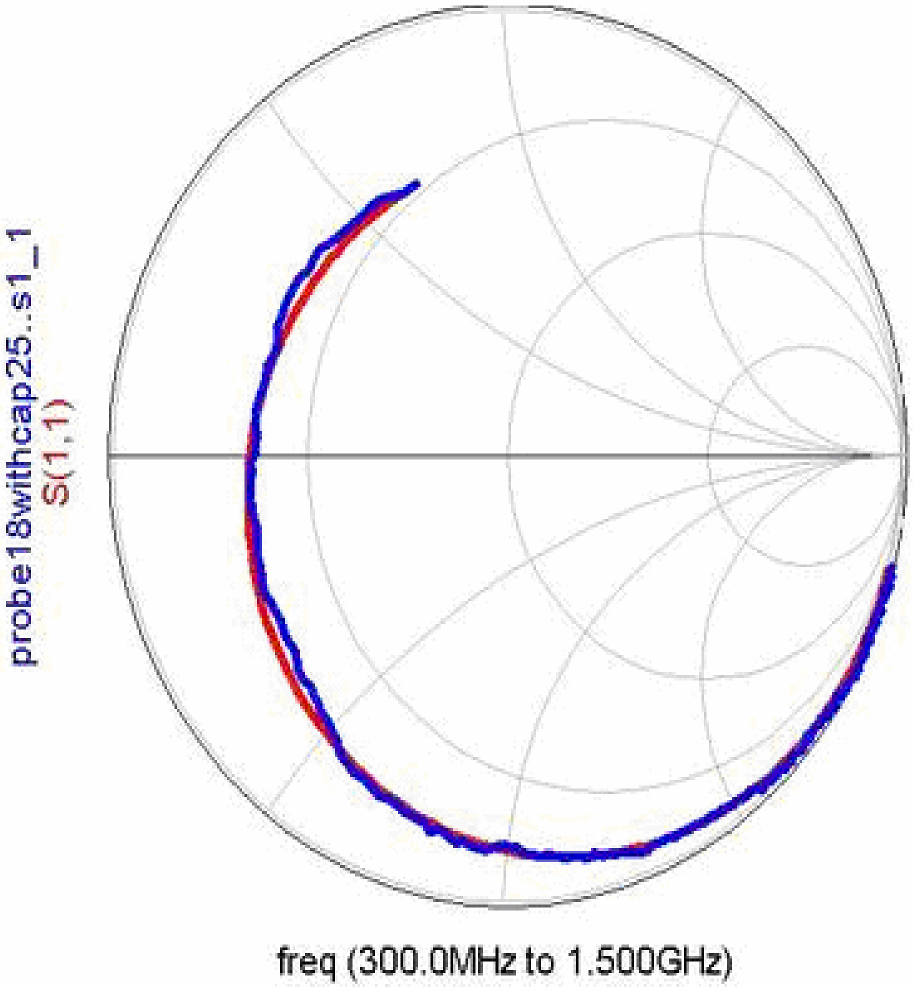


Fig. 3.40 The optimized comparison of S-parameter

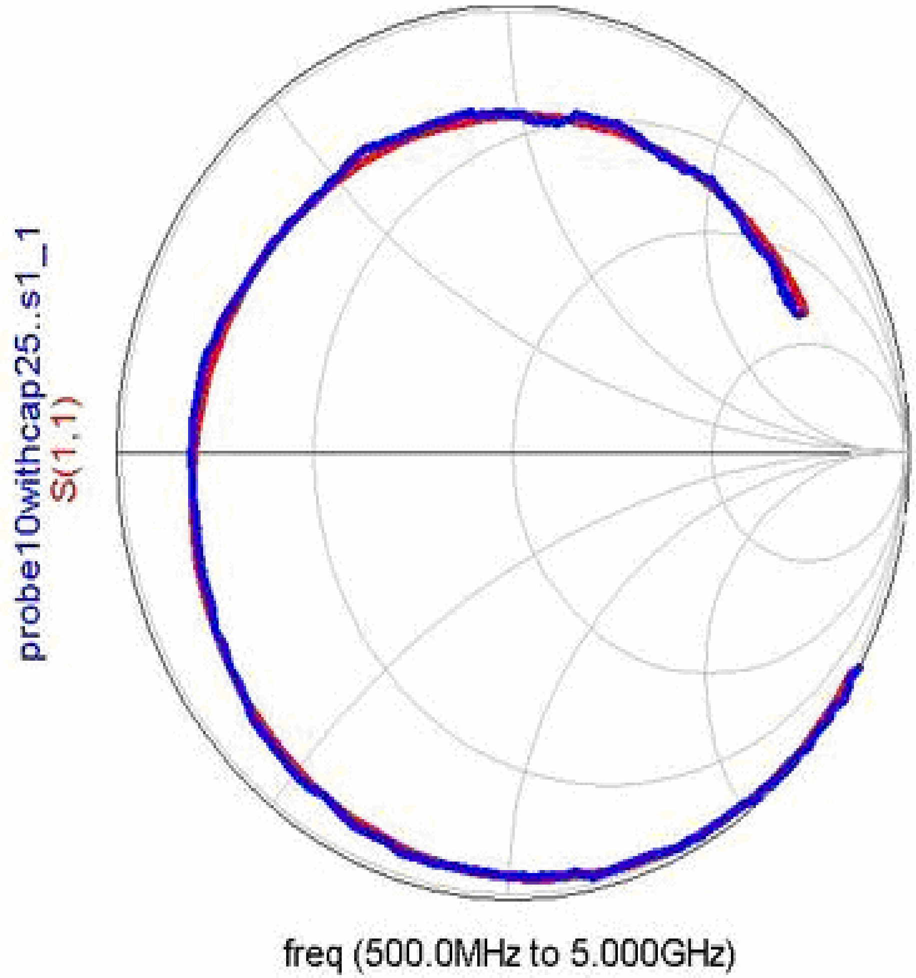


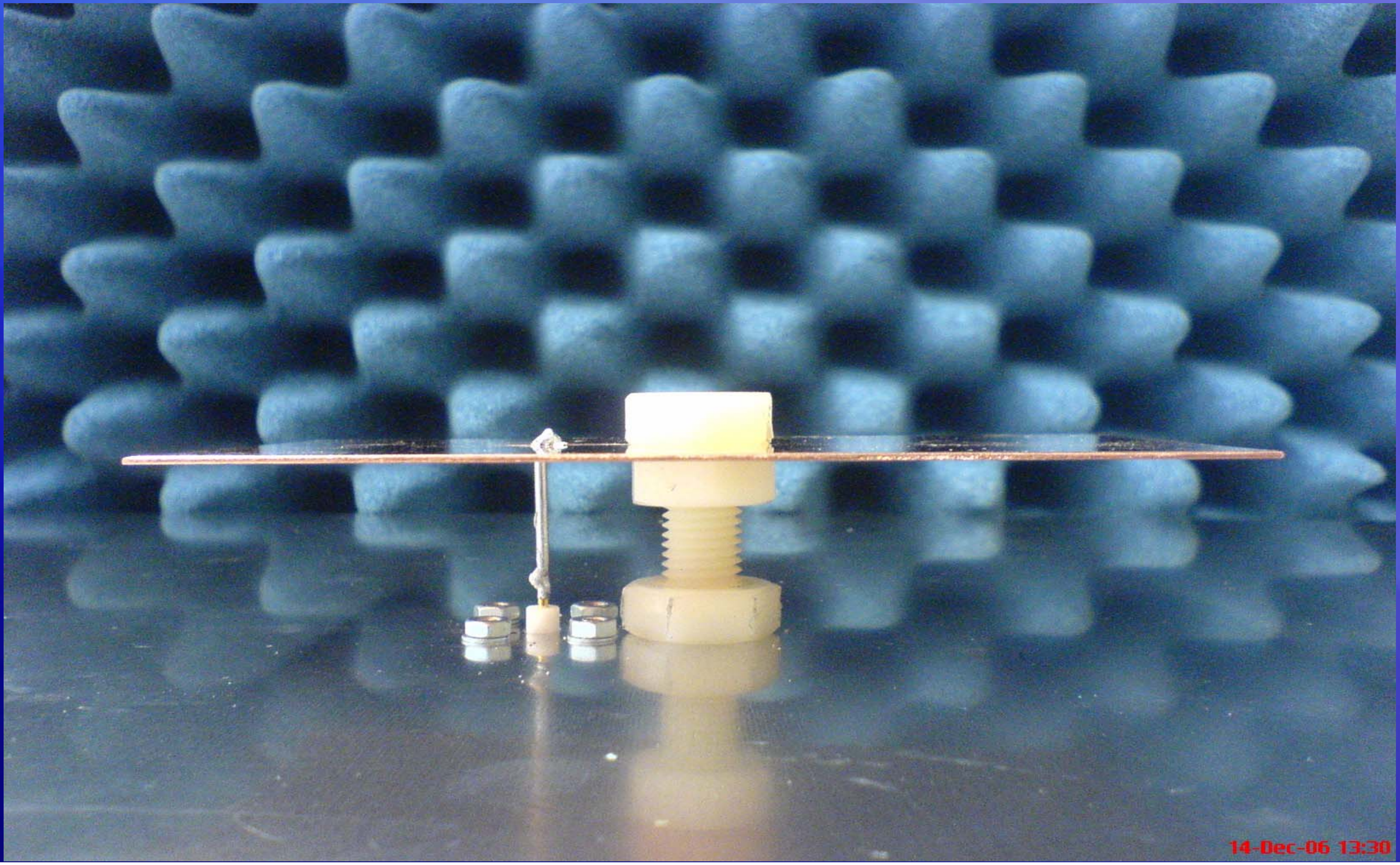
Fig. 3.42 The optimized comparison of S-parameter

Modeling of disk-loaded monopoles

From above figures we see the measured curves and optimized curves fit very well that proves the equivalent circuit network is quite valid. And the elements R,C and L have good agreements with measured values. Thus we may say the network model is valid and may simulate the short dipole antenna after experimental and theoretical analysis.

Modeling of a Patch-Antenna

In this thesis the patch antenna we study is fed by a probe, shown in the figure below.



Modeling of a Patch-Antenna

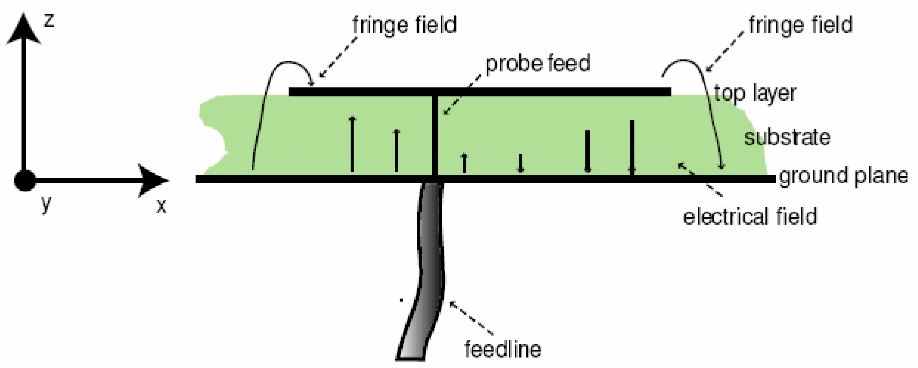
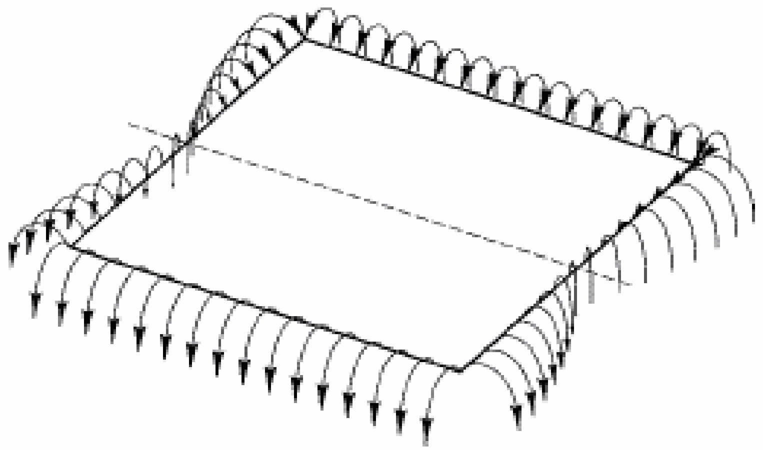


Fig. 4.7 A microstrip patch antenna fed by a probe



In these two pictures we may see the field distribution of the probe-fed patch antenna.

Modeling of a Patch-Antenna

First we talk about the asymmetric E-field distribution. The probe-fed patch antenna can be simulated by HFSS and Matlab.

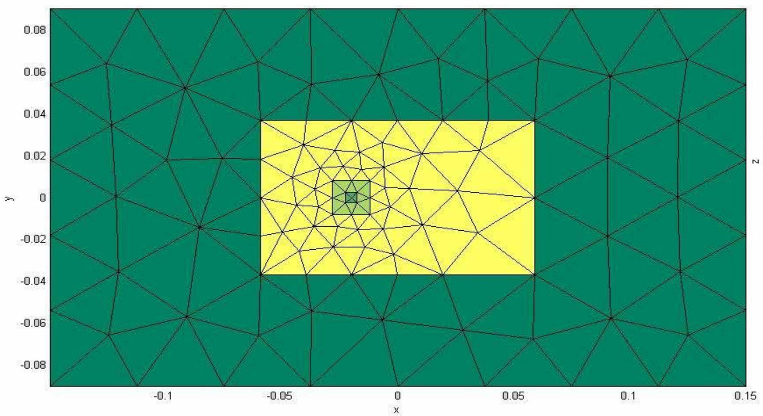


Fig. 4. 17 Created surface mesh

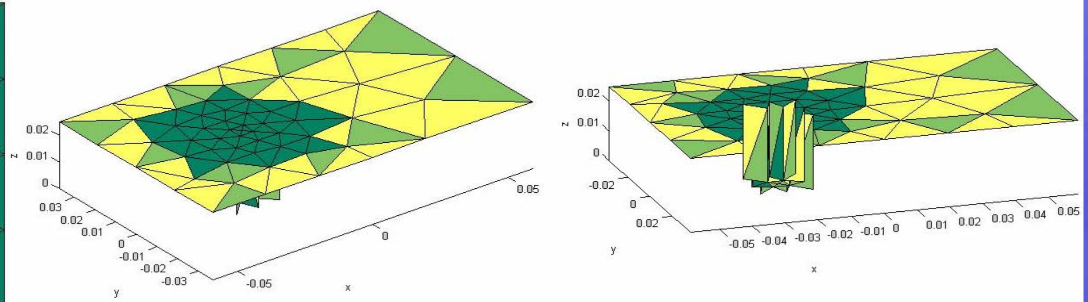


Fig. 4. 18 Metal surface grid

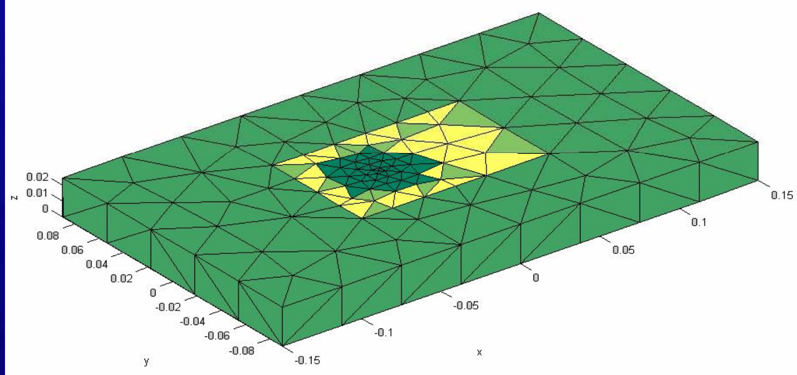


Fig. 4.19 Metal and substrate grid

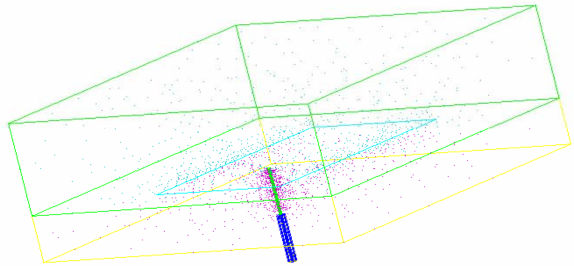


Fig. 4.20 A patch antenna mesh simulated by HFSS

Modeling of a Patch-Antenna

The E-field in HFSS and Matlab.

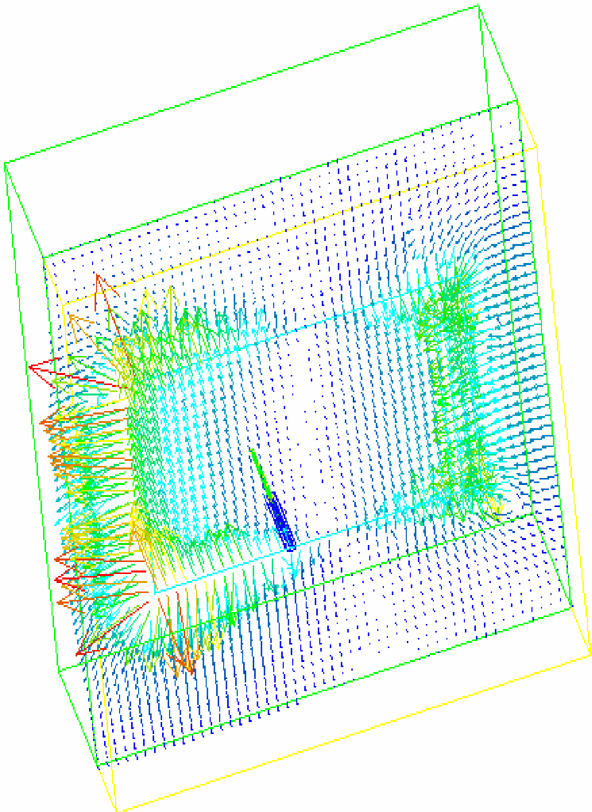


Fig. 4.21 E-field in HFSS

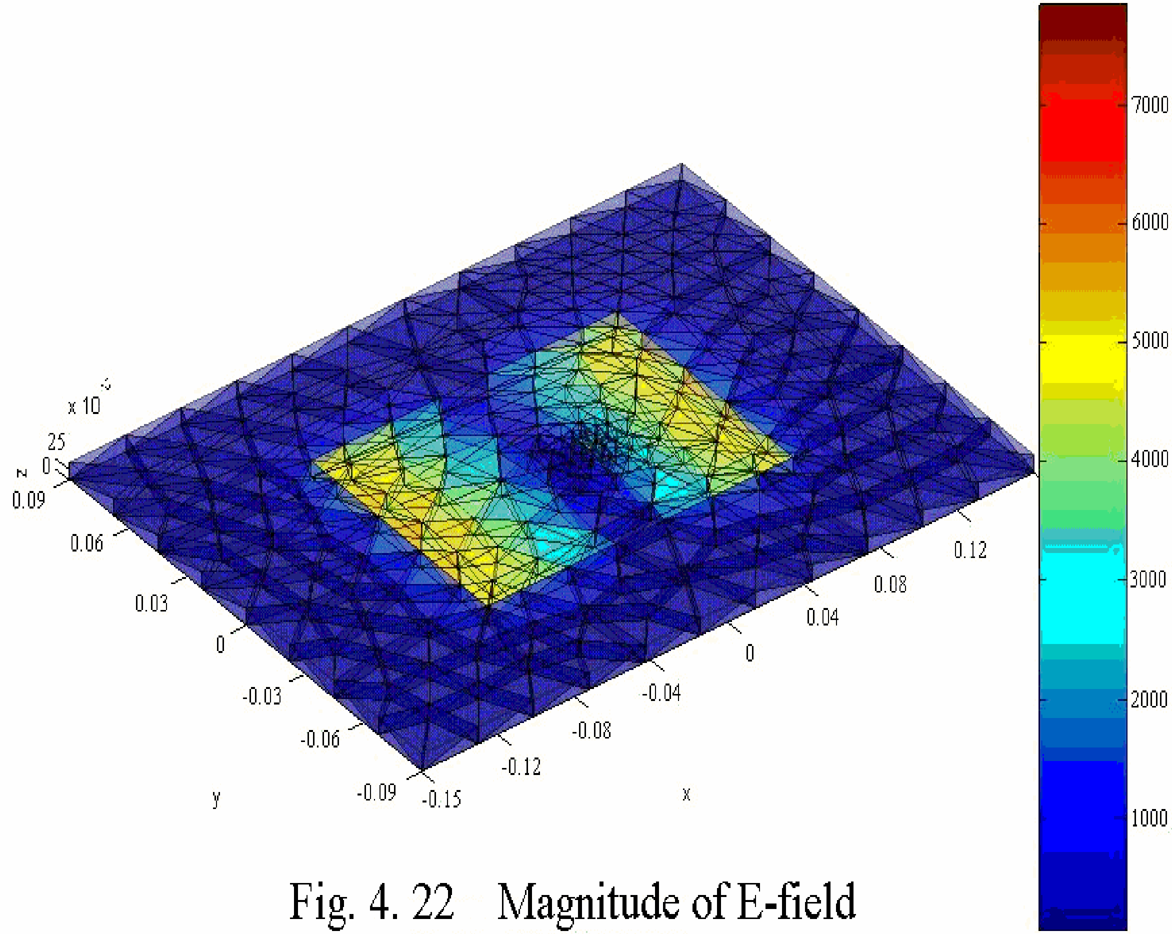


Fig. 4. 22 Magnitude of E-field

Modeling of a Patch-Antenna

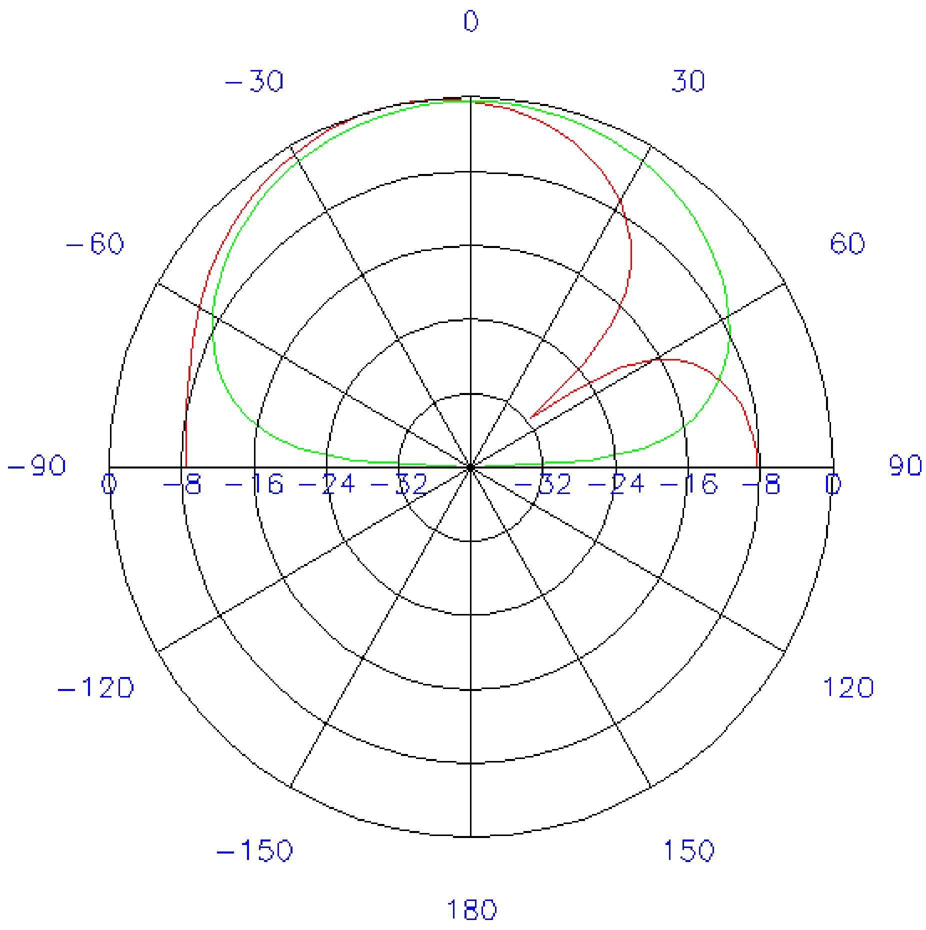


Fig. 4. 23 E- and H- field in HFSS

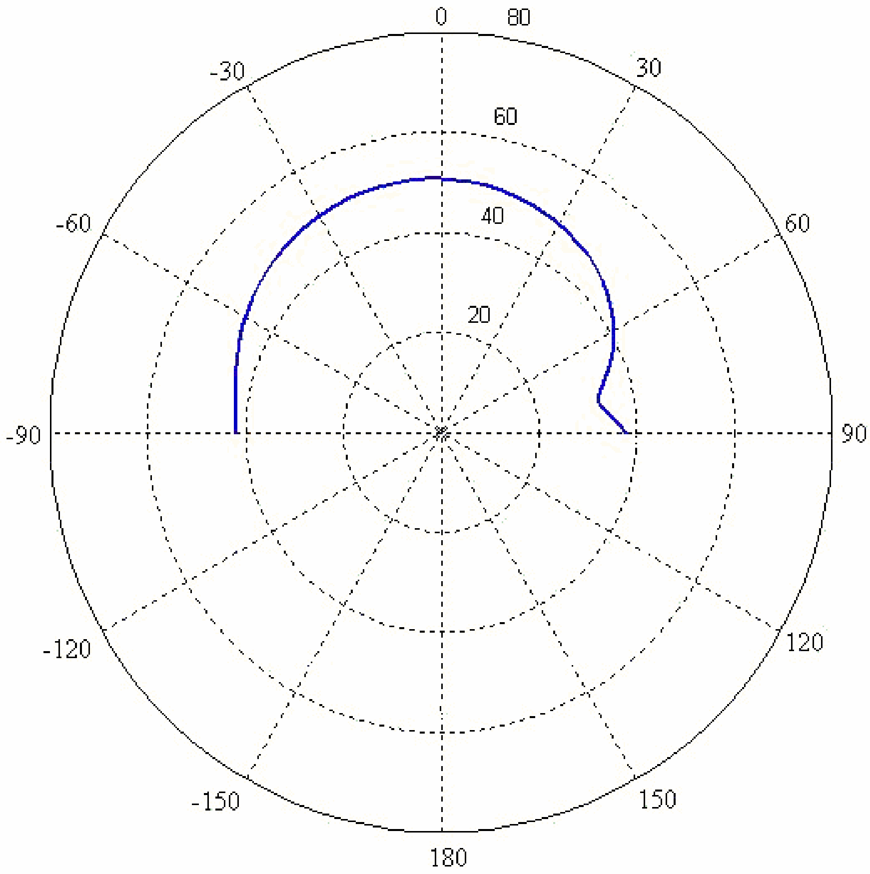


Fig. 4.24 E-field in Matlab

Modeling of a Patch-Antenna

As we know, the field of a dipole in E plane is like the following figure.

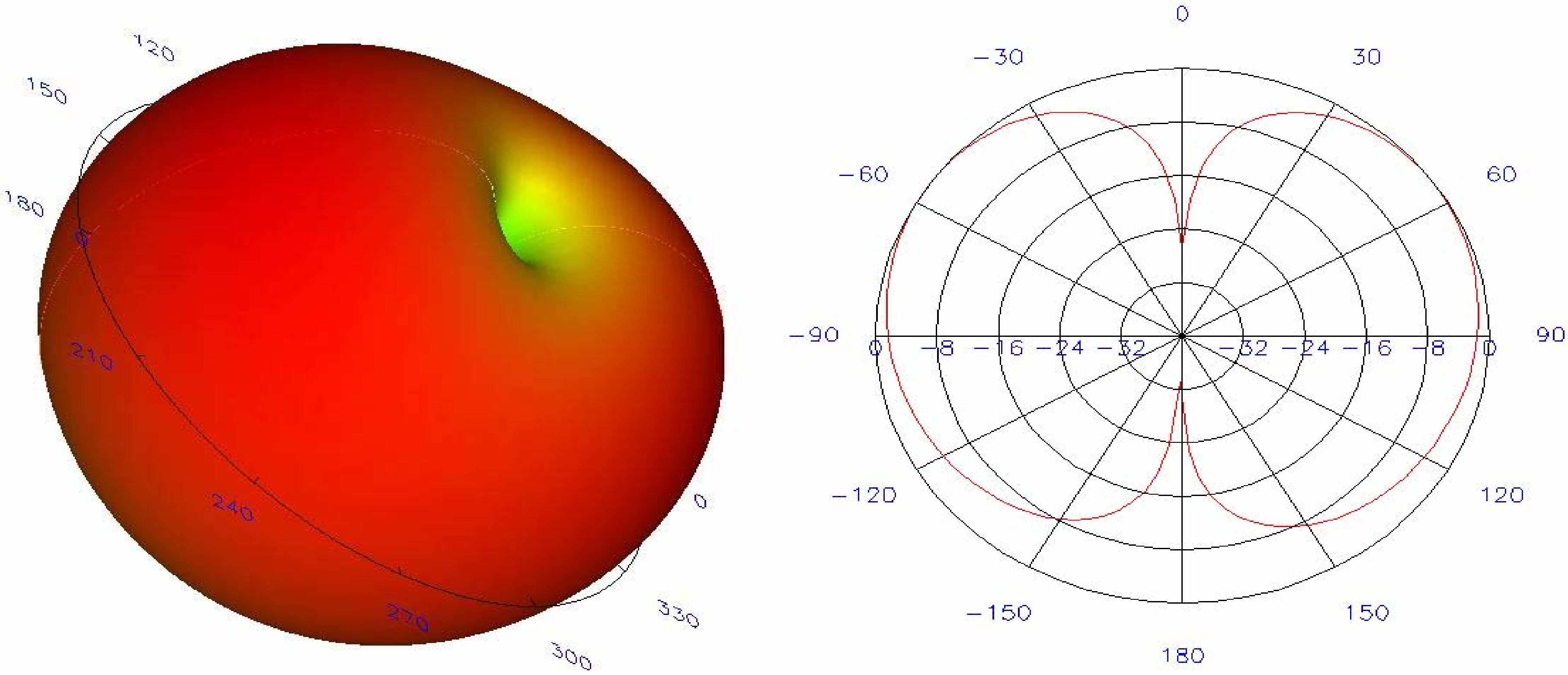
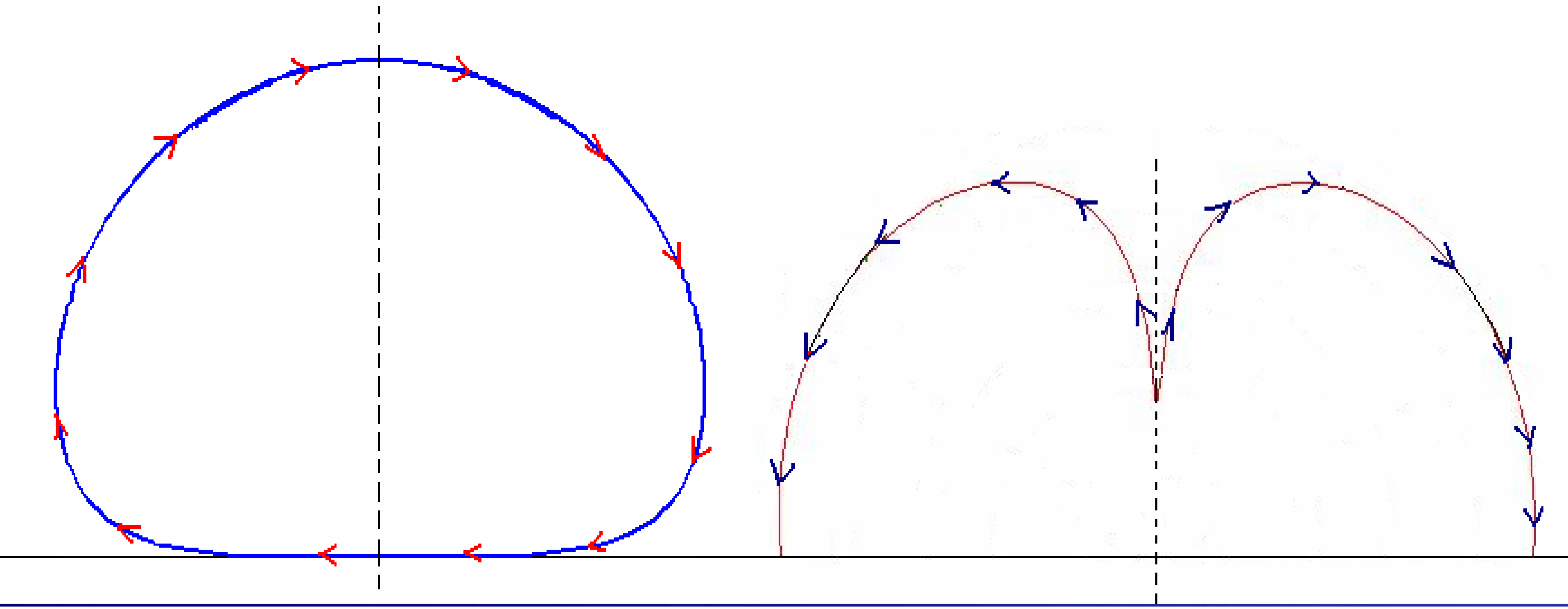


Fig. 4. 25 3D and 2D E-field patter of a dipole

Modeling of a Patch-Antenna

The reason for the asymmetric E-field is one of the disadvantages of the probe-fed patch antenna, the spurious radiation from the feeding probe. On one side the spurious radiation adds and on the other side it subtracts from the E-pattern.



Modeling of a Patch-Antenna

From the above figure we may understand the creation of asymmetric E-plane pattern. One side the direction of E-field is same and the other side is opposite. On the horizontal level the E-plane field of the patch is null but that of the feeding probe is maximum. The superposition of these two E-plane fields produces the asymmetric field pattern.

Modeling of a Patch-Antenna

The efficiency of antennas can be calculated as

$$\eta = \frac{R_r}{R_r + R_l}$$

An improved model of efficiency measurement is defined shown in the following figure.

Measurement 1: **Measurement 2:**

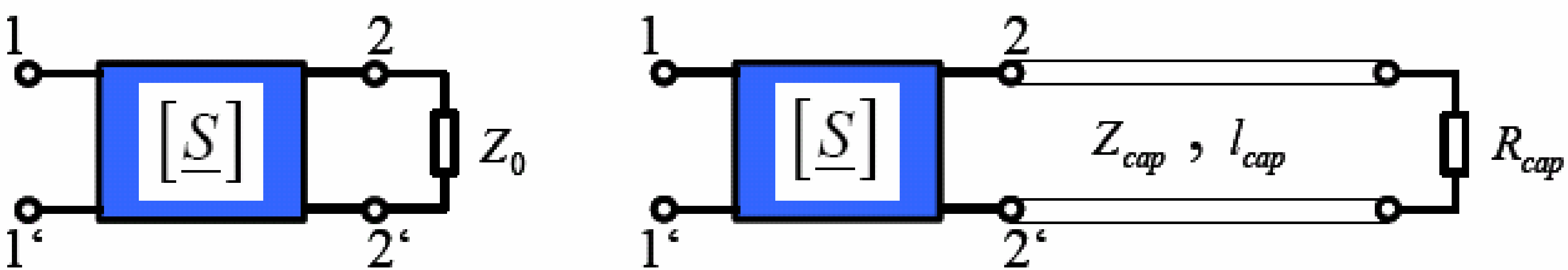


Fig. 4.28 Equivalent circuits for the free space measurement (measurement 1) and the cap measurement (measurement 2)

Modeling of a Patch-Antenna

The above circuit describes the cap as a small ohmic resistance R_{cap}
Connected via a transmission line . Its length l_{cap} describes the effective electrical distance between the device and the cap. The efficiency can be calculated based on the following equations:

$$\eta_{tot} = \frac{2}{\left(\Delta s_{\max}\right)^{-1} + \left(\Delta s_{\min}\right)^{-1}}$$

$$\eta_{tot} = \left(1 - \left|S_{11}\right|^{2}\right)\eta_{rad}$$

Modeling of a Patch-Antenna

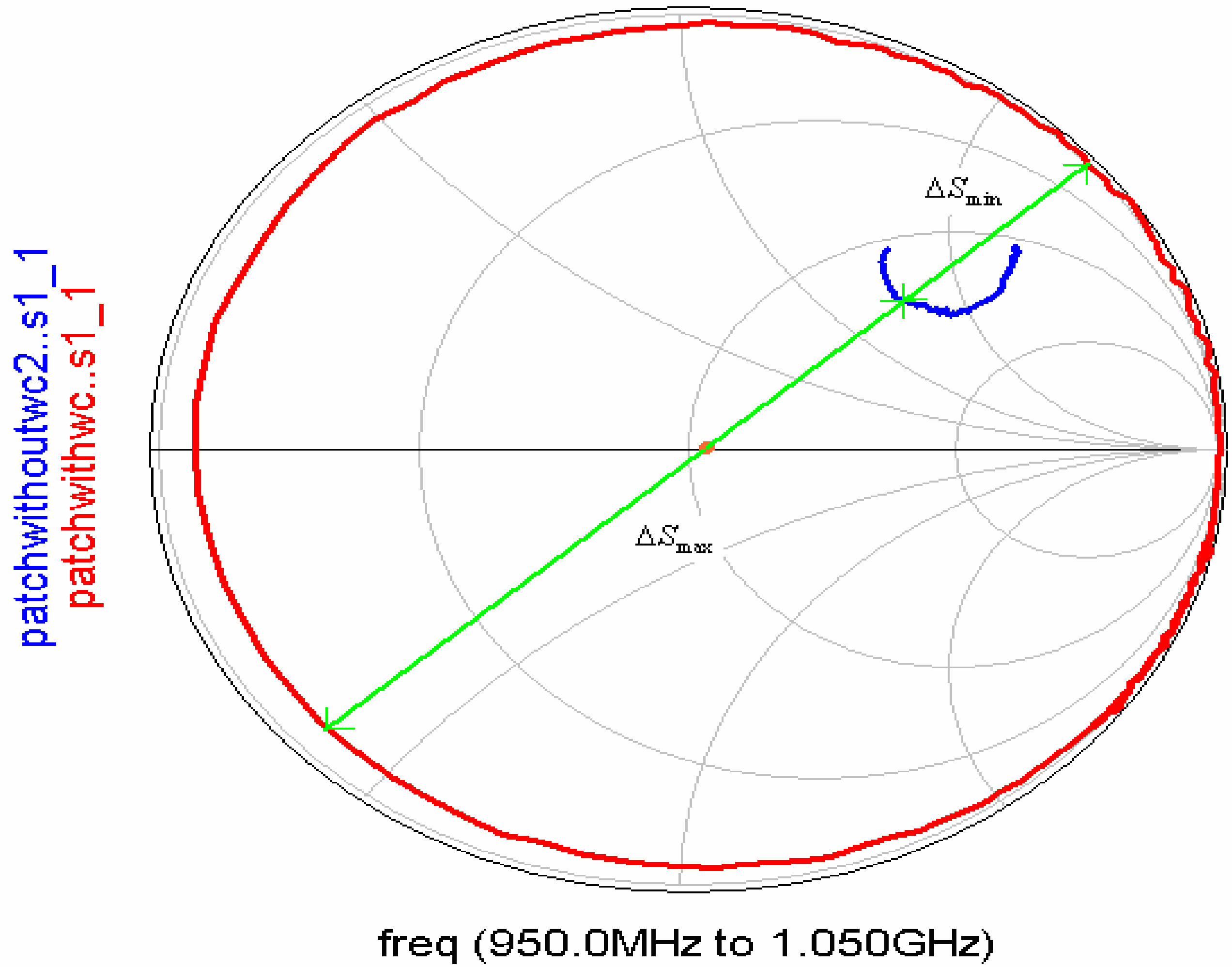


Fig. 4.29 Measured data in the cap measurement method

Modeling of a Patch-Antenna

The height of the patch antenna we measured is 25 mm. The measured frequency range is from 0.95 GHz to 1.05 GHz.

Another way to measure efficiency is to model an equivalent circuit network in ADS. This circuit network model is based on the loss resistance.

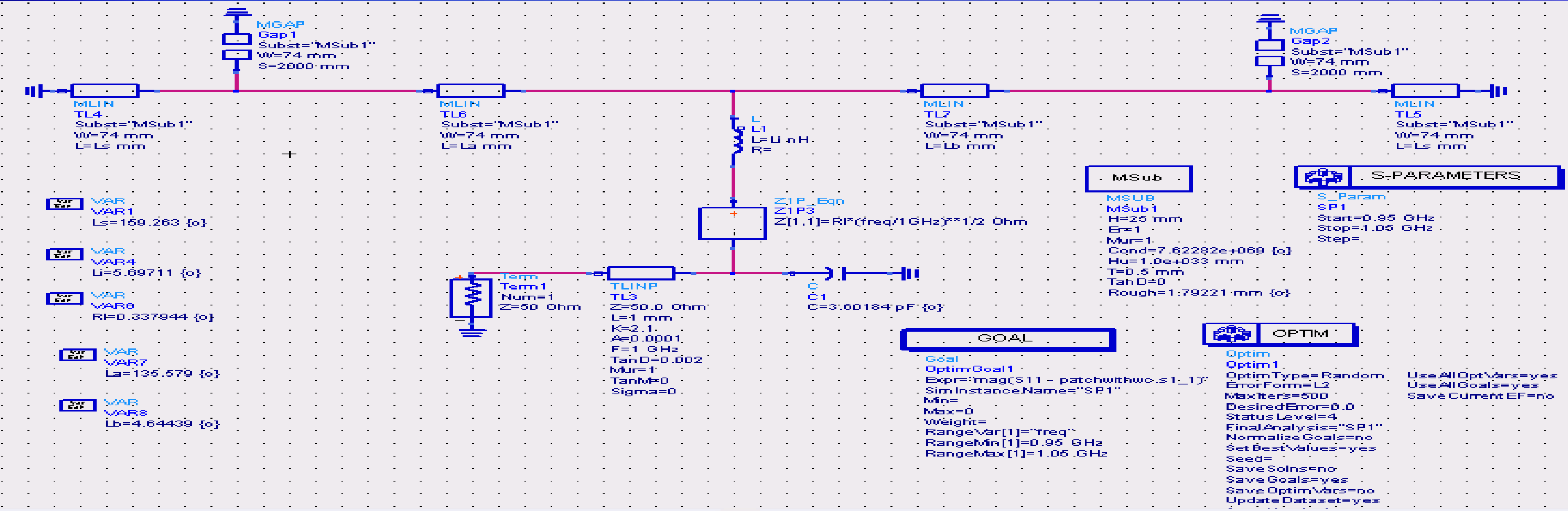
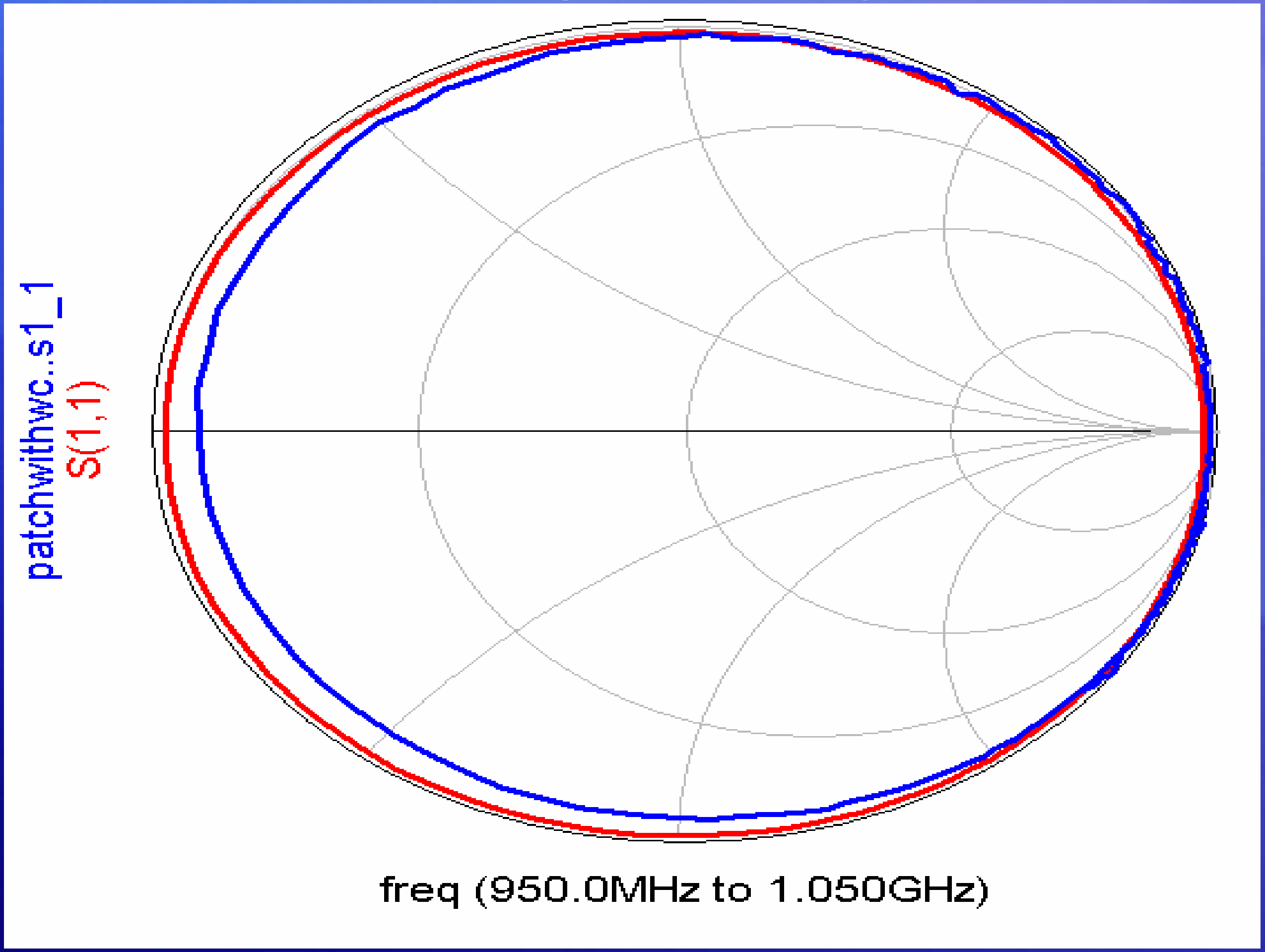


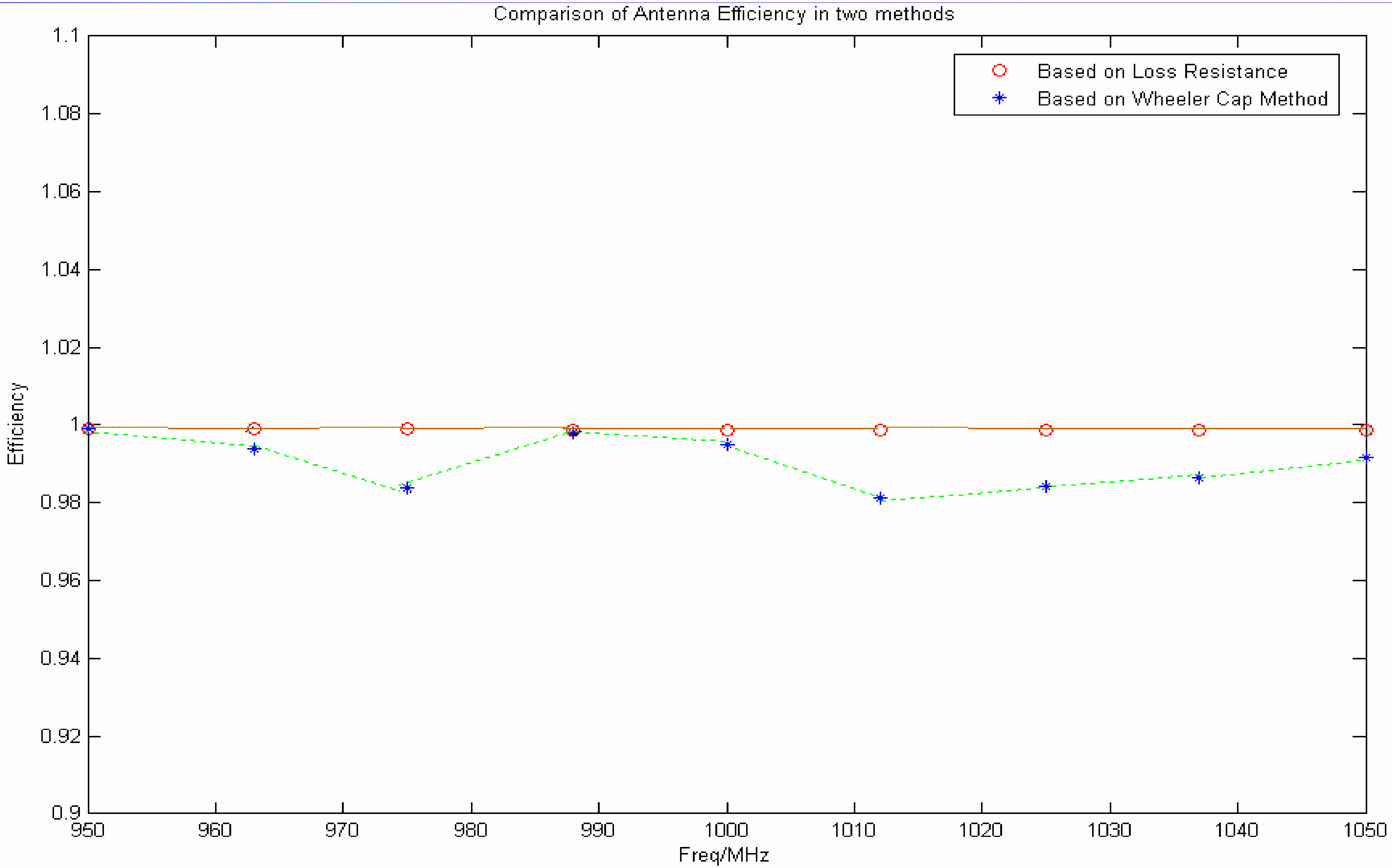
Fig. 4.30 Loss circuit of under test antenna

Modeling of a Patch-Antenna

We use this network model to fit the measured circuit and then get the loss resistance. The final optimized agreement is shown below.



Modeling of a Patch-Antenna



Modeling of a Patch-Antenna

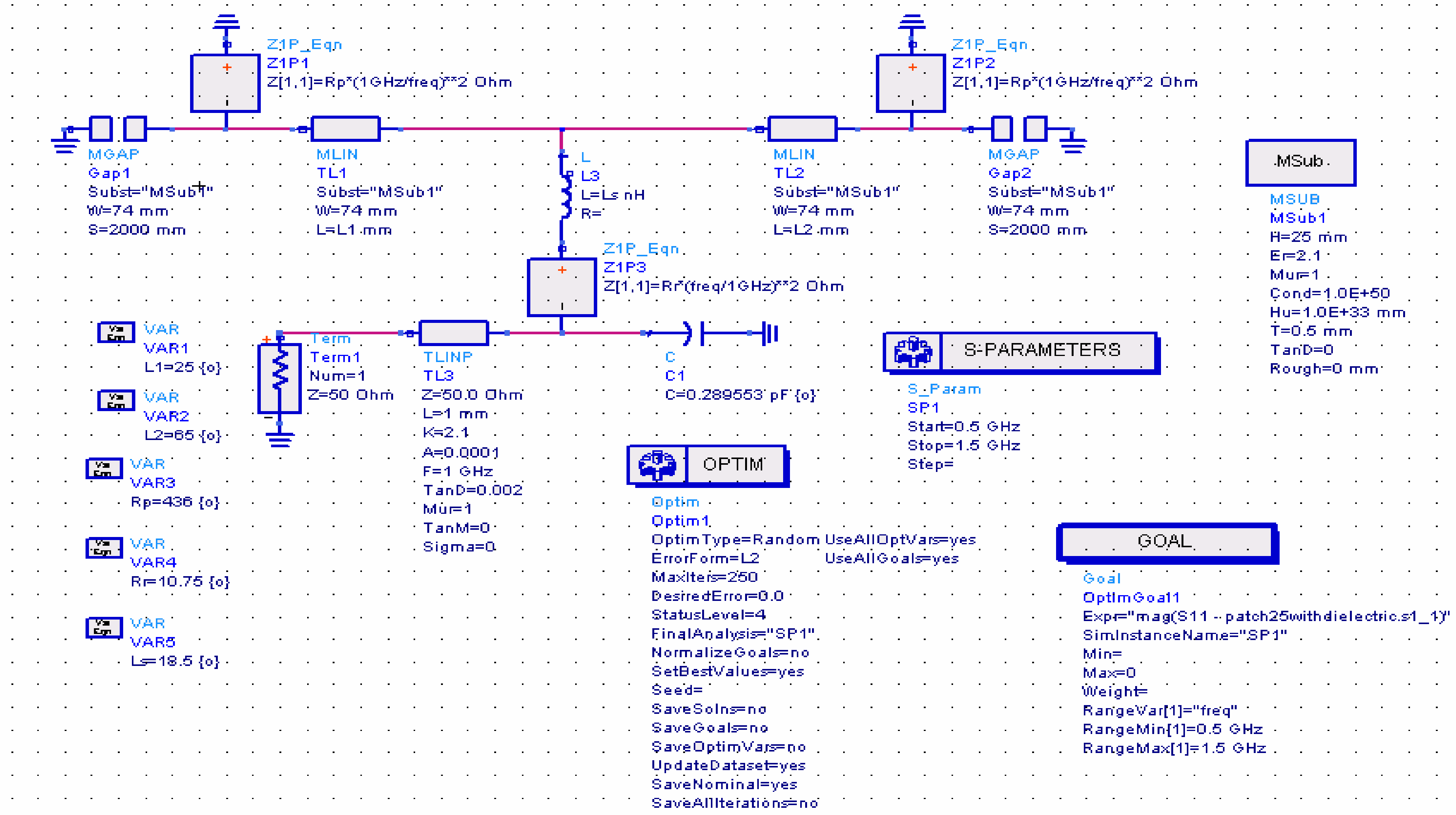
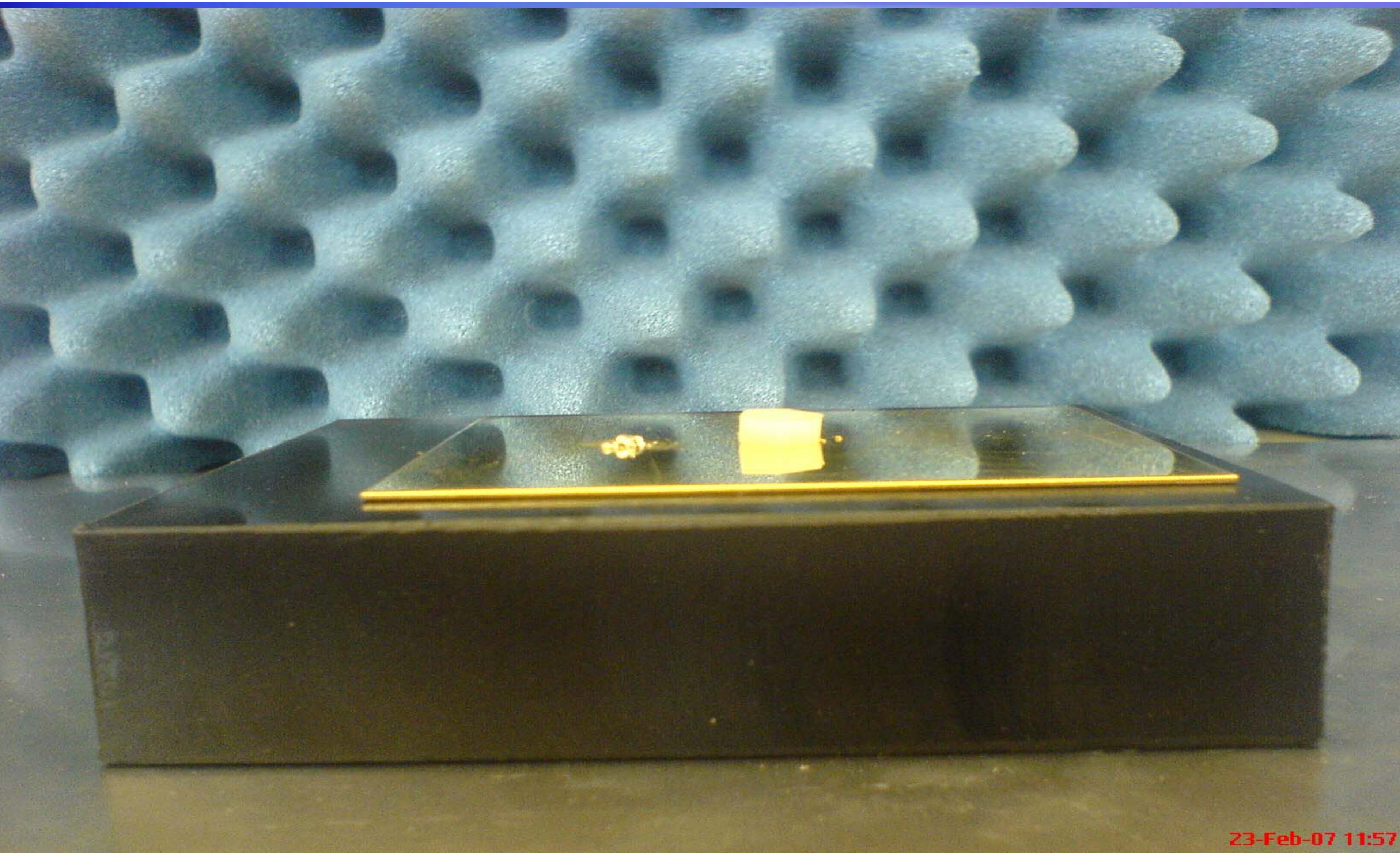


Fig. 4. 33 Equivalent circuit of a patch antenna over a dielectric substrate

Modeling of a Patch-Antenna



Modeling of a Patch-Antenna

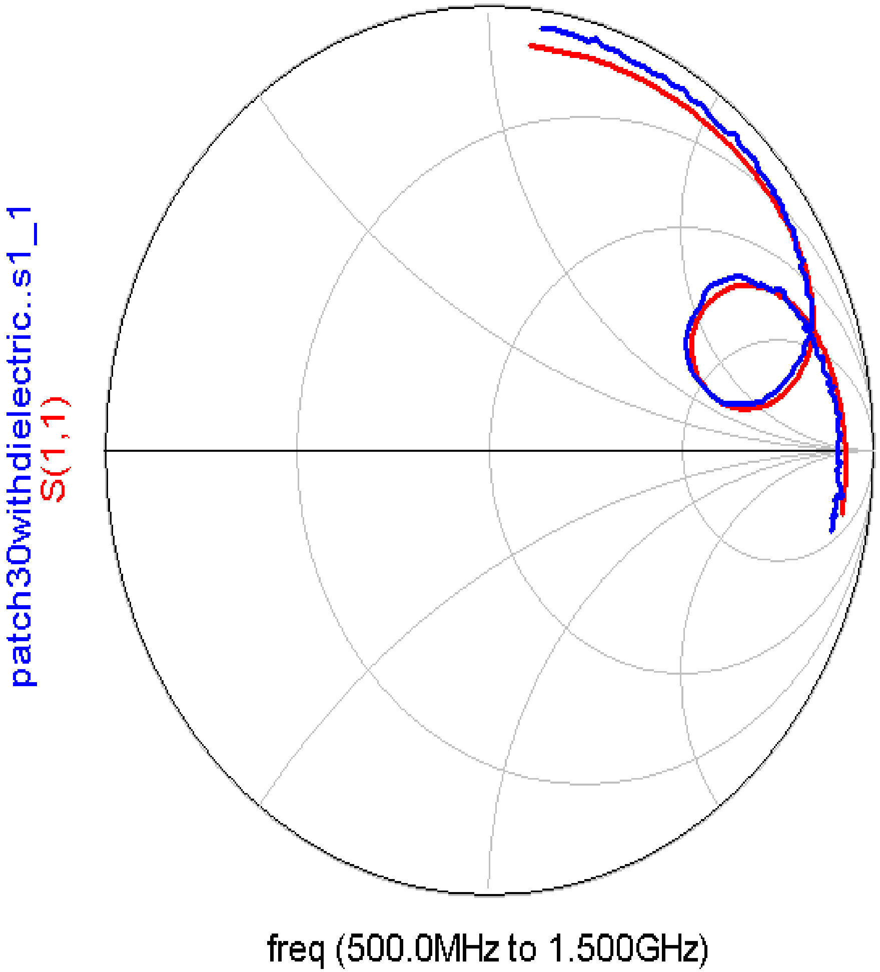


Fig. 4.34 h= 30 mm

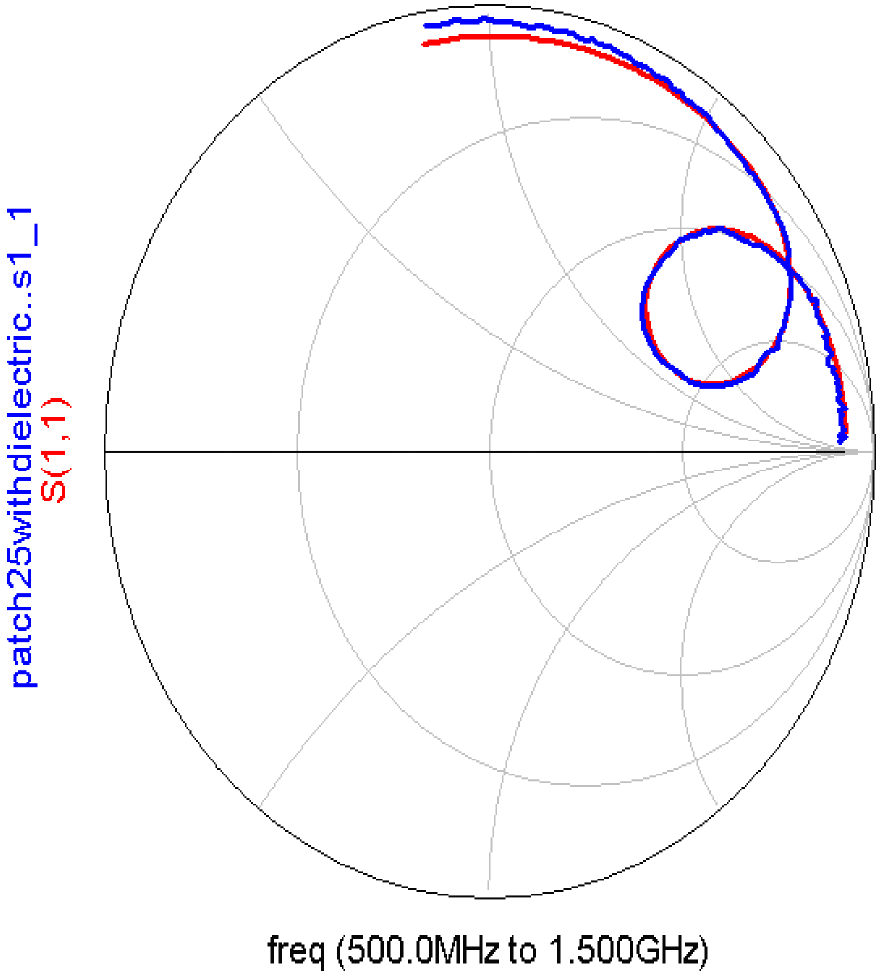


Fig. 4.35 h= 25 mm

Modeling of a Patch-Antenna

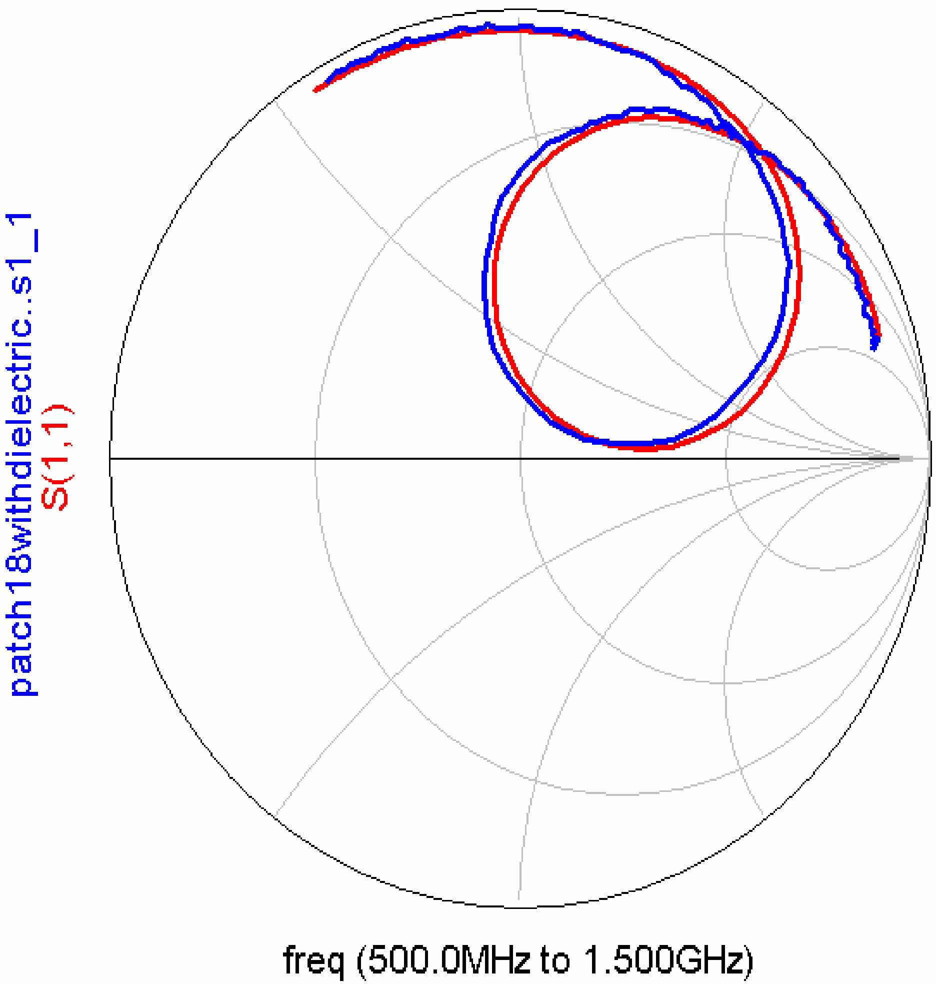


Fig. 4.36 h= 18 mm

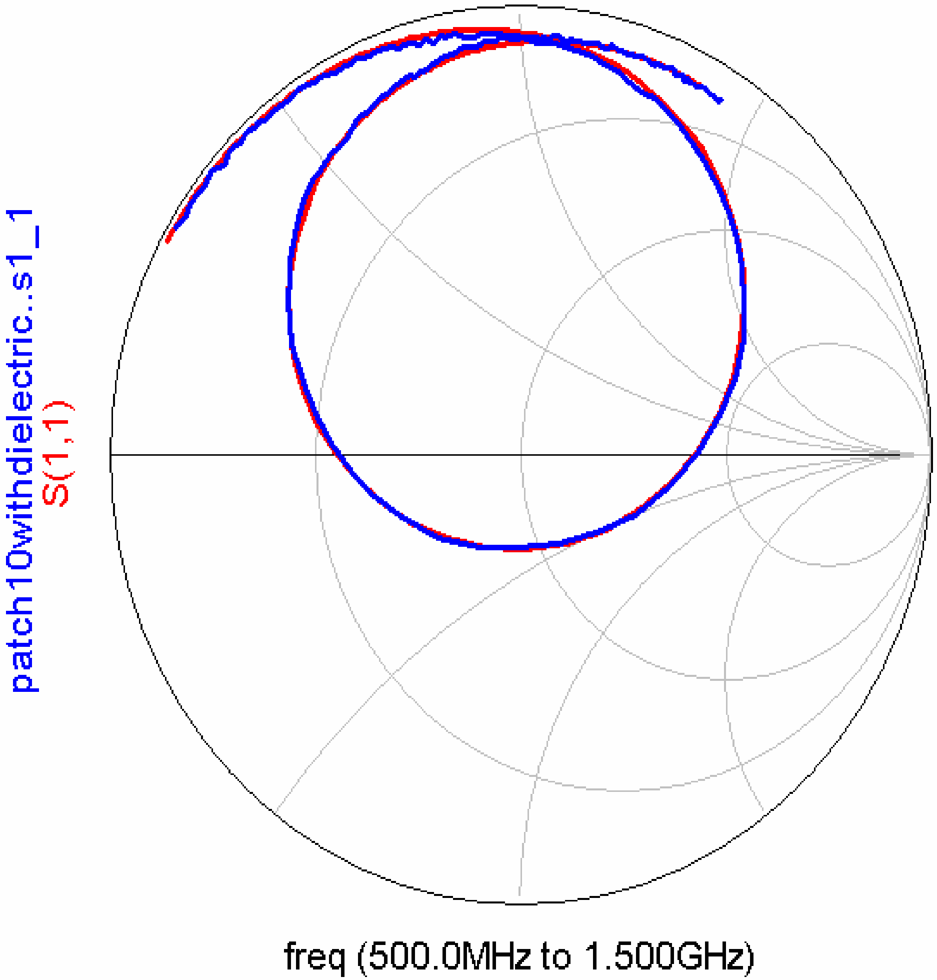


Fig. 4. 37 h= 10mm

Modeling of a Patch-Antenna

From the above figures we see curves fit well each other. Thus we can say the equivalent circuit network modeling is valid to present patch antennas.

Modeling of a Patch-Antenna

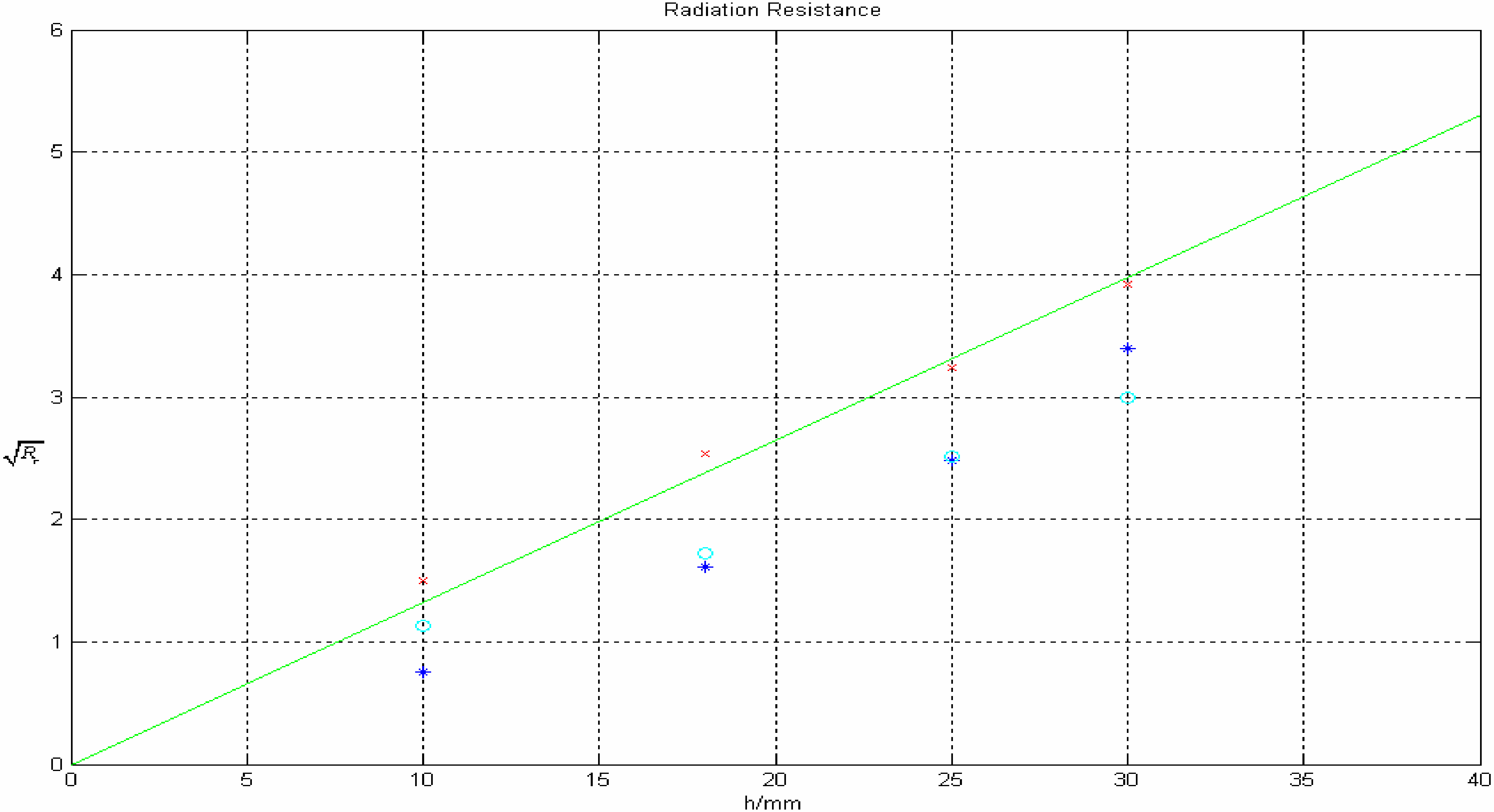


Fig. 4.38 Theoretical (green line); measured results in air (red x);
measured results in dielectric (blue *);
measured results of a disk-loaded monopole in dielectric (cyan o).

Modeling of a Patch-Antenna

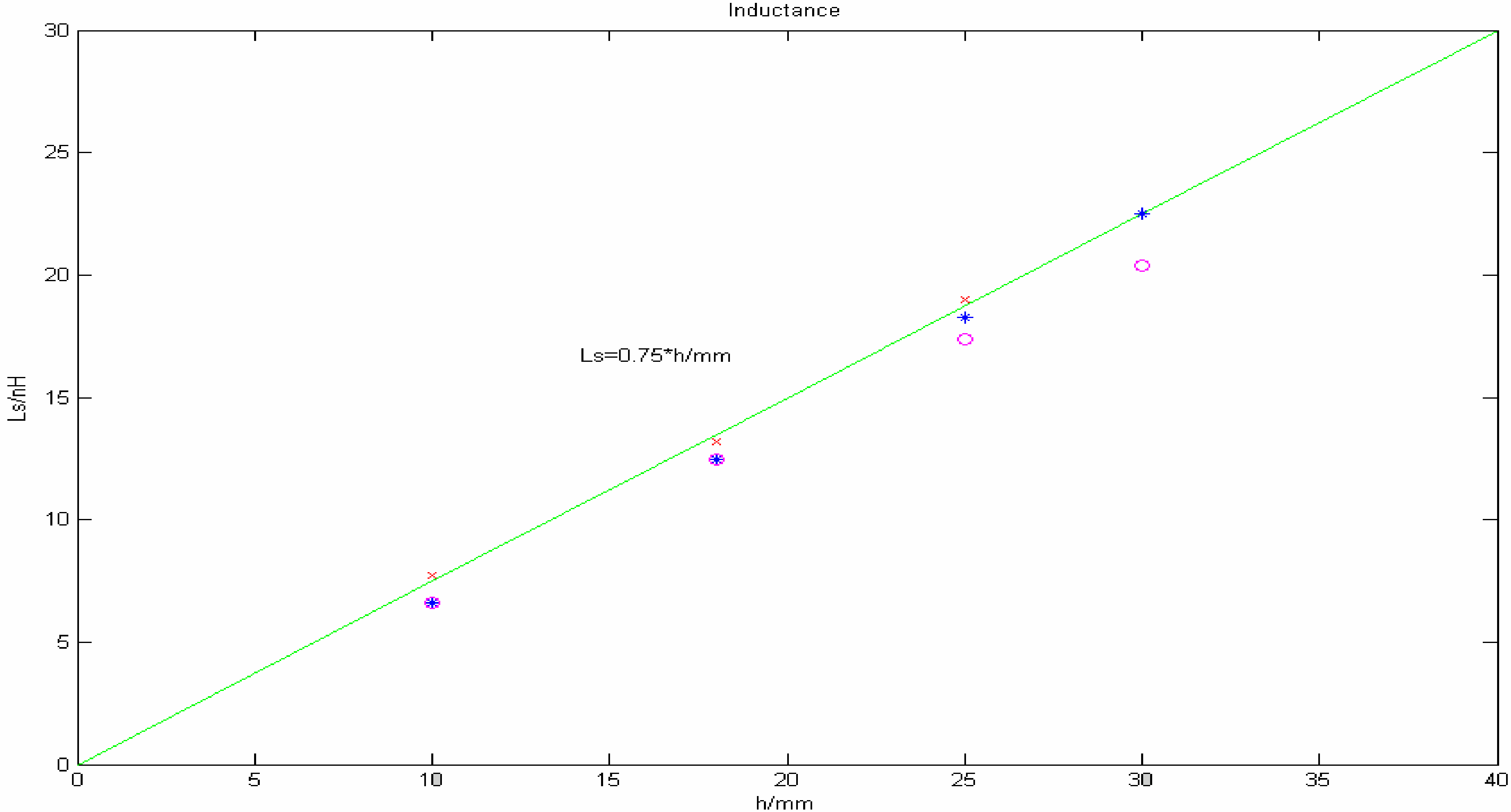


Fig. 4.39 theoretical data (green line); in air (red x);
the feeding probe in dielectric (blue *);
the disk-loaded monopole in dielectric (magenta o).

Modeling of a Patch-Antenna

In the first figure it shows the comparison of resistance in different situations. The green line is Hertzian theoretical values; the measured values in air is red x; the measured values in dielectric material is blue *; the measured results of a disk-loaded monopole in dielectric material is cyan o.

In the second figure it shows the comparison of inductance in three different situations. The theoretical values is the green line; the feeding probe values in dielectric material is blue *; the disk-loaded monopole values in dielectric material is magenta o.

Modeling of a Patch-Antenna

Through the comparison of resistance and inductance in different situations the equivalent circuit network model is proved again and the current distribution along the feeding probe is uniform.

Conclusion

The equivalent circuit networks of disk-loaded monopoles and probe-fed patch antennas are proved experimentally and theoretically. Moreover, through the final results and comparison we see the modeling is valid to present the disk-loaded monopoles and patch antennas.

Meanwhile, we measured the efficiency of the patch antennas in two ways: adapted Wheeler Cap method and equivalent circuit network model based on loss resistance. And the asymmetric E-plane pattern is analyzed also.

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Thanks for your attention!!