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Guiding Electromagnetic Systems

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Project 2

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1 Introduction

In this report, we propose to design an edge-fed rectangular single patch radiator with the following specifications:

- operating frequency equal to $f = 2.4\ GHz$;
- circuit board dielectric material $\varepsilon_r = 2.55$;
- height of Microstrip Board $h = 0.8\ mm$;
- Reference impedance $Z_0 = 50\ \Omega$;

Starting from these specifications, we want to design the patch antenna shown in the Fig.1, following this procedure:

a) Design the circuit layout;
b) Insert an impedance transformer to 50 Ω and allow a segment of input microstrip line for the connection to the connector;
c) Simulate the frequency response of the complete system using PUFF tool;
d) Using a CAD tool, print the full scale layout in the PDF file format (please check carefully all the dimensions on the paper printed layout);
e) Measure the frequency response of the device;

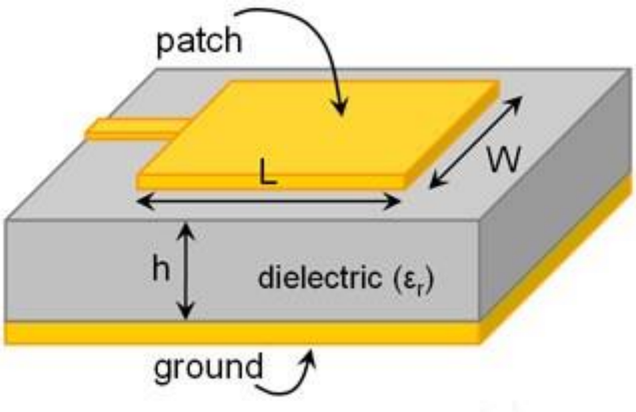


Fig. 1 - *Edge-Fed Microstrip patch Antenna*

2 Design

The first step to design the proposed Microstrip patch is to evaluate the width W of the Patch using the following relation:

$$W = \frac{c}{2 \cdot f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \cong 46.9\, mm$$

where f_r is the operating frequency. Therefore, the effective dielectric constant for a Microstrip is defined as:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12\, \frac{h}{W}}} \cong 2.4811$$

Now, to evaluate the geometric length of the Patch, we need to compute the effective length L_{eff} of the patch, that by definition is around $\lambda_g / 2$, and the ratio $\Delta L/h$; so we have:

$$L_{eff} = L + 2\Delta L \cong \frac{\lambda_g}{2} = \frac{1}{2} \cdot \frac{\frac{c}{\sqrt{\varepsilon_{eff}}}}{f_r} \cong 39.7\, mm$$

$$\frac{\Delta L}{h} = 0.412 \frac{\left(\varepsilon_{eff} + 0.3 \right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{eff} - 0.258 \right)\left(\frac{W}{h} + 0.8\right)} \cong 0.5108$$

$$\Delta L \cong 0{,}41\, mm$$

At this point L can be immediately obtained by this relation:

$$L = L_{eff} - 2\Delta L \cong 38.9\, mm$$

The next step of the design consist to evaluate the radiation parameters using the transmission line equivalent model of the patch.
In fact the Microstrip patch can be seen as the characteristic impedance of the line closed on the admittances, as shown in the next Fig.2:

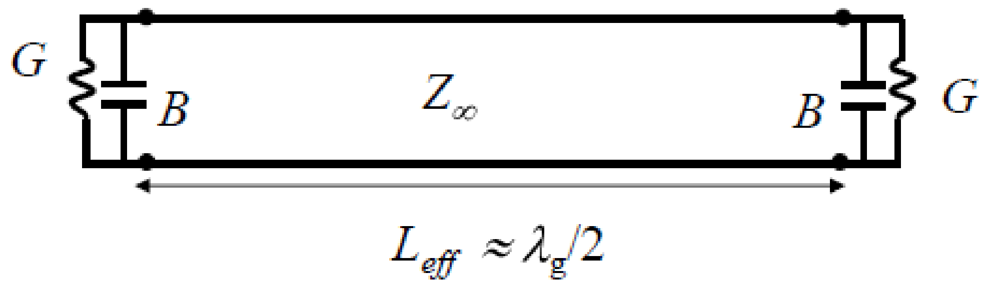


Fig. 2 - *Equivalent transmission line model of the rectangular patch*

The equivalent conductance G and susceptance B, can be computed as:

$$G = \frac{W}{120\,\lambda_0}\left[1 - \frac{1}{24}\left(\frac{2\pi h}{\lambda_0}\right)^2\right] \cong 3.1\ mS$$

$$B = \frac{W}{120\,\lambda_0}\left[1 - 0.636 \cdot ln\left(\frac{2\pi h}{\lambda_0}\right)^2\right] \cong -17.4\ mS$$

The input radiation impedance can be approximated as:

$$Z_{IN} = \frac{1}{Y_{IN}} \cong \frac{1}{2G} = 160\ \Omega$$

Now, to evaluate the characteristic impedance Z_∞ of the microstrip line, we must evaluate the ratio W/h in order to extrapolate the formula to be used for computation:

$$\frac{W}{h} = 58.6 > 1 \quad \Longrightarrow$$

$$Z_\infty = \frac{120\,\pi}{\sqrt{\varepsilon_{eff}}\left[\frac{W}{h} + 1.393 + 0.067\,ln\left(\frac{W}{h} + 1.444\right)\right]} \cong 3.86\ \Omega$$

Finally, we design the impedance transformer of 50 Ω with the purpose to connect the antenna at the external connector. The impedance transformer is equal to:

$$Z_1 = \sqrt{Z_{IN} \cdot Z_0} \cong 89.41\ \Omega$$

While the length dimensions of this impedance transformer

$$L_1 = \frac{\lambda_g}{4} = \frac{c_0}{4\ f_0\ \sqrt{\varepsilon_{eff}}} \cong 20.1\ mm$$

3 Simulation

The complete rectangular patch antenna designed in the previous section, is implemented by PUFF software in order to check the specifications, simulating the scattering parameters.
In the following Fig.3 we have the schematic circuit of the antenna implemented on the PUFF.

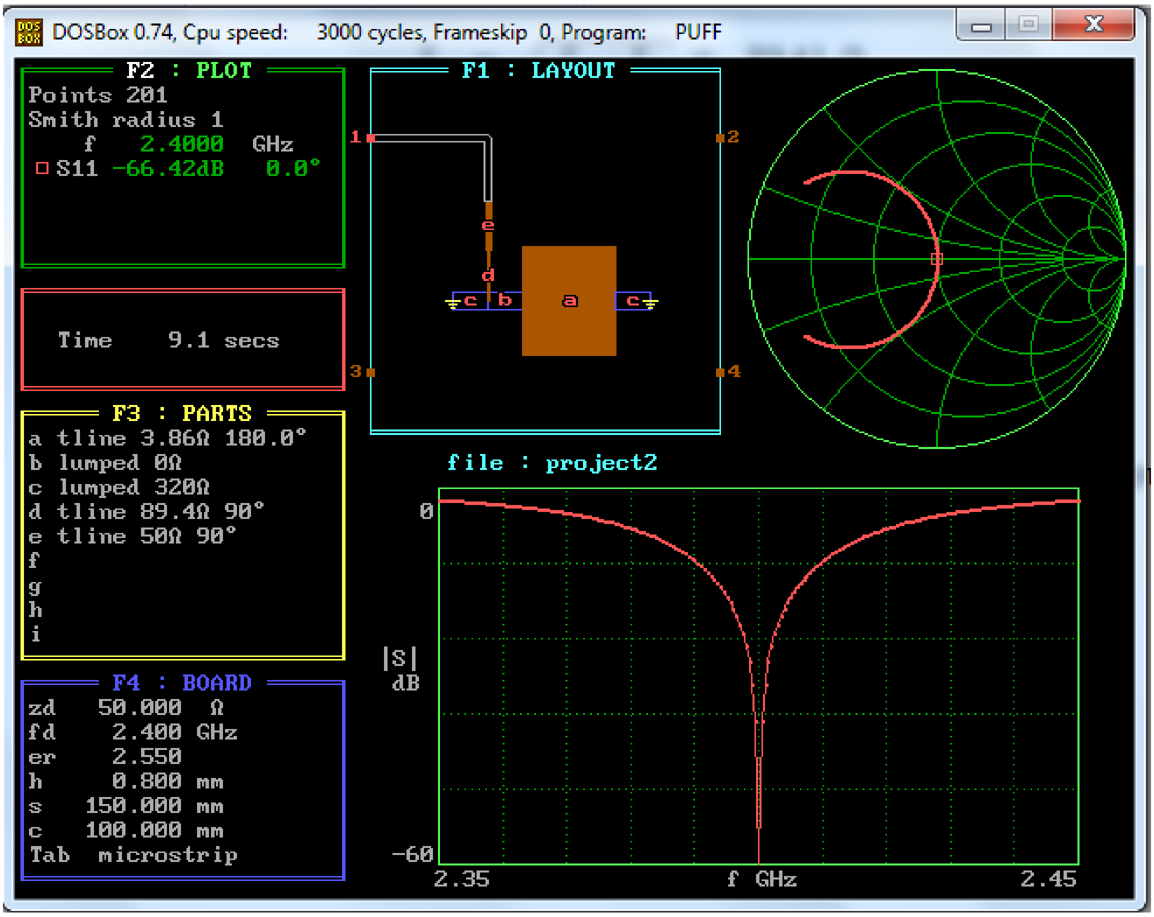


Fig. 3 - *S11 of the Patch Antenna*

The Transmission line ‘a’ is needed to simulate the characteristic impedance of the microstrip line, while the two lumped resistance ‘c’ connected in parallel approximate the behavior of the radiation impedance. The impedance transformer is implemented by the transmission line ‘d’. In our design we have added another one piece of line; this line have a characteristic impedance of 50 Ω and electrical length of 90° in order to have a reference impedance input interface.
Once drawn the layout, we have simulated the scattering parameter behavior, in particular we need to check the reflection coefficient S_{11}.
From the graph of the figure 3, we can observe that the magnitude of the input reflection coefficient in a very narrow band centered at resonance frequency is very low, around -66.4 dB.
In the figure 4, we have the effective dimensions of the rectangular patch in the PUFF software. While the dimensions of the impedance transformer and the line of 50 Ω are shown respectively in Fig.5 and Fig.6, while the following table (Tab.1) summarizes all dimensions.

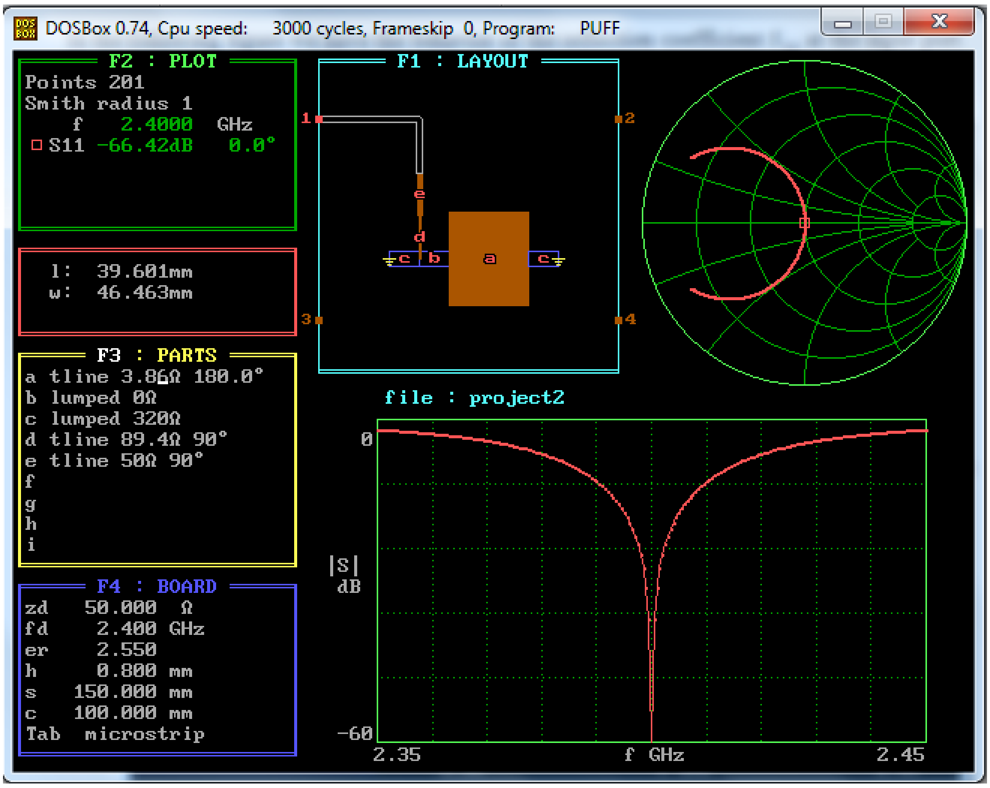


Fig. 4 - *Patch Antenna Dimensions*

Device	Length	Width
Patch	39.601 mm	46.463 mm
50 Ω Line	21.369 mm	2.258 mm
Impedance Transformer	22.046 mm	0.804 mm

Tab. 1 - *Summary table of the dimensions*

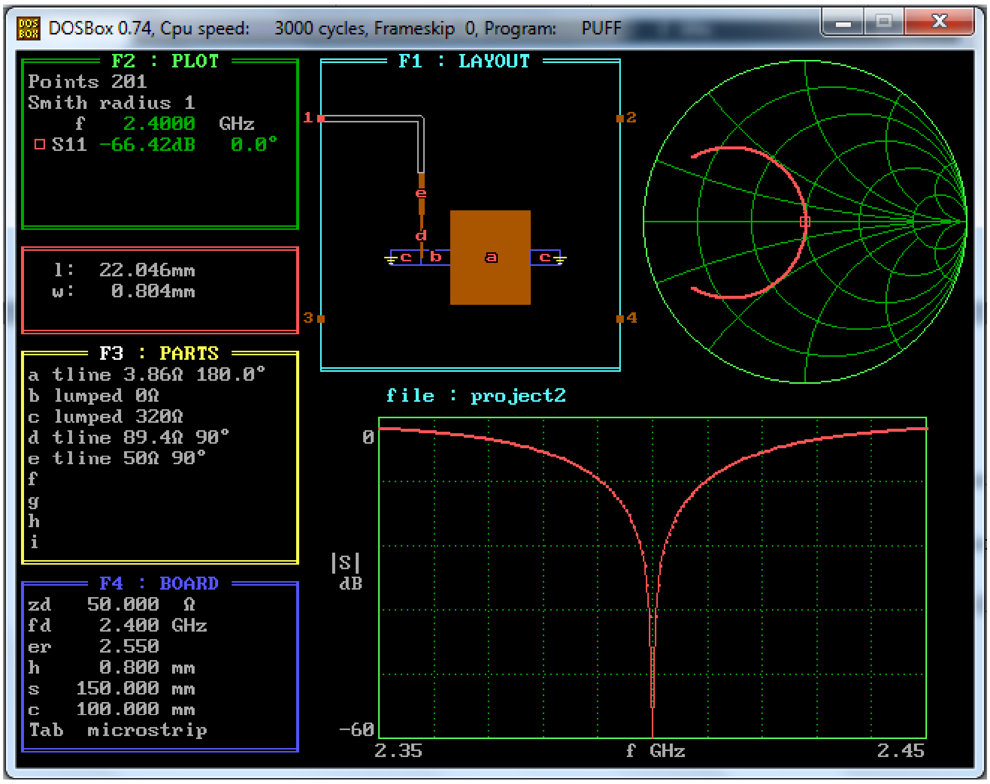


Fig. 5 - *Impedance transformer Dimensions*

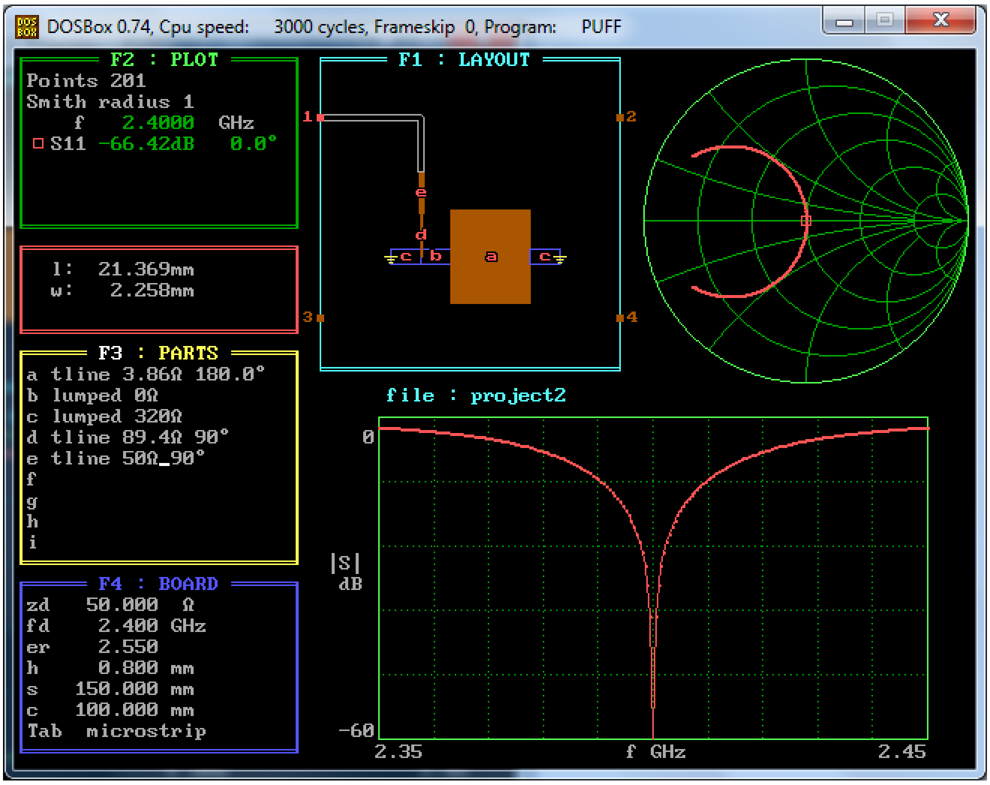


Fig. 6 - *50 Ω Line Dimensions*

The screenshots confirm that the reflection coefficient is the one that describes well the circuit. In fact, we have reflection coefficients with magnitude around -66 dB, that correspond to a very good-matched port, however this reflection coefficient is obtained using an ideal model (without losses) of the transmission lines.
Thus, to have a more realistic results, we used an advanced model of the transmission line which is called *tline!* In the PUFF software. This model includes the losses of the lines, so we expect that the reflection coefficient increases.
In the figure 7, is shown the implemented patch antenna using the advanced model of the transmission lines.

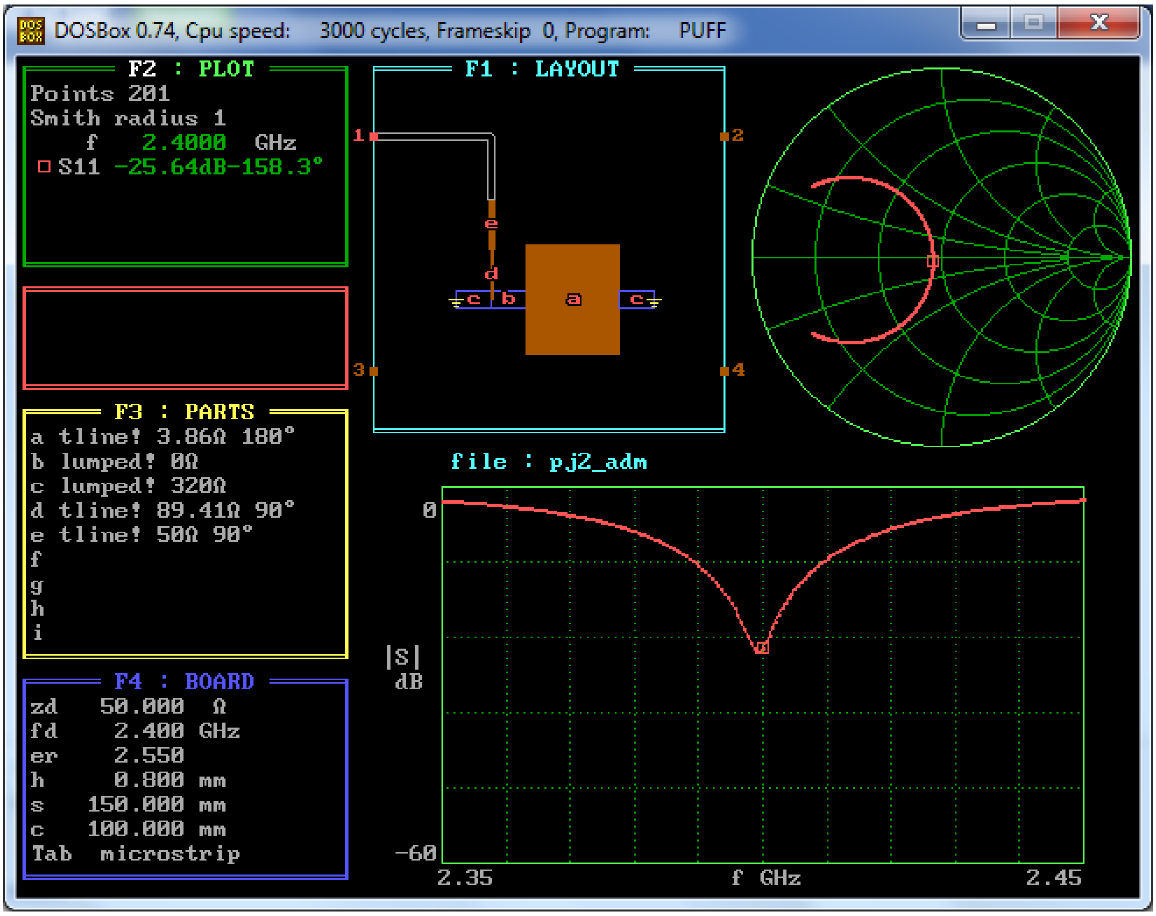


Fig. 7 - *S11 of the Patch Antenna using advanced models*

As we expected, in this case the magnitude of the s11 is more greater with respect to the previous case with transmission lines without losses. Therefore, we have a model more realistic which will be compared to the measurements.
After the simulations, we have to confirm those results with an experiment, while using a real microstrip device and a vectorial network analyzer.

4 Layout

In order to print the full scale layout in the PDF file format, we have used a CAD tool (Multiboard). The final Layout is shown in the Fig.8.

For this Layout, We have used the dimensions extracted from the Puff software.

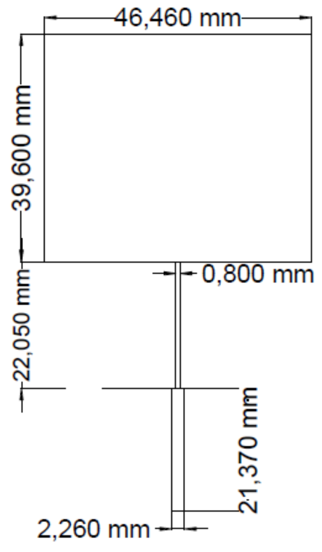


Fig. 8 – *Layout of the Patch Antenna*

5 Measurements

Once manufactured the patch with Microstrip Rexolite technology, we verified the correctness of the project proceeding with measurements. The Figure 9 shows the Microstrip Antenna realized with the technology process provided by the specifications. We can observe that have been inserted a coaxial-to-microstrip transition to connect the device to the measurement instrumentation.
At a first step, we verified the effective dimension of the patch comparing with the ones of the project as shown in the following pictures (Fig. 10).

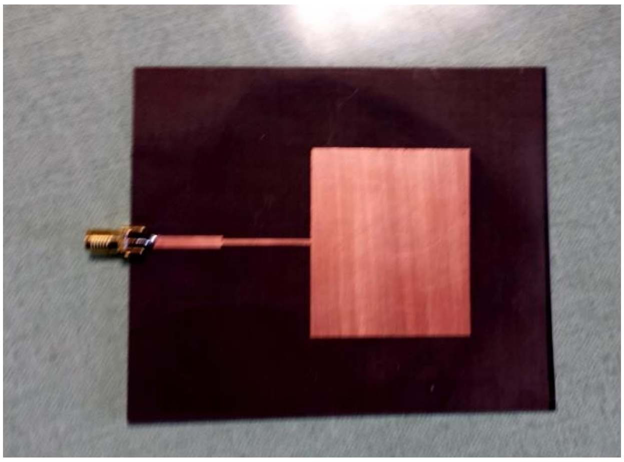
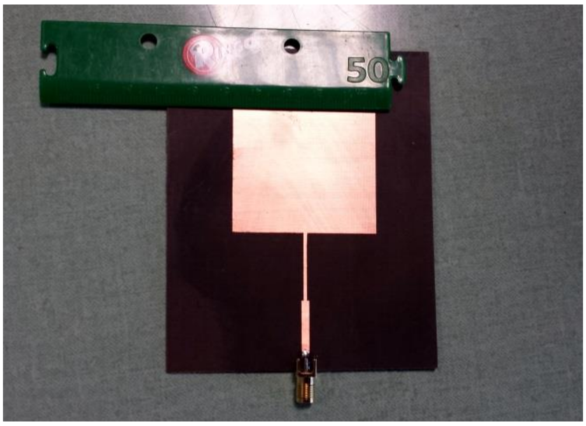
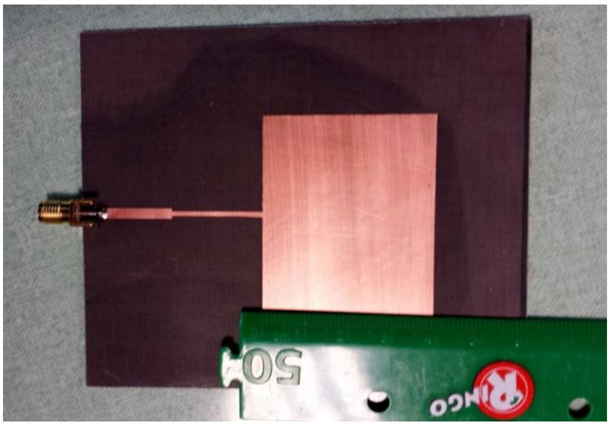


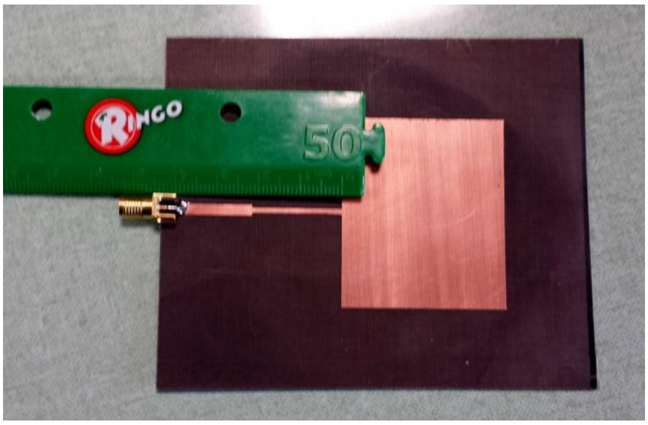
Fig. 9 - *Microstrip Patch Antenna* + *Coaxial-to-Microstrip Transition*



(a)



(b)



(c)

Fig. 10 - *Dimensions of the manufactured patch: (a) L ≅ 4cm; (b) W ≅ 4.6 cm; (c)* $L_a + L_{50} \cong 4.4$ *cm*

In order to evaluate the reflection coefficient, we used a network analyzer in the LED Laboratory. This kind of instrument measures the scattering parameters of an n-port network. The first step, consist on the calibration of the instrument using a calibration kit, which it is often provided with the analyzer.

After the calibration step, we start the measurements connecting the patch antenna at the port 1 of the analyzer. We set the frequency range from 1 GHz to 6 GHz, and we put the marker on the lowest value in the plot of S_{11} near the operating frequency.

This result is shown in the figure 10, where we can immediately observe that in the point when the input reflection is minimum the operating frequency is around 2.3 GHz. This frequency does not corresponds to the operating frequency at which we have designed the antenna. Moreover, the magnitude of the reflection coefficient is around -12 dB which is much higher than the value obtained in the simulation with lossless lines, and greater than the value obtained with lossy lines.

An operating frequency smaller than the desired frequency, means to have an antenna a bit longer than it should be, so we need to reduce the length of the antenna. Since is not possible to realize another device, in order to reduce the antenna dimensions we have reduced manually the length of the antenna through a cutting operation, as shown in Fig. 11.

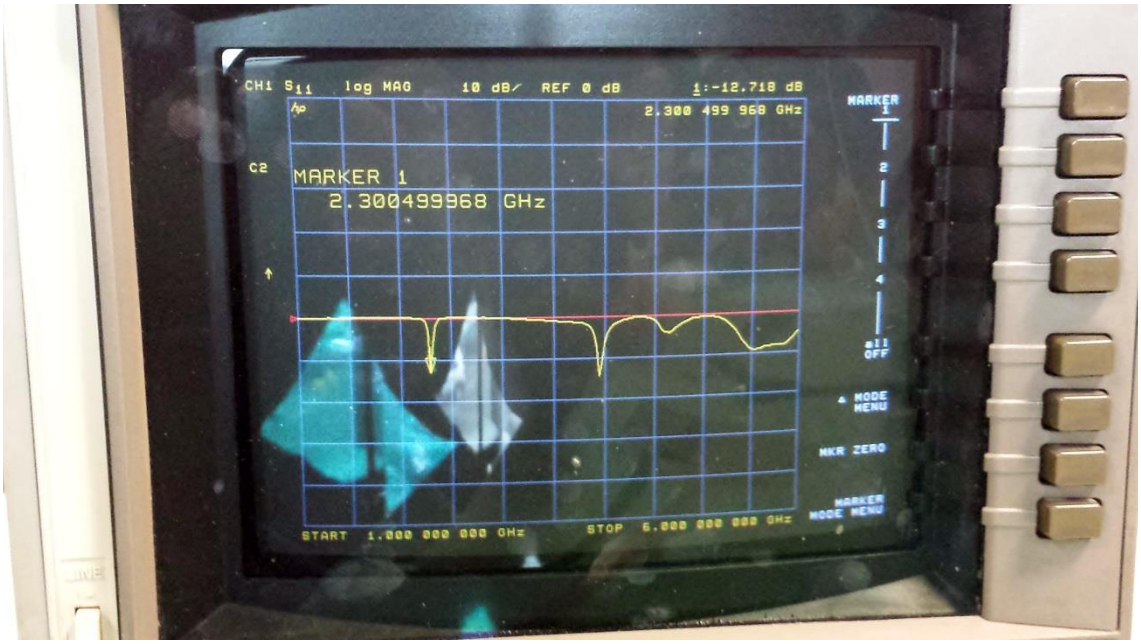


Fig. 10 - *First* S_{11} *measurement through the network analyzer*

Fig. 11 – *Cutting operation manually on the antenna*

Thanks to several cutting operation, we were able to bring the operating frequency at the desired frequency which is 2.4 GHz. The figure 12 shows the reflection coefficient at 2.4 GHz; at this frequency the magnitude of S_{11} is equal to around -10 dB which is smaller than the previous case. Therefore we have obtained the desired operating frequency but the scattering parameter is different from the simulation.

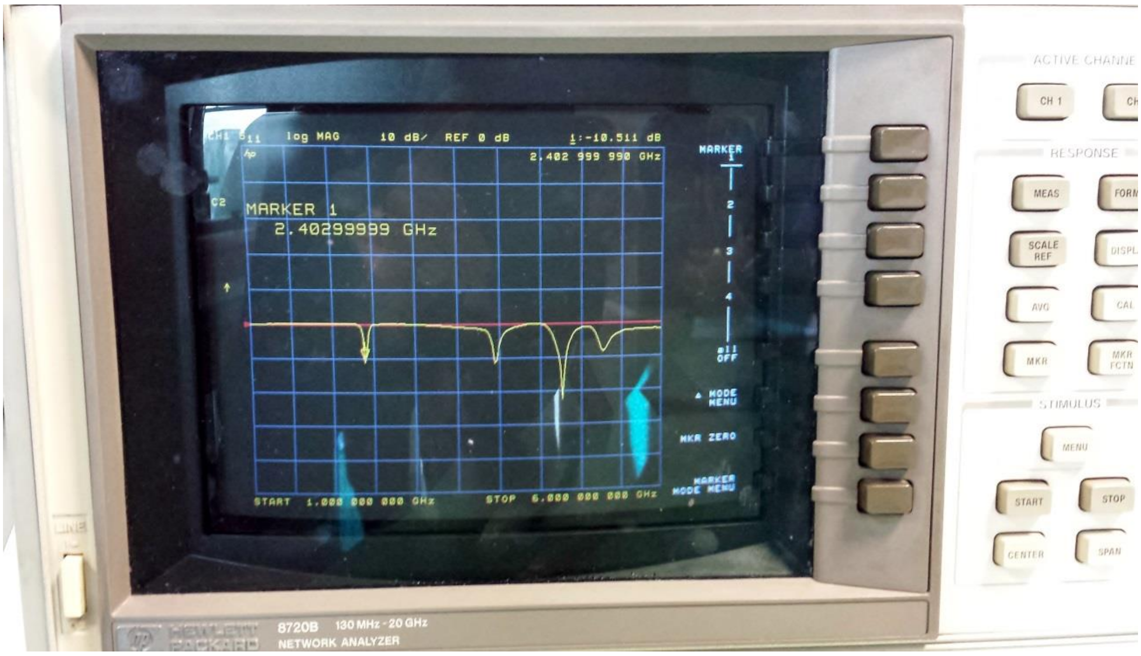


Fig. 12 – *Second* S_{11} *measurement through the network analyzer*

6 Conclusions

Finally, to conclude this report we can say that we have obtained different results between the simulation of PUFF software and the measurement through the network analyzer.

The first point to analyze, is the difference of the frequencies between the simulation and the measurements. This can be attributed to the possibility that the model and formulas using for this project, are different by the model of the constructor's process technology, moreover the difference of around 100 MHz can be also associated to the fact that the model used is an approximated prototype.

The second point, concerns the fact that the measured reflection coefficient is much higher than the simulations. The first cause is certainly the introduction of the coaxial-to-microstrip transition that reduces the total reflection coefficient, moreover also in this case can be influenced by the diffent models used.

However the value obtained from the measurements is good, but to have a better mapping between the project and the realized model we need a more accurate models.