# EFFICIENCY MEASUREMENT IN PLANAR MONOPOLE ANTENNA OF SIZE REDUCTION WITH BRANCHES FOR WIRELESS APPLICATION

C. M. Costa Jr[1], G. Fontgalland[1], R. C. S. Freire[1], R. M. Valle[1], N. I. Morimoto[2]

[1]Electrical Engineering Department, Federal University of Campina Grande - UFCG
Av. Aprígio Veloso, 882, 58.429-140, Campina Grande, Paraiba, Brazil
Phone: +55-83-3310-1535, Fax: +55-83-3310-1418, Emails: crezojr@yahoo.com, fontgalland@dee.ufcg.edu.br
rcsfreire@dee.ufcg.edu.br, rvalle@dee.ufcg.edu.br

[2]Head of Microsystem Division Integrated System Lab, Polytechnic School, University of São Paulo, Brazil
Av. Prof. Luciano Gualberto, 158 – Trav. 305508-900 - São Paulo, São Paulo, Brazil.
Phone: +55-11- 3091-5314/5666, Email: morimoto@lsi.usp.br

**Abstract:** In this paper we present the radiation efficiency in planar monopole antenna of size reduction with branches for wireless application. These antennas were made using two type of substrate: FR4 and LTCC. The former is most commercially used in PCB circuits and the latter widely used in communication systems. The miniaturized antennas used in this work were obtained after introduced short circuit pin and slots in its structures. To get the radiation efficiency will be used a reverberation chamber and measured the scattering parameters for transmission and reflection coefficient of the excitation in the relation the antenna under test and the reference antenna.

**Keywords:** planar antenna, efficiency, reverberation chamber.

## 1. INTRODUCTION

Due a high demand to wireless electronic equipment, one of the greatest technological challenges and essential to the success of these equipments is to provide the greatest number of services possible, have a small size and low cost. The wireless electronic equipment usually operates in multipath environment, for example receiving signals from many directions [1]. An important device in this kind of equipment is the antenna that should be compact and lightweight [1]-[2] and have high efficiency, to reduce the consumption of the battery.

An appropriate environment to measure the radiation efficiency is the reverberation chamber [3]-[5]. It is a closed setting, very similar to a resonant cavity, to reproduce the real operating environment of an electronic equipment. The reverberation chamber is appropriate to reproduce a car or a screened room and require low measurement cost.

To measure the radiation efficiency is need only the scattering parameters for transmission and reflection coefficient of the excitation in the relation the antenna under test and the reference antenna [3]-[4]. The disadvantage is the fact that needs three antennas, and the antenna used as reference to be calibrated

After the scattering parameters obtained for the reference antenna and to antenna under test is then calculated the power transfer function for both, $P_{ref}$ and $P_{aut}$, respectively. The antenna efficiency is obtained through the relationship between $P_{aut}$ and $P_{ref}$.

When these antennas become too small some important characteristics maybe changed, as antenna radiation, input impedance and resonance frequency [2], [6]-[9]. Consequently, we have antennas that have small efficiency, reduced bandwidth and distortion of the radiation pattern.

The technique for the reduction of the antennas physical size applied in this work is the use of a short circuit pin [2], [7] and a modification in the antenna geometry with introduction of two and three slots [9].

These antennas were made using two type of substrate: FR4 and LTCC (Low Temperature Co-fired Ceramic). The former is most commercially used in PCB circuits and the latter widely used in communication systems. The substrate LTCC Dupont 951-AX have high permittivity and stable for a wide range of frequency, has a small loss tangent and presents electrical and mechanical properties that are compatibility with applications in communication systems [10]. The central frequency adopted in this work is 2.45 GHz that is used in the free ISM range (Industrial, Scientific and Medical).

After a briefly introduction in section 1 about micro-antennas and radiation efficiency, the planar antenna geometry with short circuit pin and slot for the size reduction, is presented in section 2. In this section it is also presented the simulated results to return loss using the software CST-Microwave Studio, well as, the measured results. In the section 3 is described the procedure used to measure the antennas efficiency. In the section 4 are presented the measured result. In section 5, the conclusions are drawn.

## 2. ANTENNA GEOMETRY

The patch antenna geometry with three branches (E-antenna) is shown in Fig. 1a. The antenna consists of a rectangular patch with length $L$ and width $W$, supported by dielectric substrate of thickness $h$, dielectric constant $\varepsilon_r$ and loss tangent $tan\delta$. The feeding point is positioned at a distance $d_f$ from edge. The feeding connection radius is identified as $r_f$, and the short circuit pin is identified as $r_s$ and is located at a distance $d_s$ from edge. The width of the arms is identified as $w_a$ and length as $l_a$. The patch is $d$ mm smaller than the substrate in all edges. The coaxial probe-feed was chosen to the antenna excitation (Fig 1c), to facilitate the matching by just making an adjustment in the probe position.

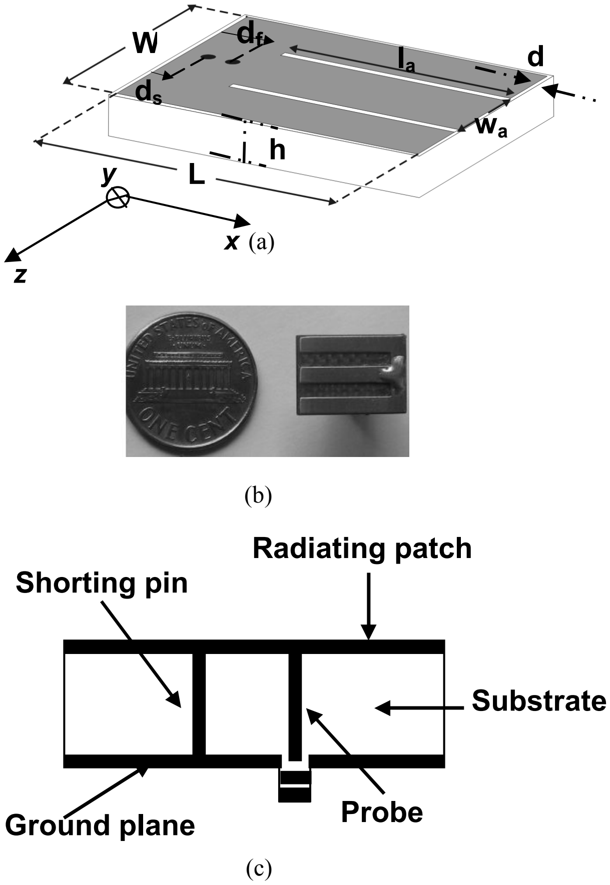


Fig. 1. (a) Patch antenna geometry with three branches, (b) photograph of top of the antenna, (c) Feeding structure.

The parameters used in the patch antenna with three branches (E-antenna) were: $L$ = 13.6 mm, W=9.6 mm, $l_a$=11.6 mm, $w_a$=2.0 mm, $r_f$ = 0.3 mm, $r_s$ = 0.3 mm, $d_f$ = 1.4 mm, $d_s$ = 0.4 mm and $d$ = 0.2 mm. The substrate used was FR4 with electrical characteristic ($\varepsilon_r$=4.6 and $tan\delta$=0.02) and h=1.6 mm. The values $l_a$=11.7 mm and $w_a$=2.0 mm were chosen to study.

The variation in the resonance frequency when the branches were introduced in the structure was compared with the patch antenna of same length $L$ and width $W$. To obtain a better adaptation, the $d_f$ was fixed as 1.7 mm. The patch antenna and to E-antenna return loss results are shown in the Fig 2.

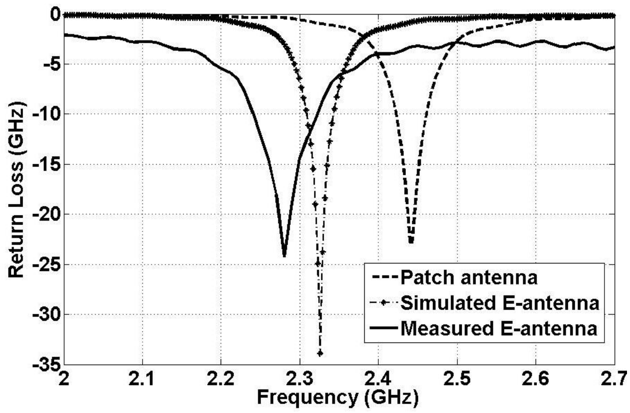


Fig. 2. The return loss results for patch antenna and E-antenna.

The patch antenna return loss simulated result (Fig. 2) was -23.0 dB, in 2.44 GHz. The return loss simulated result to E-antenna was -33.9 dB, in 2.32 GHz. It was observed a shift of 120 MHz between the simulated result to patch antenna and E-antenna. The measured result to E-antenna was -24.24 dB, in 2.28 GHz with a difference of between 49 MHz in the resonance frequency between the result simulated e measured. The radiation pattern simulated for E-antenna is shown in Fig. 3.

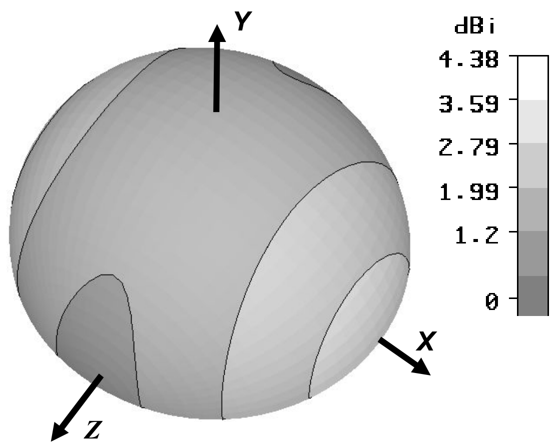


Fig. 3. The radiation pattern simulated for E-antenna.

The radiation pattern (Fig. 3) has a maximum intensity in the $x$-axis around of 4.38 dBi, and present a minimum intensity in relation to the $z$-axis around of 0 dBi.

The other antenna designed was a patch antenna with four branches (Fig. 4). The substrate used was the LTCC Dupont 951-AX with electric characteristic ($\varepsilon_r$=7.8 and $tan\delta$=0.006) and h=4.0 mm. To better adaptation was used a rectangular short circuit pin of length $l_s$ and width $w_s$. The physical parameters used were $L$ = 11.2 mm, $W$=10.2 mm, $d_f$ = 1.0 mm, $r_f$ = 0.3 mm, $d_s$ = 0.35 mm, $l_s$ = 0.3 mm, $w_s$ = 1.6 mm and $d$ = 0.2 mm. The length and width of the branches are: $w_a$= 2.1 mm and $l_a$=8.2 mm. The feeding point is shift 1 mm of the center structure, well as, the short circuit pin.

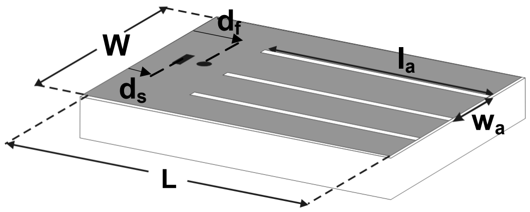


Fig. 4. Patch antenna geometry with four branches.

The return loss results to patch antenna with four arms is shown in the Fig 5.

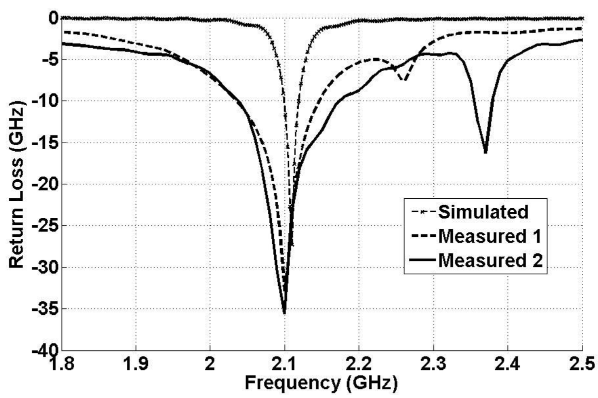


Fig. 5. The return loss results simulated and measured for patch antenna with four branches.

The simulated result for loss simulated (Fig. 5), was -27.3 dB, in 2.11 GHz. The return loss measured result, measured 1, was -32.8 dB, in 2.1 GHz. It was observed one peak in frequency of 2.26 GHz, probably due to the parasitic coupling in the structure. Then, a second measurement was done, where there was a shift of the peak to 2.37 GHz with value of -16.3 dB. The structure is very sensitive to solder and metal oxidation, which could have greatly influenced the input impedance and resonance frequency of peak.

The radiation pattern simulated for patch antenna with four arms is shown in Fig 6.

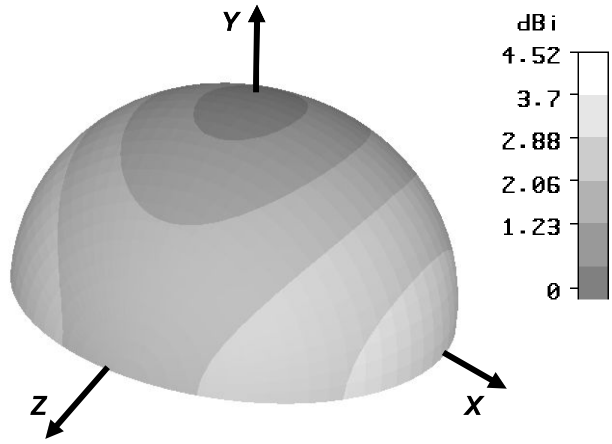


Fig. 6. The radiation pattern simulated for patch antenna with four branches.

The radiation pattern (Fig 6) have a maximum intensity in the $x$-axis around of 4.52 dBi, and presented minimum intensity in the $y$-axis around of 0 dBi.

## 3. PROCEDURE FOR THE EFFICENCY MEASUREMENT

To measure the antenna radiation efficiency was used the reverberation chamber of the LEMA (Laboratory of Applied electromagnetism and microwave) [5] located in the UFCG. For the calculation of the antenna efficiency is need the scattering parameters for transmission and reflection coefficient of the exciting antenna, reference antenna and also of the antenna under test. The antennas under test are the small antenna in Fr4 and LTCC substrate described in section 2. To exciting antenna and reference antenna were choose two wideband dipole antennas, Fig. 7. Due the small antennas have distinct resonance frequency.

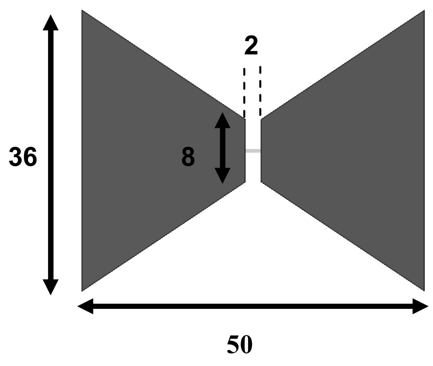


Fig. 7. Wideband dipole antenna (dimensions in millimeters).

The simulated and measured results to return loss are shown in Fig. 8.

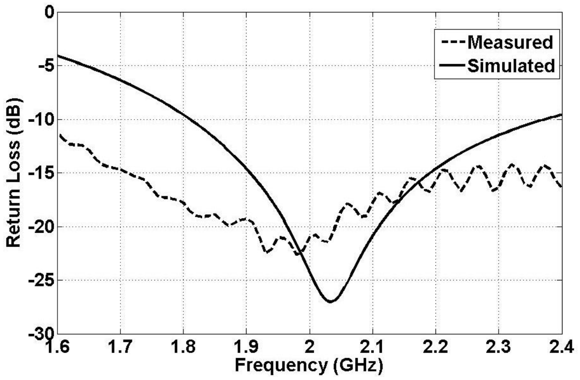


Fig. 8. Simulated and measured results to dipole antenna.

The return loss simulated result (Fig. 8) was -27.0 dB, in 2.03 GHz and presented a bandwidth of approximating 580 MHz. The measured result presented a bandwidth above of 800 MHz, thus covering the frequency range of the antennas under test, as designed in the simulation.

The procedures used for measurement are described with an emphasis in [3] and [4]. First, the reference antenna, which has known characteristics is positioned within of the chamber and then is calculated power transfer function ($P_{ref}$) by Eq.1.

$$P_{ref} = \frac{\overline{\left|S_{21,ref}\right|}}{\left(1-\overline{\left|S_{11}\right|}^2\right)\cdot\left(1-\overline{\left|S_{22,ref}\right|}^2\right)} \tag{1}$$

The reference antenna is replaced by antenna under test and then calculated the power transfer function ($P_{aut}$) by Eq.2.

$$P_{aut} = \frac{\overline{\left|S_{21,aut}\right|}}{\left(1-\overline{\left|S_{11}\right|}^2\right)\cdot\left(1-\overline{\left|S_{22,aut}\right|}^2\right)} \tag{2}$$

To calculate the radiation efficiency ($e_{rad}$) is used the eq. 3.

$$e_{rad} = \left(1-\overline{\left|S_{22,aut}\right|}^2\right)\cdot\frac{P_{aut}}{P_{ref}} \tag{3}$$

Where:

$S_{11}$ is the reflection coefficient at the excitation antenna.

$S_{22,ref}$ is the reflection coefficient at the reference antenna.

$S_{21,ref}$ is the transmission coefficient at the reference antenna.

$S_{22,aut}$ is the reflection coefficient at the antenna under test.

$S_{21,aut}$ is the transmission coefficient at the antenna under test.

$e_{rad}$ is the radiation efficiency.

## 4. RESULTS

To obtain a result more accurate, usually the antenna is placed in three different positions within of the reverberation chamber to avoid that uniform fields changed the results. The reverberation chamber have a volume of approximating 1.0 m$^3$. First, the reference antenna is positioned in the chamber and then measured, the average transmission and reflection coefficient parameters ($S_{22}$ and S21). Also, is obtained the parameters S11, of the transmitting antenna. Second, the procedure is repeated for other positions in the chamber. The reference antenna is replaced by antenna under test and procedure is repeated.

The results obtained for the transmission and reflection coefficient to patch antenna with four branches are show in the Fig. 9.

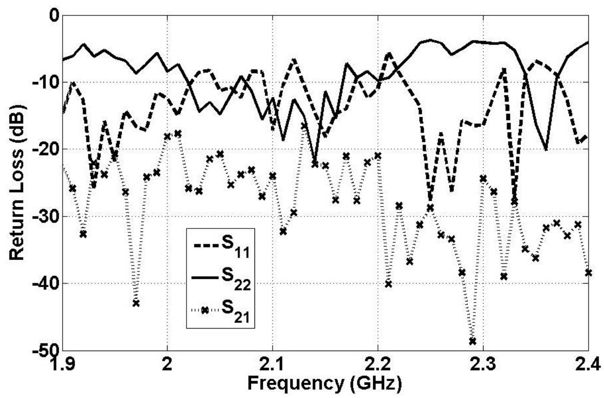


Fig. 9. Measured results to transmitting and reflection coefficient.

It was observed a distortion in the transmitting antenna reflection coefficient due the approximating of the antenna with metallic wall of the chamber. Also, is observed three peaks of resonance to patch antenna with four branches. The first peak was between 2.03 and 2.05 GHz. The resonance second was between 2.03 and 2.05 GHz 2.08 and 2.16 GHz, presenting a bandwidth of 80 MHz. It was observed that the resonance frequency in 2.36 GHz practically unchanged, probably due to the parasitic coupling in the structure. After realized the measurement, it was observed degradation in efficiency in one of points of measurement. Maybe to have approximated of the metallic wall, then the result was discarded. The radiation efficiency obtained to patch antenna with four branches was 48.4%, while to antenna with three branches (E-antenna) was 28.51%. Would have to be investigated the effects of the metallic wall presence in radiation efficiency of the antenna under test.

The structure size is very small comparing to the SMA connector, the structure is also very sensitive to solder and metal oxidation, which could have greatly influenced the input impedance and the radiation efficiency.

## 5. CONCLUSION

To measure the efficiency antenna was made two planar monopole antenna of size reduction with branches**.** To obtain the miniaturized antennas was introduced short circuit pin and slots in the structures. The simulated and measured results to return loss are in good agreement. To obtain the radiation efficiency was used a reverberation chamber and measured the scattering parameters for transmission and reflection coefficient of the excitation in the relation the antenna under test and the reference antenna. To patch antenna with four branches was obtained a radiation efficiency of 48.4% while to antenna with three branches (E-antenna) was 28.51%. During the measurement was observed a distortion in the transmitting antenna reflection coefficient due the approximating of the antenna with metallic wall of the chamber. Also, was observed three peaks of resonance to patch antenna with for branches.

The structure size is very small comparing to the SMA connector, the structure is also very sensitive to solder and metal oxidation, which could have greatly influenced the input impedance and the radiation efficiency.

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