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DESIGN AND ANALYSIS OF UWB ANTENNA FOR USE IN AERONAUTICAL RADIO NAVIGATION

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ABSTRACT

Air radio navigation and fixed satellite communication from Earth to space may need special characteristics like ultra-wideband antenna technology, UWB.UWB was initially developed for military application, but today it is used to many other applications like transfer of data from digital camcorders and wireless printing of digital pictures. In this context, high frequency performance and low-profile antennas may be required. As example, the use of Micro strip antennas. These antennas have low cost, and are widely used due to the advantages such as reduced weight and size, low fabrication cost and easy installation. This paper presents the design and analysis of UWB antenna for military use. Specifically, in air radio-navigation services with frequency band between 15.4GHz and 15.7GHz. The focus was to construct and simulate an antenna with the characteristics of an ultra-wide band, along with a low return loss in the desired resonance frequency. Simulations were made using specific software with small modifications in the proposed antenna. Results indicated that small changes can show differences in important antenna parameters. It was concluded that the adaptation of the standard antenna with a half circular ring is capable to improve its parameters.

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INTRODUCTION

Globalization leads communication among people to impressive levels. With the aim to improve and accelerate interconnectivity, the advanced of technology and communication has got faster and better. Nowadays one can communicate with somebody anywhere in the world. The communication needs just a device with internet access. In this regard, mobile phones became the most important electronic devices to the century. This potential gadget has become so important for people's lives that the failure of a data signal and/or connection for few hours can cause panic to people. That is the reason why telecommunication and related areas of study have gained more space and importance in research areas. The antenna is one of the most important devices for telecommunication. It can send and receive electromagnetic signals of information, which is processed by the receptor device, and then translated in intelligible form to the end user. Thereby, end users can evaluate whether the data exchange was successfully completed or not, enabling the measurement of the quality of the transmission. Portable electronic devices have gotten smaller over the years, with their size becoming a parameter for quality. However, it is not enough to only build a good device endowed by high processing power and good resources. It also needs to be as small and comfortable to use as possible. It is clear that the reduction of the size of the device is limited by displays and screen, due to the demand to maintain screens in an appropriated size. Planar antennas are the most used portable devices. The cause for their widely used is based on their characteristics, such as, small size and weight, low manufacturing costs, and easy installation. These reasons, among others, make planar antennas widely used in satellites, planes, missiles, smartphones, space ships, and others.

Ultra-Wideband Antenna: An UWB device is, according to the Federal Communications Commission (FCC)(the United States regulatory agency in telecommunications), any device

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that has more than 25% of the center frequency, or occupies 1.5GHz or more in spectrum. Since only a part of the UWB antenna is responsible for the radiated energy in a determined frequency, the gain of this antenna is considerably low. The UWB antennas must have acceptable levels in at least one of the relevant parameters for the antenna. Despite its low gain, it is beneficial that we obtain constant gains through all the band width, according to the frequency variations in this range.

Frequency Spectrum and Some Attributed Services: Frequency ranges are determined according to the purposes that go from civil and military communication to satellite, radio, and TV systems. The radio waves are used in telecommunications, broadcasting, TV and radars, among others, and are divided in two main types: radio waves that present frequencies up to 100MHz used in radio and TV stations. And micro-waves, that range from 100MHz to 1000GHz. These are used in telecommunications, transporting TV signals, and phone transmissions.

Focusing the study in micro-waves, there are three main operation frequency ranges.

- **VHF (Very High Frequency):** acts from 30 MHZ to 300 MHZ, used mainly by FM radio and open TV, operating from channel 02 to channel 13.
- **UHF (Ultra High Frequency):** operates from 300 MHZ to 3 GHZ. Its main uses are related do TV signals, HDTV channels, radio, transceivers, bluetooth, and wireless networks.
- **SHF (Super High Frequency):** varies from 3 GHz to 30GHz, its main uses being radio navigation and localization, satellite systems, digital systems, digital radio, and air radio navigation.

The aeronautics telecommunication service can be classified as: fixed, mobile, radio navigation, broadcasting, mobile by satellite, and radio navigation by satellite. According to the range attribution, destination and distribution of frequencies in Brazil from ANATEL, the operation frequency at this paper is destined to aeronautical navigation radio operations and fixed satellite communication from Earth to space. The aeronautical radio navigation service is used for operation security with aircrafts, including for signaling the presence of obstacles. This service operates in the frequency range that goes from 15.4GHz to 15.7GHz.

Antenna Parameters: These are some important parameters that must be taken into consideration in antenna design, being:

Radiation Diagram: The radiation diagram is an elementary parameter in antenna design. It can show the proprieties of the antenna radiation on the far field. The radiation diagram shows the radiation pattern of a determined antenna. However, as it changes according to the observation angles of the system, it is worthy convenient to allow more efficient plans of observation for these antenna parameters. The two fundamental plans for antennas are plan E and plan H.

Plan E: this plan relates to electrical field, it is the parallel plan to the electrical field vector. The plan promotes the maximum value of the electrical field, as well as the direction of the maximum radiation of the field.

Plan H: this plan is related to the magnetic intensity field, so it is parallel to the magnetic intensity vector. Using Maxwell's mathematical formula, plan H is perpendicular to plan E. Plan H contains the information of the maximum radiation of the magnetically field, and its maximum direction of the radiation.

Gain: Gain is the parameter that tells us how much the energy radiated by the antenna is concerned to a determined region in a coordinated system. This parameter takes into consideration an isotropic antenna as reference, which is a hypothetical antenna that irradiates equally in all directions. The gain determines the antenna's ability to concentrate its transmission of electromagnetic signals to a determined region in space.

Directivity: Directivity, like the gain, is related to the energy radiated by the antenna in a determined region. The directivity is the antenna's ability to radiate energy in a determined position.

Polarization: This parameter concerns the polarization of the wave radiated by the antenna in the process of transmitting data. The characteristics of the polarization in practically all the central lobule usually remain constant. This behavior on the maximum radiation point determines the polarization of the antenna.

Input Impedance: The input impedance of an antenna is the impedance presented in the antenna terminals. The input impedance of the terminals influences the efficiency of the antenna. The input impedance depends on the objects around, the coupling terminals, and the geometry of the antenna.

Bandwidht: Bandwidth is the range of frequencies that are considered operable on the antenna. The wider the band of an antenna, the bigger is the capacity of data transmission with reasonable reliability. The performance parameters of the antenna through bandwidth must be considered acceptable to the desired application. It is a challenge for the UWB antennas to meet the performance parameters through its entire bandwidth.

Antenna Design: There are many calculations for planar antenna analysis. These methods are approximate and do not offer high precision. The modeling was made considering the simplest geometry for broadband antennas, a microstrip rectangular antenna, Fig. 1.

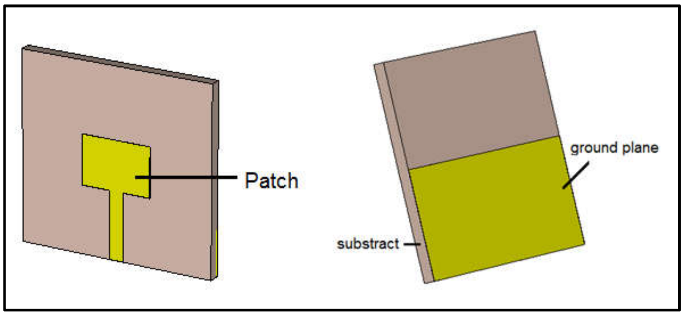

Fig. 1. Model of a planar antenna

Planar antennas are composed by a patch, which is a radiating metallic element, a layer of dielectric material called substrate, and a ground plan. The relative dielectric constant of the substrate depends on the chosen material and its most common values are between $2 < \varepsilon_r < 12$. The patch modeling the chosen method was the Transmission-Line Model. Even though it does not offer good precision, it enables a good physical perception. This method takes into consideration the fringing effects on the patch. The parameters for the construction of the rectangular planar antenna using the Transmission-Line Model according to Balanis (2005) are:

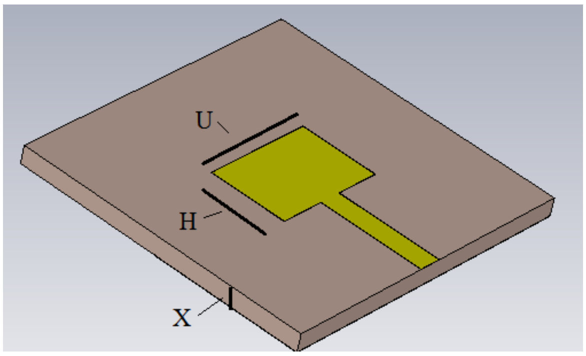

Fig. 2. Parameters for the construction of the rectangular planar antenna

To determine the width of the radiating element, eq. 1.

$$U = \frac{1}{2f_r\sqrt{\varepsilon_0\mu_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{V_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad \text{......................(1)}$$

We have that U/X > 1. As the frequency increases, the value of the dielectric constant undergoes alterations, where the effective value of the dielectric constant is given by the eq. 2.

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\left(\frac{X}{U}\right)\right)^{-1/2} \qquad \text{......................(2)}$$

Approximate relation for the normalized extension of the length is given, considering the fringing effects, by eq. 3.

$$\frac{\Delta H}{X} = 0{,}412\,\frac{(\varepsilon_{reff}+0{,}3)\left(\frac{U}{X}+0{,}264\right)}{(\varepsilon_{reff}-0{,}258)\left(\frac{U}{X}+0{,}8\right)} \qquad \text{....................(3)}$$

The real length of the antenna is given by eq. 4.

$$H = \frac{1}{2f_r\sqrt{\varepsilon_0\mu_0}\sqrt{\varepsilon_{reff}}} - 2\Delta H \qquad \text{....................(4)}$$

The resonance frequency of the antenna is a function of its length, eq. 5.

$$F_r^{010} = \frac{V_0}{2H\sqrt{\varepsilon_r}} = \frac{1}{2H\sqrt{\varepsilon_0\mu_0}\sqrt{\varepsilon_r}} \qquad \text{..................(5)}$$

Since it depends of its length, the calculation of the frequency depends on the fringing effects, eq. 6.

$$f_{rc}^{010} = \frac{1}{2H_{eff}\sqrt{\varepsilon_0\mu_0}\sqrt{\varepsilon_{reff}}} = \frac{1}{2(H+2\Delta H)\sqrt{\varepsilon_0\mu_0}\sqrt{\varepsilon_{reff}}} \qquad \text{............(6)}$$

$$f_{rc}^{010} = q\,\frac{1}{2H\sqrt{\varepsilon_0\mu_0}\sqrt{\varepsilon_r}} = q\,\frac{V_0}{2H\sqrt{\varepsilon_r}} \qquad \text{................(7)}$$

$$q = \frac{f_{rc}^{010}}{f_r^{010}} \qquad \text{...............(8)}$$

On equation 8, which represents the fringe factor, the increase in the height L leads to lower frequencies. For these calculations, we have:
U = patch width
H = patch length
ΔH = patch length variation
f_r = resonance frequency
ε_{reff} = effective dielectric constant
ε_r = dielectric Constant
X = substrate width
V_0 = speed of the electromagnetic waves on free space

Using this mathematical formulation, we find the constructive parameters (U, H) for the standard rectangular antenna, considering f_r around 10Ghz. The first antenna constructed supported by the formula above was a standard antenna with a rectangular patch, as shown in Fig. 3.

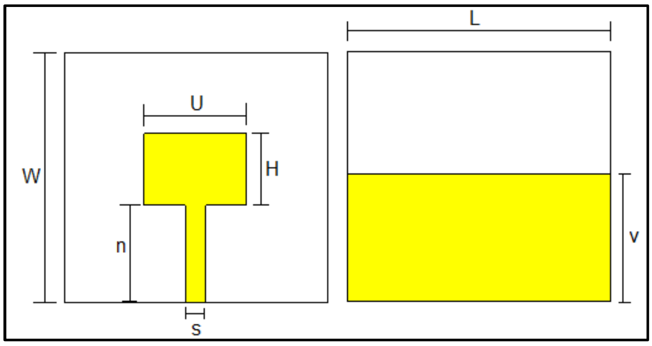

Fig. 3. Standard rectangular antenna design

Starting from the standard antenna, it was proposed an antenna with a half-circular ring section, according to Fig. 4.

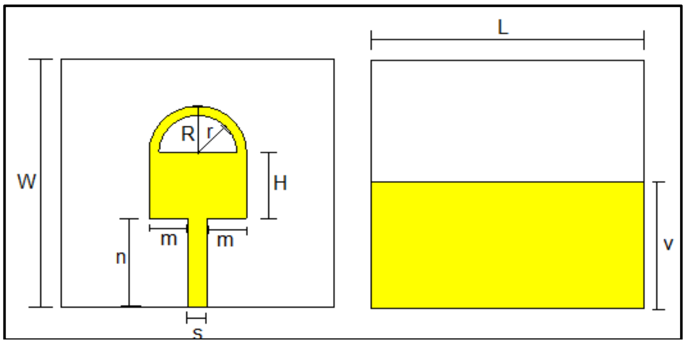

Fig. 4. Antenna design with half-circular ring section

The last proposed configuration is an antenna with both a section of a half-circular ring, and a section in the ground plan, as shown in Fig. 5.

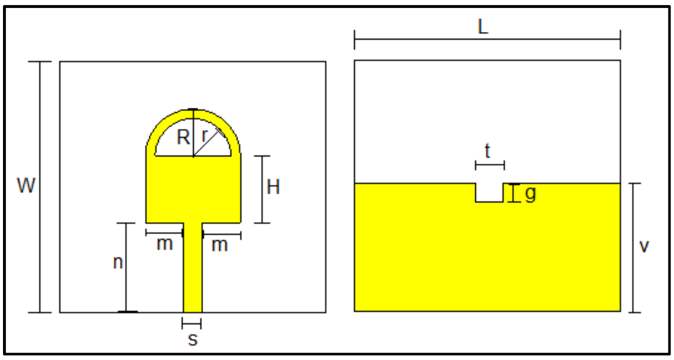

Fig. 5. Antenna design with half-circular ring section and a cut in ground plane

The dimensions of the antennas are, in mm: L=28, W=26.5, H=7, n=9.5, m=4, s=g=2, R=5, r=4, v=13.5, U=10 and t=2. The substrate thickness is 1.6mm, and the material FR-4 (ε = 4.3). The thickness of the ground plan and patch of the analyzed antenna was 0.035mm. The waveguide port of this antenna was constructed according to the dimensions shown in Fig. 6, where “s” is the width of the patch-feeding rectangle.

Fig. 6. Measures for the construction of waveguide port

RESULTS

Fig. 7 shows the graphic for the S parameter of the standard antenna. This parameter is responsible for saying how much of the radiated signal is reflected, diverting from its final structure. The lesser the loss by return (measured in dB), the better the chances of the transmitted signal in that frequency to reach its destination. Results lower than -10dB are expected for all the bandwidth and below -20dB for the operation frequency.

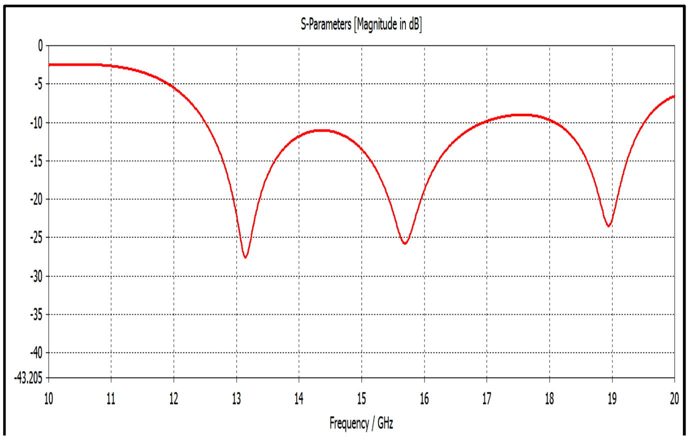

Fig. 7. S Parameter for the standard antenna

The standard antenna presents a bandwidth of 12.5GHz to 16.97GHz. The frequency for the desired operation was from 15.4 to 15.7GHz and the return loss was -26dB. Fig. 8 shows the 3D graphs for gain and directivity in the resonance frequency of 15.4GHz, and Fig. 9 shows the same parameters in the resonance frequency of 15.7GHz.

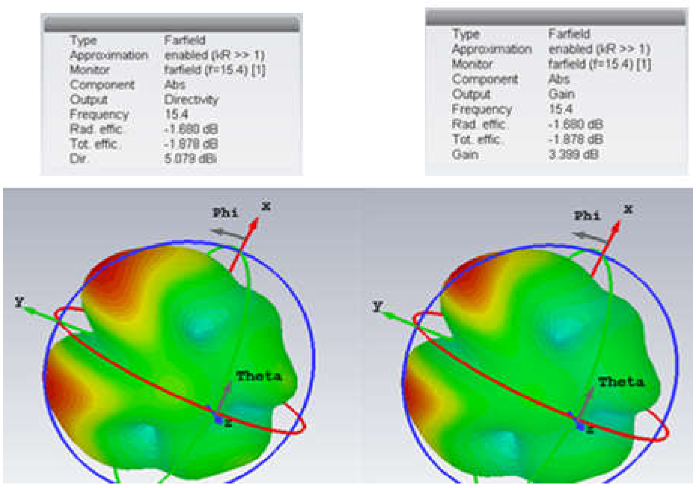

Fig. 8. The S Parameter for the antenna with a half circular ring section compared with the S Parameter for the standard antenna

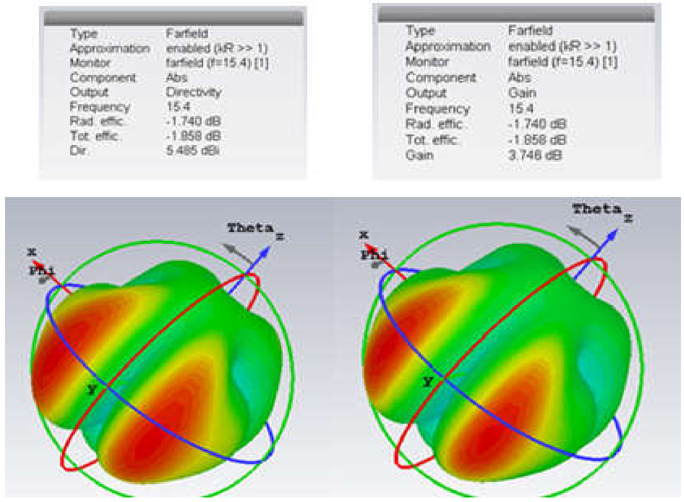

Fig. 9. 3D Graph for gain and directivity in the resonance frequency of 15.4GHz - Antenna with a half-circular ring section

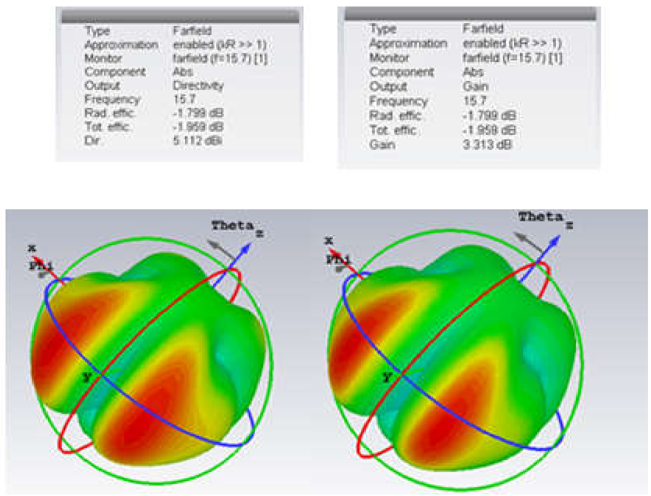

Fig. 10. 3D Graph for gain and directivity in the resonance frequency of 15.7GHz - Antenna with a half-circular ring section

Fig. 13 shows the S parameter graph for the antenna designed with a half-circular ring and section in the ground plane, in green, comparing it to the graphic of the standard antenna, shown in red. The modification also resulted in improvement in the desired operating frequency. The return loss was -26 dB (standard antenna) to -36 dB (antenna designed with a half-circular ring), lower result than the antenna without the cut in the ground plane. However, gain and directivity parameters were improved, as shown in the 3D graph for these parameters in Fig. 14, for 15.4GHz, and in Fig. 15, for 15.7GHz. During the entire bandwidth of the antenna with a half-circular ring and section in the ground plane. The lowest return loss was -11.18dB.

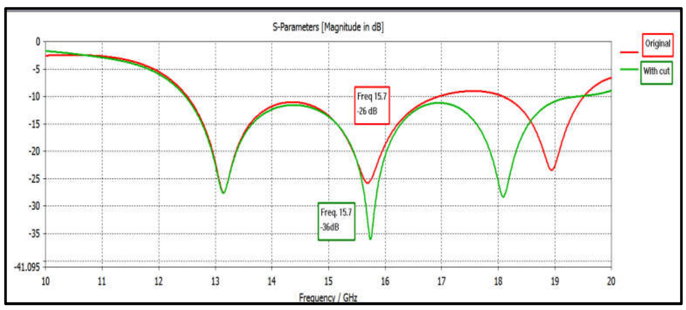

Fig. 11. The S Parameter for the antenna with a half-circular ring section and section in the ground plane compared with the S Parameter for the standard antenna

The results of the three antennas can be compared in relation to their main parameters. Fig. 16 shows the comparison of the S parameter of the antennas, and table I shows the comparison of the other parameters like return loss, gain and directivity.

Table 1. Antennas comparison

F [GHz]	*Parameter*	*Standard Antenna*	*Projected Antenna*	*Projected Antenna + Cut in the Ground Plane*
	Bandwidth [GHz]	4.47	7.39	7.03
15.4	Return loss [dB]	-19.64	-27.17	-20.45
	Gain [dB]	3.339	3.746	3.910
	Directivity [dBi]	5.079	5.485	5.672
15.7	Return loss [dB]	-26	-48	-36
	Gain [dB]	3.179	3.313	3.495
	Directivity [dBi]	4.931	5.112	5.314

Conclusions

This paper presented the design for an UWB antenna for military use, specifically in air radio-navigation services. The focus was to construct and simulate an antenna with the characteristics of an ultra-wide band, along with a low return loss in the desired resonance frequency. The simulations were made in a specific software. Small modifications were made in the proposed antenna and then the results were compared, verifying that small changes can show differences in important antenna parameters. It was concluded that the adaptation of the standard antenna with a half-circular ring improved its parameters.

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