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TITLE:

DESIGN OF DUAL-BAND SLOT ANTENNA IN LOW COST INVERTED MICROSTRIP GAP WAVEGUIDE TECHNOLOGY

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Abstract

This document will present an example of gap waveguide technology use. The main advantage of this technology is that it has low losses. Specifically, we will present the design, simulation and construction of a dual band slot antenna made in this technology. It does not need contact between components, provides packaging of the circuits and prevents unwanted couplings and radiation.

The antenna presented throughout this project is slot type and will be fed by a microstrip line. In general, these type of antennas produce back radiation, so it will be necessary to combine dual-band antenna with a structure that simulates the behavior of Perfect Magnetic Conductor (PMC). Therefore we wil be able to eliminate almost all of this unwanted radiation.

To achieve the dual-band slot antenna final result we have to perform some previous steps.

The first step will be the design of the periodic structure that provides the PMC condition. This structure will be a **bed of nails**. In order to make this design, we have to perform a previous parametric study that will analyze how the different parameters of the strucuture are going to affect the stopband. We will use the scatter plots to see how this changes the bandwith. This stopband is a bandwidth which forbids wave propagation in unwanted directions. This design will be made also two versions, as throughout the rest of the project. In these two versions the difference will be the gap position will affect the gap position as follow:

- Between dielectric and pins surface AMC $\rightarrow$ Conventional microstrip technology.
- Between antenna (metal + slot) and the dielectric $\rightarrow$Inverted microstrip gap technology.

Once the pin structure is designed the next step will be the design and study of the simple antenna by, changing the gap position in the two different ways as we said before. To make a good antenna matching it is necessary to respect the “rules” imposed by the slot antenna. They are:

- The substrate’s width and power line’s thickness must be less than λ.
- The slot’s length will be approximately $\lambda/2$.
- The slot’s width must to be less than its length.
- Permittivity of the substrate should give low losses to obtain a dielectric which achieves the maximum efficiency.

The third step is the combination of the two antenna designs with their respective AMC structures, analyzing the results of the simulations and comparing the results obtained in terms of radiation. The parameter S_{11} will help us measure our antenna matching.

Once we had performed all of these steps we can construct the final antenna which finally is going to be sent to the lab in order to complete the research for this project.

Previously to this step we are going to design a dual band antenna based on the conclusions drawn from the previous steps and the information that we had previously to make the project. This antenna consists of two U-shaped slots which produce an antenna matching at two frequencies. Furthermore, we will do a study in order to define the dimensions of these new slots and we will analyze which are the most important parameters to define the dual-band.

All of this development is going to be done in CST Microwave Studio program. This will help us to obtain the results as well as the calculation of important parameters such as the dimensions of the microstrip line.

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Chapter 1

INTRODUCTION

1.1 Motivation

Nowadays the saturation of the radio spectrum and the increase of data transmitted over radio communications make an increase in frequencies necessary to meet the demand for bandwidth. This increase(for example on the 60GHz band) requires the emergence of new technologies that are low loss (technologies such as microstrip have excessive high losses in these bands). Also, if we want these technologies to be massively used, the cost must be reduced.

One of the new technologies that have been proposed is called "waveguide gap". This technology uses AMC structures to confine the electric field in the air gap between a metal cap and some printed line as we described in Chapter 2 of this report.

This is a developing technology and, therefore, is not yet mature, so the design of antennas and other components is essential. This report aims to contribute on the development of this technology with the design of a dual band slot antenna.

Because of our lab's technology limitations this design is going to be performed in a lower than 60 GHz band. Also the AMC structure will be realized in a "low cost" version of the known periodic structure called **bed of nails**.

The study of this structure and the AMC limitations of the frequency band in which our antenna can operate are another aim of the project. This kind of structures offer electromagnetic properties that we can not get in normal conditions.

1.2 Objectives

This project aims to meet several objectives in the study of the groove or slot antennas:

- **Study of AMC structures**: Our antenna will be fed by a microstrip line which will cause much of the energy to be radiated back. Our first objective is to design a ground plane, which consists of a pins surface, that will eliminate much of this radiation.

- **Combination of ground plane and simple antenna study**: Our second objective is to incorporate this ground plane, designed previously, into our simple antenna. We will evaluate two options: the first is to add the ground plane on a conventional microstrip technology slot antenna and the second is to use the microstrip technology gap waveguide itself.

- **Dual- band antenna study**: Our ultimate objective will be the study, design and construction of an antenna with an AMC structure which works in two frequency bands. As we discussed earlier it will be done for the two proposed versions.

1.3 State of art

The Institute of Electrical Engineers(IEEE) defines an antenna like a medium to receive and radiate radio waves. That is, these devices are responsible to adapt the guide waves to the waves which propagate through free space.

We have two different groups in order to classify these devices:

- **Omnidirectional**: They are the antennas that radiate radio waves evenly in all directions in a plane.
- **Directional**: They are able to concentrate most of localized radiate energy so the power transmitted to the receiver will increase.

1.3.1 Characteristic parameters of antennas

- **Bandwidth**: Is the frequency range over which the antenna operates in a satisfactory manner. Usually, it is calculated between half-power points but sometimes refers to variations in the input antenna impedance.

- **Matching**: Receiving antennas have a Thevenin equivalent circuit with an antenna impedance and a voltage generator. Also is important to identify the S_{11} parameter because this parameter brings the information about the power transfer from the antenna generator to the antenna. The S_{11} parameter is the input reflexion coefficient.

- **Impedance**: It consists of a real part called resistance antenna and an imaginary part called reactance antenna. In addition the impedance is defined as the ratio between the voltage and the input current terminals:

$$Z_i = \frac{V_i}{I_i} = R_a + jX_a \tag{1.1}$$

- **Polarization**: It is the polarization of the radiated antenna wave in a given polarization direction. A specified geometric shape determined by the end of the vector represents the electric field as a function of time in a given position.

  There are three types of polarization in function of differences phases and the components amplitudes:

  Linear Polarization occurs when the two phases of the electric field orthogonal components differ by integral multiples of π radians.

  Circular: We are in this polarization when the orthogonal components amplitudes are equal and the phase differences are $pi/\ 2$ or $3\pi/\ 2$ radians.

  Elliptical: We have an elliptical polarization when we are not in any of the previous cases.

- **Radiation pattern**: It is the graphical representation of the radiation characteristics depending on the angular direction. Thanks to this radiation pattern we can see which group our antenna belongs to.

- **Power density**: It is defined as the power per unit area in a certain direction

$$P = \oiint_S < S > \cdot ds = \oiint_S < S > \cdot \hat{n} da \tag{1.2}$$

  where

  P = Total instantaneous power.
  S = Average power density and Poynting vector (W).
  $\hat{n}$= Normal vector to the surface

- **Directivity**: It is the ratio of antenna radiation power compared with the isotropic antenna radiation power, both calculated at a certain distance:

$$D = \frac{U}{U_{ISO}} = \frac{4\pi U}{P_{rad}} \tag{1.3}$$

where

D = Directivity (Dimensionless).
U =Radiation intensity (W / unit of solid angle).
U_{iso} = Isotropic antenna radiation intensity (W / unit of solid angle).
P_{rad} = Total radiated power (W)

If no direction is specified this directivity is calculated using maximum radiation direction.

$$D_{max} = D_0 = \frac{U_{max}}{U_{ISO}} = \frac{4\pi U_{max}}{P_{rad}} \tag{1.4}$$

where

U_{max} = Maximum radiation (W / unit solid angle) .
D_{max} = D_0 = Maximum directivity (Dimensionless).
The minimum value that directivity can achieve is 1. This value is achieved in an isotropic case which is when an antenna radiates equally in all directions.

- **Gain**: It is the ratio of antenna radiation power density compared with the isotropic antenna radiation power density, both calculated at a certain distance. With directivity, if no angular direction is specified this gain is calculated on maximum radiation.

$$G = 4\pi \cdot \frac{U}{P_{in}} = e \cdot D_{max} \tag{1.5}$$

where

P_{in} =Total accepted power
e = efficiency

Directivity and the gain are equal in the case of not having ohmic losses, that is, not having power dissipated by the antenna.

1.3.2 Slot antenna

These antennas characteristics are similar to dipoles characteristics, such as elevation and azimuth patterns, but its construction is only a slit slot in a metallic plane.

These kind of antennas offer several advantages , such as easy adaptation in microwave integrated circuits, easy to mass produce and versatile in terms of impedance , resonant frequency and polarization. On the other hand, the disadvantages are the limited bandwidth and its low power radiation and efficiency.

These kind of antennas are based on microstrip technology. This is the result of an evolution which always had the objective to construct small antennas and transmission lines and therefore allow its easy adaptation into all kinds of devices.

At 1951 the first printed circuits appeared with the name **striplines**. These circuits have most of the electrical field within the dielectric. They consist of a thin conductive strip which have a metal top and a metal bottom and both of them have the same potential(GND).

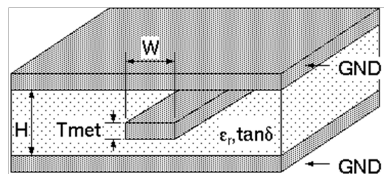

Figure 1.1: Stripline

But a year after this, in 1952, the top was removed resulting in microstrip technology in which the conductor line is in air.

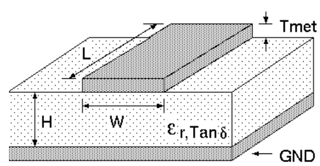

Figure 1.2: Microstrip

This kind of slot can be fed in two differents ways:

- **By waveguide**: The slots do not usually allow current passage where the coupling between the guide and the slot is proportional to that effect.

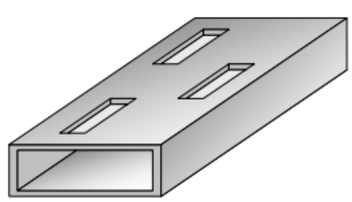

Figure 1.3: Waveguide feeding.

- **By Microstrip line**: The slot is located over the ground plane and the line has an open circuit at a $\lambda/4$ distance from the slot:

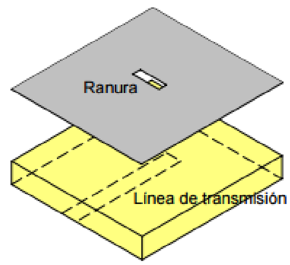

Figure 1.4: Microstrip feeding.

The dimensions will be chosen so that the structure dissipated power in the form of radiation. The issue is that a lot of this radiation will be in the antenna's back.

Chapter 2

CONCLUSIONS AND FUTURE LINES

2.1 Conclusions

This Final Project the study and subsequent construction of a dual-band antenna using gap waveguide technology has been performed. There have been two different designs: one in conventional microstrip technology but with an packaging made in gap waveguide technology and another with inverted gap waveguide technology. Both designs have been exhaustively analyzed and compared.

To achieve this final dual-band design we have had to realize some previous steps, which have helped us to obtain this final result.

The first step we have done has been building a pin surface in order to avoid the back radiation due to the antenna feed. This is the result of a periodic structure which, as we have said before, provides high impedance. These structures are aimed to the creation of parallel-plate stopbands. Due to this, the bandwidth will be limited so we have done an analysis varying one component and setting the rest. This study was performed using dispersion diagrams. The conclusions are:

- The pin's height is strongly affecting the stopband limits considering that if we increase the value we will achieve and the stopband will move to lower frequencies.
- Gap varies lower frequencies of the stopband slightly while the radius varies higher frequencies slightly. However, we can say that none of these parameters provides us with major changes at the stopband.

- On the other hand if we decrease the period the bandwidth will be wider. Therefore the closer we have the pins wider the bandwidth will be.
- With the thickness of the substrate we have the same result as occurred with the period if we increase the value of said thickness, the stopband becomes narrower. So these two parameters must be taken into account in the design of the stopband.

We have performed analysis of the effect of each parameter on the two different structures designs. One design was with the gap between the substrate and the pins surface and other with the gap between the antenna and the substrate. Both have been compared throughout the project. The conclusion drawn at this level is that the gap, before the dielectric, causes the stopband's frequency to move towards lower frequencies.

After wards, we have designed a slot antenna. Two different designs are shown in this document. One design in which the antenna was on a commercial substrate and another in which the antenna used air as a substrate. This second case aims to emulate gap waveguide technology. Therefore we have to conclude that, in both versions, the antenna is barely directive since the lobe that we obtain in the radiation pattern is very wide. Furthermore both antennas have a significant back radiation.

We analyzed each structure separately. The third step was the combination of the simple antenna structure with the **bed of nails** surface. Here we achieved our initial aim to reduce back radiation which it is produced by microstrip line in both cases, and also in the case of gap waveguide technology it is assumed that power losses provided by the feeding line will be lower due to the electric field propagates over the air. To really see that these losses are lower in the case of inverted microstrip gap waveguide technology it would be necessary perform two different designs which works at higher frequency. Frequencies such as 60 GHz would be suitable considering that when substrate losses are higher, the greater the resonant frequency is.

To conclude, to improve slot antennas research, we have done a last design in order to obtain two different resonant frequencies. Therefore we needed two U-shaped slots over the metal while maintaining a single feeding line. As we did not have many references about these type of antennas, we performed a new parametric study varying the dimensions of the slots and derived the following conclusions:

- By increasing the outer slot's length the two frequencies move to lower frequencies. However, if we increase the same value we obtain the opposite effect. Therefore this parameter must be taken into account because it causes severe variations in the two obtained frequencies.
- If we increased the inside slot's length the two frequencies slightly decreased, so this parameter is not very meaningful to obtain dual-band purpose.
- If we increase the width of shorter sides the two antennas frequencies will increase, so it means that the width is proportional to the frequencies.

- Increasing the outer slot's width of the long sides does not affect the frequencies practically. However, this parameter makes several changes in the antenna matching. If we decrease the same value, we obtain a better matching, so this parameter is so important in order to obtain a better matching of the antenna.

In this case, as shown when we combined the pins surface with the simple antenna, when we have the gap below we get an increase in the resonant frequencies. Due to the maintenance of slot dimensions, we also got a higher directivity in the case of lower frequencies.

Finally the two designs were sentto the lab in order to manufacture the two dual-band antenna versions. For one of them, the inverted microstrip gap version, new simulations were required because the slot can not be manufactured in our lab on an isolated metal as it must to be made in a substrate. Unfortunately antenna manufacturing has been delayed and the measurements are not available at the time of writing this report, but there wil be the day of the presentation of work.

Note that the pin structure was hand made using an aluminum plate and screws.

2.2 Future developments

Future developments that can be made from the project could be:

- Perform antenna measurments in, both matching and radiation patterns for radiation patterns.
- Design an array using as elements these slot type antennas. Study coupling that would occur between the elements and compare with open case structure.
- Design a new AMC structure that is not a **bed of nails** but another kind. In that case we could analyze the new result and see what this new structure provides.
- Investigate a new design in higher frequencies (for example 60 GHz) where this technology will clearly show its advantages.
- Further investigation about how to obtain dual-band antennas with a new slot design.