Design of cubesat planar antennas using Niobium Pentoxide substrate

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In the context of the small satellites and the space industry, this paper addresses the use of Niobium Pentoxide (Nb_2O_5) as substrate for a nanosatellite plannar antenna. The antenna design must satisfy strict requirements for a successful operation in the harsh space environment. To date, no works have examined the suitability of existing planar antenna designs for use in nanosatellites using Niobium Pentoxide as substrate. This paper investigates the ability of planar antennas to achieve high gain, beam steering, and wide bandwidth with a substrate made with Nb_2O_5 obtained using a powder metallurgy process. Numerical simulation and experimental measurements are done to obtain the antenna performance.

***Index Terms*—Antenna design, planar antennas, cubesat, dielectric materials.**

I. Introduction

NANOSATELLITES are small small, lightweigth, have low power consumption, have a short development time, and are inexpensive compared to conventional polar orbiting satellites. Consequently, nanosatellies are revolutionizing the space industry [1] allowing developping countries to gain experience in the aerospace industry.

However, nanosatellites must satisfy safety requirements and comply with the CubeSat Standard [2]. Some of the constraints imposed by the nanosatellite platform are: a) mass and deployer constraints; b) size; c) modularity; d) deployment; e) attitude constraints; f) compactness and g) power limitations. Considering this, the antenna project for nanosatellites has stringent requirements, because the entire satellite structure behaves as an antenna, influencing in the way the radiation pattern. Niobium pentoxide (Nb_2O_5) has been used in several works as a component for the production of substrates. However, it is rarely applied to antennas for use on substrates in the microwave frequency range [3] [4].

Typically, the UHF antennas are used for telemetry and telecommand requiring low bitrate, whereas S-band antennas as the range 2000-4000 MHz are used for applications that require high bitrate, such as receiving high definition images. An important aspect is the reliability. Due to the distance between the ground station and the satellite and the limited energy available, it is necessary to have high gain antennas in order to implement applications that demand a higher data rate.

The design of a planar antenna for nanosatellite communication has many challenges in terms of the radiation pattern, bandwidth and antenna size. Though, this problem demands a computational approach based on the Maxwell equations solutions considering real world constraints imposed to the model. This model will be validated using experimental tests to verify the proposed methodology. In this paper, we will study the performance of planar antennas using Nb_2O_5 substrate when attached to a 3U CubeSat body in terms of volume, gain at S-Band, bandwith, return loss, robustness and cost.

II. Dielectric Properties of Nb_2O_5

Niobium pentoxide (Nb_2O_5) has been used in several works as a component for the production of substrates. However, this oxide is rarely applied to antennas for use on substrates in the microwave frequency range [3] [5] [6] [7].

In one hand, several performance factors of the antennas such as gain, efficiency, bandwidth, operational range etc. deteriorate due to the high permittivity, conductor losses and surface wave effects generated by the substrate material [8].

On the other hand, the size of the antenna depends on the materials used in the substrate. In this way, antenna miniaturization can be done using high-permittivity materials to achieve the low profile, compactness, and ease of integration needed for nanosatellite integration.

In [3], several samples of niobium pentoxide were produced by powder metallurgy process, in which the process variables were the compaction pressure and the sintering temperature. These samples were electrically characterized in a Vector Network Analyzer with a coaxial probe with open termination to analyze the frequency range from $200MHz$ to $4GHz$. The $S_{(1,1)}$ scattering parameter is measured by the VNA and the value is used to calculate the sample complex permittivity. The measurement of complex permittivity can be correlated with the compaction pressure and the sintering temperature of the material.

The samples were compacted at pressures 55 MPa, 111 MPa and 166 MPa. The sintering temperature used was $800°C$, $900°C$ and $1000°C$. For preparation of the samples, initially, the niobium pentoxide powder was dried at a temperature of $120°C$ for 24 hours. Each sample was produced with 5g oxide with 15 mm circular diameter. In the compacting procedure, it was given a relaxation time of 10 s every half a ton, and the maximum pressure achieved, each sample was left for, at least, 15 seconds before the load pickup. The sintering time was 4.0 hours and the sintered samples were cooled in the oven for 24.0 h to room temperature.

Fig. 1 shows samples sintered at $900°C$, higher permittivity values occurred in the sample pressed at 166 MPa, intermediate values for the compressed sample to 111 MPa and smaller values for the samples compacted at 55 MPa. It can be seen that we can obtain different values of the permittivity by modifying the pressure. This will be important to modify the antenna in the CubeSat structure. Higher pressure and temperature values will be used in order to get different permittivity results.

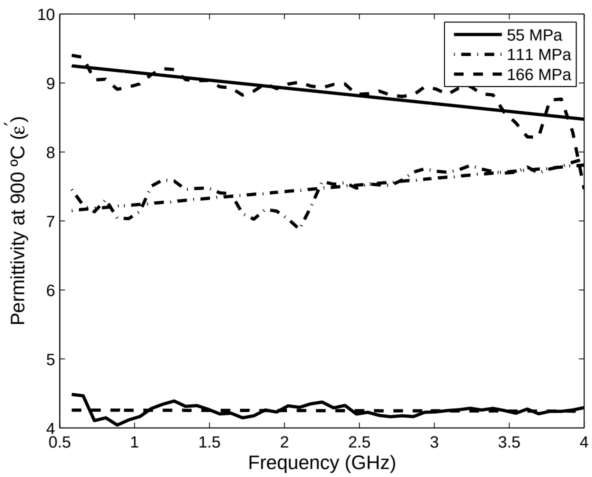

Fig. 1. Real part of permittivity vs. frequency for samples sintered at $900°C$.

III. Antenna Design

The antennas used in nanosatellites are, for reasons of portability, usually electrically small and consequently exhibit low gain. This has an important effect on the performance of the overall telemetry, tracking and command (TTC) system and is probably the only example of a satellite system where antenna gain is, in general, very low.

However, the bandwidth of the planar antennas is much greater than that normally used in conventional UHF frequency range (monopole and helix antennas). The bandwidth impacts in the bit rate between the nanosatellite and ground station and consequently the payload.

The choice of planar antenna for nanosatellite is generally not straightforward. The main challenges that must be considered for a nanosatellite antenna are [9]: 1) small size and low mass, 2) circular polarization, 3) impedance matching, 4) high gain and wide bandwidth, 5) frequency re-configurability, and 6) beam steerability.

In general, nanosatellite antennas should meet specific requirements dictated by the payload specifications, which strongly depend on the aimed purpose and application.

There are several different possible designs for planar antennas [9]. This work intend to investigate their performance in terms of return losses, gain, bandwidth when operating in two different nanosatellites structures: 1)Floripa Sat (1U), Fig. 2, and 2)Serpens (3U). In addition, this investigation will be done using Nb_2O_5 as substrate in the planar antennas considering the S-band.

IV. Results

In this work, High Frequency Structure Simulator (HFSS) is used to study the antenna performance with when the Nb_2O_5 substrate. Fig. 2 shows the simulation performed with a patch antenna [10] in the S-band. It was observed the Nb_2O_5 effect in the return loss and bandwidth.

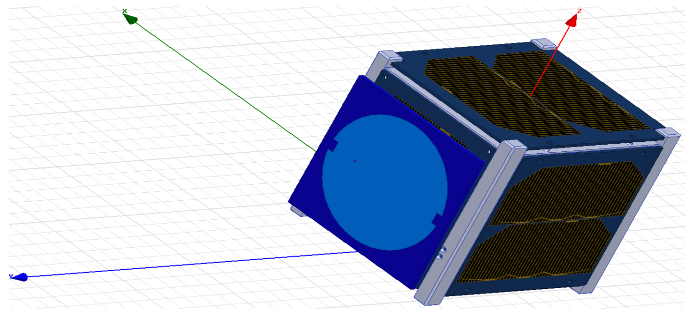

Fig. 2. Patch antenna [10] simulation in the Floripa Sat structure.

V. Conclusion

A preliminary investigation about the use of Nb_2O_5 in the substrate of patch antennas for nanosatellite communication was performed. Evidences of the Nb_2O_5 influence on the antenna performance were identified and they will be discussed in the full version of the paper. Additionally, new numeric simulation results will be presented.

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