Dual Frequency GPS Antennas for Space Monitoring

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Abstract: This work focuses on design and study of low cost corners truncated antennas arrays, printed on alumina, operating at L1/L2 GPS frequencies. This device consists on one patch antennas array to be integrated, in a warning system, with the aim of detecting ionosphere disturbances associated with land-based perturbations and tsunami's arrivals at the coast. To address such concerns, we studied a dual frequency patch antennas array. The performances of the antenna have been measured in terms of return loss, frequency of operation, axial ratio, bandwidth, and radiation pattern. Particularity and major advantage of this antenna, compared to conventional marketed GPS antennas, is the simultaneous use of both GPS frequencies L1 and L2.

1 INTRODUCTION

Natural disasters (volcanoes, tsunamis, floods ...) are creating significant property damage and casualties. Last decades, significant progress in detecting and modelling the atmosphere disturbances induced by climatic phenomena and seismic waves, were performed. This research is now an important part of the assignment and monitoring projects in the upper atmosphere (Lognonné, Artru, Garcia, Crespon, Ducic, Jeansou, Occhipinti, Helbert, Moreaux, and Godet, 2006). In this framework, we are particularly interested in the behavior of the ionosphere, which is considered as the seat of physical phenomena. Investigations of (Fenn, 2008) show that an antenna array with adaptive directional beams is a promising method to detect, using GPS /GNSS signals, some disturbances in the ionosphere. For microstrip antennas to be exploited in such systems, high polarization purity and isolation between orthogonal polarizations being linear or circular are needed. Many shapes of the patch like rectangular patch, elliptical patch, patch with loops, or Square ring microstrip antenna with truncated corners (Chen, Wu, and Wong, 1998) were used to obtain Circular Polarization (CP). The circular polarization can be obtained by well known method of a single-feed square microstrip antenna with truncating a pair of patch corners design. The main goal is the industrial manufacturing of a GNSS/GPS network of smart antennas. GNSS systems, however, offer other perspectives, not initially intended to designing the system, thanks to reflected GNSS signals. Therefore, could we use the GNSS satellites as opportunity of transmitters, and develop systems at ground surface, airborne or embedded for imaging GNSS reflections to deduce deformation of the Earth's surface, or maps of variation of sea level for tsunami survey and monitoring ? Especially after the Sumatra's tsunami on 2004 and Fukushima on 2011. The development of this new approach is the main objective of one of the 'Institut de Physique du Globe de Paris' (IPGParis) project, which focused on demonstration of the use of satellite navigation (GNSS) in existing and new application areas, such as the Land and sea monitoring. This is precisely the main objective of this work which will go through system design, based on GNSS antennas. The total size of the array is about 90 mm ×90 mm.

Compared to similar works in this area, the proposed antenna array offers relatively small dimensions, low weight, ease in fabrication, simple structure, smaller number of layers and works at the two GPS receiver frequencies, compared to conventional existing GPS antennas which work at L1 frequency only. The dual frequency antenna shall be passive and requires no electrical power.

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In this paper, a 1× 4 dual frequency patch antenna array, suitable for use in space monitoring with Circular Polarization is presented.

2 CONTEXT & METHODOLOGY

GNSS which stands for Global Navigation Satellite Systems, allow to measure positions in real time with an accuracy ranging from a few meters to a few centimetres. In terms of public used, GPS receiver requires compact, low power lightweight, low cost, high reliability and with mobility capability. In the field of natural hazards, they are also used to measure deformations, such as volcanoes or to monitor changes in sea level in order to confirm a tsunami and estimate its height in the open sea. The development of a technique to detecting tsunami, thanks to the GPS data, could therefore improve warning systems in the seismogenic and tsunamigenic zones. The information provided by this method is complementary to those provided by classical seismology. Hence, the proposed methodology is the study of dual frequency antenna to be used in Global Positioning System (GPS) receivers operating at Ll (1575.42 MHz) and L2 (1227.6 MHz) frequency bands.

3 SIMPLE ELEMENT ANTENNA CONFIGURATION

Low profile, light weight, ease in fabrication, rugged, conformal, and in some cases lower cost than comparable antennas, are among favourable features which help microstrip antenna to be used in a broad range of modern applications. Microstrip antennas have been designed and incorporated in very wide range of systems, from commercial car navigation GPS systems, biomedical systems, to sophisticated satellite communication system.

The configuration of a single element of the array is shown in Figure 1. To reduce the cost of antenna manufacturing and making it more rigid, FR4 substrates are used, in a first time (Hamoudi, Haddad and Lognonne, 2012) (Hamoudi Haddad and Lognonne, 2013), but given constraining specifications of the project such as satellite, it was necessary to reduce the size of the device. For this purpose, the miniaturization of the radiating element using a substrate of acceptable cost and suitable for space missions (mechanical properties, electrical and thermal stresses) was our guideline. We also consider the design of another antenna with dual frequency. Our choice, for dielectric material, fell on alumina (ε_r=9.8 and h = 0.635 mm). To achieve a CP operation, we have chosen a truncated corner antenna, which consists of a squared patch with two opposites corners cut in angle of 45°. After computation, using equations (Sainati, 1996) and simulation we obtain: a) A L2 antenna with the dimension of 38mm and truncated length 2mm and b) L1 truncated square patch with the dimension of 30 mm and truncated length 4mm. The initial truncation length is kept 0.5mm, which is subsequently increased by 0.5mm in each successive step while obtain satisfactory performances.

We note that with a substrate constant about 9.8 it was possible to reduce, significantly, the antenna size from 43.1 mm and 57.4 mm (for epoxy glass) to 30 mm and 38 mm, so a reduction of approximately 35%. To verify the proposed design, a prototype of the single element antennas with optimized dimensions has been simulated. The simulation results show the impedance bandwidth (VSWR < 2) of 4% at L1 and 3.5% at L2 frequencies. For the operating frequency, a peak antenna gain of 4.8 dB is observed The simulated radiation patterns in two principle planes at 1.57 GHz and 1.22 GHz are satisfactory and suitable for our application.

With this configuration, we have shown that we have two separate antennas for L1 and L2 frequencies, but we have not yet been able to optimize the dimensions and size. The goal of this work is then precisely the study of a two GPS frequencies that fit to the same specifications previously mentioned for receiving antennas

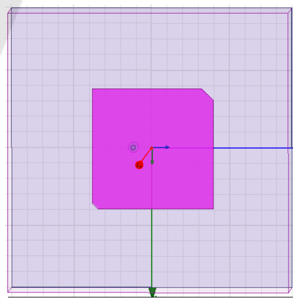

Figure 1: Simple element antenna geometry.

Dual frequency antennas consist of a single radiating structure, which exhibits a resonant behavior, both in terms of radiation and impedance matching at two separate frequencies. In microstrip antenna technology, dual frequency operation can be achieved through several numbers of different configurations. The basic three categories are mentioned in (Sharma and Gupta, 1983). As discussed in the cavity model, two different modes can be excited on a single rectangular patch to obtain dual frequency operation by adjusting the width and the length of the patch according to the two separate resonant frequencies. Orthogonal modes can be excited either by using a single feed or by using two separate feeds. The choice depends on the type of application. When separate field configuration is used, as long as the spacing between the feed points is physically realizable, feeds must be positioned close to the centre of the corresponding edges in order to obtain good isolation levels between the ports. Following this approach and based on the previous results of two single patch antennas and using EM simulator, we obtain a rectangular patch printed on alumina with a length about 39 mm and width of 30 mm excited by two feed located at P1 (-0.75,+1) and P2 (-0.75,+1).

By packaging this antenna configuration into a compact patch type structure it will be suitable for use on a 3U Nano-satellite for spatial missions. The simple structure of microstrip antenna, previously, was used to form two configurations of antennas with 2 patches and four patches. The compact configurations of microstrips antennas dual-band with 2 patches and 4 patches is shown on Fig. 2.

4 NTENNA ARRAY DESIGN

In the case of single patch element, it has been observed that the antenna gain is quite low. That is why we consider using an array of antennas in order to increase the gain and improve the radiation characteristics. The major advantage of antenna arrays compared to a single antenna element is the electronic scanning capability. To reduce the cost of antenna fabrication and making it more rigid during construction, FR4 substrates are used, in a first time (Hamoudi et al., 2012) (Hamoudi et al., 2013), but given specifications of the project such as satellite geometry, volume and weight allocated to the antenna, we were forced to reduce the size of the device. To verify the proposed design, a prototype of the single element antennas with optimized dimensions has been simulated. We note that with a substrate constant about 9.8 it was possible to reduce, significantly, the antenna size from 43.1mm and 57.4 mm (for epoxy glass) to 30 mm and 38 mm, which corresponds to a reduction of approximately 35%. A single patch antenna can be used in a great majority of applications; nevertheless, the gain of these antennas is typically not sufficient to overcome path loss. For this reason, we use an antenna array. The gain of an array is typically many times larger than the gain provided by a single radiating element. Therefore, it is necessary to employ a number of elements in an array combination to achieve the required gain and pattern characteristics.

First, a two element array is simulated (1*2). The most important points in the design of an antenna array are the feed network and the element spacing (d). In our case, we have opted for a parallel feed. The parallel feed, also called the corporate feed, where the patch elements are fed in parallel by the power division transmission lines. The transmission line divides into two branches and each branch divides again until it reaches the patch elements. This is first constructed by connecting two adjacent elements together with a transmission line, calculated from (1) and (3). Now, two separate groups need to be connected together with a transmission line drawn between the centre of the 4 mm wide transmission line.

$W/t \geq 1$

$$Z_0 = \frac{\eta_0}{\sqrt{\varepsilon_{eff}}}\left[\frac{W_e}{t} + 1.393 + 0.667\ln\left(\frac{W_e}{t} + 1.444\right)\right]^{-1} \quad (1)$$

and, for $W/t \leq 1$

$$Z_0 = \frac{\eta_0}{2\pi\sqrt{\varepsilon_{eff}}}\ln\left(\frac{8t}{W_e} + 0.25\frac{W_e}{t}\right) \quad (2)$$

Where

For $W/t \leq 1/2\pi$

$$\frac{W_e}{t} = \frac{W}{t} + \frac{1.25}{\pi}\frac{h}{t}\left[1 + \ln\left(\frac{4\pi\pi}{h}\right)\right] \quad (3)$$

For $W/t \geq 1/2\pi$

$$\frac{W_e}{t} = \frac{W}{t} + \frac{1.25}{\pi}\frac{h}{t}\left[1 + \ln\left(\frac{2\pi}{h}\right)\right] \quad (4)$$

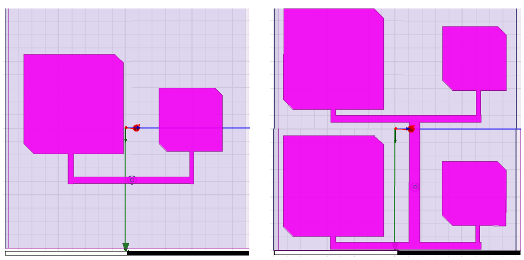

Figure 2: (1*2) and (1*4) element antennas geometry.

Where W_e is the effective width of the patch, t is the thickness of the dielectric substrate, and ε_{eff} effective dielectric constant of the patch, Z_0 is the impedance of the transmission line and η_0 is the free space intrinsic impedance (120π). The transmission line is split using T-junction with equal power split.

In general, the array elements should be as far as possible from each other, so the mutual coupling becomes negligible. In our case, the inter-element distance at set and fixed at 25 mm. Once the performance of the single antenna (2 patches) established, we went further to the study and simulation of the network (1*4) (four patches) in terms of S_{11}, VSWR, radiation pattern and gain. The major characteristics of adaptation and radiation are shown, in table 1

Table 1: Antennas array parameters.

Parameters	antenna array	
Frequency	1575.42 MHz	1227.6 MHz
LxW	(90 x 90)mm^2	
Truncated length	4 mm	2 mm
V.S.W.R	1.8 dB	0.3 dB
Return loss (S_{11})	-17 dB	-46 dB
Gain (G)	10 dB	
Axial Ratio	Good (<3dB)	
Bandwidth	3.5 %	4%
Polarization	RHCP	

The civilian signals issued from GNSS satellites are all right hand circularly polarized (RHCP). These antennas are made of Right Hand Circular Polarization. This property will be used for our antenna. Recall that circularly polarized antenna arrays are more often used in wireless communication systems as they can be easily mounted on mobile devices. They provide: (1) more focused radiation beams for better weather penetration and (2) good cross polarization rejection.

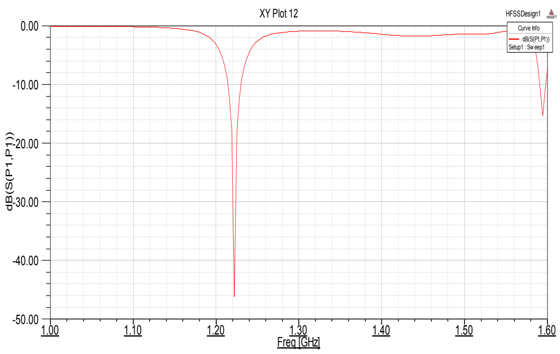

Figure 3: S_{11} diagram for (1*4) antennas array.

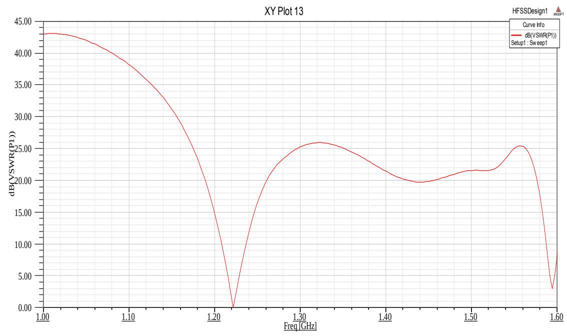

Figure 4: V.S.W.R diagram for (1*4) antenna array.

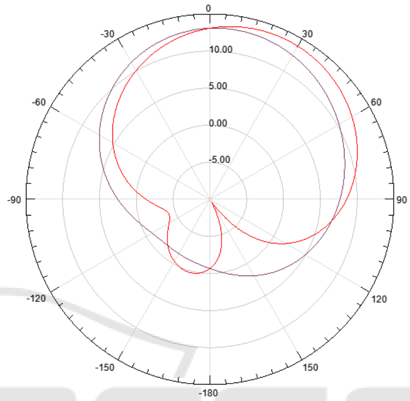
Figure 5: Simulated E&H plane radiation pattern at L1.

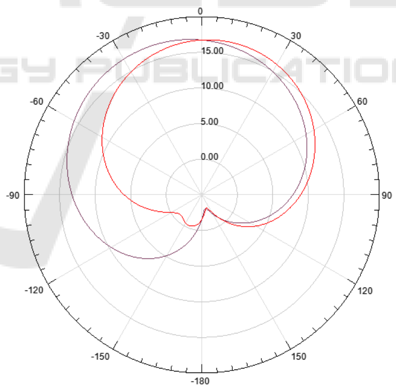
Figure 6: Simulated E&H plane radiation pattern at L2.

A good agreement of the return loss value is obtained at the operating frequencies, -17 dB and -46 dB, respectively, at L1 and L2. As can be seen in comparison with single element and two elements array, the return loss performance is increased. The dual antenna VSWR is well below 2 at L1 and L2 frequency. Radiation patterns of all the proposed antennas are derived using Electromagnetic Simulator. The results at their resonating frequencies are shown on Fig.5 and Fig.6. The antenna radiates to the upper half-space, ideally to track visible satellite, with a beamwidth at 3 dB of approximately 60º. Moreover, we went from a gain of 4.8 dB for a configuration with one patch to a gain of about 10 dB with a configuration of 4 elements. The measured performance of this antenna showed good agreement with the specifications required to meet the application needs.

5 CONCLUSION

A compact and low cost dual frequency array antenna, operating at L1 and L2 is proposed. The simulated characteristics of the proposed configuration satisfy the requirements for GPS application and spatial mission. The study of printed antennas shows that, we were able to design an antennas arrays consisting of four truncated square elements, which will be used for tsunami warning system and Total Electronic Content (TEC) measurement.

As it is seen on Section 4, simulation results are satisfactory for input reflection coefficient, VSWR, radiation patterns, beam-width at 3 dB and axial ratio. The present network thus proposed with acceptable gain, ease in manufacturing, low cost, lightweight and small footprint meets our goal. In comparison with similar works in this area, the proposed antennas array offers relatively small dimensions, simple structure, low cost and the major advantage is operation at both GPS L1 and L2 frequencies at the same time. The antenna prototypes will, thereafter, be related to a GPS OEM board and integrated to a NanoSat "triple cube" designed for space monitoring. As perspective to this work, we will consider the study of a dual frequency network with 4 bi-frequency elements.

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