DOWN-CONVERTER FOR GPS APPLICATIONS

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***Abstract*— An RF down/up converter system is presented for indoor GPS applications. Transmission of GPS signals directly into indoor environments are limited and in some cases prohibited for regular operation of GPS system. However, ISM frequency bands, especially 433MHz can be used to retransmit the GPS signals to indoors. In this paper, RF down-converter building blocks are designed and implemented for sending GPS signals in ISM band. The down-converter system has heterodyne architecture which has LNAs, mixer, oscillator and filters. Received signals from the satellites are amplified, down-converted, filtered and again amplified. The overall performance of the designed system is 54.3dB gain and 2 dB noise figure while it is drawing 78mA current with 3V supply.**

***Keywords*— GPS, Down-Converter, Amplifier, Mixer, Oscillator**

I. INTRODUCTION

Recently, there has been an increasing demand for indoor GPS applications as the usage area of GPS increases. Indoor GPS systems can be used in many applications such as locating the products in markets, tracking subjects or cars, helping visually impaired people or Alzheimer patients to find their ways. Although conventional GPS receivers work properly in outdoor areas, it cannot detect the GPS signals and cannot perform positioning on their own in indoor areas like tunnels, mines, buildings due to the already low power levels of the GPS signals reaching the earth, and additional loss of 10-30dB due to some physical obstacles like walls of the buildings.[1] There are many works on indoor GPS systems and some of them perform the positioning by using repeater[2], wireless[3], bluetooth[4] and RFID system[5]. The power level of GPS signals which are retransmitted to the indoor areas is limited. To compensate this limitation, the frequency of the signal can be decreased, so transmission of more power levels to the indoor areas can be provided. The goal of our work is to perform indoor positioning by sending the GPS signals in 433MHz and retransmitting the signals to the receiver in GPS frequency, 1575MHz, with the help of an up-converter, which will be designed, to make GPS receiver to detect the signals. Due to fact that the penetration of signals at lower frequencies is easier to the physical obstacles like walls, these signals can propagate in longer distance and be transmitted in higher power level. Therefore, 433MHz is chosen for the transmission frequency of the GPS signals. In this paper, down-converter system, which decreases the frequency of GPS signals to the 433MHz, is introduced.

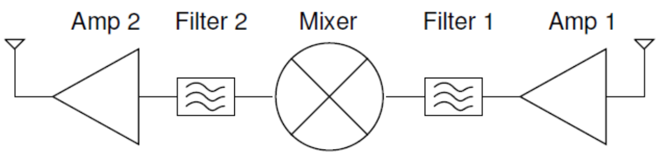


Fig. 1 Down-Converter System Schematics

II. SYSTEM DESIGN

The signals received by directional antennas are the input of the down-converter circuit with -157dBW power level.[6] The reason for using directional antennas for receiving GPS signals is the need for receiving the signals from three different satellites for performing position calculation.[2][7] GPS signals, reaching the earth with low power level, should be amplified and filtered firstly, later, down converted with the help of a mixer and a local oscillator. The signals which are down converted are filtered, amplified again and sent to the indoor areas with the help of 433MHz antenna which will be connected to the output of the circuit. Designed system schematics are shown in Fig. 1. Down-Converter system is composed of low noise amplifiers, filters, a mixer, a local oscillator and power amplifiers. The system is designed on FR4 PCB board. GPS signals are received firstly by a directional antenna and transmitted to the input of the circuit by coaxial cable with 50Ω input impedance. Transmitted low power GPS signals are amplified with an LNA which is shown in Fig. 1 with Amp 1. After the signal filtered with the help of the filter shown in Filter 1, it is down converted to the 433MHz ISM band by the mixer shown in Mixer in Fig. 1 with the help of a local oscillator. Later, the signal is filtered by a filter shown in Filter 2 and amplified with 433MHz LNA shown in Amp 2 in Fig. 1. Lastly, with a 433MHz antenna, the down converted signal is retransmitted into the building. For the first component of the system, an amplifier with low noise figure and high gain should be chosen. To make lower the noise figure of a heterodyne system, it is very crucial that first amplifier should have very low noise figure. For the first step, an LNA in GPS frequency is chosen and the chosen LNA has a filter in it, so there is no need for second component in the Fig. 1. This would decrease the size of the board and also decrease the cost. The chosen LNA is drawing 8mA from 3V power supply. Its performance is 0.82dB noise figure and 13.5dB gain in its datasheet. Second component of the system is a filter in GPS frequency to eliminate the signals at the other frequencies and it should have low insertion loss. It is used within the first LNA. For the third component of the system, a mixer with high conversion gain and a local oscillator at 1142MHz for helping to the mixer should be chosen. This mixer down converts the GPS signals to 433MHz by multiplying the signal with the signal produced by the local oscillator at 1142MHz. Chosen mixer draws 15mA current from 3V power supply. Its performance is 9.6dB noise figure and 11dB gain. The local oscillator oscillates at 1142MHz with -5dBm output power while it is drawing 50mA from 3V power supply. For the fourth component of the system is a filter to eliminate unwanted frequency components of the signal, comes out from mixer and it should have low insertion loss. The chosen filter has 2dB insertion loss and 1.7MHz bandwidth. Its pass band is between 433MHz and 434.71MHz. For the fifth component, an amplifier should be chosen with high gain. The LNA is chosen to be used in up-converter system. The reasons for choosing this LNA is to decrease the number of different components in the circuit and also decrease the power that the system consumes. The chosen LNA draws 3mA current from 3V power supply. Its performance is 0.9dB noise figure and 15.8dB gain with output 1dB compression point -6dBm. The LNA at the last stage is used twice for obtaining more gain and so the system has about 30dB gain after mixer stage.

III. MEASUREMENTS

The system is realized on FR4 PCB board by using coplanar waveguide transmission lines. The reason for using coplanar waveguide topology is to enlarge the effective ground plane so as to increase isolation. Noise figure can be calculated by using well-known Friis equation in Eq. 1.

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} + \frac{F_5 - 1}{G_1 G_2 G_3 G_4} \qquad (1)$$

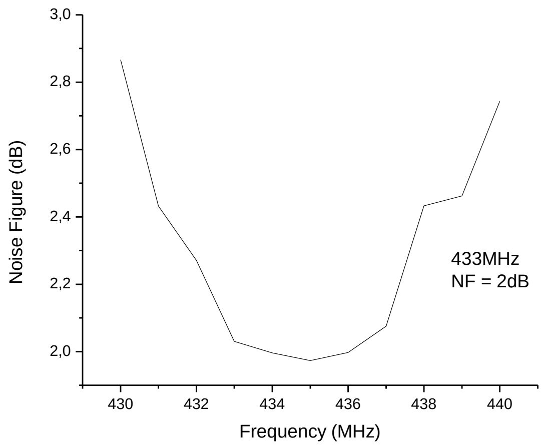
F1 = 1.2 G1 = 22.387
F2 = 9.12 G2 = 12.589
F3 = 1.122 G3 = 0.63
F4 = F5 = 1.23 G4 = G5 = 38

After calculation of noise figure of the system, expected noise figure is 1.56dB. Expected total performance of the system is given in table 1.

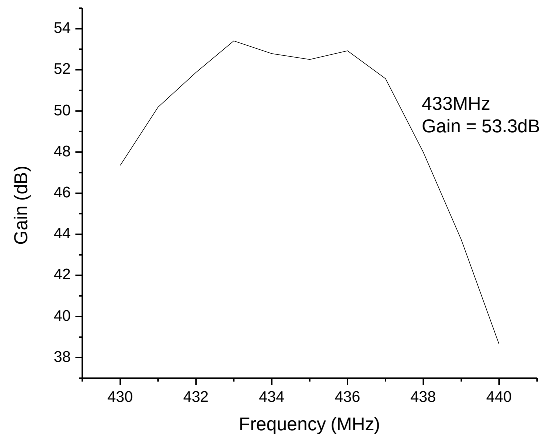
	Amp 1	Mixer	Filter 2	Amp 2	Amp 2	TOPLAM
Gain	13.5dB	11dB	-2dB	15.8dB	15.8dB	54.1dB
Noise Figure	0.82dB	9.6dB	0.5dB	0.9dB	0.9dB	1.56dB
Power	8mA	65mA	0mA	3mA	3mA	78mA

Table 1 Expected total performance of the system and comparison of performances of each building blocks

The measured results can be seen in figure 2, and figure 3. The produced board has 53.3dB gain and 2dB noise figure. When the expected results are compared with measured results, the difference between expected gain and measured gain is about 1.5%. The noise figure is measured 28% more than expected. The discrepancy between the expected and the measured noise figure may stem from the board material, FR4 or error in measurement setup. The measured S_{11} is -9dB and S_{22} is -19dB. The S_{11} of the system is dominated by the S_{11} of the first LNA, Amp 1 in Fig. 1 and the S_{22} of the system is dominated by the S_{22} of the last LNA, Amp 2 in Fig. 1. The complete circuit is drawing 78mA current from 3V power supply and so consumes 234mW power.



(a)



(b)

Fig. 2 (a) Down-Converter System Noise Figure (b) Gain

The OIP3 of the system can be calculated by using Eq. 2.

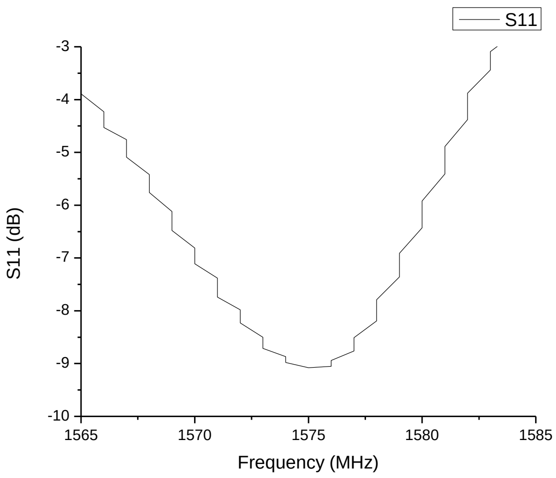
$$\frac{1}{OIP3} = \frac{1}{OIP3_1 \cdot G_2 \cdot G_3} + \frac{1}{OIP3_2 \cdot G_3} + \frac{1}{OIP3_3} \qquad (2)$$

$OIP3_1 = 100$ $OIP3_2 = 25.11$
$OIP3_3 = 3.16$ $OIP3_4 = 3.16$

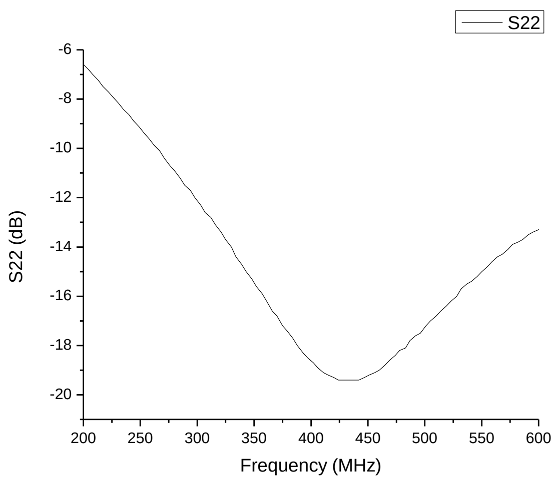
After calculation of OIP3 of the system, OIP3 is 4.87dBm. OIP3 values for each component are shown in table 2.

	Amp 1	Mixer	Amp 2	Amp 2
OIP3	20dBm	14dBm	5dBm	5dBm
1dB Output Compression Point	16dBm	-1dBm	-6dBm	-6dBm

Table 2 Comparison of output third-order intercept points and 1dB output compression points of each building block



(a)



(b)

Fig. 3 (a) Measured S11 (b) Measured S22

IV. CONCLUSIONS

In this paper, a new repeater model defined for indoor GPS applications is presented. GPS signals will be received by three directional antennas, amplified, down-converted, filtered, re-amplified and transmitted to the indoor area by designed 433MHz antenna. The signals sent to the indoor areas will be up-converted and amplified. Lastly, GPS receiver will detect these signals at GPS frequency and find the location of the receiver. For this system, a board which is composed of 3 LNAs, one oscillator, one mixer, two filters and transmission lines on FR4 PCB board is designed. The designed board has measured 53.3dB gain and 2 dB noise figure while it consumes 234mW power. Designed this system can be used without any need of infrastructure by locating the system to the glasses of the buildings, entrance and exit of the tunnels, etc. It can be used for location detection of medical personnel or equipment in a hospital, location detection of firemen in a building on fire.

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