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Frequency Reconfigurable Printed Monopole Antenna using a Quarter Wave Stub Resonator

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Abstract

This paper presents a frequency reconfigurable printed monopole antenna that can be reconfigured to two operating bands - UWB (3.1 - 10.2 GHz) and sub-6 GHz (3.1 – 6 GHz). To attain frequency reconfigurability, the partial ground plane of the printed monopole is loaded with a quarter wave stub resonator which can be either connected or disconnected with the ground plane with the aid of a p-i-n diode. The quarter wave stub resonator is designed in such a way that it provides a wide stopband in the UWB band of the antenna giving the sub-6 GHz band. The proposed resonator structure has minimal effects on the antenna's radiation characteristics while providing good stopband performance. The antenna is suitable for UWB, sub-6 GHz 5G and Cognitive Radio applications.

1. Introduction

Reconfigurable antennas [1] are popular due to their ability to adapt to different frequency/polarization/pattern as per the need and requirement. There are three types of basic reconfigurabilities possible – Frequency, Polarization and Pattern. A reconfigurable antenna can have any one of these reconfigurability feature or combinations of these reconfigurations (hybrid reconfigurability).
The basic principle for attaining reconfigurability in any antenna is to alter the current flow on the antenna surface. By altering the surface current distribution on the antenna's surface, it's characteristics such as return loss, radiation pattern, polarization, etc. can be changed. This can be done using various methods such as creating slots in the antenna, by adding parasitic stubs or lines or by embedding split ring resonators on the antenna as shown in literature [2-9].
Further, with the help of a switching device such as a p-i-n diode or RF transistor, the reconfiguring structure can be switched ON/OFF to obtain different working states of the antenna.

However, the challenge lies in designing a reconfiguring structure (slot, stubs, SRSs, etc.) such that it has a minimal effect on the antenna characteristics of the original antenna. Another challenge is selecting the proper RF switch for the application. An ideal switch has infinite isolation in OFF state and infinite conduction in ON state. However, RF switches are active devices such as p-i-n diodes and transistors. These devices act as a resistor in forward bias (ON) and capacitor in reverse bias (OFF). This leads to a resistance in the forward bias causing a loss in the RF power due to power dissipation in the resistor and RF leakage in the reverse bias due to capacitance which has undesirable effects on the antenna.

In this paper, a simple, general and effective method is presented to achieve frequency reconfiguration in a printed monopole antenna. The proposed technique is general in nature i.e., it can be used with any shaped printed monopole antenna.
First, a printed monopole antenna is designed to operate in the UWB band. Since in a printed monopole antenna, the ground plane is also responsible for the impedance matching, any change in the ground plane will affect the return loss of the antenna [10]. This principle is used to attain frequency reconfiguration. A stub is connected to the partial ground plane of the monopole to alter the surface current distribution of the antenna. The length of the stub is then optimized to get a perfect sub-6 GHz passband and a good stopband at other frequency band while keeping the adverse effects on the original UWB antenna to a minimum.
A p-i-n diode is then used to connect/disconnect this stub with the ground plane achieving two frequency bands – UWB and sub-6 GHz.
The proposed reconfigurable antenna shows good gain and efficiency in both the bands (UWB and sub-6 GHz) and good stopband characteristics with gain <0 dBi and efficiency <70 % for the stopband.

2. Antenna Design

The base antenna consists of a truncated circular shaped printed monopole antenna. The antenna is fed with a stepped impedance line for good impedance matching.
The overall dimension of the antenna is $(X \times Y)$ = 24 X 31 mm^2. The other dimensions of the antenna (all in mm) are as follows: a = 6.5, r = 10, w = 1.5, L_1 = 12.2, L_2 = 1.9, L_g = 13.5, t_s = 0.3, s_1 = 2, s_2 = 2.5 and g = 0.6. The antenna is simulated using CST Microwave Studio.
The antenna configuration is shown in Figure 1.
Next, to alter the surface current of the base antenna, the partial ground plane of the antenna is loaded with a stub of certain length. The length of the stub is optimized by doing

a parametric study and observing the impedance vs. frequency response of the antenna.

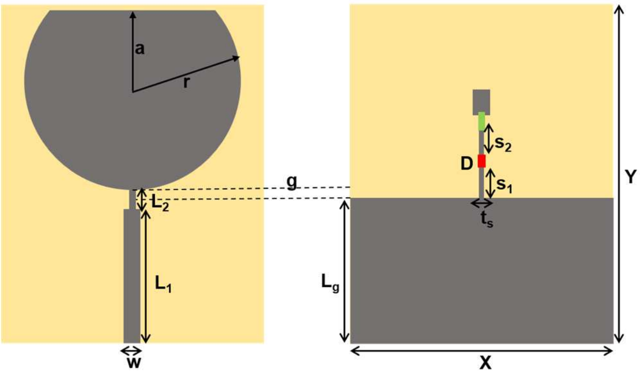

Figure 1. Printed monopole antenna loaded with stub

3. Parametric Study and Working Principle

3.1 Parametric Study of Variation of length of Stub on the VSWR vs Frequency Response

To achieve frequency reconfigurability in any antenna, the antenna's surface current distribution has to be altered using the methods mentioned in Section 1.
Since in a printed monopole antenna, the partial ground plane of the antenna is also responsible for impedance matching and radiation, any change in the partial ground plane will affect the antenna's radiation characteristics.
This principle is used and a stub is connected to the partial ground plane of the monopole antenna.
A parametric study is conducted to understand the effect of the stub on the impedance bandwidth of the antenna.
From Figure 2. It can be seen that as the length of the stub increases, the passband bandwidth becomes smaller. A certain length of the stub p = 4.5 mm is chosen as it gives a perfect passband from 3.1 – 6 GHz (sub-6 GHz) band and s stopband after 6 GHz.
With the help of a p-i-n diode, this stub can be either connected or disconnected with the partial ground plane and hence the working frequency of the antenna can be switched between the sub-6 GHz and UWB bands.

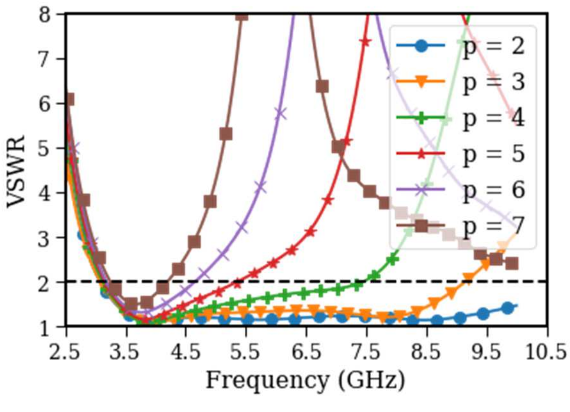

Figure 2. Parametric variation of stub length VSWR vs frequency response (p is in mm)

3.2 Analysis of stub using Impedance vs Frequency Response

In order to understand the effect of the stub, the impedance vs frequency response of the antenna before and after connecting the stub is analyzed. From the impedance vs frequency response in Figure 3 it can be observed that when the stub is connected to the partial ground plane, the real part of the impedance is maximum = 355 Ω and the imaginary part is 0 Ω indicating that the stub behaves as a parallel resonator at the frequency of 8.5 GHz. Further, the length of the stub = 4.5 mm which is quarter wavelength ($\lambda_g/4$) of 8.5 GHz, indicating that the stub behaves as a quarter wavelength resonator at 8.5 GHz.

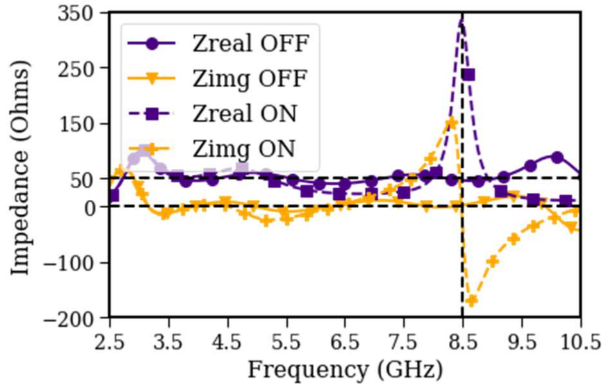

Figure 3. Impedance vs Frequency response before and after connecting the stub with the partial ground plane

4. Simulation and Experimental Results

The proposed antenna is fabricated on FR-4 substrate with dielectric constant of 4.3, loss tangent of 0.025 and thickness of 0.8 mm.
As seen from the Section 1, the proper choice of diode is important, a p-i-n diode from MACOM MADP-000907-14020P is selected as the RF switch. From the datasheet of the diode, the diode has a forward resistance of 5.2 Ohms and a capacitance of 0.03 pF in the reverse bias [11].
The diode is soldered at an appropriate location on the stub such that the extra length stub will affect the bandwidth of the printed monopole antenna. Two wires are soldered to bias the p-i-n diode. The fabricated prototype is shown in Figure 4.

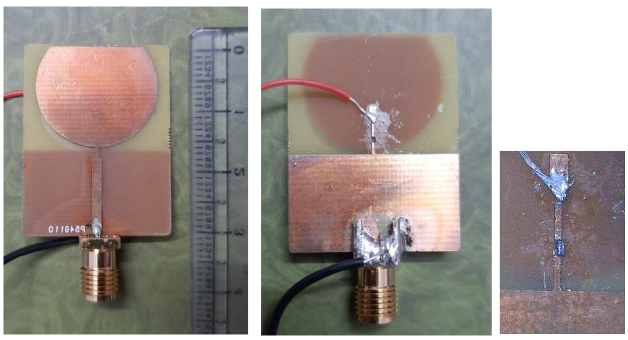

Figure 4. Fabricated prototype of the antenna

The simulated and measured VSWR vs. Frequency response of the fabricated antenna is shown in Figure 5. It can be observed that the simulation and experimental agree with each other. A slight shift is observed in the measured results which may be attributed to the fabrication tolerance and the effect of the biasing wires. The VSWR response shows a UWB band from 3.1 – 10.6 GHz when the p-i-n diode is OFF. When the p-i-n diode is ON, the bandwidth of the antenna is limited to the sub-6 GHz band from 3.1 – 5.7 GHz.

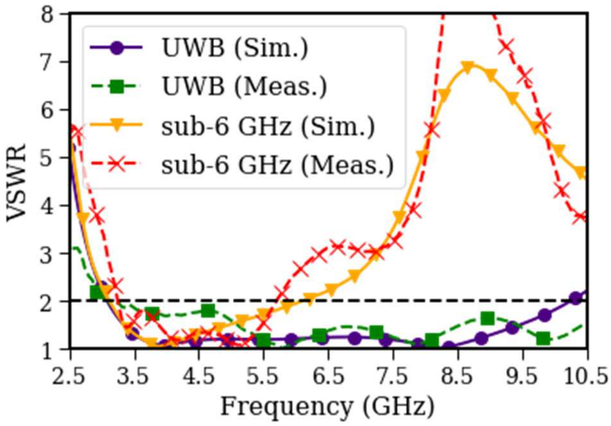

Figure 5. Simulated vs. Measured VSWR Response

The measured vs simulated radiation pattern is shown in Figure 6. It can be seen that the antenna exhibits omnidirectional pattern in both the cases: diode ON as well OFF indicating that the proposed reconfiguring structure (quarter wavelength stub) has minimal or no effect on the radiation pattern of the antenna.

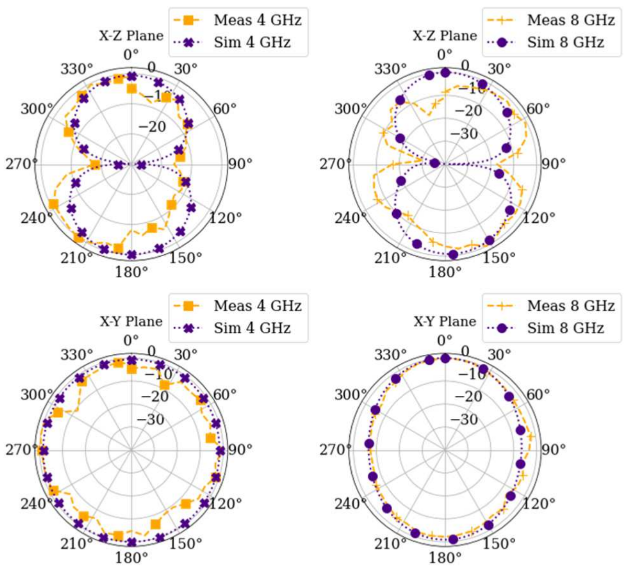

Figure 6. Simulated vs. Measured Radiation Pattern at 4 GHz and 8 GHz

In order to evaluate the performance of the stopband in the diode ON case (sub-6 GHz band), the gain vs frequency response as well as efficiency vs frequency response is studied.

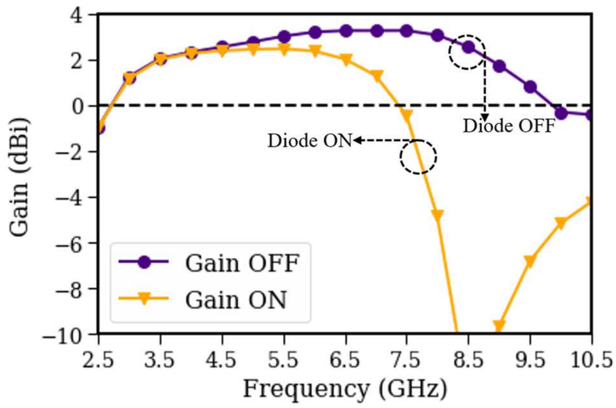

Figure 7. Gain vs Frequency for UWB and sub-6 GHz band

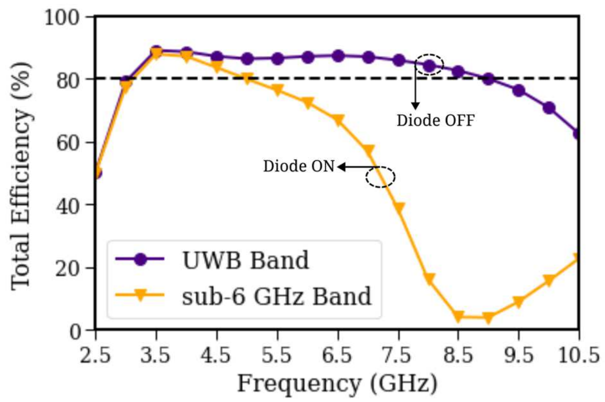

Figure 8. Efficiency vs Frequency response for UWB and sub-6 GHz band

From Figure 7 it can be observed that the gain of the proposed antenna is greater than 0 dBi for the UWB case when p-i-n diode is OFF, whereas when the p-i-n diode is ON, at the out-of-band frequency, the gain drops sharply and is below 0 dBi indicating good stopband performance. Similarly, the efficiency vs frequency response in Figure 8 it can be observed that the efficiency in the UWB band is greater than 80% whereas in the out-of-band frequency for the sub-6 GHz band, the efficiency drops sharply indicating good stopband performance.

5. Conclusion

The proposed antenna exhibits two band reconfigurability using a quarter wavelength stub resonator.
The proposed reconfigurability structure has minimal effect on the radiation characteristics of the printed monopole antenna and can be used with any shaped printed monopole antenna thereby, giving a general reconfigurability technique for printed monopole antennas. The antenna also exhibits good stop band characteristics with gain below 0 dBi for the stopband and efficiency

reducing sharply below 80% for the stop band with minimum efficiency of 5% in the stopband.
The antenna is suitable for UWB, sub-6 GHz 5G and Cognitive Radio applications.

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