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Designing and Optimization of Frequency and Beam Steering Reconfigurable MPA Antenna

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Abstract: In this paper single band antenna is converted to dual band reconfigurable antenna. The converted antenna is reconfigurable in both dual band frequency agility (with central frequencies 912 MHz and 1102 MHz) and radiation pattern. The direction of the main lobe is being varied in both E and H planes with the change in the switches' states. The Antenna's re-configurability in frequency is obtained with the use of two copper tapes acting as switches between the four copper annealed patches which are embedded on FR4 substrate. There is no need to change the material or dimension of the antenna to turn it into reconfigurable but the antenna is showing the reconfigurable properties only by changing the internal structure of the antenna using the switches. The antenna is fed by coaxial cable which is connected with SMA connector. The dimension of the designed antenna is 100 mm × 100 mm × 33.4 mm. The reconfigured antenna is optimized to get maximum directivity 1.687 dBi in H Plane at angel 0ºwhen the area of substrate is 90 mm ×90mm and the area of patch is 43.2 mm × 43.2 mm. The CST MW studio is used for design of antenna and simulating the results. The structure and dimensions of the antenna's components paly important role in antenna design and improving the antennas' parameters the future work is recommended to use diode switches in place of copper tapes to make an antenna reconfigurable.

Keywords: Frequency Agility, FR4, Substrate, Directivity, CST

1. INTRODUCTION

To reconfigure anything means to organize or arrange the partial or complete parts of that thing in order to get some purpose or goal. The antenna can be a reconfigurable antenna if the basic parameters of the antenna can be changed or improved by arranging the antenna's structure. The reconfigurable antenna may change or vary the polarization, operating frequency bands or radiating pattern in E and H planes in some desirable way according to system requirement to avoid noise and unwanted signal in the communication. The reconfigurable antennas dynamically adopt the changes or variations in the communication channels or to meet the system requirement (Eslami, *et. al*, 2010), (Cetiner, *et. al*, 2004) without any external complex system. A single reconfigurable antenna can be used instead of two or more antennas for multiband communication services. A comparative research study between the fixed antenna and the reconfigurable antenna where both antennas were tuned for the laptop model was performed to judge their performance. The results presented that the reconfigurable antenna performed better for coverage, gain and diversity than the fixed antenna (Roach *et. al*, 2007). Reconfigurable antennas are getting popularity in antenna's design. In this paper single band antenna is converted to reconfigurable by using the switches. Reconfigurable antenna is showing frequency agility and beam steering characteristics.

Recently researchers have worked a lot t and they invented the different methods to turn an antenna into the reconfigurable antenna by connecting or disconnecting the internal elements of the antenna. The switching elements may be PIN diodes (Nikolaou, *et. al*, 2006) which changed the antenna radiation pattern and frequencies, Switches (Photo Conductive) (Pana-gamuwa, *et. al*, 2006) connected the antenna elements and subsequently frequency is shifted to the 40%more to the central frequency. Polarization reconfigurable antenna is designed by controlling the RF switches with two set of DC biases (Lin, 2016). Twelve PIN diodes are used to get twelve linear polarizations at interval of 30º (Chang, *et. al*, 2014). Bias voltages of FETs (Wang, 2005) are varied to change the radiation pattern of the arrays. Radiation pattern reconfigurable antenna is obtained by the changing the states of switch 1 and switch 2 (Nguyen, 2016). Reconfigurable antenna is obtained by changing the ON/OFF state of plasma (fluorescent lamp) (Barro, *et. al*, 2016), the reduction of ground plane (Sabapathy, *et. al*, 2016) also led to beam steerable antenna. Two multiband antennas are designed by switching between antenna's two feeding points and switching of the two ground planes (Mak, *et. al*, 2007).

In this paper, single band antenna operating in GSM (Global System for Mobile Communication) frequency band designed by IEEE members in 2012, is converted

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into dual frequency band and radiation pattern reconfigurable antenna. The antenna is designed by using MW CST Studio. The designed antenna is micro strip patch antenna (MPA). The MPA has many advantages compared to any another antenna types. The MPA has light weight, compact size and easy to design, integrate and fabricate (Valizade, *et. al*, 2014). MPA antenna is mostly used in wireless communication services.

The chemistry of the single band antenna consists of FR4 substrate, four square patches, one dipole and two wires. The single band antenna turned into reconfigurable antenna by inserting two copper tapes between the four patches. The working characteristics of copper tape as switch is similar to the diode switch which is used to connect the internal parts of the antenna. The reconfigurable antenna operates for two frequency coverage bands when one of the copper tape switch is connected with the patches. Return Loss or S11 parameter is better when both switches are connected with four patches. The other beauty of the designed reconfigurable antenna is that it shows the variation in the direction of main lobes in horizontal and vertical planes when the states of the switches are changed. In section-II single band antenna is designed and parametric analysis is performed in section-III. In section-IV and V the single band antenna is converted into reconfigurable antenna and simulation results are discussed. Conclusions are described in the section-VI and future work is recommended to use diode switches in place of copper tapes.

2. DESIGN OF SINGLE BAND ANTENNA

In 2012, Leonardo Lizzi member, IEEE, Fabien Ferrero member IEEE, Jean-Marc Ribero, and Robert Staraj presented single band omnidirectional radiation antenna (Lizzi, *et. al*, 2012) operating in frequency band from 890 MHz to 960 MHz with central operating frequency at 925 MHz The single band antenna consists offour square patches of length and width "p", dipole of length "d_1". and two leads of diameter 1 mm each. **(Fig-1)** is showing the layout of the single band antenna. SMA connector is used for feeding of the antenna.

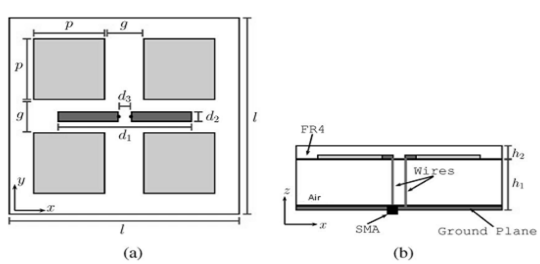


Fig-1 Geometry of Antenna (a) Top view (b) Side View

The **(Table-1)** shows the detail of values of the variables as described in **(Fig-1)**. The unit of each measurement of the antenna's element described in Table I is millimeter (mm)

Table-1 Values Of Single Band Antenna Parameters

Parameters	Values (mm)	Parameters	Values (mm)
l	**100**	**g**	**9**
d_1	**71.5**	**p**	**38.5**
d_2	**2**	**h_1**	**0.4**
d_3	**5**	**h_2**	**33**

A. *Simulation Results of single band antenna* CST MWS is used for simulation.
The simulation frequency: 500 MHz to 1500 MHz

1) *S11 parameter:* Return loss or S11parameter is shown in **(Fig-2)**.The antenna has central frequency at 914 MHz and VSWR (Voltage Standing Wave Ratio) is 1.042. The antenna is useful for the wireless devices which are operating in GSM frequency band.

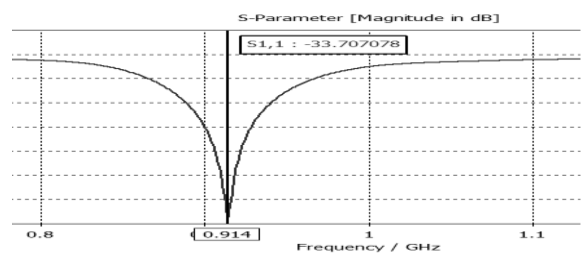


Fig-2 Return Loss or S11 Parameter of single band antenna

2) *Directivity of the single band antenna*: From the **(Fig-3)**. the maximum directivity of the antenna in E-Plan is 1.4 dBi at 180º and the angular width (3 dB) is 99.3º

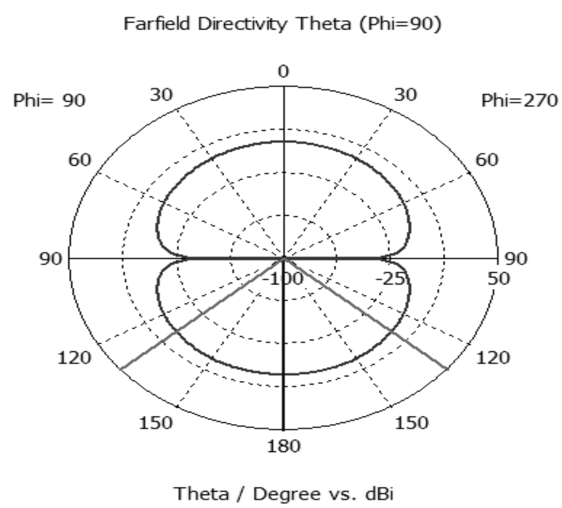


Fig-3 Antenna directivity in E-Plane (maximum at E_θ = 180º)

The **(Fig-4)** Shows that the maximum directivity of the antenna in H-Plan is 13.1 dBi at 90º and the angular width (3 dB) is 149.8º

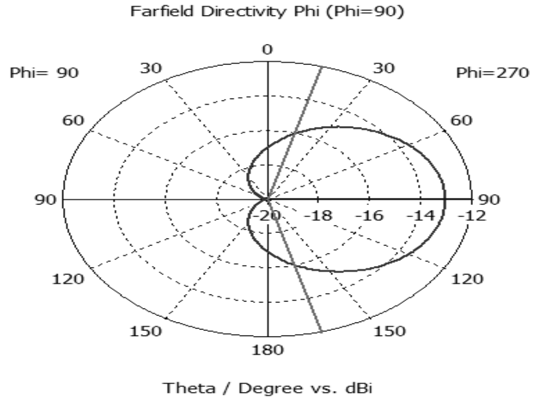


Fig-4 Antenna directivity in H-Plane (maximum at E_{φ} = 90º)

The **(Fig-3, 4)** show that the single band antenna has omnidirectional radiation pattern and it is useful for the devices whose location is priori unknown

3. PARAMETRIC ANALYSIS OF SINGLE BAND ANTENNA

In this section parametric analysis of the single band antenna is performed by

- Variation in area of the substrate from 94 × 94 mm^2 to 110 × 110 mm^2
- Variation in area of the patches from 33.5 × 33.5 $mm^2$to 43.5 × 43.5 mm^2
- Variation in area of the length of the dipole 67.5 m to 75.5 m

With the decrease in area of the substrate, the return loss is improving and the resonant frequency is also being shifted towards the lower frequency band as shown in **(Fig-5)**.

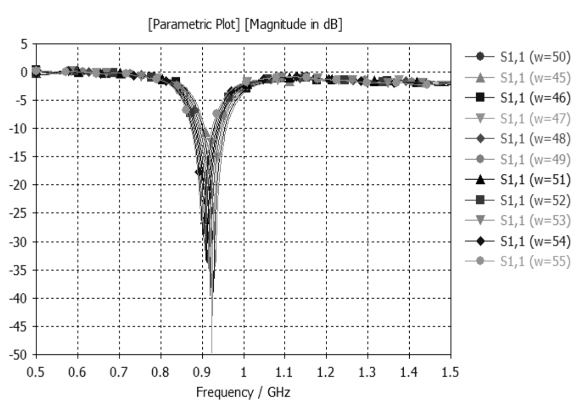


Fig-5 Variation in the S11 parameter with change in the area of substrate

As the area of the patches increases return loss is decreasing and the resonant frequency is also being shifted towards the lower frequency band as shown in **(Fig-6)**.

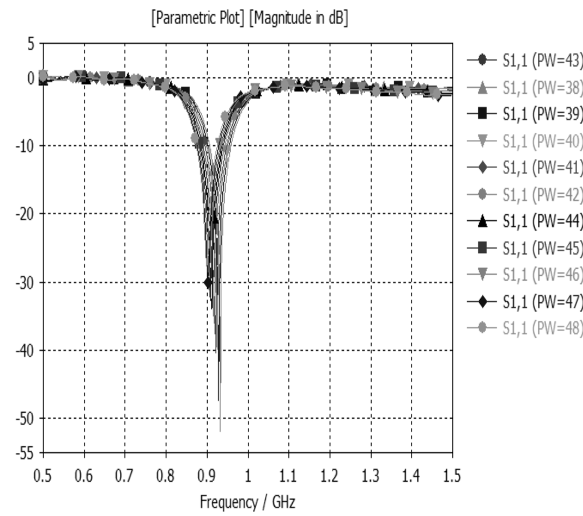


Fig-6 Variation in the S11 parameter with change in the area of patches

The S11 parameter is decreased and central frequency is moved toward lower frequency as dipole's length increases.

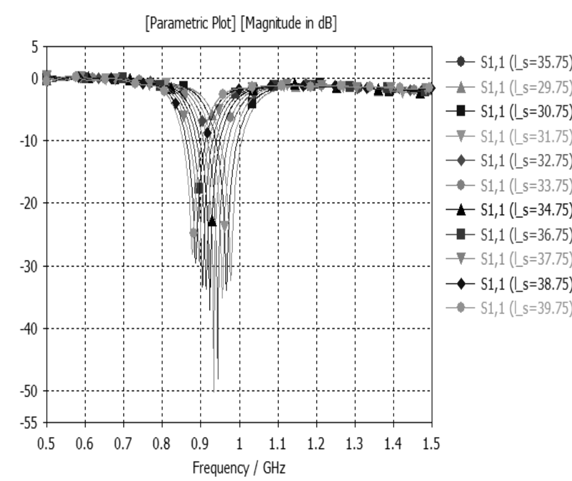


Fig-7 Variation in the S11 parameter with change in the length of the dipole

4. DUAL BAND RECONFIGURABLE ANTENNA DESIGN

Two copper tapes S1 and S2 are inserted between the patches as shown in **(Fig-8)**. We preferred to insert the copper tapes because they offered the same effects as diode switches, the length of each copper tape is equal to "g" and width is 1mm.

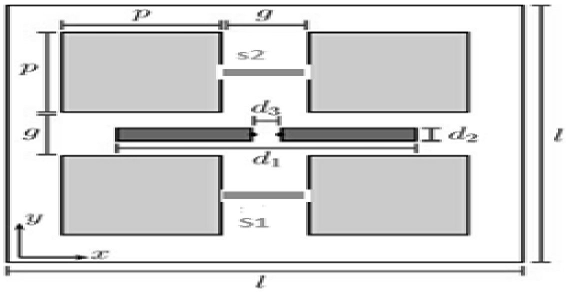


Fig-8 Geometry of Reconfigurable Patch Antenna

The antenna is designed and simulated in CST MW studio from frequency range 0.5 GHz to 1.5 GHz. When both switches are in OFF position, the only GSM band is achieved having same S11 parameter, VSWR and bandwidth of single band antenna. The **(Fig-9)**. shows the return loss of the reconfigurable antenna when one of the switch is ON state and other is in OFF state. The second frequency band is achieved.

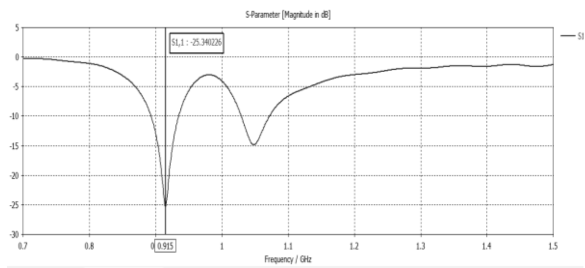


Fig-9 Return Loss when one of switch is ON

The **(Fig-10)** shows return loss of the reconfigurable antenna when both switches are in ON position. The position of switch is selected in the middle of the patches. The second frequency band is achieved with good return loss -14.69 as compared to when one of the switch is in OFF position

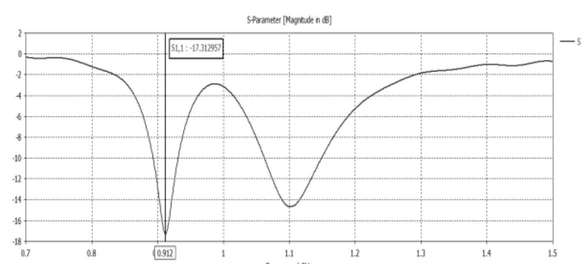
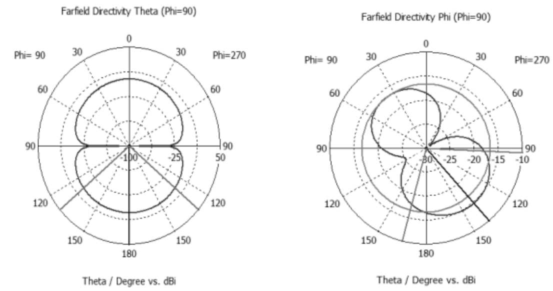


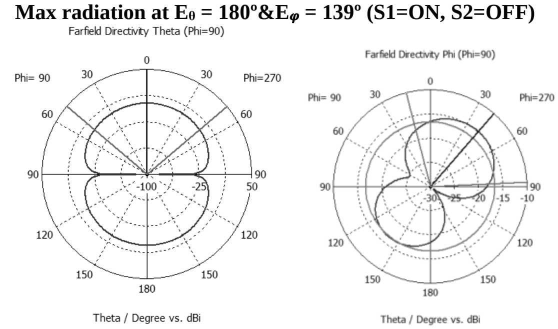
Fig-10 Return Loss when Both Switches are in ON states

5. RECONFIGURABLE ANTENNA SIMULATION RESULTS

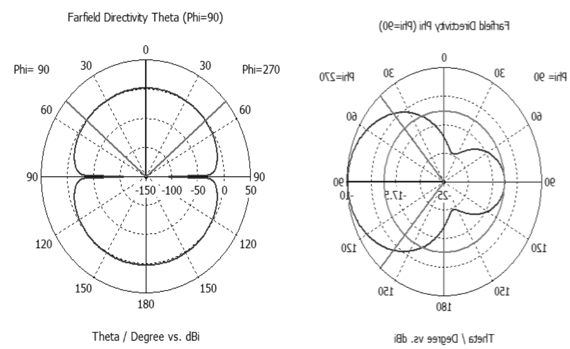
For 1^{st} frequency band, the frequency is shifted from 912 MHz to 915 MHz the maximum lobe direction in E-plane is varying from 0º to 180º and in H-Plane from 41° to 139°at different switches' states as described in **(Table-2)**



Max radiation at E_0 = 180º&E_φ = 139º (S1=ON, S2=OFF)



Max radiation at E_0 = 0º &E_φ = 41º (S1=OFF, S2=ON)



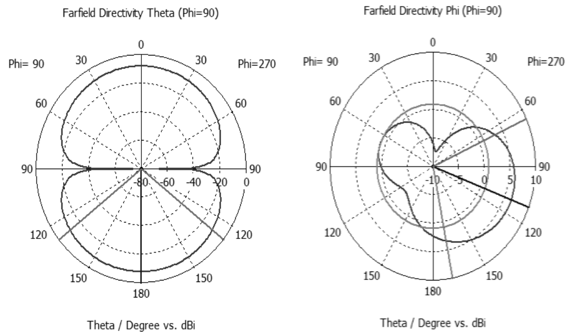
Max radiation at E_0 = 0º&E_φ = 90º (S1=ON, S2=ON)

Fig-11 Maximum radiation pattern directions for 1^{st}frequency band of dual band reconfigurable antenna in E and H Planes

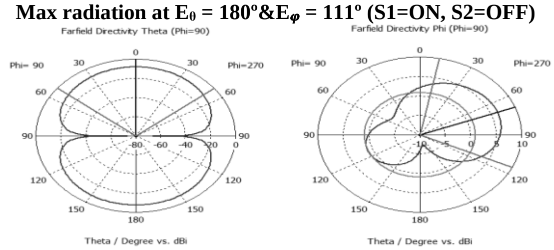
Table-2 Summary of Simulating Results (1st frequency band)

S#	Switch States	Operating Point (MHz)	θ	φ	Peak-Gain (dBi)
1	S1=OFF, S2=OFF	914	0°	90°	1.53
2	S1=ON, S2=OFF	915	180°	139°	1.613
3	S1=OFF, S2=ON	915	0°	41°	1.613
4	S1=ON, S2=ON	912	0°	90°	1.58

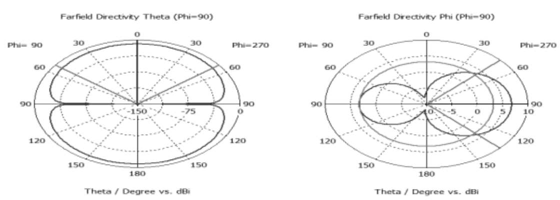
For 1^{2nd} frequency band, the frequency is shifting between 1048 MHz to 1102 MHz The maximum lobe direction in E-plane is varying from 0º to 180º and in H-Plane from 69° to 111°at different switches' states as described in **(Table-2)**.



Max radiation at E_θ = 180º&E_φ = 111º (S1=ON, S2=OFF)



Max radiation E_θ = 0º&E_φ = 69º (S1=OFF, S2=ON)



Max radiation at E_θ = 0º&E_φ = 90º (S1=ON, S2=ON)

Fig-12 Maximum radiation pattern directions for 2nd frequency band of dual band reconfigurable antenna in E and H Planes

TABLE-3 Summary of Simulating Results (2nd frequency band)

S#	Switch States	Operating Point (MHz)	θ	φ	Peak-Gain (dBi)
1	S1=OFF, S2=OFF	No 2nd Frequency Band			
2	S1=ON, S2=OFF	1048	180°	111°	6.282
3	S1=OFF, S2=ON	1048	0°	69°	6.282
4	S1=ON, S2=ON	1102	0°	90°	6.274

6. OPTIMIZATION OF RECONFIGURABLE ANTENNA

The reconfigurable antenna is optimized. The area of substrate and area of patches are varied to get maximum directivity in H-Plane (φ =0°).The maximum directivity 1.687 dBi is achieved when both the length and width of the substrate are 90 mm & both length and width of the patches are 43.2 mm. The **(Fig-13)** shows the values of maximum directivity of the reconfigurable at different areas of the substrate and patches while keeping length of dipole keeping constant at 71.5 mm.

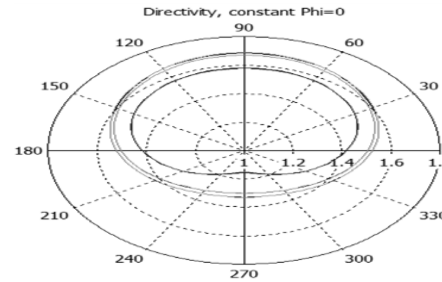


Fig-13 Optimized maximum directivity of reconfigurable antennaat phi=0°

7. CONCLUSIONS

A reconfigurable antenna both in frequency and radiation pattern is designed by using copper tapes. The reconfigurable antenna is optimized for maximum directivity in H-Plane. Simulation results are tabulated in **(Tables-2 and 3)**.For 1st frequency band the operating point i.e. resonant frequency almost remains the same i.e. approx. 915MHz but the direction of the main lobe varies from 0° to 180° and 41° to 139° in E and H Planes respectively for different states of the copper tape switches. For 2nd frequency band of the reconfigurable antenna, resonant frequency is shifted to 1048 MHz when one of the switch’s states is ON and other switch’s state is OFF. When both switches’ states are ON the resonant frequency is shifted to 1102 MHz the maximum radiation of the antenna in E-Plane is directed from0° to180° and in H Plane the direction of main lobe varies from 69° to 111° when the state of one switch is ON and other switch state is OFF. When both switches’ states are ON, the direction of maximum lobe is 0º and 90º in E and H Planes respectively. The designed reconfigurable antenna can be used as a beam steering antenna & frequency reconfigurable antenna when one or the both switches’ states are ON Future work is recommended to use the diode switches in place of copper tapes and the losses due to diode switches should be observed. The reconfigurable antenna has the resonant frequency is at 1.1 GHz for 2nd frequency band. Further efforts are required to shift the resonant frequency of 2nd frequency band beyond the 1.1 GHz. The position and the size of switches may effect on the parameters of the reconfigurable antenna.

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