ISSN 2320 2599
Volume 2, No.5, September - October 2013
International Journal of Microwaves Applications
Available Online at http://warse.org/pdfs/2013/ijma05252013.pdf

Design of Selective and Wideband Frequency Response Tunable Planar Spiral Antenna

[1]**Rahul Yadav**
[1]Dept. of Electronics & Telecommunication, TCET, Mumbai University, India
[1]Email: ryrahulyadav01@gmail.com

ABSTRACT

The paper presents design of planar spiral antenna operating in the frequency range of 1.06-15 GHz. The spiral arms are configured as rectangular monopole of λg/4 width to provide impedance matching with standard 50Ω and thereby eliminating the need of wideband balun design to feed the antenna. The effect of spiral turns and spacing between the turns on frequency response is demonstrated here. Two different design iterations are performed to enhance the selective and wideband response of the antenna. Varactor diode model MA46H070-74 GaAs is used for the coarse and fine tuning of selective frequency bands of the antenna. A detail analysis of diode location and biasing network is also explained. The antenna is fabricated on FR-4 substrate with ε_r = 4.3 and loss tangent of δ =0.025. The designed antenna having both selective band and wideband frequency response makes it suitable to use for wireless communication, electronic warfare jamming purpose and cognitive radio.

Key words: Spiral, rectangular monopole, frequency tuning, DC bias, selective band, wideband, varactor diode.

1. INTRODUCTION

The rapid growth in the field of microwave communication has put a demand to develop antenna with wideband response due to their high data rates, great capacity, simplex design and low power consumption. The Ultra wideband systems are usually used for personal wireless communication in home or office networks. However an antenna with ultra-wide band response mainly finds its application in electronic warfare and military purpose. The main drawback of UWB antennas is their interference with existing communication channels like GSM (900-1800GHz), UMTS (1.92-2.71GHz), local area network (WLAN5.15-5.825GHz), worldwide interoperability for microwave access (Wi-MAX, 3.3-3.7 GHz) IEEE 802.11a in the United States (5.15-5.35 GHz, 5.725-5.825 GHz) and HIPERLAN/2 in Europe (5.15-5.35 GHz, 5.47-5.725 GHz). The interference produces a high impulse noise which is difficult to eliminate at the receiver system and thereby increases the complexity of the whole system.

So a need is there to develop a hybrid antenna which can support both selective bands and wideband frequency response. It is found in [1-3], that frequency independent like log-spiral, rectangular spiral and Archimedean- spiral are the suitable to provide a wideband frequency response, but the problem arises with such antennas is with the feeding system due to increase in the antenna impedance which is generally in the range of (140-200)Ω. So special wideband balun are required to designed [4-6] for providing an impedance matching in the wide microwave range of frequency and thereby making the whole system much more bulky, putting a constraint in their applications. Next another important issue which needs to be considered is achieving selective resonant frequency bands. Generally slot loaded microstrip antennas (MSA) are employed for resonating multiple frequency band [7-8].However such antennas cannot be used for ultra wideband communication due to narrow frequency bands.

So to overcome the technological barrier of present and future wireless communication, a spiral antenna has been designed in this paper having both selective band in lower range of frequencies and wideband for higher range of frequencies. The presented designs are classified in two different iterations. The 1st iteration is a spiral with only four arms of equal width and each configured as rectangular monopole assuming higher range of operating frequency. In the 2nd iteration design, effect of increasing number to turns and width of adjacent spiral arm is investigated. A frequency tuning of resonant bands is also incorporated in the designs by introducing varactor diode at an appropriated position along the spiral antenna arms. A detail analysis of biasing of diode and RF/DC isolation network is also presented in the paper.

2. THEORY AND DESIGN APPROACH

A FR-4 substrate with relative permittivity (εr = 4.3) and loss tangent (δ = 0.025) is taken for the designing of antenna. A simplified planar spiral antenna is designed with its arms configured as rectangular monopole. The rectangular monopole width is taken as λg/4 where,

$$\lambda_g = \frac{\lambda_r}{\sqrt{\varepsilon_{eff}}} = \frac{c}{f_r\sqrt{\varepsilon_{eff}}} \qquad (1)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \qquad (2)$$

ε_{eff} - Effective dielectric constant, f_r - higher resonant frequency and λ_r - resonant wavelength

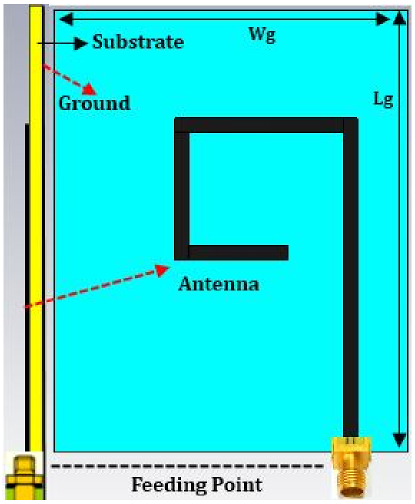


Figure 1 Layout of planar spiral antenna- 1st iteration

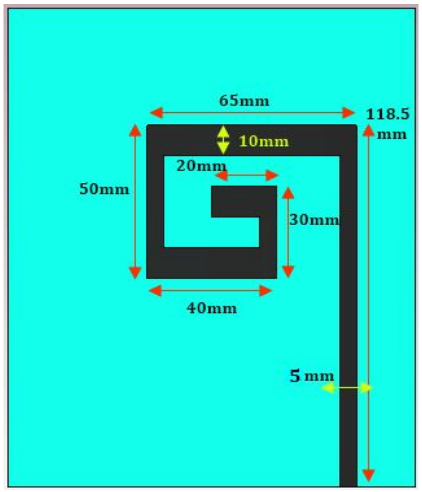


Figure 2 Layout of planar spiral antenna-2nd iteration

Assuming 9.2 GHz as the higher range of resonant frequency, the width of rectangular monopole is calculated as 5mm. The monopole length is here is independent of the resonant frequency and will not alter the characteristic impedance. However total length (L) of the antenna will affect the frequency response. The antenna ground plane dimensions are calculated using transmission model [9]. The calculated ground plane dimension is length (Lg) of 157mm and width (Wg) of 126mm. Figure1 shows the initial basic geometrical design of planar spiral antenna which is defined as the first iteration. The effect of increasing turns of the rectangular monopole arm spiral antenna is also demonstrated here. Figure.2 shows the geometrical design which is defined as 2nd iteration. For 2nd iteration design, the turns are 1½. Also the width of alternate spiral arm is double to increase the effective surface area of antenna so that surfaces current can decay exponentially ($e^{-\beta l}$) in the first two arm which not happen in the case of 1st iteration design.

3. ANTENNA TUNNING & BIASING NETWORK

The designs are made reconfigurable by introducing varactor diodes at an appropriate position along the antenna. Varactor diode MA46H070-74 GaAs model are used in the design. The main purpose for introducing varactor diodes instead of PIN diode is to control the electrical length (βl) and hence the resonant frequency with the help of DC bias. The equivalent circuit of diode proposed by the vendor is a series RLC circuit with a parallel capacitance as shown in Fig.3.

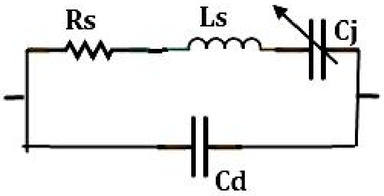


Figure 3 Equivalent circuit model of varactor diode

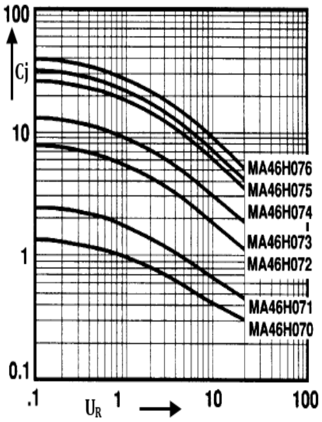
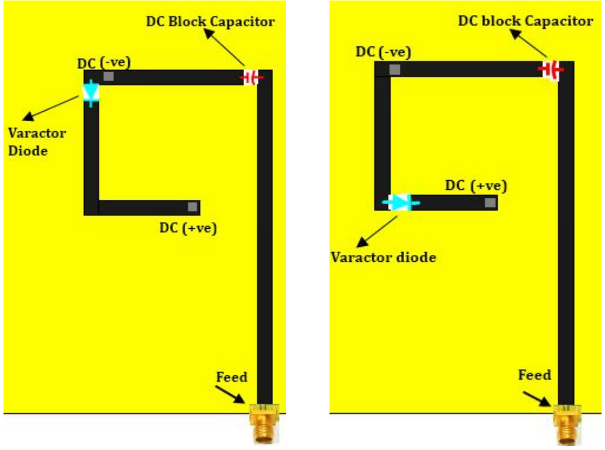


Figure 4 Diode junction capacitance as a function of reverse voltage

For diode model, the typical value of series resistance (Rs) is 5Ω and series inductance (Ls) is 5nH. The plot for junction capacitance (Cj) as function of reverse bias voltage for MA46H070 is shown in Fig.4.

Since the designed antennas are expected to have dual nature of frequency response i.e. selective band and wideband, so placement of diode along the antenna becomes more critical. The location of diode along the antenna must be decided in such a way that the electrical length variation which is also a function of diode junction capacitance varies only the selective range of frequency without affecting the wideband response. The variation in diode location with respect to RF feed is also demonstrated here. Figure 5 shows the design of 1st iteration with two different varactor diode locations. The D1 location of diode is between 2nd-3rd monopole arm of spiral and D2 location of diode is between 3rd-4th arm. For both 1st and 2nd iteration designs the biasing of diode is done using a simple adjustable voltage regulator as shown in Fig.6.



(a) (b)

Figure 5 1st iteration design with (a) D1 location (b) D2 location

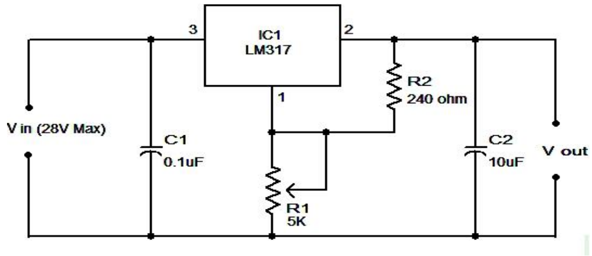
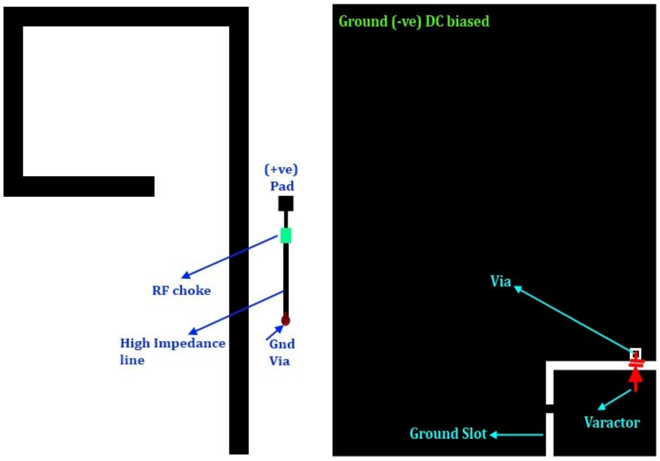


Figure 6 Typical voltage regulator circuit

It is important to provide RF/DC isolation in the designs. The DC isolation is given by capacitor having low impedance at the RF frequency whereas RF choke is used along with resistance or higher impedance line to isolate RF getting into DC bias. It found that at very high frequency the parasitic package effect and self-resonance of the lumped components becomes more significant. Then distributed passive transmission line such as open radial stub is used along with high-impedance transmission line [10]. However, alternative approach exit which possibly eliminates the need of RF isolation. This is done by placing the diode in ground plane and then modifying the ground plane geometry with diode switching action. The 1st iteration design is practically implemented with varactor diode placed along the ground plane of the antenna as shown in Fig.7. With the diode placed in the ground plane, the RF is completely isolated from the DC and thereby making the design simpler. Blocking capacitor of 100pF and RF choke of 47nH is used for 1st iteration with ground loaded diode.

Next for the 2nd iteration design, varactor is placed along the opposite arm of main spiral feed arm and the design of RF/DC isolation network as lumped ceramic SMT components is shown in Fig.8. The RF/DC isolation network is taken as Johanson low-pass filter (LPF) due to its simplified analysis and synthesis calculation. Nuhertz Technologies Filer Solutions-2009 Tool is used to design the LPF. Figure 9 shows the plot of RF/DC isolation for the operational range of frequency of 2nd iteration design.



(a) Top view (Antenna) (b) Bottom view (Ground plane)

Figure 7 1st iteration design with diode along the antenna ground

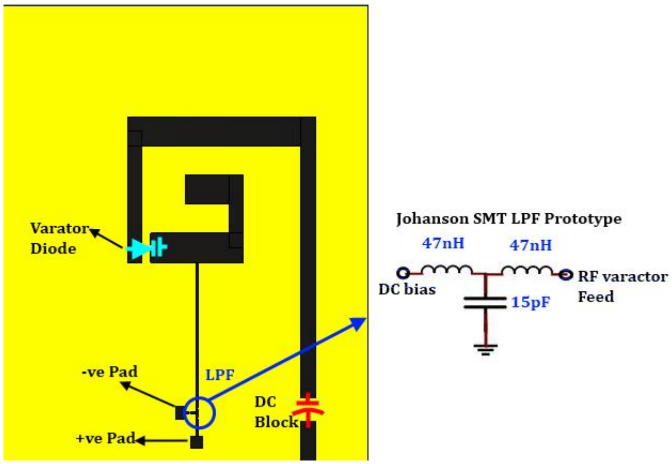


Figure 8 2nd iteration design with varactor diode and RF/DC isolation network

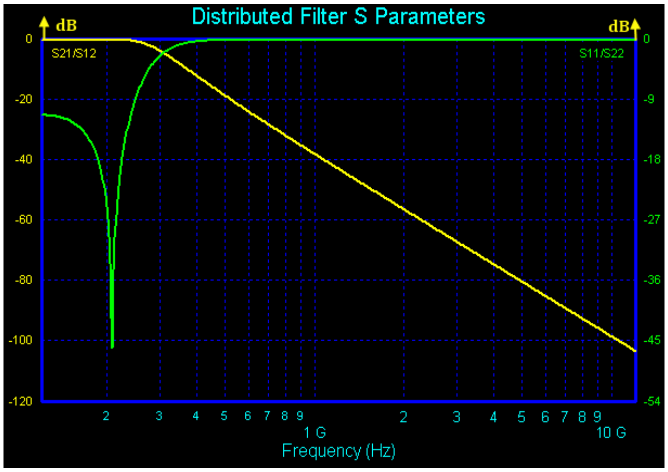


Figure 9 RF isolation graph

The circuit simulation of LPF in Fig.9 shows that the isolation beyond the lowest operating frequency of antenna which is 1.2GHz is even below -40 dB and hence high frequency signals can be effectively isolated. The parasitic package effect here is not taken into consideration; however this has been automatically accounted to some extent by the use of high impedance transmission line in each of the iteration design.

4. RESULTS & DISCUSSION

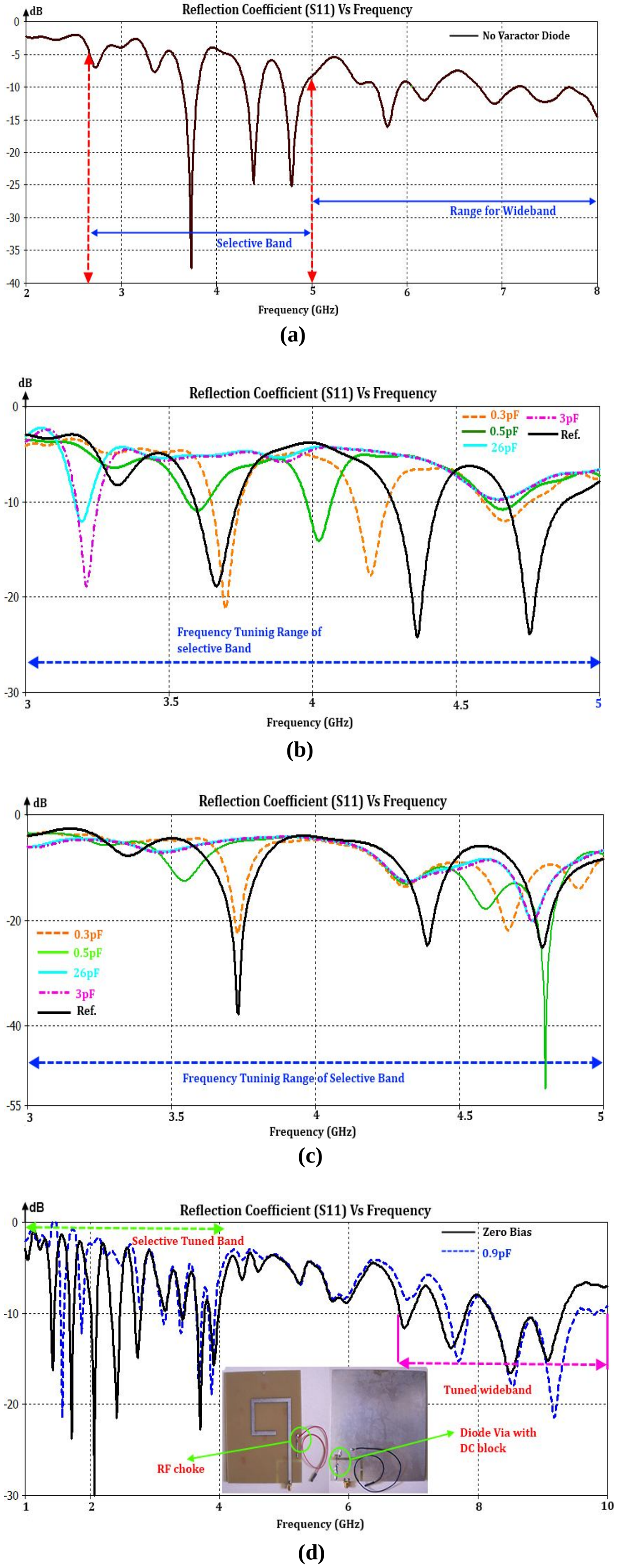
The analysis begins with the simulation of antenna designs in Computer Simulation Tool (CST MWS). All the simulations are done using time domain solver of CST in order to reduce the simulation time and Finite Integral Numerical Technique (FIT) is involved in the solving of antenna design problem. Since the antenna are designed to have to selective band and wide-band frequency response together with the impedance matching to standard 50Ω excitation, so mainly the results of reflection coefficient are analyzed. A comparative analysis is also performed for the frequency tuning which is function of diode junction capacitance and input bias voltage.

4.1 1ST ITERATION DESIGN

Figure 10 shows the plot of reflection coefficient (S_{11}) for 1st iteration designs. For the rectangular monopole spiral antenna without varactor diode as shown in Fig.10a, triple frequency bands at (3.73, 4.69, 4.79) GHz are resonated well below -10dB and an effective wideband frequency response is observed between 5.5-8GHz. It is noted that the wideband response is weak due to the non-continuous decay of surface current along the spiral arms. However with the introduction of varactor diode at D1 and D2 location, a better coarse frequency tuning is obtained for the selective frequency range of spiral antenna as shown in Fig.10 (b-c). Tabel1 shows the detail analysis of frequency tuning as a function of diode junction capacitance for spiral antenna with D1 and D2 diode location. It is found that when the diode is placed at D1 location, more frequency tuning for the selective band is achieved compared to diode at D2 location. This is due to the variation in antenna electrical length which changes greatly for D1 location compared to D2 location.

Hence an observation is made that when the diode is placed closer to the RF feed, a signification variation in antenna electrical length is achieved. It is important to note that the location of diodes (D1, D2) is only varying the electrical length for the selective range of frequency band and keeping the wideband range intact.

Next for the more simplified biasing network as shown in Fig.7, more number of frequency band are resonated in the selective frequency band. This is due to the modification of ground plane which near to the RF feed. However the wideband spectrum as shown in Fig.10d which is between 6.4-10 GHz is not much affected. The detail analysis of selective band and wideband response is shown in Table 2.



(a)

(b)

(c)

(d)

Figure 10 Plot of reflection coefficient (a) without diode (b) diode at D1 location (c) diode at D2 location (d) diode placed along the antenna ground

Table 1 Resonant frequency of selective-band for diode capacitance (D1, D2)

Diode Location	Diode Capacitance (Cj)pF	Resonant Frequency (GHz)
D1	0.3	3.69, 4.2, 4.67
	0.5	3.6, 4.02, 4.66
	3	3.21, 4.64
	26	3.19, 4.64
D2	0.3	3.72, 4.31, 4.66, 4.91
	0.5	3.55, 4.32, 4.59, 4.8
	3	4.33, 4.75
	26	4.33, 4.75

Table 2 Resonant frequency of selective-band and wideband for diode along spiral ground

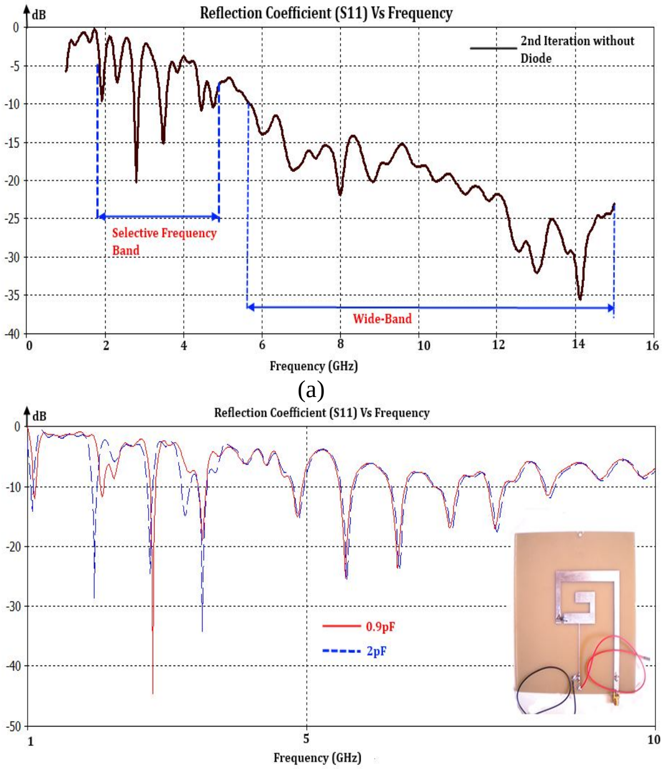
Frequency response	Bias Voltage (volts)/Cj	Resonant Frequency (GHz)
Selective Band	0/0	1.42, 1.69, 2.05, 2.4, 2.73, 3.15, 3.44, 3.71, 3.92
	1.2/0.9pF	1.58, 1.85, 2.77, 3.12, 3.4, 3.68, 3.87
Wideband	0/0	6.78-9.32
	1.2/0.9pF	7.55-10

4.2 2nd ITERATION DESIGN

In the 2nd iteration design, an increase in spiral turns and adjacent arm width not only excites more number of resonant bands in the selective range of frequency spectrum but also improves the wideband frequency response well below -10dB between 5.7-15 GHz as shown in Fig.11a. This wider range of frequency occurs due to increased effective area of spiral rectangular monopole antenna which provides a continuous exponential decay of surface current along the spiral arms. Table 3 shows the detail analysis resonant frequencies of 2nd iteration without any diode placement along the spiral arms. Next a fine tuning is obtained for the selective range of frequency band by placing the diode at an appropriate position along the spiral arms as shown in Fig.8, so that the electrical length of the antenna doesn’t changes significantly due to diode junction capacitance. Figure 11b show the plot of reflection coefficient as function of diode junction capacitance.

Table 3 Frequency analysis of 2nd iteration design without diode

Selective Resonant Bands (GHz)	Wideband (GHz)
1.93, 2.79, 3.47, 4.45, 4.74	5.7-15



(a)

(b)

Figure 11 Plot of reflection coefficient (a) without diode (b) with diode

5. FABRICATED ANTENNAS

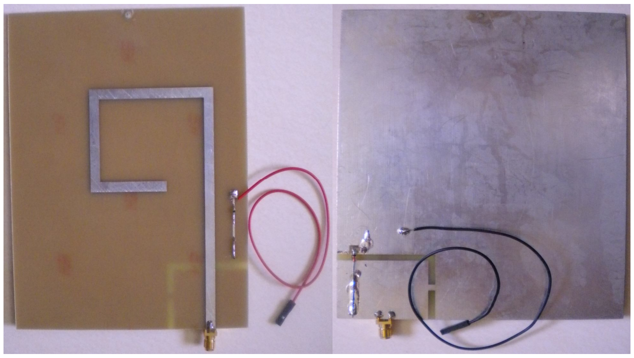


Figure 12 Photos of fabricated design with diode in ground plane

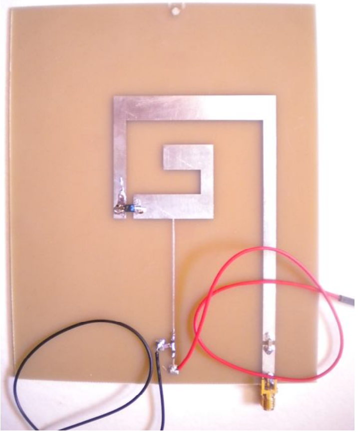


Figure 13 Photo of 2nd iteration fabricated design with diode

The fabricated designs for 1st and 2nd iteration are shown in Fig.12-13. All the antennas are fabricated on FR-4 substrate which was assumed for the design consideration as discussed in section-2. The copper material which was there on the substrate is coated with a thin layer of tin to prevent the oxidation of copper due to environmental affect and this allows soldering of SMD components with good accuracy. The red wire indicates a connection of +ve DC and black wire for –ve DC. Standard 50Ω SMA connector has been used to provide RF signal at the feed location.

6. CONCLUSION

The results of designed rectangular monopole arm spiral antennas are well within the acceptable limit and meeting all the design specifications. The antenna having both fixed and tunable wideband and selective band finds important application in GSM, DCS, PCS, ISM, WLAN, WiMax and WiFi. The antenna is also suitable for cognitive radio which is the upcoming wireless technology for higher data rates. There also exist a wide scope in the optimization of antenna for beam switching which will enable the antenna to be used as smart antennas for efficient power use and communication.

REFERENCES

1. P. E. Mayes, **Frequency-independent Antennas and Broadband Derivatives Thereof**, *Proceeding of IEEE* , vol. 80, pp. 103-112, 1982.
2. J. D. Dyson, **The Equiangular Spiral Antenna**, *IRE Transaction of Antenna and Propagation*, pp. 181-187, 1959.
3. J.A Kaiser, **The Archimedean two-wire Spiral Antenna**, *IEEE Transaction on Antennas and Propagation*, pp. 312-323, May-1960.
4. J. Thaysen, K. Jakobsen, and J. Appel Hansen, **A Wideband Balun-How does it works?**, *Applied Microwave and Wireless*, vol. 12, no. 10, pp. 40-50, Oct-2000.
5. J. Thaysen, K. Jakobsen, and J. Appel Hansen, **Four Decade Bandwidth Unipolar Balun**, *Electronics Letter*, vol. 28, no. 6, pp. 534-535, 1992.
6. R. Bawer and J.J. Wolfe, **A Printed Circuit Balun for use with spiral antennas**, *IEEE Transaction on Microwave Theory and Techniques*, vol. 8, no. 3, pp. 319-325, 1690.
7. Wong, K. L. and W. H. Hsu, **Broadband triangular microstrip antenna with U-shaped slot**, *Electronics Letter*, vol. 33, pp. 2085-2087, 1997.
8. Garg, R., P. Bhartia, I. Bahl, and A. Ittipiboon, **Microstrip Antenna Desing Handbook**, *Artech House*, Boston, London, 2003.
9. C. A. Balanis, **Antenna Theory**: *Analysis and Design*, 3rd ed. New York: John Wiley and Sons, Hoboken, NJ, 2005.
10. Liang, J., **Frequency reconfigurability analysis of electrically small antenna**, *Ph.D. Dissertation*, University Illinois at Chicago, June 2008.