International Journal of Engineering Research
Volume No.3, Issue No.10, pp : 618-623
ISSN:2319-6890)(online),2347-5013(print)
01 Oct. 2014

Enhancement of Band width and Gain by Using 3×4 Array of Metamaterial Based Patch Antenna for RF Energy Harvesting at GSM 1800

K. K. A. Devi[1], Ng Chun Hau[1], C. K. Chakrabarty[2], Norashidah Md. Din[2]
[1]Faculty of Science, Technology, Engineering and Mathematics, INTI International University, Malaysia
[2]Centre for RF and Microwave Engineering College of Engineering, Universiti Tenaga Nasional, Malaysia
Email: kavurik.adevi@newinti.edu.my, chunhau.ng@s.newinti.edu.my, chandan, norashidah(@uniten.edu.my)

Abstract-Using metamaterial based 3 × 4 array split ring resonators on to a stepped rectangular patch antenna with defective ground plane is proposed for energy harvesting at downlink radio frequency range of GSM 1800 band. The study is focused on investigation for improvement in the performance of antenna over the conventional patch antenna by shaping the meta-material structure of superstrate layer. The results showed an improvement of 17.25% (109MHz) impedance bandwidth and gain of 61.16% (1.907). Also the effects of position, the distance of superstrate layer (air gap) and the dimensions of antenna are analysed. The results of the simulation without and with metamaterial structure on the performance of the antenna were discussed in this article.

Keywords : Metamaterial, superstrate layer, defective ground, downlink radio frequency, GSM 1800

I. Introduction

RF energy harvesting uses the idea of capturing the transmitted RF energy at ambient, either using it directly to power a low-power circuit or storing it for later use. The concept needs an efficient antenna along with a circuit which is capable of converting ambient RF signals to DC voltage and the conceptual block diagram of energy harvesting system is shown in Fig. 1.

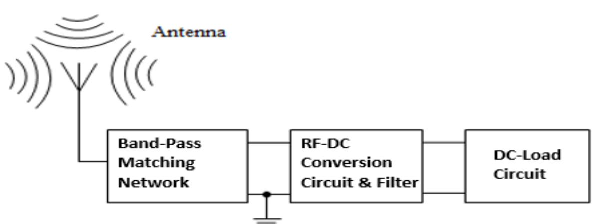

Fig. 1. Conceptual block diagram of RF energy harvesting system

Planar patch antennas offer many attractive features for wireless applications. However, the major disadvantages are low gain and narrow bandwidth. Amongst various techniques, one of the advanced approaches is to introduce the metamaterial structure on to antenna's superstrate. The properties of metamaterial structure-based antennas have been considered for high-gain applications (Wang et al. 2006, Feresidis et al. 2005, Kim et al. 2009). Left handed material (LHM) is a substance with negative values of permittivity and permeability and can be obtained by using combination of split ring resonator and metallic wired based structure. In microstrip patch antenna design, used the split ring structure improved its bandwidth and gain (Buroker et al. 2005, Eleftheriades et al. 2002, Sanada et al. 2004); applying metamaterial based electromagnetic band gap structure had enhanced its efficiency, return loss values, directivity and radiation patterns (Kumar et al.2011); implementing mu-negative (MNG) metamaterial structure achieved maximum gain values at 3.1dBi at 0.47 GHz and 6.3 dBi at 2.44 GHz (Bilotti et al. 2011); designing with a metamaterial reflecting surface at 2.45 GHz for WLAN and achieving gain improvement of 6.91dBi (Chaimool et al. 2009); applying LHM characteristics of metamaterial achieved bandwidth of 44% and gain of 5 dB at the operating frequency range of 1.61 GHz - 2.52 GHz by simulation (Gou, et al.2011); LH metamaterial characteristics by simulation showed the return loss of -34.4 dB at 1.5 GHz (Garg and Gautam 2011); with metamaterial ground plane structure contributed the return loss of more than -22 dB and 386 MHz wider bandwidth at 3.188 GHz (Garg, et al. 2011). In this article, the proposed antenna with defective ground plane utilized the LHM characteristics of metamaterial as superstrate, which operates at the impedance bandwidth range of 1532 MHz to 2333 MHz (741 MHz) and gain of 5.025dB. This fulfilled the requirement of wideband antenna for RF energy harvesting at downlink radio frequency range of GSM-1800 band. The special features of this proposed antenna is on the use of metamaterial, its design structure, ground plane technique and the frequency of operation which are all differed from the previous works described.

II. Antenna Design

The proposed antenna geometry and configuration is shown in Fig. 2 and the 2D side view is shown in Fig. 3. The design structure consists of three layers: a planar stepped rectangular patch with defective ground plane, air gap, and metamaterial superstrate layer. The FR4 substrate with 1.6 mm thickness and dielectric constant (ε_r) of 4.3 was used for both the patch antenna and metal layer structure. The structure of the stepped patch antenna was printed on one side of the substrate with the partial ground plane on the other side. The partial ground plane width and length are denoted by G_L and G_W, the two steps on the patch antenna are denoted by S_1 and S_2 and the feed line is denoted by F. The existence of these steps provides the different resonant frequencies in the specified frequency band. The change in the resonant frequency is due to the role played by various factors such as step dimension, position, feed line and the partial ground plane. This causes a change in electric and magnetic field distributions near the discontinuities. The altered electric field distribution exhibits a change in the capacitance and the change in magnetic field distribution presents in terms of equivalent inductance. When these steps are cascaded, the resulting bandwidth of antenna structure will be increased. The basic width and length of a patch antenna are denoted by *W* and *L*, formalized by the equations (1), (2) and the effective dielectric constant ϵ_{reff} is determined from the equation (3) which was obtained from (Balanis 2005, Stutzman et al. 1997).

For W/h > 1

$$W = \frac{1}{2f_r\sqrt{\mu_o\varepsilon_o}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_o}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

$$L = \frac{\lambda}{2} - \Delta L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_o\,\varepsilon_o}} - 2\Delta L \quad (2)$$

and where

$$\Delta L = 0.412 \times h \times \frac{(\varepsilon_{reff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.8\right)}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}[1+12\frac{h}{w}]^{-\frac{1}{2}} \quad (3)$$

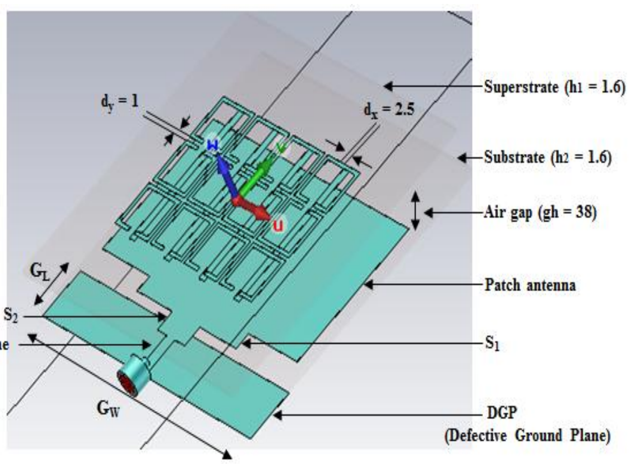

Fig. 2. Configuration of rectangular stepped patch antenna with defective ground and superstrate layer

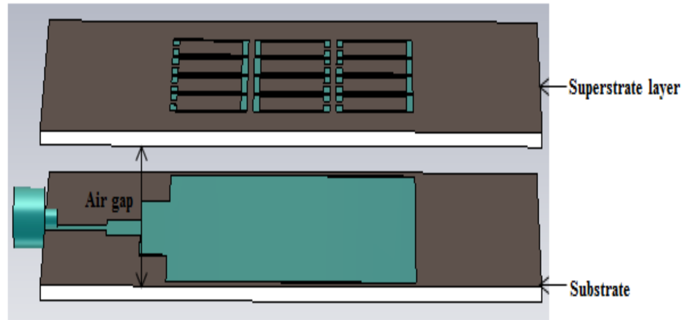

Fig. 3. 2D side view of rectangular stepped patch antenna with defective ground and superstrate layer

The proposed patch antenna dimensions were optimized to obtain the better gain and wide impedance bandwidth; the patch is excited by a 50 **Ω** feed line. The optimized dimensions of the antenna structure are shown in Table 1.

Table 1. Dimensions of stepped patch antenna geometry

Basic Configuration	**Patch antenna**						**Feed Line**		**Ground Plane**	
Variable	W	L	S1		S2					
			W	L	W	L	W	L	W	L
Dimensions (mm)	74.5	40	38	4.5	10.5	5.5	3.14	4.5	80	13.7

The superstrate structure was designed on FR4 substrate with the same characteristics as patch antenna and was supported by foams so that it keeps an air-gap above the patch, which provides the improvement of impedance bandwidth and gain in this study. The resonant condition can be satisfied by adjusting the metamaterial structure, including dimensions of unit-cell and strip conductor sizes. There is a compromise amongst the gain improvement, impedance matching and the overall height of the antenna. The superstrate structure consisted of an array of (3×4) unit cells. The unit-cell was a single squared split-ring resonator with a side length of 12.3 mm. Each cell had a spacing of 1 mm in *x*-direction and 1 mm to the adjacent ones and its equivalent circuit is shown in as shown in Fig. 4 and Fig. 5. The gap and metallic of SRR represents the capacitance and inductance respectively. In this article, the unit cell consists of a combination of paired ring and single resonators, with a strip conductor behind aligned to the center of ring resonators. The PRRs possess both pronounced magnetic and electric responses.

The superstrate structure of split rings resonator (SRR) array was on the top of FR4 and four strip conductors were at the bottom of superstrate layer and were aligned to the each column center of squared split rings, which was suspended over a transmission line fed patch antenna. The geometry and dimension details of squared split ring and strip conductor are shown in Fig. 4. The thickness of the air-gap, which was sandwiched between the patch and the superstrate layer, was adjusted to obtain good impedance matching and best performance at the down link radio frequency range of GSM1800 band.

 ISSN:2319-6890)(online),2347-5013(print)
01 Oct. 2014

The effect of ground plane is the vital factor in the present design of antenna for the required application. This result was made by selecting the partial ground plane with the dimension of 80 mm × 13.7 mm which is about 3.4 times less than the size of the patch antenna used by the technique developed in (Garg et al. 2001).

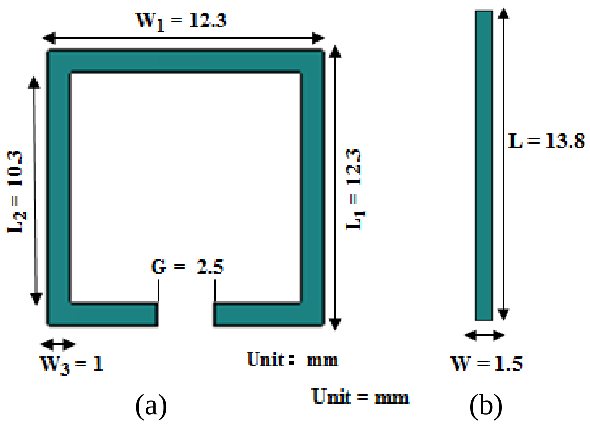

Fig. 4. Geometry and dimensions of (a) Single squared split ring structure (b) Strip conductor

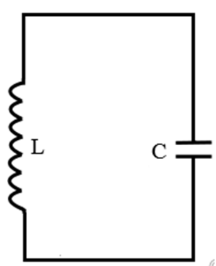

Fig. 5. Equivalent circuit of single SRR's

III. Methodology

On the properties of the antenna designed without and with metamaterial superstrate, all of the full wave analysis was performed, simulated and had been optimized through Technology (CST) microwave studio, version 14, using electromagnetic transient solver. First, the patch antenna designed was simulated and optimized the dimensions at down link radio frequency range of GSM1800 band and the results of simulation were recorded. Next the metamaterial structure was introduced above the patch antenna with an air gap (gh) and parametric optimization was carried out in CST environment to obtain better gain, and impedance bandwidth for the desired frequency band.

Also a Nicolson-Ross-Weir (NRW) method (Ziolkowski, 2003) was used to verify the double negative properties of 3 x 4 array metamaterrial structure resonator for the desired frequency band.

Permittivity & permeability for NRW approach was obtained (Garg et al. 2012) using equations (4) and (5).

Metamaterial superstrate structure was placed (Hrabar, S. and Bartolic, J. 2003, Hrabar et al. 2005) between the two waveguide ports at the left and right hand side of the X axis. Y-Plane and Z-Plane are defined as Perfect Electric and Magnetic Boundaries (PEB and PMB) respectively as shown in Fig.5 to create internal environment of waveguide. The simulated S-Parameters S_{11} and S_{21} are then exported to Microsoft Excel Program for verifying the Double-Negative properties of the proposed metamaterial structure.

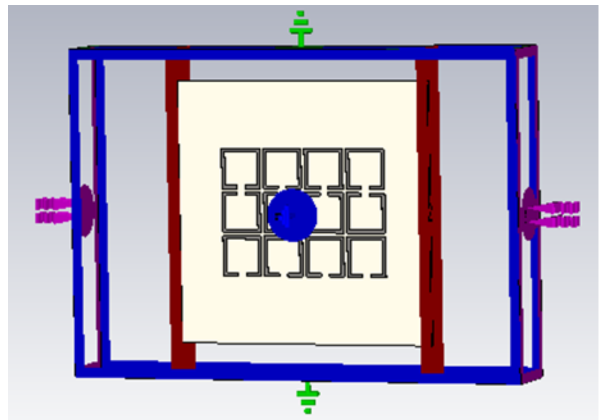

Fig. 6 Proposed metamaterial structure between the two waveguide ports at the left and right of the X-axis

$$\mu r = \frac{2 * c(1 - v_2)}{\omega * h * i * (1 + v_2)} \quad (4)$$

$$\varepsilon r = \mu r + \frac{2 * S_{11} * c * i}{\omega * h} \quad (5)$$

where,

$v_2 = S_{21}$-S_{11},
ω = Frequency in Radians,
h = Thickness of the substrate,
c = Speed of light,
v_2 = Voltage Minima,
μr = Relative permeability,
εr = Relative permittivity.

IV. Results and Discussion

The simulation results of return loss versus frequency for the proposed antenna with superstrate structure at different heights (gh) of patch are shown in Fig. 7and its performance was shown in Table 2. The results from the graph indicates the better return loss of -30.3 dB for the air gap (gh) of 40 mm, and a return loss of -26.89 dB for the air gap (gh) of 38 mm at 1841/42 MHz, the center frequency of the desired radio frequency band (1805 MHz -1880 MHz). Decrease in air gap still lowering the return loss and the frequency is slightly shifted away from the desired center frequency, hence chosen to use the best one as 38 mm air thickness for implementation.

ISSN:2319-6890)(online),2347-5013(print)
01 Oct. 2014

Table 2. Performance of proposed antenna for variation in air thickness

Air gap (gh)(mm)	Resonant Frequency(MHz)	Return Loss(dB)	Impedance Bandwidth(MHz)
36	1848	-24.6	739
37	1846	-25.6	740
38	1842	-26.89	741
39	1841	-28.44	741
40	1841	-30.3	741

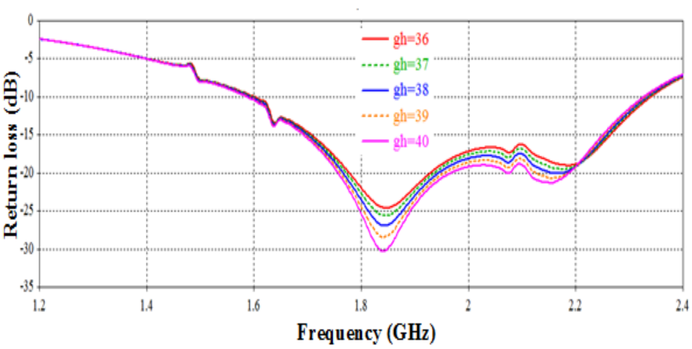

Fig. 7. Comparison of return loss results for the proposed antenna with variation in height (gh) from patch to superstrate layer

The results of return loss versus frequency for the proposed patch antenna without and with the metamaterial structure are shown in Fig. 8. At the desired operating frequency1842 MHz (the center down link radio frequency band of GSM 1800) without superstrate layer the return loss and impedance bandwidth are -43.14dB, 632 MHz and with superstrate are -26.89dB, 741 MHz respectively. The bandwidth of proposed antenna is increased by 109 MHz (17.25 %) compared with conventional patch antenna. This clearly indicates good impedance matching, and this was also supported by the height (thickness) of the air gap, which was close to the value of λ/4.

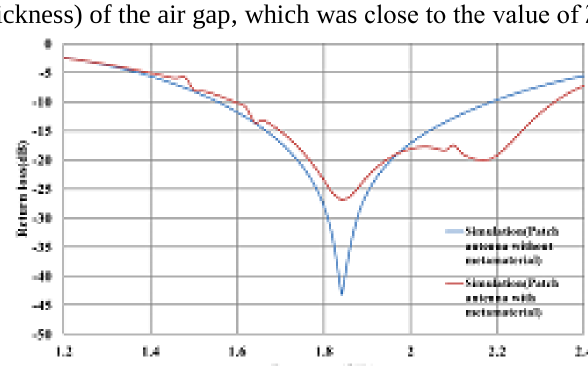

Fig. 8. Simulated results of return loss for the proposed patch antenna with and without the superstrate structure

The results of gain obtained without and with metamaterial superstrate structure is shown in Fig. 9 and Fig. 10. The gains of the antenna without and with superstrate are 3.118 dB 5.025 dB at the center radio frequency (1842 MHz) of desired frequency band. This shows that the proposed metamaterial structure has a positive effect in focusing energy within a narrow beam width. The work involved basically to harvest energy from ambient at GSM1800, antennas having reciprocal characteristic, this antenna with superstrate structure provided very good harvesting characteristics, and is highly directional, comparing with without superstrate layer patch antenna.

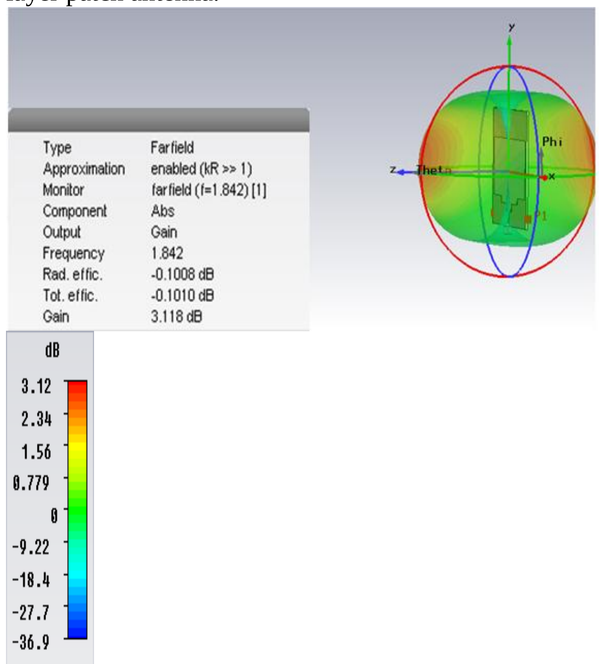

Fig. 9. Computed results of gain for the proposed patch antenna without superstrate structure

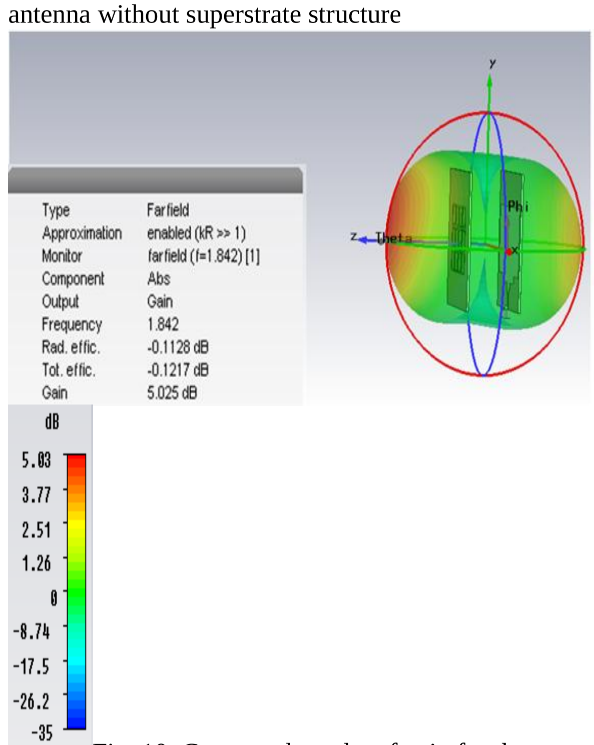

Fig. 10. Computed results of gain for the proposed patch antenna with superstrate structure

Fig. 11 shows the comparison of gain for the proposed antenna without and with meta-material structure. The results indicate that the gain was improved by 61.16 % in the desired range of frequency band over the conventional patch antenna.

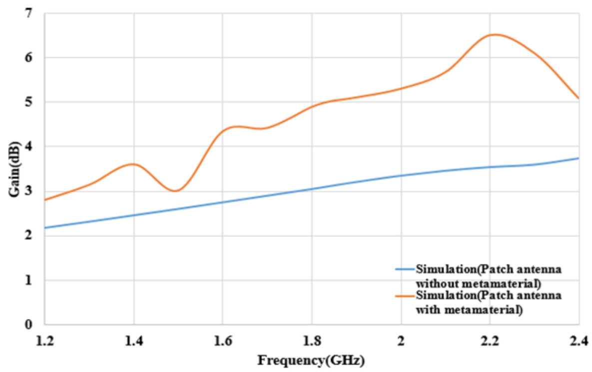

Fig 11 Comparison of gain for the proposed patch antenna without and with superstrate structure

Fig.12 and Fig. 13 shows the result of double negative (DNG) characteristics i.e. permeability (μ_r) and permittivity (εr) of the proposed antenna for desired frequency range of GSM 1800 band.

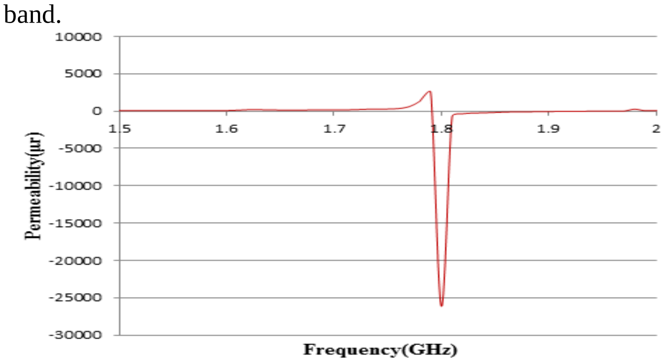

Fig. 12 Permeability versus Frequency

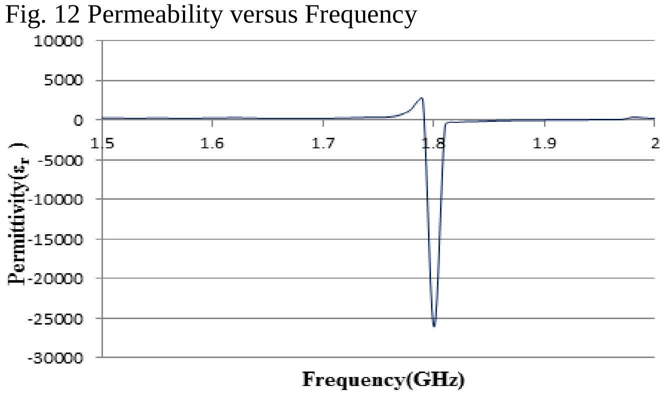

Fig. 13 Permittivity versus Frequency

Table 3. Summary performance of metamaterial based stepped rectangular patch antenna with defective ground plane

Simulation Results	At -10 dB f_l and f_h frequency(MHz)	Impedance Bandwidth (MHz)	Return loss(dB)	Gain(dB)
(without metamaterial)	1555 and 2187	632 (34.3%@1842)	-43.14 (1842MHz)	3.118
(with metamaterial)	1592 and 2333	741 (40.22%@1842)	-26.89 (1842 MHz)	5.025

V. Conclusion

The 3×4 array of metamaterial based squared split ring resonator on to a rectangular stepped patch antenna with defective ground plane has been proposed in this article. From the achieved results, it can be inferred that with the use of metamaterial structure in antenna increases Gain and Bandwidth over the conventional patch antenna. This also shows the focusing effect on properties of metamaterial for the performance improvement. Therefore, from the results and analysis, the designed antenna is well suited and can be employed for the energy harvesting at the downlink radio frequency range of GSM-1800 band.

References

i. *Wang, S., Feresidis, A. P., Goussetis, G., Vardaxoglou, J. C., "High-gain sub-wave length resonant cavity antennas based on metamaterial ground planes", IEE Proc.-Microw. Antennas Propag, vol. 153, No. 1, pp. 1-6, Feb. 2006.*

ii. *Feresidis, A. P., Goussetis, G., Wang, S., Vardaxoglou, J. C., "Artificial magnetic conductor surfaces and their application to low-profile high-gain planar antennas", IEEE Trans. Antennas Propag., vol. 53, No. 1, pp. 209-215, Jan. 2005.*

iii. *Kim, D., Ju, J., Lee, W. J., Choi, J. I., "Wideband high-gain antenna using metamaterial superstrate with the zero refractive index", Microw. Opt. Technol. Lett., vol. 51, No. 8, Aus. 2009.*

iv. *Buroker, S. N., Latrach, M., Serge, T., "Theoretical Investigation of a Circular Patch Antenna in the Presence of a Left-Handed Metamaterial", IEEE Antenna and Wireless Propagation Letters, Vol. 4, 2005.*

i. *Eleftheriades, G.V., Iyer, A.K., Kremer, P.C., "Planar negative refractive index media using periodically L-C loaded transmission lines", IEEE Trans. Microw. Theory Tech., 2002, 50, (12), pp. 2702–2712.*

ii. *Sanada, A., Caloz, C., Itoh, T., "Planar distributed structures with negative refractive index", IEEE Trans. Microw. Theory Tech., 2004, 52, (4), pp. 1252–1263.*

iii. *Kumar, H., Kanth, R. K., Liljeberg, P., and Tenhunen, H., "Metamaterial Based Slotted Patch Antenna", TELSIKS 2011,Serbia, Niš, October 5 - 8, 2011(IEEE 2011).*

iv. *Bilotti, F., Alœ, A., and Vegni, L., "Design of Miniaturized Metamaterial Patch Antennas With -Negative Loading", IEEE Trans. Antenna & Prop., VOL. 56, NO. 6, June 2008.*

v. *Chaimool, S., Chung, K. L., Akkaraekthalin, P., "A 2.45-GHz WLAN High-Gain Antenna Using A Metamaterial Reflecting Surface", The 2009 International Symposium on Antennas and Propagation (ISAP 2009) October 20-23, 2009, Bangkok, THAILAND.*

vi. *Gou, Y., Hua, J., Wu, Q., Wang, H., "Broadband Microstrip Antennas Using Complementary Metamaterials*

Structure", 2011 Cross Strait Quad-Regional Radio Science and Wireless Technology Conference. 978-1-4244-9793-5/11 ©2011 IEEE.

vii. Garg, B., Gautam, M., "Microstrip Patch Antenna using Left-Handed Metamaterial Structure for Bandwidth Improvement", IJECT Vol. 2, Issue 3, Sept. 2011.

viii. Garg, B., Tiwari, R., Kumar, A. and Thakur, S. K., "Design of Broadband Rectangular Microstrip Patch Antenna Inset 'L' Shaped Feed with Rectangular 'L' Slots in Ground Plane", International Journal of Computer Applications (0975 – 8887) Volume 29– No.1, September 2011.

ix. Balanis A., "Antenna Theory", John Wiley & Sons, New York, NY, 3rd edition, 2005.

x. Stutzman, W. L. and Thiele, G. A., Wiley, "Antenna Theory and Design", (2nd edition), 1997, ISBN 0-471-02590-9.

xi. Garg, R., Bhartia, P., Bahl, I., Ittipiboon, A., "Microstrip Antenna Design Handbook", Artech House, Boston London, 2001, pp. 534–538.

xii. Ziolkowski, R. W., "Design, fabrication, and testing of double negative metamaterials," IEEE Transactions on Antennas and Propagation, Vol. 51, No. 7 (2003), pp.1516-1529.

xiii. Garg, B., Verma, R.D., Samadhiya,A., "Design of Rectangular Microstrip Patch Antenna Incorporated with Innovative Metamaterial Structure for Dual band operation and Amelioration in Patch Antenna Parameters with Negative μ and ε", IJET, 1 (3) (2012) 205-216.

xiv. Hrabar, S.and Bartolic, J., "Backward Wave Propagation in Waveguide Filled with Negative Permeability Meta Material", Antennas and Propagation Society International Symposium, vol. 1 (2003), pp. 110 – 113.

xv. Hrabar, S., Jankovic, G., Zivkovic, B., Sipus, Z., "Numerical and Experimental Investigation of Field Distribution in Waveguide Filled with Anisotropic Single Negative Metamaterial", Applied electromagnetics and communications (ICEcom), (2005), pp. 1- 4