International Journal of Engineering Works
Kambohwell Publisher Enterprises
ISSN: 2409-2770 Vol. 3, Issue 4, PP. 19-25, April 2016
www.kwpublisher.com

Gain Enhancement of the Patch Antenna Using TSRR NRI Superstrate

K.A. Devi, Ng Chun Hau,C. K. Chakrabarty, Norashidah Md. Din

***Abstract*—**This article presents a high gain patch antenna with negative refractive index (NRI) superstrate for the application of Radio frequency energy harvesting system. Triangular split ring resonators (TSRR)-strip line are used as a NRI superstrate to enhance the gain of the patch antenna. It is demonstrated that the proposed triangular split ring resonator (TSRR) structure metamaterial yields negative value of an effective refractive index that over the frequency range of 774 MHz to 974 MHz. The negative refractive index structure is applied as a superstrate to a microstrip patch antenna. The simulation results show that the gain is effectively improved by 2.326 dB (85.96 %) after the incorporation of negative refractive index metamaterial superstrate on to the conventional patch antenna. The results illustrated that the gain of the proposed antenna is enhanced over the desired frequency band 935 MHz to 960 MHz. The air gap between the antenna and superstrate was also studied by applying the theory of Fabry-Perot (F-P) resonant cavity to obtain the optimum air gap of 55 mm to achieve the maximum gain. The proposed antenna is also fabricated and tested, the measured results shown that have good agreement with the simulated results in term of S - parameters and radiation characteristics.

***Keywords*—** Microstrip patch antenna; triangular split ring resonator; negative refractive index; radio frequency harvesting system; gain

I. INTRODUCTION

Nowadays, batteries are the important sources for portable devices. However, there are some drawbacks on using the batteries as the energy sources such as limited batteries life. Recently, energy harvesting technique is one most popular technique and has the potential to solve this problem.

There are various sources that can be used in energy harvesting such as s piezoelectric are the most popular sources to utilize in the energy harvesting for low power are the most popular sources to utilize in the energy harvesting for low power application. application.olar energy, kinetic, radio frequency, piezoelectric Antenna is the vital component in the RF energy harvesting system and the microstrip antennas are widely used due to its inherent characteristics such as low profile and low cost. Regardless of their advantages, they also consists of some advantages such as low gain and narrow bandwidth. Various techniques have been proposed to solve the problem such as low permittivity and thick substrate [1], stacking of microstrip element[2], truncating and slotting the microstrip patch antenna[3] to improve the bandwidth of the antenna.

In recent years, metamaterials have shown tremendous potential on the performance enhancement of the antenna. It can use as a lens to focus the Electromagnetic (EM) wave radiated from the free space toward the normal direction of the antenna. It is a medium consists of permeability and permittivity simultaneously negative at certain frequency range. In 1968, Veselago[4] explored the properties of isotropic media where both the permittivity and the permeability are simultaneous negative will exhibit unusual physical properties such as negative refraction. The propagation vector k, electric field, E and magnetic field, H vector of these materials form a left handed set of vectors which are opposite to the commonly known right handed material. Therefore, these materials also known as the left-handed materials (LHM). In 2000, Smith [11] successfully made the first left-handed metamaterial prototype using split ring resonator (SRR) and thin wire (TW). Enoch[5] proposed that the gain of the antenna through the use of near zero refractive index metamaterial. He exploited the thin wires structure to make the metamaterial place on a dipole antenna to enhance the gain. Various structures have been proposed In the recent years such as Omega -shape, S -shape [6], Fishnet -shape [7], Labyrinth –shape [8], the combination of modified square rectangular Split Ring Resonator (SRR) and the Capacitance Loaded Strip (CLS)[9], triangular–shape [10] and all of them exhibit the properties of NRI. Due to the special properties of NRI metamaterial, a large number of researches have been done by using it to enhance the microwaves device such as antennas and the filter[9], [11]–[14].

In this article, the design of defective ground plane patch antenna with 6 layer of triangular split ring resonator (TSRR) NRI superstrate for gain enhancement is presented. The nested SRR is proposed by Yong Liu [15] in 2013. To the best of author's knowledge, the nested SRR hasn't been used before to improve the antenna gain. The proposed antenna is designed for RF energy harvesting system at downlink radio frequency band of GSM 900. The objective of the work in this paper, is to increase gain of the antenna by using the NRI

This Research work is funded by Ministry of Higher Education Malaysia Grant No. is FRGS/2/2013/ ST02INTI/ 02/01.

K.A. Devi: INTI International University Nilai, Malaysia,
kavurik.adevi@newinti.edu.my
Ng Chun Hau: INTI International University Nilai, Malaysia
chunhau.ng@s.newinti.edu.my
C. K. Chakrabarty: Universiti Tenaga Nasional, Kajang, Malaysia,
chandan@uniten.edu.my
Norashidah Md. Din: Universiti Tenaga Nasional, Kajang, Malaysia,
norashidah @uniten.edu.my

superstrate layer and the impedance bandwidth to cover the desired frequency band.

This article is organized to describe the antenna design and configuraton in section II, design and simulation study of NRI unit cell in section III, analysis on the air gap of the proposed antenna structure in section IV, methodology in section V, discussion on results in VI and paper is concluded in section VII.

II. ANTENNA DESIGN AND CONFIGURATION

The proposed NRI superstrate based patch antenna configuration with its design parameter is shown in Figure 1. The proposed patch antenna is printed on a $102\ mm \times 84\ mm$ of FR4 substrate with thickness of 1.6 mm, permittivity of 4.7, and loss tangent of 0.014. As shown in Figure 2, the patch antenna consists of one ring slot at the center and smooth bevel and bevel at the edge of the patch antenna to enhance the impedance bandwidth of the antenna and it direct fed by a 15 mm length of transmission line and excited by a 50 Ω microstrip feed line of a width of 2.93 mm through a SMA connector. Furthermore, a partial ground plane is printed on the bottom of the FR4 substrate and it also used to increase the impedance bandwidth of the antenna. The final optimal design parameter of the antenna are listed in Table1 1. The standard formulas for the width *(W)*, length *(L)*, effective dielectric constant (ε_{eff}) and effective length (ΔL) of the patch antenna are calculated using the equations (1), (2), (3) and (4) obtained from [16].

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

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

Normalized extension of ΔL is given by

$$\Delta L = 0.412 \times h \times \frac{(\varepsilon_{reff} + 0.3)(\frac{w}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{w}{h} + 0.8)} \qquad (3)$$

For W/h > 1, Effective dielectric constant is given by

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}} \qquad (4)$$

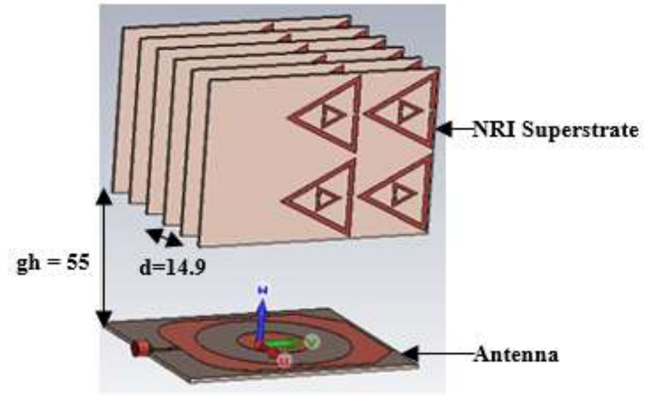


Figure 1. Configuration of proposed antenna with NRI superstrate

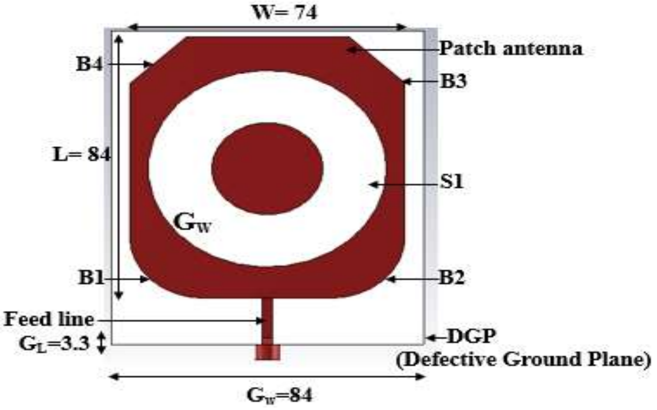


Figure 2. Configuration of proposed patch antenna

TABLE I. DIMENSIONS OF THE PATCH ANTENNA

Basic Con.	**Patch antenna**						**Feed Line**		**Ground Plane**	
Vari.	W	L	B1, B2		C1	C2				
			W	L	Ra.	Ra.	W	L	G_W	G_L
Dimn. (mm)	74	83	21	15	32	15	2.93	15	84	5.5

III. DESIGN OF THE NRI SUPERSTRATE

The configuration of the proposed NRI unit cell is illustrated in Figure 3 which is the combination of the triangular SRR and strip line. 6 layer of 2×2 triangular split ring resonators and strip lines are patterned onto the top and bottom surfaces of a 1. 6mm thick FR4 substrate ($\varepsilon_r = 4.7, \tan\delta = 0.014$) to form an NRI superstrate layer. The triangular split ring resonator (SRR) has a width and length of 33 mm. The strip line has a length of 35 mm and a width of 0.5 mm. The NRI unit cell is periodic structure and the period of the unit cell is mm 35 mm. The characteristic of the unit cell was analysed by using the full-wave 3D electromagnetic simulation software Computer Simulation Technology (CST).

Figure 3 show the simulated results of S_{11} and S_{21} of the unit cell. The electromagnetic parameter of the unit cell can be obtained from the scattering parameter using a standard retrieval algorithm[17]. Figure 4, 5, 6 illustrate the permittivity, permeability and refractive index of the unit cell respectively. According to the retrieval result shown in Figure 4 and 5 , the proposed unit cell has the negative permittivity and permeability around 947 MHz. Referring to the Figure 6, the range of negative refractive index starts from 774 MHz to 974 MHz and it also can be seen that the loss is very low around that frequency range. It is evident that the TSRR-strip structure has a negative refractive index, low loss and high transmission properties at the downlink frequency band of GSM 900. In order to investigate the focusing effect of the NRI superstrate, the NRI superstrate layers are incorporated with a patch antenna and the performance of the antenna is presented in the following section

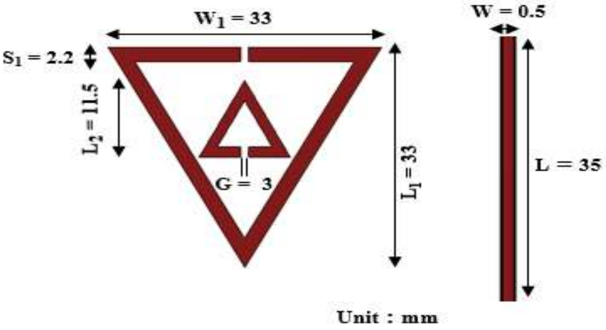


Figure 3. Configuration of TSRR-strip line unit cell

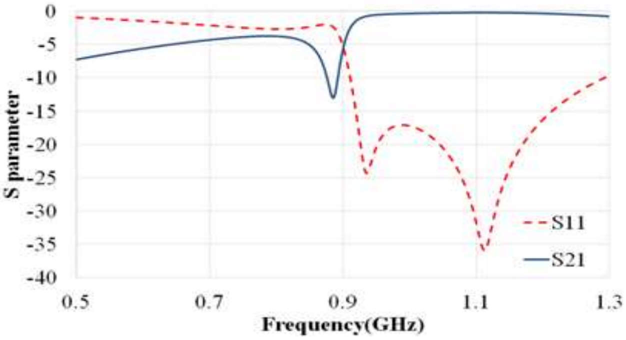


Figure 4. Results of reflection and transmission coefficients of unit cell

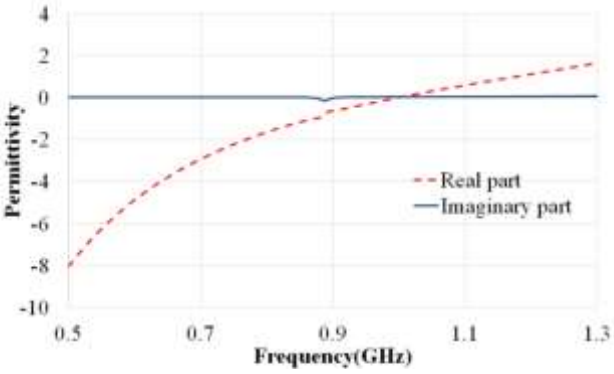


Figure 5. Results of permittivity of the unit cell

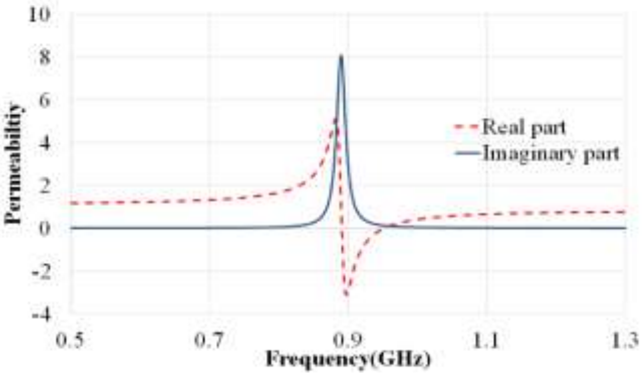


Figure 6. Results of permeability of the unit cell

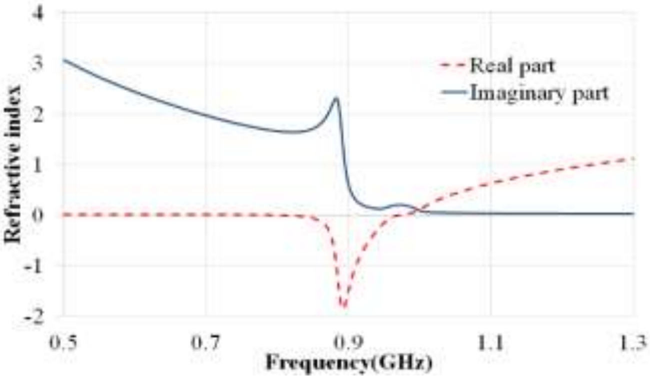


Figure 7: Results of refractive index of the unit cell

It can be observed from Figure 7 the refractive index of the unit cell is negative within the frequency range of 774 MHz to 974 MHz and approach negative one at 947 MHz.

IV ANALYSIS ON THE AIR GAP OF THE PROPOSED ANTENNA WITH NRI SUPERSTRATE

Figure 1 shows the geometry of the proposed NRI superstrate based patch antenna which consists of patch antenna backed with partial ground plane and 6 layers of NRI superstrate. The air gap gh between two structures, with reflection coefficient phases φ_{GND} and φ_{NRI} respectively. In order to superimpose in phase, the phase shift of the EM waves is the multiple of 2π, which can be written as

$$\frac{-4\pi h}{\lambda_o} + \varphi_{NRI} + \varphi_{GND} = N \times 2\pi , N = 0,1,2.... \tag{5}$$

According to the equation (5), the thickness of the air gap of the NRI superstrate based patch antenna is determined by

$$h = (\varphi_{NRI} + \varphi_{GND})\frac{\lambda_o}{4\pi} + \frac{\lambda_o}{2}N , N = 0,1,2.... \tag{6}$$

Generally, the antenna profile has always close to $\lambda/2$ because the $\varphi_{GND} = \varphi_{NRI} = \pi$. In this paper, φ_{GND} is the reflection phase of the antenna ground plane, which is smaller than 180 degree for a defected ground plane, h is the height of the air gap and λ_o is the free-space wavelength. It can be observed from Figure 8 the reflection phase φ_{NRI} of the NRI unit cell is 75 degree at the frequency of 947 MHz and the reflection phase φ_{GND} of the antenna approximately equal to 180 degree. Furthermore, the cavity height h between antenna and the NRI superstrate was obtained by equation (6) which is equal to 46.08 mm. This is a close to with the simulated result of 55 mm. Thus, the optimized gain of the antenna can be achieved by using the resonant height of the F-P cavity.

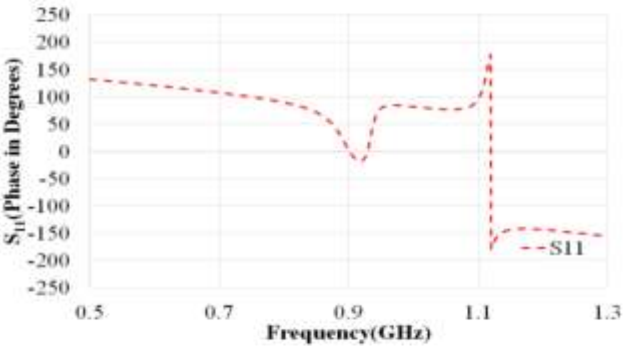


Figure 8. Results of phases of reflection coefficients for the unit cell.

V. METHODOLOGY

The proposed antenna is designed using CST Microwave Studio, which is based on Finite Integration Technique (FIT) approach. First, a patch antenna is designed and simulated to obtain the desired performance at down link radio frequency of GSM 900 band. Next, the triangular split ring resonator (TSRR) unit cell is designed and simulated by using frequency domain solver in CST environment. All the parameters of the TSRR are optimized to achieve a low loss NRI TSRR unit cell. After that, the NRI superstrate is introduced on to the patch antenna and the air gap between the antenna and NRI superstrate is optimized based on F-P theory. Finally, in order to achieve prove the simulated result, the proposed antenna is fabricated and measured to get the S parameter and radiation pattern of it.

VI. RESULTS AND ANALYSIS

A prototype of the proposed patch antenna with NRI superstrate as shown in Figure 9 and Figure 10 is designed, fabricated and measured. All the numerical and experimental results in term of S-parameter and radiation characteristic are presented and discussed in this section. A comparison between the simulated and measured radiation pattern of the patch antenna with and without NRI superstrate is depicted in Figure 11 and 12. The radiation patterns of the antenna with and without NRI superstrate are simulated and measured at 936 MHz, 947 MHz and 959 MHz which are the corresponding lower, centre and upper frequency of desired frequency band. The measured radiation patterns are seem to have good agreement with the simulated result.

The measured E plane and H plane radiation pattern of the proposed antenna with NRI superstrate at resonance frequency of 947 MHz are presented in Figure 11 and 12; it seems to have good agreement with the simulated result. The simulated gain result of the proposed antenna at 947MHz depicted that the gain of the patch antenna is increased from 2.706 dB to 5.033 dB by using the NRI superstrate. In addition, it also can be noted that by using of the NRI superstrate, half power beam width (HPBW) for the E-plane of the antenna is narrowed down from 82.3° to 71.7° and half power beamwidth in H-plane narrowed down to 98.6°. It seems to have good agreement between measured and simulated half power beamwidth in E and H plane. In the Figure 13, comparison gain of the antenna with and without NRI superstrate from 500 MHz to 1300 MHz is illustrated. It shown that the gain of the antenna significantly improved along the desired frequency band 935 MHz and 960 MHz by introducing of the proposed NRI superstrate and it is clear that the gain of the antenna is affected by the NRI superstrate

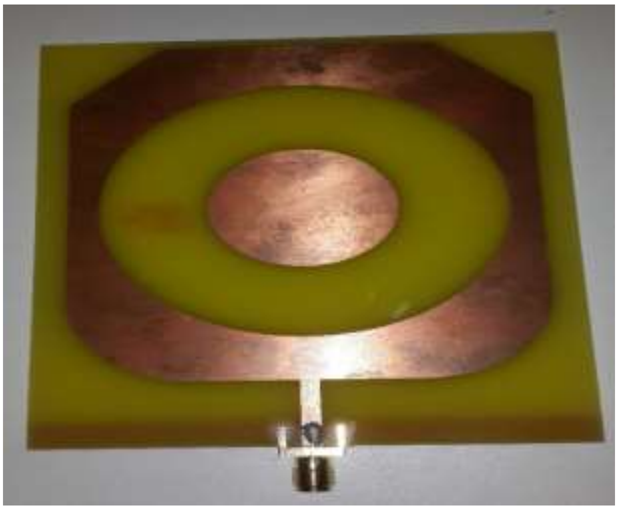
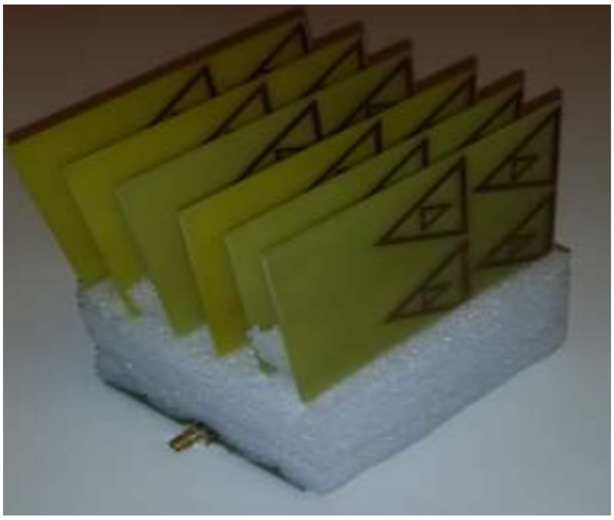
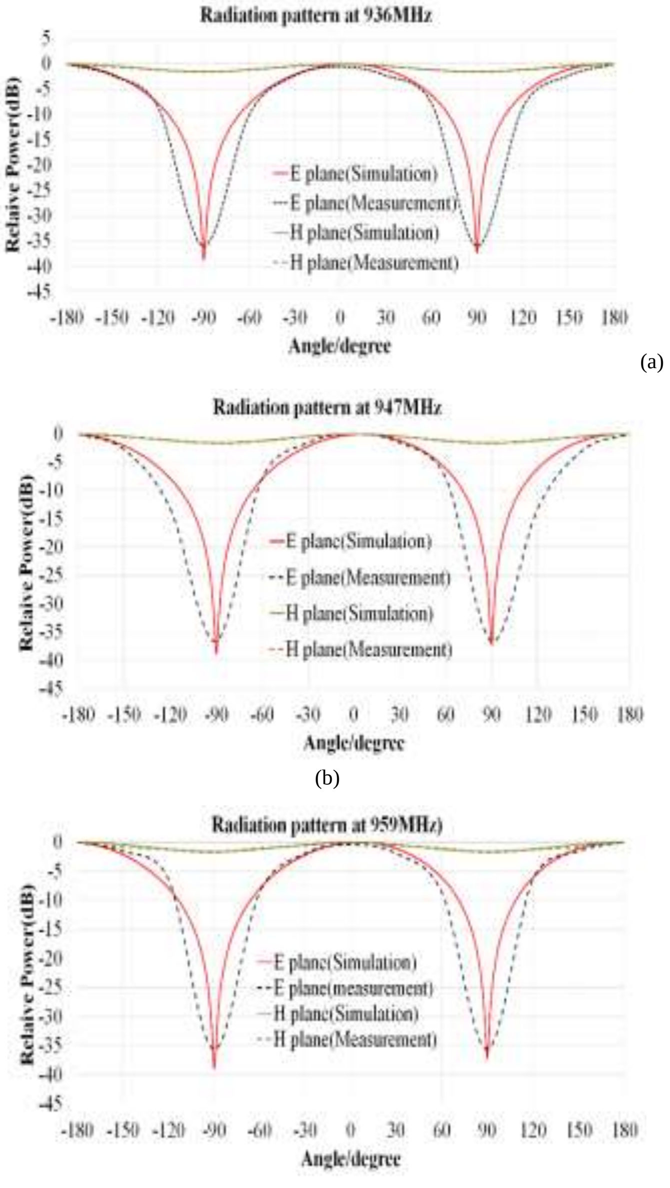


Figure 9. Photograph of the fabricated patch antenna



.

Figure 10. Photograph of the fabricated patch antenna with NRI superstrate

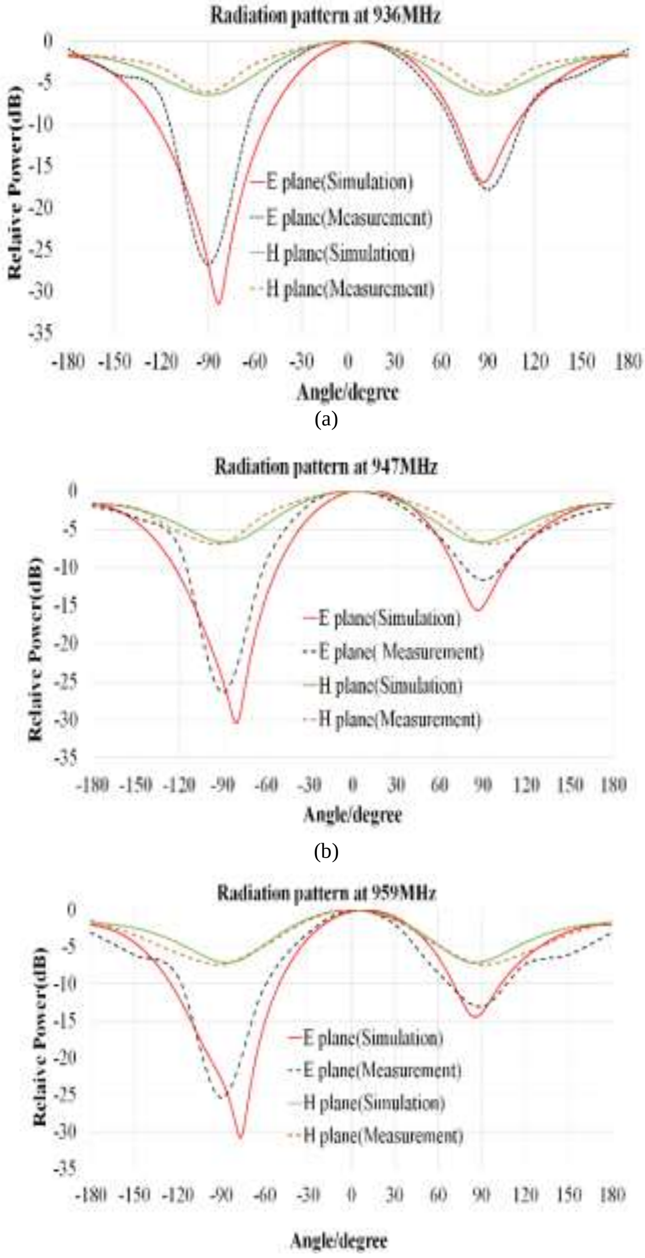


(a)

(b)

(c)

Figure 11. Radiation pattern of patch antenna without NRI superstrate at (a) 936 MHz (b) 947 MHz (c) 959 MHz



(a)

(b)

(c)

Figure 12. Radiation pattern of patch antenna with NRI superstrate at (a) 936 MHz (b) 947 MHz (c) 959 MHz

The simulated reflection coefficient and impedance bandwidth of the proposed structure and the microstrip patch antenna alone are compared in Figure 14. It can be observed in Figure 15 the use of NRI superstrate decrease the impedance bandwidth of the antenna from 281 MHz to 160 MHz but the impedance bandwidth still able to cover the desired frequency band of 935 MHz to 960 MHz. The main reason on the decrement of the impedance bandwidth is because the NRI superstrate is high Q structure so the impedance bandwidth of the antenna is decreased. The simulated and measured reflection coefficients of the proposed antenna are also compared in this section and it depicted in Figure 15. It is observed that the measured and simulated S parameters r results are in good agreement with each other. Although there is slight difference between the simulated and measured results, that may be due to the fabrication error but the measured result still satisfy the requirement. The measured reflection coefficients in Figure 15 also reveal that by the implementation of the proposed NRI superstrate to form the proposed antenna structure, the impedance bandwidth slightly decreased as predicted from simulation result. In addition, the return loss of the fabricated proposed antenna also slightly decreasd because the use of NRI superstrate. A summary of the simulated and measured results are presented in Table II and comparison resulta for gain and half power beamwidth in Table III to conclude the results presented in this section.

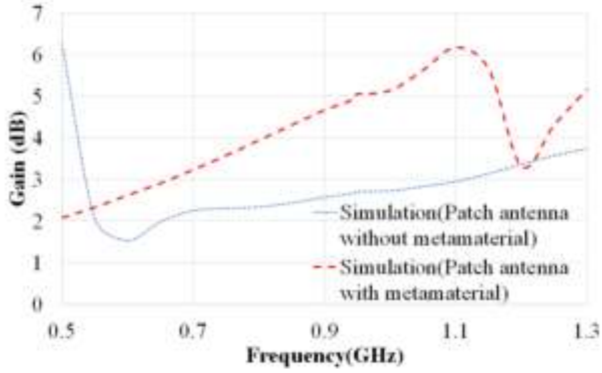


Figure 13. Comparison gain results of the proposed antenna with and without NRI superstrate

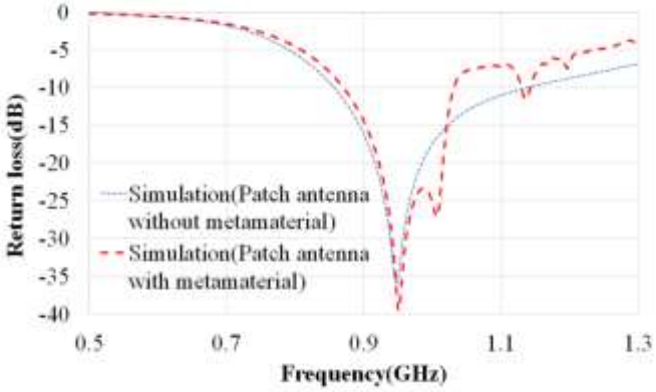
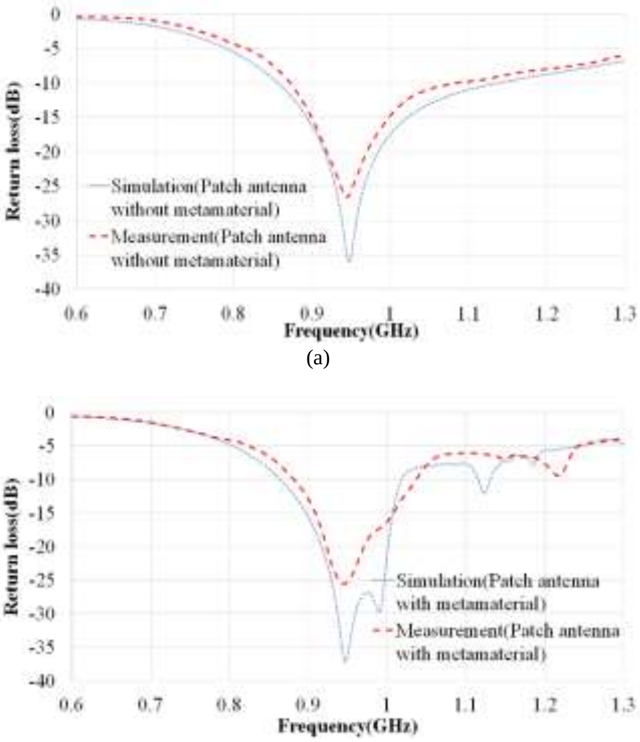


Figure 14. Comparison results of returns loss of the proposed antenna with and without NRI superstrate structure



(a)

(b)

Figure 15. Comparison between simulated and measured results of (a) Patch antenna alone (b) Patch antenna with NRI

TABLE II. COMPARISON RESULT FOR IMPEDANCE BANDWIDTH AND RETURN LOSS.

Structre	**Impedance Bandwidth**		**Return Loss (at 947 MHz)**	
	Sim	***Meas***	***Sim***	***Meas***
Antenna alone	281 MHz	210 MHz	-36.85 dB	-26.5 dB
Antenna with NRI superstrate	160 MHz	153.5 MHz	-39.44 dB	-25.6 dB

TABLE III. COMPARISON RESULTS FOR GAIN AND HALF POWER BEAMWIDTH

Stru.	**Gain** (947 MHz)	**Half Power Beamwidth (at 947 MHz)**			
		Simulation		***Measurement***	
	Sim.	**E plane**	**H plane**	**E plane**	**H plane**
Ant. alone	2.706 dB	82..3°	-	93 °	-
Ant. with NRI supst.	5.033 dB	71.7 °	98.6 °	80 °	120 °

ISSN: 2409-2770

VII. CONCLUSION

In this article, a TSRR-strip line NRI superstrate based microstrip patch antenna has been proposed for RF energy harvesting application. In the proposed antenna, the 2.326 dB (85.96 %) gain improvement is obtained by using 6 layers of NRI superstrate which consists of 2 × 2 TSRR-strip line unit cell. There is some trade-off of performance between the impedance bandwidth and gain as shown in the result but the impedance bandwidth of the proposed antenna still able to cover the desired frequency band. The proposed antenna is also fabricated and tested, the impedance bandwidth of the fabricated antenna is also satisfies the impedance bandwidth requirement for frequency band of 935 MHz to 960 MHz. From the result, it shown that the measured radiation pattern at three desired frequency are in good agreement with the simulated result so we concluded that the proposed antenna is suitable to apply on the RF Energy Harvesting System.

ACKNOWLEDGMENT

We would like to acknowledge and thank the Ministry of Higher Education Malaysia for funding this project under the Fundamental Research Grant Scheme (FRGS);Grant No: FRGS/2/2013/ ST02INTI/ 02/01.

REFERENCES

[1] D. H. Schaubert, D. M. Pozar, and A. Adrian, "Effect of microstrip antenna substrate thickness and permittivity: comparison of theories with experiment," *IEEE Trans. Antennas Propag.*, vol. 37, no. 6, pp. 677–682, 1989.

[2] J. A. Ansari and R. B. Ram, "Broadband Stacked U-slot microstrip patch antenna", ***Progress In Electromagnetics Research Letters,***A. Ansari and R. B. Ram," vol. 4, pp. 17–24, 2008.

[3] T. A. RAHMAN, "Reconfigurable Ultra Wideband Antenna Design and Development for Wireless Communication," Universiti Teknologi Malaysia, 2008.

[4] V. G. Veselago, "The Electrodynamics of Substances With Simultaneously Negative Values of ε and μ," *Sov. Phys. Uspekhi*, vol. 509, no. 4, pp. 509–514, 1968.

[5] S. Enoch, G. Tayeb, P. Sabouroux, N. Guérin, and P. Vincent, "A metamaterial for directive emission.," *Phys. Rev. Lett.*, vol. 89, no. 21, p. 213902, 2002.

[6] B.-I. Wu, W. Wang, J. Pacheco, X. Chen, T. M. Grzegorczyk, and J. A.Kong, "A Study of Using Metamaterials As Antenna Substrate To Enhance Gain," *Prog. Electromagn. Res.*, vol. 51, pp. 295–328, 2005.

[7] P. Ding, E. J. Liang, W. Q. Hu, L. Zhang, Q. Zhou, and Q. Z. Xue, "Numerical simulations of terahertz double-negative metamaterial with isotropic-like fishnet structure," *Photonics Nanostructures - Fundam. Appl.*, vol. 7, no. 2, pp. 92–100, 2009.

[8] P. Dawar and A. De, "Bandwidth Enhancement of RMPA using ENG metamaterials at THz," *Mater. Sci. Appl.*, vol. 4, pp. 579–588, 2013.

[9] H. a. Majid, M. K. a. Rahim, and T. Masri, "Microstrip Antenna'S Gain Enhancement Using Left-Handed Metamaterial Structure," *Prog. Electromagn. Res. M*, vol. 8, pp. 235–247, 2009.

[10] C. Sabah, "Progress In Electromagnetics Research B, Vol. 22, 341–357, 2010," *Prog. Electromagn. Res. B*, vol. 22, pp. 341–357, 2010.

[11] K. Inamdar, Y. P. Kosta, and S. Patnaik, "Proposing a Criss-Cross Metamaterial Structure for Improvement of Performance Parameters of Microstrip Antennas," *Prog. Electromagn. Res. C*, vol. 52, no. August, pp. 145–152, 2014.

[12] M. Ullah, M. Islam, and M. Faruque, "A Near-Zero Refractive Index Meta-Surface Structure for Antenna Performance Improvement," *Materials (Basel).*, vol. 6, no. 11, pp. 5058–5068, 2013.

[13] J. Wang, L. Gong, Y. Sun, Z. Zhu, and Y. Zhang, "High-gain composite microstrip patch antenna with the near-zero-refractive-index metamaterial," *Opt. - Int. J. Light Electron Opt.*, vol. 125, no. 21, pp. 6491–6495, 2014.

[14] H. Zhou, Z. Pei, S. Qu, S. Zhang, J. Wang, Z. Duan, H. Ma, and Z. Xu, "A novel high-directivity microstrip patch antenna based on zero-index metamaterial," *IEEE Antennas Wirel. Propag. Lett.*, vol. 8, pp. 538–541, 2009.

[15] Xiaolong Huang, Yong Liu, Xiaohong Tang, Zhongxun Zhang, "Novel Nested SplitRring-Resonator SRRr) for CompactFfilter Application," *Prog. Electromagn. Res.*, vol. 136, pp. 765–773, 2013.

[16] C. A. Balanis, *Antenna Theory Analysis and Design*, Third Edit., no. 3. 2005.

[17] D. R. Smith, D. C. Vier, T. Koschny, and C. M. Soukoulis, "Electromagnetic parameter retrieval from inhomogeneous metamaterials," *Phys. Rev. E*, vol. 71, no. 3, p. 036617, 2005.