

# RADIO FREQUENCY (RF) ENERGY HARVESTING USING METAMATERIAL STRUCTURE FOR ANTENNA/RECTENNA COMMUNICATION NETWORK: A REVIEW

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## ABSTRACT

Starting from the year 2000, metamaterial structure has been one of the favorite techniques used by several researchers to improve the performance of many radio frequency (RF) device designs, especially in the microwave range area. Wireless charging technologies that have emerged are also one of the highlighted discussions among users, fabricators and researchers. This paper presents a literature review of radio frequency energy harvesting, using a split ring resonator (SRR) and other metamaterial structure in antenna network applications. The objective of this paper is to define and compare the several performances such as the technique used, the material of the substrate, dimension, return loss and the resonant frequency of the antenna. The split ring resonator is an interesting metamaterial structure, that is applied in several researcher's work compared with other metamaterial structure such as electronic band gap (EBG), photonic band gap (PBG), and artificial magnetic conductor (AMC). This structure has the capability to improve the performance of the resonant frequency, minimizing the size and improving the return loss of the design, while sometimes creating a filter notch to the design. SRR structure is a good candidate for energy harvesting because it can increase the conversion efficiency.

**Keywords:** *Radio Frequency, Energy Harvesting, Antenna Network, Split Ring Resonator, Metamaterial, Rectenna*

## 1. INTRODUCTION

Urgent need caused by environmental conditions which are less secure and energy consuming to have caused widespread contamination in need of alternative energy such as energy harvesting from natural energy. Energy harvesting or energy scavenging is a practice where natural energy is derived from external sources that is caught and stored in small wireless devices.

The examples of energy harvesting sources are mechanical energy, thermal energy (heat), vibration, movement, sound, light energy, electromagnetic energy, natural energy, human body energy and others [1]. One of the advantages of energy harvesting is firstly, to improve the

efficiency of the devices or the system. Secondly, to enable the implementation of a new technology, for example wireless sensor networks while the third is to reduce the cost of fabrication, for example the computing cost which can be reduced by harvesting the waste heat and this can be used to power the computer.

Previously, several reviews on energy harvesting has been carried out. Babayo [2] reviewed on the energy management scheme, in energy harvesting wireless sensor networks while Guo [3] focused on the piezoelectric and thermoelectric technologies for energy harvesting. In another review paper, Mohrehkesh [4] described energy harvesting in electromagnetic nanonetwork areas while Zhao [5], Invernizzi [6] and Albrni [7]

focused on wind energy harvesting, the technique of energy harvesting on human motion and ultra-low power energy harvester wireless communication devices, respectively. Apart from that, Shaikh [8] reviewed wireless sensor networks while Soyata [9], Qasem [10] and Monticone [11] reviewed the RF energy harvesting in embedded system, rectenna design in energy harvesting, and metamaterial on the optical range, respectively. Sothman [12] focused on thermoelectric energy harvesting while Le [13] and Sum [14] focused on energy harvesting in aeronautical applications and metaresonator array on energy harvesting.

Radio Frequency (RF) energy harvesting is an emerging technology that will drive the next generation of wireless sensor networks (WSN) without the need of batteries. The battery is the main source of goods, but the disposal of it is causing extreme toxic pollution to the environment. In addition, the replacement and disposal of the battery are a hassle, because of its limited useful life [15]. Therefore, environmentally friendly technology is needed to avoid disposal of batteries that contain hazardous chemicals and metals.

RF energy harvesting is a green technology that has the potential to provide power indefinitely. It is suitable for an inclusive range of wireless applications, such as RFID tags, wireless sensor networks and implantable electronics devices. Figure 1 shows the block diagram of an effective antenna including a circuit capable of converting RF signals to DC voltage.

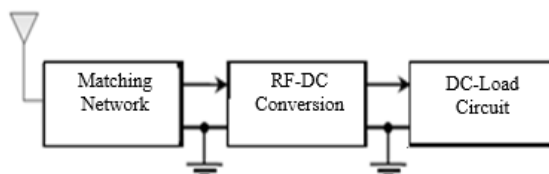


Figure 1: Block diagram of an effective antenna network alongside a circuit capable of converting RF signals to DC voltage.

The efficiency of an antenna mainly depends on its impedance and the impedance of the energy converting circuit [16-17]. A normal RF energy harvesting system consists of an antenna as the main component with an impedance matching circuit, voltage booster rectifier and a charging circuit.

The discussion of this study will focus on previous literature findings on several applications, such as antenna and rectifier antenna (rectenna) which apply the metamaterial structure like split ring resonator (SRR), electronic band gap (EBG),

photonic band gap (PBG), and artificial magnetic conductor (AMC) for energy harvester.

Firstly, the focus is about the limitations of the previous antenna design works which only considered the patch antenna works, without other antenna such as the YagiUda, helical, horn antenna or parabolic type antenna. Secondly, the selected antenna of the previous study is only on the patch antenna with metamaterial structure such as SRR, EBG, PBG and AMC that is applied in the energy harvesting works. Also, the limit consideration of antenna is only focused on the microwave range antenna with antenna resonant frequency between 300 MHz and 300 GHz. It also focusses on the antenna or rectenna that with embedded structure of metamaterial.

The research gap of this work is that there are limited literature review papers which focus on the energy harvesting devices that apply the metamaterial structure in the antenna design. The previous research. The need of this research is to collect and describe the previous work about the metamaterials, which applied several works of the energy harvesting. The review of this study can be used for other researchers and show meaningful gaps in this topic. This collected literature review can be used to other researcher to compare and guide their next research. The limitation and demerits in this work is when searching for information including not open access manuscript in several libraries.

Again, this study of literature review will compare the several types of the metamaterial structure used in antenna or rectenna application. It also shows the material of the substrate used for fabrication, the resonant frequency used, antenna gain result and return loss achieved.

## 2. BASIC CONCEPT OF METAMATERIAL STRUCTURE

The metamaterial resonator structure has an artificial media that is not usually found in nature, but their parameters can be engineered to any specified value. Research on metamaterial resonator structure started in the late 1960s by Veselago [18] who introduced the electrodynamics of substances with simultaneously negative values of dielectric permittivity and magnetic permeability. Split ring resonator (SRR) is a popular and basic metamaterial resonator structure. Veselago explained that, if a material had both negative values (the magnetic and the electric response functions), i.e.  $\epsilon^-$  and  $\mu^-$ , the index of refraction would show a negative,  $n^-$ . In the year 2000, the real design of the metamaterial structure was made

by Smith [19], although a year before, the test was conducted by Pendry [20-21], who presented the split ring resonator structure, but it was not fabricate it that year.

Other types of metamaterial structure are the electronic band gap (EBG), photonic band gap (PBG), and artificial magnetic conductor (AMC). Other than SRR, the EBG structure is also becoming a rapidly advancing research area, in the field of the electromagnetic study. This EBG structure basically affects the ground plane to be like a perfect magnetic conductor.

In the microwave area range, the SRR structure is popular and can be found in many devices, such as antenna [22], RF oscillator [23], microwave filter [24], microwave absorber [25], RF amplifier [26], and frequency selective surface (FSS) [27].

One of the benefits of SRR and other metamaterial resonator structures, is the small unit cell structure with wide frequencies in order for radio frequency to be visible. The split ring resonator affects the improvement of coupling between the individual rings, while it can also reduce the electrical size [28]. In addition, [29] supported that the decrease of electrical size in split ring resonators can boost the coupling between the ring structures. Almonneef [30] discussed in his findings that, the SRR is viable for electromagnetic energy harvesting. In his experiment, a 9 x 9 SRR array with 3 x 3 microstrip patch antenna array was designed using numerical simulations. After the experiment was done, it was found that, the SRR array had a larger power collection compared to the microstrip patch alone.

The basic structure of the split ring resonator SRR, namely the edge couple SRR (EC-SRR), is shown in Figure 2. This structure consists of two similarly shaped couples with different dimensions of split rings. The rings create a strong distributed capacitance in between their region [31]. The other types of SRR structures are broadside couple SRR (BC-SRR) that consists of a single ring with a gap above and side of it [32], while a nonbianisotropic couple (NC-SRR) is a uniplanar design of SRR to avoid the bianisotropy effect in the EC-SRR bianisotropy in the EC-SRR.

The SRR functions as a magnetic field, for the electromagnetic radiation to be driven as a resonant LC circuit through the inductance. The induced currents flow in the directions indicated, with charges assembling at the gaps of the rings. The large gap in each ring avoids the current from floating around in a single ring, and the circuit is completed across the small capacitive gap between

the two rings [33]. In a different study, Palazzi [34] introduced a wireless energy harvesting rectenna with a broadband slot antenna for commercial telephony frequencies in the UHF band. The antenna design is based on an annular slot with an intersection of two ellipses and the slot aperture. The rectenna conversion efficiency was more than 60 %.

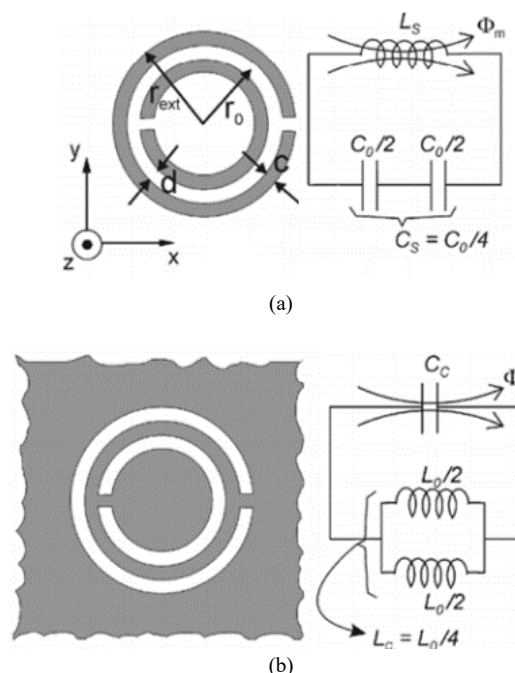


Figure 2: (a) Basic SRR structure, (b) Complementary SRR structure [35-36]

### 3. WORKS USING METAMATERIAL STRUCTURE

The above finding is consistent with a later study by Ashoor [37], that proposed a design of electromagnetic energy harvesting using small 1x3 elements of a dielectric resonator antenna (DRA) array. This DRA array structure was considered an outstanding radiator because it had a negligible metallic loss of its main radiator and the dielectric resonator (DR), as there were no metallic losses associated with DRAs. His finding showed that, the dielectric resonator has the highest absorption efficiency when compared with 1 x 3 dielectric resonator with  $d = n$  mm inter-element spacing ( $n = \lambda/2, \lambda/4, \lambda/5, \lambda/10$  mm). Also, Jung [38] proposed a novel RF energy harvesting antenna with a main radiator and a parasitic radiator in the design. This parasitic radiator contained a two-turn loop structure that generally receives the RF power radiated at the outside of the 3-dB beam width of

the main radiator. This parasitic radiator did not have any effect on the electrical performance of the main radiator, because DC power can be generated by the dissipated RF energy. Finally, the gain was 8.35 dBi, which was nearly like the printed dipole without the parasitic radiator performance.

Table 1: Summary of the several types of metamaterial structure at its microwave applications

Author	Application	Types of metamaterial	Material used	Frequency range	Remarks
Wang [42]	electrically small antenna (ESA)	SRR	FR4	at 934 MHz and 1.55 GHz	Reduce size by SRR
Ong, 2015 [43]	Wideband monopole antenna	SRR	FR4 epoxy board	Wideband 4.61 GHz to 10.23 GHz.	20 mm x 25 mm
Abu, 2016 [50]	Patch array antenna	AMC	RT 5880	Bandwidth between 66.68 GHz - 71.56 GHz	For millimetre wave
Alahnomi, 2016 [51]	microwave sensors	symmetrical SSR	Roger RT / Duroid 5880	2.30 GHz, 4.58 GHz, 6.86 GHz, 9.12 GHz	a high Q-factor with small insertion loss
Nikfalazar, 2012 [52]	Tuneable planer filter	SRR	Barium-Strontium-Titanate (BST) thick film ceramic	Passband frequency 2.8 GHz to 3.1 GHz	14 mm × 3 mm
Ezanuddin, 2011 [53]	Circular microstrip antenna	Circularly SRR	Rogers RT / D 5880	5.85 GHz - 7.075 GHz, resonant frequency of 6.438 GHz	Using for High Altitude Platform Station (HAPS)
Silva, 2016 [54]	microstrip patch antenna	EBG - PBG	RT / Duroid 6006	5.8 GHz with – 32 dB return loss	Gain 6.4 dB
Hamidkhani, 2016 [55]	low phase noise oscillators and diplexers	Complementary SRR	Rogers RT / Duroid 5880	oscillation frequency 5.36 GHz,	–128 dBc/Hz phase noise at 100 KHz frequency
Aznabet, 2011 [56]	metasurface	stacked SRR	ARLON CuClad 25	8.66 GHz, 11.49 GHz, 17.03 GHz, 18.73 GHz	200 mm × 200 mm (25 × 25 elements)
Bilotti, 2006 [57]	SRR microwave absorber	SRR	Not stated	Resonant frequency at 2 GHz	thickness of $\lambda/20$ (i.e., 7.5 mm)
Li, 2009 [58]	Microstrip bandpass filter	Complementary SRR	dielectric constant 2.65	centred at 1.93 GHz	insertion loss 1.7 dB
Huang, 2013 [59]	Substrate integrated waveguide filters	broadside-coupled SRR	Rogers 4350	Type III - 5.73 to 9 GHz	stopband rejection better than 20 dB.
Zuffanelli, 2017 [60]	UHF-RFID passive tags	Complementary SRR	Rogers RO3010	$f_0 = 923$ MHz	distance operate reaches 6.8 m
Mantash, [61]	wearable antenna	AMC	textile materials	2.4 GHz to 2.69 GHz, 5.15 GHz to 5.875 GHz	Cover WiFi and 4G LTE frequency bands
Sanz-Izquierdo, 2016, [62]	frequency selective surface	AMC	Rogers 5870	1.15 GHz - 1.60 GHz	FSS to reconfigurable antenna technology



Liu [39] proposed a new system of cooperative cognitive radio network (CRN) with capabilities in harvesting energy. This network consists of  $N$  single-antenna secondary users (SU), one control centre with multi-antennas and one primary user (PU). Each secondary user harvests energy to power its uplink information transmission and spectrum sensing. Maher [40], also introduced a broadband planar antenna with a semi-circular patch fed as radiator and four stubs in the bottom part for radio frequency (RF) energy harvesting. The antenna had shown a high gain and good radiation pattern, with a broadband between 2.1 GHz to 7 GHz range and resonant frequencies of 2.4 GHz, 3 GHz, 4.1 GHz, and 5.8 GHz, acceptable for RF energy harvesting condition. Table 1 shows several types of metamaterial structure at its microwave applications.

In 2016, Khan [41] presented a design and the implementation of a novel of highly efficient UHF folded dipole meandering antenna, with a grounded parasitic loop and associated circuitry for energy harvesting at 915 MHz. The antenna was implemented on FR4 board with a dimension of 41.3 mm X 17.5 mm. The conversion efficiency of the harvesting circuit was measured to be 0.005% at a distance of 1.5m from the radiation source. In the test, a commercial UHF RFID reader was used as the radiation source. According to his findings, the implemented system could harvest around 200  $\mu$ W at an optimal distance of 1.5 m, with the peak value of 647  $\mu$ W at a distance of 0.5m from the radiation source. The split ring resonator structure was applied in many designs of radio frequency range and presented in several researches [44-49].

All these designs showed the improvement or the enhancement of performance that affects the result. In this table, several applications were added by the metamaterial structure, such as the antenna, planar filter, low phase noise oscillator, Diplexers and microwave absorber. In summary, metamaterial such as split ring resonator, photonic band gap, artificial magnetic conductor, and electromagnetic band gap have affected the different parameters of performance for each type of application in the RF range. Figure 3 shows the examples of metamaterial structure on several devices.

#### 4. ENERGY HARVESTING ANTENNA/RECTENNA WITH METAMATERIAL

Energy harvesting antenna or rectenna antenna (rectenna) is an interesting topic in the research field right now, because many researchers are focusing on this subject. Nowadays, the microwave rectenna systems have been fabricated to function in the range of frequencies between 1 GHz and 35 GHz. A rectenna is a sub-system of a wireless power transfer system (WPT). In the normal circuit using components such as antenna and rectifier, the incoming signal that will be received is from free space caught by the antenna. In 1968, Glasser introduced a rectenna as an energy harvesting medium, called the Space Solar Power which converted solar energy into electricity [63]. After that, the process continued with a pre-rectification filter before being sent to a diode and a post rectification. This is the filter cut off the unwanted spectrum and unwanted harmonics. In the energy harvesting system, the important component of the receiver part is the rectifier-antenna or rectenna. This rectenna receives the electromagnetic power from corresponding

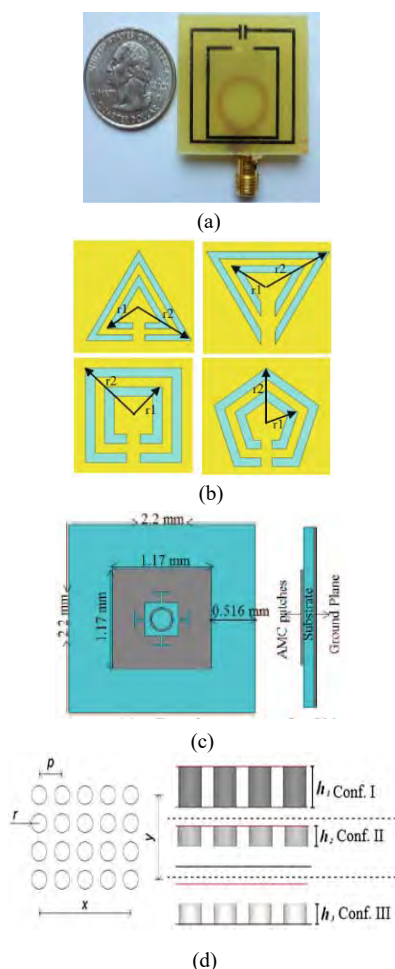


Figure 3: Examples of metamaterial structure on several devices, (a) Dual-band antenna with capacitive SRR [42], (b) Triangular SRR (point up), triangular SRR (point down), square SRR and pentagonal SRR [43], (c) AMC unit cell, (d) EBG/PBG structure for patch antenna design

frequencies. A typical rectenna system contains a microstrip antenna to capture the microwave energy and convert into AC power and a high frequency rectifying circuitry, that converts the AC power into DC power. Figure 4 presents the block diagram of transmitting antenna and receiving antenna via a travelling medium or free space.



Figure 4: Block diagram of transmitting antenna and receiving antenna network

Assimonis [64] designed a low-cost lossy substrate and low-complexity rectenna grid that contain matching network and DC converter part. The design highly affected the efficiency of low-power input and captured as much power as possible that is offered at the load. A lossy substrate is used to reduce the cost of fabrication while the increased efficiency is affected by the additional of a single series circuit with a single diode. Two 868 MHz frequency bow-tie antennas are located between the rectifiers. Cao [65], introduced the CSRR-Fed SIW cavity-backed fractal patch antenna. The multi-band frequency difficulty requires that, any energy harvesting device should be well matched with all the frequency bands of the application available on site. This matter usually can be explained over the use of multi-band antennas, which has been broadly studied by other researchers [66]. An example of antenna for energy harvesting, is the novel efficient 3-D multi-frequency antenna that operates in five different frequency bands of GSM 1800MHz, UMTS 2100MHz, WLAN 2.4GHz, and WLAN 5.2GHz and WLAN 5.8 GHz. This small antenna is fabricated for the reception of ambient RF energy from a cellular network frequency [67]. Agrawal in 2013, introduced a compact sized 2.4 GHz antenna with an array J-cross-sectional reactive impedance surface (RIS) metamaterial structure of the circular slotted truncated corner square patch (CSTCSP).

Kamoda [69] carried out a research on the loop antennas over artificial magnetic conductor (AMC) surfaces for dual-band RF energy harvesting antenna. AMC is another type of metamaterial besides the SRR structure. His parametric study showed that the AMC surface with metal posts has a different frequency range compared with no metal posts. This design contains the energy harvesting panel with the antenna substrate, polystyrene as a spacer, rectifier circuit, power management circuit and ground plane using

aluminium. Figure 5 shows Zhou [70] work which indicated as follows: (a) designed a multi-band fractal antenna for RF energy harvesting WLAN in 2.4 GHz and 5.8 GHz frequencies with a wider bandwidth between 1.6 GHz and 3.2GHz for the first resonant frequency and (b) between 4.88 GHz and 6.68 GHz for the second resonant frequency.

Moreover, Shrestha [71] had fabricated a miniaturised dual band patch antenna using Sierpinski fractal for radio frequency energy harvesting. In his design as shown in Figure 5, (b) a miniaturised antenna was operable at two different resonant frequencies of 2.45 GHz and 5.8 GHz. This antenna was constructed by modifying the standard microstrip patch antenna geometry into a Sierpinski fractal structure. His proposed antenna can also potentially remove unwanted harmonics without the use of additional radio frequency filter components. Again, Zhou [72] introduced a multiband antenna for energy harvesting using plasmonic metamaterial. A corrugated ring resonator was printed on a thin dielectric substrate of Roger RO4350 with a spiral-shaped defect ground structure (DGS) at the ground plane. On the other side, there was a T-shaped design with a periodic array of rectangular-shaped grooves. The presence of this DGS structure, formed more resonant frequencies. This structure also shifted the resonant frequencies into a lower point. Although, Devi [73] had proposed C-shaped antenna with the SRR array structure, he had designed a 5 x 5 metamaterial array split ring resonator at the patch antenna to resonate at 900 MHz with the improvement of the return loss and impedance bandwidth and gained 19.0 % (increase 6.71 dB), 23.33%, and 44.4% respectively.

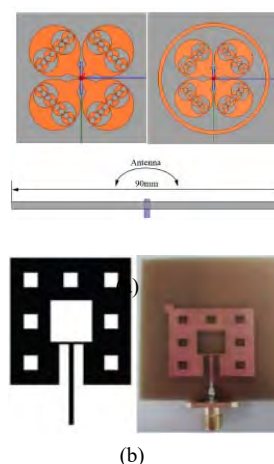


Figure 5: Previous research on antenna/rectenna design with metamaterial structures, (a) multi-band fractal antenna for RF energy harvesting [70], (b) Miniaturized dual band patch antenna using Sierpinski [71].

Another study was carried out by Jalil [74], where he proposed an octagon-shaped radiator fed microstrip antenna with matching ultra-wideband impedance and partial grounded substrate. This antenna was designed on Taconic TLC-30 substrate and operated as an ultra-wideband region between 2.8 GHz and 11 GHz with the band notch between 3.3 GHz to 3.6 GHz (WiMAX frequency operating

band) from the inverted U-shaped slot at the patch. The novel receiving dual band geometry antenna for 2.45 GHz and 5 GHz by Bakkali [75] is another example of antenna for RF energy harvesting. Table 2 shows the summary of the several researches on metamaterial structure that is used in antenna / rectenna for energy harvesting.

Table 2: Summary of the several researches on metamaterial structure that used in antenna / rectenna for energy harvesting

Author, year	Technique used	Material used	Dimension size	Resonant frequency (GHz), Return loss (dB)	Gain (dB)
Cao, 2015 [65]	CSRR-Fed SIW cavity-backed fractal	F4B	40 mm x 40 mm	3.9 GHz 4.3GHz	4.6 dB 5.9 dB
Agarwal [68]	reactive impedance surface (RIS) metamaterial, circular polarized (CP)	dual-layer FR4 substrate	35 mm x 35 mm x 3.7 mm	2.44 GHz with better than - 35 dB	4.6 dB
Zhou, 2015 [72]	Spiral defected ground structure (DGS) metamaterial, T-shaped groove structure at patch	Rogers RO4350	60 mm x 60 mm	0.91 GHz, 1.79GHz, 2.53GHz	Directivity 1.71dBi, 5.69 dBi, 5.78 dBi
Devi, 2014 [73]	SRR metamaterial, stepped rectangular patch, air gap	Three layers FR4 substrate	74.4 mm x 49.9 mm	1.846 GHz, - 27.7 dB	-
Xu, 2016 [79]	SRR arc-shaped slot, 2x2 array, air gap	FR4	24.7 mm x 15 mm	1.89 GHz 2.05 GHz	5.3 dB 6.6 dB
Fhafhiem, 2016 [83]	Mushroom like electromagnetic band gap (EBG), partially reflective surface (PRS), air gap	Dual layer FR4	120 mm x 120 mm	2.45 GHz with > 10 dB	-10.05 dB
Shen [84]	anisotropic zero-index metamaterial (ZIM), Vivaldi antenna shaped	F4B	125 mm x 210 mm	2.45 GHz with > 10 dB	1.2 dB

The proposed receiving antenna achieved the essential bandwidth specification and delivered a peak gain of more than 4 dBi across the operating frequency bands. Besides, there are many antennas designs for RF energy harvesting such as MIMO relay by Samy [76], RF energy harvester antenna by Ramesh [77], RF energy harvesting rectenna by Abdullah [78], dual broadband antenna array for RF energy harvesting by Xu [79], bow-tie antenna using SRR for energy harvesting by AlShareef [80], antenna with circular polarization for energy harvesting by Ahmed [81], and compact tree-shaped coplanar waveguide (CPW) antenna for RF energy harvesting by Zakaria [82]. Fhafhiem also designed a patch microstrip and EBG including PRS superstrate [83]. Figure 6 shows another work on antenna with metamaterial structures.

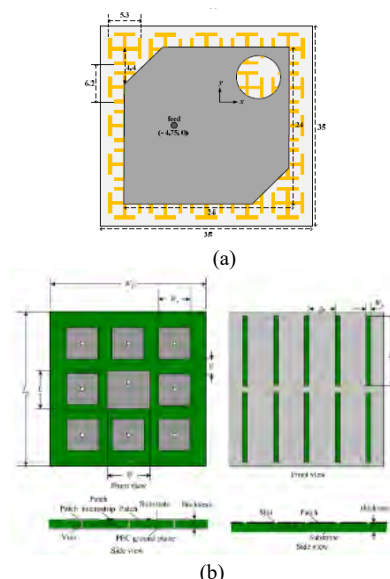


Figure 6: (a) RIS based antenna design [68], (b) Patch antenna with EBG and PRS superstrate

## 5. RF ENERGY HARVESTING SYSTEM NETWORKS

Figure 7 shows the RF energy harvesting system networks by [68]. In this case, a single stage Dickson charge pump was applied as a rectifier and as a voltage multiplier circuit. The miniaturized size circularly polarized microstrip antennas (CPMAs) with metamaterial reactive impedance surface RIS structure and charger chip BQ25504, which had been installed as part of the complete system. This antenna has the capacity to boost the antenna gain and improve the bandwidth, which functions the energy harvesting system. This proposed antenna includes, the whole CP frequency range of 2.40 GHz to 2.48 GHz with a size reduction of approximately 22% and increase the efficiency of the system to 28.9 %.

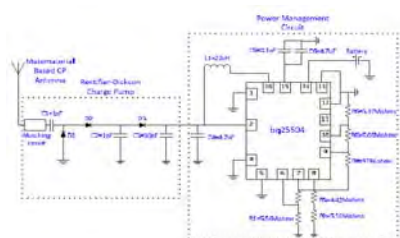


Figure 7: Proposed RF energy harvesting system networks with circularly polarized microstrip antennas (CPMAs).

After the review on the application of the rectenna and the antenna for energy harvesting, it shows that there are many design works that applied the SRR structure, but limited work is done on the other metamaterial structure like SRR, EBG, PBG and AMC structure. This is because, the SRR structure is easier to design compared with the others and has the capability to miniaturize the size of the antenna. Besides that, this structure also has the potentials to create a multiband frequency effect to the antenna. Among the gaps that can be reduced by future researchers is by applying the others structure in their design. Their research can be combined with several types of metamaterials in one antenna, in order to see the performance effect of the antenna. Improvement work can be done, by using other material substrate to increase the performance of the antenna.

## 7. CONCLUSION

Metamaterial such as the SRR, AMC, PBG and EBG has the potential to improve the performances of the design in many RF applications. A five-year

range of research showed that, there are many researchers who focused on this area by providing enhancement work on its efficiency and higher return loss performance. Based on the above review, it is summarized that there are several additional aspects to be considered when designing a good energy harvester device using several RF range applications, in comparison with a conventional basic RF application design. It can be concluded that the addition of the metamaterial structure had been improve the performance of the return loss or can effect to reduces the dimension of the antenna. The antenna with metamaterial for the energy harvesting area is a favorite subject, because in contemporary studies, there have been many researches covering the topic. It shows that, the antenna performance can be improved upon by adding the metamaterial structure. The significant improvement of the metamaterial antenna is that, it reduces the size, creates more resonant frequency for multi-application and creates the band-notch rejecting frequency.

The result of this review shows that, RF application that is incorporated with metamaterial can be successfully applied as energy harvesting devices in many designs, such as in the antenna and rectenna (antenna with rectifier). The addition of SRR and several structures of metamaterial to the antenna can reduce the size of the antenna and sometimes can be a notch band to filter certain ranges of frequency.

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