Design of RF Harvester with Diffirent Matching Circuits

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***Abstract*— In this paper, an RF harvester along with a power conditioning unit is presented. The proposed solution is tuned to work at 2.42 GHz. RF harvested front-end is simulated, and its supporting back-end power conditioning unit is discussed in detail. The variation in the harvester's Gain, Directivity and Efficiency at different frequencies is analyzed. Different power conditioning units are proposed, and the best one for the proposed RF harvester is discussed in detail. The proposed low-cost solution is highly suitable for far-field RF power harvesting, especially for small portable gadgets.**

Keywords—RF harvester, Antenna, Impedance matching, Power conditioning, Far field RF harvesting

I. Introduction

Nowadays, Electrical energy is being produced in multiple ways, which include solar, wind, thermal generation and many others. Each method of energy production has its advantages along with shortcomings. The referred techniques are bound to be installed outside the building or far away from the population where input energy is abundant. Another drawback of the mentioned systems is the need for the required source in a specific geographical location, like the wind. RF harvesting doesn't have any of the above-cited issues, but the production of energy using this harvester is on the scale of milliwatts which is enough to power low-energy sensors or ICs only[1]. As the application of the harvester is frequently found in places where equipment monitoring is required using a particular sensor, the power requirement could easily be met by using an RF harvester.

Another advantage of an RF harvester is that electromagnetic waves are present everywhere, which acts as the source of the RF harvester and can produce energy even inside the building. The harvester system converts electromagnetic energy into usable DC power, as shown in Fig. 1. The different methodologies of this technique are reviewed in [2].

It has been a dream of humanity to deliver electrical energy without the usage of any wire. Unfortunately, the energy cannot be transmitted wirelessly on a large scale as the power loss is enormous. According to (1), P_r is inversely proportional to the square of the distance between the transmitter and receiver [3],

$$P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi R)^2} \tag{1}$$

In [4], two different step-up converters are used to notice the difference in the output. Also, two stages of rectifier and matching networks are tested. A dual patch antenna is designed at the resonant frequency of 2.45GHz in [5]. Using the capacitor as primary and secondary storage to gather charge instead of a battery makes this system long-lasting [6].

In the following section II, the RF harvester development is described before designing the front end of a system in section III. A complete system is simulated with a discussion of the result in section IV. Finally, a conclusive statement is given in the last section.

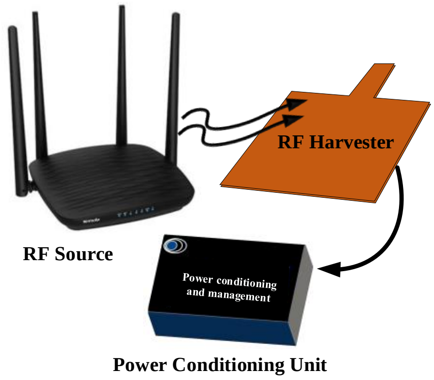


Fig. 1. Conceptual diagram, which shows diffirent units of complete RF harvester

II. Development Of RF Harvester

In an overall circuit, RF source transmits the wave through free space towards the receiver as shown in Fig. 2. RF harvester front-end patch antenna captures the available frequency waves and connects through a microstrip feedline with the impedance matching network. The L-network circuit is designed so that the impedance of the source and load are matched so that maximum power can be transferred.

The rectifier circuit is attached to the output of the matching network to convert the RF signal into usable DC voltages, which then pass through a low-pass LC filter before reaching the connected load [7].

The load can vary according to the application in which the RF harvester is used. In most cases, the selected load consumes power on the microwatts scale. The current passing through the load generally is in the range of nano-amperes [8].

A. Impedance Matching

The impedance at the antenna output is 50 Ohms, whereas the input impedance of the proceeding circuit differs. In this case, there is an impedance mismatch, and the signal is reflected towards the antenna, so it is necessary to have a matching network that translates the impedance of the antenna to the impedance of the proceeding circuit.

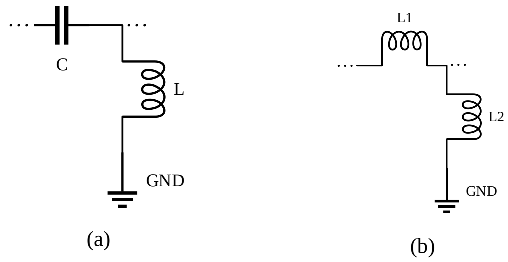


Fig. 3.Impedence macting circuit (a) LC matching circuit, (b) LL matching circuit

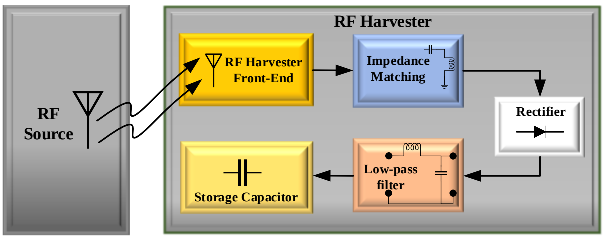


Fig. 2. Block Diagram of overall System, the system contains RF Sources, RF harvester Front-End, Impedance Matching, Rectifier, Low-pass filter and Storage capacitor

There are many different techniques of the matching network discussed in [9]. The used LC and LL impedance matching networks are shown in Fig.3 (a) and (b).

The difference between these two approaches mainly lies in the range of load impedances that could be matched through any of these networks. LC configuration can match the more extensive range of loads on the output compared to the LL configuration.

B. *Rectifier*

The input of the rectifier is AC which has positive and negative cycles. When the positive cycle passes through the diode, it is forward-biased and allows the positive half to pass

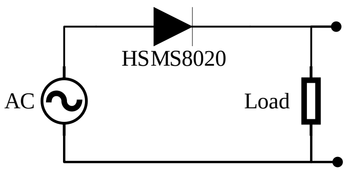


Fig. 4. Half-wave rectifier

through it but stops the negative part. So, the output has only the positive half cycle. The schematic of a rectifier is shown in Fig. 4. The design of a rectifier for high-frequency applications can be seen in [10].

Since the circuit needs to be operated at an RF frequency of 2.4GHz, the diode selection is essential. The diode should operate in the frequency band; otherwise, the circuit wouldn't work correctly. HSMS8020 is selected for the design. It works in the frequency band from 0.1 to 9 GHz.

C. *LC Filter*

The output of the rectifier needs to pass through a low-pass filter. The filter's cut-off frequency should allow the frequencies of interest and block the higher frequencies. The LC filter is shown in Fig. 5.

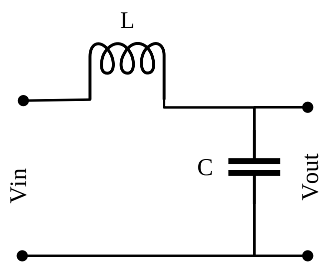


Fig. 5. LC Filter

The inductive resistance XL increases with frequency, while the capacitive reactance XC is inversely proportional to it – it decreases as the frequency increases. The cut-off frequency is the frequency at which XC=XL. Thus, XC is less than XL at a frequency more significant than the cut-off frequency. At a lower frequency, XC is greater than XL.

The cut-off frequency for an LC low pass is calculated using (2):

$$fc = \frac{1}{2\pi\sqrt{LC}} \qquad (2)$$

III. RF HARVESTER FRONT-END

The front end of an RF harvester is designed using ADS software. The selected antenna type for further designing and simulation is a patch due to its directivity, so maximum power can be extracted on the output using an antenna of small dimensions.

A. *Design of Antenna*

A rectangular patch antenna is designed on a 1.6mm substrate (FR4), fed through a wave port, as shown in Fig. 6, acting as an RF receiver.

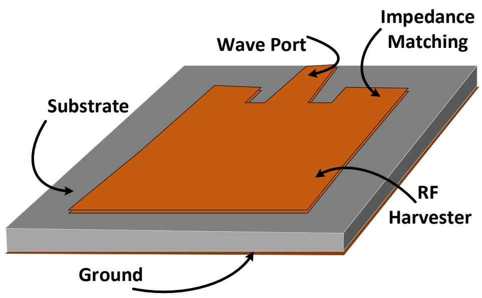


Fig. 6. Rectangular Patch RF harvester.

The designed antenna needs to be used on the receiver side along with some other electrical components to convert the electromagnetic energy into electrical energy for low-powered devices. The field intensity of an antenna is shown in Fig. 7 where the maximum field areas are shown with the red color and are approaching 2.89 A/m while the blue areas indicate the lowest field intensity.

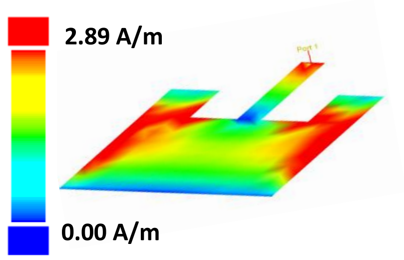


Fig. 7. Field intensity plot of the RF harvester in reverse mode

After tuning and tweaking, the resonant frequency of 2.42GHz is verified by visualizing the magnitude [dB] plot in simulation results, as shown in Fig. 8.

B. *Parameters of RF Harvester Front End*

The RF harvester is also an antenna in receiving mode. For analysis the harvester is analyzed as antenna in the transmission mode. The structure is developed on ADS software, as shown in Fig. 6, to simulate the results and tune the changes as required before finalizing the model. The resonant frequency of the patch antenna is 2.42GHz, as verified above.

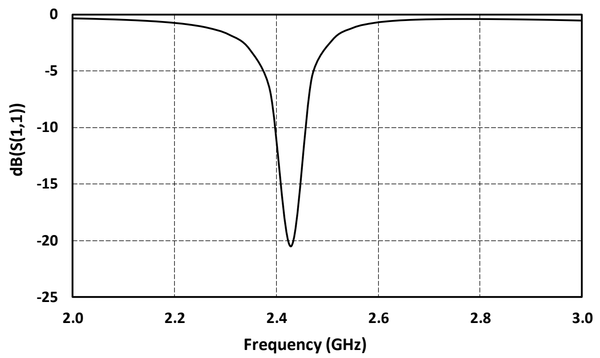


Fig. 8. Change in the magnitude response vs frequency

In Fig. 9, the maximum gain achieved is 3.58 and radiation efficiency is 51.3% at the f_r of 2.42GHz. On the other hand, directivity remained unchanged until the steep rise near the 3GHz frequency.

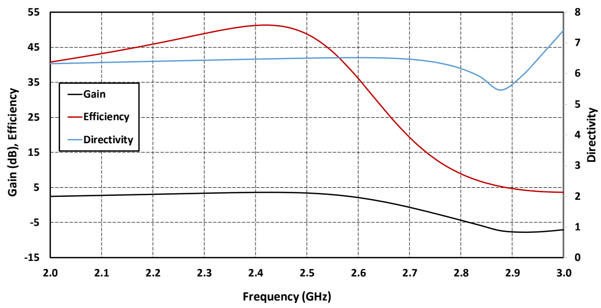


Fig. 9. Change in Gain, Efficiency, Directivity vs frequency

The received power by the antenna is almost $25 \times 10^{-4} W$, and the output power is approximately half of the input power, i.e., $\approx 12.5 \times 10^{-4} W$ as shown in Fig. 10.

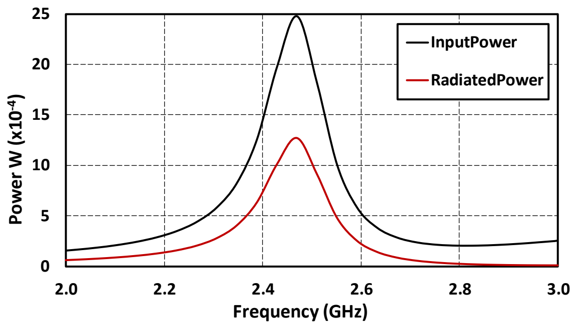


Fig. 10. Input and Radiated Power vs Frequency

Some of the antenna parameters are shown in Table I.

TABLE I. ANTENNA PARAMETERS

Quantity	Value
Peak Directvity	7.403
Peak Gain	3.580
Radiated Power	1.27 mW
Accepted Power	2.47 mW
Radiation Efficiency	0.513

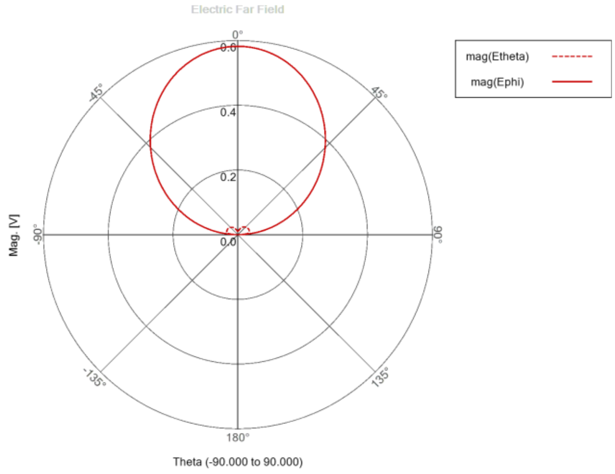


Fig. 11. Electric Far Field

C. Electric Field and Radiation Pattern

The electric field pattern of the antenna is shown in Fig. 11, in which the lobe is symmetrical. The symmetry of the figure results in radiating the field towards the relevant front end. The even shape is helpful when creating an array of these patch antennas as it doesn't produce an irrelevant field on the plane's back end [11].

In Fig. 12, more radiation is emitted along the z-axis, and less radiations are transferred along the other two axes, i.e., x-axis and y-axis. This behavior shows that most fields are directed upward or in one direction with fewer outward field lines on the right or left side [12].

IV. Working Of Complete System

In Fig. 2, the impedance matching network is implemented in two ways, i.e., with LC and LL configurations. The rest of the circuit remained the same to visualize the effect of the matching network on the output of load.

A. With LC impedance matching network

The circuit in Fig. 13 is implemented on Advanced Design System (ADS) simulation software. The antenna with the exact specifications is selected in ADS along with other electrical components to harvest the energy. The antenna's resonant frequency is 2.455GHz, and the impedance is 50 ohms, as verified in the above simulation. The matching network configuration can be seen in the schematic, where the capacitor of 0.304pF is used in combination with the inductor of 7.24nH.

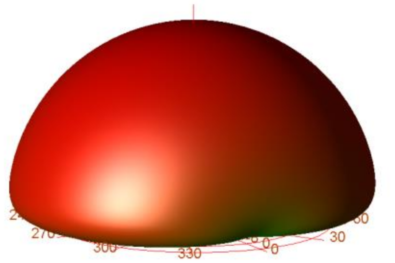


Fig. 12. 3D Radiation Pattern

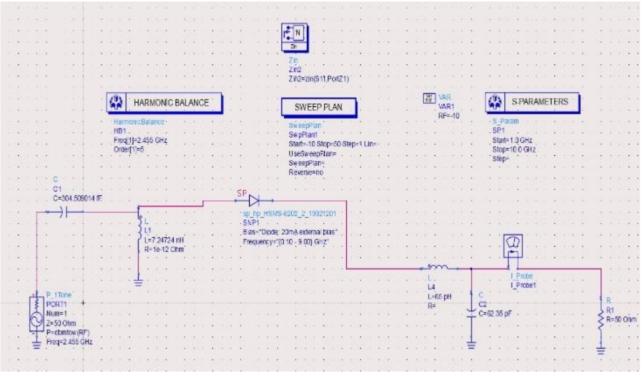
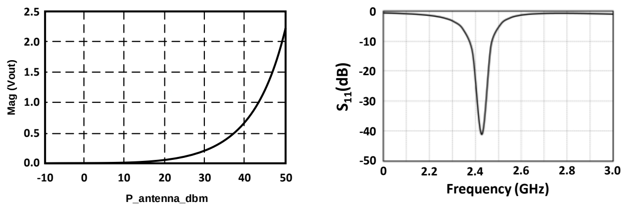


Fig. 13. RF Harvester Circuit Design 1

The output DC voltages increase with the rise in the power of the antenna, as shown in Fig. 14(a). The resonant frequency of 2.455GHz is verified by visualizing the reflection co-efficient curve in Fig. 14(b), but the magnitude is increased to -40dB due to the matching circuit.



(a) (b)

Fig. 14. Design 1 (a) Output DC voltage vs Antenna Power (b) Reflection co-efficient

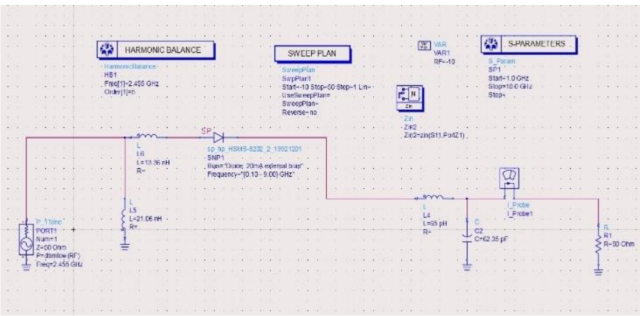


Fig. 15. RF Harvester Circuit Design 2

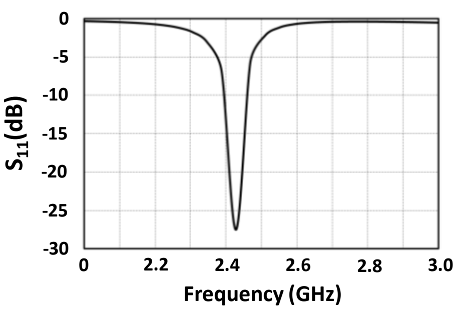


Fig. 16. Reflection co-efficient of Design 2

B. *With LL impedance matching network*

A similar circuit is developed in Fig. 15, but the change lies in the type of L network where both components are inductors instead of LC combinations. A comparable trend can be seen in Fig. 16 with less magnitude.

V. Conclusion

In this study, an RF harvester along with a power conditioning unit was presented. The resonant frequency of the proposed solution was 2.42 GHz. On the receiver side, the front-end i.e., the RF harvester and back-end i.e., the power conditioning unit simulated and discussed in detail. The different parameters, such as harvester's Gain, Directivity and Efficiency were visualized at different frequencies. The best power conditioning unit for the harvester was discussed in detail after proposing multiple units. After analysis, it is concluded that the proposed low-cost solution is appropriate for far-field RF harvesting, mainly in the case of portable gadgets.

VI. Acknowledgment

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VII. References

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