Development of Broadband EMF Sensors for Energy Harvesting using RF and Microwave Signals

Mohd Azlishah Othman, Abd Shukur Jaafar, Nurmala Irdawaty Hassan

Abstract: ***Telecommunication Tower has been built for giving the wide coverage on UHF for communication devices. The radiation power from the tower gives awareness that radiation by the cellular tower might affect the human health. Hence, this contribution leads to invention of EMF Meter exists specifically focus on power radiation which is known as RF power meter. The RF power meter is use to detect broadband frequency of UHF in ranging from 300 MHz to 3 GHz radiation power. Within the UHF range, Radio Energy Harvesting technology was introduced. This gives the innovative opportunity of Radio Energy harvesting application on RF power meter. By combining both technologies, the RF power meter could detect the power radiation while harvesting RF energy at the same time. The solution provide on having devices able to power up with less consumption on power supply. In this project, RF power meter was programmed by Arduino and RF energy harvesting was designed. The RF power meter able to achieve 98.6% accuracy and at the input power level of -10 dBm, the measured result shows a RF to DC conversion efficiency achieving 63.3% with the corresponding DC output voltage of 2.11 V.***

Index Terms: ***About; Broadband EMF Sensor, Harvest RF Energy, 1.8 GHz to 2.4 GHz, Voltage Multiplier Circuit.***

I. INTRODUCTION

The world has reached at the 4th Generation Telecommunication System (4G) which has been giving a lot of improvement towards nowadays communication. In conjunction with the 4G Telecommunication System technology, there are increment of cellular towers numbers have been built just to increase the coverage of the new technology. Cellular tower responsible to radiate the Radio Frequency that transmitted from Base Station. By having numerous cellular towers that have been built, there will be a high potential for Radio Frequency energy harvesting. Radio

Frequency energy harvesting are known for its free energy and environmental friendly. This energy harvested on ambient air as long as there is electromagnetic wave radiated around the area. Mainly, the energy is originated from the radiation in coverage area which is provided by the cellular tower.

The important part of Radio Frequency energy harvesting is that the source is unlimited which radiated multiple cellular towers around the area. The ambient Radio Frequency energy harvesting techniques offer the capability of converting the received RF signals from environment into electricity. Therefore, it has recently emerged as an alternative method to operate low-power devices, such as wireless sensors. Ambient RF energy harvesting aims to capture and recycle the environmental energy such as broadcast TV, radio and cellular signals, which are essentially free and universally present, making this technique even more appealing. As it is appealing, it can be one of the technique that will important component in green energy technology which is unlimited and resourceful in critical situations.

As non-renewable energy resource had undergone depletion, the researcher nowadays had focus on developing devices or machines that effectively functioning with renewable energy. One of the techniques was developing energy harvesting which may come in vary categories.

According to X. Lu [1], this technique is knowledgeable to be the solution to power energy-constrained in wireless networks. Regarding the energy-constrained devices, such as wireless sensor networks, have a limited usage of time, which may affect its performance. In contrast, an RF energy harvesting can have a power supply from a radio environment.

Consequently, RF energy harvesting network have found their applications quickly in various forms, such as wireless sensor networks [2]. As the world had developed into future technologies, people may now available to use renewable energy resources as the main energy consumption for their devices and machines. In contrast, these renewable energies should have its sustainability for further importance in future technologies.

II. METHODOLOGY

The selective frequency range is from 1.8 GHz to 2.6 GHz is the mainly focuses on detected the RF radiation for harvesting. Both the rectification and voltage pump process are in the RF-DC conversion block where the RF energy is converted into DC power. The combination of both processes known as the Conckcroft Walton voltage multiplier.

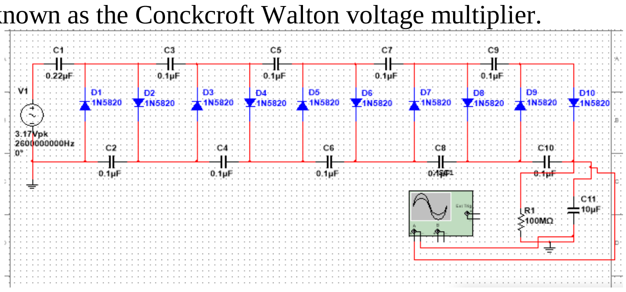

Figure 1: Energy harvesting circuit design in multisim

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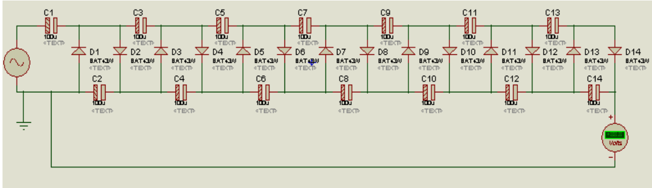

Figure 2: 7 stages of Cockcroft Walton's rectifier

$$Efficiency, \%\eta = \frac{Output\ power\ (po)}{Input\ power\ (pin)} \times 100 \quad (1)$$

where;

Power output at -10dBm input power = current output x voltage output

Power output (dBm) = 10 log (power output $_{(mW)}$)

The voltage drop and the ripple are depend based on its frequency of input signal, peak amplitude, load current and the value of capacitance used. The voltage drops (ΔV) and the ripple voltages (Vrip) are given by following [15,16]:

$$\Delta V = \frac{I}{f.c}\left(\frac{2}{3}n^3 + \frac{n^2}{2} - \frac{n}{6}\right) \quad (2)$$

$$Vrip = \frac{I}{f.c}\left(\frac{n(n+1)}{2}\right) \quad (3)$$

Where;

I: load current (Ampere)

f: Input frequency (Herze)

c: Capacitance per stage

N: Number of stages

It is known for combination of a circuit clamping combine with a half wave rectifier on first stage. From equation (2) and (3), it is state that the voltage drop and the ripple voltage will increase as the load current and the number of stages is increased.

III. RESULTS AND DISCUSSION

The proposed design was programmable with specification variable by using Arduino programmed RF Power Meter as shows in Table 1.

Table 1: Specification variable for RF power meter accuracy test

Parameter	Remarks
Operating Frequency	2.40 GHz
Power Transmission	0.00 dBm to – 80.00 dBm

Based on Table 2 and Figure 3 shows below, the accuracy shows that the power measured by Arduino programmed RF Power Meter were minimal at 97% to maximum at 100% accuracy. This show that ZX47-60+ Power Meter power meter can only detect up until -60 dBm of power transmitted as explained in the data sheet of the Power Meter.

More than -60 dBm, the ZX47-60+ Power Meter did not reach out because the limitation of its aperture power. As for the power transmit below than a value of -60 dBm, the reading power is not 100% accurate. This is because the loss occurrence at the antenna port and the interference from other electronic component within the RF Power Meter circuit. The results bring average accuracy of 98.6% within its limitation at 5 dBm to -60 dBm only.

Table 2: Output parameter of RF power meter

Transmitted power (dBm)	Power reading (dBm)	Power reading (W)	SWR (V)	Accuracy (%)
0.0000	0.0000	0.1000	0.5300	100.0000
-10.0000	-10.3200	93.3200 µ	0.8600	97.0000
-20.0000	-20.5500	8.8100 µ	1.0400	97.3000
-30.0000	-30.7000	605.3000 n	1.2600	97.7000
-40.0000	-40.4500	90.1500 n	1.5900	98.9000
-50.0000	-50.1200	9.7200 n	1.8800	99.8000
-60.0000	-60.3300	926.8200 p	2.3400	99.5000
-70.0000	-104.0000	0.3980 p	4.3000	51.4000
-80.0000	-120.0000	0.0015 p	4.7600	50.0000

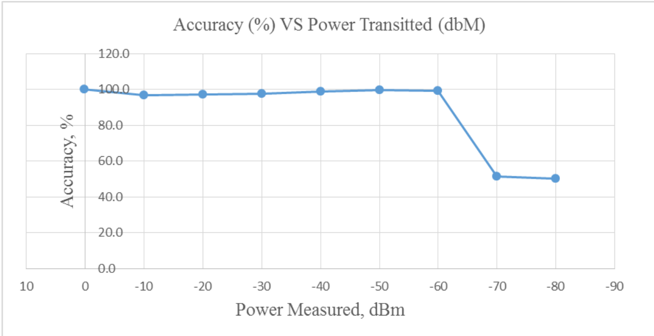

Figure 3: Graph of accuracy against power measured by RF power meter

The output can be seen on the Figure 4 and Table 3 was shown the result of the simulation.

Figure 4: Output voltage for 0.1 W power output

The simulation was carried out to find and analyze the initial output of the voltage output that had been harvested by the harvesting circuit design. The variable changes were the only power input, which is from 0.1 W to 2 W.

Table 3: Results of energy harvesting circuit in simulation

Power Input (W)	AC Vrms (V)	Current RMS (A)	AC Vpeak (V)	Current RMS (A)	Voltage DC (V)
2	10.00	0.20	14.4	0.28	6.4
1	7.07	0.14	10.0	0.20	5.0
0.5	5.00	0.10	7.07	0.14	2.9
0.25	3.16	0.06	4.47	0.08	1.9
0.1	2.24	0.04	3.17	0.06	1.3

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Ranging from power input from 0.1W to 2W the results for voltage output was at steady state which grows steadily along the increment. It showed that the circuit design was stable enough to be design as long as the appropriate component applied for the RF energy harvesting circuit design.

The RF energy harvesting circuit was combined with the Arduino programmed RF Power Meter. Although it was considered as a one prototype, the analysis of the harvested energy can be done as both are two different core circuits for the prototype.

The preparation was made for energy harvesting at minimum 1.8 GHz of the proposed frequency which setting the frequency and power transmission as the controlled variables. The manipulated variables were the capacitance value of capacitor and the number of stages of Cockcroft Walton's rectifier of the RF energy harvesting circuit as shown in Table 4. The form of energy harvested was in voltage parameter and the voltage output was boosted by DC-DC step-up booster.

Table 4: Specification variable for energy harvesting at 1.8 GHz

Parameter	Remarks
Operating frequency	1.8 GHz
Power transmission	0dBm
Cockcroft Walton voltage multiplier number of stages	5 stages and 7 stages
Capacitance of Capacitor	200µ, 100µ and 220p

Table 5: Results of voltage output and boosted voltage output at 1.8 GHz

Capacitance (F)	Voltage output (V)		Boosted Voltage output (V)	
	5 Stages	7 Stages	5 Stages	7 Stages
200µ	0.09	0.21	0.09	0.21
100µ	0.15	0.33	0.15	0.33
220p	0.93	1.5	1.3	2.66

The results of harvested energy were shown in Table 5 and the graph of the output voltage of harvested energy against different value of capacitor at both stages together with graph of boosted output voltage against different value capacitor at both stages were shown in Figure 5 and Figure 6.

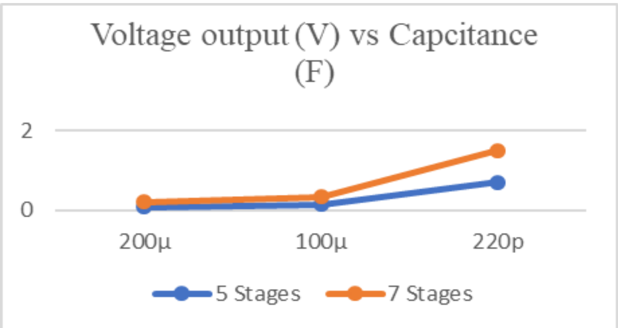

Figure 5: Output voltage against capacitance value at 1.8 GHz

In Figure 5, the value of capacitance for 220 pF on both 5 stages and 7 stages rises at the value of 1.5 V for 7 stages while 0.93 V on 5 stages. The lowest value produce at 200 µF where the voltage for 5 stages is 0.09 V and 7 stages is 0.21 V.

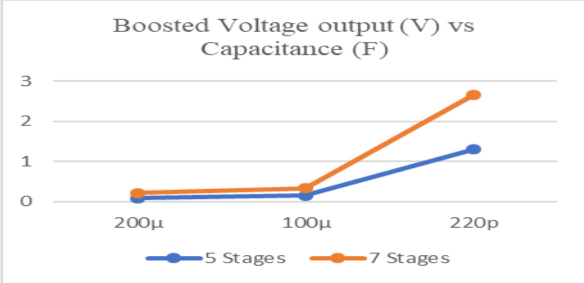

Figure 6: Boosted output voltage against capacitance value at 1.8 GHz

In Figure 6, the boosted output value of capacitance for 220 pF on both 5 stages and 7 stages rises at the value of 3.81 V for 7 stages while 1.41 V on 5 stages. The lowest value produce at 200 µF where the voltage for 5 stages is 0.14 V and 7 stages is 0.22 V.

At the final verdict, at 2.4 GHz of 7 stages of Cockcroft Walton at 220 pF capacitance of capacitor was chosen as the best energy harvesting circuit. After the measurement of the harvested energy, the efficiency of the rectifier at -10dBm power level was determined by using the Equation (1). All the measured parameters were shown in Table 6.

Table 6: Measured variables for rectifier efficiency

Parameter	Remarks
Frequency	2.4 GHz
Cockcroft Walton voltage multiplier stages	7 Stages
Capacitor value	220 pF
Measured voltage output	2.11V
Measured current output	19.92 mA

For harvested energy discussion, there were two categories that affect the value of energy harvested from RF energy harvesting circuit. These two categories were the effect of the capacitance value and number of stages and the efficiency influence. When compare to the simulation results, the hardware test has greater output voltage harvested. This occurred because there were no power level options for the simulation 0dBm.

The initial power level for the simulation test was at 0dBm while the hardware test on -10dBm.

At this perspective, greater number of Cockcroft Walton Voltage Multiplier stages might increase the voltage value of energy harvested. The downside was the longer the of number of stages, the greater the charging of capacitors were required since the application of this prototype operated at low voltage diode. By having low voltage diode but high capacitance of capacitors made the charging of capacitors became longer time consumption. The time consumption would be increased when the longer the stages of Cockcroft Walton Voltage Multiplier. Hence, small and suitable value of capacitors should be used to have and efficient time charging of capacitors and reaching at the output of the energy harvesting circuit. This proves that at 7 stages of multiplier, the smaller value of capacitance tends to have greater value of voltage output from harvested. From the analysis of the efficiency, the RF energy harvesting circuit only able to harvest the RF ambient energy at 63.3%.

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From generalize hypothesis, the greater the efficiency of the circuit, the greater the energy harvested. The other remaining 36.7% were the loss occurred within the circuit. Loss occurred when the wiring of the component and mismatch of impedance occurred. The prototype had many wiring since the Arduino was involved for the prototype.

IV. CONCLUSION

An optimum design of the RF energy harvesting circuit operating at frequency of 1.8 GHz for a minimum frequency to 2.6 GHz maximum is successfully designed, simulated, fabricated and measured. For the simulation result, the best parameter was having 220 pF of capacitance of capacitor with 7 stages of Cockcroft Walton's Voltage Multiplier resulting voltage output generating at 2.11 V at the raw input of harvested RF energy at the 20 dBm power level and boosted by DC-DC Step-up booster at 3.81 V with an efficiency of 63.3%. The DC-DC step-up booster only manage to boost the input voltage at minimum 0.9 V only resulting other experiments of number of stages and capacitance value of capacitor were not satisfied the requirement of the booster. The Arduino programmed RF Power Meter had worked at its fines level which bring average accuracy of 98.6% within ZX47-60+ Power Meter limitation ranging from 5 dBm to -60 dBm only.

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