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Design of a GSM 900 Energy Harvesting Model for a Remote-Control Device

Deepak Kumar Nayak, and Arjuna Muduli

***Abstract*—This paper deals with designing and simulation of an efficient RF-DC energy harvesting system for a remote control device. GSM down-link frequency of 935MHz to 960MHz and uplink frequency of 890MHz to 915MHz is taken as the RF source with centre frequency as 950MHz and 900MHz respectively. The simulation model has been created by using Advanced Design System (ADS) software. Performance of the circuit has been tested with matching and without matching circuits. The output voltage obtained was 0.372V DC and maximum efficiency up to 35.73% was achieved for the downlink GSM frequency by the lumped method for -10dB input source power. By considering more number of rectifier stages, output DC voltage can be increased and it can be utilized for replacing DC battery of the remote control device.**

***Keywords*—GSM 900; Lumped matching; Villard multiplier; RF-DC**

I. Introduction

PRESENTLY radio frequency (RF) energy harvesting technique is very popular among all the energy harvesting techniques [1-2]. The main advantages of RF energy are that it is available in variety of frequencies, propagate in all directions and is available at all times. The fundamental disadvantage of RF energy harvesting is that the efficiency of RF to DC conversion is very less due to availability of less RF power.

The main components in a RF energy harvesting system are antenna, impedance matching circuit and voltage multiplier circuit [3-4]. An Antenna is used to receive RF signal and impedance matching circuit is used for matching input impedance with the output impedance so that maximum power transforms to the load. The diode rectifier circuits called voltage multiplier devices convert AC to DC and when compared to the input voltage, it can deliver a higher output voltage [5-8].

Several rectifier topologies have been studied in the literature. In 2016, Assimonis et al. [9], employed a rectenna with 889 MHz working frequency and a maximum RF to DC conversion efficiency of 45.9% for input power of - 10 dBm. In 2017, Zeng et al. [10] demonstrated a rectifier operating at 1.8GHz with 65 % efficiency for 0-dBm input power. The design of an efficient rectifier circuit is given in [11] where the circuit has been built with a two-stage Dickson charge pump and ADS has been used to optimize various parameters. The efficiency of Dickson and Villard type voltage multipliers for 868 MHz was examined in [12] and the results showed that Dickson multiplier provides great efficiency and high output power can be obtained by increasing the number of stages.

For remote control systems, infrared (IR) technology is typically used with batteries. As a result, the cost of battery maintenance is required. Many academics are working on a solution of replacing the requirement for 9V, 3V, and 1.5V batteries that are significantly lower in size, capacity, and weight. Only a little amount of research and analysis has been done on the total removal of batteries. Many researchers are working on energy harvesting techniques to deal with the battery solution.

In this work attempt has made to replace the battery of remote control devices which is very important now a days in military sectors, by GSM 900 downlink frequency (935MHz to 960MHz) and uplink frequency (890MHz to 915Mhz).

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II. RF-DC Energy Harvesting System

Figure 1 shows the fundamental block diagram of RF-DC energy harvesting system. The receiving antenna is used to receive the available RF energy. Here GSM 900 downlink band (935MHz-960MHz) and uplink band (890MHz-915MHz) is used as the power source. The impedance matching networks which are the second subsystem operate as a filter.

The third subsystem is a voltage multiplier circuit which is a normal rectifier that converts AC to DC and when compared to the input voltage, it can deliver a higher output voltage.

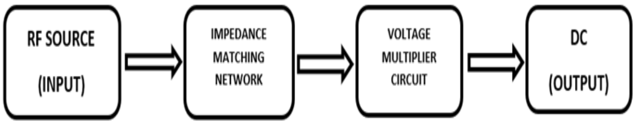

Fig. 1. Block diagram of RF-DC energy harvesting system

A. Voltage multiplier circuit

Because the power received from the ambient is low and has distortion, the AC signal generated from the receiving antenna is usually inconsistent. As a result, the signal is boosted using a voltage multiplier circuit (VMC). Depending on the end-user applications, a greater DC voltage could be attained by increasing the number of stages of VMC. However, because of the amount of diodes and capacitors involved, increasing the number of stages may reduce circuit efficiency. As a result, the number of steps used for VMC design is important. A single-stage VMC is used to simulate and analyses the developed radio frequency harvesting system in this work. There are different type of multipliers like Villard, Cockcroft Walton and Dickson etc. [13]. The Villard voltage multiplier circuit is used in this study to achieve RF to DC power conversion and maximum DC output for remote control applications.

B. Analysis for GSM downlink frequency

Figure 2 shows a single-stage Villard voltage multiplier circuit with GSM 900 downlink frequency input. In the voltage multiplier circuit, Schottky diode is used because it has a fast switching speed and a low cutoff voltage, making it useful for rectifying low-power and high-frequency signals. Table I shows the parameters of the diode and output filter capacitor. In Villard multiplier, the output capacitor's voltage is twice the RF source's peak voltage. Figure 3 shows the input impedance without matching circuit. Input power and output power for the source input of -10dB without matching circuit is shown in Figure 4 and Figure 5 respectably. Figure 6 shows the reflection coefficient (S_{11}) before matching.

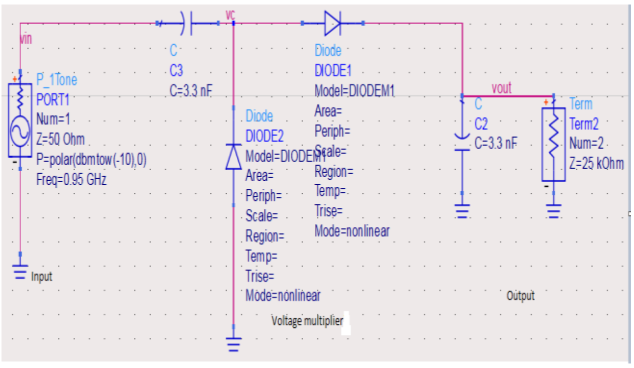

Fig. 2. A single stage Villard voltage multiplier circuit with GSM 900 downlink frequency input of -10dbm source

TABLE I
PARAMETERS OF DIODE

Parameter	Value
Rs	20Ω
Cj0	0.14pf
Bv	2V
Is	5*10-6
IBV	1*10-4
N	1.05
C	3.3nF

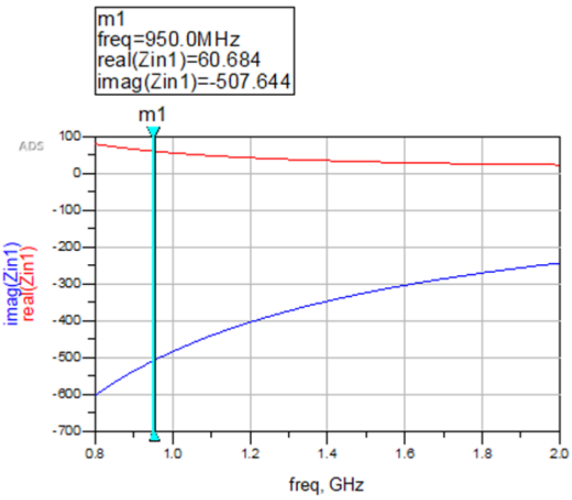

Fig. 3. Input impendence before matching with GSM 900 downlink frequency input of -10dbm source

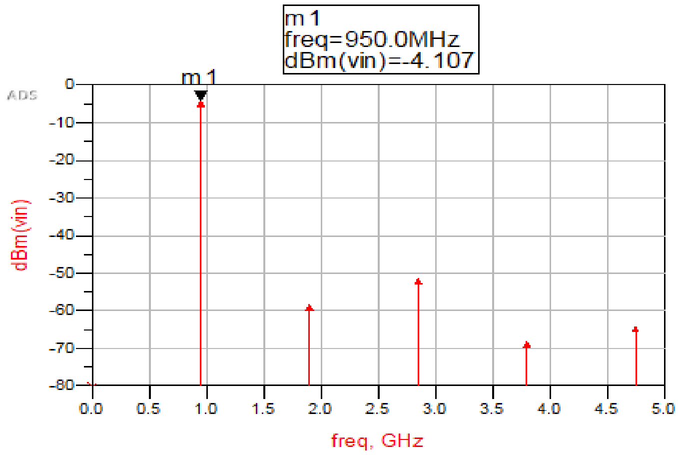

Fig. 4. input power without matching with GSM 900 downlink frequency input of -10dbm source

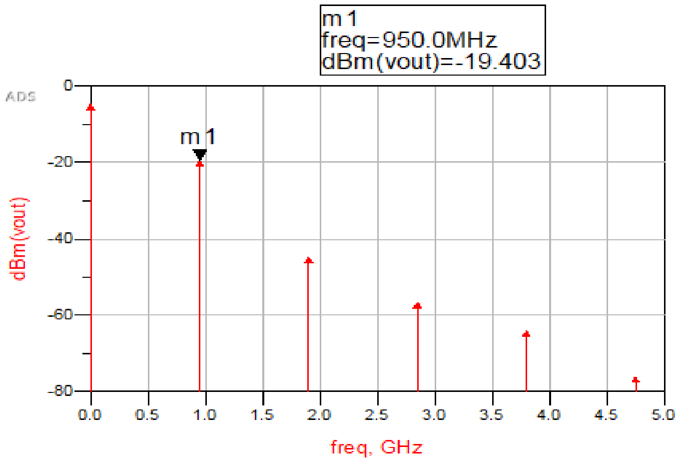

Fig. 5. Output power without matching with GSM 900 downlink frequency input of -10dbm source

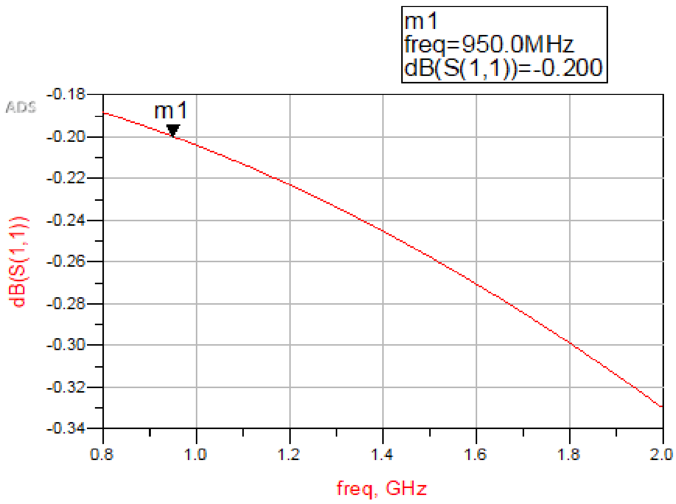

Fig. 6. reflection coefficient (S_{11}) before matching with GSM 900 downlink frequency input of -10dbm source

C. Analysis for GSM 900 uplink frequency

Figure 7 shows a single-stage Villard voltage multiplier circuit with GSM 900 uplink frequency input. Figure 8 shows the input impedance without matching circuit. Input power and output power for the source input of -10dB without matching circuit is shown in Figure 9 and Figure 10 respectably. Figure 11 shows the reflection coefficient (S_{11}) before matching.

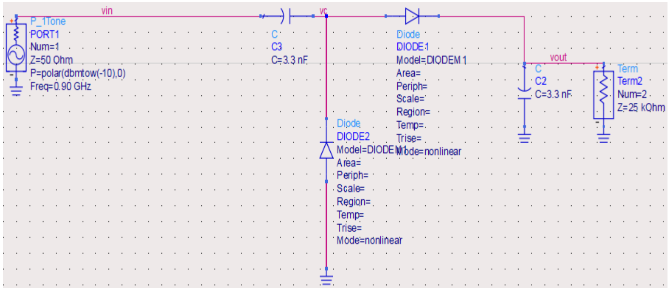

Fig. 7. A single stage Villard voltage multiplier circuit with GSM 900 uplink frequency input of -10dbm source

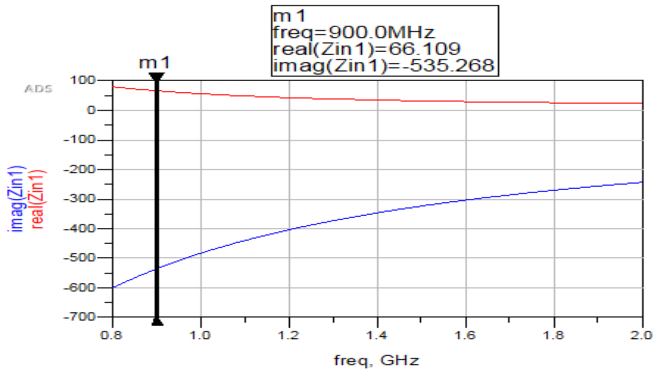

Fig. 8. Input imendance before matching with GSM 900 uplink frequency input of -10dbm source

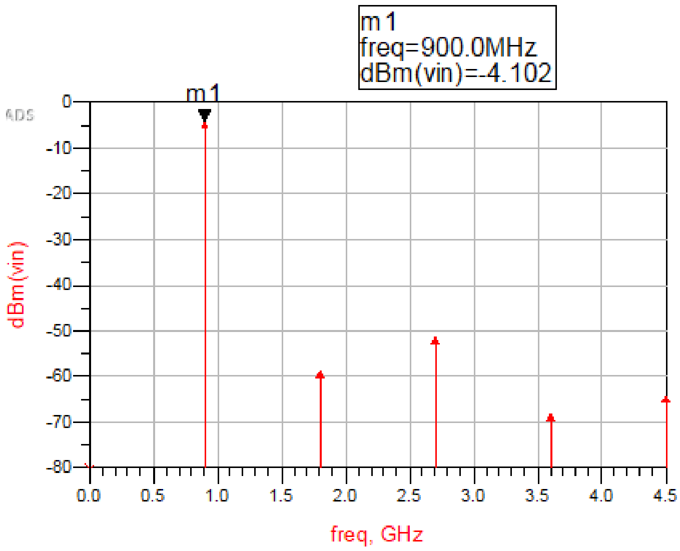

Fig. 9. input power without matching with GSM 900 uplink frequency input of -10dbm source

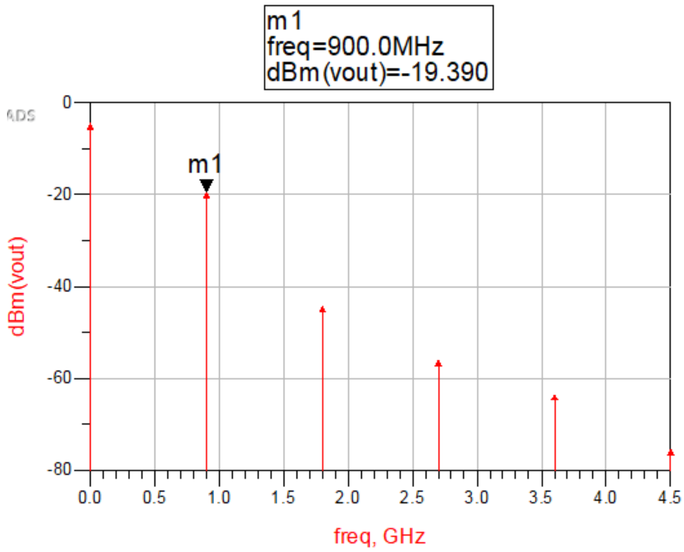

Fig. 10. Output power without matching with GSM 900 uplink frequency input of -10dbm source

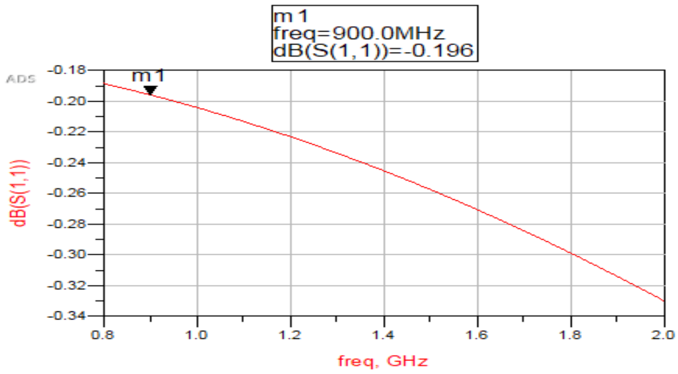

Fig. 11. reflection coefficient (S_{11}) before matching with GSM 900 uplink frequency input of -10dbm source

D. Designing the Impedance Matching Network

Impedance matching networks (IMNs) is used to increase output energy harvested with less reflection coefficient. There are two types of (IMNs): lumped component based and distributed component based. Although IMNs based on lumped components are often small, they are not recommended in circuits that operate at higher frequencies (above 1 GHz) because the inherent loss increases at high frequency.

The input voltage is properly matched and passively amplified by the L-section matching circuit [14-15]. The reactance of matching section inductor and capacitor L and C can be calculated by

$$\frac{1}{X_c} = \frac{1}{Z_0}\sqrt{\frac{(Z_0 - R_L)}{R_L}} \qquad (1)$$

$$X_L = \sqrt{R_L(Z_0 - R_L)} - X_L \qquad (2)$$

Where Z_0= Input impedance of the source which has been assumed as 50Ω here.

R_L= real part of load impedance which has been assumed as 25KΩ here.
X_L=imaginary part of load impedance which has been assumed as 0Ω here.

III. SIMULATION RESULTS OF GSM 900 DOWNLINK FREQUENCY AS RF SOURCE

Smith chart utility for impedance matching using capacitor and inductor is shown in Figure 12 and Smith chart connection in ADS for impedance matching is shown in Figure 13. Figure 14 shows designed high pass impedance matching circuit and Figure 15 shows the energy harvesting circuit design after including the designed matching circuit. After matching the value of vin (input power), vout(output power), reflection coefficient $S_{11}$for -10dbm source is shown in Figure 16 and input Impedance after matching is shown in Figure 17.We are observing from Figure 3 and Figure 17 that there is a very good improvement is matching which is nearly equal to source impendence 50Ω.

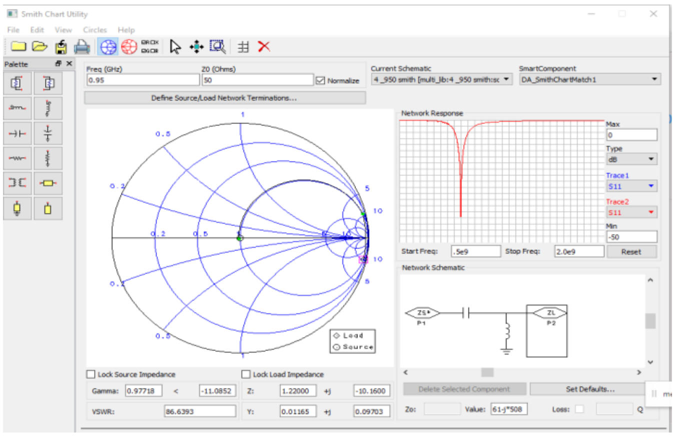

Fig. 12. Smith chart utility for impedance matching using capacitor and inductor with GSM 900 downlink frequency input of -10dbm source

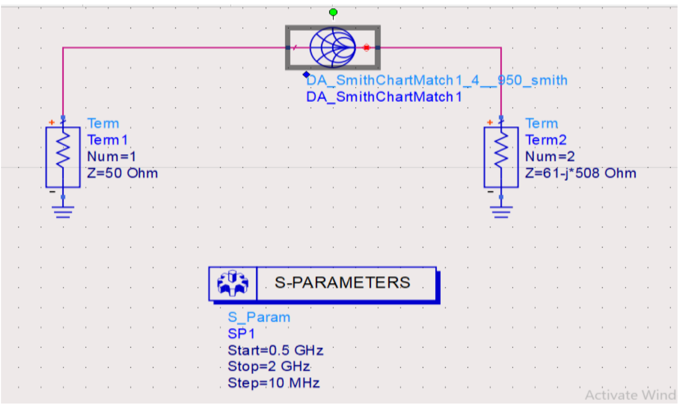

Fig. 13. Smith chart connection in ADS for impedance matching with GSM 900 downlink frequency input of -10dbm source

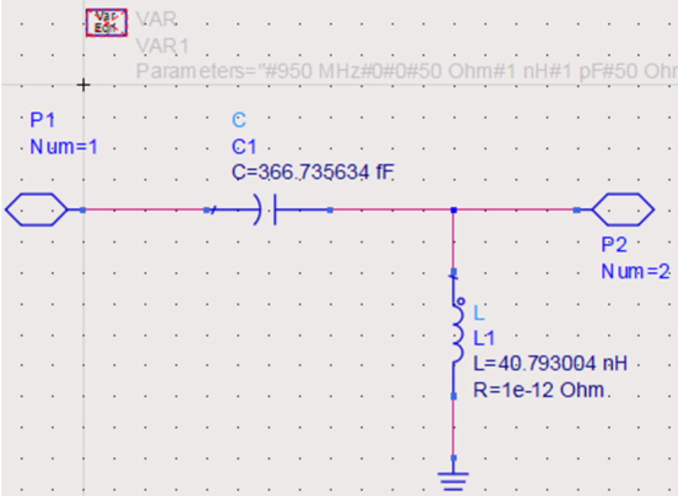

Fig. 14. Designed High Pass Impedance Matching Circuit with GSM 900 downlink frequency input of -10dbm source

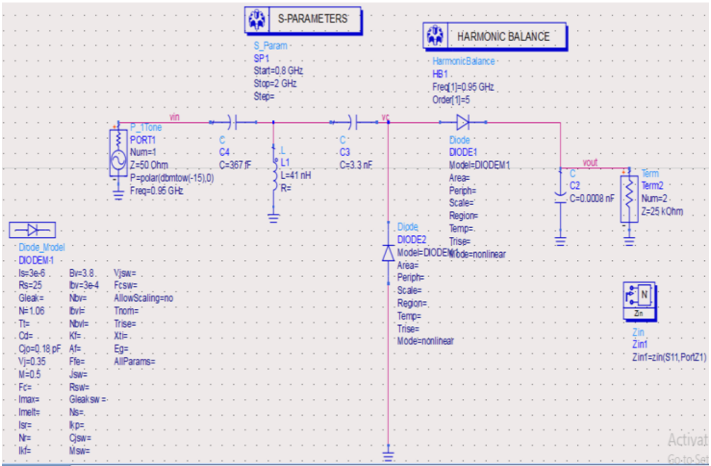

Fig. 15. Energy harvesting circuit design after including the designed matching circuit with GSM 900 downlink frequency input of -10dbm source

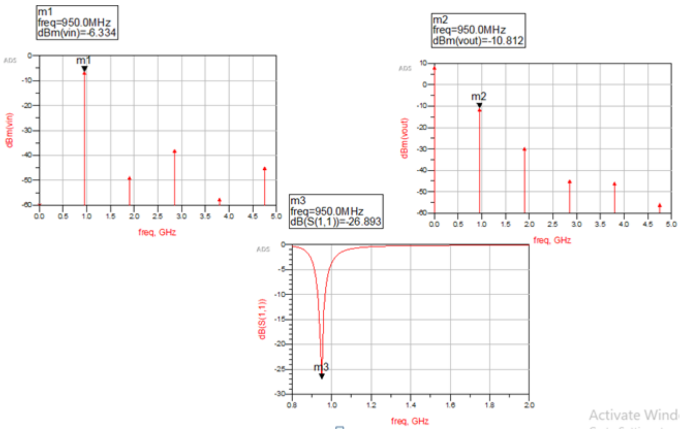

Fig. 16. After matching vin (input power), vout(output power), reflection coefficient S11 with GSM 900 downlink frequency input of -10dbm source

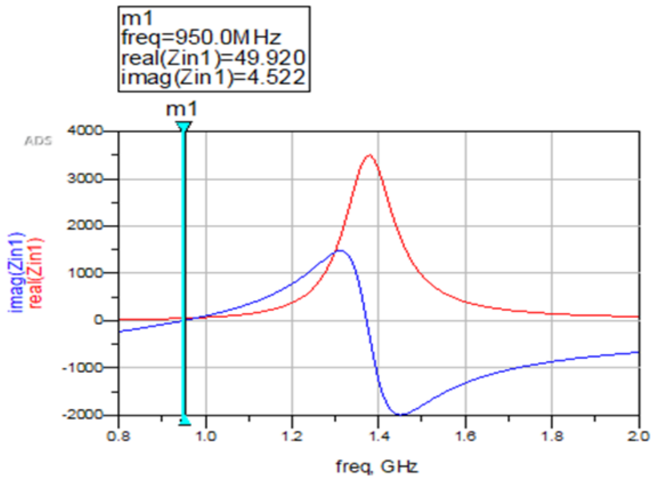

Fig. 17. Input Impedance after matching with GSM 900 downlink frequency input of -10dbm source

IV. Simulation Results of GSM 900 uplink frequency as RF source

Smith chart utility for impedance matching using capacitor and inductor is shown in Figure 18 and Smith chart connection in ADS for impedance matching is shown in Figure 19. Figure 20 shows designed high pass impedance matching circuit and Figure 21 shows the energy harvesting circuit design after including the designed matching circuit. After matching the value of vin (input power), vout(output power), reflection coefficient $S_{11}$for -10dbm source is shown in Figure 22 and input Impedance after matching is shown in Figure 23.We are observing from Figure 8 and Figure 23 that there is a very good improvement is matching which is nearly equal to source impendence 50Ω.

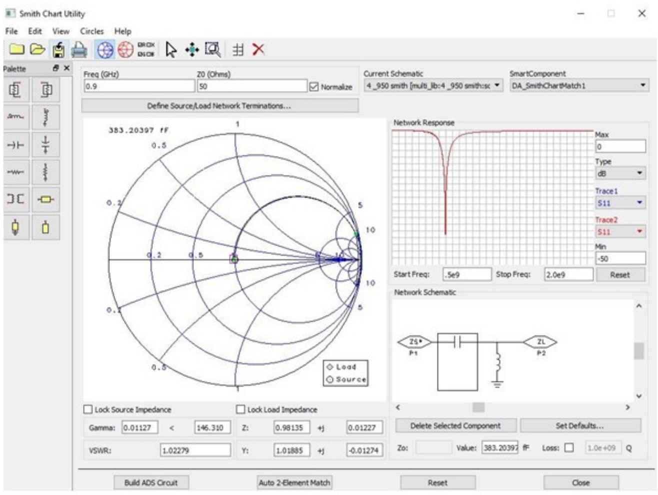

Fig. 18. Smith chart utility for impedance matching using capacitor and inductor with GSM 900 uplink frequency input of -10dbm source

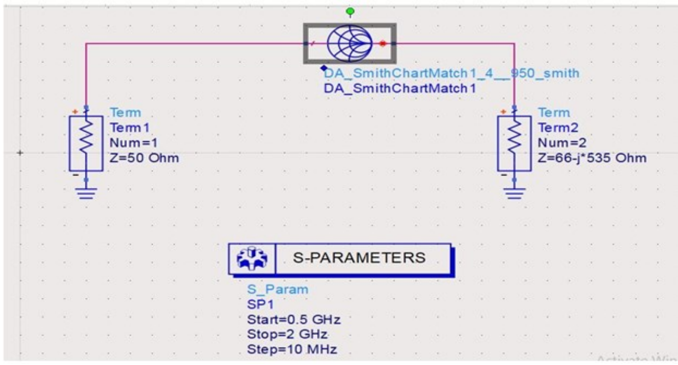

Fig. 19. Smith chart connection in ADS for impedance matching with GSM 900 uplink frequency input of -10dbm source

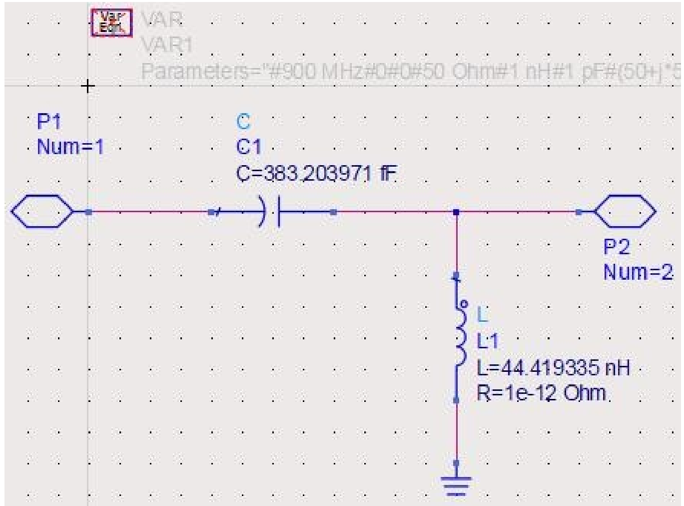

Fig. 20. Designed High Pass Impedance Matching Circuit with GSM 900 uplink frequency input of -10dbm source

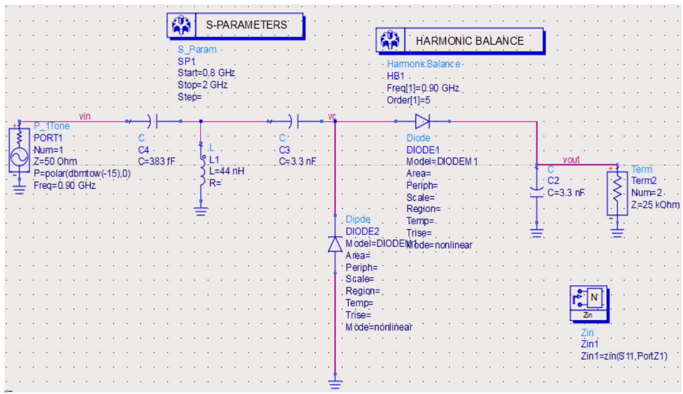

Fig. 21. Energy harvesting circuit design after including the designed matching circuit with GSM 900 uplink frequency input of -10dbm source

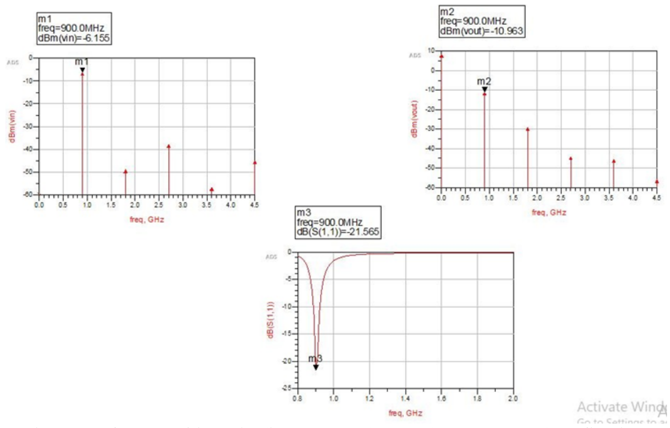

Fig. 22. After matching vin (input power), vout(output power), reflection coefficient S11 with GSM 900 uplink frequency input of -10dbm source

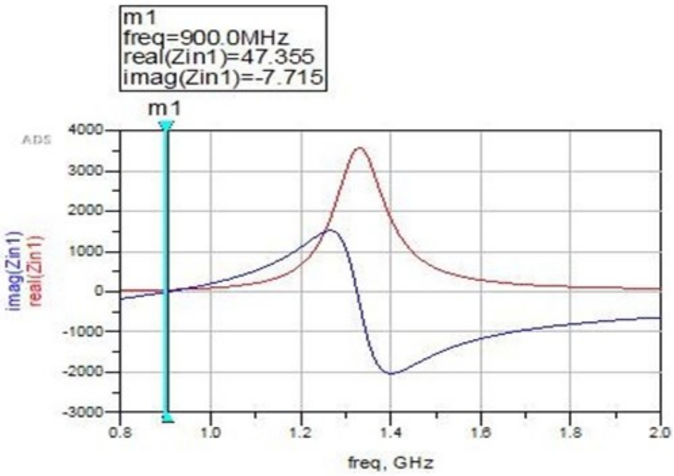

Fig. 23. Input Impedance after matching with GSM 900 uplink frequency input of -10dbm source

V. Comparison of GSM 900 Uplink and Downlink Frequency as RF Source

Table II shows the comparison of return loss before and after the matching with GSM 900 downlink and uplink frequency input of -10dbm source. Table III shows the performance of the harvesting circuit without matching with GSM 900 downlink and uplink frequency input of -10dbm source. Table IV shows the performance of the harvesting circuit with matching with GSM 900 downlink and uplink frequency input of -10dbm source. We are observing from Table II that there is a very good improvement in return loss for both the cases and the performance of downlink is better due to less return loss. From Table III and Table IV, we are observing that after matching efficiency and output voltage has increased for both the cases. From Table IV we are observing that the performance of the downlink is better due to high output voltage and efficiency than the uplink.

TABLE II
RETURN LOSS BEFORE AND AFTER MATCHING

Frequency(MHz) Column 1	S11 Without matching(dB)	S11With matching(dB)
950(down link)	-0.2	-26.893
900(up link)	-0.196	-21.565

TABLE III
PERFORMANCE OF THE HARVESTING CIRCUIT WITHOUT MATCHING FOR -10DBM SOURCE

GSM 900	Input power (dBm)	Output power (dBm)	Input power (mw)	Output power (mw)	Efficiency (%)	Output Voltage (V)
GSM downlink	-4.107	-19.403	0.388	0.0114	2.9	0.024
GSM uplink	-4.102	-19.390	0.388	0.0115	2.96	0.021

TABLE IV
PERFORMANCE OF THE HARVESTING CIRCUIT WITH MATCHING FOR -10DBM SOURCE

GSM 900	Input power (dBm)	Output power (dBm)	Input power (mw)	Output power (mw)	Efficiency (%)	Output Voltage (V)
GSM downlink	-6.334	-10.812	0.232	0.0829	35.73	0.372
GSM uplink	-6.155	-10.963	0.2423	0.0801	33.06	0.313

Conclusion

This work has done investigation for RF energy harvesting by using GSM 900 downlink frequency of India 935MHz to 960 MHz and uplink frequency of India 890MHz to 915Mhz. By using ADS software, a model was created for centre frequency of 950 MHz and 900 MHz for downlink and uplink respectively. A single Villard voltage multiplier was taken as a rectifier. Although according to literatures, for high frequency, distributed matching method is better than lumped method but by assuming that GSM 900 frequency ranges are not very high, only lumped method of matching has been verified here. We have obtained moderate efficiency of 35.73% for downlink with 0.372 DC output voltage and efficiency of 33.06% for uplink with 0.313 DC output voltage. This work has taken input source power only -10 dB considering that RF power amplitude is very small. We are obtaining the performance of downlink is better than uplink and in future both can be combined for higher efficiency and the performance can be tested by distributed method.

For remote control car applications although only 0.372V is not sufficient but we can keep more number of stages of multipliers and required voltage can be generated. Here only Villard voltage multiplier has been taken in future we will consider other multiplier like Cockcroft-Walton multiplier and combine both uplink and downlink for better output.

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