Combine RF Ambient for Power Harvesting using Power Detector for Sensor Application over L, S, C Bands

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Abstract - *This paper presents a model of a circuit receiver for self-power harvesting to connect wirelessly to an ambient base station. The circuit receiver combines dual alternative current into matching network for rectifier voltage doubler to produce a direct current. This work designs, simulates, fabricates, and measures for output power. The verification simulation and measurement were confirmed in the far-field distance radiation. In the measurement, input power from transmitter side was 0 dBm. The multiband was covered (L, S, and C bands) in 1650 - 3650, 6600 - 7250 MHz's. The power receiver measurements listed in table 2 and 3 could be useful for self-powering sensor applications through 3, 4, and 5G.*

Key Words: Base transceiver station, radio frequency for energy harvesting, power scavenging, wireless communications, RF–DC conversion, voltage doubler.

1. INTRODUCTION

The base transceiver stations (BTSs) of radio frequency (RF) are everywhere, transmitting information due to ubiquitous RF, and they carry energy [1]. The process of radio transmitters and receivers signals between BTS and circuit receiver systems are able to operate wireless apparatus. BTS's role is widely broadcasting through the environment to sense electronic devices such as cellular phones. These developments are progressing and permanent especially through advent of the Internet of things (IoTs). As long as the signals are continuous over the ambient, it should harness it in multi aspects such as transceiver information and self-powering components. It is useful for green sustainability, and drives wireless systems by scavenging energy. According to [2] the different RF wireless applications require power harvesting via integrated system components for recycling harvesting, from ambient power that provides direct wireless communications. Based on [3], it presented the possibility of harvesting the amount of power spectrum density from ambient RF sources. It calculated that the power received, which achieved from 800 MHz of BTS band mobile telephone was 25 dBm. Their study declared that transmission power of digital TV is 3 kW, and of mobile telephone BS is 30 W. The effective radiation power of digital TV is 25 kW and of mobile telephone BS is 500 W.

The receiver side is converted from an alternative current (AC) that collected from BS ambient to a direct current (DC). This method is called power scavenging, which is becoming indispensable to operate wireless communication systems. Accordingly, most researchers tend to investigate the RF sources to see if they could be used as DC source. They study the use of available BTS and the design of a circuit receiver for self-powering.

The research in [4] presented an integrated rectifier-receiver (IRR) for lower power consumption, which employs the AC collecting signals. Their system for signal modulation using double signals, that has the potential to transfer a constant DC power to the sensor. Another experiment performed in [5] integrated energy rectifier at four bands to harvest the ambient electromagnetic energy in low and large-range energy density setting. It measured high conversion efficiency at 47.8%, 33.5%, 49.7%, and 36.2% of four two frequencies 0.89, 1.27, 2.02, and 2.38 GHz, respectively. The input power was −10 dBm. The rectifier has also a huge input strength. According to [6], it presented the circuit with Wilkinson power combiner (WPC) that harnesses two different RF inputs. It allows broadband operation the multi section Chebyshev impedance matching technique was used in the sections of the WPC circuit. The size of the circuit is large, which is dissipated energy, and not favorable for devices.

According to numerous researchers [1-6], self- powering green achievement is one of the most essential problems for low-power wireless communication systems. In addition, the case of power carries out and combined is extremely paramount parameters that characterizes the process of basic circuit and system possession. Moreover, determining the energy source is an issue usually required to power the electronic devices due to circuit size and cost of power harvesting approach.

This work proposes a receiver circuit exploiting energy supplied by the existing BTS for self-power energy harvesting. Figure 1 illustrates diagram of an ambient transmitter and receiver circuit. The receiver circuit is designed with T-Junction power combiner coupler (TJ-PCC) for employing two antennas for RF signal inputs. Matching network is a crucial component to increase the efficiency. The rectifier stage is vital due to converting AC to DC into the load stage to power sensors devices through industrial, scientific, and medical (ISM) applications of RF.

2. EH SYSTEM ARCHITECTURE

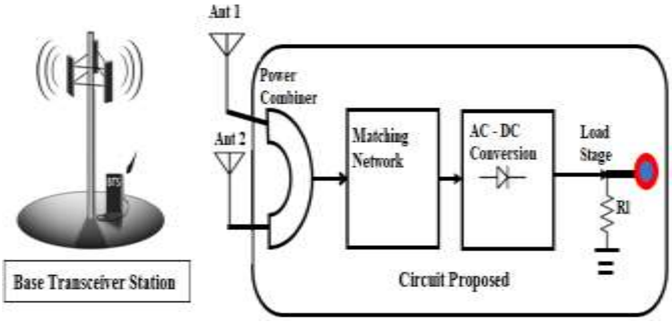

Figure 1. Diagram of an Ambient RF-EH Model.

Nowadays, BTS is pervasive in urban areas, and versatile, which communicates wireless systems, and the solution technology for self-powering of electronic devices. The BTS equivalent isotropic radiated power EIRP of GSM BTS about 50-55 dBm operators of considered territory and some countries in urban areas [7]. Figure 1 describes the primary architecture of the RF energy harvesting system with ambient BTS signals as an available RF source.

RO4350B substrate from the Rogers Company is selected for the circuit implementation. It is a broad material, available, and facilitates low-cost fabrication. The substrate parameters are determined from the datasheet: dielectric constant (ϵ_r) = 3.48, thickness (*h*) = 1.52 mm, loss tangent (TanD) = 0.004 mm. Also, the thickness of the copper line (T) = 0.0175 mm. Advanced Design System (ADS) Software is used for design and system simulations. The Harmonic Balance is well-suited for simulating analog RF and microwave circuits for the proposed prototype.

Energy harvesting system contains the independent component as a source for the energy emission, and a circuit integrated three components, which paramount for self-powering devices. In this work BTS is the source of energy production versus the circuit dependent on BTS. The circuit consists of three parts: receiving component which is collecting energy, the matching network is maximizing output power, and the rectifier circuit for converting AC to DC and doubling the output power in the load stage.

TJ-PCC takes place of receiving component. It combines a dual input RF signals passes into the third port for output signal. L-type matching network component mediates between TJ-PCC and the RF rectifier element was connected to the output of the L-type matching network for maximizing output power. Voltage doubler drives the rectifier component to convert AC to DC, as well as the load stage to produce DC for powering sensor applications.

This circuit can be connected with two antennas that enable to receive signals from the BTS. Thus, it is an endeavor to gather various RF powers to a single rectifier circuit. The advantage of this design is it can transform multiple RF input powers into DC and voltage with the benefit of a single rectifier circuit by using TJ-PCC. Meanwhile, it offers minimum components, less cost, and easiest configuration.

3. CIRCUIT DESIGN AND SIMULATION

Figure 2 illustrates the schematic design of the circuit proposed, the physical parameters are calculated to form the TJ-PCC using ADS.

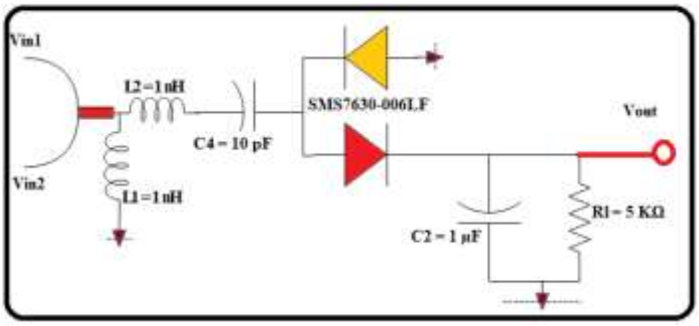

Figure 2. Schematic of circuit power harvesting.

The electrical parameters are the characteristic impedance Z_0 and the electrical length. Microstrip lines with Z_0 = 50 Ω and $Z_0\sqrt{2}$ = 70.7 Ω are used. Two ports for input are designed by microstrip line width (W) = 2 mm, length (L) = 3 mm, and the third one is output W = L = 3 mm. The two curves of microstrip transmission lines to connect the ports, each curve is $Z_0\sqrt{2}$= 70.7 Ω, length of the transmission line (TL) = λ/4, the W = 1.895130 mm, angle = 90°which they connected each side of the curve by TL in the same width and L = 2 mm.

Figure 3 displays the simulation results of TJ-PCC. As seen wideband results were obtained; from 2 GHz to 8.6 GHz S11 is under -10 dB, and a value of -22.344 is obtained at 6 GHz. Also, S12, S13 are reached -3.038 dB. Proper results in high isolation, matching, and lossless are obtained.

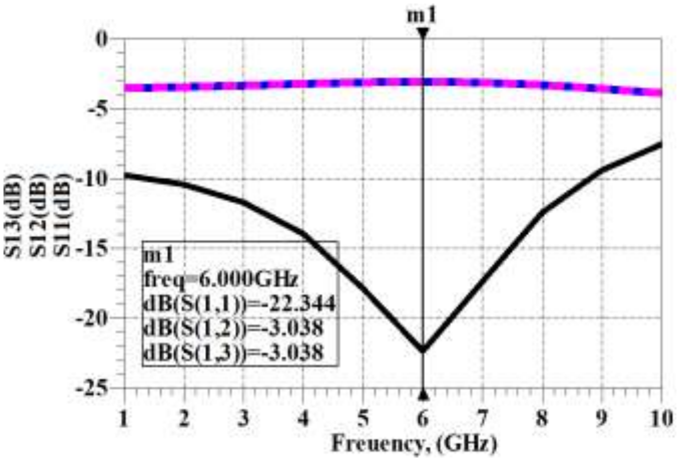

Figure 3. Simulation of TJ-PCC S-parameters.

L-type matching network circuit is used to match the impedance between TJ-PCC and voltage doubler rectifier in order to maximize output power. The elements of the L-type matching network contain two inductors (L1 = L2 = 1 nH), and the capacitor C4 = 10 pF form an L-shape as seen in Figure 2. In addition, the voltage doubler rectifier involves SMS7630_006LF Schottky diode connect to DC-filter capacitor = 1 μF, and the load resistance termination Rl = 5 KΩ. SMS7630_006LF is preferable to its tiny package with its SPICE model parameters are shown in Figure 4.

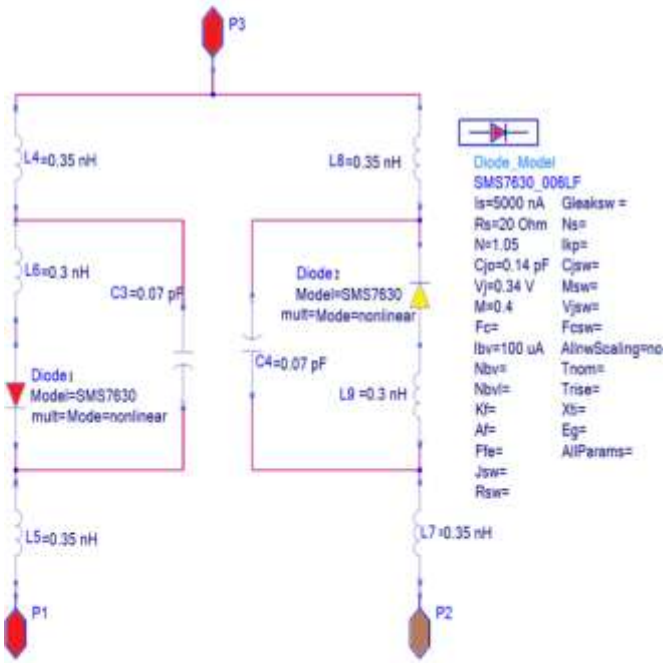

Figure 4. Diode SMS7630_006LF model.

The output power is obtained using Equation (1) in ADS simulation, and results are plotted in Figure 5.

Output power (dBm) =

$$10 \log_{10} (0.5 \text{ real } (Vout^* \text{ I load})) + 30 \quad (1)$$

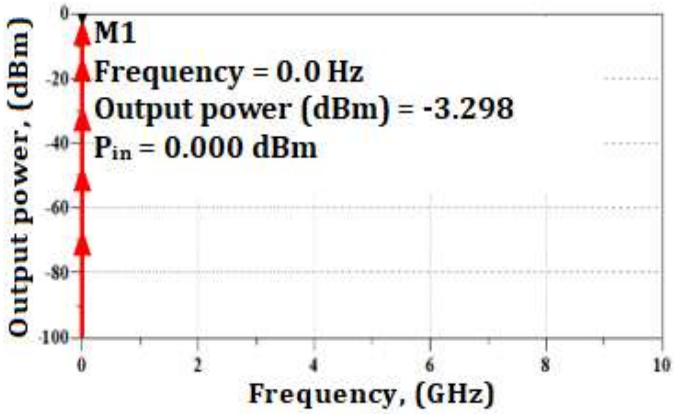

Figure 5. Output power (dBm) versus frequency (GHz).

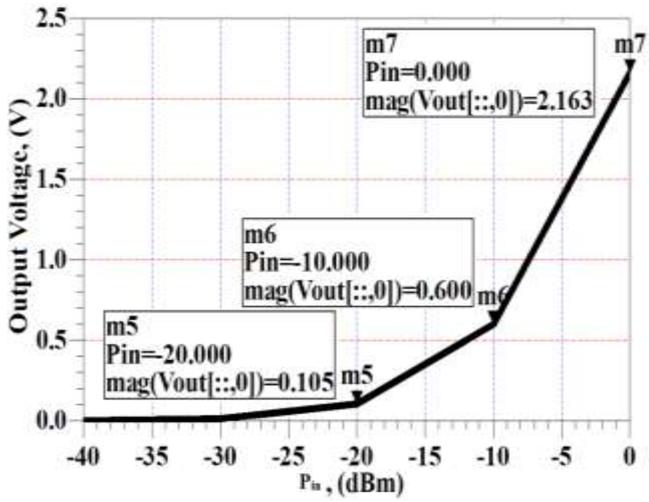

Figure 6. Output voltage (V) versus, input power, Pin (dBm).

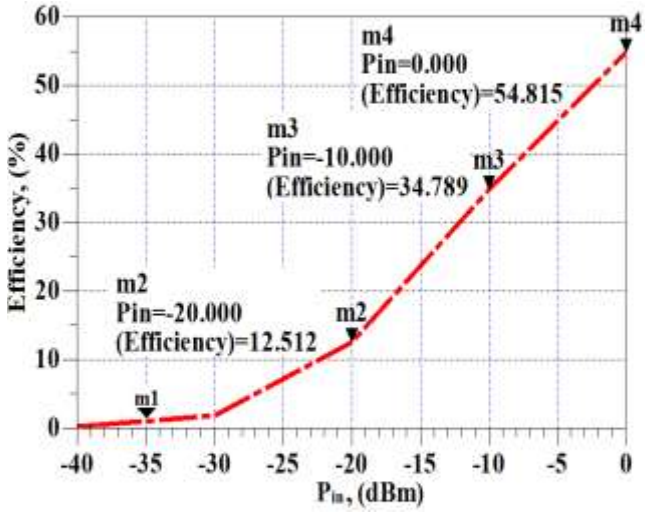

Figure 7. Simulation of efficiency (%) versus input power Pin (dBm).

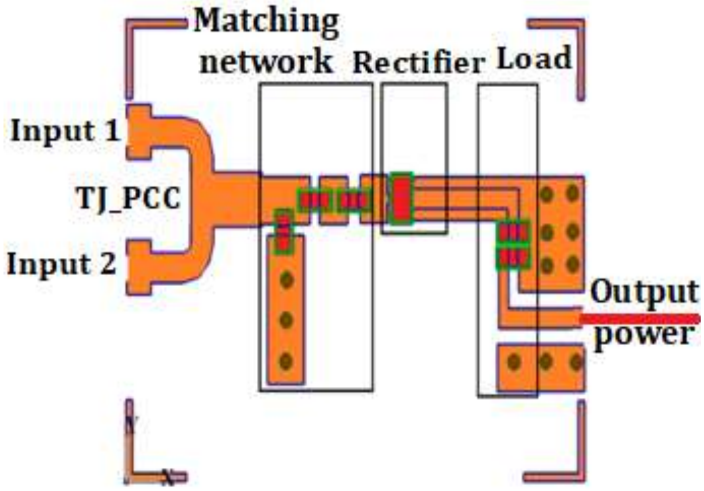

Figure 8. Layout of the proposed circuit.

4. FABRICATION AND MEASUREMENTS

TJ-PCC is integrated with voltage doubler via L-type matching network, as shown in Figure 9.

The measurement setup was conducted on test bench: the transmitter side, which contains a microwave signal generator model DS_SG6000LDQ and a switching 12 V DC power supply (DM-330FX). This signal generator is connected to the transmitter antenna. The RF power at the transmitter side is 0 dBm. In addition, the frequency is swept from 1 GHz to 8 GHz. On the receiver side is the fabricated prototype connected to Agilent 34401A, 6 1/2 Digit Multimeter for reading the DC output power.

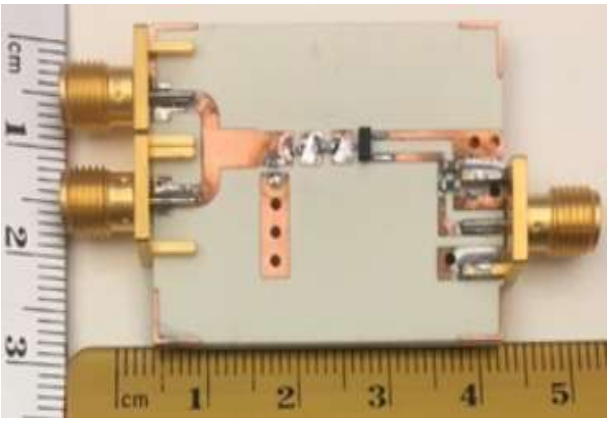

Figure 9. Prototype circuit.

The distance between the two sides is found according to calculations using the near-field and far-field in equations (2), and (3).

Figure 10 shows the antenna used in the reference transmitter. The antenna characteristics are: bandwidth 1.35-9.5 GHz, and the gain around 6 dB.

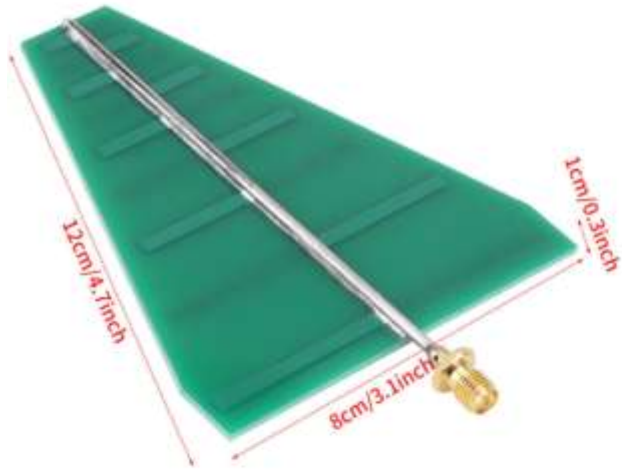

Figure 10. The dimension of transmitter antenna (D = 0.12 m).

$$\text{Near field (d)} \leqq \frac{2D^2}{\lambda} \quad (2)$$

$$\text{Far field (d)} \geqq \frac{2D^2}{\lambda} \quad (3)$$

Table 1. Calculate wavelength (λ) of three frequencies (f) with Near-Field, and Far-Field (d).

f (GHz)	2	5	7.5
λ (m)	0.15	0.06	0.04
Near-Field d (m) ≦	0.19	0.48	0.72
Far-Field d (m) ≧	0.19	0.48	0.72

After determine near-field and far-field, it can calculate power receiver using Friis equation (4).

$$P_{rx} = P_{tx} + G_{tx} + G_{rx} + 20 \log_{10} \left(\frac{\lambda}{4\pi d}\right) \quad (4)$$

Three results based on substitute (λ) = 0.15, 0.06, 0.04 m respectively, and d = 1 m.

= 0 + 6 + 12 + (−38.46) = -20.46 dBm

= 0 + 6 + 12 + (−46.45) = -28.42 dBm

= 0 + 6 + 12 + (−49.44) = -31.93 dBm

Table 2. Measurements of output power.

Transmitter input power (Pin = 0 dBm), and the distance (d = 1 m)			
L Band		C Band	
(MHz)	Output power (dBm)	(MHz)	Output power (dBm)
1650	-21.522	6600	-34.141
1700	-16.569	6650	-32.412
1750	-16.312	6700	-29.824
1800	-15.147	6750	-22.441
1850	-21.565	6800	-34.505
1900	-19.334	6850	-27.977
1950	-20.941	6900	-23.506
1650	-21.522	6950	-25.564
1700	-16.569	7000	-32.814
1750	-16.312	7050	-31.916
1800	-15.147	7100	-33.327
1850	-21.565	7150	-36.991
1900	-19.334	7200	-33.544
1950	-20.941	7250	-33.413
2000	-20.414	-	-

Table 3. Result measurements of output power.

Pin = 0 dBm, and the distance (d = 1 m) over S Band.			
(GHz)	Output power (dBm)	(GHz)	Output power (dBm)
2.050	-25.500	2.900	-28.788
2.100	-27.816	2.950	-25.433
2.150	-24.403	3.000	-23.230
2.200	-20.965	3.050	-24.488
2.250	-19.214	3.100	-27.651
2.300	-24.141	3.150	-22.649
2.350	-25.355	3.200	-22.650
2.400	-33.625	3.250	-20.611
2.450	-27.889	3.300	-13.914
2.500	-25.981	3.350	-14.587
2.550	-30.056	3.400	-20.821
2.600	-30.559	3.450	-29.916
2.650	-34.697	3.500	-31.099
2.700	-34.887	3.550	-37.77
2.750	-30.636	3.600	-36.281
2.800	-27.300	3.650	-37.852
2.850	-27.981	-	-

EIRP of GSM BTS transmits at the rate of about 50-55 dBm/channel and more [7], which can be applied for this circuit receiver to increase the distance, and the following results related to (λ) are 0.15 m, 0.06 m, and 0.04 m. In this case, it will obtain the distance d = 250 m from the BTS.

$$Prx = Ptx + Gtx + Grx + 20 \log_{10} \left(\frac{\lambda}{4\pi d}\right)$$

$$= 47 + 15 + 12 + (-86.41) = -12.41 \text{ dBm}$$

$$= 47 + 15 + 12 + (-94.37) = -20.37 \text{ dBm.}$$

$$= 47 + 15 + 12 + (-97.89) = -23.89 \text{ dBm.} \quad (5)$$

From Friis equations in two distances 1, and 250 m, Table 2, and Table 3, which are in agreement with obtained output power. These results can be applied in ISM electronic devices.

5. CONCLUSION AND FUTURE WORK

This work utilizes TJ-PCC for a dual input RF with voltage doubler for twice DC via L-type matching network. These components are integrated in a simple and small size circuit, as well as performed the output power is maximized, and increased at the load stage. The feasibility from this work is able to obtain EH in three bands (L, S, and C), which are enhanced by the outcome powering devices in multi-bands. The prototype is highest achievable efficiency in the operational incident power range of -40 dBm to 0 dBm, with a 5 kΩ load, and the sensitivity is initiated in -35 dBm. The results measured give confidence to serve sensors, and should be applicable over 3, 4, and 5G of wireless communication systems.

The idea presented can be applied in real life. It also could be improved for use in a wider range of applications. Future work will improve a dual RF with multi power detector to increase power scavenging.

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