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Dual-band Monopole Antenna and Conditioning Circuit for Wireless Energy Harvesting

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Abstract

Energy harvesting from the environment for powering sensor nodes have been increasingly in popularity as the rapid growth of wireless sensor networks in internet of things. Compared to other energy extraction, wireless energy has several advantages such as the limitless of time and weather in application environments. For cellular communication network band, a new type dual-band planar monopole antenna is designed and fabricated at 900MHz and 1.8GHz, its simulated results show that it has -23.8dB and -20.4dB return loss and 100MHz and 260MHz -10dB bandwidth at each band respectively. A conditioning circuit designed is constructed and used in a testing system of energy harvesting along with the antenna. From the measured data in a lab environment, the extracting energy 0.5m away from the source at 900MHz achieved more than 10V DC with empty-load output voltage, and 7.7V with a 33kΩ load; its energy harvesting efficiency reaches 40.5%.
Keywords: antenna; energy harvesting; rectifying Circuits; wireless networks; internet of things

1. Introduction

With a large number of sensor devices gradually applied to various fields, studies for power supply of sensor nodes have drawn more and more attention in the coming era of internet of things(IoT). Since the sensor devices must be used with high stability for a long time more than years, in addition to the inconvenient of system maintenance and conventional battery replacement, it is undesirable to interrupt the system service. If the powered device built into the passive sensor applications, it is not need to replace the battery of the sensor. More and more researches are working on passive-powered device to obtain energy from radio waves, solar and other forms of energy in the environment. Among these energy sources, the ambient wireless signal energy is a very attractive new comer. Many wireless signal sources, including television, radio, mobile phone base stations and the application system itself continually radiate radio wave into the environment continuously, make the wireless signal a stable source of energy. Besides the wide applications to the sensors in IoT such as in the field of radio frequency identification technology(RFID), in which passive RFID tags replace the traditional setting of the bar code data collection as a new data collecting form in more long distances and mobile sceneries[1], these power devices are often applied among the telemetry system to collect signal in remote areas and sent back to the central processing unit[2,3].

The key problems in wireless energy harvesting are caused by the weakness of signals from a certain source, it is lucky that the sources are complex with great numbers in different bands, the antenna[4~6] and conditioning circuits[7,8] suitable for wireless environments must be achieved which will be multiband to extract as more energy of the radio environment as possible. These two problems are challenges in itself atmosphere of antenna and circuitry. In this work, a G-shape dual-band monopole antenna and its conditioning circuit is designed and fabricated, their characteristics and harvesting capabilities are tested.

2. The Dual-band Monopole Antenna

2.1 Objective Antenna

Because of the enormous number of base station and subscribers in mobile communication, the operating bands at 900MHz and 1.8GHz are widely used in service, and the energy of the signals exist with high reliability and stability. This can meet the energy requirements to the sensors in the wireless network of low power consumption, a dual-band antenna should be made to collect the energy in the signal. According to the design theory and method of antenna, the size of a G-shape monopole antenna[4~6] are selected, and with the aid of microwave field simulator, the determined structure of the antenna is optimized for expected pattern and impedance.

Antenna designed is to work at 900MHz and 1.8GHz bands, which are the GSM cellular communication and 3G network bands. If electromagnetic waves propagate in free space, then the corresponding wavelengths are 33.3cm and 16.7cm respectively. If in the substrate filled with dielectric constant of 4.4, the wavelengths are 15.89cm and 7.95cm respectively. For the working frequency of 900MHz, $\lambda/4$ wavelengths are 39.7mm and 83.2mm in the substrate and free space respectively, for the working frequency of 1.8GHz, are 19.8mm and 41.8mm.

The geometry of the dual-band monopole antenna consists of three parts: a ground layer, a substrate layer and the radiating antenna. Three strip lines connected to form a planar monopole antenna structure, the antenna is fed by a microstrip connected to feed coaxial line. The substrate

material of the antenna is FR4, its relative dielectric constant is 4.4 and a thickness of 1.6mm. The material of antenna and ground plane is copper, whose thickness is 0.035mm and antenna strip width is 4mm. The structure of antenna is shown as figure 1.

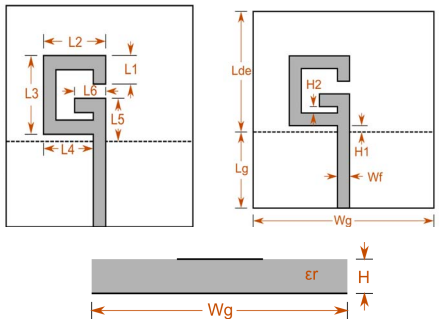

Figure 2. Structure of monopole antenna.

2.2 Results of Design and Measurements

The antenna is designed and simulated with HFSS. The optimized sizes are listed in table I when the simulated characteristics of the antenna shown in figure 2 are output. The simulated results show that the expected dual-band S_{11} and impedance of the antenna meet the design requirements, because the S_{11} at 900MHz and 1.8GHz have minima of -23.8dB and -20.4dB with 100MHz and 260MHz bandwidth respectively, and the imaginary of impedances is nearly zero at these frequencies. The antenna fabricated is measured with PNA-X 5247A, it shows good agreement of the measured with the simulated data, especially at 900MHz, as drawn in figure 3.

TABLE I. SIZES AND SUBSTRATE PARAMETER OF THE DESIGNED ANTENNA

Structure Sizes and Substrate Parameter		**Sizes of the Stripes**	
Wg	72.5mm	L1	11.78mm
H	1.6mm	L2	24.17mm
Lg	60mm	L3	29.48mm
Lde	64.95mm	L4	20.19mm
H1	3.4mm	L5	21.95mm
H2	7.217mm	L6	14.43mm
er	4.4	wf	4mm

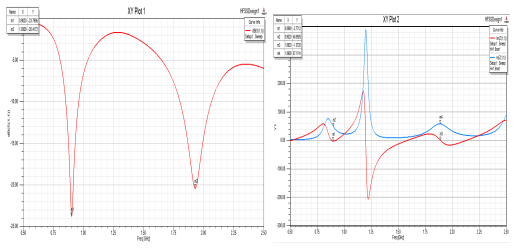

Figure 2. The simulated return losses and impedances of the dual-band antenna.

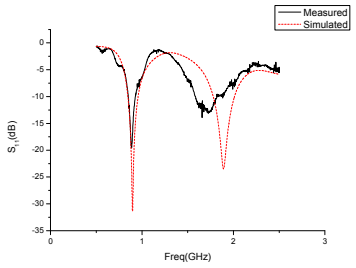

Figure 3. Comparison of measured and simulation S_{11}.

3. The Conditioning Circuit

It is a circuit consisted of a rectifier followed by a voltage multiplier in this energy harvesting investigation.

3.1 Rectifier Circuit

A rectifier is a device or a rectifying circuit that converts an alternating current(AC) to a direct current(DC). The rectifying circuit was designed using Agilent's ADS software. The designed circuit consists of a microstrip line, a Schottky diode, an inductor and a capacitor. Load resistance value is 50kΩ, inductance and capacitance values are 1μH and 1μC respectively. Schottky diode was used in this rectifying circuit because it has very low forward voltage drop and fast switching action. Figure 4 is the designed circuit.

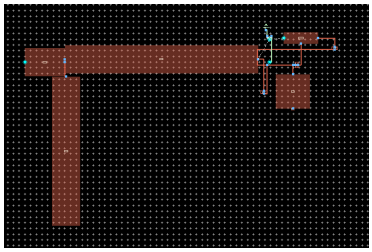

Figure 4. ADS layout of rectifying circuit.

3.2 Voltage Multiplier

The voltage multiplier used in the voltage boost stage is a Villard voltage multiplier, the greater the order of Villard voltage multiplier circuit, the boost effect is more obviously. In general, the voltage boost effect is better with higher circuit orders. A 9-stage circuit is designed and fabricated with HSMS-2852 schottky diodes. For 9-order circuit, the circuit output voltage without load could achieve more than 25V when the input power is 20dBm.

4. Systematic Test of the Antenna and Circuit

A measurement setup is constructed to test the capability of the antenna and circuit consisting of a transmitting system and an energy harvesting evaluating system. And the measured energy harvesting results are obtained for 900MHz and 1.8GHz with different transmitting power when the dual-band antenna is 0.5 meter away from the horn.

4.1 Test Setup

The transmitting system is constructed with a Agilent N9310A and a horn antenna is used to radiate radiowaves at 900MHz and 1.8GHz with different transmitting power ranging from -10dBm to 20dBm every 5dBm apart.

The energy harvesting evaluating system is constructed with an Energy Harvesting Multi-source Demoboard manufactured by Linear Technology, which is used as a voltage stabilizing circuit for the energy harvested by the antenna and conditioning circuit. The board consists of four modules. LTC3588EMSE-1 is for piezoelectric conversion, LTC3108EDE for thermoelectric conversion suitable to ultralow voltage step-up, LTC3105EDD for magnet-electric conversion and is a step-up DC/DC converter with power point control and LDO Regulator, LTC3459EDC for solar conversion and a 10V micropower synchronous boost converter. The last one is chosen for the test, because of its low current, high efficiency, static current up to 1μA and other excellent circuitry characteristics.

4.2 Results and Analysis

Placed in the same 0.5m transmission distance and same load resistance 33kΩ, the energy input power under different conditions is transmitted to measure harvest performance. The power received by the antenna was measured with spectrum analyzer N9320B, and then measured the output power at the load ports, the overall efficiency of the harvesting system can be evaluated. The collect characters of the two bands are obtained. Shown in table II and table III are results of 900MHz and 1.8GHz. The difference between antenna received signal power and antenna transmitted is about 15dB. The larger the transmitted powers and received powers, the higher conversion efficiency of the collection system is. And the received power is lower at 1.8GHz compared with 900MHz corresponding to the same transmitted power, and differences is 3.2-4dB while transmitted power increased from -5dBm to 20dBm. The more the received power, the larger the harvesting efficiency is, and it is larger at 900MHz than at 1.8GHz, the largest one at 900MHz is 40.5% for 5.8dBm received power, at 1.8GHz 28.9% for 1.8 dBm.

TABLE II. HARVESTING EFFICIENCY OF 900MHZ

Transmit Power (dBm)	Received power (dBm)	Output voltage (V)	Load power (mW)	Harvesting efficiency (%)
-10	-23.9	0.056	9.50E-05	2.33
-5	-18.8	0.141	5.94E-04	4.51
0	-13.8	0.392	4.66E-03	11.18
5	-8.7	0.95	2.73E-02	20.24
10	-3.6	2.01	1.22E-01	27.95
15	1.6	4.26	5.50E-01	38.05
20	5.8	7.13	1.54	40.51

TABLE III. Harvesting efficiency of 1.8GHz

Transmit Power (dBm)	Received Power (dBm)	Output Voltage (V)	Load Power (mW)	Harvesting efficiency (%)
-10	-27.1	0.011	3.67E-06	0.19
-5	-22.1	0.038	4.38E-05	0.71
0	-17.2	0.087	2.29E-04	1.20
5	-12.2	0.396	4.75E-03	7.88
10	-7.3	1.01	3.09E-02	16.59
15	-1.9	2.1	1.34E-01	20.75
20	1.8	3.8	4.38E-01	28.94

5. Summary

To obtain efficient and economical energy harvesting technique, the receiving antenna and conditioning circuit are designed, and its efficiencies are investigated for cellular communication network band. The dual-band planar monopole antenna at 900MHz and 1.8GHz are fabricated of designed -23.8dB and -20.4dB return loss respectively, and an conditioning circuit is designed and constructed. They are tested in a testing system of energy harvesting. The overall harvesting system test is carried out in a lab environment, extracting energy 0.5m away from the source. The measured data show that more than 10V DC with empty-load output voltage is achieved at 900MHz, and 7.7V with a 33kΩ load, its energy harvesting efficiency reaches 40.5%.

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