A MANAGEMENT CIRCUIT FOR VIBRATING ENERGY HARVESTER

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Abstract: A piezoelectric/magnetostrictive composite vibrating energy generator is introduced, and its output characteristic is analyzed. In order to increase the maximum output power of the vibrating energy harvester, a new up-conversion matching circuit is proposed, which can change the low frequency vibrating signal into a narrow bandwidth signal focused on a higher frequency. The matching circuit with a small-size permalloy transformer has a stronger capacitor charging power due to up-conversion. It can obviously improve the charging time and the storing energy at capacitor. In order to increase the output power, a power management circuit can release the energy for driving power load in a short time. Experiments show that the management circuit can drive a WSN node with an output power of 75mW at a distance of over 60m.

Keywords: energy harvesting, vibrating generator, power management circuit, frequency-changeable matching circuit, instantaneous discharged circuit

INTRODUCTION

Due to the nature of some structures in many applications, such as the status monitoring in danger circumstance, implantable medical devices in animal and embedded smart sensors in buildings, the micro-sensor array system must be completely embedded in the structure, with no physical connection to the outside world. In long-lived systems where battery replacement is difficult and in applications with no physical links to the outside world, it is difficult that sensor motes continuously work for a very long time. A promising alternative to batteries is the use of energy harvesting that converts existing source energy within their environment into electrical energy [1]-[3].

Among many types of energy, electricity is the most commonly used form for modern devices. There are many ways to complete electrical conversions. The most familiar ambient energy source is solar power. Photocells convert light to electricity [4]. Thermal energy is another ambient energy source. Thermocouples convert heat to electricity when placed across a temperature gradient [5]. The existing energy source is a necessary condition for the energy harvesting application.

Another general type of transducer converts the mechanical energy contained in a vibrating, movement object and gravitational field into electrical energy, such as self-winding watches that wind themselves from the swing of a person’s arm, a capacitively tuned vibration absorber [6], and a foot-powered radio identification “tag” over several meters during walking [7]. A magnet attached to the mass induces a voltage in a coil as it moves and magneto-electric generators convert mechanical energy to electricity [8]. Because of strong power density to convert the vibrating energy from environmental power source into electric energy, vibrating energy harvester may have many advantages over other self-powered methods and can be used in many fields. A potential and promising renewable power supply is the use of miniature vibrating energy harvester. The vibrating energy harvesters based on piezoelectric/magnetostrictive composites have good energy conversion efficiency in small size. The maximum output power of over 1 mW can be obtained under a load resistance of 1 megaohm and an acceleration of 1 g [9].

The conventional management circuit of the vibrating energy harvesting circuit consists of an ac-dc rectifier, a storing capacitor/battery, and a dc-dc converter [10]-[12]. A synchronized switch harvesting inductor (SSHI) can allows a typical gain of eight [13]. The output voltage induced from piezoelectric material should be rectified in order to charge the capacitor/battery with a proper current. However, due to the capacitive output impedance of the piezoelectric vibrating source, it has proven difficult to directly charge for a large storage supercapacitor of 1F since the charging current will rapidly decrease at a heavy load. The normal matching circuit with a bulky transformer hardly works at low frequency or varied vibrating frequencies.

This paper proposes a new management circuit for the vibrating energy harvester, which can change the low frequency vibrating signal into a narrow bandwidth signal focused on a higher frequency. A matching circuit with a small-size permalloy transformer has a stronger capacitor charging power. It can obviously improve the charging time and the storing energy at capacitor. In order to increase the output power, a power management circuit can release the energy for driving power load in a short time.

VIBRATING ENERGY GENERATOR

Fig. 1 shows the vibrating energy harvester structure based on piezoelectric/magnetostrictive composites. The transducer is fixed in this structure, and two U-type magnets in two sides are vibrated. The piezoelectric PZT-5H plate (P plate) with dimensions of 12 mm × 6 mm × 1 mm is located at the center of two magnetostrictive Terfenol-D plates (M plates) with same sizes. Terfenol-D plates are magnetized and
oriented along the longitudinal direction, which has the highest longitudinal magnetostrictive strain ($\lambda > 1000$ ppm) under a dc magnetic bias ($H_{dc}$) of 600 Oe. The PZT-5H plate works at $d_{31}$ model, which is polarized along the thickness direction. The magnetic loop consists of four NdFeB magnets with dimensions of 10 mm $\times$ 6 mm $\times$ 5 mm and two magnetic yokes with dimensions of 10 mm $\times$ 18 mm $\times$ 2 mm. The remnant magnetism is 1.39 T. The distance of up and down magnets is 6 mm and the gap of left and right magnets is 14.2 mm.

Fig. 1: Vibrating transducer structure.

Fig. 2: Output power and voltage as a function of load resistance.

In the vibrating transducer structure, the piezoelectric/magnetostrictive transducer is located at center of two U-type magnets in y axis and can obtain the maximum magnetic field change at four locations in z axis ($z = \pm 3$ mm or $z = \pm 9.8$ mm) while two U-type magnets are vibrated. Therefore, one or multiple piezoelectric/magnetostrictive transducers are located at the four locations in order to efficiently convert the vibrating energy into the ac magnetic energy. The large strain can be obtained in two Terfenol-D plates. A strong electric power can be produced in the PZT-5H plate.

Fig. 2 shows the output power and the voltage as a function of load resistance under an acceleration of 0.5g and a resonant frequency of 31.7 Hz. The output voltage increases with the load resistance and a voltage of over 100V can be obtained at a resistance of over 4 megaohm. The maximum output power of 1.1mW can be obtained under a load resistance of 3.59 megaohm. For a large charging supercapacitor, the charging power is very weak due to capacitive output characteristic of vibrating transducer. Normally the output power induced by vibrating transducer is less than 10 microwatt at a load capacitor of 1F. The charging time for a capacitor of 1F is more than 10 hours at a voltage of 0.5V. Therefore, the vibrating piezoelectric/magnetostrictive transducer can not directly charge for a large capacitor.

MANAGEMENT CIRCUIT OF VIBRATING ENERGY HARVESTER

The management circuit of the ME energy harvesting is composed of an up-conversion circuit, a matching circuit, a rectifier, a burst pulse generator, and an instantaneous discharge circuit, as shown in Fig. 3. A matching circuit with an up-conversion circuit is designed at a higher frequency point where the transducer has maximum output voltage. In order to increase the output power from the supercapacitor, an instantaneous discharging circuit is designed.

![Energy harvesting management circuit](image)

The traditional matching circuit with an inductor and a transformer can obviously improve the output power and the transducer output efficiency. Fig. 4 shows a traditional transformer matching circuit. The maximum output power can be obtained while working frequency is equal to the resonant frequency of the primary and secondary transformer loop. That is, the working frequency of the matching circuit can be expressed as

$$f_{Transducer} = \frac{1}{2\pi \sqrt{L_1C_p}} = \frac{1}{2\pi \sqrt{L_2C_2}}. \quad (1)$$

![Traditional transformer matching circuit](image)
Normally, the capacitance of the vibrating transducer is less than 10 nF, and the vibrating frequency is less than 100 Hz. Thus, a bulk transformer with a large primary inductance of more than 253H is necessary. Besides, due to the narrow bandwidth of the resonant loops, the matching circuit cannot work at varied vibrating frequency.

In order to decrease the transformer size and work at varied vibrating frequency, a nonlinear frequency-changeable matching circuit is proposed as shown in Fig. 5. A capacitor and a switch with a small on-state resistance are connected in the primary loop of the transformer in series. The working frequency of the switch is a high fixed frequency (500-1000 Hz). The output signal frequency of the vibrating transducer is modulated to new frequencies by using the switch.

In order to decrease the transformer size and work at varied vibrating frequency, a nonlinear frequency-changeable matching circuit is proposed as shown in Fig. 5. A capacitor and a switch with a small on-state resistance are connected in the primary loop of the transformer in series. The working frequency of the switch is a high fixed frequency (500-1000 Hz). The output signal frequency of the vibrating transducer is modulated to new frequencies by using the switch.

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composed of sensor units (humidity SHT11), a high-speed lower-power 8-bit processing (ATmega32L), and a low-power transceiver (CC1100). The operating time (600ms) of the humid sensor is much longer than that of other sensors. The normal communication distance of the sensor node is 50-130 meters. The current and the power of the node are less than 25mA and 75mW at a time interval of 620ms, respectively.

Fig. 8 shows the driving power in wireless sensor. The experimental results show that the discharged power of the proposed circuit reaches 110mW and the discharge time can last for 620ms. Thus, this management circuit can provide enough power for wireless sensors at a distance of 60-130 meters.

Fig. 8: Driving power in wireless sensor.

CONCLUSION

This paper introduces a vibrating energy generator based on the piezoelectric/magnetostrictive composite. The maximum output power of the energy harvester can be obtained under a large load resistance. In order to increase the maximum output power for the large capacitor load, a new matching circuit for the vibrating energy harvester is proposed. This up-conversion circuit can change the low frequency vibrating signal into a narrow bandwidth signal at a higher frequency. The matching circuit with a small-size permalloy transformer has a stronger capacitor charging power at a higher frequency. Thus, the up-conversion and matching circuit can obviously improve the charging time and the storing energy at capacitor. An energy management circuit can release a stronger power for driving a heavy load in a short time. Experiments show that the management circuit can drive a WSN node with an output power of 75mW at a distance of over 60m.

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