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# Wireless sensor network using low-power microwave power transmission and wireless communication techniques for future space systems

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## I. Introduction

Adaptation of wireless sensor network (WSN) system could greatly contribute to reduce setup and removal time required for verification tests of satellites and rockets by eliminating wire-harnesses because there are hundreds of sensors to monitor physical quantities such as temperature, acceleration, and pressure. As first step, we research on replacing hundreds of thermocouples with the WSN system used for a thermal vacuum test.

Batteries used for the WSN are not appropriate since the batteries have to work in long time and in a vacuum without leaking or blowing up, although they are used for commercial WSN in many case. Accordingly, this paper focuses on a wireless sensor node providing temperature data measured by a T-type thermocouple, which is externally powered by a microwave at 2.4 GHz without using battery and communicate with base station at 2.4 GHz ISM band, as shown in Fig. 1.

It is difficult to operate a battery-less sensor node because a power supplied from an RF energy source is extremely low. To resolve this problem, the main solutions are described in Chapter II and Chapter III, and the performance of WSN incorporating these solutions is described in Chapter IV.

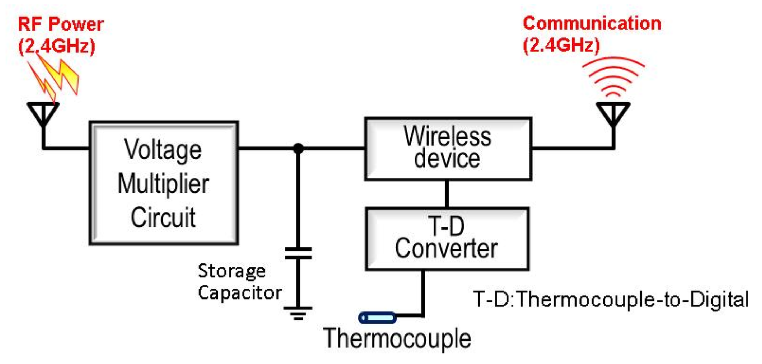


Fig. 1. Wireless sensor node block diagram.

## II. Voltage Multiplier Circuit

The voltage multiplier (VM) circuit was developed using two key technologies for improvement of a power conversion efficiency as follows [1].

1. Silicon On Insulator (SOI) process: Since the parasitic capacitance around the S/D region is 1/10 of that in the bulk silicon technology, it reduces transmission loss through the VM circuits.
2. Body bias control: Each SOI MOSFET can be individually controlled by a body bias. As shown in Fig.2(b), the proposed circuit has additional connections for body bias control applied to the conventional circuit (Fig.2(a)) composed of diode-connected MOSFETs and capacitors. The diode-connected MOSFETs with body bias control make its I-V characteristics close to ideal diode.

As a result, the power conversion efficiency of the current-version is over 10 % at 6V-output under the input power of + 2 dBm condition, in contrast to the conventional circuit with 1 % or less as shown in Fig. 3.

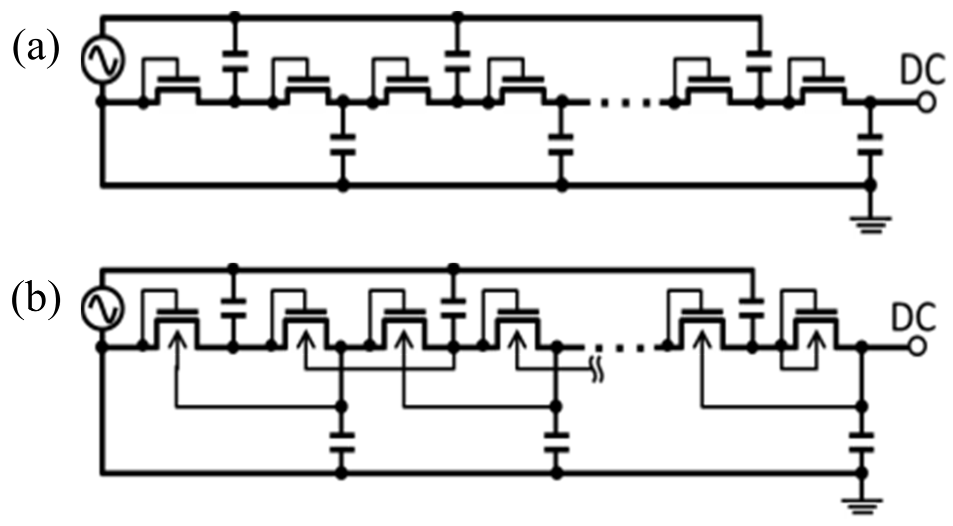


Fig. 2. Schematics of SOI VM circuits. (a) Conventional circuit. (b)Proposed circuit with body bias control.

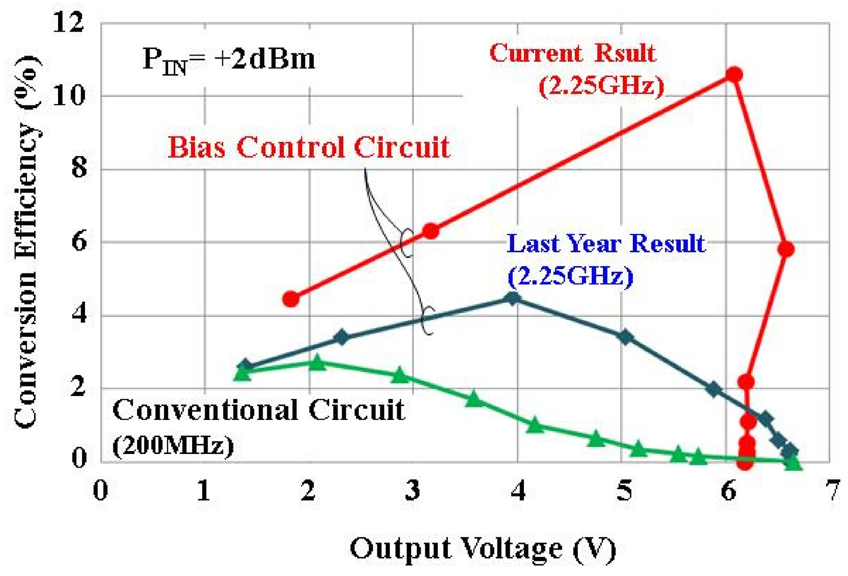


Fig. 3. Measurement results of the power conversion efficiency in VM circuit.

## III. Wireless Communication System

We adopted IEEE802.15.4 devices having ultra low power and low bandwidth requirements in order to reduce the power consumption in the sensor node. The WSN was embedded the two following protocol stacks to Network (NWK) and Application (APP) Layers which are responsible for message routing and construction respectively, without using such ZigBee:

1. Time-division (TD) operation

   The TD operation is aimed at automatic message routing in cases where the transmitted signals from sensor nodes fail to reach the base station. Figure 4(a) shows the scheduling for the TD operation. The divided timeslot is assigned to each sensor node according to its ID number and a common frame to receive any commands from the base station.
2. Asynchronous (ASY) operation

   The ASY operation is aimed at very low power running on sensor nodes. Sensor nodes randomly transmit signals to the base station without receiving signals from other sensor nodes and have a Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) scheme as shown in Fig. 4(b).

The protocol test for packet loss was performed using 75 sensor nodes with batteries that were embedded both TD and ASY operation. Each sensor node operated at 1Hz. Table 1 shows the test results monitored by a base station 5 minutes later from booting sensor nodes. For TD operation, the packet loss of 1.2 % is higher than expectations. The cause of the problem was that each clock of sensor nodes was not synchronized with that of the base station. By resolving this problem, the packet loss would be lower. For ASY operation, the packet loss of 0.4 is reasonable. This result suggested that the CSMA-CA scheme in the ASY operation is effective against signal collision.

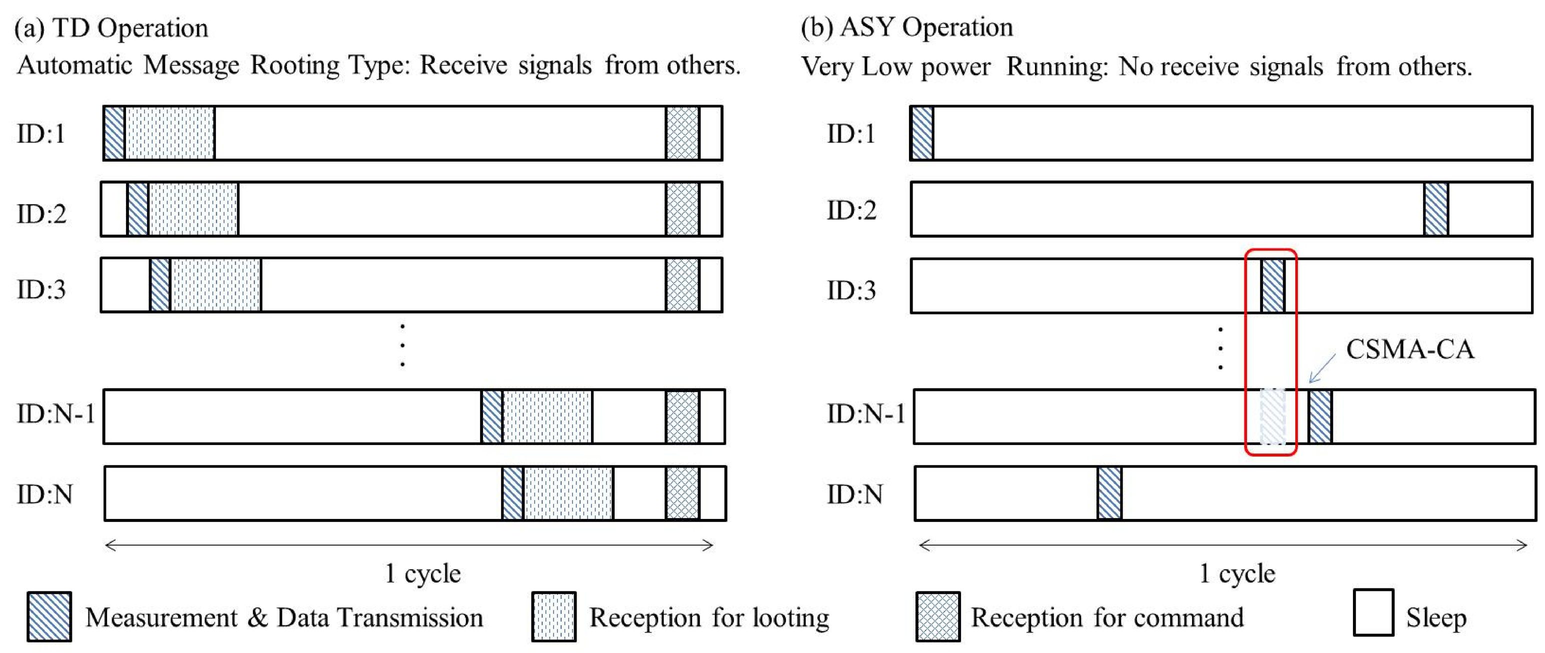


Fig. 4. Communication schedules. (a) TD operation. (b) ASY operation.

Table 1. Results of protocol test for packet loss.

| | TD operation | ASY operation |
|---|---|---|
| Packet Loss (%) | 1.2 | 0.4 |

## IV. Wireless Sensor Node Performance

The performance test of the WSN embedded the ASY operation was performed. The WSN system consisted of one microwave power transmitter (MPT) as RF energy source, one base station, and one sensor node as shown in Fig. 5. The sensor node was powered using MPT with the transmission antenna (input power: 15 mW) at a distance of 15 cm from the sensor node. The sensor node measured ambient air temperature by using thermocouple.

The WSN successfully operated within 1000 sec operation in the performance test as shown Fig. 6. The sensor node sent the temperature data to the base station every approximately 44 sec depending on charge-up time of the storage capacitor in the sensor node.

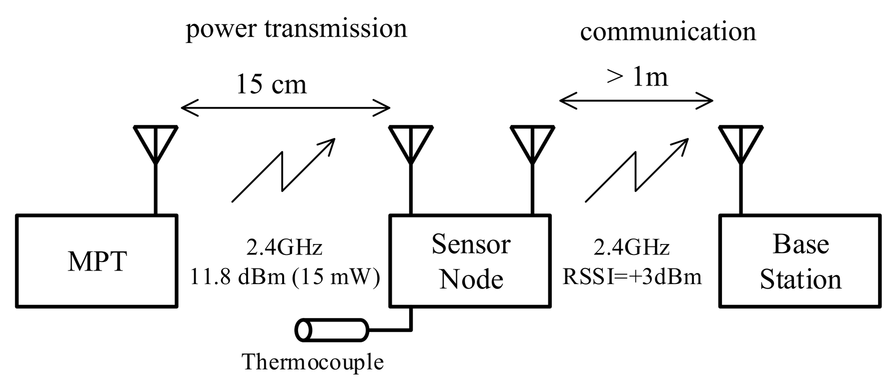


Fig. 5. Performance test set up.

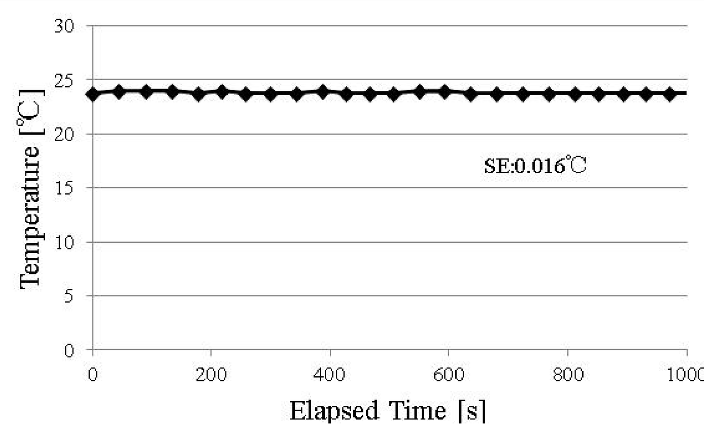


Fig. 6. Temperature measurement results within 1000 sec operation in the performance test.

## V. Conclusion

We demonstrated the 2.4GHz wireless sensor network system providing temperature data measured by a T-type thermocouple, which is externally powered by a microwave at 2.4 GHz. The power conversion efficiency of the voltage multiplier circuit consisting of diode-connected SOI MOSFETs with self-control of the body bias was improved in contrast to that of the conventional circuit . The WSN was embedded the time-division operation and the asynchronous operation to reduce the power consumption in the sensor node. As a result of improvements on the whole system, the sensor node for asynchronous operation successfully operated using the microwave power transmitter with the transmission antenna (input power: 15 mW) at a distance of 15 cm from the sensor node.

## VI. Future Steps

Next, we will develop the power management circuit and enhance protocol stacks for lower power running on a sensor node . We will also demonstrate the wireless network system with 100 sensor nodes installed in a mechanical test model of a satellite.

## Acknowledgments

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## References

[1] Y.Igarashi et al.: "SOI CMOS Voltage Multiplier Circuits with Body Bias Control Technique for Battery-Less Wireless Sensor System",IEICE Trans. Fundamentals, Vol.E97-A, No.3, pp.741-748, 2014.