A Wideband and High Gain Antenna on Multilayer Insulation Blanket for RF Energy Harvesting

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***Abstract*—This paper addresses a wideband and high gain antenna integrated with a multilayer insulation blanket. The proof-of-concept antenna is fabricated and measured, then used in a simulation of an energy harvester. The antenna is designed at 12 GHz with a rectangular antenna element, a frame-shaped ground and a reflector slightly apart from the antenna element. The antenna is fabricated by inkjet printing technique and has 2.85 GHz bandwidth and 10.06 dBi realized gain. In the simulation, the energy harvester produces 1.55 mW and 1.24 V with the RF-dc conversion efficiency of 46.3 % at 50V/m in far field, which corresponds to 5.25 dBm RF input power given from the designed antenna.**

I. INTRODUCTION

The interest in RF energy harvesting (EH) has increased dramatically, especially in Internet of Things, wireless sensor networks and wearable devices [1], [2]. This technique enables low power electrical devices to collect ambient RF energy and to power their load wirelessly. Besides terrestrial applications, EH on satellites is also discussed [3]. For satellite health monitoring, the EH technique is capable of powering sensors with few wires, less weight, simpler design and low possibility of electrical accidents. In [3], the boardcasting antenna (17.7 GHz, 70 W) provides the satellite surface with intense electric field ranging up to around 100 V/m, and the harvester produces dc power ranging 0.256–1.28 mW at 91–121 V/m respectively. On the other hand, the practical implementation of a harvester in existing artificial satellites is not well discussed. In general, satellites are covered with either multilayer insulation (MLI) blankets or radiator surfaces to protect inside electric devices from harsh environmental changes in space[4]. Therefore, we propose a novel additive manufacturing approach to fabricate a rectenna topology on MLI blankets without degrading the original function of the insulator.

In this paper, an antenna integrated with a MLI blanket is designed, fabricated, and measured to characterize its performance in terms of impedance matching bandwidth, radiation pattern and realized gain. Through the design process, we lay out the antenna to cover 11.73–12.15 GHz which is radiated at Japanese broadcasting satellite BSAT-3C (120 W). The antenna is also designed to have high gain and high directivity in the one side of the antenna to effectively collect RF energy from the satellite maximizing the RF input power of the RF-dc conversion circuit.

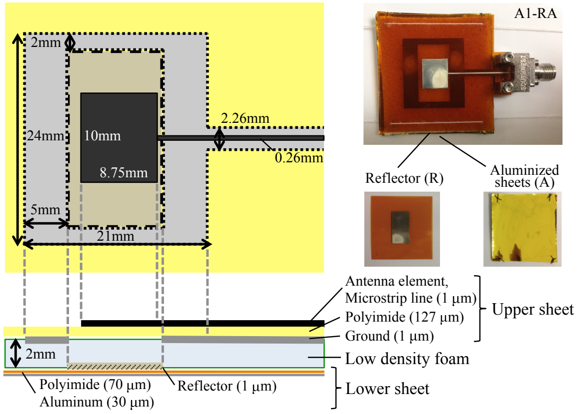

Fig. 1. Antenna simulation model and fabricated antenna A1-RA

II. ANTENNA GEOMETRY

Typical conventional MLI blanket is composed of a polyimide film (50.8 μm) with vapor deposited aluminum (VDA, 35nm) on one side, multiple polyimide films (7.6 μm) with VDA on two sides, multiple thin polymer spacers and another one-side-alminized polyimide film. Accordingly, the designed antenna, shown in Fig. 1, consists of an upper sheet, a low density foam and a lower sheet corresponding to multiple films of the MLI blanket. The upper sheet adopts a polyimide film (127 μm, dielectric constant: 3.5), and has a rectangular antenna element and a frame-shaped ground similar to ultra wideband antennas [5]. As the lower sheet in the antenna simulation model, a composite ”effective” polyimide layer (70 μm) and an aluminum layer (30 μm) are substituted for the multiple aluminized films because HFSS, which is used to optimize the antenna design, cannot generate effective meshes for a thin sheet like VDA (35nm). A reflector as large as the rectangular aperture of the ground is arranged on the lower sheet to maximize the gain of the antenna in one side.

Once designed, the antenna is fabricated with inkjet printing technique, which provides a rapid, low-cost, and environmentally preferable alternative to typical cleanroom fabrication methods [6]. Conductive silver nanoparticle-based ink is used with the Dimatix-2831 printing platform. As the lower sheet in the fabricated antenna, a polyimide film (50.8 μm) with the

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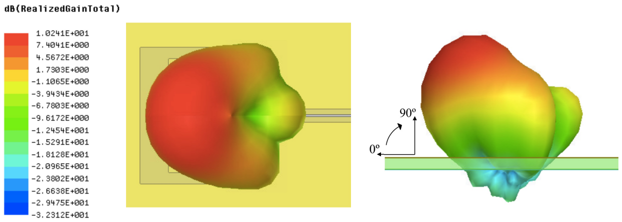

Fig. 2. Simulated radiation pattern of A1-RA at 12 GHz

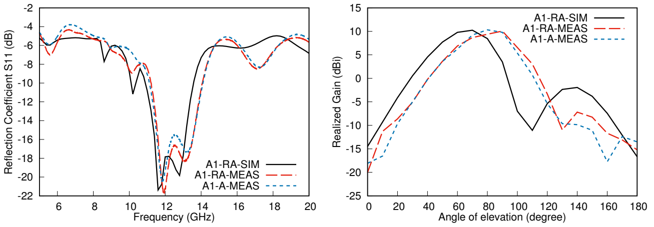

Fig. 3. Simulated and measured reflection coefficient S11 and realized gain at 12 GHz in the vertical plane along the microstrip line

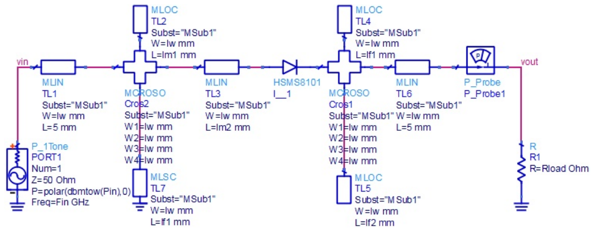

Fig. 4. Energy harvester model (ADS)

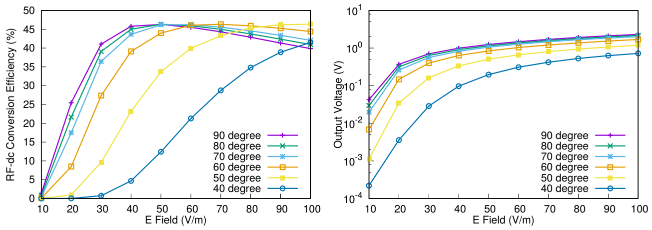

Fig. 5. RF-dc conversion efficiency and dc output voltage of the harvester

printed reflector (R) and 20 pieces of thin one-side-aluminized polyimide films (A) are prepared. Once each parts is ready, the upper sheet, the low density foam, the reflector (R) and the aluminized sheets (A) are carefully aligned with strings (antenna A1-RA). Furthermore, another antenna A1-A, which is A1-RA without the reflector (R), is also assembled to confirm that the aluminized sheets solely works as a reflector.

III. SIMULATION AND MEASUREMENT RESULT

Simulated radiation pattern of A1-RA at 12 GHz, shown in Fig. 2, has the directivity tilted forward and 10.24 dBi in peak gain. As shown in Fig. 3, measured reflection coefficient and realized gain of A1-RA nicely agree with simulation results. A1-RA experimentally performs 2.85 GHz (11.21–14.06 GHz) in -10 dB bandwidth and 10.06 dBi at 90 degree. The antenna has greater than 6 dBi ranging 60-90 degree. It is considered that differences between measured and simulated results derive from misalignment of antenna components and difference of structure between the simulation model and the fabricated antenna. Similarly, A1-A performs 2.97 GHz (11.12–14.09 GHz) bandwidth and 9.78 dBi at 90 degree. Although A1-RA has higher gain than A1-A, VDA layers work well as a reflector and another reflector is not necessarily designed explicitly. This fact leads the possibility to simplify the antenna design and the fabrication process.

IV. SIMULATION OF ENERGY HARVESTING

To confirm the antenna performance in terms of EH, the measured gain of A1-RA is representatively used in the simulation on the advanced design system (ADS). As shown in Fig. 4, the energy harvester model consists of a RF source, a matching component (an open stub and a transmission line), a rectifier in series, a low pass filter (two open stubs) and a load. Insertion of a $\lambda/4$ short stub makes RF-dc conversion efficiency a few percent greater. The circuit is modeled on 127 μm polyimide film with HSMS8101 Schottky diode as a rectifier due to its low conversion loss at 10-14GHz. The matching component is optimized at 12 GHz, 1 kΩ load and 0 dBm in RF input power given from the antenna. As shown in Fig. 5, the harvester produces 0.14 mW (25.4 %) and 0.37 V at 20 V/m, 1.55 mW (46.3 %) and 1.24 V at 50 V/m which corresponds to 5.25 dBm RF input power given from the 10.06 dBi antenna. Furthermore, for E-field at 50 V/m or greater, RF energy received at low angle ranging 50-60 degree can be also harvested at around 40 % efficiency.

V. CONCLUSION

This work demonstrated the antenna on the MLI blanket which has 2.85 GHz bandwidth and 10.06 dBi gain, and experimentally verified that thin sheets with VDA can be used as a reflector. We also confirmed that the harvester using the designed antenna produces 1.55 mW and 1.24 V with the RF-dc conversion efficiency of 46.3 % at 50V/m. Note that this work is based not on JPO's opinion but on individual opinion.

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