60 GHz-band compact photonic antenna module with integrated photodiode

Kotoko Furuya, Shigeyuki Akiba, Jiro Hirokawa, and Makoto Ando
Dept. of Electrical and Electronic Eng., Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8552, Japan

Abstract **– We propose and fabricate a 60 GHz-band compact photonic antenna module where a cavity antenna element and a photodiode as well as an optical fiber for RF power feeding are integrated. The operation of the fabricated photonic antenna is demonstrated, which is almost coincident to the simulation result.**

Index Terms **— radio-over-fiber, antennas, propagation, photodiode, millimeter-wave.**

1. Introduction

The emergence of intelligent and high-speed mobile terminals such as smart phones and tablet PCs causes the consecutive growth of mobile data traffic. In order to accommodate such explosive data traffic, deployment of more wireless base stations (BSs) than ever is demanded. In this situation, however, radio-interference among plural BSs will increase, which results in the degradation of signal quality. In addition, installation of many BSs causes the increase of the total cost, weight, and power consumption of radio access networks. In order to alleviate these problems, radio-over-fiber (RoF) transmission technology is a promising solution because it has capabilities of remote beam control and power feeding to antennas from the control site (CS) [1][2], which will contribute to significant simplification of the antenna sites (AS). From these perspectives, we have studied a scheme for beam forming of array-antennas by RoF technology [3]. Figure 1 shows conventional and RoF schemes for RF transmission from CS to AS. In case of conventional method as shown in (a), where the propagation loss of coaxial cable is quite large, RF amplifiers and phase shifters to control antenna beam forming are required. But utilizing RoF system, we can transmit RoF signal through low-loss optical fiber and therefore AS consists of only antennas and photodiodes as shown in (b).

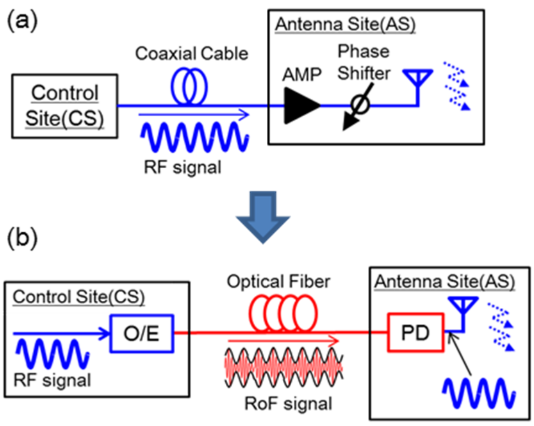

Fig. 1. Radio access with antenna site (AS) utilizing the conventional scheme (a) and RoF scheme (b).

In order to simplify the current AS architecture, we fabricate an integrated photonic antenna (IPA) where an antenna element and a photodiode are integrated into one module. The modules will be arranged to form an array for antenna beam forming in the future. In this paper, we design and fabricate an IPA module mentioned above and evaluate the characteristics.

2. Design of Integrated Photonic Antenna

Figure 2 shows a schematic overview of the IPA as well

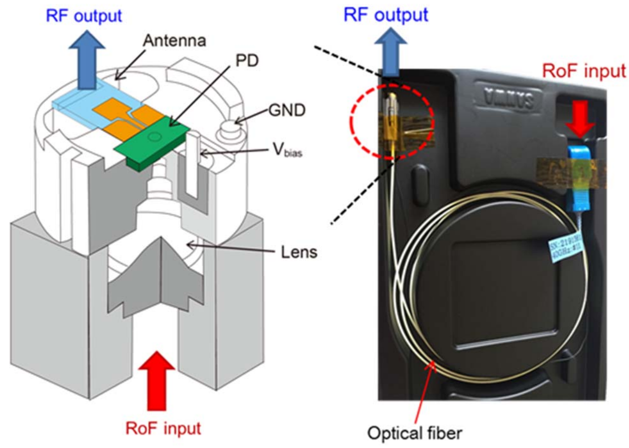

Fig. 2. Antenna over all structure.

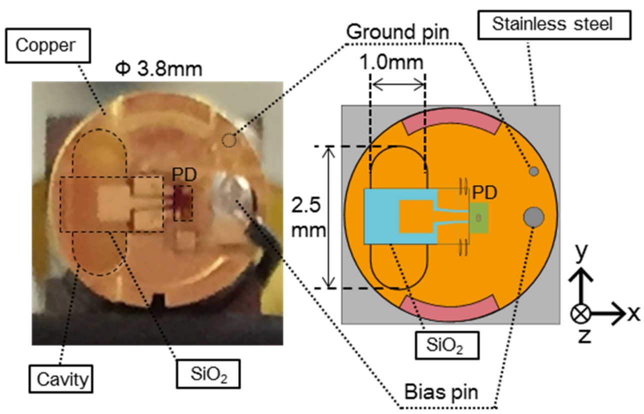

Fig. 3. Photograph and figure of the top surface.

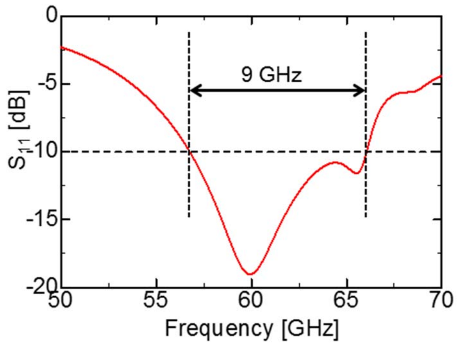

Fig. 4. Calculated frequency characteristics of the reflection.

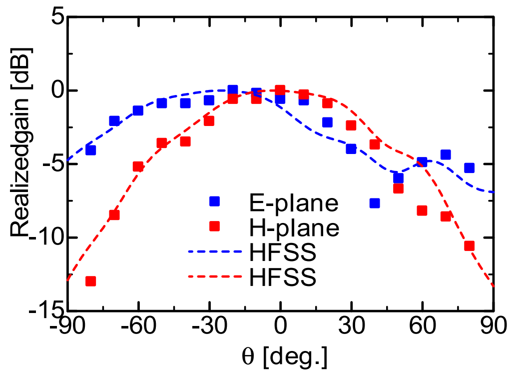

Fig. 6. RF radiation patterns

as a photograph of the whole module with a fiber. The IPA consists of the antenna element, which is basically a cavity antenna, integrated with a PD and an optical fiber. The RoF signal through the fiber is focused onto the light receiving area of the PD chip by a lens. The output RF signal from the PD chip is fed to an RF strip line formed on the top surface of an aperture of the cavity antenna.

Figure 3 shows a photograph and a figure of the top surface of the IPA. The diameter of the IPA is 3.8 mm. The RF strip line to connect the PD to the aperture is a coplanar line (CPL) formed on an SiO_2 dielectric substrate. The dielectric substrate is buried 0.1mm in the top surface and stretched out to the other side of the aperture so that the CPL doesn't slip off. The aperture is a cavity of 1.2 mm in the *x*-axis direction, 2.5 mm in the y-axis direction and 1.0 mm in the *z*-axis direction. It is designed so that the RF wave is radiated to the opening front direction with the resonance in the 60 GHz-band. Figure 4 shows the frequency characteristics of the reflection calculated by HFSS. The reflection is below -10 dB from 56.8 GHz to 66.1 GHz and we can confirm that the broad bandwidth of approximately 9 GHz becomes available.

3. Experiment and Result

(1) Experimental Setup

Figure 5 shows an experimental setup in a RoF system employing the IPA. An optical signal with the wavelength of 1550 nm was amplitude-modulated by an intensity modulator (IM) at 60-GHz. After being boosted by the erbium-doped fiber amplifier (EDFA), the RoF signal was

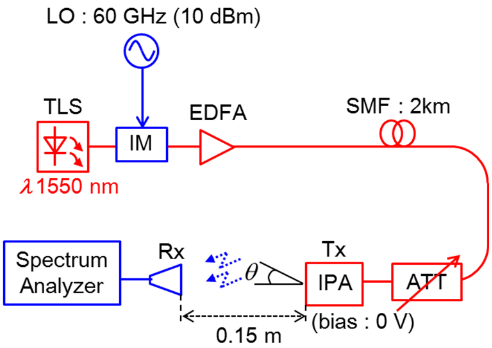

Fig. 5. Experimental setup.

propagated through a 2 km-long single-mode fiber (SMF) and a variable optical attenuator (ATT) and fed to the IPA. Note that this experiment was conducted without supplying any bias voltage for the PD. After 0.15 m-long radio propagation, the 60 GHz RF signal was received by a receiver horn antenna (Rx) and was observed by a spectrum analyzer.

(2) Results and Discussion

Figures 6 shows the RF radiation pattern where the change of relative RF power was plotted against the observation angle. The dotted lines in Fig. 6 are calculated by HFSS. The measured RF powers almost coincided with the dotted lines. So, we confirmed the fabricated IPA performed according to the design value.

4. Conclusion

We have designed and fabricated 60 GHz-band compact photonic antenna module, in which an antenna is integrated with a PD and a fiber. The presented IPA will be useful for a wide range of array antenna applications because we can arrange various array patterns for required beam forming capabilities.

Acknowledgment

We thank Dr. K. Nishimura and Mr. T. Kobayashi at KDDI R&D Laboratories in the preparation of measurement equipment. This research is partially supported by the Center of Innovation Program for Japan Science and Technology Agency, JST.

References

[1] M. Y. Frankel and R. D. Esman, "True time-delay fiber-optic control of an ultrawideband array transmitter/receiver with multibeam capability," IEEE Trans. Microw. Theory and Techn., vol. 43, no. 9, pp. 2387-2394, Sept. 1995.

[2] M. Tadokoro et al., "Optically-controlled beam forming for 60 GHz-ROF system using dispersion of optical fiber and DFWM," Proc. 2007 IEEE/OSA Optical Fiber Communication conference (OFC), paper OWN2, Anaheim, CA, Mar. 2007.

[3] S. Akiba et al., "Effects of chromatic dispersion on RF power feeding to array antenna through fiber," Proc. the 2012 17th Opto-Electronics and Communications Conference (OECC), pp. 323-324, Busan, Korea, July 2012.