Novel Multi-Layer Active Integrated Antenna Configuration using Teflon Substrate

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1. INTRODUCTION

System studies and hardware investigations of high-speed wireless communications were conducted at the quasi-millimeter and millimeter-wave frequency bands in order to secure a wide frequency band [1]-[4]. However, the loss of the feeding circuit cannot be ignored at these frequencies. Therefore, it is difficult to decrease the noise figure of the system. In order to address this, we must develop an active antenna that connects the radiation element directly to the active devices [5]. However, since the active devices have uni-directional characteristics, individual feeding circuits must be prepared for transmission and reception in the communication system. Therefore, a multi-layer structure must be used to decrease the size and suppress the coupling between the transmission and reception feeding circuits[6]-[8].

We previously constructed the active integrated antenna incorporating a multi-layer aluminum-ceramic substrate[9]. The alumina-ceramic substrate, however, has drawbacks such as narrow bandwidth characteristics due to its high dielectric constrant. On the other hand, a Teflon substrate is often used in the construction of planar antenna for the quasi-millimeter and millimeter-wave frequency bands due to its low dielectic constant and loss-tangent making it a good candidate for the multi-layer structure. However, it is difficult to fabricate through holes that connect between multi-layers. In addition, there is a limitation with respect to connecting Teflon layers. The reason for this is that a bonding film is required to connect Teflon substrates. Furthermore, by using an electro-magnetic coupling is difficult to realize a low-loss connection and design accuracy. Therefore, it is necessary to establish a connection method that establishes direct connections between Teflon substrates.

This paper proposes a multi-layered Teflon substrate structure that uses a solder bump connection and that clips the bonding film in order to establish a connection between layers. Furthermore, we construct and test a prototype pin-fed active integrated array antenna employing distinct transmission and reception feeding circuits.

2. PROPOSED ACTIVE INTEGRATED ANTENNA CONFIGURATION

The target image of the active integrated antenna using the multi-layered Teflon substrate is shown in Fig. 1. An MSA array is placed on the multi-layer Teflon substrate. The MMIC amplifier chips for transmission and reception are mounted on the multi-layer polyimide substrate. The individual feeding circuits for transmission and reception are constructed on the inner layer of the Teflon substrate. The ceramic substrate is arranged for heat radiation.

Figure 2 shows the concept of the interconnection between the layers. This construction method is realized using a solder bump connection and clipping of the bonding film in order to establish the connection. The Teflon substrate is superior with re-

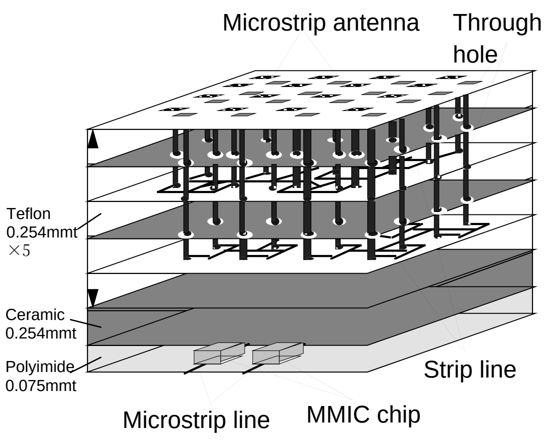

Fig. 1 Antenna structure

spect to high frequency characteristics, but there is a problem with heat dissipation. The radiated heat must be dissipated when the high-power-consuming active antenna is functioning. This connection method is useful in binding high heat conductive substrates such as the alumina-ceramic substrate. This heat radiation problem can be resolved by arranging different substrates with high heat conductivity.

As mentioned above, a multi-layered Teflon substrate is achieved through which connection between layers is established and that dissipates the heat of the active devices. Therefore, we can construct a large active integrated antenna on one substrate.

The Teflon substrate achieves low loss characteristics such that the insertion loss of the microstrip line is approximately 0.01 dB/mm at 20GHz. However, it is necessary to design the through hole so that it improves the performance at a high frequency. Next, we present the characteristics of the through hole that are important in realizing the multi-layered substrate. Here, we present the characteristics of the multi-layered substrate using two examples, a two-layer and a three-layer substrate. The spectrum domain moment method is employed in the simulation. We use the Teflon substrate (substrate thickness = 0.254 mm, $\varepsilon_r = 2.2$, $\tan\delta = 0.0007$ at 10 GHz) where the diameters of the through hole and cover pad are 1.0 mm and 1.5 mm, respectively, for the manufacturing process. The length and the width of the microstrip line is 10 mm and 0.77 mm, severally. Here, the relationship of the through hole characteristics versus the clearance between the cover pad and the ground plane is shown in Fig. 3. The figure clearly shows that the characteristics of the through hole are affected by the clearance, and the peaks show that the characteristics are present. We confirmed that the differences between the through hole without the cover pad and the proposed structure are minor. Furthermore, it is clear that the peak of the through hole characteristics slides toward the higher clearance values, when the number of the substrate layers increases.

3. PIN-FED MICROSTRIP ANTENNA AND VERIFICATION

The characteristics of the pin-fed microstrip antenna (MSA) are described. Here, the frequency is 18.5 GHz. When there are three layers, the return power and the maximum undesirable radiation level characteristics against the clearance of

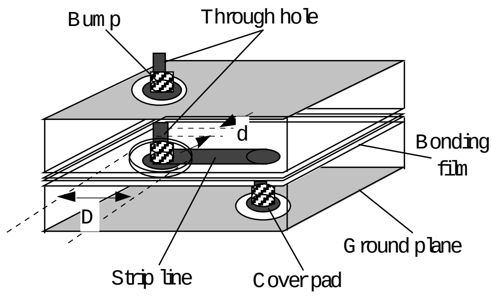

Fig. 2 Interconnection model

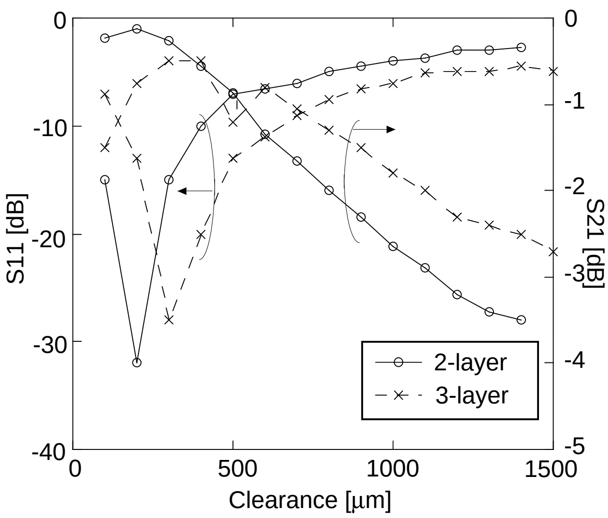

Fig. 3 Through-hole characteristics versus clearance

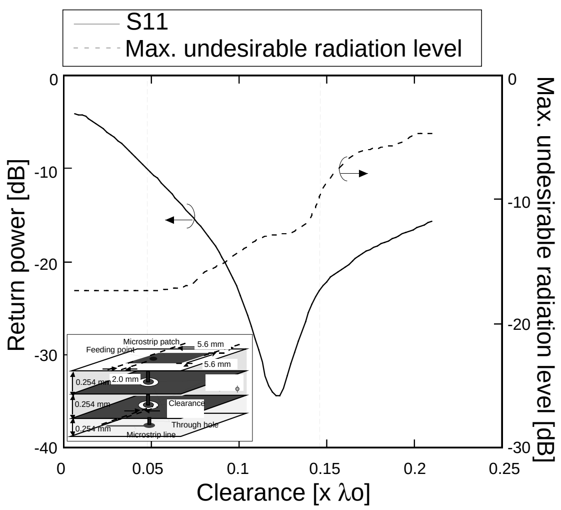

Fig. 4 Return power and maximum undesirable radiation level characteristics versus clearance (3-layer substrates)

the cover pad are shown in Fig. 4. In this figure, when the clearance is higher than 0.05 λ_o, the return power is less than -10 dB. Furthermore, when the clearance is lower than 0.15 λ_o, the maximum undesirable radiation level is less than -10 dB.

4. PROTOTYPE ACTIVE INTEGRATED ANTENNA

We constructed the prototype active antenna shown in Fig. 1. For reference, a photograph of this prototype antenna is shown in Fig. 5. Figure 5(a) shows the feeding circuit including the amplifiers, and Fig. 5(b) shows the antenna array. The antenna substrate is constructed using a five-layer Teflon substrate (substrate thickness = 0.254 mm,ε_r = 2.2, tanδ= 0.0007 at 10 GHz). The ceramic substrate (substrate thickness = 0.254 mm,ε_r = 5.0, tanδ= 0.002 at 10 GHz) for heat radiation is one layer. Additionally, the polyimide substrate (substrate thickness = 0.025 mm,ε_r = 3.2, tanδ= 0.002 at 10 GHz) for the power circuit and control circuit is constructed using three layers. This antenna is constructed using a patch antenna for two individual frequencies on the same plane and the individual feeding circuits are constructed using a strip line circuit in two planes. Here, we use the pin-fed MSA where the diameter of the feeding through hole is 1.0 mm, the diameter of the cover-pad is 1.5 mm, and the clearance of the cover pad is 1.5 mm. The lower microstrip line connects the individual feeding circuits via the through hole. This antenna structure cannot utilize the conventional through hole. Here, the patch size for a 12-GHz band is 6.7 mm and the feeding position is 2.5 mm offset from the center of the patch. The patch size for a 13-GHz band is 5.6 mm and the feeding position is 2.0 mm offset from the center of the patch. The array antenna is constructed with 16 elements (4 x 4 structure). The upper layer feeding circuit is for reception, and the lower layer feeding circuit is for transmission. The low noise amplifier used for reception is CHA2063A (United Monolithic Semiconductors SAS, Orsay Cedex, France) with the noise figure of 2.0 and the gain of 19 dB. The power amplifier for transmission is HMMC-5027 (Agilent Technologies, Palo Alto, CA, USA) with the gain of 7 dB and the P-1 dB is 22 dBm.

The horizontal radiation patterns for reception and transmission are shown in Figs. 6 and 7, respectively. The results clearly show that the measured and calculated results are in good agreement for the main lob; however, there is diffraction in the side lobe characteristics. One reason for this is

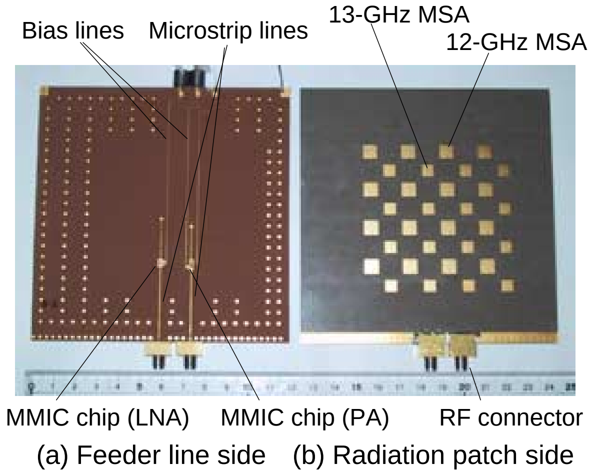

Fig. 5 Photograph of the prototype antenna

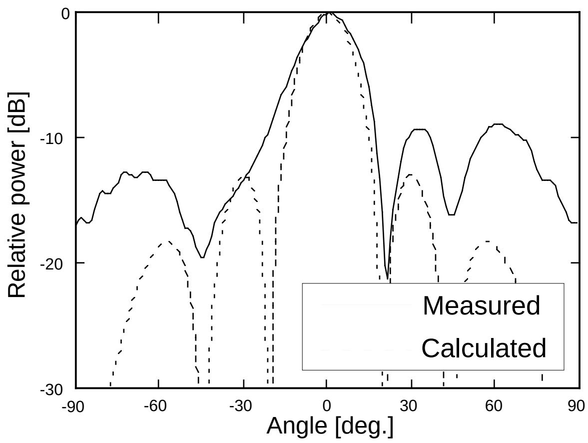

Fig. 6 Horizontal plane reception characteristics

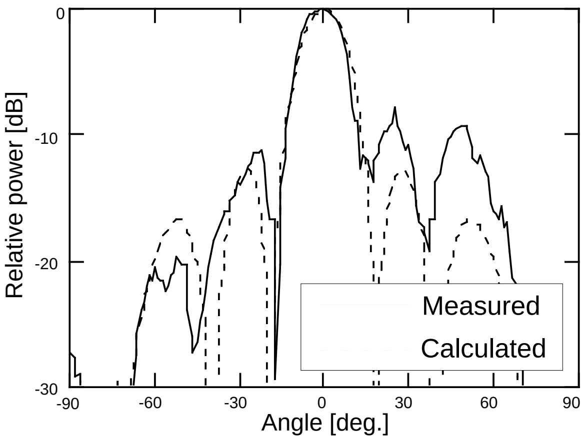

Fig. 7 Horizontal plane transmission characteristics

that the diffraction affects the bias line arranged on the power supply circuit and the control circuit. Furthermore, in the transmission, the diffraction was caused by the RF connector.

The difference in gain during transmission between the passive antenna and the active antenna is 14.3 dB. The difference in gain during reception between the passive antenna and the active antenna is 6.3 dB. Based on these results, we confirm that the difference in the passive antenna and active antenna is in good agreement with the gain of the mounting amplifier. It is clear that the Au-wire bonding used in mounting the active device is useful and that employing this multi-layered Teflon substrate is beneficial in constructing a large active integrated antenna.

5. CONCLUSION

We proposed a multi-layered Teflon substrate structure for an active integrated antenna using a solder bump connection and clipping of the bonding film that enables connection between layers. Furthermore, we showed the peaks of the through hole characteristics and the pin-fed MSA with clearance between the cover pad and the ground plane. Additionally, we manufactured a prototype pin-fed active integrated antenna.

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REFERENCES

[1] Y. Takimoto," Recent activities on millimeter wave indoor LAN system development in Japan," in IEEE MTT-S Int. Symp. Dig., pp.405-408, June 1995.

[2] N. Morinaga and A. Hashimoto," Technical trend of multimedia mobile and broadband wireless access systems," Trans. IEICE., Vol. E82-B, No.12, pp.1897-1905, Dec. 1999.

[3] L. A. Bergman," Gigabit satellites in distributed supercomputing for global research," Digest of Compcon '95 Technologies for the Information Superhighway, pp. 71-76, 1995.

[4] T. Ihara and K. Fujimura," Research and development of millimeter-wave short-range application systems," Trans., IEICE, Vol. E79-B, No. 12, pp. 1741-1753, Dec. 1996.

[5] J. Lin, and T. Itoh," Active integrated antennas," IEEE Trans. MTT, Vol. 42, pp. 2186-2194, Dec. 1994.

[6] T. Tokumitsu, T. Hiraoka, H. Nakamoto, and M. Aikawa," Multilayer MMIC using a 3mm x N-layer dielectric film structure," IEICE Trans. Electron., Vol. E75-C, No.6, pp.698-706, June 1992.

[7] T. Seki, H. Yamamoto, T. Hori, and M. Nakatsugawa, "Active antenna using multi-layer ceramic-polyimide substrates for wireless communication systems," Digest on IEEE MTT-S 2001 Int. Microwave Symp., pp. 385-388, May 2001.

[8] H. Yamamoto, T. Seki, and T. Hori, "Multistage dispersed amplifier arrangement method for active array antenna," Digest on ISAP2000, pp. 1521-1524, August 2000.

[9] T. Seki, H. Yamamoto, and T. Hori, "Multi-layer Teflon substrate constructing method suited for HIC structure active antenna," General conference of IEICE, B-1-153, March 2001.