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Design of High Efficiency Multi-Layer Parasitic Microstrip Array Antenna

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1. *Introduction*

System studies and hardware investigations on high-speed wireless communications are being conducted at millimeter and quasi-millimeter-wave frequencies [1]-[3]. These applications require compact, high performance, and low-cost wireless equipment. A highly integrated RF module, the so-called system-on-package module, which employs a multi-layer structure, is effective in achieving the above requirements [4]-[7]. It is necessary to adopt active integrated antenna technology to achieve a module with antennas that are low-power consuming and have low-noise characteristics [8]-[10]. Several approaches to achieve the RF module integrated with antennas were reported. One approach uses a semiconductor chip antenna such as a microstrip antenna (MSA) that is integrated with RF circuits on the same semiconductor substrate [4]. However, it is difficult to establish a high-gain antenna that employs an array antenna configuration on a semiconductor substrate due to the substrate size.

Therefore, high-gain compact antennas have not yet been integrated with MMICs. A multi-chip module approach was also proposed to construct a module integrated with antennas [5],[6]. In this module, antennas and MMICs are connected by wire bonding or a ribbon, which results in high connection loss. This approach also needs a low-loss feeding circuit. The dielectric lens antenna is adopted to achieve a high-gain antenna [7]. However, the commonly used lens antenna is constructed using a crystal material that is high cost and it is difficult to mount it on the MMIC package. Additionally, a dielectric lens antenna constructed using resin was investigated for low cost. There are problems, however, regarding mounting the antenna on the MMIC package and achieving high efficiency.

To overcome the above problems, we proposed a multi-layer parasitic MSA array (MPMAA) based on a parasitic antenna configuration [11]. Furthermore, we demonstrated a novel multi-layer parasitic MSA array (MPMAA) structure using a low-temperature co-fired ceramic substrate (LTCC) suited to packaging the MMIC chip [12]. However, since the LTCC substrate has a high-electric constant, it is difficult to achieve wideband and high efficiency characteristics.

In this paper, we propose a high efficiency multi-layer parasitic MSA array (MPMAA) structure constructed on a TEFLON substrate for a system-on-package at quasi-millimeter and millimeter-wave frequency bands. The new proposed antenna achieves high radiation efficiency that is greater than 91%.

2. *System-on-Package Using MPMAA*

The concept of a system-on-package module integrated with an antenna is shown in Fig. 1. The system-on-package module has a highly integrated transceiver MMIC mounted on a multi-layer structure with the proposed MPMAA. The multi-layer structure for the MMIC chips and the MPMAA are vertically stacked and both are assembled using flip-chip technology. A feeding element is constructed on the MMIC chip and the MPMAA is fed by electromagnetic coupling without feed lines. In Fig. 1, the MPMAA employs two parasitic layers. Four parasitic elements are arranged on each parasitic layer (1st layer and 2nd layer).

3. *Design of Parasitic Element Arrangement Construted on TEFLON Substrate*

The MPMAA design for the 60-GHz band is presented. We use the moment

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method as the calculation method and assume that the ground plane is infinite. We adopt the multi-layer TEFLON substrate (ε_r = 2.2, tanδ = 0.0007 at 10 GHz) as the antenna substrate due to its superior characteristics such as a high gain and a wider bandwidth. The simulation model is shown in Fig. 2. The size of the feeding element is 0.30 λ_o x 0.30 λ_o and the feeding point is 0.01 λ_o away from the center of the patch. The size of the parasitic elements mounted on the first parasitic layer is 0.32 λ_o x 0.32 λ_o and the patch size of the second parasitic layer is 0.28 λ_o x 0.28 λ_o. The four parasitic elements mounted on the first parasitic layer are arranged such that they are equidistant from the center of the feeding MSA. For convenience, the width (horizontal direction) is expressed such that the width of the first parasitic layer and that of the second parasitic layer are w1 and w2, respectively, as shown in Fig. 2. In addition, t1 and t2 represent the substrate thicknesses of the first and second parasitic layers, respectively. The calculated maximum absolute gain and the relationship between w1 and w2 that achieve the maximum value when w2 is varied are shown in Fig. 3. Here, t1 and t2 are set to 0.25 mm and 0.55 mm, respectively. In this figure, it is clear that w1 is proportional to w2. Next, the relationship of the maximum absolute gain and the radiation efficiency versus w2 is shown in Fig. 4. Here, the substrate thickness parameters are the same. In this figure, it is clear that the maximum absolute gain is 11.1 dBi and that the radiation efficiency is 91%, when w1 is 0.22 λ_o and w2 is 0.28 λ_o. Moreover, the antenna achieves the maximum radiation efficiency of 97% when w2 is 0.32 λ_o. We must also clarify the effect of the variation in the substrate thickness for the parasitic elements. The dependency of the gain on t1 and that on t2 are shown in Fig. 5 and Fig. 6, respectively. Here, w1 is 0.22 λ_o and w2 is 0.28 λ_o. In these figures, it is clear that the manufacturing margins of t1 and t2 are approximately 150 μm and 200 μm, respectively, and the gain reduction is less than 0.5 dB. And it is clear that the substrate thickness precision of the conventional multi-layer TEFLON substrate process is enough to make this proposed antenna. Figure 7 shows the frequency characteristics of the proposed antenna. In this figure, it is clear that the bandwidth is 2.6%, when the S11 characteristics are less than -10 dB.

4. *Prototype Antenna*

We manufactured a prototype antenna that is constructed using the TEFLON substrate to confirm the design in the 60-GHz band. We use the microstrip line and the via hole to feed the MSA, which demonstrates the operation of the feeding element shown in Fig. 2. Two parasitic layers are arranged such that the size and location of the MSA and parasitic elements, the substrate thickness, and the location of the feeding points achieve the maximum absolute gain as described in the previous section. The fabricated prototype antenna chip size is 10.0 mm x 10.0 mm x 1.1 mm. The measured gain is approximately 7 dBi including the loss of the connection between the antenna and the connector. The reason for the gain reduction is due to the dispersion of the substrate thickness constructed on the multi-layer TEFLON substrate because the multi-layer TEFLON substrate uses bonding film that is several tens of micrometers thick to bond the substrate layers.

5. *Conclusion*

This paper proposed a high efficiency MPMAA constructed on a multi-layer TEFLON substrate for millimeter-wave system-on-package modules. The design and performance of the proposed array antenna were described. Moreover, we showed the operation of this antenna such as the return loss characteristics and the radiation characteristics in the 60-GHz band. It is clear that the antenna radiation efficiency is greater than 91% when the achieved maximum gain is 11.1 dBi. Additionally, we manufactured the prototype antenna for the 60-GHz band. Now, we are adjusting and examining the manufactured antenna.

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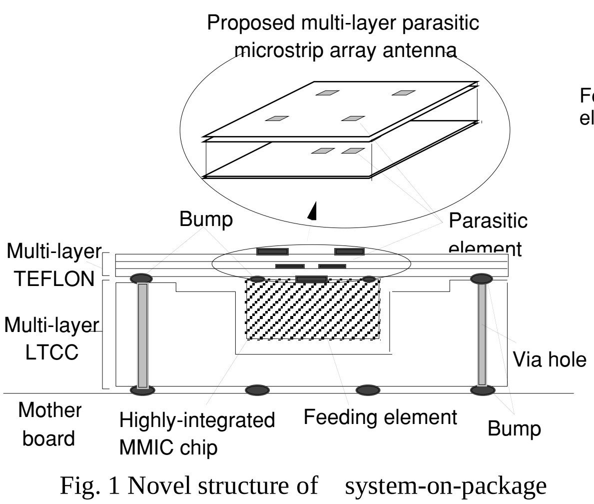

Fig. 1 Novel structure of system-on-package integrated with antenna

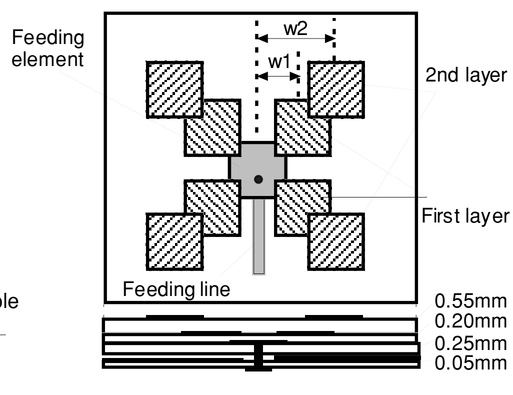

Fig. 2 Antenna model

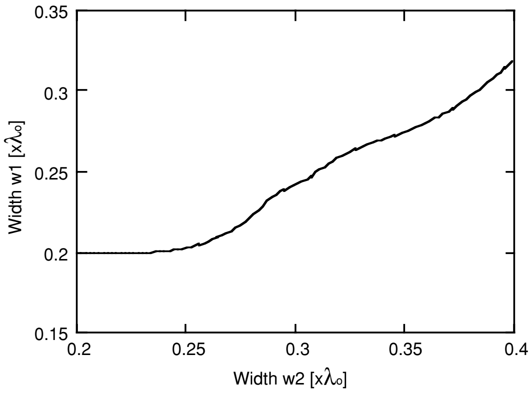

Fig. 3 Relationship between w1 and w2 that achieves the maximum absolute gain

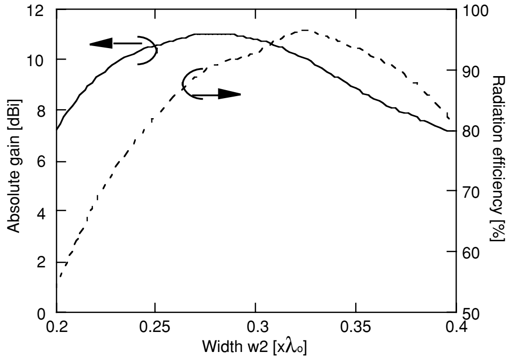

Fig. 4 Absolute gain and radiation efficiency characteristics versus w2

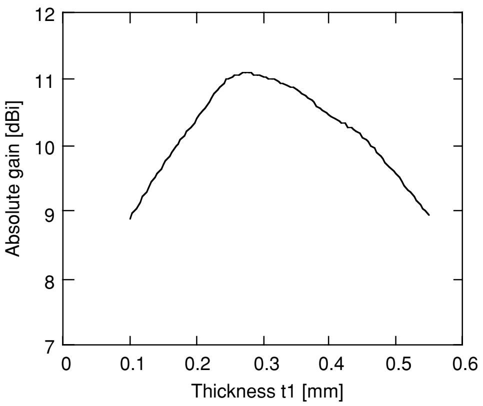

Fig. 5 Absolute gain characteristics versus substrate thickness t1 (t2=0.55 mm)

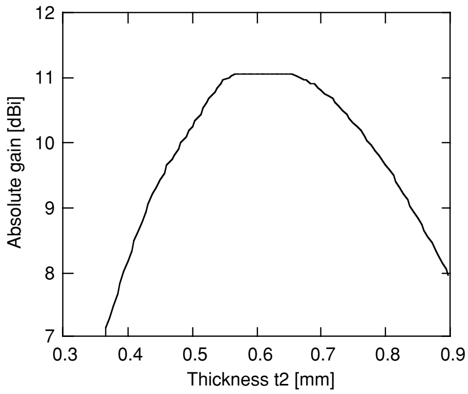

Fig. 6 Absolute gain characteristics versus substrate thickness t2 (t1=0.25 mm)

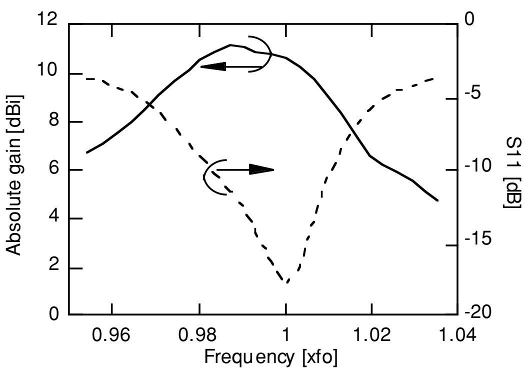

Fig. 7 Calculated frequency characteristics