WIDEBAND COAXIAL-LINE FEED FOR POST-WALL WAVEGUIDE IN MILLIMETER WAVE BAND

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1. Introduction

The authors propose a millimeter-wave band interface between a post-wall waveguide and a microstrip line through a coaxial structure as shown in Fig.1. The specific application of the proposed transformer is to connect a post-wall waveguide feed antenna and a microstrip-line-based RF circuit with small loss in order to realize cost-effective 60 GHz modules [1]. The modules have been developed for general purpose millimeter-wave band wireless systems, which use the 60 GHz band where a wide bandwidth more than 7.0 GHz (11.7 %) is prepared for un-licensed use in Japan. Design of a low loss transformer between an RF circuit and an antenna is essential for the high performance and the low cost of the modules.

A post-wall waveguide is an attractive candidate for transmission lines with low loss and simple fabrication in the millimeter-wave bands [2]. The post-wall waveguide is fabricated by simply making via-holes in a dielectric substrate and metal-plating their walls. Therefore, we proposed the transformer between microstrip line and post-wall waveguide via coaxial cable, consisting of many via-holes as in Fig.1. Authors have developed the microstrip line to the coaxial line transformers [3]. This paper focuses upon another part of the transformer, that is, the coaxial line and the post-wall waveguide transformer.

Two kinds of dielectric substrates are considered, PTFE (Poly Tetra Fluoro Ethylene) and LTCC (Low Temperature Co-fire Ceramic) substrates in practical manufacturing. A PTFE substrate has a low loss tan $\delta = 0.00085$ at 10 GHz as shown in Table.1. Large sized antennas of gain up to 35dBi can be fabricated in a PTFE substrate. The substrate is fiberglass-reinforced and mechanically strong; precise fabrication such as length control of open-ended pins is difficult. A LTCC substrate has a multilayer structure of several laminated layers. Embedded passive components and interconnecting lines can be placed between adjacent layers in the substrate. Since the loss of the LTCC is high (tan $\delta = 0.002$), a relatively small antenna with gain less than 20 dBi is suitable for this material. The cost effective structure for manufacturing is important. We have proposed feeding structures as presented in Fig.1 to satisfy different features of materials. From a manufacturing point of view, the connection between an inner conductor of a coaxial line and a post-wall waveguide is sensitive to fabrication errors in millimeter-wave bands. The reflection and transmission characteristics of the transformers are investigated and verified experimentally in the 60 GHz band. Not sufficient but reasonable characteristics are presented.

2. Structure

Figure 1 shows a bird's-eye view of the proposed transformers between a post-wall waveguide and a microstrip line. The microstrip line is connected to the inner conductor of the coaxial line and feeds the post-wall waveguide. Several posts are located coaxially around the inner conductor on the same layer of the microstrip line. These posts serve as the outer conductor of the coaxial structure and suppress undesired leakage into the substrate [3]. The inner conductor and the posts are manufactured with metal-surface via-holes in a dielectric substrate. The structure is symmetric with respect to the center axis of the waveguide. We have proposed three types of transitions between the inner conductor and the post-wall waveguide, that is, (a) for a LTCC substrate and (b) and (c) for PTFE substrate.

Structure (a) is an open-ended structure [4]. The inner conductor is cut at the middle of a

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dielectric substrate. The input impedance is controlled dynamically by changing the insertion length *h* in a LTCC multilayer substrate and the position of the shorting wall *s*. The insertion length *h* is controlled precisely by placing the end of the inner conductor on an interface between adjacent layers as shown in Fig.1 (a). It assures the manufacturing repeatability of the transformer. This structure, however, is not suitable for a PTFE substrate since the control of the length by metallization of a blind alley is very difficult and type (a) can not be mass produced for the PTFE.

Figure 1 (b) presents the short-ended structure [5]. The inner conductor penetrates a PTFE substrate in this structure and then metallization of the inner conductor is easy. Unfortunately, the inner conductor couples excessively with the field in the waveguide and the input impedance is much larger than 50 Ω. Reflection suppression over a broad bandwidth would be difficult even if the posts are located to suppress the reflection at a specific frequency. Another type of transformer with a short-stepped structure is shown in Fig.1 (c) [5]. The inner conductor in a PTFE substrate has a stepped structure at the end. The stepped structure decreases the input impedance and matches to a coaxial line. Precise manufacturing and metallization of the inner conductor are promising in a PTFE substrate.

3. Design

The transformers are designed at 60 GHz to suppress the reflection over a wide frequency range for given dimensions of post-wall waveguides. A post-wall waveguide is replaced with a metal-wall waveguide with equal guided wavelength in the design [2]. The insertion length *h* (in (a) and (c)), the step width *d* (in (c)), the short position *s* and the reflection canceling posts position *p*, *q* (in (b)) are determined by iteration in a few turns. We use an electromagnetic field simulator based on FEM, "Ansoft HFSS", for the design. Table 1 summarizes the parameters of the LTCC and the PTFE substrates. Structure (a) is connected to a transition between a microstrip line and an inner conductor in the design [3]. Figure 2 and 3 show the calculated frequency characteristics of the reflection for the feeding structures. The reflection of structure (a) has a very wide frequency characteristic and remains less than −15 dB in the frequency range higher than 55 GHz. In the short-ended structure (b), the bandwidth less than −15 dB is not wide (2.0 %). On the contrary, the short-stepped structure (c) gives a wide bandwidth of 16.7 % where the reflection is below −15 dB.

4. Experimental Results

A. Reflection

Figure 2 shows the measured frequency characteristics of the reflection for the open-ended structure (a). It is connected to a transformer between a microstrip line and an inner conductor [3]. A bandwidth of 11.3 % is realized for the reflection smaller than −15 dB. The measured reflection increases up to a level of −16 dB from −24 dB in the calculation at 60 GHz while it does not exceed −10 dB in a frequency range higher than 55.5 GHz. Figure 3 presents the measured reflections of the structures (b) and (c). The short-ended structure (b) has a very narrow bandwidth, 1.1 %, for the reflection less than −15 dB. The discrepancy between the analysis and the measurement is small so that accurate manufacturing is assured. The reflection of the structure (c) degrades to −12.5 dB in the measurement from −40.5 dB in the design. The frequency range below −10 dB is wide, 56.0−64.5 GHz (14.2 %). The structure (a) and (c) fulfill the required bandwidth of 7.0 GHz for the reflection less than −10 dB.

B. Transmission Loss

We fabricated various lengths of straight post-wall waveguides with the open-ended structure (a) and the short-stepped structure (c) at both ends and measured the transmission coefficients. From the measured transmission characteristics as a function of the waveguide length, we calculate the insertion loss of the transformer and the transmission loss per centimeter. Figures 4 and 5 show the frequency dependence of the measured transmission of each waveguide, the loss per centimeter and the insertion loss for the structure (a) and (c). The thin lines show the transmission coefficients. The loss increases as the waveguide becomes longer. As for Fig.5, the thin lines are the transmission after eliminating the reflection loss of the input aperture in order to compensate for the difference in the reflection loss among the waveguides. The loss of the post-wall waveguide is around 0.69 dB/cm in (a) and 0.06 dB/cm in (c) at 60 GHz. The waveguide loss of (a) is approximately 10 times as large as that of (c). Assuming 1 cm as the typical size of the connection, we can estimate the total connector loss of about 0.82 dB and 0.43 dB for the structures (a) and (c), respectively.

C. Overall reflection and gain of a prototype antenna with transformer (C)

We manufacture a post-wall waveguide planar antenna [2] fed by the short-step structure (c) as shown in Fig.6. A post-wall feed waveguide in the antenna has several coupling windows to excite a TEM wave in a parallel plate waveguide, where slot pairs are arrayed and designed to obtain a uniform aperture distribution. Figure 7 shows the frequency dependence of the overall reflection at the input port and the gain of the antenna. The reflection is around −8.9 dB (13 %) at 60.1 GHz but is degraded otherwise, which may be improved in the next antenna design. This degradation seems to come from the accumulated reflection from several coupling windows in the post-wall feed waveguide. The peak of the measured antenna gain is 26.3 dBi with 45.3 % efficiency at 60.1 GHz for the aperture size 40×46 mm. The frequency range in which the gain is larger than 25 dBi is 59.6−60.8 GHz (2.0 %). The gain loss due to the reflection is about 0.6 dB (100−13 % = 87 %) around 60 GHz but is much larger otherwise. In order to identify the gain loss due to these, the thin dotted line in Fig. 7 indicates the antenna gain if not for the reflection loss. This result reveals that the antenna with the transformer would have the potential for efficiency up to 60 %.

5. Conclusion

The authors have proposed a millimeter-wave band interface to a post-wall waveguide through a coaxial structure and investigated the fabrication tolerance and the reflection characteristics, where PTFE and LTCC substrates are used. A 60.0 GHz model transformer (a) gives 11.3 % bandwidth for the reflection below −15 dB. We have found that the transmission loss is around 0.69 dB/cm and the overall connector loss with 1cm post-wall is 0.82 dB. As for the PTFE substrate, two kinds of the structures as shown in Fig.1 (b) and (c) are proposed and discussed. The analysis result of the short-ended structure (b) predicts well the measured bandwidth. The short-stepped structure (c) gives 14.2 % bandwidth for the reflection smaller than −10 dB. The transmission loss of a post-wall waveguide is around 0.06 dB/cm and the loss of the transformer (c) is 0.43 dB. We fabricated a 40×46 mm size post-wall planar antenna with the structure (c). The peak of the measured antenna gain is 26.3 dBi with 45.3 % efficiency at 60.1 GHz, though the bandwidth is drastically narrowed due to the imperfect reflection characteristics of the array. Post-wall antenna design with better and wide-banded reflection characteristics, is left for future study.

Acknowledgements

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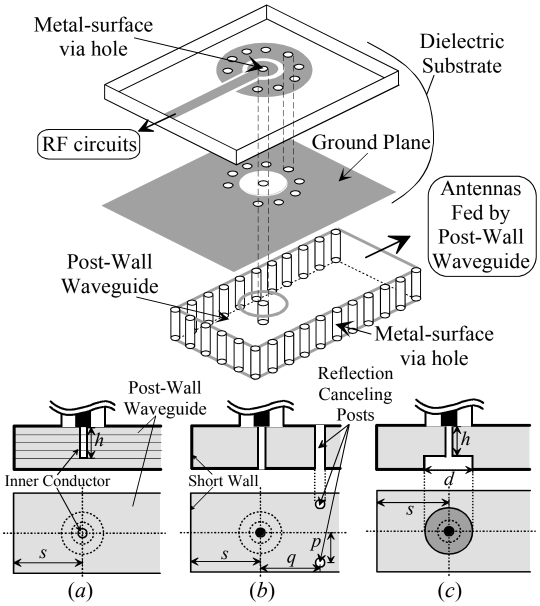

(a) LTCC substrate
(b)
(c) PTFE substrate

Fig.1 Feeding Structures

Table.1 Substrate Parameters

	LTCC substrate	PTFE substrate
Thickness	0.8mm	1.2mm
Permittivity	6.28	2.17
tan δ	0.002	0.00085
Posts diameter	0.2mm	0.5mm
Post spacing	0.4mm	1.0mm

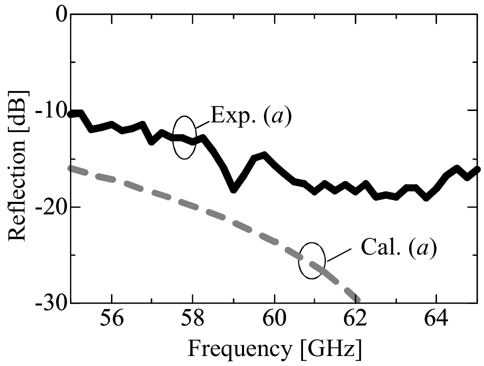

Fig.2 Reflection of Structure (a)

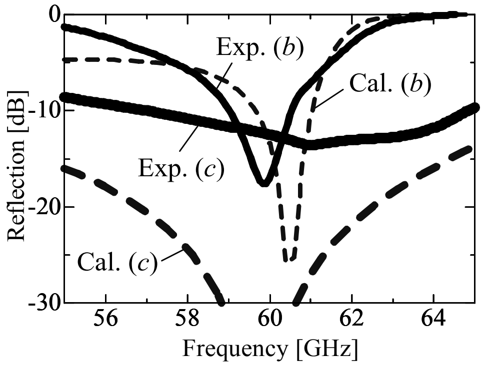

Fig.3 Reflection of Structure (b) and (c)

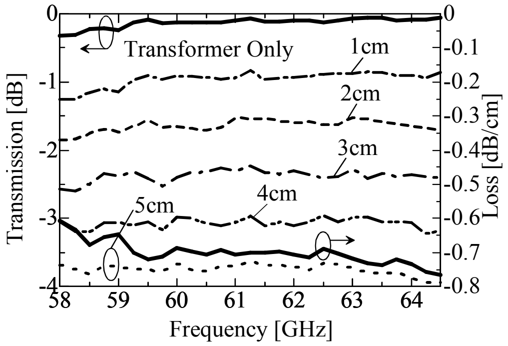

Fig.4 Transmission Loss of Structure (a)

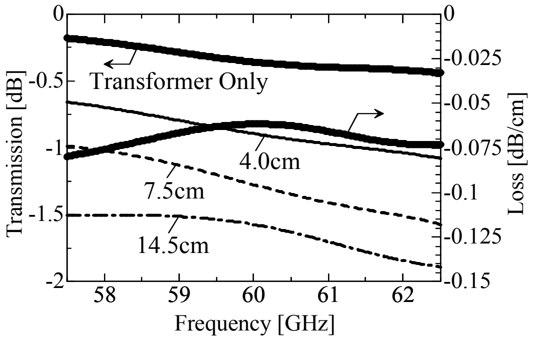

Fig.5 Transmission Loss of Structure (c)

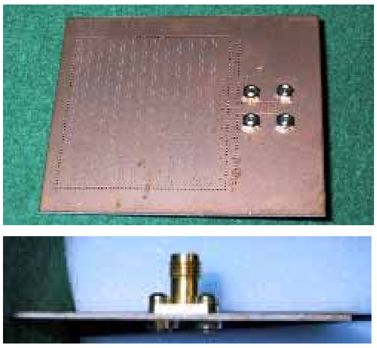

Fig.6 Post-wall waveguide slot array antenna

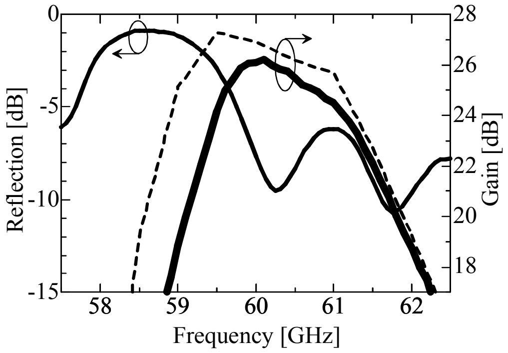

Fig.7 Reflection and gain of antenna