Experiments on Dielectric Leaky-Wave Antennas with Parallel-Plate Waveguide Feed

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1. Introduction

As highly efficient and low cost planar antennas in millimeter- or quasi-millimeter-wave bands, dielectric leaky-wave antennas (DLWA) have been developed [1],[2] which consists of dielectric substrates periodically loaded by parallel metallic strips. One of the key technologies for DLWAs is a feed that launches a dominant surface-wave mode into the substrate slab. We have developed several types of the feeds so far [2]-[4]. Recently we proposed a new feed using a parallel-plate waveguide excited coupling slots which provides high antenna efficiency and good compatibility with a planar RF integrated circuit, and clarified its feasibility by computer simulation [5].

In this paper, we will describe experimental results of two types of 24 GHz high gain DLWA having the proposed feed.

2. Configuration of the DLWA

A typical DLWA consists of a dielectric substrate slab placed on a ground plane which is periodically loaded by parallel metallic strip pairs, and a feed which excites a surface-wave of TM_{01}-mode into the substrate. Each strip pair, being separated almost a quarter guide-wavelength of the TM_{01}-mode, cancels reflections each other caused by the strips[2].

We developed a novel feed with good compatibility to printed RF circuits. The feed is composed of a microstrip line (MSL) printed on the surface of the bottom substrate, coupling slots on the ground plane, and a parallel-plate waveguide in the upper layer as shown in Fig.2. The feed MSL has a T-junction, two main lines, and branch stubs periodically loaded to the main lines with a spacing of λg, the guide-wavelength of the main MSL as shown in Fig.3. Each branch stub is electromagnetically coupled to the corresponding slot.

In general configuration, the dielectric slab waveguide is composed of a dual-layer substrate. The lower layer has thickness t_1, permittivity ε_1, while the upper layer has t_2 and ε_2, respectively, where ε_1 is higher than ε_2. The excitation of the substrate is carried out by using a parallel-plate waveguide as shown in Fig.2.

As a special case, a single-layer structure is available where the upper layer is air, i.e. $\varepsilon_2 = 1.0$. In this case, a metallic roof is required as the upper plate of the parallel-plate waveguide.

We developed two DLWAs with different types of the feed. One (Model A) is single-layer configuration. In this case a metallic roof is mounted over the substrate. The other (Model B) has a dual-layer structure. In this case, because the upper plate of the parallel-guide section can be fabricated by printing technology, mass productive and low cost planar antennas are expected.

3. Design example of DLWAs

The decomposed structures of Mode A and Mode B antennas are shown in Fig. 4 (a) and (b), respectively. The design specifications are listed in Table 1. For Model A, Rogers substrate (RO4003C, ε_1=3.55), while for Model B, Nippon Pillar substrate (ε_1= 6.04, ε_2 = 2.17) were used. The target gain of these antennas was specified to be higher than 27 dBi, and Taylor aperture distributions providing -20 sidelobes was assumed in the two orthogonal planes. The parameters of the feed, such as slots, stubs, matching notches in Fig.3 were determined so as to achieve the desired aperture distribution along the feed lines. We applied two design steps. In the first step, we analyzed a transmission line loaded by periodic lumped loads using ADS eesof, and determined impedances of them which provide the desired power distributions to the loads. In the second step, we determined the structural parameters of the slots and the branch stubs which give the equivalent load impedances by applying ADS Momentum simulator.

4. Measured results and considerations

We developed the two types of DLWA described above. The photograph of Model A is shown fig. 5. Fig. 6 and Fig. 7 show frequency characteristics of measured gain and reflection (S_{11}) for Model A and Model B antennas, respectively. Fig. 8 and Fig. 9 also show radiation patterns for both antennas.

Model A achieved the maximum gain of 27.9 dBi at 24.15 GHz, sufficiently higher than the specification, which corresponds to approximately 40 % antenna efficiency. Furthermore, from Fig. 7, we can see that the E-plane pattern has a beam tilt of 5 degrees in the minus direction as designed in order to reduce reflections due to the radiating strips. All the sidelobes are maintained below –20 dB. From these results, we can conclude that Model A is well designed and provides satisfactory antenna performances.

On the other hand, Model B exhibits lower gain and frequency shift, i.e. 26.8 dBi at 23.8 GHz, and a distorted gain curve, and slightly higher sidelobes than -20 dB. Furthermore from the E-plane radiation pattern in Fig. 9, the beam tilt cannot be seen in spite of the same design as Model A. The reason of these discrepancies can be considered due to differences of the dielectric constants of the dual substrate layers between the designed and the actual values which causes beam tilt in the radiation pattern and non-in-phase distributions along the feed line. This difficulty can be solved by adjusting the dielectric constants taking account of the measured beam tilt.

5. Conclusions

We made two prototypes of the DLWA with a parallel–plate waveguide feed through coupling slots and verified their effectiveness experimentally. Mode A, a single layer configuration, achieved satisfactory antenna performances, 27.9 dBi gain, 40 % antenna efficiency, and below -20 dB sidelobes. Mode B, a dual-layered structure exhibited a lower gain, the frequency shift of the maximum gain, and the different beam direction compared with the design based on computer simulation. However these problems will be solved by using the actual ε values of dielectric substrate in the antenna design.

The proposed antenna provides not only highly efficient planar antenna in quasi-millimeter- or millimeter-wave bands, but also advantages such as mass-productivity, low cost, and good compatibility with planar RF integrated circuits.

References

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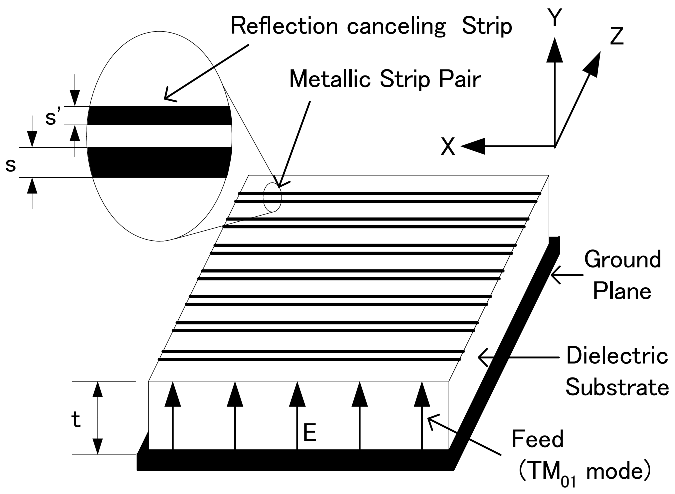


Fig. 1 Dielectric leaky-wave antenna (DLWA)

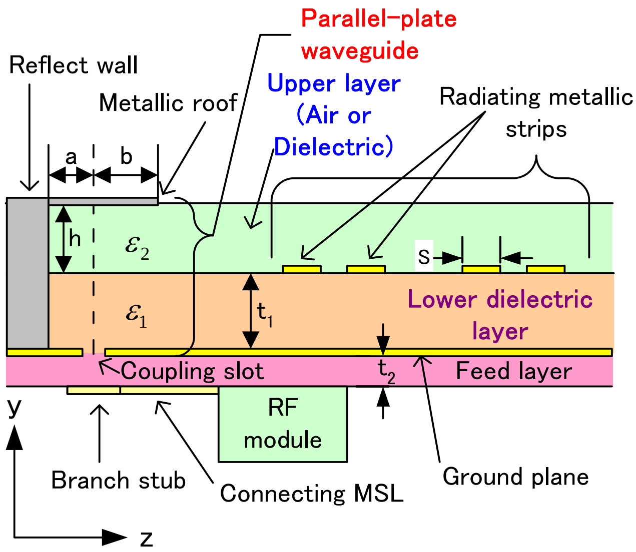


Fig. 2 Cross-sectional view of the antenna

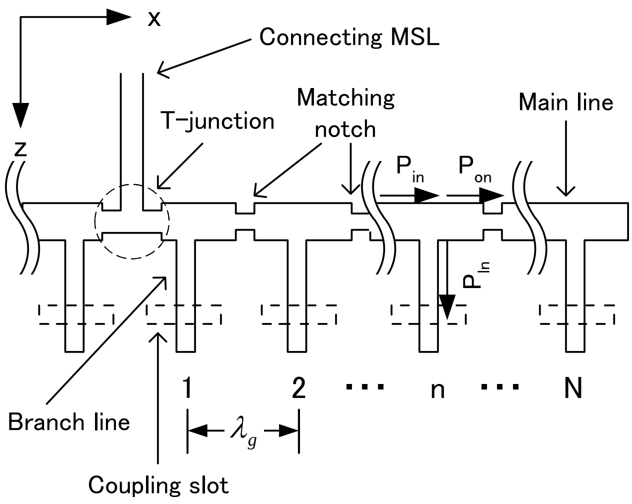
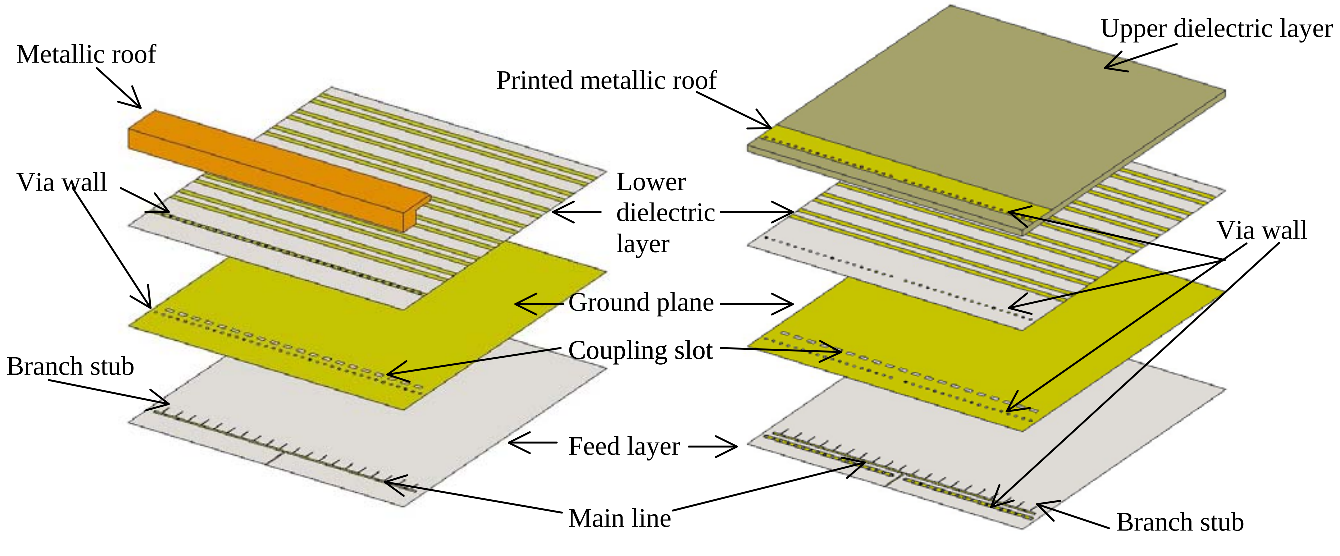


Fig. 3 Microstrip feed line

Fig. 5 Photograph of Model A



(a) Model A

(b)Model B

Fig. 4 Structure of the designed antenna

Table 1: Specifications.

Type	Model A	Model B
Frequency	24.15 GHz ±100 MHz	
Dielectric substrate (lower and feed layer)	Rogers RO4003C (ε_r = 3.55, tan δ = 0.004)	Nippon Pillar NPC-F600A (ε_r = 6.04, tan δ = 0.0021),
Dielectric substrate (upper layer)	Air	Nippon Pillar NPC-H220A (ε_r = 2.17, tan δ = 0.0005)
Size of radiating section	150 mm (W) × 140 mm (L)	
Substrate thickness (t_1)	1.4 mm	1.0 mm
Height of upper-layer (h)	3.0 mm	1.6 mm
Antenna Gain	> 27 dBi	
Sidelobe level	< -20 dB	
Beam tilt (E-plane)	-5 deg.	

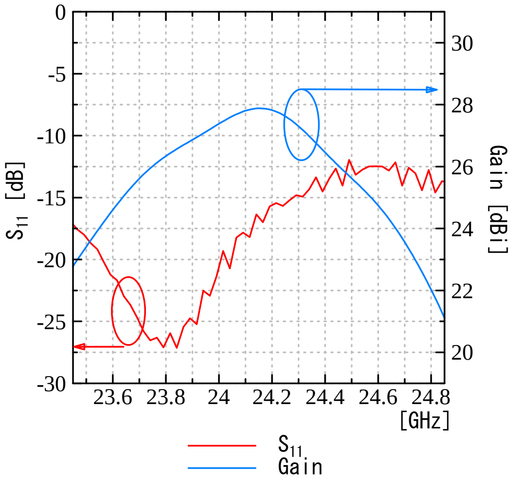


Fig. 6 Gain and S11 (Model A)

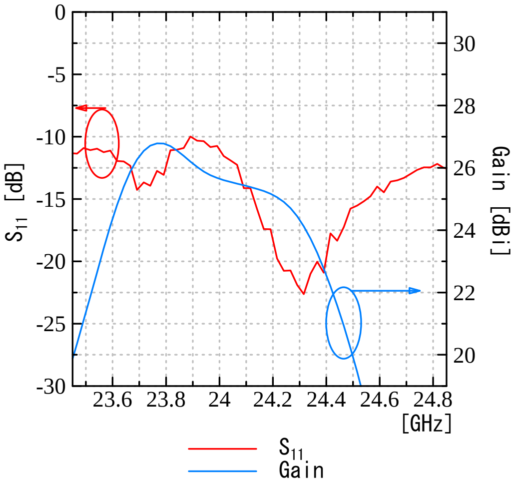


Fig. 7 Gain and S11 (Model B)

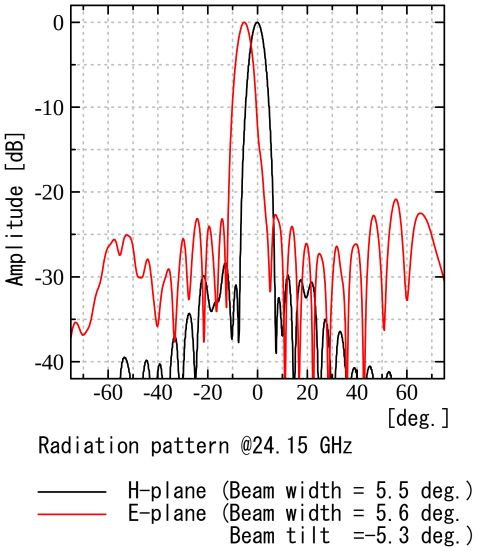


Fig. 8 Radiation pattern (Model A)

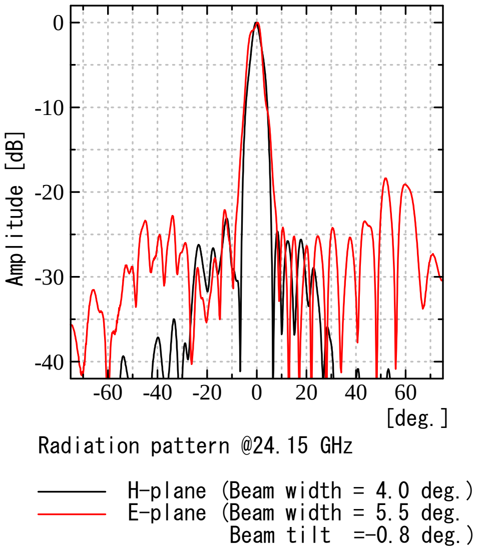


Fig. 9 Radiation pattern (Model B)