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Dual-Layer Parallel-Plate Waveguide Feed for Dielectric Leaky-Wave Antenna

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1. Introduction

Recently, developments of Radio systems using millimeter- and quasi-millimeter-waves, such as automotive radars, fixed wireless access, or high-speed wireless LANs have been promoted worldwide. As planar antennas for such applications, microstrip antennas, and waveguide slot antennas are most well known.

A dielectric leaky-wave antenna (DLWA) [1], [2] is promising candidate for these applications, because it exhibits advantages such as low-cost, low profile structure and good compatibility with planar integrated circuits, and it performs relatively high antenna efficiency compared with microstrip antennas. In DLWAs developed so far, dielectric substrates have been excited by a rectangular waveguide [3], a parabolic reflector [2], and a waveguide slot [4]. Afterwards, a planar leaky-waveguide feed immersed within the substrate was reported [5]. It provides the optimal design both for the feeding and the radiating sections independently, but it has a problem that leak radiation from the feed occurs and affects the radiation pattern of the antenna.

In this paper we will propose a novel feed system for DLWA consisting of a dual-layer parallel-plate waveguide which suppresses the leak radiation and provides a highly efficient DLWA. Design method and the simulated performances of a 24 GHz high gain antenna will be described.

2. DLWA with Dual-Layer Parallel-Plate Waveguide Feed

2.1 Configuration of DLWA

As shown in Fig. 1, a typical DLWA consists of a dielectric substrate placed on a ground plane which is periodically loaded by parallel metallic strip pairs in the x-direction, and a feed which excites a surface-wave of TM_{01} mode into the substrate. It is well known that a structure composed of surface-waveguide with periodic perturbations becomes a leaky-wave antenna. Each strip pair, separated almost a quarter guide-wavelength of the TM_{01} mode of the dielectric waveguide, cancels reflections each other caused by the strips [2].

2.2 Structure of the feed

The feed system is composed of feed microstrip lines(MSL) printed on the bottom substrate layer, coupling slots, and the parallel-plate waveguide in the upper layer as shown in Figs. 2. The microstrip feed lines have a T-junction, two main lines, and branch lines periodically loaded to the main lines with the spacing of λ_g, the guide wavelength of the main MSL as shown in Fig.3. Each branch line is coupled to a corresponding slot. The lengths of the slot and the matching stub attached to the top of the branch line are controlled so as to achieve the desired aperture distribution.

The parallel-plate waveguide consists of dual layers, i.e. the dielectric layer of thickness t_1, and air layer of height h. This configuration can excite efficiently TM_{01} mode into the substrate.

2.3 Design method

Since the feed consists of a planar transmission lines (2-dimensional) and the slots and the parallel-plate (3-dimensional), we designed these separately by using different simulators.

First, from the desired aperture distribution, such as Taylor distribution, the power to be supplied to the n-th branch is calculated sequentially for all n (n=1, 2, ..n,..N) assuming the transmission loss of the main line. Then we obtain S_{31} and S_{21} for n-th branch as shown in Fig.4.

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The second step is to obtain the impedance Z_L of the load connected to the branch and parameters of the matching section, w_m and d_m, in the main line. As a matching section, we developed a notch in the main line as shown in Fig.3. By expressing the slot and the matching stub in terms of Z_L, we can determine the optimal parameters, Z_L, w_m and d_m which achieves the desired S_{21} under the condition of S_{11} to be minimum by using the optimizing function of a 2-dimensional circuit simulator, such as ADS-eesof. Fig.5 shows a computed example of Z_L versus S_{21}.

The third step is to optimize the lengths of the slot and the matching stub which gives the required load impedance, Z_L. This was carried out using 2.5-dimensional simulator. We used ADS-Momentum. Fig. 6 shows computed slot- and stub-lengths to realize the load impedance, Z_L.

3. Design Example of a DLWA and Its Radiation Characteristics

3.1 Specifications and design

We designed a 24 GHz DLWA with a feed mentioned above and investigated the radiation characteristics. The specifications for this antenna are summarized in Table 1. In order to achieve sidelobes lower than -20 dB in the E- and H-planes, we adopted Taylor distribution for -25 dB sidelobes in both planes. Fig. 7 illustrates a decomposed structure of the antenna.

The thickness t_l of the radiating dielectric layer was determined to be 1.4 mm from consideration on control of radiation rate per unit length over the aperture [5]. Corresponding to t_l, the height h of the air layer was optimized so that the coupled energy through each slot may excite the radiating dielectric layer efficiently. Finally, we determined the parameters of the parallel-plate waveguide as h = 3.0 mm, a = 4.95 mm, and b = 5.0 mm.

In the radiating section, the spacing between the strip pairs is slightly changed from a guide-wavelength, so that we may avoid all reflections to be added in-phase. This causes a small beam tilt from the boresight. In our case, it was approximately two degrees. The aperture distribution for Taylor pattern in the E-plane is obtained by adjusting strip width “ s ” and “ s’ ”.

3.2 Performances of the antenna

In Figs. 8 and 9, the simulated radiation patterns in the H-plane and the E-plane are shown, respectively. The half-power beam widths of these patterns are 5.0 and 5.4 degrees. The sidelobes indicate the desired aperture distributions are almost realized in the both planes. In Table 2 the estimated gain factors are listed. The feed efficiency is defined as the ratio of all output power supplied to the load impedance Z_L versus the input power. The overall antenna efficiency becomes approximately 48 %. The major loss factors are transmission loss of the microstrip main line and radiating dielectric waveguide. They are 0.24 dB / 10 mm, and 0.08 dB / 10 mm, respectively.

4. Conclusion

A DLWA with a dual-layer parallel-plate waveguide feed was proposed. The antenna makes optimal design possible both for the feed section and the radiating section individually, and can suppress leakage radiation from the feed. Computer simulation showed effectiveness of the feed, and a 24 GHz planar antenna was obtained. This 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 integrated circuits. At present, we have been developing an antenna, its result will be presented in the near future.

References

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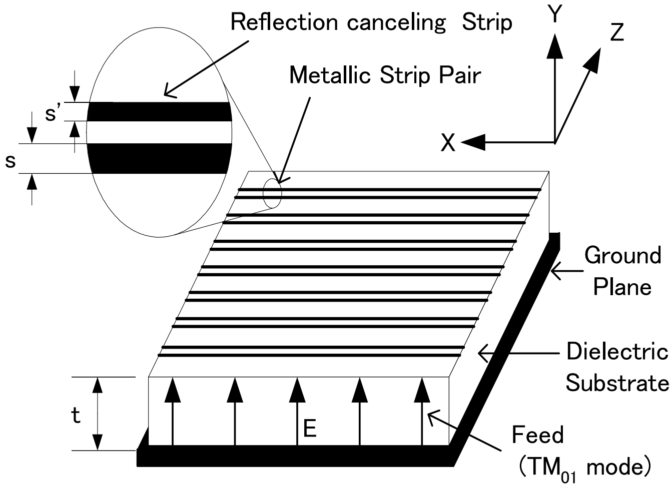

Fig. 1 Dielectric leaky-wave antenna (DLWA)

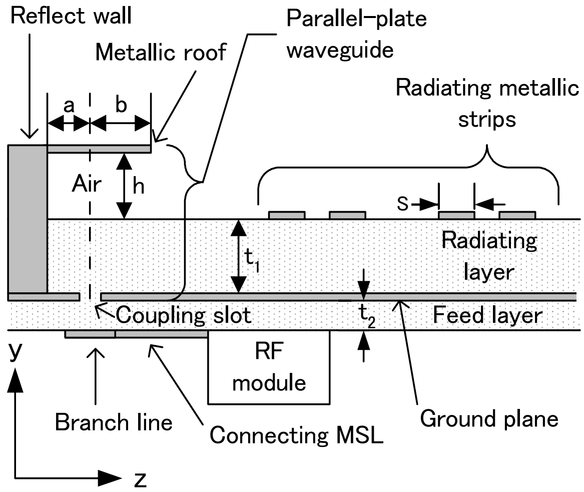

Fig. 2 Cross-sectional view of the antenna

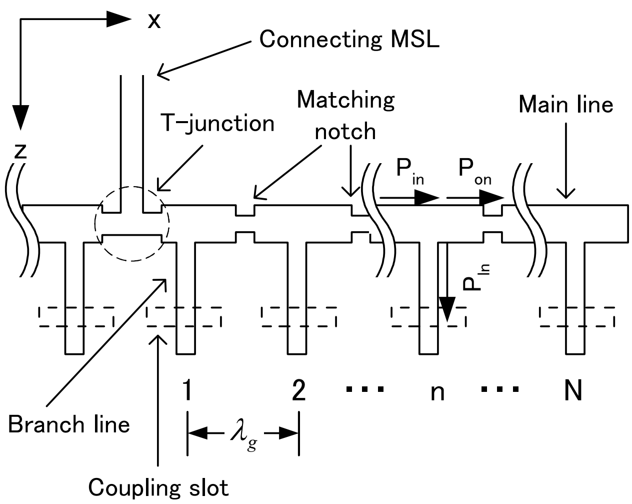

Fig. 3 Microstrip feed line

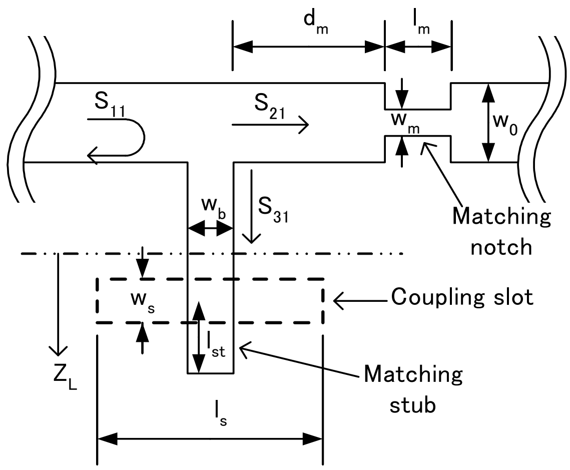

Fig. 4 Branch section

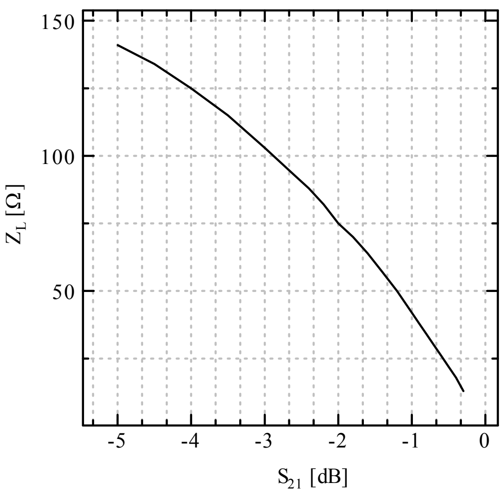

Fig. 5 Load impedance Z_L vs. S_{21}

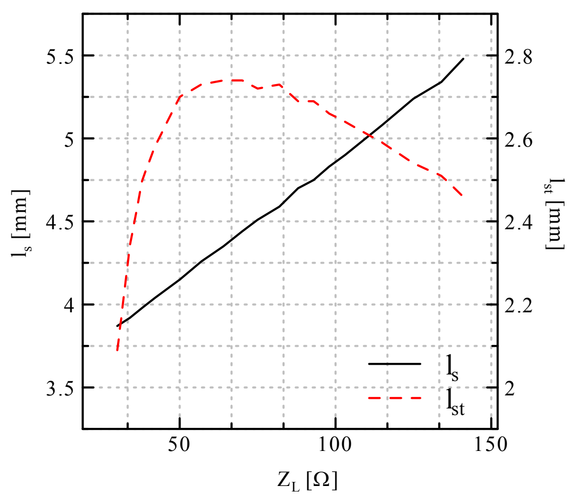

Fig. 6 Slot and stub lengths vs. Z_L

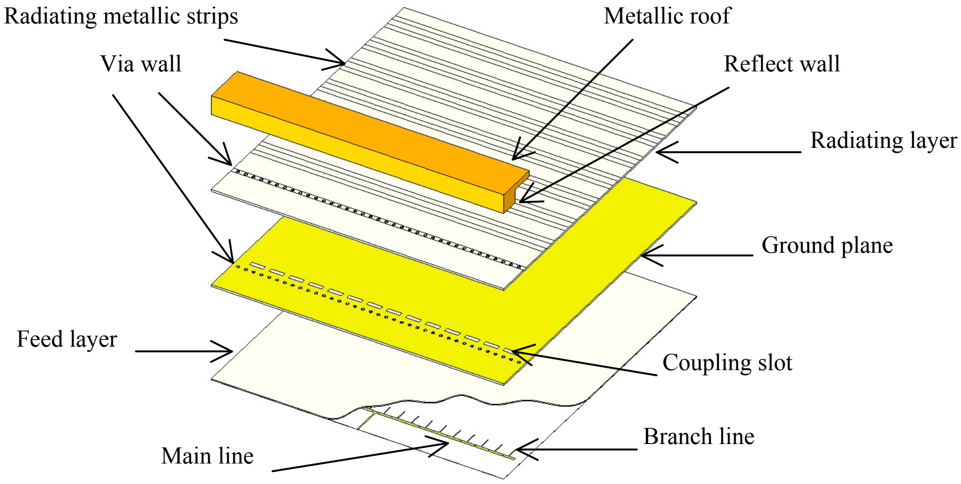

Fig. 7 Structure of the designed antenna

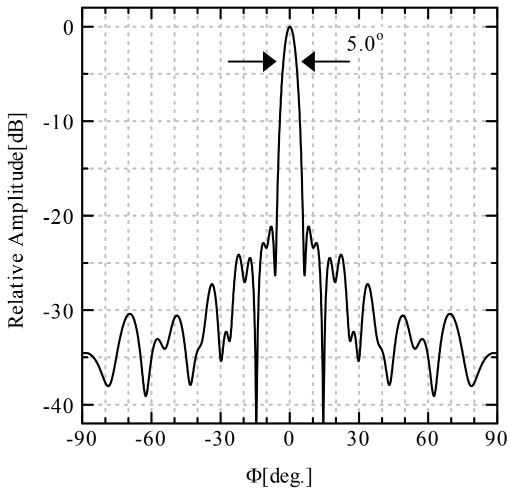

Fig. 8 Radiation pattern in the H-plane

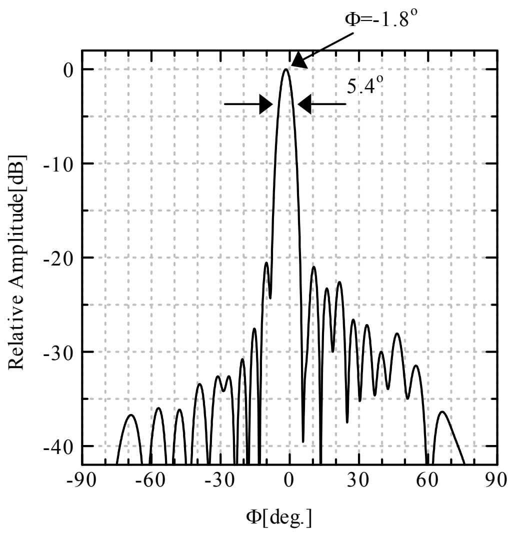

Fig. 9 Radiation pattern in the E-plane

Table 1: Specifications

Frequency	24.15 GHz ± 100 MHz
Dielectric substrate	Rogers RO4003C (ε_r = 3.55, tan δ = 0.004)
Size of radiating section	150 mm (W) × 140 mm (L)
Substrate thickness (t_1)	1.4 mm
Height of air-layer (h)	3.0 mm
Antenna Gain	> 27 dBi
Sidelobe level	< -20 dB

Table 2: Estimation of Loss Factor and Antenna Gain

	Loss factor	dB
Feed section	• Feed efficiency of leaky-waveguide (Transmission loss and residual power included)	-0.7
	• Coupling-slot loss	-0.4
	• Connecting MSL loss (including T-junction)	-0.4
	• Aperture efficiency in H-plane (-25 dB Taylor)	-0.4
Radiating section	• Radiation efficiency (Transmission loss of dielectric-guide and residual power included)	-0.8
	• Aperture efficiency in E-plane (-25 dB Taylor)	-0.4
Overall Antenna	• Total antenna efficiency	-3.2 (47.8 %)
	• 100 % antenna gain (150 × 140 mm aperture)	32.0 dBi
	• Predicted antenna gain	28.8 dBi