A MILLIMETER-WAVE DIELECTRIC LEAKY-WAVE ANTENNA WITH LOW-PROFILE AND HIGH-EFFICIENCY

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1. Introduction

In millimeter-wave applications, such as automotive radars or high-speed LANs, high efficiency antennas are key components. In general, antenna efficiency deteriorates due to losses within the conductor and the dielectric materials. Conductor loss, in particular, is the major cause of losses in microstrip antennas, triplate antennas, and waveguide-slot antennas. Leaky-wave antennas, LWA, based on dielectric waveguide loaded with metallic strips, are considered promising. By concentrating the electromagnetic energy in the waveguide, the electric current on the ground plane of a LWA can be significantly reduced, thus allowing the realization of millimeter-wave antennas with high efficiency. This type of antenna also has other advantages such as a low-profile structure, low-cost, and electronic scanning capability [1], [2], [3].

In this paper, we will describe several new techniques to reduce conductor loss and to synthesize a desired radiation pattern accurately. Then we will show a prototype model antenna developed at 76.5 GHz and its radiation characteristics which realize almost 60% efficiency.

2. A Dielectric LWA with Reduced Conductor Loss

2-1 Principle of a Dielectric LWA with Periodic Perturbations

An original configuration of the LWA is shown in Fig. 1. It consists of a dielectric slab placed on a ground plane with parallel metallic strips loaded periodically on the surface of the slab. In such a periodic structure, an infinite number of space harmonics are generated, some of which become leaky modes that radiate an electromagnetic beam in the direction ϕ_n (which is defined by the frequency, the propagation constant of the unperturbed dielectric waveguide β, the mode number n, and the period of strips d [2]). The amount of leakage depends mainly on the width of strip s, but also some degree on the period of the strip d. And the beam direction depends mainly on d, with same secondary effects due to s. Thus, in order to synthesize a desired pattern more exactly, these secondary effects should be taken into account [4]. Leakage, as a function of z, which synthesizes the desired pattern is determined according to the theory of LWA including conductor- and dielectric- losses [5].

2-2 Reduction of Conductor Loss by Dual-Layered Dielectric Slabs

In the original type of LWA as shown in Fig. 1, the energy density in the dielectric waveguide is relatively high near the surface of the ground plane where a large electric current flows. This problem can be solved by using a dual-layer structure of dielectric substrates, in which the lower substrate has a lower ε than the upper substrate where the metallic strips are loaded. Table 1 shows losses of several dielectric waveguides obtained by computer simulation. From this table, it can be seen that the single-layer structure with a finite conductivity has a large loss, while the dual-layer structures has significantly lower losses.

3. Canceling of Reflections Due to Metallic Strips

In the design of the dielectric LWAs, a traveling wave which propagates in one-way is assumed. However, in actual LWAs, reflections occur at the metallic strips that disturb the aperture distribution. In order to control this more accurately, we developed a reflection canceling technique. On the bottom surface of the upper substrate, the same metallic-strip array (canceling array) as those on the top surface (radiating array) is printed with the proper shift *d* (almost a quarter wavelength of the guide) in the direction of *z* as shown in Fig. 3. Since the amplitude of the reflected wave generated by the strip on the top surface may be almost the same as the amplitude of the reflected wave corresponding to the strip on the bottom surface, but with a 180-degree phase difference, the reflected waves cancel each other. Fig. 4 shows an example of an electric field distribution within a waveguide for an antenna with a broadside beam. It can be seen that this technique can effectively suppress reflections, while providing an almost uniform traveling wave with small fluctuations in the waveguide.

4. The Developed Antenna and Its Radiation Characteristics

4-1 Feed System

The feed of this LWA must have line-source characteristics that provide a uniform amplitude and phase along a line parallel to the metallic strips. We developed a new folded-horn feed with a parabolic-cylinder reflector as shown in Fig. 5. This feed shows very satisfactory performances as shown in Fig. 6 with a return loss of about 20dB and an insertion loss of 0.8dB at 76.5 GHz.

4-2 Antenna Configuration

We developed a dielectric LWA at 76.5 GHz, which demonstrates a Taylor pattern with -20 dB sidelobes. The beam is tilted to -15 degrees. The antenna is fabricated by using an alumina substrate (ε=9.7) 0.8 mm thick with a 60 x 60 mm aperture that is suspended by an air-gap 0.2 mm thick by inserting spacers between both side edges of the substrate and the ground plane. On the top and the bottom surfaces, two identical arrays consisting of long metallic strips parallel to the x-axis are printed. The strip parameters, *d* and *s*, are optimally designed to provide the desired Taylor distribution. The substrate has a taper at the edge of the input side and is excited by the folded-horn feed mentioned above. Fig. 7 shows the photograph of the developed LWA.

4-3 Radiation Characteristics

Fig. 8 (a) and (b) show the measured E- and H-plane radiation patterns. Although the measured sidelobes are slightly higher than the designed value, it has been verified that almost the same radiation pattern can be obtained by using the dielectric LWA. Fig. 9 shows the measured gain and antenna efficiency as a function of frequency. The gain is 32.4 dB and the efficiency exceeds 58%.

5. Conclusions

We proposed a dielectric LWA with high efficiency, and described its design method and radiation characteristics for a developed prototype. By using a dual-layer structure, the current density on the ground plane can be drastically reduced. Furthermore, by introducing a reflection-canceling array loaded on the bottom surface of the substrate, the desired aperture distribution can be obtained. We demonstrated that the LWA realized a low-sidelobe radiation pattern with a very high efficiency, exceeding 58% at 76.5 GHz.

[References]

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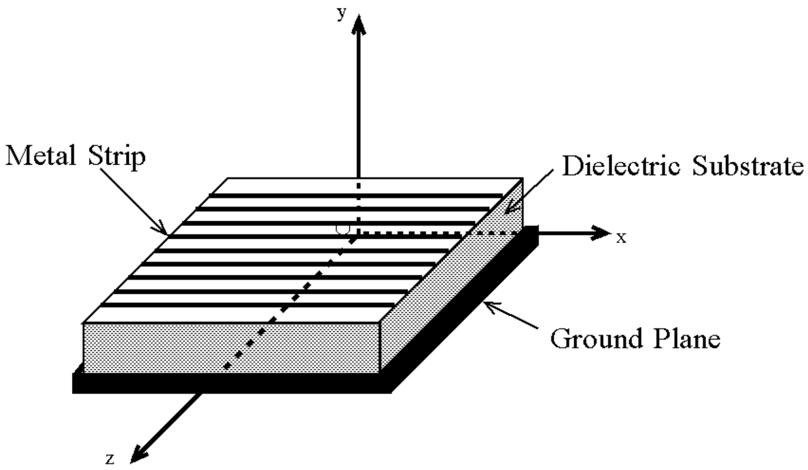


Fig.1 A periodically strip-loaded dielectric LWA

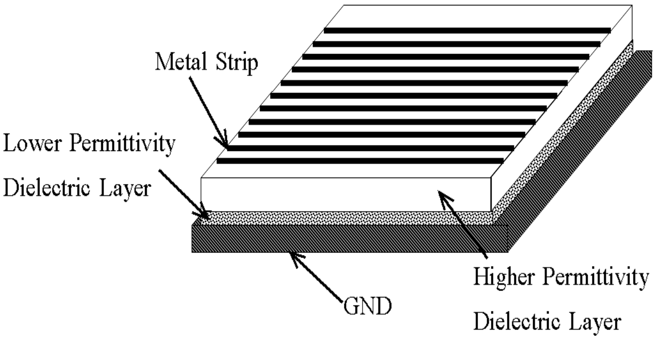


Fig.2 A LWA with dual-layered dielectric slab

Table 1 Tr. losses of various dielectric slab waveguides

(dB/100mm, f=76.5GHz)

	dielectric + perfect conductor	dielectric + silver
single-layer (t_1=0.4mm)	0.636	2.27
double-layer (t_1=0.8mm,t_2=0.2mm)	0.467	0.530
double-layer(air gap) (t_1=0.8mm,g=0.2mm)	0.534	0.551

*dielectric 1:alumina(ε_r=9.7,tan δ =2.2×10^{-4})
dielectric 2:PTFE(ε_r=2.1,tan δ =2.0×10^{-4})
silver: σ =6.17×10^{7}(S/m)

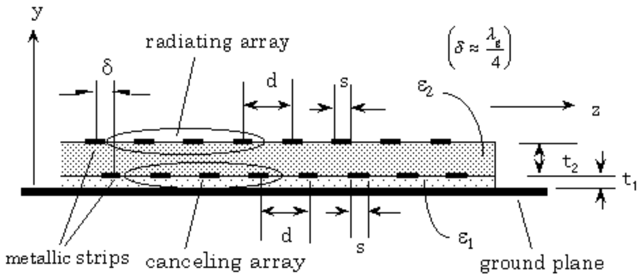


Fig.3 Paired-array for canceling reflections due to metallic strips

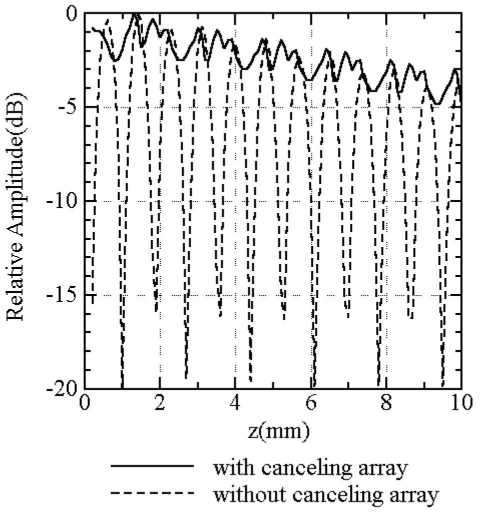


Fig.4 Effect of canceling array

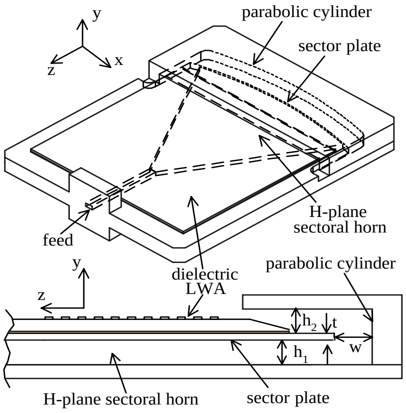


Fig.5 Folded-horn feed system for the dielectric LWA

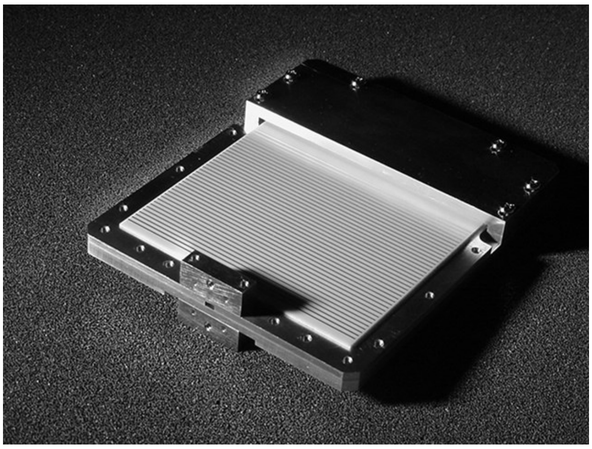
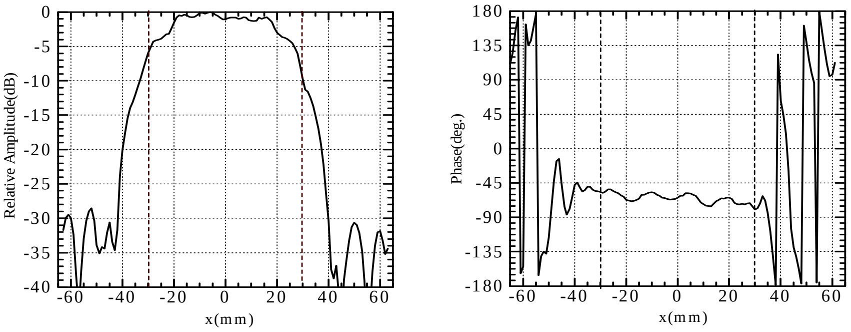


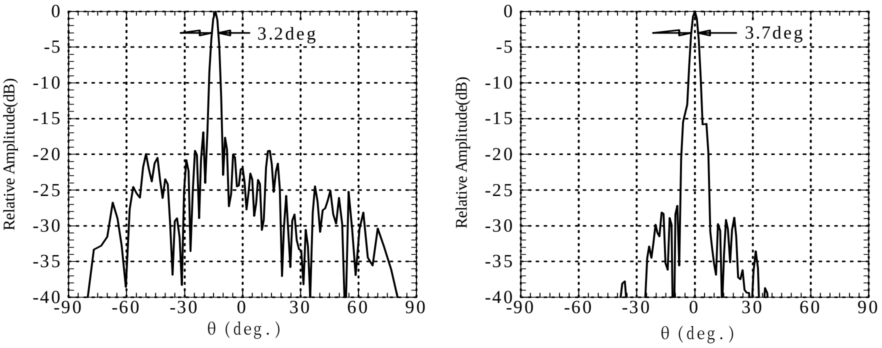
Fig.7 Photograph of the developed LWA



(a) Amplitude

(b) Phase

Fig.6 Aperture distribution of the feed



(a)E-plane pattern

(b)H-plane pattern

Fig.8 Radiation patterns of the LWA with a Taylor distribution

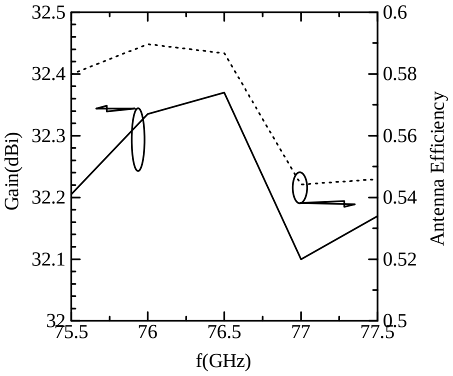


Fig.9 Measured gain and efficiency of the LWA with a Taylor distribution