A study on parallel-arranged leaky wave antenna with dielectric superstrate

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***Abstract*— In this report, a parallel-arranged leaky wave antenna with dielectric superstrate is proposed. The proposed antenna consists of a ground plane, a substrate layer, and a superstrate layer. Half of the substrate layer is filled with dielectric, and the other half is filled with air to create a quasi-cutoff region. We parallelly arranged three types of elements with different effective relative permittivity in substrate layer along the E-plane direction. Each element has a different beam direction, and by changing the feeding port, the beam direction can be controlled. The influence of parallel LWADS configuration on the radiation pattern was examined, and its suitability as a beam switching antenna was studied.**

Keywords—Leaky wave antenna, Tilted beam

I. INTRODUCTION

In next-generation mobile communication systems, high-frequency signals such as millimeter wave bands are expected to be used. One of the factors behind this trend is the increasing usage of large-capacity data services such as video streaming and cloud services. As a result, the demand for high-frequency signals capable of transmitting data at high speed has grown significantly. Since high-frequency signals have high attenuation characteristics, it is necessary to compensate for the attenuation by beamforming. A phased-array antenna has been proposed as a beamforming technique, but it has the problem of expensive phase shifters[1]. Beam-switching antennas have also been proposed as a way of forming beams, and they have the advantage of not requiring a phase shifter.

In this report, a parallel configuration of leaky wave antenna with dielectric superstrate (LWADS) is discussed. When used as a beam-switching antenna, LWADS is supposed to be arranged in parallel. Each element has different radiation directions and switching the feeding element can form a beam at with different radiation direction. Also it is discussed how the parallel arrangement of LWADS affects radiation pattern, and investigated their use as beam-switching antennas.

II. DESIGN

A leaky wave antenna with dielectric superstrate (LWADS) has been studied as a way to obtain a high gain pencil beam[2]-[5]. LWADS has a low profile and can achieve high gain with a single element. LWADS with super straight layer was also proposed [6], and this antenna can form a quasi-cutoff region in $x > 0$ by setting the thickness of the substrate layer to an appropriate value. As a result, leaky wave modes can be formed only in the $x < 0$ region, producing a non-conical tilt beam. In Fig. 1, h_1, h_2 and $\epsilon_{r1}, \epsilon_{r2}$ are the height and relative permittivity of substrate and superstrate layers, respectively. The conditions for maximizing gain in the desired direction θ_p are expressed in (1) and (2). λ_o is the free-space wavelength and m, n are positive integers.

$$h_1 = \frac{m\lambda_o}{2}\frac{1}{\sqrt{\epsilon_{r1} - \sin^2\theta_p}} \tag{1}$$

$$h_2 = \frac{(2n-1)\lambda_o}{4}\frac{1}{\sqrt{\epsilon_{r2} - \sin^2\theta_p}} \tag{2}$$

$$\epsilon_{reff} = \frac{\pi r^2 h_1 + (p^2 h_1 - \pi r^2 h_1)\epsilon'_{r1}}{p^2 h_1} \tag{3}$$

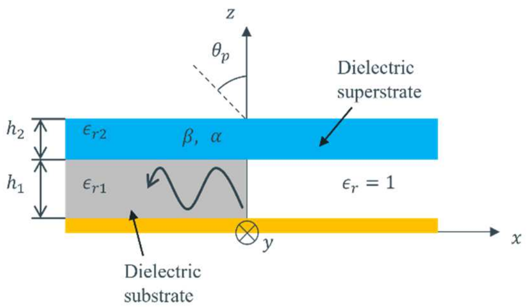

Fig. 1 LWADS with half-filled substrate layer

When used as a beam-switching antenna, LWADS is supposed to be arranged in parallel and the beam direction can be controlled by switching the feeding elements. The parallel-arranged LWADS are shown in Fig. 2. As shown in (1), when ϵ_{r1} is fixed at a single value, a substrate layer of different height is required for different radiation direction θ_p, which results in increasing complexity of the antenna. For this reason, each substrate layer is made of perforated dielectric, and the effective relative permittivity is controlled by changing the radius of the hole [7],[8]. The effective dielectric constant is expressed by (3), where p is the period at which the holes are drilled, and ϵ'_{r1} is the relative permittivity of the material used in the substrate layer. The effective dielectric constant is determined by the volume fraction of air to dielectric used in the substrate layer. Perforated dielectrics with hole radius r of 1.9 mm, 3.4 mm, and 4.3 mm are placed in the substrate layers of ANT1, 2, and 3. The electromagnetic field input from the waveguide couples with the leaky wave mode in the substrate layer and propagates in the substrate layer with different propagation constants in each antenna. Since these antennas have different radiation directions, switching the feeding elements can form a beam with different radiation direction. The antenna gains of the H-plane when feeding Port 1, 2, and 3 respectively, and when feeding a single LWADS with a perforated dielectric with hole radius r of 1.9 mm, 3.4 mm, and 4.3 mm is compared in Fig. 3. As it is shown in the figure, antenna gain does not change significantly between the parallel-arranged antenna and the single element. Even in the case of r=3.4mm, where the peak gain was decreased the most, the gain reduction was 1.2 dB. Peak radiation directions also remain the same. The wave input from each port propagates in the substrate layer of other antenna elements. However, these waves are confined in the substrate and superstrate layers, so the antenna gain in the H-plane was not significantly affected. This fact suggests that LWADS has a high degree of freedom in terms of placement, indicating its high potential as a beam switching antenna.

III. Conclusion

In this report, a parallel-arranged leaky wave antenna with dielectric superstrate is investigated. Each substrate layer is made of perforated dielectric, and the effective relative permittivity is controlled by changing the radius of the hole. Since each element has substrate layer of different effective relative permittivity, these elements have different radiation directions. Therefore, switching the feeding elements can form a beam with different radiation direction. When LWADS is placed in parallel in the E-plane direction, the antenna gain in the H-plane does not change significantly compared to single element LWADS. Even in the case of r=3.4mm, where the peak gain was decreased the most, the gain reduction was 1.2 dB. Peak radiation directions also remain the same. This suggest that waves propagating through the substrate layers of other antennas do not affect to radiation much. This characteristic of LWADS demonstrates its high potential as a beam switching antenna. However, further investigation is required for a detailed understanding of the mechanism.

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Table 1 Antenna design parameter

Parameter	Value
L	240mm
L_{sub}	240mm
W	60mm
h_1	12.5mm
h_2	3.3mm
a	22.9mm
b	10.2mm
p	10mm
ε_{r1}	2.34
ε_{r2}	6.8

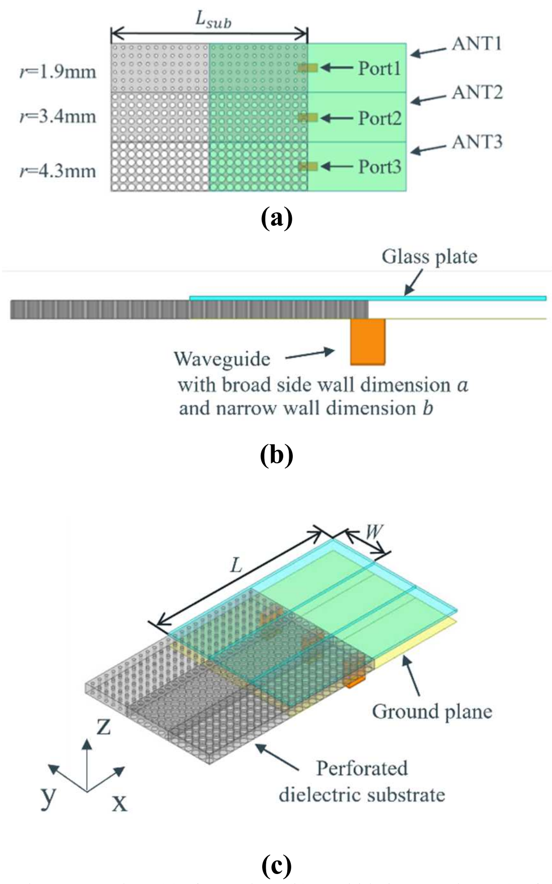

Fig. 2 Top view (a), front view (b), and bird's-eye view (c) of parallel-configured LWADS

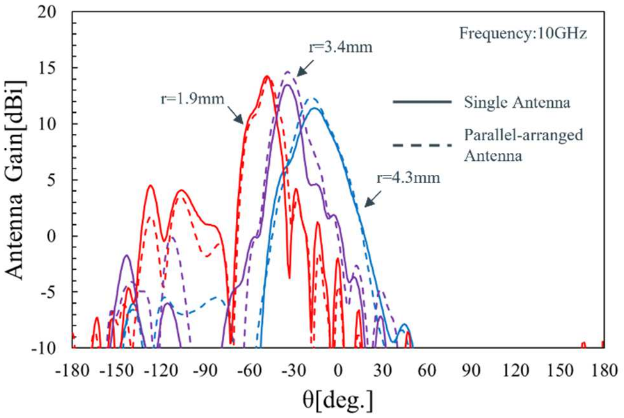

Fig. 3 Comparison of H-plane antenna gain between parallel-arranged and single element