A Dual Polarized Suspended Stripline Fed Open-Ended Waveguide Antenna Subarray for Phased Arrays

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Abstract—**This paper presents the design and experiment of an antenna subarray for wideband and dual linear polarized phased arrays. The proposed antenna is a one-dimensional linear array which consists of two feeding networks for each polarization and radiating elements. The suspended stripline is used as the transmission line of the feeding network because of its low loss and low mutual coupling. The radiating element is an open-ended square waveguide antenna with a parasitic element inside and a transition from waveguide to two orthogonal suspended strip feed lines. In order to achieve a good transition performance of both polarizations, a compact transition, in which the waveguide between two feed lines is double ridged and the waveguide at the junction to the aperture waveguide is quadruply ridged, is proposed. The prototype subarrays with ten radiating elements have been fabricated and measured in 16 element array. The experimental results show a good impedance bandwidth of 18%, low cross polarization levels less than −27 dB, and low losses with antenna efficiency above 70% in the frequency band of 14%.**

Keywords—Antenna arrays, open-ended waveguide antenna, dual polarization, suspended stripline, ridge waveguide.

I. INTRODUCTION

A wideband and dual-polarized antennas have been required for phased arrays to be applied to various applications such as mobile satellite communications, weather radars, and synthetic aperture radars [1]-[3]. In many phased array systems, the array is organized into subarrays to reduce cost by decreasing the number of T/R modules. Therefore, a wideband and dual-polarized antenna suitable for subarray structure is required herein. A stacked patch antenna is one of candidates for the wideband and dual-polarized antenna [4], [5]. It shows a good impedance bandwidth between 10% and 25%, but the loss of the feeding network becomes significant when the subarray size is larger because the microstrip line is often used as the transmission line of the feed network. A waveguide slot antenna array shows a low cross polarization levels and very low loss because its feeding network is hollow rectangular waveguides. The impedance bandwidth, however, is at most about 10%, and the radiation performance such as the sidelobe level and the beamwidth degrade at the end of the frequency band because of the series feeding. An open-ended waveguide antenna is the most promising candidate because it shows a low cross polarization level and a good impedance bandwidth between 10% and 30%. However, the coaxial feeding which is not suitable for the subarray structure is used in [6], and stripline is used as the transmission line of the feed network in [7],[8], which may cause large loss when the subarray size is large. Suspended stripline is a promising transmission line for the feeding network because of its lower loss and lower mutual coupling than stripline [9]. However, the space for the feeding network becomes larger than stripline because of the size of shield case of the suspended stripline.

In this paper, a dual polarized suspended stripline fed open-ended waveguide antenna subarray is presented. In order to provide space for the feeding networks, a compact transition between the waveguide and the suspended strip line is proposed, which also shows a good isolation between two polarization ports. For impedance matching, the parasitic element is attached inside the aperture waveguide [8]. The design and measurement results of the prototype array of 16-subarrays with ten radiating elements are also presented to show the feasibility of the proposed antenna.

II. ANTENNA STRUCTURE

The structure of the proposed antenna is shown in Fig. 1. In this figure, we show only a radiating element and its transition between the waveguide and the suspended stripline. The proposed antenna consists of seven components: (A) open-ended square waveguide aperture, (B) printed square parasitic element on a dielectric substrate, (C) junction of the square waveguide and the quad-ridge waveguide and the upper shield case of the suspended stripline for the horizontal polarization (H-pol.), (D) feeding network and an excitation probe of stripline for the H-pol. on a dielectric substrate, (E) double-ridge waveguide and the lower shield case of the suspended stripline for H-pol. and the upper one of the suspended stripline for the vertical polarization (V-pol.), (F) feeding network and an excitation probe of stripline for the V-pol. on a dielectric substrate, and (G) back-short waveguide and the lower shield case of the suspended stripline for V-pol.

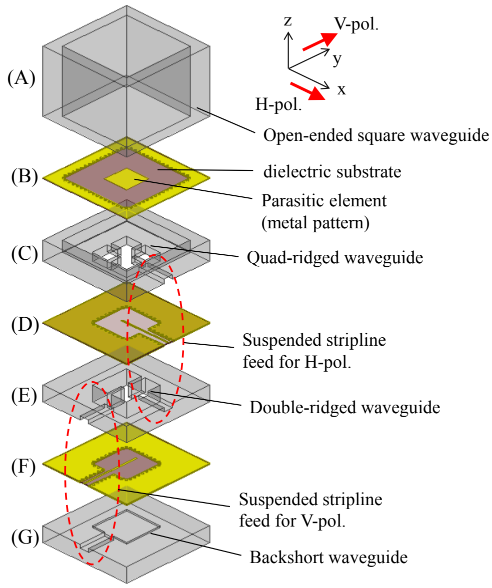


Fig. 1. Structure of the proposed antenna.

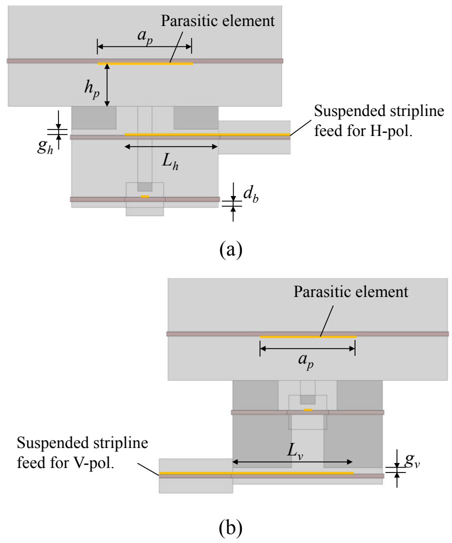


Fig. 2. Geometry of the proposed antenna: (a) side view in the *xz*-plane and (b) side view in the *yz*-plane (a part of the open-ended waveguide is omitted.).

The aperture dimension of the open-ended square waveguide is determined so that only the dominant mode can propagate in it and the desired element spacing is satisfied. The feeding networks for each polarization are arranged in separated layers to avoid the structural interference between them. The waveguides in the layers (C)-(G) have to be narrowed to provide space for each feeding network. If the waveguide is kept square in these layers, even the dominant modes can't propagate because of the cutoff. Therefore, the waveguide is ridged to reduce the cut-off frequency. In most transitions between the quad-ridge waveguide and two orthogonal excitation probes, the probes are arranged close to each other to have almost equal distance to the back-short waveguide [10]. In the proposed antenna, however, there is some distance between two probes because of the size of the shield case of the suspended stripline, which degrades the transition performance of one of the polarizations. In order to achieve a good transition performance of both polarizations, the waveguide between two probes is double-ridged and the waveguide at the junction to the aperture waveguide is quadruply ridged. In this structure, the dominant mode of the H-pol. cannot propagate through the double ridge waveguide between two probes, but the one of the V-pol. can do, and both can propagate through the quad-ridge waveguide. Therefore, the transition for each polarization has a reactive load on the back-short side in an equivalent circuit. In order to achieve a good impedance matching, the parasitic element which acts as a resonant element is attached inside the aperture waveguide.

III. Design of the Prototype Subarray

A prototype subarray with ten radiating elements is designed to show the feasibility of the proposed antenna. The subarray is a one-dimensional linear array and its aperture dimensions are $7.429\lambda_c \times 0.666\lambda_c$, where λ_c is the free space wavelength at the design frequency f_c. The dimension of the square aperture is $0.608\lambda_c$. The width and depth of the upper and lower shield cases of the suspended stripline are $0.032\lambda_c$ and $0.083\lambda_c$ respectively and the width of the stripline at the transitions is $0.013\lambda_c$, so that the characteristic impedance is about 120 Ω at f_c. In order to provide space for the feeding networks described later, the dimension of the waveguides in the layers (C), (D), and (G) is narrowed to be $0.327\lambda_c$. The width of ridges is $0.032\lambda_c$ and the length of the double-ridge and the quad-ridge are $0.128\lambda_c$ and $0.099\lambda_c$ respectively so that the cutoff frequency of the dominant mode becomes below the operation frequencies. The gap between two excitation probes is $0.128\lambda_c$ to achieve a good isolation between two feed ports.

The input impedance for the H-pol. is less affected by the structural variations of the layers (E)-(G) because the dominant mode of the H-pol. cannot propagate toward the back-short. In the design of the proposed antenna, therefore, the structures of the layers (A)-(D) are first adjusted for impedance matching for the H-pol., and then the structures of the layers (E)-(G) are adjusted for impedance matching for the V-pol.. The waveguide is made of aluminum and RT/duroid 6002 materials are used as the dielectric substrate. The design of the antenna element and feeding network are performed with Ansys HFSS.

A. Antenna Element Design

Fig. 2 shows the side view of the proposed antenna. The size (a_p) and the position (h_p) of the parasitic element, the length of the excitation probe of the H-pol. (L_h), and the gap between the probe and the bottom of the ridges (g_h) are important for impedance matching for the H-pol.. On the other hand, the length of the excitation probe of the V-pol. (L_v), the gap between the probe and the bottom of the ridges (g_v), and the distance to the back-short plane (d_b) are important

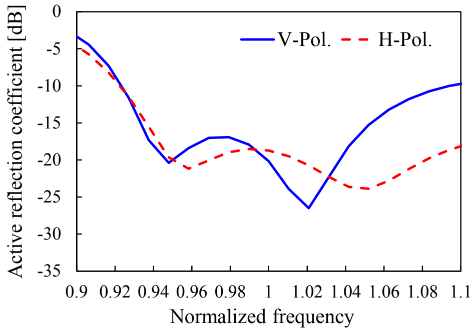


Fig. 3. The calculated reflection coefficient of the designed antenna element.

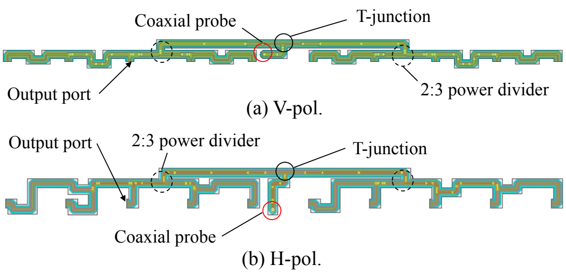


Fig. 4. Schematics of the feeding networks for (a) V-pol. and (b) H-pol..

parameters for the V-pol.. g_h, g_v, and d_b have large effects on the input reactance because the gap between the probe and the conducting plane works as capacitance. L_h and L_v have significant effects on the input resistance. The above geometric parameters are adjusted for a good impedance matching. Fig. 3 shows the calculated reflection coefficient of the designed antenna element. We find that the calculated reflection coefficients are less than -10 dB from $0.92f_c$ to $1.10f_c$.

B. Feeding Network Design

The prototype subarray is a 10-element linear array and is fed by a coaxial line for each polarization. A feeding network of the parallel/series type is adopted to arrange it in a limited space. Fig. 4 shows the calculation model of the feeding network for each polarization. The feeding network consists of a transition between the coaxial probe and the suspended stripline, a T-junction with equal-power division, two T-junctions with the 2:3 power divisions, and some T-junctions to form series feeds. The feeding network is designed to have a good impedance matching and small differences in amplitude and phase between the output ports. The resultant reflection coefficient at the coaxial input port is less than −22 dB, the maximum deviation of the output amplitude is less than 0.3 dB, and the insertion loss is about 0.3 dB from $0.9f_c$ to $1.1f_c$.

C. Prototype Subarray

The designed antenna elements and the feeding networks are combined to compose a subarray. Fig. 5 shows an exploded view and a photo of a fabricated prototype subarray. The total height of the subarray (except SMA connectors) is about $1.1\lambda_c$.

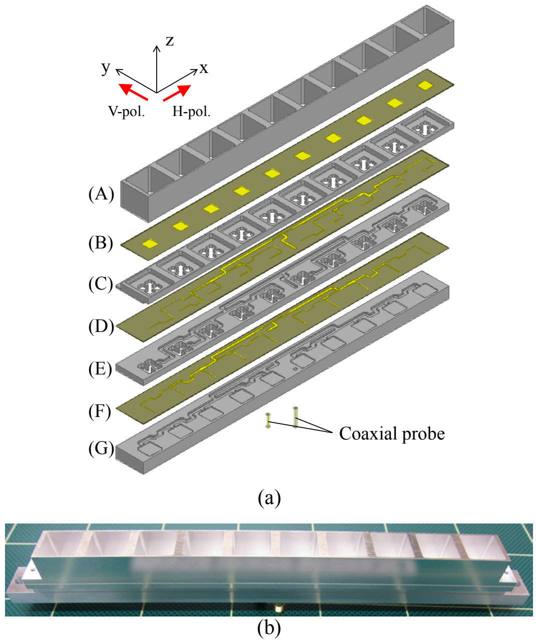
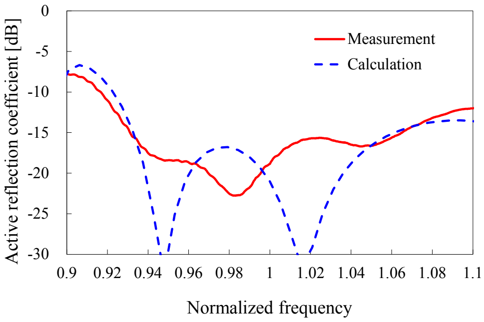


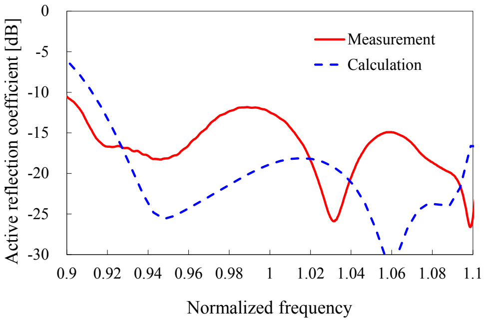
Fig. 5. (a) Exploded view of the prototype subarray and (b) a photo of a fabricated subarray.

IV. Experimental Results

An array of 16-subarray along the y-axis was measured. S-parameters were measured for the array, and the active reflection coefficient of each subarray was calculated. Fig. 6 shows the active reflection coefficient at broadside scan. The measurement shows the average among 16 subarrays. The measured active reflection coefficient is less than −10 dB from $0.92f_c$ to $1.1f_c$ (18%) for the V-pol. and from $0.9f_c$ to $1.1f_c$ (20%) for the H-pol. respectively. We consider that the differences between the calculation and measurement are due to the assembly errors of the dielectric substrates. The radiation pattern and gain of each subarray were also measured in the xz-plane. Fig. 7 shows the measured and calculated radiation patterns of the subarray at the center of the array at f_c. A very good agreement between the measurement and calculation is observed for each polarization. The cross-polarization level is less than −31 dB for the V-pol. and −27 dB for the H-pol. respectively. Fig. 8 shows the measured gain of the subarray in the broadside direction. The gain shows the average among 16 subarrays and the theoretical gain shows the gain limit given by $4\pi S_e/\lambda^2$, where S_e is the aperture area of the subarray and λ is the free-space wavelength at each frequency. We find that the gain at f_c is 17.6 dBi with 92% antenna efficiency for the V-pol. and 17.2 dBi with 84% efficiency for the H-pol. respectively. The antenna efficiency remains above 70% from $0.92f_c$ to $1.07f_c$ (15%) for the V-pol. and from $0.93f_c$ to $1.07f_c$ (14%) for the H-pol. respectively. The gain reductions at lower and higher frequencies are mainly due to the radiation pattern degradations which are caused by the series feed of the feeding network. The increase of the return loss also causes the gain reduction at lower frequencies.

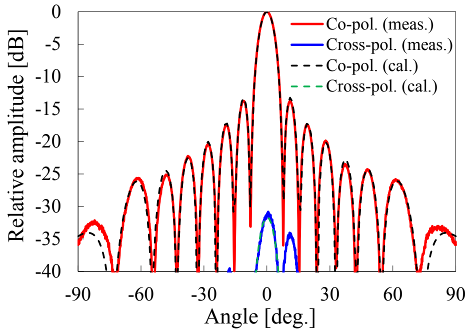


(a)

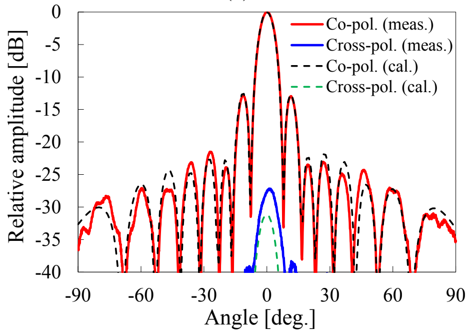


(b)

Fig. 6. Averaged active reflection coefficient at broadside scan. (a)V-pol. and (b) H-pol..



(a)



(b)

Fig. 7. Radiation pattern of a subarray at f_c. (a)V-pol. and (b) H-pol..

V. Conclusion

A dual polarized suspended stripline fed open-ended waveguide antenna has been proposed and demonstrated. A compact transition, in which the waveguide between two feed lines is double-ridged and the waveguide at the junction to the aperture waveguide is quadruply ridged, is employed and a parasitic element is introduced into the aperture waveguide for impedance matching. A prototype subarray has been designed, fabricated, and measured. The measured impedance bandwidth (active reflection coefficient < −10 dB) is 18% and the cross polarization levels are less than −27 dB. The measured antenna efficiency remains above 70% in the frequency band of 15% for the V-pol. and of 14% for the H-pol. respectively.

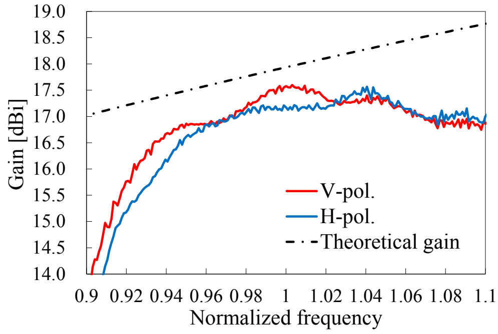


Fig. 8. Measured gain in the broadside direction.

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