Two-Dimensional Scanning Leaky-Wave Antenna by Utilizing the Phased Array

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***Abstract*—An aperture-fed patch antenna array is connected to the open end of a short leaky-wave antenna (LWA) to demonstrate the two-dimensional beam-scanning capability in this paper. This design not only offers another radiation path of the reflected wave, but also creates another scanning radiation pattern on the back plane of the substrate. The reflected wave of the LWA is equally separated by a power divider, modulated by each varactor-tuned phase shifter, and injected into two radiating aperture-coupled antennas. The operated frequencies are tuned to control the LWA main position in the elevation plane; meanwhile, by tuning the phase difference between two phase shifters, the main beam of the aperture-coupled antenna array can be scanned in the backside E plane. Experimental result shows that the suppression of the reflected wave can be 7 dB at 10.0 GHz with a short LWA length of 6 cm (two wavelengths). The H-plane and backside E-plane scanning radiation patterns have great potential in many applications and provide more flexibility to traditional designs.**

***Index Terms*—Phase shifter, reflected wave, two-dimensional scanning capability.**

I. Introduction

A major problem of the leaky-wave antenna (LWA) is the long length of the structure for the microwave or RF commercial applications. Generally speaking, the length of the LWA acquires about five wavelengths to radiate effectively; otherwise, the open end of LWA results in large reflection power of microwave signals [1], [2]. As a result, the reflection power would cause undesired interference in communication systems. The two-dimensional (2-D) scanning LWA has received much attention in recent years [3]–[5]. In [3], Oliner first proposed the idea of the two-dimensional (2-D) scanning capability using one-dimensional LWA antenna line-source phased array. Attempts have been made to extend the work of encompassing the phase control technique of coupling oscillators [4] or utilizing the 4×1 aperture-coupled, series-fed electronically steerable microstrip LWA array [5]. These designs produced the beam-scanning radiation patterns in the elevation plane (the H plane) and the cross plane (quasi-E-plane). However, the power in the cross plane is much lower than that of the broadside beam.

Here, an alternative method is introduced to solve the reflected wave for the reduced area (two wavelengths) of the short

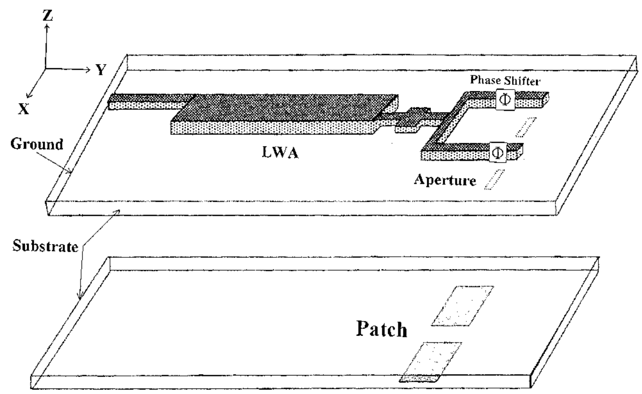
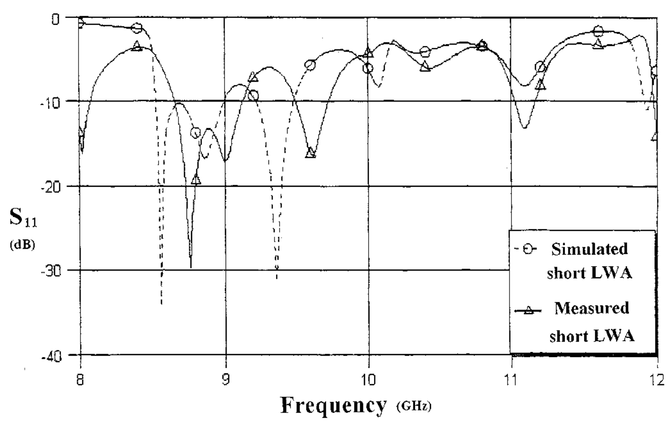
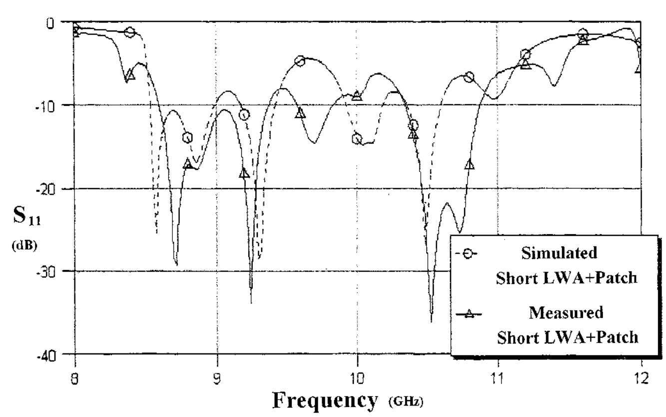


Fig. 1. Proposed circuit configuration of the 2-D scanning LWA.



(a)



(b)

Fig. 2. (a), (b): Simulated and measured S-parameters (S_{11}) of the conventional short LWA (two wavelengths) with the open end and the proposed LWA integrated with the two-element phased array.

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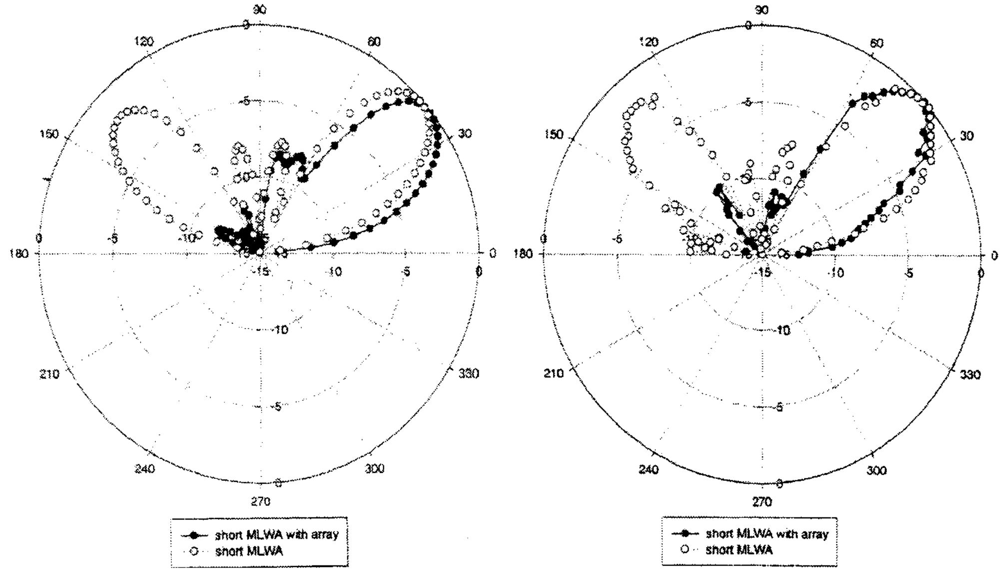


(a) (b)

Fig. 3. (a), (b): Comparison of the simulated and measured radiation patterns (the H plane) of the conventional and proposed LWAs.

LWAs. By adding a radiating element (a leaky path) at the end of the LWA, we can avoid the residual power reflecting and suppress the back lobe effectively. The aperture induces the residual power to the patch antenna on the backside and the power will radiate out of the backside E plane. By changing the operating frequency, the LWA can be scanned in the H plane. Meanwhile, by tuning the bias voltage of the phase shifters and modulating the phase difference between the injection signal of the apertured-coupled patch antennas, the main beam of the aperture antenna array can be power-combined and electronically scanned into the backside E plane.

II. Circuit Design

Fig. 1 shows the proposed circuit configuration of the 2-D scanning LWA. The configuration consists of three parts: the LWA, the network of one power divider and two phase shifters, and the aperture-coupled patch antenna array on the backside. The whole circuit is fabricated on the RT/Duroid microwave substrate with the dielectric constant of 2.2 and the thickness of 0.508 mm. In order to excite the first higher order mode, the LWA is fed asymmetrically. In the radiation region, the injected power leaks into the space in the form of the space wave. The residual power of the LWA is split up into two ways via the power divider. Half of the injected power is equally fed to the input terminals of the phase shifters. The aperture etched on the ground plane is designed to couple the remaining power of the LWA into the patch antenna on the backside of the substrate. To suppress the residual power effectively in the proposed configuration, the aperture-coupled patch antenna is designed so as to operate over the scanning frequency (9.0 GHz to 10 GHz) of the LWA.

III. Theoretical and Experimental Results

Fig. 2(a) and (b) show the simulated and measured S-parameters (S_{11}) of the conventional short LWA (two wavelengths)

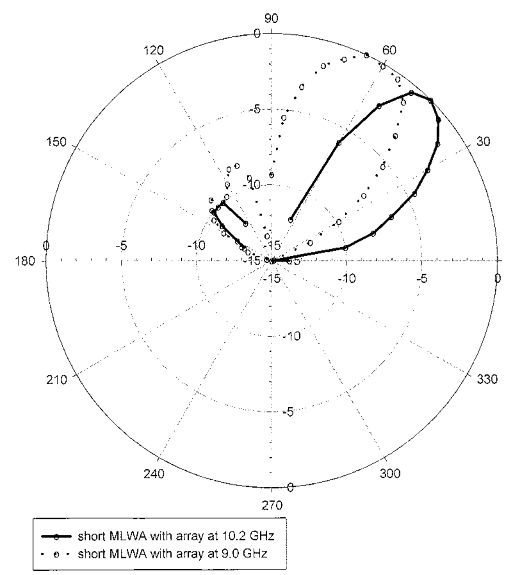
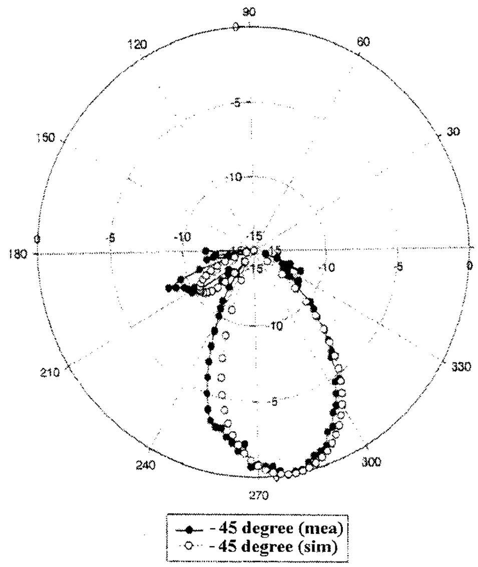
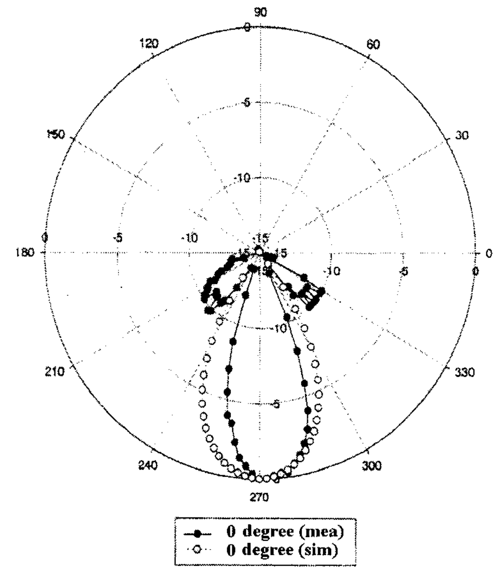


Fig. 4. Measured H-plane scanning radiation patterns of the proposed LWA design.

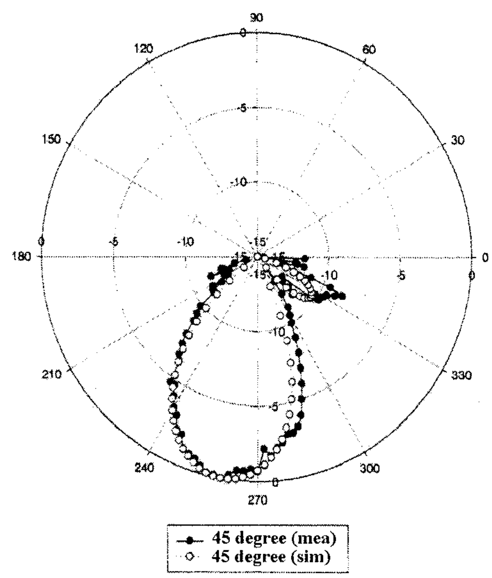
with the open end and the proposed LWA integrated with the two-element phased array. The results indicate that the backside patch antenna array indeed enhances the radiation efficiency. Meanwhile, the power radiated from the patch array results from the reflected wave, so the gain of the proposed design is as same as the one of the conventional LWA. Fig. 3(a) and (b) illustrate the comparison of the simulated and measured radiation patterns (the H plane) of the conventional and proposed LWAs. The back lobe of the proposed LWA is suppressed to be -10 dB approximately when the back lobe of the conventional LWA is -3 dB less than the main beam. Comparing to the proposed structure and the conventional LWA with the open end, we observe that the proposed design successfully suppressed the reflected power by 7 dB at 10.0 GHz. The main beam steers toward the end-fire direction in the H plane when the oper-



(a)



(b)



(c)

Fig. 5. (a)–(c): Simulated and measured radiation patterns of the two-element aperture-coupled patch antenna array in the backside E plane when the phase differences are 45°, 0°, and −45°.

ating frequency increases. The measured H-plane scanning radiation patterns of the proposed LWA design are shown in Fig. 4. The scanning angle of 20° can be achieved from 9.0 GHz to 10.0 GHz. Fig. 5(a)–(c) show the simulated and measured radiation patterns of the two-element aperture-coupled patch antenna array in the backside E plane when the phase differences are 45°, 0°, and −45°. The main beam can scan approximately from 280° to 250° in the backside E plane, which corresponds to the dc bias of the phase shifters.

IV. Conclusion

We have successfully employed the phased array to suppress the reflected power and demonstrate the two-dimensional canning capability. By reusing the reflected power, two antenna modes, including a leaky mode and a patch mode, have been created on the H and backside E planes. This novel design provides more flexibility and can be utilized in military and commercial communications.

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