High Scanning-Rate Periodic Leak-Wave Antennas using Complementary Microstrip-Slotline Stubs

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***Abstract* - A series-fed patch (SFP) array leaky-wave antenna can realize the frequency scanning. To increase the scanning rate, we add complementary microstrip-slotline stubs between the patches. The complementary microstrip-slotline stub is an all-pass filter and its group delay is smooth and continuous, and it maintains a flat magnitude response within an ultra-wide bandwidth. It significantly increases the slope of phase versus frequency and hence the scanning rate when cascading with the series-fed patch leaky-wave antennas. Three examples are provided in comparison with the conventional one. The results show that the new leaky-wave antennas increase the scanning rate by 42%-72%.**

***Index Terms* —group delay, series-fed patch (SFP) array, leaky-wave antennas, dispersive delay line, microstrip line, slotline.**

I. INTRODUCTION

LEAKY-WAVE antennas (LWAs) have been applied in many communication systems or radars at microwave frequency because they have a lot of advantages such as low cost, simple configuration, light weight, easy manufacturing and integrability with other electronic components [1]. Therefore, since nineteenth century, they have been widely studied and used in many fields [2], [3]. A typical example of these applications is millimeter-wave imaging systems. Usually they require the antennas with high scanning-rate within a narrow bandwidth so that the system is simple [4]. Leaky wave antennas are attractive for imaging applications due to their simple feeding network and system architecture.

Leaky-wave antennas can be broadly classified into periodic and continuous structures [5]. Periodic leak-wave antennas are achieved by introducing periodic perturbations, such as short-circuited stubs, dielectric gratings, and slot oriented structures. Continuous leaky-wave antennas are based on fast-wave transmission lines, e.g. metallic waveguides. One important feature of leaky-wave antennas is that it scans the beam as the frequency changes. Usually, it requires several gigahertz to scans the half space, and thus the scanning rate is low. A high scanning rate antenna is highly demand in narrow-band applications. One possible way is to employ all-pass delay lines [6]-[9]. However, C-section structures requires stripline implementation, which make the fabrication difficult.

This paper presents an approach to increase the scanning rate using complementary microstrip-slotline stubs, which has a smooth and continuous group delay curve and a flat magnitude response in a wide frequency band [10]. The advantages of this structure are simple structure, wide operational bandwidth and easy fabrication.

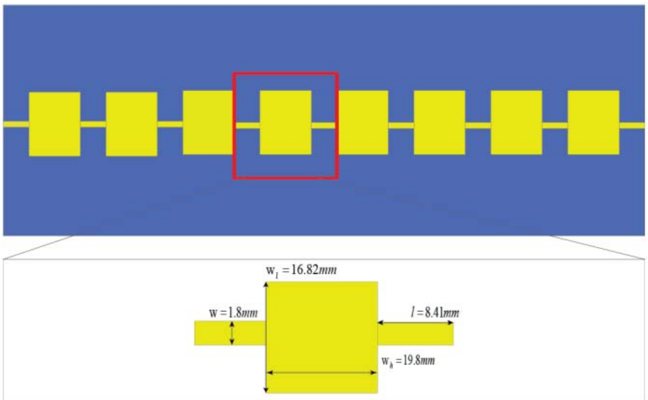

Fig. 1. The series-fed patch (SFP) array antenna (the permittivity of the substrate is ε_r =2.2 and the height is h =1.5mm).

II. PERIODIC SERIES-PATCH LEAKY-WAVE ANTENNA

Fig. 1 shows the structure of the periodic series-fed patch (SFP) leaky-wave antenna that we use in this paper. We consider that the antenna structures are terminated by matched loads, so as to operate in a traveling-wave regime. Following the standard frequency-angle scanning law [2], [11-12], we have

$$\theta_{\mathrm{MB}}(\omega) = \sin^{-1}[\frac{\beta_n(\omega)}{k_0}] = \sin^{-1}[\frac{c\beta_n(\omega)}{\omega}] \tag{1a}$$

with

$$\beta_n(\omega) = \beta_0(\omega) + n\frac{2\pi}{p} \tag{1b}$$

where $\theta_{\mathrm{MB}}(\omega)$ is the main-beam radiation angle, $\beta_n(\omega)$ presents the n^{th} space harmonic, ω is the angular frequency, c is the speed of light in free space, $k_0 = \omega / c$ is the free-space wavenumber, p is the period of the structure.

This configuration consists of 8 unit cells and the working frequency range is from 5.2 GHz to 6.2 GHz. Fig. 2 and Fig. 3 show the simulated scattering parameters and beam scanning property of this antenna, respectively.

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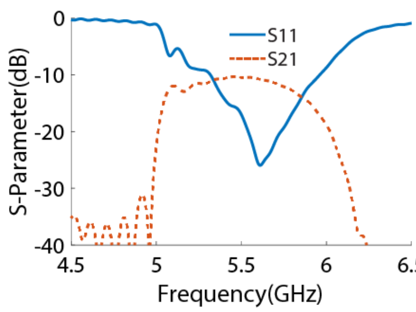

Fig. 2. The S-parameter of the SFP leaky-wave antenna.

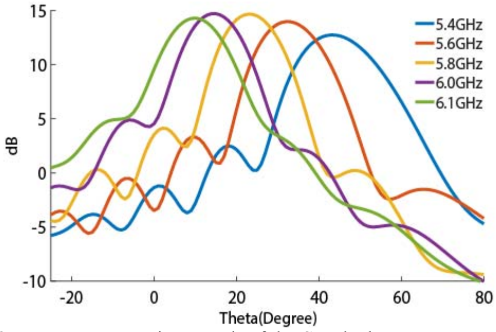

Fig. 3.Frequency scanning result of the SFP leaky-wave antenna.

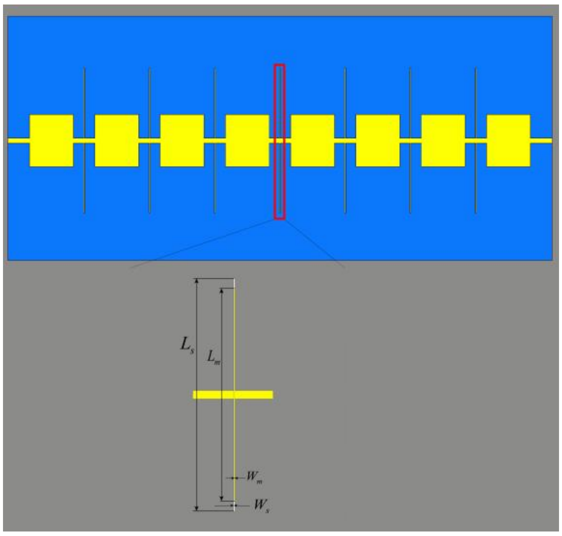

Fig.4. The proposed new leaky-wave antenna with complementary microstrip-slotline stubs ($W_S = W_m$ =0.2mm).

III. Leaky-Wave Antenna with Complementary Microstrip-Slotline Stubs

To increase the scanning rate, we propose a new leaky-wave antenna in Fig.4, which is realized by inserting complementary microstrip-slotline stubs between the series patch elements. The microstrip-slotline stub, as shown in the zoomed figure of Fig. 4, is composed of an open stub and slotline on the ground plane with equal widths ($W_m = W_s$) but different lengths (L_s longer than L_m). Fig. 5 and 6 show the S-parameters and group delay of this microstrip-slotline stub, respectively. Note that it exhibits a flat magnitude within a wide frequency band and a group delay peak at some specific frequencies. By aligning the peak group delay with the operational frequency band of the SFP antenna, we can increase the scanning rate.

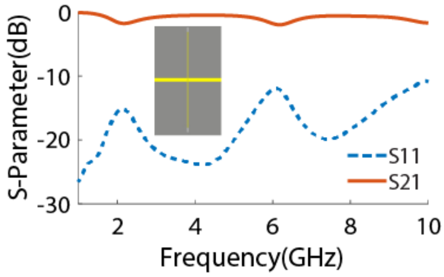

Fig. 5. S-parameter of the complementary microstrip-slotline stub

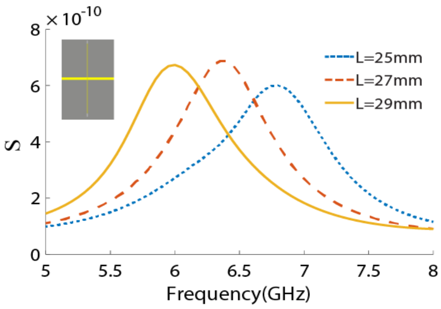

Fig. 6. Group delays for different lengths L_m.

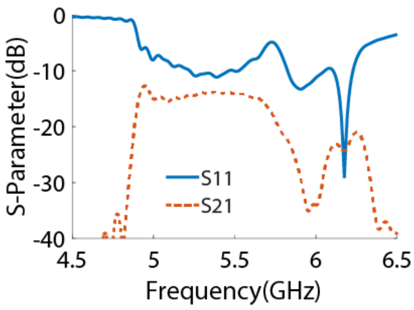

Fig. 7. S-parameter of the overall leaky-wave antenna in Fig. 4.

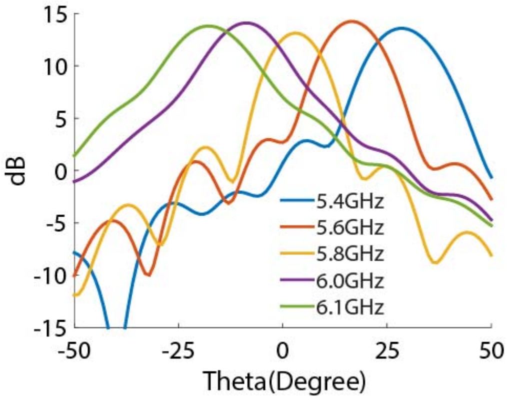

Fig. 8. Scanning beams of the antenna (L_m =26.4mm, L_s =28mm).

Fig. 7 shows the scattering parameters of the overall leak-wave antenna including both microstrip-slotline stubs and SFPs. By comparing it with Fig. 2, one finds that the reflection is slightly degraded after inserting microstrip-slotline stubs. To verify the scanning rate of the new antenna, we design three different microstrip-slotline stubs, namely stub 1, stub2 and stub3. Their scanning responses are shown in Figs. 8-10. Note that, the scanning range clearly increases

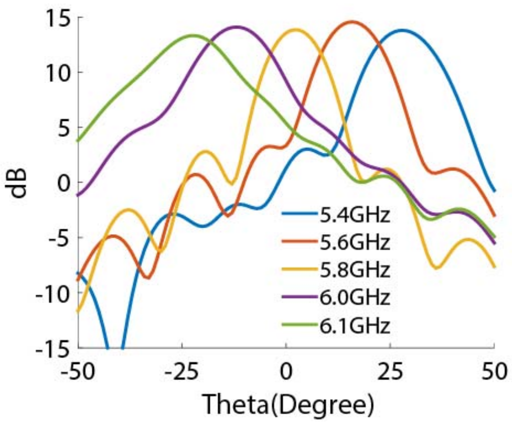

Fig.9. Scanning beams of the antenna (L_m =26.4mm, L_s =29mm).

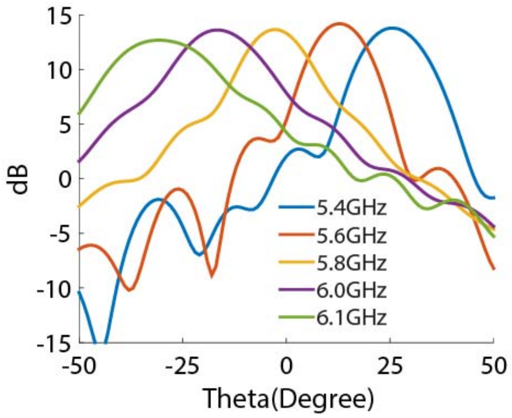

Fig.10. Scanning beams of the antenna (L_m =27mm, L_s =29mm).

TABLE I Comparison of Beam Angles and Ranges

	5.4GHz	5.8GHz	6.1GHz	Range
SFP	43°	23°	10°	33°
SFP with stub1	29°	3°	-18°	47°
SFP with stub2	28°	2°	-22°	50°
SFP with stub3	26°	-3°	-31°	57°

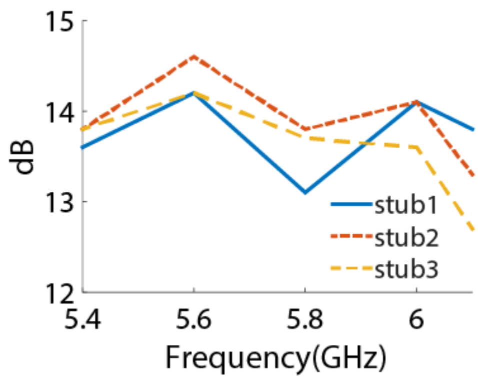

Fig. 11. The gain versus frequency responses of stub1, stub2 and stub3.

compared with the one without stubs in Fig. 3. To better see the improvement, Tab. I summarize the beam angles and ranges for different leaky-wave antennas from 5.4 GHz to 6.1 GHz. Note that, the scanning range of the original SFP without stubs is only 33°. Stub 1 has improved the scanning ranges by 42.4%, stub 2 has improved by 51.5%, and stub 3 has improved by 72.7%. Accordingly, one increases the scanning rate by employing the microstrip-slotline stubs in the conventional leaky-wave antennas. In general, the SFP leaky-wave antennas can be replaced by other configurations. Therefore, the proposed approach is a general technique to increase the scanning rate.

IV. Conclusion

A SFP leaky-wave antenna with complementary microstrip-slotline stubs has been proposed and illustrated. The complementary microstrip-slotline stub significantly increased the slope of phase versus frequency and hence the scanning rate when cascading with the series-fed patch leaky-wave antennas. Three examples were provided in comparison with the conventional one. The results revealed that the new leaky-wave antennas increased the scanning rate by 42%-72%.

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