Single-Feed, Highly-Directive, Higher-Order-Mode Cavity Antenna and Its Beam Tilting Realization

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***Abstract*—Fast-speed, mast-capacity, and low-cost communications are highly desired for future wireless systems. Single-feed overmoded slot-based rectangular cavity antennas are developed to meet this demand. A TE$_{(10)(11)(0)}$ mode is excited in the cavity with a rectangular waveguide. A total of 110 slots appropriately etched in its top surface yields a system that radiates its beam into the broadside direction with a gain of 26.6 dBi. An engineered phased patch surface is then introduced to facilitate tilted-beam pattern for high-order-mode cavity antennas. The realized cavity antenna augmented with an appropriately-shaped phased patch surface attained a tilted beam at 30° with respect to the broadside direction. An antenna prototype was fabricated, and measured results agree well with the simulated ones.**

***Index Terms*—cavity antenna, high gain, higher-order-mode (HOM), single feed**

I. Introduction

Future wireless systems are in high demand of fast-speed, mast-capacity, and low-cost communications. Single-feed highly-directive antennas are affirmative candidates to meet this demand. They could generally produce single or multiple narrow focused beams in far-field radiations. Moreover, their beam angles are usually required to point towards desired directions, e.g., broadside or tilted angles. Several antenna technologies have been reported to achieve these specific beam functionalities.

One is to use an array of individual radiating elements [1]. These elements are excited with an integrated feed network that can provide requisite phases and amplitudes. The array is always able to obtain good qualities and flexible characteristics of main beams. However, the realization of feed network usually requires a complex configuration. The second is to employ a spatial-feed large surface. Typical examples are transmitarray- and reflectarray-antennas [2]–[4]. A phased surface comprised of sub-wavelength elements is illuminated by a feed source with an appropriate focus-to-diameter (F/D) ratio. Their profiles are very high in order to obtain a highly-directive beam. The third is to utilize a leak-wave surface. They include Fabry-Perot (FP) antennas [5], modulated surface antennas [6], and radial-line slot antennas [7], etc.. Their profiles are low, but there is a trade-off between the aperture efficiency and edge losses. The fourth is to employ a large phased surface backed with an excited cavity. An engineered Huygens surface is loaded above a single-source excited cavity to produce a highly directive beam [8]. However, a high profile of more than one wavelength is usually demanded.

Higher-order-mode (HOM) cavity antennas can avoid the high profile of Huygens' cavity-excited antennas. The HOM cavity antennas excite a high resonant mode inside the cavity, and slots are etched appropriately for radiating a highly directive beam. It is found that all of the previously reported HOM antennas can only achieve broadside beams [9], [10]. This is caused by the inherent resonant characteristics associated with the HOM cavity.

This paper focuses on realizing highly directive tilted beams for HOM cavity antennas. First, we develop a TE$_{(10)(11)(0)}$-mode slot-based cavity antenna. It achieves a high-gain broadside beam with a 60.3% aperture efficiency. To enable the tilted-beam functionality, an engineered patch surface with appropriately sized metallic patches is introduced and positioned above the proper-offset radiating slots. The subsequent high-gain tilted-beam antenna system is then attained. It radiates a single tilted beam at 30° with respect to the broadside direction. Antenna prototype was fabricated and tested successfully.

II. TE$_{(10)(11)(0)}$-Mode Cavity Antenna

A. Antenna Configuration

Configuration of the TE$_{(10)(11)(0)}$-mode cavity antenna is depicted in Fig. 1. It is comprised of a substrate, a slot layer, an air-filled rectangular cavity, and a rectangular waveguide. Characteristics of the substrate are, dielectric constant ε_r = 2.2; loss tangent $\tan\delta$ = 0.001; height h_s = 0.5 mm. A slot layer is printed on bottom of the substrate. It is a metal layer etched with 110 slots. An air-filled rectangular cavity with a height

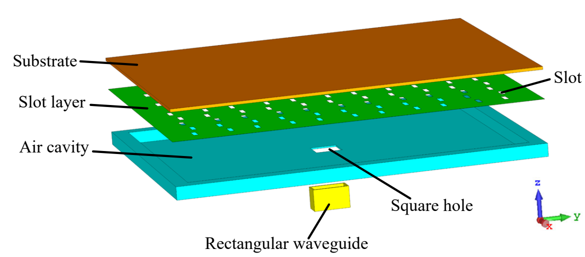

Fig. 1. Exploded view of the TE$_{(10)(11)(0)}$-mode cavity antenna.

of 4 mm is backed to the slot layer. A rectangular waveguide is selected as the feed source, and it is placed at the center position. A square hole is drilled on bottom of the cavity for impedance transition between the waveguide and the cavity.

Top view of the antenna with the excited $TE_{(10)(11)(0)}$-mode at 10.5 GHz is shown in Fig. 2. One finds that there are 10 half-wavelengths along the x-axis and 11 along the y-axis. Slots are etched in a way that can compensate the opposite E-fields between two adjacent half-wavelengths and, hence, the total E-field can add up at broadside. Values (in millimeters) of the main parameters are given as follows: L = 234, W = 192, L_s = 10, W_s = 3.

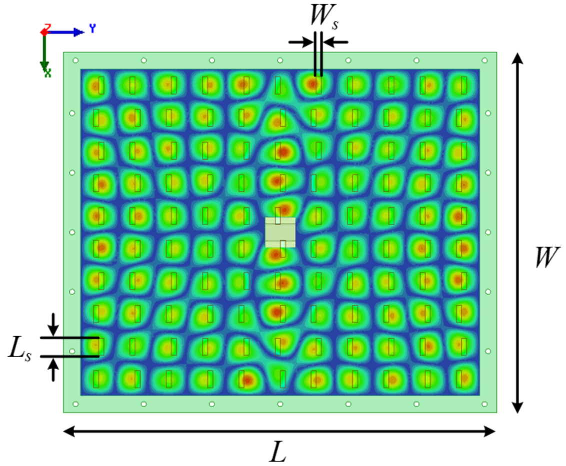

Fig. 2. Top view of the antenna with the excited $TE_{(10)(11)(0)}$-mode at 10.5 GHz.

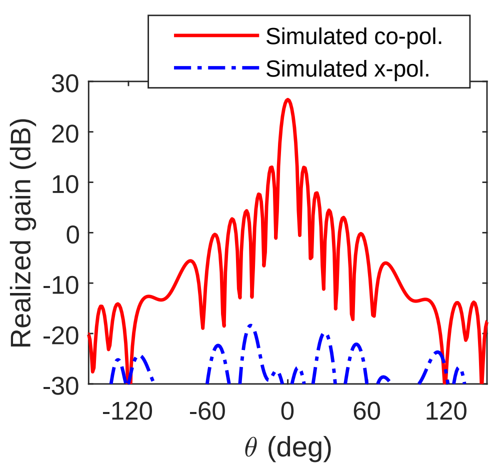

Fig. 3. Simulated co-pol. and x-pol. E-plane realized gain patterns at 10.5 GHz.

B. Simulated Results

Antenna's operating frequency is chosen at 10.5 GHz. The simulated $|S_{11}|$ value is -14.4 dB. Fig. 3 shows the simulated co-polarization (co-pol.) and cross-polarization (x-pol.) realized gain patterns in E-plane (yz-plane). The realized gain value is 26.6 dB, and the x-pol. level is less than -44 dB. Antenna's aperture efficiency is 60.3%. The 3-dB beamwidth is 7.5°. It indicates a focused highly-directive broadside beam is obtained.

III. $TE_{(10)(11)(0)}$-Mode Cavity Antenna Loaded with Patch Surface

A. Antenna Configuration

In order to facilitate tilted-beam patterns with HOM cavity antennas, a technique that employs a closed-spaced patch surface is implemented to control radiating phase from each slot. An example of tilted beam angle at (θ_0 = 30°, ϕ_0 = 0°) is considered. Fig. 4 shows configuration of the patch-surface loaded $TE_{(10)(11)(0)}$-mode cavity antenna. Another substrate printed with a patch surface is introduced and loaded above the aforementioned $TE_{(10)(11)(0)}$-mode cavity antenna.

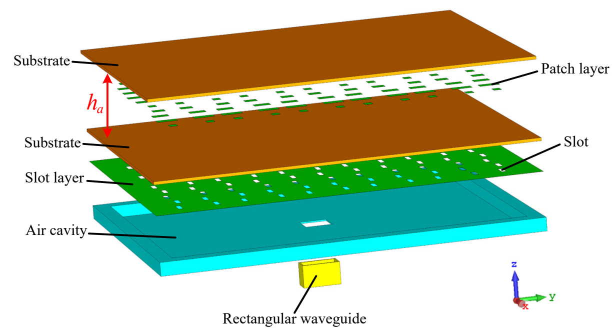

Fig. 4. Exploded view of the $TE_{(10)(11)(0)}$-mode cavity antenna loaded with patch surface.

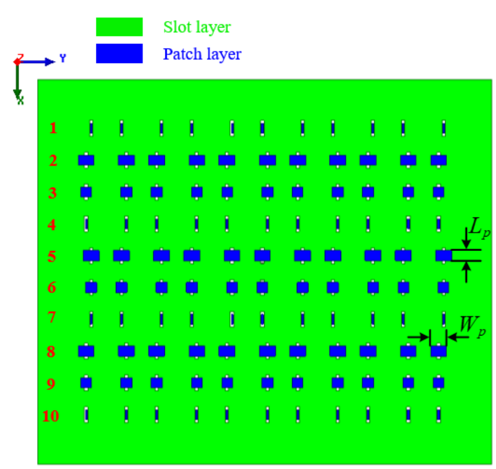

Fig. 5. Top view of the $TE_{(10)(11)(0)}$-mode cavity antenna loaded with patch surface. (Substrates are not presented)

Fig. 5 shows top view of the antenna without its substrates being presented. Each patch is centrally located above a slot with a height of h_a = 2.5 mm, and its size is appropriately sized to provide required phase for beam tilting. As the main beam is only tilted in xz-plane, all of the 11 slots/patches in a row have same dimensions. Opposite offsets are utilized for the adjacent slots/patches in the same row to achieve far-field in-phase composition. All of the patches have the same width W_p = 6 mm, and the patch length L_p from Row 1 to 10 is 1 mm, 9.5 mm, 6.5 mm, 1 mm, 9.5 mm, 6.5 mm, 1 mm, 9.5 mm, 6.5 mm, and 1 mm, respectively.

B. Simulated and Measured Results

An antenna prototype was fabricated. Fig. 6 shows measured and simulated normalized radiation patterns at 10.5 GHz. It is observed that measured results agree well with the simulated ones. This illustrates effectiveness of our developed phased technique that employs an appropriately-sized patch surface. Measured gain value is 25.3 dBi, and it is around 0.9 dB lower than the simulated value of 26.2 dBi. Sidelobe levels of the measured and simulated patterns are -11.0 and -12.6 dB, respectively. Small difference may be caused by fabrication inaccuracy. Antenna's measured x-pol. level is lower than -36.8 dB.

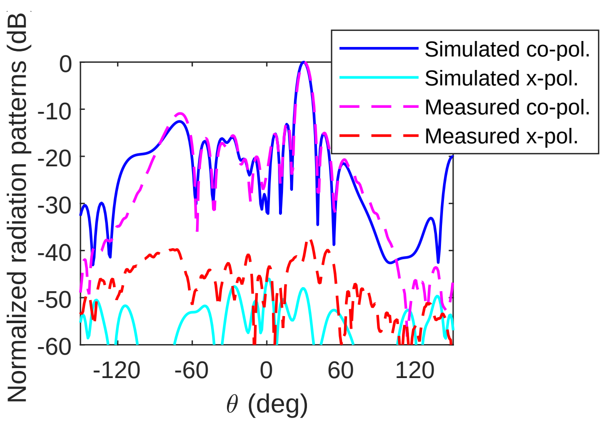

Fig. 6. Simulated and measured co-pol. and x-pol. H-plane realized gain patterns at 10.5 GHz.

IV. Conclusion

An engineered patch surface was developed to facilitate the higher-order-mode cavity antennas with tilt-beam functionality. A $TE_{(10)(11)(0)}$-mode slot-based cavity antenna with a highly broadside beam was designed first. A single-tilted beam was attained by introducing the appropriately-sized patch surface with proper slot offsets. This phased technique is promising for the resonant antennas that desire various beam functionalities.

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