A Broadband Probe-Fed 4×4 Array Antenna for Ku-band Applications

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***Abstract* - A broadband probe-fed array antenna for Ku-band applications covering 10.7– 12.75 GHz, a bandwidth of 2.05 GHz, is proposed. The array antenna adopted 4×4 configuration with a parallel branch feeding network to set up required equal current magnitudes and phases. The antenna element in the array utilizes a vertical pillar to reduce the surface wave loss and increase operation bandwidth. The bandwidth of the array was about up to 30 percent (from return loss); the radiating gain of the antenna system was about 16.3 dB. The gain flatness within the bandwidth was about ± 1.25 dB; the aperture efficiency was about 38%.**

***Index Terms* —Array Antenna, Ku-Band, Aperture Efficiency.**

1. INTRODUCTION

Since 1979, world's satellite broadcasting technology has commonly employed C-band and Ku-band [1] regulated by ITU's World Administrative Radio Conference (WARC, later changed its name to the World Radio communication Conference, WRC). The Ku-band downlink band is between 10.7 GHz and 12.75 GHz; it has a larger bandwidth (it is only 400 MHz in C-band); thus, higher signal capacity. Ku-band does not overlap with the spectrum of general communications applications (*i.e.*, 2- 6 GHz) [2]. Owing to a higher gain (smaller wavelengths), the receiving antenna of Ku-band can have better performance than C-band; thus, better quality TV images. The Ku-band aperture can be significantly reduced; effectively reducing the cost [3]. In recent years, many television operators have also adopted the Ku-band to broadcast their TV programs; thus, more Ku-band applications [4].

Planar array antenna designs have been reported. In [5], the antenna system was based on printed circuit board (PCB) technology, due basically to easier and mass production. However, the dish antenna array in general has higher transmission efficiency than those using PCB. One main goal of this paper is to improve the efficiency of feeding and transmission structure of the proposed printed array antenna.

2. ANTENNA DESIGN

In this paper, a broadband, high-gain and high directivity 4×4 array for Ku-band (10.7 GHz–12.75 GHz) applications is proposed. The purpose of the design is to reduce the production cost, but at the same time, achieve high gain and high directivity for the array antenna with printed feeding network. The operation bandwidth of a micro-strip patch antenna is in general narrow (about 2%), much smaller than the bandwidth requirement of Ku-band (BW≈17.5%). The operation bandwidth of the micro-strip patch based array antenna, thus, needs to improve drastically [6].

Figure 1 shows configuration of the proposed 4 x 4 patch array. The protruded 4 x 4 patch array sits on a metal ground, and it uses pillars to connect the patches to the feeding and transmission network under the ground. The pillar design offers multi-advantages; for example, a broader operation bandwidth through the area current flows; reduced coupling between the feeding network and array antenna through the ground plane. Taking advantages of air as the dielectric material between the patches and the ground results in a design with even broader bandwidth.

Because the metal sheet edges of the element patch represent a high impedance; it is difficult to match to the feeding and transmission network, fed by a 50Ω cable. A triangular shape metal sheet is added to the metal patch at the antenna feeding side [5], right of Figure 1. The triangular metal sheet is bent 90° from the patch to reduce the length of the pillars.

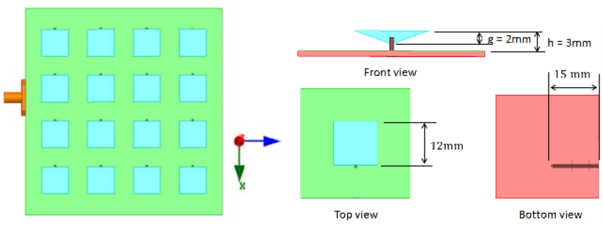

Fig. 1. The array (Left) and an element patch (Right). The FR-4 is a double layer organic PCB: ε_r =4.4, loss tangent = 0.02, and thickness = 0.8 mm.

Firstly, the triangle shape probed feed avoids the high impedance caused by the patch's metal edges; secondly, it enables the current flows, which then form multiple resonance paths to achieve the broadband characteristics [7]. The gain for an individual patch element was between 8.2 and 9.1 dB at 10.7 to 12.75 GHz.

Figure 2 is a photo of the 4×4 array antenna prepared for experimental validation. Owing to symmetrical feeding network (relative to center of the feeding network, the first T from SMA), all sixteen patches are of the same amplitude and phase. The array elements are on x-y plane (Figure 1), the +z direction is the radiation direction. The E-field pattern is a function of the distance between elements. Array antenna gain is optimized when the center-center distance between the radiation metal patches is between 0.7 λ– 0.9 λ. From simulation, we picked X-axis and Y-axis center-center distance of 0.8 λ for optimized array antenna gain.

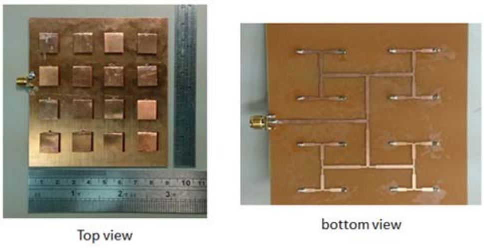

Fig. 2. A photo of the 4×4 array antenna configuration.

Owing to the antenna feeding path losses (ohmic and radiated), the substrate dielectric losses, and SAW (Surface Acoustic Waves) substrate losses, the gain is reduced [8]. Ideally, the 4×4 array, would have a gain of 18 dB (assuming individual patch gain of 8 dB, plus 3 dB*4 (4 x 4 = 2^4), minus the feeding and transmission loss, 2 dB).

3. Experimental and Results

Figure 3 (a) shows the reflection coefficients of the simulated and measured results. Figure 3 (b) shows simulated and measured gain and aperture efficiency of the 4×4 array antenna near the central frequency. Simulated and measured 2D radition patterns at 11.7 GHz are shown in Figure 4. The measured results are in general in good agreement with the simulated ones. The array utilized the pillars to connect the patches to the feeding network, as a mean to reduce the surface wave loss and to increase the operation bandwidth. The operation bandwidth of the array was up to 30 % (from Figure 3 (a)); the maximum radiation gain of the antenna system was about 16.3 dB (11.2 GHz, from Figure 3 (b)).

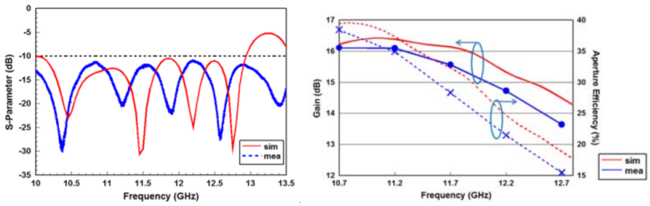

Fig. 3. (a) S-parameters of the 4×4 array antenna. (b) Radiation gain and efficiency of the proposed array.

The gain flatness within operation band was about ±1.25 dB, the aperture efficiency was about 38% (the wavelength λ was obtained using central frequency of 11.2 GHz, and the entire ground size was used as the aperture area). The difference between the simulated and the measured gain results is 0.1 dB to 0.6 dB (in Fg. 3 (b)). The reason for the difference may be caused by the vendor provided FR4 material properties. A better gain would occur when a lower loss substrate is used. However, a lower loss board costs more. Between cost and performance (gain, flatness, and efficiency), we believe the proposed design provides a satisfactory trade-off.

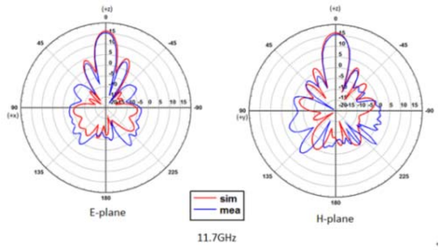

Fig. 4. The 2D radiation patterns of simulated and measured results for the proposed array antenna (at 11.7 GHz).

4. Conclusion

In this paper, a regular FR-4 board (loss tangent = 0.02) was utilized to fabricate the feeding network for the proposed array antenna. One main goal is to provide a satisfactory cost-performance array antenna design. This proposed high-gain directional array antenna took advantage of probed feed configuration and air for a broader operational band. The array antenna was design to cover operation band of 10.7~12.75 GHz, a BW of 2.05 GHz. The operation bandwidth of the array is up to 30 %; the radiating gain of the antenna system was about 16.3 dB. The gain flatness within operating band is about ±1.25 dB, the aperture efficiency was about 38%.

Acknowledgment

The authors wish to acknowledge the support of Taiwan's National Science Council through the grant of NSC 102-2221-E-110-013-MY3.

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