DESIGN AND TESTING OF HIGH-PERFORMANCE ANTENNA ARRAY WITH A NOVEL FEED NETWORK

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Abstract—A novel feed network for microstrip antenna array is presented. By using the novel feeding structure, a high-performance Ku-band antenna is designed and fabricated. The 32 elements of the array are arranged in a 2-by-16 configuration. The measured peak gain at centre frequency is 22.93 dBi with an aperture efficiency of 70.5% and SLL of -12.3 dB from 11.75 GHz–12.75 GHz.

1. INTRODUCTION

Microstrip antenna arrays are intensively utilized for applications on satellite, global position and mobile communications because of many outstanding features, such as ease to be manufactured, low cost, low profile, and light weight [1–4]. However, when applied to higher microwave frequencies, microstrip antenna arrays should suffer from low efficiency due to ohmic and dielectric losses of the connecting microstrip lines, as well as undesired coupling and radiation of the feed network [5, 6]. The efficiency limitation will be more severe in large arrays where the feed network becomes complicated and mutual coupling becomes increased [7–11]. Recently, a circularly polarized array antenna using a four-way power divider to feed its 2×2 subarray has been reported, showing an improvement of gain and radiation characteristics, but the great precision is required in the size of feed line [12]. Low-loss microstrip and waveguide feed network has been adopted to design a high-gain Ku-band array of circularly polarized microstrip antennas, but its reported high aperture efficiency of 51% is only obtained at centre frequency [5]. In this article, a novel feed network for microstrip antenna array is proposed. Instead of using the typical single-layer structure, shaped T junctions and bend discontinuities, the presented array employs a new multilayer feeding structure using quasi-orthogonal feed lines. This novel structure

improves the performance of the array dramatically. A prototype antenna array has been fabricated and measured to verify the design. The measured return loss and radiation patterns are also presented.

2. FEED NETWORK CONFIGURATION

Large antenna array shows low efficiency due to the influence of mutual coupling and transmission line discontinuity within the feed network and the coupling between antenna elements and feed network.

    To reduce the loss within the feed network, we introduce the circular-arc feed line to feed each array element. Figure 1 shows the feed network for a 2×2 sub array. In principal, we make the main feed lines orthogonal to each other while ensuring that all the four radiating elements get the same amplitude and phase distribution. Compared to using typical T junctions and bend discontinuities to form a 2×2 element subarray (Examples can be found in [5, 13, 14]), this kind of feed network dramatically improves efficiency due to two facts: 1). Proximity coupling among feed lines causes multiple reflection within the feed network resulting in an increase of loss and a change of excitation currents, while proximity coupling among orthogonal feed lines is relatively weak; 2). T junctions and bend discontinuities generate unwanted radiation at the discontinuity of the feed line which can seriously deteriorate the desired amplitude distribution, while
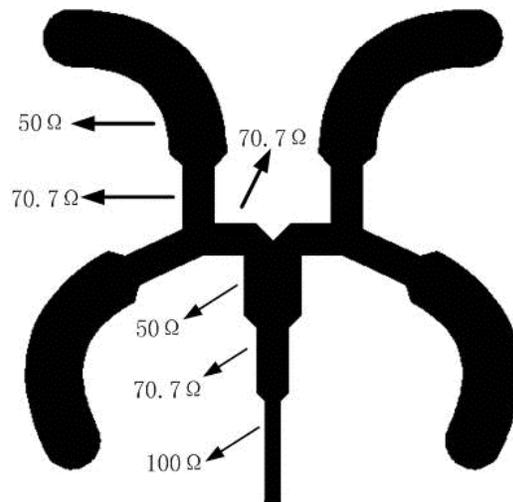

Figure 1. Geometry of the proposed 2×2 feed network.

circular-arc feed lines alleviate the discontinuity. When four 2×2 sub arrays form a 4×4 sub array, main feed lines in the network remain quasi-orthogonal to each other, resulting in a great enhancement of network efficiency.
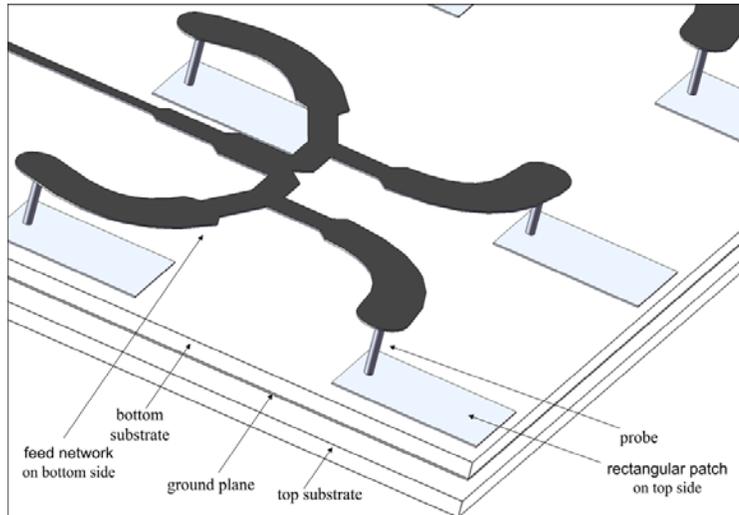

Figure 2. Configuration of the antenna (back view).

In order to reduce the coupling between antenna elements and feed network, we adopt a two-layer structure, as shown in Figure 2. The antenna consists of two Taconic TLT-6 substrates with permittivity 2.65 and thickness 1 mm. Patch elements are pasted on the top side of the top substrate, while the feed network is pasted on the bottom side of the bottom substrate. On the top side of the bottom substrate there is a ground plane, which is designed to separate the two planes and reduce unwanted radiation from various transmission line discontinuities exposed to the radiation plane.

Simulated S-parameters of the proposed 2×2 feed network using CST Microwave Environment are shown in Figure 3. The simulated $S11$ is observed to be better than -15 dB and $S21$, $S31$, $S41$, $S51$ are about -6.3 dB over the desired 11.75–12.75 GHz range. The insertion loss of the 2×2 feed network is estimated to be 0.3 dB, which shows excellent performance.
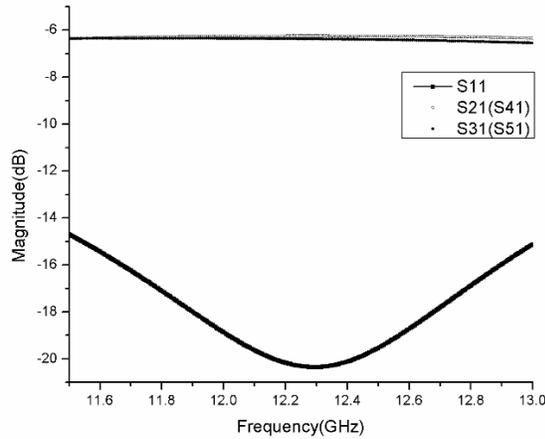
Figure 3. Simulated S-parameters of the proposed 2×2 feed network.

3. ARRAY CONFIGURATION

The configuration of the proposed antenna array is shown in Figure 2 and photos of fabricated antenna are shown in Figure 4. Simple rectangular patches are used to test the performance of proposed feed network. Rectangular elements ($8.65 \, \text{mm} \times 5 \, \text{mm}$) are pasted on the top side of the top substrate. The element spacing of the array is $20.36 \, \text{mm}$ (or 0.82λ at centre frequency $12.25 \, \text{GHz}$). Using reflow soldering technique, probes between the top substrate and bottom substrate connected the rectangular patches and feed network together. A suitable air gap of $1.3 \, \text{mm}$ thickness is maintained between the two substrates to increase the bandwidth of the antenna due to a decrease in the effective dielectric constant. A ground plane and corporate network is pasted on the top and bottom side of the bottom substrate respectively. The dimensions of the elements and the feed network are optimized to suit a particular requirement of SLL and gain. In short, from the top to the bottom, we have rectangular patch, top substrate, probe, ground plane, bottom substrate and feed network.

4. EXPERIMENTAL RESULTS

A 2×16 antenna array is fabricated and measured for input impedance in microwave anechoic chamber, and furthermore its radiation characteristics are obtained on the far field range. All experimental results are found to agree with simulated results. First
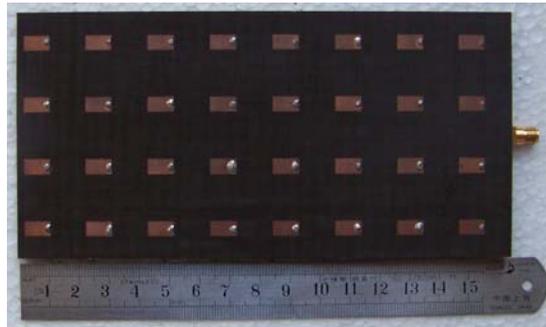
(a)
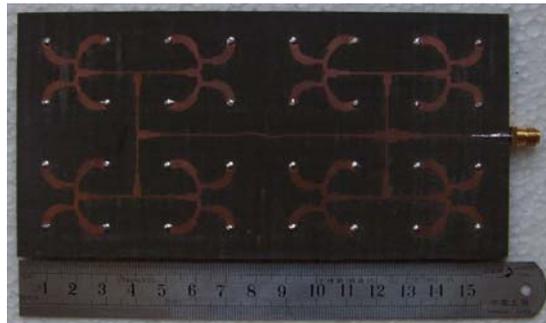
(b)

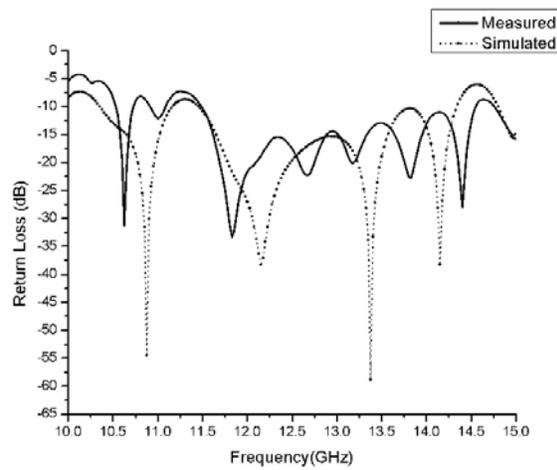**Figure 4.** Photograph of the fabricated antenna (a) front view (b) back view.

Figure 5. Measured and simulated return loss of the antenna.

of all, Agilent 8722ES Network Analyzer is used to measure the return loss of the antenna and the result is shown in Figure 5. It can be seen that a good input impedance match characteristics of $|S11| < -15\,\text{dB}$ over the desired 11.75–12.75 GHz range is obtained.
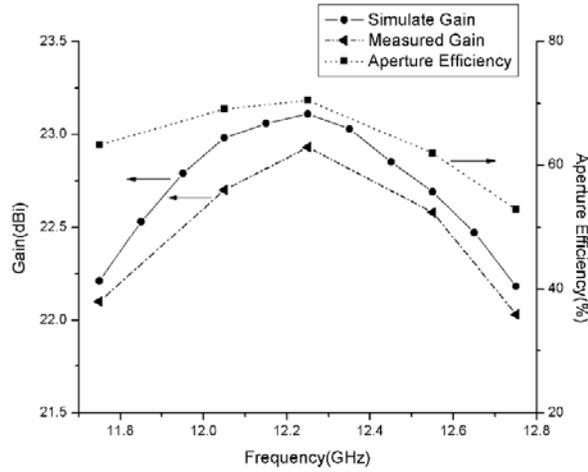

Figure 6. Measured gain, simulated gain and calculated aperture efficiency of the antenna.
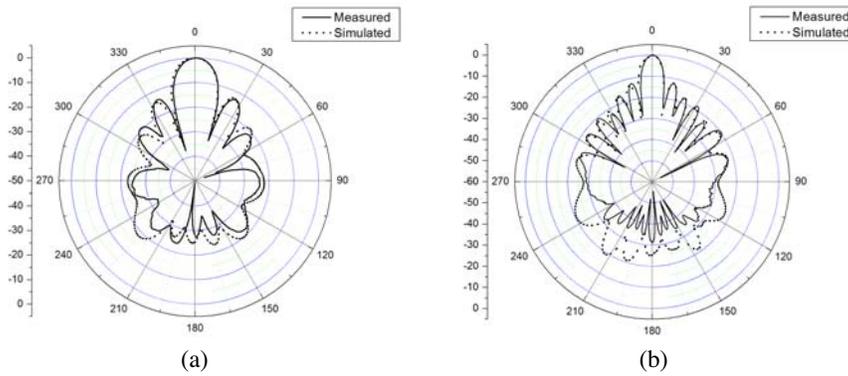
Figure 7. Measured and simulated normalized radiation pattern (a) E-plane at $f = 12.25\,\text{GHz}$ (b) H-plane at $f = 12.25\,\text{GHz}$.

Measured gain, simulated gain and calculated aperture efficiency of the antenna are shown in Figure 6. The measured peak gain is 22.93 dBi at 12.25 GHz, which presents a high aperture efficiency of 70.5%. For frequencies over the desired range, a stable antenna gain

of over 22 dBi is obtained, and the aperture efficiency is above 50%. Radiation patterns in E-plane and the pattern in H-plane at centre frequency are measured and plotted in Figure 7, which show the SLL of 13.29 dB in E-plane and 12.3 dB in H-plane, respectively. All experimental results indicate that a high-performance antenna array is obtained by simply using the proposed feed network.

5. CONCLUSION

A novel feed mechanism for high-performance microstrip antenna array is presented. We have used the techniques discussed here to design, develop, manufacture, and measure a 2×16 array antenna. The complete structure has a 22.93 dBi gain and an aperture efficiency of 70.5% at centre frequency, as well as a stable antenna gain of over 22 dBi and an aperture efficiency of above 50% over the desired 11.75–12.75 GHz range. This feed network also features a stable and reproducible structure, and can be used for microstrip antenna arrays requiring high gain and broadband performance.

ACKNOWLEDGMENT

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