A Microstrip Patch Array Antenna with Metal Mesh Structure for Cross Polarization Suppression

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***Abstract* ─** A 1×4 microstrip patch array antenna is presented for Ku-band radar systems. A metal mesh structure working as a polarizing filter (twist reflector) is employed to reduce the cross-polarization of the antenna. The metal mesh structure is simple and easy to be printed on a commercial substrate. The proposed antenna has been designed and analyzed by using commercially available software – Computer Simulation Technology Microwave Studio (CST MWS), which is based on the finite-difference-time-domain algorithm. A prototype antenna is built and tested. The return loss has been compared between measured and simulated data under the criterion of VSWR less than 2 throughout the designed 14.9 to 15.1 GHz frequency range. The cross-polarization levels in both E and H planes are better than -21 dB, with fair regular radiation patterns.

***Index Terms*─** Cross polarization, metal mesh, microstrip antenna, patch array.

I. INTRODUCTION

Microstrip patch radiators are widely used due to their compact size, low-profile, low-weight, low-cost, easy integrability into arrays or with microwave integrated circuits [1, 2]. An array of these elements is commonly employed in order to meet required specific applications, such as wider bandwidth, lower sidelobes, and higher power [3–5].

In microstrip patch array design, stacked patches (including parasitic elements and low-loss substrates) and aperture coupled patches are usually considered capable of enhancing the antenna performance. However, the stacked patches will increase antenna layers. Increased layers will lead to the antenna further thickness and fabrication errors. In the aperture-coupled patch antenna, ground plane is above the feed line, a parallel plate mode between the back plate and the ground plane will be excited [6].

In this paper, a novel low-cost 1×4 microstrip patch array antenna is presented. The antenna is easy to be fabricated and the whole structure is low-profile. A simple coplanar patch array antenna is designed on a single layer substrate. The radiation and reflection characteristics of the coplanar patch array are calculated. The return loss of the coplanar patch array is low, but the cross-polarization is high. In order to discriminate the cross-polarization, a metal mesh structure which is a twist reflector is employed. The principle of twist reflector is presented in Section II. Section III describes the antenna design procedure. A detailed description of the simulation and measurement results are explained in Section IV followed by the conclusion drawn in Section V.

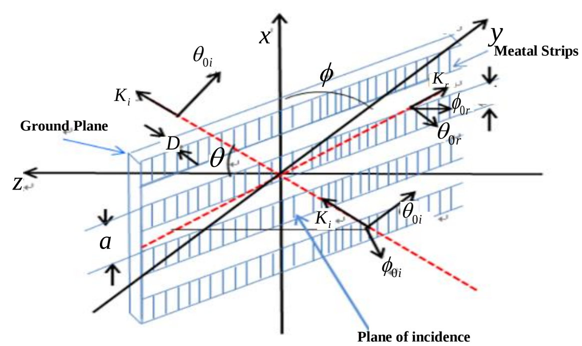

Fig. 1. Geometry of twist reflector for arbitrary plane wave incidence.

II. PRINCPLE OF TWIST REFLECTOR

The twist reflector is made up of a unidirectional periodic metallic grating approximately a quarter wavelength above a conducting ground plane [7]. The geometry of the twist reflector for arbitrary angle and plane of incidence is shown in Fig. 1. It is assumed that the grating is planar, periodic in *x* direction and uniform in the *y* direction.

The angle of incidence θ is depicted in Fig. 1 as the angle between k_i and *z*. The reflected angle is π-θ. The plane of incidence makes angle φ with *x*-axis:

$$k_z = j(k^{'} - jk^{''}), \tag{1}$$

where $k^{'} = \omega\sqrt{\mu'\epsilon'}$, $k^{''} = \frac{1}{2}\omega\sqrt{\mu'/\epsilon'} \times \epsilon''$, $\tan\delta = \epsilon''/\epsilon'$, $\omega = 2\pi f$. f is the frequency of operation, δ is dielectric loss angle, μ', ϵ', and ϵ'' are the permeability, permitivity and loss factor of the material respectively.

The equivalent circuits applicable to both the strip grating and parallel plate twist reflectors is given in [7].

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In the E-type mode, the circuits consists of an inductive reactance (X'_L), and in the H-type mode, a capacitive susceptance (B''_c) is included. Considerate the loss factor, the modal reflection coefficients of E-type (Γ') and H-type (Γ'') modes given in [7] are modified as [8]:

$$\Gamma' = \frac{jX'_L \frac{Z'_\varepsilon}{Z'} \tanh\left(k_z D\right) - \frac{Z'_\varepsilon}{Z'} \tanh\left(k_z D\right) - X'_L}{jX'_L \frac{Z'_\varepsilon}{Z'} \tanh\left(k_z D\right) + \frac{Z'_\varepsilon}{Z'} \tanh\left(k_z D\right) + X'_L}, \quad (2)$$

$$\Gamma'' = \frac{1 - j\left(B''_c - \frac{Y''_\varepsilon}{Y} \coth\left(k_z D\right)\right)}{1 + j\left(B''_c - \frac{Y''_\varepsilon}{Y} \coth\left(k_z D\right)\right)}. \quad (3)$$

Assumed the incident field $E_{\theta i}$=1 and $E_{\varphi i}$=0, the cross-polarization suppression ratio for 90° polarization rotation after reflection, which is defined as the ratio of field in the undesired polarization after reflection to the incident filed is given by [7]:

$$E_{\theta r} = \frac{-\Gamma' \cos^2\phi \cos^2\theta}{1 - \sin^2\phi \sin^2\theta} \left(\tan^2\phi + \frac{\Gamma''}{\Gamma'} \sec^2\theta\right), \quad (4)$$

$$E_{\phi r} = \frac{\Gamma' \sin\phi \cos\phi \cos\theta}{1 - \sin^2\phi \sin^2\theta} \left(1 - \frac{\Gamma''}{\Gamma'}\right). \quad (5)$$

If the material is lossless, the two conditions for perfect conversion of $E_{\theta r}$ into $E_{\varphi r}$ are:

$$\Gamma''/\Gamma' = 1 \quad \text{electrical}, \quad (6)$$

$$\tan\phi = \sec\theta \quad \text{geometrical}. \quad (7)$$

The important parameters in the twist reflector design are dielectric material, copper strip width, periodicity of the grating and thickness of the substrate material [8].

III. ANTENNA DESIGN PROCEDURE

A. Coplanar patch array antenna

In this section, a coplanar patch array antenna with power divider network is proposed. The geometry of the 1 × 4 array is shown in Fig. 2. The antenna array is employed to increase the antenna gain. The equal power distributed network is printed on the same plane. The antenna is fed by copper cable. Four patch elements and power divider network are printed on a 1-mm-thick Rogers RT/duroid 5880 substrate (ε_r = 2.2, tanδ = 0.0009). The parameters of the antenna dimensions are optimized according to impedance bandwidth, and radiation requirements.

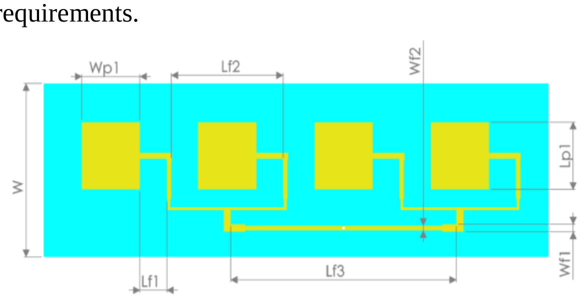


Fig. 2. Geometry of the coplanar patch array antenna.

The simulated return loss of the coplanar array antenna is shown in Fig. 3. The return loss is less than -10 dB in 14.8GHz-15.2 GHz. At 15GHz, the return loss is -23dB.

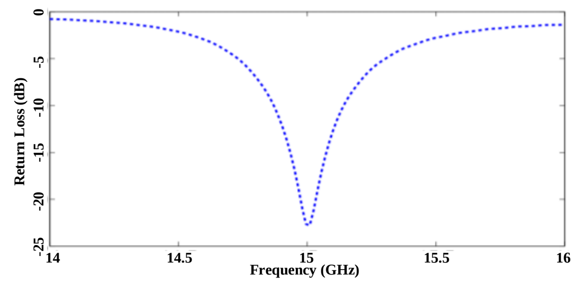
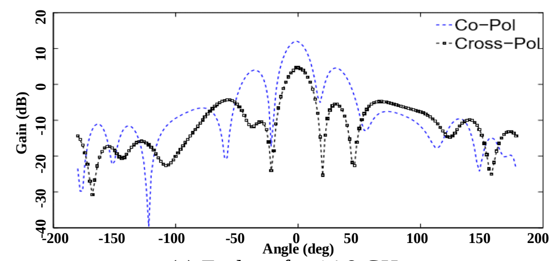
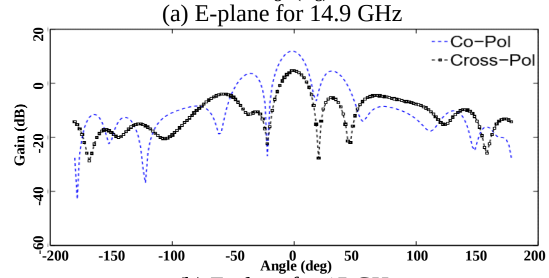


Fig. 3. Simulated return loss of the coplanar patch array antenna.

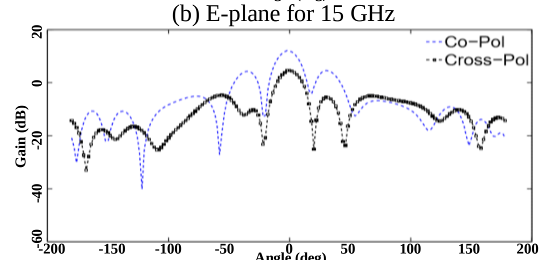
The co-polarizations lower than -10 dB from 14.9 to 15.1 GHz, the cross polarizations are higher than -8 dB, as shown in Fig. 4. To overcome this disadvantage, a metal strip structure is employed subsequently.



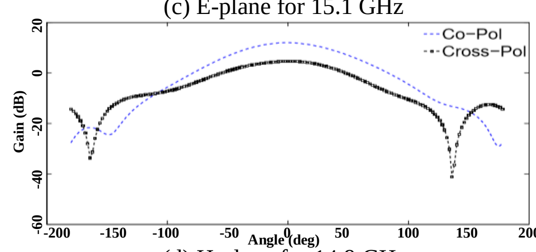
(a) E-plane for 14.9 GHz



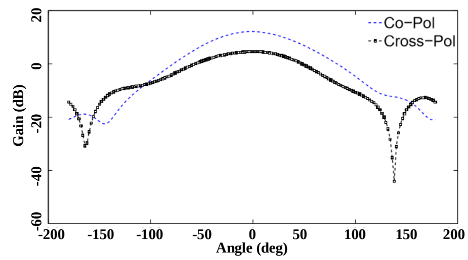
(b) E-plane for 15 GHz



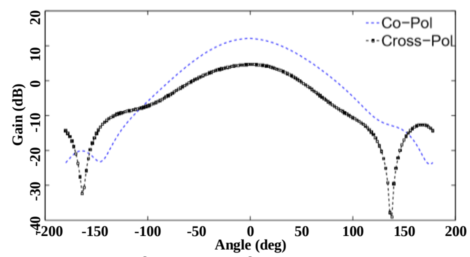
(c) E-plane for 15.1 GHz



(d) H-plane for 14.9 GHz



(e) H-plane for 15 GHz

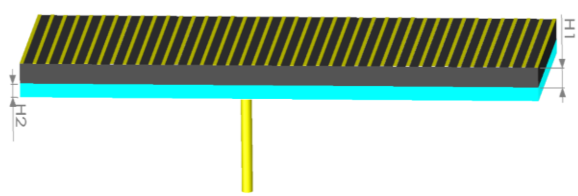


(f) H-plane for 15.1 GHz

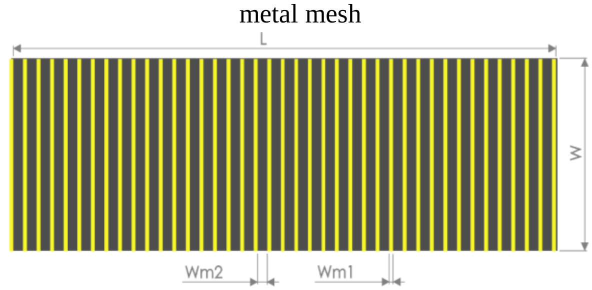
Fig. 4. Simulated radiation patterns in the E-plane of the coplanar patch array antenna for: (a) 14.9 GHz, (b) 15 GHz, (c) 15.1 GHz, as well as in the H-plane for (d) 14.9 GHz, (e) 15 GHz, and (f) 15.1 GHz.

B. Patch array with metal mesh structure

The basic geometry of the novel array proposed is shown in Fig. 5, which introduces a metal mesh structure printed on a commercial FR4 substrate.



(a) Whole structure of the patch array antenna with a metal mesh



(b) Top structure of the proposed antenna

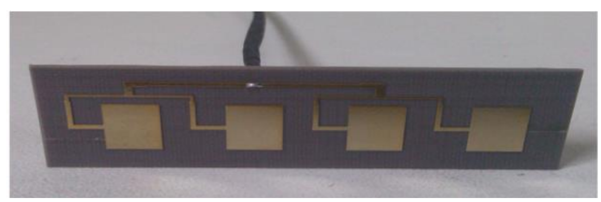
Fig. 5. Configuration of the patch array antenna with a metal mesh.

In order to simplify the antenna fabrication process, the antenna is separated into two parts: bottom part (the same as Fig. 5 (a)) and top part (as shown in Fig. 5 (b)). The same as the antenna described above, four patch elements and power divider network are printed on a 1-mm-thick Rogers RT/duroid 5880 substrate. Different from the coplanar patch array, there is a metal strip structure discriminating the cross-polarization. The metal strip is printed on a 1.5-mm-thick FR4 substrate ($\varepsilon_r = 4.8$, $\tan\delta = 0.016$), which is low-cost and used widely in industry or commerce.

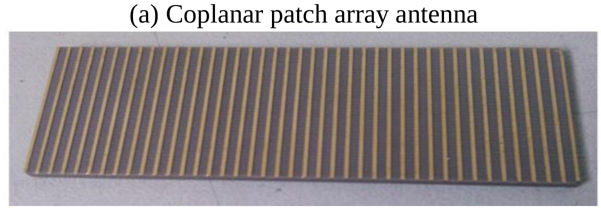
IV. ANTENNA PERFORMANCE

The performance of the antenna is studied numerically and verified experimentally. The numerical results are obtained by using CST MWS based on the finite-difference-time-domain algorithm. The dual-polarized antenna configuration finally selected has the following dimensions: L = 56.5 mm, W = 18 mm, Wp1 = 6.5 mm, Lp1 = 7 mm, Wf1 = 0.8 mm, Wf2 =0.5 mm, Lf1 = 3 mm, Lf2 = 12.5 mm, Lf3 = 25.2 mm, Wm1 = 0.4 mm, Wm2 = 1 mm.

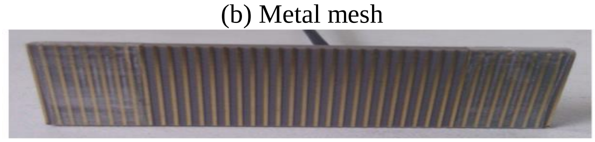
The antenna discussed above has been realized, and a photograph of the antenna is shown in Fig. 6. The S-parameter measurements are carried out with Agilent E8362B vector network analyzer (VNA). The simulated and measured reflection characteristics of the antenna are shown in Fig. 7. The proposed antenna offers a bandwidth from 14.9 to 15.1 GHz for 2:1 VSWR.



(a) Coplanar patch array antenna



(b) Metal mesh



(c) Patch array with a metal mesh structure

Fig. 6. Photographs of the designed antenna.

Antenna radiation performance is measured and recorded in two orthogonal principal planes (E-plane and H-plane). The pattern is plotted in the form of rectangular coordinates. The radiation characteristics of the proposed antenna in E and H principal planes for both ports are shown in Fig. 8. Generally, agreement between the measurement and simulation results are good for both co-polar and cross-polar components. The slight deviations may be manufacturing inaccuracies.

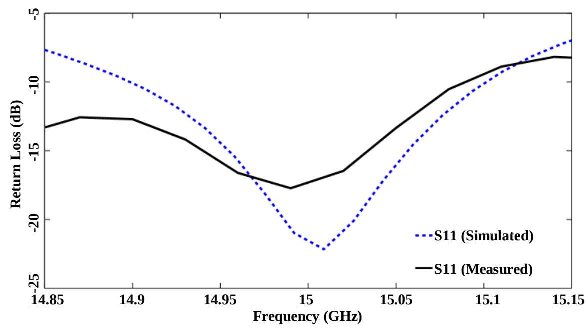


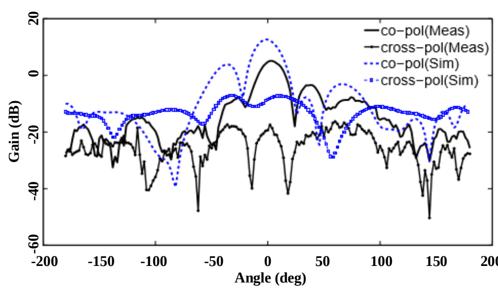
Fig. 7. Simulated and measured return loss of the patch array antenna with a metal mesh structure.

As illustrated in Fig. 8, the cross polarizations are reduced more than 13 dB. The proposed antenna exhibits cross-polar discrimination of better than -21 dB along the boresight direction.

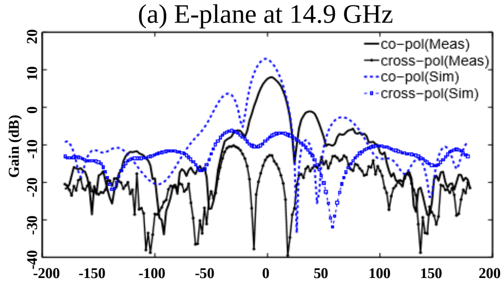
The measured half power beam width in the E plane are wider than 20°, and those are wider than 72° in the H plane. The measured gains of the proposed antenna are higher than 5.8 dBi throughout the designed frequency.

V. CONCLUSION

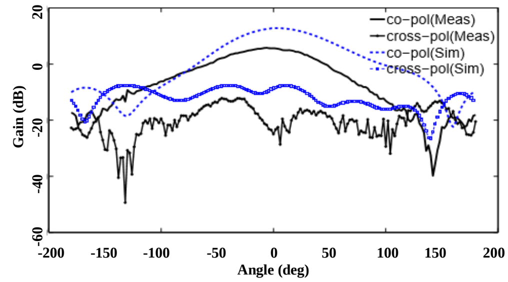
A novel patch array antenna has been designed, fabricated, and tested. The cross polarizations significantly discriminated when a metal strip structure is employed. The whole structure is compact, low-profile, and can be easily arranged in larger arrays. Promising features make it a potential candidate for *Ku*-band radar systems.



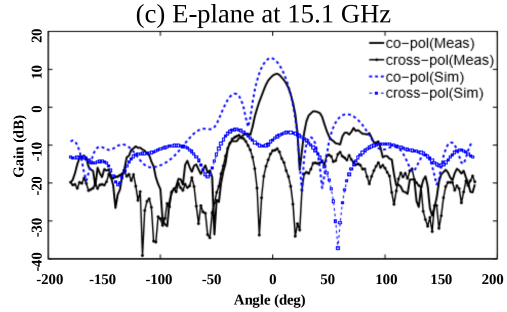
(a) E-plane at 14.9 GHz



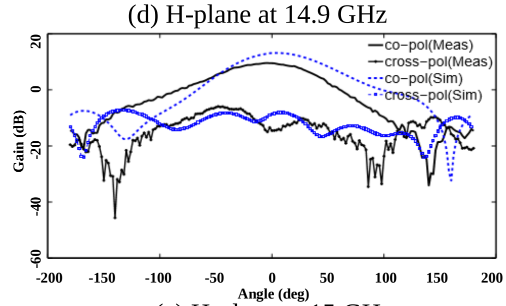
(b) E-plane at 15 GHz



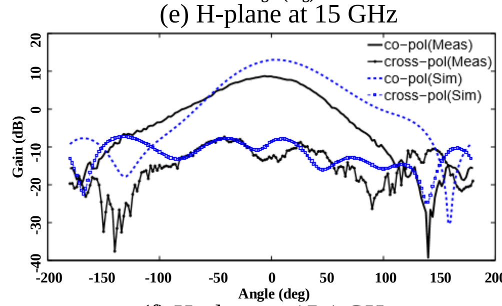
(c) E-plane at 15.1 GHz



(d) H-plane at 14.9 GHz



(e) H-plane at 15 GHz



(f) H-plane at 15.1 GHz

Fig. 8. Simulated (blue dashed) and measured (black solid) radiation patterns of the patch array antenna with a metal mesh.

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