Design of X-band Ultra-wide-angle Scanning Phased Array Antenna

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Introduction

For radars, in order to expand target search range, improve survivability and combat capability, it is desirable to extend the beam scanning range to the full hemisphere or quasi-hemisphere space.

Munk proposed a Tightly Coupled Dipole Array (TCDA) to cancel the inductance component introduced by the ground plane by capacitive coupling between adjacent components. Due to the close cell spacing and tight coupling, the current on the dipoles is almost constant, realizing Wheeler's current sheet.

In order to achieve ultra-wide-angle scanning, we present a new TCDA design with simple structure and low profile. Simulation results show the TCDA can scan up to 80° and 70° in the E-plane and the H-plane, respectively, with VSWR<3 from 8-12GHz.

ANTENNA DESIGN

A prototype of the unit cell of the proposed TCDA is shown in Fig. 1. The antenna consists of dipole radiating layer, Marchand balun, ground plane and wide -angle matching layer (WAIM).

Three copper layers are hosted by two RT/6002 (10mil, =2.94) substrates. These layers are bonded using a 0.1mm thick FR28 material resulting in a total PCB thickness of 0.608 mm. The dipoles are printed on the two substrates, and the stacked portions form a plate capacitor structure to increase the coupling capacitance. This design simplifies the antenna structure compared to TCDA with end-loaded interdigital capacitor.

Fig. 2 shows the simplified equivalent circuit of the unit cell with WAIM. The balun, substrate, superstrate and free space layers are represented by transmission line sections with properties determined by the propagated Floquet mode within each respective layer. The dipoles' inductance represented by , and inter-element coupling capacitance represented by serve to cancel the inductance component introduced by the ground plane to further broaden the bandwidth.

The mutual coupling between the cells causes the input impedance of the array elements to vary with the scan angle. To achieve wide-angle scanning, WAIM is introduced over the array aperture. WAIM consists of vertical parasitic superstrate and horizontal dielectric layer. The horizontal slab is made of RT/6002 with a thickness of 30 mil, = 2.94. The vertical superstrate can be regarded as a frequency selective surface, equivalent to an L-C series circuit. However, its operating frequency is lower than the resonant frequency. It is designed to provide capacitive loading for plane waves propagating along the z-axis. The vertical superstrate cooperates with horizontal dielectric layer to reduce the characteristic impedance of the medium, and mitigate the inductance component introduced by the ground plane.

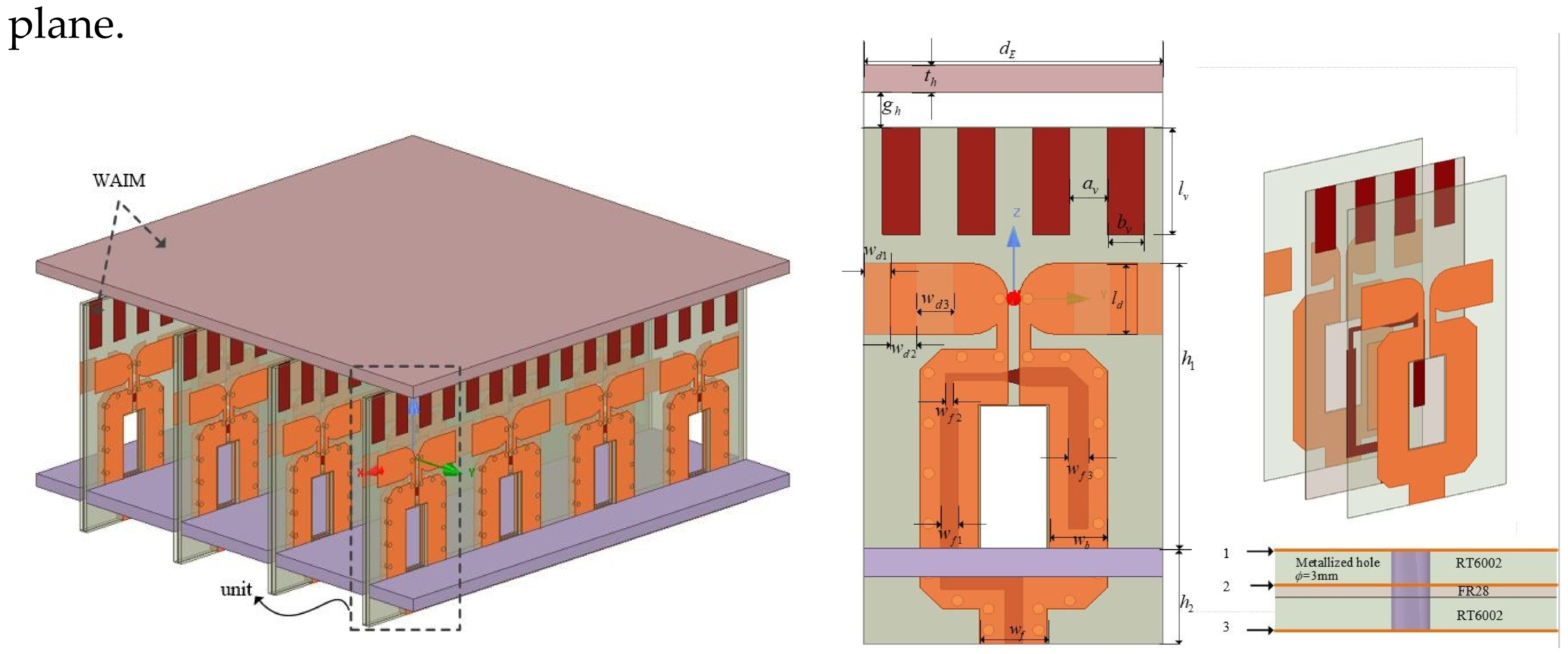
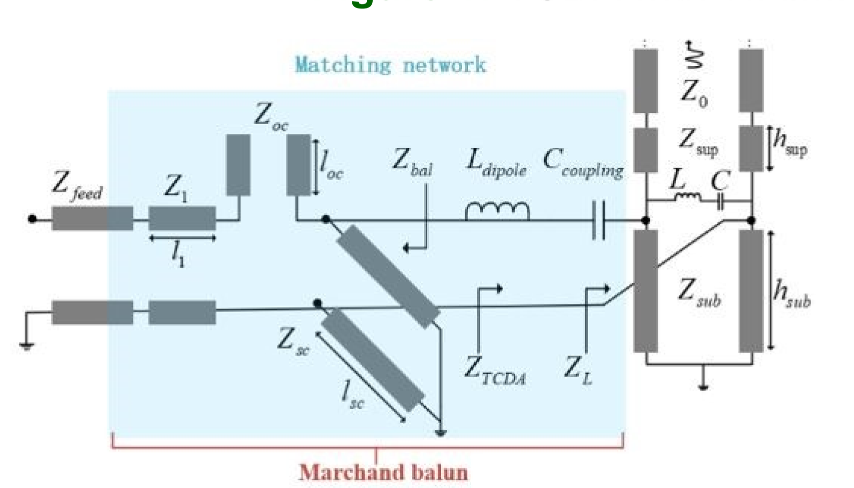


Figure 1: TCDA with WAIM: (left) 4×4 array; (right) Unit cell



Parameter	d_E	d_H	w_{f1}	w_{f2}	w_{f3}	w_b	w_{d1}
Value (mm)	8.0	8.0	0.45	0.19	0.52	1.56	0.7
Parameter	w_{d2}	w_{d3}	w_f	a_v	b_v	l_v	l_d
Value (mm)	0.7	1.0	1.8	1.0	1.0	1.0	2.0
Parameter	t_h	g_h	h_1	h_2	l_{f1}	l_{f2}	l_{f3}
Value (mm)	0.762	1.0	8.0	2.69	5.09	1.0	4.0

Figure 2: (left) TCDA equivalent circuit with WAIM; (right) optimized parameter values

INFINITE PERIODIC ARRAY

The proposed TCDA is optimized using electromagnetic simulation software HFSS. To simulate an infinite array, there are periodic boundaries around the unit cell and a Floquet port at the top. By jointly optimizing the parameters of the WAIM, electric dipoles, ground plane height and balun, the optimal parameters are achieved and shown in figure 2.

Scanned results of the infinite array are given in Fig. 3/4. The array maintains a good match over the entire bandwidth (8~12 GHz), and the active VSWR is less than 2 at broadside. The scanning angle ranges up to 80° and 70° (with VSWR<3) in the E-plane and H-plane, respectively. If the VSWR is relaxed to 3.6, an ultra-wide-angle scan of 85° in the E-plane and 75° in the H-plane can be realized. As the scanning angle increases, the mismatch at low frequency of the H-plane and high frequency of the E-plane becomes serious, and the VSWR fluctuations in the entire frequency band become large.

The cross-polarization level in the D-plane was calculated using Ludwig's third definition [9] and is shown in Fig. 5. As seen, the cross-pol level is lower than -15dB at 45° in the 75% bandwidth and -10dB at 60° in the whole bandwidth. Although it has some growth at the high frequency of 45°, it is still less than -10dB. These values are close to the ideal linearly polarized dipole apertures where the cross-pol levels are -15dB and -10dB at 45° and 60° respectively.

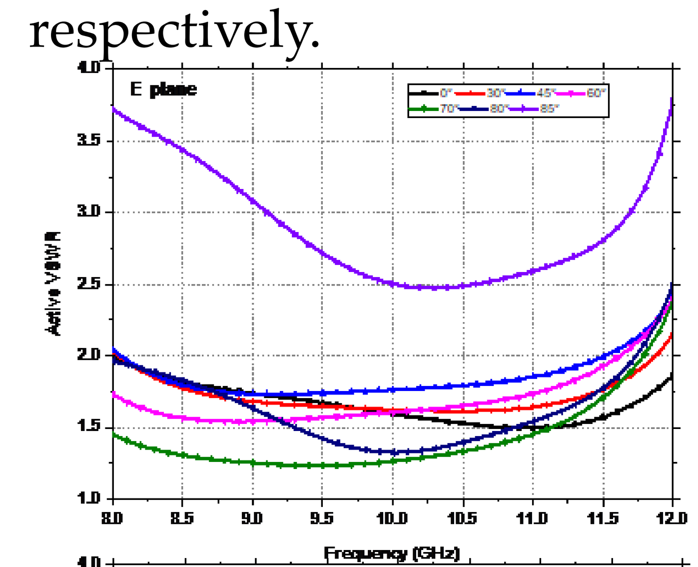


Figure 3: VSWR of the infinite array. E-plane

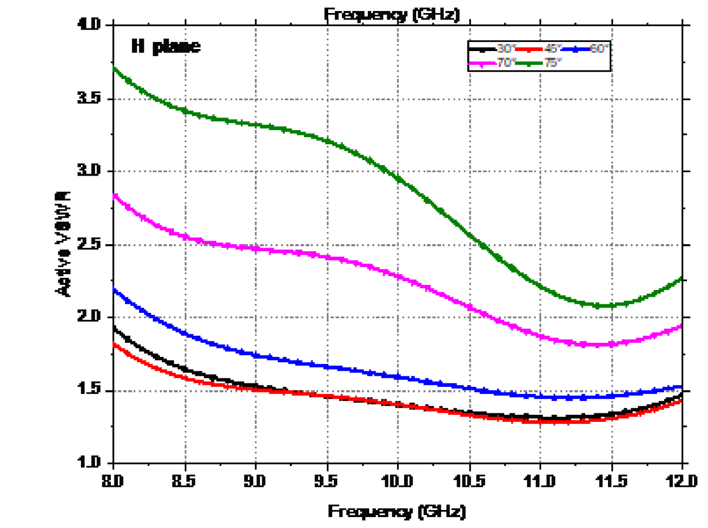


Figure 4: VSWR of the infinite array. H-plane

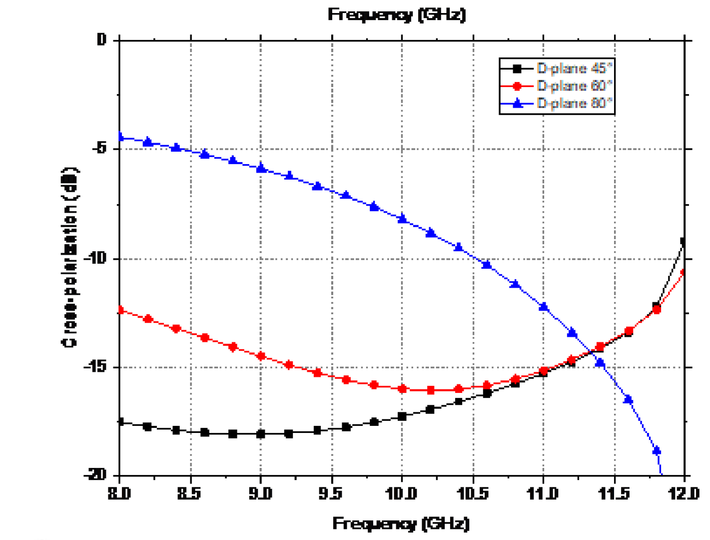


Figure 5: Cross-polarization level along the diagonal plane

Summary

A novel tightly coupled dipole array is presented in order to realize X-band ultra-wide-angle scanning. The vertical parasitic superstrate and horizontal dielectric layer are placed above the antenna aperture for wideband and wide-angle impedance matching. The proposed antenna has characteristic of broad bandwidth, large scan angle, and lightweight, which has certain reference value in solving the full hemisphere scanning of the radar phased array antenna.