The Optimum Design of A 3-10GHz Linear-polarized Fragmented Aperture Array with Integrated Balun

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***Abstract*-A linear-polarized fragmented aperture array operating over 3-10GHz is presented. The array element uses an integrated balun proposed in the planar ultrawideband modular antenna (PUMA) array, without external balun or hybrid. The array element is optimized using the embedded genetic algorithm (GA) toolbox of MATLAB together with the software Ansoft HFSS. The simulated VSWR in the whole operating frequency band is less than 3. The cross-polarization level in the E-plane is lower than that of the H-plane. Cross-polarization levels remain more than 15dB below the co-polarization out to 60° for both planes.**

***Index Terms*-fragmented aperture array, integrated balun, simulation.**

I. INTRODUCTION

Ultra-wideband (UWB) phased arrays are of much interest for multi-functional apertures supporting communications, electronic warfare and radar functions. These applications desire low-cost, low-profile and low-weight phased arrays that can even be integrated seamlessly with platforms. In recent two decades, a lot of tightly coupled broadband arrays including long slot arrays [1-2], various kinds of tightly coupled dipole arrays (TCDA) [3-6] and fragmented aperture arrays have been proved. Fragmented aperture arrays have documented up to 33:1, even 100:1 bandwidth at 60° scan [7-8]. Early versions of the fragmented aperture arrays are fed by feed towers and require external 180° hybrids, an improved integrated design of an X band array is successfully built up out of laminated dielectric layers, fed by two closely spaced vias, but no details are given in [7]. This paper presents the optimum design and simulation results of a 3-10GHz fragmented aperture array, which utilizes shorting posts to support an integrated unbalanced feed adopted from the PUMA array [5-6].

II. ARRAY AND DESIGN

A. Geometry of the Array

The linear-polarized printed fragmented aperture array is fabricated with etched circuits and plated vias as a simple multilayer microwave PCB. The proposed geometry is shown in Fig. 1, the multilayer PCB is composed of three dielectric layers: superstrate layer with relative permittivity ε_1, thin radiation layer with relative permittivity ε_2, and substrate with relative permittivity ε_3. Substrate layer appropriately spaces the fragmented patch from the ground plane, a lot of holes which are not shown in the figure are plated in this layer to

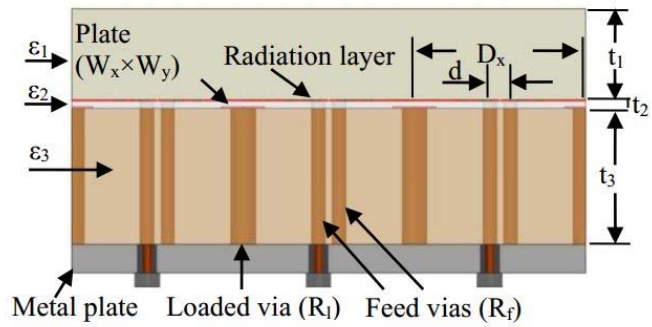


Figure 1. Side view of the proposed linear-polarized fragmented aperture array topology.

decrease the effective permittivity. Superstrate layer improves matching and serves as a wide-angle impedance matching (WAIM) layer to improve scanning.

The fragmented patch is printed on the top of the radiation layer. The design goal is to find the optimum distribution of metalized conducting regions in the array element aperture shown in Fig. 2, and the suitable choice of permittivity and thickness of the three dielectric layers will produce a well-matched array over the expected frequency range for all scan directions. The element aperture is gridded into N×N pixels where each pixel can be assigned either conducting, labeled ‘1’ or non-conducting, labeled ‘0’ properties. The electric contact between adjoint diagonal pixels should be addressed

Figure 2. Geometry of the fragmented patch in the element aperture.

during the design process. A simple way of dealing with the problem is to make the corners of diagonal pixels overlapped to ensure electrical contact.

A simple feed structure is adopted which is reported in [5], a pair of copper-plated vias in the radiation layer and substrate as two parallel conductors are used to form the unbalanced feed line structure. The right-side feed line is directly connected to the ground and the left-side one is connected to the inner conductor of a 50Ω coaxial line. A problematic broadside common mode resonance developed in unbalanced-fed arrays. An additional pair of via/plate structure connected directly to ground is used to push the common-mode resonance out of the operating band. The vias are copper-plated in the substrate layer, while the plates are printed on the bottom of the radiation layer.

B. Design Method

The optimization of physical parameters and fragmented patch is realized in the MATLAB environment. As shown in Fig. 3, the main algorithm based on the genetic algorithm (GA) toolbox is used to optimize the array element terminated by periodic boundary conditions (PBC). The electromagnetic simulator HFSS is used to build the geometry, run simulation and export results to the main algorithm. Then the main algorithm calculates the fitness function and synthesizes a better solution, based on current solution fitness.

The number of pixels in the element aperture used in the optimization is 20×20. The conducting regions are constrained to be symmetric, thus only a quadrant of the element aperture needs to be optimized. The quadratic pixels in the 10×10 quadrant is binary coded as a 100 bits chromosome series, labeled as *FA*. Additional gene codes corresponding to the other physical parameters such as the relative permittivity, the supstrate/substrate thickness, the dimension of the antenna and the parameters of the feed structure are added after the above chromosomes. The fitness function is designed to minimize the sum reflected energy for three scan directions, broadside, 45° in the E-/H-plane over the design band, referring to [9], expressed as

$$F(x) = \Sigma_i \Sigma_j w_{ij} \Gamma(\Omega i, f_j). \quad (1)$$

where $x = [FA\ \varepsilon_1\ \varepsilon_2\ \varepsilon_3\ t_1\ t_2\ t_3\ D_x\ D_y\ d\ R_f\ R_l\ W_x\ W_y]^T$ is the optimized parameter chromosome series, w is the weight, Ω is the scan direction. The relative dielectric permittivity is constrained to that of commercial dielectrics.

III. SIMULATION RESULTS AND DISCUSSION

As an example, a linear-polarized phased array operating over 3-10GHz was simulated. The optimized array lattice dimension is $D_x=D_y=12\text{mm}=0.4\lambda_{high}$. The supstrate and substrate are comprised of Rogers RT/duriod 6002 and Rogers RT/duriod 5880LZ respectively, both layers are thick, with $t_1=6.4\text{mm}\approx\lambda_{low}/15.6$, $t_3=10\text{mm}\approx\lambda_{low}/10$, where λ_{high}, λ_{low} are the wavelength at the highest and lowest operating frequency respectively. Rogers RT/duriod 5880 with thickness 0.508mm

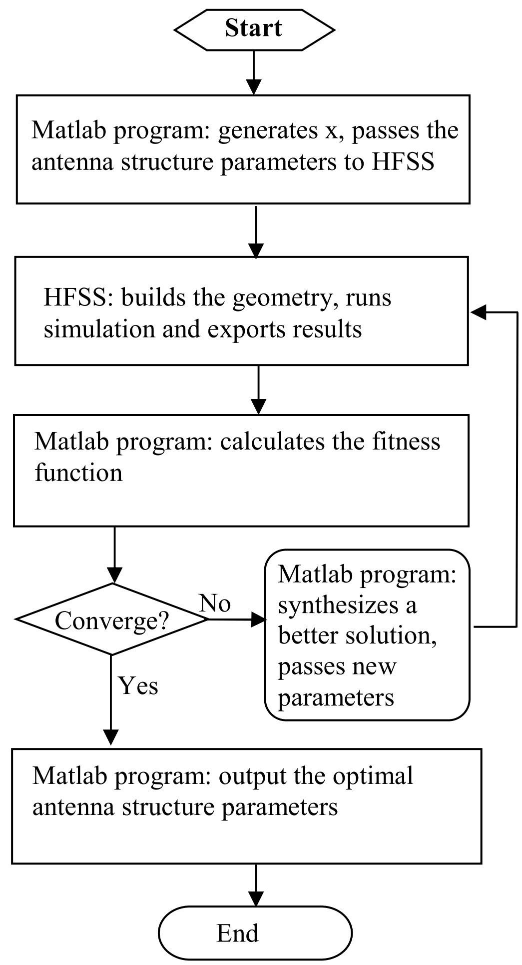


Figure 3. Schematic flow of the optimization.

is chosen for the radiation layer. The optimized fragmented patch geometry in the element aperture is shown in Fig. 2. Table I summarizes the optimum value of element physical parameters.

Fig. 4 illustrates VSWR of the optimized element in an infinite array environment at broadside, 45° scan in the E-/H-planes respectively. The bandwidth obtained is 3.3:1 with VSWR<3.0 for all scan directions. E-plane scanning is better-matched than that of the H-plane.

The embedded element pattern is a good indication of the scan performance in a large array. A 16×16 linear-polarized

TABLE I
ARRAY GEOMETRIC PARAMETERS AND DIMENSIONS

D_x	D_y	t_1	t_2	t_3
12mm	12mm	6.4mm	0.508mm	10mm
d	R_f	R_l	W_x	W_y
0.62mm	0.5mm	0.9mm	1.5mm	4mm
ε_1	ε_2	ε_3		
2.94	2.2	1.96		

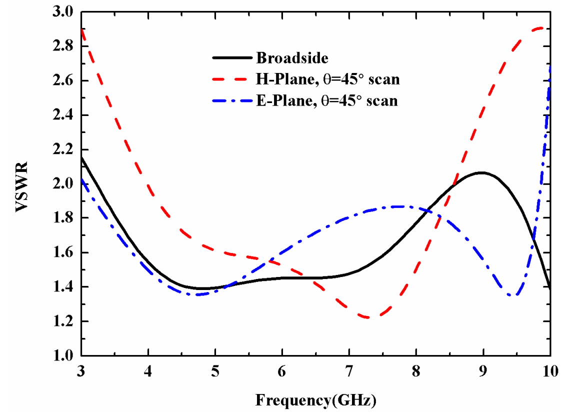
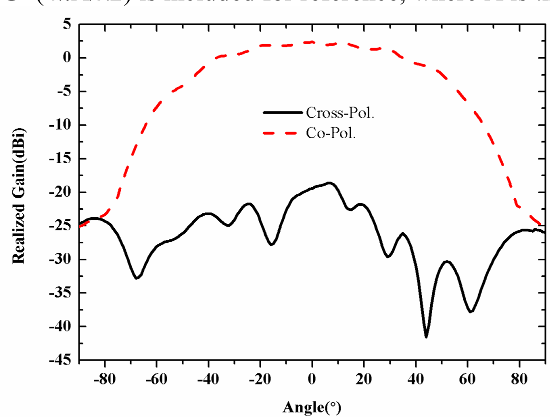
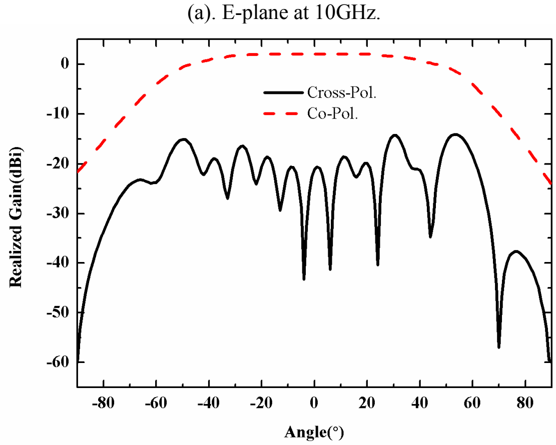


Figure 4. Simulated active VSWR of the infinite 3-10GHz array element

array is simulated to examine the embedded element far-field results. Element realized gain patterns are presented in Fig. 5 for E-/H-plane cuts, respectively, at the highest frequency 10GHz.The cross-polarization level in the E-plane is lower than that of the H-plane, perhaps reason is the fragmentation of patch complicates the current paths. Cross-polarization levels remain more than 15dB below the co-polarization out to 60° for both planes. The relationship of realized gain versus frequency is displayed in Fig. 6, The theoretical maximum gain G=($4\pi A/\lambda 2$) is included for reference, where A is the



(a). E-plane at 10GHz.



(b). H-plane at 10GHz.

Figure 5. Simulated embedded central element patterns of the 16×16 finite array.

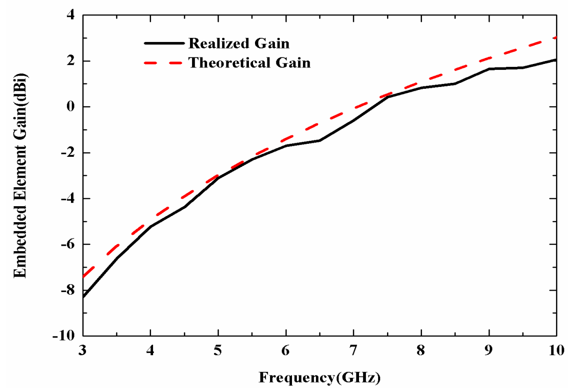


Figure 6. Simulated embedded central element gain of the 16×16 finite array compared with the theoretical gain.

element aperture area. The difference between them is due to mismatch loss, ohm and dielectric loss, the maximum total loss is about 0.8dB.

IV. CONCLUSION

A linear-polarized fragmented aperture array operating over 3-10GHz was presented. The array uses the integrated balun proposed in the PUMA without external balun or hybrid. The optimization method and simulation results of VSWR and far field patterns are presented.

REFERENCES

[1] Jennifer Rayno, Nuri Celik, and Magdy F. Iskander, "Dual-polarization cylindrical long-slot array (CLSA) antenna integrated with compact broadband baluns and slot impedance transformers," *IEEE Antennas Wireless Propag. Lett*., vol. 12, pp. 1384-1387, November 2013.

[2] J. J. Lee, S. Livingston, and D. Nagata, "A low profile 10:1(200-2000MHz) wide band long slot array," *Proc. IEEE Antennas Propag. Soc. Int. Symp*., July 2008, pp. 1-4.

[3] Jonathan P. Doane, Kubilay Sertel, and John L. Volakis, "A wideband, wide scanning tightly coupled dipole array with integrated balun (TCDA-IB)," *IEEE Trans. Antennas Propag*., vol. 61, pp. 4538-4548, September 2013.

[4] W. F. Moulder, K. Sertel, and J.L. Volakis, "Ultrawideband superstrate-enhanced substrate-loaded array with integrated feed," *IEEE Trans. Antennas Propag*., vol. 61, pp. 5802-5807, September 2013.

[5] S. S. Holland, D. H. Schaubert, and M. N. Vouvakis, "A 7-21GHz dual-polarized planar ultrawideband modular antenna (PUMA) array," *IEEE Trans. Antennas Propag*., vol. 60, pp. 4589-4600, October 2012.

[6] John T. Logan, Rick W. Kindt, Michael Y. Lee, and Marinos N. Vouvakis, "A new class of planar ultrawideband modular antenna arrays with improved bandwidth," *IEEE Trans. Antennas Propag*., vol. 66, pp. 692-701, February 2018.

[7] James G. Maloney, Bradford N. Baker, R. Todd Lee, Gregory N. Kiesel, James J. Acree, "Wide scan, integrated printed circuit board, fragmented aperture array antennas," *IEEE AP-S/URSI*, July 2011, pp. 1965-1968.

[8] William F. Croswell, Tim Durham, Mark Jones, Daniel Schaubert, Paul Friederich, and James G. Maloney, "Wideband arrays," in *Modern antenna Handbook*, Constrantine A. Balanis, Eds. Canada: John Wiley &Sons, Inc., 2008, pp. 612-27.

[9] Björn Thors, Hans Steyskal, and Henrik Holter, "Broad-band fragmented aperture phased array element design using genetic algorithms," *IEEE Trans. Antennas Propag*., vol. 53, pp. 3280-3287, October 2005.