Design and optimization for the satellite Ku-band CP array antennas

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Abstract

The goal is to design a Ku-band circular polarization array for satellite application, and an array of circular polarization satellite antenna covering 11.45~12.75GHz is reported. The Wilkinson equal-power splitter is first used to feed the signal power into the array, for which we have examined the simulated characteristics of the 2X1 and 2X2 arrays, while the prototype of the 2X2 array is fabricated and measured for verification purpose. Then the phased array antenna is optimized by genetic algorithms to determine the optimum parameters for the phase shifter. Note that the coupling effect between the antennas elements must be took into account to achieve good accuracy. To accomplish this, we have to calculate in advance the radiated E fields of the entire antenna array (at least including the neighboring components) with only a single antenna element being excited. The far zone E fields Er of all the angles (up to one degree resolution) are obtained and saved for successive optimization using GA algorithm. The optimum result could be programmed into a microprocessor to control the array antenna steering electronically.

Introduction

Phased array antennas are gaining in popularity. They are not only of interest to remote sensing and military applications, but are employed today in mobile communication systems, for example in satellite mobile multimedia service: satellite news gathering, point to point transmission in fixed outdoor customer terminal equipment [1-2]. The phased array antennas have the advantages of high gain, low sidelobe, while the mainlobe can steered to the desired signal direction. Furthermore, the phased antenna array can reduce the interference caused by multipath signals and improve the data rate, capacity and performance of mobile communication systems.

The goal is to design a Ku-band circular polarization array for satellite application and an array of circular polarization satellite antenna covering 11.45~12.75GHz is reported. The array structure is based on a simple slot-coupled patch antenna element with three metallic layers, of which a square radiator patch resides on the upper layer [3-6]. The Wilkinson equal-power splitter is first used to feed the signal power into the array, for which we have examined the simulated

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characteristics of the 2X1 and 2X2 arrays, while the prototype of the 2X2 array is fabricated and measured for verification purpose.

Then, the genetic algorithm is applied to further optimize the design for the circular polarization array antenna. The optimization goals include: (1) to scan the main beam by suitable adjustments of the phase of the excitation current [7], (2) during the course of scanning the characteristics of circular polarization must be maintained, (3) the sidelobe level (SLL) need to be kept low. Note that the coupling effect between the antennas elements must be took into account to achieve good accuracy. To accomplish this, we have to calculate in advance the radiated E fields of the entire antenna array (at least including the neighboring components) with only a single antenna element being excited. The far zone E fields Er of all the angles (up to one degree resolution) are obtained and saved for successive optimization using GA algorithm [8-9]. Then through the genetic algorithm the optimal solution to achieve the required scanning angle can be obtained, and the list of the excitation phases of the current is calculated and saved for practical usage. The results of GA optimization are compared with the simulation results of the whole array by commercial software, and the results show very good accuracy and consistency with error less than 1%.

Design Processes and Results

The objective of this paper is to explore the circular polarization array antenna for fixed satellite services and satellite broadcasting services covering 11.45~12.75GHz frequency range. First, one needs to design a single antenna element with circular polarization that meets the Ku-band satellite bandwidth requirements. The single antenna element is required to have broadband characteristics of circular polarization, but also have high isolation. A simple slot-coupled patch antenna with three metallic layers is the structure tested, of which a square patch radiator resides on the upper layer, and the middle layer is the metallic ground plane, where the coupling slots are etched. Finally, the bottom layer serves to provide the 50Ω feed line and/or the feeding network. When the feed ports for slot 1 and slot 2, respectively, exhibit 90-degree phase difference the circular polarization of radiation can be achieved. In addition, in order to reduce the backscattered radiation another metal surface is added to form a four-layer metallic structure.

It is found that placing the excitation slot at the corner (instead of the edge) of the patch can improve the isolation. Hence corner-fed slot coupled structures adopted for the successive studies of this paper. In addition, for the feeding network the Wilkinson power splitter is used to feed the power into the array. Taking into account of the coupling effect between the feed lines of near paths, careful adjustment for the path length is made as shown in Fig.1. We have examined the simulated characteristics of the 2X1 and 2X2 arrays, while the prototype of the 2X2 array is fabricated and measured, of which the results are shown in Fig.2.

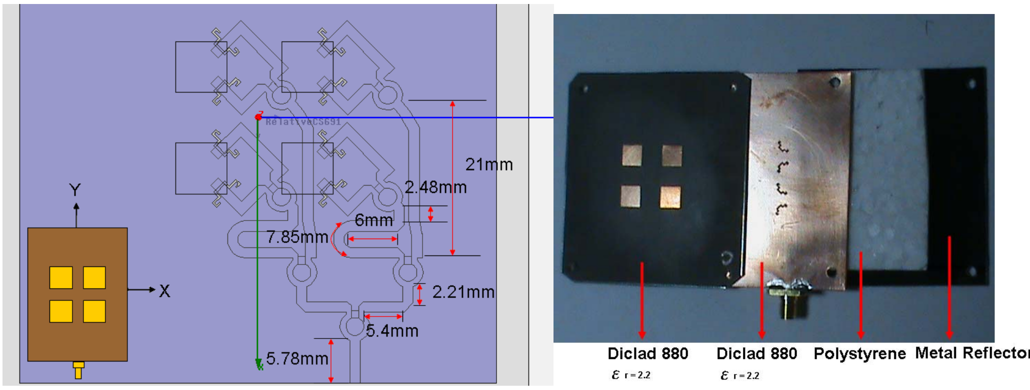

Fig.1 The structure of 2X2 array including the feeding network

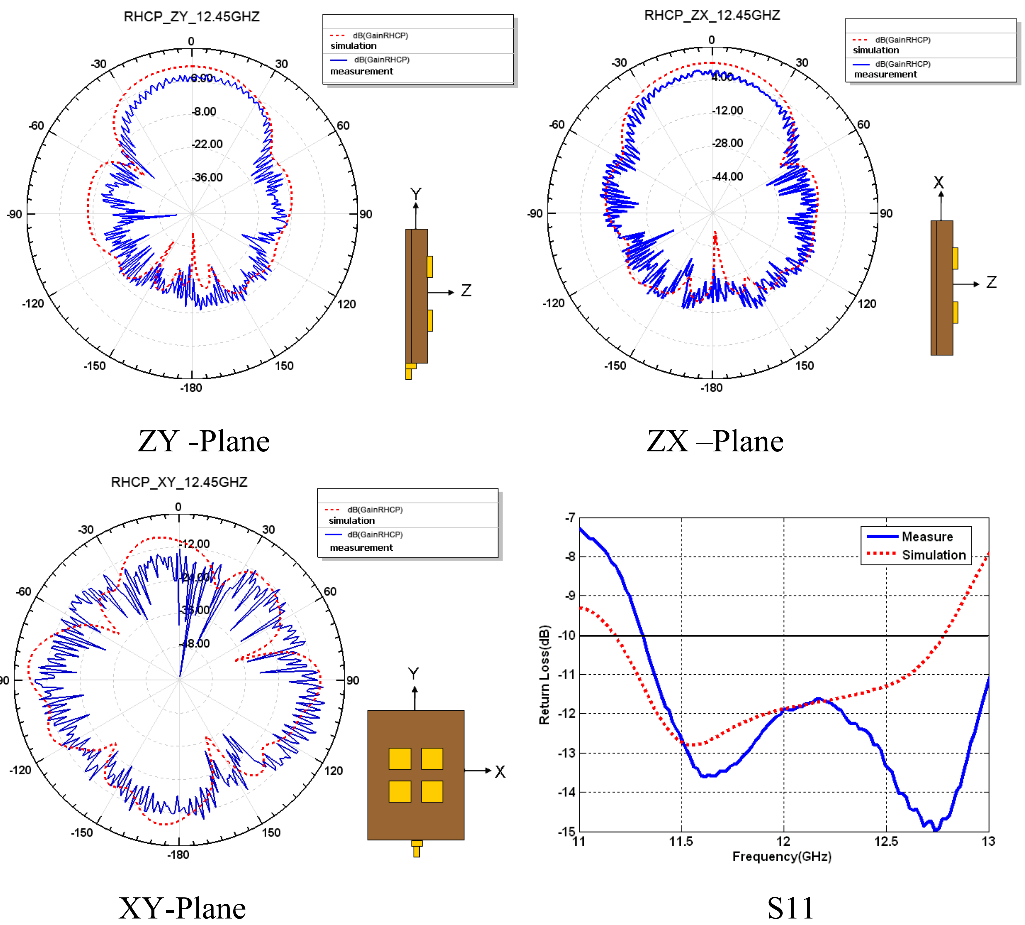

Fig.2 The simulated and measured results of the 2X2 array.

In this paper the genetic algorithm is applied to further optimize the design for the circular polarization array antenna. The optimization goal is to scan the main beam by suitable adjustments of the phase of the excitation current. In addition, during the course of scanning the characteristics of circular polarization must be maintained. and the sidelobe level (SLL) is kept low. Note that the coupling effect between the antennas elements must be took into account to achieve high accuracy. To accomplish this, we have to calculate in advance the radiated E fields of the entire antenna array (at least including the neighboring components conceptually) with only a single antenna element being excited. The full-wave commercial software is employed to simulate the 2X2 array antenna as mentioned. The far zone E fields Er of all the angles (up to one degree resolution) are obtained and saved for successive optimization using GA algorithm. In GA, the far zone E fields must be updated for different phase adjustments of the excitation current.

Finally, for the searching of the optimal excitation phase for the 2X2 phase array, one must first select the appropriate optimization conditions and weights. As a circular polarization array antenna is considered, the conditions of high-gain, low sidelobe level (SLL) and low axial ratio are included into the fitness criteria (1). Then through the genetic algorithm the optimal solution to achieve the required scanning angle can be obtained, and the list of the excitation phases of the current is generated and saved for practical usage.

$$\textit{Fitness} = F1\ (\textit{main beam direction}) + F2\ (\textit{power of main beam}) + F3\ (SLL) + F4\ (AR<1.5dB) + F5\ (\textit{weight of RHCP}) \quad (1)$$

The optimization phase parameters by GA are examined by commercial software, and the results of two cases as listed in Fig.3 show very good accuracy and consistency with error less than 1%. Hence, GAs can be the suitable optimum algorithm for the main beam direction controlling for a CP array via phase tuning of the excitation current.

Case 1

	Group	Excitation_1		Excitation_2		Excitation_3		Excitation_4	
	Port	1	2	3	4	5	6	7	8
	Scale	1	1	1	1	1	1	1	1
	Phase	350	260	344	254	343	253	342	252
Direction		Phi	7			Theta	0		
HFSS	Gain	13.081517486688							
GA	Gain	13.02554							
HFSS	AR	0.822177057576248							
GA	AR	0.8221655							

Case 2

	Group	Excitation_1		Excitation_2		Excitation_3		Excitation_4	
	Port	1	2	3	4	5	6	7	8
	Scale	1	1	1	1	1	1	1	1
	Phase	190	100	290	200	290	200	90	0
Direction		Phi	160			Theta	33		
HFSS	Gain	9.61851							
GA	Gain	9.558243							
HFSS	AR	0.925355							
GA	AR	0.9253519							

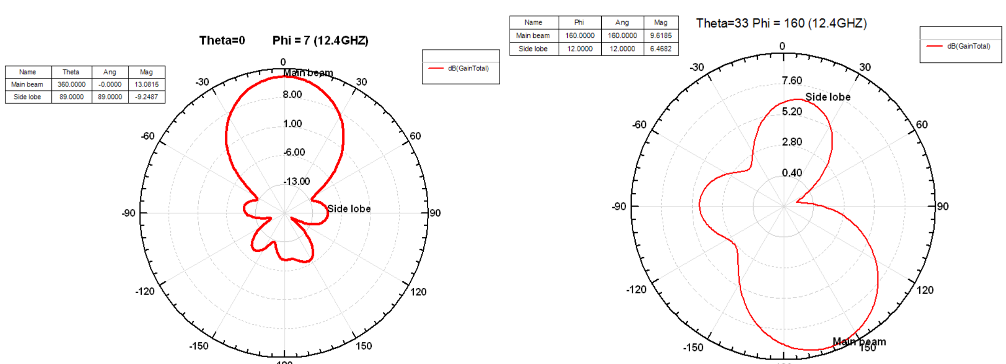

Fig.3 The GA optimization parameters are tested by commercial software.

Conclusion

The proposed phased array antenna are optimized by the genetic algorithm in order to steer the direction of the main beam. For the array structure a simple slot-coupled patch antenna element with high-isolation is examined, of which a square radiator patch resides on the upper layer of the four-metallic-layer structure. The prototype of the 2X2 array with feeding network is fabricated and measured for verification purpose. The measured and simulated results compare quite well. Then via the GA optimization procedure and hence some pre-generated table lists it is expected that the steering of the circular polarization phased array antenna can be realized in real time application. Future works will include the extension of the present work to a larger antenna arrays such as 4x4, 8x8 and 16X16 cases to offer a practical applications.

References

[1] Hirose, K.; Tajima, R.; Nakano, H.;"Ladder antennas for dual circular polarization", Antennas and Propagation Society International Symposium, 2005 IEEE Volume 2A, 3-8 July 2005 Page(s):242 - 245 vol. 2A

[2] Baggen, L.; Bottcher, M.; Eube, M.; "3D-Butler matrix topologies for phased arrays", Electromagnetics in Advanced Applications, 2007. ICEAA 2007.International Conference on 17-21 Sept. 2007 Page(s):531 - 534

[3] Ching-Lieh Li, Jian-Ping Chang and Wen-Yen Lin, Oct. 2004, A Broadband Microstrip-fed Notch Antenna with Multiple Rejection Zeros, ICEMAC'2004, Taipei, Taiwan

[4] Ching-Lieh Li, Pei-Ying Lin, Chien-Ping Chang and Shao-Hon Chen, Sept. 2004, Broadband Extended Double Folded Slot Antenna Fed By a Microstrip Line, Cross Strait Tri-regional Radio Science and Wireless Technology Conference, HsinChu, Taiwan

[5] Microstrip-fed dual-frequency printed triangular monopole Chen, H.-M.; Electronics Letters , Volume: 38 Issue: 13 , 20 Jun 2002 Page(s): 619 -620

[6] Shahabadi, M.; Busuioc, D.; Borji, A.; Safavi-Naeini, S.; " Low-cost, high-efficiency quasi-planar array of waveguide-fed circularly polarized microstrip antennas", Antennas and Propagation, IEEE Transactions on Volume 53, Issue 6, June 2005 Page(s):2036 - 2043

[7] V. Varadan et al,"Ceramic Phase Shifters for Electronically Steerable Antenna Systems," Microwave Journal(January 1992):116-127.

[8] Seong Ho Son; Eom, S.Y.; Jeon, S.I.; Woonbong Hwang; "Automatic Phase Correction of Phased Array Antennas by a Genetic Algorithm", Antennas and Propagation, IEEE Transactions on Volume 56, Issue 8, Part 2, Aug. 2008 Page(s):2751 - 2754

[9] Yu Fan; Ronghong In; Bo Liu; "Synthesis of antenna arrays using a modified complex number coded genetic algorithm", Antennas and Propagation Society International Symposium, 2004. IEEE Volume 3, 20-25 June 2004 Page(s):2667 - 2670 Vol.3