URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

Dual-Band Shared-Aperture Antenna Array for High Gain Applications

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Abstract

This paper has illustrated an optimization method for a shared aperture dual-band antenna array suitable for radar applications. A shared-aperture antenna array (SAA) has been formed using two different frequency band linear arrays. Both the linear arrays are designed on the underlying concept of the array thinning process. To design the transmitting thinned array having radiation characteristics identical to a uniformly fed periodic array, an optimization algorithm has been formulated using a genetic algorithm (GA). A feed signal is obtained to produce the desired peak sidelobe level (PSL) by employing this. In order to validate the proposed optimization technique, a prototype is fabricated using a Vivaldi antenna as the radiating elements for the C- and Ku-bands, respectively. The radiation characteristics of the fabricated array antennas are measured, and the performances of the prototypes are analyzed in terms of the half-power beamwidths (HPBW) and Gain.

1 Introduction

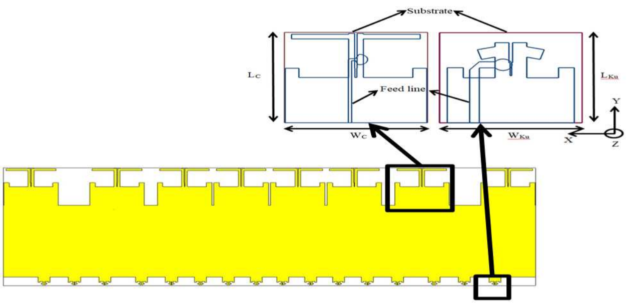
Modern communication and radar systems require multi-functional capabilities and, subsequently, dual-band or multi-band antenna systems. Precisely, in various military applications, the need for frequency diversity is of prime importance. Shared aperture dual-band antennas are highly active to fulfill these requirements [1]. Even the size and weight of the antenna system can be minimized by incorporating more than one frequency band antenna element on the same aperture. Many microstrip-based Shared aperture antenna arrays (SAA) operating on numerous dual frequency bands have been reported. In literature, an SAA in the L- and C-band is proposed by Pokuls et al. in [2]. The structure makes use of slots operating in the L-band and interleaved with the C-band operating microstrip patches. Other SAA designs made utilization of perforated patches for the low band, which permits higher band patches to radiate through the aperture. In [3] and [4], an L/C-band and an L/X-band interleaved antenna arrays are designed. The design makes utilize of slots working within the L-band and interlaced with microstrip patches working within the C-band. Moreover, this design layout was used in conjunction with array thinning. Array thinning is a process in which some of the antenna element is intentionally deactivated, in order to get a better peak sidelobe level. It additionally makes the antenna array cost-effective with minor exchange off in beamwidth. To address the difficulties in thinning operation, stochastic

Optimization algorithms have been formulated. Nature-based optimization algorithms have been verified to be effective in solving such problems. Algorithms such as particle swarm optimization (PSO) [6]-[8], genetic algorithm (GA) [9]-[12], simulated annealing (SA) [13], ant colony optimization (ACO) [14] were effectively conceived to synthesize thinned antenna arrays. Most of these algorithms focused mainly on the reduction of peak sidelobe level at broadside but have not addressed the problem of grating lobes. This problem is addressed in the present study, and the results obtained support the claim for the supremacy of the algorithm. However, such optimization methods assume various constraints. By taking into consideration, a genetic algorithm (GA) is devised to find out the optimum distribution of antenna elements in an unequally spaced linear antenna array.

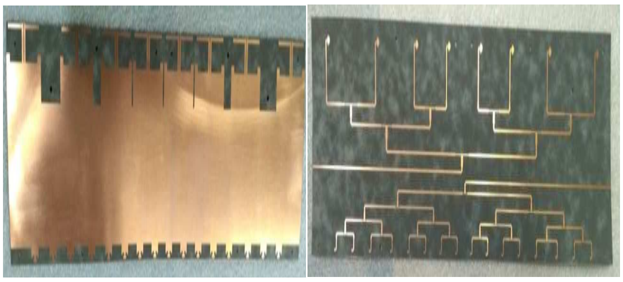
This paper proposed a nearly omnidirectional radiation pattern in a dual-band shared aperture antenna array with permissible sidelobe level and optimum Gain. To validate the design algorithm, an 8 element C-band array and a 16 element Ku-band unequally spaced linear antenna array are designed, fabricated, and measured by utilizing a Vivaldi antenna element for each type of array, separately. In order to guarantee exactness in radiation characteristics, mutual coupling between the arrays is taken into consideration. The simulated Gain for the C- and Ku-band arrays are 13.1 and 15.9 dB, and the HPBW are 191.6° × 8.3° and 19.4° × 3.3°, respectively. The rest of the paper is organized as follows. The proposed antenna array is described in Section 2. In Section 3. the novel optimization technique is presented. Section 4. gives a comparison between the theoretical and experimental results. Finally, some conclusions are drawn in Section 5.

2 Proposed Antenna Array

By using the proposed optimization method of the linear antenna array, a linear antenna array is designed using CST simulation software for both the C-band and Ku-band. The proposed structure of the dual-band shared aperture antenna array is formed by interleaving the unequally spaced linear array on a single-substrate fed by a power divider. Figure 1. shows the proposed structure. The optimized dimension of the substrate and ground is



(a)



(b)

Figure 1. Proposed Dual-band SAA. (a) Simulated structure (b) Fabricated Structure (Top-View and Back-View)

376.12 mm × 123 mm × 0.508 mm and 75.6859 mm × 376.12 mm × 0.035mm, respectively. Both the radiation elements consist of a pair of radiation metal arms and a microstrip line feed. The radiation metal arms are etched onto the bottom of the substrate and connected to the ground plane. The proposed antenna is employed to function in C and Ku band. The size of the substrate for the C & Ku- band is $W_c = L_c = 39$ mm and $W_{ku} = L_{ku} = 9$ mm, respectively. The antenna is excited with the help of 50-ohm characteristics impedance microstrip line. It is designed using RT Duroid 5880 ϵ_r =2.2. The substrate thickness is 0.508 mm (20 mils).

3 Optimization Technique

There are specific issues that need to be addressed while placing constraints for optimization, i.e., beamwidth, sidelobe level, directivity, etc. Mentioned parameters can be reduced by varying the inter-element spacing between the antenna elements. The spacing between two adjacent elements should be in a discrete range to limit the grating lobes and the aperture size, transforming into a practically applicable design. A genetic algorithm is used to optimize arrays of isotropic point sources and arrays of dipoles modeled. It results in narrow beamwidths while avoiding high sidelobes [12]. The Improved Genetic Algorithm (I-GA) simultaneously adjusts the weight coefficients and inter-sensor spacings of a linear aperiodic array in more details and extend the investigations to include the effects of mutual coupling and the sensitivity of the PSL to steering angles, is discussed in [14]. The implementation of GA begins with the prime definition of variables and associating them with antenna arrays. A total number of elements in the array are termed as a chromosome, and each element is a gene. For efficacious optimization, a set of chromosomes that consists of a population was generated. Genetic Algorithm (GA), as explained, requires an objective to shift the chromosomes towards it. The novelty in GA has been implemented in terms of the following:

1) It has been considered through literature that the crossover operator has the primary obligation in finding an optimum solution during the search process, thereby is one of the components to be taken into consideration to improve the GA. So, this novel GA technique comes up with the two-point crossover process, which is different from the conventional approach.
2) Further, To enhance the population's structural variability, the mutation probability is taken into consideration with 0.01% of randomization.

For this specific structure, the least possible PSL with high Gain was achieved utilizing the given number of elements. The optimization for unequally spaced linear antenna arrays have approximately an infinite solution space from which the best possible combination was chosen. The flow of the process of optimization for an unequally spaced linear array is as per following Figure 2:

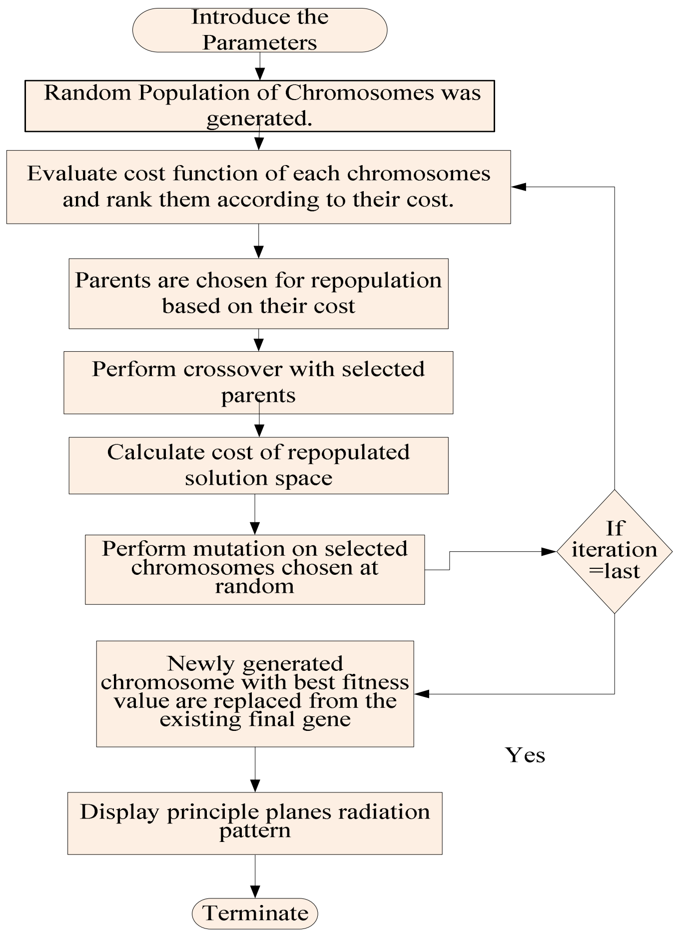


Figure 2. Proposed I-GA Flowchart

Table 1. Geometry of the array positions obtained for C-band a Ku-band of the array elements

C-band		Ku-band	
Element Number (n)	Inter Element Spacing(d_i) (value in mm)	Element Number (n)	Inter Element Spacing (d_i) (value in mm)
1	40	1	18.7143
		2	19.7143
2	40	3	19.7143
		4	20.542
3	47.76	5	21.129
		6	25.974
4	60.8	7	21.43
		8	21.5

The proposed results for the inter-element spacing are given in Table 1 for C-band and Ku-band elements. The unequally spaced linear antenna array is further interleaved to design the proposed SAA.

4 Experimental Validation

The Proposed dual-band shared aperture antenna array is fabricated and experimentally validated in the Anechoic chamber. A performance network analyzer (Keysight N5221A) was used to measure the reflection coefficient of the proposed antenna. The proposed shared aperture antenna is designed to operate in the 4-5 GHz frequency band, .i.e. C-band, and 13.5-15 GHz frequency band, i.e., Ku-band. S-parameters for the C-band and Ku-band are shown in Figure 3. (a) and (b), respectively. The proposed structure has an impedance bandwidth of 23.25% from 4 to 5 GHz for the C-band and 10.34% from 13.5 to 15 GHz for the Ku-band, respectively.

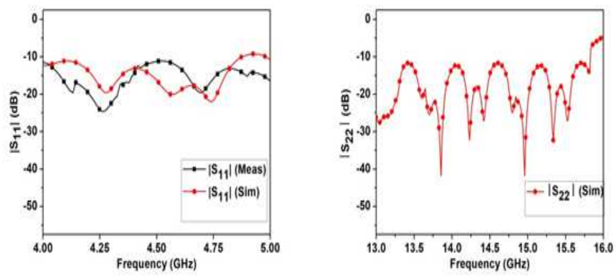


Figure 3. S_{11} of the proposed fabricated antenna (a) C-band and (b) Ku-band

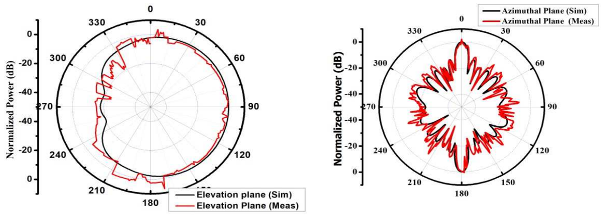


Figure 4. Radiation pattern of the proposed array for C-band at 4.5 GHz in both planes.

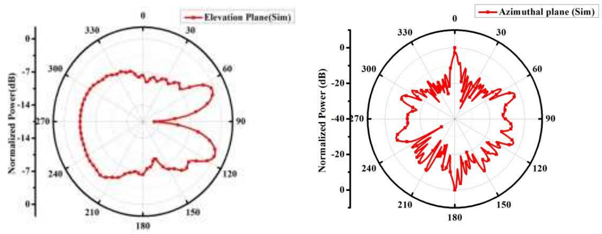
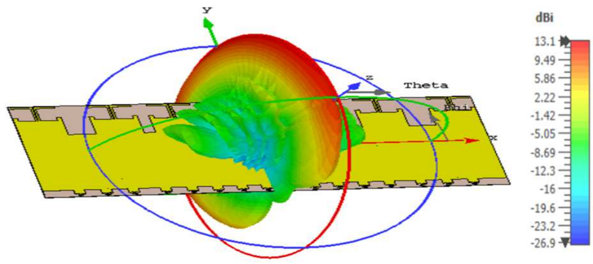
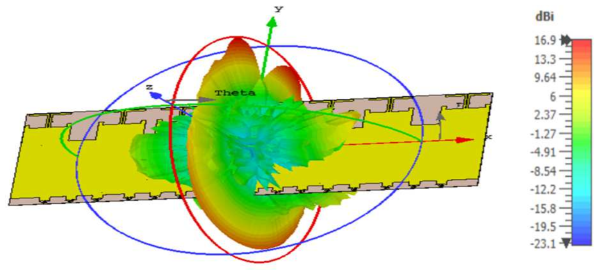


Figure 5. Radiation pattern of the proposed array for Ku-band at 14.5 GHz in both planes.



(a)



(b)

Figure 6. 3D- Radiation pattern of the proposed shared aperture antenna array. (a) 4.5 GHz and (b) 14.5 GHz.

The radiation pattern in both azimuth, and elevation plane, is shown in Figure 4. for C-band at a resonant frequency. Similarly, radiation patterns for Ku-band at a resonant frequency in respective planes are shown in Figure 5. The simulated 3D- radiation pattern has been

Table 2. Simulated results of the proposed dual-band shared aperture antenna array (C – band).

	(Elevation Plane $\phi = 90^0$)						(Azimuth Plane $\phi = 0^0$)					
	Array without PD			SAA with PD			Array without PD			SAA with PD		
Frequeny (GHz)	4	4.5	5	4	4.5	5	4	4.5	5	4	4.5	5
HPBW (°)	10	9.6	9.6	9.6	8.3	7.8	193	164	164	164	191.6	211
Gain (dB)	10.8	9.43	9.43	9.43	10.9	11.7	12.8	13.3	13.3	13.3	13.1	13.1

Table 3. Simulated results of the proposed dual-band shared aperture antenna array (Ku – band).

	(Elevation Plane ϕ = 90^0)						(Azimuth Plane ϕ = 0^0)					
	Array without PD			SAA with PD			Array without PD			SAA with PD		
Frequeny (GHz)	13.5	14.5	15	13.5	14.5	15	13.5	1.25	15	13.5	14.5	15
HPBW (°)	95	121	125	21.9	19.4	18.9	3.6	3.2	3	3.6	3.3	9.1
Gain (dB)	16	14.6	13.8	15	16	17	16	14.6	13.8	9.56	10.6	8.05

shown in Figure 6. The measured results are then compared with the simulated results. A good agreement has been observed in both planes. It is seen that the proposed antenna is close to Omni-design at the elevation plane, and in azimuth plane provides directional pattern individually. It signifies the enhanced HPBW and low PSLL with a high gain of >13 dB in both planes. The HPBW and Gain's simulated value between the frequency range (4-5 GHz) and (13.5-15 GHz) is given in Tables 2 and 3. From Tables 2 and 3, it can be observed that the simulated data satisfies the defined design objective.

5 Conclusion

An optimization technique is proposed to design a shared aperture dual-band antenna array. The C- and Ku-band unequally spaced linear antenna arrays are interleaved on a single aperture to satisfy the condition of a dual-band shared aperture array. Validation of this structure is led by fabricating a prototype array antenna. In spite of sharing the single planar aperture and using approximately 50% fewer elements in comparison to the periodic array, the radiation characteristics of the proposed dual-band thinned arrays are comparable with that of the periodic array. Therefore, the proposed design method for the shared aperture array antenna is expected to be appropriate and applicable in the area of active array antenna design for multi-band radar applications.

7 References

1. J. C. Eade and J. Whitehurst,“ Dualband phased array antenna design for radar applications,” *in Proc. Int. Conf. Antennas Propag.,* **11** *Manchester, U.K.*, February 2001,.pp. 480, doi: 10.1049/cp:20010242.
2. R. Pokuls, et. al, “Dual-frequency and dual-polarization microstrip antennas for SAR applications,” *IEEE Trans. Antennas Propag.,* **46**, 9, Sept. 1998, pp. 1289–1296, doi: 10.1109/8.719972.
3. L.L.Shafai, W.A.Chamma, M. Barakat, P.C. Strickland, G.Seguin,“Dual-band dual-polarized perforated microstrip antennas for SAR applications,” *IEEE Trans. Antennas Propag*., **48**, 1, January 2000, pp. 58–66, doi: 10.1109/8.827386.
4. D.M. Pozar, S.D. Targonski, “A shared-aperture dual-band dual-polarized microstrip array,” *IEEE Trans. Antennas Propag.*, **49**, 2, February 2001, pp. 150–157, doi: 10.1109/8.914255.
5. Randy L Haupt, Antenna Arrays: A Computational Approach, *John Wiley & Sons, Inc.*, 2010.
6. M. Donelli, A. Martini, and A. Massa, “A hybrid approach based on PSO and hadamard difference sets for the synthesis of square thinned arrays,” *IEEE Transactions Antennas Propag.*, **57**, 8, September 2009, pp. 2491-2495, doi: 10.1109/TAP.2009.2024570.
7. W.B. Wang, Q.Y. Feng, and D. Liu, “Synthesis of thinned linearand planar antenna arrays using binary PSO algorithm,”*Progress In Electromagnetic Research*, **127**, 2012, pp. 371-387, doi: 10.2528/PIER12020301.
8. V. S. Gangwar, A. K. Singh, E. Thomas and S. P. Singh, “Side lobe level suppression in a thinned linear antenna array using particle swarm optimization,” *ICATCCT*, *Davangere*, 29-31 October 2015, pp. 787-790, doi: 10.1109/ICATCCT.2015.7456989.
9. R.L.Haupt, “Thinned arrays using genetic algorithms,” *IEEE Transactions on Antennas and Propagation*, **42**, 7, July 1994, pp. 993-999, doi: 10.1109/8.299602.
10. R. L. Haupt, “Interleaved thinned linear arrays,” *IEEE Transactions on Antennas and Propagation*, **53**, 9, 6, September 2005, pp. 2858-2864, doi: 10.1109/TAP.2005.854522.
11. G. K. Mahanti, N. Pathak, and P. Mahanti, "Synthesis of thinned linear antenna arrays with fixed side lobe level using real-coded genetic algorithm," *Progress In Electromagnetic Research*, **75**, 2007, pp. 319-328, doi: 10.2528/PIER07061304.
12. L. Cen, Z. L. Yu, W. Ser and W. Cen, “Linear aperiodic array synthesis using an improved genetic algorithm,” *IEEE Transactions on Antennas and Propagation*, **60**, 2, February 2012, pp. 895–902, doi: 10.1109/TAP.2011.2173111.
13. A .Trucco, “Thinning and weighting of large planar arrays by simulated annealing,” *IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control*, **46**, 2, March 1999, pp. 347-355, doi: 10.1109/58.753023.
14. O. S. Quevedo-Teruel, and E. Rajo-Iglesias, “Ant colony optimization in thinned array synthesis with minimum side lobe level,” *IEEE Antennas and Wireless Propagation Letters*, **5**, 21, August 2006, pp. 349-352, doi: 10.1109/LAWP.2006.880693.