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OPTIMIZATION OF SLL OF APCP ANTENNA ARRAY

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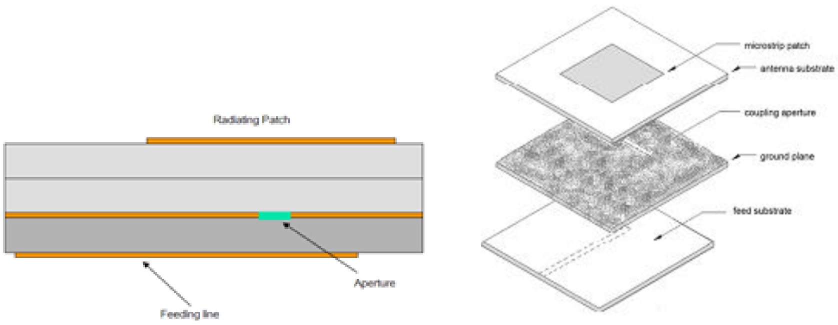
ABSTRACT

An experimental study on multilayered printed antenna array is carried out to optimize SLL of the radiation pattern of APCP antenna. To reduce the size of the antenna to a reasonable extent as well as to enhance some selective properties of the radiation pattern multi-layered arrays are designed [1]. In this work a simple multi-layer Aperture Coupled Configuration is considered as a building block of a large array where the design parameters of the antenna such as gain, side lobe level, impedance bandwidth and efficiency are analyzed theoretically. In order to design and develop the antenna for optimum performance, theoretical computations with simulations are carried out to compute the VSWR and Radiation pattern of the same and details are included in this paper. The different parameters of the radiation pattern of the array antenna are modeled using ANN and optimized with GA algorithm. Finally measured radiation pattern of the fabricated array are compared with the computed results and found to be in close agreement.



(a) (b)

Figure 1: APCP Antenna Configuration (a) 2D View (b) 3D View

KEYWORDS: Optimize SLL, Optimal Design, Compute the VSWR, Modeled Using ANN

INTRODUCATION

Aperture Coupled (APCP) Antenna Structure

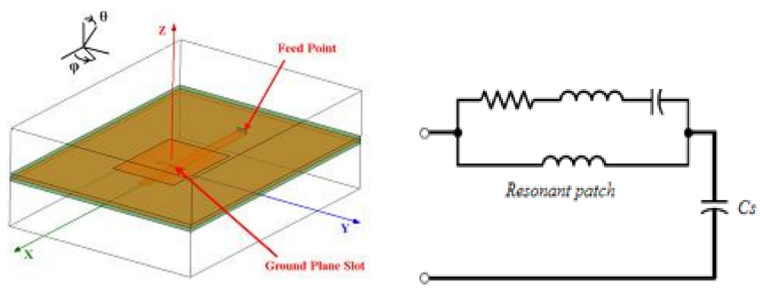
The geometry of a basic aperture-coupled micro strip antenna is shown in Figure 1. Parameters of the feed and antenna substrate layers are chosen in a manner to optimize the feed radiation independently. The impedance matching is done using proper choice of the aperture dimensions and the stub length. A shifting in the resonant frequencies is corrected by altering the electrical dimension of the patch. The selection of a thick low permittivity substrate is necessary to obtain a broadband micro strip antenna.

There should be no resonance due to the slot aperture within the operating frequency band of the antenna because this would produce radiation towards the back of the antenna. The radiator is shielded from the feed structure due to the ground plane. There is small spurious radiation caused by the feed line and coupled through the slot. The substrate parameters for the feed line and the substrate for the radiating patch are optimized simultaneously using ANN-GA algorithm. The feed substrate is usually thin with high permittivity, whereas the patch substrate is thick with low permittivity. The slot interrupts the longitudinal current flow in the feed line and the patch, resulting in a coupling between them. The coupling between the patch, aperture, and the feed line can be described by two impedance transformers [3] having a turns ratio approximately equal to the fraction of patch current intercepted by the aperture to the total patch current.

APERTURE-COUPLED FEEDING

Energy is electromagnetically coupled through the aperture in the ground plane which is usually centered with respect to the patch where the patch has its maximum magnetic field. For maximum coupling a rectangular slot parallel to the two radiating edges is used here. This arrangement allows independent optimization of the feed and the radiating element. Two very similar coupling mechanisms take place, one between the feed line and the slot and another between the slot and the patch. The coupling amplitudes are non-linearly dependent on the offset of the slot from the patch edge.

An aperture coupled antenna can be replaced by the equivalent circuit shown in Figure 2. The resonant patch dimensions are determined by theoretical equations [4-5]. The slot introduces a capacitance Cs determined by patch dimension, layer thickness, aperture dimension and feeding line length and width. Impedance matching is performed by controlling the length of the feed line and the length of the slot. The coupling through the slot can be modeled using the theory of Bethe [6]. Wider bandwidth is achieved by adjusting the width and length of the coupling slot and using a thicker patch substrate.



(a) (b)

Figure 2: Aperture Coupled Patch Antenna (a) HFSS Model (b) Equivalent Circuit

ANALYSIS

There are several methods to analyze aperture-coupled micro strip antennas such as the integral equation approach, cavity model, transmission line model, model expansion method and a hybrid approach. Aperture coupled feeds are difficult to analyze [4] using the approximate model of micro strip antenna. Transmission line model or multiple network models uses single mode analysis and considers a number of simplifying assumptions. Hence they suffer from a number of limitations, which can be overcome in full wave MOM technique that maintains rigor and accuracy at the expense of numerical simplicity. Integral equations are formulated by rigorously enforcing the boundary conditions at the air dielectric interface and at patch metallization. This is done by using the exact Green`s function for the composite dielectric which include the effect of dielectric loss, conductor loss, loss due to surface wave modes and space wave radiation [4].

The theoretical analysis based on the finite-difference time-domain (FDTD) method is carried out to find out the dimension of the aperture for impedance matching of the APCP antenna [5-7]. MATLAB code based on FDTD is used to predict VSWR and radiation pattern of a single APCP antenna. Linearly-polarized APCP antenna is modeled in HFSS. Simulation results are used to determine antenna performance for comparison with theoretical computation using FDTD. Frequency dependent resistance and reactance of the antenna is computed as a function of normalized slot length.

Parametric adjustments are made to determine the center frequency, input impedance, VSWR, bandwidth, polarization ratio, and radiation patterns of a single APCP antenna where patch, feed, and slot dimensions are adjusted to tune the operating frequencies. It is found that VSWR is minimized and gain is maximized when the patch and slot dimensions are used to tune the operating frequencies. The operating frequency is adjusted by inversely scaling patch and slot dimensions.

DESIGN OF APCP ANTENNA

Different variables parameters of this APCP antenna are patch width, patch length, slot length, aperture length, aperture position, substrate thickness, substrate dielectric constants. The dimensions of micro strip feed line, substrate thickness; ground plane slot and patch are varied in IE3D to determine their effects on antenna performance. Effect on operating frequency, Input impedance, VSWR, Gain and % bandwidth are computed for variation of slot width and slot length. Effects of Percent Bandwidth, Gain are also computed for variation of aperture position relative to feed line. Operating frequency, VSWR, and Bandwidth are computed for variation of feed substrate height. The feed line creates an electric field in the aperture (ground plane slot), which induces surface currents on the patch. The patch edges perpendicular to the feed line create fringing fields that radiate into free space. The ground plane slot acts as an impedance transformer and modeled using parallel LC circuit in series with the micro strip feed line. The APCP antenna at 18.5 GHz and the feed with aperture is modeled on RT Duroid Substrate. A single aperture coupled patch is designed at K band having 10% impedance bandwidth (1.5:1) over center frequency. Impedance bandwidth and radiation pattern of a single APCP antenna are initially computed with MATLAB code using FDTD. A corporate feeding network is designed for APCP antenna array where the impedance bandwidth of the array is same as that of the single patch. Theoretically computed VSWR and radiation pattern of the array antenna is verified using IE3D.The parameters chosen for the array design are

- **Substrate Thickness:** 20 mil for feed circuit & ground plane.
- **Substrate Thickness:** 31 mil for patch antenna.
- **Substrate Dielectric Constant:** 2.2(for both the layers).
- **Patch Dimension:** 4.36 mm x 7.0mm
- **Slot Dimension:** 3.2mm x 0.5 mm

ANTENNA ARRAY

A single APCP antenna is unable to meet the required gain and radiation pattern. So the solution is to combine several single element antennas to form an antenna array. Antenna arrays are used to direct radiated power in a particular direction. There are many types of Antenna Arrays. In this paper, several 2D arrays having APCP as basic resonator is considered where corporate feeding are used to combine array elements and Chebyshev amplitude distribution is applied to each antenna element. To find the array response, EM signals are weighted and summed to obtain the beam pattern [7-8]. Inter-element spacing plays a fundamental role in achieving the desired array pattern. Several parameters are indirectly dependent on the array spacing. In order to optimize the array parameters such as impedance bandwidth, side lobe level and gain for this array, inter-element spacing are varied and the corresponding radiation patterns are computed for this APCP array structure. The simulated results for several arrays are tabulated in Table 1. The frequencies of operation are varied and radiation pattern of the array is computed. Near field and far field radiation characteristics of a three layer 16x16 APCP array is shown in Figure 3 and is computed using MATLAB code using MOM and verified with IE3D.

Antenna Array Pattern synthesis problem consists of finding the optimum weights to satisfy the requirements of radiation pattern. Literatures are available on antenna array optimization by direct methods like Genetic Algorithms [9] and Particle Swarm Optimization [10]. These methods are feasible because of increased computing power. The formulation of optimization problem for SLL and antenna beam width is carried out using ANN-GA algorithm where it is observed that it is possible to optimize the pattern in terms of other antenna parameters. For a linear array of n isotropic elements of equal amplitude and spacing d is the total electric field E in direction ø is given by $E = 1 + e^{j1\psi} + e^{j2\psi} + e^{j3\psi} + ... + e^{j(n-1)\psi}$ Where ψ is the total phase difference of fields from adjacent sources and is given by $\psi = 2\Pi (d / \lambda) * \cos\phi + \alpha$ where ϕ is the phase difference between the feed currents of adjacent sources.

In case of linear arrays, elements are equally spaced at $\lambda/2$ distance.

The array factor of this linear antenna depends upon the number of elements, the element spacing, amplitude and phase applied to each element. Array factor is given by

$$A = \sum_{i=1}^{N} \exp\left(\frac{j2\Pi}{\lambda(x_i \cos\varphi + y_i \sin\varphi)}\right)$$

The N signal outputs are converted to complex numbers weighted by weights w_i and summed up to give the linear array beam pattern

$$H(\varphi) = \sum_{i=1}^{N} w_i \exp\left(\frac{j2\Pi}{\lambda(x_i \cos\varphi + y_i \sin\varphi)}\right)$$

Where $w_i = [w_1, w_2, w_{3,} .... w_N]^T$ is the complex weight vector to be designed.

ANN-MODEL

Antenna Array Pattern synthesis problem consists of finding the optimum weights to satisfy the given requirements. Literatures are available on antenna array optimization by direct methods like Genetic Algorithms [9] and Particle Swarm Optimization [10]. These methods are feasible because of increased computing power. The formulation of optimization problem for SLL and antenna beam width is carried out using ANN-GA algorithm where it is observed that it is possible to optimize the pattern in terms of other antenna parameters. Antenna Array patterns can be analyzed and synthesized in a variety of ways and are very important in almost every field of antenna applications. Antenna Array patterns can be expressed as sum of series and can be optimized by a number of methods, e.q. Interior Point Methods, Genetic Algorithm, Schelkun off's method, These methods usually analyzed the Antenna Patterns in terms of Side Lobe Level, Main Lobe, Noise Power, Signal to Noise ratio. In this paper, a uniform 2D Antenna array with 256 elements is considered. It is verified through the simulation results, that the side lobes, major lobes and beam width of side lobes can be optimized with precision.

In this work an ANN model of the APCP antenna array is designed where number of elements, element spacing, amplitude distribution, frequency of operation are selected as input parameters and VSWR, Radiation Pattern are taken as output parameters. The ANN model consists of three layers with number of neurons taken for individual layers are 4,36,2 and are trained and tested using the theoretically computed data. Desired training and testing accuracy is achieved by repetitive iteration. Within the frequency band of interest radiation pattern predicted by the ANN model matches with that of the real pattern within reasonable accuracy. Table 1 shows Antenna radiation pattern for different configurations of the

APCP array where the results are extracted from trained and tested ANN model of the antenna array. A Comparison of array configuration / number of array elements with Gain and efficiency of APCP antenna is shown in Table 2. A significant conclusion is that with same number of array elements radiation pattern (SLL, Gain, and efficiency) is dependent on array configuration. Due to mutual coupling effect array spacing along E plane and H plane also plays a vital role in deciding the array performance.

ANN-GA MODEL

The trained ANN model of the Radiation Pattern of the APCP antenna array is used with GA optimization process to enhance the SLL of the same. The optimization of radiation pattern of a 16x16 and 32x32 APCP antenna array by ANN-GA algorithm is the main achievement for this paper. Here suitable fitness functions are used to optimize the SLL where the numbers of elements, element spacing, amplitude distribution etc are modified to minimize the SLL for a 16x16 array and for 32x32 arrays. The optimal radiation pattern minimizes the side lobe level between 0 and 180 degrees. The main lobe shape and position is same as without optimization. In the process of optimization the amplitude distribution of the array elements, element spacing normalized to frequencies are modified and SLL is optimized. Table 3 shows optimized array parameters using GA for 16x16 arrays and 32x32 array. The results obtained from the ANN -GA algorithm is simulated using IE3D to verify the suitability of the process.

Fitness Function used by GA for minimization of SLL of the radiation pattern of the APCP array antenna

$$\text{Fitness = maximize } \sum_{i=1}^{N}\sum_{j=1}^{M} W_{ij} \sum_{\theta=\theta_{10dB}}^{90^0} K_{\theta} \frac{1}{ARR\_AMP_{\theta}} \quad \text{where} \quad \begin{array}{l} ARR\_AMP_{\theta} = A_{MAX}\ for\theta = 0^0 to \theta_{10dB} \\ ARR\_AMP_{\theta} = A_{SLL}\ for\theta_{10dB} to \theta_{90^0} \end{array}$$

Where W_{ij} and K_{θ} are constants, M, N being number of array elements along X, Y direction, θ being the discrete angle of the radiation pattern of APCP array.

Beam width is a measure of directivity and is the product of individual antenna pattern and array factor shape. Here optimization is carried out to minimize the beam width. By adjusting the phase of central element one can increase the directivity and decrease the beam width as well as minimize the side lobe level. The directivity of a N element equiphased array consists of isotropic radiators with element spacing d = $m\lambda_0/2$ (m = 1; 2; 3 . . .) is $10\log_{10}N$ dB. Table 6 shows variation of E plane and H plane beam width for different APCP antenna array configuration.

It is observed that in an APCP array the impedance bandwidth and side lobe level can be achieved to a reasonable extent but the gain is limited due to the conductor loss, dielectric loss and radiation loss generated from discontinuities in impedance transformer, right angle corner of micro strip lines. As the array size increases, the directional gain will increase proportionately. However feed line length also become longer with increasing array size and the feeder loss will eventually increase faster than the directional gain, the power gain will therefore decrease.

ARRAY PERFORMANCE

(a) (b) (c)

Figure 3: 16 X16 Aperture Coupled Array Antenna (a) Feed Layer, (b) Slot in Ground Plane (c) Patch Layer

After few iteration and optimization several APCP antenna are fabricated as 2x2 array, 4x4 array, 16x16 array, 32x32 array and 32x64 array. Return Loss and Radiation patterns are measured for these array configurations by varying frequency of operation. The measured return loss of 16x16 APCP array antenna and that of 32x32 APCP array antenna are shown in Figure 4. The nature of the measured radiation parameters like side lobe level, gain, efficiency etc. matches with that of the simulated results to a reasonable extent.

It is observed that in an APCP array the impedance bandwidth and side lobe level can be achieved to a reasonable extent but the gain is limited due to the conductor loss, dielectric loss and radiation loss generated from discontinuities in impedance transformer, right angle corner of micro strip lines.

As the array size increases, the directional gain will increase proportionately. However feed line length also become longer with increasing array size and the feeder loss will eventually increase faster than the directional gain, the power gain will therefore decrease.

The radiation pattern of 16x16 APCP array antenna and that of 32x32 APCP array antenna are measured and Figure 5 shows the same for 32x32 APCP array antenna. Finally the measured array parameters for a 16 x 16 array are tabulated in Table 4 and are compared with the simulated performance. The measured SLL for 32 x 32 arrays is shown in Table 5 and also compared with the simulated performance.

It is observed that apart from SLL the measured radiation parameters like gain, efficiency etc. matches with that of the simulated results to a reasonable extent. Measured results for variation of beam width for APCP antenna is shown in Table 6 where different number of elements of APCP array configuration is considered.

It is observed from the measured result that in order to get narrow beam width in both planes number of elements has to be increased and practical limit of achieving beam width for APCP array is limited by fabrication and loss from feeding network of large array.

CONCLUSIONS

In this process of APCP antenna design micro strip configuration is chosen which is inherently narrowband and its bandwidth is increased by multi-layer coupling technique while keeping its gain constant. In order to achieve ultra low side lobe level effort are made to minimize unwanted feed radiation and thus maximum achievable power gain imposes a limitation for the designer. However the configuration chosen for this purpose is easily reproducible and has a vast application in radar, missiles, tracking antenna system and many more

The ANN-GA technique of optimization has several advantages, which makes it suitable for widespread applications in communication systems. Also, the isolation of the feed network from the patch reduces the spurious radiations and provides more space for the feed network, being suitable for phased arrays

Table 1: Simulated Results of Antenna Radiation Pattern for Different Configurations of the APCP Array

Array Configuration	Number of Elements	Beam Width (Degrees)	Gain Dbi	Efficiency	Array Configuration	Number of Elements	Beam Width (Degrees)	Gain Dbi	Efficiency
2x2	4	29.1x34.2	12.8	80.20%	16x16	256	5.0x6.9	27.8	56.40%
4x4	16	12.8x13.6	18.9	77.10%	32x4	128	3.0x14.2	23.06	64.80%
8x8	64	6.4x6.8	24.7	60.08%	32x2	64	3.0x35.1	20.75	81.14%
16x8	128	5.0x6.1	25.65	41.83%	32X32	1024	3.0X3.0	30.4	35.60%

Table 2: Comparison of Array Configuration / Number of Array Elements with Gain and Efficiency of APCP Antenna

Array Configuration	No of Array Elements	Gain	Efficiency	Array Configuration	No of Array Elements	Gain	Efficiency
16x8	128	25.65	41.83%	8x8	64	24.7	60.08%
32x4	128	23.06	64.8%	32x2	64	20.75	81.14%

Table 3: Optimized Parameters Using GA for APCP Arrays (18.5 Ghz)

	Spacing (E Plane)	Spacing (H Plane)	Gain in dB	SLL in dB (E Plane)	SLL in dB (H Plane)
16x16 array	$0.51\lambda_0$	$0.51\lambda_0$	27.2	-27.0	-24.5
32x32 array	$0.6\lambda_0$	$0.6\lambda_0$	30.2	-28.5	-30.2

Table 4: Measured Results for 16x16 Arrays

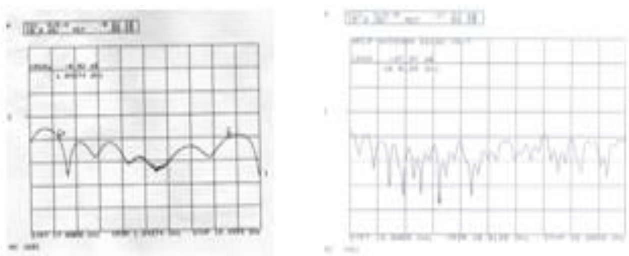
Frequency / Parameters	Gain in dB	SLL in dB (H Plane) Left Side	Right Side	SLL in dB(E Plane) Left Side	Right Side
17.7 GHz	22.8	-25.4	-25.8	-27.0	-24.0
18.5 (GHz)	23.2	-25.2	-23.5	-29.4	-30.0
19.4 GHz.	23.0	-25.0	-22.8	-20.4	-24.9

Table 5 Measured Results for 32x32 Array

Frequency / Parameters	Gain in dB	SLL in dB(H Plane) Left Side	Right Side	SLL in dB(E Plane) Left Side	Right Side
17.5 GHz	22.5	-24.29	-26.62	-30.04	-24.81
18.5 (GHz)	23.2	-31.96	-26.25	-23.12	-25.38
19.5 GHz.	22.7	-22.41	-24.19	-22.41	-24.19

Table 6: Variation of Beam Width for APCP Antenna Array Configuration

Array Configuration	Number of Elements	Beam Width (H Plane) (Degrees)	Beam Width (E Plane) (Degrees)
2x2	4	29.1	34.2
4x4	16	12.8	13.6
8x8	64	6.4	6.8
16x8	128	5.0	6.1
16x16	256	5.0	6.9
32x4	128	3.0	14.2
32x2	64	3.0	35.1



(a) (b)

Figure 4: Measured Return Loss of APCP Array Antenna (a) 16x16 (b) 32x 32

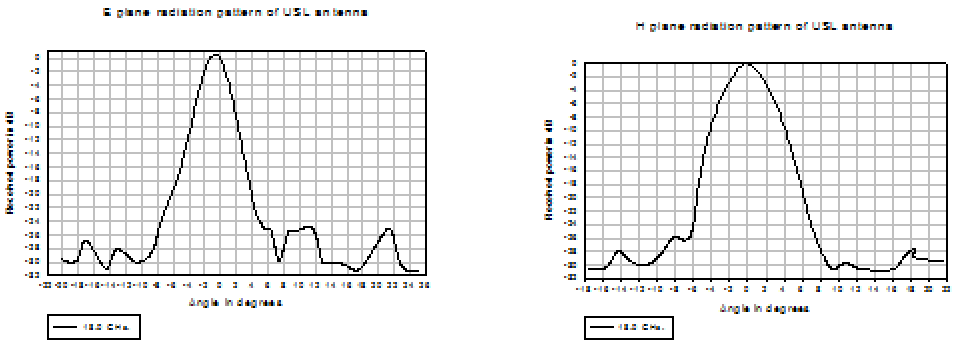


Figure 5: Measured Radiation Pattern of 32X32 APCP Array Antenna (18.0 Ghz.)

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