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Linear High Gain Dual Band Notch Scanning Beam Circularly Polarized Electronically Steerable Smart Antenna Array for 2.4 GHz W-lan and 5.8 GHz UHF RFID Reader Application Without any Central Null using Buttler-Matrix Beam-former Formulation.

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Abstract:

An antenna Array is subjected to the same measurable parameters as any antenna but these parameters change as the array is scanned. In other words, we can say that the array characteristics become a response to the periodic environment and the resulting array parameters have to be determined as a function of scan. As far as the individual isolated elements in the array are concerned, they behave very differently when embedded in an array, still the elements determine the array polarization, fundamental bandwidth and gross features of the array radiation pattern and the inter-element mutual-coupling within the array lattice. The only condition imposed by the array is that the spacing between the elements need to be small enough to avoid the grating lobes or "blindness". In this paper we propose a circularly polarized scanning beam array which has dual band notching characteristics in the 2.4 GHz and 5.8 GHz range. This array is able to scan the whole 0-360° of angular space providing enormous spacio-temporal angular diversity and has a high gain of over 15dBi. The axial ratio has been plotted as a function of frequency in the X-band (8-12 GHz) and it has been found that the array provides an axis ratio of 1:2(major axis=0.8; minor axis=0.4) i.e. Perfect polarization ellipse at 5.8 GHz. Also the array is able to notch two different frequencies for "WLAN" as well as "UHF RFID Reader" application in the 2.4 and 5.8 GHZ band. At the end of the paper a Buttler Matrix formulation of a Multi-Beam Beam Former Array is carried out and simulated. Simulation Results substantiate with experimental and theoretical outcomes.

***Keywords*: Scanning beam, Beam former, UHF, RFID, notch, Buttler Matrix, axial ratio.**

I. Introduction:

I.[a]. Electronic Scanning and the Phased Array

The potential for increased target handling capacity available in "**Track While Scan"** radars is limited by the requirement to steer the radar antenna mechanically. Existing mechanical scanning methods are comparatively slow and require large power concern in order to respond rapidly enough to deal with large numbers of high speed manoevearing targets.

With mechanically scanned systems, optimum radar beam positioning patterns can reduce reaction times and increase target capacity. With ESA, the radar beams are positioned almost instantaneously and completely without the inertia, time lags, and vibration of mechanical systems. Since the numerical superiority of adversaries is expected to remain large, electronic scanning can offset that advantage.
The fundamental principles underlying the concept of electronic beam steering are derived from electromagnetic radiation theory employing constructive and destructive interference.

Methods of Beam Steering:
Previously the literature discusses about the theory required to compute the relative phase shift between adjacent radiating elements in order to position the beam of an array-type antenna to a specific angle off of the antenna boresight axis. In practice there are three methods of accomplishing this phase difference.

Time Delay Scanning

The employment of time delay as a means of achieving the desired phase relationships between elements allows greater flexibility in frequency utilization than other methods. However, in practice the use of coaxial delay lines or other means of timing at high power levels is impractical due to increased cost, complexity, and weight.

Frequency Scanning

One of the simpler methods of phased-array radar implementation is frequency scanning. This method is also relatively inexpensive The length of the serpentine wavelength line (*l*) is chosen such that for some centre frequency, *f0*, the length of signal travel between elements is an integral number of wavelengths, or

= *n* (*n* = any integer greater than zero)

where

0 = wavelength in the serpentine line at frequency *f0*.

Phase Scanning

In a phase-scanned radar system, the radiating elements are fed from a radar transmitter through phase-shifting networks or "phases." The aim of the system is again to position the beam at any arbitrary angle, at any time. In this case the means of accomplishing the phase shift at each element is simply to shift the phase of the incoming energy to each element. These phases are adjustable over the range 0 to + 2 radians. The task of the system is to compute the phase shift required for each element, and set each phase to the proper value to accomplish the desired beam offset.

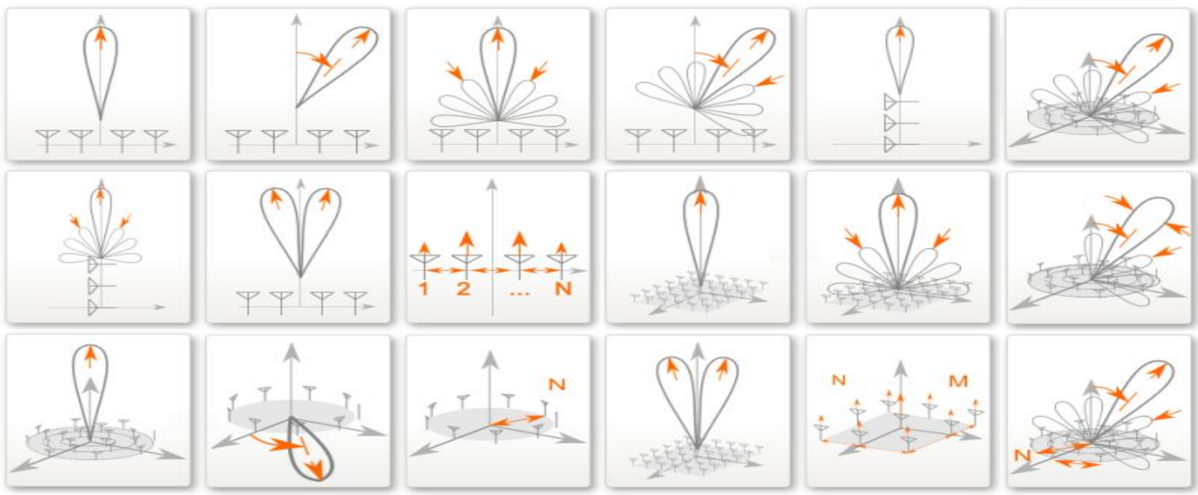


Fig.1. Electronically Scanned Arrays.

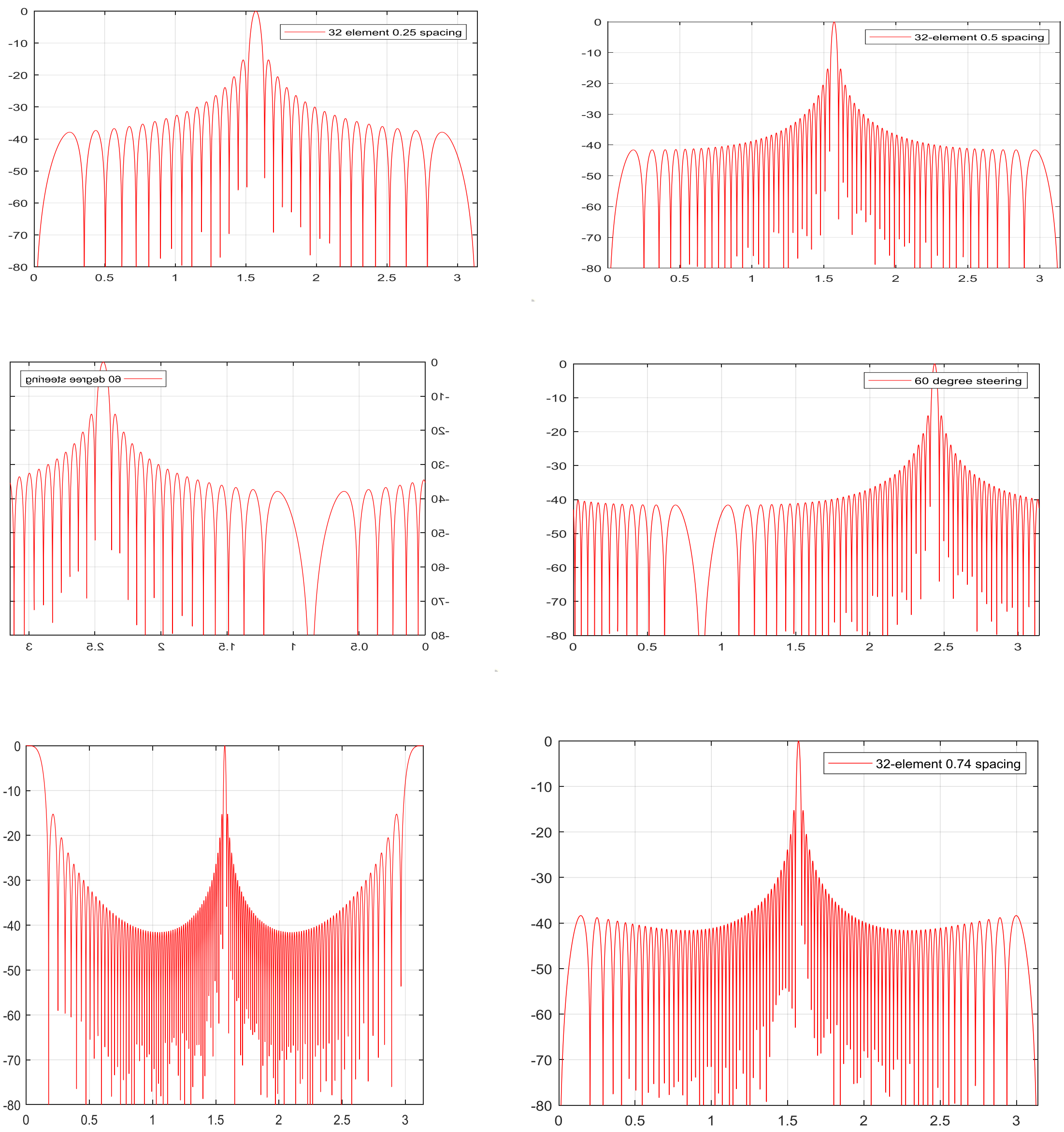


Fig.2. (a) Array factors for 32-element array.(a) 0.25λ spacing. (b) 0.50λ spacing.(c) 0.25λ spacing steered to 60-degree.(d) 0.5λ spacing steered to 60-degree.(e)and(f)0.75λand λ-spacing shows the presence of grating lobes.

II. Mathematical Formulation:

II.[a]. Complex gain pattern of the array:

For Amplitude only/Phase only synthesis the complex Gain of the array can be formulated as:

$\vec{G}_{array}(\theta,\Phi) = \vec{G}(\theta,\Phi) \sum_{n=1}^{N} An\ exp(jK0\ n\ a\ sin\ \theta\ cos\Phi)/\sqrt{\sum_{n=1}^{N} | An|^2}$ (i)

Normalized Gain:

$$\iint_{0}^{2\Pi} |\vec{G}(\theta,\Phi)|^2 sin\theta\ d\theta\ d\Phi$$

$= 4\Pi(1-L)$ (ii)

Where L=antenna loss factor.

$$B_n = A_n/\exp(j\psi_n)\ ;\ \ \psi_n = -K_0\,(n-1)\,a \sin\theta_0 .\text{(iii)}$$

III. **Circularly Polarized Phased Scanning Arrays**.

Phase scanning arrays are capable of providing commendable, agile high gain beams as opposed to reflector antennas which require mechanical movements to steer the array. In contrast Electronically scanned arrays are capable of electronically steer the array beam in space without any mechanical movements. This enables low delay of around µsec. for scanning as opposed to msec. for reflector antennas used for RADAR, Imaging and weather surveillance applications.

ESA design engineers need to have expertise in fundamental design parameters of ESA such as grating lobes, beam width, polarization, Instantaneous beam width, beam width etc. as well as practical aspects of ESA such as pattern optimization, subarrays and Digital Beamforming(DBF).

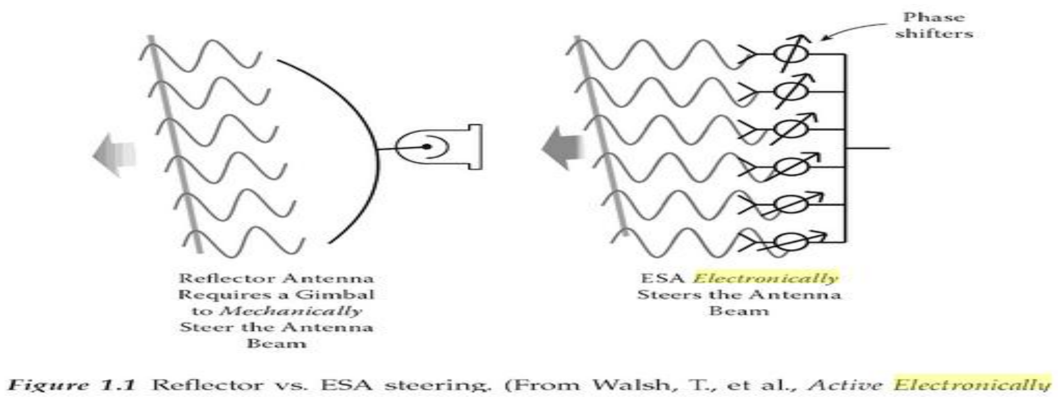


Fig.3. Reflector Vs ESA steering

III.[a]. **General 1-D Formulation:**

III.[a1]. Pattern expression without electronic scanning:

Consider a 1-D array of M-elements as shown in Fig. The elements are uniformly spaced with a spacing of d. The overall length of the array, L, is equal to Md. The elements are centered about x=0, and their position can be denoted as

$$\mathbf{x_m = (m-0.5(M+1))d, \text{ where } m=1,2\ldots\ldots M.} \qquad \textbf{(iv)}$$

Each element has a complex voltage denoted as a_m . A signal that is incident on the array from a direction θ is captured by each of the array elements and is then summed together coherently for the composite signal. The expression for the coherent sum of voltages is represented as:

$$\mathbf{AF}= \sum_{m=1}^{M} Am\ exp(\frac{j2\pi}{\lambda xm} sin(\theta)) \qquad \textbf{(v)}$$

AF is the array factor and describes the special response of the M array elements.

The array factor does not completely describe the special response of the array. Each of the elements in the array has an element pattern that is the elements special response. A good expression for modelling the element pattern is the cosine function raised to the power that is called the element factor (EF). The expression for the element pattern EP is

$$\text{EP}= \cos\frac{EF}{2}\,\theta \qquad \text{(iv).}$$

In real applications, the EP does not go to 0 at θ =90°. An ESA, in its installed environment or in a measurement range, will be subject to diffraction and reflections near the edges of the array that will modify the EP near the edges.

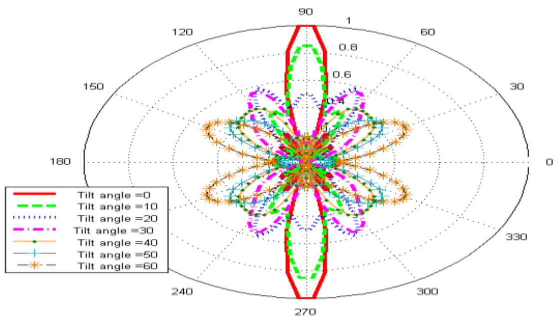
$$F(\theta) = \cos\frac{EF}{2}\,\theta \,.\, \sum_{m=1}^{M} Am\, exp(\frac{j2\pi}{\lambda xm} sin(\theta)) \qquad \text{(vii)}$$

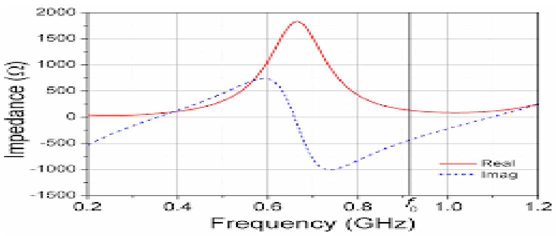
III.[b]. **Pattern expression with Electronic Scanning:**

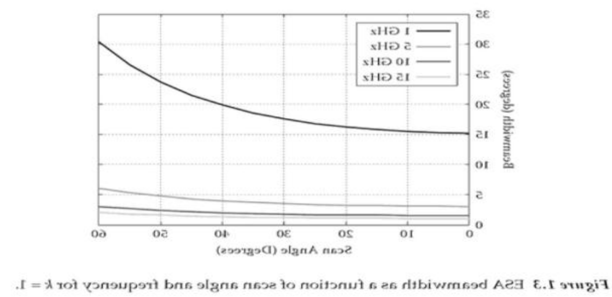
Scanning the beam of the array requires adjusting the phase or time delay of each element in the array. By rewriting the equation in eq. (iv) above and expanding the complex voltage at each element the resulting eq. becomes

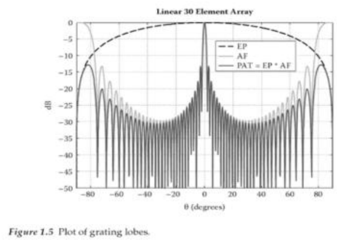
$$AF = a_m\, e^{j\theta m}\, exp(\frac{j2\pi}{\lambda xm} sin(\theta)) \qquad \text{(viii)} \qquad \text{(v)}$$

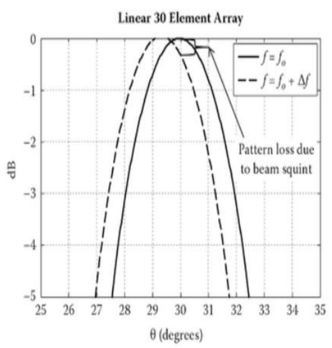
$$F(\theta) = \cos\frac{EF}{2}\,\theta \;\; .\sum_{m=1}^{M} am\, exp(\frac{j2\pi}{\lambda xm} sin(\theta) - \frac{j2\pi}{\lambda xm} sin(\theta 0)) \qquad \text{(ix)}$$











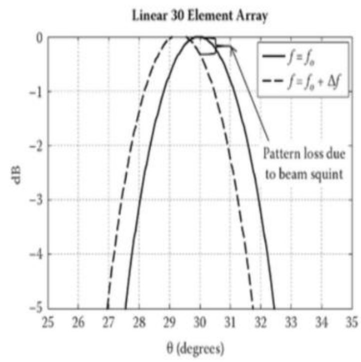


Fig.4. (a) plot of scan vs tilt angle.(b) Frequency vs. impedence of scanning array.(c) Beamwidth as a function of scan angle and frequency at k=1.(d) Plot of grating lobes.(e) and (f) Array pattern squint.

IV. Beam former configurations using FPGA, DSP, etc.

The FPGA technology has lately become an attractive alternative for implementation of a wide range of DSP applications. Here we discuss an implementation of radar phase array antenna system. The final implementation of this beam former is to be used in a demonstrator of such a radar system. The critical component of the digital beam former when both throughput and chip area is considered is the complex multiplication. Here a bit-serial complex multiplier based on distributed arithmetic has been identified as a suitable structure for implementation in an FPGA circuit.

IV.[a]. The Digital Beam former

A digital phase array antenna consists of several antenna elements. The signals from these antenna elements are used to form a main beam which may be changed using the beam former, i.e., the main beam can be made to point in a specific direction and at the same time reduce the side lobes. This is obtained by applying different weights on the signals from each of the different antenna elements. Both signals and weights are represented with complex numbers. The signals are weighted by multiplication of a signal with a corresponding weight. The weighted signals are then added together to form the beam. The computation involved in the digital beam former is

$$Y= \sum_{i=1}^{n} wi.xi \qquad \text{(x)}$$

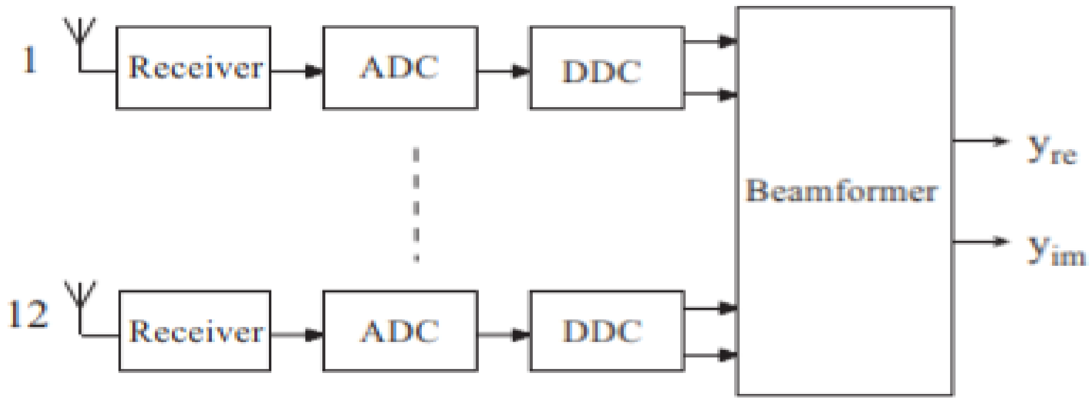


Fig.5. Digital Beamforming.

V . Buttler Matrix Formulation of Multiple Beam Phased Scanning Arrays.

The switched beam based on basic switching selects the scan with the strongest received signal by adjusting the phase difference between the antenna elements, directing the main beam in the desired direction throughout the 360° angular space. Instead of shaping the directional antenna patterns, the switched beam system combines the outputs of multiple antennas to form narrow sectored (directional beams) with more special selectivity as opposed to conventional single element approaches. Other sources in literature defines this as Phased Array or multibeam antenna. Such approaches either consist of multiple beams with one beam switched towards the desired user or a single beam formed by (phase adjustment only), that is steered towards the desired signal. A more generalization to the switched lobe concept is the Dynamic Phased Array(DPA). In this approach a DOA algorithm is embedded inside the system. The DOA is first estimated and then the parameters are adjusted according to the steering direction. This maximizes the received power but has a trade-off between Power and Design complexity.

The elements used in these arrays must be connected to the sources and/or feed network. Buttler Matrix is a widely known multiple beamforming network. It is a linear, passive feeding N*N network with beam steering capability of Phased arrays with N outputs and N inputs or “Beam Ports”. The Buttler Matrix forms a spacial FFT operation providing N orthogonal beams when N is a power of 2. A Buttler Matrix feed array can scan the entire 360° angular space and the appropriate beam can be selected by an RF switch. A Buttler Matrix also has the capability of beam steering by exciting the beam ports with amplitude and Phase weights followed by a variable uniform phase taper. A total of $N/2*\log_2 N$ hybrids and $N/2 * \log_2(N-1)$ fixed phase shifters are used to form the network. The hybrids can be either 90° or 180° 3-dB hybrids, depending upon the symmetrical distance of the beams towards the broadside or whether one of the beams is to be in the broadside boresight direction.

A Buttler-Matrix serves two functions:

(a) Distribution of RF signal to radiating antenna elements.
(b) Orthogonal beamforming and beam steering.

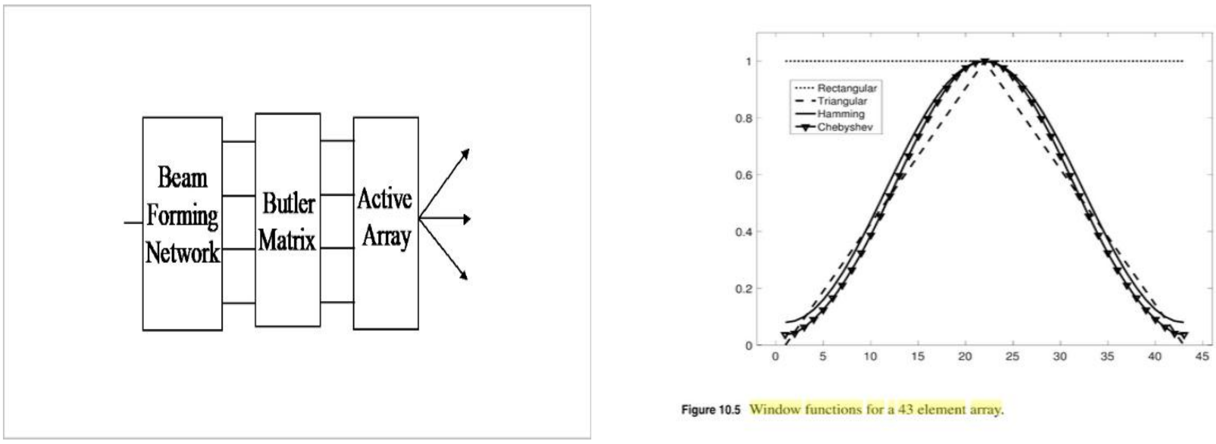
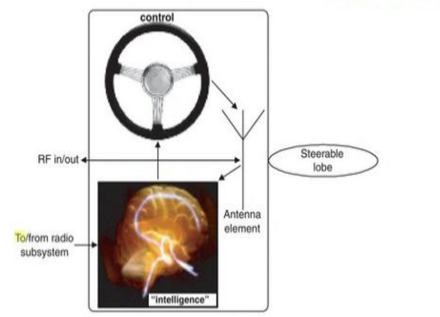
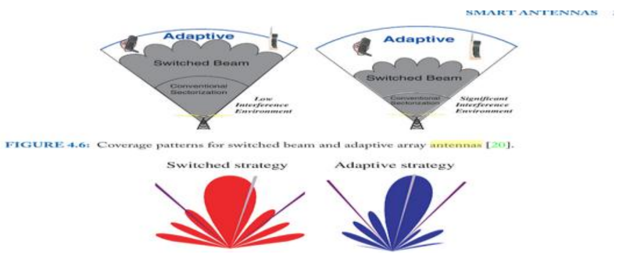
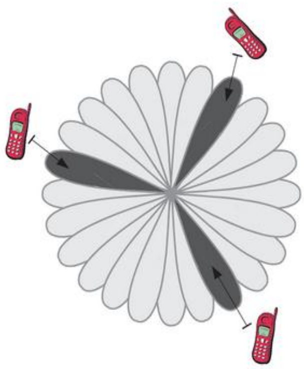
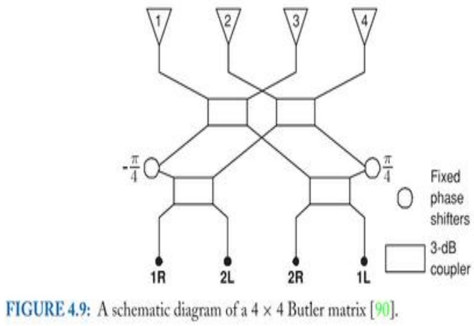


Fig.6. (a) Buttler Matrix Beamforming Array.(b) Window function(Amplitude distribution) of a 43-element array.









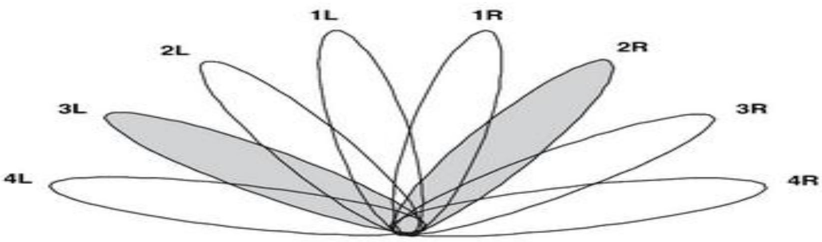


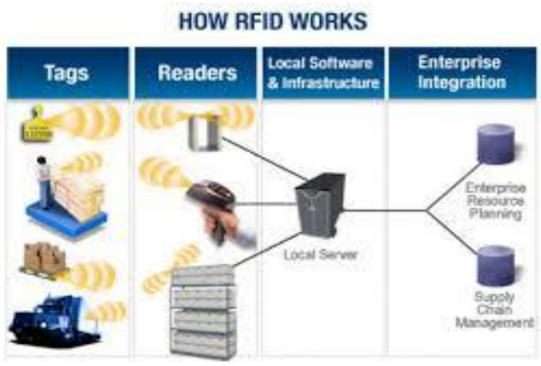
Fig.7.(a) Smart antenna.(b) Coverage pattern for switched beam and adaptive array.(c) Multiple-beamforming.(d) A 4*4 Buttler Matrix.(e) Orthogonal beams of an 8*8 Buttler Matrix.

VI. RADIO FREQUENCY IDENTIFICATION(RFID)

Radio-frequency identification (RFID) technology enables remote and automated gathering and sending of information between RFID tags or transponders and readers using a wireless link. Using RFID, the exchange of data between tags and readers is rapid, automatic and does not require direct contact or line of sight.

When a Card (tag) is brought near the RFID reader, it tries to communicate with the tag, receives the data and decodes it. Finally, it sends the data over the TX line. The UART module in MCU receives the data and thus used for further applications. By employing RFID, much secured entry systems can be developed without incurring huge costs. These are the reasons of excessive use of RFID technology.

	LF	HF	UHF	Active
Frequency	125 – 134.2 KHz	13.56 MHz	860 – 960 MHz	100 KHz – 2.45GHz
Range	0.2 – 3m	Up to 1m	Up to 3m	Up to 100m
Cost	Typ. 3 GBP	(Typ. 0.50 GBP)	(Typ. 0.30 GBP)	(Typ. 20 GBP)
Memory	Typ. 64 bits	Typ. 2048 bits	Typ. 96 bits	Typ. 32 bits
Penetration of Materials	V. Good	Good	Poor	V. Good
Data Rate	Slow	Fast	Fast	Fast
Reader Cost	50 – 500 GBP	50 – 3000 GBP	1000- 3000 GBP	200-600 GBP
Read Multiple Tags	Poor	Good	Very Good	Good
Applications	Animal Tags, Vehicle Immobilisers, Industrial Applications	Item Tracking, Access Control, Smart Labels	Box and Pallet tracking Some Item Tracking	Industrial Applications. Asset Tagging Location Systems



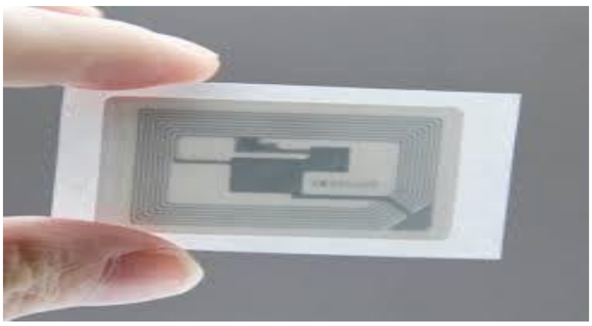


Fig. 8(a) RFID module.(b) Frequency range of RFID.(c) Working principle of RFID.(d) Active and Passive RFID tags.(e) Types of RFID tags.

VII. Results:

In the initial part of the paper a 100-element antenna array gain was synthesized using Genetic Algorithm. The optimized gain obtained after applying Meta-Heuristics to the problem Space was obtained to be -19.17dBi.. It took about 15 minutes to complete the simulation over a 1-GHz Quad-Core Pentium processor with RAM expanded to 8GB.The algorithmic parameters are:

Posize=500
Mutrate=0.10
No. of bits=10
No. of generations=10000
The designed array antenna was applied at the loadside of an X-band(8-12 GHz) microwave test bench and the antenna gain was estimated. It was observed that the optimization results substantiates with the experimental outcome. Also the return loss at the measured VSWR of 1.5 was calculated. A typical return loss value of an ESA is -13dB and experimentally it was found out to be -13.97dB which is far excellent.

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optimized function is testfunction
popsize = 300 mutrate = 0.10 # par = 43
#generations=1000 best cost= 0.11
Calculated Gain=-20*log(best cost)=-19.17dBi.
best solution or array co-efficients(Amplitude only):
0.17595 0.01173 0.13099 0.21603 0.10948 0.21408 0.044966 0.053763 0.025415 0.8739
0.021505 0.19355 0.40567 0.77126 0.9912 0.46334 0.30596 0.71554 0.24438 0.032258
0.3304 0.11437 0.066471 0.21505 0.91789 0.44966 0.0029326 0.012708 0.12805 0.041056
0.40469 0.63539 0.93646 0.13587 0.083089 0.30401 0.42033 0.5826 0.82502 0.54936

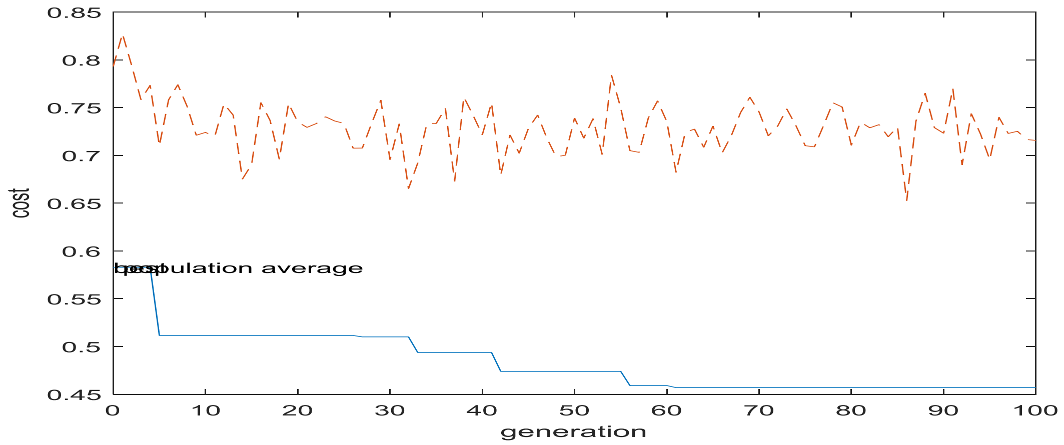
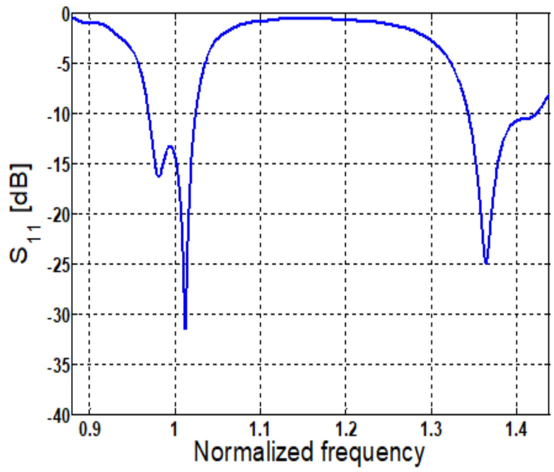


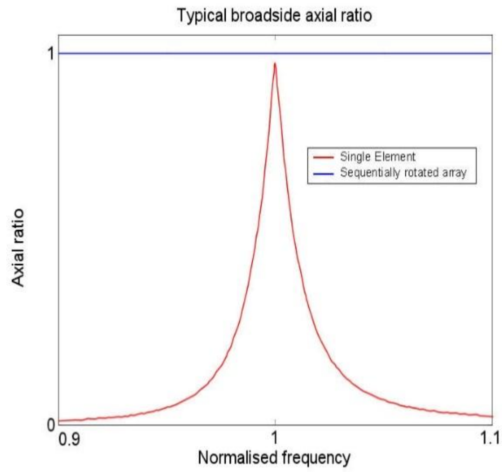
Fig.9.Global Best Fitness values.(Convergence).

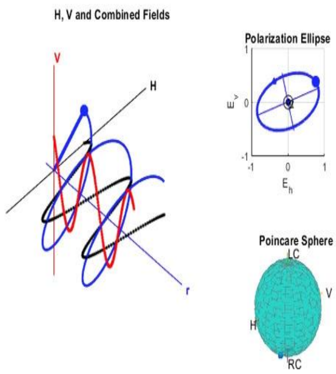
For Phase only calculate using equation. (iii):
binary genetic algorithm
each parameter represented by 10 bits

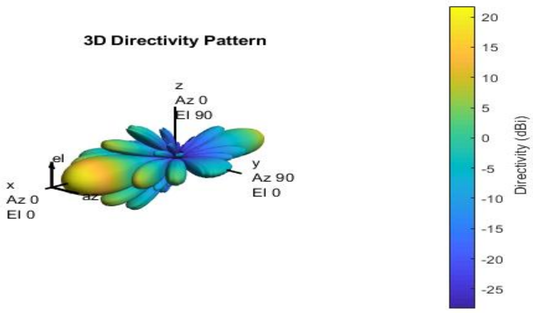
Fig.10. Design of the Sequentially rotated 2-by-2 circular patch array with stubs in Antenna Magus Software.

The axial ratio has been plotted as a function of frequency for 8-12GHz X-band microwave and has been plotted using Antenna Magus software. The axis ratio at 5.8 GHz was found to be 1:2 means aperfect Polarization ellipsoid. Simulated results calculate the axis ratio as Major:0.8 and Minor=0.4, ie.major/minor Ratio is 1:2.









The first fig. below shows the plot of axial ratio vs Normalized frequency for a scanning array. The second figure shows the Polarization ellipse and the third fig. shows the scanning beam beamforming simulation for Buttler-Matrix formulation of Electronically steered Arrays. Both second and third figures are plotted using MATLAB 2019a Phased Array Antenna System toolbox.

VIII. Acknowledgement:

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