A 16x8 Cavity Backed Patch Antenna Array for a Phased Array Radar

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***Abstract*— The proposed paper presents the design and development of a 16X8 Phased array antenna along with a *Wilkinson* based feeding network (A 128-way equal Power divider) for RADAR application based on a cavity backed patch antenna element. This has been implemented for an operation over the X-band, 8.6 GHz – 9.5 GHz with a scan range of ± 45^0 in the H-Plane and ±30^0 in the E-Plane. The simulated results show a return loss > 10 dB, 3 dB beamwidth of 12.1^{0}X6.2^0 in H-/E-planes with a gain of 26.4 dB over a bandwidth of ~10% in X-band.**

Keywords*— *Cavity, Active phased array antenna, Radar, Microstrip Patch

I. Introduction

The Radar system for which this antenna is being implemented is basically a bi-static radar system capable of searching and tracking multiple targets in X-band (8.6 GHz – 9.5 GHz). The antenna used is a planar active phased array antenna capable of electronically scanning in both the Azimuth & Elevation planes. The antenna element chosen for this purpose is a **Cavity backed patch** antenna element as it offers various unique advantages like reduced size, suppressed surface waves, low mutual coupling, conformal structure, provision for adding calibration lines (for performing the periodical online calibration of antenna at the element level) with an ease & improved heat transfer for elements (when active devices are used) as compared to a microstrip patch antenna array.

In microstrip patch antennas, when we try to increase the bandwidth, the amount of input power lost to Surface Waves increases with the increase in thickness of the substrate. The excitation of surface waves causes potential scan blindness in large arrays of microstrip elements at particular scan angles and is dependent on the substrate parameters and the array spacing. From literature, the usage of cavity backed patch antennas has shown quite a good improvement in the bandwidth without corresponding decrease in the scan coverage [2]. So, here we propose a microstrip patch antenna backed by a metal cavity for suppressing the surface waves and overcoming the other disadvantages.

II. Antenna and Array

A. Basic Single Antenna Element

The cavity backed patch antenna is basically a regular rectangular microstrip patch antenna backed by a metallic cavity. Fig. 1 shows the model of the proposed cavity backed patch antenna with different perspective views showing the dimensions and overall structure. A microwave substrate, RT Duroid 5880, with dielectric permittivity 2.2, a loss tangent of 0.0009 and a thickness of 0.789 mm has been chosen as the base for printing the patch. The simulation tools Ansoft HFSS & CST have been used extensively for designing and implementing the proposed antenna structure.

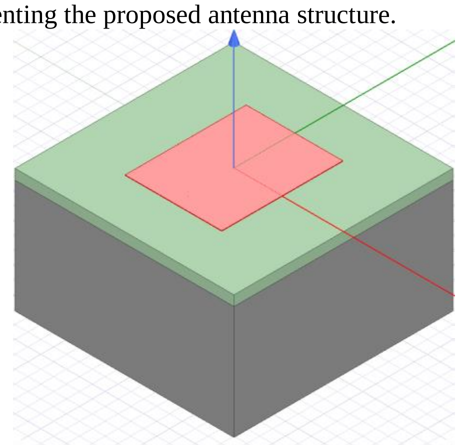

Fig. 1(a) Antenna structure

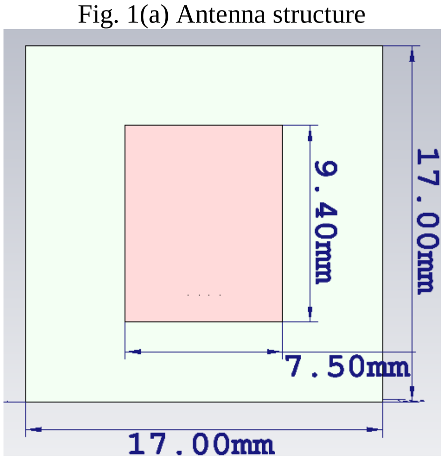

Fig. 1(b) Antenna top view

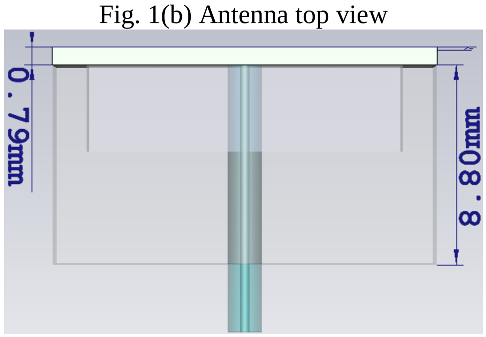

Fig. 1(c) Antenna side view

The cavity dimensions have been chosen to be $0.6\lambda_0$(L) X $0.5\lambda_0$(W) X $0.15\lambda_0$(D) as the starting point with 'λ_0' being the wavelength at the center frequency of 9.05 GHz [1]. The cavity base plate thickness has been chosen to be 5mm. Further, the starting values for patch dimension have been chosen as $0.23\lambda_0$(a) X $0.26\lambda_0$(b). Owing to cavity backed, a reduction in patch size has been achieved as compared to conventional patch antenna. All these dimensions are optimized using the HFSS simulation environment and the obtained values are shown in Fig. 1 above.

B. *Antenna Array*

The element spacing, 'd' in both X & Y planes is identical & has been chosen based on the amount of scanning required for the array in these planes by using the equation,

$$d < \lambda/(1+\sin|\theta max|) \quad (1)$$

where 'λ' is the free space wavelength corresponding to maximum frequency (9.5 GHz) and 'θ_{max}' is the maximum scan angle for the array without producing any grating lobes in the visible space. This amounts to **d <18.5mm** for a scan angle of $\pm45^0$. So, the value for spacing has been chosen as **17mm** after performing a few iteration of simulations for mutual coupling by providing some margin. The transmit antenna array consists of 128 elements arranged in a 16X8 rectangular grid.

A 16X8 array of elements arranged in a **rectangular** grid has been chosen as the radiating element for transmission due to the gain & beamwidth requirements. A provision for calibrating the antenna online has also been provided by designing the CAL lines and placing them appropriately on the H-plane for minimizing the coupling thereby providing minimum effect on the radiation from transmit antenna array. The Fig. 2 shows the structure of the transmit antenna array.

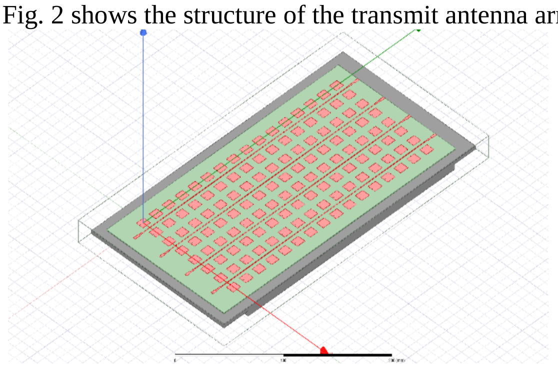

Fig. 2 A 16X8 Transmit Antenna Array with CAL Lines

C. *Feed network for 16X8 Array*

A feed network based on stripline wilkinson 128 way power divider was designed for testing the Transmit antenna array (16X8). The structure of the feed network modeled using HFSS showing different layers of PCB's is presented in Fig. 3 below.

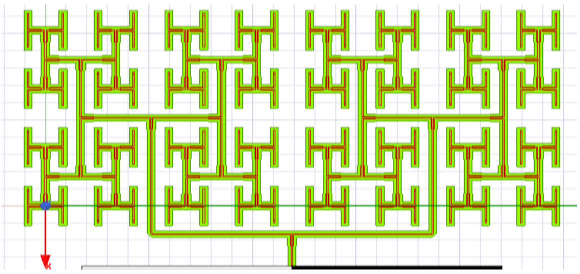

Fig. 3(a) A 128 way Stripline based Wilkinson Power divider - Bottom PCB

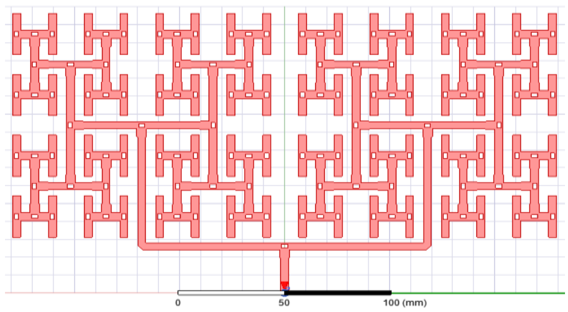

Fig. 3(b) A 128 way Stripline based Wilkinson Power divider – Top PCB

III. SIMULATED RESULTS

This section provides the simulated results of all the models described in the above sections. All these results were achieved using the HFSS EM simulation software from Ansys Electronics Desktop 2018.

A. *Basic Single Antenna Element*

For the optimized antenna in a Finite Array Environment, the Return loss characteristics are shown in Fig. 4(a), the radiation patterns in the principal planes Phi=0^0 and Phi=90^0 are shown in Fig. 4(b) and the corresponding Cross Pol. plots in Fig. 4(c).

Similarly, the results for an antenna optimized in infinite array environment are presented in Fig's 5(a), 5(b), 5(c) & 5(d).

Finite Array Environment

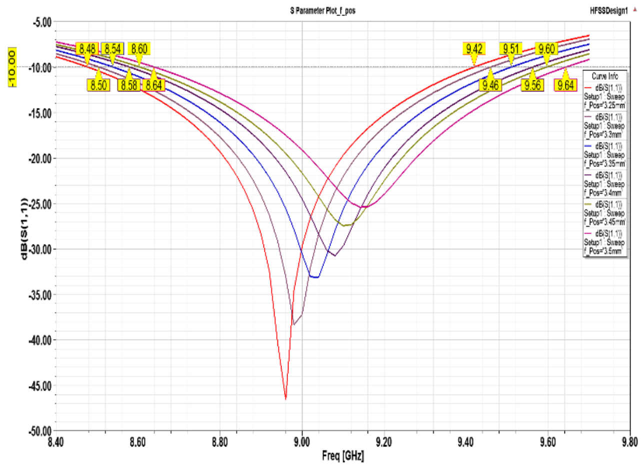

Fig. 4(a) Return Loss parametric with feed position

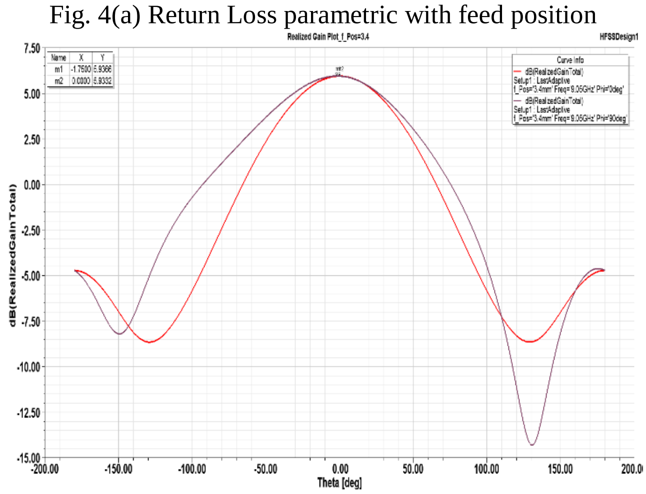

Fig. 4(b) Radiation pattern for Phi = 0^0, 90^0

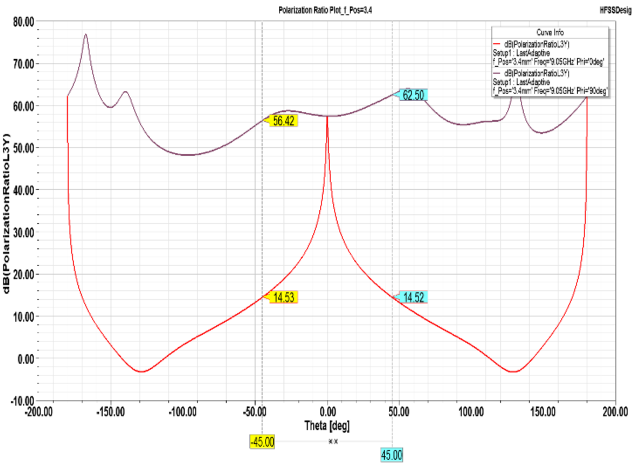

Fig. 4(c) Cross Pol. pattern for Phi = 0^0 & 90^0

Infinite Array Environment

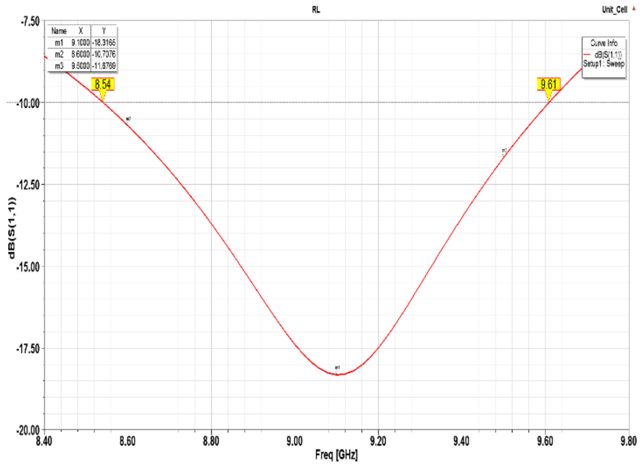

Fig. 5(a) Return Loss

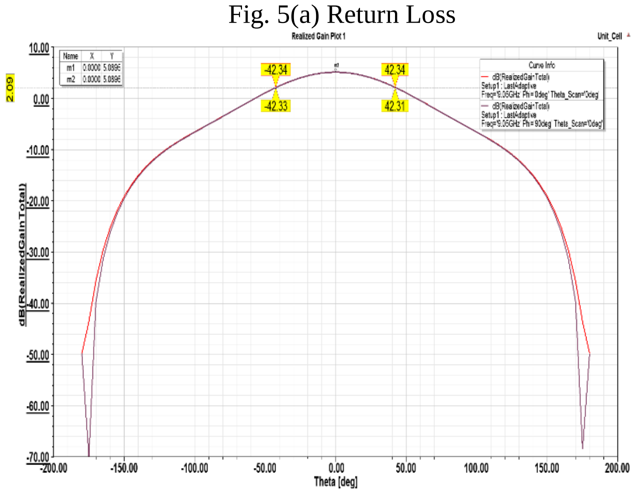

Fig. 5(b) Radiation pattern for Phi = 0^0, 90^0

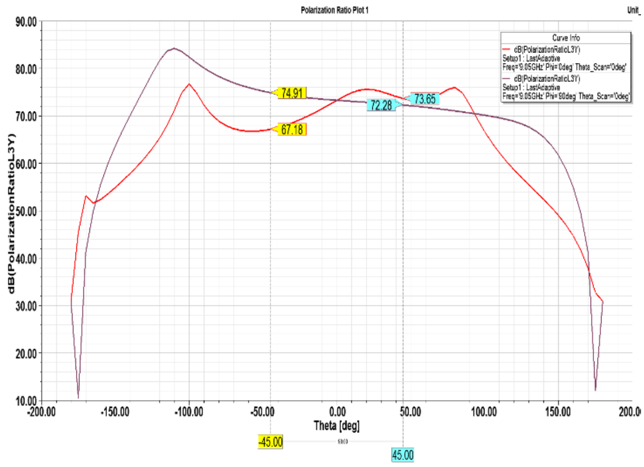

Fig. 5(c) Cross Pol. pattern for Phi = 0^0, 90^0

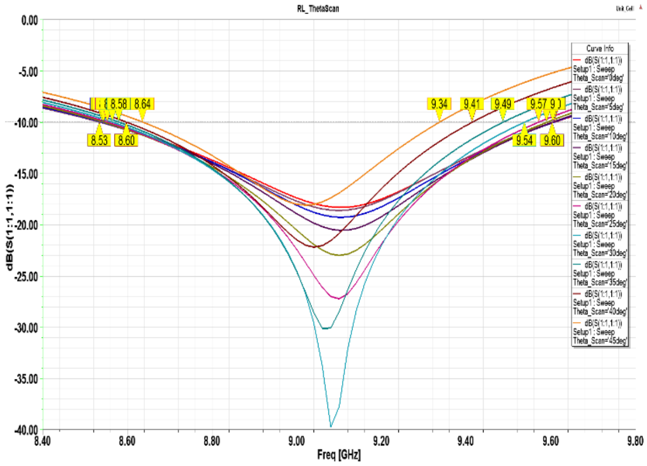

Fig. 5(d) Scan performance of a Unit cell

B. *Transmit Antenna Array (16X8)*

The simulated results of the Transmit Antenna Array (16X8) and the 128 way Wilkinson based feed network are presented in Figs. 6 & 7 7 respectively.

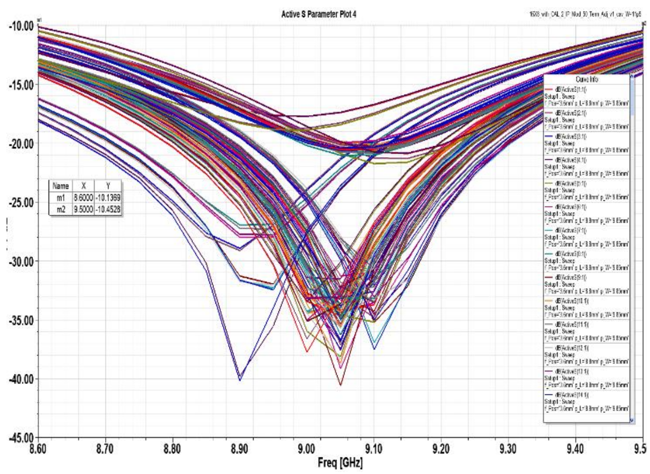

Fig. 6(a) Return Loss

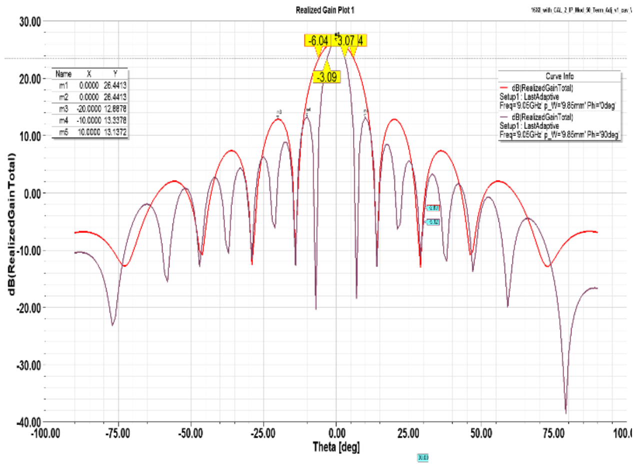

Fig. 6(b) Radiation pattern for Phi = 0^0, 90^0

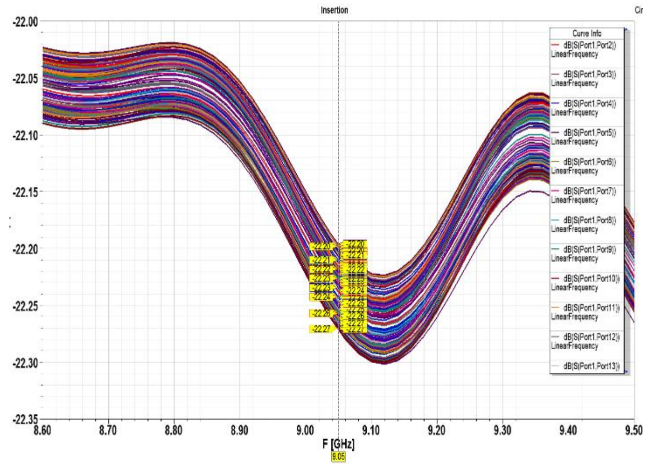

Fig. 7(b) Insertion Loss

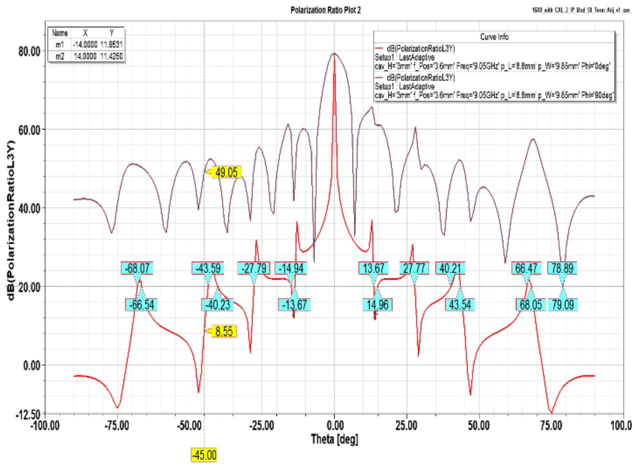

Fig. 6(c) Cross Pol. pattern for Phi = 0^0, 90^0

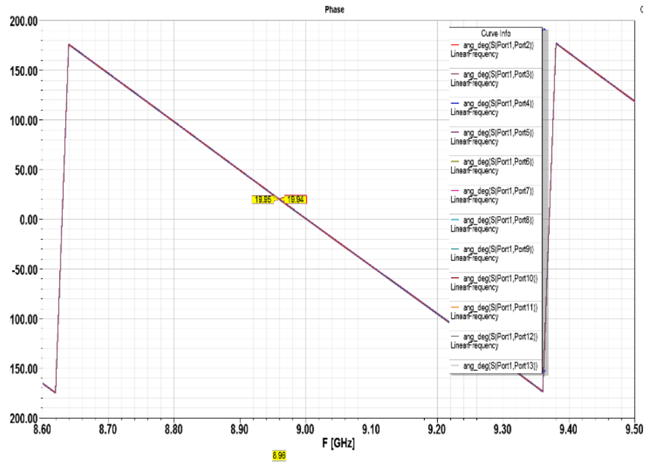

Fig. 7(c) Phase

C. Feed network for 16X8 Array

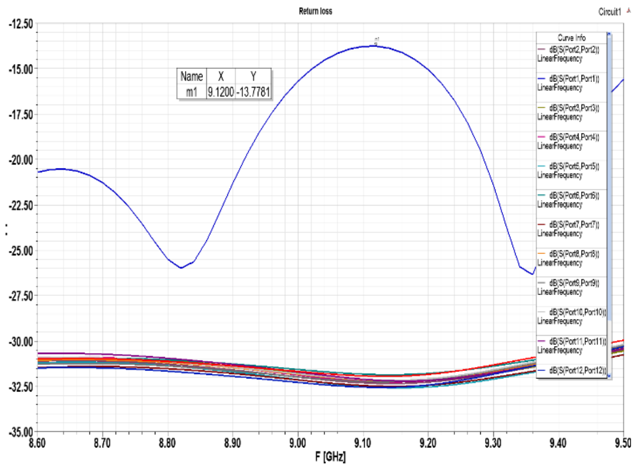

Fig. 7(a) Input & Output Return Loss

So, it's clear from these results that, the antenna performance, array performance and the feed network performance are quite satisfactory within the operating band.

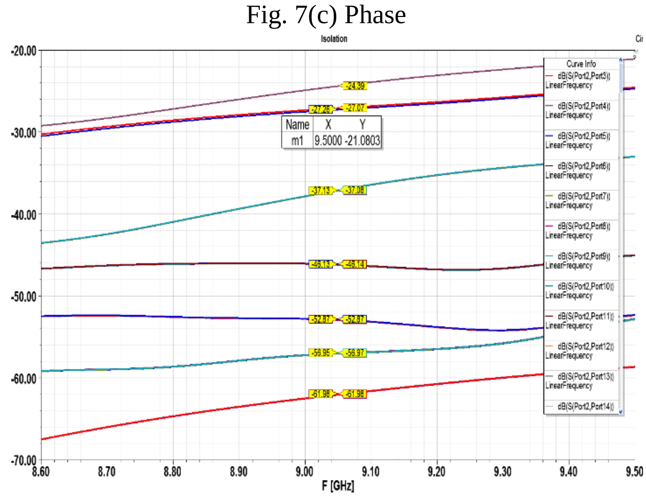

Fig. 7(d) Isolation

IV. FABRICATED PROTOTYPES

The prototypes of the Transmit Antenna array (16X8) and 128-way Feed network have been fabricated as discussed above and are presented in Figs. 8 & 9 respectively.

A foam material, Rohacell has been placed in the cavity slot for providing mechanical support to the patch antenna and a thin bonding film (temperature heated) has been used for attaching the antenna PCB to the cavity. The Fig. 10 below shows the Rohacell blocks that are placed into the cavities.

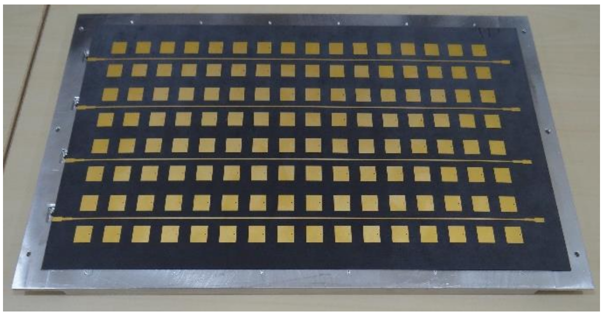

Fig. 8 Transmit Antenna Array (16X8) Proto

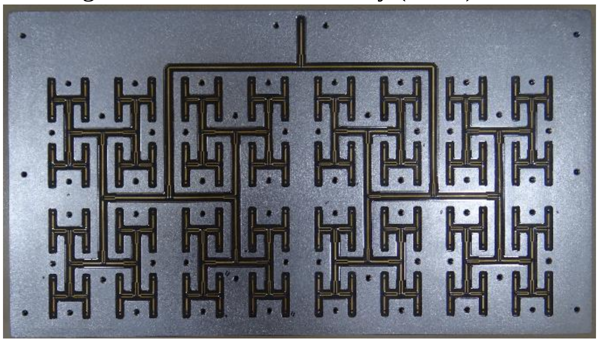

Fig. 9 128-way Feed network – Bottom PCB

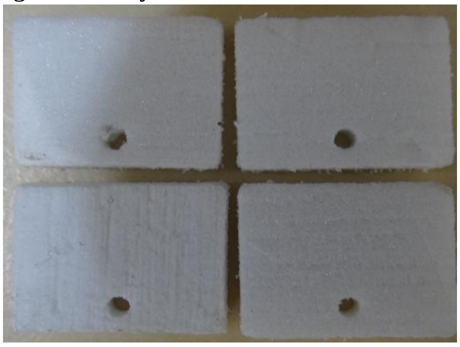

Fig. 10 Rohacell Foam placed in Antenna cavity

CONCLUSION

A single cavity backed patch antenna element has been designed & implemented over the frequency band 8.6 GHz – 9.5 GHz for a Phased array radar application. The antenna exhibits a return loss > 10 dB over the band of 8.55 – 9.53 GHz which covers the desired operating band (8.6-9.5 GHz). Also, the 3 dB beamwidths obtained in both the planes are above 90^{0}. This guarantees a good scan performance for array operation. The Cross-pol level > 20 dB is achieved over a wide beamwidth for an infinite array model.

On this basis, a Full Transmit antenna array (16X8) has been designed and fabricated and the corresponding feeding network based on stripline technology has been designed and fabricated. Both the antenna array & the feed network exhibits a RL (<-10 dB) bandwidth of 8.6 – 9.5 GHz independently. The maximum insertion loss of -22.9 dB, Isolation of -20 dB with a good phase matching are exhibited by the Feed network. The array presents a beamwidth of around $12^{0}X6^{0}$ in the H/E-planes respectively with a good cross-pol level of 20 dB. The presented antenna seems to be suitable for radars requiring large power-aperture products with wide scan volume requirements.

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