DESIGN OF PHASED ARRAY OF H-PLANE SECTORAL HORNS WITH LOW V.S.W.R AND HIGH GAIN

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Abstract
Modern electronic systems like Radars, jammers, satellite transponders, trackers, etc., were designed with phased array antennas in their transmitter and or receiver sections, to provide electronically steered beam with very high gain in the required direction. Linear array of horns was one of the antennas used for high power radiation applications like jamming. In these applications the antenna should operate with high powers in wide frequency ranges like 6-18 GHz. Therefore, the antenna should have low V.S.W.R over these operating frequency ranges, to protect costly high power amplifier. Further, the jamming was effective only when high power noise signal is transmitted towards the victim radar. In this paper, a 6-18 GHz band high power linear array of H-plane sectoral horns with V.S.W.R less than 2.5:1 and gain more than 15.8 dBi is designed, simulated, manufactured and tested. It is observed that the simulated and measured results are in agreement.
Indexed Terms: Band Width Ratio (BWR), Electronic Warfare, Impedance, Matching networks, Traveling Wave Tubes (T.W.T), Ultra Wide Band (U.W.B)

I. INTRODUCTION

Modern Electronic Counter Measures (E.C.M) systems are configured with high power transmitters consisting of Digital Radio Frequency Memory (D.R.F.M), high power microwave amplifiers and highly directive and electronically steerable antenna [1-2]. The antenna should withstand high power signals and shall have good matching with free space impedance (Z_0) of 120π Ω. The active V.S.W.R of the array is very critical parameter in these applications and depends on V.S.W.R of each element in the array. Many engineers have experimented standard and modified techniques to improve V.S.W.R of pyramidal horns, such as dielectric loading, stub matching, etc., [3 – 5]. These authors also explained the disadvantages of these methods like reduction in gain and operating bandwidths, though low V.S.W.R is improved to great extent. In this paper, the details of design, simulation and measurements of 6-18 GHz linear array of H-plane sectoral horns with "Tuning post loading on aperture" is presented to improve the V.S.W.R and gain. The simulated and measured results are in agreement.

II. DESIGN EQUATIONS

2.1 Design equations

The geometry of H-plane sectoral horn antenna is shown at "Fig. 1" [3 - 4] along with design parameters.

21 Feb 2017. This work is supported by D&E department, Bharat Electronics Limited, Hyderabad, India.
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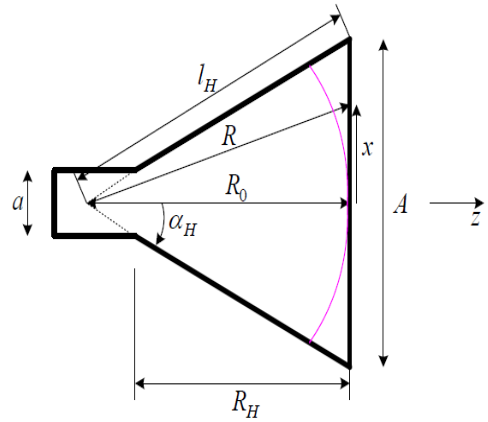

Fig. 1: Geometry of H-plane sectoral horn

Where, $l_H =$ Slant length of the horn, $R_0 =$ Straight length of the horn, $A =$ Aperture, $\alpha_H =$ Flare angle, $R_H =$ Flare length and $a =$ Waveguide height

2.2 Field equations

The derivations of E and H field equations of H-plane sectoral horn are given in [6]. These equations are extracted and shown at (1) and (2) for ready reference.

$$F_E(\theta) = \left(\frac{1+\cos\theta}{2}\right)\left[\frac{\sin(0.5\beta b.\sin\theta.\sin\phi)}{0.5\beta b.\sin\theta.\sin\phi}\right] \quad (1)$$

$$F_H(\theta) = \left(\frac{1+\cos\theta}{2}\right).f_H(\theta) \quad (2)$$

Where

$$f_H(\theta) \propto \int_{-A/2}^{+A/2} \cos\left(\frac{\pi x'}{A}\right) e^{-j\beta\sqrt{R_0^2+x'^2}} e^{j\beta x' \sin\theta} dx'$$

2.3 Directivity

The directivity of H-plane sectoral horn antennas is calculated using following procedure [6 -7, 9].

Step-1: Calculation of X using the formula

$$X = \frac{A}{\lambda}\sqrt{\frac{50}{l_H/\lambda}} \quad (3)$$

Step-2: Using this value of X, we have calculated G_H value from "Fig. 2", since $X > 2$. Otherwise we need to calculate G_H using formula

$$G_H = \frac{32}{\pi} X \quad (4)$$

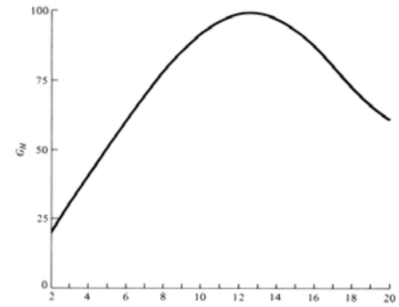

Fig. 2: G_H as a function of X

Hence $G_H = 70$.

Step-3: Now we have calculated D_H using the formula

$$D_H = \frac{b}{\lambda}\frac{G_H}{\sqrt{\frac{50}{l_H/\lambda}}} \quad (5a)$$

And Gain in

$$\text{dB} = 10\log(D_H) \quad (5b)$$

2.4 V.S.W.R

The V.S.W.R of the waveguide fed horn element is given [7] by

$$Z(z_i) = Z_0 e^{(\alpha z_i)}, z_i = \frac{iR_H}{n}, \alpha = \frac{1}{R_h}\ln\left(\frac{R_H}{Z_0}\right) \quad (6)$$

Where 'z_i' the impedance of each section of the horn and 'n' is the total number of sections of the horn.

2.5 Array Gain

The array gain with N elements is given [5, 14] by

$$G_{Array} = G_{element} + 10\log(N) \quad (7)$$

III DESIGN CALCULATIONS & SIMULATIONS

3.1 Specifications of Array

The specifications of linear array of H-plane sectoral horns with 8 elements are given at Table-1.

TABLE-1
DESIGN SPECIFICATIONS OF ARRAY

Sl. No.	Parameter	Linear array of H-plane sectoral horns
1.	Frequency range	6-18 GHz
2.	No of elements	8
3.	V.S.W.R Max.	2.5:1
4.	Gain (Min.)	15.8 dBi
5.	3-dB beam width (Az & El)	5-20°
6.	Power handling of element	100 Watts CW

3.2 Design Calculations of the element

Based on the above requirements, the design parameters of H-plane sectoral horn element at 6 GHz are calculated and given at Table-2. The simulation and measurement of V.S.W.R of the H-plane sectoral horn element is beyond the scope of this paper.

The improvements of the array in V.S.W.R by 0.3 (from 3.0 to 2.7) and gain by 0.44 dB (from 14.04 to 14.48 dBi) is demonstrated with hybrid tapering [9]. These parameters need further improvement to achieve targeted V.S.W.R of 2.5:1 and gain of 15.8 dBi without changes in the dimensions of the element (Table-2), as the array is required for air-borne applications. Thus a new technique, tuning post loading on aperture is proposed in this paper.

TABLE-2
DESIGN CALCULATIONS OF THE ELEMENT

D_H (dBi)	D_H	G_H	X	A	R_0	l_H
6.5	4.2	70	7.3 mm	136.4mm	344.6 mm	351.3 mm

3.3 Simulation of Array

The arrangement of the array of H-plane sectoral horns is shown at “Fig. 3”.

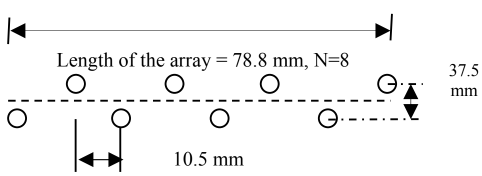

Fig. 3: Arrangement of elements of linear array of H-plane sectoral horns

The elements of the array are arranged symmetrically on both sides of the center line without loss of generality to meet the spacing requirement of the elements of the array (i.e. 25 mm which is < λ/2 @ 6 GHz) to avoid grating lobes. The simulated model consists of hybrid tapering, aperture smoothening [9, 11] and tuning post loading on aperture. The Solid model diagrams of the simulations are shown at “Fig. 4”. A pair of brass tuning posts of 1.4 mm diameter with λ/2 apart at the center on the aperture have created a large wave front and exhibited improvement in matching impedance of the waveguide impedance (Z_g) at low frequencies near S.M.A port. The location and the separation distance between these posts on the aperture are optimized in simulation. Also, the aperture area and thus gain of the array is increased due to hybrid tapering.

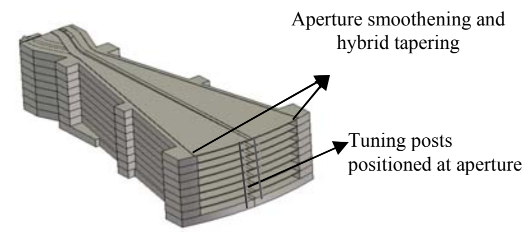

Fig. 4: Simulated Model hybrid tapering, aperture smoothening and tuning post loading on aperture of linear array of H-plane sectoral horns

The simulated V.S.W.R for 5th element of the array is shown at “Fig. 5”. The V.S.W.R data for single post at center, dual posts at center and dual posts at center with λ/2 separation is plotted. The V.S.W.R in 98% of the band is within 2.5:1 when dual tuning posts loading at center with 25 mm separation is simulated. The simulation of radiation pattern and gain is carried out at all frequencies from 6 to 18 GHz at 1 GHz step and the radiation patterns in azimuth and elevation plane of port 5 of 8 element array at 6 GHz and 18 GHz are shown at “Fig. 6 to Fig. 9” respectively. The peak gain in simulation for azimuth pattern at port 5 is 15.45 dBi and 21.46 dBi at 6 GHz and 18 GHz respectively.

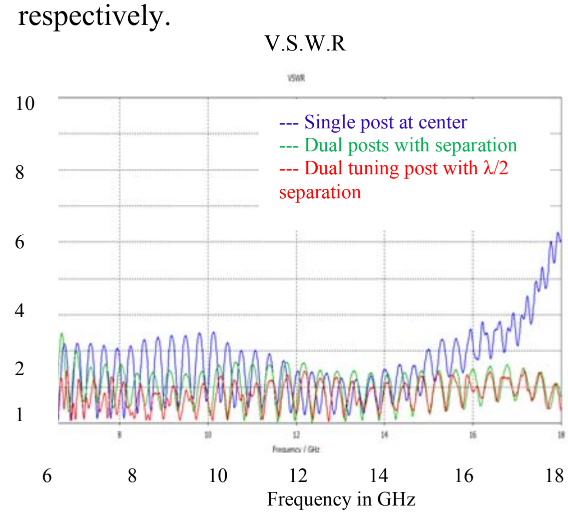

Fig. 5: Simulated V.S.W.R with Hybrid tapering, aperture smoothening and tuning

post loading on aperture of linear array of H-plane sectoral horns

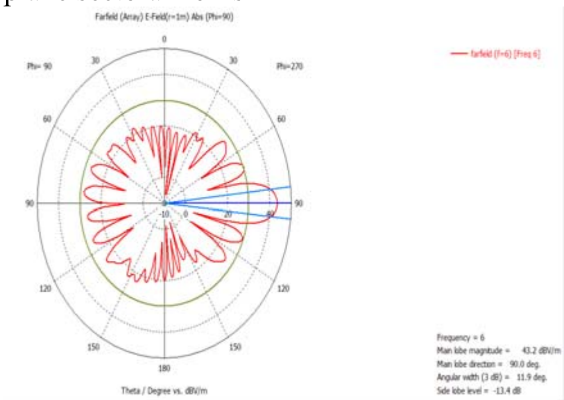

Fig. 6 Azimuth radiation pattern at 6 GHz

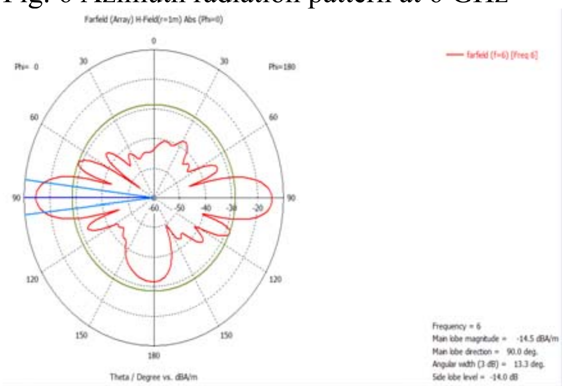

Fig. 7 Elevation radiation pattern at 6 GHz

IV. PROTOTYPE FABRICATION & RESULTS

The antenna array with eight elements is manufactured, out of which four elements are fabricated with hybrid tapering, aperture smoothening and the array is loaded with dual tuning posts on aperture with separation of 25 mm (corresponding to $\lambda/2$ at 6 GHz) between them. Additional two similar plates (spares) are manufactured and attached to the sides of the array to address the mounting issues, which are used as dummy plates in the array. The pictures of the prototype model are shown at "Fig. 10".

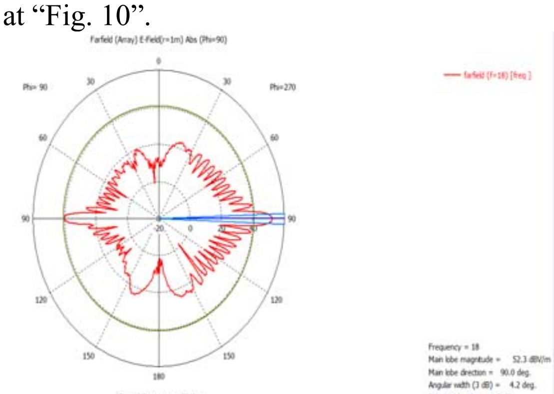

Fig. 8 Azimuth radiation pattern at 18 GHz

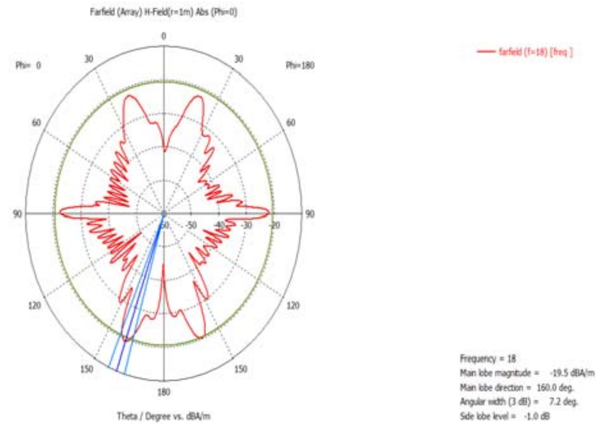

Fig. 9 Elevation radiation pattern at 18 GHz

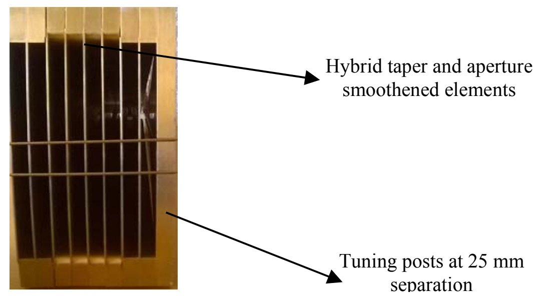

Fig. 10: Prototype of linear array of eight H-plane sectoral horns

V. EXPERIMENTAL RESULTS

The measured V.S.W.R for 5^{th} element is shown at "Fig. 11". The maximum V.S.W.R obtained is 2.45. The array has exhibited similar results for V.S.W.R for all other seven ports. The radiation pattern is measured from 6 to 18 GHz with 1 GHz step when excited with Rotman lens network and the radiation pattern in azimuth and elevation planes at 6 GHz and 18 GHz for 5th element is shown at "Fig. 12" and "Fig. 13". The radiation patterns of all ports from 6 to 18 GHz are not presented here, but in agreement with simulated results. The measured gain for 5^{th} port of the array for Azimuth Plane (A.P.) and Elevation Plane (E.P) is tabulated at Table-3. The radiation patterns at "Fig. 6 to Fig. 9" are compared with that of "Fig. 12 to 13". The measured V.SW.R and gain are meeting the specifications given at Table-1.

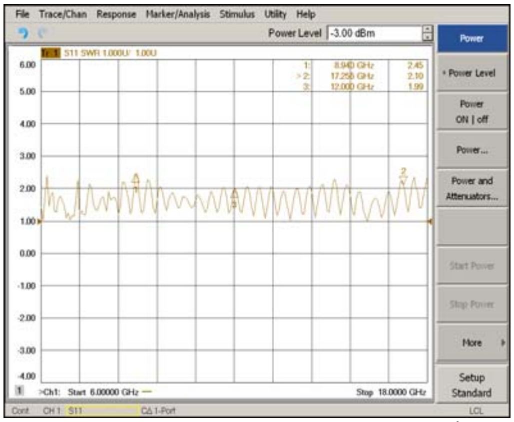

Fig. 11 Measured V.S.W.R plot of 5th element in the 8 element array

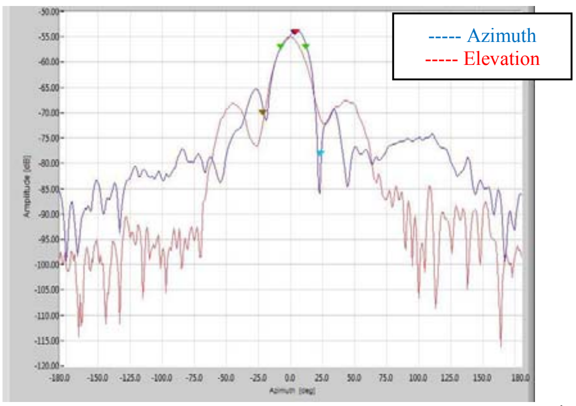

Fig.12. Measured radiation pattern of 5th element of linear array of H-plane sectoral horns at 6 GHz, Azimuth and Elevation planes

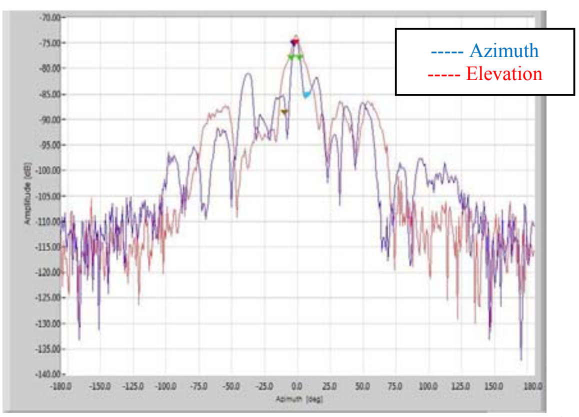

Fig.13. Measured radiation pattern of 5th element of linear array of H-plane sectoral horns at 18 GHz, Azimuth and Elevation planes

VI. CONCLUSION

A linear array with eight sectoral horn elements using hybrid taper, aperture smoothening and *tuning post loading* is simulated, manufactured and tested for V.S.W.R and Gain. The radiation patterns at 6 GHz and 18 GHz for both simulation and measured results are presented in the paper for comparison. It is concluded that the simulated and measured results are in agreement.

TABLE-3
SIMULATED & MEASURED GAIN WITH TUNING POST LOADING

S. No.	Freq. in GHz	Gain simulated in dBi in. A.P.	Gain measured in dBi in A.P.	Gain simulated in dBi in. E.P.	Gain measured in dBi in E.P.
1.	6.0	15.45	15.62	15.35	15.52
2.	18.0	21.46	21.98	21.36	21.29

ACKNOWLEDGEMENT

The authors are thankful to the engineers working at BEL for sparing their valuable time during the simulation and measurements. We also extend our sincere thanks to management of B.E.L for providing all the facilities like Simulation tools, High end work stations, Compact Antenna Test Range (C.A.T.R), Vector Network Analyzer, etc., during the work. We sincerely extend our gratitude to Prof. P Rajesh Kumar, HOD, ECE department, Andhra University, Hyderabad for his support during the preparation of the paper.

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