The Comparison of Two Monopulse Tracking Systems: Four – Horn and Multimode (based on the simulation results of HFSS)

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Abstract— The tracking system is a functional block of satellite and navigating system that detects the presence of various electromagnetic scatterers and determines their location. During the past two decades, a considerable amount of work has gone into the development of tracking schemes for the satellite communication system.Here is a review of few techniques based on the recent researches being carried out in this field. Comparison of the most widely used four – horn and multimode monopulse tracking systems are made and as a further study of the part of dissertation, appropriate simulations based on HFSS has been carried out to support the comparison made indicating the significances and insignificances.

Key words — Antenna feed, aperture coupled antennas, hybrid junction, radar tracking

I. INTRODUCTION

Tracking system detects the electromagnetic dispersers and predicts its location using antenna. One of the most widely used tracking techniques is monopulse tracking (also known as simultaneous sensing). Monopulse radar was being adapted in late 1970s. The concept of monopulse is that the antenna beam is split and then signals are sent out of antenna in slightly different directions. Upon reception, these are compared and stronger one is taken as detected target.

Monopulse tracking is divided further as amplitude comparison and phase comparison. In amplitude comparison method, two antenna beams separated by an angle theta (θ) and form sum and difference signals. Sum channel produces a beam with high SNR and this is used to find the range. The difference channel tends to output the error signal which is proportional to the angular deviation of the aimed object (target) from boresight. The error signal is zero or absent if the target is lying on the boresight. However, the error signal if received actuates the servo motors and the sign of the error signal determines which way to move antenna so as to make its boresight coincide with the target.

II. FOUR – HORN MONOPULSE COMPARATOR

Four-horn monopulse system comprises of four horns situated around the focal point of reflector antenna (as shown in figure 1) symmetrically. So, when the tracking target is on – axis, the wavefront would be pointed onto the focal point and hence the amount of energy falling on the four-horn feeds will be the same. When the target is located off – axis, the amount of energy falling on four feeds will vary depending upon the new location of the target.

Figure 1Monopulse feed placed at the focal point of reflector antenna

The structure of four – horn monopulse tracking system that is used in satellite tracking consists of four cross patterns centered to the antenna axis which are produced by using four horn system described earlier. Feed horns are somewhat shifted, as a result, echo is received from slightly different position at somewhat varied power.
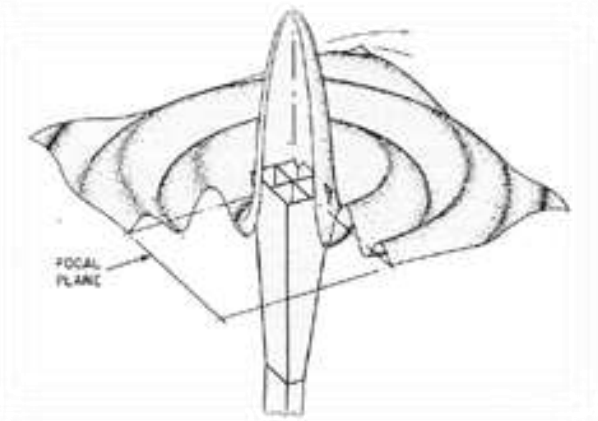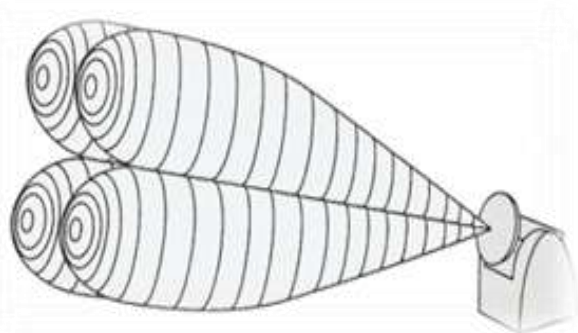
Figure 2 Sum Pattern [9]

Figure 3 Difference Pattern[9]

The received power forms a sum pattern when added from opposite horns and forms difference pattern when subtracted. Sum pattern allows us to find the range and manipulation of the amplitude of the received pulse. Difference pattern gives the angular information about the target.

In our design of four horn monopulse comparator, we have started with individually optimized 90° hybrid couplers. In the conjunction of three folded H-arm magic tees and one folded E – arm magic tee, a sum pattern and difference pattern is obtained (refer figure 4 and 5).
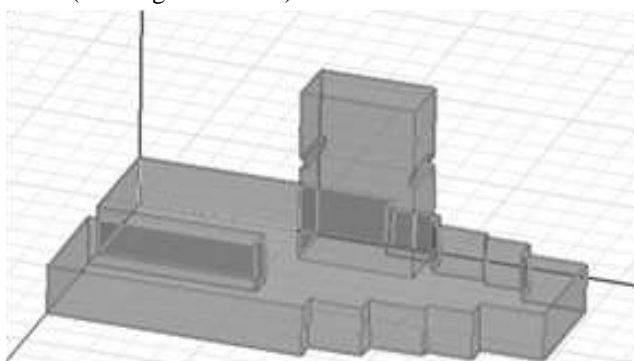

Figure 4 Folded H - arm Magic Tee

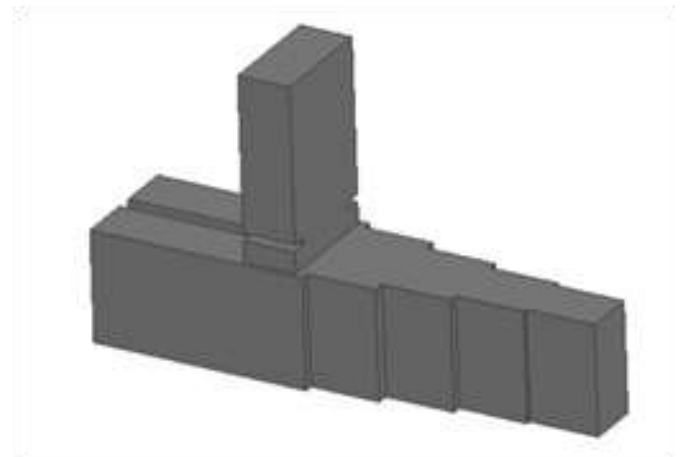The optimization is done for S–band specifically, 2.7 – 2.9GHz.

Figure 5 Folded E – arm Magic Tee

The step transition in rectangular waveguide structure was needed in order to connect folded H – arms with output H-arm. The rectangular waveguide we have used here is WR – 284 (a = 72.14mm; b = 34.04mm). MultisectionChebyshev[12] transformer that optimizes bandwidth at the cost of passband ripple is used for calculating step transition dimensions.

Chebyshev transformer is designed by equating $\Gamma(\theta)$ to a Chebyshev polynomial, which has optimum characteristics needed for this type of transformer. The nth order Chebyshev polynomial is a polynomial of degree n, denoted by $T_n(x)$. Chebyshev polynomials that we have used for our design are as below:

$$T_1(\sec\theta_m\cos\theta) = \sec\theta_m\cos\theta$$

$$T_2(\sec\theta_m\cos\theta) = \sec^2\theta_m(1+\cos 2\theta) - 1$$

$$T_3(\sec\theta_m\cos\theta) = \sec^3\theta_m(\cos 3\theta + 3\cos\theta) - 3\sec\theta_m\cos\theta$$

$$T_4(\sec\theta_m\cos\theta) = \sec^4\theta_m(\cos4\theta + 4\cos2\theta + 3) - 4\sec2\theta_m(\cos2\theta+1) +1$$

A matlab program algorithm is given in order to compute the step size. All we need here to do is just enter the dimension of input waveguide and the output waveguide plus state the number of steps you want in your design; the program outputs various step sizes for the step number entered. We optimized our structure with four steps. The dB plot of return loss of E – arm and H – arm at output is shown in fig. 5 and summarized in table 1.

Similarly, for optimizing folded E – arm magic tee, we have used four transition steps. The return loss for folded E – arm magic tee after optimization is as shown in fig. 6.

Both the above models have been simulated using HFSS (High Frequency Structure Simulator). The final Four – Horn structure and related sum and difference patterns have been

shown in fig. 7.Necessary connections between folded magic tees have been achieved using individually optimized E – bends and H – bends. The structure has been designed in order to achieve the most compact design so it will not add to any bulky tracking system feed.
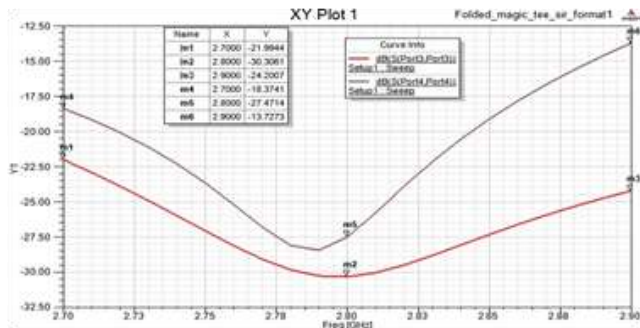

Figure 5 Return loss of folded H arm magic tee

Table 1

Summary of the return loss for folded H- arm Magic Tee

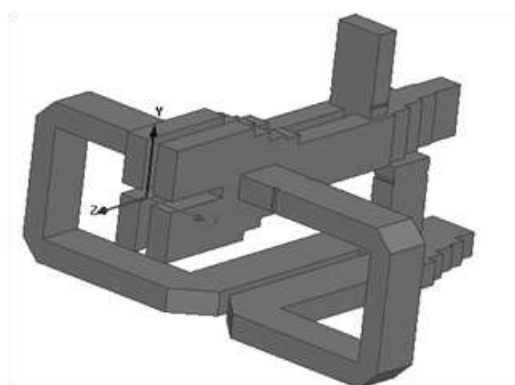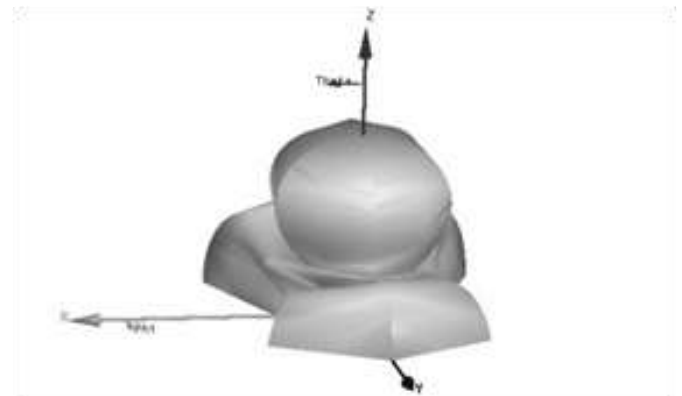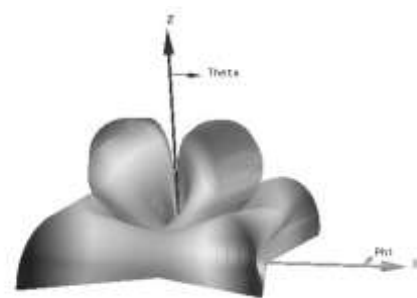| Arm	Return Loss (dB)		
	2.7GHz	2.8GHz	2.9GHz
E - arm	-18	-27.5	-13.72
H - arm	-21.99	-30.3	-24.2
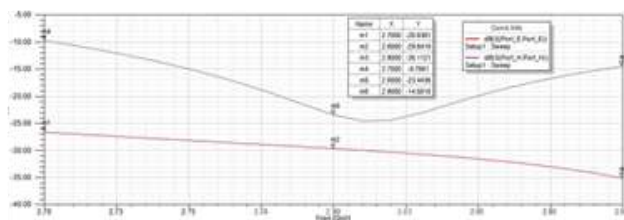
Figure 6 Return loss of folded E - arm magic tee

Figure 7 Four – Horn monopulse comparator

(a)

(b)

Figure 8 (a) Sum pattern (b) Difference pattern for Four – Horn monopulse comparator

III. MULTIMODE MONOPULSE COMPARATOR

Multimode monopulse design offers more simplicity and flexibility. In this design, a circular waveguide with perpendicular transition between circular and rectangular waveguides has been used. Four rectangular slots working in two pairs are used. These two pairs are separated by 45° angles on the circumference of circular waveguide wherein TE_{21} modes get coupled in order to travel as TE_{10} mode through rectangular waveguides. Owing to the circular symmetry of guide, five modes can travel. These modes are a degenerate pair of TE_{11} (modes with spatially orthogonal fields), TM_{01} mode and degenerate pair of TE_{21} modes (again with spatially orthogonal fields).

Advantage of using more waveguides is to obtain mode purity (symmetry of radiation pattern) but it comes at the cost of more hardware. Fig. 10 shows the structure of multimode system we designed on HFSS and the fig. 11 shows the sum pattern and the difference pattern which was obtained from this structure upon simulation.
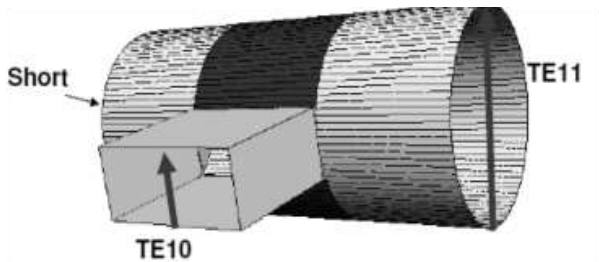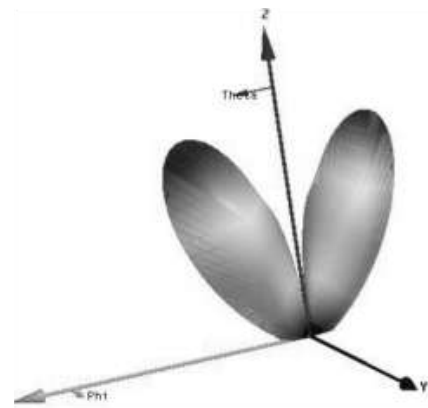
Figure 9 Perpendicular transition between rectangular and circular waveguides

The difference pattern is obtained as a result of TE_{21} modes being coupled at rectangular slot region forming TE_{10} modes. The sum pattern is obtained by TE_{11} mode.

(b)

Figure 11 (a) Sum pattern (b) Difference pattern of multimode monopulse comparator
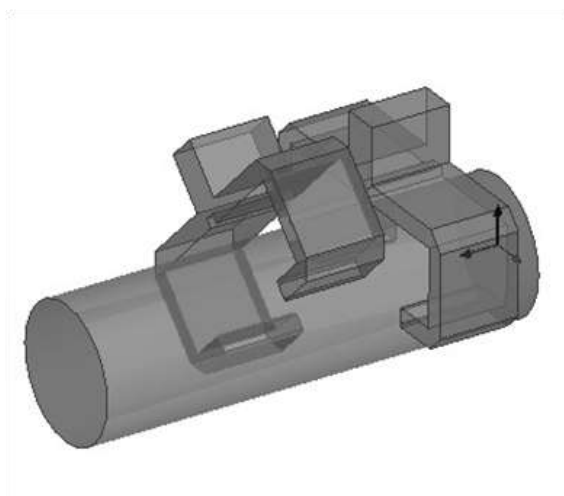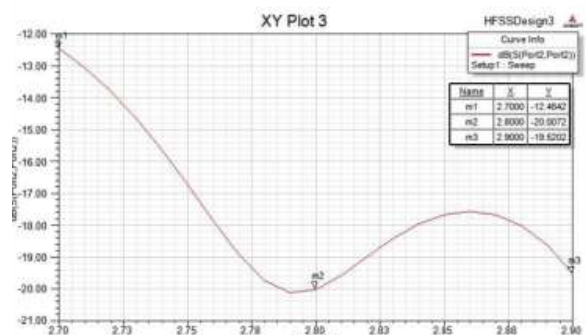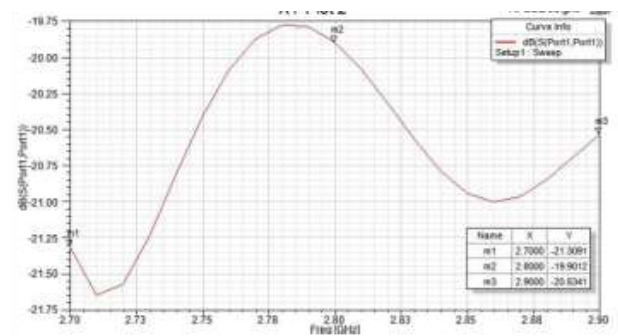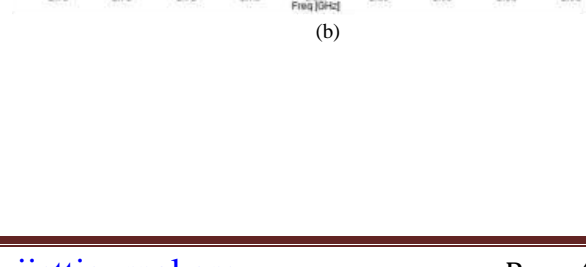

Figure 10 Multimode Monopulse Comparator

IV. COMPARISON BETWEEN FOUR – HORN AND MULTIMODE MONOPULSE COMPARATORS

Design of multimode monopulse comparator is quite compact as compared to four – horn. The -20 dB bandwidth for rectangular waveguide emerging from a rectangular slot is narrower as compare to four – horn comparator. Table 2 summarizes the comparison between the two comparators.
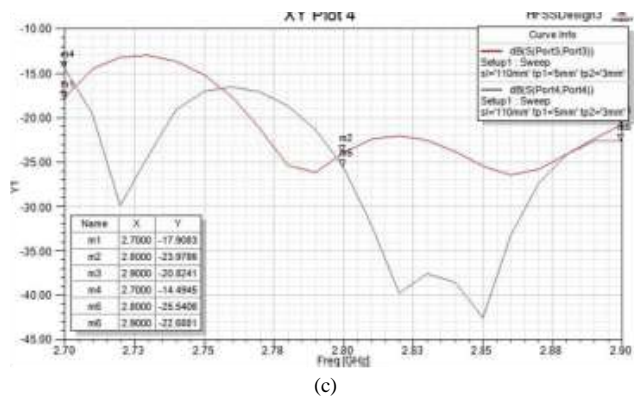

(a)

(b)

(a)

(c)

Figure. 12 Reflection coefficient for Four – Horn Monopulse (a) S_{11} (b) S_{22} (c) S_{33} & S_{44}
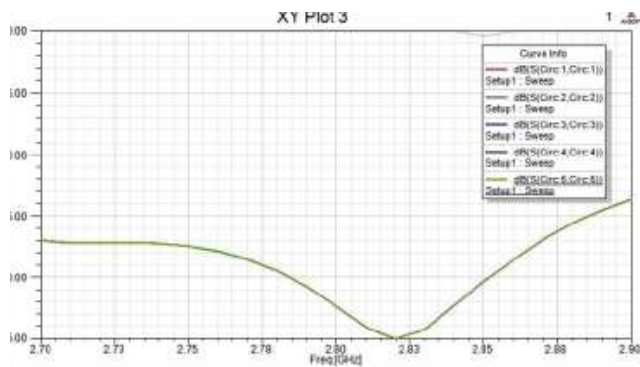

Figure 13 Reflection coefficient for Multimode Monopulse

Table 2
Summary of the comparison between Four- horn and Multimode monopulse comparators

Characteristics	Four Horn Monopulse	Multimode Monopulse
Extraction of Sum and Difference patterns	Collectively	Separate controls are available hence individually both the patterns can be extracted and processed
Structure	Little bulky	Compact
Gain	Considerably more	Comparatively less
Bandwidth	Wide band	Narrow band
RMSE (root mean square error) estimation	Better only if theta is θ_b(half power beam width)/2	Better

V. CONCLUSION

The optimization of four – horn and multimode is done for higher accuracy at the cost of low bandwidth. The results from HFSS have been used to compare the two designs in S – band. Both the methods have their pros and cons and it is subjective in order to decide which is superior. Depending upon the requirements and the kind of applications for which it is to be used, designer would seek some modification in either of the design.

VI. ACKNOWLEDGMENT

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