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Design and Fabrication of 430MHz Unequal Amplitude Hybrid Coupler for T-Radar Beam Forming Unit

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Abstract

Background/Objectives: This letter describes the design simulation and fabrication the design, simulation and fabrication of an P-band frequency band unequal amplitude 90^0 hybrid coupler. This hybrid coupler is used to design a feeder network with 4 output ports for T-Radar Wind Profiler Operating at 430MHz is achieved with a frequency bandwidth exceeding 50MHz. **Methods/Statistical Analysis**: The hybrid coupler is designed with the help of conventional microstrip technology. Measured and simulation results has been provided for the components (Equal amplitude hybrid couplers, Unequal amplitude hybrid coupler) used to implement the feeder network. The microstrip hybrid coupler with unequal amplitudes with 90^0 phase difference is achieved with varying impedances of the one of the arms in a hybrid coupler. **Findings:** The proposed coupler is easily fabricated on the glass epoxy PCB without any lumped element. There is a good agreement between measured, simulated and theoretical prediction validated the feasible configuration of the proposed coupler and amplitude weights are designed based on array synthesis so called Taylors 1-parameter method for side lobe level -17 dB down from the main beam. A full wave EM simulator zeland IE3D V12.02 and Ansoft designer is used for designing hybrid coupler. **Applications/ Improvements:** The fabricated coupler is best suited for shared aperture antenna beam forming network and Feeder network using hybrid coupler for 430 MHz Radar applications. To demonstrate our design theory, a practical unequal power hybrid coupler is designed, simulated and fabricated. The measured results shows that the Return losses are larger than 25dB. The power couplings S21 and S31 is -4.38 dB and -3.17 dB and the output phase difference is 88.318^0 at the operating frequency.

Keywords: Coupling and Returnloss, IE3D, Troposphere, Unequal Hybrid Coupler

1. Introduction

T-Radar Wind Profiler system provides wind speed and direction as a function of height and also weather observation and forecasting however, other applications have been identified, including severe wind condition warnings, flight planning, space shuttle support, and pollution studies. Some of the other methods to measure wind speed and direction are smoke trail, balloon technique etc. Measurement of wind velocity using Radar was found to eliminate the disadvantages of the smoke trail, balloon technique methods. Such radars are also known as WIND PROFILERS[1]. WPR also play a part in making air travel safer. WPRs are used for wind profiling in operational meteorological networks[2–4]. Tropospheric-Radar operates at 430 MHz frequency band. Backscattering of the power/energy from the irregularities in the atmosphere is the basic principle behind the Radar wind profiler operation. Energy reflection occurs preferentially from irregularities of a size on the order of one half wavelength of the incident wave. These irregularities are primarily due to the variations in the temperature and humidity of the air, which are carried out with the wind in the form of turbulent eddies. These irregularities exist in a size range of a few centimetres to meters[5,6]. A small portion of the scattered beam is returned to the radar location where it is received in the form of Doppler shift and analyzed. The principle involved in these radars is the same as that of the MST Radar.

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2. Atmospheric Radar Feeder Network Mechanism

In an Antenna array each element must be fed with proper amplitude and phase such that the array will performs desired functions. The feeder network that distributes the proper amplitude and phase excitation to each element. The microwave power to the radiating antenna is feeding through a coaxial cable like RG214. The feeder network consists of coaxial cables, power combiners/dividers and hybrid couplers with equal or unequal amplitude 90^0 phase difference. The RF signal to the TRMs or Antennas through a chain of let us say in this article 1:4 Power Dividers/Combiners (PDC) or equal amplitude splitter with unequal amplitude hybrid coupler. The position of feeder network (i.e.,) before TRM (or) after TRM is depends on configuration of the radar system. The designed unequal amplitude hybrid coupler is for the SLL reduction of -17dB low level from the main lobe. The amplitude weighting coefficients are derived from the array synthesis technique Taylors 1-parameter method. The design specifications for feeder network are shown in Table 1.

3. Theory and Design

3.1 System Realization by Microstrip Technique

A microstrip structure consists of a copper layer of metal on one side (CS side) of a thin sheet of dielectric material and is fully covered with copper material on the Second Side (SS). The shaped metal layer on the front side is often printed, and could act as a circuit or an antenna. The metal usually copper is very thin, about some micrometers. The dielectric material, termed substrate is the mechanical backbone of the microstrip circuit. The substrate is made of low-loss material, and its thickness, height, permittivity and permeability determine the electrical characteristics of the RF passive component[7–9]. The complete copper layer on the other side of the substrate is grounded (SS) and hence called ground plane.

Table 1. Specifications

Sl No.	Parameter	Value
1	Frequency	430MHz
2	Feeder type	Unequal amplitude quadrature hybrid coupler and Equal power splitter
3	No of input ports	1[1,46816 W]
4	No of output ports	4[0.30777,0.42631,0.30777,0.42 631W]
5	Side lobe level	-17dB
6	Amplitude taper	Taylor 1-parameter
7	Bandwidth	40MHz

3.2 Substrate Information

The design is based on Fire Retaurdant–4 substrate (εr = 4.4, tan δ = 0.02, and h = 1.6 mm) as shown in Figure 1(b). A low permittivity is essential for good radiation efficiency and satisfying the bandwidth of the antennas at the cost of an increased radiation of the feed network. The other specifications of substrate information and electrical characteristics are shown in Table 2[10–14].

Another influencing parameter is substrate selection which is less cost and the dimensions of transmission line length/width and the losses[15,16]. These results are derived using the MOM based zeland IE3D V12.02 Momentum and its optimization engine. The transmission line length and widths and substrate for this design given in Case 1 of the Table 2.

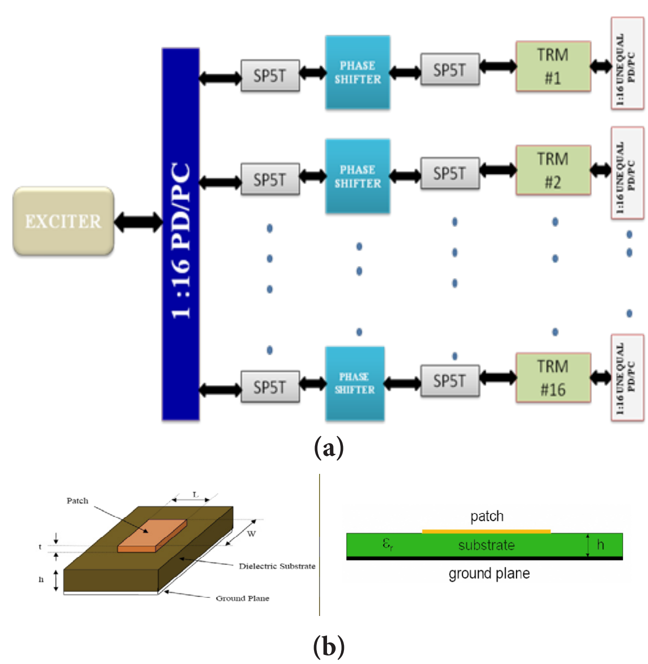


Figure 1. **(a)** Configuration of t-radar system. **(b)** Microstrip structure.

3.3 Quadrature Hybrid Coupler with Equal (or) Unequal Amplitude

The hybrid coupler is a mirowave passive component in microstrip technique used for to generate RF signals 90^0 out of phase with respect to output port and coupled port. It consists, of a main line that is coupled to a secondary line by two quarter-wavelength transmission lines parted one quarter wavelength apart as shown in Figure 2. When a signal is introduced at port-1, the signals at the two output arms (2, 3) are equal in power and 90 degrees phase difference between the output ports. The port located on the same side as the input port is isolated port since there is no power reaching it. The power applied at a input port is equally or unequally distributed between the ports located on the other side of the coupler called output port and coupled port. There is a 90^0 phase difference between these output port and coupled ports, the port closer to the input port is leading in phase by 90^0. In the same way by varying the impedances of the quite opposite arms in a branch line coupler, unequal power splits can be obtained.

Table 2. Substrate details

Parameter	Notation	Unit	Case-1
ResonantFrequency		MHz	430
Substrate material			FR4 GLASS EPOXY
Relativepermittivity	εr		4.4
tangent Loss	tanδ		0.02
Height of substrate	H	mm	1.6
Impedance	Z0	Ω	50
Wavelength	λ	m	0.6976
Line Width	W	mm	3.06
Electrical length		degrees	90^0

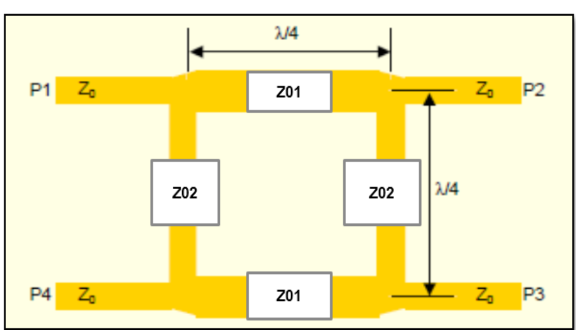


Figure 2. Quadrature hybrid built around transmission lines. All arms are λ/4 in length.

3.4 Design Equations of hybrid Coupler with Equal and Unequal Amplitude

The characteristic impedances can be calculated by using the following design equations shown below

Case 1:- For equal amplitude

$$Z01 = \frac{Z0}{\sqrt{2}} \tag{1}$$

$$Z02 = Z0 \tag{2}$$

Case 2:-For unequal amplitude

$$Z01 = Z0\left[\frac{\left[P1/P2\right]}{\left[P1/P2+1\right]}\right]^{0.5} \tag{3}$$

$$Z02 = Z0\left[P1/P2\right]^{0.5} \tag{4}$$

The widths and lengths of each section of the hybrid couplers for the above impedances in the coupler has been calculated by using design Equations[8].

4. Simulation Results

To characterize the coupler, a full-wave numerical simulations were performed using Method of Moments zealand IE3D software and Ansys Ansoft Designer.

4.1 Quadrature Hybrid Coupler

The coupler has been designed in the both layout and circuit environment of the ansoft designer and MOM zealand IE3D. The proper dimensioning has been made with design steps[8]. As expected, the phase difference between port 2 and port 3 is 90 degrees. Insertion loss bandwidth of 50MHz is around 0.4 dB at for each branch, which is typical for this type of transmission at UHF/P-band frequencies. The designed equal and unequal ampliude quadrature hybrid coupler schematic and layout at center frequency of 430 MHz in ansoft designer and IE3D simulation software is shown below. The electrical length of the line is chosen to be 90^0 and the corresponding width and length of the lines are calculated by using equations[8].

The Tables 3 and 4 shows that the characteristic impedances of the series and shunt arms for a given power divisions and power division ratio for both equal and unequal amplitude division which can be obtained from Equations (1) to (4).

4.2 Design of Equal Amplitude Hybrid Coupler Schematic in Ansoft Designer

Figure 3 shows the calculated S-parameters for the equal amplitude hybrid coupler has a characteristic impedance with widths and lengths with 50 ohms matchings designed at the resonant frequency of 430MHz. Now the circuit computed S-parameters of the proposed coupler are illustrated in Figures 4, 5, 6 and 7 and Table 5.

Table 3. Power levels

Parameter	Unit	Hybrid[equal amplitude]	hybrid[unequal amplitude]
P total	W	0.73408	0.73408
P1	W	0.36704	0.42631
P2	W	0.36704	0.30777
k sq	---	1	1.38515

Table 4. Impedance lengths and widths

S.no	Parameter	Impedacnes[Ω]	Length[mm]	Width [mm]
For equal amplitude hybrid coupler				
1.	Z0	50	95.56	3.06
2.	Z01	35.35	93.4	5.223
3.	Z02	50	95.56	3.06
For unequal amplitude hybrid coupler				
1.	Z0	50	95.56	3.06
2.	Z01	38.104	93.85	4.683
3.	Z02	58.84	96.64	2.301

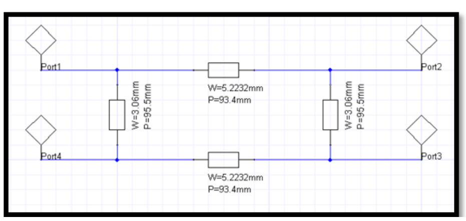


Figure 3. Equal amplitude quadrature hybrid coupler.

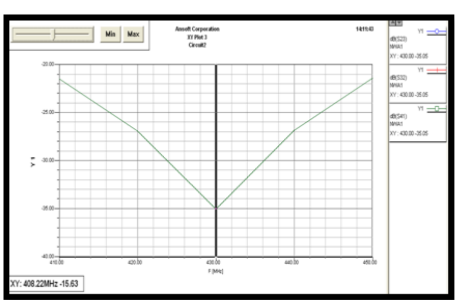


Figure 4. Simulated isolation.

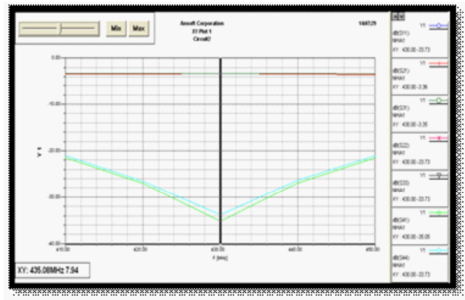


Figure 5. Simulated power divisions.

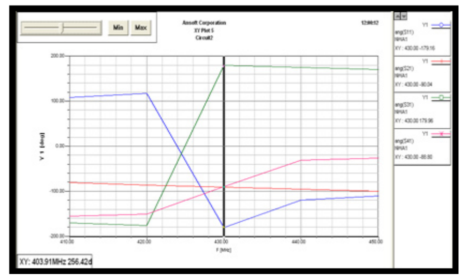


Figure 6. Simulated phase angle.

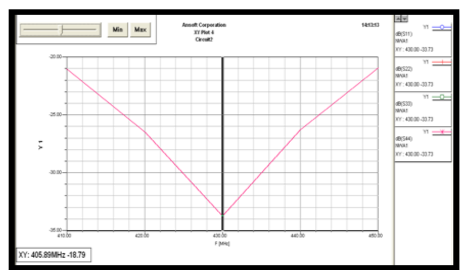


Figure 7. Simulated return loss.

Table 5. Simulation results

Equal amplitude hybrid coupler design simulation results in ansoft designer				
Parameter	IL or coupling [dB]	Phase [degrees]	Isolation [dB]	Return loss [dB]
S(1,1)	_____	**-179.1**	_____	**-33.73**
S(2,1)	**-3.36db**	**-90.04**	_____	_____
S(3,1)	**-3.35db**	**179.9**	_____	_____
S(4,1)	_____	**-88.08**	**-35.05**	_____
S(2,3)	_____		**-35.05**	_____

4.3 Design of Equal Amplitude Hybrid Coupler Layout in IE3D Simulation Software

Figure 8 shows the calculated S-parameters for the equal amplitude hybrid coupler has a characteristic impedance with appropriate widths and lengths with 50 ohms matching designed at the center frequency of 430MHz. Now the full wave and circuit computed S-parameters of the proposed coupler are illustrated in Figures 9, 10, 11, 12, 13 and 14 and Table 6.

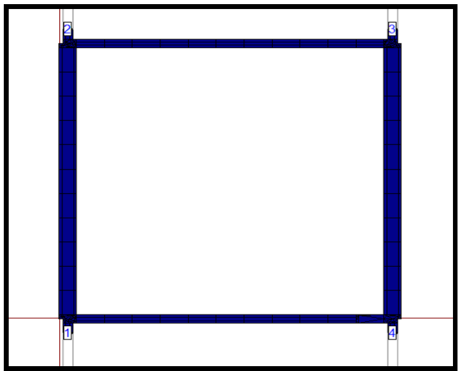


Figure 8. Equal amplitude hybrid coupler.

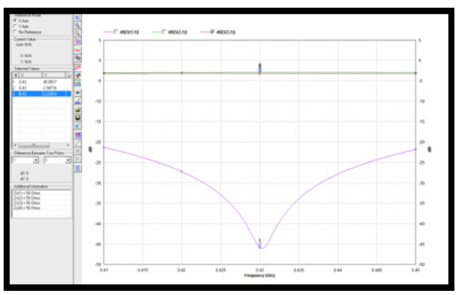


Figure 9. Simulated power divisions.

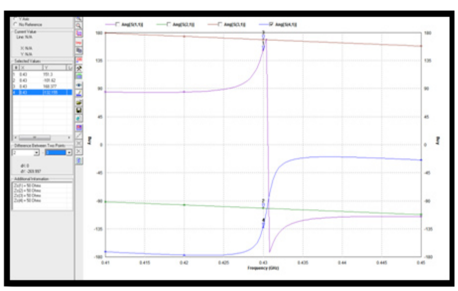


Figure 10. Simulated phase angle.

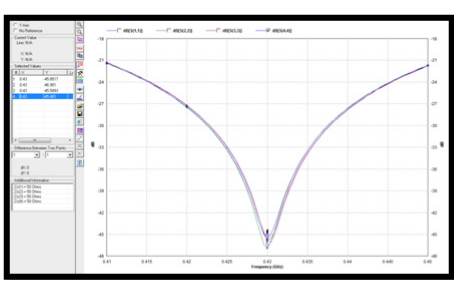


Figure 11. Simulated return loss.

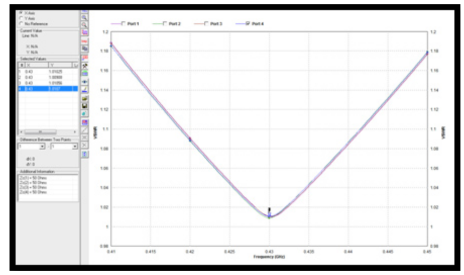


Figure 12. Simulated VSWR.

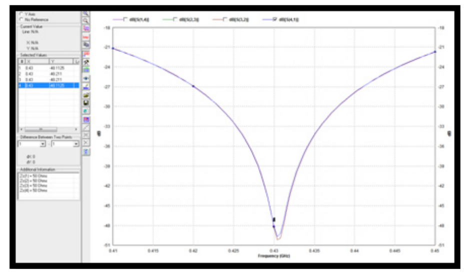


Figure 13. Simulated isolation.

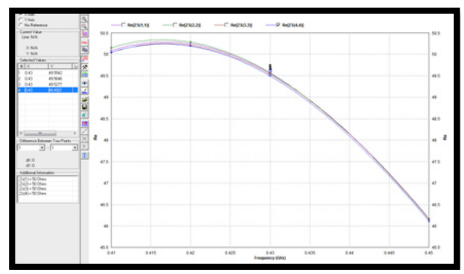


Figure 14. Simulated impedance.

Table 6. Simulation results

Un equal amplitude hybrid coupler design simulation results in ansoft designer				
Parameter	Power division [dB]	Phase[degrees]	Isolation [dB]	Return loss[dB]
S(1,1)	_____	-176	_____	-28.49
S(2,1)	-2.65	-90.37	_____	_____
S(3,1)	-4.13	179.6	_____	_____
S(4,1)	_____	25.80	-49.10	_____
S(1,4)	_____	_____	-49.10	_____
S(2,3)	_____	_____	-49.10	_____

4.4 Design of unequal amplitude hybrid coupler schematic in ansoft designer

Figure 15 shows the computed S-parameters for the unequal amplitude hybrid coupler has a characteristic impedance with appropriate width and lengths with

50 ohms matching designed at the center frequency of 430MHz.Now the circuit computed S-parameters of the proposed coupler are illustrated in Figures 16, 17, 18 and 19 and Table 7.

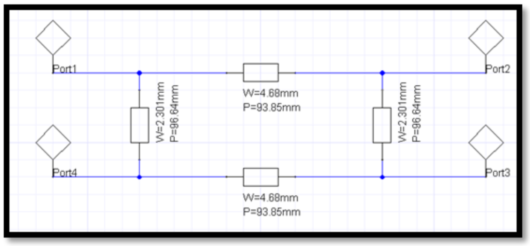


Figure 15. Unequal amplitude quadrature hybrid coupler.

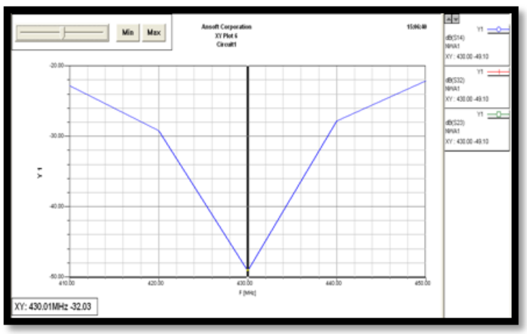


Figure 16. Simulated isolation.

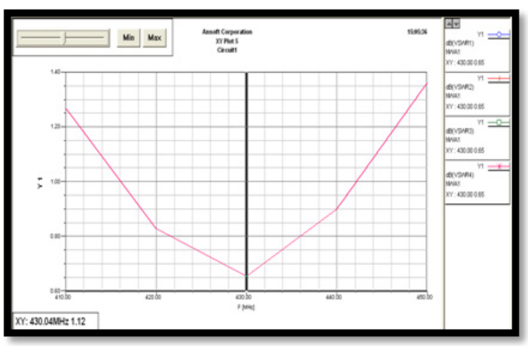


Figure 17. Simulated return loss.

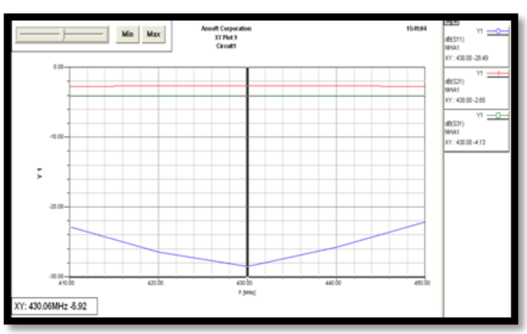


Figure 18. Simulated power divisions and matchings.

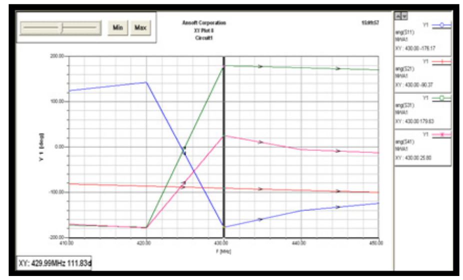


Figure 19. Simulated phase angle.

Table 7. Simulation results

Equal amplitude hybrid coupler layout design simulation results in IE3D					
Parameter	IL or coupling [dB]	Phase[degrees]	Isolation[dB]	Return loss [dB]	VSWR
S(1,1)	_____	151.3	_____	-45.85	1.0102
S(2,2)	_____		_____	-46.9	1.009
S(3,3)	_____		_____	-45.58	1.0105
S(4,4)	_____		_____	-45.48	1.0107
S(2,1)	-3.0	-101.62	_____	_____	_____
S(3,1)	-3.23	168.377	_____	_____	_____
S(4,1)	_____	-132.155	-48.11	_____	_____
S(1,4)	_____		-48.21	_____	_____
S(2,3)	_____		-48.21	_____	_____
S(3,2)	_____		-48.11	_____	_____

4.5 Design of Unequal Amplitude Hybrid Coupler Layout in IE3D Simulation Software

Figure 20 shows the computed S-parameters for the unequal amplitude hybrid coupler has a characteristic impedance of width and lengths with 50 ohms matching terminations designed at the center frequency of 430MHz. Now the full wave and circuit computed S-parameters of the proposed coupler are illustrated in Figures 21, 22, 23, 24, 25 and 26 and Table 8.

4.6 1:4 Feeder Network using Equal Amplitude Power Splitter and Unequal Amplitude Quadrature Hybrid

Figure 27 shows the feeder network composed of equal power splitter and unequal amplitude hybrid coupler has a characteristic impedance transmission lines with widths and lengths with 50 ohms matchings designed at the frequency of 430 MHz. Now the full wave and circuit

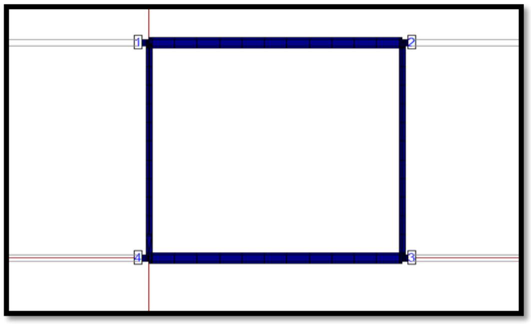


Figure 20. Proposed microstrip unequal amplitude quadrature hybrid coupler.

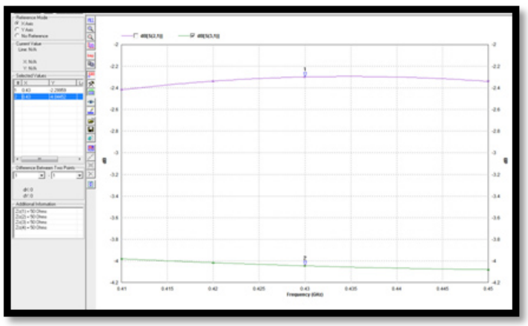


Figure 21. Simulated power divisions.

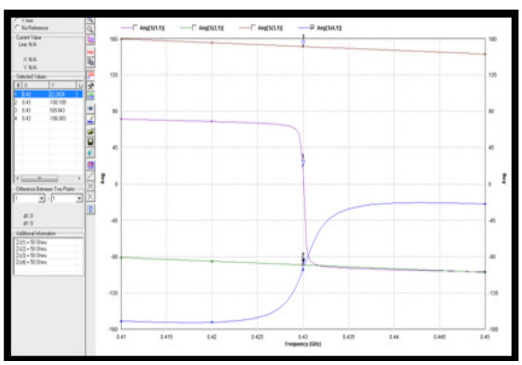


Figure 22. Simulated phase angle.

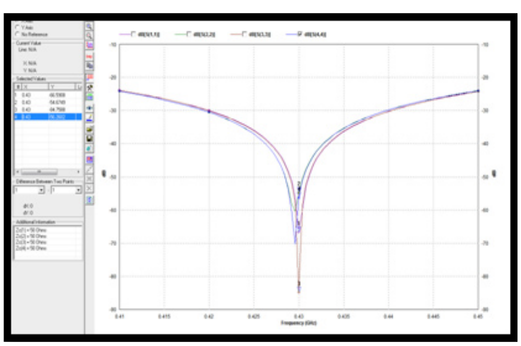


Figure 23. Simulated return loss for all ports.

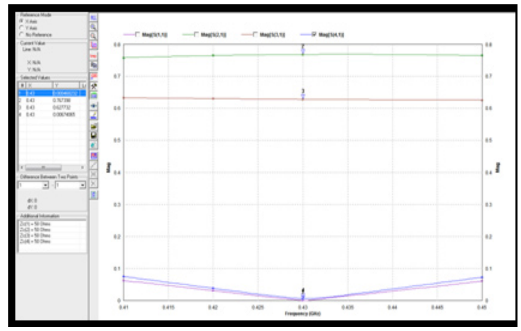


Figure 24. Simulated magnitude for all ports.

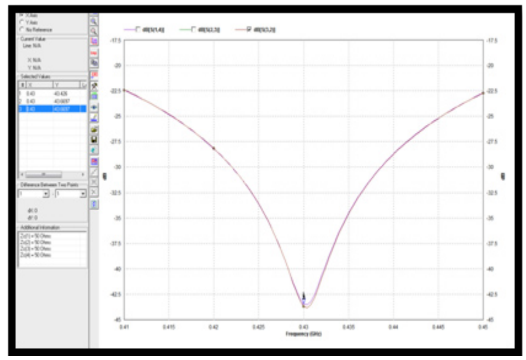


Figure 25. Simulated isolation loss for all ports.

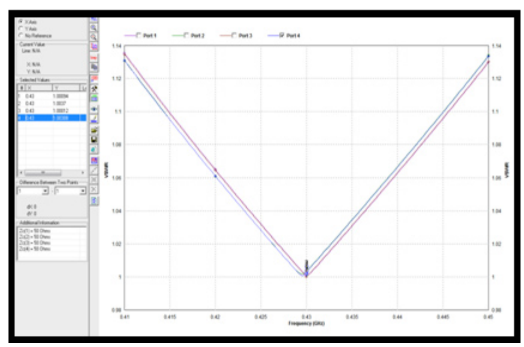


Figure 26. Simulated VSWR.

computed S-parameters of the proposed coupler are illustrated in Figures 28, 29, 30 and 31 and Table 9.

5. Fabrication of Unequal Amplitude Quadrature Hybrid Coupler

The unequal hybrid coupler layout has been designed in MOM based IE3D EM simulation software[1]. Practically, the unequal hybrid coupler has been fabricated based characteristic impedances with proper lengths and widths

Table 8. Simulation results

Unequal amplitude hybrid coupler design simulation results in IE3D software						
Parameter	**IL or coupling [dB]**	**Phase[degrees]**	**Isolation[dB]**	**Return loss[dB]**	**VSWR**	**Magnitude [v]**
S(1,1)	_____	**22.24**	_____	**-66.59**	**1.00094**	**0.000468232**
S(2,2)	_____	_____	_____	**-54.67**	**1.0037**	_____
S(3,3)	_____	_____	_____	**-84.75**	**1.00012**	_____
S(4,4)	_____	_____	_____	**-56.26**	**1.00308**	_____
S(2,1)	**-2.31**	**-100.1**	_____	_____	_____	**0.767398**
S(3,1)	**-4.13**	**169.8**		_____	_____	**0.627732**
S(4,1)	_____	**-106.0**	**-42.42**	_____	_____	**0.00674065**
S(1,4)	_____	_____	**-43.42**	_____	_____	_____
S(2,3)	_____	_____	**-43.66**	_____	_____	_____

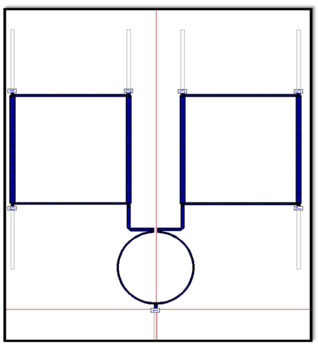


Figure 27. 1:4 feeder network.

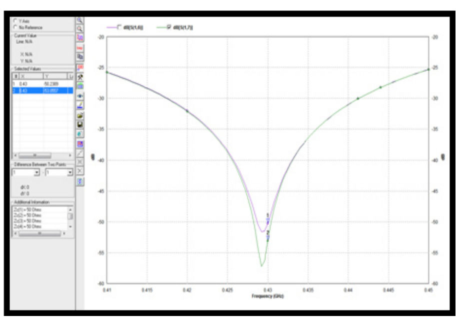


Figure 28. Simulated isolation.

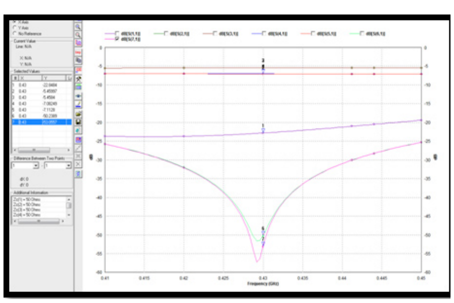


Figure 29. Simulated power divisions and matchings.

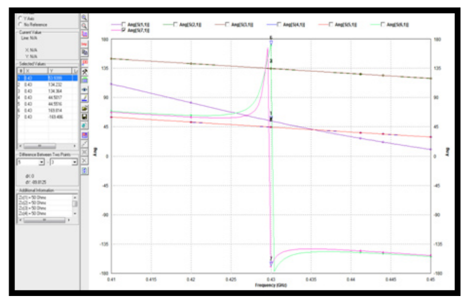


Figure 30. Simulated phase angle.

of required amplitudes are given in Table 3 and Table 4 and component realization on FR4 substrate with thickness or substrate height, Relative Permittivity, electrical length and Loss tangent are given in Table 2. The fabricated coupler and measured graphs are shown in Figures 32-35. The measured and simulated comparision results of S-parameters are given. The Measurement has been taken from Network Analyzer (300 KHz-6 GHz) Agilent make.

6. Results and Discussions

The proposed unequal hybrid coupler has been fabricated on a FR-4 (Fire Retardant) substrate with height of 1.6 mm relative Dk of 4.4. The unequal hybrid coupler has been designed for center frequency 430 MHz. The design parameters are calculated first. According to Equations (1) and (2), the line impedance values are $Z_0 = 50\Omega$, $Z_{01} = 38.104$ and $Z_{02} = 58.84\ \Omega$ based on these impedance values the widths and lengths of characteristics impedances can be calculated $Z_0 = 50\Omega$ (L = 95.65 mm, W = 3.06 mm) $Z_{01} = 38.104$ (L = 93.85 mm, W = 4.68 mm) and $Z_{02} = 58.84\ \Omega$ (L = 96.64 mm, W = 2.301 mm). Figure 4 shows the

Table 9. Simulation results

1:4 unequal amplitude feeder network design simulation results in IE3D software					
Parameter	Coupling [dB]	Phase [degrees]	Isolation[dB]	Return loss[dB]	VSWR
S(1,1)	_____	53.93	_____	-22.8484	1.15527
S(2,2)	_____	_____	_____	-10.5432	1.84518
S(3,3)	_____	_____	_____	-10.4559	1.85738
S(4,4)	_____	_____	_____	-13.703	1.52038
S(5,5)	_____	_____	_____	-13.6375	1.52535
S(6,6)	_____	_____	_____	-41.2473	1.01748
S(7,7)	_____	_____	_____	-42.4957	1.01512
S(2,1)	-5.4599	134.232	_____	_____	_____
S(3,1)	-5.4584	134.364	_____	_____	_____
S(4,1)	-7.082	44.5017	_____	_____	_____
S(5,1)	-7.1128	44.5516	_____	_____	_____
S(6,1)	_____	169.814	-50.238	_____	_____
S(7,1)	_____	-169.48	-53.055	_____	_____

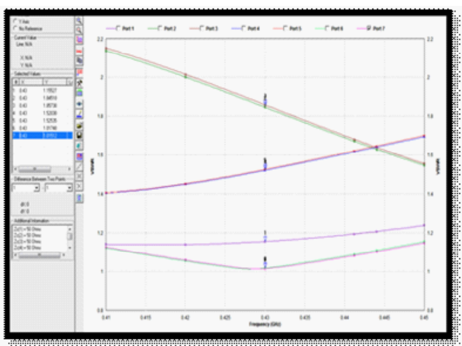
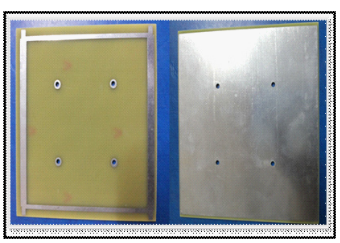
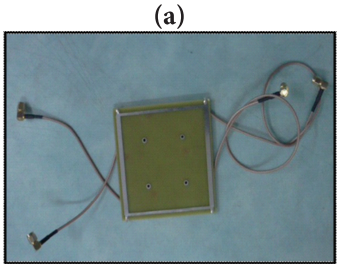


Figure 31. simulated VSWR for all ports



(a)



(b)

Figure 32. **(a)** Fabricated unequal hybrid coupler. **(b)** Both conducting and ground plane.

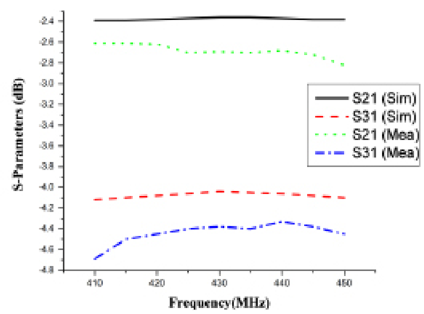


Figure 33. $|S_{21}|$, $|S_{31}|$ Simulated & Measured.

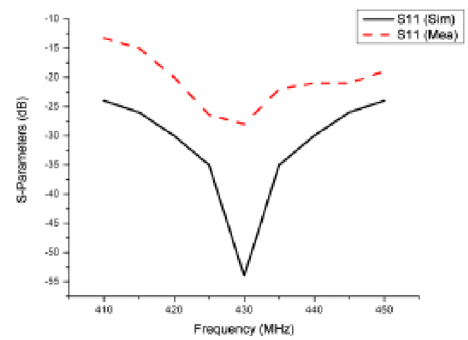


Figure 34. ($|S_{11}|$ Simulated & Measured.

photo of the fabricated unequal power hybrid coupler. The measured S-parameter data collected from Network Analyzer (300KHz-6GHz) Agilent make along with simulated results using IE3D are presented in Figure 34. The measured and simulated results with the unequal power division and good impedance matching at 430MHz for all ports matched. The Return loss is –64 dB @P1 and

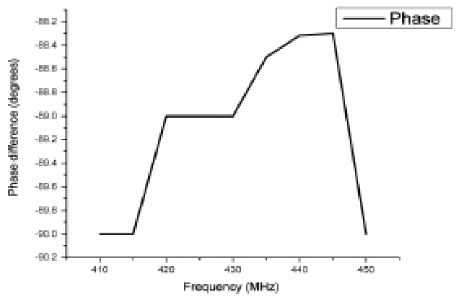


Figure 35. Phase difference of the proposed out of phase hybrid coupler.

–54 dB @P2. The simulated S21 is –4.04 dB and S31 is 2.36 dB. The measured S11 is –32.52 dB and S22 is –26.43 dB and the measured S21 is –4.38 dB and S31 is –2.69 dB. It is found that the transmission values are not ideal at port 2 and 3 are –3.776 dB and –2.3 dB. There is a loss inserted in port–2 and Port–3 is –0.6 dB and 0.39 dB because of lossy substrate used for realization of the passive component.

7. Conclusion

In this letter, an unequal amplitude microstrip hybrid coupler has been proposed. The coupler with unequal amplitude can be obtained with the assistance of varying impedances of opposite arms of the coupler. The corresponding design equations and measured responses are given. The coupler can be fabricated with conventional microstrip technology which is applicable to the design of beam forming network with unequal amplitudes for side lobe reduction and proper phase control to generate N-number of beams including zenith beam. The results are motivating towards new designs 4, 8 and 16-Port beam forming network using unequal amplitude hybrid coupler in the linear and planar phased array antennas for beam forming shared aperture antenna applications.

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