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Design and Fabrication of Unequal Power Divider using Impedance Limitation Method

Venkata Kishore Kothapudi*, Vijay Kumar, Mukundala Sai Rohit and Dangeti Anu Preetham

School of Electronics Engineering, VIT University, Vellore - 632014, Tamil Nadu, India; kothapudi@gmail.com, vijaykumar@vit.ac.in, rohit22244@gmail.com, anupreetham2@gmail.com

Abstract

Objectives: In this letter, the achievability of an unequal power divider utilizing a microstrip innovation as a part of the P/UHF band is designed. **Methods/Statistical Analysis**: Unequal power divider with 3-alternatives/approaches is composed in this research work, these are traditional microstrip configuration, power divider with input transformer and discretionary outline impedance (A-arbitary) is acquainted with control high impedance values and Power divider with general outline comparisons (Determination of Z1 or Z2 with required Impedances). **Findings:** At long last Power divider with general outline comparisons is figured it out. In this case the impedance of any one of the quarter wave impedance transmission line chosen is 30/35Ω which is most appropriate for impedance confinement of 10-60 ohm with a large power partitioning proportion radar applications where the side projection levels are most negative required. The unequal amplitudes of the 8-way power divider is designed utilizing Taylors 1-parameter method to get the side projections levels – 17 dB down from the fundamental beam. **Application/Improvements:** The 2-way and 8-way power divider was simulated using Method of Moments based Zealand IE3D software (MOM) an aggregate bandwidth of 40MHz was accomplished at an resonant frequency 0.43GHz. The simulated 2-way and 8-way unequal power divider is simulated and results are given. A prototype of 2-way unequal power divider with power levels P1 and P2 are 0.79622 and 0.89352 with power ratio of 1.1222 is fabricated to verify our proposed design. Measured results are given good agreement with simulated results to confirm our proposed design.

Keywords: Arbitary, Impedance, MOM, Unequal, Zealnd IE3D

1. Introduction

Microwave power splitters such as Wilkinson dividers are commonly used, mainly in microwave circuits and antenna array feeder networks. The power dividers generally quarter wave λ/4 transmission lines at the design resonant frequencies in the Radio frequency and microwave band where the wavelength is too large. Various examiners have done research about planar variants of power divider topologies[1–4]. These methodologies are typically constrained by the physical measurements of the large impedance quarter wave transformers neighboring the common port and in addition by their higher insertion loss. With n = 2, the Wilkinson's power divider may be a three-port power divider and perfect isolation was accomplished at particular resonance. In[10] displayed a three-port power divider with in phase and discretionary amplitude distinction between two ports. In[11] introduced a class of broadband three port half and halves with high isolation between two output ports and great matching at all ports. In[12] described a three-port hybrid which consists of n sections in cascade with each section composed of two coupled transmission lines of electrical length zero and an intermediate resistor. Since that time, the literature about three-port hybrids has been continued up to now[13–16]. The power dividers are matched with arbitary impedances, the total size of microwave component can be minimized. Asymmetric power dividers were first proposed by[17,18] for ring hybrids, hybrid couplers[19] asymmetric three-port power dividers[20]. The main N-way in-phase power divider was designed by Wilkinson in 1960[21]. He explained a circularly symmetric power divider, which divide a signal

*Author for correspondence

into N-equal phase, equal amplitude signals. Since that time, there are numerous research for the N-way power dividers[21–27]. In any case, they are for equivalent power dividers. It comprises of N transmission lines with a $\lambda/4$ long and N number of resistors. In the high characteristic impedance of the unequal power divider can be expanded utilizing the Defected Ground Structure (DGS). Be that as it may, the increment of the impedance is extremely limited, and the design procedure is generally intricate. Fortunately, the offset Double-Sided Parallel-Strip Line (DSPSL) allows an additional design freedom[28–36], for characteristic impedance besides the strip width.

2. Design Methodology

2.1 Specifications

The specifications of unequal power divider is shown in Table 1

Table 1. Specifications

Parameter	Specifications
Frequency	430MHz
Type of network	Unequal power divider
No. of inputs	1
No. of outputs	8
Illumination taper	Taylors1-parameter method
Bandwidth	> 40MHz
Coupling	-12.6,-11.2,-10.06,-9.17, -8.48,-7.98,-7.65,7.49dB
Insertion loss	< 0.5dB
Isolation	> 20dB
VSWR	1.5
Impedance	50Ω

2.2 Taylors 1-Parameter Method

Taylor line source 1-parameter technique that produce radiation patterns with narrow beams and low side lobes levels. The power levels are designed for a SLL of -17 dB down from the main beam. Refer Table 2 and Figure 1 for parameters.

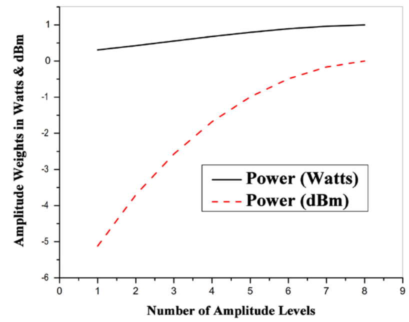

Figure 1. Number of amplitude levels Vs amplitude weights.

Table 2. Power levels

Factor	Z	L(mm)	W(mm)	R
Unequal Power divider -1				
Z0	50	95	3.06	-
Z01	98.66	100.53	0.65826	32.47
Z02	53.12	95.96	2.762	31.02
Z01’	58.36	96.59	2.336	-
Z02’	42.83	94.57	3.925	-
Unequal Power divider -2				
Z0	50	95	3.06	-
Z01	76.33	98.49	1.348	31.82
Z02	65.68	97.4	1.862	31.48
Z01’	51.88	95.8	2.876	-
Z02’	48.17	95.32	3.256	-
Unequal Power divider -3				
Z0	50	95	3.06	-
Z01	93.17	100.04	0.7938	32.32
Z02	55.47	96.24	2.56	31.11
Z01’	56.91	96.42	2.445	-
Z02’	43.92	94.73	3.77	-
Unequal Power divider -4				
Z0	50	95	3.06	-
Z01	83.77	99.19	1.072	32.05
Z02	60.47	96.83	2.187	31.29
Z01’	54.22	96.09	2.665	-
Z02’	46.1	95.04	3.496	-
Unequal Power divider -5				
Z0	50	95	3.06	-
Z01	78.58	98.7	1.258	31.89
Z02	63.96	97.22	1.963	31.42
Z01’	52.63	95.9	2.806	-
Z02’	47.5	95.23	3.33	-

Unequal Power divider -6				
Z0	50	95	3.06	-
Z01	74.96	98.35	1.405	31.78
Z02	66.8	97.52	1.799	31.51
Z01’	51.45	95.75	2.917	-
Z02’	48.59	95.37	3.209	-
Unequal Power divider -7				
Z0	50	95	3.06	-
Z01	72.04	98.06	1.535	31.69
Z02	69.41	97.79	1.662	31.6
Z01’	50.46	95.62	3.01	-
Z02’	49.53	95.5	3.10	-

2.3 Design Equations for Length and Width Calculation

The design parameters of unequal power divider can be calculated using the equations mentioned below. The width and quarter wave lengths of the characteristic impedances can be calculated using design equations given steps 1-5 and shown in Figure 2.

Figure 2. Calculator for length and width of λ/4 line.

Step-1:- B

$$B = \frac{377\Pi}{2Z_0\sqrt{\varepsilon_r}}$$

Step-2:- width (W)

$$\frac{W}{H} = \frac{2}{\Pi}[B-1-\ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}[\ln(B-1)+0.39-\frac{0.61}{\varepsilon_r}]]$$

Step-3:- Effective dielectric constant (Eeff)

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}[1+\frac{12H}{W}]^{-1/2}$$

Step-4:- Quarterwave guided wavelength

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{reff}}}$$

Step-5:- Length of transmission line

$$L = \frac{\lambda_g}{4}$$

2.4. Power Levels for PD-1 to PD-7

The power levels at different ports for all power dividers is shown in Table 3 with the help of graph shown in Figure 3.

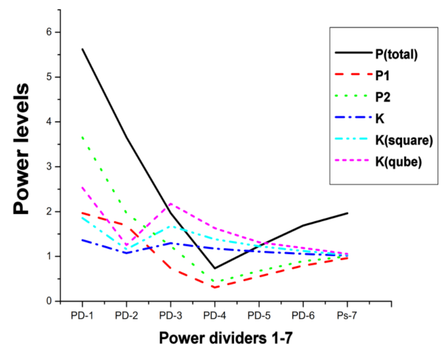

Figure 3. Different power splitters Vs power levels.

Table 3. Power levels at different power dividers 1-7

Sl. No	S_{ij}	Amplitude levels (watts)	Amplitude levels (dBm)
1	S21	0.30777	-5.1177
2	S31	0.42631	-3.7021
3	S41	0.55318	-2.5713
4	S51	0.67967	-1.67701
5	S61	0.79622	-0.9896
6	S71	0.89352	-0.4889
7	S81	0.96345	-0.1617
8	S91	1	0

2.5 Substrate Selection

First we have to design the unequal power divider using Fire Retardant-4 substrate. The required parameters of the design are:

Frequency-430MHz/0.43GHz λ=0.6976.
Dielectric constant -4.4.
Tan δ-0.02.
Height of the substrate -1.6 mm.

Line impedance-50.

3. Design and Simulation

Methods used for the design of unequal power divider are

- Approach-1

Conventional power splitter.

- Approach-2

Power divider with input quarter wave transformer and arbitrary impedance is introduced to control large impedance values.

- Approach-3

Power divider with general design equations Impedances.

3.1 Approach-1

The schematic of unequal power divider is shown in Figure 4.

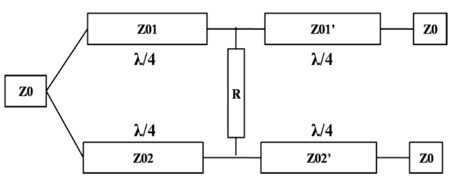

Figure 4. UPD Schematic for approach-1.

3.1.1 Design Equations

The unequal power divider designed with the help of design Equations (1)-(5).

$$Z_{01} = Z_0 \sqrt{k(1+k^2)} \tag{1}$$

$$Z_{02} = Z_0 \sqrt{\frac{(1+k^2)}{k^3}} \tag{2}$$

$$Z'_{01} = Z_0 \sqrt{k} \tag{3}$$

$$Z'_{02} = \frac{Z_0}{\sqrt{k}} \tag{4}$$

$$R = Z_0 \frac{k^2+1}{k} \tag{5}$$

3.1.2 Quarter Wave Length and Transmission Line Widths of Impedances

The length and widths of the transmission line as shown in Table 4 and Figure 5.

Figure 5. Impedance calculator for approach-1.

3.1.3 Design of 2-Way Unequal Power Divider

Figures 6, 7, 8, 9, 10, 11and 12 shows the layout in EM simulation software and S-parameters at the resonant frequency of 0.43GHz are calculated.

Table 4. Impedance, length and widths

Factor	P total	P1	P2	K	K²	K³
PD-1	5.6201	1.9669	3.65319	1.3628	1.8573	2.531
PD-2	3.6531	1.6893	1.96345	1.077	1.161	1.2525
PD-3	1.9669	0.7340	1.23285	1.2959	1.679	2.176
PD-4	0.7340	0.3077	0.42631	1.176	1.3851	1.63
PD-5	1.2328	0.5531	0.67967	1.108	1.228	1.316
PD-6	1.6897	0.7962	0.89352	1.059	1.1222	1.188
PD-7	1.9634	0.9634	1	1.0187	1.0379	1.0574

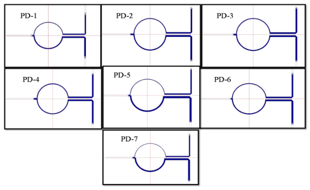

Figure 6. 2-way unequal power divider 1-7.

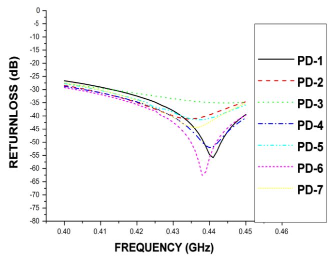

Figure 7. Simulated return loss.

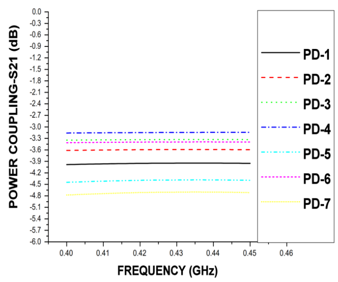

Figure 8. Power coupling S21.

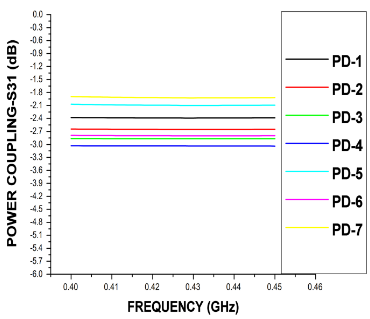

Figure 9. Power coupling S31.

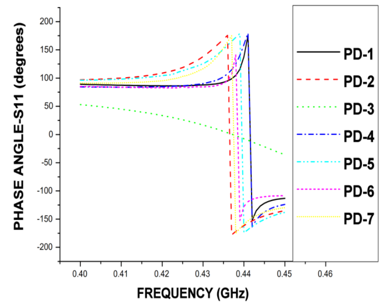

Figure 10. Phase angle S11.

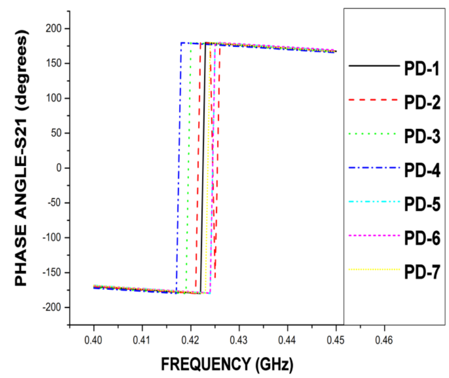

Figure 11. Phase angle S21.

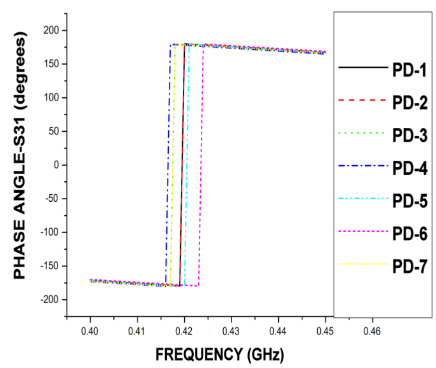

Figure 12. Phase angle S31.

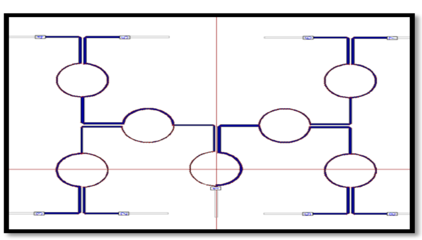

Figure 13. 8-way unequal power divider for approach-1.

3.1.4 Design of 8-Way Unequal Power Divider

Figures 13, 14 and 15 shows the layout in EM simulation software and S-parameters at the resonant frequency of 0.43GHz are calculated.

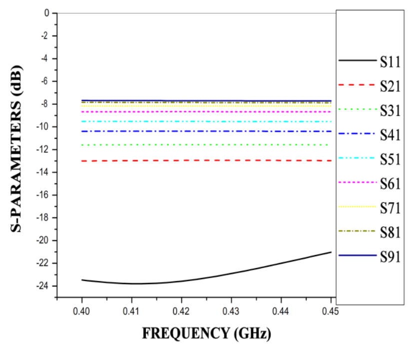

Figure 14. Power coupling and return loss (dB).

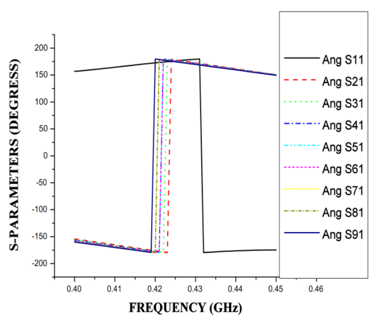

Figure 15. Phase angle in degrees.

3.2 Approach-2

The schematic of unequal power divider is shown in Figure 16.

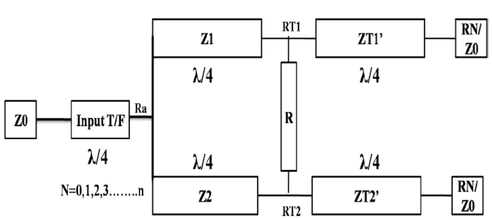

Figure 16. UPD schematic for approach-2.

3.2.1 Design Equations

The unequal power divider designed with the help of design Equations (6)-(8).

$$R_{TN} = \frac{P_{total}}{P_N}.A \tag{6}$$

$$Z_N = \sqrt{R_a R_{TN} \frac{P_{total}}{P_N}} \tag{7}$$

$$Z_{TN} = \sqrt{R_{TN} R_N} \tag{8}$$

3.2.2 Quarter Wave Length and Transmission Line Widths of Impedances

The length and widths of the transmission line as shown in Table 5 and Figure 17

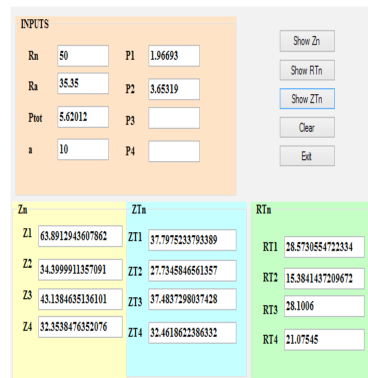

Figure 17. Impedance calculator for approach-2.

Table 5. Impedance, length and widths

Parameter	Impedance (Ω)	Length (mm)	Width (mm)	Radius
Unequal Power divider -1				
Z0	50	95	3.06	-
Z01	55.719	97.33	1.901	31.45
Z02	35	93.34	5.298	30.18
Z01’	38.45	93.91	4.621	-
Z02’	28.21	92.1	7.139	-
Unequal Power divider -2				
Z0	50	95	3.06	-
Z01	40.63	94.24	4.255	30.47
Z02	35	93.34	5.298	30.18
Z01’	27.64	91.99	7.336	-
Z02’	25.65	91.58	8.096	-
Unequal Power divider -3				
Z0	50	95	3.06	-
Z01	58.76	96.63	2.307	31.23
Z02	35	93.34	5.298	30.18
Z01’	35.91	93.49	5.106	-

Z02’	27.7	92	7.315	-
Unequal Power divider -4				
Z0	50	95	3.06	-
Z01	48.47	95.36	3.223	30.83
Z02	35	93.34	5.298	30.18
Z01’	31.34	92.7	6.187	-
Z02’	26.67	91.79	7.692	-
Unequal Power divider -5				
Z0	50	95	3.06	-
Z01	42.98	94.59	3.904	30.58
Z02	35	93.34	5.298	30.18
Z01’	28.78	92.21	6.949	-
Z02’	25.98	91.65	7.961	-
Unequal Power divider -6				
Z0	50	95	3.06	-
Z01	39.27	94.03	4.478	30.40
Z02	35	93.34	5.298	30.18
Z01’	26.94	91.85	7.59	-
Z02’	25.45	91.54	8.179	-
Unequal Power divider -7				
Z0	50	95	3.06	-
Z01	36.32	93.56	5.023	30.25
Z02	35	93.34	5.298	30.18
Z01’	25.44	91.54	8.183	-
Z02’	24.97	91.44	8.384	-

3.2.3 Design of 2-Way Unequal Power Divider

Figure 18, 19, 20, 21, 22, 23 and 24 shows the layout in EM simulation software and S-parameters at the resonant frequency of 0.43 GHz are calculated.

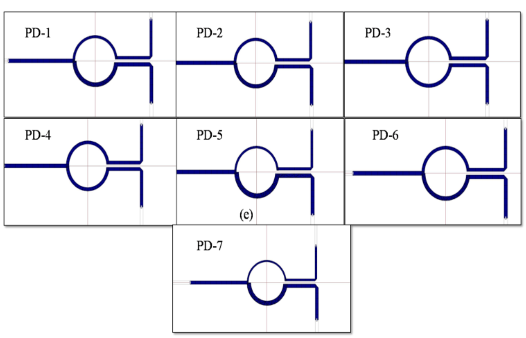

Figure 18. 2-way unequal power divider 1-7.

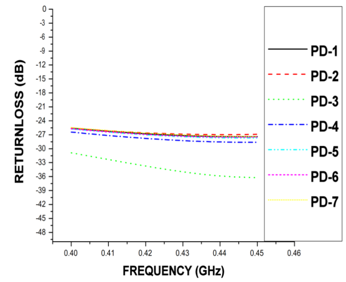

Figure 19. Simulated return loss.

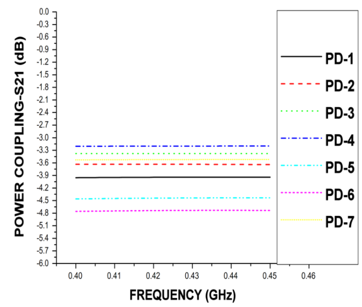

Figure 20. Power coupling S21.

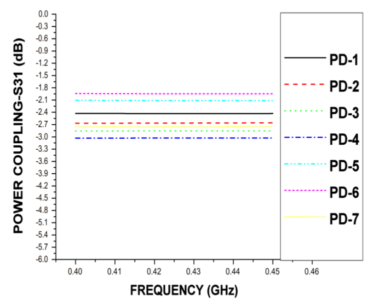

Figure 21. Power coupling S31.

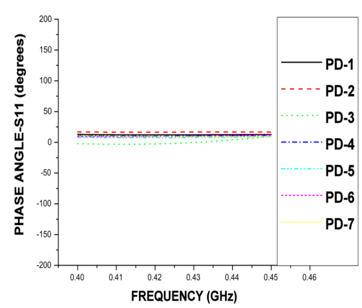

Figure 22. Phase angle S11.

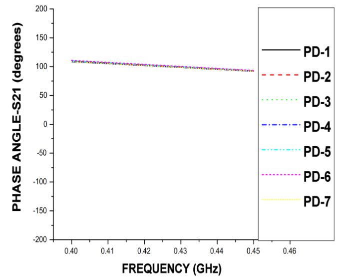

Figure 23. Phase angle S21.

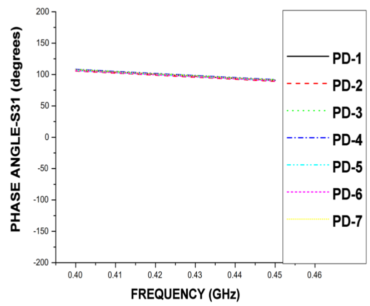

Figure 24. Phase angle S31.

3.2.4 Design of 8-Way Unequal Power Divider

Figure 25, 26 and 27 shows the layout in EM simulation software and S-parameters at the resonant frequency of 0.43 GHz are calculated d.

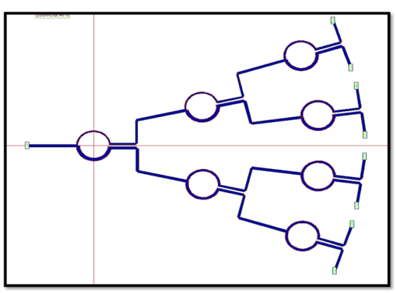

Figure 25. 8-way unequal power divider for approach-2.

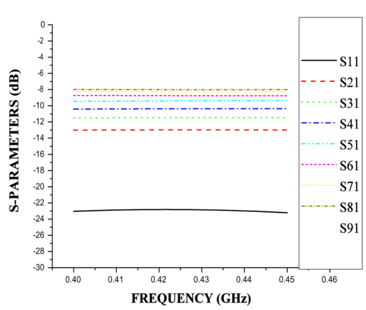

Figure 26. Power coupling and return loss (dB).

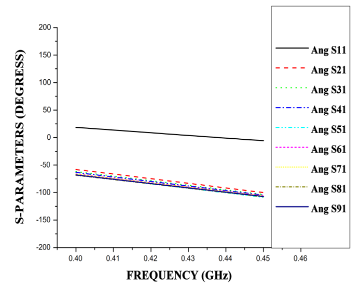

Figure 27. Phase angle in degrees.

3.3 Approach-3

The schematic of unequal power divider using general design equations is shown in Figure 28.

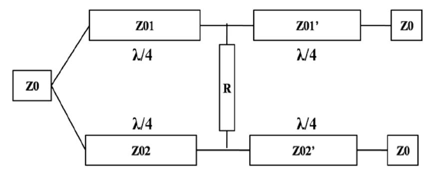

Figure 28. UPD schematic for approach-3.

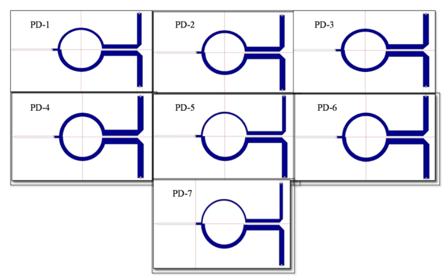

Figure 29. 2-way unequal power divider PD-1 to PD-7.

3.3.1 Design Equations

The unequal power divider designed with the help of design Equations (9)-(13).

$$a = Z_0\sqrt{\frac{(1+k^2)}{k^3}} \text{ or } Z_1 = a \quad (9)$$

$$Z_{02} = k^2 a \quad (10)$$

$$Z_{01}^{'} = Z_0\sqrt{\frac{(k^4 a^2 R_b)}{(1+k^2)R_a}} \quad (11)$$

$$Z_{02}^{'} = Z_0\sqrt{\frac{(k^2 a^2 R_c)}{(1+k^2)R_a}} \quad (12)$$

$$R = \frac{k^2 a^2}{R_a} \quad (13)$$

3.3.2 Quarter Wave Length and Transmission Line Widths of Impedances

The length and widths of the transmission line as shown in Table 6 and Figure 17

Table 6. Impedance, length and widths

Factor	Z	L(mm)	W(mm)	R
Unequal Power divider-1 a=10Ω, Rn=50Ω				
Ra	35.35	93.4	5.223	-
Z1	63.89	97.21	1.967	31.42
Z2	34.39	93.24	5.433	30.15
ZT1’	37.79	93.8	4.74	-
ZT2’	27.73	92.01	7.304	-
Unequal Power divider -2				
Ra	35.35	93.4	5.223	-
Z1	59.59	96.77	2.225	31.28
Z2	35.67	93.45	5.156	30.22
ZT1’	36.602	93.61	4.967	-
ZT2’	28.24	92.11	7.128	-
Unequal Power divider -3				
Ra	35.35	93.4	5.223	-
Z1	48.34	95.34	3.237	30.82
Z2	41.6	94.39	4.101	30.52
ZT1’	32.87	92.97	5.791	-
ZT2’	30.5	92.54	6.423	-
Unequal Power divider-4				
Ra	35.35	93.4	5.223	-
Z1	53.33	95.98	2.743	31.02
Z2	38.503	93.91	4.611	30.36
ZT1	34.33	93.26	5.401	-
ZT2	29.34	92.32	6.771	-
Unequal Power divider -5				
Ra	35.35	93.4	5.223	-
Z1	49.83	95.54	3.07	30.88
Z2	40.55	94.23	4.267	30.47
ZT1	33.38	93.06	5.667	-
ZT2	30.11	92.47	6.537	-
Unequal Power divider -6				
Ra	35.35	93.4	5.223	-
Z1	47.45	95.22	3.336	30.78
Z2	42.28	94.49	4	30.55
ZT1	32.57	92.92	5.865	-
ZT2	30.74	95.59	6.354	-
Unequal Power divider-7				
Ra	35.35	93.4	5.223	-
Z1	45.56	94.96	3.562	30.7
Z2	43.9	94.73	3.776	30.63
ZT1	31.92	92.8	6.032	-
ZT2	31.33	92.7	6.19	-

3.3.3. Design of 2-Way Unequal Power Divider

Figures 29, 30, 31, 32, 33, 34 and 35 shows the layout in EM simulation software and S-parameters at the resonant frequency of 0.43 GHz are calculated.

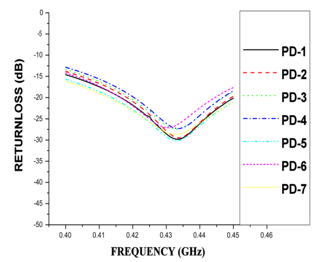

Figure 30. Simulated return loss.

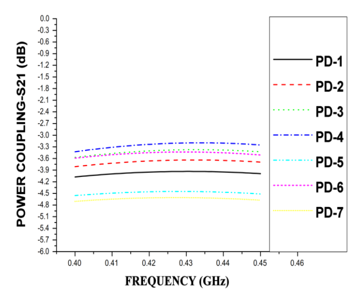

Figure 31. Power coupling S21.

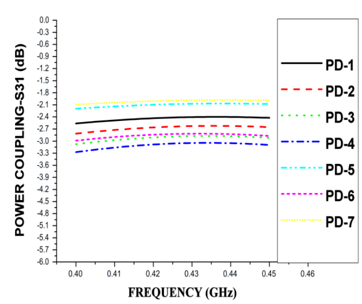

Figure 32. Power coupling S31.

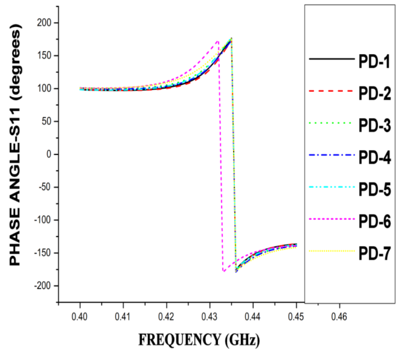

Figure 33. Phase angle S11.

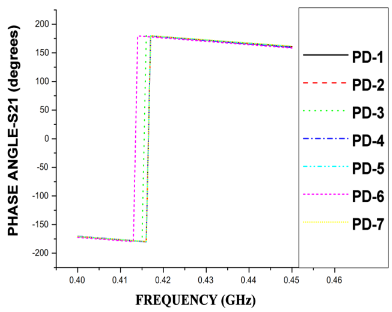

Figure 34. Phase angle S21.

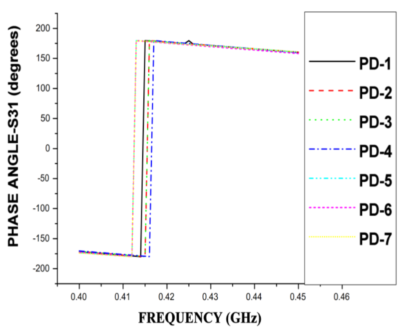

Figure 35. Phase angle S31.

3.3.4 Design of 8-Way Unequal Power Divider

Figures 36, 37 and 38 shows the layout in EM simulation software and S-parameters at the resonant frequency of 0.43 GHz are calculated.

4. Fabrication of 2-Way Unequal Power Divider for Approach-3

The unequal power divider fabricated on FR4 substrate. The amplitude levels for 2-port power divider and corresponding impedances are given in Table 7 and 8. The realized power divider shown in Figure 39. The measured results are collected from Network Analyzer (300KHz-3GHz) are given in Table 9.

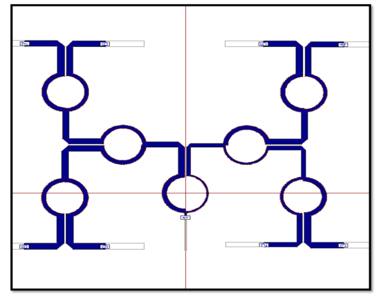

Figure 36. 8-way unequal power divider for approach-3.

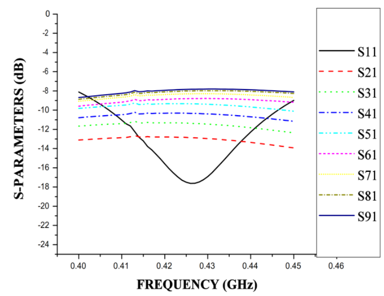

Figure 37. Power coupling and return loss (dB).

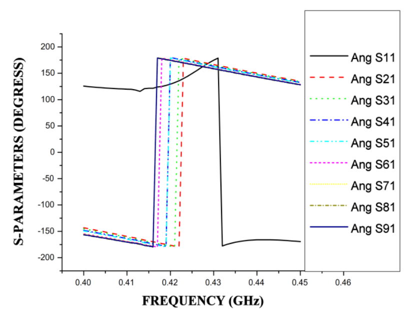

Figure 38. Phase angle in degrees.

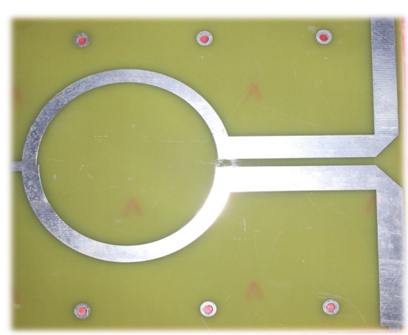

Figure 39. Fabricated 2-way UPD.

Table 7. 2-way power levels

Parameter	Power splitter
P total [watts]	1.68974
P1[watts]	0.79622
P2 [watts]	0.89352
K	1.059
K^2 , K^3, K^4	1.1222, 1.188, 1.2577

Table 8. UPD approach-3

Unequal power divider approach-3				
Z0	50	95	3.06	-
Z01	39.27	94.03	4.478	30.40
Z02	35	93.34	5.298	30.18
Z01’	26.94	91.85	7.59	-
Z02’	25.45	91.54	8.179	-

Table 9. Result analysis

Parameter	Coupling [dB]	Return loss[dB]
Ideal	-3.26[S21] -2.767[S31]	Infinity
Simulated	-3.4331[S21] -2.816[S31]	-27.093[S11]
Measured	-3.7331 [S21] -3.21 [S31]	-23 [S11]

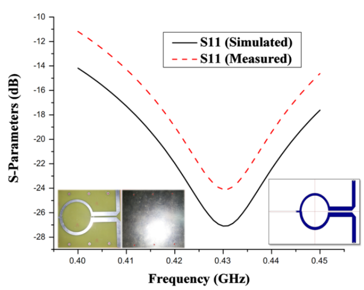

Figure 40. Measured return loss S11.

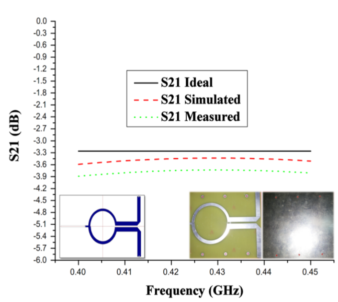

Figure 41. Measured power coupling S21.

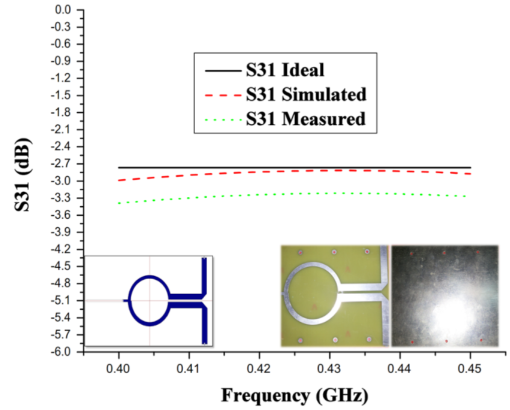

Figure 42. Measured power coupling S31.

5. Conclusion

In this letter, the Impedance Limitation Methods (ILM) for 2-way UPD with arbitrary termination impedances is compared to provide the impedance limitations are presented. The 2-way and 8-way unequal power divider is has been designed using all the three approaches ILM was compared with the conventional microstrip technology design and power divider with input transformer. Finally concluded that approach-3 is better than approach-1 and approach-2 (a = 10 Ω). Using arbitrary impedance a = 35 Ω, there are advantages not only reducing the impedances of approach-1 to our limit in all λ/4 transmission lines and also reduce the complexity of the component compared to approach-2. The power at two output ports (S21 and S31), RL (S11) and phase are giving the appropriate in the desired application. The unequal power divider with arbitrary impedance is more easy to design than approach-1 and 2 and therefore very irresistable for high power dividing ratio applications.

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