Design and Fabrication of Unequal Power Divider using Impedance Limitation Method

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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-arbitrary) 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: Arbitrary, 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 topologies1–4. 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. In10 displayed a three-port power divider with in phase and discretionary amplitude distinction between two ports. In11 introduced a class of broadband three port half and halves with high isolation between two output ports and great matching at all ports. In12 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 now13–16. The power dividers are matched with arbitrary impedances, the total size of microwave component can be minimized. Asymmetric power dividers were first proposed by17,18 for ring hybrids, hybrid couplers19 asymmetric three-port power dividers20. The main N-way in-phase power divider was designed by Wilkinson in 196021. He explained a circularly symmetric power divider, which divide a signal

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into N-equal phase, equal amplitude signals. Since that time, there are numerous research for the N-way power dividers\textsuperscript{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\textsuperscript{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.

| 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.](image)

**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 | 31.78 |
|------|-----|-----|------|-------|
| Z₀1  | 74.96 | 98.35 | 1.405 | 31.51 |
| Z₀2  | 66.8 | 97.52 | 1.799 | 31.69 |
| 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:-**

\[ B = \frac{377 \pi}{2Z_0 \sqrt{\varepsilon_r}} \]

**Step-2:-**

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

**Step-3:-**

Effective dielectric constant (\( \varepsilon_{\text{eff}} \))

\[ \varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ 1 + \frac{12H}{W} \right]^{-1/2} \]

**Step-4:-**

Quarterwave guided wavelength

\[ \lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{\text{eff}}}} \]

**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 \( \lambda = 0.6976 \).
- Dielectric constant -4.4.
- \( \tan \delta = 0.02 \).
- 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.](image)

3.1.1 Design Equations

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

\[ Z'_{01} = Z_0 \sqrt{k} \quad (3) \]

\[ Z'_{02} = \frac{Z_0}{\sqrt{k}} \quad (4) \]

\[ R = \frac{k^2 + 1}{k} \quad (5) \]

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.](image)

3.1.3 Design of 2-Way Unequal Power Divider

Figures 6, 7, 8, 9, 10, 11 and 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 | K^2 | K^3 |
|--------|---------|----|----|---|-----|-----|
| 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.

\[ Z_N = \sqrt{\frac{R_a R_N}{P_{total}}} \]

(7)

\[ Z_{TN} = \sqrt{R_{TN} R_N} \]

(8)

3.2 Approach-2

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

\[ R_{TN} = \frac{P_{total}}{P_N} A \]

(6)

3.2.1 Design Equations

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

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         | 93.91       | 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      | -      |
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.

| Z02' | 27.7 | 92 | 7.315 | - |
|------|------|----|-------|---|
| 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| -  |

| Z02' | 27.7 | 92 | 7.315 | - |
|------|------|----|-------|---|
| 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| -  |

| 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| -  |

| 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| -   |

| 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| -   |

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.
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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.

3.3 Approach-3

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

3.3.1 Design Equations

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

\[ a = Z_0 \sqrt{\frac{1 + k^2}{k^3}} \quad \text{or} \quad Z_1 = a \]  
\[ Z_{a2} = k^2 a \]  
\[ Z_{a1} = Z_0 \sqrt{\frac{k^4 a^2 R_s}{(1 + k^2) R_a}} \]  
\[ Z_{a2} = Z_0 \sqrt{\frac{k^2 a^2 R_s}{(1 + k^2) R_a}} \]
\[ R = \frac{k^2 a^2}{R_o} \]  \hspace{1cm} (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  |

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.
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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 |
| K₁, K₂, K₃, K₄ | 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 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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