# Design and Implementation of Broadband RF Power Divider over 800 MHz -12 GHz

Kiran M V
122101019

Electrical Engineering
Indian Institute of Technology Palakkad
Advisor : Dr Sukomal Dey

November 26, 2024

INDIAN INSTITUTE
OF TECHNOLOGY
PALAKKAD

# Contents

# Introduction

## Objective

Design a Broadband Multi-Section Wilkinson Power Divider for a frequency range of 800 MHz -12 GHz

## Design Targets

- **Frequency Range**: 800 MHz to 12 GHz
- **Input Reflection Coefficient**: $S11$ value below -10 dB across the bandwidth, ensuring minimal reflection at the input.
- **Power Split**: $S12$ and $S13$ values between -3 to -3.5 dB, indicating a balanced power distribution between the two output ports.
- **Isolation**: $S23$ and $S32$ below -10 dB, ensuring minimal cross-coupling and interference

## Wilkinson Power Divider

- Provides equal power split between output ports with good isolation and matching properties

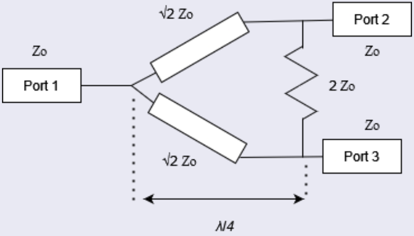


Figure 1: Wilkinson Equal Power Divider

- The S parameters for Wilkinson Power Divider is as follows

$$[\ S\ ] = \frac{-j}{\sqrt{2}} \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

## Limitations of Wilkinson Power Divider

- Optimized for narrowband performance
- $\lambda/4$ transmission lines are typically designed for a specific center frequency

## Multi-Section Broadband Wilkinson Power Divider

- Cascading multiple $\lambda/4$ sections with different characteristic impedances increases broadbandness
- Smooth impedance transitions ensure expanded bandwidth and effective matching

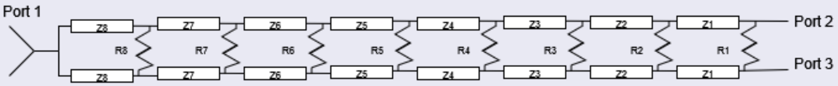


Figure 2: Multi-Section Power Divider

# Proposed Design

## Calculation of Frequency Parameters

- Center Frequency $f_c = \frac{0.8+12}{2}$ GHz = 6.4 GHz
- Bandwidth (BW) = (12-0.8) GHz = 11.2 GHz
- Fractional Bandwidth (FBW)= $\frac{BW}{f_c} = \frac{11.2}{6.4}$= 1.75

## Calculation of Number of Sections

- Number of Sections $N = \frac{f_c}{f_l} = \frac{6.4}{0.8} = 8$,
  where $f_c$ is the center frequency and $f_l$ is the lower frequency of the broadband frequency range.
- Reference: Microwaves101 - How many sections do you need?

# Proposed Design

## Impedance Calculation

- Line impedances calculated using Chebyshev transformer model to ensure smooth impedance transitions and a low $S_{11}$ at the input
- Applied even and odd mode analysis to simplify the mathematical modeling of the Wilkinson power divider

## Calculation of Isolation Resistors

- Ensured minimal crosstalk by optimizing resistor values based on the virtual ground effect in odd mode
- Even mode analysis
  - Signals at ports 2 and 3 are in phase; Isolation resistors are ignored
- Odd mode analysis
  - Signals at ports 2 and 3 are $180^{\circ}$ out of phase; Virtual ground forms along the symmetry axis, halving the values of isolation resistors

# Proposed Design

## Calculated Line Impedance

- Followed Seymour Cohn's 1968 IEEE paper, "A Class of Broadband Three-Port TEM-Mode Hybrids," for naming conventions of line impedances, isolation resistors and ports. (Fig 1)

| $Z_n$ | **Values** |
|---|---|
| Z1 | 58.66 ohms |
| Z2 | 61.59 ohms |
| Z3 | 64.96 ohms |
| Z4 | 68.72 ohms |
| Z5 | 72.76 ohms |
| Z6 | 76.97 ohms |
| Z7 | 81.18 ohms |
| Z8 | 85.23 ohms |

Table 1: Section impedances

| $R_n$ | **Values** |
|---|---|
| R1 | 339 ohms |
| R2 | 389 ohms |
| R3 | 613 ohms |
| R4 | 478 ohms |
| R5 | 362 ohms |
| R6 | 257 ohms |
| R7 | 162 ohms |
| R8 | 403 ohms |

Table 2: Isolation resistor values

# Implementation

## Simulation

- Software Tool: **Ansys HFSS** for electromagnetic simulations
- Substrate Selection: Initially **FR4 epoxy**, but switched to **Taconic** for better high-frequency performance
- The physical length of each section was derived from the Chebyshev transformer calculation and based on the required impedances and the operating frequency range
- Isolation resistors are modeled using lumped RLC boundaries
- Lumped port excitations were applied to the ports to simulate the signal inputs and outputs
- An open region of air was applied around the entire structure to simulate the real-world operating conditions

## Simulation

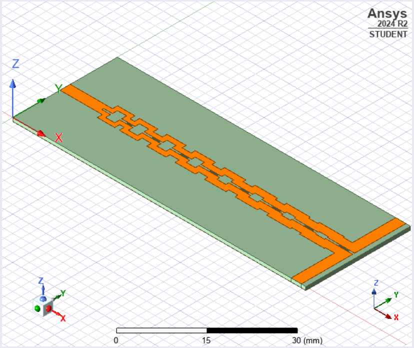


Figure 3: Wilkinson Equal Power Divider (Overview)

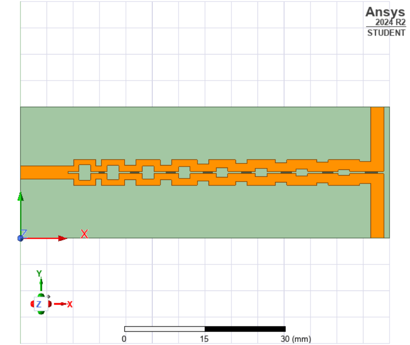


Figure 4: Wilkinson Equal Power Divider (Top View)

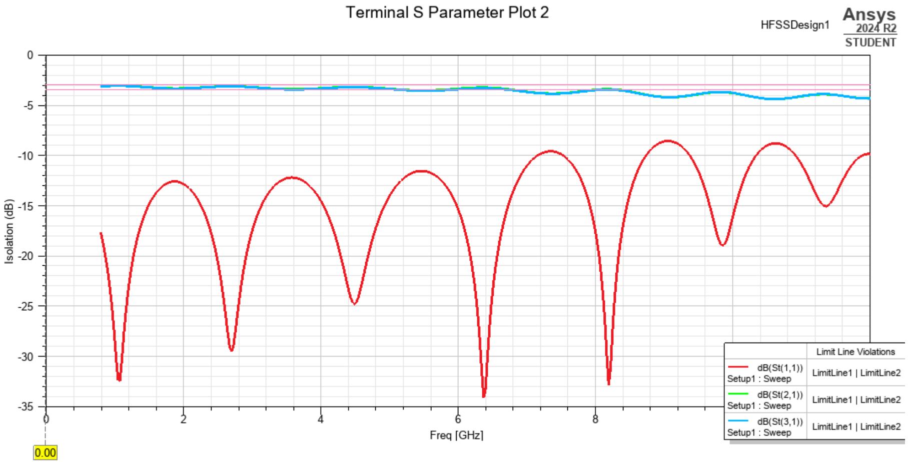


Figure 5: Terminal S Parameter Plot for S11, S21, S3

# Results

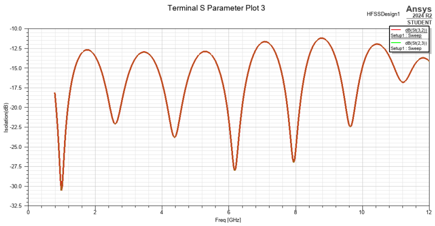


Figure 6: Terminal S Parameter Plot for $S_{23}$ and $S_{32}$


Figure 7: Terminal S Parameter Plot for $S_{22}$ and $S_{33}$

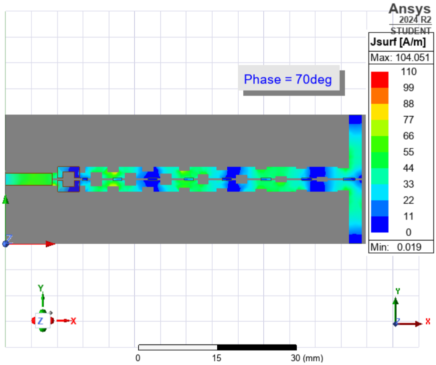


Figure 8: Flow of Surface current density (Top View)

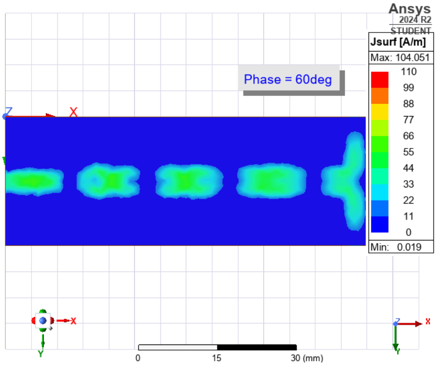


Figure 9: Flow of Surface current density (Bottom View)

# Future Work

- Some small error in length or disturbance in power flow can cause this irregularity
- Refinement of transmission line lengths using parameter sweep
- Extending the design to cover higher frequency ranges
- Electromagnetic coupling considerations
- Experimental validation of the design by fabricating and testing the power divider

# Acknowledgement

I wish to express my deepest gratitude to **Dr. Sukomal Dey**, my project mentor, for his unwavering support, guidance, and invaluable insights throughout the course of this work. His expertise and constructive feedback have been pivotal to the successful completion of this project. I am also profoundly thankful to **Mrs. Athira Manoharan** for her invaluable guidance, prompt clarifications of my doubts, and encouragement, which have been crucial to my progress. Lastly, I extend my sincere appreciation to my family and friends for their unwavering support and motivation, which have greatly contributed to the successful realization of this endeavor.

# References


- S. B. Cohn, "A Class of Broadband Three-Port TEM-Mode Hybrids," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 16, no. 2, pp. 110-116, February 1968. Available: doi.org/10.1109/TMTT.1968.1126617
- M. M. Honari, L. Mirzavand, R. Mirzavand, A. Abdipour and P. Mousavi, "Theoretical Design of Broadband Multisection Wilkinson Power Dividers With Arbitrary Power Split Ratio," in *IEEE Transactions on Components, Packaging and Manufacturing Technology*, vol. 6, no. 4, pp. 605-612, April 2016. Available: doi.org/10.1109/TCPMT.2016.2518581
- Ö. Kasar and M. Kahriman, "A theoretical design of ultra-wideband multisection Wilkinson power divider using Euler polynomials," in *Microwave and Optical Technology Letters*, vol. 62, pp. 3869–3875, 2020. Available: doi.org/10.1002/mop.32589