Design and Simulation of a Wideband Branchline Balun

Abstract

A balun (balanced-to-unbalanced transformer) is a critical RF/microwave component used to convert single-ended signals into balanced signals with equal amplitude and opposite phase. Conventional branchline baluns suffer from narrow bandwidth, which limits their use in modern wideband wireless systems. This project focuses on the design and simulation of a wideband branchline balun operating at 2.4 GHz. A multistage branchline configuration is employed to enhance bandwidth while maintaining good impedance matching, isolation, and phase balance. The balun is designed and simulated using microwave CAD tools, and its performance is evaluated using S-parameters, phase response, and VSWR analysis.

Introduction

With the rapid growth of wireless communication systems such as WLAN, WiMAX, and IoT, RF front-end components must support wide bandwidth and stable performance. Baluns are widely used in mixers, power amplifiers, antennas, and differential circuits. Among different balun structures, the branchline balun is popular due to its planar structure and ease of fabrication. However, conventional branchline baluns operate effectively only around a narrow frequency range. This project investigates a wideband branchline balun design that overcomes bandwidth limitations while preserving simplicity and low cost.

Problem Statement

Conventional branchline baluns provide good performance only at a single design frequency and exhibit poor return loss and phase imbalance outside this narrow band. As modern wireless systems require wider operating bandwidths, there is a need to enhance the bandwidth of branchline baluns without significantly increasing design complexity, cost, or loss. The challenge is to achieve wide bandwidth, good impedance matching, equal power division, and 180-degree phase difference using a planar microstrip structure.

Objectives

The main objectives of this project are to design a wideband branchline balun operating at 2.4 GHz, to improve bandwidth using a multistage branchline approach, to analyze the balun performance using simulation tools, and to evaluate key parameters such as return loss, insertion loss, phase difference, isolation, and VSWR. Another objective is to compare the wideband design with a conventional branchline balun to demonstrate performance improvement.

Proposed System

The proposed system consists of a two-stage branchline balun implemented using microstrip transmission lines. Each stage contains quarter-wavelength series arms and half-wavelength shunt arms designed for a characteristic impedance of 50 ohms. By cascading multiple stages, impedance matching is improved over a wider frequency range. The balun is designed on an FR4 substrate to ensure low fabrication cost and easy integration with other RF circuits.

Tech Stack

The project uses microwave simulation software such as ADS or HFSS for design and analysis. FR4 substrate material with a dielectric constant of 4.4 and thickness of 1.6 mm is used for the microstrip layout. Standard RF design equations are applied for calculating transmission line dimensions. S-parameter analysis is used to evaluate performance metrics.

Scope and Limitations

The scope of this project is limited to the design and simulation of a wideband branchline balun at 2.4 GHz. Fabrication and experimental validation are not included. While bandwidth is significantly improved, increasing the number of stages results in larger circuit size. Advanced miniaturization techniques are not explored in this work.

Stakeholders & User Roles

The primary stakeholders include RF design engineers, students, and researchers working in microwave communication systems. Students use the design for academic learning, researchers use it as a reference for further enhancement, and engineers can adapt the design for practical wireless applications.

System Architecture

The system architecture consists of an unbalanced input port connected to a multistage branchline network that splits the signal into two balanced output ports. The outputs deliver equal power with a 180-degree phase difference. Each stage acts as an impedance-matching section, collectively improving wideband performance.

Methodology

The methodology begins with the design of a conventional branchline balun using transmission line theory. The design is then extended to a two-stage configuration to improve bandwidth. Transmission line dimensions are calculated, and the layout is simulated using microwave CAD tools. S-parameters, phase response, and VSWR are analyzed across a wide frequency range. Results are compared with conventional designs to validate improvement.

Conclusion

This project successfully demonstrates the design and simulation of a wideband branchline balun using a multistage approach. The proposed design achieves enhanced bandwidth while maintaining good impedance matching, equal power division, and near-ideal phase difference. The planar structure and low-cost substrate make the design suitable for modern wireless applications. The work provides a strong foundation for future fabrication, miniaturization, and multi-band extensions.