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A dual-band filtering push–pull power amplifier with a large frequency ratio employing a hybrid-mode bandpass response balun

Key words: Large frequency ratio; Dual-band filtering balun; Harmonic suppression; Push–pull power amplifier

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Introduction & Motivation

Research background

With rapid 5G and radar advancements, demand for high-power microwave components surges. Push–pull power amplifiers (PAs) are critical for combining low-power signals into a single high-power output.

Key challenge

Traditional PAs face limitations in achieving both high output power and multi-band operation with effective filtering and harmonic suppression.

Research motivation

Aim to design a dual-band filtering push–pull PA with a large frequency ratio, enabling compact, high-performance solutions for modern communication systems.

Core Performances

Hybrid-mode filtering balun

Frequency Ratio: **5:1**

Integrates microstrip line (MSL) and substrate integrated waveguide (SIW) technologies to cover S-band (2.60–2.86 GHz) and Ku-band (13–13.65 GHz) simultaneously.

Integrated filtering & harmonic suppression

Suppression: **second harmonic**

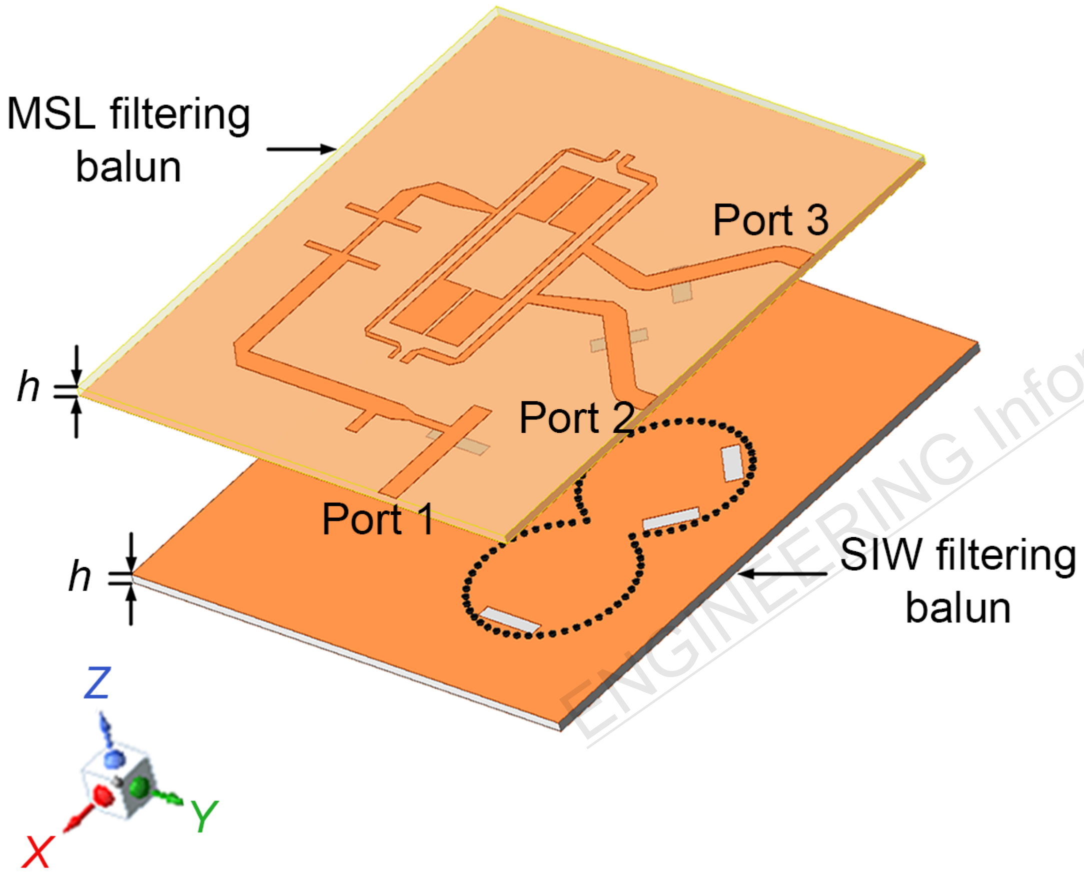
Push–pull architecture inherently suppresses second-harmonic signals, eliminating the need for external filters in both bands.

High output power

Peak power: **36.8 dBm (5W)**

Delivers 36.8 dBm (5W) at high frequency and 36 dBm (4W) at low frequency with a consistent 7-dB small-signal gain across both operational bands.

Design Architecture



Hybrid balun design

The key to the design is a hybrid-mode filtering balun combining MSL and SIW technologies.

MSL balun (low-frequency)

Operates at S-band (2.60–2.86 GHz), based on a modified Marchand topology with stepped-impedance resonators (SIRs) for filtering and differential signal generation.

SIW balun (high-frequency)

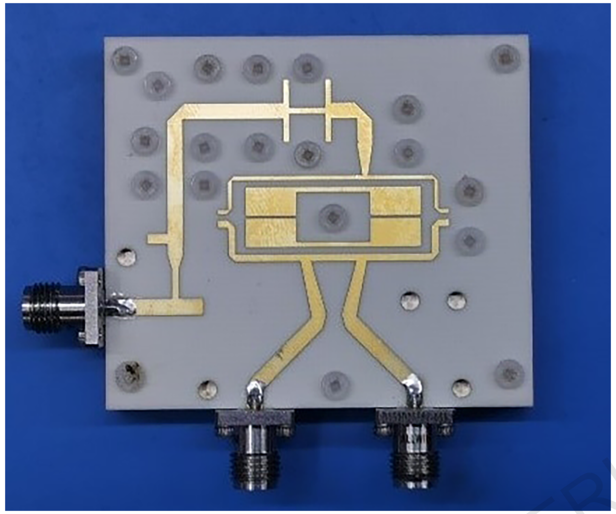
Operates at Ku-band (13–13.65 GHz), using the vertical TM_{110} mode in a circular SIW cavity to create the necessary 180° phase difference.

Integration

The two baluns are stacked on separate substrates and coupled via slots, achieving a large frequency ratio of 5:1 in a compact form factor.

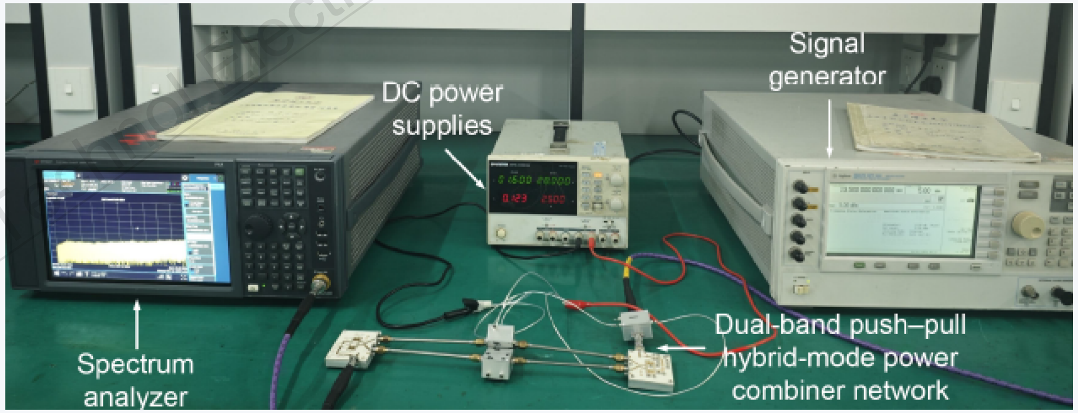
Prototype & Experimental Setup

Fabrication & assembly



- **Substrate stacking:** MSL and SIW filtering baluns are fabricated on two separate Rogers 4003 substrates and stacked together.
- **Integration:** The push–pull PA prototype integrates the hybrid baluns with commercial GaN monolithic microwave integrated circuit (MMIC) PA modules.

Test environment & setup



- **Key instruments:** Equipped with a signal generator, direct current (DC) power supplies, and a spectrum analyzer for comprehensive testing.
- **Characterization:** Characterizes amplifier performance including gain, output power, and harmonic suppression.

Passive Results

Passive balun performance

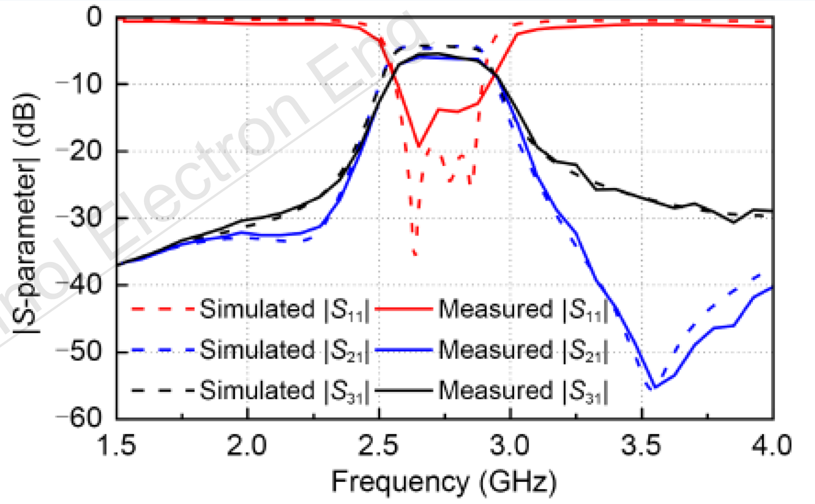
Low-band return loss >19 dB (insertion loss 1.3 dB), high-band return loss >13.5 dB (insertion loss 2.3 dB), with phase balance of 180° ±5° across band.

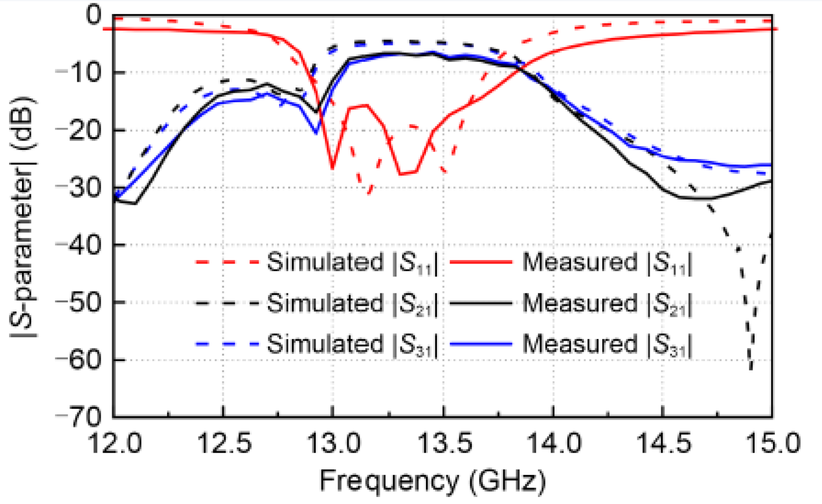
Consistent active gain

Stable gain of **7 dB** across S-band (2.60–2.86 GHz) and Ku-band (13–13.65 GHz), ensuring flat response for communication applications.

Filtering & bandwidth robustness

Superior out-of-band rejection maintained in active mode, with active bandwidth closely matching passive balun measurements.



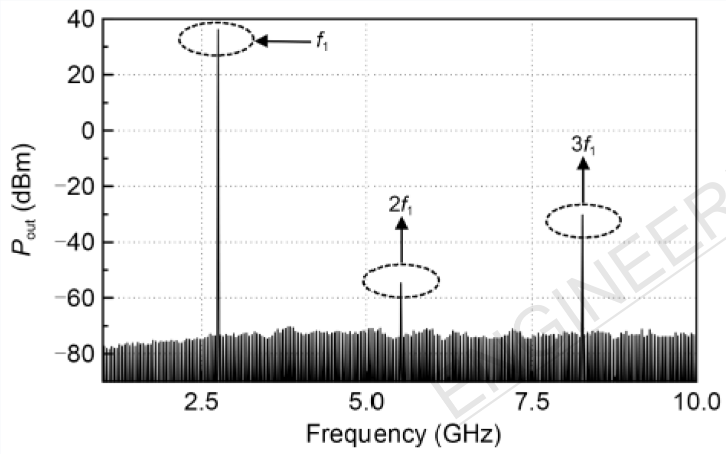


Active Results: Power & Harmonics

Low-frequency band (2.75 GHz)

36.8 dBm (5 W)

Peak saturated output power

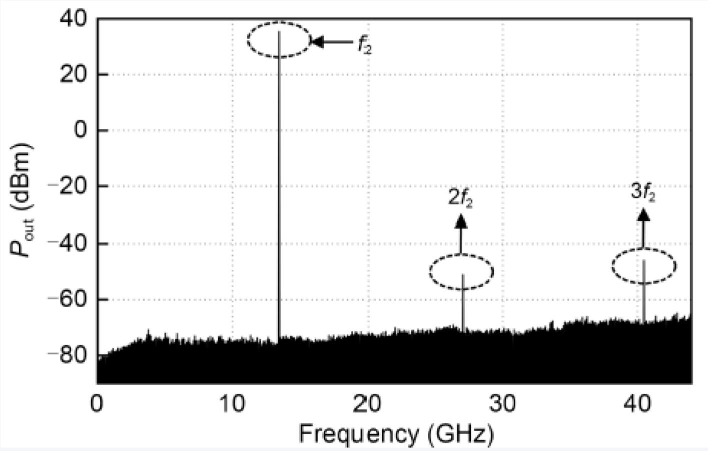


Second harmonic (5.5 GHz): **−54.7 dBm**

High-frequency band (13.5 GHz)

36.0 dBm (4 W)

Peak saturated output power



Second harmonic (27 GHz): **−53 dBm**

This excellent harmonic suppression is an inherent advantage of the push–pull architecture.

Conclusion & Future Work

Key achievements

- Demonstrated a novel dual-band filtering push–pull PA with a large frequency ratio (5:1).
- Integrated MSL and SIW technologies to achieve high output power (up to 5 W) and excellent harmonic suppression.
- The hybrid architecture offers a compact and efficient solution for multi-band high-power applications.

Future directions

- Explore further integration with antenna systems for a complete front-end module.
- Investigate designs for even larger frequency ratios or more frequency bands.
- Optimize the design for higher efficiency and linearity in next generation systems.

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