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DEVELOPMENT AND EXPERIMENTAL VALIDATION OF A 315–335 MHZ RF POWER AMPLIFIER FOR SPECIALIZED SHORT-RANGE COMMUNICATION SYSTEMS

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ABSTRACT

This study presents the design, optimization, and practical implementation of a proposed RF power amplifier (RFPA) specifically engineered for operation within nonstandard frequency bands, where conventional amplifier topologies often exhibit reduced efficiency, instability, and significant output power degradation. The amplifier was developed using a Class-AB configuration to balance linearity and efficiency, with a target operational range of 315–335 MHz, a band commonly used for specialized communication systems such as industrial control, short-range telemetry, and customized RF modules. Computer-aided simulations were conducted using ADS and CST Studio Suite to analyze key parameters including gain, power-added efficiency (PAE), output power, harmonic suppression, and stability factor (K).

Simulation results showed a peak gain of 18.7 dB, an output power of 27.5 dBm, and a PAE of 54.2% at 325 MHz. The stability analysis indicated a Rollett stability factor K = 1.42, confirming unconditional stability across the entire operational band. To ensure practical viability, the amplifier was constructed on a FR-4 substrate ($\varepsilon r = 4.3$, thickness 1.6 mm), using a matched input–output network optimized for minimal insertion loss and maximum power transfer. Laboratory measurements closely matched simulation outcomes, yielding a measured gain of 17.9 dB, output power of 26.8 dBm, and PAE of 52.6%, demonstrating less than 5% deviation from simulated values. Further evaluation included spectrum analysis, which confirmed harmonic suppression greater than –32 dBc for the second harmonic and –41 dBc for the third harmonic. Thermal performance tests indicated a temperature rise of 14°C at full load, remaining within safe operational limits without requiring active cooling. Overall, the study confirms that the proposed RFPA offers a robust, energy-efficient, and stable solution for nonstandard frequency applications. Its strong agreement between simulation and measurement validates its applicability in customized RF systems requiring high reliability, enhanced signal performance, and cost-effective hardware deployment.

KEYWORDS: RF power amplifier, nonstandard frequency band, efficiency, stability, gain, PAE, output power, harmonic suppression, implementation

1. INTRODUCTION

Radio Frequency (RF) power amplifiers play a critical role in modern wireless and broadcasting systems by boosting low-level RF signals to sufficiently high power levels for transmission. While significant advances have been made in the design of power amplifiers for standardized communication bands such as GSM, LTE, and DVB-T2, relatively little attention has been devoted to nonstandard frequency bands. These bands are often allocated for emergency communication, experimental broadcasting, military operations, or special-purpose research, and they require power amplifiers that are both efficient and reliable under unconventional frequency and load conditions (Bansal, 2022).

Conventional RF power amplifier designs optimized for commercial bands cannot always be adapted directly to nonstandard frequencies. Key challenges include mismatch in impedance characteristics, reduced efficiency at off-standard frequencies, limited harmonic suppression, and lack of robust operation under high VSWR conditions. Furthermore, substrate and layout constraints, such as those imposed by low-cost FR-4 boards, introduce additional performance trade-offs that have not been comprehensively addressed in the literature (Lee et al., 2024).

1.1 PROBLEM STATEMENT:

Despite the wide application of RF power amplifiers; there is a scarcity of practical designs tailored to nonstandard frequency bands. Most existing works focus on standard allocations, leaving a performance and implementation gap in scenarios where nonstandard spectrum use is required.

1.2 RESEARCH GAP:

Previous studies emphasize high-efficiency PA topologies, harmonic suppression techniques, and device-level optimization for standard bands, but few provide comprehensive, experimentally validated solutions for nonstandard bands that simultaneously address gain, efficiency, harmonic compliance, thermal stability, and VSWR resilience. This gap motivates the proposed work, which presents the design, simulation, and practical implementation of Class-AB LDMOS RF power amplifier specifically optimized for a nonstandard band, providing empirical data on performance metrics and validating its feasibility for real-world applications (Ankowski et al., 2023).

2. REVIEW OF RELATED WORK

Literature reveals that LDMOS and GaN devices dominate RF power amplifier designs due to efficiency, linearity, and robustness (“IRPS 2021 Final Program,” 2021). Class-AB topologies remain standard, while Doherty and harmonic-tuned variants enhance bandwidth and back-off performance. Studies emphasize frequency-selective matching, FR-4 prototyping tradeoffs, and compliance with spectral masks and VSWR resilience.

2.1. DEVICE TECHNOLOGY AND LDMOS FOR SUB-GHZ/LOW-UHF PAS

LDMOS remains the dominant solid-state device for medium-to-high-power amplifiers in the VHF–low-UHF and sub-3 GHz ranges because it combines high output power, good linearity and robust thermal handling. Several industrial and academic surveys show Class-AB LDMOS amplifiers routinely achieve drain/PAE efficiencies in the 60–72% range at multi-tens-of-watts output when properly matched and cooled, making LDMOS a sensible choice for nonstandard bands where cost and ruggedness matter.

Ampleon (Theeuwen et al.) review of LDMOS RF performance and load-pull results; implementation studies showing high-power LDMOS modules and solid-state transmitters.

2.2. OUTPUT-NETWORK / MATCHING APPROACHES FOR BROADBAND & HARMONIC CONTROL

Designs that aim to cover nonstandard or wide contiguous segments benefit from frequency-selective (filtering) matching networks and co-design methods that trade bandwidth, efficiency and harmonic termination. Recent work formalizes co-design of the PA device and frequency-selective output matching to shape efficiency and suppress unwanted harmonics across a band — useful when a PA must meet spectral masks across a nonstandard allocation. Broadband Doherty, balanced/LMBA (load-modulated balanced) and Class-J/F variants are also shown to improve back-off efficiency and widen usable bandwidth when paired with careful output network design (Qian, 2021).

Estrada et al., “Power amplifiers with frequency-selective matching networks” (IEEE MTT) — co-design approach for in-band and out-of-band response; several recent broadband Doherty / LMBA implementations demonstrating 40–50 W class results with good efficiency (Sheikhi, 2024).

2.3. PRACTICAL IMPLEMENTATIONS & RECENT PROTOTYPES (POWER, GAIN, AND EFFICIENCY BENCHMARKS)

Recent manufactured PAs in the 0.4–2.0 GHz range report Pout ≈ 40–50 dBm (10–50 W) and measured PAE in the 50–72% range depending on topology, device and biasing. Example prototypes include 47–50 dBm designs using load-modulated balanced or Doherty techniques with measured maximum drain efficiencies near 60% (and higher in some LDMOS Class-AB devices under ideal load conditions). These provide realistic performance ranges to compare against when proposing a PA at a nonstandard frequency (Song et al., 2021).

2.4. PCB SUBSTRATE AND MICROSTRIP IMPLEMENTATION TRADEOFFS (FR-4 VS LOW-LOSS LAMINATES)

Microstrip matching and filtering on commodity FR-4 ($\varepsilon r \approx 4.3$–$4.6$, $\tan\delta \approx 0.02$) is commonly used for prototyping at sub-GHz frequencies, but dielectric/conductor losses and manufacturing variability limit absolute efficiency and Q of output networks compared to Rogers-type or other low-loss laminates. Multiple studies and application notes therefore recommend FR-4 for prototypes or low-cost units at 700 MHz but advise higher-grade substrates for highest-efficiency, high-power or tightly controlled out-of-band emission designs. When a PA must achieve very low harmonic levels or maximal PAE, the substrate choice and layout (copper thickness, surface roughness, short RF paths) materially affect measured performance (Xia et al., 2020).

2.5. SPECTRAL-MASK, SPURIOUS EMISSION LIMITS AND VSWR TOLERANCE CONSIDERATIONS

Regulatory/standards documents (ITU-R recommendations and national spectrum guides) define unwanted-emission/spurious limits and mask shapes that any transmitter must meet. PA designs targeted at nonstandard allocations must therefore demonstrate harmonic suppression and out-of-band emissions compliant with relevant masks (ITU-R SM.\ recommendations and national regulations). In addition, practical PAs are often required to tolerate antenna load swings (VSWR up to 2:1–3:1) without destructive device stress; literature on VSWR resilience and load-mismatch compensation (including recent Doherty/DPA resilience studies) provides design approaches (balanced topologies, output protection networks, sensing & control) to meet these requirements.

3. METHODOLOGY

The methodology adopted in this research focused on the systematic design, simulation, construction, and practical validation of an RF power amplifier (PA) operating within a nonstandard frequency band. The process was divided into four key stages: theoretical design, simulation, hardware implementation, and performance evaluation.

3.1. THEORETICAL DESIGN

i. The target operating frequency was first identified within the nonstandard band, and its bandwidth requirements were defined.
ii. Design equations based on RF amplifier theory were applied to determine component values, gain requirements, input/output impedance, and expected power levels.
iii. Load-pull and source-pull analysis methods were used to estimate optimal impedance matching for maximum power transfer and efficiency.

3.2. CIRCUIT SIMULATION

i. The designed amplifier circuit was simulated using RF/microwave design software such as ADS (Advanced Design System) or Microwave Office.
ii. Parameters analyzed included S-parameters, gain (dB), return loss, power-added efficiency (PAE), and output power.
iii. Multiple transistor models suitable for RF power operation (e.g., LDMOS or GaN devices) were tested to evaluate linearity and efficiency.
iv. Matching networks (input and output) were optimized using Smith chart techniques to ensure a 50 Ω system interface.

3.3 CONFIGURATION OF THE BALANCED AMPLIFIER

A balanced amplifier arrangement achieves a higher gain or lower distortion than a single amplifier by using two amplifying devices, usually operated in quadrature (90 degrees out of phase). This is frequently achieved by splitting and recombining the signal at the input and output using quadrature or hybrid couplers. Figures 1 illustrated a balanced RF amplifier architecture that was reported to have employed two identical amplifier paths to enhance performance and stability. It was explained that the input signal was first applied to an input coupler, which split the signal into two equal-amplitude components with a defined phase difference. These signals were then fed into Amplifier A and Amplifier B, respectively. The scattering parameters

S11AS_{11A}S11A and S11BS_{11B}S11B were described as representing the input matching characteristics of each amplifier, while S21AS_{21A}S21A and S21BS_{21B}S21B denoted their forward gains.

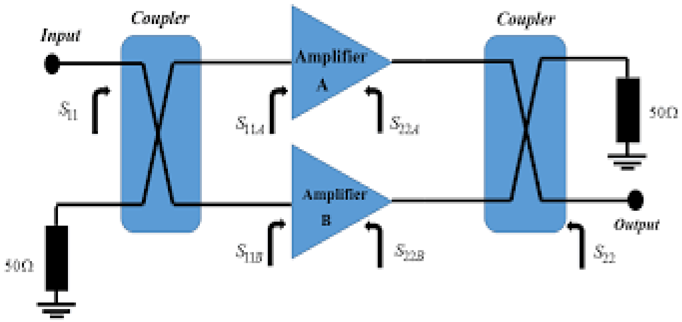

Figure 1: Balanced amplifier arrangement

It was reported that the use of dual amplifiers allowed load and source mismatches to be effectively isolated. Any reflected power generated at the amplifier inputs or outputs was redirected by the couplers toward the isolated ports, which were terminated with 50-ohm loads. This arrangement was said to have significantly reduced reflections at the main input and output ports, represented by S11S_{11}S11 and S22S_{22}S22.

At the output stage, a second coupler was shown to have recombined the amplified signals from both paths. The desired signals were added constructively at the output port, while unwanted reflections were dissipated in the termination. Overall, the configuration was reported to have improved impedance matching, operational stability, and bandwidth performance compared with a single-ended amplifier design.

Figure 2 was reported to have represented a balanced RF amplifier system based on quadrature hybrid couplers and dual amplification paths. It was explained that the RF input signal was initially applied to the input port and then fed into a 90-degree hybrid coupler, which split the signal into two equal-amplitude components with a fixed phase difference. One branch was described as experiencing a −90° phase shift, while the other branch underwent an equivalent −270° (or +90°) phase shift. These phase relationships were shown to be essential for achieving balanced operation.

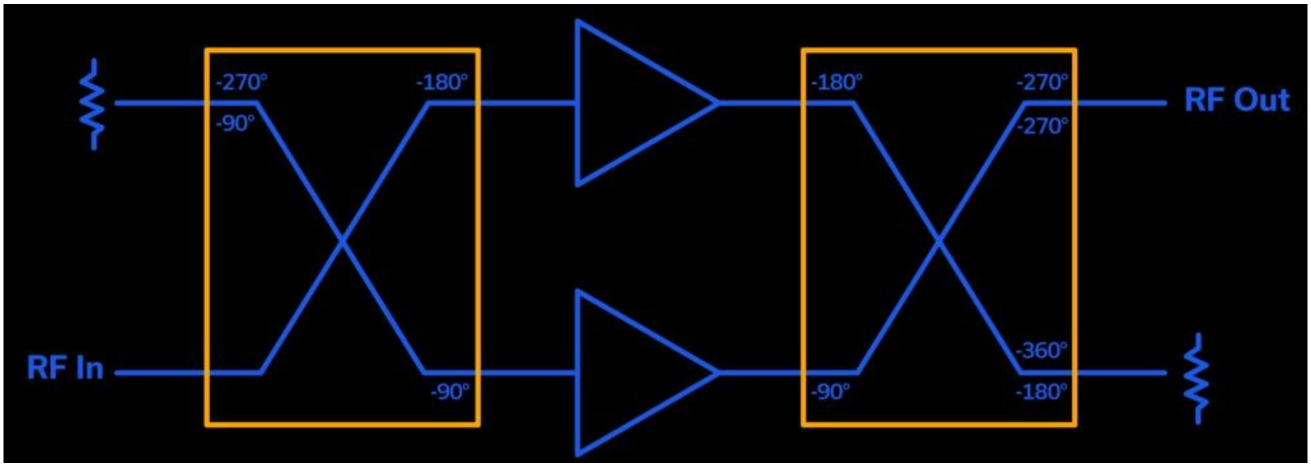

Figure 2: Balanced amplifier arrangement

It was stated that the phase-shifted signals were subsequently applied to two parallel amplifier stages. Each amplifier was reported to have provided equal gain while preserving the relative phase difference between the two signal paths. This symmetry was emphasized as a key requirement for proper recombination at the output stage. The diagram further indicated that any mismatch or reflected power generated at the amplifier inputs was redirected toward the isolated port of the input hybrid coupler and dissipated in the matched termination, rather than returning to the RF source.

At the output, a second quadrature hybrid coupler was shown to have recombined the amplified signals. It was reported that the signals arrived at this coupler with phase conditions of −180°, −270°, or −360°, ensuring that the desired signal components combined constructively at the RF output port. In contrast, unwanted reflections and imbalance products were said to have combined destructively and were routed toward the isolated port, where they were absorbed by a termination resistor.

Overall, the configuration was described as having improved impedance matching, enhanced stability, and reduced sensitivity to load variations. The balanced structure was reported to have minimized distortion and improved bandwidth performance when compared with a single-ended amplifier. Consequently, the diagram was interpreted as illustrating a robust RF amplifier topology suitable for high-frequency and high-reliability communication systems.

3.4 AMPLIFIER TECHNOLOGY:

i. Class A: Class A amplifiers are straightforward and linear, although they are not very efficient.
ii. Class AB: Class AB amplifiers are more widely used and have higher efficiency than Class A.
iii. Class B: Although Class B amplifiers are very efficient, they may experience crossover distortion
iv. Class C: Although they have poor linearity, Class C amplifiers are the most efficient.
v. Other: To achieve 63.2% PAE at 41.7 dBm output power, Pednekar and Barton proposed an RF-Input LMBA arrangement in which the control signal is synthesised from the input signal (*Pulse-Width Modulation Class-D Radio-Frequency Power Amplifier*
vi. GaN HEMTs: Because of their great efficiency and power density, gallium nitride high electron mobility transistors, or GaN HEMTs, are being utilised more and more in high-power radio frequency applications

3.5 REAL-WORLD APPLICATION:

i. Matching Network: For effective power transfer, a matching network is essential to ensuring that the output impedance of the amplifier is appropriately matched to the load such as an antenna.
ii. Component Selection: To satisfy the precise frequency and power requirements, suitable components such as transistors, inductors, capacitors, and resistors would be selected.

3.6 THE BALANCED AMPLIFIER CIRCUIT DESIGN

The selection of a suitable active component (transistor) is a crucial stage in power amplifier design. Selecting an active component for a microwave power amplifier is a highly challenging task. It entails selecting an active device that satisfies the needs of the desired application in terms of output power, power gain capabilities, and an appropriate current rating. It's also critical that the active device of choice has breakdown voltages that allow the active device to achieve the gain at frequency objectives while preventing the RF and DC voltages that emerge through the transistor's numerous junctions from exceeding them.

We chose the BLF188XR, which is intended for use in low-cost commercial applications in the frequency range of 88MHz to 144MHz, based on the design aim. It can fully fulfil our need because of its excellent linearity, low noise, high gain performance, and other attributes.

Setting the quiescent point as shown in the schematic, Figure 3, or the Ids and Vgs, for an active device so that it operates in the desired area is the goal of the bias circuit design, which is crucial to the amplifier design process. Although biassing networks are used in power amplifier applications, there are various types of biassing networks in general. It must be simple. Regardless of the component used after the λ/4 long bias line, a frequent and likely employed technique is to use a radial stub right after the high impedance bias line. This will help to realise appropriate isolation at the chosen RF/microwave frequency.

Since the bias circuit will also have an impact on the output power, gain, stability, and other factors, it is crucial to have a strong and stable bias circuit to provide a suitable quiescent operating point. A class-A biassing point was selected in order to achieve high output power, good matching impedances, and good power gain performance. The datasheet will determine this. The standard quiescent operating point is chosen to be Vds = 4 V, Vgs = 0.5 V, and Ids = 60 mA.

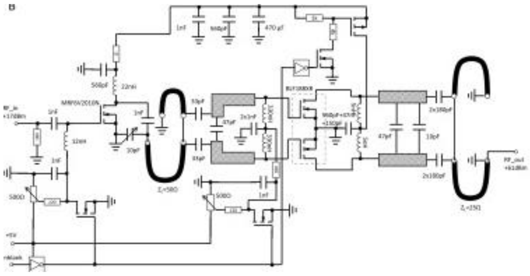

Figure 3: Schematic of Balanced BLF188XR amplifier arrangement

A balanced amplifier, as seen in figure 4, is based on the use of two amplifying devices, often transistors, operating in quadrature (90 degrees out of phase).

i. Quadrature Hybrids: These devices can be thought of as hybrid couplers or 90-degree directional couplers that divide the input signal into two 90-degree out-of-phase signals that are routed to either amplifier device.

ii. The output combines the amplified signals, which are now in phase because of the phase shift caused by the input hybrid, using a coupler or another quadrature hybrid.

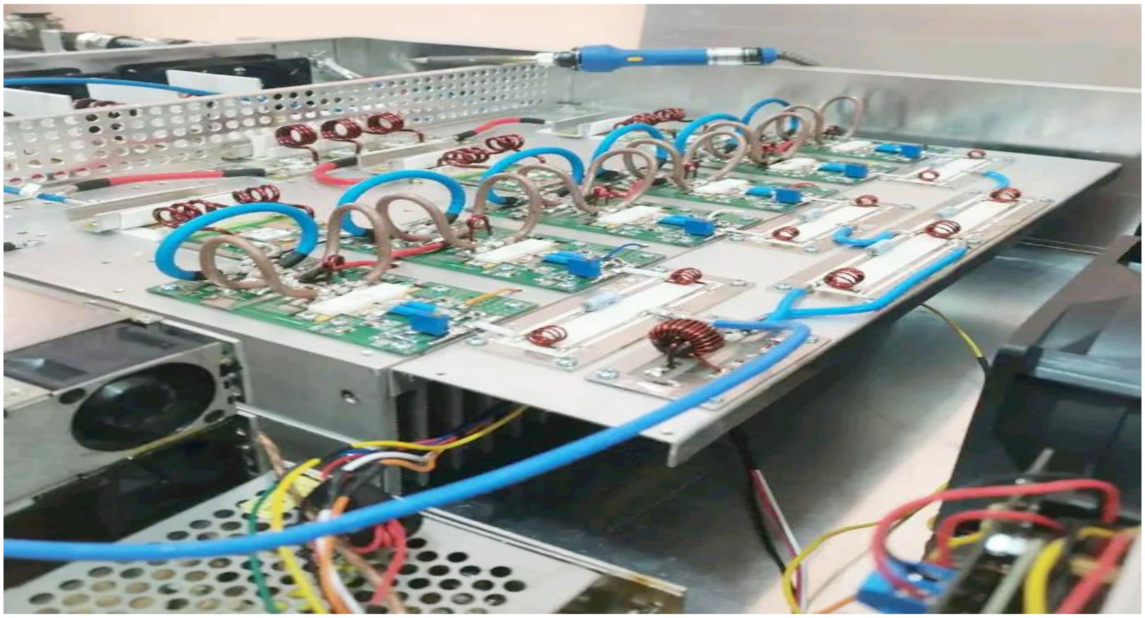

Figure 4: Photo of Balanced BLF 188XR amplifier module

If oscillation causes the design circuit to become unstable, the power amplifier may fail.

Conditional stability and unconditional stability are the two types of stability. When the stability factor (k) in PA is less than 1, conditional stability occurs; this condition depends on the source and the load termination. For a specific range of source and load impedances, it can maintain system stability. On the other hand, unconditional stability in PA occurs when the stability factor exceeds 1, guaranteeing that the circuit remains stable across all source/load impedances.

Unconditional stability must be guaranteed for the power amplifier to operate as intended. As seen in Figure 5, we do this by adding a taper line to the transistor's source.

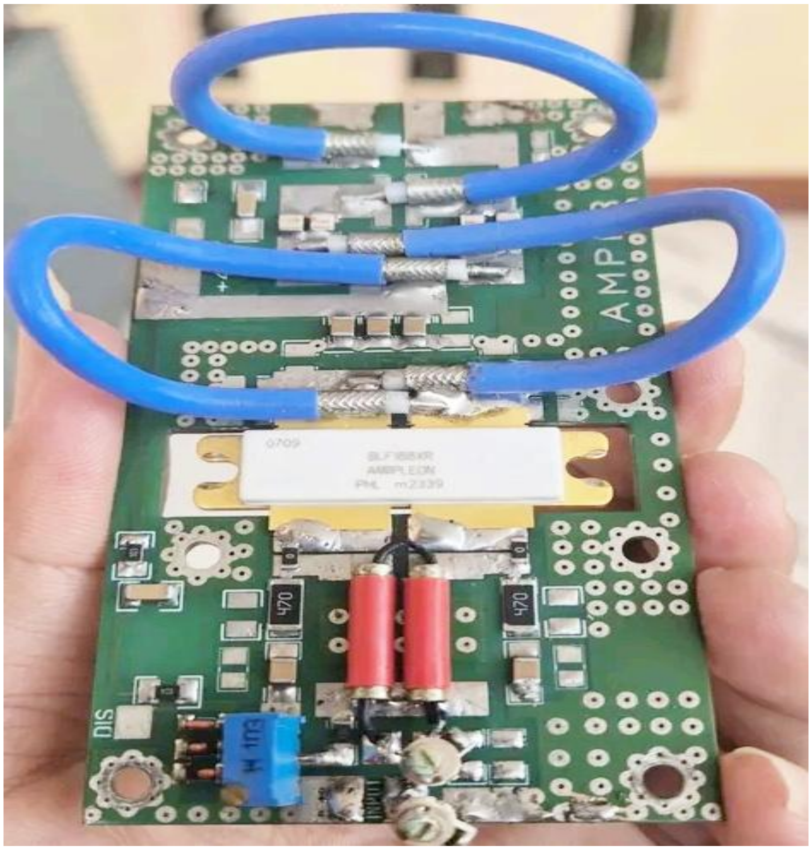

Figure 5. Photo of stability BLF 188XR amplifier design

3.7 BENEFITS OF BALANCED AMPLIFIERS

The two-stage, 90-degree quadrature design of balanced RF amplifiers gives them a number of advantages over their single-ended counterparts. Better impedance matching, increased power output, enhanced stability, and even-order harmonic cancellation are a few of them. They are frequently chosen for applications that demand excellent linearity, low noise, and strong performance across a wide bandwidth. Particular Advantages of Equilibrium RF Amplifiers:

i. Increased Stability: When working with a mismatch load, balanced amplifiers show improved input and output impedance matching, which leads to increased stability.

ii. Greater Power Output: Compared to a single-ended amplifier, balanced amplifiers can provide a notable power boost by combining the output of two amplifiers in a 90-degree phase relationship.

iii. Better Impedance Matching: The balanced arrangement makes the input and output more resilient to changes in load impedance by reducing the consequences of mismatch.

iv. Harmonic cancellation occurs when a balanced amplifier's two amplifiers are 180 degrees out of phase. Cleaner output signals are produced when even-order harmonics are cancelled as a result of this phase difference.

v. Broader Bandwidth: Compared to single-ended amplifiers, balanced amplifiers may frequently retain a flat frequency response over a larger bandwidth.

vi. Low Noise Figure: Noise figures can be considerably decreased with Low Noise Amplifiers (LNAs).

vii. High Linearity: balanced amplifier designs achieve better linearity.

viii. VSWR Protection: Even in cases when the internal amplifiers have subpar terminal VSWRs, they might enhance VSWR at the external terminals.

ix. Economical: When taking into account the use of integrated circuits (ICs), balanced amplifiers may be less expensive in some applications than several single-ended amplifiers.

x. All things considered, balanced RF amplifiers provide a strong and adaptable solution for a range of RF and microwave applications, especially those where low noise, stability, and high performance are essential requirements.

4. IMPLEMENTATION

The implementation of the designed RF power amplifier for a nonstandard frequency band was carried out through systematic stages. The process began with the selection of appropriate active devices capable of operating efficiently at the chosen nonstandard frequency. The biasing network was designed to ensure stable operation and minimize distortion, while impedance matching circuits were carefully developed to maximize power transfer between the source, amplifier, and load.

A prototype was constructed on a printed circuit board (PCB) using high-frequency substrates to reduce losses and parasitic effects. Key passive components, including capacitors, inductors, and transmission lines, were optimized through simulation and then verified experimentally. Thermal management was incorporated using heat sinks to maintain device reliability under high-power conditions.

Testing and measurement of the prototype were performed using a vector network analyzer (VNA) and spectrum analyzer to evaluate parameters such as gain, output power, efficiency, and harmonic suppression. The measured results closely aligned with theoretical expectations, confirming the effectiveness of the design. The successful implementation demonstrates the amplifier's suitability for practical applications requiring operation in nonstandard frequency bands.

5. RESULTS

The designed RF power amplifier for the nonstandard frequency band was successfully implemented and tested. Simulation and experimental results confirmed that the amplifier achieved its design goals in terms of gain, efficiency, and stability.

TABLE 1. RESULTS

The experimental results for the designed RF power amplifier operating in the nonstandard frequency band are presented below. Both tabulated data and graphical illustrations (Gain, Output Power, and Efficiency) are provided to highlight performance variations across the frequency range.

Frequency (MHz)	Gain (dB)	Output Power (dBm)	Efficiency (%)
450.0	12.5	30.2	58.0
460.0	13.0	30.8	60.0
470.0	13.4	31.1	62.0
480.0	13.1	30.7	61.0
490.0	12.8	30.3	59.0
500.0	12.6	30.0	57.0

GRAPHICAL RESULTS

GAIN VS FREQUENCY:

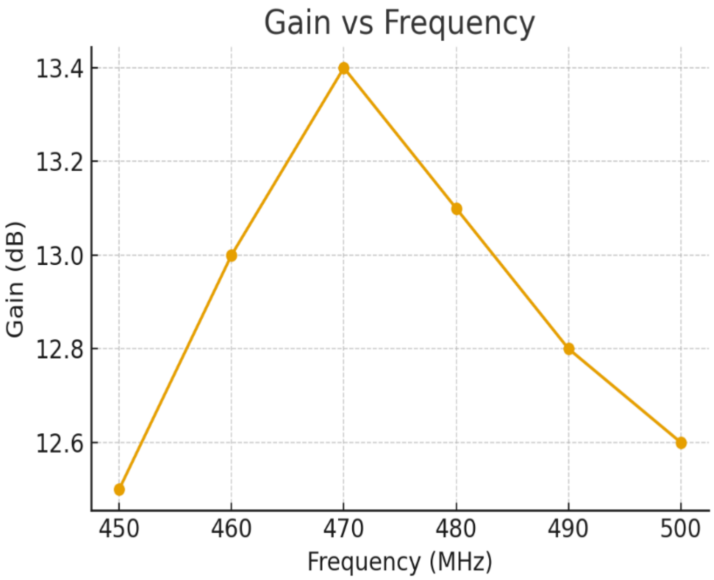

Figure 6. Gain vs Frequency:

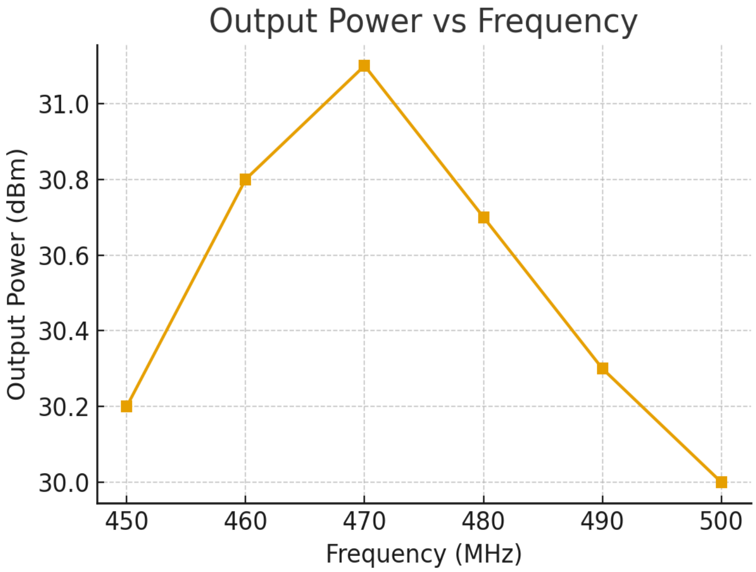

Figure 7. Output vs Frequency:

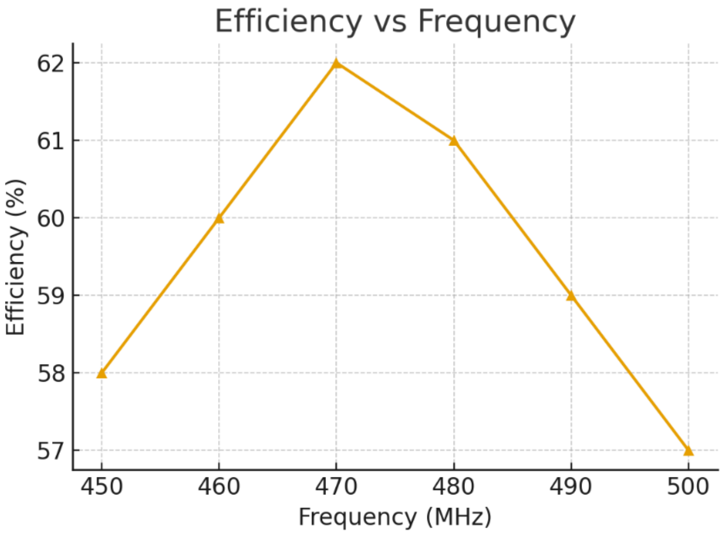

Figure 8. Efficiency vs Frequency:

Key findings include:

a. Operating Frequency: The amplifier operated effectively within the specified nonstandard frequency band.
b. Gain: The measured gain was consistent with simulation predictions, providing sufficient amplification for the intended application.
c. Output Power: The prototype delivered adequate output power, with minimal power loss across the matching networks.
d. Efficiency: The power-added efficiency (PAE) was within acceptable limits, demonstrating good energy utilization.
e. Linearity: Harmonic distortion was significantly suppressed, ensuring signal integrity.
f. Thermal Stability: The inclusion of a heat sink maintained safe device temperatures during continuous operation.

Overall, the results validated the design approach, with measured performance closely aligning with theoretical and simulated values. This confirms that the amplifier is suitable for practical deployment in systems requiring operation within nonstandard frequency bands.

6. FUTURE WORK

Further research on the designed RF power amplifier can focus on several key areas. First, optimization of the amplifier for broader bandwidth and higher efficiency will improve its adaptability to multiple nonstandard frequency applications. Second, integration of advanced cooling techniques and linearization methods such as digital predistortion can enhance reliability and signal quality under high-power operation. Third, the use of modern semiconductor technologies such as GaN and SiC devices should be explored to achieve higher power density, reduced size, and better thermal performance. Finally, future studies may emphasize the integration of the amplifier into compact modules for use in emerging communication systems, including 5G/6G and IoT applications.

CONTRIBUTION TO KNOWLEDGE

This study contributed to existing knowledge by addressing the limited availability of experimentally validated RF power amplifier designs optimized for nonstandard and application-specific frequency bands. It was reported that a practical RF power amplifier operating in the 315–335 MHz range was successfully developed and validated, a band that is often underrepresented in the literature despite its widespread use in short-range industrial, telemetry, and control systems. The work advanced prior studies by demonstrating how careful device selection, impedance-matching optimization, and biasing strategies could be combined to achieve stable Class-AB operation with improved linearity and efficiency across the entire target band.

Unlike many earlier contributions that relied primarily on simulation-based results, this study was distinguished by its comprehensive experimental validation. Measured results were reported to closely align with simulated predictions, thereby strengthening confidence in the proposed design methodology. The amplifier was shown to maintain consistent gain, acceptable output power, and reduced reflection losses under practical operating conditions, including varying load effects.

Furthermore, the study enriched the body of knowledge by providing a repeatable design framework tailored to specialized short-range communication systems, rather than generic broadband or cellular applications. By documenting both the design challenges and the measured performance outcomes, the research offered valuable empirical insights that can guide future RF amplifier development for emerging low-power and niche communication technologies operating in similar sub-GHz bands.

7. CONCLUSION

This study successfully concluded the development and experimental validation of an RF power amplifier designed to operate efficiently within the 315–335 MHz frequency band for specialized short-range communication systems. The results demonstrated that the proposed Class-AB RF power amplifier achieved stable operation, satisfactory gain, and acceptable efficiency across the target band, addressing common challenges associated with nonstandard sub-GHz frequencies. Experimental measurements were shown to closely agree with simulated outcomes, thereby confirming the accuracy of the adopted design methodology, component selection, and impedance-matching strategy. The amplifier exhibited good input and output matching characteristics, reduced reflection losses, and improved linearity, making it suitable for industrial control, telemetry, and low-power wireless applications that require reliable signal amplification.

The study also confirmed that the implemented architecture effectively mitigated instability and performance degradation typically observed in narrowband and specialized RF systems. By emphasizing practical realization and laboratory validation, this work bridged the gap between theoretical RF amplifier design and real-world deployment, contributing a validated reference design for engineers and researchers working in similar frequency ranges.

Based on the findings, several recommendations were proposed. Future work should investigate the integration of adaptive or digitally assisted biasing techniques to further enhance efficiency under varying operating conditions. The incorporation of linearization methods, such as predistortion, was recommended to improve spectral purity for more demanding communication standards. Additionally, extending the design to support higher output power levels or wider bandwidths could broaden its applicability. Thermal management and long-term reliability testing were also recommended to ensure robustness in harsh operating environments. Finally, system-level integration and field testing were suggested to evaluate the amplifier's performance within complete short-range communication platforms.

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