Multi-Mode Extension of Non-Commensurate Transmission Line Combiner for Outphasing Power Amplifier

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***Abstract*—This report presents the research outcomes supported by the 2024 IEEE MTT-S Graduate Fellowship Program, focusing on advancements in multi-mode extensions for Outphasing power amplifier (OPA) design. First, non-commensurate transmission line combiner (NCTLC)-based OPA and inverted OPA (IOPA) operating modes are proposed. Using this approach, a dual-mode dual-band OPA is designed. Subsequently, the delta length in the NCTLC is extended, and similarly, a dual-mode dual-band OPA is performed for theoretical verification. Future work will explore multi-mode OPAs to address the demands of multi-band communication systems.**

***Index Terms*—Outphasing power amplifier, non-commensurate transmission line combiner, delta length, multi-mode, multi-band.**

I. Introduction

In modern communication systems employing high peak-to-average power ratio (PAPR) modulated signals, power amplifiers (PAs) must maintain high efficiency across an output back-off (OBO) range. In addition, as spectrum resources are constantly used, high-efficiency broadband or multi-band PAs are highly expected. In such circumstances, load-modulated PAs gradually dominate the stage. In particular, the Outphasing PA (OPA), distinguished by its exceptional back-off drain efficiency (DE), becomes one of the most competitive amplifiers [1].

To simplify the design, the non-commensurate transmission line combiner (NCTLC) for OPA has been developed and widely used in recent years. But notice that, the bandwidth of the OPA is always limited by the frequency dispersion of the combiner [2]. Therefore, it is an interesting topic to develop novel architecture and method to design wideband and multi-band OPAs [3]–[5].

In this project, we present a novel dual-band OPA architecture that exploits the periodicity of NCTLC to enable inter-band mode switching, thereby significantly improve the significant DE decrease in a large frequency range [6]. Furthermore, the unique delta length characteristics of NCTLC are investigated to achieve multi-mode expansion [7]. The proposed approach enhances the design flexibility of dual-band OPAs while maintaining high-efficiency performance.

II. Project Outcome

This research focuses on multi-mode OPA architectures. The detailed research is organised as follows. First, we present a novel dual-mode dual-band OPA leveraging on periodicity of NCTLC. Subsequently, we extend this approach through multi-mode expansion of NCTLC, building upon prior research foundations.

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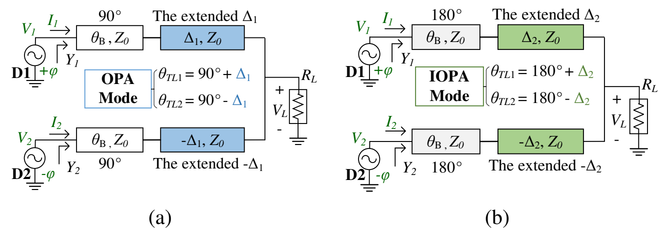


Fig. 1. Proposed OPA block diagrams based on the non-commensurate transmission line combiner of (a) OPA mode and (b) IOPA mode.

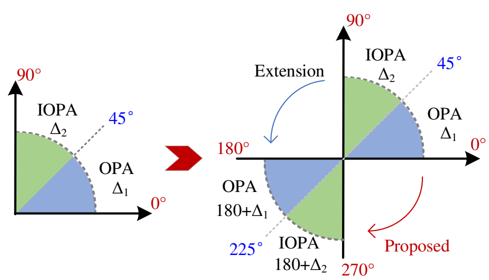


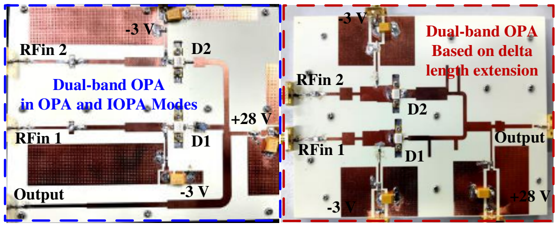
Fig. 2. Conceptual scheme of the delta length extension in OPA mode and IOPA mode.

A. Dual-Mode Dual-Band OPA Leveraging on Periodicity of NCTLC

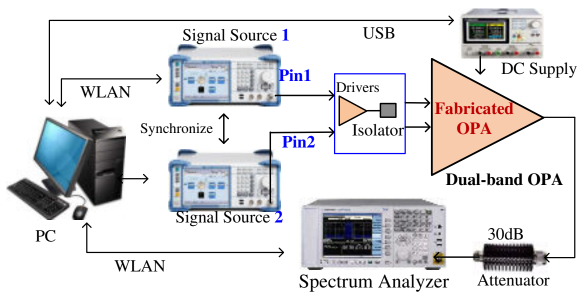
To enhance the frequency coverage of the OPA, we propose a dual-mode dual-band OPA based on NCTLC. OPA and inverted OPA (IOPA) operation modes are enabled at two frequency bands, as shown in Fig. 1. Dual-mode operation comes from the periodicity of the NCTLC. The design of a dual-band OPA by combining of two operation modes without increasing the circuit complexity is presented for the first time. Consequently, a dual-mode dual-band OPA operating over 0.89-0.93 GHz and 1.89-1.96 GHz is implemented in this work to validate the proposed theory. The results show that the proposed architecture provides a practical power amplifier design solution for wireless communication systems that need to cover multiple frequency bands.

B. Multi-mode Extension of NCTLC for Dual-Mode Dual-Band OPA

Considering the delta length of the NCTLC plays an important role, we consider delta length expansion operations for both OPA and IOPA modes, as shown in Fig. 2. Theoretical

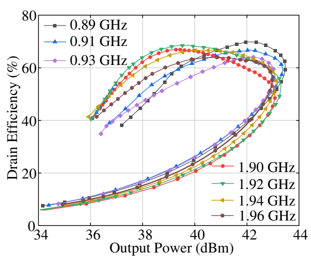


(a)

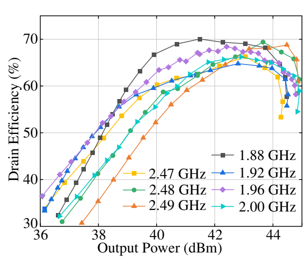


(b)

Fig. 3. (a)Photograph of the fabricated OPA and (b) its experimental environment.



(a)



(b)

Fig. 4. Measured drain efficiency and versus output power. (a) At 0.89-0.93 GHz and 1.89-1.96 GHz. (b) At 1.88-2 GHz and 2.47-2.49 GHz.

analysis shows that both the OPA and IOPA modes maintain the same performances before and after delta length extension. So, the delta length extension of the NCTLC means more design margin in the OPA design and more freedom for the frequency of the dual-band OPA design. To validate the proposed theory, a dual-mode dual-band OPA is fabricated and measured, operating at 1.88-2 GHz in OPA mode and 2.47-2.49 GHz in IOPA mode. The results obtained demonstrate that the proposed theory provides a feasible and practical solution for the design of dual-band and even multi-band OPAs.

C. Experimental Results

The two dual-band OPAs designed are further fabricated and tested. Fig. 3 shows a photograph of the fabricated OPAs and the experimental environment. The measured DEs of the fabricated OPAs with respect to the output power are shown in Fig. 4. For the dual-band OPA based on periodicity of NCTLC, it delivers a maximum output power of 42.8–44.3 dBm, while maintaining over 41.3% DE across a 6 dB back-off range in both 0.89-0.93 GHz and 1.89-1.96 GHz bands, as shown in Fig. 4(a). The dual-band OPA after delta length extension demonstrates a measured saturated output power of 43.3-44.7 dBm, maintaining more than 45.6% DEs over a 6 dB back-off range across both 1.88-2 GHz and 2.47-2.49 GHz bands, as shown in Fig. 4(b). The results obtained demonstrate that the proposed theory provides a feasible and practical solution for the design of dual-band and even multi-band OPAs.

It is also worth noting that the choice of base length is equally important as the delta length changes. Therefore, this project will continue to explore the operation modes of the NCTLC-based OPA, considering the frequency periodicity of the TL. To achieve dual-band or multi-band operation, the line structures selection for frequencies is crucial because it is closely related to the feasibility and complexity of the realized power combiner. This architecture can provide new approaches for the design of multi-band OPAs.

III. Career Plan and Fellowship Impact

I am deeply honored to be awarded the 2024 IEEE MTT-S Graduate Fellowship. This recognition inspires me to continue to pursue research in PAs design that addresses the evolving demands of modern wireless communication systems. The fellowship program has provided me with the invaluable opportunity to attend the 2024 IMS, where exposure to cutting-edge research in microwave technology has significantly broadened my perspective and provided me with essential guidance for my work. In the future, I remain committed to advancing research in RF PAs and contributing to innovations in microwave field. I will continue to maintain active engagement with the MTT-S while closely monitoring new developments in the industry.

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