Amplifier Input Matching for NF–Gain–Linearity Compromise

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***Abstract*— In this paper we investigate the effect of amplifier input matching on the noise figure, gain, and linearity design tradeoff, with the goal of developing a single-amplifier solution able to operate as either a PA or LNA. We evaluate the large-signal linearity performance of an amplifier with a noise-matched input compared to an identical amplifier with gain-matched input, and the effects on efficiency and noise figure. The prototype amplifier is designed at 3 GHz and realizes 42.86 dBm CW output power and 67% PAE at 3 dB gain compression. With a noise-matched input the amplifier realizes a 2 dB reduction in gain and 7.7 percentage point reduction in PAE compared to the gain-matched amplifier, but a 3 dB improvement in IMD3 at 33.5 dBm output power under a 1-MHz spaced two-tone signal excitation.**

I. Introduction

Next-generation communication systems are increasingly employing multi-antenna basestations (e.g., massive MIMO) to enable targeted spectrum use. As the number of elements increases, so does the associated cost of fabricating and integrating the RF front-ends containing the power amplifiers (PAs) and low-noise amplifiers (LNAs). Therefore, a single common amplifier module that can operated as both a PA and LNA is an attractive solution. Although such an amplifier will have degraded performance compared to specialized PAs and LNAs, the tradeoff in terms of system cost and size may be desirable.

This work examines the design space for PA and LNA input matching to evaluate the performance compromise for a single-amplifier solution. In particular, we compare the performance of an amplifier having a standard output power match when its input matching network is designed according to the standard PA (i.e., gain-matched) and LNA (i.e. noise-matched) approaches. To enable direct comparison, the stability network and output matching network (OMN) of the amplifier is held fixed.

We focus here on a gallium nitride (GaN) realization, as this technology is of interest for cellular basestations for both the PA due to their high device power periphery and efficiency compared to other semiconductor technologies [1], and for LNAs due to the low noise, high linearity, and high input power tolerance of GaN [1], [2]. Compared to previous investigations of GaN LNA-PA structures [3], [4], we focus on linearity characterization through large-signal third order intermodulation distortion product (IMD3) response to two-tone excitation rather than the third order output intercept point (OIP3).

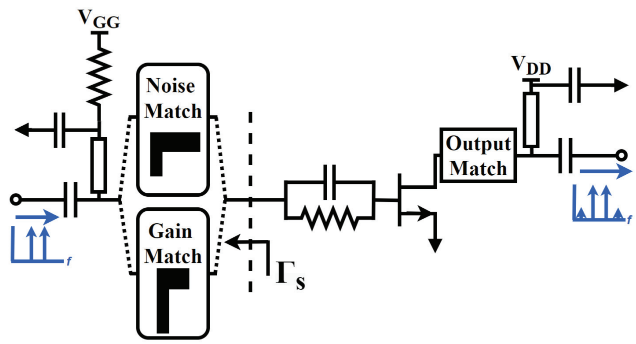


Fig. 1: Simplified schematic of the amplifier designed in this work for operation as either a PA or LNA. The performance with source impedances matched for noise and for gain are compared when the remainder of the amplifier design is held constant.

II. Prototype Design

The amplifiers discussed in this work are designed using the Wolfspeed CG2H40010F (10W) packaged GaN device. An appropriate output match for high output power and efficiency was first designed to realize a 3 dB gain compressed output power (P3dB) of 40 dBm in simulation at 3 GHz. For this initial OMN design, a 50-Ω source impedance was assumed, and an RC stability network ($R = 58\,\Omega$ and $C = 2\,\text{pF}$) and series gate bias resistor ($14\,\Omega$) included as indicated in the simplified schematic in Fig. 1.

With this common OMN and stability structure in place, the amplifier was then source-pulled to determine the gain match impedance and noise match impedance, as shown in Fig. 2 and referenced to the Γ_S plane in Fig. 1. The simulated gain and noise figure (NF) are G= 13.5 dB and NF= 6.7 dB at the gain match source impedance, and G= 12 dB and NF= 3.1 dB for the noise match impedance. For an amplifier able to function as either PA or LNA, then, this tradeoff indicates that a noise match at the input is needed, due to the 3.6-dB difference in NF.

Because linear performance is important to both PA and LNA operation, we consider the IMD3 response to a two-tone excitation, simulated with 1-MHz tone spacing and 35 dBm total output power. The contours of upper and lower IMD3 tones are shown in Fig. 2 for the fixed OMN

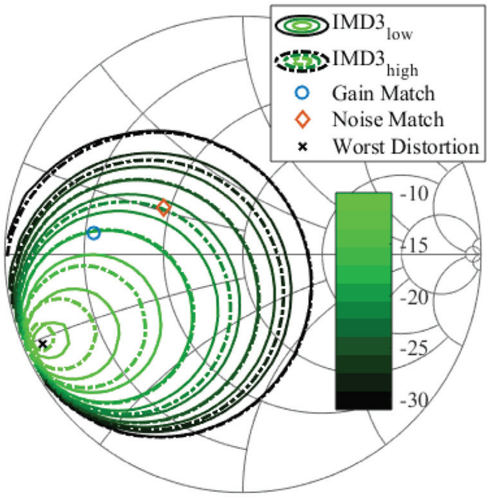


Fig. 2: Source-pull simulation results showing the optimal source impedance for a gain match and noise match, as well as contours of upper and lower IMD3 product (in dBc) for a 1 MHz tone spacing at 3 GHz with 35 dBm total output power with 2 dB IMD steps.

and stability network described above. This simulated result indicates that the noise-matched source impedance produces improved IMD3 tones compared to the gain match, suggesting that while the noise match will lose gain (and the associated PAE) the amplifier will also exhibit a more linear response up into compression, potentially enabling operation at higher output power.

Two different input matching networks corresponding to the gain and NF matches were designed based on the single-stub topology indicated in Fig. 1. The resulting source impedance trajectories are shown in Fig. 3 and meet the intended source impedance targets. The two fabricated PAs with identical OMNs, stability networks, and bias structures are shown in Fig. 4 (in measurement, the same transistor and output PCB are used). The slight difference in input match can be observed in the photographs.

III. Measurements

Each amplifier is first characterized under CW excitation at 3 GHz. Fig. 5 reports the output power and power-added-efficiency (PAE) of the amplifiers and compares the measured results to simulation. The measured results compare favorably with simulated results for both output power and PAE in both amplifiers. Although the use of an input noise match results in the expected gain reduction of at most 2 dB and an associated 7.7 percentage point degradation in PAE compared to the gain-matched input, it is interesting to observe that the measured output power at 3-dB compression is 0.8 dB higher.

Fig. 6 reports the measured output power per tone for the fundamental and IMD3 products of the power amplifier

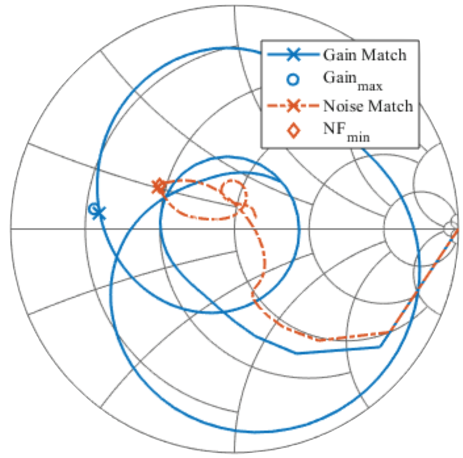
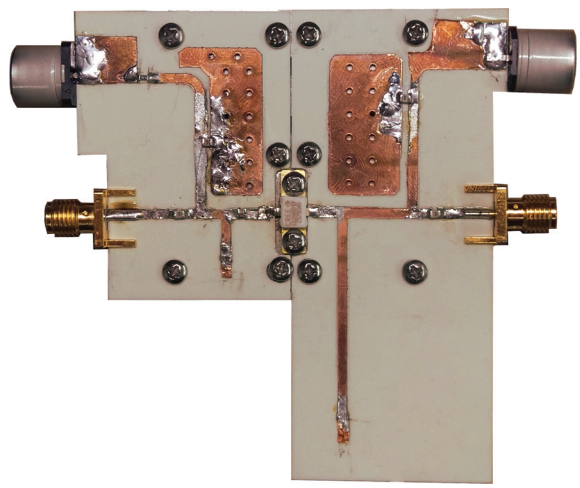
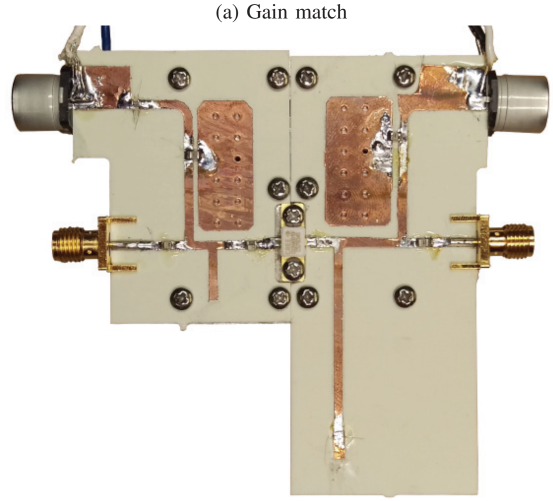


Fig. 3: Source impedance trajectory of the noise-matched and gain-matched input matching network designs.



(a) Gain match



(b) Noise match

Fig. 4: Photograph of the amplifiers characterized in this work. The transistors and output PCBs are identical, while the input networks differ only in the source match.

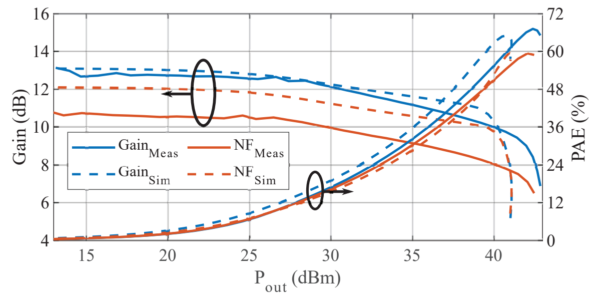


Fig. 5: RF performance of the gain- and noise-matched amplifiers under CW excitation at 3 GHz.

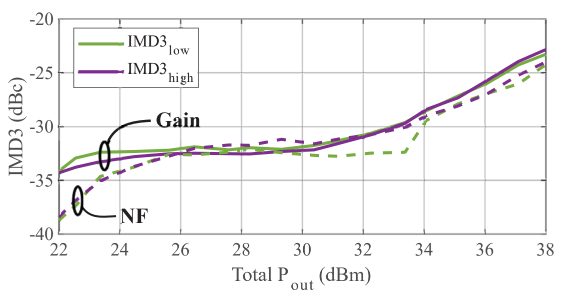


Fig. 6: Measured IMD3 at 1 MHz tone spacing within the power range of interest.

under two-tone excitation at 1 MHz tone spacing. As expected, the IF impedance compensation network does not introduce any power loss in either upper or lower fundamental output tones compared to an amplifier without IF impedance control. While slight IMD3 degradation can be observed around 27–30 dBm total output power, overall the noise-matched amplifier exhibits improved linearity compared to the gain-matched amplifier.

Fig. 7 reports the device response under 3.84 MHz W-CDMA excitation with the noise-matched and gain-matched inputs. Based on these results we can see that the noise-matched amplifier's output realizes an ACLR that is on average 1.75 dB lower than that for the gain-matched amplifier. The gain-matched amplifier has an average modulated drain efficiency of 16.5% while the noise matched amplifier has a drain efficiency of 18.7%, a 2 percentage point improvement. No predistortion was applied to any of the reported measurements.

The reported improvement in ACPR when the amplifier is noise matched is consistent with the two-tone results reported in Fig. 6. The average output power of the W-CDMA signal corresponds to the output power point where the IMD3 of the noise-matched amplifier is most suppressed compared to the gain-matched amplifier. This suggests that the noise-matched amplifier could be operated at a higher average output power while maintaining the same spectral profile as with the gain match.

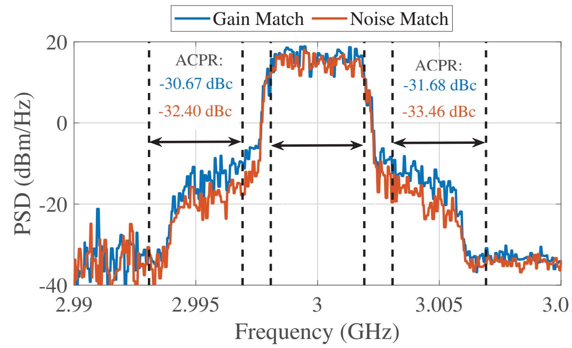


Fig. 7: Measured 3GPP W-CDMA output spectrums for the gain- and noise-matched amplifiers, both operating with 33.5 dBm average output power.

IV. Conclusion

In this work the large-signal performance of a GaN amplifier with power-matched output and gain-matched input is compared to an almost identical amplifier with noise-matched input. Counter to intuition, the 2-dB lower gain of the noise-matched design is correlated with improvements in most other amplifier metrics. Measurements show that the noise-matched input results in improved amplifier linearity in terms of both IMD3 and ACPR, while performing with comparable modulated efficiency. Although not validated in measurement, the noise-matched amplifier is also expected to have a 3.6-dB improvement in noise figure compared to a gain match. This suggests that the conventional gain-match used in power amplifiers does not necessarily maximize overall amplifier performance. Therefore, this unconventional choice of input matching is a promising compromise for applications in which a single amplifier must operate as either a PA or LNA.

Acknowledgment

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References

[1] Micovic, *et al.*, "GaN MMIC technology for microwave and millimeter-wave applications," in *IEEE Compound Semiconductor Integrated Circuit Symposium*, Oct 2005, pp. pp. 1–3.
[2] Rudolph, *et al.*, "Analysis of the survivability of GaN low-noise amplifiers," *IEEE Transactions on Microwave Theory and Techniques*, vol. 55, no. 1, pp. 37–43, Jan 2007.
[3] Kobayashi, *et al.*, "A 2 watt, sub-dB noise figure GaN MMIC LNA-PA amplifier with multi-octave bandwidth from 0.2-8 GHz," in *IEEE MTT-S International Microwave Symposium*, June 2007, pp. 619–622.
[4] Kobayashi, "Bias optimized IP2 amp; IP3 linearity and NF of a decade-bandwidth GaN MMIC feedback amplifier," in *IEEE Radio Frequency Integrated Circuits Symposium*, June 2012, pp. 479–482.