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Abstract

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Electronic Design Innovation (EDI)

Novel Impedance Flattening Network for Wideband GaN Doherty Power Amplifier at 3.4-3.8 GHz

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***Abstract*— This work reports a novel impedance flattening network for wideband Doherty power amplifier (PA) targeting 4G and beyond base-stations. Conventional Doherty PA performance is limited in terms of operational bandwidth due to frequency dependent load modulation network involved. Our proposed impedance flattening network mitigates this constraint by introducing frequency less-dependent impedance characteristic at back-off power level. To demonstrate the proposed technique, a wideband Doherty PA is designed using commercially available GaN-HEMT device at 3.4-3.8 GHz. The PA design achieves 58-68% peak drain efficiency over 400 MHz bandwidth while maintaining more than 45% drain efficiency at 7-dB output power back-off. Furthermore, it delivers 42.5-dBm of saturated output power, 14.5 dB of power gain and 0.5 dB of average gain fluctuation across 3.4-3.8 GHz bands.**

Keywords—RF power amplifier, impedance flattening network, wideband, Doherty power amplifier, 4G, base station, high efficiency, back-off.

I. Introduction

Exploding demand applications in wideband frequency with high peak-to-average power ratio (PAPR) modulated signals in cellular communication have generated immense interest towards wideband Doherty power amplifier (PA) [1-5]. The benefit of high back-off (average) efficiency from Doherty PA manifest themselves as a prime candidate for the next generation high-efficiency PA. However, the load modulation network in a conventional Doherty PA is only suitable for narrowband operation because of the nature of quarter wavelength transformer. Hence, there is a significant demand of Doherty PA which is able to support both wide bandwidth and high efficiency simultaneously.

In this work, a novel impedance flattening network is proposed as shown in Fig. 1(b) to overcome the efficiency degradation at back-off while maintaining wide bandwidth. Significant improvement in power-efficiencies across wideband frequencies are demonstrated using GaN-HEMT technology at 3.4-3.8 GHz.

Section II describes the proposed impedance flattening network. Design of wideband Doherty PA and simulation results are summarized in section III and IV.

This work was done while Sheikh Nijam Ali was an intern at MERL.

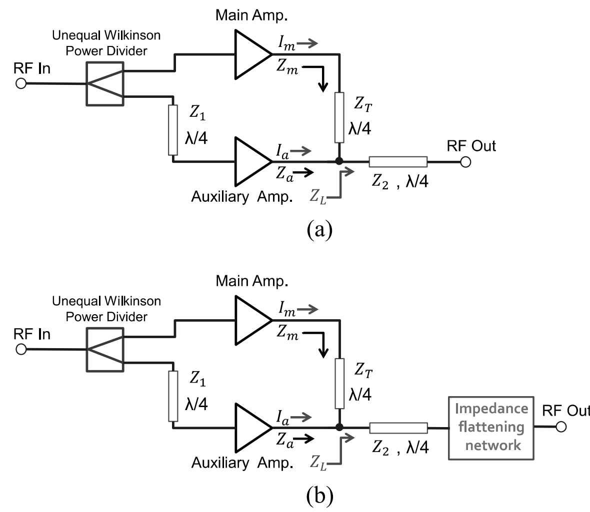


Fig. 1: Block diagram of (a) conventional Doherty power amplifier, (b) proposed wideband Doherty power amplifier with impedance flattening network.

II. Proposed Impedance Flatteing Network

Ideally, to design a wideband efficient Doherty PA, the real-part of the back-off impedance, $Re[Z_{m,bo}]$ of main amplifier needs to be frequency independent over the desired bandwidth as shown in Fig. 1(a). However, this is very challenging to achieve in practice due to the bandwidth limitation of quarter-wave transformer and output parasitic capacitance of power device, particularly at high frequency above 3 GHz. More importantly, PAs at RF frequencies are designed based on load-pull impedance to get maximum efficiency for a certain output power requirement. As the frequency increases, $Re[Z_{m,bo}]$ usually monotonically drops and it creates impedance mismatch at back-off and compromises the performances especially at the edges of frequency bands. To resolve these issues, an L-C based impedance flattening network is introduced as shown in Fig. 2(a) with the combination of reduced impedance transformation ratio at back-off power level by modifying the characteristic impedance of quarter-wave transformer in the load modulation network. The characteristic of this network is monotonically increasing, i.e., opposite characteristic of the real-part of conventional load line with frequency. The practical realization of this impedance flattening network consists of one inductor and one capacitor which are connected in parallel configuration and in series with the load modulation network. The inclusion of the L-C network with rest of the Doherty PA architecture creates distinct desirable impedance characteristics at the input of load matching network as shown in Fig. 2(b). First, this impedance flattening network creates a gain modification of $Re[Z_{m,bo1}]$ with respect to center frequency(f_o) by creating a high impedance at second harmonic which essentially starts to pull-down the $Re[Z_{m,bo1}]$ from f_o-BW/2 to f_o and pull-up the $Re[Z_{m,bo1}]$ from f_o to f_o+BW/2. The resultant characteristic becomes flatten at back-off and independent of frequency across the desired bandwidth and so the realized Doherty PA exhibits wideband performance. Fig. 2(c) depicts the frequency response of the resultant real part of back-off impedance, $Re[Z_{m,bo1}]$. Second, it also helps to compensate the output-capacitance of the device. Typically, this reactive part is matched to its proper value to extract maximum efficiency from Doherty PA using matching network with single/multiple stage. But, here the impedance flattening network is capable to compensate this reactive part by selecting the appropriate value of the L-C components.

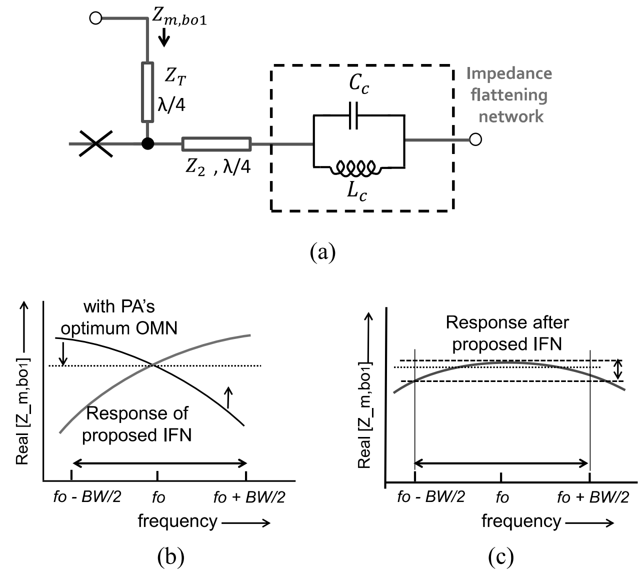


Fig. 2: Block diagram of (a) proposed impedance flattening network (IFN), (b) frequency responses of PA's optimum output matching network in typical condition and proposed IFN alone, (c) resultant frequency response after incorporating the IFN in load modulation network.

III. Wideband Doherty Power Amplifier Design

To demonstrate the performances of proposed impedance flattening network, a wideband Doherty PA at 3.4-3.8 GHz (400 MHz of RF BW) is designed using commercially available GaN-HEMT devices. Complete block diagram of the proposed wideband Doherty PA architecture is shown in Fig. 3. Reduced optimum impedance transformation ratio (ITR) of 2 is used at both back-off and saturation power levels. The transmission lines $\delta_{1,2,3,4}$ are primarily to balance the main and auxiliary amplifier phases. All input and output matching networks (IMNs and OMNs) are designed based on Chebyshev real to real frequency synthesis technique. The optimum input and output impedances are obtained from load-pull simulation results using ADS. Main and auxiliary amplifiers are biased at class AB and C mode respectively. Drain supplies of 47 V are used both in main and auxiliary PA branches. Further, a 90-degree hybrid-coupler is included at the RF input for a 2/3 power distribution ratio between main and auxiliary PAs.

IV. Simulation Results

The S-parameter simulation results are shown in Fig. 4(a). More than 11 dB of small signal gain (S_{21}) is achieved while maintaining better than -5 dB and -8.5 dB of input matching (S_{11}) and output matching (S_{22}) respectively across 3.4-3.8 GHz. Simulated $Re[Z_m]$ with respect to input power variations are shown in Fig. 4 (b) where reduced variations of $Re[Z_m]$ are

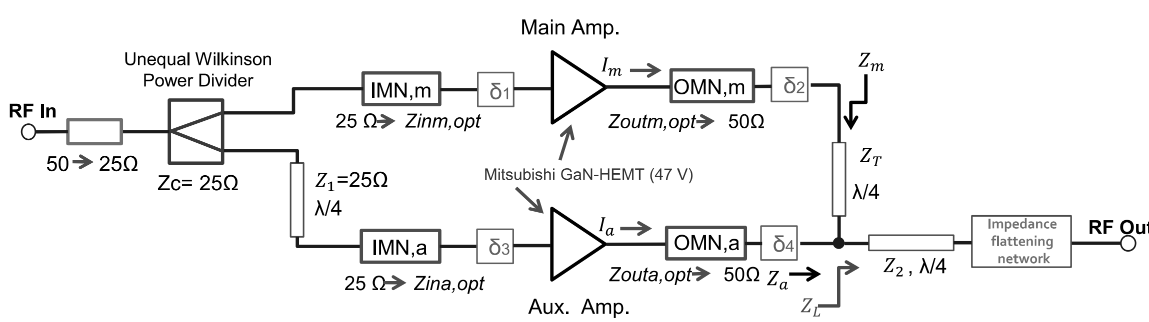
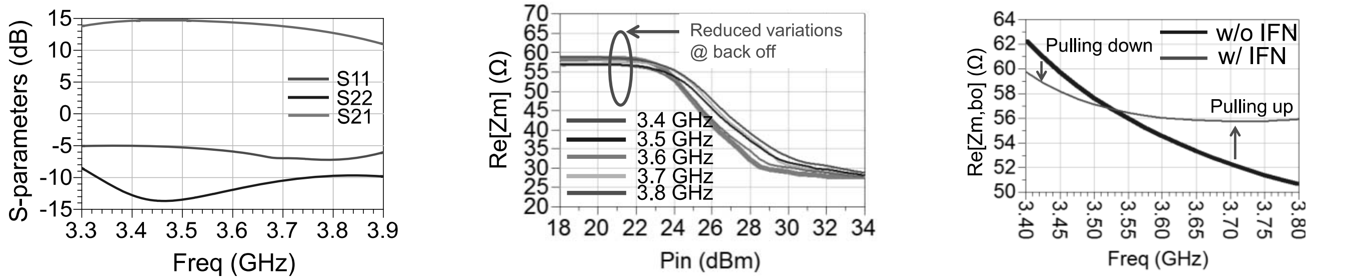
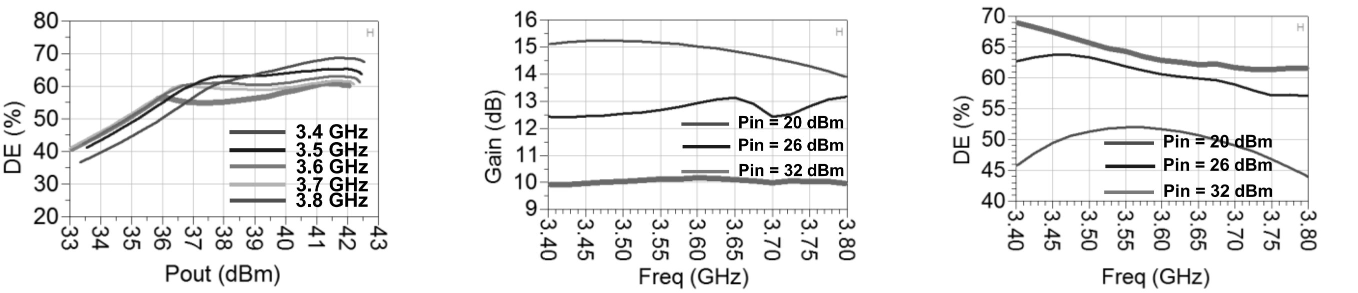


Fig. 3: Complete block diagram of the proposed wideband Doherty power amplifier with impedance flattening network.



(a) (b) (c)

Fig. 4: (a) S-parameter simulation results, (b) real part of Z_m both at back-off an peak input power, (c) frequency response of real part of Z_m at back-off with and without impedance flattening network across 3.4-3.8 GHz.



(a) (b) (c)

Fig. 5: Large-signal simulation results of proposed wideband Doherty PA (a) output power versus drain efficiency (DE), (b) gain response at 3.4-3.8 GHz , (c) drain efficiency across 3.4-3.8 GHz for various conditions of input power.

achieved both at back-off and peak input power. The functions of impedance flattening network is illustrated in Fig. 4(c). Here, the impedance flattening network helps to pull-down the Re[$_{Zm,bo}$] variations at lower band while it pulls-up the Re[$_{Zm,bo}$] at upper band resulting a flatten impedance characteristic at back-off.

The large-signal simulation results of the proposed wideband PA design are summarized in Fig. 5. About 68-59% peak drain efficiencies are achieved while maintaining > 45% 7-dB output power back-off efficiency. Moreover, approximately 0.5 dB of average gain flatness across 3.4-3.8 GHz band are achieved.

V. Conclusions

In this work, practical design challenges of wideband Doherty power amplifier especially above 3 GHz are investigated. To address the solution, a novel impedance flattening network is proposed. This dramatically reduces the variation of impedance at back-off and helps to improve the power-efficiency performances in a wideband Doherty PA design. Further, simulation results of the realized wideband DPA using Mitsubishi GaN-HEMT devices are presented and high drain efficiency of > 45% at 7dB back-off is demonstrated over 400 MHz of bandwidth.

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