Linearity improvement of class-E Doherty amplifier using g_{m3} cancellation

J.H. Kim, C.S. Cho, J.W. Lee and J. Kim

Conventional Doherty amplifiers usually use a class-A or class-AB amplifier for the main amplifier to maintain high linearity while inherently showing low efficiency. Presented is a high efficiency Doherty amplifier that employs a class-E amplifier as the main amplifier and also improves the linearity using the g_{m3} cancellation method. The g_{m3} cancellation method is an effective way to remove third-order intermodulation distortion (IMD3) with proper gate voltage biasing for the auxiliary amplifier. The power added efficiency of the proposed Doherty amplifier is 52.8% with Pout of 28.5 dBm at 1.95 GHz. The IMD3 performance is improved by 11 dB compared to the Doherty amplifier without the g_{m3} cancellation method.

Introduction: Various methods for increasing the power added efficiency (PAE) of linear power amplifiers have been introduced. The Doherty amplifier provides improved efficiency owing to the role combination of the main and auxiliary amplifiers. The Doherty amplifier composed of a class-F amplifier and an inverse class-F amplifier shows higher efficiency than the conventional linear Doherty amplifier. Linearity, another important factor for characterising power amplifiers, cannot be enhanced with the conventional Doherty configuration. Conventional linearity enhancement methods such as feed-forward and pre-distortion have also been widely implemented with Doherty amplifiers [1–5]. In this Letter, two class-E amplifiers with different bias conditions are employed for the main and auxiliary amplifiers for increasing the PAE of the Doherty amplifier. Since the class-E amplifier as the main amplifier in the proposed Doherty configuration provides higher PAE than the conventional Doherty amplifier for which the main amplifier adopts class-A or class-AB, the overall PAE of the Doherty amplifier increases significantly. However, since the class-E amplifier ensures a high PAE only, the g_{m3} cancellation method can also be employed for improving the linearity as utilised by other applications [6–10].

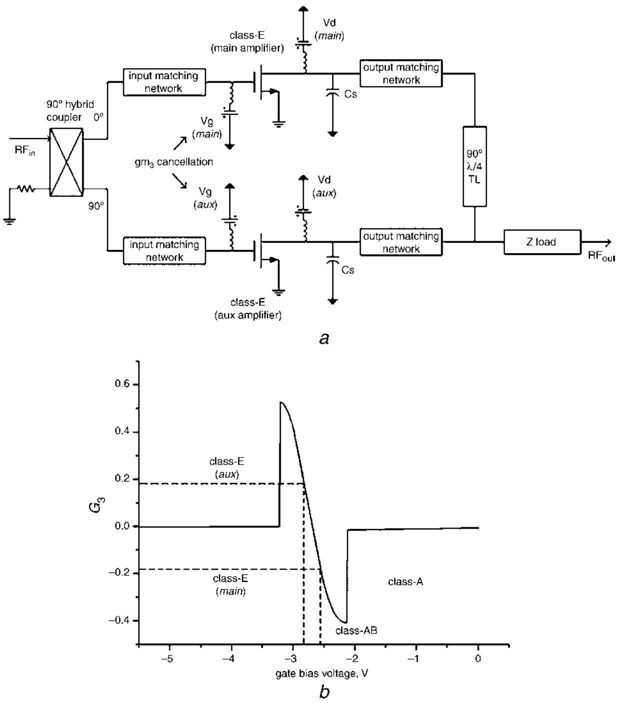

Fig. 1 *Schematic diagram of proposed Doherty amplifier and transfer function derivatives of FET model as function of gate voltage*

a Schematic diagram of the proposed Doherty amplifier
b Transfer function derivatives of an FET model as function of gate voltage

Doherty theory using class-E amplifiers: In the conventional Doherty amplifier design, while the main amplifier operates in the saturation mode, the auxiliary amplifier is suitably designed so that the PAE is significantly improved. Fig. 1*a* shows the proposed Doherty configuration with the class-E amplifier used as the main amplifier for obtaining higher efficiency. A proper biasing of the gate voltage enables the auxiliary amplifier to turn on when the main amplifier reaches saturation mode. However, since the linearity of Doherty amplifier is not taken care of in general, the Doherty amplifier using a class-E amplifier requires special care in its design if linearity is to be enhanced.

Implementation of g_{m3} cancellation: Various techniques have been exploited to resolve the linearity problem in Doherty power amplifier design. g_{m3} cancellation is one of the useful methods that increase third-order intermodulation distortion (IMD3). Fig. 1*b* shows the transfer function derivatives of FET model expressed as a function of gate voltage. The main peak amplifier of the proposed Doherty amplifier can have various transfer function derivatives by varying the gate voltage. Additionally, amplifier classes are defined through the transfer function derivatives of FET model as the function of gate voltage.

The transfer function derivatives of FET can be modelled by Taylor series expansion as follows [6–10]:

$$\begin{aligned} I_{out}(v_{in}(t)) &= I_{out,DC} + g_m v_{in} + \frac{g_{m2}}{2!}v_{in}^2 + \frac{g_{m3}}{3!}v_{in}^3 \\ &\quad + \frac{g_{m4}}{4!}v_{in}^4 + \frac{g_{m5}}{5!}v_{in}^5 + \cdots \\ &= I_{out,DC} + G_1 v_{in} + G_2 v_{in}^2 + G_3 v_{in}^3 \\ &\quad + G_4 v_{in}^4 + G_5 v_{in}^5 + \cdots \end{aligned} \tag{1}$$

where the coefficients G_n are the transfer function derivatives of the nth-order intermodulation product and input voltage consisting of two-tone input signals is injected. The upper sideband IM3 (the third-order intermodulation product) terms of the main and auxiliary amplifiers are expressed as follows:

$$I_{out}(2\omega_2 - \omega_1) = \frac{3A^3}{4} G_3 e^{j(2\omega_2-\omega_1)t} \tag{2}$$

It is also expressed by phases of the main and auxiliary amplifiers as follows:

$$I_{out(main)}(2\omega_2 - \omega_1) = \frac{3A^3}{4} G_{3(main)} e^{j\theta_{main}} \tag{3}$$

$$I_{out(aux)}(2\omega_2 - \omega_1) = \frac{3A^3}{4} G_{3(aux)} e^{j\theta_{aux}} \tag{4}$$

where θ_{main} and θ_{aux} are phases of the third-order intermodulation product which are dependent on G_3 of the main and auxiliary amplifiers. Negative value of the G_3 factor occurs when the main amplifier is biased to operate as the class-E amplifier. If the auxiliary amplifier is biased to exhibit positive G_3 providing the same magnitude as that of the main amplifier, the overall third-order intermodulation would be eliminated.

Design and simulation results: The proposed class-E Doherty amplifier with g_{m3} cancellation has been design and simulated using Agilent ADS2003A. The circuit was designed using the Mitsubishi MGF2415A (GaAs FET) at 1.95 GHz. For proper comparison, simple Doherty amplifiers employing a class-E or class-A amplifier for the main amplifier were also designed. The class-E amplifier has been used for the auxiliary amplifiers for all the different designs. Fig. 2*a* shows that the simulated PAE of the proposed Doherty amplifier is 52.8% at 18 dBm RF input. It gives higher efficiency than the conventional Doherty amplifier using the class-A amplifier as the main amplifier (39.4% PAE).

Measurement results: The proposed Doherty amplifier was fabricated on Duroid RT5880 substrate. Fig. 2*a* also shows the simulated and measured PAEs of the proposed Doherty amplifier where the maximum measured Pout is observed as 28 dBm and the maximum measured PAE obtained is 50.2%. Fig. 2*b* shows comparison of IMD3 between simulation and measurement for the proposed circuit compared to the Doherty amplifier without g_{m3} cancellation. The IMD3 of the proposed Doherty amplifier with g_{m3} cancellation was improved by 11 dB (at Pout 18 dBm), compared to the Doherty amplifier without g_{m3} cancellation.

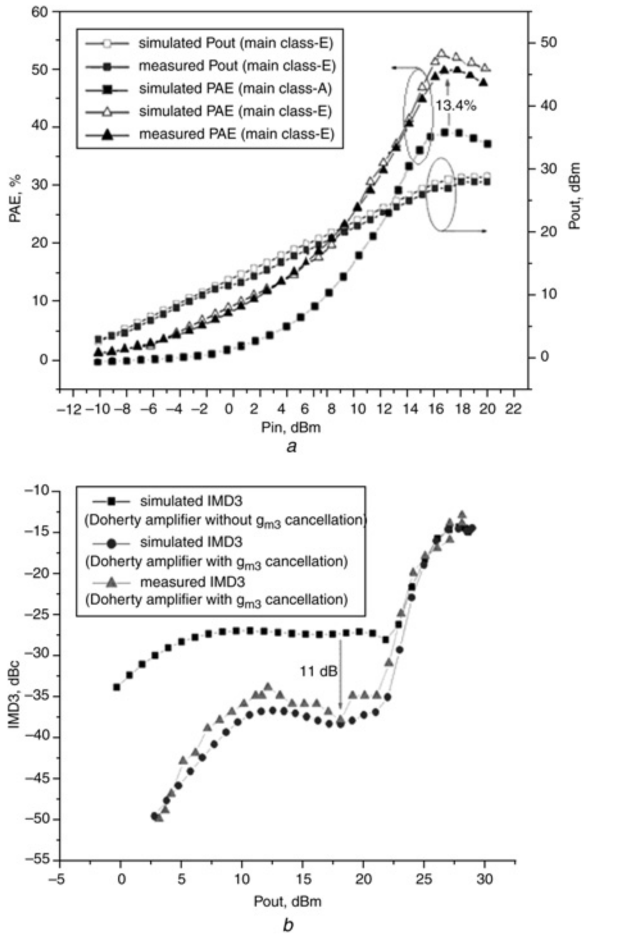

Fig. 2 *PAE and Pout and measured IMD3 results of proposed Doherty amplifier*

a PAE and Pout results
b Measured IMD3 results

Conclusion: g_{m3} cancellation has been applied successfully to the class-E Doherty amplifier. The proposed Doherty amplifier improves linearity compared to that of the Doherty amplifier using the class-E amplifier without g_{m3} cancellation. The PAE is also maintained high. The proposed Doherty amplifier presents higher efficiency and linearity than the conventional Doherty amplifier.

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