A Novel Configuration for the Doherty Amplifier for Load Modulation Enhancement and Bandwidth Improvement

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***Abstract* — A novel topology for Doherty amplifiers has been proposed to overcome the size and bandwidth issues associated with the conventional approach. The commonly used, bulky and narrowband quarter-wave impedance inverter has been replaced by a varactor-based impedance transformer which is controlled adaptively by envelope tracking. A 2W Doherty amplifier has been fabricated using discrete pHEMT devices and low loss varactors. Measurements have been carried out at 2GHz over a 400 MHz bandwidth. Power added efficiency of better than 45.3% has been achieved at maximum power level and 6-dB power backoff and maintained over the entire bandwidth. Measured IM3 is better than -42.2dBc at P1dB of 33dBm for all design frequencies.**

***Index Terms* — Power added efficiency, Doherty power amplifier, Doherty, bandwidth.**

I. INTRODUCTION

Modern communication systems require stringent capabilities in terms of linearity and efficiency. The need to amplify a variable envelope signal with high peak-to-average power ratio in multi-carrier technologies such as WCDMA or OFDM imposes tough challenges on the amplifiers that typically deliver their highest efficiency at their maximum output power. The Doherty power amplifier [1] has recently gained a lot of attraction due to its simple concept, ease of implementation and promising efficiency enhancement in backed-off power region. However, the conventional Doherty power amplifier suffers from some disadvantages such as narrow bandwidth and large size due to its critical use of passive quarter-wave transmission lines as impedance inverters. Fig.1 shows the block diagram of the Doherty configuration.

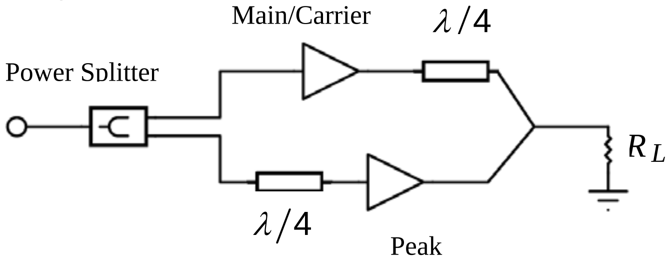

Fig. 1. Block diagram of the conventional Doherty amplifier

An additional amplifier named as the “Peak” amplifier is employed to pull the load seen by the “Main/Carrier” amplifier in order to maintain the maximum efficiency as the input power decreases. A quarter-wave impedance inverter is placed at the output of the main amplifier to ensure the decrease of the impedance seen by the carrier amplifier as the input power increases [2]. There are a few problems associated with the use of a passive quarter-wave transmission line. The quarter-wave impedance inverter appears to be large and bulky. With the current trend of RF transceivers toward miniaturization and the ongoing downscaling of the semiconductor components, this is specially a barrier against realization of highly integrated Doherty power amplifiers. The most commonly used solution for this problem is to realize the impedance inverter using lump components [3] [4], but this solution restricts the bandwidth even further. Another problem associated with using a quarter-wave transmission line is that the impedance seen at the output of the carrier and peak amplifiers is modified by the parasitic capacitors (such as voltage dependant drain-source capacitance) and inductors (such as bond wires). In other words, the load impedance seen from the device lead reference plane is different from the one seen at the current generator reference plane. In this work, a novel topology is proposed which could replace the passive impedance inverter and emulate its function while eliminating its disadvantages.

II. DYNAMIC IMPEDANCE TRANSFORMATION

Fig.2 shows the current and voltages of main and peak amplifiers. At the maximum power level the impedance seen by the main amplifier is R_{opt}. As the input power decreases, the impedance seen by the main amplifier increases due to the load pulling effect of the peak amplifier. At the 6dB backoff point, the impedance seen by the main amplifier reaches $2R_{opt}$. This will help maintain the maximum voltage swing at the output of main amplifier as the output power changes within the 6dB power backoff and hence the efficiency enhancement within the range.

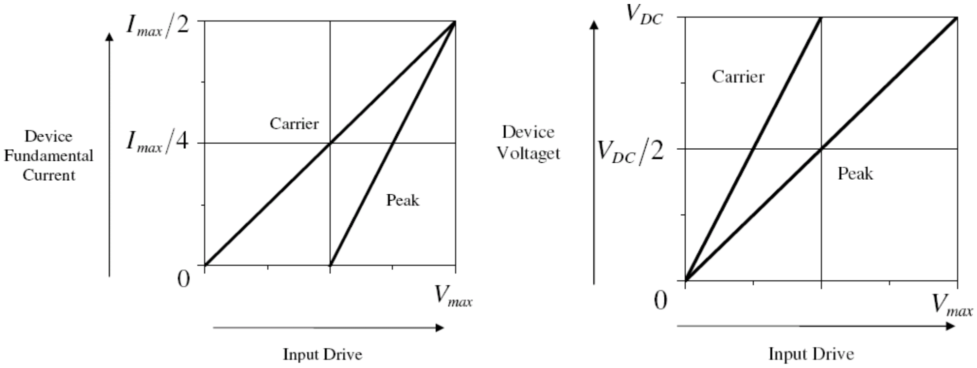

Fig. 2. Device currents and voltages of the main and peak amplifiers

The above transformation can not be efficiently carried out in real devices due to presence of parasitics. The situation is even worse when voltage dependent parasitics are involved. In this case it is impossible to perform the required transformation using passive elements. An adaptive nonlinear arrangement is required to present the correct impedance to the main amplifier at every input power level.

Based on above discussion, the quarter-wave impedance inverter is eliminated and replaced by a varactor-based adaptive impedance transformer. Fig.3 shows the proposed topology to replace the conventional quarter-wave transmission line.

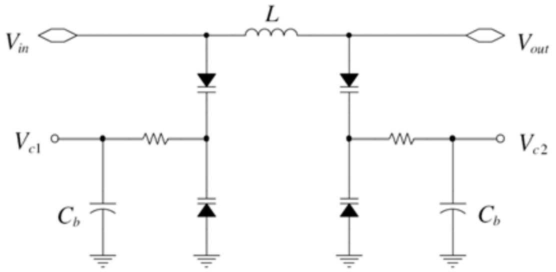

Fig. 3. The proposed adaptive impedance transformer

It consists of shunt variable capacitances realized by anti-series connected varactor diodes. It has been shown in [5] that an anti-series connection of varactors with the correct device size ratio can offer a theoretically linear performance. The varactor capacitance is modeled as

$$C(V) = \frac{K}{(\phi + V)^n}, \qquad (1)$$

where, K is a constant, ϕ is the built-in potential and V is the total voltage, and n is the power law exponents which is determined by the device size. This configuration has previously been used for an adaptive class AB amplifier [6] which achieves higher efficiency at the expense of linearity.

This configuration can perform enhanced load modulation controlled by the input envelope in a wide bandwidth.

III. CIRCUIT DESCRIPTION

A schematic diagram of the proposed topology is shown in Fig.4. The quarter-wave impedance inverter is replaced by the proposed circuit shown in Fig.3. A similar arrangement is placed before the peak device to compensate for the phase delay created by the impedance transformation at the main path so that the peak and main device currents combine in phase. The bias voltages of the varactors are adaptively modified according to input power via a wave shaping circuit controlled by an envelope detector.

Supply modulation [7] has been employed to adaptively modify the gate bias of the peak transistor using based on the input envelope. This is to facilitate the use of devices with equal size as the main and peak devices which otherwise would have required different sizes [2]. Indeed, the function of the envelope detector has been extended to perform adaptive load modulation as well as bias adaptation. It is easy to see that with this arrangement the load modulation can be carried out in multiple frequency bands with different control voltage profiles. The proposed circuit can be miniaturized with a high level of integration without compromising the bandwidth.

IV. MEASUREMENTS

A 2W discrete Doherty amplifier has been fabricated using Transcom's TC2571 GaAs pHEMT transistors and Infineon's BB837 varactors. The performance of the proposed Doherty amplifier has been compared to a class-AB power amplifier and a conventional 2-stage Doherty amplifier using the same devices. The measurements have been carried out at three sample frequencies, 1.8GHz, 2GHz and 2.2GHz in order to evaluate the multi-band performance of the proposed structure. The main transistor of the proposed structure operates in class AB. At 1.8GHz, the new topology achieves an improvement of 12% at 6-dB power back off and 5% at maximum power level over the conventional approach.

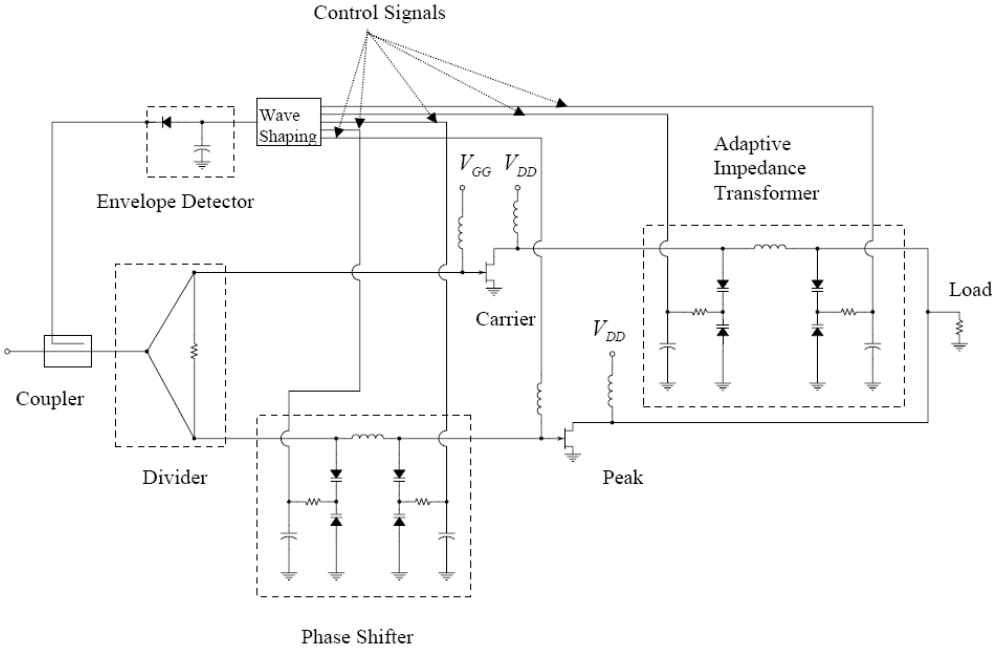

Fig. 4. The schematic diagram of the proposed topology for the Doherty amplifier

The peak amplifier's class of operation changes from deep class-C to class AB as the input power level increases from the 6-dB backoff point to maximum power level. Table.I shows how Z_L seen at the drain lead of the main transistor should change for the correct load modulation at the current generator reference plane.

TABLE I

MAIN PA LOAD IMPEDANCE TRANSFORMATIONS

Freq	Z_L at 6-dB backoff	Z_L at maximum power
1.8GHz	61.6+j27.2	31.5+j25.4
2GHz	50.4+j31.4	28.4+j28.1
2.2GHz	47.8+j36	20.1+j30

The wave-shaping circuit adaptively sets the bias voltages of the varactors to realize the transformation shown in Table.I for the carrier amplifier path and compensate its phase delay in the peak amplifier path. Measured output power and gain of the proposed Doherty amplifier versus the input power are shown in Fig.5. It can be seen that the proposed topology can achieve multi-band performance. Fig.6 compares power added efficiency of the design with a conventional Doherty amplifier and a class AB amplifier at 3 different design frequencies. It can be seen that at 2GHz, power added efficiency of the proposed design is 49.4% at 6-dB power backoff which shows an improvement of 6% over the conventional Doherty amplifier with a quarter-wave transmission line. At 2.2 GHz, an improvement of 10% at 6-dB power backoff and 4% at maximum power level has been achieved.

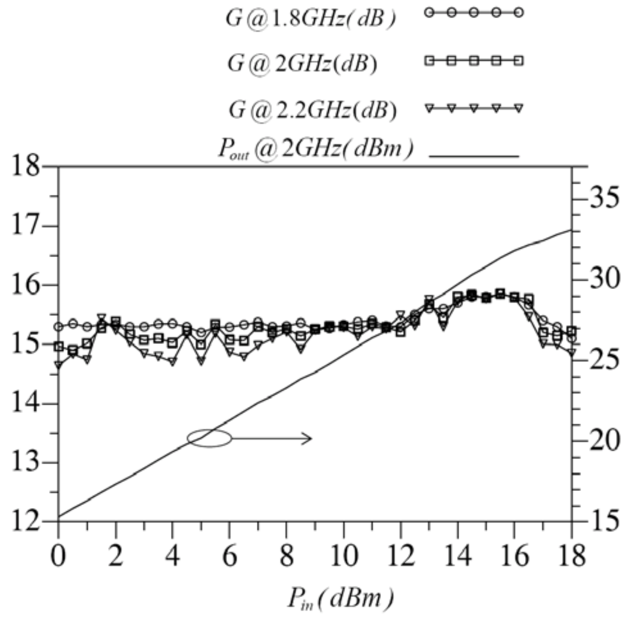

Fig. 5. Measured gain and output power of the proposed structure

It can be concluded that the proposed topology is capable of achieving broadband efficiency enhancement and improved load modulation. Fig.7 shows the linearity performance of the design. Since the anti-series connection of the varactors with proper power law exponents can achieve inherently linear performance, linearity is not significantly degraded. Measured IM3 at P1dB of 33dBm is better than -42.2dBc.

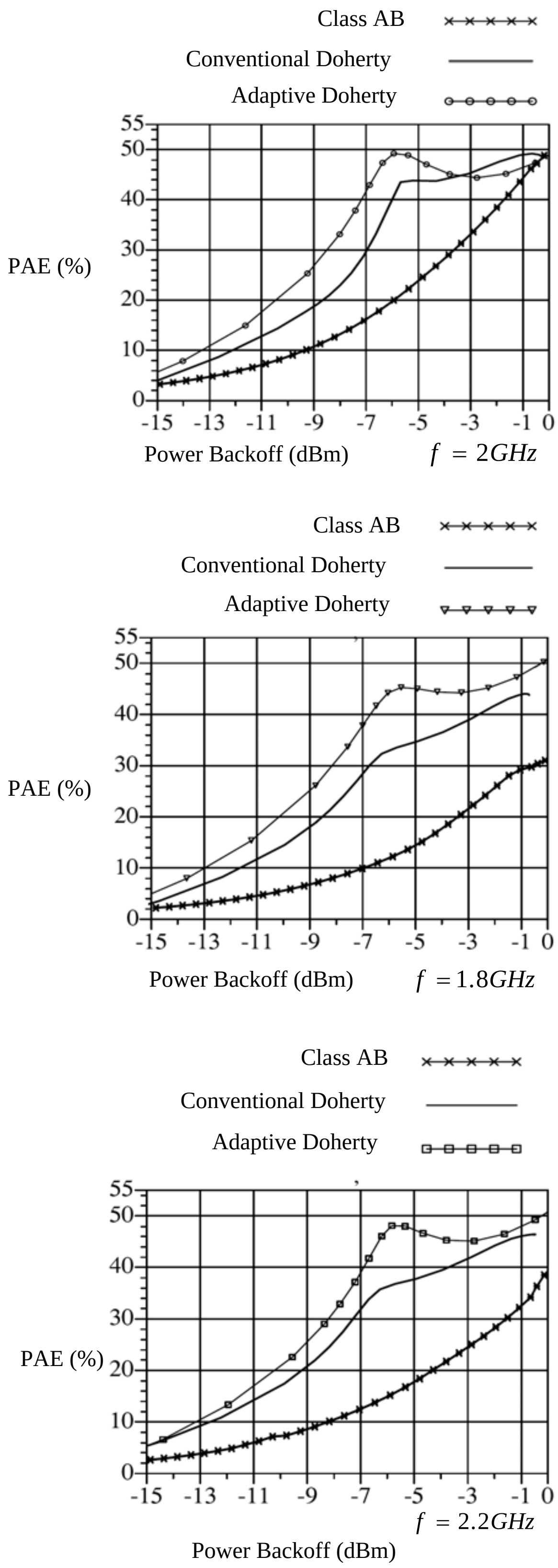

Fig. 6. Measured PAE of the class-AB, conventional and the proposed Doherty amplifier at 1.8GHz, 2GHz and 2.2 GHz

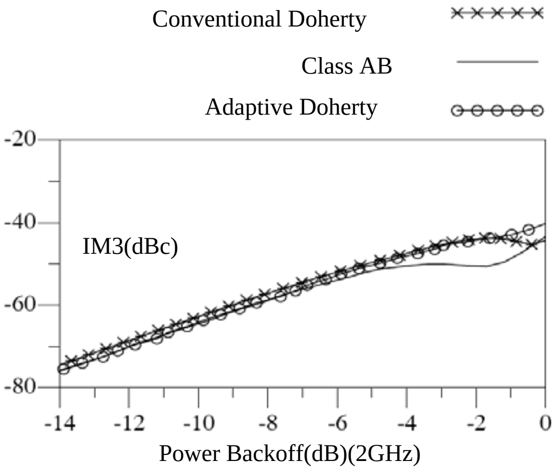

Fig. 7. Measured IM3 distortion of the class-AB, conventional and the proposed Doherty amplifier (2-tone, 100 KHz carrier spacing)

VII. CONCLUSIONS

A novel configuration for the Doherty amplifier has been proposed which proves to achieve high bandwidth, enhanced load modulation and high integration level. The realized design achieves a minimum efficiency of 45.3% within the 6-dB power backoff and maintains it over a bandwidth of 400MHz. IM3 has been measured to be better than -42.2dBc at P1dB of 33dBm.

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