IMPROVEMENT OF EFFICIENCY AND LINEARITY OF A HARMONIC CONTROL AMPLIFIER BY ENVELOPE CONTROLLED BIAS VOLTAGE

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ABSTRACT

The concept of a half sinusoidally driven class A harmonic control amplifier (hHCA) for a center frequency of 1.6125 GHz is expanded by a dynamic bias control, that uses the DC drain current of the driver stage for an envelope detection of the input signal. At two-tone stimulus the control of drain voltage and drain current of the power stage according to the envelope of the input signal improves either intermodulation distortion distance (IMDD) by 10 dB or raises overall power-added efficiency (PAE) for two-tone signals to 60%, a value similar to single-tone excitation.

INTRODUCTION

For a lot of modulation schemes the transmitter amplifier of a radio-link has to deal with a highly time-varying envelope of the input signal. A conventional class A amplifier design solves this problem by driving the amplifier far below output power compression to offer a sufficient dynamic range. This leads to good linearity but poor efficiency of the power amplifier.

Adel A. M. Saleh et. al. have shown that a dynamic control of the gate bias can improve the efficiency of a class A amplifier by lowering the drain current for small input power levels [1]. C. Buoli et. al. reported a DC power-saving by use of an envelope controlled drain power supply without any degradation of the transmitted spectrum [2]. S. Bouthilette et. al. have shown the relation between efficiency, noise power ratio, and input power level for different drain voltages. As conclusion they found optimum drain voltages for given two-tone or noise input power levels [3].

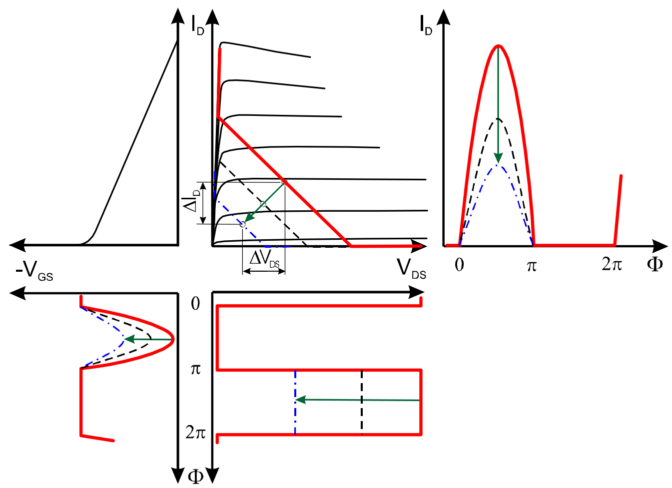

Fig. 1: Dynamic load line and signal waveforms of an hHCA for three different input power levels

THE hHCA CONCEPT

The concept of the hHCA [4] is based on a class F amplifier which is a class B amplifier with a special harmonic output matching. The same matching is used for an hHCA but the input signal of the hHCA is half sinusoidal. This signal is generated by a class B driver stage. The advantage of an hHCA is that its gain is similar to the class A gain of the amplifying device which is 3 dB to 6 dB higher than that of a class F or class B amplifier and that the drain efficiency is as high as in class F (ideally 100 %). Therefore, an hHCA can reach very high power-added efficiencies.

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This high efficiency is caused by the relation of current and voltage waveform at the output of the amplifying device. The harmonic matching forces the current waveform to be half sinusoidal and the voltage waveform to be rectangular (Fig. 1). Drain voltage and drain current are phase-shifted so that drain current reaches zero when drain voltage is unequal to zero and vice versa. When the bias is fixed this relation is true only for one special input power level even in the ideal case. So, if input power level decreases, drain current and drain voltage have also to be decreased to get maximum efficiency (Fig. 1).

For a real device the gain gets too small when the drain voltage V_{DS} and the drain current I_D is lowered too much. An upper bound is reached when the device is overdriven. In practice there is a device dependent range ΔI_D and ΔU_{DS} for changing the bias according to the input power level to get an improvement in efficiency.

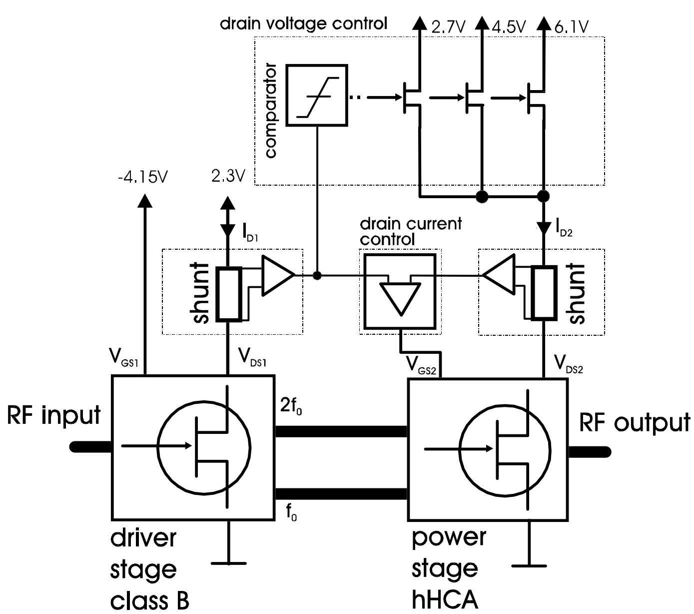

Fig. 2: Block diagram of the hHCA with dynamic bias control

IMPLEMENTATION (Fig. 2)

The class B driver stage is realized with a THOMSON TC6519 GaAs MESFET. It delivers a fundamental frequency signal (f_0) and a second harmonic frequency signal ($2f_0$) to the hHCA power stage. When these two signals have the right magnitude and phase relationship the superposition is a good approximation of a half sinusoidal signal. Combining of these two signals is done by the input matching network of the hHCA.

Because the driver stage is biased at class B, the DC drain current I_{D1} depends on the amplitude of the RF input signal. This effect is used to detect the envelope of the input signal [5]. We use a shunt and a video operational amplifier to get a reference input signal for the drain current control and the drain voltage control.

The hHCA power stage consists also of a THOMSON TC6519 GaAs MESFET. The drain current control uses the gate voltage V_{GS2} as actuating signal to control I_{D2}. The feedback signal is generated by a shunt and a video operational amplifier. Offset and ratio of I_{D1} to I_{D2} can be tuned to adjust the essentially linear control characteristic.

To provide the drain voltage V_{DS2} with high efficiency, a switched mode power supply is state of the art. To cope with the large bandwidth of the control signal it would be necessary to use a very high switching frequency. Because such switched mode power supplies are not commercially available, we implemented the voltage control with three fixed voltages and switch them according to the reference signal. The threshold values of the comparator can be set to adjust the control characteristic of the voltage control. For our first experiments we used 2.7 V, 4.5 V and 6.1 V as fixed voltage values.

MEASUREMENTS

We performed single carrier and two-tone measurements on the amplifier with two different control characteristics for the bias voltages. The center frequency for all measurements was 1.6125 GHz. The frequency spacing for the two-tone measurements was 4 kHz. To characterize the intermodulation distortion we use the intermodulation distortion distance (IMDD) which we calculated according to

$$\mathrm{IMDD[dBc]} = 10 \cdot \log\left(\frac{\sum P_{carrier}}{\sum_n IMD_n}\right) \quad n=3,5,7,9,$$

where $\Sigma P_{carrier}$ is the power delivered by the amplifier at the signal frequencies and ΣIMD is the sum of the power delivered at the 3^{rd}, 5^{th}, 7^{th}, and 9^{th} order intermodulation frequencies.

Fig. 3 shows the result of a single carrier and a two-tone measurement. Both measurements were taken with the same control characteristic that raises the overall power-added efficiency (PAE) for low input power levels. Two remarkable effects appear to the PAE. The first effect which can be seen in Fig. 3 is that PAE for a two-tone signal is almost as high as PAE for a single carrier signal. The second effect gets evident by comparing Fig. 3 with Fig. 4: For low input power levels the two-tone PAE with bias control (Fig. 3) is twice as high as in the fixed bias case (Fig. 4). The price one has to pay for this improvement is the lower output power level of the amplifier with bias control which can be seen by comparing Fig. 3 with Fig. 4. An interesting feature of this control characteristic is that IMDD for high input power levels is almost the same as for fixed bias.

In Fig. 4 the result for a different control characteristic is shown. The feature of this control characteristic is that IMDD for high input power levels (above -2 dBm) is improved as compared to fixed bias conditions. This improvement is up to 10 dB at 0 dBm input power level with almost the same efficiency as in the fixed bias case (Fig. 4). The unsteady IMDD curve is caused by the drain voltage switching and can be smoothened out by adjusting the three fixed voltage values and the thresholds of the comparator.

It is important to note that for this control characteristic the gain for a two-tone signal is almost constant over the whole input power range, but the output power level is even lower than with the control characteristic adjusted for a high PAE.

CONCLUSION

We have improved a harmonic control amplifier for 1.6125 GHz by a dynamic bias control. Measurement results for two different control characteristics show that overall power-added efficiency can be doubled for small input power levels. Alternatively intermodulation distortion distance can be improved by up to 10 dB for large input power levels. In principle, this two control characteristics can be combined to get high efficiency amplifiers with good linearity over a large input power range.

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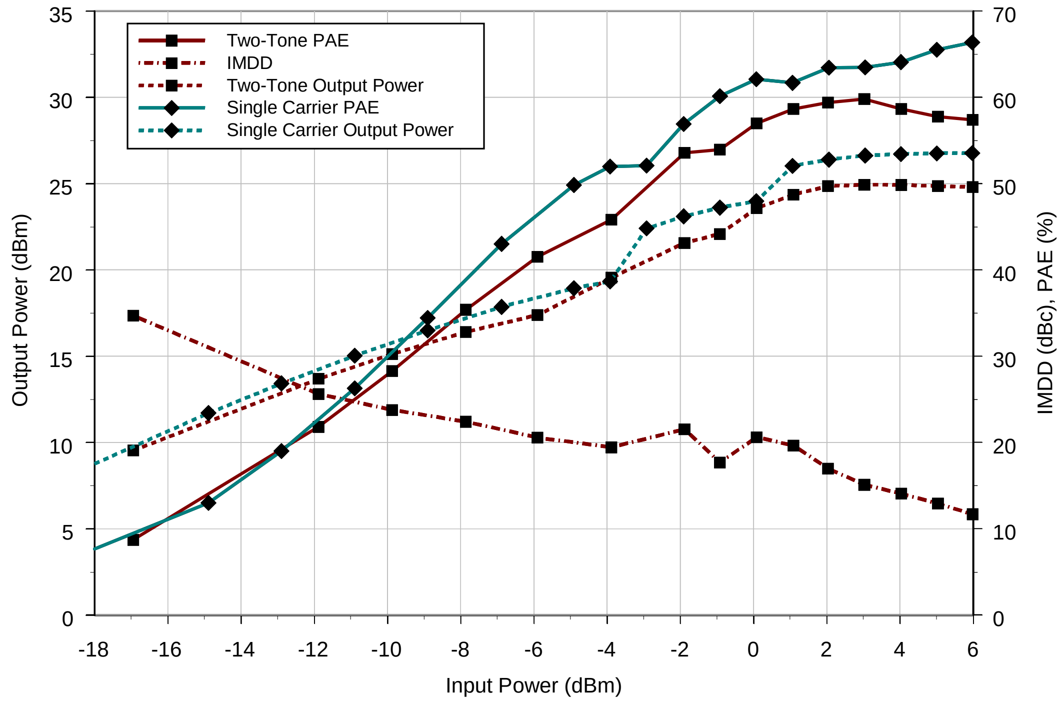

Fig. 3: Comparison of single carrier performance and two-tone performance with a control characteristic adjusted for high power-added efficiency

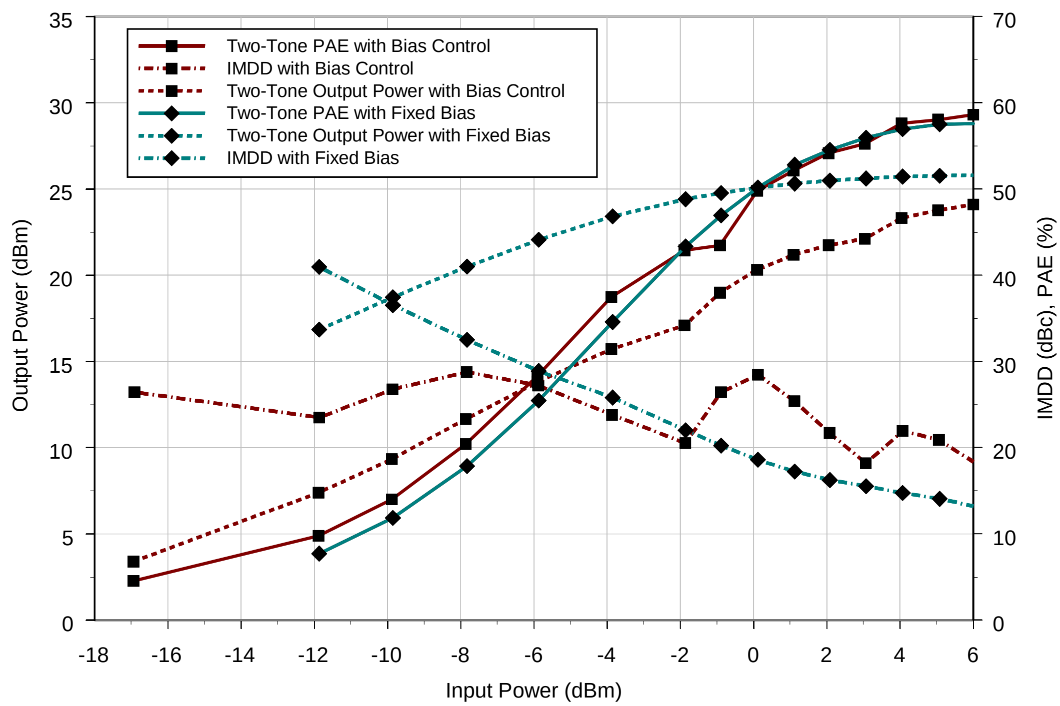

Fig. 4: Comparison of two-tone performance with fixed bias at V_{DS2}=6.1 V and I_{D2}=100 mA and two-tone performance bias-control adjusted for high IMDD