Broadband Microstrip Doherty Amplifier Design and Linearization

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Abstract – **In this paper the linearization of a broadband two-way Doherty amplifier designed for application in the frequency range 0.9-1.05 GHz is considered. The amplifier is characterized by the maximum output power 8 W and a broadband microstrip matching circuit combined with real lumped SMD components. The linearization of the amplifier is carried out by the second- and fourth-order nonlinear signals that are extracted at the output of the peaking cell, adjusted in amplitude and phase and fed at the input and output of the carrier cell in Doherty amplifier. The effects of linearization are considered for two tone signals separated by various frequency interval from 2 MHz to 30 MHz at different input power levels (5 dBm to 15 dBm), as well as for WCDMA digitally modulated signal.**

Keywords – **Doherty amplifier, Broadband, Microstrip, Linearization, Second- and fourth-order nonlinear signals, Intermodulation products.**

I. INTRODUCTION

In modern wireless communication, power amplifiers in transmitters need to support multi-standard modulation schemes and to provide a high efficiency, wideband operation, and linear performances.

The Doherty amplifier architecture is one of the most attractive among various techniques for efficiency enhancement. Significant efforts have been devoted to the development of the linearization techniques for suppression of the nonlinear distortions in a Doherty amplifier: the post-distortion-compensation [1], the feedforward linearization technique [2], the predistortion linearization technique [3] and their combination [4].

The linearization effects of the fundamental signals' second- (IM2) and fourth-order nonlinear signals (IM4) at frequencies that are close to the second harmonics on the standard (two-way, three-way and three-stage) Doherty amplifiers were investigated in simulation, [5]. We applied the approach where the IM2 and IM4 signals are injected together with the fundamental signals into the carrier amplifier input and fed at its output [6]. Additionally, the influence of IM2 and IM4 signals on Doherty amplifier linearity was verified experimentally on a standard symmetrical two-way Doherty amplifier [6], [7].

A broadband two-way Doherty amplifier with an additional circuit for linearization was designed in configuration with combined matching circuits comprising the ideal transmission lines and lumped elements, [8]. The impact of band-pass filters in the linearization circuit on the amplifier performance was analyzed for four different types: doubly and singly terminated ideal bandpass filters, hairpin band-pass filter and the combination of a singly terminated stop-band filter with a hairpin filter.

In this paper, a broadband two-way Doherty amplifier with an additional circuit for linearization is designed in microstrip technology to operate over the frequency range 0.9-1.05 GHz. The linearization technique applied utilizes the even-order nonlinear signals, (IM2 and IM4) at frequencies close to the second harmonics, which are generated at the output of the peaking cell. They are adjusted in amplitude and phase through the linearization branches and run at the carrier transistor input and output over the microstrip hairpin band-pass filters. The effects of the linearization are considered through the simulation for two sinusoidal signals with different frequency interval between them starting from 2 MHz and going up to 30 MHz. Additionally, Doherty amplifier is linearized for WCDMA digitally modulated signal.

II. BROADBAND DOHERTY AMPLIFIER DESIGN

A two-way Doherty amplifier in standard configuration [1], [2], [4], [5], whose schematic diagram is shown in Fig. 1, is designed by using Agilent Advanced Design System-ADS.

Output combining circuits comprise two quarter-wave impedance transformers with the characteristic impedance R_0=50 Ω and $R_t = R_0/\sqrt{2}$. Phase difference of 90° caused by the 50 Ω quarter-wave impedance transformer at the output is compensated at the input by a 3dB quadrature branch-line coupler. Since the peaking amplifier starts to operate in a higher power region it should be an open circuit for a low-power to prevent current leakage from the carrier amplifier; therefore its strongly reactive impedance is transformed to the open by the output matching circuit and the proper offset line.

The carrier and peaking cells were designed using Freescale's MRF281S LDMOSFET which non-linear MET (Motorola's Electro Thermal) model is incorporated in ADS library. The transistor shows a 4-W peak envelope power. The matching impedances of carrier and peaking cells for source

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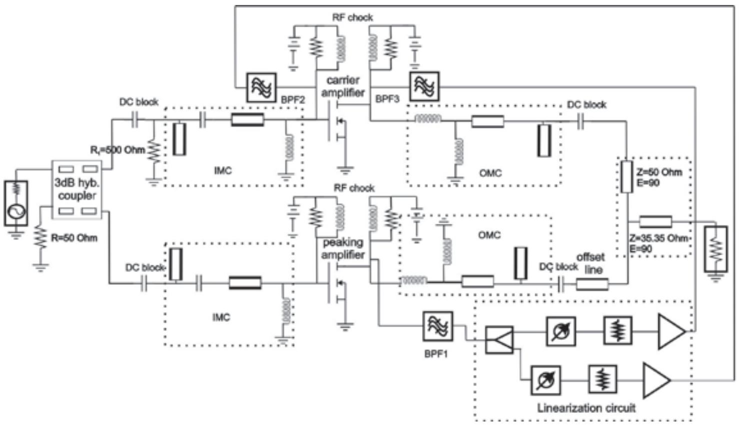

Fig. 1. Schematic diagram of microstrip broadband two-way Doherty amplifier with additional circuit for linearization

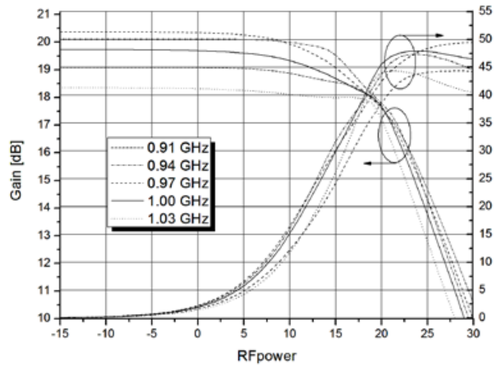

Fig. 2. Gain and DE in terms of one-tone input power at 0.91 GHz, 0.94 GHz, 0.97 GHz, 1 GHz and 1.03 GHz

and load at 1 GHz were determined by using source-pull and load-pull analysis in ADS, so that for the carrier stage they are $Z_S = (5.5 + j15)\Omega$ and $Z_l = (12.5 + j27.5)\Omega$, respectively, and for the peaking stage $Z_S = (3.55 + j15.7)\Omega$ and $Z_l = (3.95 + j30.85)\Omega$.

The carrier amplifier is biased in class-AB ($V_D = 26$ V, $V_G = 5.1$ V (13.5% of IDSS-transistor saturation current)), whereas the peaking amplifier operates in class-C ($V_D = 26$ V, $V_G = 3.6$ V).

A broadband operation of the amplifier circuit needs broadband input and output matching circuits of the transistor that are based on the filter structures with lumped elements. A detailed insight into the design process with all necessary transformations is given in [9]. The lumped element matching circuits were then transformed into the matching circuits with transmission lines determined by appropriate characteristic impedances and electrical lengths, [8]. In the next step, the calculation of dimensions of the microstrip lines that correspond to the ideal transmission lines was carried out. In order to design a matching circuit possible to be realized in microstrip technology, the microstrip lines were combined with commercially available SMD (Surface Mounted Devices) components instead of the additional lumped elements in the matching circuits. The microstrip substrate parameters are: dielectric constant ε_r=2.2, substrate height h=0.635mm and metallization thickness t=17μm.

The stabilization of the carrier and peaking amplifier was performed by the resistances connected in parallel with RF chocks in DC power supply circuits of the transistor, as well as by the resistance parallel to the input matching circuit in carrier cell, as shown in Fig. 1. The values of these resistances were selected in the range 300-600 Ω in order to prevent losses of the fundamental signals.

The IM2 and IM4 signals generated at the output of peaking transistor were extracted through the band-pass filter (BPF1) characterized by the centre frequency around the second harmonics to pass the signals for linearization (IM2 and IM4 signals). The linearization circuit comprises two independent linearization branches consisting of the variable attenuator, voltage variable phase shifter and amplifier to adjust IM2 and IM4 signals in amplitude and phase. They are supplied at the carrier transistor input and output over the band-pass filters BPF2 and BPF3, respectively, as illustrated in Fig. 1.

The attenuators, phase shifters, amplifiers are ideal circuits taken from ADS library. The band-pass filter was designed as a hairpin filter (HP) with three sections at the centre frequency 2 GHz and 20% bandwidth on the microstrip substrate. The band-pass filters have the greatest influence on the amplifier behaviour since they are directly connected to the gate and drain of the transistors in the Doherty amplifier. The performances of the Doherty amplifier deteriorate by the insertion of the linearization branches. Accordingly, in order to correct degradation and improve the amplifier characteristics, we performed an additional optimization of the microstrip line parameters in the input and output matching circuits of carrier and peaking amplifiers.

Figure 2 shows the gain and drain efficiency, DE, of the Doherty amplifier as a function of the input power for single-tone excitation at frequencies 0.91 GHz, 0.94 GHz, 0.97 GHz, 1 GHz and 1.03 GHz. In a low power range, the gain observed at the excitation frequencies varies in the range of approximately 2 dB. However, the gain achieved at the considered frequencies differs less and less with the power rise from 15 dBm to 20 dBm. The drain efficiency at 0.91 GHz and 1.03 GHz deviates from the DE at 1 GHz by maximum 5% going up to 15 dBm input power, whereas differences at higher power range go up to 7% maximally.

III. Linearization Results

In order to assess the impact of the proposed linearization technique that uses the second- and fourth-order nonlinear signals on the designed microstrip Doherty amplifier, a two-tone test was performed in ADS. One sinusoidal signal at frequency 1 GHz and the other shifted in frequency by 2 MHz, and 5 MHz to 30 MHz with an increment of 5 MHz were simultaneously driven at the amplifier input.

The third-order intermodulation products, IM3, before and after the linearization, in terms of the frequency interval between the signals are represented in Fig. 3 for different power levels of fundamental signals at the amplifier input, 5 dBm, 8 dBm, 12 dBm, and 15 dBm (total power is 2 dB below 1-dB compression point).

According to the theoretical analysis of the linearization approach given in [5], [7] and [8], it is possible to reduce spectral re-growth caused by the third-order distortion of fundamental signal by choosing the appropriate amplitudes and phases of the IM2 signals injected at the input and output of the amplifier transistor. Additionally, the fifth-order intermodulation products can be suppressed by adjusting the amplitudes and phases of the IM4 signals that are inserted at the input of amplifier transistor and fed at its output.

The parameters of the linearization circuits in the designed microstrip Doherty amplifier were optimized to suppress third-order intermodulation products while the fifth-order intermodulation products were required to retain at as low as possible power level.

It should be noted that, after the linearization, a significant reduction of the IM3 products was attained in the considered power range. However, the figures clearly indicate that the augmentation of the input signal power lessens the grade of IM3 reduction. In the case of 5 MHz interval between the signals, the IM3 products are suppressed by 22 dB for the input power 5 dBm, whereas the rise of the input power 15 dBm leads to around 12 dB reduction of the IM3 products. When the frequency interval between two signals is 30 MHz the IM3 products decrease by approximately 20 dB at 5 dBm input power and around 8 dB for higher power levels.

We should indicate that the results achieved in the linearization of microstrip Doherty amplifier are very similar to the results that were achieved in the linearization of the broadband two-way Doherty amplifier designed with the ideal lumped elements matching circuit represented in [9], but for the smaller interval between two-tone frequencies up to 30 MHz, which corresponds to the results considered in [9] for maximum frequency interval of 80 MHz. This is the consequence of the distributed nature of the microstrip lines and frequency dependence of the real SMD lumped elements in the combined matching circuits regarding to the ideal lumped elements of the amplifier matching circuit applied in [9].

In order to evaluate the impact of the proposed linearization technique, the microstrip broadband Doherty amplifier with HP filters in the linearization circuit was also tested for WCDMA signal. This signal is characterized by the spectrum width of 3.84 MHz around the central frequency 1 GHz.

The test was carried out for different power levels of fundamental signals at the amplifier input, from 8 dBm, to 17 dBm. The parameters of the linearization circuits were optimized to suppress the third-order intermodulation products. The results of the analysis, the adjacent channel power ration-ACPR before and after the linearization in terms of the output power, which are observed at ±4 MHz offset from the carrier (the range of dominant third-order distortion) over 1.9 MHz frequency span, are shown in Fig. 4. It can be noted that the ACPR was improved by around 8 dB to 10 dB for the input power levels of 8 dBm to 12 dBm. It decreases with input power rise, so that the improvement is around 5 dB at maximum observed power level.

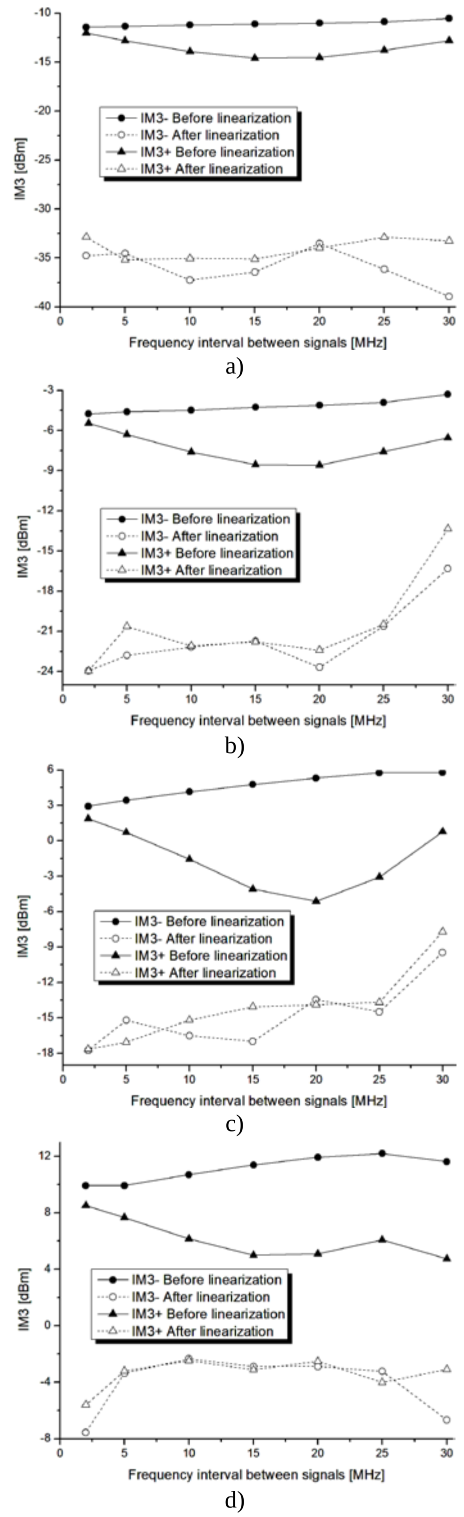

Fig. 3. Third-order intermodulation products of amplifier for combined microstrip matching circuits for different input power levels P_{in} =: a) 5 dBm, b) 8 dBm, c) 12 dBm, d) 15 dBm

Additionally, Fig. 5 represents the input spectrum for a WCDMA digitally modulated signal as well as output spectra before and after the linearization for 12 dBm input power.

Simulated results indicate that we have achieved around 10 dB better ACPR at ±4 MHz offset from the carrier by the linearization approach.

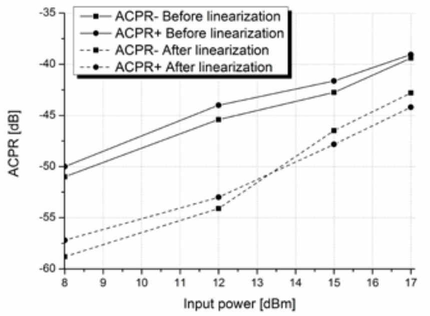

Fig. 4. ACPR before linearization (solid line) and after linearization (dashed line) for WCDMA signal in a range of input power

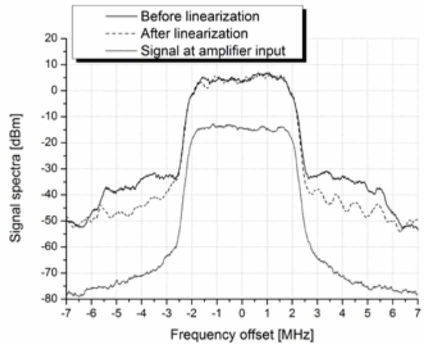

Fig. 5. Signal spectra at input and output of amplifier before (solid line) and after linearization (dashed line) for WCDMA signal at 12 dBm input power

If we consider the ACPR in the region of dominant fifth-order intermodulation products in output spectrum at ±6.5 MHz offset from the centre frequency, it follows from the Fig. 5 that the IM5 products are kept on the level before the linearization or reduced by a few decibels after the linearization.

According to the theoretical analysis of the linearization approach [7]-[9], IM2 and IM4 signals can reduce both IM3 and IM5 products. However, the suppression grade depends on the relations between the amplitudes as well as phases of the IM2 and IM4 signals generated at the peaking amplifier output. Nevertheless, when the required relations are not fulfilled, only one kind of the intermodulation products can be lowered sufficiently that is confirmed by the simulated results presented in this paper.

V. Conclusion

The effect of the linearization technique that uses the second- and fourth-order nonlinear signals of the fundamental signals at frequencies close to the second harmonics on the two-way Doherty amplifier designed in microstrip technology is considered in this paper. A broadband Doherty amplifier is designed to operate over the frequency range 0.9-1.05 GHz in configuration with matching circuits that consist of real SMD lumped components and microstrip lines. In the applied linearization method, the second- and fourth-order nonlinear signals are extracted at the output of the peaking transistor, adjusted in amplitude and phase throughout two independent branches and inserted into the input and output of the carrier cell over the hairpin microstrip band-pass filters. The results attained in simulation for two-tone test indicate a satisfactory suppression of the IM3 products, even when the frequency interval between signals increases. However, it should be pointed out that the decrease of intermodulation products becomes smaller when the power levels and interval between signals grow up. Moreover, the linearization of the designed Doherty amplifier for broadband WCDMA digitally modulated signal improves ACPR in the range of dominant third-order intermodulation products and retains the fifth-order nonlinearities at the sufficiently low power.

Acknowledgment

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