Linearization of microwave power amplifier for broadband applications

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Abstract — **The linearization of broadband power amplifier for application in the frequency range 0.7-1.1GHz is considered in this paper. The amplifier comprises Freescale's transistor MRF281S LDMOSFET characterized by the maximum output power 4W and the broadband lumped element matching circuits. The linearization of the amplifier is carried out by the second harmonics of the fundamental signals injected at the input and output of the amplifier transistor. The effects of linearization are considered for the case of two sinusoidal signals separated in frequency by 5, 10, 20, 40 and 80MHz for different input power levels of -5, 2 and 10 dBm, as well as for broadband WCDMA digitally modulated signal.**

Index Terms — **amplifier, linearization, second harmonics, intermodulation products**

I. INTRODUCTION

Modern wireless comunication systems (CDMA-2000, WCDMA, OFDM etc.) are developing toward the augmentation of frequency bandwidth to transmit a large number of carriers, with high velocity. In wireless comunication systems, Peak-to-Average power ratio (PAR) is very high, so that the power amplifiers (PA) in base stations need to satisfy the requirement of high linearity to amplify the signals with high PAR with a low distortion. The impact of the linearization tehnique that uses the second harmonics of fundamental signals (IM2) to suppress the intermodulation products of power amplifiers for narrowband applications has been analyzed in [1], [2] through the simulation process.

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The linearization was applied by simultaneous injection of the second harmonics to the input and output of the amplifier transistor. The experimental verification of the linearization method was performed on a standard narrowband amplifier at 1GHz for two cases: when the linearization signals are led only at the output of the amplifier transistor and when linearization signals are simultaneously inserted at the input and output of the amplifier transistor [3].

In this paper, a broadband power amplifier is designed to operate over the frequency range 0.7-1.1GHz and the linearization of the amplifier is carried out by simultaneous insertion of the second harmonics at the input and output of the amplifier transistor. The effects of the linearization are considered through the simulation for two sinusoidal signals with different frequency interval between them starting from 5MHz and going up to 80MHz, and for input signal power levels rangeing up to 1dB commpression point. Additionally, the amplifier are analyzed for the broadband WCDMA digitally modulated signal.

II. PA DESIGN APPROACH

Agilent Advanced Design System-ADS software was used for designing the broadband microwave amplifier. The amplifier was designed at central frequency 1GHz to operate over the frequency range 0.7-1.3GHz on the bases of the MET model of Freescale transistor MRF281S LDMOSFET. The source and load impedances $Z_S = (5.5 + j15)\Omega$ and $Z_l = (12.5 + j27.5)\Omega$, respectively, were obtained by load-pull and source-pull analysis in ADS. The satisfactory gain characteristic and matching at the input and output of the amplifier were attained over the frequency range 0.7-1.1GHz. Detailed insight into the amplifier design process will be given in the following steps:

Matching network design approach

In order to design a broadband amplifier circuit, the input and output matching circuits of the transistor are based on the filter structures with lumped elements. Primarily, a lowpass prototype of filter with the order N=3 was designed.

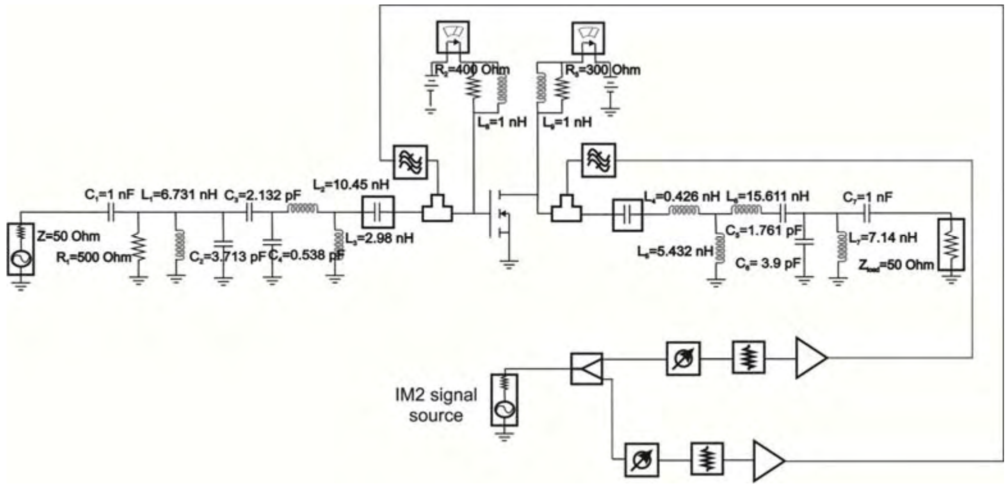

Fig. 1. Amplifier with lumped element matching circuit after applying Norton transformations with an additional circuit for linearization

The method of minimum reflection [4], [5] was used for calculating the normalized admittances of the prototype elements. The values of the reactive elements of the lowpass filter were calculated using the appropriate transformations [6]. Then, lowpass filter was transformed into a bandpass filter in a way that each series element was replaced by series resonant circuit, and each parallel element was replaced by a parallel resonant circuit at $\omega_0 = 1\text{GHz}$ [6].

Application of Norton transformations to the matching circuits

Norton transformations [5] were applied in order to reduce values of some inductances and capacitances in the matching circuits, which values did not correspond to the commercially available components. These transformations provide the scaling of the terminating resistors of matching circuits upwards or downwards to 50Ω using an ideal transformer with a certain transformation ratio *n*. After applying Norton transformations, approximately the same transmission characteristic and reflection losses were achieved in comparison with the basic matching circuit with lumped elements. Transformation ratio n=0.941 was selected for the output matching circuit, whereas n=1.2525 for the input matching circuit. Norton transformations implemented at the output matching circuit reduces the terminating load value from 56.45Ω to 50Ω, while at the input matching circuit another type of Norton transformations was exploited to increase the terminating load from 31.87Ω to 50Ω.

Stabilization of the amplifier

The designed matching circuits were then inserted at the input and output of LDMOS transistor as shown in Figure 1. Transistor is biased to operate in class-AB, V_D=26V, V_G=5.1V (13.5% I_{DSS}). The stabilization of the amplifier was performed by the resistances that are connected in parallel with RF chocks in DC power supply circuits of transistor, as well as by the resistance connected in parallel with the input matching circuit, as shown in Figure 1. The values of these resistances were selected in the range 300-600Ω in order to prevent losses of the fundamental signal.

Linearization circuit

With the aim to reduce the third-order intermodulation products of the amplifier, the linearization technique that utilizes the second harmonics of fundamental signals, IM2, was applied [1], [2]. For linearization purpose, IM2 signals were generated by an additional nonlinear source, as shown in Figure 1. The circuit for linearization consists of two independent branches which adjust amplitude and phase of the second harmonics and conduct them to the input and output of the transistor. The proposed linearization technique applied to the narrowband amplifiers [1], [2] feeds the IM2 signals to the input and output of the amplifier transistor over the frequency diplexers that separate fundamental signals and their second harmonics. As this paper analyzes the broadband amplifier linearization, the application of diplexers will not give satisfactory results. The IM2 signals are delivered to the input and output of the amplifier transistor throughout the bandpass filters characterized by 2GHz center frequency and 0.5GHz frequency bandwidth.

Figure 2 compares the parameters S_{21}, S_{11} and S_{22} in the case when the signals for linearization are led to the amplifier through an ideal bandpass filter (grey curve), and in the case when they are put throughout a coupled line filter designed in microstrip technology (black curve). Microstrip filter of the third order was designed on the substrate with parameters: ε_r=4.3, substrate height h=0.625mm, metallization thickness t=0.04mm and the tangent losses tgδ=0.002.

It visible from the graph that, although the broadband matching circuits were designed for amplifier to operate in the frequency range 0.7-1.3GHz, S_{11} and S_{22} parameters fulfill the requirements of acceptable matching at input and output of the transistor in a narrower frequency range. Thereby, in the case of microstrip bandpass filter in the circuit for linearization, S_{21} parameter as well as the input and output matching of the amplifier becomes a slightly worse with the increase of frequency. The frequency range where these parameters reach the acceptable values is 0.7-1.1GHz.

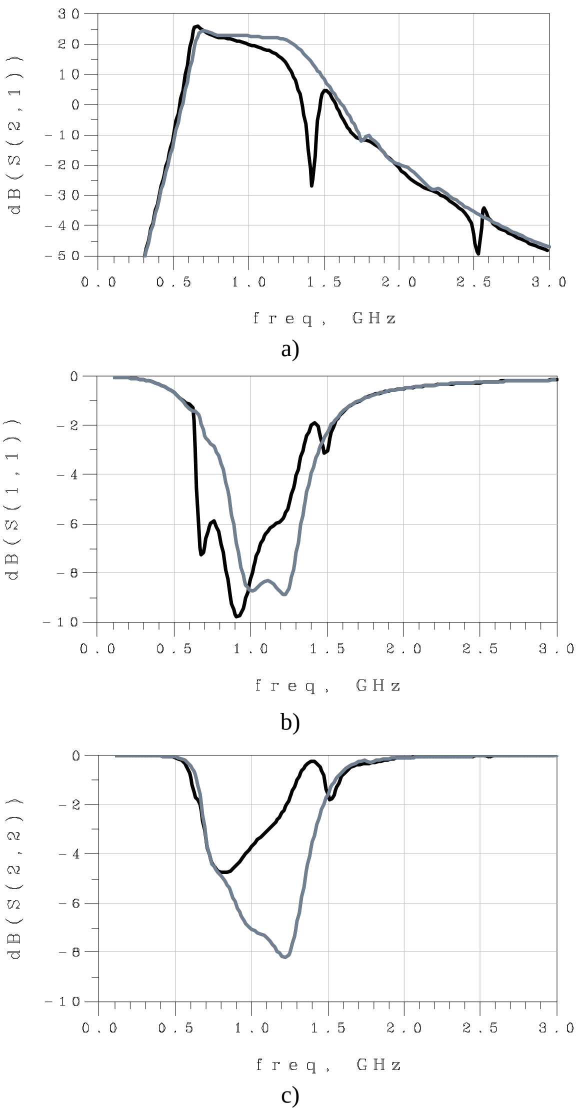

Fig. 2. S-parameters of the amplifier with lumped element matching circuits obtained by applying Norton transformations with ideal bandpass filter in circuit for linearization (gray curve) and with coupled line microstrip filter (black curve): a) S_{21}, b) S_{11}, c) S_{22}

III. LINEARIZATION OF THE AMPLIFIER

In order to assess the impact of the proposed linearization technique on the designed broadband power amplifier, two-tone test was performed in ADS. One sinusoidal signal at frequency 1GHz and the other shifted in frequency by 5, 10, 20, 40 or 80MHz were simultaneously driven at the amplifier input. The analysis was carried out for different input signal power levels of -5, 2, and 10dBm. At this stage of the analysis, the influence of the real structure of bandpass filter with microstrip coupled lines was observed, while the impact of other devices in the circuit for linearization - attenuator, phase shifter and amplifier will be considered in the next phase of research. Power level of the third-order intermodulation products, IM3, before and after the linearization, in terms of the frequency interval between the signals is presented in Figure 3 for power levels of fundamental signals at the amplifier input -5, 2 and 10dBm.

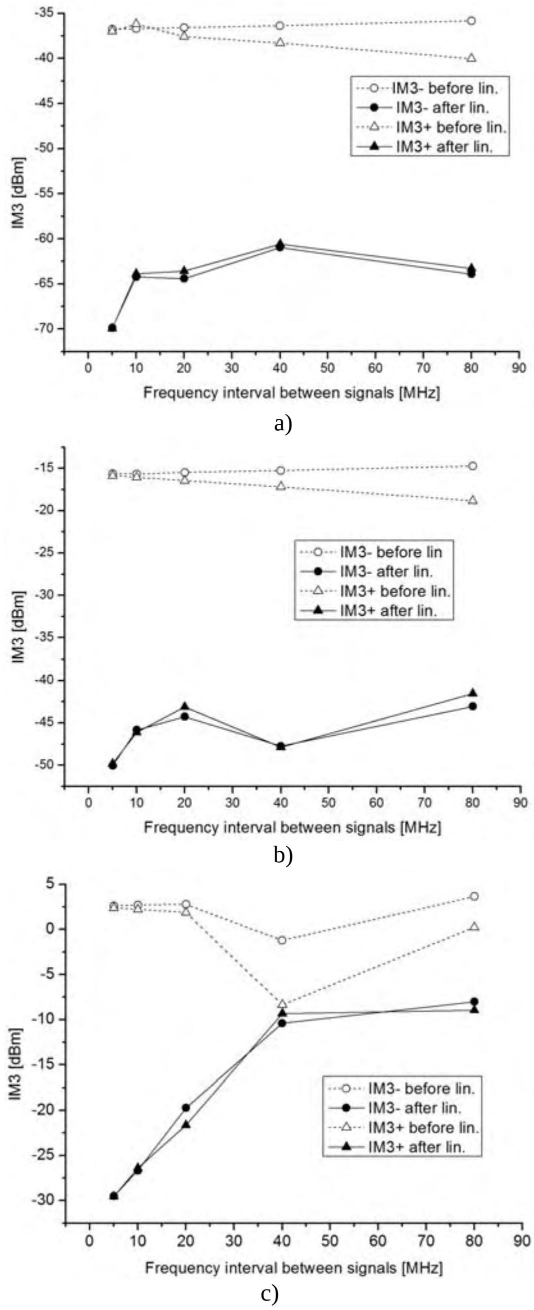

Fig. 3. Third-order intermodulation products of amplifier with lumped element matching circuits obtained by applying Norton transformations for input power levels: a) P_{in}=-5dBm, b) P_{in}=2dBm, c) P_{in}=10dBm

It can be noted that, after the linearization, a significant reduction of IM3 products was achieved in a considered power range. The figures clearly indicate that the augmentation of the signal power negligibly lessens the grade of IM3 reduction in the case of a small frequency interval between the signals; therefore, the IM3 are suppressed by approximately 35dB for 5MHz shifted signals. In the cases of -5dBm and 2dBm input power, almost an uniform drop of the third-order intermodulation products was achieved for the various frequency interval between the signals. However, the linearization grade of IM3 falls from 30dB in case of 10MHz frequency interval to the value of 10dB for 80MHz interval when input power is 10dBm.

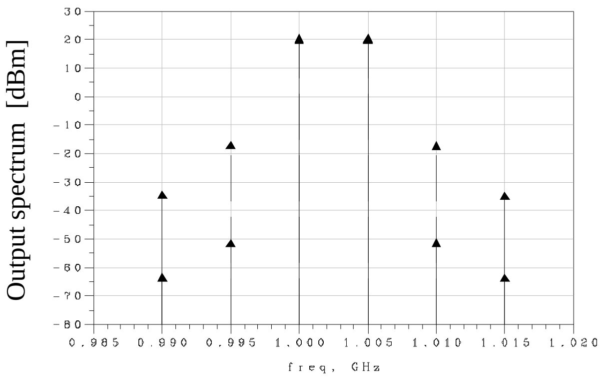

Fig. 4. Output spectra before linearization (dashed line) and after linearization (solid line) for two sinusoidal signals for frequency interval of 5MHz and input power level of 2dBm

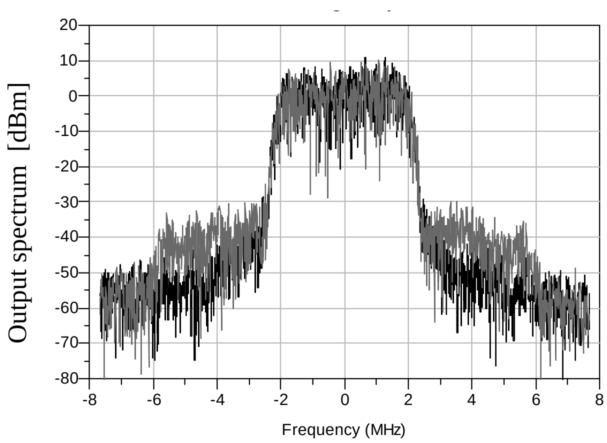

Fig. 5. Output spectra before linearization (grey line) and after linearization (black line) for WCDMA signal

The output spectra before and after the linearization are ilustrated in Figure 4 for two-tone test when signals are shifted by 5MHz and input power levels are 2dBm per signal. It is observed that the level of IM3 products descends from -16dBm to -50dBm after the linearization, while the level of the fundamental signal goes up slightly by approximately 0.5dB. The figure also shows degradation of the fifth-order intermodulation products that will be analyzed in the further research.

Moreover, the broadband amplifier was tested for WCDMA signal at central frequency 1GHz, the spectrum width of 3.28MHz and input power of 7dBm. The results of the analysis are shown in Figure 5. Parameter - Adjacent channel power ratio, ACPR, is improved by 10dB at ±4MHz offset from the carrier.

IV. Conclusion

This paper presents the analysis of the impact of the linearization technique, which uses the second harmonics of the fundamental signals, on suppression of the third-order intermodulation products in case of broadband power amplifier. The amplifier is designed to operate over the frequency range 0.7-1.1GHz in configuration with lumped element matching circuits. In the applied linearization method, the second harmonics are adjusted in amplitude and phase throughout two independent branches and inserted into the input and output of the amplifier transistor over the bandpass filter. The effect of the real microstrip filter designed in configuration with coupled lines is analyzed. Very good results are achieved in reduction of the third-order nonlinearity of the amplifier observing the two-tone test for a signal power range, all up to the point of saturation. Furthermore, the satisfactory results are gained in cases when the frequency interval between signals rises. However, it can be noticed that the intermodulation products decrease by smaller values when the power levels and interval between signals grow up. In addition, test of the amplifier for the broadband WCDMA digitally modulated signal also shows positive effect of the applied linearization method.

Acknowledgement

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