

Experimental Verification of the Impact of the 2nd Order Injected Signals on Doherty Amplifiers Nonlinear Distortion

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Abstract—In this paper, an asymmetrical Doherty amplifier fabricated in microstrip technology is tested in the experiments to verify the impact of the 2nd order signal for the linearization prepared in baseband. The measurement set-up consists of three USRPs programmed by LabVIEW to generate the useful 64QAM signal and the signals for linearization that are set in amplitude and phase and modulate the 2nd harmonic of fundamental carrier. The USRPs instruments should be synchronized for performing measurements for two scenarios: the signals for linearization are injected at input of the transistor within the main Doherty amplifier or are injected at its output.

Keywords—Doherty amplifier, baseband signal, second harmonic, linearization, experimental verification

I. INTRODUCTION

Doherty amplifier (DA) is very adequate topology for applications in modern wireless communication systems, especially in 5G due to its performances regarding the high efficiency and linearity.

In literature, the various solutions for the DA linearization can be found. In the contemporary technology, the most popular and applicable is digital predistortion technique [1], [2]. In order to linearize power amplifiers PA, single stage and DA, the authors of this paper have been processed the I and Q components of the useful signal, shaping them adequately in the 2nd order nonlinear signals, whose amplitude and phase angles are set on the required values in the baseband. These signals then modulate the 2nd harmonic of the fundamental carrier. The linearization signals formed in this manner are led at the gate and drain (input and output) of the amplifier transistor to decrease the nonlinearity of the power amplifier. The results of the linearization were predominantly analyzed in simulation software for the single stage PA [3], and the two-way DA [4] in terms of the input signal power and also in experiments. Measurements included in [4], which carried out on a DA, compare three cases – when the signals for linearization are inserted only at the input of the main DA amplifier transistor, only at its output and simultaneously at its input and output, but for the certain power levels.

In this paper, we represent the experimental results of the first and the second cases i.e. only input or output insertion of the linearization signals into the transistor of the main DA [5] for a range of 64QAM signal power. The measurements

were performed to improve the adjacent channel power ration - ACPR at the range of dominant the third-order intermodulation products IM3, while we analyzed also behavior of ACPR parameter in the range of the fifth-order nonlinearities, IM5. In the future work, the experiments will be performed by using the simultaneous injection of the linearization signals at the input and output of the main Doherty amplifier transistor for the range of the input signal power.

II. MEASUREMENT SET-UP

In order to verify the linearization method developed within our research group, the measurement set-up shown in Fig. 1 was realized.

When forming the measurement system, it was considered that the measurement system should enable verification of the linearization methods, which generally uses two linearization signals, which after the digital processing in the baseband modulate the second harmonic of the fundamental signal. The measurement system was designed to provide possibility of generating three independent, synchronized signals – the fundamental signal and two linearization signals at the frequency of fundamental signal second harmonic.

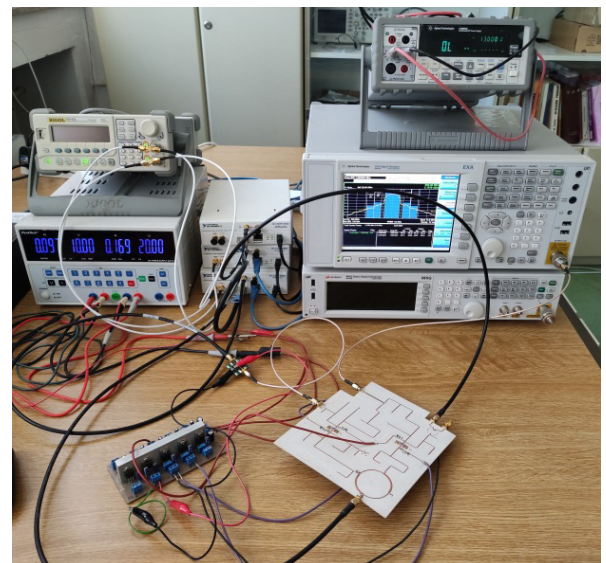


Fig. 1. Measurement set-up.

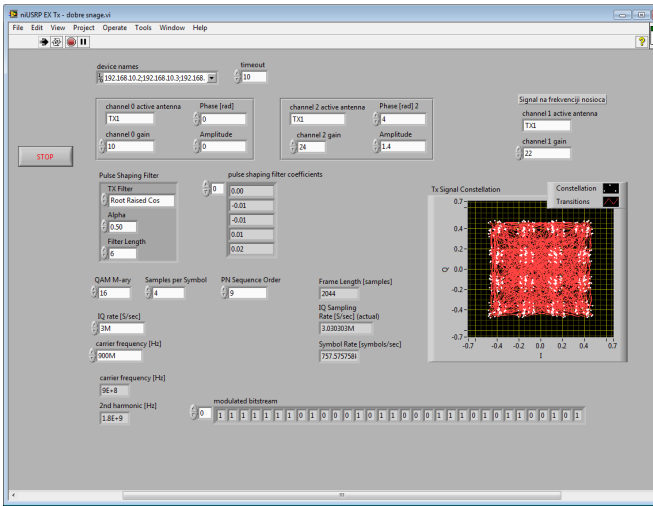


Fig. 2. Interface for management and control of the NI USRP devices.

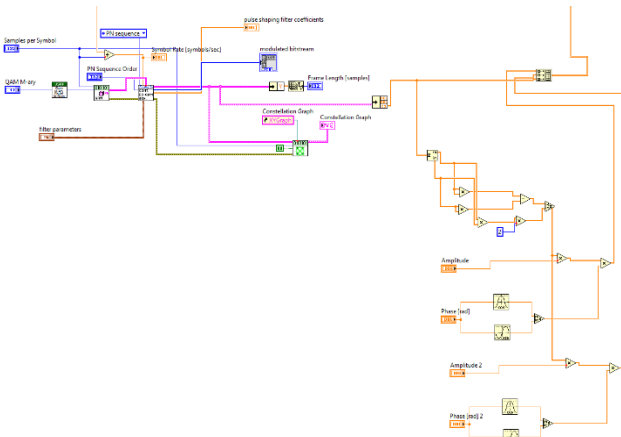


Fig. 3. Block diagram of implemented interface

Due to the low cost and good performances, software-defined radio (NI USRP) [6] in combination with the LabVIEW graphical programming environment [7] was chosen as the signal generation option. Two NI USRP 2920 models and one NI USRP 2922 model were used for the measurement system, which are connected to the computer via an Ethernet switch. The Keysight EXA Signal Analyzer N9010A was used for the signal measurement and analysis. The interface for management and control of the NI USRP devices was implemented in the LabVIEW environment (Fig. 2). The NI Modulation Toolkit, as a part of the LabVIEW, was used to generate the appropriate modulation signals. Using the designed interface, it is possible to set-up parameters related to the fundamental signal (operating frequency, modulation type - M-QAM ($M = 16, 64, 256$), IQ rate - signal bandwidth, samples per symbol, etc.) as well as the parameters related to the linearization signal - amplitude and phase adjustment in the baseband. Also, for each of the generated signals, it is possible to independently adjust the gain of the NI USRP devices. Figure 3 shows block diagram details in the LabVIEW environment for the realization of the above mentioned functionalities.

In the experiments carried out in this paper when the signals for the linearization are injected either at the input or at the output of the main Doherty amplifier, only two NI USRP devices which are synchronized by the use of MIMO

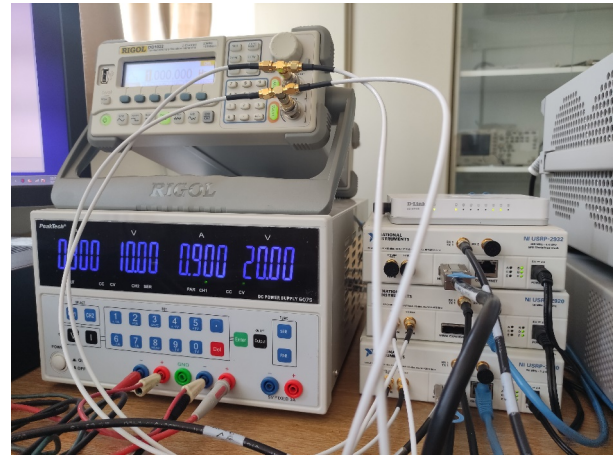


Fig. 4. Details of the NI USRPs synchronization.

cable may be used. Nevertheless, we set up the whole instrumentation required for the application of the linearization technique that implements both the input and output injection at the main DA transistor. Besides, this enabled us easier hardware application for the measurements done in this paper, avoiding exchange of the USRP, which generates and processes the signals for the linearization, between the input and output linearization approach.

A unique challenge during the implementation of the measurement system was the synchronization of the NI USRP devices. In accordance with the manufacturer's recommendations, the synchronization of the NI USRP devices was performed by a combination of MIMO cable (which was used to synchronize two of the three USRP devices - using MIMO EXPANSION input), while the third device was synchronized with the previous two via external referent 10 MHz and 1 PPS signals. A two-channel function/arbitrary waveform generator (RIGOL DG1022) was used as the generator of these signals, whereby the outputs from the function generator were distributed to the corresponding inputs of the NI USRP device (REF IN and PPS IN). Figure 4 shows the part of the measurement system where it can be seen how the NI USRP devices were synchronized, while Fig. 5 shows the LabVIEW block diagram which shows the details how the synchronization was implemented. When using the NI USRP with the LabVIEW environment, it is necessary to provide high processing power, large amount and high speed of memory as well as fast Ethernet connection to the computer on which the NI USRPs are connected, which is especially required if multiple USRP devices are used at the same time. The lack of any of these resources can significantly affect the reliable operation of the NI USRP and lead to frequent downtime.

III. RESULTS

The measurements of the linearization effects were performed on the Doherty amplifier fabricated in asymmetrical two-way topology (Fig. 6), which design and characteristics are given in [5]. The amplifier operates at 900 MHz central frequency, and 9 dB of the maximal transducer gain was measured when the main amplifier is in class-AB and the auxiliary amplifier in class-C regime, characterized with 15 dBm output power at 1-dB compression and 18 dBm maximum output power. The amplifier characteristics are in the range of ± 0.5 dB across 10 MHz bandwidth relating to their values at 900 MHz.

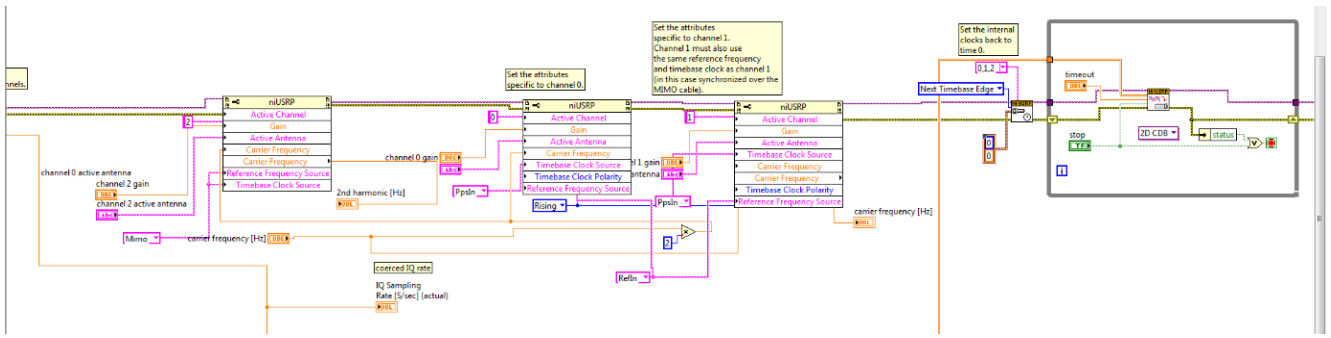


Fig. 5. Block diagram with synchronization details.

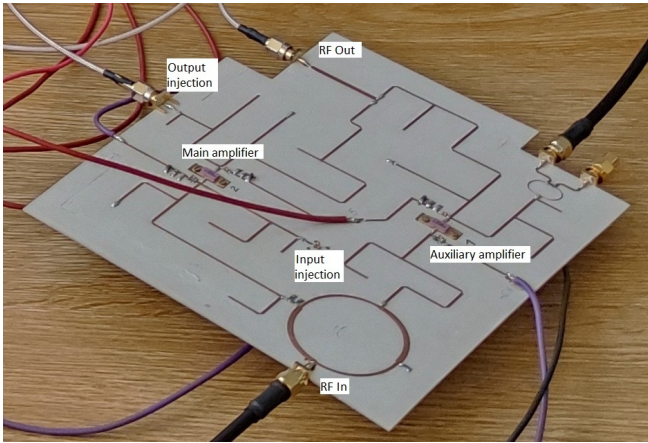


Fig. 6. Asymmetrical two-way Doherty amplifier

The Doherty amplifier was tested for the 64QAM signal with 2 MHz channel bandwidth for diverse power levels of the output signal from 0 dBm to 15 dBm.

The Figures 7 to 10 show the ACPRs measured before the linearization and when the linearization signals are put at the input of the main DA amplifier transistor (input injection/linearization) and when they are inserted at its output (output injection/linearization). The results of ACPRs are compared at ± 2 MHz and ± 3 MHz or adjacent channels (dominant IM3 products) and alternate channels (dominant IM5 products). We can notice that improvement of the ACPR in adjacent channels are better for the linearization of the DA by the output injection of the linearization signals especially for higher output power of the useful signal, i.e. for the input injection the maximum augmentation of the ACPR is approximately 5 dB, whereas in the case of the output injection that is 7 dB. It should be stressed that for the maximum considered output power, the output linearization approach achieves 5 dB the ACPR increase, when the input injection approach does not reach any results.

Observing the alternate channels, no evident ACPR improvement can be noticed for the output approach excepting at the output power levels close to maximum considered case where the ACPR becomes better by 5 dB. The input injection linearization approach gives better results in the ACPR enhancement but maximally up to 2 dB in the lower output power levels of the useful signal, while at the maximum power does not approach any improvement.

It can be expected that the better linearization results of DA will be achieved when the injection of the signals for the linearization are applied at the input and output of the main amplifier transistor in Doherty configuration and that will be comparable with the DPD linearization results available in the literature.

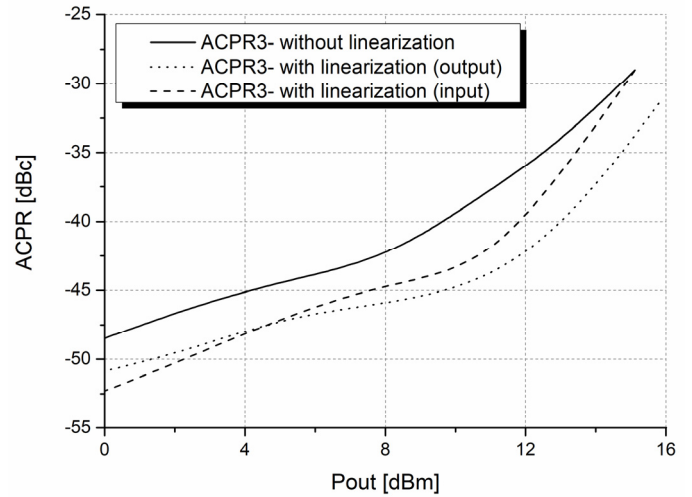


Fig. 7. ACPRs in terms of output fundamental signal power for 64QAM signal of 2 MHz useful signal frequency bandwidth at -2 MHz offset from carrier over 1 MHz frequency band.

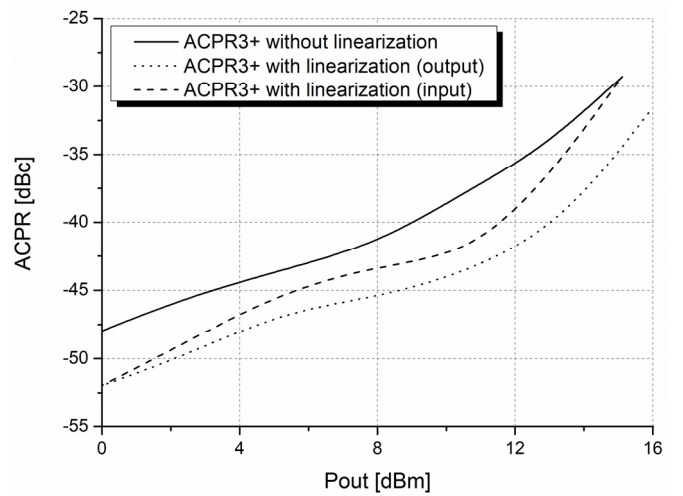


Fig. 8. ACPRs in terms of output fundamental signal power for 64QAM signal of 2 MHz useful signal frequency bandwidth at +2 MHz offset from carrier over 1 MHz frequency band.

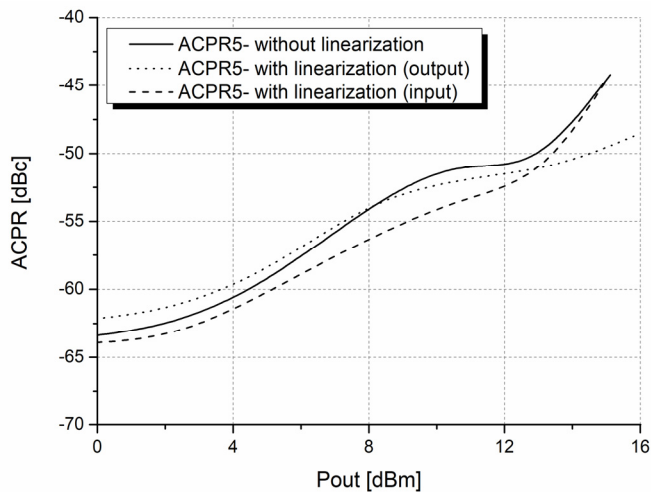


Fig. 9. ACPRs in terms of output fundamental signal power for 64QAM signal of 2 MHz useful signal frequency bandwidth at -3 MHz offset from carrier over 1 MHz frequency band.

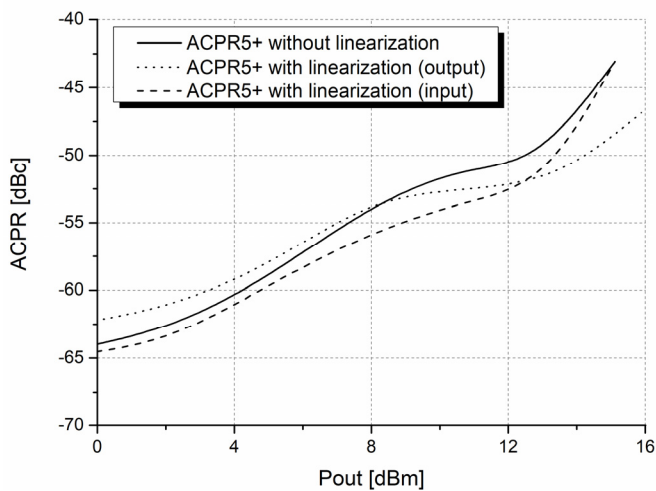


Fig. 10. ACPRs in terms of output fundamental signal power for 64QAM signal of 2 MHz useful signal frequency bandwidth at +3 MHz offset from carrier over 1 MHz frequency band.

CONCLUSION

The microstrip Doherty amplifier designed as two-way in asymmetrical topology is linearized by applying to approaches of the injection of the 2nd order digital nonlinear signal adequately processed in the baseband, which then modulate the second harmonic of the fundamental carrier forming the linearization signals.

The useful 64QAM signals and signals for the linearization were generated and processed by the two NI USRP 2920 models and one NI USRP 2922 model

programmed by the LabVIEW software. The Keysight EXA Signal Analyzer N9010A was used for the signal measurement and analysis. In the first experiments, the linearization was performed by the injection of the signal for linearization at the input of the DA main amplifier transistor, whereas in the second experiment those signals were led to the output of the transistor in the DA main amplifier. The parameter ACPR was measured at the adjacent (± 2 MHz) and alternate channels (± 3 MHz) over 1 MHz frequency band for the 64QAM signal with the 2 MHz channel bandwidth. On the basis of the measured results we can infer better influence of the output injection linearization considering adjacent channels. In the case of the alternate channels, slightly better improvement that is maximum 2 dB was measured in the input injection experiments. However, the output linearization attains significantly better results in the ACPR enhancement in the both adjacent and alternate channels for the higher output power of the useful signal close to saturation.

ACKNOWLEDGMENT

Fund for Science of Republic of Serbia supported this work, Grant: 6398983-Programme of collaboration of Serbian science with diaspora-project Digital Even-Order Linearization of 5G Power Amplifiers in Bands below 6GHz-DELFIN.

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