Joint Evaluation of I /Q Imbalance and Reconfigurable RF Filter Nonlinearity in LTE Transmitters

M. BOZIC, A. ANASTASIJEVIC, K. RABBI, N. MOHOTTIGE, D. BUDIMIR

Wireless Communications Research Group, Faculty of Science and Technology
University of Westminster, London, W1W 6UW, UK

Abstract: In this paper, a joint evaluation of I/Q imbalance and reconfigurable bandpass filter nonlinearity in wireless transmitters is described. An experimental analysis of complete Orthogonal Frequency Division Multiplex (OFDM) transmitter is presented for the purpose of quantifying these nonlinearities using LTE R9 3 MHz 16 QAM and LTE R9 3 MHz 64 QAM signals.

Keywords: LTE, Nonlinear distortion, reconfigurate filters; I/Q imbalance; wireless transmitters.

Received: June 28, 2021. Revised: December 2, 2021. Accepted: December 17, 2021. Published: January 5, 2022.

1. Introduction

Wireless communication systems are developing to support more users and provide higher data rates in a limited radio-frequency (RF) spectrum. Protocols that support modern wireless communication systems allow users to access a variety of multimedia services, potentially providing it with a speed of 100 Mb/s. In the transmitter chain, modulator, PA and filter are the most challenging blocks. As nonlinear elements, these components cause distortion to the transmitted signals which significantly degrade the quality of the signal. The Quadrature and In-phase carriers in the analog modulator do not have exactly the same amplitudes and phase differences. These discrepancies are called gain/phase imbalance and can cause crosstalk between the I and Q channels, which degrade quality of the signal [1]-[4].

This paper is an evaluation of the nonlinearity effects with and without I/Q imbalance in reconfigurable RF circuits for wireless transmitters. It is applied for analyzing 16 QAM OFDM/64 QAM OFDM signal in wireless transmitter. It will be shown that by introducing I/Q imbalance an additional distortion appears in wireless transmitter. Experimental analysis for LTE R9 16 QAM (16 QAM OFDM) and LTE R9 64 QAM (64 QAM OFDM) signals of a wireless transmitter shows that out-of-band distortion increase correspondingly with addition of the mentioned undesired effect. The paper is organized as follows. At first, the effects of I/Q imbalance is explained using baseband methodology. Experimental setup and results are presented in section III. Finally, the conclusion is given in section IV.

2. I/Q Imbalance

Nonlinearity of the components in transmitter chain produces compression of signal amplitude and phase, degrades the quality of the transmitted signal. Modulator is nonlinear element which up-converts the baseband signal to RF. Problem with modulator is that it has phase and gain imbalances that affect transmitter's performances. This disturbs the ideal 90˚ degree phase relationship between I and Q signals along with gain imbalance [5]-[7]. The output of modulator can be represented as:

$$y = x[\cos\theta - ja\sin\theta] \\ -x^{*}\,[a\cos\theta - j\sin\theta] \qquad (1)$$

where y is the imbalanced signal, a is gain imbalance, θ is phase imbalance and x is 16/64 QAM OFDM input signal.

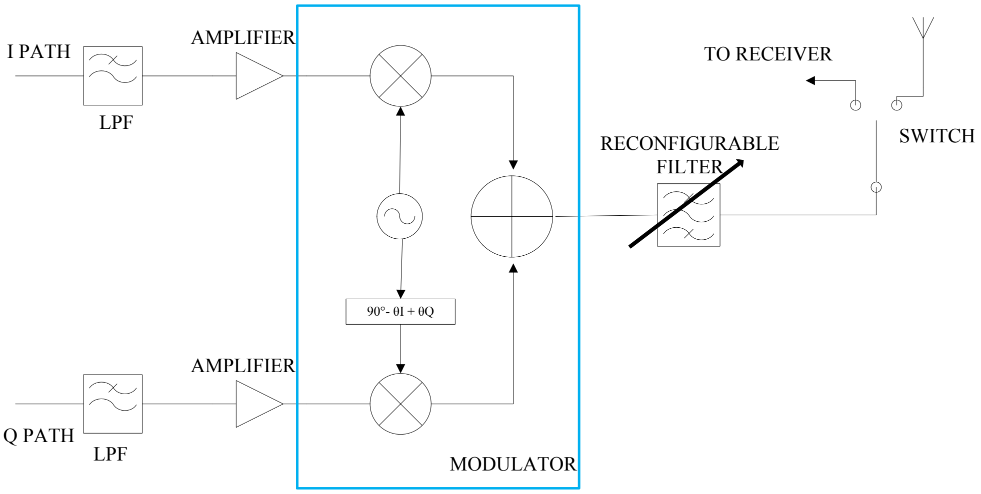

Fig. 1. Wireless transmitter with undesired effects

3. Results

3.1 Measurement Setup

Measurement setup consists of signal generator Agilent MXG N5182A, reconfigurable microstrip bandpass filter as DUT, which is illustrated in Fig. 2, used to emulate wireless transmitters. The layout of the reconfigurable circuit (bandpass filter) is based on the combination of a bent single $\lambda_g/2$ resonator and a pair of bent $\lambda_g/4$ short circuited resonators. The filter is inductively coupled to the source. Compactness of this filter is attained through the reduction of filter length and width. In addition, two bent short stubs are shorted to common ground in order to miniaturize the filter. This filter is designed to have a 3 dB passband from 925 MHz – 960 MHz (LTE band 8) with a mid-band frequency of 942.50 MHz. The proposed filter layout comprises of lines of width 1.2 mm and the open circuited stub leading to the gap is 2.4 mm wide.

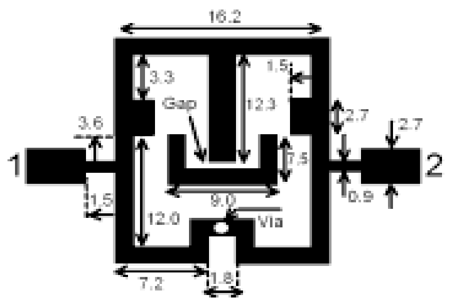

Fig. 2. Reconfigurable bandpass filter as DUT.

General-purpose interface bus (GPIB) was used to connect this generator with PC. The signals were created in Matlab and download to MXG using Agilent Signal Studio Toolkit. The signal named RF output was passed through DUT (reconfigurable pin switch based bandpass filter). Finally, the signal was captured with VSA 4406A for signal analysis. The measurement setup is shown in Fig. 3.

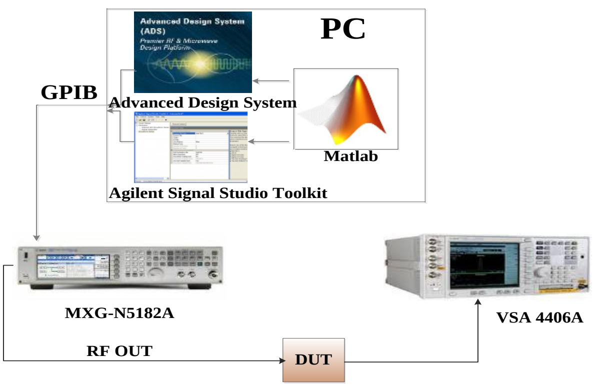

Fig. 3. Measurement setup of wireless transmitter.

3.2 Measurement Results

Experiment was conducted for two different cases of input signals, LTE R9 3 MHz 16 QAM and LTE R9 3 MHz 64 QAM signals with and without I/Q imbalance. Spectrum of the LTE R9 3 MHz 16 QAM signals with and without I/Q imbalance are shown in Figs. 4a, 4b, 4c and 4d respectively. The measured power spectrum of the LTE R9 3 MHz 64 QAM signals with/without I/Q imbalance are shown in Figs. 5a, 5b, 5c and 5d respectively.

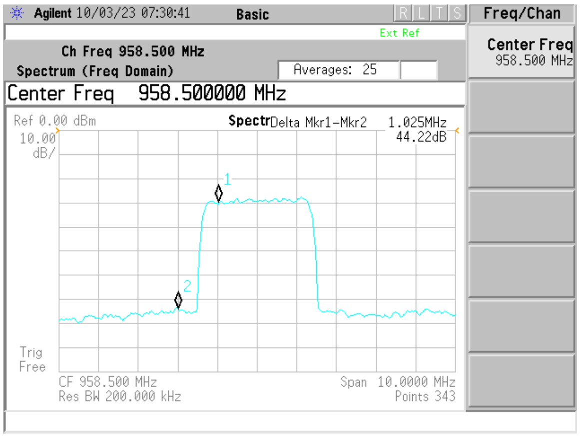

Fig. 4a. The measured power spectra of the LTE R9 3 MHz 16 QAM signal at the input of the reconfigurable filter without I/Q imbalance.

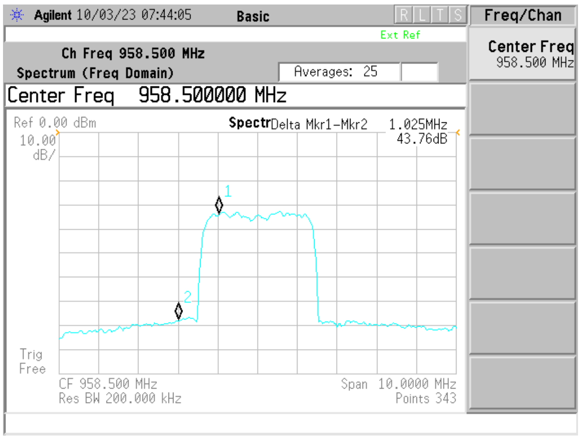

Fig. 4b. The measured power spectra of the LTE R9 3 MHz 16 QAM signal at the output of the reconfigurable filter without I/Q imbalance.

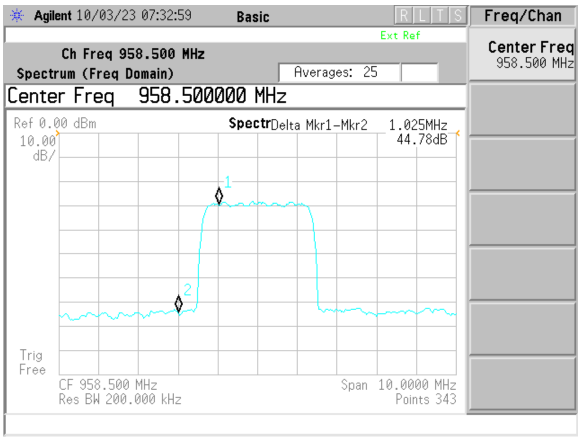

Fig. 4c. The measured power spectra of the LTE R9 3 MHz 16 QAM signal at the input of the reconfigurable filter with I/Q imbalance.

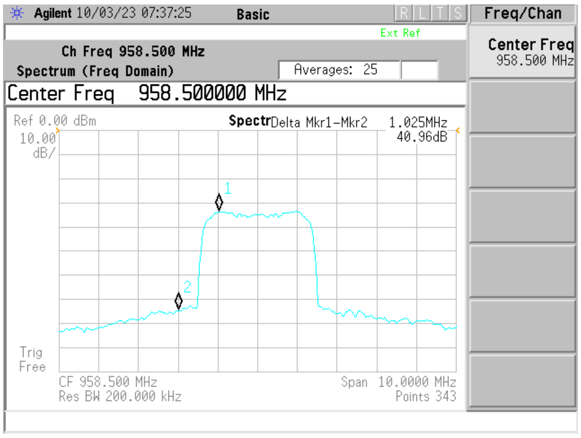

Fig. 4d. The measured power spectra of the LTE R9 3 MHz 16 QAM signal at the output of the reconfigurable filter with I/Q imbalance.

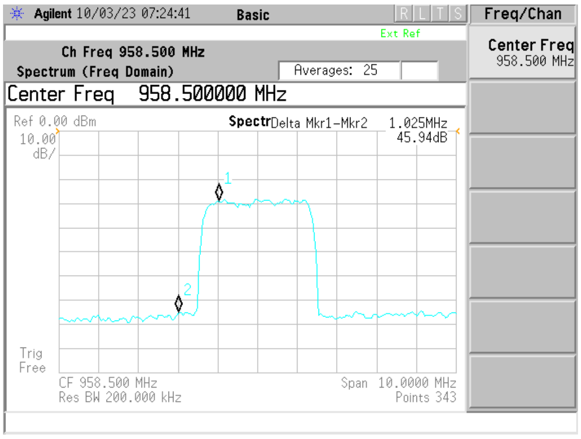

Fig. 5a. Spectrum of the LTE R9 3 MHz 64 QAM signal at the input of the reconfigurable filter without I/Q imbalance.

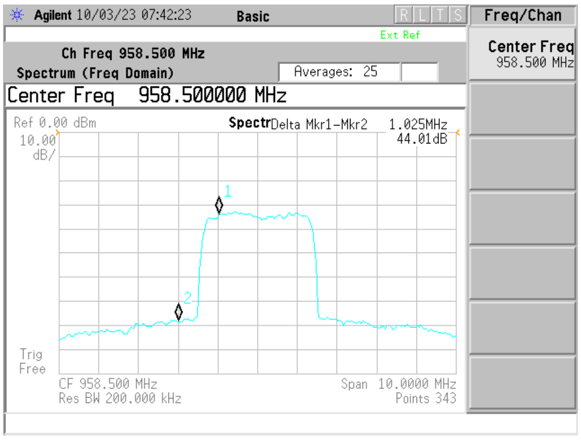

Fig. 5b. Spectrum of the LTE R9 3 MHz 64 QAM signal at the output of the reconfigurable filter without I/Q imbalance.

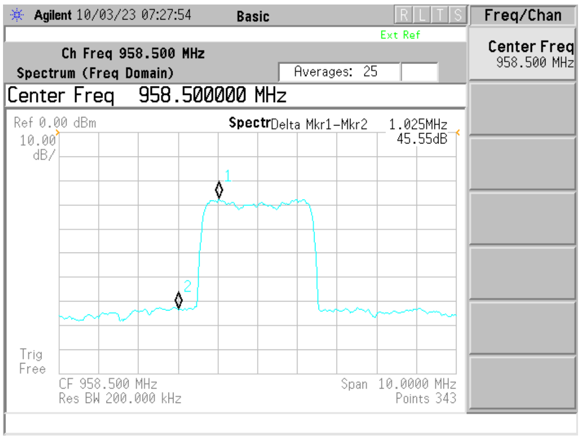

Fig. 5c. Spectrum of the LTE R9 3 MHz 64 QAM signal at the input of the reconfigurable filter with I/Q imbalance.

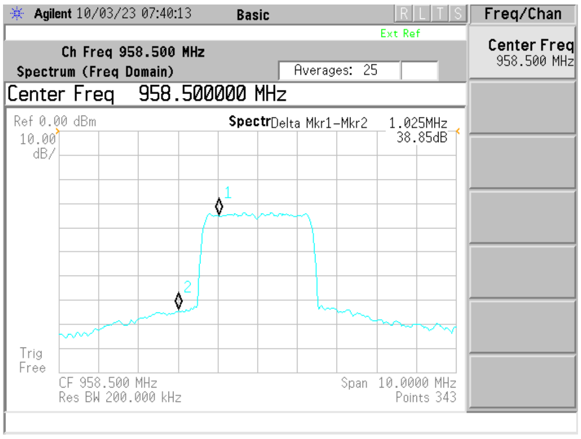

Fig. 5d. Spectrum of the LTE R9 3 MHz 64 QAM signal at the output of the reconfigurable filter with I/Q imbalance.

Quantitative measures of distortion is defined as:

$$\Delta = P_{OUT} - P_{IMD} \quad (2)$$

where P_{OUT} represents output power of the transmitted signal and P_{IMD} represents distortion power. Measurement results with and without I/Q imbalance are presented in Tables 1 and 2, respectively.

TABLE 1: DISTORTION OF RECONFIGURABLE BANDPASS FILTER IN WIRELESS TRANSMITTER WITHOUT I/Q IMBALANCE

M QAM modulation	***Input Power [dBm]***	***Δ [dB] without I/Q imbalance***
16	16	0.46
64	16	1.93

TABLE 2: DISTORTION OF RECONFIGURABLE BANDPASS FILTER IN WIRELESS TRANSMITTER WITH I/Q IMBALANCE

M QAM modulation	***Input Power [dBm]***	***Δ [dB] with I/Q imbalance***
16	16	3.82
64	16	6.7

Acknowledgement

Financial support was provided by the EU-Erasmus Mundus Action 2 project EUROWEB.

References

[1] D. Saffar, N. Boulejfen, F. Ghannouchi , M. Helaoui and A. Gharssalah, “Behavioral Modeling of MIMO Transmitters Exhibiting Nonlinear Distortion and Hardware Impairements,” Proceedings of the 6th European Microwave Integrated Circuits Conference

[2] Y.-D. Kim, E.-R. Jeong and Y. H. Lee, "Adaptive Compensation for Power Amplifier Nonlinearity in the Presence of QuadraturModulation/Demodulation Errors," IEEE Transactions Signal Process., vol. 55, no. 9, pp. 4717-4721, Sep. 2007

[3] F. H. Raab, P. Asbeck, S. Cripps, P. B. Kenington, Z. B. Popovic, N. Pothecary, J. F. Sevic, and N. O. Sokal, “Power Amplifiers and Transmitters for RF and Microwave“, IEEE Transactions on Microwave Theory and Techniques, vol. 50, no. 3, pp. 814-826, March 2002.

[4] P. B. Kenington, "High Linearity RF Amplifier Design", Artech House, 2000.

[5] S.Bhattacharjee, Rawat, K.; Rawat, M.; Donglin Wang; Helaoui, M.; Leung, H.; Ghannouchi, F.; , "Joint evaluation and mitigation of RF impairments and nonlinear distortion in WiMAX Transceiver under Nakagami-m fading channel," Electrical and Computer Engineering (CCECE), 2011 24th Canadian Conference on , vol., no., pp.000926-000929, 8-11 May 2011

[6] L.Ding, Z. Ma, D. Morgan, M. Zierdt, and G. Tong Zhou, “Compensation of frequency-dependent gain/phase imbalance in predistortion linearization systems,” IEEE Transactions Circuits and Systems I, vol 55, no. 1, pp. 390-397, Feb. 2008.

[7] L. Anttila, P. Handel, and M. Valkama, “Joint mitigation of power amplifier and IQ modulator impairments in broadband direct-conversion transmitters,” IEEE Transactions Microwave Theory and Techniques, vol. 58, no. 4, pp. 730-739, Apr. 2010.