Investigating the USRP: I/Q Imbalance

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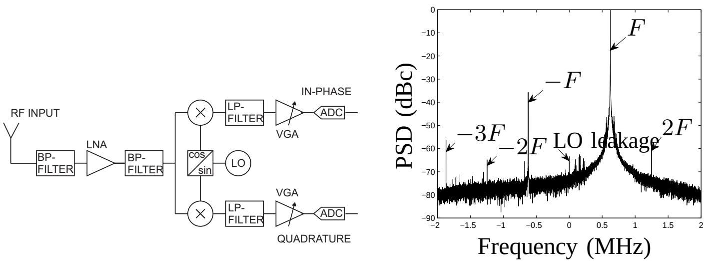

Fig. 1. (Left) Exemplary direct conversion radio receiver. (Right) Power spectral density of a USRP receiver output, showing the single tone at F MHz, mirror distortion, LO leakage, and other spurious frequencies.

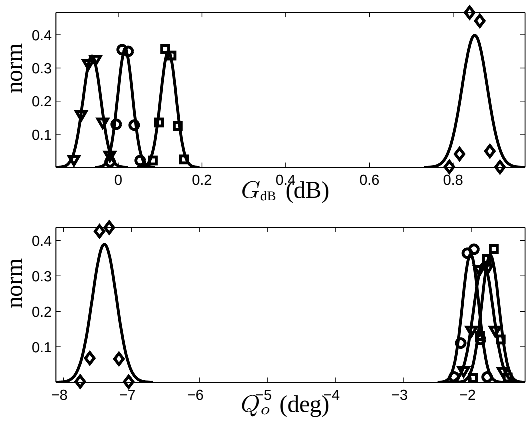

Fig. 2. USRP results based on 1500 non-overlapping segments, each of length $N = 64$. Histograms of the estimated *gain imbalance* $\widehat{G}_{\text{dB}}$ and *quadrature skew* $\widehat{Q}_o$. In comparison, the Gaussian probability density functions $\mathcal{N}(\bar{G}, \bar{\sigma}_G^2)$ and $\mathcal{N}(\bar{Q}, \bar{\sigma}_Q^2)$ are shown (solid lines), where the bar indicates that a parameter value is calculated as an average over all available data. USRP #1: Ch. 1 (○), Ch. 2 (□), USRP #2: Ch. 1 (◇), Ch. 2 (▽).

I. Introduction

The development of contemporary and future wireless communication systems puts high demands on accurate and time-efficient test methods for production and product validation. Reducing the time for a test is essential and the accuracy of the applied method with respect to the length of the recorded data sequence is an important figure of merit to trade test time versus accuracy of the output of the test. Efficient measurement methods are also required as a prerequisite for digital correction to combat impairments produced by the analog circuitry – in line with the dirty radio frequency (RF) paradigm [1]. Rapid prototyping of new digital communication technologies is essential, and often relies on software defined radio implementations. A widespread hardware platform is the available variant of the universal software radio peripheral (USRP) by Ettus Research LLC, which is becoming a common technology for research, education, and development [2].

We have proposed a least-squares approach to determine the I/Q imbalance of a direct conversion receiver, based only on receiver baseband data. We use I/Q imbalance parameters defined as in [3]. Under a Gaussian assumption, the accuracy of the method has been addressed, yielding closed form results. Experimental data from four different USRP receivers has been collected. It has been shown that gain imbalance and quadrature skew are accurately estimated employing data that covers only a handful of full periods of the test stimuli, which highlights the practical relevance of the derived test method.

It has also been shown that that estimating the LO leakage is a more complicated problem, not due to the accuracy aspects but to the systematic errors, providing errors in order of $10 - 20$ dBs in scenarios where gain imbalance and quadrature skew are accurately estimated.

By examining samples of the USRP receiver, we have not only validated its data-sheet performance, but also observed some outlier performance of a sample receiver. The evaluation of USRP receivers has an interest of its own, owing to the widespread use of the USRPs for research, education and development.

Measurement results (Fig. 2): The USRP receivers were excited by a $F_{\text{RF}} = 882.3$ MHz sine wave at 12 dBm by a HP8656B, followed by a Mini-Circuits FK3000 frequency doubler, Mini-Circuits SHP-900 high-pass filter, Mini-Circuits attenuators (3×10 dB and 2×5 dB), and a ZAPD-30 splitter for simultaneous excitation of the two RF inputs of the USRP. Measured input signal level was -60 dBm. No internal down-conversion was employed in the USRP. For each USRP receiver, 100k of baseband data was collected. The sampling rate of the USRP ADCs were $F_{\text{S}} = 4$ MHz, followed by a digital filtering and subsampling. With the $F_{\text{LO}} = 1764$ MHz, we end up with normalized angular frequency $\omega_o = 0.15$.

In an experiment, the baseband output from a USRP receiver was divided into nonoverlapping blocks of length $N = 64$ samples. The proposed imbalance test was employed. The results based on the statistics employing 1500 nonoverlapping segments of data are shown in Fig. 2. We note that three out of the four receivers have performance according to the data-sheet of the AD8347 direct conversion quadrature demodulator, whereas the fourth unit has outlier performance. More details can be found in [4].

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