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MASTER OF SCIENCE THESIS

Airplane tracking system using ADS-B

System lokalizacji samolotów z wykorzystaniem ADS-B

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Nomenclature

ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
FPGA	Field Programmable Gate Array
SDR	Software Defined Radio
QAM	Quadrature Amplitude Modulation
RF	Radio Frequency
SoC	System on Chip

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Chapter 1

Introduction

1.1 Purpose and aim

The purpose of this paper is to study various parameters defining RF signal quality and models of IQ imbalance. Research concept of Software Defined Radio, principles of operation of such devices and capability of Xilinx Zynq SoC in such domain. Evaluate different correction algorithms implementation. Compare it performance for various type of signals: singletone, multitone, broadband, and 4-QAM, 8-QAM8 and 16-QAM modulated. The comparison include simulation in Matlab, implementation hardware (FPGA part of ZYNQ SoC) and native correction inside RF transceiver chip.

1.2 Thesis outline

Chapter 2

Theoretical background

In this chapter the theoretical operation of quadrature modulators and demodulators is explained. Widely used in RF communication IQ signal model is explained together with it imbalance model. For last the Software Defined Radio concept is presented.

2.1 Theoretical operation quadrature modulator/demodulator

2.2 IQ signal model

The term IQ is an abbreviation for in-phase and quadrature. Signal are considered in-phase when phase of both is equal and quadrature when it differs by 90deg. IQ data model shows changes in phase and magnitude of a sine wave. Modification of these parameters allow to encode information upon a sine wave.

Equation of the sine wave is:

$$Acos\left(2\pi ft + \phi\right),$$

where:

- A is amplitude,
- f is frequency,
- ϕ is phase shift

According to equation only amplitude, phase and frequency of the sine wave can be modified. Moreover frequency is first derivative of phase. Therefore it can be collectively referred to as the phase angle. According to these assumptions the instantaneous state of a sine wave can be described in complex plain using magnitude and phase as polar coordinates.

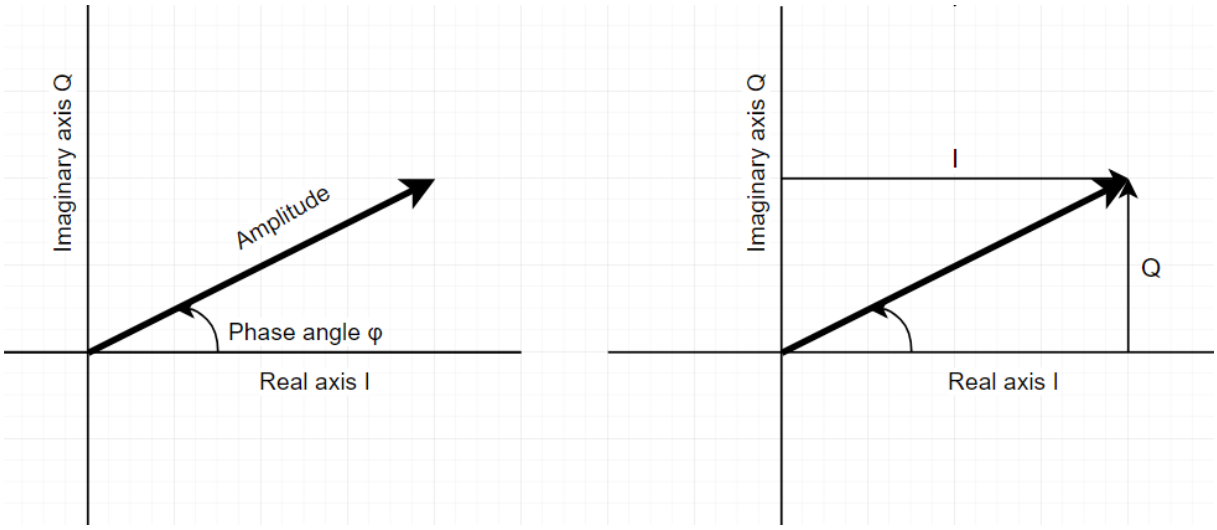

Figure 2.1: *Representation of sine wave in complex plain*

Using trigonometry, the polar coordinates can be converted into I and Q components of the signal using equations:

- $I = Acos\,(2\pi ft)$,
- $Q = Asin\,(2\pi ft)$,

IQ data model is widely used in RF communication systems. It allows to distinguish type of modulation used on carrier. Allows to introduce concept of positive and negative frequency. Amplitude and phase angle form seems to be more intuitive, however precisely varying the phase of a high-frequency carrier sine wave in a hardware circuit according to an input message signal is difficult. Therefore such hardware modulators will be expensive and hard to design and build. To avoid direct modulation of RF signal phase signal is decomposed to I and Q components.

According to Ptolemy's identitie for the cosine of sum sine wave carrier can be represented as:

$$Acos\,(2\pi ft + \phi) = Acos\,(2\pi ft)\,cos\,(\phi) - Asin\,(2\pi)\,.ft)sin(\phi)$$

Using equation 2.2 following formula is obtained:

$$Acos\,(2\pi ft + \phi) = Icos\,(2\pi ft) - Qsin\,(2\pi ft)\,,$$

where:

- I - is amplitude of in-phase signal,
- Q - is amplitude of quadrature signal.

Using this data samples representation, modulation of phase of the RF signal is possible just by modulation of I/Q signals amplitudes and then mix it with carrier and quadrature of carrier using mixers. Schematics below shows structure of IQ modulator and demodulator.

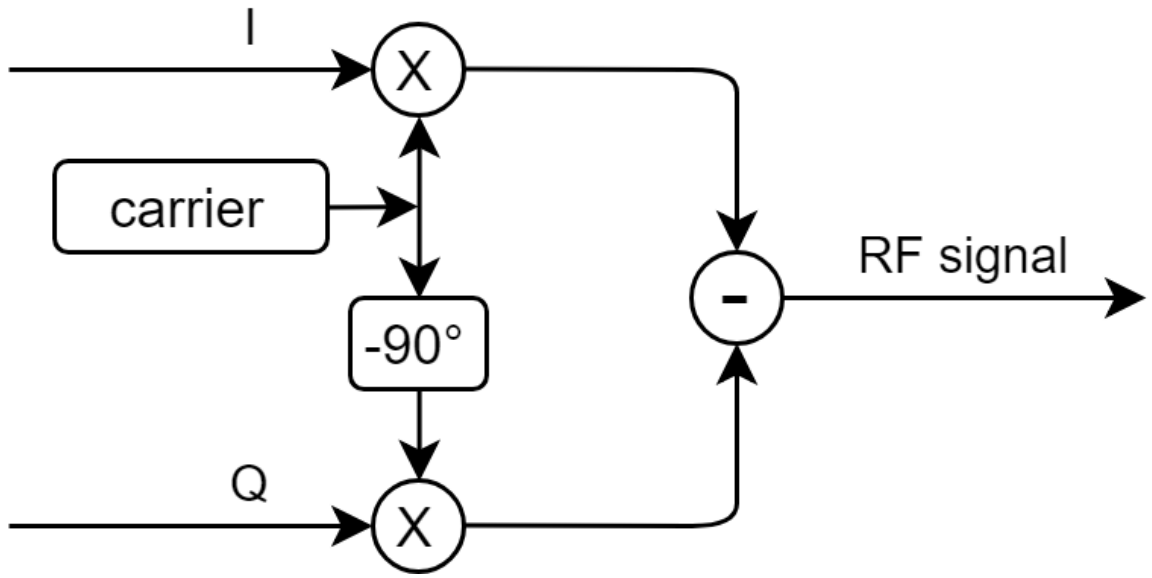

Figure 2.2: *Schematic of IQ modulator*

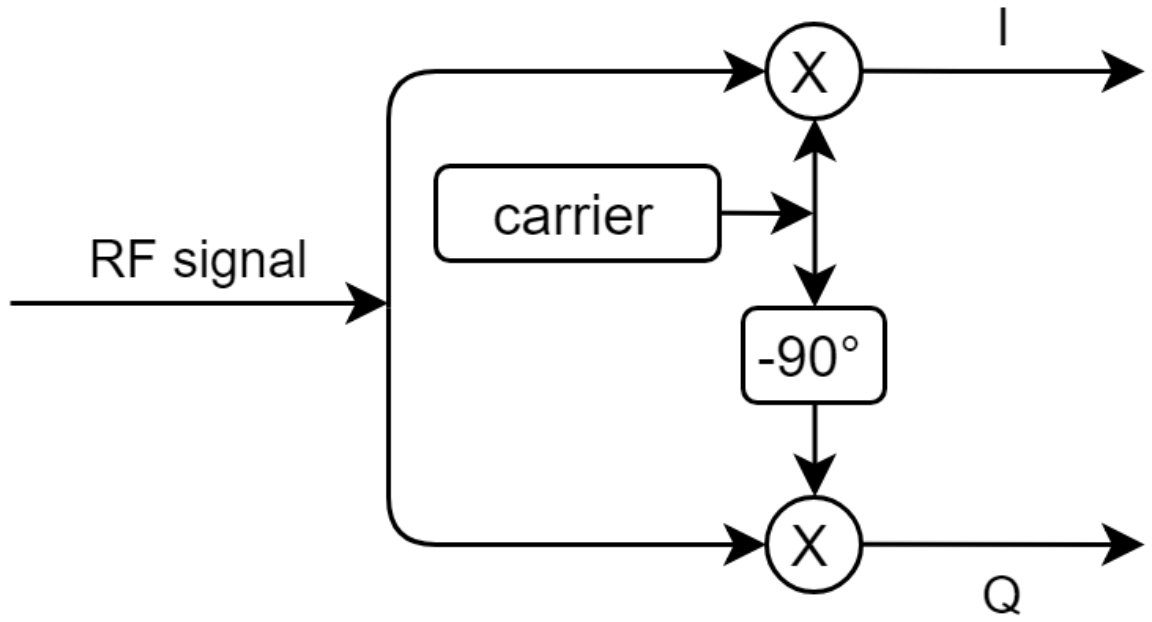

Figure 2.3: *Schematic of IQ demodulator*

The flexibility and simplicity of this solution compared to direct phase manipulations is a reason why I/Q modulators and demodulators are so widely used and popular in RF hardware.

2.3 IQ imbalance models

2.4 Software Defined Radio

SDR (Software Defined Radio) is a radio communication system where components typically implemented in hardware (e.g. mixers, filters, amplifiers, modulators/demodulators), are instead implemented by the means of software.

Chapter 3

Hardware and tools

3.1 Zynq and Xilinx tools

3.2 Adalm Pluto and AD tools

3.3 Simulation environment

Chapter 4

Algorithms

4.1 DC offset correction

Moving average filter and Gaussian filter

4.2 Magnitude correction

4.3 Phase correction

Blind phase correction algorithm

Chapter 5

Simulations

Chapter with all algorithms simulation in Matlab.

5.1 Single tone signal

5.2 Multitone signal

5.3 QAM modulation

Chapter 6

Measurements

Chapter with all algorithms implemented in Zynq PL.

6.1 Single tone signal

6.2 Multitone signal

6.3 QAM modulation

Chapter 7

Conclusions

Bibliography

[1] Stephen H. Hal, Garrett W. Hall, and James A. McCall. *High-Speed Digital System Design - A Handbook of Interconnects Theory and Design Practices*. New York, Chichester, Weinheim, Brisbane, Singapore, Toronto, 2000.