Advanced quadrature imbalance compensation techniques for the SDR mobile platform (Work in progress)

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Abstract— The flexibility that software-defined radio (SDR) affords the mobile platform poses very attractive solutions to scenarios such as satellite and rural communications. Currently SDR is an active research focus at Stellenbosch University (SU). The architecture of the SDR analogue front-end adopted by the US involves quadrature mixing, since it enables single stage upmixing. However, if the two quadrature signal paths in the modulator or demodulator are not exactly matched, the image frequency band is not suppressed completely which causes severe deterioration of the data signal. In order to realise a practically implemented SDR mobile platform at the US, a fully compensated physical layer needs to be developed. Digital compensation techniques have been shown to perform very well. The development of effective, adaptive, digital compensation techniques is the main focus of the research proposed in this paper.

Index Terms— Quadrature imbalance compensation, software-defined radio (SDR), adaptive compensation, I/Q imbalance.

I. Introduction

SOFTWARE-DEFINED radio (SDR) is considered to be the replacement of the analogue functionality of radio transceivers with their software signal processing equivalent [1]. SDR is revolutionising the mobile platform, making instantly reconfigurable, multi-standard mobile platforms a real possibility (see e.g. [2]). In scenarios where physical maintenance and configuration would pose considerable logistical problems, e.g. satellite or remote rural communications, SDR also presents an attractive solution.

The ideal software defined radio, called the software radio, has its digital domain extending up to the antenna – thus defining its functionality completely in software. Unfortunately, this ideal is often not realisable with current technology, mainly due to the inability of signal converters to accurately function at radio frequencies (RF). Thus, today's SDR implementations usually employ some analogue frequency translation/mixing in collaboration with software processing.

The conventional approach to SDR is to employ direct-digital synthesis (DDS) and signal conversion at an intermediate frequency (IF). The IF is generally chosen as high as possible in order to relax the specifications of the filters required in the mixing process as well as the number of expensive mixing stages.

An alternative approach to SDR was implemented by Stellenbosch University's digital signal processing group, employing a direct conversion DDS (a.k.a. zero-IF DDS) approach. This approach is similar to single sideband modulation and involves forming the transmitted signal as a complex baseband signal and transmitting the real part. The main advantages of this architecture are the facts that signal conversion occurs at baseband (low data rate) and the signals can be frequency translated in a single mixing and filtering stage. The basic architecture of this direct conversion DDS modulator and demodulator is shown in Fig. 1.

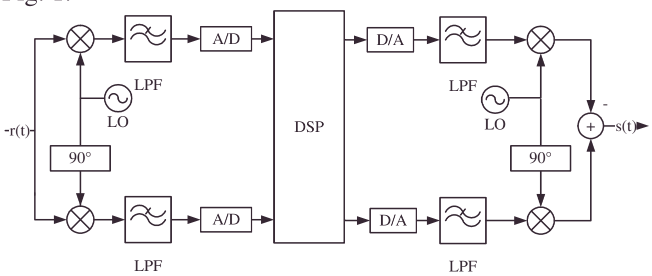

Fig. 1. Basic architecture of the direct conversion DDS demodulator and modulator.

The direct conversion DDS modulator and demodulator each require the use of two quadrature mixers. The impairments of quadrature mixing are well documented in literature (see e.g. [2]–[9]). The most significant of these are caused by gain and phase imbalances between the in-phase (I) and quadrature (Q) channels as well as DC offsets in these signal paths, all caused by component tolerances in the analogue front-end. Even with careful analogue design, there are still typically 1 to 3 percent gain, and 1 to 3 degrees phase mismatch between the I and Q signals [3].

The aim of the proposed research is to develop effective compensation techniques, which would be able to compensate in the digital domain for mismatches in the analogue front-end.

II. Related work

Digital I/Q imbalance compensation are shown in literature to provide superior results compared to analogue techniques [3]. Various techniques have recently been proposed in literature to adaptively compensate for I/Q imbalances (see e.g. [2]–[9]).

The main obstacle in developing I/Q imbalance compensation algorithms is the fact that only the combined effect of the modulator and demodulator's imbalance is observed in the demodulated signal. Some reference is thus needed to be able to separate the distortion contribution of the modulator from that of the demodulator.

In [4], [5] and [6] an envelope detector feedback path is added to the transmitter. This feedback is then used as input to adaptive algorithms aimed at pre- and post distorting the data signal to compensate for I/Q imbalances. Another popular approach is to use test signals along with adaptive compensation algorithms (see e.g. [5] and [6]). These techniques only compensate for frequency independent mismatches. In [7] and [8] the work of [9] was extended and algorithms to compensate for frequency dependent mismatches caused by the two lowpass filters (LPFs) were proposed. These techniques also involved adding extra hardware feedback paths after the LPFs in order to be able to characterise these filters.

III. Motivation of Research

SDR opens exciting new doors for the mobile communications platform and is currently an important research area of Stellenbosch University's digital signal processing group. With this theoretical and experimental development as background, it is now desirable to implement the research in a practical communications system.

The proposed context of the practical implementation is the development of a data relay system for rural wireless communications. A ground station would typically provide elementary services such as e-mail. A communication link is then set up whenever a transponder (e.g. an aeroplane) comes within range of the ground station. SDR provides an attractive solution, since system upgrading and reconfiguration can be done through remote software updating, thus solving inaccessibility problems. In particular, a compensated physical layer employing quadrature mixing needs to be implemented.

IV. Goals of the Project

The following project goals may be identified.

- Conduct a thorough literature study into existing quadrature compensation techniques.
- Develop *adaptive* quadrature imbalance compensation techniques which would compensate for I/Q imbalances *over the whole allocated frequency band*. This means that the quadrature calibration techniques will have to be extended to characterise the hardware non-idealities of the mixers, filters, and converters over a range of frequencies. The need for additional hardware should be limited. The compensation should be fully automatic and should be able to adapt to parameter changes.
- Develop mathematical models that make it possible to fully prototype the system's architecture in simulation prior to physical implementation.
- Implement the compensated physical layer in hardware employing an appropriate modulation scheme such as quadrature amplitude modulation (QAM), to demonstrate the communications quality achievable by the compensated system. These results should be accompanied by a full theoretical performance analysis of the techniques and its expected improvement on the uncompensated system.
- Further research into digital compensation may include compensating for integral distortion in the converters, saturation effects in the RF amplifiers, and inter-modulation components of the analogue mixers.

V. Conclusion

The flexibility and control that SDR can add to mobile platforms can be extensively utilised in applications such as satellite and rural communications. In order to further the current research at the University of Stellenbosch, a practical compensated physical layer needs to be developed. The proposed research of this project will focus on developing effective adaptive digital compensation techniques for the SDR front-end.

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