Comparison of Downconversion Techniques for Software Radio

Milan Patel and Phil Lane

Department of Electronics and Electrical Engineering, University College London

Abstract: *Software radio is an enabling technology for future radio transceivers, allowing the realisation of multimode, multiband, and reconfigurable base stations and terminals. This paper describes work comparing two suitable methods of downconverting RF signals to baseband, which may be used in software radios. These are direct conversion and bandpass sampling. The performance of each method is evaluated and the effects of the specifications of the front end bandpass filter on the receiver performance are analysed, in terms of bit error rate.*

1. Introduction

Recent trends in cellular radio terminals towards smaller handsets, and the proliferation of radio standards around the world place many demands on the future of radio terminals. Software radio is an enabling technology which may provide a solution for the realisation of multiband, multimode radio terminals by defining radio functionality in software [1]. This allows the radio terminal to be adapted to different systems or customised for various services by reprogramming the radio functionality.

Traditionally the superheterodyne architecture has been used extensively for radio systems since it provides a number of advantages such as image rejection and adjacent channel selectivity. A variation on the superheterodyne receiver is to eliminate the IF stages altogether. This architecture is known as zero-IF or direct conversion and eliminates the need for image rejection and is shown in Figure 1. However direct downconversion is not without its own problems, which are briefly presented elsewhere in this paper.

The sampling of bandpass signals can be carried out at rates lower than conventional lowpass Nyquist sampling, causing intentional aliasing the signal. Bandpass sampling can allow for received signals to be digitised closer to the antenna using manageable sampling rates and hence could be favourable for downconversion in software radios. Figure 1 shows the bandpass sampling receiver architecture. Significant improvement in ADC performance is required for sampling at RF.

The work presented in this paper describes a short overview of software radio and some of the problems faced by this concept. The methods of downconversion mentioned, bandpass sampling and direct conversion are reviewed and then compared by means of computer simulation. The effects of the RF bandpass filter on the performance of each downconversion architecture are observed. Initial results are discussed and future work to enhance this investigation is described.

2. Software Radio

Software radio is often described as a radio whose functionality is extensively defined in software, and with the placement of data converters as close to the antenna as possible [1]. The flexibility of the radio terminal to adapt to different systems or to advances in services or technology is made possible by using reconfigurable hardware such as digital signal processors (DSP) or field programmable gate arrays (FPGA). This flexibility also relies on the radio to be wideband in nature and as linear as possible, so as to minimise distortion of the signal. This is by no means an easy task, with a lot of research being concentrated in this area [2].

As the ADC is moved closer to the antenna, more radio functions can be written in software and embedded on programmable logic. However, ADC performance still isn't sufficient enough to perform digitisation at RF. In particular, the input analogue bandwidth, sampling rate, dynamic range and therefore resolution need considerable amounts of improvement if wideband front-ends and sampling at RF are to become a reality.

The performance of DSP must be able to cope with the increased amount of programmable radio functionality as a result of moving the ADC closer to antenna. Schemes using a mixture of DSP and FPGA have been proposed [3]. Needless to say power consumption in all components of the software radio is a very important factor to consider, particularly in handheld terminals.

In the following sections two receiver architectures are described. Bandpass sampling allows for the ADC to digitise at RF, providing the ADC is of adequate performance, whereas direct conversion, although consisting of more analogue components, places fewer demands on ADC performance since digitisation occurs at baseband.

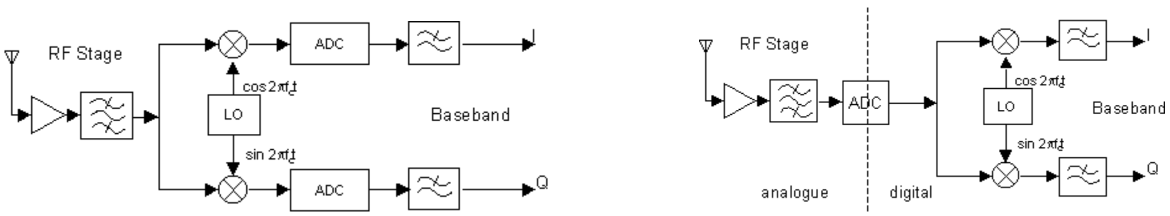

Figure 1: Direct conversion (left) and bandpass sampling (right) receiver architectures.

3. Bandpass Sampling

The use of bandpass sampling in the digitisation process of the received signals can significantly lower the sampling rate required. Instead of sampling at a rate which is at least twice the maximum frequency, bandpass sampling which is an extension of the sampling theorem, requires a sampling frequency which is only at least twice the information bandwidth. The signal of interest is intentionally aliased, and exhibits an inherent frequency translation. The sampling process folds the information bandwidth, together with noise, into the resulting sampled bandwidth, which is translated to an IF without the use of mixing and filters, unlike heterodyning.

The sampling frequency f_s, is related to the carried frequency f_c, and the IF, f_{IF} by [4]

$$\mathrm{fix}\left[\frac{f_c}{\frac{f_s}{2}}\right] \text{is} \begin{cases} \text{even}, f_{IF} = \mathrm{rem}(f_c, f_s) \\ \text{odd}, \ f_{IF} = f_s = \mathrm{rem}(f_c, f_s) \end{cases} \tag{1}$$

To prevent the signal from folding on top of itself, and causing further interference the following statements must be true

$$0 < f_{IF} - \frac{BW}{2} \quad (2) \qquad \text{, and} \qquad f_{IF} + \frac{BW}{2} < \frac{f_s}{2} \quad (3)$$

where BW is the information bandwidth.

Bandpass sampling may be the answer to achieving digitisation closer to the antenna within the receiver, but a number of factors currently limit its realisation. Significant improvements in DSP performance are required to cope with the large number of samples, and the extra digital radio functions which result as a consequence of sampling at RF. Current ADC products do not have sufficient analogue input bandwidths to cope with RF signals, and therefore this solution is difficult to achieve at present. The use of a fast sample and hold circuit prior to the ADC may alleviate this problem.

4. Direct Conversion

Direct conversion, also sometimes called zero-IF, due to the lack of an intermediate frequency, converts the received RF signal direct to baseband. This is particularly attractive for the use in wireless systems, especially in handsets since direct conversion receivers lend themselves more easily to monolithic integration than heterodyne architectures, since the IF components are replaced by lowpass filters and baseband amplifiers [5]. Direct conversion exhibits immunity to the problem of image since there is no IF.

There are a number of design issues associated with the direct conversion architecture. The most serious problem is dc offset in the baseband, following the mixer [6]. This offset appears in the middle of the downconverted signal spectrum, and may be larger than the signal itself. This phenomenon can be caused by local oscillator leakage and self-mixing. I/Q mismatch, occurring in the quadrature downconversion can lead to corrupted signal constellation, and hence increasing the number of bits in error, due to the differences which may occur in the amplitudes of the I and Q signals. RF receivers are typically susceptible to odd-order intermodulation distortion. However, direct conversion receivers are also prone to problems arising from even-order distortion. Flicker noise too can be a problem in direct conversion architectures.

5. Comparison of Downconversion Methods

Models for the bandpass sampling and the direct conversion architectures have been built using the SPW signal processing platform. Within these models, the GSM band of 890–915 MHz has been adopted, neglecting the enhanced spectrum allocation. BPSK has been implemented as a preliminary modulation scheme with a baud rate of 250 kHz, so as to simplify the model in terms of sample rates and decimation factors. Additive white Guassian Noise is added to the input of the receiver to approximate the effects of the channel. Amplifiers have been omitted from these preliminary models, and there for the front-end bandpass filter being the foremost component encountered in the receiver. The ADC is modelled as a sampling function, which in this case due to the discrete time nature of the simulations, is actually an adjustment of the system sampling frequency, together with a quantiser. Note the performance of the ADC for the bandpass sampling receiver is not achievable using current technology.

The bandpass filter at RF is an important component of the system, and its purpose is to attenuate out of band noise prior to downconversion. This is especially essential for the bandpass sampling receiver, since out of band nose is folded on to the information band during sampling and frequency translation. For this comparison of bandpass sampling and direct conversion, the affect of varying the specifications of the RF bandpass filter was investigated. The performance of the two systems was monitored in terms of bit error rate (BER). Two bandpass filters with differing stopband attenuation levels of 20 dB and 45 dB were designed. Two bandpass filters with differing transition widths were also design with passband-to-stopband ratios of 0.72 and 0.38. These filters are shown in Figure 2.

Initial results indicate that the performance of the two different systems, in terms of BER, is very similar. Both the bandpass sampling architecture and the direct conversion receiver respond better to a RF filter with a lower stopband attenuation level, as expected. Also, both systems give better performance when a bandpass filter with a narrow transition width is used. A point to note is that both receiver architectures seem to be more sensitive to differences in transition width compared to stopband attenuation, suggesting that transition width requires more attention during the design and selection of bandpass filters for these architectures.

The investigation presented in this paper shall be enhanced considerably in the future. Particular attention shall be paid to the design of the front-end filters, and toward the ADC implementation within the model. The goal is to implement a multiband receiver with wideband front-end and evaluate its performance, once again investigating the performance achieved when the RF filter specifications are varied. The model can be further enhanced and additional investigations can be made in to the effect of non-linearities, particular from amplifiers and the ADC, on the performance of bandpass sampling and direct conversion receivers.

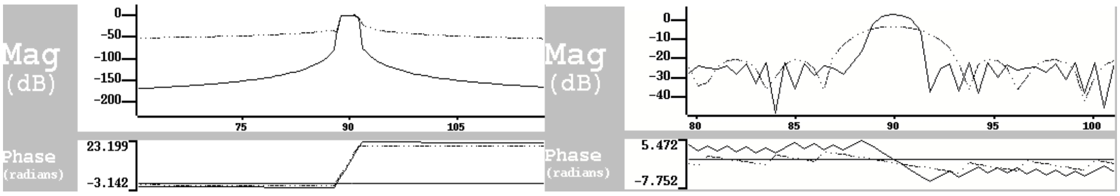

Figure 2: frequency characteristics of bandpass filters with varying stopband attenuation (left) and varying transition width (right).

6. Conclusion

Bandpass sampling and direct conversion are two receiver architectures that are suitable for software radios. However, considerable research efforts and breakthroughs in technology are required before the ideal software radio can be realised.

An overview of software radio and its problems has been briefly discussed. Bandpass sampling and direct conversion receiver methods have been described, and preliminary investigations comparing the two receiver architectures have been presented. Trends indicated by initial results indicating the effects of varying the RF filter specifications have been presented, together with an overview of further work to be carried out.

References

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