Compensation for Multipath at Quadrature Baseband Versus Radio Frequency

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Abstract— **Advancements in digital signal processing technology has been a key factor in promoting research into the implementation of most signal processing algorithms at baseband. Traditionally, most algorithms have been carried out at radio frequency (RF). With the coming of software defined radio (SDR) and other related technologies, there has been a need to investigate the possibility of implementing some of the signal processing algorithms at baseband frequencies which are more compatible with the fast developing software radio technology. This paper looks at simple multipath compensation and investigates the possibility and benefits of carrying the compensation process at quadrature baseband (QBB). Analogue quadrature amplitude modulation (QAM) is considered in the analysis. The analysis is carried out using MatLab simulations at RF and QBB and the results do show the possibility of carrying out the compensation process at QBB with the expected benefits as compared to carrying out the process at RF**.

***Index Terms*— Quadrature, baseband, Radio frequency, Multipath, Compensation.**

I. INTRODUCTION

Multipath distortion is an undesirable factor in most communication systems [1]. A multipath channel comprises a component of the direct path signal and the delayed multipath signal. The multipath signal is undesired and hence the need for us to compensate for its presence and thus eliminate its effects. The goal of the compensation is to recreate the characteristics of the original signal just as it was before the delayed signal was introduced. This requires us to have knowledge of the characteristics of the channel (i.e. frequency or impulse response) in order to determine the correct compensator denoted as *Hc*. It is well known that convolving in the time domain is equivalent to multiplication in the frequency domain and vice-versa [2]. This means that we can equally have a model for the multipath signal by convolving in the time domain. However, using the time domain method, there are some important limitations in that we are restricted to discrete sample delays 'nTs' and thus the compensation process is limited by the fact that we cannot carry out down-sampling beyond a point where the echo does not lie on a sample instant anymore and this has much to do with the echo positioning. The multipath channel modeling was done in the frequency domain and hence the signal compensation equally took place in the frequency domain. The famous time delay Fourier transform [2, 3] does facilitate for operating in the frequency domain. For this paper, simple multipath compensation is analyzed with fading neglected and narrow and signals are considered.

II. MULTIPATH COMPENSATION:–RADIO FREQUENCY

RF multipath compensation represents a traditional method of compensating for unwanted multipath signal effects. In this study, we assumed noiseless channels since, we are basically showing the possibility of compensating for multipath at RF and QBB with the latter being the new method and showing the expected benefits of compensating at quadrature baseband.

Theoretical Analysis

The theoretical analysis for the multipath compensation at RF is given below. In this paper, analogue QAM modulation was analyzed. The direct path signal is represented as x_d. The received multipath signal being the sum of the direct path and its delayed echo is thus given as

$$x_{mp} = x_d + kx_d(t-\tau) \qquad (1)$$

The compensator should thus eliminate the delayed signal component in the received multipath signal. The block diagram below is a representation of the Matlab analysis simulation structure showing the expected outputs at various points of the simulation.

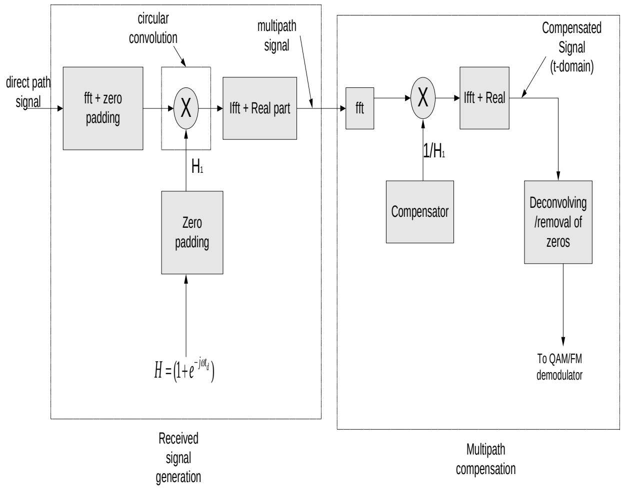

Figure 1: *RF multipath compensation theoretical analysis structure flow diagram.*

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In order to test the accuracy of the compensation process, a parallel path was created in the simulation where the direct path alone was under analysis giving us a basis for comparing the compensated demodulated outputs with the direct path demodulated outputs. The results will be shown in a latter stage of the paper.

III. MULTIPATH COMPENSATION AT QUADRATURE BASEBAND

The analysis moves down to quadrature baseband where the compensation will now take place. This in itself presents a major advantage of operating at lower sampling frequencies added on to the fact that operating at baseband also facilitates for downsampling which further reduces the operating frequency of the compensation process.

Theoretical analysis:-QBB

The input parameters used for this analysis are the same as those of their RF counterparts. This implies that we have the same signal parameters like amplitude, phase etc. Similarly we have the same initial sampling rate (f_s) and the local oscillator frequency used in the complex down-mixing process is coherent with the carrier frequency.

Upon analysis of the results, a decisive conclusion was to be reached about the possibility of compensating at QBB accompanied by the various benefits that come with working at QBB frequencies. Some of the advantages of working at baseband frequencies are attributed to the ease of handling of baseband digital signals by software defined radios and hence resulting in the immense benefits of SDR technology being utilized [4]. The expressions for the direct path and multipath signals have already expressed under the RF theoretical analysis. And thus the analysis moves on to the receiver where it is required that we compensate at QBB. The received signal 'x_{rmp}' is down-mixed and low-pass filtered so as to generate its QBB equivalent.

$$x_{rmpqbb} = [x_{rmp} e^{-jw_c t}]_{LPF} \tag{2}$$

where x_{rmpqbb} represents the QBB version of the received multipath signal. The block diagram on the next page is a representation of the Matlab analysis simulation structure showing the expected outputs at various points of the simulation. Figure 2 summarizes the theoretical analysis.
The compensation is thus done at QBB as required by the study. The simulation results will verify the compensation process illustrated theoretically by the figure above.

Upon generating the QBB equivalent of the multipath signal, down sampling is also carried out. The quadrature baseband signal is downsampled by a factor 'n' whose value is restricted to the point where there is no aliasing in the spectrum. What this statement implies is that, one can only downsample up to a certain point and that point is where aliasing begins to take place. It is a well known factor that aliasing is an undesirable situation and thus it has to be avoided at all costs. The downsampled signal is given in Matlab as

$$x_{rqbbds} = xrqbb(1:n:end) \tag{3}$$

where x_{qrbbds} represents the downsampled QBB signal. At this stage, the analysis focuses on the compensation process where it was required to compensate for the multipath effects. Now, in order to compensate for multipath at this stage, it is required to shift the compensation down to baseband because the signal now sits at baseband. This presents the advantage of compensating at QBB which entails that the compensation takes place at much lower frequencies unlike for the RF situation.

The compensator should equally be downsampled before the compensation can take place. The QBB downsampled compensator is denoted as H_{cds}. The compensation can now take place and this is done by multiplying H_{cds} with the FFT [5] of x_{rbbds} denoted as X_{rqbbds}. This is shown below as;

$$X_{rc} = X_{rqbbds} H_{cds} \tag{4}$$

where X_{rc} denotes the compensated signal in the frequency domain whose time domain equivalent is given in Equation 5 below. The padded zeros [6] should be eliminated at this stage. There is need to take into consideration the fact that the signal length has reduced by a factor 'n' and hence this should not be overlooked when removing the padded zeros. The IFFT of X_{rc} is given below as

$$x_{rc} = ifft(X_{rc}) \tag{5}$$

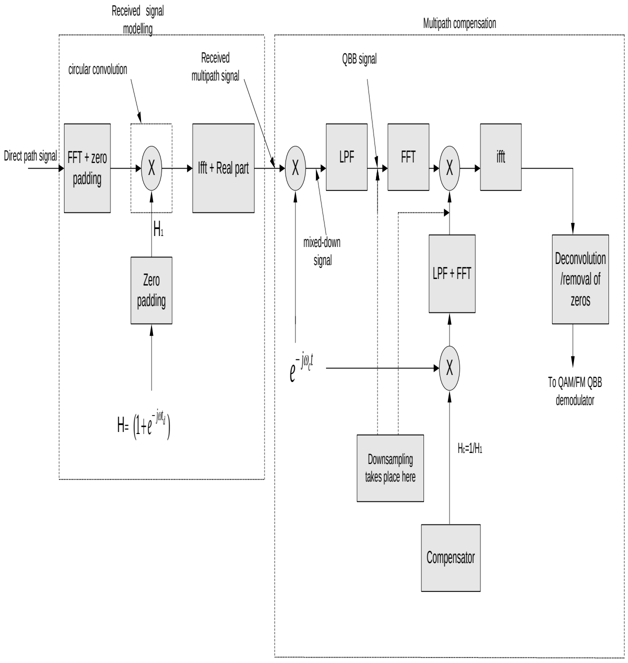


Figure 2: *QBB multipath compensation theoretical analysis flow structure.*

The signal x_{rc} is then demodulated and is denoted as x_{rcd}. In the simulations that follow, a parallel analysis is run for the direct path signal which is demodulated and compared with the compensated output so as to test the accuracy of the compensation process. The demodulated output from the parallel analysis is denoted as x_{rd}. The next section of the paper gives the RF simulation results.

IV. SIMULATION RESULTS:– QAM RF COMPENSATION

The figures on the next page are the results obtained from the multipath compensation simulation at RF. The sampling frequency f_s used was 4000Hz and x_1 and x_2 shown in Figure 3(a) are the unmodulated inputs of the QAM direct path signal shown in Figure 3(b). As mentioned under the RF theoretical analysis, the zero padding [6] during the multipath signal generation doubles the signal length and this is evidenced in Figure 3(c). Compensating for multipath as outlined in the theoretical analysis results in the output shown in Figure 3(d). It can be seen here that the QAM signal has been retrieved and the multipath effects compensated for.

The demodulated outputs and difference plot should further consolidate the accuracy of the compensation.

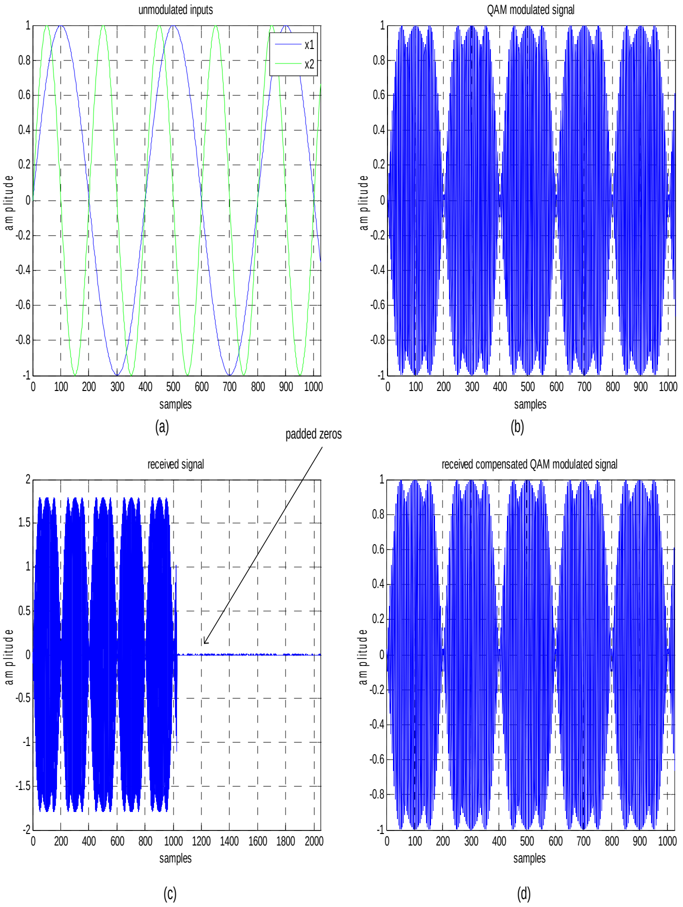


Figure 3: *Simulation results* **(a)** *Unmodulated inputs:- these represent the inphase and quadrature phase inputs of the QAM signal* **(b)** *QAM modulated signal* **(c)** *Received signal:-the last 1020 samples consist of padded zeros* **(d)** *Compensated signal.*

It is necessary to again verify the accuracy of the compensation process by comparing the direct path and compensated output and producing error plots to show the difference between the too. The figures on the next page show the demodulated outputs and difference plot.

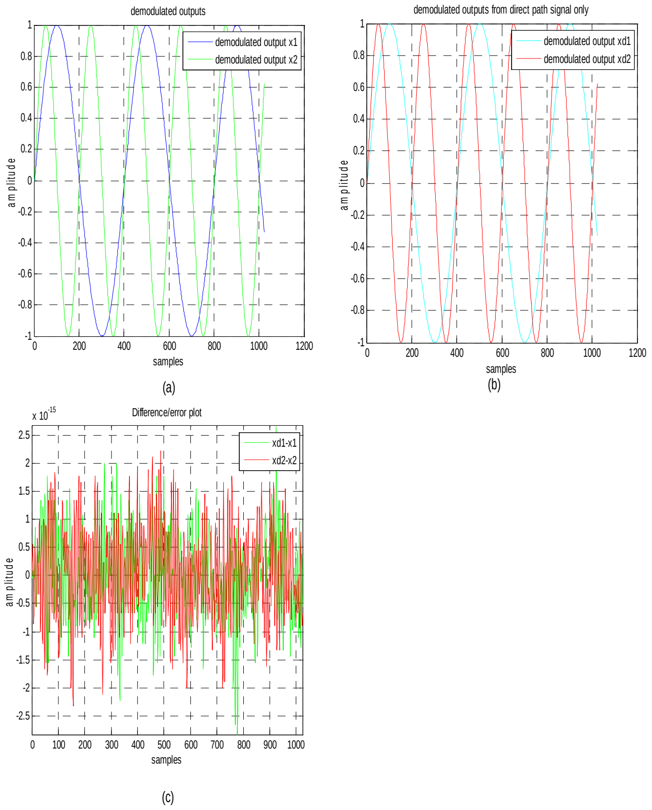
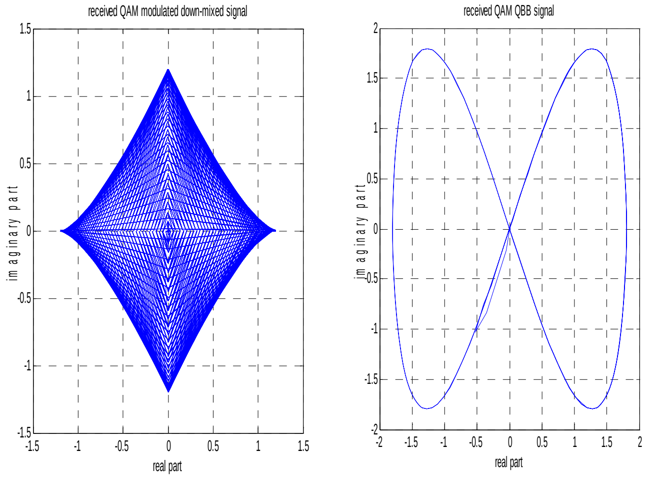


Figure 4: *Simulation results.* **(a)** *Demodulated output after compensation* **(b)** *Demodulated output from direct path* **(c)** *Difference plot between direct path and multipath compensated demodulated outputs.*

The difference plot clearly shows a very small and insignificant error. This proves that the compensation was accurate and successful.

V. SIMULATION RESULTS:– QAM QBB COMPENSATION

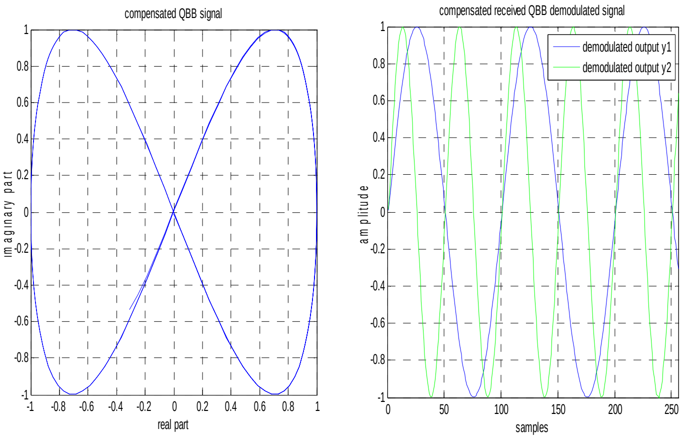
The results of the MatLab simulations are now given and analyzed in this section of the chapter. It should be noted that the generation of the received signal remains the same as was done under RF and so the graphical results to be analyzed will be from the receiving end down to the compensation and demodulation. The figures below show the plots resulting from the simulation of the QBB multipath compensation.



(a) (b)

Figure 5: *Simulation results* **(a)** *Down-mixed received signal* **(b)** *QBB received signal before compensation..*

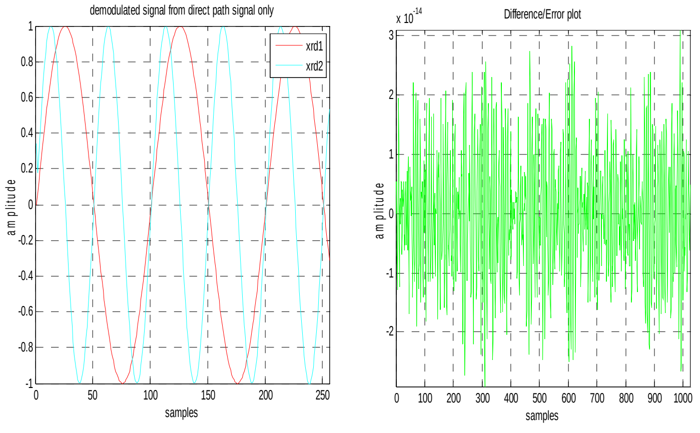
The figures below show the QBB signal after compensation and the demodulated output. It is seen that the original inputs were successfully retrieved from the multipath signal.



(d) (b)

Figure 6: **(a)** *QBB signal after compensation* **(b)** *Demodulated compensated output.*

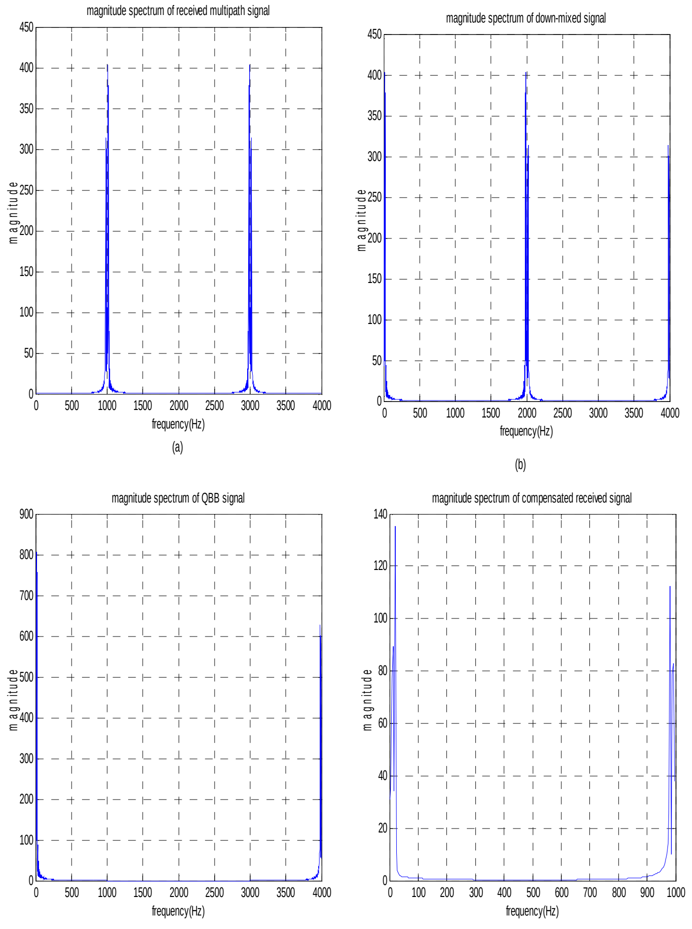
The compensated signal had the padded zeros, that were introduced in the generation stage, removed, and the original signal length was thus restored. The signal length was reduced by the downsampling factor ‘n’ and in this particular case, the demodulated signal outputs have a length of 256 samples the due to the downsampling factor being equal to 4. The figures below show the demodulated outputs from the direct path signal demodulation for comparison purposes. A difference plot is also given to further verify the compensation accuracy.



(a) (b)

Figure 7: **(a)** *Direct path demodulated output:-forms the basis for comparison so as to determine the preciseness of the compensation process.* **(b)** *Difference/error plot:-indicates that the compensation was successful despite the error being slightly higher than for the previous analyses.*

The spectral changes for the QBB compensation process analyzed above are shown in the figures on the next page. The spectral changes elaborate more on the compensation process and also show that the compensation process took place at quadrature baseband.



(a) (b) (c) (d)

Figure 8: *Magnitude spectra plots.***(a)** *Received signal* **(b)** *Down-mixed signal* **(c)** *QBB downsampled signal* **(d)** *QBB downsampled compensated signal. A 4 fold reduction in the sampling results from the sub-sampling by a factor of 4.*

It is thus seen that the compensation process took place at quadrature baseband and the original direct path signal was retrieved from the multipath signal by the compensation process.

VI. CONCLUSION

The analysis results do show that indeed it is possible to compensate for simple multipath at quadrature baseband. The core benefit of working at quadrature baseband is the lower operating frequency as compared to working at radio frequency. This inturn facilitates for more sub-sampling at QBB than at RF. Complexity of the operating equipment can inturn be reduced. The study thus is a contribution to the vast research taking place in line with signal processing technology advancement. More research can be done considering more parameters for other modulation schemes.

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