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Implementation of High Signal to Error Variable Logarithmic Based Quantization Steps for Continuous Time Analog to Digital Converter

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Abstract: In this paper, logarithmic spacing quantization technique has been extensively implemented for continuous time digital signal processing (CT-DSP), which significantly reduces the in-band error power for a sinusoidal test signal. The test signal is converted into a logarithmic domain and the obtained compressed signal is further quantized non-uniformly without any sampling, which is the basis of CT-DSP. Moreover, the quantization error spectrums of both conventional quantization method and logarithmic spacing technique are simulated on MATLAB. Contrasting both the spectrums, a distinct reduction in error power is observed in the latter case. The proposed logarithmic spacing technique, which has been implemented for the first time in continuous time domain shows that in-band error power for 16-level quantization is reduced by 20.97% which ultimately enhances the Signal to Error Ratio (SER).

Keywords: Quantization, Continuous Time Digital Signal Processing (CT-DSP), Continuous Time Analog-to-Digital Converter (CT-ADC), In-band SER, Logarithmic spacing, Error spectrum.

1. INTRODUCTION

Continuous time digital signal processing (CT-DSP), a recent trend in digital signal processing systems is coming up with a number of advantages and applications. CT-DSP combines the best attributes of both DTDA (discrete time with discrete amplitude) and CTCA (continuous time with continuous amplitude) systems, thus, producing a new area of systems which works by being discrete in amplitude but continuous in time (CTDA)[1]. It processes without sampling, thereby eliminating the aliasing effect[2]. This reduces the in-band distortion power by not aliasing into out-of-band distortion components and hence the reduction in quantization error and noise.

The basic block diagram of continuous time digital signal processing system has been illustrated in Figure 1[5], however the paper targets on improving the performance parameters of the operation of CT-ADC system.

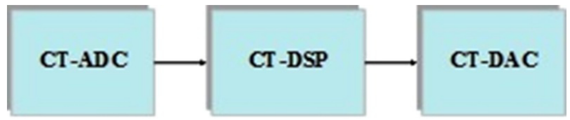


Figure 1: Basic Block Diagram of CT-DSP5

CT-ADC has appealed to a variety of applications in almost every day-to-day field[3]. A chip has also been presented[4] that process the signal as the operation of an analog to digital converter (ADC) without sampling. Mariya and Yannis[5] had experimentally achieved a scheme of resolution that keeps adjusting according to the speed of the input sinusoid. According to proper thresholds selected[6], the resolution is varied in comparison to the activity of the input signal[7]. They had illustrated the operation of a two-step quantizer, in which, when the slope is below the threshold, the input is quantized with maximum resolution, whereas in the case where the slope transcends the threshold, the step size is tripled.

Moving on these lines of twofold quantization, initially a variable quantization method has been implemented where higher slope gives more quantizing steps and lesser slope gives considerably less number of steps, hence improving the performance of the quantizer. Furthermore, in order to achieve a decrease in error, a logarithmic spacing quantizing technique based on companding has been executed using μ-Law compression.

Additionally, a bell shaped waveform of quantization error is due to slowly varying inputs and a sawtooth waveform is due to fast varying input is seen. It is observed that distortion is high at sawtooth frequency; however the amplitude of distortion decreases as the resolution is increased[8].

In the presented paper, the host signal is compressed logarithmically followed by quantization. Further, the simulation result of power spectrum of quantization error is obtained in addition to the spectrum of uncompressed signal. A comparison in the error spectrums of both the signals is drawn hence showing a significant decrease in error. The proposed algorithm has not yet been previously studied and researched on; only applications based on the last implemented techniques have been coming up[10].

The paper contains the following sections where the first section explains the processing and simulation results of conventional quantization method and the next section elaborates on quantization using logarithmic spacing. Next section displays the contrast between their error spectrum plots for different number of bits for input signal and last section concludes the work.

2. INVESTIGATION ON CT-ADC FOR FIXED QUANTIZATION STEPS

A sinusoidal wave with an input frequency of 1000Hz has been taken for processing, as shown in Figure 2.

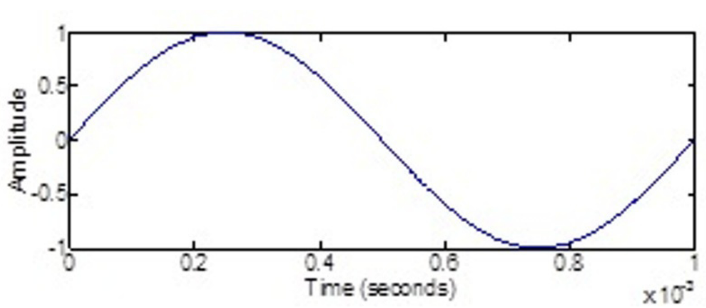


Figure 2: The input sinusoidal

The signal was further classically quantized over the length of the time of the signal under a clock frequency of 10^8 Hz as shown in Figure 3.

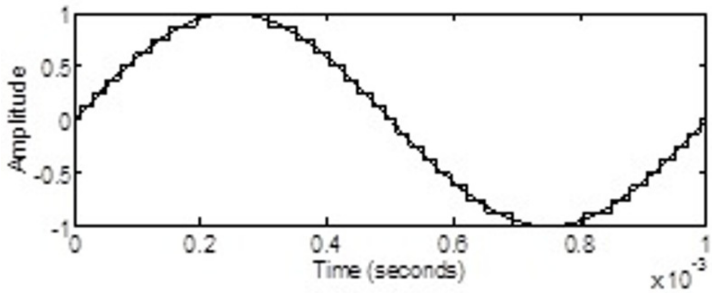


Figure 3: 4-bit quantization of input signal

The ratio of signal to quantization error and noise can be defined as the in-band SER, which precisely contains the power within the specific band of interest[1].

Though the total mean square error of the signal might increase, the technique makes sure that the in-band SER would not suffer.

The error spectrum then observed (Figure 4), showed a maximum power of 3.29dB/Hz at 55Hz, within the in-band frequency.

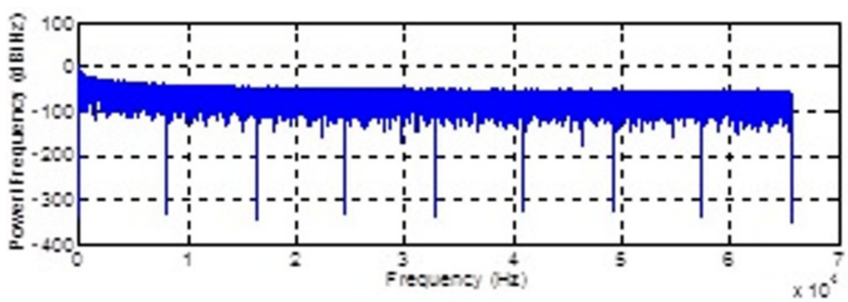


Figure 4: Quantization error spectrum (3.29dB/Hz)

3. PROPOSED VARIABLE LOGARITHMIC BASED QUANTIZATION STEPS

Companding techniques are widely used in signal processing for compressing the amplitude, with an aim to achieve better precision and accuracy in quality of voice/speech signals.

This compressing/expanding method prompted the urge to implement a new technique of logarithmic spacing quantization. While using this concept, more step sizes are devoted in quantizing small amplitudes and less to be associated with larger amplitudes.

In logarithmic quantization, the test signal *x* which is a sinusoidal wave of 1000Hz frequency has been converted using the below function:

$$f(x) = \text{sgn}(x)\frac{\ln(1+\mu|x|)}{\ln(1+\mu)}\ ;\ -1 \le x \le 1$$

where, μ is the μ-law parameter of the compander, ln is the natural log and sgn(*x*) is the signum function.

The new modified test signal is then quantized non-uniformly for further analysis of error power.

Experimental testing of signals has been illustrated where quantization for a 1KHz sine wave using 4-bit, 6-bit and 8-bit encoding has been performed. A comparison of the host signal coincided with the quantized signal, with and without logarithmic spacing, for the respective bits has been shown in Table 1. As expected, the number of steps increases with increasing bit.

Further, the difference between the test signal and quantized signal has been plotted. In Table 2, a contrast of the waveforms of quantization error has been illustrated.

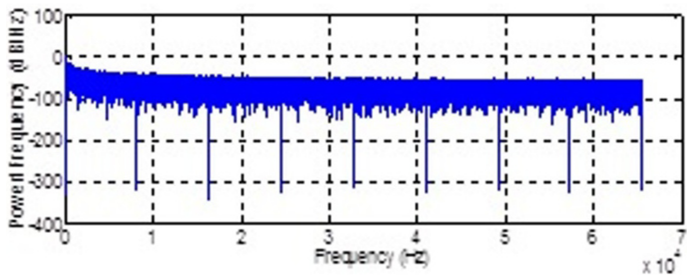
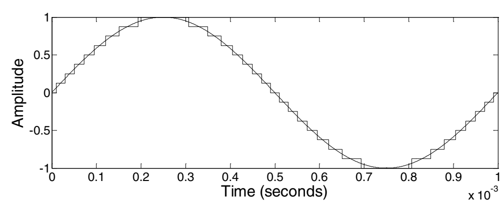
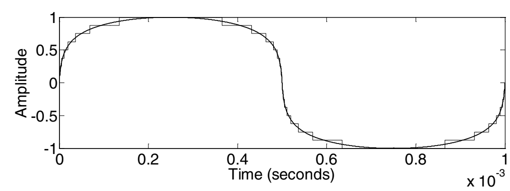
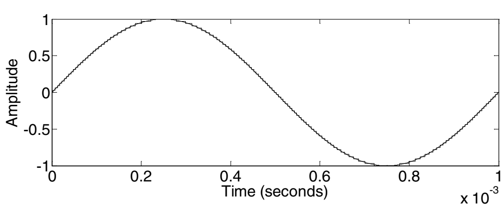
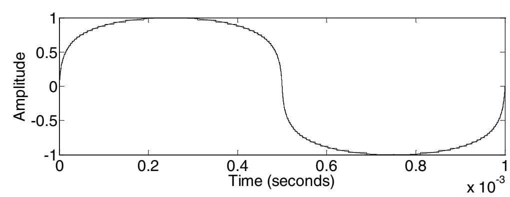
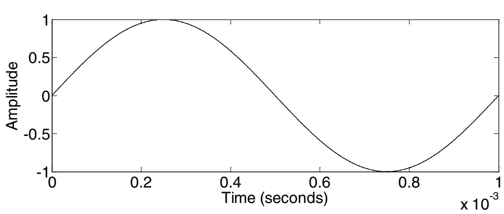
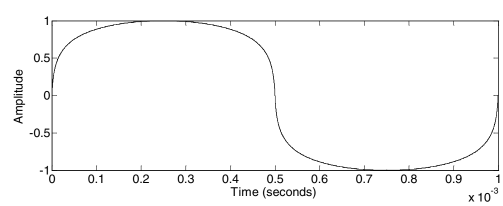


Figure 5: Quantization error spectrum of companded signal (2.6dB/Hz)

It is to be noted, that only 'in- band' quantization error power is of main interest disregarding the output in the out-band frequency. Here, the band of interest is 1 KHz where the maximum observed power in the band is 2.6dB/Hz at a frequency of 21Hz for 4-bit encoding.

Table 1
Comparison of Conventional Quantization and Logarithmic Quantization of Sinusoid

No. of Bits	*Conventional Quantization*	*Proposed Logarithmic Spacing Quantization*
$n = 4$		
$n = 6$		
$n = 8$		

4. RESULTS

Logarithmic quantization is performed using a fixed step size and clock frequency to analyze the output spectrum in terms of error and power that showed a considerable increase in SER substantiated with analysis and simulations on MATLAB.

Table 2
Contrast of Waveforms of Quantization Error

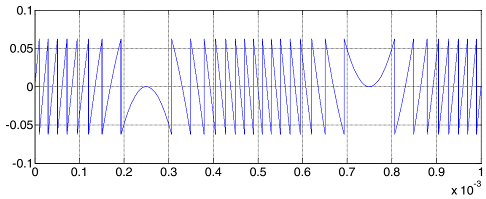
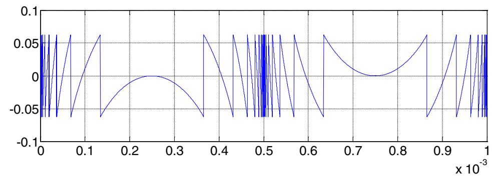
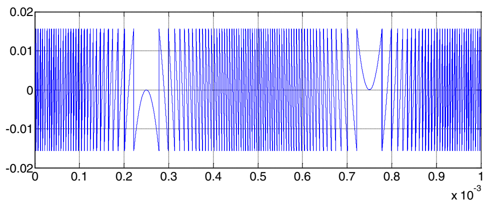
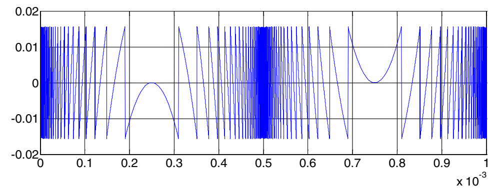
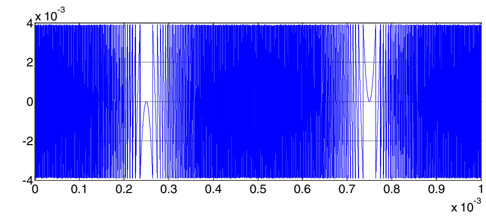
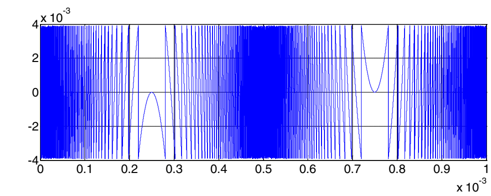
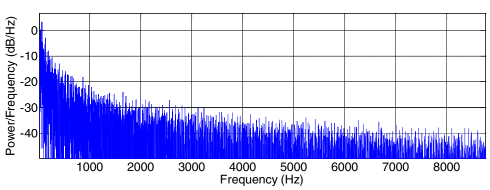
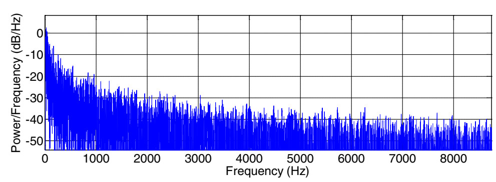
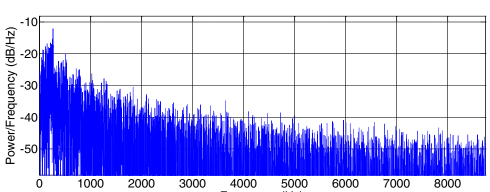
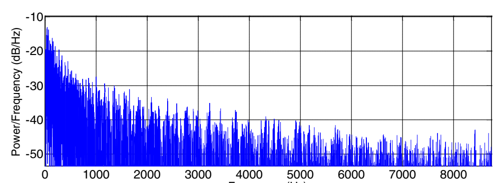
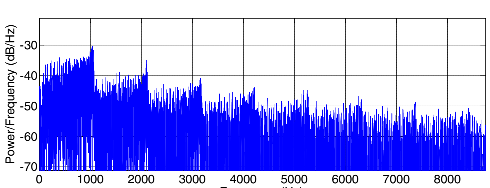
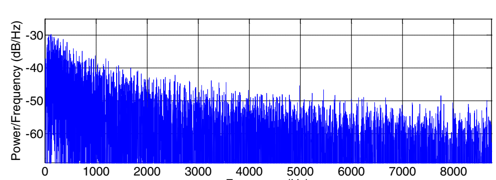
No. of Bits	*Conventional Quantization*	*Proposed Logaritmic Spacing Quantization*
$n = 4$		
$n = 6$		
$n = 8$		

Table 3
Comparison of Error Power Spectrum

No. of Bits	*Conventional Quantization*	*Proposed Logaritmic Spacing Quantization*
$n = 4$		
$n = 6$		
$n = 8$		

Moreover, in order to distinguish with a clear eye, a comparison of the error power spectrum has been displayed in Table 3 supported with its approximate values of maximum in-band quantization error power in dB/Hz at their particular frequencies in Table 4.

Table 4
Approximate values of maximum in-band quantization error power

No. of Bits	*Conventional Quantization*		*Proposed Logarithmic Spacing Quantization*	
	Power (dB/Hz)	*Frequency (Hz)*	*Power (dB/Hz)*	*Frequency (Hz)*
$n = 4$	3.29	55	2.6	21
$n = 6$	–12.1	259	–13	39
$n = 8$	–29.66	975	–32	115

The maximum in-band quantization error power of 3.29dB/Hz at a frequency of 55Hz was seen. As expected, the quantization error of compressed signal showed reduction which was noted to be 2.6dB/Hz at a frequency of 21Hz for 4-bit encoding.

For 8-bit encoding, –32dB/Hz of error power in case of companding, against –29.66dB/Hz was seen.

Similarly, error power using conventional technique of –12.1dB/Hz versus –13dB/Hz using logarithmic spacing was observed for 64-levels of quantization.

5. CONCLUSION

From the illustrations of results shown in the previous section, it can thereby be inferred that, the SER in case of the logarithmic domain is higher when compared with the SER of a conventional quantization technique, as less error (20.97%) power implies more signal to error ratio.

This improvement has found many widespread applications, primarily in bio-medical implantable diagnostic devices which can work on low input power with higher accuracy[9].

Thus, it can be complied that a considerable reduction in error power was observed, without any degradation in in-band performance, hence further improving the SER.

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