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Implementation of Radio Frequency Digital to Analog Converter Design for Satellite Telecommunication System

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Abstract:
In satellite communications applications, the radio frequency digital to analog converter is a crucial building block. Radio frequency digital to analog converter (RFDAC) is the fundamental link between analog and digital electronics. The DAC converts the input digital signal into an equivalent analog output signal. Dynamic performance is high-speed and high-resolution digital to analog converters (DACs) limit the distortion at the data switching instants. For this paper, 8 bits digital to analog converters are designed by using the Flash method. A D/A converter simulation circuit converts the parallel digit bits (d_o~d_7) to the analog voltage equal to the original sample with some quantization errors. These ADC bits are summed and differed by using the Flash method to produce the digital pulse string. This production can write by using high-level language for the digital signal processing (DSP). The digital pulse string of digital signal processing (DSP) passes through DAC block for the required analog output signal. The MATLAB programming is used to simulate the required ADC, DAC and DSP functions and the post analysis of simulated results.

Keywords: ADC, DAC, DSP, MATLAB Signal Processing, Quantization Error, Satellite Communication.

1. Introduction

A digital to analog converter is a device for converting a digital (usually binary) code to an analog signal (current, voltage or charges). Digital to analog converter is the interface between the abstract digital world and the analog real life. Simple switches, a network of resistors, current sources or capacitors may implement this conversion. Digital signals (RF) are sent as input signals and then the analog output signal for voice band are produced by using DAC. Today, most of the signal processing performed in electronic systems is digitals, and the performance of the digital to analog converters (DACs) present at the border of the digital domain becomes very important.

The DAC resolution and speed requirement is ever increasing in the most recent applications in consumer electronics, telecommunication and test and measurement instrumentation. Wireless communications are the speed and frequency domain performance of modern data converter. Digital to analog converters (DACs) are the important building blocks in telecommunication systems. The wireless

market is poised for more growth in the future, with the demand increasing due to the addition of new services which provide more functionality for the end users.

One of the main reasons for this growth has been the major progress in the field of radio frequency (RF). The number of wireless standards has also increased drastically along with the market growth, with each standard catering to specific market segments. The data converter is the important building block in today's satellite telecommunication systems.

2. Radio Frequency Digital to Analog Converter

The RFDAC system is designed and built by using MATLAB software controlled codes. The block diagram of radio frequency digital to analog converter is shown in Fig 1. The overall block operations of radio frequency digital to analog converter are; the analog input signal (1GHz) is sampled with 100 times of signal and these analog signals are held before the next input signal. Then, these signals are converted from the S/H output signals to the digital signals by using the Flash ADC method. These digital signals are processed by using digital signal processing method. Digital to Analog Converter transforms digital signals (discrete in time with amplitude quantization) to analog signals (continuous in time and amplitude). This digital output signal is the same as the analog input signal. The error level and quantization error can be calculated by using the error calculation method. So, the required analog output signal can be produced.

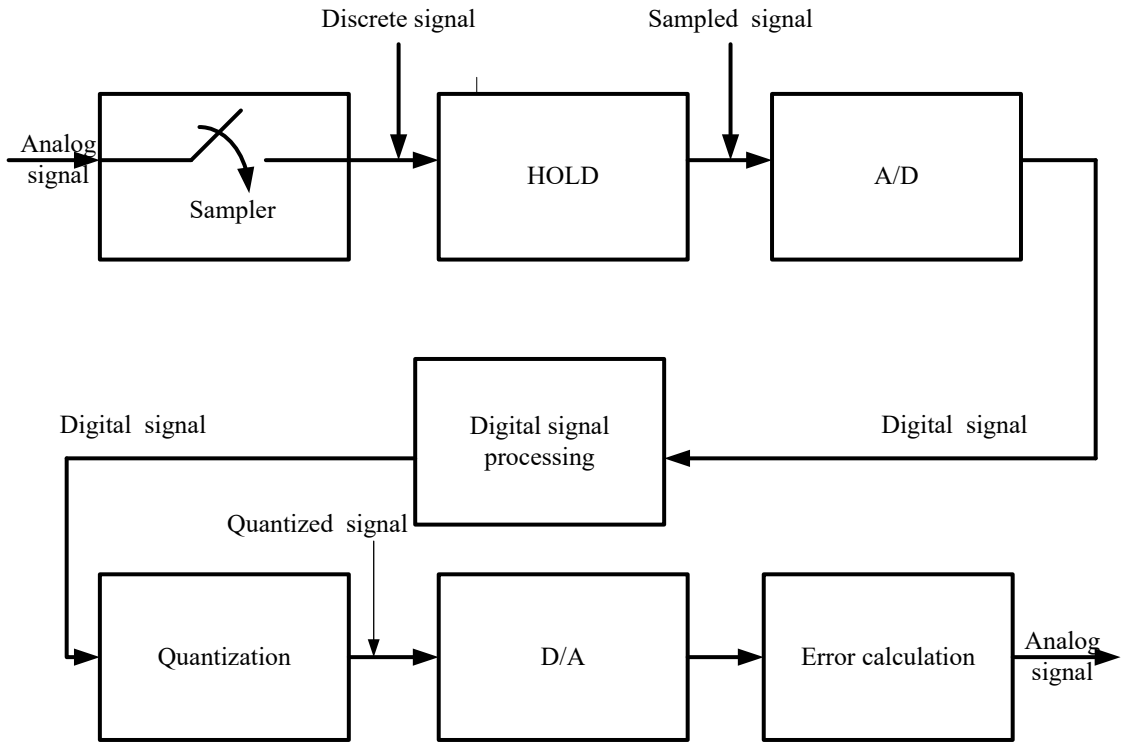


Figure.1. Overall Block Diagram of radio frequency digital to analog converter

3. Methodology

3.1. Overview of the Digital to Analog Converter

DACs regard them simply as devices with digital input and analog output. But the analog output depends on the presence of that analog input known as the reference, and the accuracy of the reference is

almost always the limiting factor on the absolute accuracy of a DAC. DACs use external references as shown in Fig 2 and have a reference input terminal, while others have an output from an internal reference.

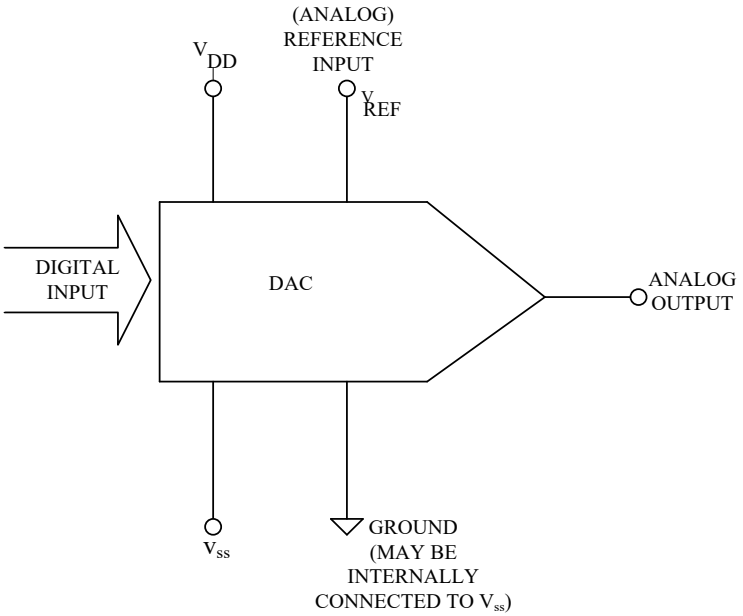


Fig 2. Basic DAC with External Reference

If a DAC has an internal reference, the overall accuracy of the DAC is specified when using that reference. If such a DAC is used with a perfectly accurate external reference, its absolute accuracy may actually be worse than when it is operated with its own internal reference. This is because it is trimmed for absolute accuracy when working with its own actual reference voltage, not with the nominal value.
If there is a reference input, the first specification will be the reference input voltage and of course this has two values, the absolute maximum rating, and the range of voltages over which the DAC performs correctly. The reference input terminal of a DAC may be buffered is shown in Fig 3.

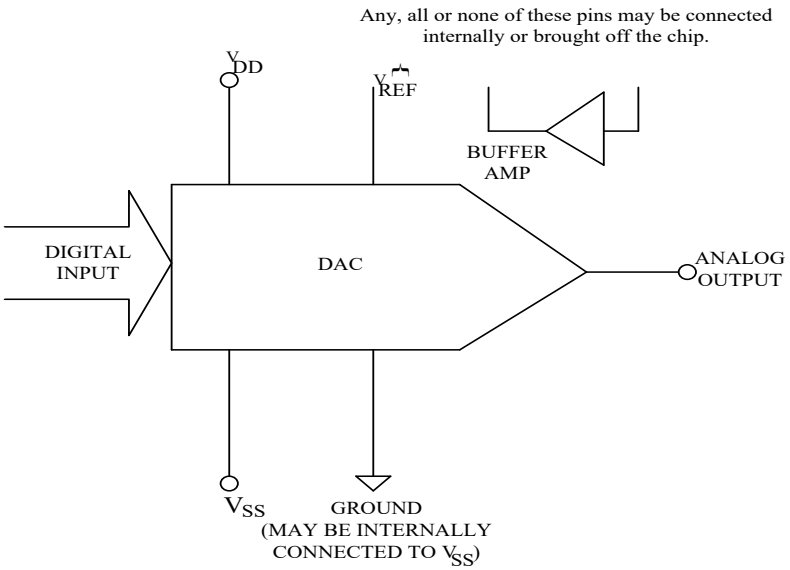


Figure.3. DAC with Reference and Buffer

In this case the input impedance specification may become more complicated since some DAC structures have input impedance that varies substantially with the digital code applied to the DAC. Where the reference input impedance does not vary with code, the input impedance should be specified. Surprisingly for such an accurate circuit, the reference input impedance of a resistive DAC network is rarely very well-defined.

3.2. DSP Basic

Digital Signal Processing is one of the most powerful technologies that shape science and engineering in these days. The real world signals are seismic vibrations, visual images, sound waves, and so on. DSP field covers the enhancement of visual images, recognition and generation of speech, compression of data for storage, transmission, and so on. DSP system uses the digital processing technique. So DSP uses the mathematics, the algorithms, and the techniques to manipulate these real world signals which are converted into the digital form. DSP provides the better control of accuracy requirement. The digital signal processing method also allows for the implementation of more sophisticated signal processing algorithms.

It is usually very difficult to perform the precise mathematical operations on signal in analog form. DSP system has three main parts; ADC (analog to digital converter), DSP (digital signal processor) and DAC (digital to analog converter). Most of the real world signals are analog in nature; sound, image, temperature and so on. To apply these analog signals, sensors and ADC/DAC converters are needed.

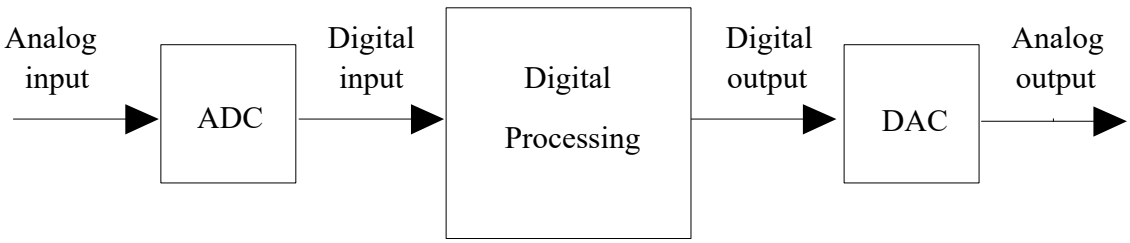


Figure.4. Block Diagram of a Digital Signal Processing System

4. System Implementation

4.1. Simulation Setup

The required program for DAC model is developed in this paper. The program is required to setup according to real environment and characteristics. The model is composed of five main parts. The input signal frequency is defined by the user or can be run as the default value. The defined value of signal frequency is 1GHz and sampling frequency is 100 times of signal, 100GHz in this case. The amplitude of signal is 1V, Vpp. The DC offset of signal is half of signal and 0.5 V in this case. Second part is ADC and this part converts input Analog signal values to Digital values.

The type of ADC is 8-bits Flash ADC type. The converted numerical string then drives to next step. The third part is the quantization circuit to detect each voltage level value and quantize the respected value. The function of this part is to simulate ADC as the realistic model. The quantization error and the distortion value are added to act simulation as a real ADC circuit. The next step is Digital to Analog

Converter parts. The function of this part is to detect each digital or numerical string and convert it to analog voltage level. The output of DAC is the same signal as the input. The DAC is 8 bits and 1Vpp parameter. The operated frequency of DAC is 1GHz but the frequency can also be changed by the user. The last part is to compare the input and output signal. Then the error level and the quantization error are calculated by error calculation stage. The waveform of each step can also be calculated and presented in the graphical form.

4.2. System Flowchart

According to the flowchart, the input signal frequency will be received after checking the predefined value (radio frequency range). The default values of signal frequency and the sampling frequency are set up. And then, the system generates analog output signal. The analog to digital converter has an input that can vary from the minimum to maximum value of volts. The results of nearest digitized signal having a quantization error. After that, the digital signals are converted by D/A converter. And the error calculation stage can calculate the errors between the input and output stage. This system is evaluated by the following MATLAB code. The program flow chart of DAC test system is shown in Fig 5.

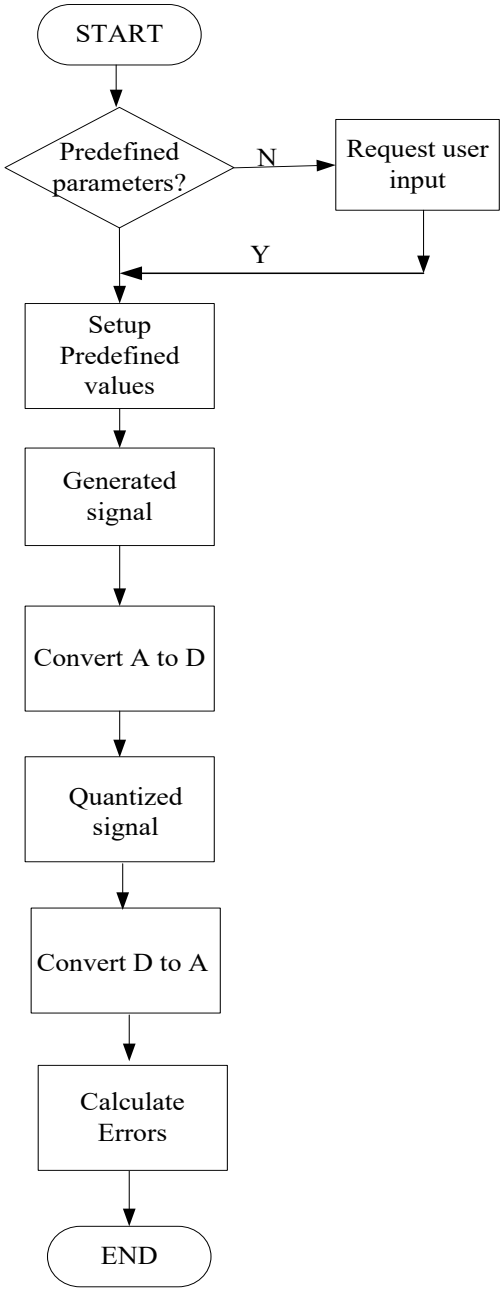


Figure.5. Program Flowchart of DAC Simulation Program

4.3. Quantization

After the sampling, a sequence of numbers can take any value on a continuous range of values. Because this range is continuous, there are infinitely many possible values for each numbers. In order to be able to represent each number from such a continuous range, an infinite number of digits would be needed. After discretizing the time variable, the amplitude variable is discretized as well. This discretizing of the amplitude values is called quantization.

$$V_Q = V_{step} \int_{v_0}^{v_{pp}} (V_{in} + V_{offset}) dv \qquad (1)$$

4.4. Digital to Analog Converter Simulation

The DAC generates an analog output (signal) that represents the digital input (signal). The analog output is a signal carrier representing the same signal as the digital input does. An essential issue is that the input is digital, hence discrete-time and discrete-amplitude. Therefore, the output signal contains the truncation noise.

The next step is to feed the generated signal to DAC to reform the analog signal. The data set from ADC is considered as a closed circuit to DAC input. The electrical characteristics of each ADC and DAC will impact the output wave form linearity and distortion. Before the signal is feeded to DAC, the signal is quantized to generate the step sine signal. The signal does not filter exactly each step of the quantized level which is monitored.

5. Simulation, Tests and Results

5.1. Results of 8 Bits RFDAC

The first observation should be done by checking the input signal. A closed step Sine waveform should be generated. The input frequency is 1GHz and the X-axis is represented as Time and should be 1 ns for 1 completed cycle. The amplitude of signal is set up as 1V, Vpp and the output is also generated as setup. The result waveform of input signal is shown in Fig 6.

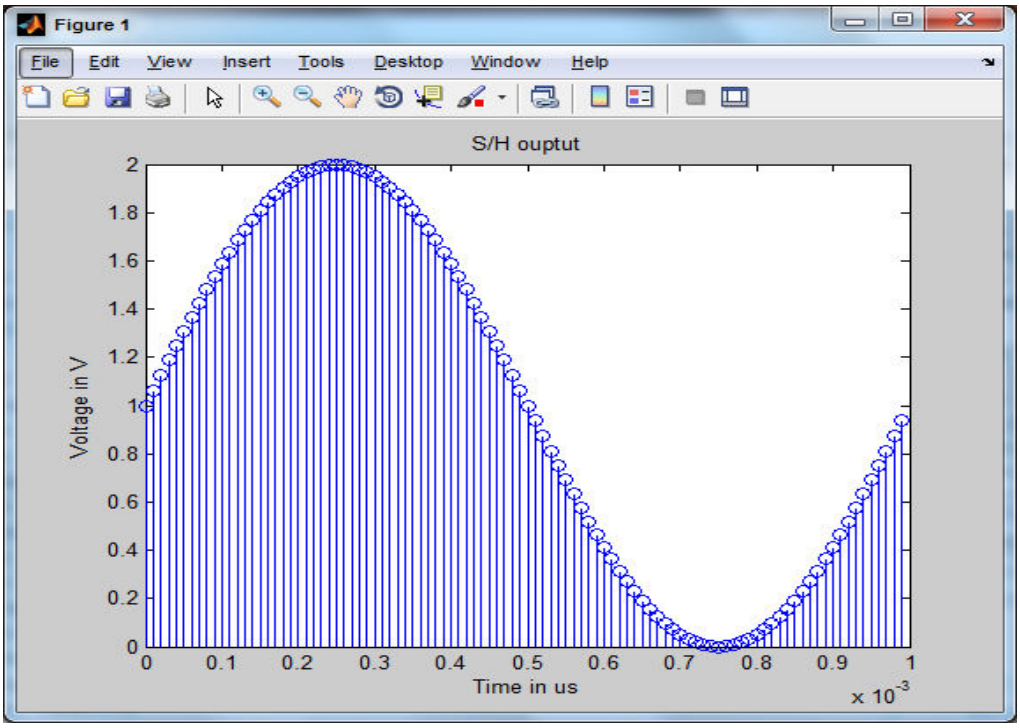


Figure.6. Input Signal of Waveform for 8 Bits

Then, the quantized value for each step can be simulated. The output of quantization circuit should not be different from the signal. The error of ADC and quantization can be calculated and checked.
Then, the resultant waveform and the waveform of ADC are compared. The simulation code can calculate and generates required quantization error of each step and also the error waveform. The error graph or waveform represents the same sampling step of previous waveforms as shown in Fig 7.

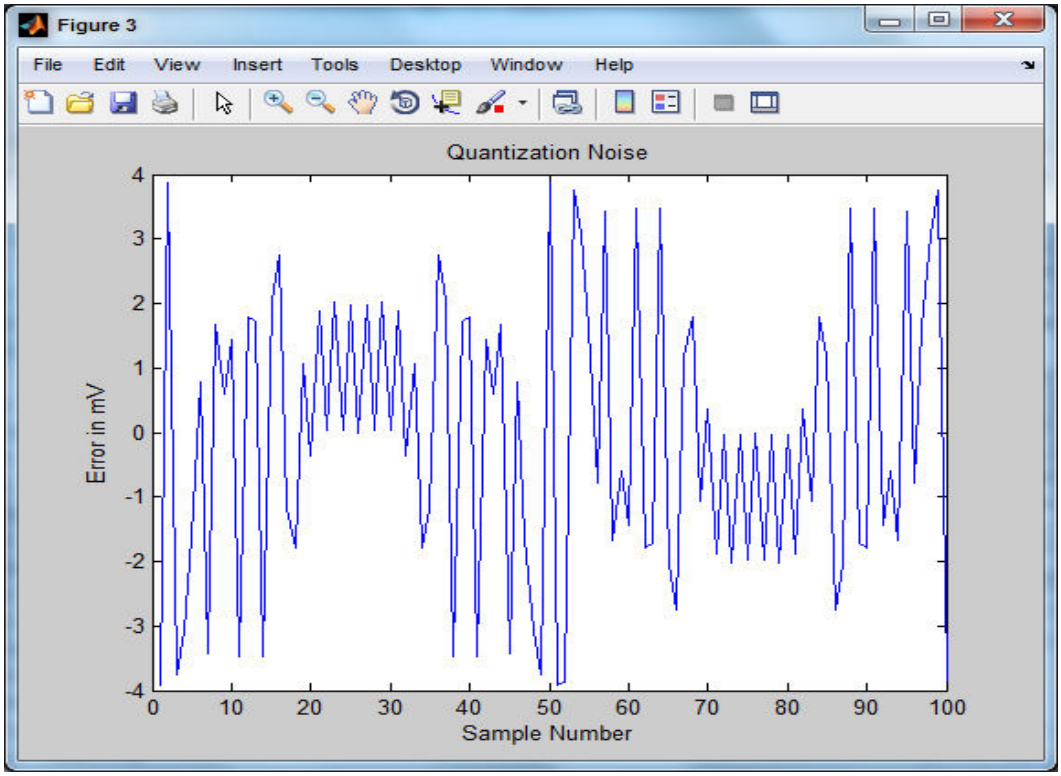


Figure.7. Quantization Error Plot for 8 Bits

Then, the DAC component is simulated. The output from the quantizer circuit is fed to DAC. The DAC then converts the input digital signal to the analog waveform. The generated signal is also observed. The DAC can generate the similar waveform as the input signal. The final output waveform from DAC simulation is shown in Fig 8.

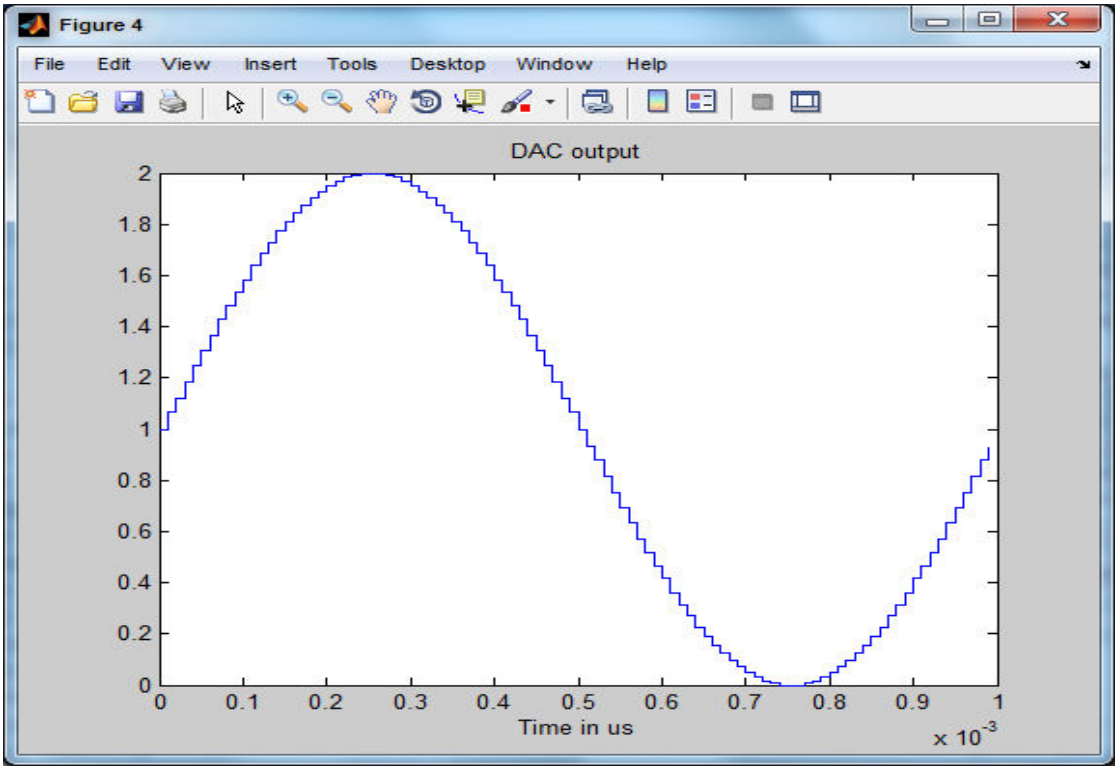


Figure.8. Output Waveform of DAC Simulation for 8 Bits

The last step is to calculate the conversion error and the accuracy. The conversion error can be calculated as follows:

Conversion Error = Input Signal – Output Signal (2)

By sampling, the extracted output signal to input signal and each step of sampling error are calculated by using the program. Then, the error chart is presented in the next Fig 9.

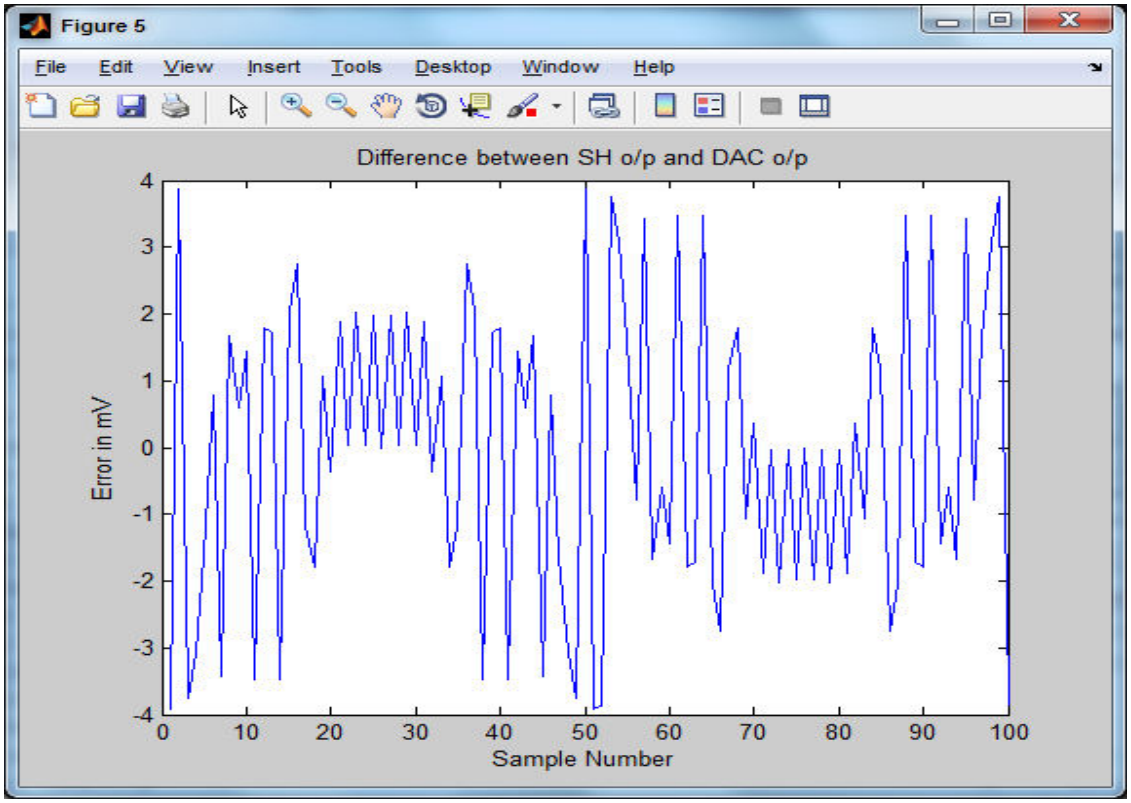


Figure.9. Conversion Error Plot for 8 Bits

5.2. Checking Statistics with Manual Input Control Analysis

The simulation can be done with auto defined values as above. After this, some simulation scenarios are used to check the statistics for simulation. The option 2 of simulation can be controlled by the user input parameters. The user-defined simulation is tested with the following parameters.

All DAC converters have an inherent Sine wave roll-off that affects the amplitude of the signal being synthesized as it gets closer to the Nyquist frequency. It is important to characterize this roll-off and to determine how the decrease in signal amplitude affects the AC performance. To measure this effect, simply generate various full-scale sine waves out of the DAC and measure the fundamental amplitude as the output frequency increases.

Signal frequency - 1000 Hz to 1000000 Hz
Frequency step - 1000 Hz
Sampling frequency - 1 MHz
Amplitude - 1V (Vpp)
DCoffset - 0.5 V (Amplitude/2)
DAC resolution - 8 bits
Waveform - Sine and Sawtooth

The Quantization error can be calculated from the following equation.

Quantization Error = Quantized level – Signal Level (3)

$$= \frac{\text{Amplitude} + \text{DC offset}}{2^{\text{resolution}}} - \text{Signal Level}$$

The result for Quantization error in 1kHz to 1000 kHz frequency range is shown in Fig 10. The sampling frequency is used as 1 MHz. The error is calculated in each sampling cycle (255 times/Hz for 8 bits DAC). Then, the mean value for each cycle is calculated and plotted.

The next calculation is the input output error of DAC. The input signal level and the output signal level are compared and the error is calculated for each sampling cycle.

$$\text{Input/Output error} = \frac{(\text{Input signal - Output signal})}{\text{Sampling cycle}} \qquad (4)$$

The I/O error in 1kHz to 100kHz simulation with sampling frequency of 1Mhz is shown in Fig 11.

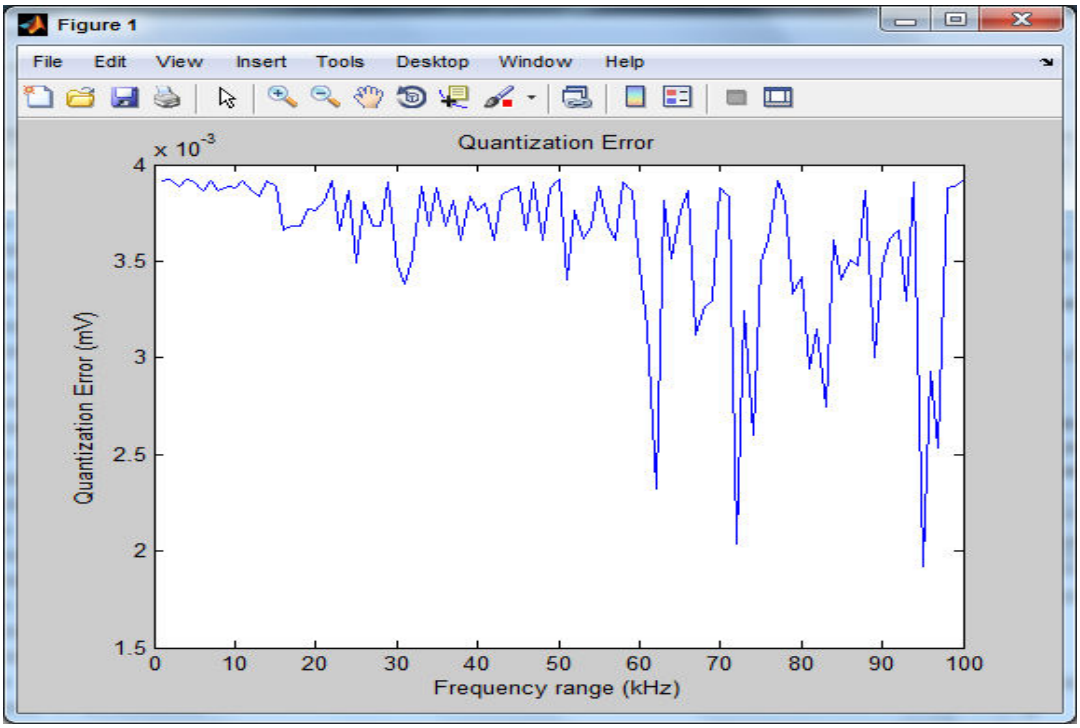


Figure.10. Quantization Error (1~100kHz)

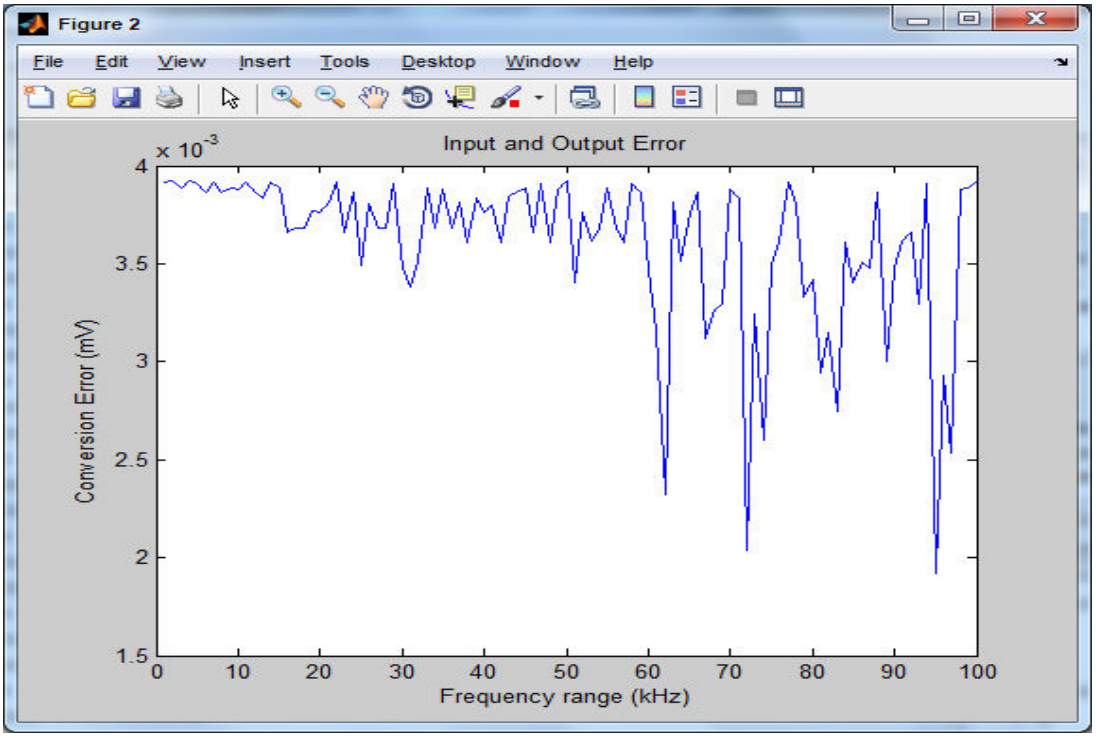


Figure.11. Input Output Error (1kHz~100 kHz)

The interesting fact is that the two graph results show the identical result. The main error for DAC mostly depends on Quantization stage and Quantization error in Sine wave.

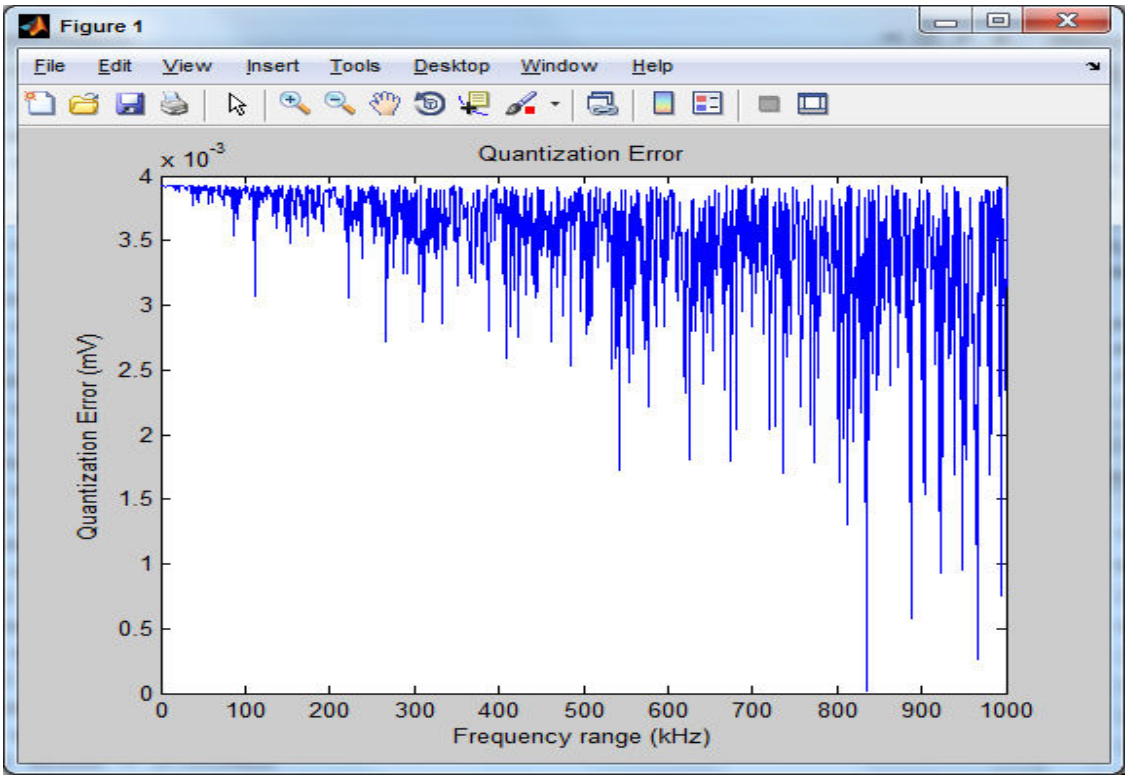


Figure.12. Quantization Error (1kHz~1MHz)

Then, the next simulation is performed with higher frequency. The Quantization and I/O error graphs of frequency 1kHz to 1MHz is presented in Fig 12. The amplitude is the same as the previous simulation, 1V. The wave from is Sine wave. The I/O error analyzed from frequency range of 1 kHz to 1 MHz is shown in Fig 13.

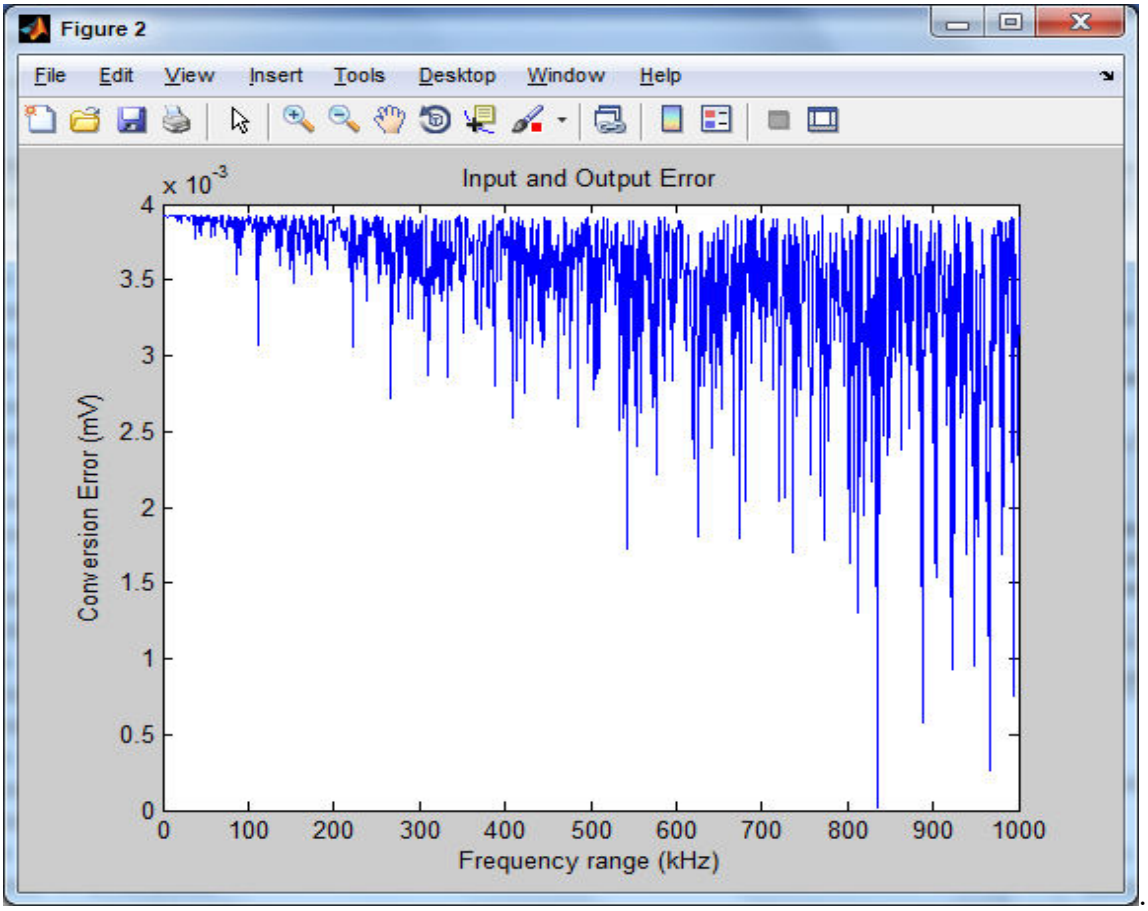


Figure.13. The Input Output Error (1kHz~1MHz)

The graph shows the same result with previous simulation. The two error plots show that the main error of DAC is the quantization error.

The interesting fact is that the error voltage range is 3.9mV to 1mV. The stepping voltage for 8 bits resolution DAC with 1V signal is as follows. The maximum error voltage is the same as DAC step voltage. For Sine wave signal simulation, when the signal frequency is low (> 100kHz), the error voltage range is between 3.9mV ~3.5mV. When the signal reaches to 1MHz, the error spans become 3.9mV~1mV.

5.3. Signal to Noise Ratio

The SNR of 1 kHz to 1MHz simulation is calculated and plotted as shown in Fig 14. The waveform uses Sine wave in the simulation with Vpp = 1V amplitude. The floor noise of DAC is nearly the same as 62 db. The spectral power and SNR is relatively high at higher frequency, 1 MHz. The SNR range is between 62~90dbs in this test.

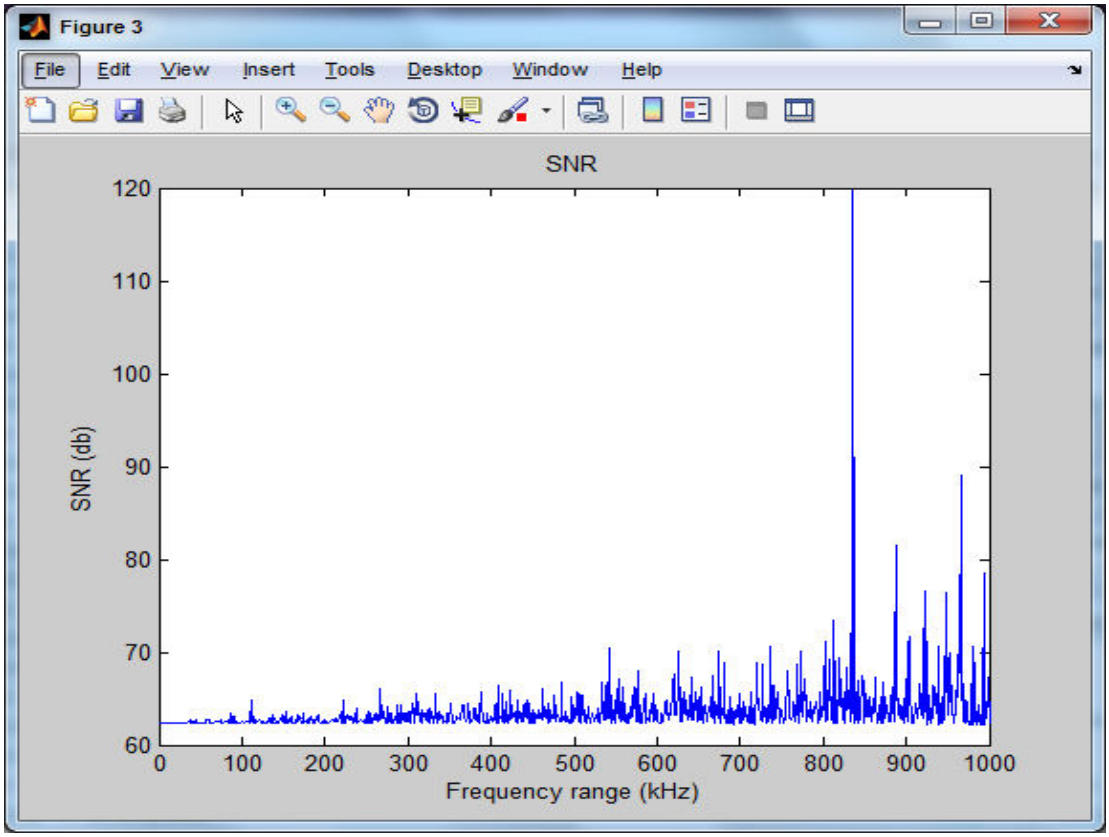


Figure.14. SNR of Sine Wave 1MHz Signal

6. Conclusion

The DAC or Digital to Analog converter is an essential part in many consumer electronics devices especially in communication devices such as telephone, mobile handset, portable music player, television, satellite receiver, and so on. The audio and signal accuracy and performance of these devices and system are affected by DAC part. The scope of simulation setup and model widely depends on these requirements. The target frequency of simulation is also variable by depending on the user requirements. The developed system coding run well as expected. The input and output signals, errors and results are also generated automatically with less effort by the user. The program coding is also flexible and reliable for any DAC simulation. The program code can also be modified by next developers to implement more complex and system models. The error results have been checked for Quantization noise and I/O error. The results show that the main error of this DAC is based on Quantization stage. The error range is higher when the frequency is higher than 100 kHz. The common error span for 8bits DAC and 1Vpp amplitude signal Sine wave is 1mV~3.9mV. Since characteristics of DAC such as reference voltage (V_{ref}), linearity and filtering are not implemented in this thesis. To achieve realistic approach of DAC, these functions should be tested by using real hardware DSP processor or complex programming techniques. The error model of prototype is also should be designed and needed in simulation process. The overall result should be summarized to gain more powerful DAC design is achieved.

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