COMMUNICATION SYSTEMS

Special Assignment: Sigma-Delta Modulation

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Aim:

The aim of this report is to provide an overview of Sigma-Delta modulation, its theory, circuit diagram, waveforms, calculations, and learning outcomes.

Objectives:

- To understand the working principle of Sigma-Delta modulation
- To analyse the circuit diagram of Sigma Delta and use it to generate and study the waveforms
- To learn the advantages and disadvantages of said modulation
- Knowledge of the applications of Sigma Delta in various fields, such as audio signal processing and sensor measurements

Introduction:

Sigma-delta modulation (SDM) is a technique used for analog-to-digital conversion (ADC) of continuous-time signals. The basic idea of SDM is to oversample the input signal and use a 1-bit quantizer to convert the oversampled signal to a digital stream of 1's and 0's. The output of the 1-bit quantizer is then processed using a feedback loop that introduces a noise-like signal to the input. The noise is shaped in such a way that the quantization error is pushed to high frequencies where it is less noticeable, resulting in a higher resolution and better signal-to-noise ratio (SNR) of the digital signal.

The SDM technique has several advantages over traditional ADCs, such as simplicity, high resolution, and low power consumption. It is commonly used in applications where high resolution and low power consumption are critical, such as in audio and sensor signal processing, and in communication systems. However, SDM has some limitations as well, such as the need for complex digital signal processing algorithms to extract the original signal from the quantized output, and the sensitivity to clock jitter and noise.

Overall, sigma-delta modulation is a powerful technique for analog-to-digital conversion that offers high resolution, low power consumption, and improved SNR compared to traditional ADCs. It has found numerous applications in various fields and is an active area of research and development.

Block Diagram:

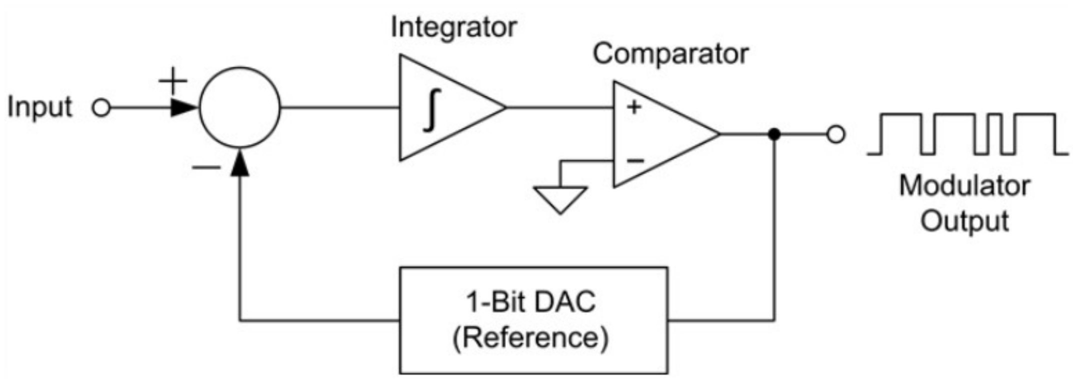

Fig 1. Block diagram of a sigma delta modulator

The circuit comprises an analog input, an operational amplifier, and a sigma-delta modulator with a comparator and a one-bit digital-to-analog converter (DAC). Demodulation involves passing the modulator output through a feedback-driven Op-amp and a low-pass filter.

The feedback loop ensures that the output of the modulator is fed back to the input of the Op-amp to reduce errors in the output signal. The low-pass filter eliminates the unwanted high-frequency noise from the output signal.

Calculations:

The output of Sigma Delta can be realized using the following formula:

$$\mathbf{Vout = (1/2^n) * \sum (di * sin(2\pi f0i))}$$

Where n is the resolution of the ADC, di is the ith bit of the modulated signal, f0 is the sampling frequency, and i is the sample number. These calculations serve as the groundwork for implementing the theoretical concepts onto python.

Code in python:

```
import numpy as np

import matplotlib.pyplot as plt
from scipy import signal

# Get simulation parameters from user input
fs = float(input("Enter sampling rate (in Hz): "))
T = 1  # total time in seconds
f0 = float(input("Enter frequency of input (in Hz): "))
Vref = 1  # reference voltage
N = int(fs * T)  # number of samples

# Define initial values
v1 = 0  # integrator output
v_quant = 0  # quantizer output
out = np.zeros(N)  # modulator output

# Generate input signal
t = np.linspace(0, T, N)
x = np.cos(2 * np.pi * f0 * t + 0.05)
```

```
# Perform sigma-delta modulation
for n in range(N):
    v = x[n] - v1  # subtract integrator output from input
    if v > 0:
        v_quant = Vref  # output high if input > v1
    else:
        v_quant = -Vref  # output low if input <= v1
    out[n] = v_quant  # save modulator output
    v1 += v_quant / Vref  # update integrator output

# Define the low-pass filter
fc = f0  # cutoff frequency
b, a = signal.butter(2, 2*fc/fs, 'low')

# Calculate scaling factor based on fs and f0
scale_factor = np.pi * f0 / fs

#time shift
shifted_t = t + (1/(4*f0))

# Filter the modulator output to obtain the demodulated signal
demod = signal.lfilter(b, a, out) * (Vref/scale_factor)  # scale by Vref to
match input amplitude

# Plot input and modulated output signals with different colors
plt.plot(t, x, color='blue', label='Input')
plt.step(shifted_t, out, where='post',color='red',label='Modulated Output')
plt.plot(t, demod, color='green', label='Demodulated Output')
plt.xlabel('Time (s)')
plt.ylabel('Amplitude')
plt.ylim([-1.1 * Vref, 1.1 * Vref])
plt.legend()
plt.show()
```

Waveforms:

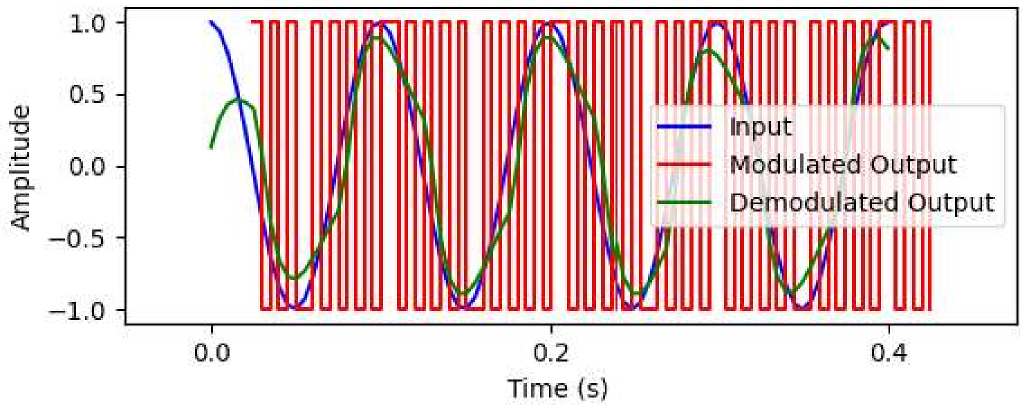

Fig.2 Waveforms of input, modulated and demodulated signals

The input signal (Vin) is first oversampled at a high frequency, resulting in a stream of bits (d0, d1, d2, ...). The one-bit DAC converts this digital stream into a high-frequency modulated signal. The modulated signal is then passed through a low-pass filter to obtain a high-resolution digital output (Vout).

Conclusion:

In conclusion, Sigma Delta modulation, with its foundation in oversampling, stands out as a potent analog-to-digital conversion technique, offering high resolution and efficiency. The report meticulously explores its operational principles, circuit design, waveform characteristics, and computational nuances. The circuit, integrating Σ-Δ Modulation for signal smoothing, exhibits notable advantages like simplicity and low power consumption. Despite its strengths, Sigma Delta faces challenges such as reliance on complex digital signal processing and susceptibility to clock jitter and noise. Clear calculations elucidate the resolution's interplay with sampling parameters. The provided Python code vividly illustrates Sigma Delta's practical implementation, showcasing its efficacy in transforming input signals into high-resolution digital outputs. In essence, Sigma Delta modulation is a versatile solution, promising advancements in precision and energy efficiency across diverse applications in signal processing and communication technologies.