Communication System Simulations

ES154 Communications and Media

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Abstract

The aim of the simulations in this assignment was to provide a basic knowledge in the use of the Simulink program for use with MATLAB. Simulink is a powerful modelling tool for simulating both mechanical and electrical systems, however we are only concerned with electronic systems in this investigation. The simulations performed involved a simulation approximating a square and a sawtooth wave by modelling a Fourier series, including analysing the spectrum of these waves. A Envelope Detector was simulated and a the detector output measured and plotted when the envelope detector was set up as an linear detector with a single sine wave input. AM Transmission of a sine wave was simulated using the provided envelope block. A low-pass RC filter was simulated in MATLAB and in Simulink and its operation tested and verified. Overall the simulations provided a useful background in the Simulink package when used to model communication systems and an introduction to the operation of those systems.

Table of Contents

Introduction

Simulink is a powerful simulation and modelling tool for use within the MATLAB environment. It is able to simulate both mechanical and electrical systems, but during this investigation we are only concerned with the electronic systems applicable to communications. The systems are designed using block diagrams where the user can manipulate blocks and connect them as required.

The aim of the simulations in this assignment is to provide a basic knowledge in the use of the Simulink package by performing various simulations relevant to communications. Also to introduce the operation and use of the systems and processes used in the simulations.

Evaluation Using Simulink/Matlab

The MATLAB variable Buf is set to 256 throughout the simulations. Matlab 5.3 is used

Laboratory 1:Introduction to Simulink

The variable Ts is set to 1e-5 unless otherwise stated

The first simulation involves an investigation into the summation of sinewaves. Initially one sinewave is used with a Signal generator block (Amplitude 1, Frequency (1/Ts)/16) this is fed through a sample block to a buffered FFT (fast Fourier transform) Frame Scope which displays the spectrum and a Scope which displays the waveform produced. The operation of this arrangement was tested and the expected results of one point on the FFT Frame scope and a sine wave on the scope were obtained. However the sinewave outputted on the scope was stepped. Reducing the sampling time of the sample block and/or the FFT Frame Scope can reduce this effect, however calculation time is increased. An extra sinewave is added with amplitude 1/3 and frequency (3/Ts)/16 (i.e. One third of the amplitude and 3 times the frequency) and connected to the input of the sample block with a sum block. An extra spike is observed on the spectrum and the waveform is observed to change. The resulting spectrum and waveform are printed (See appendix A). Extra traces are added with frequencies 5×, 7×, 9× and amplitudes 1/5× 1/7× and 1/9× the original. The results are printed at each step and selected results are included in appendix A (Pages A:I – A:IV). The final system with 5 inputs is shown the next page (Page 5), with the output from the Buffered FFT Frame Scope on page 6 and the output waveform on page 7.

The output from the Buffered FFT Frame Scope shows 5 points as expected. The waveform looks like a good approximation to a square wave and has become a better approximation, as more sinewaves have been added (See appendix A). In fact this is an example of a Fourier series, in this case approximating to a square wave. The more sine waves are added following this series the closer the output waveform will be to a square wave.

A new input waveform is now created, this time with a constant block with the value pi being added to the initial input sinewave again with Amplitude 1 and Frequency $(1/Ts)/16$ ($Ts = 1 \times 10^5$). This time additional waveforms with frequencies $2\times$, $3\times$, $4\times$ and amplitudes $1/2\times$ $1/3\times$ and $1/4\times$ the original are added. Printouts of the output waveform are taken at each additional waveform (See appendix A Pages A:V – A:VII).

The system block diagram is shown on the next page (page 9) and the output waveform on page 10.

It maybe seen that we again have a Fourier series but this time approximating to a sawtooth wave.

The next simulation involves investigating the measurement of mean and RMS values using Simulink. The model will now contain only two signal generators, one with a Sinewave of frequency $1/(8Ts)$ and amplitude 1V and a sawtooth of frequency $1/(8Ts)$ and amplitude 1V. These will be summed, passed through a sample bock and to a mean and a RMS block whose outputs will be displayed. The system is shown on page 11 (after sawtooth printouts).

The value for the mean is measured as 0.0 and the RMS as 1.2. The mean is as expected as the positive and negative portions of the wave cancel each other out and the RMS value can be confirmed using the following equation:

$$\text{RMS of } x(t) + y(t) = \sqrt{\frac{1}{T}\int_0^T (x(t) + y(t))^2 \, dt} \text{ Where T is the period}$$

Laboratory 2: The Envelope Detector

The variable Ts is set to 1e-5 unless otherwise stated

In AM transmission the size of the carrier varies with the signal to be transmitted and the received must recover the original signal. It is usual to use an envelope detector for this. A diode removes the negative part of the signal and an RC combination acts as a frequency dependant load, presenting a high impedance path for the lower frequency as shown in the diagram below:
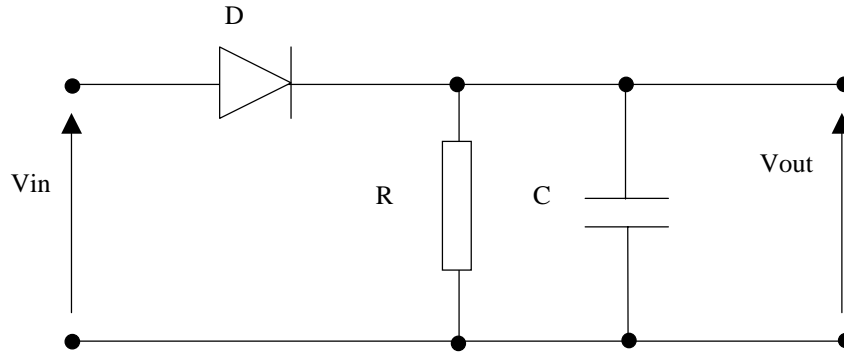
An envelope detector block is provided that simulates the above circuit. The values for R and C are inputted using constant blocks and the output can be observed without the resistor and capacitor (diode output) as well as with (output). A sample block is added to the output, followed by a running mean block with a numerical display and a scope.
The input is a sine wave frequency 1/(10Ts) Hz and amplitude, 2V.

The block diagram is shown on the next page (13).

The simulation is run with C = 0 and R = 100Ω, 200Ω, 500Ω, 1kΩ, 5kΩ and the mean values are noted at each value. This is then repeated with C = 1µF The recorded values are shown below:

R (Ω)	V (V) (C=0)	V (V) (C=1µF)
100	0.2199	0.2543
200	0.3175	0.4327
500	0.4510	0.7557
1000	0.5544	1.0280
5000	0.6150	1.5470
10000	0.6255	1.6940

The detector efficiency is given as: $\eta_d = \dfrac{V_{mean}}{V_{in}}$ $V_{in} = 2V$

A graph of $\eta_d = \dfrac{V_{mean}}{V_{in}}$ $V_{in} = 2V$ against $\dfrac{R}{r_d}$ is needed this can be plotted using Matlab as shown on page 14. ($r_d = 200Ω$ and is set within the envelope detector block)

From the graph we can see that the efficiency is higher as the capacitor is added. As R increases the voltage across the diode becomes less significant and the graph therefore flattens out.

Extra printouts (Outputs from the diode output and the standard output and output from the mean block) are shown in Appendix B: Laboratory 2: The Envelope Detector, Additional Printouts

Laboratory 3: Assignments
AM Transmission Simulation

AM stands for amplitude modulation and is used in many communication systems although FM (Frequency modulation is more popular for newer systems). The modulated wave consists of a combination of a signal wave (modulating signal) and a higher frequency carrier wave, combined according to the following equation:

$$e_{am}(t) = [E_c + k_a E_m \cos(\omega_m t)]\cos(\omega_c t)$$

which simplifies to:

$$e_{am}(t) = E_c[1 + m\cos(\omega_m t)]\cos(\omega_c t)$$

k_a = change in carrier voltage per volt of modulating signal and $m = \dfrac{k_a E_m}{E_c}$ is called

the modulation depth. An envelope detector provides a simple method of extracting a signal from a modulated wave and the envelope detector from the previous laboratory (see above) will be used in this simulation. An AM Modulation and Demodulation scheme will be simulated using a single sine wave as the modulating signal.

A signal generator will need to be used for the modulating signal and the carrier signal and these will need to be combined according to the above equation. A modulating signal of amplitude 0.5 and frequency 20Hz and a carrier signal of amplitude 1 and frequency 1kHz will be used. These must be combined using a suitable combination of multiplication, summing and constant blocks to produce to modulated wave. This modulated wave is fed into the envelope detector, with constant blocks being used to input the values of the capacitor and resistor. The output has a constant of –1 added so that the resulting waveform will oscillate about 0. Suitable values for the capacitor and resistor must be chosen to select the correct cut off frequency. This frequency is given by:

$$f_c = \frac{1}{2\pi RC}$$

We require a cut off frequency just above the frequency of the modulating wave to ensure the whole signal gets through therefore a value for f_c of 25Hz would be suitable. Arbitrarily choosing a value of 10kΩ for the resistor would require a capacitor of approximately 6.5×10^{-7}F and this will be the value used. Scopes are placed in the circuit to observe the Modulating, Carrier, Modulated and Demodulated signals.

The completed block diagram is shown on the next page (17)

The simulation is run and printouts generated of the scope outputs. These are shown on the following pages:

It may be noted that the demodulated signal is not smooth. This is because only a simple envelope detector is used. In real applications the envelope detector contains many more components. As the value of m is increased the output signal amplitude increases. However if the value of m is increased so the amplitude of the modulating wave exceeds that of the carrier wave the demodulated wave is distorted.

Lowpass RC Filter Simulation

A low pass filter allows frequencies below its cut off frequency (f_c) to pass but blocks frequencies above it. A circuit diagram is shown below:
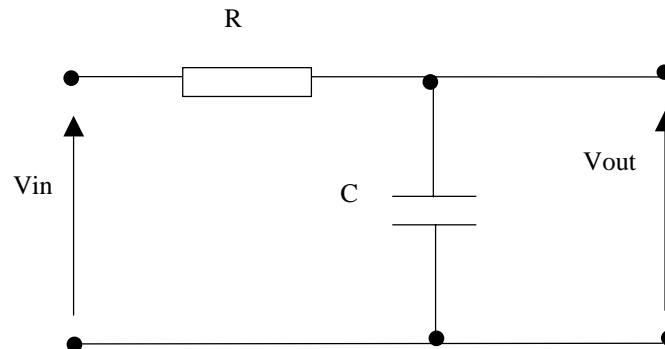
Using ac theory the output voltage is given by:

$$G(\omega) = \frac{V_{out}}{V_{in}} = \frac{1/j\omega C}{R + 1/j\omega C} = \frac{1}{1 + j\omega CR}$$

Noting that cut of frequency is given by; $f_c = \dfrac{1}{2\pi RC}$ and $\omega = 2\pi f$ it is possible to plot this function and display a log graph of the frequency characteristic. A cut of frequency of 10kHz will be defined and the frequency swept from 10Hz to 1MHz. The code for Matlab is shown below:

```
%low pass filter, lpf.m
f = 10:1000:1e6;
fc = 10000;
G = 1./(1+j*f./fc);
semilogx(f,abs(G))
xlabel('frequency (Hz)')
ylabel('Gain')
title('Low Pass Filter Transfer Characteristic')
```

And the graph is shown on the next page (23).

It is also possible to simulate a low pass filter using simulink.

Since the current flows through the resistor to charge the capacitor the following relationship may be written:

$$\frac{V_{in} - V_{out}}{R} = C\frac{dV_{out}}{dt}$$

Thus V_{out} may be expressed as:

$$V_{out} = \frac{1}{RC}\int (V_{in} - V_{out})dt$$

This may be implemented using an integrator block (in addition to others) as shown on the next page (25).

A value of 10KΩ is used for the resistor and 8×10^{-7}F for the capacitor giving a cut of frequency of about 20Hz $\left(f_c = \dfrac{1}{2\pi RC} \right)$.

Therefore the filter should pass frequencies below 20Hz and block frequencies above 20Hz The system is tested with frequencies 15Hz and 1kHz and the output signals are displayed on pages 26 and 27 respectively.

From the graphs it maybe seen that the filter allows the 15Hz signal to pass but blocks the 1kHz signal. The operation is therefore as expected.

Conclusion

The simulations all worked as expected. Laboratory 1 introduced the basic operation of simulink and the summing of sine waves to create square and sawtooth waves (implementation of Fourier series), and the use of the mean and RMS blocks to measure the mean and RMS. Laboratory 2 introduced the envelope detector and its operation as a linear and envelope detector. The detector efficiency was calculated, graphed and compared and found to be higher when the envelope detector was not used as a linear detector (C≠0). Laboratory 3 introduced AM transmission and demonstrated how this can take place. This is very important in communications. Also it introduced the theory and operation of the lowpass filter in two different simulations. The lowpass filter model however was not used to separate two signals as suggested in the text although this is an application for it.

The simulations provided an introduction to the use of Simulink to model communication systems and increased knowledge in those systems.

Bibliography

Laboratory Sheets:

ES154 Communications and Media. Laboratory 1: Introduction to Simulink
ES154 Communications and Media. Laboratory 2: The Envelope Detector
ES154 Communications and Media. Laboratory 3: Assignments

Lecture notes:

ES154 Communications and Media

Books:

Croft, A. & Davidson, R., *Mathematics for Engineers*, Addison-Wesley, 1999.

Appendices

Appendix A: Laboratory 1: Introduction to Simulink, Additional Printouts

Pages A:I – A:VII

Appendix B: Laboratory 2: The Envelope Detector, Additional Printouts

Pages B:I – B:III

Appendix C: Laboratory 3: Assignments, Additional Printouts

Pages C:I-C:III

Appendix D: Laboratory Sheets