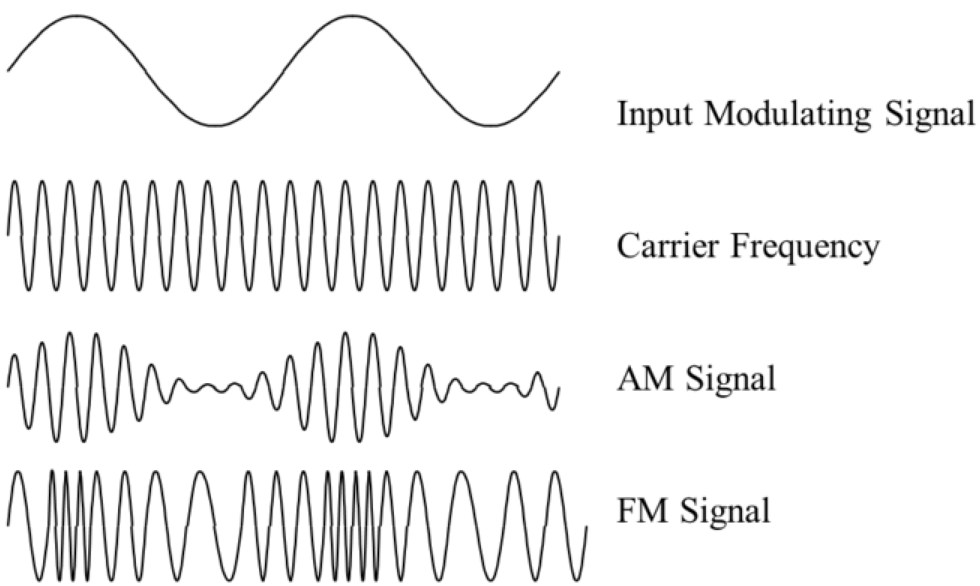
ECSE 308: Introduction to Communication Systems and Networks

L2T2: Analog Modulation Techniques

Part 1: Amplitude Modulation (AM)

Part 2: Frequency Modulation (FM)

Part 3: Power/Bandwidth Trade-off in FM



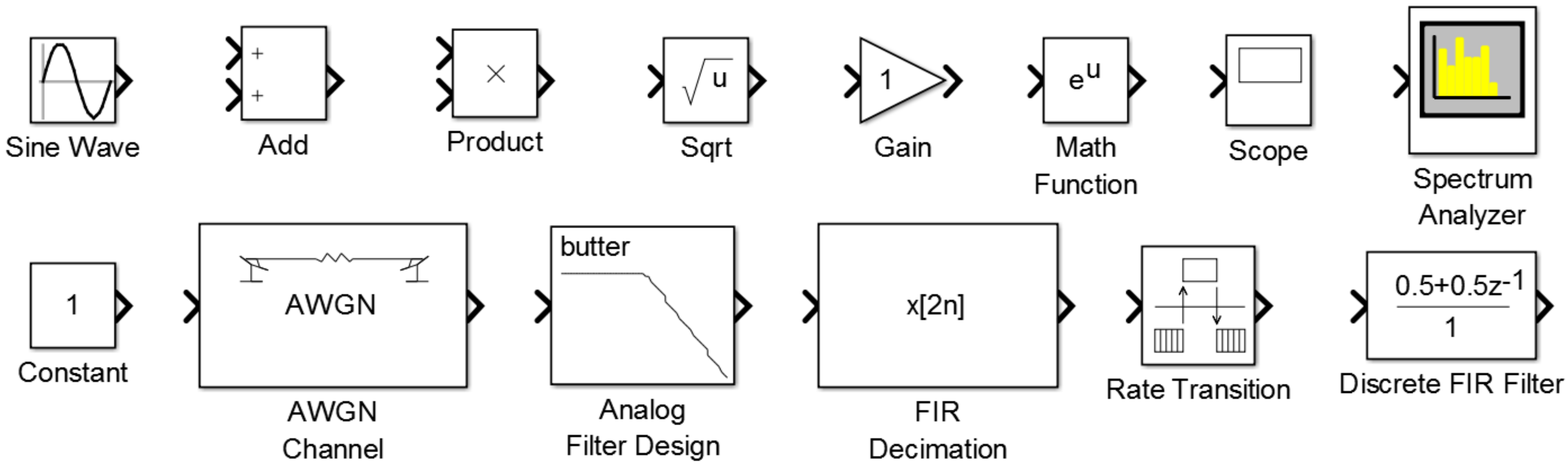
L2T2: Analog Modulation Techniques

Part 1: Amplitude Modulation (AM)

Objectives: To understand the basic principles of amplitude modulation and demodulation

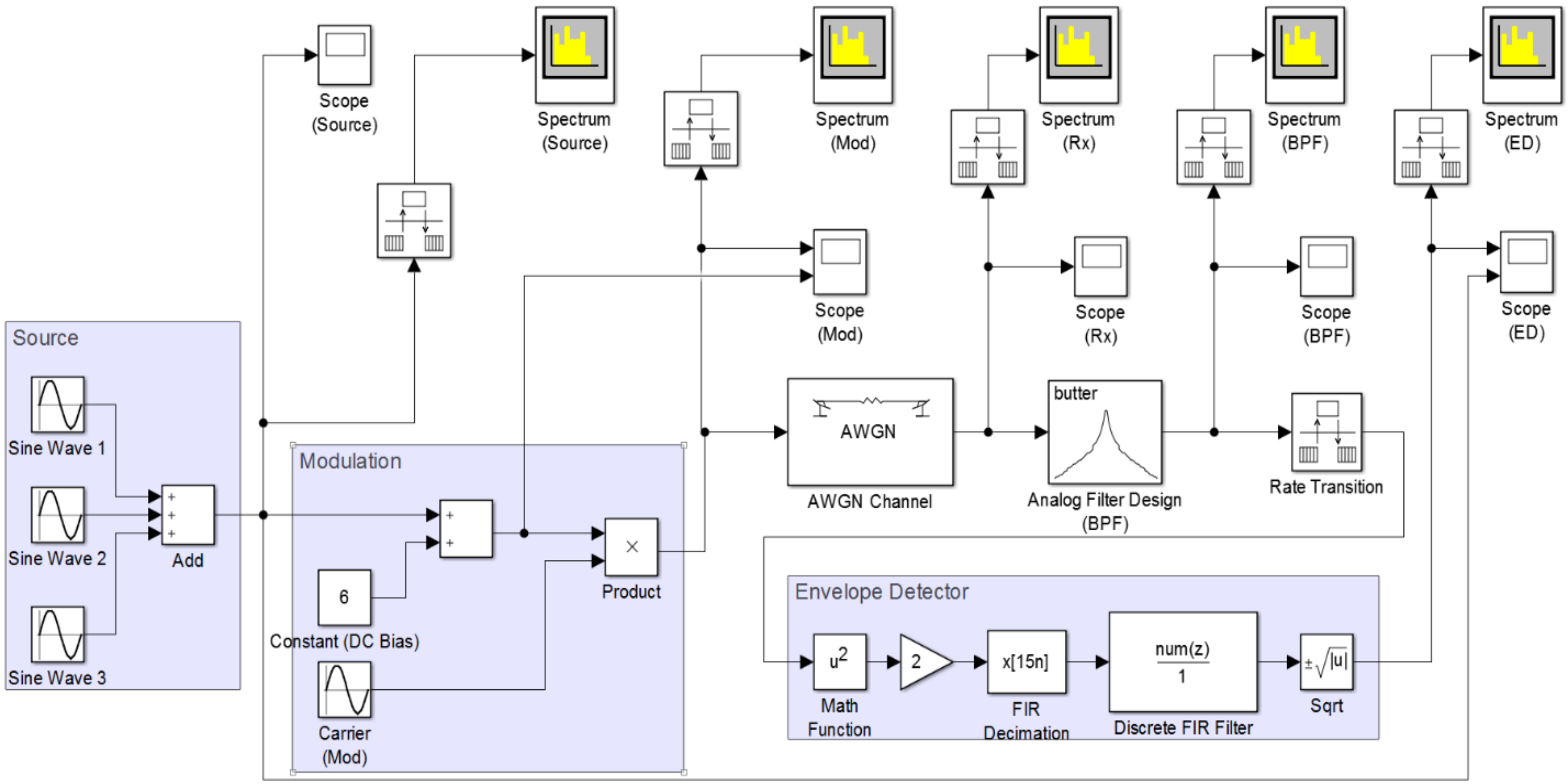
Preparations

- For this lab, the following Simulink blocks will be used.



I. DSB-LC AM System

- Build the double-sideband (DSB) large-carrier (LC) AM system as illustrated.



I. DSB-LC AM System

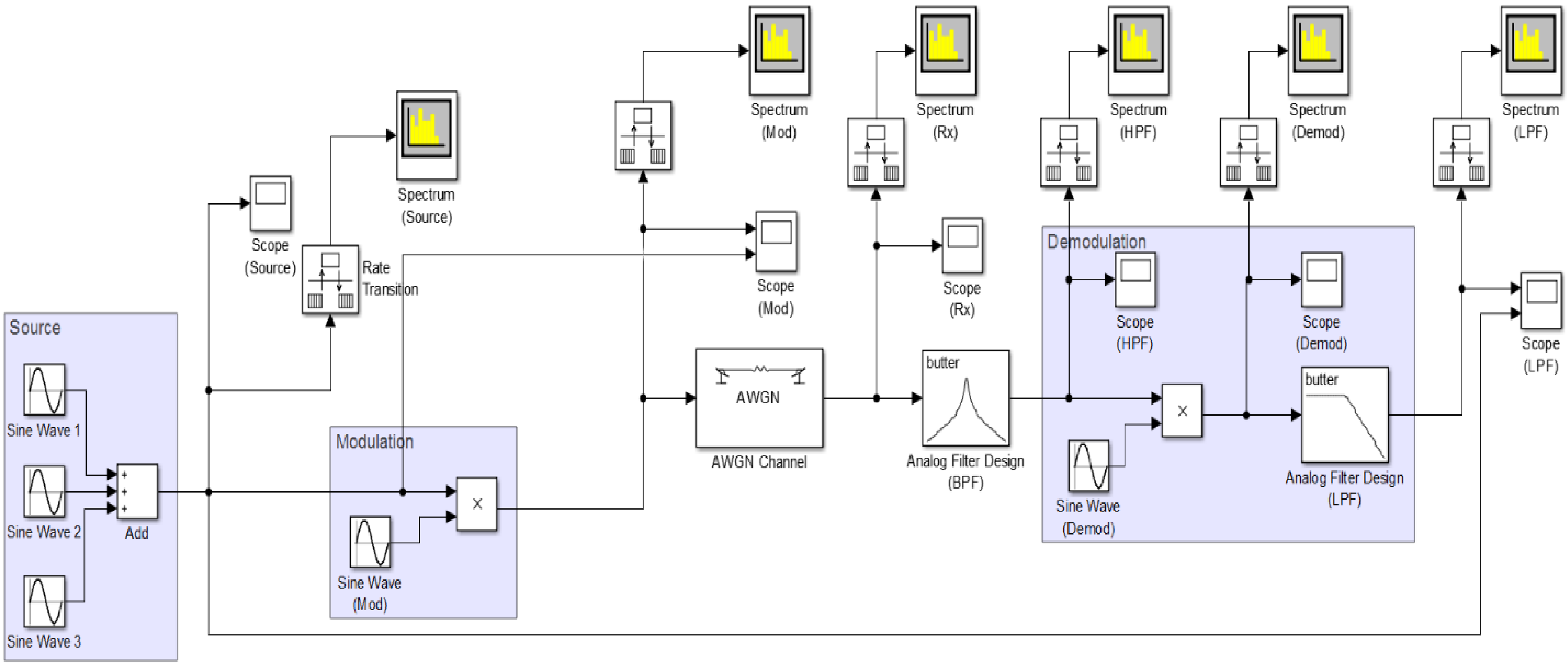
- Parameter setup:
  - **Sine Wave 1:** Sine type: Time based | Amplitude: 1 | Frequency (rad/sec): 1000*pi
  - **Sine Wave 2:** Sine type: Time based | Amplitude: 3 | Frequency (rad/sec): 600*pi
  - **Sine Wave 3:** Sine type: Time based | Amplitude: 1.5 | Frequency (rad/sec): 1200*pi
  - **Constant (DC Bias):** Constant value: 6
  - **Carrier (Mod):** Sine type: Time based | Amplitude: 1 | Frequency (rad/sec): 30000*pi | Phase (rad): pi/2
  - **AWGN Channel:** Initial seed: randseed | Mode: Variance from mask | Variance: 0.01
  - **Analog Filter Design:** Design method: Butterworth | Filter type: Bandpass | Filter order: 8 | Lower passband edge frequency (rad/s): 14300*2*pi | Upper passband edge frequency (rad/s): 15800*2*pi
  - **Rate Transition:** Output port sample time: 1/50000
  - **Math Function:** Function: square
  - **FIR Decimation:** FIR filter coefficients: [1 1] | Decimation factor: 2
  - **Discrete FIR Filter Coefficients:** firpm(20, [0 0.03 0.1 1], [1 1 0 0])
  - **Sqrt Function:** signedSqrt

I. DSB-LC AM System

1. Observe the output on **Spectrum (Source).** What are the fundamental and harmonic components of the source signal?
2. Observe the outputs on **Scope (Source)** and **Scope (Mod)**. Explain the relationship between the amplitude of the AM signal and that of the source signal.
3. Observe the outputs on **Spectrum (Source)** and **Spectrum (Mod).** Explain the relationship between the spectrum of the AM signal and that of the source signal. Comment on the transmission bandwidth of AM signals.
4. Compare the outputs on **Spectrum (Rx)** and **Spectrum (BPF).** Comment on what information is needed to filter out the noise without distorting the desired signal. Explain how and why the SNR at the output of **Analog Filter Design (BPF)** changes compared with the SNR at the input of **Analog Filter Design (BPF)**?
5. Observe the outputs on **Spectrum (ED)** and **Spectrum (BPF)**. Explain the principle of double-sideband large carrier (DSB-LC) AM demodulation.
6. Change the value of **Constant (DC Bias),** and observe how it affects the signal recovered from Envelope Detector in comparison with the source signal. Explain what is a feasible DC bias in relation to the amplitude of the source signal so that successful demodulation can be guaranteed.

II. DSB-SC AM System

- Build the DSB suppressed-carrier (SC) AM system as illustrated.



II. DSB-SC AM System

- Parameter setup:
  - **Sine Wave 1:** Sine type: Time based | Amplitude: 1 | Frequency (rad/sec): 1000*pi
  - **Sine Wave 2:** Sine type: Time based | Amplitude: 3 | Frequency (rad/sec): 600*pi
  - **Sine Wave 3:** Sine type: Time based | Amplitude: 1.5 | Frequency (rad/sec): 1200*pi
  - **Carrier (Mod):** Sine type: Time based | Amplitude: 1 | Frequency (rad/sec): 30000*pi | Phase (rad): pi/2
  - **Carrier (Demod):** Sine type: Time based | Amplitude: 1 | Frequency (rad/sec): 30000*pi | Phase (rad): pi/2
  - AWGN Channel: Initial seed: randseed | Mode: Variance from mask | Variance: 0.01
  - **Analog Filter Design (BPF):** Design method: Butterworth | Filter type: Bandpass | Filter order: 8 | Lower passband edge frequency (rad/s): 14300*2*pi | Upper passband edge frequency (rad/s): 15800*2*pi
  - **Analog Filter Design (LPF):** Design method: Butterworth | Filter type: Lowpass | Filter order: 8 | Passband edge frequency (rad/s): 800*2*pi
  - **Rate Transition:** Output port sample time: 1/50000

7. Repeat Steps 2-3 for DSB-SC AM.
8. Explain the differences between DSB-SC and DSB-LC in terms of modulation. Explain how such differences affect the transmit power efficiency and the demodulation process at the receiver.

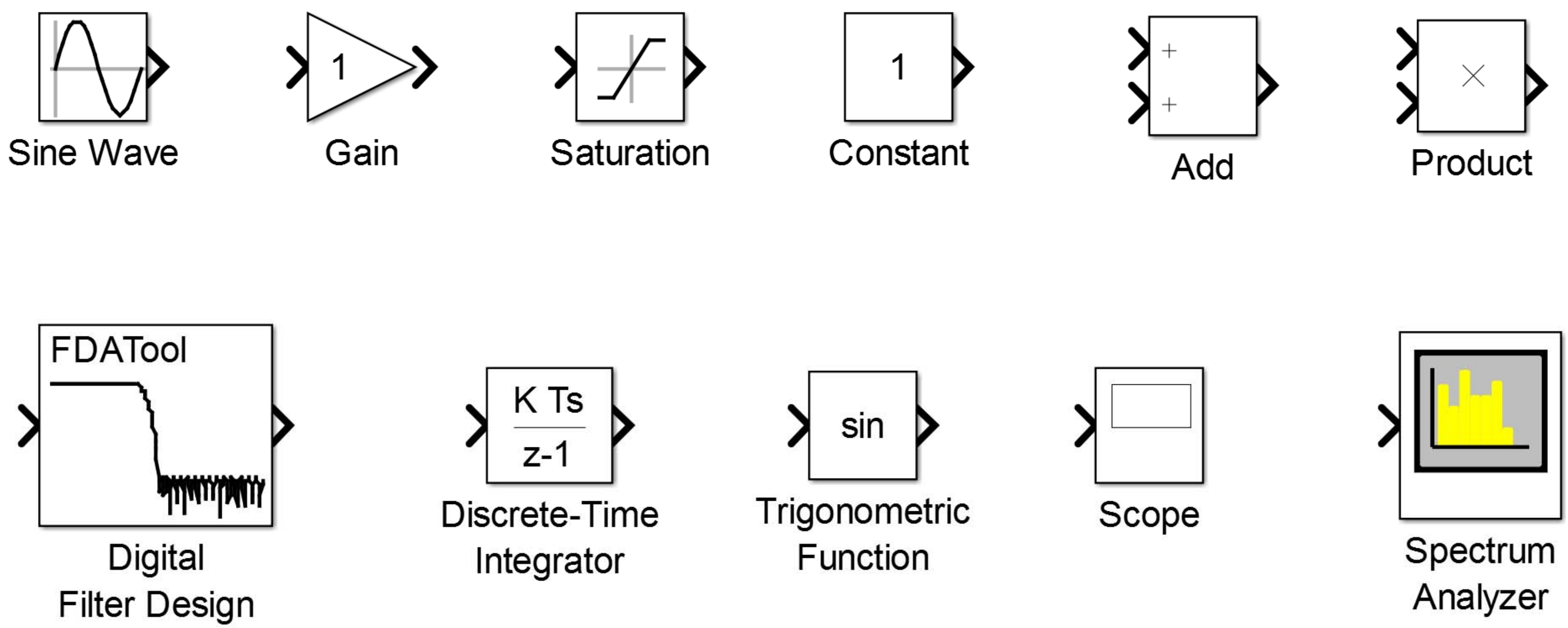
L2T2: Analog Modulation Techniques

Part 2: Frequency Modulation (FM)

Objectives: Understand the basic principles of frequency modulation and demodulation

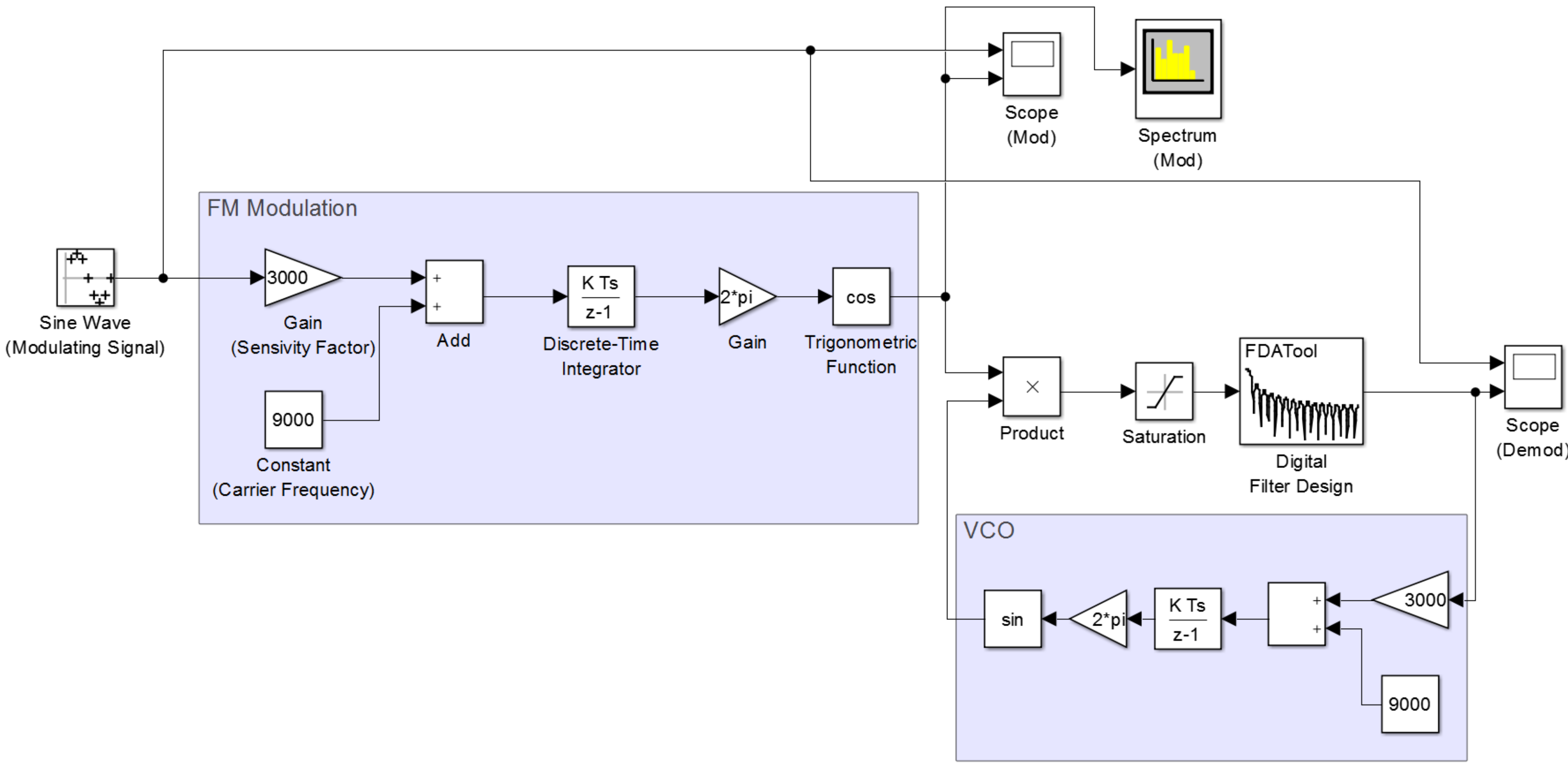
Preparations

- For this lab, the following Simulink blocks will be used.



FM System

- Build the FM system as illustrated.



FM System

- Parameter setup:
  - **Sine Wave (Modulating Signal):** Sine type: Sample based | Samples per period: 1000 | Sample time: 1e-6
  - **Constant (Carrier Frequency):** Constant value: 9000
  - **Gain (Sensitivity Factor) Gain:** 3000
  - **Discrete-Time Integrator Sample time:** 1e-6
  - **Gain Gain:** 2*pi
  - **Trigonometric Function:** Function: cos
  - **Digital Filter Design:** Response Type: Lowpass | Design Method: FIR → Window | Filter Order: Specify order → 30 | Options: Scale Passband, Window → Kaiser | Frequency Specifications: Units → Hz, Fs → 1e6, Fc → 1000

FM System

1. From the block configuration and the parameter setup, describe in mathematical terms the process of FM modulation and demodulation.
2. Observe the output on **Scope (Mod).** Explain how the FM signal is related to the modulating signal in the time domain. Use a sum signal of two sine waves as a modulating signal, and compare the output with the sum of those when each of the sine wave is used as a modulating signal separately. Comment on the linearity of FM modulation in comparison with AM modulation.
3. Vary **Gain (Sensitivity Factor)** from small (i.e., the modulation index β less than 1 radian) to large (i.e., the modulation index β greater than 1 radian). Comment on the sensitivity of the carrier to the modulating signal in terms of amplitude and frequency variation.
4. Vary the modulating frequency and the amplitude of **Sine Wave (Modulating Signal).** Observe the variations of the spectrum on **Spectrum (Mod).** Explain how the transmit power changes accordingly and why. Comment on the differences between an FM signal and an AM signal in terms of transmit power in relation to the modulating signal.

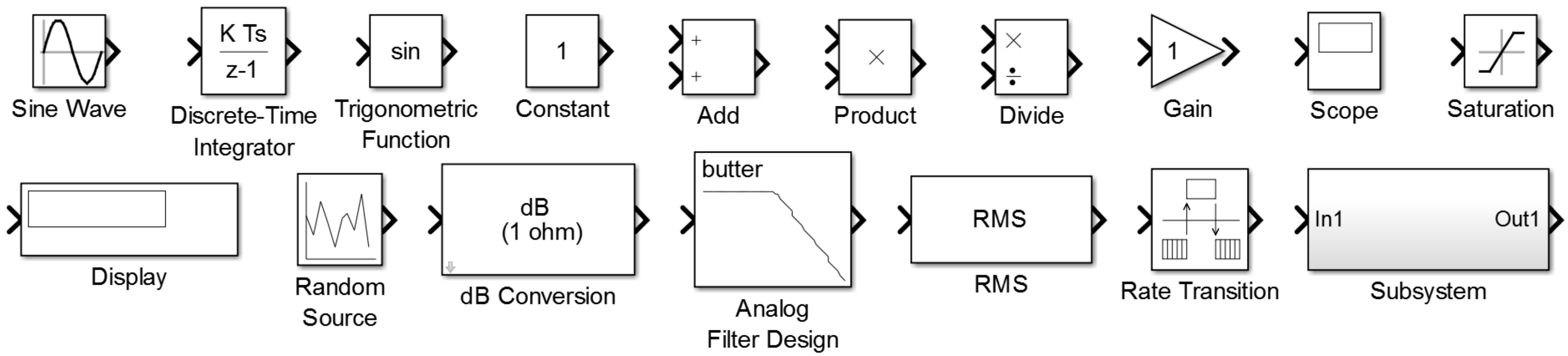
L2T2: Analog Modulation Techniques

Part 3: Power/Bandwidth trade-off in FM

Objectives: To understand the possibility of Power/Bandwidth trade-off in FM systems.

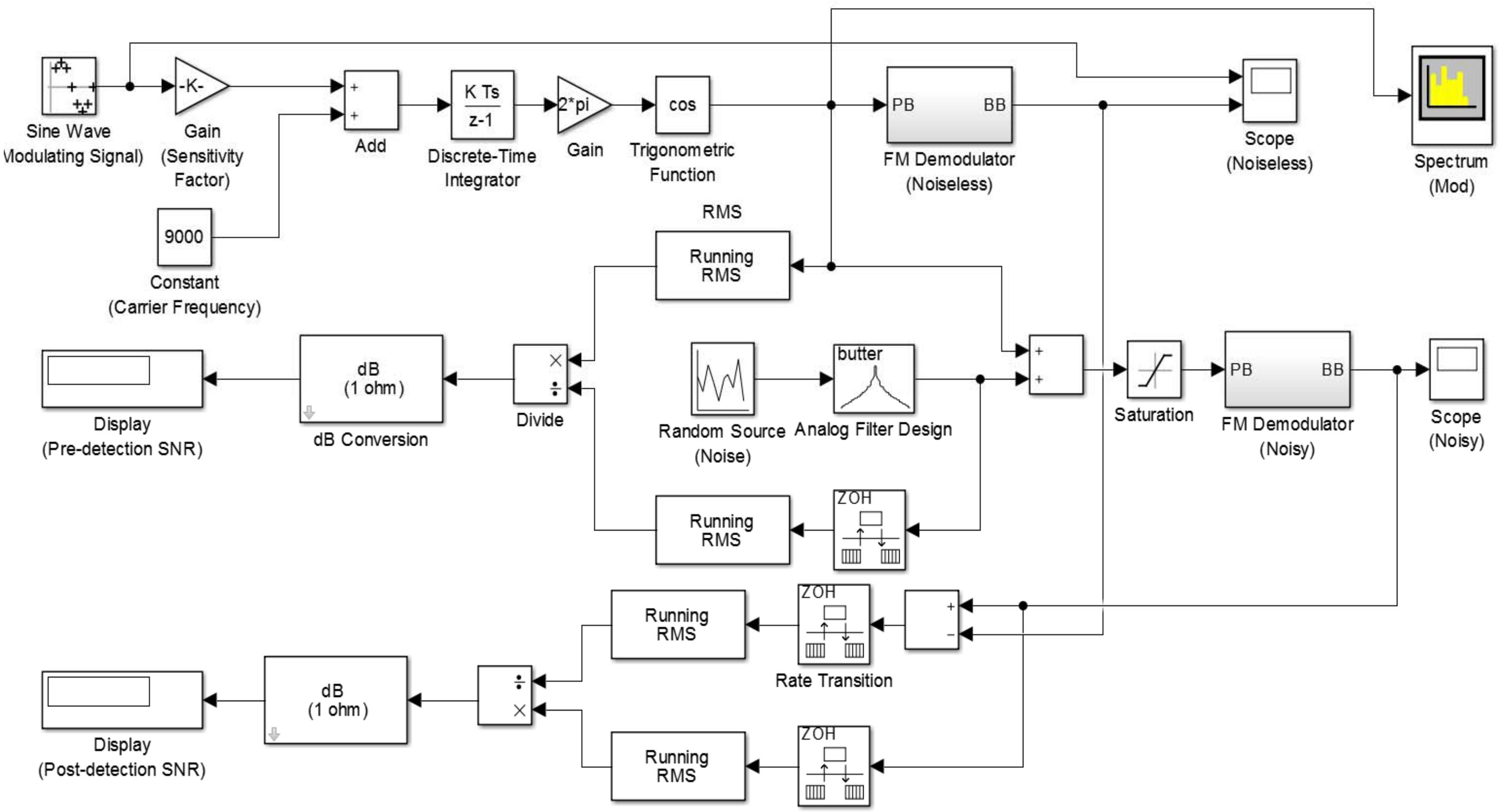
Preparations

- For this lab, the following Simulink blocks will be used.



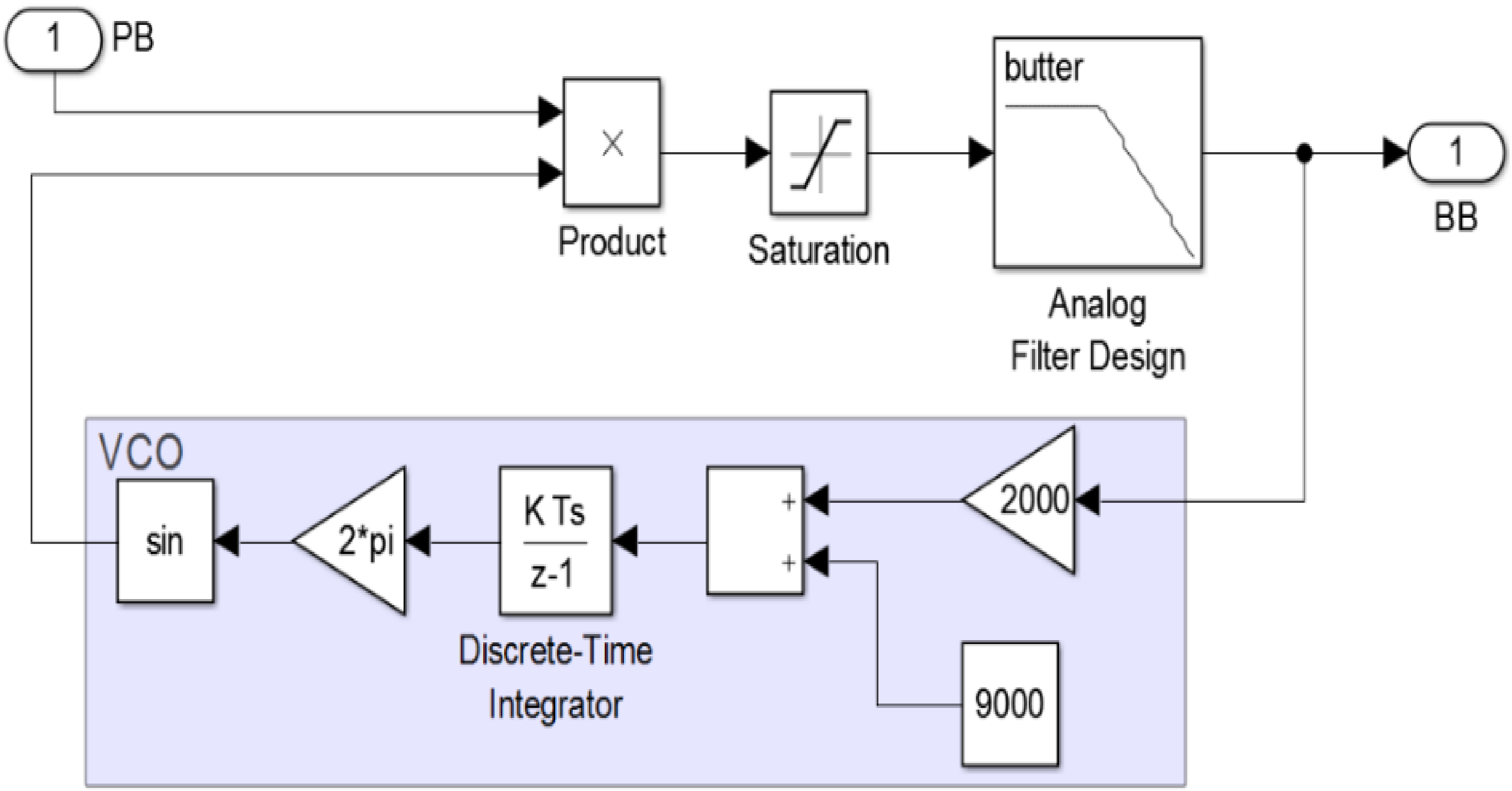
FM Transmission and Reception System

- Build the FM transmission and reception system as illustrated.



FM Transmission and Reception System

- Build the FM demodulator subsystem as illustrated.



FM Transmission and Reception System

- Parameter setup (Overall):
  - **Sine Wave:** Sine type: Sample based | Samples per second: 1000 | Sample time: 1e-5
  - **Discrete-Time Integrator:** Sample time: 1e-5
  - **RMS:** Running RMS
  - **Random Source (Noise):** Source Type: Gaussian | Variance: 0.01 | Sample time: 1e-5
  - **Analog Filter Design:** Filter order: 8 | Lower passband edge frequency (rad/s): 8000*2*pi | Upper passband edge frequency (rad/s): 10000*2*pi
  - **Saturation:** Upper limit: 1 | Lower limit: -1
  - **Rate Transition:** Output port sample time: 1e-5
  - **Trigonometric Function:** Function: cos
- Parameter setup (FM Demodulator):
  - **Saturation:** Upper limit: 0.5 | Lower limit: -0.5
  - **Analog Filter Design:** Filter order: 8 | Passband edge frequency (rad/s): 200*2*pi
  - **Discrete-Time Integrator:** Sample time: 1e-5

FM SNR

1. Denote the modulating frequency as f_m. **Vary Gain (Sensitivity Factor)** Δf as $\Delta f = 0.1f_m, 0.5f_m, f_m, \ldots, 10f_m$. Observe the output on **Spectrum (Mod)** and comment on how the number of significant sideband pairs (i.e., power above -10 dBm) varies with Δf. Explain how and why the power of the carrier component varies in the frequency domain.

2. For each $\Delta f = 0.1f_m, 0.5f_m, f_m, \ldots, 10f_m$, determine the actual transmission bandwidth. Record the amount of power in percentage contained in the bandwidth as estimated by Carson rule.

3. For each $\Delta f = 0.1f_m, 0.5f_m, f_m, 5f_m, 10f_m$, plot the SNR curves in one figure, where the y-axis is labeled with pre-detection SNRs and the x-axis is labeled with post-detection SNRs. Comment on how the SNRs vary in response to Δf.