ECSE 308:
Introduction to
Communication Systems and Networks

L3T3: Digital Transmission Techniques

Part 1: baseband digital transmission

Part 2: basic digital modulation schemes: binary ASK, PSK, FSK, and 4-QAM

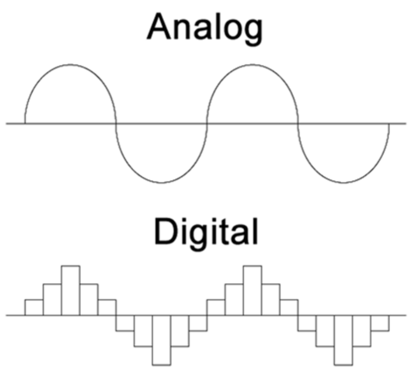
Part 3: M-QAM modulation & demodulation

L3T3: Digital Transmission Techniques

Part 1: baseband digital transmission

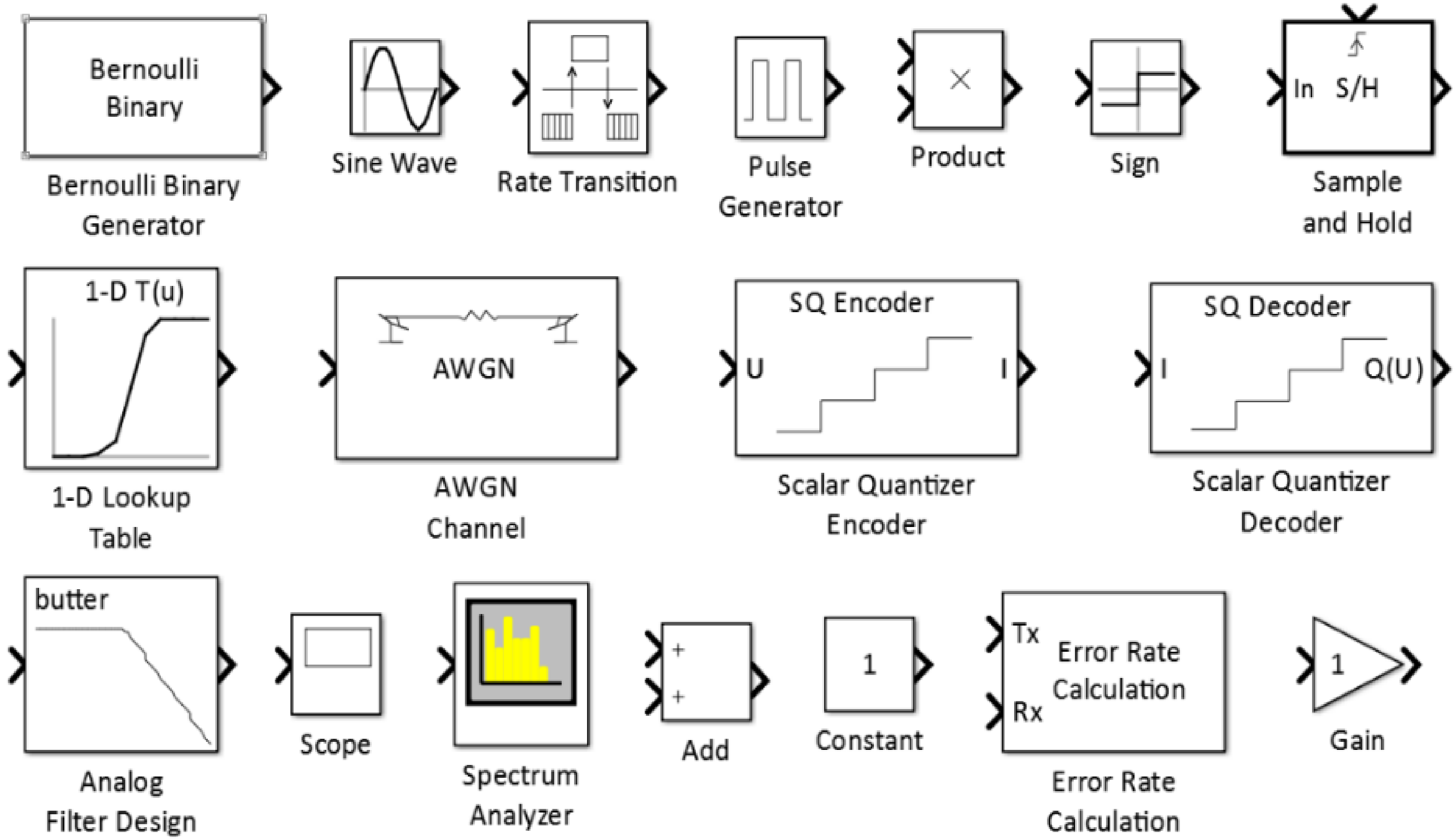
Objectives: To understand the basic concepts of

- analog-to-digital & digital-to-analog conversions.
- baseband digital transmission over AWGN channels.
- SNR and BER.



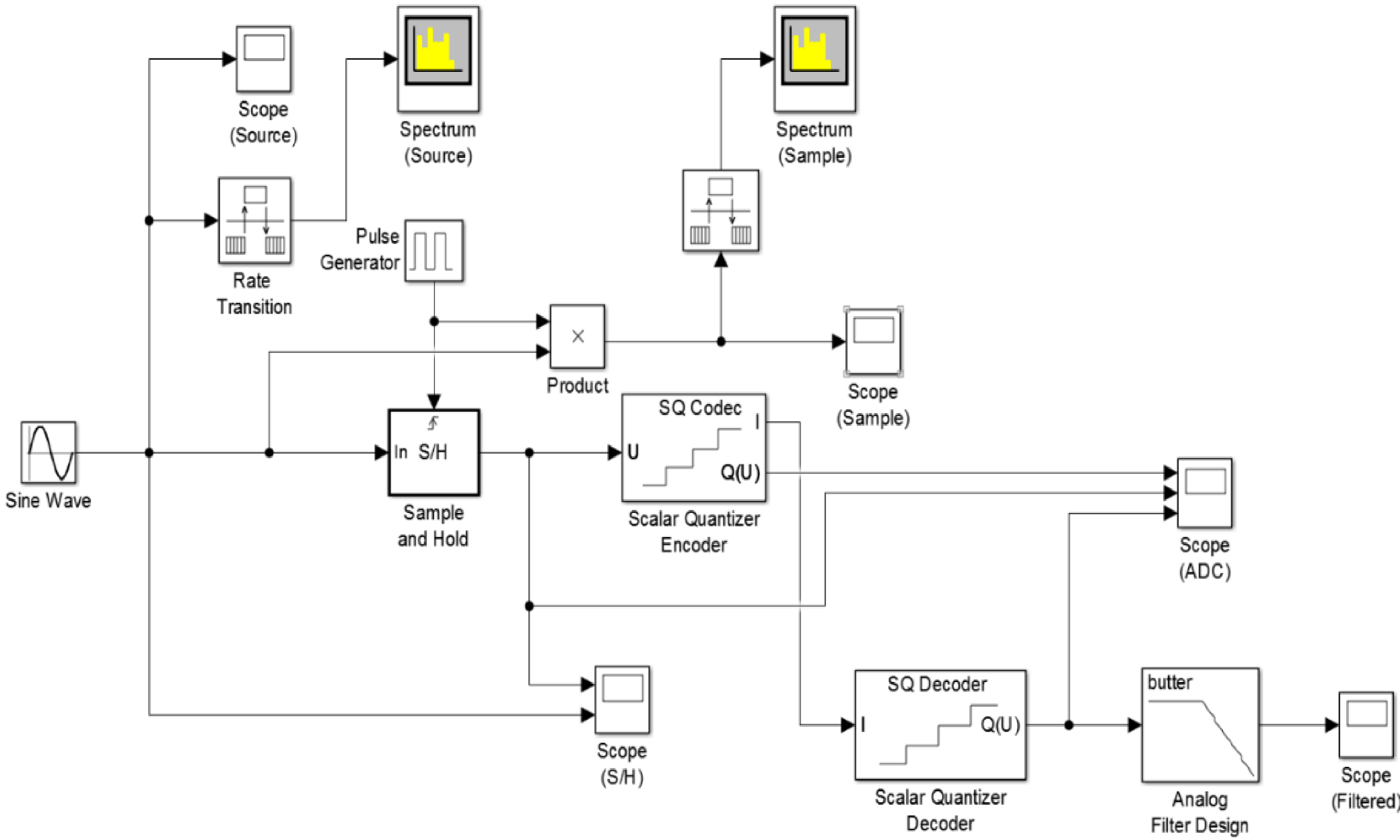
Preparation

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



ADC/DAC System

- Build the ADC/DAC system as illustrated.



ADC/DAC System: Parameter setup

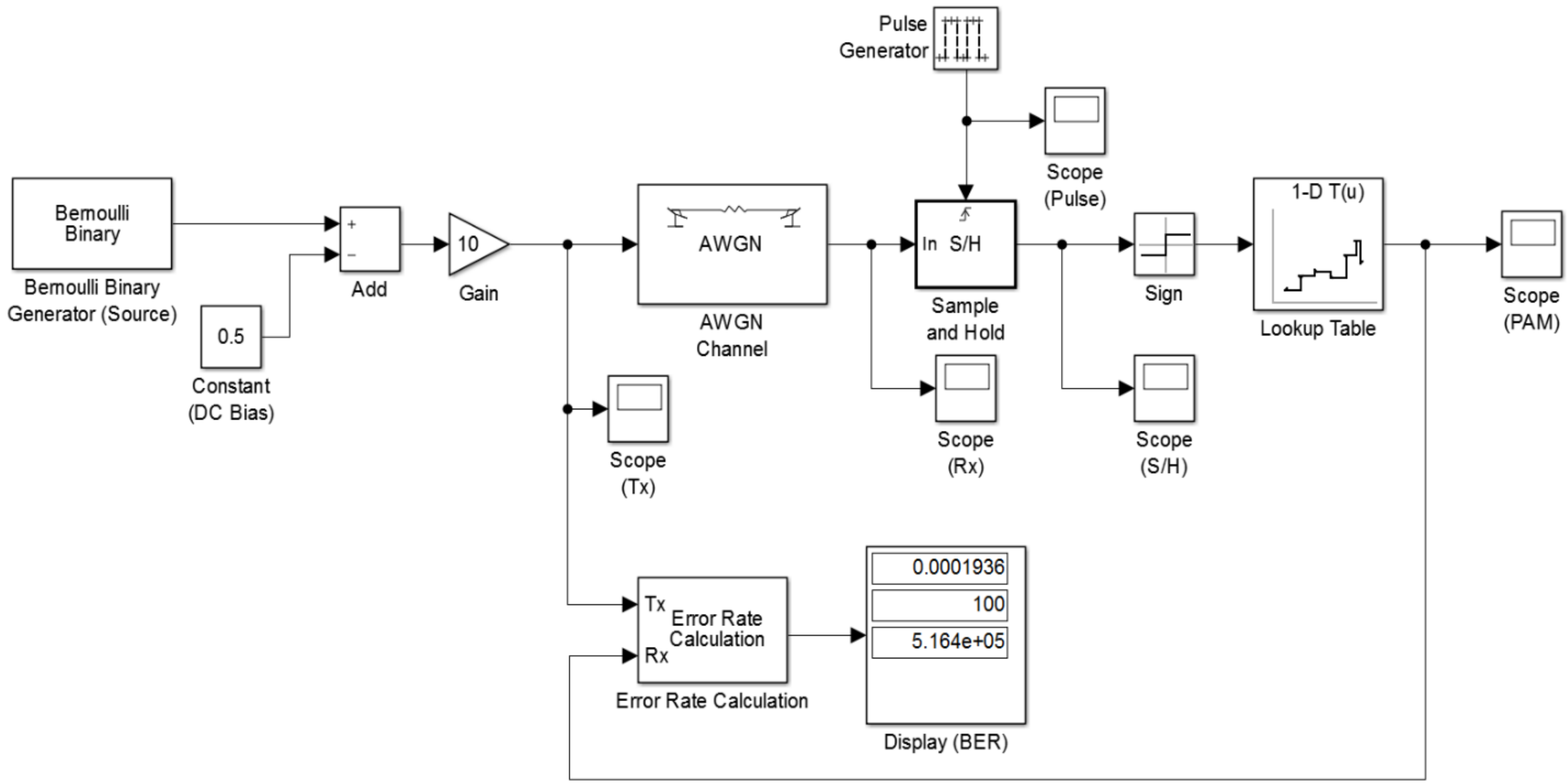
- **Sine Wave:** Sine type: Time based | Amplitude: 2 | Frequency (rad/sec): 500*2*pi
- **Rate Transition:** Output port sample time: 1e-5
- **Pulse Generator:** Pulse type: Time based | Amplitude: 1 | Period (secs): 0.001/8 | Pulse Width (% of period): 50
- **Scalar Quantizer Encoder:** Partitioning: Bounded | Boundary points: -2:0.5:2 | Output codeword | Codebook: [-1.75:0.5:1.75]
- **Scalar Quantizer Decoder:** Codebook values: [-1.75:0.5:1.75]
- **Analog Filter Design:** Design method: Butterworth | Filter type: Lowpass | Filter order: 20 | Passband edge frequency (rad/s): 500*2*pi

ADC/DAC System: Experiments

1. Compare the outputs on **Scope (ADC)** and **Scope(S/H)**. Explain how the Scalar Quantizer Encoder converts the analog input to the digital output.
2. Compare the outputs on **Spectrum (Source)** and **Spectrum (Sample).** Comment on the effect on the spectrum of the source signal when multiplying with a pulse train. Explain why the output of the analog lowpass filter is the recovered source signal.
3. Observe the output on **Scope (ADC).** Comment on the number of quantization levels and quantization bits utilized. Repeat for the following parameter setup: **Scalar Quantizer Encoder** Boundary points: [-2:2] | Codebook values: [-1.5:1:1.5]; **Scalar Quantizer Decoder** Codebook values: [-1.5:1:1.5]. Comment on the performance difference.

Baseband Transmission over AWGN Channel

- Build the baseband transmission and reception model as illustrated.



Baseband Transmission over AWGN Channel: Experiment

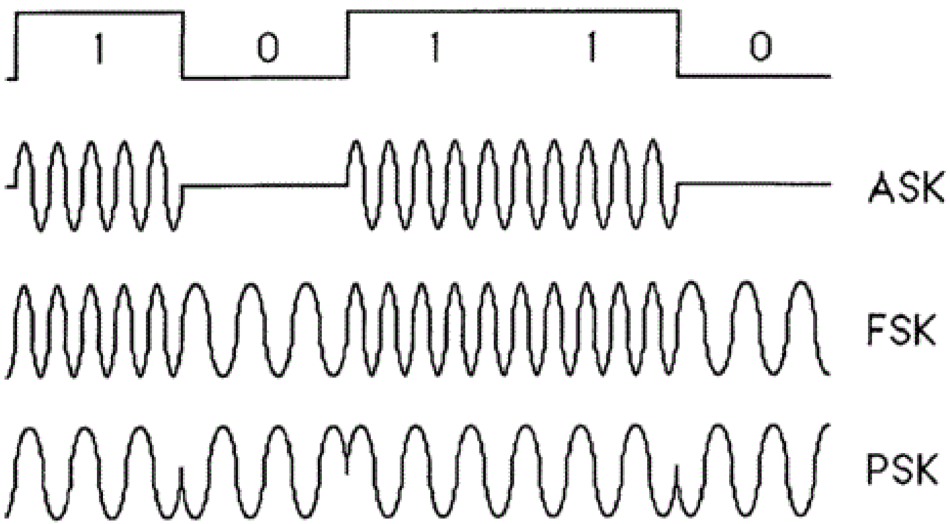
- Parameter setup:
  - **Bernoulli Binary Generator (Source):** Sample time: 0.001
  - **Constant (DC Bias):** Constant value: 0.5
  - **Gain Gain:** 10
  - **AWGN Channel:** Initial seed: randseed | Mode: Signal to noise ratio (Eb/No) | Number of bits per symbol: 1 | Input signal power, referenced to 1 ohm (watts): 25 | Symbol period (s): 0.001
  - **Pulse Generator:** Pulse type: Sample based | Amplitude: 1 | Period (number of samples): 2 | Pulse width (number of samples): 1 | Phase delay (number of samples): 1 | Sample time: 0.5e-3
  - **Lookup Table:** Table data: [-5,-5,5] | Breakpoints specification: Explicit values | Breakpoint 1: [-1,0,1]
  - **Error Rate Calculation:** Receive delay: 1 | Output data: Port

- Plot the BER-versus-Eb/No curve with Eb/No (dB)= 0, 2, 4, 6, 8, 10.

L3T3: Digital Transmission Techniques

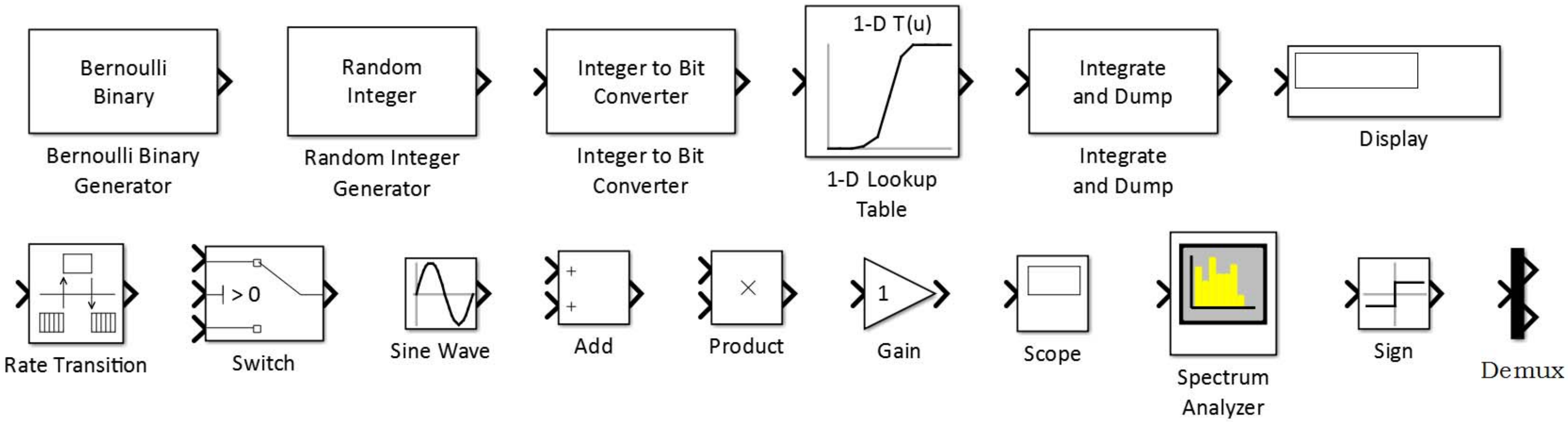
Part 2: basic digital modulation schemes

Objectives: To understand the basic concepts of digital modulation schemes: binary PSK, ASK,FSK, and 4QAM, and the modulated signal power spectra



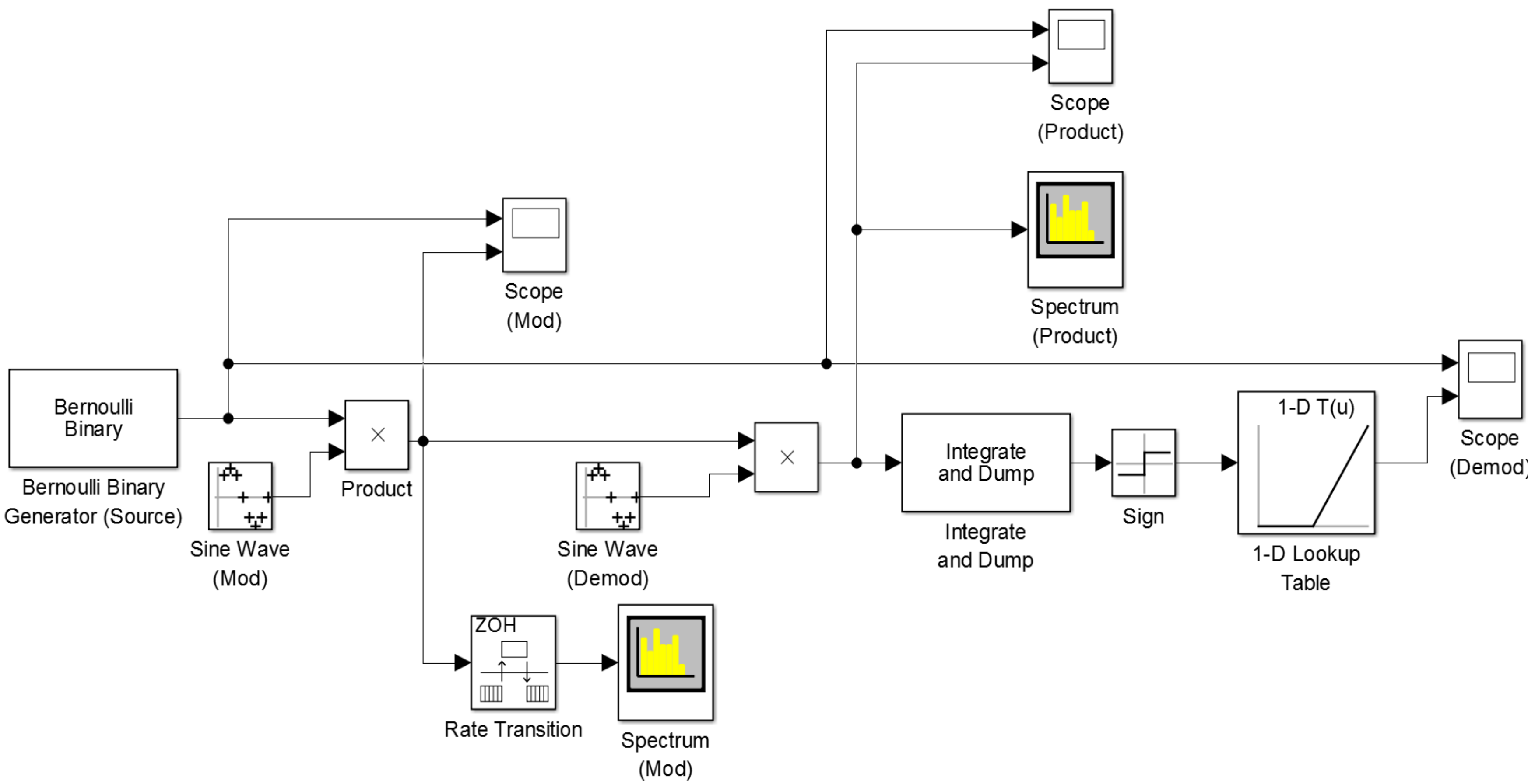
Preparation

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



Binary ASK Modulation

- Build the Binary ASK modulation and demodulation model as illustrated.



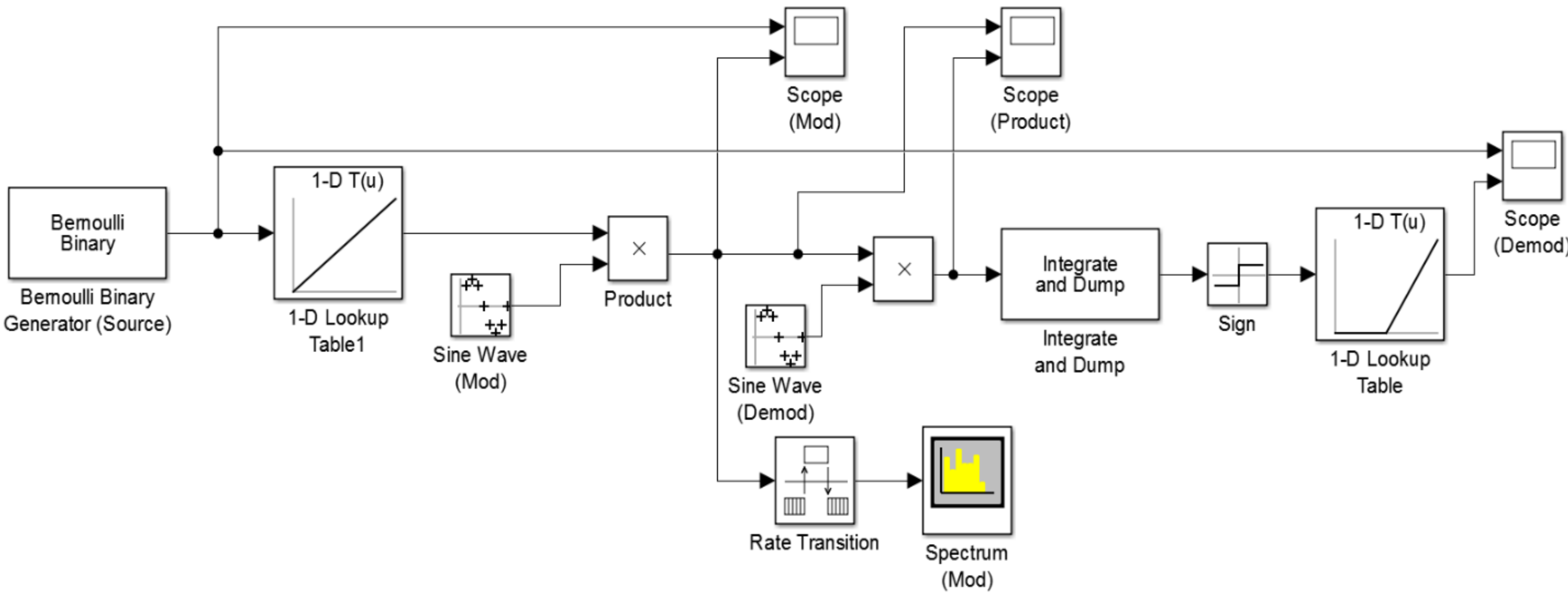
Binary ASK Modulation: Experiment

- Parameter setup:
  - **Bernoulli Binary Generator (Source):** Probability of zero: 0.5 | Source of initial seed: Parameter | Initial seed: randseed | Sample time: 0.001
  - **Sine Wave (Mod):** Sine type: Sample based | Samples per period: 5000 | Sample time: 1e-7
  - **Sine Wave (Demod):** Sine type: Sample based | Samples per period: 5000 | Sample time: 1e-7
  - **Rate Transition:** Output port sample time: 0.5e-4
  - **1-D Lookup Table:** Table data: [0,0,1]| Breakpoints 1: [-1,0,1]

1. Consider binary ASK. Observe the output on **Scope (Mod).** Describe how the transmitted signal is generated from the binary data streams.

Binary PSK Modulation

- Build the Binary PSK modulation model as illustrated.



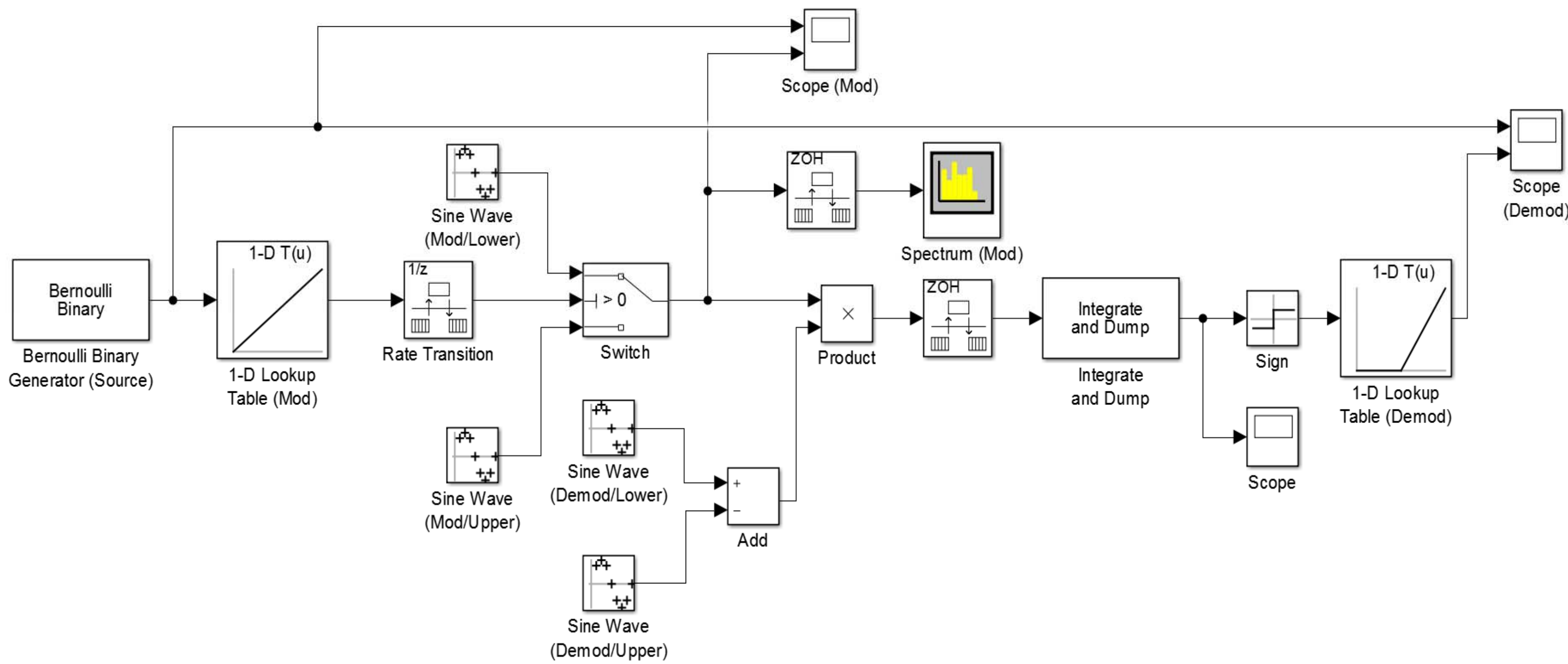
Binary PSK Modulation: Experiment

- Build the Binary PSK modulation model as illustrated.
  - **Bernoulli Binary Generator (Source):** Probability of zero: 0.5 | Initial seed: randseed | Sample time: 0.001
  - **1-D Lookup Table1:** Table data: [-1,1]| Breakpoints 1: [0,1]
  - **1-D Lookup Table:** Table data: [0,0,1]| Breakpoints 1: [-1,0,1]
  - **Sine Wave (Mod):** Sine type: Sample based | Samples per period: 5000 | Sample time: 1e-7
  - **Sine Wave (Demod):** Sine type: Sample based | Samples per period: 5000 | Sample time: 1e-7
  - **Rate Transition:** Output port sample time: 0.5e-4

2. Consider binary PSK. Observe the output on **Scope (Mod).** Describe how the transmitted signal is generated from the binary data streams.

Binary FSK Modulation

- Build the Binary FSK modulation model as illustrated.



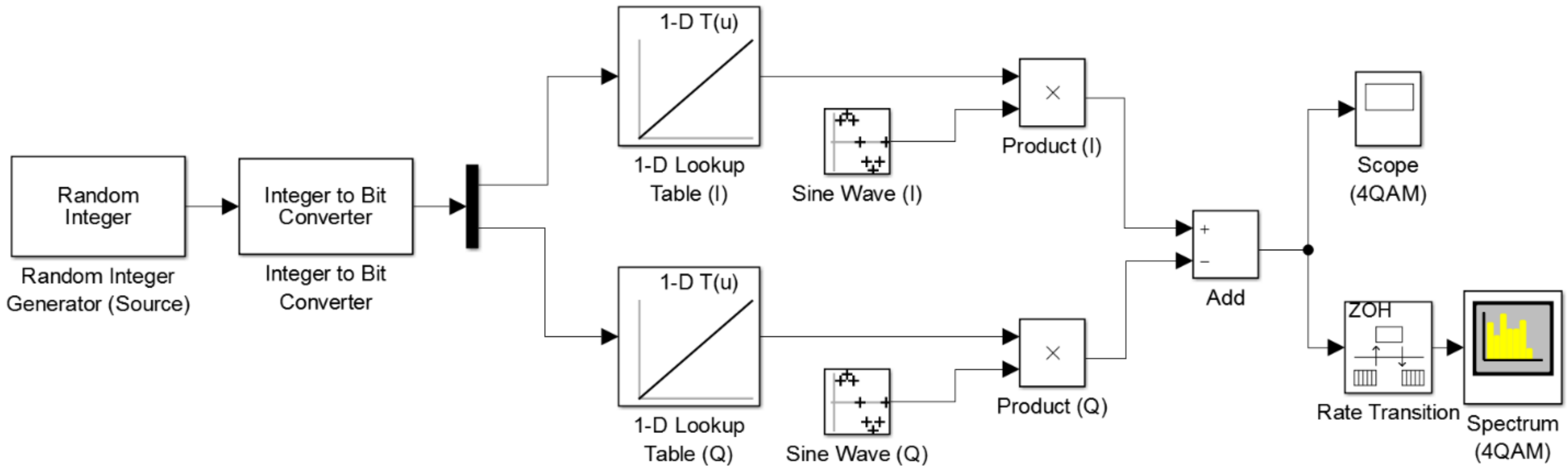
Binary FSK Modulation: Experiment

- Parameter setup:
  - **Bernoulli Binary Generator (Source):** Probability of zero: 0.5 | Initial seed: randseed | Sample time: 0.001
  - **1-D Lookup Table (Mod):** Table data: [-1,1]| Breakpoints 1: [0,1]
  - **1-D Lookup Table (Demod):** Table data: [0,0,1]| Breakpoints 1: [-1,0,1]
  - **Sine Wave(Mod/Lower):** Sine type: Sample based | Samples per period: 4000 | Sample time: 1e-7
  - **Sine Wave(Mod/Upper):** Sine type: Sample based | Samples per period: 2857 | Sample time: 1e-7
  - **Sine Wave(Demod/Lower):** Sine type: Sample based | Samples per period: 4000 | Sample time: 1e-7
  - **Sine Wave(Demod/Upper):** Sine type: Sample based | Samples per period: 2857 | Sample time: 1e-7
  - **Switch:** Threshold: 0
  - **Rate Transition:** Output port sample time: 0.5e-4

3. Consider binary FSK. Observe the output on **Scope (Mod).** Describe how the transmitted signal is generated from the binary data streams. Specify the carrier frequencies used for modulation and the corresponding frequency separation.

4-QAM Modulation

- Build the 4-QAM modulation model as illustrated.



4-QAM Modulation: Experiment

- Parameter setup:
  - **Random Integer Generator (Source):** Set size: 4 | Sample time: 0.001
  - **Integer to Bit Converter:** Number of bits per integer(M): 2
  - **1-D Lookup Table (I):** Table data: [-sqrt(0.5),sqrt(0.5)] | Breakpoints 1: [0,1]
  - **Sine Wave (I):** Sine type: Sample based | Samples per period: 5000 | Number of offset samples: 1250 | Sample time: 1e-7
  - **1-D Lookup Table (Q):** Table data: [-sqrt(0.5),sqrt(0.5)] | Breakpoints 1: [0,1]
  - **Sine Wave (Q):** Sine type: Sample based | Samples per period: 5000 | Number of offset samples: 0 | Sample time: 1e-7
  - **Rate Transition:** Output port sample time: 0.5e-4

4. Consider 4-QAM. Observe the output on Scope (Mod). Describe how the transmitted signal is generated from the binary data streams. Explain how 4-QAM can be implemented from binary PSK. Explain how the power spectrum of 4-QAM is related to that of binary PSK.

ASK, PSK, FSK: bandwidth comparison

5. What are the transmission bandwidths of binary ASK and binary PSK? Explain how their power spectra are related.

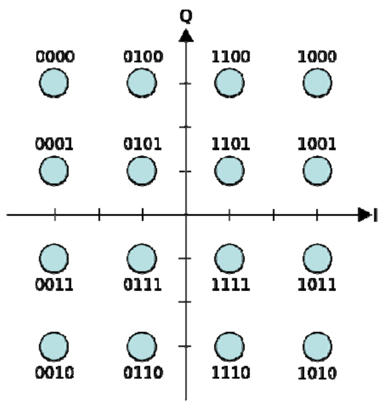
6. What is the transmission bandwidth of binary FSK? For binary ASK, PSK, and FSK, which one(s) is most bandwidth efficient?

L3T3: Digital Transmission Techniques

Part 3: M-QAM modulation & demodulation

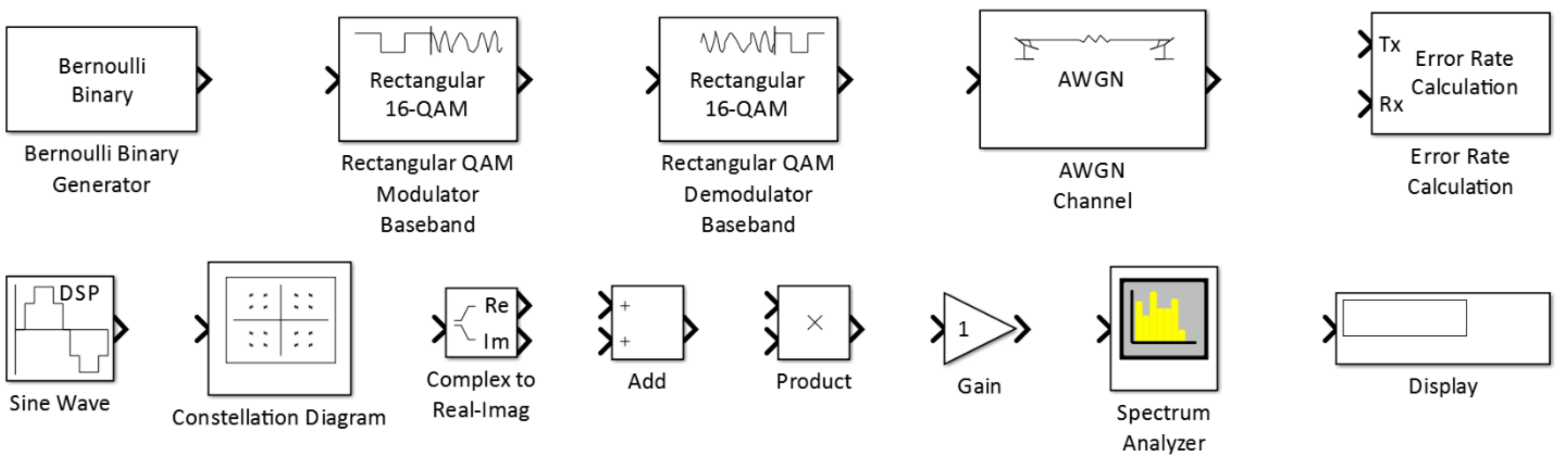
Objectives: To understand

- the basic principles of 16-QAM modulation and demodulation.
- the effect of noise through scatterplots.
- the relationship between SNR and BER.
- M-QAM: power and bandwidth efficiencies



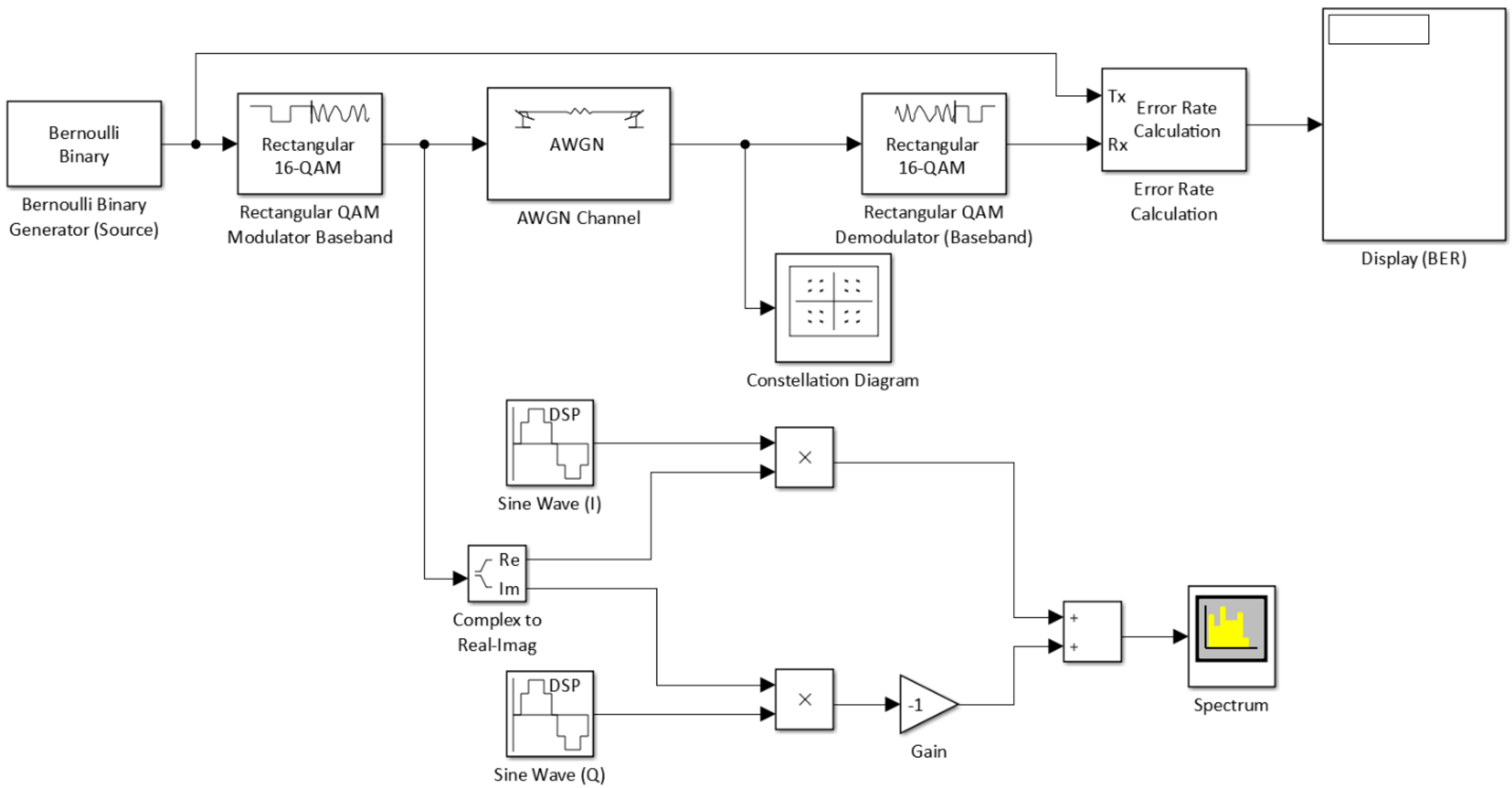
Preparations

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



16-QAM Modulation

- Build the 16-QAM modulation model as illustrated.



16-QAM: Parameter setup

- **Bernoulli Binary Generator (Source):** Probability of zero: 0.5 | Sample time: 1e-6 | Samples per frame: 4
- **Rectangular QAM Modulator:** Baseband M-ary number: 16 | Input type: Bit | Normalization method: Average power | Average power, referenced to 1 ohm (watts): 1
- **AWGN Channel:** Initial seed: randseed | Mode: Signal to noise ratio (Es/No) | Es/No (dB): 15 | Input signal power, referenced to 1 ohm (watts): 1 | Symbol period (s): 6e-6
- **Constellation Diagram:**  → Main → Samples per symbol: 1 | Reference constellation → Reference constellation: 16-QAM | Average reference power: 1
- **Rectangular QAM Demodulator Baseband:** M-ary number: 16 | Input type: Bit | Normalization method: Average power | Average power, referenced to 1 ohm (watts): 1
- **Sine Wave (I):** Frequency 100 | Phase offset (rad): pi/2 | Sample time: 1e-6
- **Sine Wave (Q):** Frequency 100 | Phase offset (rad): 0 | Sample time: 1e-6
- **Gain:** Gain: -1
- **Error Rate Calculation:** Stop simulation: Target number of errors → 100, Maximum number of symbols: 1e6

16-QAM: Experiment

1. Observe the output on **Constellation**. How many bits does each symbol carry? Describe the mapping between bits and symbols. Explain how 16-QAM can be expressed as an orthogonal superposition of two lower-order real modulation schemes.
2. Describe how a noisy received signal is demodulated.
3. Observe the output on **Constellation Diagram**. Explain the effect of additive white Gaussian noise on the transmitted signals.
4. Change Es/No (dB) in **AWGN Channel**. Run the simulation. Observe the output on **Constellation Diagram**. Explain how SNR affects the received constellation and therefore the BER.
5. Plot the BER-versus- Es/No curve for Es/No from 5 dB to 20 dB.

M-QAM: Experiment

6. Repeat Step 5 for 64-QAM (Es/No from 5 dB to 25 dB).
   - **Bernoulli Binary Generator (Source):** Samples per frame: 6
   - **Rectangular QAM Modulator Baseband:** M-ary number: 64 | Input type: Bit | Normalization method: Average power | Average power, referenced to 1 ohm (watts): 1
   - **Rectangular QAM Demodulator Baseband:** M-ary number: 64 | Output type: Bit | Normalization method: Average power | Average power, referenced to 1 ohm (watts): 1
   - **AWGN Channel:** Symbol period (s): 6e-6
   - **Constellation Diagram:**  → Main → Samples per symbol: 1 | Reference constellation → Reference constellation: 64-QAM | Average reference power: 1
7. Repeat Step 5 for 256-QAM (Es/No from 10 dB to 30 dB, **AWGN Channel**: Symbol period (s): 8e-6).

   How to set **Bernoulli Binary Generator (Source), Rectangular QAM Modulator Baseband, Rectangular QAM Demodulator Baseband, AWGN Channel**, and **Constellation Diagram**? Comment on the differences in BERs. Observe the outputs on **Constellation Diagram** and **Spectrum**. Explain why the BER performances are different from the viewpoint of transmission bandwidth and the distance between constellation symbols.