Section 1: Amplitude modulation (AM)

a. Preliminary discussion

In an amplitude modulation (AM) communications system, speech and music are converted into an electrical signal using a device such as a microphone. This electrical signal is called the message or baseband signal. The message signal is then used to electrically vary the amplitude of a pure sinewave called the carrier. The carrier usually has a frequency that is much higher than the message's frequency.

Figure 1.1 below shows a simple message signal and an unmodulated carrier. It also shows the result of amplitude modulating the carrier with the message. Notice that the modulated carrier's amplitude varies above and below its unmodulated amplitude.

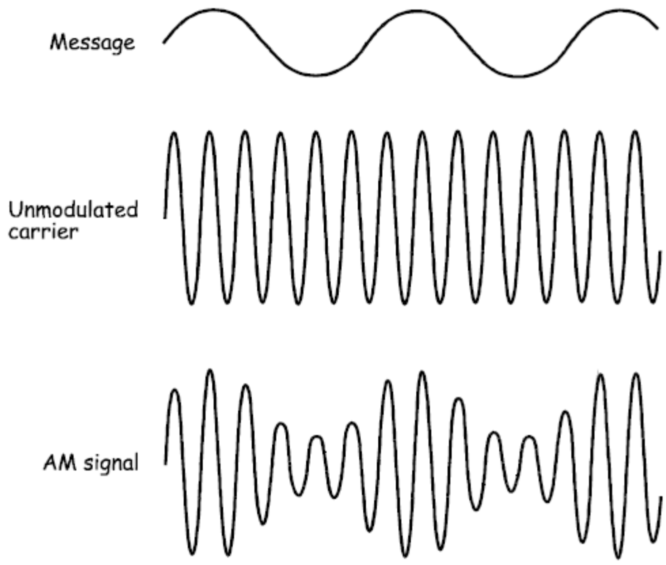


Figure 1-1

Figure 1.2 below shows the AM signal at the bottom of Figure 1 but with a dotted line added to track the modulated carrier's positive peaks and negative peaks. These dotted lines are known in the industry as the signal's envelopes. If you look at the envelopes closely you'll notice that the upper envelope is the same shape as the message. The lower envelope is also the same shape but upside-down (inverted).

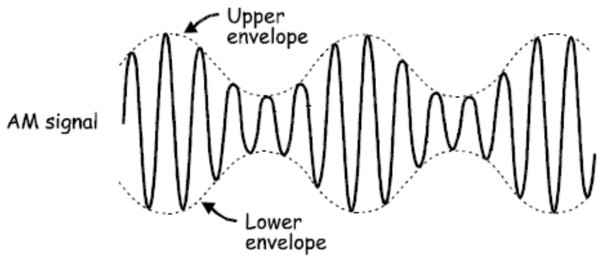


Figure 1-2

In telecommunications theory, the mathematical model that defines the AM signal is:
AM = (DC + message) × the carrier

When the message is a simple sinewave (like in Figure 1.1) the equation's solution (which necessarily involves some trigonometry that is not shown here) tells us that the AM signal consists of three sinewaves:

One at the carrier frequency
One with a frequency equal to the sum of the carrier and message frequencies
One with a frequency equal to the difference between the carrier and message frequencies

In other words, for every sinewave in the message, the AM signal includes a pair of sinewaves – one above and one below the carrier's frequency. Complex message signals such as speech and music are made up of thousands sinewaves and so the AM signal includes thousands of pairs of sinewaves straddling carrier. These two groups of sinewaves are called the sidebands and so AM is known as double-sideband, full carrier (DSBFC).

Importantly, it's clear from this discussion that the AM signal doesn't consist of any signals at the message frequency. This is despite the fact that the AM signal's envelopes are the same shape as the message.

b. The experiment

In this experiment you'll use Matlab Simulink to generate a real AM signal. You'll examine the AM signal using the scope and compare it to the original message. Following this, you'll vary the message signal's amplitude and observe how it affects the modulated carrier. You'll also observe the effects of modulating the carrier too much. Finally, you'll measure the AM signal's depth of modulation using a scope.

c. Procedure

Implement an AM modulation using a sinusoid signal based on the following

Carrier amplitude: A_c=1;

Carrier frequency: f_c=100 kHz;

Modulating frequency: f_m= 10 kHz;

Following the Simulink block diagram, configure each block appropriately to demonstrate AM modulation with modulation index 0.5 and 1.0 respectively. Observe the modulating signal using Scope 1 and modulated AM wave using Scope. Compare the signal in Scope 2 and Scope 1. Use the spectrum scope to observe the frequency spectrum of both modulating signal and modulated signal.

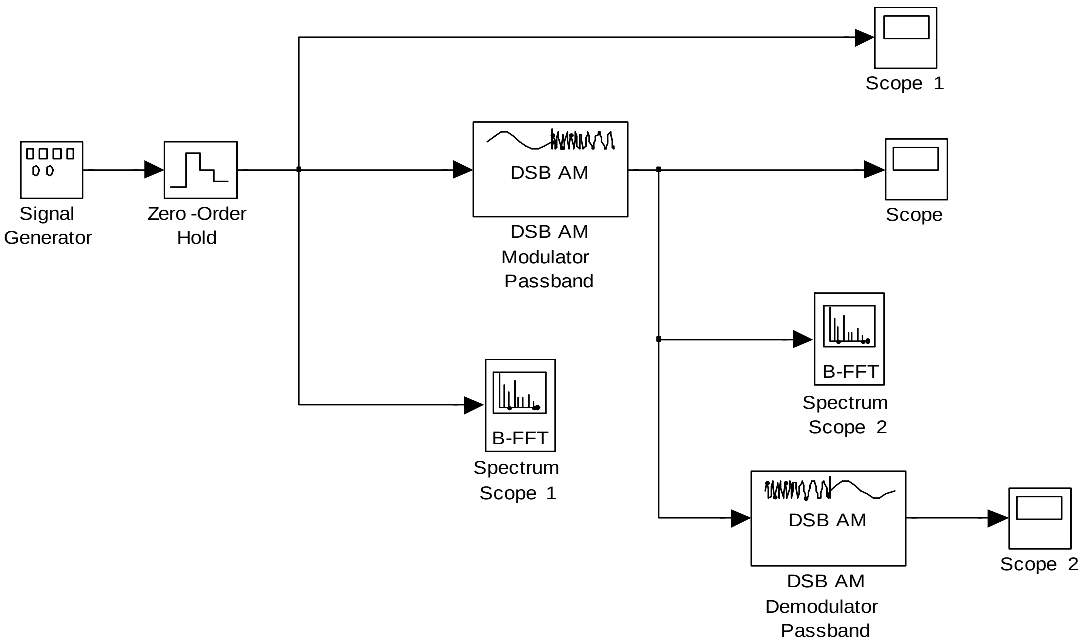


Figure 1-3

d. Questions

1. Decide the appropriate sampling rate for the Zero-order hold block.
2. If we want to see 10 cycles of the modulating signal in scope 1, decide simulation time.
3. Given an appropriate sampling rate, and expected frequency resolution, decide the minimum FFT size for the spectrum scope.
4. Compare the power of carrier and each side frequency component using the spectrum scope.

Section 2: DSBSC modulation

a. Preliminary discussion

DSBSC is a modulation system similar but different to AM.

Like AM, DSBSC uses a microphone or some other transducer to convert speech and music to an electrical signal called the message or baseband signal. The message signal is then used to electrically vary the amplitude of a pure sinewave called the carrier. And like AM, the carrier usually has a frequency that is much higher than the message's frequency.

Figure 2.1 below shows a simple message signal and an unmodulated carrier. It also shows the result of modulating the carrier with the message using DSBSC.

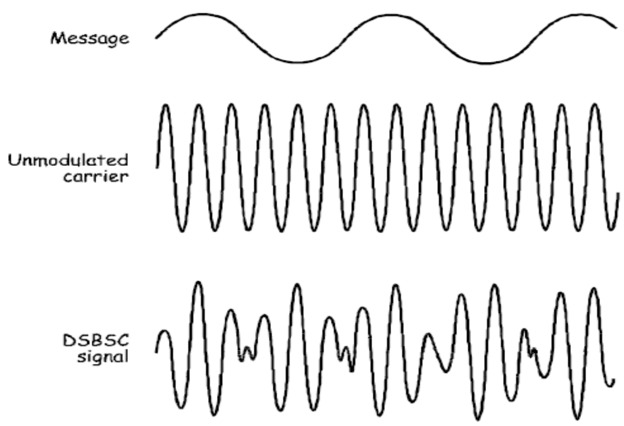


Figure 2-1

So far, there doesn't appear to be much difference between AM and DSBSC. However, consider Figure 2.2 below. It is the DSBSC signal at the bottom of Figure 2.1 but with dotted lines added to track the signal's envelopes (that is, its positive peaks and negative peaks). If you look at the envelopes closely you'll notice that they're not the same shape as the message as is the case with AM.

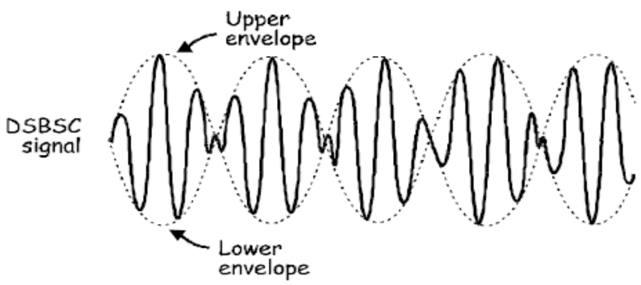


Figure 2-2

Instead, alternating halves of the envelopes form the same shape as the message as shown in Figure 2.3 below.

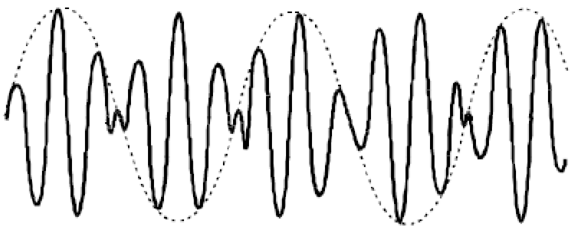


Figure 2-3

Another way that DSBSC is different to AM can be understood by considering the mathematical model that defines the DSBSC signal:

DSBSC = the message × the carrier

Do you see the difference between the equations for AM and DSBSC? If not, look at the AM equation.

When the message is a simple sinewave (like in Figure 2.1) the equation's solution (which necessarily involves some trigonometry) tells us that the DSBSC signal consists of two sinewaves:

- One with a frequency equal to the sum of the carrier and message frequencies
- One with a frequency equal to the difference between the carrier and message frequencies

Importantly, the DSBSC signal doesn't contain a sinewave at the carrier frequency. This is an important difference between DSBSC and AM. That said, as the solution to the equation shows, DSBSC is the same as AM in that a pair of sinewaves is generated for every sinewave in the message. And, like AM, one is higher than the unmodulated carrier's frequency and the other is lower. As message signals such as speech and music are made up of thousands of sinewaves, thousands of pairs of sinewaves are generated in the DSBSC signal that sit on either side of the carrier frequency. These two groups are called the sidebands.

So, the presence of both sidebands but the absence of the carrier gives us the name of this modulation method - double-sideband, suppressed carrier (DSBSC).

The carrier in AM makes up at least 66% of the signal's power but it doesn't contain any part of the original message and is only needed for tuning. So by not sending the carrier, DSBSC offers a substantial power saving over AM and is its main advantage.

b. The experiment

In this experiment you'll use Matlab Simulink to generate a real DSBSC signal. You'll examine the DSBSC signal using the scope and compare it to the original message. Following this, you'll use the spectrum scope to observe the frequency spectrum of the modulated waveform, and compared it with that of AM modulation.

c. Procedure

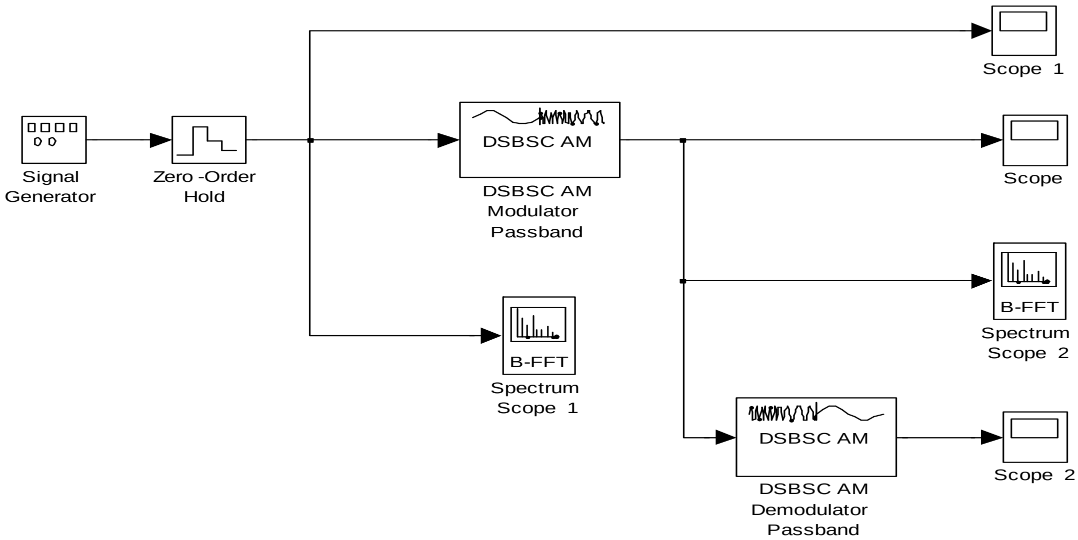
Implement an AM modulation using a sinusoid signal based on the following

Carrier amplitude: A_c=1;

Carrier frequency: f_c=100 kHz;

Modulating frequency: f_m= 10 kHz;

Following the Simulink block diagram, configure each block appropriately to demonstrate DSBSC modulation. Observe the modulating signal using Scope 1 and modulated wave using Scope. Compare the signal in Scope 2 and Scope 1. Use the spectrum scope to observe the frequency spectrum of both modulating signal and modulated signal.



d. Questions

1. Decide the appropriate sampling rate for the Zero-order hold block.
2. What feature of the Scope's display suggests that it's a DSBSC signal?
3. Given a sampling rate, and expected frequency resolution, decide the minimum FFT size for the spectrum scope.
4. Compare the frequency spectrum of DSBSC signal and AM signal. What makes DSBSC signals better for transmission than AM signals?

Section 3: Frequency modulation

a. Preliminary discussion

A disadvantage of the AM, DSBSC and SSB communication systems is that they are susceptible to picking up electrical noise in the transmission medium (the channel). This is because noise changes the amplitude of the transmitted signal and the demodulators of these systems are affected by amplitude variations.
As its name implies, frequency modulation (FM) uses a message's amplitude to vary the frequency of a carrier instead of its amplitude. This means that the FM demodulator is designed to look for changes in frequency instead. As such, it is less affected by amplitude variations and so FM is less susceptible to noise. This makes FM a better communications system in this regard.

There are several methods of generating FM signals but they all basically involve an oscillator with an electrically adjustable frequency. The oscillator uses an input voltage to affect the frequency of its output. Typically, when the input is 0V, the oscillator outputs a signal at its rest frequency (also commonly called the free-running or centre frequency). If the applied voltage varies above or below 0V, the oscillator's output frequency deviates above and below the rest frequency. Moreover, the amount of deviation is affected by the amplitude of the input voltage. That is, the bigger the input voltage, the greater the deviation.

Figure 5-1 below shows a simple message signal (a bipolar squarewave) and an unmodulated carrier. It also shows the result of frequency modulating the carrier with the message.

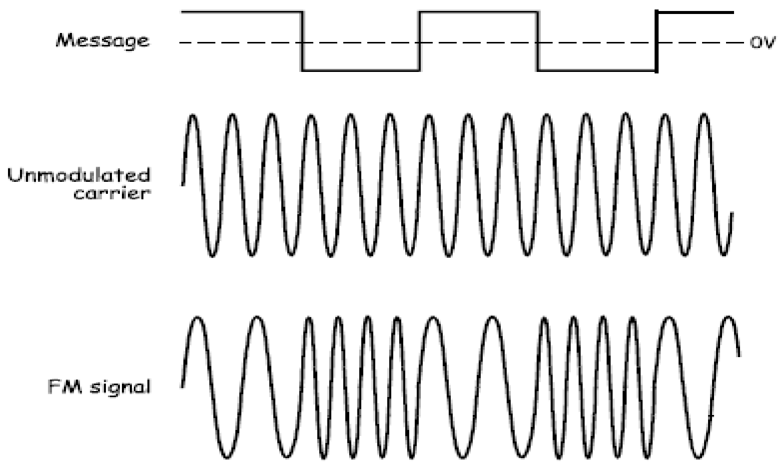


Figure 3-1

There are a few things to notice about the FM signal. First, its envelopes are flat – recall that FM doesn't vary the carrier's amplitude. Second, its period (and hence its frequency) changes when the amplitude of the message changes. Third, as the message alternates above and below 0V, the signal's frequency goes above and below the carrier's frequency. (Note: It's equally possible to design an FM modulator to cause the frequency to change in the opposite direction to the change in the message's polarity.)

b. The experiment

In this experiment you'll use Matlab Simulink to generate FM signal. You'll use a scope to observe the effect of frequency modulating with sine wave. You'll vary the frequency deviation and observe how it affects the spectral composition of an FM signal.

c. Procedure

Implement a FM modulation using a sinusoid signal based on the following

Carrier amplitude:	$A_c=1$;
Carrier frequency:	$f_c=100$ kHz;
Modulating frequency:	$f_m= 1$ kHz;

Following the Simulink block diagram, configure each block appropriately to demonstrate FM modulation with modulation index 0.5 and 10.0 respectively. Observe the modulating signal using Scope 1 and modulated AM wave using Scope. Compare the signal in Scope 2 and Scope 1. Also use the spectrum scope to observe the frequency spectrum of the modulated signal.

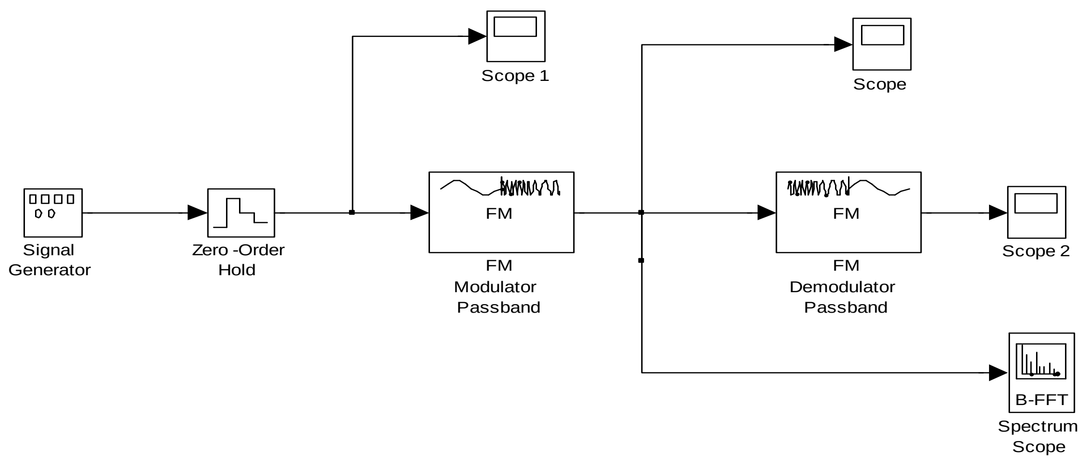


Figure 3-2

d. Questions

1. Decide the appropriate sampling rate for the Zero-order hold block.
2. If we want to see 10 cycles of the modulating signal in scope 1, decide simulation time.
3. Given a sampling rate, and expected frequency resolution, decide the minimum FFT size for the spectrum scope.
4. Compare the frequency spectrum of narrowband FM and broadband FM.

Lab Report and Marking Scheme

1. Good overview of each modulation theory, including system parameters, signal before and after modulation (both time and frequency domain). 20%

2. Demonstrate results observed in each scope. 30%

3. Answer questions: 40%

   a) Nyquist Sampling rate; 5%

   b) Simulation run time; 5%

   c) FFT size (i.e. time samples to take for FFT) to achieve a required frequency resolution; 10%

   d) Power efficiency; AM vs DSB-SC; 10%

   e) Bandwidth comparison: narrow band FM vs wideband FM;10%

4. Report organization and presentation. 10%