Experiment 3: Double Sideband Modulation (DSB)

This experiment examines the characteristics of the double-sideband (DSB) linear modulation process. The demodulation is performed coherently and its strict requirement for a perfect synchronization to the carrier is discussed.

1 Introduction

In communication systems information is transmitted from one place to another using electrical signals (telephone, TV and radio broadcast etc.). Usually the information bearing signals (message signals) are not suitable for transmission due to its propagation qualities (a large wavelength). Also, since these signals generally exist in the same frequency range it is necessary to transmit them using different frequency allocations to avoid interference. One of the methods used to solve these problems is *linear modulation*, which is merely the frequency translation of the spectrum of the information (or message) signal to a usually much higher frequency. The translated spectrum can be modified before transmission in different forms resulting in different linear modulation schemes. Specifically, there are four linear modulation methods: double-sideband (DSB) (also known as double-sideband with suppressed carrier DSB-SC), amplitude modulation (AM) or DSB-LC (large carrier), single-sideband (SSB) and vestigial-sideband (VSB). This experiment examines the characteristics of the DSB modulation.

1.1 DSB signal generation

The simplest modulation method to implement is DSB, in which the translated spectrum of the message signal is transmitted without further modification. From the real signal frequency translation property of the Fourier transform, the spectrum of the *message* signal $x(t)$ is translated to the frequency f_c by multiplying $x(t)$ with a *carrier* waveform $A_c \cos(2\pi f_c t)$. The modulated waveform $x_c(t)$ is

$$x_c(t) = A_c x(t) \cos(2\pi f_c t) \tag{1}$$

whose spectrum is

$$X_c(f) = \frac{A_c}{2}[X(f + f_c) + X(f - f_c)] \tag{2}$$

The message signal is usually referred to as the baseband signal and the spectral range that occupies is called the baseband frequency range. In communication systems the baseband signal is limited in frequency to a bandwidth of f_x Hz, and the carrier frequency f_c is much higher than f_x. The spectral components of the baseband signal that occupy the positive side of the frequency axis appear in the range f_c to $f_c + f_x$ in the spectrum of the DSB signal, this portion of the spectrum is called the *upper sideband*. Similarly, the spectral components of the baseband signal that occupy the negative side of the frequency axis are translated to the *lower sideband* of the spectrum of the DSB signal in the frequency range $f_c - f_x$ to f_c. Hence the (one-sided) spectrum consists of two sidebands that occupy the frequency range $f_c - f_x$ to $f_c + f_x$ and therefore the bandwidth B_T required for transmission is

$$B_T = 2f_x \tag{3}$$

1.2 Demodulation of DSB signals

In order to recover the message signal from the *received* DSB signal another frequency translation is required. That is, the spectra of the two sidebands must be translated back to the baseband frequency range. Assuming that the received signal $x_r(t)$ has the same form as $x_c(t)$ except for an attenuation factor a_c/A_c introduced by the channel

$$x_r(t) = a_c x(t)\cos(2\pi f_c t)$$

the message signal can be recovered from the received signal by multiplying $x_r(t)$ with a local carrier waveform (identical to the transmitter carrier scaled by 2) and lowpass filtering the product signal $z(t)$,

$$z(t) = [a_c x(t)\cos(2\pi f_c t)] \cdot 2\cos(2\pi f_c t) = a_c x(t) + a_c x(t)\cos(4\pi f_c t) \tag{4}$$

whose spectrum $Z(f)$ is

$$Z(f) = a_c X(f) + \frac{a_c}{2}[X(f-2f_c) + X(f+2f_c)] \tag{5}$$

Notice that scaled replicas of the message spectrum appear at the baseband frequency range and at $2f_c$. Therefore, a lowpass filter with cut-off frequency B, $f_x < B < 2f_c - f_x$ is necessary to remove the high frequency components. The output $y(t)$ of the lowpass filter is

$$y(t) = a_c x(t)$$

which is the message signal scaled by a factor a_c.

1.2.1 Requirements for coherent demodulation

The demodulation process described in the previous section involves the multiplication of the received signal by a *local* carrier at the receiver. Such demodulation scheme is called *synchronous* or *coherent* because a local carrier completely synchronous to the carrier of the DSB signal is required. This is a very strict requirement for practical systems and increases the complexity of the receivers. Lack of synchronism produces distortion in the recovered signal. In fact, a small difference in frequency and/or phase between the carrier of the DSB signal and the local carrier is sufficient to produce great distortion and in some cases a complete loss of the output signal.

Suppose that the local carrier have a frequency offset of Δf and a phase offset of θ. The resulting product signal $z(t)$ in this case is

$$z(t) = a_c x(t)\cos(2\pi\Delta f t + \theta) + \text{double frequency terms}$$

which after lowpass filtering is

$$y(t) = a_c x(t)\cos(2\pi\Delta f t + \theta) \tag{6}$$

Notice that even when the frequency of the carriers are identical ($\Delta f = 0$) if they have a phase difference of $\theta = \pi/2$ the output signal is $y(t) = 0$, and the signal is completely lost. In the opposite case, when $\theta = 0$ the output signal is $y(t) = a_c x(t)\cos(2\pi\Delta f t)$, hence the message signal cannot be recovered due to distortion.

2 Prelab instructions

Enclosed in brackets is the number of points assigned to each question/plot.

1. From Equation (1), (a) obtain the expression for $x_c(t)$ [1] when $x(t) = A_x\sin(2\pi f_x t)$ and (b) plot [3] the DSB signal. The parameters are: $A_c = 1$ V, $f_c = 9$ kHz, A_x=5 V, f_x=500 Hz, (time span for the plot) TS=4 ms. [4 points total].

2. Equation (2) describes the spectrum of the DSB signal. Using the same function and parameters as above, (a) obtain the expression for $X_c(f)$ [1] and (b) plot [3] the one-sided spectrum in the frequency span FS=20 kHz, use NF=-30 dBV. [4 points total].

3. Equation (4) describes the product signal $z(t)$ and Eq. (5) its spectrum $Z(f)$. Using the same function $x(t)$ and parameters as before but changing $A_x = 2.5$ V, (a) obtain the expressions for $z(t)$ [1] and $Z(f)$ [1] and (b) create the corresponding plot [3] in time domain with TS=4 ms and the one-sided spectrum [3] in the frequency span FS=20 kHz and NF=-30 dBV. Assume there is no attenuation and set $a_c = A_c$. [8 points total]

4. During the lab, the phase offset θ of Eq. (6) will be introduced in the local carrier by the RC network of Fig. 3. The output of this circuit is node `B`. Compute the phase shift introduced by this circuit at f =10 kHz. [Hint: Obtain the transfer function $H(f)$ of this circuit and $\theta(f) = \arctan(\Im[H(f)]/\Re[H(f)])$]. [3 points].

3 Lab procedure

GENERAL INSTRUCTIONS:

- Load the virtual instrument TIMEFREQ.VI by double-clicking the shortcut located in the computer desktop.
- **To avoid damage to the integrated circuits, keep the power supply off during the assembling of the circuits**.
- **After taking each plot make sure to ask your TA to verify that your results are correct. This also serves to monitor your progress and performance.** Your TA have the correct plots from actual circuits so you can compare yours.

3.1 DSB signal generation

In this section DSB signals are generated by multiplying message signals with a carrier. The multiplier chip utilized is the AD633. From its data sheet notice that the product of the two signals is divided by 10 V. Hence two signals with amplitude of 10 V will result in a signal with amplitude (10*10)/10 = 10 V.

1. Keeping the power supply off, assemble the circuit of Fig. 1. Use FG1 as the message signal and FG2 as the carrier signal. Set the following parameters in FG1: Amplitude=5 V, Frequency=500 Hz, sine wave. For FG2: Amplitude=10 V, Frequency=9 kHz, sine wave. Connect channel 1 probe of the oscilloscope to the output of the modulator (at pin 7).
2. Turn on the power supply and capture the DSB signal and its spectrum by executing TIMEFREQ.VI with the following parameters: Channel=1, TS=4m (meaning milliseconds), FS=20, Save data=ON, a proper file name. [Plot P1, 5 points].
3. Change the waveform of FG1 (the message signal) to triangle and repeat the previous step using the same parameters but different file name. [P2, 5 points].

3.2 Coherent demodulation of DSB signals

In this section the message signal is recovered by coherent demodulation. The case of a synchronous local carrier at the receiver is implemented here.

1. Keeping the power supply off, assemble the circuit of Fig. 2. Use FG1 as the message signal and FG2 as the carrier signal. Set the following parameters in FG1: Amplitude=5 V, Frequency=500 Hz, sine wave. For FG2: Amplitude=10 V, Frequency=9 kHz, sine wave. Connect channel 1 probe of the oscilloscope to observe the product signal (at pin 7 of the second AD633), and the channel 2 probe to the output of the filter to observe the recovered message signal.
2. Turn on the power supply and capture the product signal and its spectrum by executing TIMEFREQ.VI with the following parameters: Channel=1, TS=4m, FS=20, Save data=ON, a proper file name. [P3, 5 points].
3. Capture the output (recovered message) signal and its spectrum by repeating the previous step with Channel=2 and a different file name. [P4, 5 points].
4. Change the following parameters in FG1: Frequency=1 kHz, triangle wave, in FG2: Frequency=18 kHz. Repeat the previous **two** steps using TS=2m, FS=50, and different file names. [P5 and P6, 5 points each].

3.3 Synchronization problems of the coherent demodulation

In this section the problems associated with lack of synchrony of the local carrier are observed. A phase offset is introduced in the local carrier and later the effect of a frequency offset is considered.

3.3.1 Phase offset in the local carrier

1. Keeping the power supply off, assemble the circuit of Fig. 3. Use FG1 as the message signal and FG2 as the carrier signal. Set the following parameters in FG1: Amplitude=10 V, Frequency=500 Hz, sine wave. For FG2: Amplitude=10 V, Frequency=10 kHz, sine wave.

2. Connect the channel 1 probe of the oscilloscope to node `A` and the channel 2 probe to node `B`. Disconnect the synchrony cable from channel 4. Turn the power supply on and press `Autoscale` .

3. Set an attenuation factor of 10 for both channels by pressing `1` (`2` for channel 2) and selecting `10` in the softmenu `Probe`.

4. Measure the amplitude peak-to-peak of these two signals by pressing `Voltage` and selecting `Vp-p` for each of the two channels. These two voltages should be approximately the same. If they are different to each other, adjust the carrier frequency of FG2 to change the voltage at node `B` until these voltages are equal.

5. Measure and record the phase difference θ between these two signals by pressing `Time` , selecting `Next Menu` twice and then `Phase`. The phase value displayed in the oscilloscope might be changing constantly, pick an average value, $\theta =$ ____________ .

6. Connect the synchrony cable from FG1 to channel 4. Connect node `C` to node `A`. Connect channel 1 probe of the oscilloscope to observe the product signal (at pin 7 of the second AD633), and the channel 2 probe to the output of the filter.

7. Capture the output signal with the following parameters: Channel=2, TS=4m, FS=25, Save data=ON, a proper file name. [P7, 5 points]. This is the recovered message signal using a synchronous local carrier, i.e. $\Delta f = 0$ and $\theta = 0$. This plot is taken as a reference in order to observe the effect of a phase offset in the next step.

8. Disconnect `A` from `C` and now connect node `B` to node `C`. Now the local carrier has a phase offset of θ but the *same* frequency and amplitude as in the previous step. Capture the product signal and its spectrum by executing TIMEFREQ.VI with the following parameters: Channel=1, TS=4m, FS=25, Save data=ON, a proper file name. [P8, 5 points]. Capture the output signal by executing the VI with Channel=2 and a different file name. [P9, 5 points].

3.3.2 Frequency offset in the local carrier

1. Load the virtual instrument *DSB.vi* by double-clicking the shortcut located in the computer desktop. This VI generates a DSB signal and loads the waveform to the volatile memory of FG1. Run the VI by pressing Ctrl-R. No further adjustments to the parameters of FG1 are required.

2. Keeping the power supply off, assemble the circuit of Fig. 4. Use FG1 as the received DSB signal and FG2 as the local carrier signal. In FG2 set Amplitude = 10 V, frequency = 20 kHz, sine wave.

3. Turn on the power supply. Connect the channel 1 probe of the oscilloscope to FG1 to observe the DSB signal and the channel 2 probe to the output of the filter. Run TIMEFREQ.vi to observe the spectrum of the DSB signal with Channel=1, TS=2m, FS=25, Save data=**OFF**. This plot is **not** required for the lab report, but helps to verify that the carrier frequency for this DSB signal is 20 kHz and the message signal is a sinusoid of 1 kHz.

4. Connect the channel 1 probe to observe the product signal (at pin 7 of the AD633). At this point you should see that the product signal and the output signal change slowly. Set the local carrier frequency (FG2) to 20001 Hz and observe the effect of a frequency offset of only 1 Hz on the output and product signals. Since this effect cannot be recorded using the computer write a note describing what you observe.

Please shut down properly the computer and the equipment.

4 Analysis

This section contains questions regarding the obervations you made during the lab.

1. Include in your report all the plots obtained during the lab. Make sure to label properly all the plots. The number of points assigned to each plot is specified in the lab procedure. Refer to Appendix B section 3.4 for instructions regarding the plotting of experimental results.
2. From plot P2, (a) estimate the bandwidth B_T of the DSB signal. [2]. Suppose the upper sideband is suppressed before transmission, (b) Could the message signal (a triangle wave) be recovered at the receiver? Justify your answer.[2]. (c) What would be the frequency of the local carrier? [2].
3. From plot P3, explain why the component at 500 Hz (the message signal) is about 6 dBV higher than the components (the translated sidebands) at 17.5 kHz and 18.5 kHz. [2].
4. Observe from plot P3 that the envelope of the product signal has the shape of the message signal, which is recovered as the output signal in plot P4. Plot P5 shows that the message signal is a triangle wave, however plot P6 shows a recovered signal that resembles more closely a sine wave, (a) explain why a triangle wave was not recovered. [2]. (b) What modifications should be made to the circuit of Fig. 2 in order to recover the triangle wave? [2].
5. Plot P7 shows the output signal $y(t)$ when $\Delta f = 0$ and $\theta = 0$. Estimate its peak amplitude (in volts). Using Eq. (6) and the value of the phase offset θ you measured during the lab, (a) calculate the peak amplitude of the output signal when is affected by the phase offset in the local carrier. [2]. Plot P9 shows the output signal affected by a phase offset, (b) estimate the peak amplitude of this signal and compare it with the theoretical value just found. [2].
6. Describe the effect of the frequency offset on the output signal that you observed in section 3.3.2. [2].

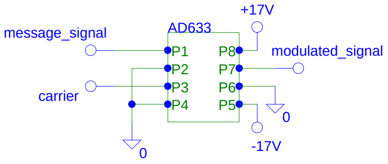

Fig. 1 DSB Modulator

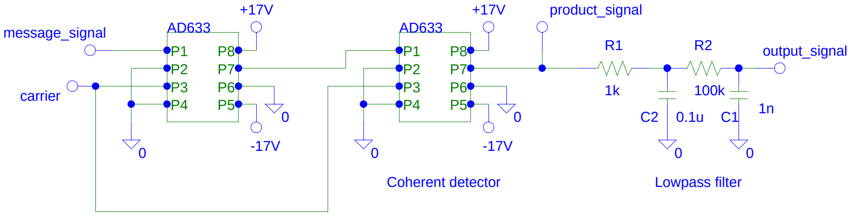

Fig. 2 Coherent demodulation of DSB signals

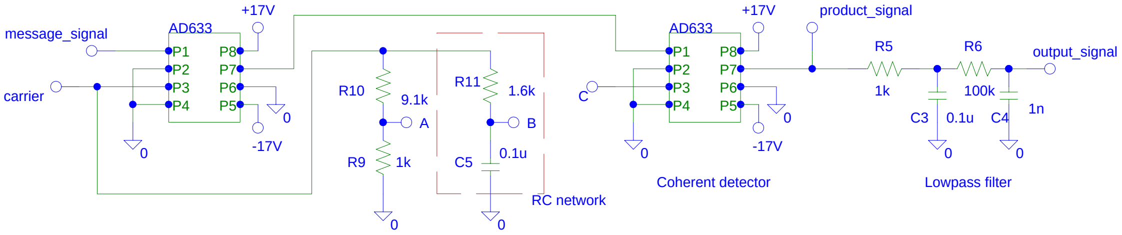

Fig. 3 Test circuit to observe the effect of a phase offset

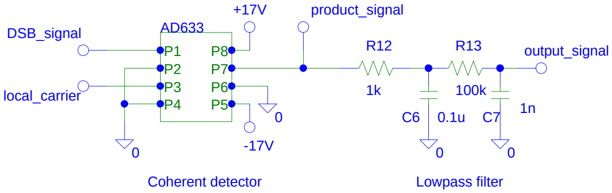

Fig. 4 Test circuit to observe the effect of a frequency offset

EE3150 Communication Systems Lab
Experiment 3. Linear modulation:DSB
Spring 2002
E. Cura

Page Size: A

Revision: - Feb 19, 2002 Page 1 of 1