AM Modulation and Demodulation

AN62582

Author: Pavankumar Vibhute and Praveen Sekar
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Application Note Abstract

The application note describes how to implement amplitude modulation (AM) and demodulation using PSoC® 3 and PSoC 5. Amplitude modulation is achieved by using an up-mixer to multiply the carrier and message. Demodulation is achieved by down mixing the signal with the same carrier frequency. This application note demonstrates examples of modulation and demodulation.

Introduction

Amplitude Modulation is defined as modifying the amplitude of the carrier wave according to the message or information signal. The AM generation involves mixing of carrier and information signal. There are two methods to generate AM: low level modulation and high level modulation.

In low level modulation, the message signal and carrier signal are modulated at low power levels and then amplified. The advantage of this technique is that a small audio amplifier is sufficient to amplify the message signal. The disadvantage is that the linear amplifiers should be used to amplify the modulated signal to transmitter levels. The nonlinear amplifiers cause distortion of the modulated wave. In this application note, the modulation is inside PSoC 3 and PSoC 5 at low power levels (not at the transmitting power levels); this is low level modulation technique.

In high level modulation, the carrier and message signals are sufficiently amplified to the transmitting levels and modulation is done at high power levels.The advantage of this technique is that nonlinear high efficient amplifiers can be used to amplify the signals. The disadvantage is that large audio amplifier needs to be used to amplify the message signal..

The modulation in PSoC 3 and PSoC 5 is achieved by using the up-mixer component. A square with carrier frequency is multiplied with the message signal. The output of the mixer is filtered using a band pass filter to remove harmonics.

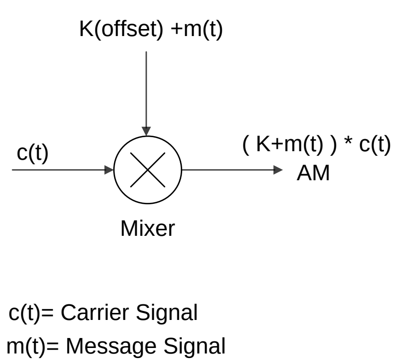
The modulation index of AM is the extent of amplitude variation about an unmodulated carrier amplitude level. Higher the message signal amplitude, larger the variation on the amplitude of the AM wave. In the section, Examples – Modulation on on page 4, examples 1, 2, and 3 show the AM for different modulation indices. The message signal power is increased keeping the carrier level constant to get different modulation indices. Example 4 shows the AM waves with different carrier power levels.

In some applications, power is saved by suppressing the carrier from the AM wave. Example 5 shows the Double Side Band Suppressed Carrier (DSBSC) AM wave.

Coherent detection is used for demodulation. The coherent demodulation involves multiplication of the AM wave by a carrier wave. In this implementation, the square wave with the same frequency as carrier wave is generated by passing the input AM wave through Zero Crossing Detector (ZCD). This square wave and the AM are given to the down-mixer component. The output of the mixer is filtered by a low pass filter to get the message signal.

AM Generation

Figure 1. AM Generation



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m(t) is message signal,

$$m(t) = A_m \cos(2\Pi f_m t) \qquad \text{Equation 1}$$

c(t) is a carrier signal,

$$c(t) = \cos(2\Pi f_c t) \qquad \text{Equation 2}$$

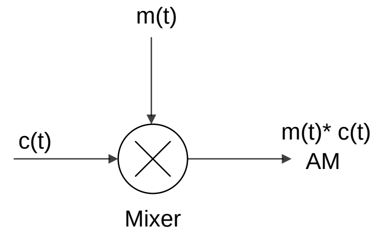
Offset of ‘K’ is added to the message signal:

$$AM = (K + m(t)) \times c(t) = K\cos(2\Pi f_c t) + A_m \cos(2\Pi f_m t) \times \cos(2\Pi f_c t) \qquad \text{Equation 3}$$

If the message signal is given with zero offset, you get a suppressed carrier AM,

$$AM = m(t) \times c(t) = A_m \cos(2\Pi f_m t) \times \cos(2\Pi f_c t) \qquad \text{Equation 4}$$

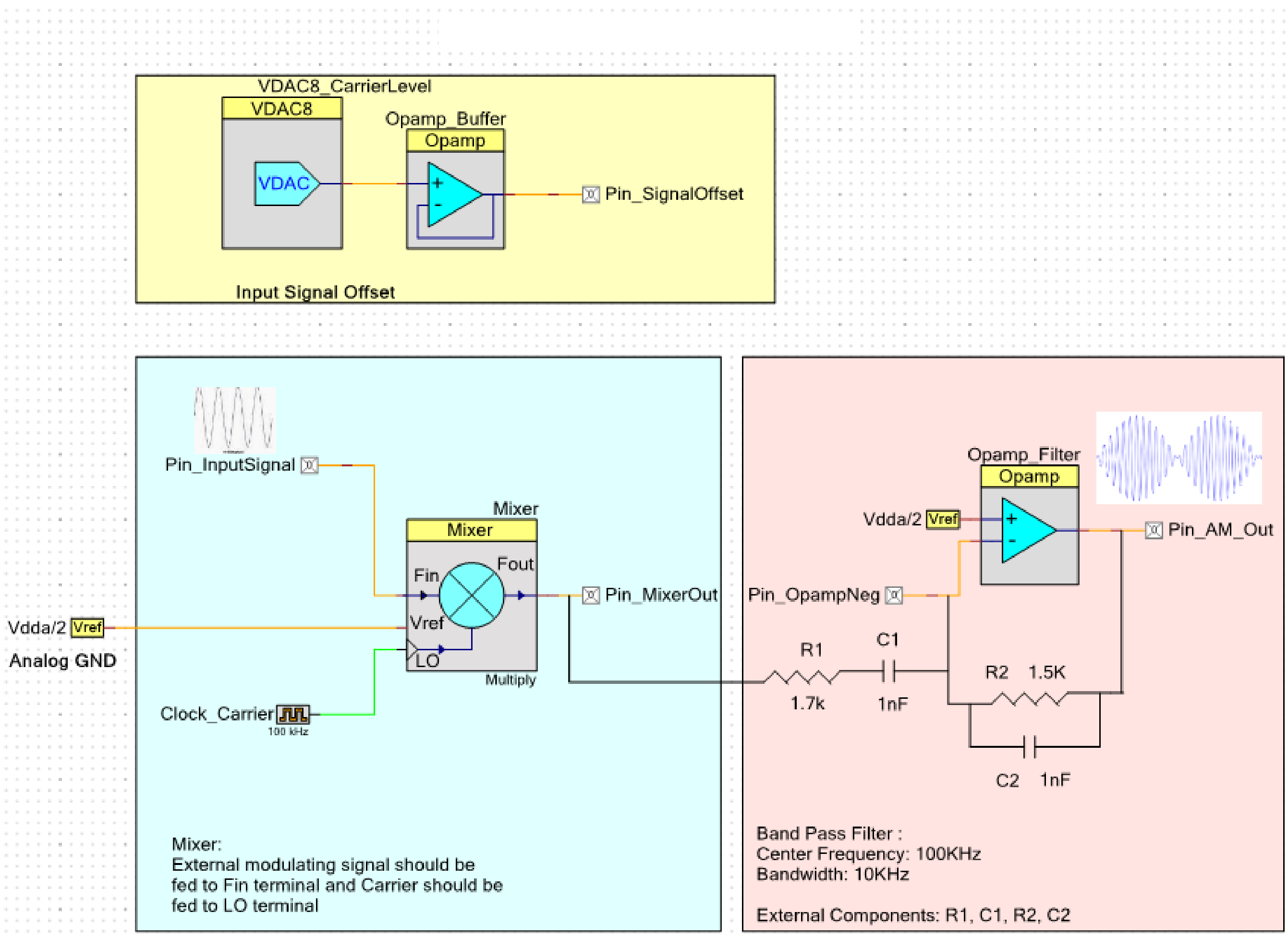
Figure 2. Suppressed Carrier AM Generation



c(t)= Carrier Signal
m(t)= Message Signal

PSoC 3 / PSoC 5 Implementation

Figure 3. Amplitude Modulation



The VDAC provides offset to the message signal m(t). The message signal and carrier signal are multiplied by mixer; therefore, the carrier component strength in the resulting AM wave is determined by this offset voltage (see Figure 1 on page 1). By varying this offset voltage, the carrier level in AM can be controlled. The message signal should be biased on top of this DC offset voltage and fed to mixer.

The reference Vdda/2 with buffer provides the AGND for all signals and to the mixer. The offset of the message signal should be above AGND. Thus, VDAC voltage value should be VDAC = AGND + offset (K).

The square wave of 100 kHz is used as a carrier signal. The square wave has odd harmonics such as 300 kHz and 500 kHz in it. When it is multiplied with the message signal with frequency, $f_{M,}$ it produces double sided AM with components '$f_C + f_M$' and '$f_C – f_M$'. However, there are also harmonics '$3f_C + f_M$', '$3f_C – f_M$', and so on. To remove these higher harmonics the band pass filter with bandwidth 10 kHz, and center frequency 100 kHz is put at the mixer output.

The mixer component type is set to 'Up-Mixer' (or 'Multiply Mixer'). The up-mixer is used for modulation because it gives a gain of 1 for the up converted frequency; the down mixer gives a lesser gain.

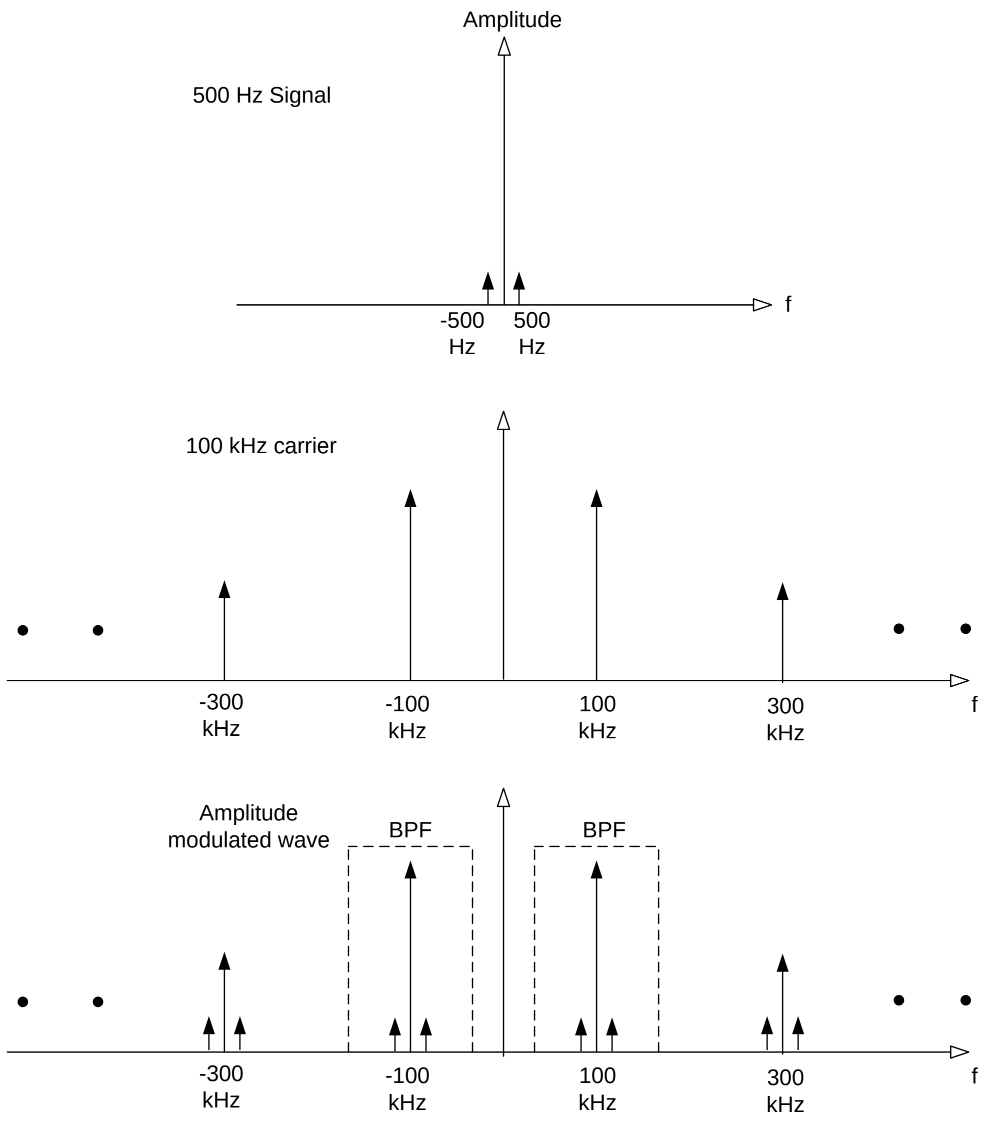
The band pass filter with cutoff frequency 100 kHz and bandwidth of 10 kHz is built as follows. This is a simple band pass filter with low Q factor.

Lowest frequency of pass band f_L= 90 kHz

Highest frequency of pass band f_H= 110 kHz

f_L= 1/2 Π R_1C_1, f_H = 1/2 Π R_2C_2.

Figure 4. Frequency Spectrum for AM



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Examples - Modulation

In the following figures, the waveform in cyan color is message signal and waveform in yellow is the AM.

Example with Modulation Index (u) = 50 %

Vdda = 5 V

AGND = Vdda/2 = 2.5 V

VDAC = AGND + 1 V (K) = 3.5 V

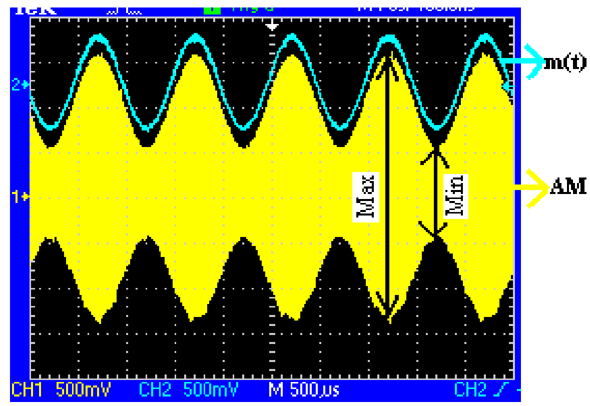
Message amplitude = A_m = 0.5 V

Carrier amplitude = K = 1 V

u = (Max – Min)/(Max + Min); Max and Min are shown in Figure 5.

u = (3 – 1) / (3 + 1) = 0.5

Figure 5. AM with 50% Modulation



Example with Modulation Index (u) = 25 %

Message signal strength is reduced keeping the carrier strength same.

Message amplitude= A_m = 0.25 V.

Vdda = 5 V

AGND = Vdda/2 = 2.5 V

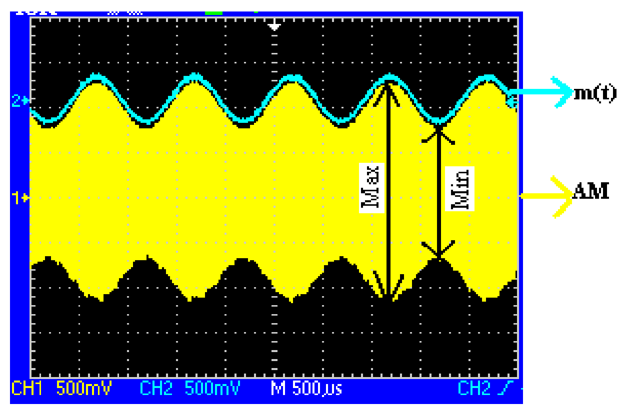
VDAC = AGND + 1 V (K) = 3.5 V

Carrier amplitude = K = 1 V

u = (Max – Min) / (Max + Min); Max and Min are shown in Figure 6.

u = (2.5 – 1.5) / (2.5 + 1.5) = 0.25

Figure 6. AM with 25% Modulation



Example with Modulation Index (u) = 100 %

Message signal strength is amplified, keeping the carrier strength same.

Message amplitude= A_m = 1 V.

Vdda = 5 V

AGND = Vdda/2 = 2.5 V

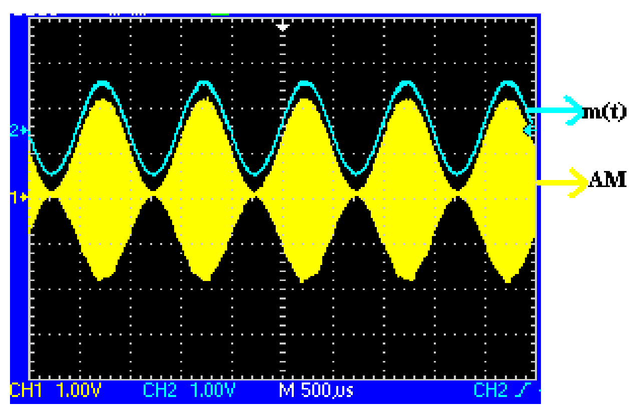
VDAC = AGND + 1 V (K) = 3.5 V

Carrier amplitude = K = 1 V

u = (Max –- Min) / (Max + Min); Max and Min are shown in Figure 7.

u = (4 - 0) / (4 + 0) = 1

Figure 7. AM with 100% Modulation



Example Showing Different Carrier Level for 50% Modulation

Carrier amplitude = K= 0.5 V

Message amplitude = A_m = 0.25 V

Vdda = 5 V

AGND = Vdda/2=2.5 V

VDAC= AGND + 0.5V (K) = 3 V

u = (Max – Min) / (Max + Min),

u = (1.5 – 0.5) / (1.5 + 0.5) = 0.5

Carrier amplitude = K = 1 V

Message amplitude= A_m = 0.5V

Vdda = 5 V

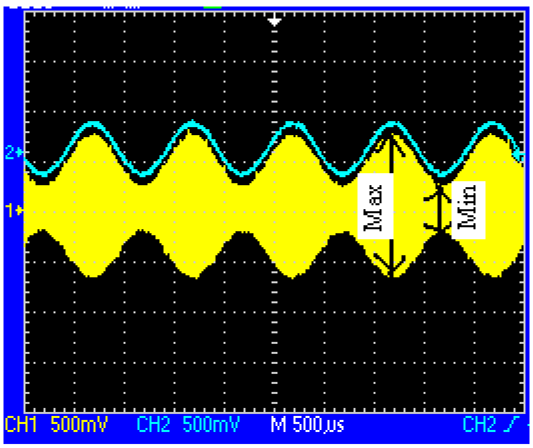
AGND = Vdda/2 = 2.5 V

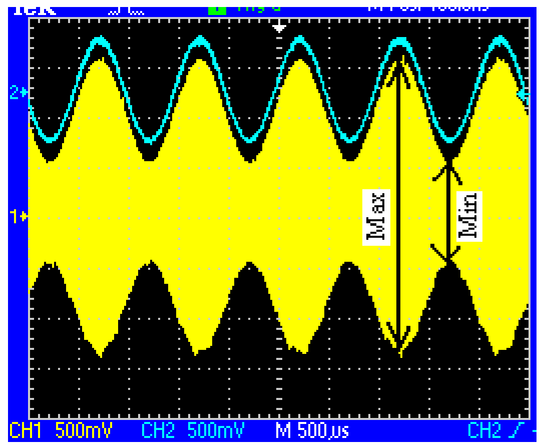
VDAC = AGND + 1 V (K) = 3.5 V

u = (Max – Min) / (Max + Min),

u = (3 – 1) / (3 + 1) = 0.5

Figure 8. AM with Different Carrier Levels





Example with Carrier Suppressed

Carrier amplitude = K = 0 V

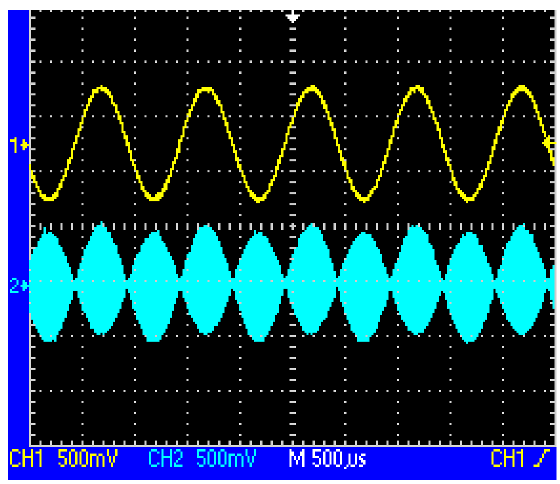
Message amplitude = A_m = 0.5 V

Vdda = 5 V

AGND = Vdda/2 = 2.5 V

VDAC = AGND + 0 (K) = AGND

Figure 9. AM with suppressed carrier



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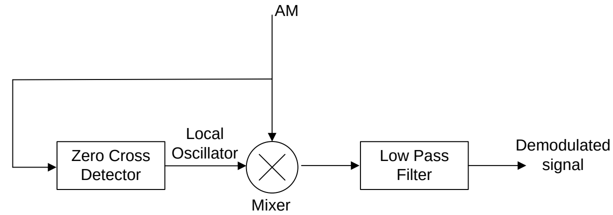
Demodulation

This section explains the coherent detection of AM signal. In this method, the incoming AM signal is multiplied with the local oscillator signal of same frequency as carrier frequency. The local oscillator signal is generated from the AM by passing the AM signal through the zero crossing detector. The envelope detector method can also be implemented for demodulation using opamp, but it requires external components.

Figure 10. AM Demodulation



PSoC 3 / PSoC 5 Implementation

Figure 11. TopDesign for AM Demodulation Page1 - AM_Demodulator

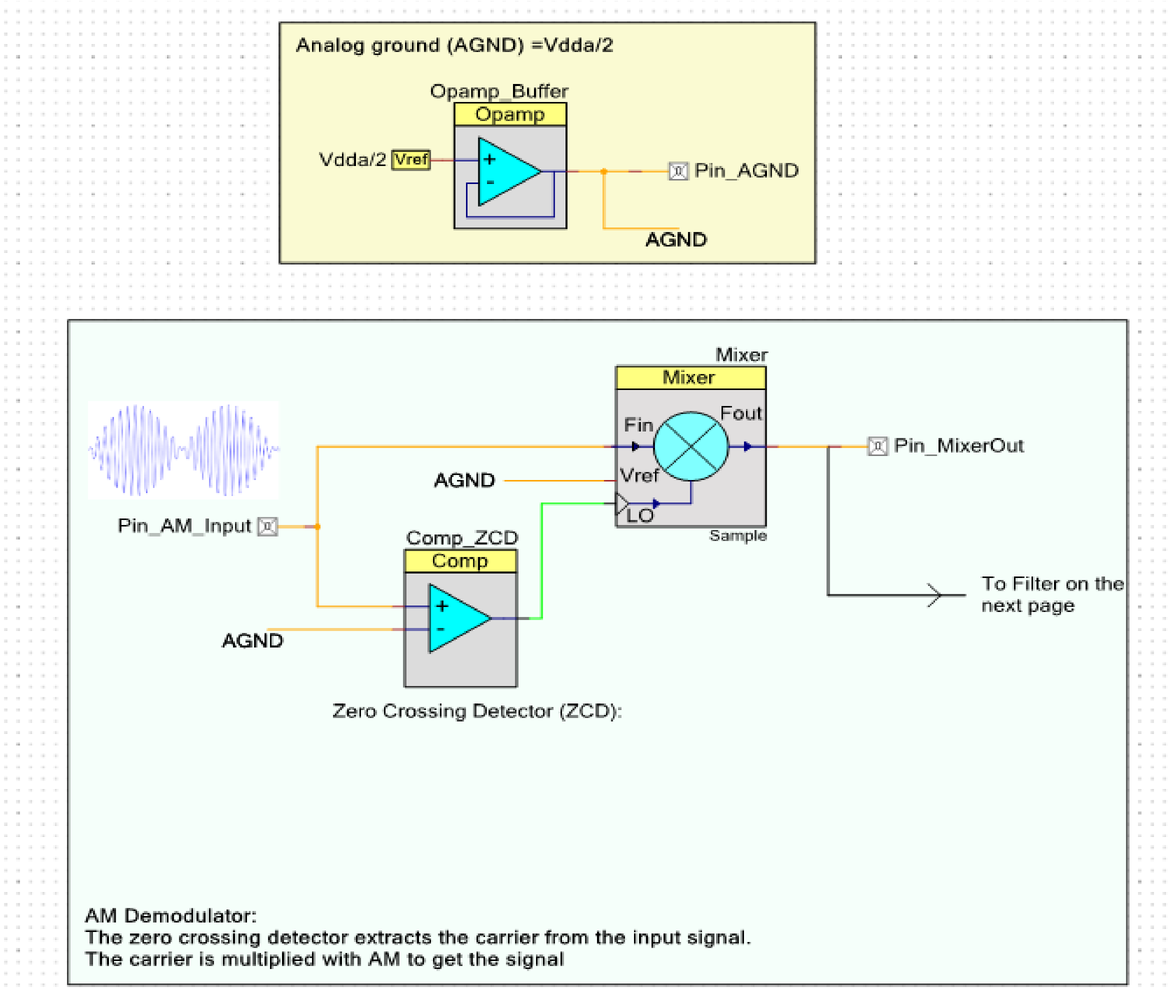
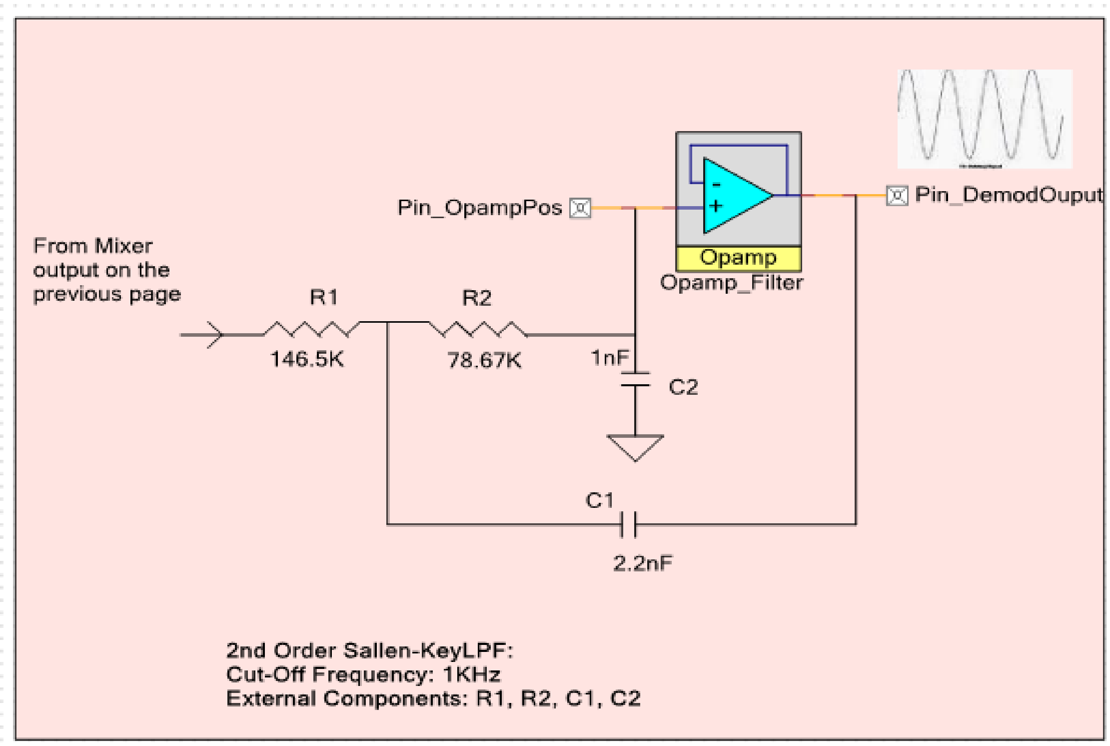


Figure 12. Top Design for AM Demodulation Page2 - Filter

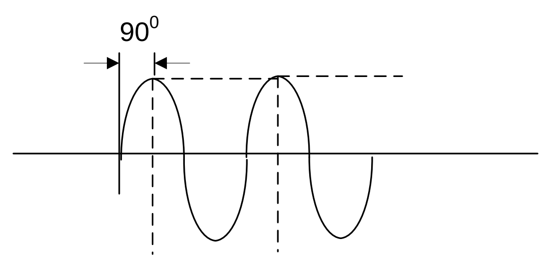


The Vdda/2 reference voltage is buffered and used as an analog ground (AGND) for the circuit. The incoming AM signal should be biased at this DC voltage.

The AM signal is given to comparator whose reference is AGND. The output of the comparator is used as a local oscillator signal for the mixer. The mixer type is set to Down Mixer (or Sample Mixer).The down mixer gives a gain close to ‘1’ (when the signal is sampled at peaks) for the down converted signal. The low pass filter is used to filter the demodulated output to remove the sample and hold effect on the output of mixer.

The sample and hold gives maximum output when the signal is sampled at peaks. The comparator output delay plays a very important role in the demodulation. The ideal delay that gives maximum output is quarter period (90°) of the carrier. See Figure 13. When the delay is 90°, the mixer samples the AM wave at the peaks. A delay lesser than 90° still gives a demodulated output; however, the amplitude level is reduced. The comparator typical delay is 90 ns. This delay makes the mixer sample the AM wave within 45° to 135° from the zero crossing for the frequency range 1.25 MHz to 4 MHz. If the signal frequency is out of this range then, either external delay circuit should be added on the signal before giving it to zero crossing detector or the signal should be brought within the range before demodulating it.

Figure 13. Comparator Delay of 90° Making Sampling at Peak



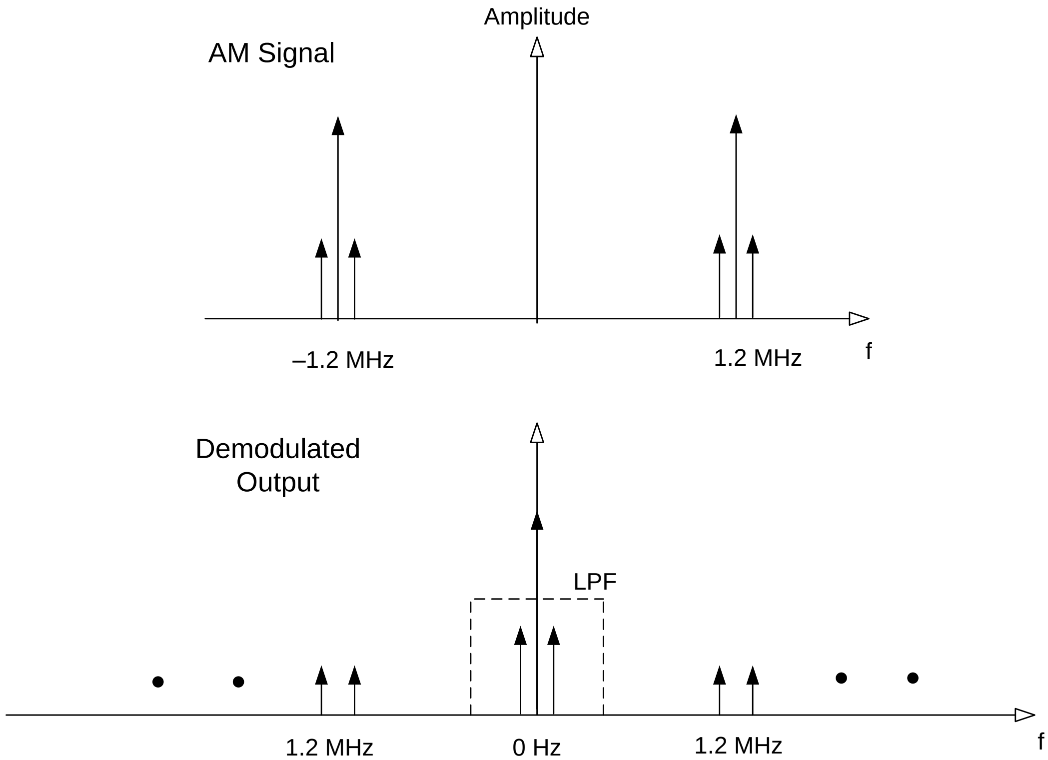
The low pass filter is needed to remove the high frequency components of the mixer output. The Sallen-Key low pass filter with 1 kHz cutoff is built using opamp as follows.

For Sallen-Key low pass filter,

Cutoff frequency, $f_C = 1/2\Pi(R_1 R_2 C_1 C_2)^{1/2}$

$f_C = 1/ 2\Pi(146.5k \times 78.67k \times 1n \times 2.2 n)^{0.5} = 1$ kHz.

Figure 14. Frequency Spectrum for AM and Demodulated Signal



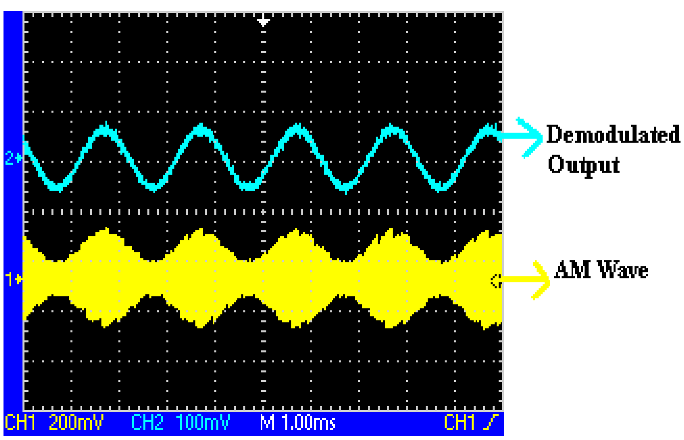
Example - Demodulation

AM wave amplitude = 1 V

Carrier frequency = 1.2 MHz

Message frequency = 500 Hz.

Figure 15. Example of AM Demodulation



Summary

Implementing the AM modulation and demodulation is straight forward using the mixer component in PSoC 3 and PSoC 5. The AM modulation with different modulation indices, carrier levels, and suppressed carrier is discussed in this application note. AM demodulation using the coherent detection method is also demonstrated.

Document History

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Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	2968090	PVKV	07/02/10	New application note

Cypress Semiconductor
198 Champion Court
San Jose, CA 95134-1709
Phone: 408-943-2600
Fax: 408-943-4730
http://www.cypress.com/