AN62582

AM Modulation and Demodulation

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Associated Project: Yes

Associated Part Family: CY8C38xx/CY8C55xx

Software Version: PSoC® Creator™ 2.0

Related Application Notes: None

AN62582 explains how to implement amplitude modulation (AM) and demodulation using PSoC® 3 and PSoC 5. AM is achieved by multiplying carrier and message signals. Demodulation is achieved by sampling the AM signal at carrier frequency.

Introduction

Amplitude modulation (AM) is defined as modifying the amplitude of the carrier wave according to the message or information signal. AM generation involves mixing of a carrier and an 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 are necessary to amplify the modulated signal to transmitter levels. 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-efficiency 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 using the mixer component in “Up Mixer” mode. A square wave 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. The higher the message signal amplitude, the larger the variation on the amplitude of the AM wave.

In the section, “Examples - Modulation” 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.

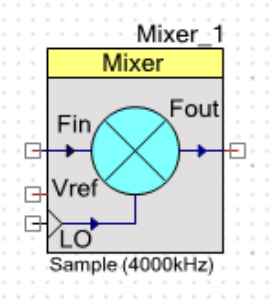
In some applications, power is saved by suppressing the carrier from the AM wave. Example 5 shows the double side band suppressed carrier (DSBSC) AM wave.

The “coherent detection” method is used for demodulation. Coherent demodulation involves multiplication of an AM wave by a carrier wave. In this implementation, a square wave with the same frequency as that of carrier wave is generated by passing the input AM wave through a zero crossing detector (ZCD). This square wave and the AM wave are given to the Mixer component in “Down Mixer” mode. The output of the mixer is filtered by a low-pass filter (LPF) to get the message signal.

Mixer Component

PSoC Creator provides a “Mixer” component. It can be used for frequency conversion of an input signal using a local oscillator (LO) signal as the sampling clock. Figure 1 shows the mixer component in PSoC Creator.

Figure 1. Mixer Component



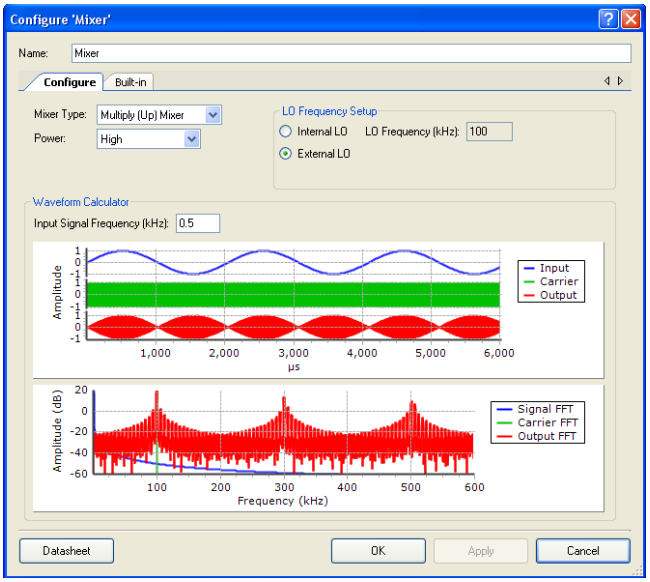
The Mixer component can be configured in two configurations:

1. Up Mixer
2. Down Mixer

Up Mixer

The Up Mixer (or Multiply Mixer) multiplies the input signal with LO. The Mixer component is configured as Up Mixer or Multiply Mixer by setting the “Mixer Type” parameter to “Multiply (Up) Mixer” as shown in the following figure.

Figure 2. Configuration of Up Mixer

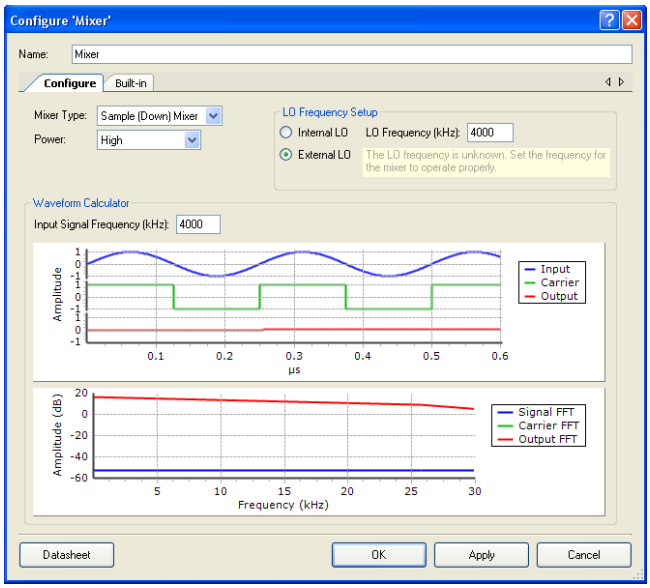


LO frequency setting: The LO source can be set to internal or external. When it is set to internal, the frequency of the LO is set in the box provided as “LO Frequency”. When the LO Source is set to external, an oscillator signal is connected externally to the LO terminal of the Mixer component.

Down Mixer

The Down Mixer (or Sample Mixer) operates as a sample and hold circuit on the input signal. The Mixer component is configured as Down Mixer by setting the “Mixer Type” parameter to “Sample (Down) Mixer” as shown in the following figure.

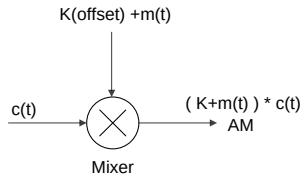
Figure 3. Configuration of Down Mixer



LO frequency setting: The LO Source can be set to internal or external. When it is set to internal, the frequency of the LO is set in the box provided as “LO Frequency”. When the LO source is set to external, an oscillator signal is connected externally to the LO terminal of the Mixer component.

AM Generation

Figure 4. AM Generation



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

m(t) is message signal,

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

where, f_m is frequency of message signal and A_m is amplitude of message signal.

c(t) is a carrier signal,

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

where, f_c is frequency of carrier signal and A_m is amplitude of carrier signal.

Offset of 'K' is added to the message signal:

$$AM = (K + m(t)) \times c(t)$$
$$= K \cos(2 \Pi f_c t) + A_m \cos(2 \Pi f_m t) \times \cos(2 \Pi f_c t)$$

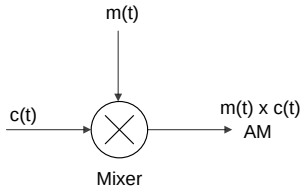
Equation 3

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

$$AM = m(t) \times c(t) = A_m \cos(2 \Pi f_m t) \times \cos(2 \Pi f_c t)$$

Equation 4

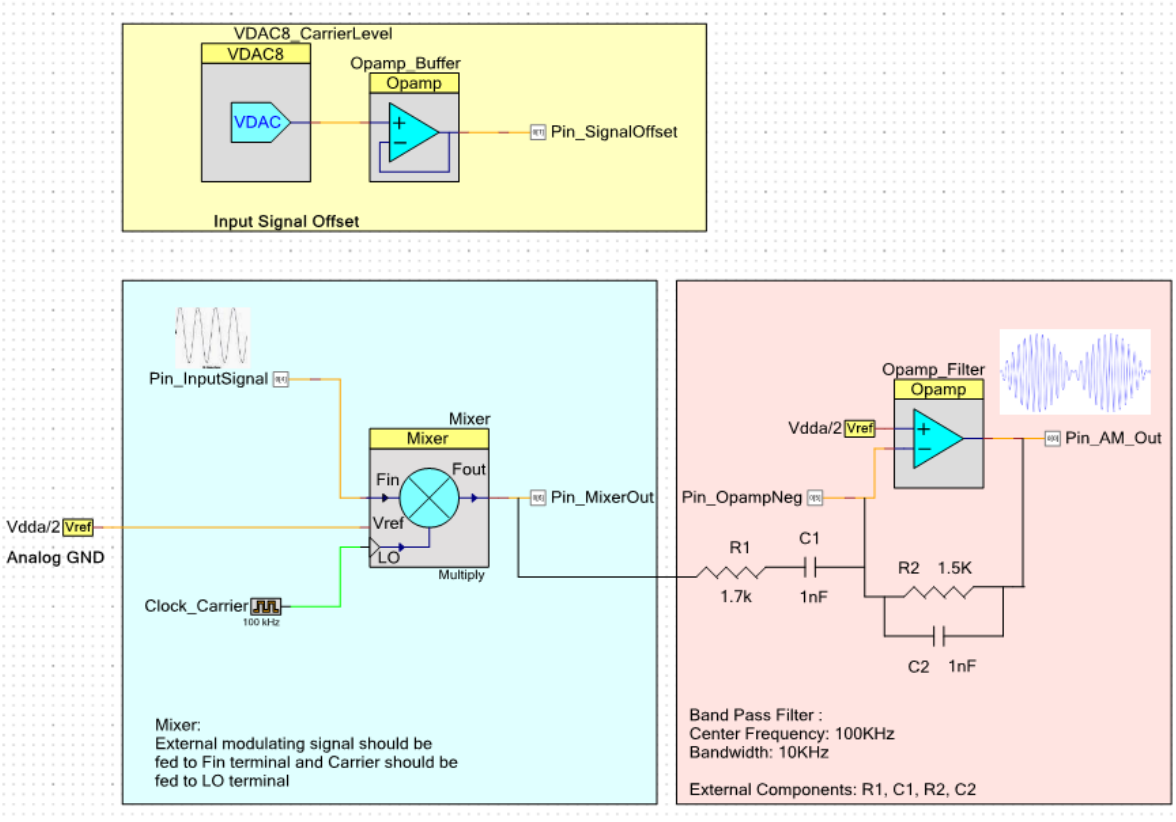
Figure 5. Suppressed Carrier AM Generation



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

PSoC 3 and PSoC 5 Implementation

Figure 6. Amplitude Modulation



The Voltage DAC (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 4).

By varying this offset voltage, the carrier level in AM is controlled. The message signal should be biased on top of this DC offset voltage and fed to mixer.

The reference Vdda/2 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).

As an example, a 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 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

$f_L = 1/2\ \Pi\ R_1C_1$, $f_H = 1/2\ \Pi\ R_2C_2$.

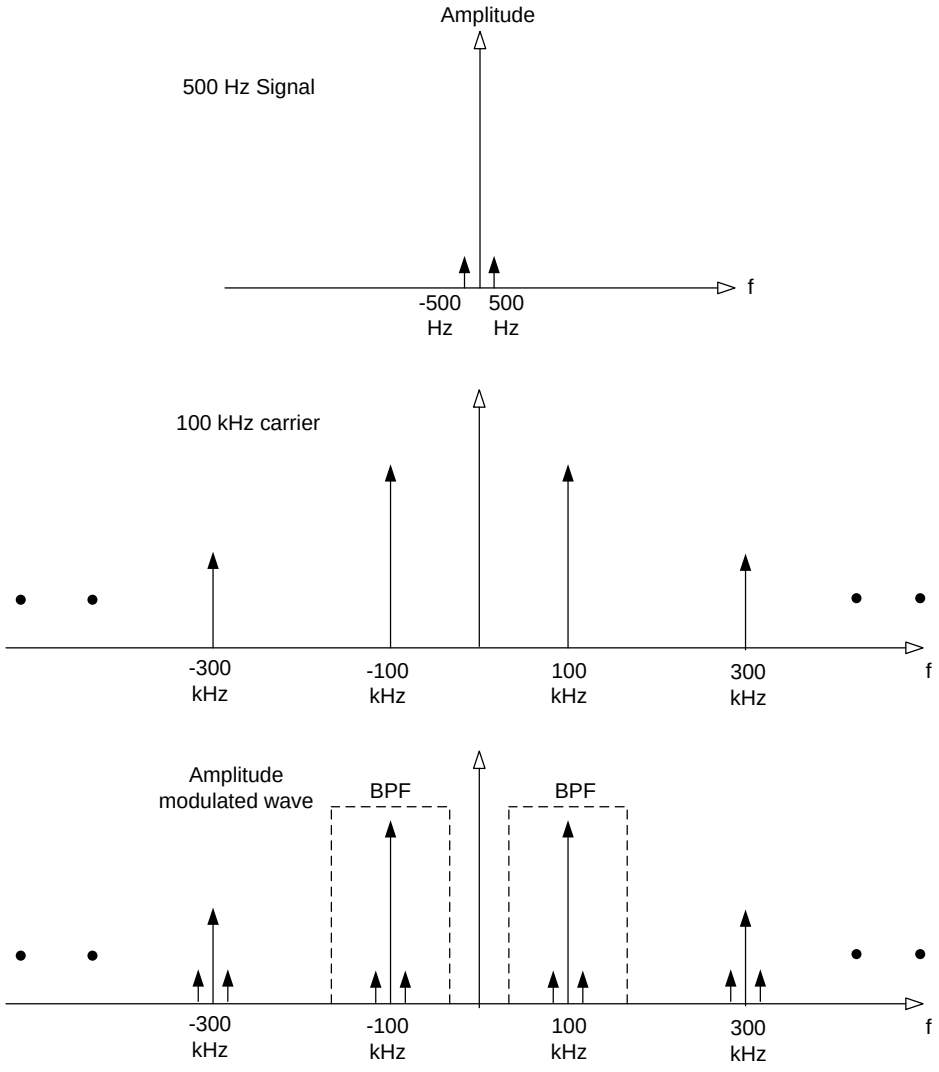
Frequency Range

The Up_Mixer maximum frequency ranges are as below:

Max message signal frequency: 500 kHz

Max carrier signal frequency: 1 MHz

Figure 7. Frequency Spectrum for AM



Examples - Modulation

The following examples show AM waveforms for different modulation indices. Modulation index can be defined as the measure of extent of amplitude variation about a unmodulated carrier. The modulation index is an important factor. When a level of modulation is too low, the modulation does not utilize the carrier efficiently and if a level of modulation is too high, the carrier can become over modulated causing sidebands to extend out beyond the allowed bandwidth causing interference to other users. In the following figures, the waveform in cyan color is message signal and waveform in yellow is the AM.

Example 1: With Modulation Index (u) = 50%

Vdda = 5 V

AGND = Vdda/2 = 2.5 V

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

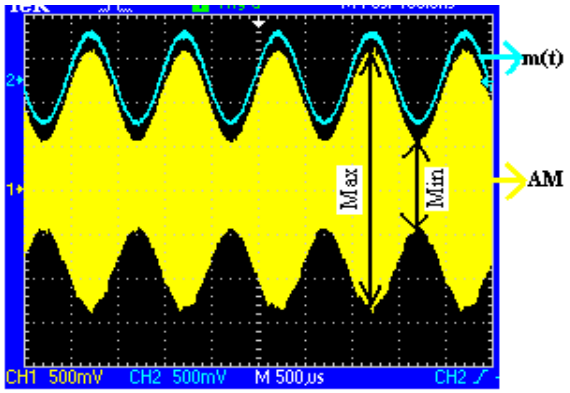
Message amplitude = A_m = 0.5 V

Carrier amplitude = K = 1 V

u = (Max – Min) / (Max + Min); Max and Min are shown in Figure 8.

u = (3 – 1) / (3 + 1) = 0.5

Figure 8. AM with 50% Modulation



Example 2: 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

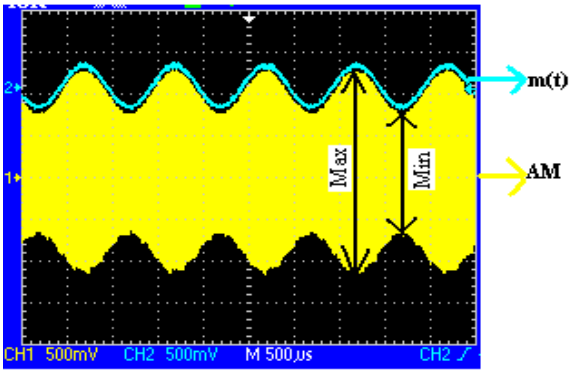
VDAC = AGND + 1 V (K) = 3.5 V

Carrier amplitude = K = 1 V

u = (Max – Min) / (Max + Min); Max and Min are shown in Figure 9.

u = (2.5 – 1.5) / (2.5 + 1.5) = 0.25

Figure 9. AM with 25% Modulation



Example 3: 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

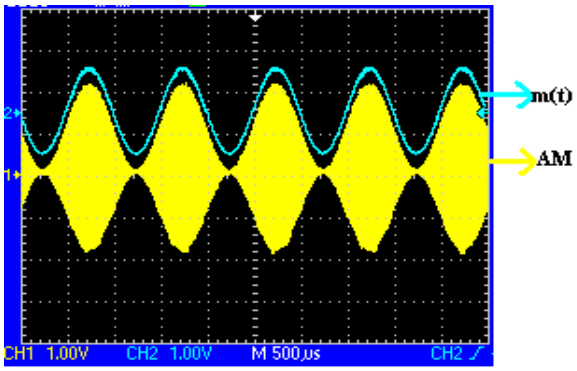
VDAC = AGND + 1 V (K) = 3.5 V

Carrier amplitude = K = 1 V

u = (Max –- Min) / (Max + Min); Max and Min are shown in Figure 10.

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

Figure 10. AM with 100% Modulation



Example 4: Showing Different Carrier Level for 50% Modulation

Carrier amplitude = K= 0.5 V

Message amplitude = Am = 0.25 V

Vdda = 5 V

AGND = Vdda/2=2.5 V

VDAC= AGND + 0.5 V (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= Am = 0.5 V

Vdda = 5 V

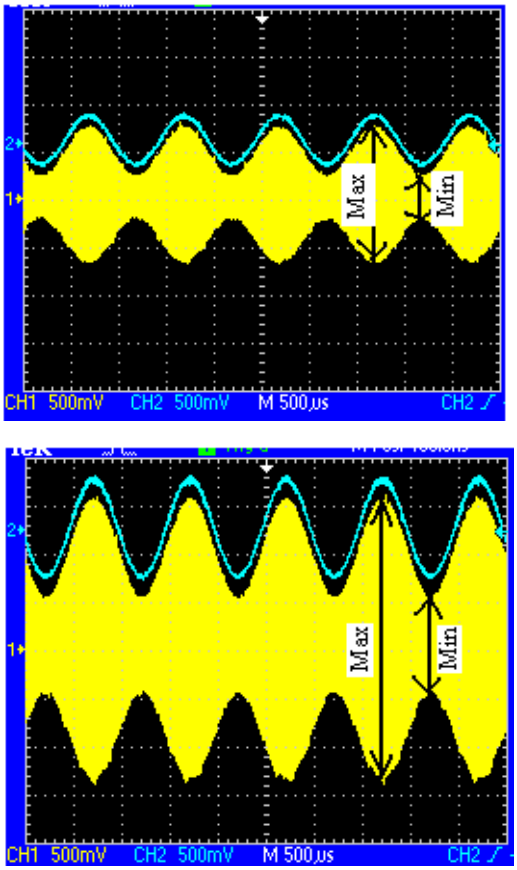
AGND = Vdda/2 = 2.5 V

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

u = (Max – Min) / (Max + Min)

u = (3 – 1) / (3 + 1) = 0.5

Figure 11. AM with Different Carrier Levels



Example 5: With Carrier Suppressed

Carrier amplitude = K = 0 V

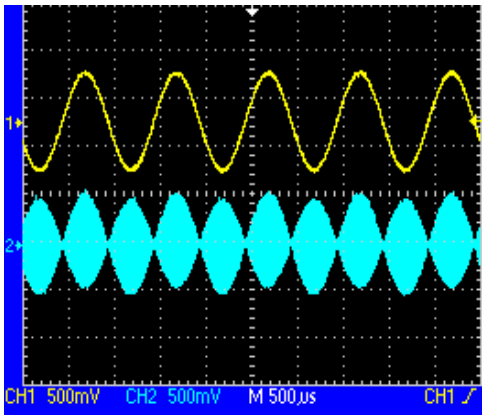
Message amplitude = A_m = 0.5 V

Vdda = 5 V

AGND = Vdda/2 = 2.5 V

VDAC = AGND + 0 (K) = AGND

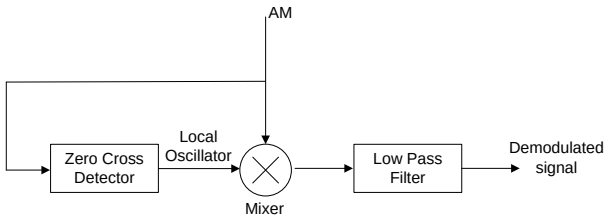
Figure 12. AM with suppressed carrier



Demodulation

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

Figure 13. AM Demodulation



PSoC 3 and PSoC 5 Implementation

Figure 14. Top Design for AM Demodulation Page1 - AM_Demodulator

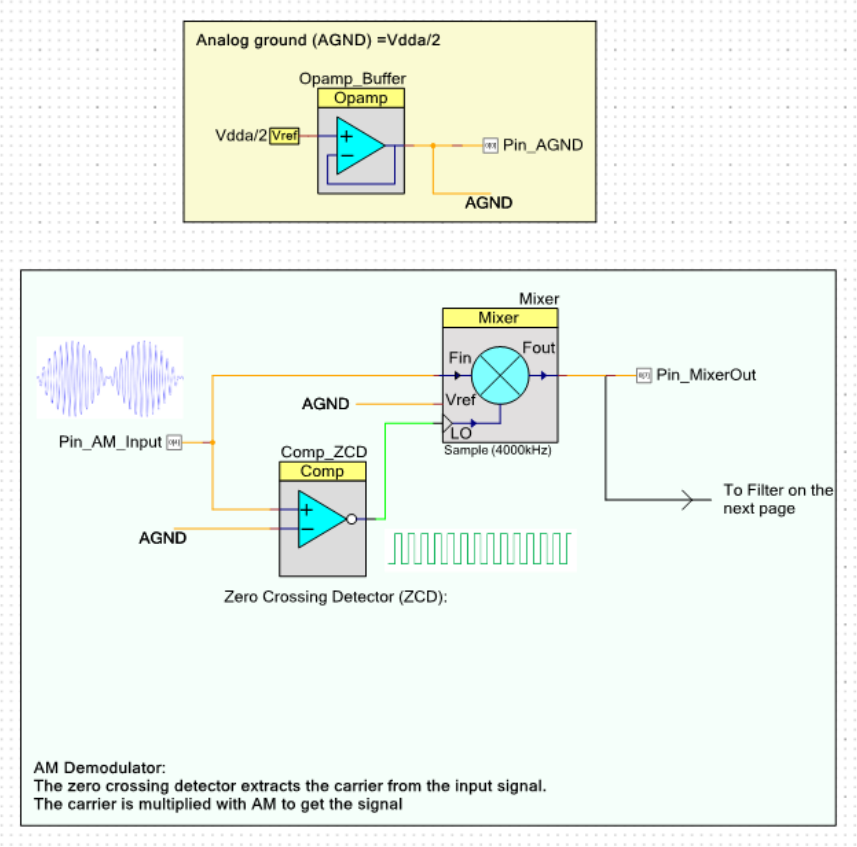
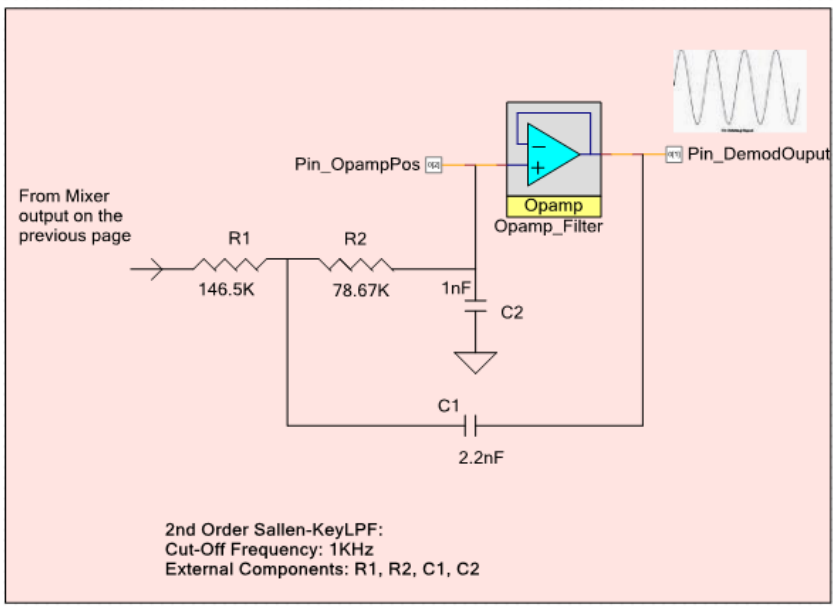


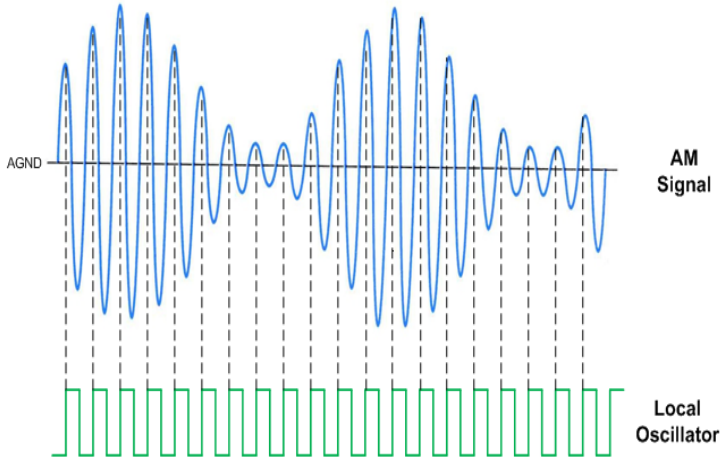
Figure 15. Top Design for AM Demodulation Page2 - Filter



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.

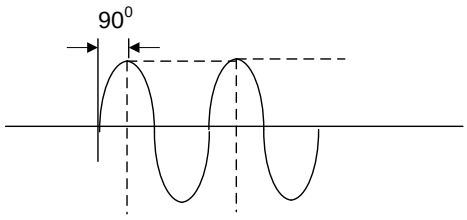
The AM signal is given to comparator whose reference is AGND. The output of the comparator is square wave with frequency same as the carrier frequency of AM signal. The output of the comparator is used as a LO signal for the mixer. The mixer type is set to Down Mixer (or Sample Mixer).The Down Mixer gives a gain close to '1' (when the signal is sampled at peaks) for the down converted signal. The Down Mixer output has lower harmonic content than up mixer when the input signal and LO signal have near same frequencies. The Mixer samples the input AM signal at the rising edges of the LO as shown in following figure. The LPF is used to filter the demodulated output to remove the sample and hold effect on the output of mixer.

Figure 16. AM Wave Sampled by Mixer Component



The sample and hold gives maximum output when the signal is sampled at peaks. The comparator output delay plays an important role in the demodulation. The ideal delay that gives maximum output is quarter period (90°) of the carrier. See Figure 17. 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 ZCD or the signal should be brought within the range before demodulating it.

Figure 17. Comparator Delay of 90° Making Sampling at Peak



You need a LPF to remove the high frequency components of the mixer output. The Sallen-Key LPF with 1 kHz cutoff is built using opamp as follows.

For Sallen-Key low-pass filter,

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

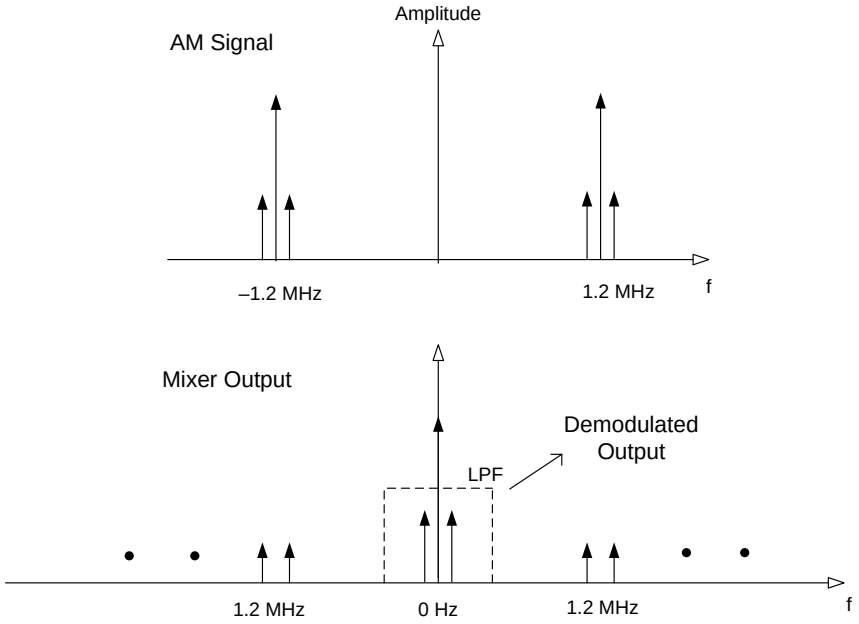
$f_C = 1/ 2\Pi(146.5k\Omega \times 78.67k\Omega \times 1nF \times 2.2\ nF)^{0.5} = 1$ kHz.

Frequency Range

The Down Mixer maximum frequency ranges are as below:

Max AM Carrier Signal Frequency: 4 MHz

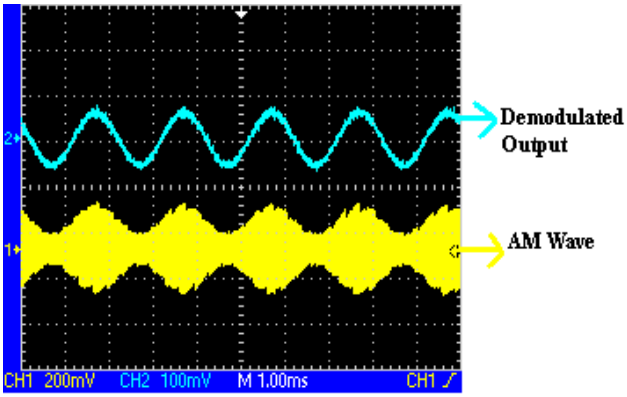
Figure 18. Frequency Spectrum for AM and Demodulated Signal



Example - Demodulation

AM wave amplitude = 1 V
Carrier frequency = 1.2 MHz
Message frequency = 500 Hz
Modulation index (u) = 50%

Figure 19. Example of AM Demodulation



Summary

Implementing the AM modulation and demodulation using the mixer component in PSoC 3 and PSoC 5 is discussed in the application note. Also, the AM modulation with different modulation indices, carrier levels, and suppressed carrier is discussed. 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
*A	3302878	PVKV	07/05/11	Minor text edits. Addition of section "Mixer Component" Addition of figure "AM Wave sampled by Mixer component"
*B	3444026	PVKV	11/30/11	Template Update Updated Software Version to PSoC Creator 2.0 Updated the figures for Creator 2.0 Modified Abstract
*C	3670276	PVKV	07/09/2012	Minor text edits to remove grammatical errors and improve readability. Updated template.

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