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

Contents

1 Introduction ................................................................. 1
2 Mixer Component ......................................................... 2
  2.1 Up Mixer .............................................................. 3
  2.2 Down Mixer .......................................................... 4
3 AM Generation .............................................................. 5
  3.1 PSoC 3 and PSoC 5LP Implementation ................. 6
  3.2 Examples - Modulation ........................................... 8
4 Demodulation .............................................................. 10
  4.1 PSoC 3 and PSoC 5LP Implementation ......... 11
4.2 Example - Demodulation ........................................... 14
5 Summary ................................................................. 15

1 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 5LP 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 5LP 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 8, 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.

2 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.

The Mixer component can be configured in two configurations:
1. Up Mixer
2. Down Mixer

Figure 1. Mixer Component
2.1 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 Figure 2.

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.
2.2 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 Figure 3.

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.
3 AM Generation

Figure 4. AM Generation

\[ K(\text{offset}) + m(t) \]

\[ (K + m(t)) \times c(t) \]

Mixer

\[ c(t) = \text{Carrier Signal} \]
\[ m(t) = \text{Message Signal} \]

\( m(t) \) is message signal,
\[ m(t) = A_m \cos (2 \pi f_m t) \]  \hspace{1cm} \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,
\[ c(t) = \cos (2 \pi f_c t) \] \hspace{1cm} \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:
\[ AM = (K + m(t)) \times c(t) = K \cos (2 \pi f_c t) + A_m \cos (2 \pi f_m t) \times \cos (2 \pi f_c t) \] \hspace{1cm} \text{Equation 3} \]
If the message signal is given with zero offset, you get a suppressed carrier AM,
\[ AM = m(t) \times c(t) = A_m \cos (2 \pi f_m t) \times \cos (2 \pi f_c t) \] \hspace{1cm} \text{Equation 4} \]

Figure 5. Suppressed Carrier AM Generation

\[ m(t) \]

\[ c(t) \]

\[ m(t) \times c(t) \]

Mixer

\[ c(t) = \text{Carrier Signal} \]
\[ m(t) = \text{Message Signal} \]
3.1 PSOC 3 and PSOC 5LP Implementation

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 π R1C1, f_H = 1/2 π R2C2.
3.1.1 Frequency Range
The Up_Mixer maximum frequency ranges are as below:
Max message signal frequency: 500 kHz
Max carrier signal frequency: 1 MHz
3.2 **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 overmodulated 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.

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

\[
\begin{align*}
V_{d\text{d}a} &= 5 \text{ V} \\
AGND &= V_{d\text{d}a}/2 = 2.5 \text{ V} \\
V_{D\text{DAC}} &= AGND + 1 \text{ V} (K) = 3.5 \text{ V} \\
\text{Message amplitude} &= A_m = 0.5 \text{ V} \\
\text{Carrier amplitude} &= K = 1 \text{ V} \\
u &= (\text{Max} – \text{Min}) / (\text{Max} + \text{Min}); \text{ Max and Min are shown in Figure 8.} \\
u &= (3 – 1) / (3 + 1) = 0.5
\end{align*}
\]

![Figure 8. AM with 50% Modulation](image)

### 3.2.2 Example 2: With Modulation Index \((u) = 25\%\)

Message signal strength is reduced keeping the carrier strength same.

\[
\begin{align*}
V_{d\text{d}a} &= 5 \text{ V} \\
AGND &= V_{d\text{d}a}/2 = 2.5 \text{ V} \\
V_{D\text{DAC}} &= AGND + 1 \text{ V} (K) = 3.5 \text{ V} \\
\text{Carrier amplitude} &= K = 1 \text{ V} \\
u &= (\text{Max} – \text{Min}) / (\text{Max} + \text{Min}); \text{ Max and Min are shown in Figure 9.} \\
u &= (2.5 – 1.5) / (2.5 + 1.5) = 0.25
\end{align*}
\]

![Figure 9. AM with 25% Modulation](image)
3.2.3 **Example 3: With Modulation Index (u) = 100%**

Message signal strength is amplified, keeping the carrier strength same.
Message amplitude = \(A_m = 1\) V
\(Vdd = 5\) V
\(AGND = Vdd/2 = 2.5\) V
\(VDAC = AGND + 1\) V (K) = 3.5 V
Carrier amplitude = \(K = 1\) V
\(u = (\text{Max} - \text{Min}) / (\text{Max} + \text{Min})\); Max and Min are shown in Figure 10.
\(u = (4 - 0) / (4 + 0) = 1\)

![Figure 10. AM with 100% Modulation](image)

3.2.4 **Example 4: Showing Different Carrier Level for 50% Modulation**

Carrier amplitude = \(K = 0.5\) V
Message amplitude = \(A_m = 0.25\) V
\(Vdd = 5\) V
\(AGND = Vdd/2 = 2.5\) V
\(VDAC = AGND + 0.5\) V (K) = 3 V
\(u = (\text{Max} - \text{Min}) / (\text{Max} + \text{Min})\)
\(u = (1.5 - 0.5) / (1.5 + 0.5) = 0.5\)

![Figure 11. AM with 0.5 V Carrier Amplitude](image)

Carrier amplitude = \(K = 1\) V
Message amplitude = \(A_m = 0.5\) V
\(Vdd = 5\) V
\(AGND = Vdd/2 = 2.5\) V
\(VDAC = AGND + 1\) V (K) = 3.5 V
\(u = (\text{Max} - \text{Min}) / (\text{Max} + \text{Min})\)
\(u = (3 - 1) / (3 + 1) = 0.5\)

![Figure 12: AM with 1 V Carrier Amplitude](image)
3.2.5 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 13. AM with suppressed carrier

4 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 14. AM Demodulation
4.1 PSoC 3 and PSoC 5LP Implementation

Figure 15. Top Design for AM Demodulation Page 1 - AM_Demodulator

AM Demodulator:
The zero crossing detector extracts the carrier from the input signal.
The carrier is multiplied with AM to get the signal.
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 17. AM Wave Sampled by Mixer Component

![AM Wave Sampled by Mixer Component](image)

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 18. 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 18. Comparator Delay of 90° Making Sampling at Peak

![Comparator Delay of 90° Making Sampling at Peak](image)

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, \( f_C = \frac{1}{2\pi R_1 R_2 C_1 C_2^{1/2}} \)

\[
f_C = \frac{1}{2\pi(146.5k\Omega \times 78.67k\Omega \times 1nF \times 2.2nF)^{0.5}} = 1 \text{ kHz.}
\]
4.1.1 Frequency Range
The Down Mixer maximum frequency ranges are as below:
Max AM Carrier Signal Frequency: 4 MHz

![Frequency Spectrum for AM and Demodulated Signal](image)

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

![Example of AM Demodulation](image)
5 Summary

Implementing the AM modulation and demodulation using the mixer component in PSoC 3 and PSoC 5LP 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.

About the Author

Name: Pavankumar Vibhute.
Title: Applications Engineer Sr.
### Document History

**Document Title:** AN62582 - AM Modulation and Demodulation  
**Document Number:** 001-62582

<table>
<thead>
<tr>
<th>Revision</th>
<th>ECN</th>
<th>Orig. of Change</th>
<th>Submission Date</th>
<th>Description of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>**</td>
<td>2968090</td>
<td>PVKV</td>
<td>07/02/10</td>
<td>New application note.</td>
</tr>
<tr>
<td>*A</td>
<td>3302878</td>
<td>PVKV</td>
<td>07/05/11</td>
<td>Minor text edits.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Added Mixer Component.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated Demodulation:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated PSoC 3 and PSoC 5LP Implementation:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Added Figure 17.</td>
</tr>
<tr>
<td>*B</td>
<td>3444026</td>
<td>PVKV</td>
<td>11/30/11</td>
<td>Updated Software Version as “PSoC® Creator™ 2.0” in page 1.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated Abstract.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated the figures for PSoC Creator 2.0.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated to new template.</td>
</tr>
<tr>
<td>*C</td>
<td>3670276</td>
<td>PVKV</td>
<td>07/09/2012</td>
<td>Minor text edits to remove grammatical errors and improve readability.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated to new template.</td>
</tr>
<tr>
<td>*D</td>
<td>3809511</td>
<td>PVKV</td>
<td>11/09/2012</td>
<td>Updated Associated Part Family as “All PSoC 3 and PSoC 5LP parts” in page 1.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated Software Version as “PSoC® Creator™ 2.1 SP1” in page 1.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated attached associated project.</td>
</tr>
<tr>
<td>*E</td>
<td>4853876</td>
<td>PVKV</td>
<td>07/27/2015</td>
<td>Updated Software Version as “PSoC® Creator™ 3.2” in page 1.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated AM Generation:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated PSoC 3 and PSoC 5LP Implementation:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated Figure 6.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated Examples - Modulation:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated Example 4: Showing Different Carrier Level for 50% Modulation:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated Figure 11 (Updated figure caption only).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated Figure 12 (Added figure caption only).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated Demodulation:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated PSoC 3 and PSoC 5LP Implementation:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated Figure 15.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated Figure 16.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated to new template.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated attached associated project.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Completing Sunset Review.</td>
</tr>
<tr>
<td>*F</td>
<td>5713104</td>
<td>AESATMP9</td>
<td>04/26/2017</td>
<td>Updated logo and copyright.</td>
</tr>
</tbody>
</table>
Worldwide Sales and Design Support

Cypress maintains a worldwide network of offices, solution centers, manufacturer's representatives, and distributors. To find the office closest to you, visit us at Cypress Locations.

Products

ARM® Cortex® Microcontrollers  cypress.com/arm
Automotive  cypress.com/automotive
Clocks & Buffers  cypress.com/clocks
Interface  cypress.com/interface
Internet of Things  cypress.com/iot
Memory  cypress.com/memory
Microcontrollers  cypress.com/mcu
PSoc  cypress.com/psoc
Power Management ICs  cypress.com/pmic
Touch Sensing  cypress.com/touch
USB Controllers  cypress.com/usb
Wireless Connectivity  cypress.com/wireless

PSoc® Solutions

PSoc 1 | PSoc 3 | PSoc 4 | PSoc 5LP | PSoc 6

Cypress Developer Community

Forums | WICED IOT Forums | Projects | Videos | Blogs | Training | Components

Technical Support

cypress.com/support

All other trademarks or registered trademarks referenced herein are the property of their respective owners.

©Cypress Semiconductor Corporation, 2010-2017. This document is the property of Cypress Semiconductor Corporation and its subsidiaries, including Spansion LLC (“Cypress”). This document, including any software or firmware included or referenced in this document ("Software"), is owned by Cypress under the intellectual property laws and treaties of the United States and other countries worldwide. Cypress reserves all rights under such laws and treaties and does not, except as specifically stated in this paragraph, grant any license under its patents, copyrights, trademarks, or other intellectual property rights. If the Software is not accompanied by a license agreement and you do not otherwise have a written agreement with Cypress governing the use of the Software, then Cypress hereby grants you a personal, non-exclusive, non-transferable license (without the right to sublicense) (1) under its copyright rights in the Software (a) for Software provided in source code form, to modify and reproduce the Software solely for use with Cypress hardware products, only internally within your organization, and (b) to distribute the Software in binary code form externally to end users (either directly or indirectly through resellers and distributors), solely for use on Cypress hardware product units, and (2) under those claims of Cypress’s patents that are infringed by the Software (as provided by Cypress, unmodified) to make, use, distribute, and import the Software solely for use with Cypress hardware products. Any other use, reproduction, modification, translation, or compilation of the Software is prohibited.

TO THE EXTENT PERMITTED BY APPLICABLE LAW, CYSPRESS MAKES NO WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, WITH REGARD TO THIS DOCUMENT OR ANY SOFTWARE OR ACCOMPANYING HARDWARE, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. To the extent permitted by applicable law, Cypress reserves the right to make changes to this document without further notice. Cypress does not assume any liability arising out of the application or use of any product or circuit described in this document. Any information provided in this document, including any sample design information or programming code, is provided only for reference purposes. It is the responsibility of the user of this document to properly design, program, and test the functionality and safety of any application made of this information and any resulting product. Cypress products are not designed, intended, or authorized for use as critical components in systems designed or intended for the operation of weapons, weapons systems, nuclear installations, life-support devices or systems, other medical devices or systems (including resuscitation equipment and surgical implants), pollution control or hazardous substances management, or other uses where the failure of the device or system could cause personal injury, death, or property damage (“Unintended Uses”). A critical component is any component of a device or system whose failure to perform can be reasonably expected to cause the failure of the device or system, or to affect its safety or effectiveness. Cypress is not liable, in whole or in part, and you shall and hereby do release Cypress from any claim, damage, or other liability arising from or related to all Unintended Uses of Cypress products. You shall indemnify and hold Cypress harmless from and against all claims, costs, damages, and other liabilities, including claims for personal injury or death, arising from or related to any Unintended Uses of Cypress products.

Cypress, the Cypress logo, Spansion, the Spansion logo, and combinations thereof, WICED, PSoc, CapSense, EZ-USB, F-RAM, and Traveo are trademarks or registered trademarks of Cypress in the United States and other countries. For a more complete list of Cypress trademarks, visit cypress.com. Other names and brands may be claimed as property of their respective owners.