

1 Preliminaries

In this week, we mainly discuss the **Phase Modulation (PM)** and review the **Frequency Modulation (FM)** that you implemented in the last week's experiment. As you already know, angle modulation is a way of modulating a sinusoidal carrier wave just like the amplitude modulation. In this method of modulation, the phase angle of the carrier wave is varied according to a baseband signal which is called as *message signal*. The two forms of the angle modulation which are the phase modulation and the frequency modulation are closely related in that the properties of the one can be derived from those of the other. Therefore, you will demonstrate both the FM and PM signals in the first part. Then, you will show the PM signals for different phase sensitivity values to visualize the effect of this parameter.

The second part of the experiment deals with the demodulation of the phase modulated signal. Demodulation of the PM signal can be done by extracting instantaneous phase using Hilbert transform. Hilbert transform is a linear operation which has a number of area of utilization. One of them is the generation of **analytic signal or pre-envelope**. Using the Hilbert transform, a complex-valued analytic signal $x(t)$ can be obtained from a real-valued signal $s(t)$. The analytic signal $x(t)$ is directly related to the Hilbert transform of $s(t)$ as well as $s(t)$ signal itself. For the demodulation, phase modulated signal is transformed into the analytic signal. Then, the instantaneous phase is extracted from that signal to recover the message.

Please learn about the MATLAB functions `sawtooth(.)`, `cumsum(.)`, `hilbert(.)`, `abs(.)`, `angle(.)`, `unwrap(.)` and `phase(.)` before doing the labwork given below.

2 Labwork

2.1 Angle Modulation (FM & PM)

- Consider the triangular message signal, $m(t)$ which is shown in Figure 1. Construct $m(t)$ by using the built-in function `sawtooth(.)` where the sampling frequency is $F_s = 2$ kHz.
Hint: Determine the signal parameters from the figure and pay attention that $m(t) = 0$ for $t = 0$.

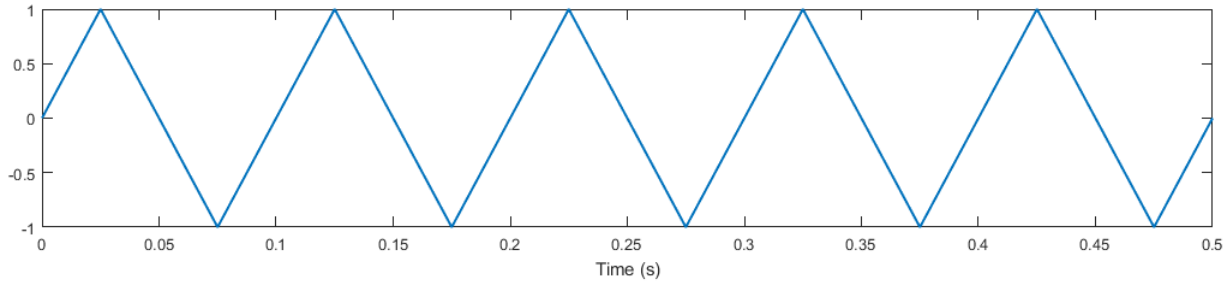


Figure 1: Triangular message signal, $m(t)$

- The **frequency modulated (FM)** signal is defined in (1) where the carrier signal is $c(t) = \cos(2\pi f_c t)$. Construct $s_{FM}(t)$ by using the built-in function `cumsum(.)` for the carrier frequency $f_c = 100$ Hz and the frequency sensitivity $k_f = 80$ Hz/V.

$$s_{FM}(t) = \cos \left(2\pi f_c t + 2\pi k_f \int_0^t m(\lambda) d\lambda \right) \quad (1)$$

- c. The **phase modulated (PM)** signal is defined in (2) where the carrier signal is $c(t) = \cos(2\pi f_c t)$. Construct $s_{PM}(t)$ for the carrier frequency $f_c = 100$ Hz and the phase sensitivity $k_p = 2\pi$ rad/V.

$$s_{PM}(t) = \cos(2\pi f_c t + k_p m(t)) \quad (2)$$

- d. Plot $m(t)$, $s_{FM}(t)$ and $s_{PM}(t)$ on the same figure by using 3×1 subplot.
- e. Comment on the relationship between **FM** and **PM** signals **in your reports**.
- f. Construct $s_{PM_2}(t)$ for $k_p = 3\pi$ rad/V and $s_{PM_3}(t)$ for $k_p = 4\pi$ rad/V. Plot $s_{PM}(t)$, $s_{PM_2}(t)$ and $s_{PM_3}(t)$ on the same figure by using 3×1 subplot.
- g. Comment on the effect of different k_p values to phase modulation **in your reports**.

2.2 Demodulation of PM Signal

- a. Read the preliminaries above carefully to understand the concept of analytic signals. Then, follow the block diagram of the demodulation of PM signal shown in Figure 2.

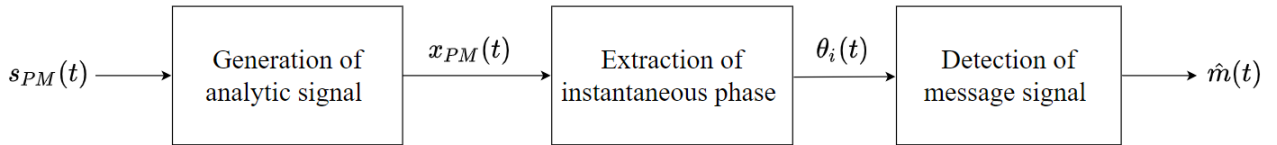


Figure 2: Demodulation of PM signal.

- b. First, obtain the analytic signal $x_{PM}(t)$ using the Hilbert Transform of $s_{PM}(t)$. Remember that $s_{PM}(t)$ was constructed for $k_p = 2\pi$ rad/V.
- c. Plot the magnitude of the frequency responses of $m(t)$, $s_{PM}(t)$ and $x_{PM}(t)$ on the same figure by using 3×1 subplot.
- d. Using $x_{PM}(t)$, extract the instantaneous phase $\theta_i(t)$ and detect the message signal as $\hat{m}(t)$.
- e. Apply the steps **2.2.b** and **2.2.d** for $s_{PM_3}(t)$ to obtain the demodulated signal $\hat{m}_3(t)$.
- f. Plot $m(t)$, $\hat{m}(t)$ and $\hat{m}_3(t)$ on the same plot by using *hold on* command. Please insert a legend.
- g. Comment on the relationship between message signal and demodulated signals and discuss the effect of different k_p values to demodulation. Put your comments to **your reports**.