ECS452 2014/1 Part A.3 Dr.Prapun

C Basic Modulation Concepts

C.1 Modulation

Definition C.1. Modulation is a process that causes a shift in the range of frequencies in a signal.

- The modulation process commonly translates an information-bearing signal to a new spectral location depending upon the intended frequency for transmission.
- More general definition: Modulation is the systematic alteration of one waveform, called the **carrier**, according to the characteristics of another waveform, the **modulating signal** or **message**.
- Fundamental goal: Produce an information-bearing **modulated wave** whose properties are best suited to the given communication task.

Definition C.2. In **baseband communication**, baseband signals (signals delivered by the source) are transmitted without modulation, that is, without any shift in the range of frequencies of the signal.

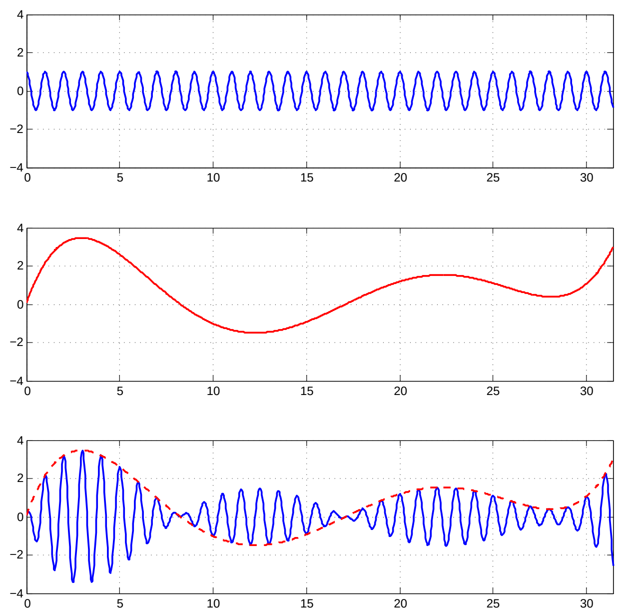
C.3. Recall the frequency-shift property:

$$e^{j2\pi f_c t} g(t) \underset{\mathcal{F}^{-1}}{\overset{\mathcal{F}}{\rightleftharpoons}} G(f - f_c).$$

This property states that multiplication of a signal by a factor $e^{j2\pi f_c t}$ shifts the spectrum of that signal by $\Delta f = f_c$.

C.4. Frequency-shifting (frequency translation) "in practice" is achieved by multiplying $g(t)$ by a sinusoid:

$$g(t)\cos(2\pi f_c t) \underset{\mathcal{F}^{-1}}{\overset{\mathcal{F}}{\rightleftharpoons}} \frac{1}{2}\left(G(f-f_c)+G(f+f_c)\right).$$



Definition C.5. $\cos(2\pi f_c t+\phi)$ is called the (sinusoidal) **carrier signal** and f_c is called the **carrier frequency**. In general, it can also has amplitude A and hence the general expression of the carrier signal is $A\cos(2\pi f_c t+\phi)$.

C.6. Examples of situations where modulation (spectrum shifting) is useful:

(a) **Channel passband matching**: Recall that, for a linear, time-invariant (LTI) system, the input-output relationship is given by

$$y(t) = h(t) * x(t)$$

where $x(t)$ is the input, $y(t)$ is the output, and $h(t)$ is the **impulse response** of the system. In which case,

$$Y(f) = H(f)X(f)$$

where $H(f)$ is called the **transfer function** or **frequency response** of the system. $|H(f)|$ and $\angle H(f)$ are called the **amplitude response** and **phase response**, respectively. Their plots as functions of f show at a glance how the system modifies the amplitudes and phases of various sinusoidal inputs.

(b) **Reasonable antenna size**: For effective radiation of power over a radio link, the antenna size must be on the order of the wavelength of the signal to be radiated.

- Audio signal frequencies are so low (wavelengths are so large) that impracticably large antennas will be required for radiation. Here, shifting the spectrum to a higher frequency (a smaller wavelength) by modulation solves the problem.

(c) **Frequency-Division Multiplexing** (FDM) and Frequency-Division Multiple Access (FDMA):

- If several signals, each occupying the same frequency band, are transmitted simultaneously over the same transmission medium, they will all interfere; it will be difficult to separate or retrieve them at a receiver.
- For example, if all radio stations decide to broadcast audio signals simultaneously, the receiver will not be able to separate them.
- One solution is to use modulation whereby each radio station is assigned a distinct carrier frequency. Each station transmits a modulated signal, thus shifting the signal spectrum to its allocated band, which is not occupied by any other station. A radio receiver can pick up any station by tuning to the band of the desired station.

Definition C.7. Communication that uses modulation to shift the frequency spectrum of a signal is known as **carrier communication**. [9, p 151]

C.8. A sinusoidal carrier signal $A\cos(2\pi f_c t+\phi)$ has three basic parameters: amplitude, frequency, and phase. Varying these parameters in proportion to the baseband signal results in amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM), respectively. Collectively, these techniques are called **continuous-wave modulation** in [17, p 111].

We will use $m(t)$ to denote the baseband signal. We will assume that $m(t)$ is band-limited to B; that is, $|M(f)| = 0$ for $|f| > B$. Note that we usually call it the **message** or the **modulating signal**.

Definition C.9. The process of recovering the signal from the modulated signal (retranslating the spectrum to its original position) is referred to as **demodulation**, or **detection**.

C.2 Amplitude modulation: DSB-SC

Definition C.10. Amplitude modulation is characterized by the fact that the amplitude A of the carrier $A\cos(2\pi f_c t + \phi)$ is varied in proportion to the baseband (message) signal $m(t)$.

- Because the amplitude is time-varying, we may write the modulated carrier as
$$A(t)\cos(2\pi f_c t + \phi)$$
- Because the amplitude is linearly related to the message signal, this technique is also called **linear modulation**.

C.3 Double-sideband suppressed carrier (DSB-SC) modulation

C.11. Basic idea:

$$\text{LPF}\left\{ \underbrace{\Big(m\left(t\right) \times \sqrt{2}\cos\left(2\pi f_c t\right)\Big)}_{x(t)} \times \Big(\sqrt{2}\cos\left(2\pi f_c t\right)\Big) \right\} = m\left(t\right). \tag{76}$$

$$
\begin{aligned}
x(t) &= m(t) \times \sqrt{2}\cos(2\pi f_c t) = \sqrt{2} m(t) \cos(2\pi f_c t) \\
X(f) &= \sqrt{2}\left(\frac{1}{2}\left(M(f - f_c) + M(f + f_c)\right)\right) \\
&= \frac{1}{\sqrt{2}}\left(M(f - f_c) + M(f + f_c)\right)
\end{aligned}
$$

Similarly,

$$
\begin{aligned}
v(t) &= y(t) \times \sqrt{2}\cos(2\pi f_c t) = \sqrt{2} x(t) \cos(2\pi f_c t) \\
V(f) &= \frac{1}{\sqrt{2}}\left(X(f - f_c) + X(f + f_c)\right)
\end{aligned}
$$

Alternatively,

$$
\begin{aligned}
v(t) &= \sqrt{2} x(t) \cos(2\pi f_c t) = \sqrt{2}\left(\sqrt{2} m(t) \cos(2\pi f_c t)\right)\cos(2\pi f_c t) \\
&= 2m(t)\cos^2(2\pi f_c t) = m(t)\left(\cos(2(2\pi f_c t)) + 1\right) \\
&= m(t) + m(t)\cos(2\pi(2f_c)t)
\end{aligned}
$$

C.12. In the process of modulation, observe that we need $f_c > B$ in order to avoid overlap of the spectra.

C.13. Observe that the modulated signal spectrum centered at f_c, is composed of two parts: a portion that lies above f_c, known as the **upper sideband** (USB), and a portion that lies below f_c, known as the **lower sideband** (LSB). Similarly, the spectrum centered at $-f_c$ has upper and lower sidebands. Hence, this is a modulation scheme with **double sidebands**.