Chapter 4. Bandpass Signaling Principles And Circuits

Chapter Objectives

- Complex envelopes and modulated signals
- Spectra of bandpass signals
- Nonlinear distortion
- Communication circuits
- Transmitters and receivers
- Software radios

4.1. Complex envelope representation of bandpass waveforms

DEFINATIONS

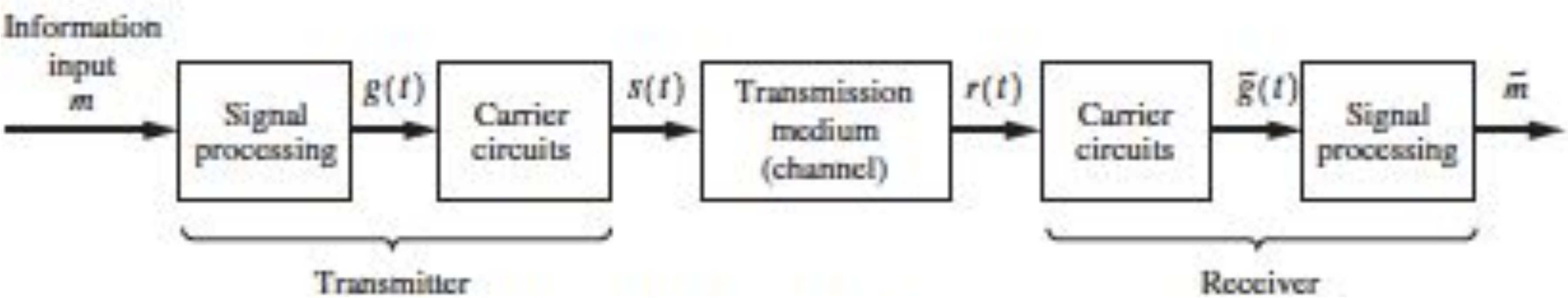
Baseband waveform: A baseband waveform has a spectral magnitude that is nonzero for frequencies in the vicinity of the origin (i.e. $f = 0$) and negligible elsewhere.

Bandpass waveform: A bandpass waveform has a spectral magnitude that is nonzero for frequencies in some band concentrated about a frequency $f = \pm f_c$, where $f_c >> 0$. The spectral magnitude negligible elsewhere. f_c is called the ***carrier frequency***.

Modulation: the process of imparting the source information onto a bandpass signal with a carrier frequency f_c by the introduction of amplitude or phase perturbation or both. This bandpass signal is called the ***modulated signal s(t)***, and the baseband source signal is called the ***modulating signal m(t).***

4.1. Complex envelope representation of bandpass waveforms

Complex Envelope Represetnation



4.1. Complex envelope representation of bandpass waveforms

Complex Envelope Represetnation

Theorem: Any physical bandpass waveform can be represented by

$$v(t) = \text{Re}\left\{g(t)e^{jw_c t}\right\}$$ **Format 1**

Here, **Re{.}** denotes the real part of {.}, ***g(t)*** is called the complex envelope of ***v*(*t*),** and f_c is the associated *carrier frequency*, where $w_c = 2\pi f_c$

$$v(t) = \text{R}(t)\cos\left[w_c t + \theta(t)\right]$$ **Format 2**

$$v(t) = x(t)\cos(w_c t) - y(t)\sin(w_c t)$$ **Format 3**

4.1. Complex envelope representation of bandpass waveforms

<u>Example 4-1. In phase and quadrature modulated signaling</u>

Let $x(t) = cos(2\pi t)$ and $y(t)$ be a rectangular pulse described by

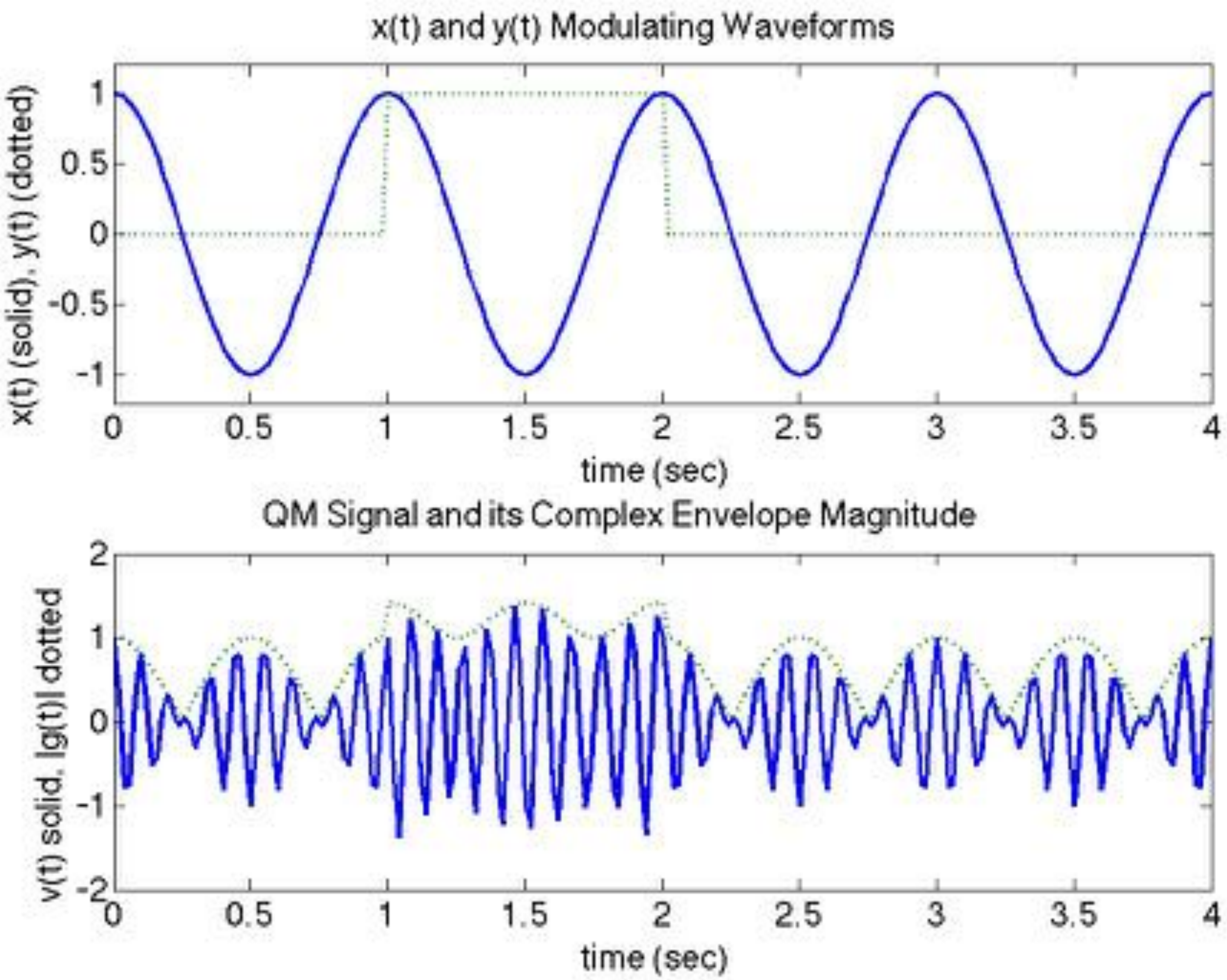
$$y(t) = \begin{cases} 0, & t < 1 \\ 1, & 1 \le t \le 2 \\ 0, & t > 2 \end{cases}$$

Using Eq. $v(t) = \mathrm{Re}\left\{g(t)e^{jw_c t}\right\}$, plot the resulting modulated

signal over the time Interval 0 < t < 4 sec. Assume that the carrier frequency is 10 Hz.

4.1. Complex envelope representation of bandpass waveforms

<u>Example 4-1. In phase and quadrature modulated signaling</u>



4.2. Representation of Modulated Signals

Modulation is the process of encoding the source information ***m*(*t*)** (modulating signal) into a bandpass signal ***s*(*t*)**.

The modulated signal is given by

$$s(t) = \mathrm{Re}\left\{ g(t) e^{j w_c t} \right\}$$

Where $w_c = 2\pi f_c$, in which f_c is the carrier frequency

The complex envelope ***g*(*t*)** is a function of the modulating signal ***m*(*t*)**

$$g(t) = g[m(t)]$$

4.3. Spectrum of Bandpass Signals

The spectrum of a bandpass signal is directly related to the spectrum of its complex envelope

Theorem: If a bandpass waveform is represented by

$$v(t) = \operatorname{Re}\left\{ g(t) e^{j w_c t} \right\}$$

Then the **spectrum** of the bandpass waveform is

$$V(f) = \frac{1}{2}\left[G(f - f_c) + G^*(-f - f_c) \right]$$

The **PSD** of the bandpass waveform is

$$p_v(f) = \frac{1}{4}\left[p_g(f - f_c) + p_g(-f - f_c) \right]$$

where $G(f) = \Im\left[g(t) \right]$ and $p_{g(f)}$ is the PSD of ***g(t)***

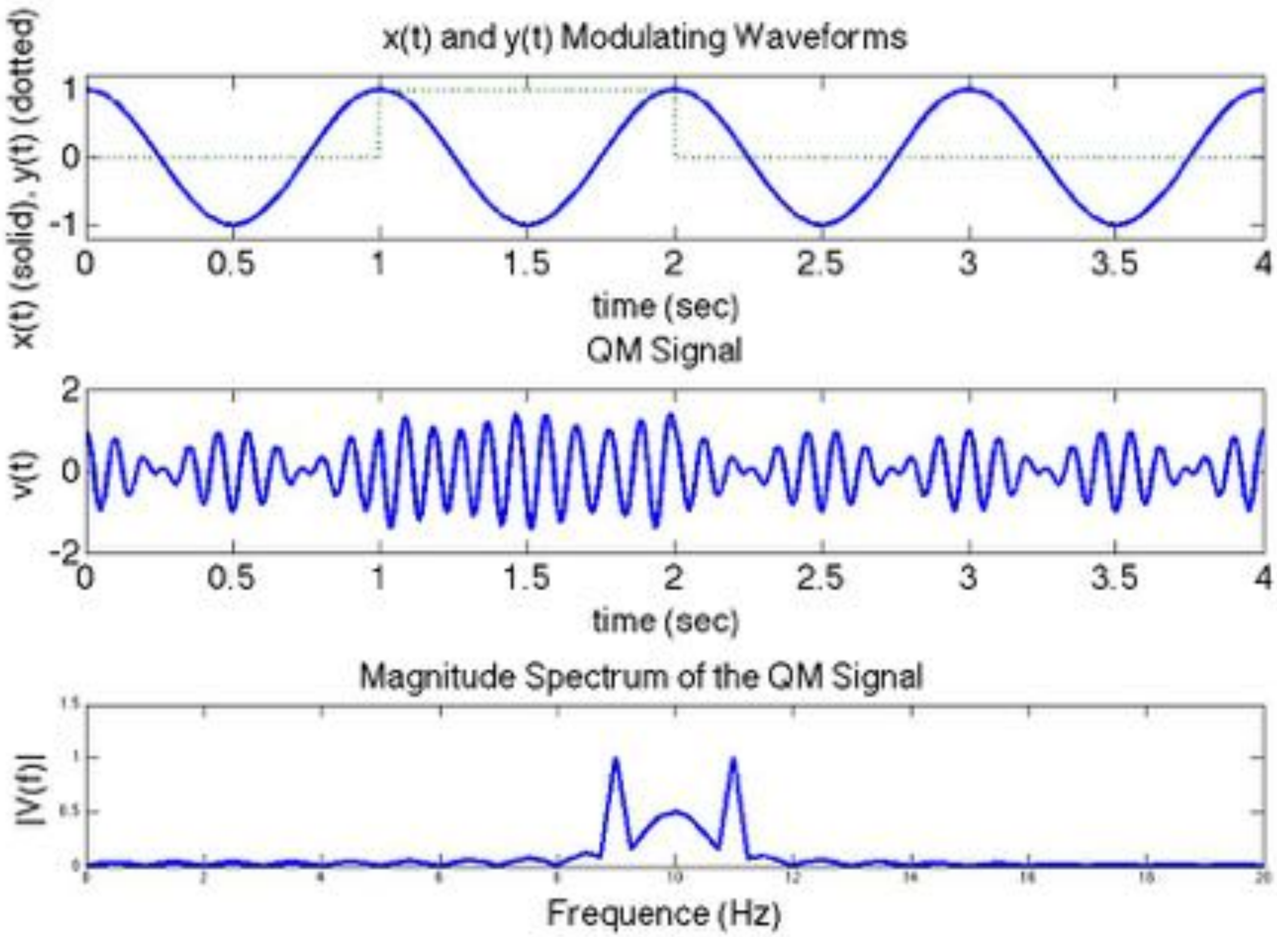
4.3. Spectrum of Bandpass Signals

Example 4-2. Spectrum for a quadrature modulated signal

Using FFT, calculated and plot the magnitude spectrum for the QM Signal that is described in Example 4.1

4.3. Spectrum of Bandpass Signals

Example 4-2. Spectrum for a quadrature modulated signal



4.4. Evaluation of Power

Theorem: The ***total average normalized power*** of a bandpass waveform *v(t)* is

$$P_v = \left\langle v^2(t) \right\rangle = \int_{-\infty}^{\infty} p_v(f)\,df = R_v(0) = \frac{1}{2}\left\langle |g(t)|^2 \right\rangle$$

where "normalized" implies that the load is equivalent to one ohm.

Theorem: The ***peak envelope power*** (**PEP**) is the average power that would be obtained if $|g(t)|$ were to be held constant at its peak value.

Theorem: The ***normalized PEP*** is given by

$$P_{PEP} = \frac{1}{2}\left[\max|g(t)|\right]^2$$