AM and FM MODULATION

Lecture 5&6

Ir. Muhamad Asvial, MEng., PhD
Center for Information and Communication Engineering Research
Electrical Engineering Department – University of Indonesia
Kampus UI Depok, 16424 – Indonesia
asvial@ee.ui.ac.id
http://www.ee.ui.ac.id
Fundamental design in Communication System

- The communication channel (wireless/wireline) characteristics need to be mathematically/statistically **modeled** with “sufficient” details in realistic manner but with “minimum” complexity.
- Given a model of the channel, how to **design the transmitted signal** for maximum robustness against channel effects?
- Given the received signal already corrupted by the channel, how best to **retrieve the transmitted information**?

- Design the transmitter/receiver under some certain practical criteria/constraints:
  - The optimal solution?
  - Sub-optimal solutions?
  - Best trade-off?
Modulation

- Modulation
  - A process that causes a shift in the range of frequencies of a signal.

- Gain advantages
  - Antenna size: half of the antenna size. Thousands of miles for baseband
  - Better usage of limited bandwidth: less side lopes
  - Trade bandwidth for SNR: CDMA
  - Robust to inter-symbol-interference (multipath delay)
  - Robust to errors and distortions

- Types
  - Analog: AM (DSB, SSB, VSB), FM, Delta modulation
  - Digital: ASK, FSK, PSK, QAM, …
  - Pulse modulation: PCM, PDM, … Fiber, phone

- Advanced: CDMA (3G), OFDM (WLAN, WMAN), ….
Modulation

From telecom application’s point of view:

*Modulation is a process of shifting center (or reference) frequency of the signal from one band to another.*

![Diagram showing base-band and modulated signal](image)

**Base-band Signal**

![Graph of base-band signal](image)

**Modulated Signal**

![Graph of modulated signal](image)

**Note:** For base band signal $f_c = 0$ Hz
Principle of Modulation

- In general, modulation is the systematic alteration of one waveform, called \textit{carrier} \([V_c(t)]\), according to the characteristic of another waveform, the \textit{modulating signal} \([V_m(t)]\). The newly created signal is called \textit{modulated signal} \([V_{\text{mod}}(t)]\).

- In telecommunication systems the modulating signal is the information signal and the carrier is a pure sinusoid of frequency \(f_c\) called \textit{carrier frequency}.

\[
\text{Carrier wave, } v_c(t) = E_c \sin(2\pi f_c t + \phi) \quad \text{with frequency } f_c
\]
Principle of Modulation

Carrier wave can 'carry' information signal by embedding the signal in its Amplitude, Frequency or Phase

Thus there are three basic types of modulations:

1. **Amplitude Modulation (AM)** - Carrier carries information signal in its amplitude
2. **Frequency Modulation (FM)** - Carrier carries information signal in its frequency
3. **Phase Modulation (PM)** - Carrier carries information signal in its phase
Application

- Radio Communications
  - AM and FM radio
  - TV broadcasting (terrestrial and satellite)
  - Cellular mobile radio
  - Satellite communications
  - Terrestrial radio links and repeaters
  - Wireless LAN (Local Area Network)

- Optical Communications
  - Infrared Remote Controller
  - Fiber-Optic communications

In all the cases the signal from the carrier source must have the right frequency and be modulated with the information signal.
Basic Type of Modulation

Analog:
1. Amplitude Modulation (AM) - Carrier carries info signal in its amplitude
2. Frequency Modulation (FM) - Carrier carries info signal in its frequency
3. Phase Modulation (PM) - Carrier carries info signal in its phase

Digital:
1. Amplitude Shift Keying (ASK) - AM but the information signal is digital
2. Frequency Shift Keying (FSK) - FM but the information signal is digital
3. Phase Shift Keying (PSK) - PM but the information signal is digital

Note 1: ASK, FSK and PSK signals are analog signals, but carrying digital information signals

Note 2: There are variety of AM/FM/PM and ASK/FSK/PSK schemes which will be briefly discussed later
AM Signal

![AM Signal Diagram](image)

- Modulated Signal $s(t)$ for $m = 0.5$ and $m = 1$
- Envelope for $m = 0.5$ and $m = 1$

**CICER**
DSB-SC

\[ m(t) \xrightarrow{\cos(\omega_c t)} \varphi(t) \]

Upper sideband (USB)

Lower sideband (LSB)

\[ \Phi(\omega) \]

\[ M(\omega) \]

\[ \mathcal{F}\{\cos(\omega_c t)\} \]

\[ F(t) \]
**QAM**

- **AM signal BANDWIDTH**: AM signal bandwidth is twice the bandwidth of the modulating signal. A 5kHz signal requires 10kHz bandwidth for AM transmission. If the carrier frequency is 1000 kHz, the AM signal spectrum is in the frequency range of 995kHz to 1005 kHz.

- **QUADRATURE AMPLITUDE MODULATION** is a scheme that allows two signals to be transmitted over the same frequency range.

- **Equations**
  - Coherent in frequency and phase. Expensive
  - TV for analog
  - Most modems
SSB Frequency

baseband

DSB

SSB

$$\Phi_{SSB}(\omega)$$  SSB (Upper sideband)
SSB Generator

- Selective Filtering using filters with sharp cutoff characteristics. Sharp cutoff filters are difficult to design. The audio signal spectrum has no dc component, therefore, the spectrum of the modulated audio signal has a null around the carrier frequency. This means a less than perfect filter can do a reasonably good job of filtering the DSB to produce SSB signals.

- Baseband signal must be bandpass

- Filter design challenges

- No low frequency components
Single Sideband (SSB)

- Purpose: to reduce the bandwidth requirement of AM by one-half. This is achieved by transmitting only the upper sideband or the lower sideband of the DSB AM signal.
**SSB vs. AM**

- Since the carrier is not transmitted, there is a reduction by 67% of the transmitted power (-4.7dBm). --In AM @100% modulation: 2/3 of the power is comprised of the carrier; with the remaining (1/3) power in both sidebands.
- Because in SSB, only one sideband is transmitted, there is a further reduction by 50% in transmitted power.
- Finally, because only one sideband is received, the receiver's needed bandwidth is reduced by one half--thus effectively reducing the required power by the transmitter another 50%.
- (-4.7dBm (+) -3dBm (+) -3dBm = -10.7dBm).
- Relative expensive receiver
Vestigial Sideband (VSB)

- VSB is a compromise between DSB and SSB. To produce SSB signal from DSB signal ideal filters should be used to split the spectrum in the middle so that the bandwidth of bandpass signal is reduced by one half. In VSB system one sideband and a vestige of other sideband are transmitted together. The resulting signal has a bandwidth > the bandwidth of the modulating (baseband) signal but < the DSB signal bandwidth.
**AM Broadcasting**

- **Frequency**
  - Long wave: 153-270kHz
  - Medium wave: 520-1,710kHz, AM radio
  - Short wave: 2,300-26,100kHz, long distance, SSB

- **Limitation**
  - Susceptibility to atmospheric interference
  - Lower-fidelity sound, news and talk radio
  - Better at night, ionosphere.
Superheterodyne

• Move all frequencies of different channels to one medium freq.
  – In **AM** receivers, that frequency is 455 kHz,
  – for **FM** receivers, it is usually 10.7 MHz.

- Filter Design Concern
- Accommodate more radio stations
- **Edwin Howard Armstrong**
Bandwidth

VSB and QAM
Frequency Modulation

- Frequency is "wobbled" higher and lower by modulating signal

![Diagram showing voltage, modulating signal, and frequency modulated carrier over time.](image)
Frequency Modulation

- Modulation by a sine wave:
  \[ \nu(t) = A_C \cos \left( 2\pi f_C t - m \sin (2\pi f_m t) \right) \]
  
  \( A_C \) = unmodulated peak carrier amplitude
  \( f_C \) = carrier frequency
  \( f_m \) = modulation frequency
  \( m \) = modulation index ("degree" of modulation)

- Modulation index:
  \[ m = \frac{\text{peak carrier deviation (} \Delta f \text{)}}{\text{modulating frequency (} f_m \text{)}} \]

- \( \Delta f = \pm 75 \text{ kHz for commercial FM} \)
- Channel spacing 200 kHz
Frequency Modulation

- No danger of overmodulation with FM
- As $m$ increased, uses more bandwidth
- As $m$ increased, more resistant to noise; S/N ratio improves
- Commercial FM broadcasting:
  \[ \Delta f = \pm 75 \text{ kHz} \]
  \[ f_m = 15 \text{ kHz maximum (audio BW)} \]
  Minimum value of $m$ is 5
- Required total bandwidth is approximately
  \[ 2 \left( m + 1 \right) f_m \text{ Hz.} \]
Frequency Error by Phase Noise

• Simplified S/N Analysis
  – Signal frequency: 1 kHz
  – Signal amplitude, $E_S$: 10
  – Frequency deviation: 5 kHz
  – Noise amplitude, $E_N$: 1
    • $(S/N)_P$: 20 dB
    • Maximum angle deviation: 0.1 rad
    • Noise modulation index, $m_N$: 0.1
  – Frequency error caused by noise
    • $1 \text{ kHz} \times 0.1 = 100 \text{ Hz}$
    – $(S/N)_F$: $5 \text{ kHz}/100 \text{ Hz} = 50; 34 \text{ dB in power}$
# FM Radio

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>FCC Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assigned carrier frequency, $f_c$</td>
<td>200 kHz increments from 88.1 MHz to 107.9 MHz</td>
</tr>
<tr>
<td>Channel Bandwidth</td>
<td>200 kHz</td>
</tr>
<tr>
<td>Noncommercial stations</td>
<td>88.1 to 91.9 MHz</td>
</tr>
<tr>
<td>Commercial stations</td>
<td>92.1 to 107.9 MHz</td>
</tr>
<tr>
<td>Carrier frequency stability</td>
<td>±2000 Hz of assigned frequency</td>
</tr>
<tr>
<td>Peak frequency deviation</td>
<td>75 kHz</td>
</tr>
<tr>
<td>Frequency deviation ratio</td>
<td>5</td>
</tr>
<tr>
<td>Audio frequency response</td>
<td>50 Hz to 15 kHz following a 75 μsec preemphasis curve.</td>
</tr>
<tr>
<td>Maximum power licensed</td>
<td>Class A (local) stations: 6 kW</td>
</tr>
<tr>
<td></td>
<td>Class B (regional) stations: 50 kW</td>
</tr>
<tr>
<td></td>
<td>Class C stations: 100 kW</td>
</tr>
<tr>
<td></td>
<td>Class D (noncommercial) stations: 10 W</td>
</tr>
</tbody>
</table>
**FM Spectrum**

- Sideband structure is more complicated than for AM; many sidebands produced
- Complexity depends on $m$
- However, spacing between carrier and sidebands (and between adjacent sidebands) is equal to $f_m$, just as for AM
- Theoretically, an infinite number of sidebands produced, but most of power is contained in first $(m+1)$ sidebands
- Thus transmission requires a bandwidth of approximately $2(m+1)f_m$ Hz
Demodulation

- “Detection”
- Most AM detectors are very simple and work by following the peaks of the modulated carrier (“peak detector”)
- FM detectors use a phase-locked loop (PLL) which uses a feedback loop to lock an oscillator to the exact frequency of the incoming signal
- The PLL produces a voltage which is proportional to the frequency shift of the signal