FM Modulation and Detection, Introduction to Digital Modulation.

Lecture Outline

- **WBFM Modulation**
- **FM Detection**
- **Baseband Digital Modulation**
- **ASK, PSK and FSK Modulation Techniques**

1. **Wideband FM Modulation (WBFM)**
   - Direct Method: use a VCO so that carrier frequency is proportional to input signal $m(t)$.
   - Indirect Method: use a NBFM modulator followed by a nonlinear device and a bandpass filter.

2. **FM Detection**
   - Demodulator must extract $m(t)$, which is conveyed through the instantaneous frequency $f_i(t) = \frac{1}{2\pi}\frac{d\theta(t)}{dt} = f_c + k_f m(t)$,
   - Differentiation and Envelope Detection: $s'(t) = A_c[2\pi f_c + k_f m(t)]\sin[2\pi f_c t + k_f \int_0^t m(\tau)d\tau]$, so we extract the information signal by differentiating and then envelope detecting, as long as $|k_f m(t)| < 2\pi f_c$.
   - In practice it is difficult to build a differentiator. A frequency discriminator approximates a differentiator within the bandwidth of interest.
   - Zero crossing detector: approximates the instantaneous frequency $f_i(t)$ by counting the number of zero crossings in a time interval T, where $f_c^{-1} < T < B^{-1}$.
   - Phase-Locked Loop (PLL): the most common FM demodulator. Relies on a feedback principle to track the modulating signal $m(t)$.
   - Hard to characterize impact of noise on FM systems.

3. **Baseband Digital Modulation**
   - Most information systems today store, process, and communicate digital information (bits).
   - Bit sequences must be transformed into analog signals for baseband channels.
   - Typically represent each bit by a square wave of duration T_b (the bit time) with amplitude A for a "1" bit and 0 (on-off modulation) or $-A$ (polar modulation) for a "0" bit. Data rate is $1/T_b$.
   - Baseband signal may be filtered to reduce bandwidth (pulse shaping)

4. **Passband Digital Modulation**
   - Used to send digital information at passband frequencies.
   - Passband digital modulation has the form $s(t) = \sum_{n=-\infty}^{\infty} A_n(t)\cos(2\pi f_c t + \theta_n(t))$, where $s(t)$ conveys one bit at a time (binary modulation).

- The values of $A_n(t)$ and $\theta_n(t)$ are constant over a bit time T_b and their values are determined by the bit at time nT_b, which is denoted $m(nT_b)$.

5. **Amplitude Shift Keying (ASK)**
   - Bits encoded in carrier amplitude.
   - In ASK $\theta_n(t) = 0$, $A_n = A_c$ if $m(nT_b) = 1$ and $A_n = 0$ if $m(nT_b) = 0$.
   - Modulated signal is $s(t) = m(t)A_c \cos(2\pi f_c t)$.
   - ASK generated using a product modulator (ASK is essentially AM with $m(t) = A_c$ or 0).

6. **Phase Shift Keying (PSK)**
   - Bits encoded in carrier phase
   - In PSK $A_n = A_c$, $\theta_n(t) = 0$ if $m(nT_b) = 1$ and $\theta_n(t) = \pi$ if $m(nT_b) = 0$.
   - Modulated signal is $s(t) = A_c \cos(2\pi f_c t + \pi - m(t)\pi)$.
   - PSK is generated using a product modulator (PSK is essentially AM with $m(t) = A_c$ or $-A_c$).

7. **Frequency Shift Keying (FSK)**
   - Bits encoded in carrier frequency.
   - In FSK $A_n = A_c$, $\theta_n(t) = 2\pi(f_1 - f_c)t$ if $m(nT_b) = 1$ and $\theta_n(t) = 2\pi(f_2 - f_c)t$ if $m(nT_b) = 0$.
   - Modulated signal is $s(t) = A_c \cos 2\pi f_i t$, $f_i \in \{f_1, f_2\}$.
   - FSK generated using an FM modulator.
   - Minimum Shift Keying (MSK) is FSK with $|f_1 - f_2| = .5/T_b$ (minimum frequency separation that can be detected in the receiver).

Main Points:

- WBFM is more complicated to generate than NBFM.
- In theory just need a differentiator and envelope detector for FM demodulation. Multiple methods used in practice, with PLL most common.
- Most information today is in bits.
- Digital baseband modulation uses simple techniques to send bits over analog channels.
- Digital passband modulation encodes bits in the amplitude, phase, or frequency of carrier signal.