Overview of Modulation Techniques for Wireless

Introduction

The purpose of analog modulation is to impress an information-bearing analog waveform onto a carrier for transmission.

The purpose of digital modulation is to convert an information-bearing discrete-time symbol sequence into a continuous-time waveform (perhaps impressed on a carrier).

Key concerns — bandwidth efficiency and implementation complexity. These are affected by:

- baseband pulse shape
- phase transition characteristics
- envelope fluctuations (channel non-linearities?)

Example Modulation Schemes for Wireless

- FM — AMPS
- MSK (minimum-shift keying) — CT2
- GMSK (Gaussian MSK) — GSM, DCS 1800, CT3, DECT
- QPSK — NADC (CDMA) - base transmitter
- OQPSK — NADC (CDMA) - mobile transmitter
- $\pi/4$-DQPSK — NADC (TDMA), PDC (Japan), PHP (Japan)
- M-ary PSK (some wireless LANs)

Frequency Modulation

Angle modulation: transmitted signal is

$$x(t) = A\cos[\omega_c t + \Phi(t)] = \Re\{Ae^{j[\omega_c t + \Phi(t)]}\}$$

with instantaneous phase

$$\Theta_i(t) = \omega_c t + \Phi(t),$$

and instantaneous frequency

$$\omega_i(t) = \frac{d\Theta_i(t)}{dt} = \omega_c + \frac{d\Phi(t)}{dt}.$$

$\Phi(t)$ is the **instantaneous phase deviation**, and $\frac{d\Phi(t)}{dt}$ is the **instantaneous frequency deviation.**

For phase modulation,

$$\Phi(t) = k_p m(t)$$

where $m(t)$ is the message signal, and k_p is the phase deviation constant (rad/volt). For FM, we have $\frac{d\Phi(t)}{dt} = k_f m(t)$ or

$$\Phi(t) = k_f \int_{t_o}^{t} m(s)ds + \Phi(t_0)$$

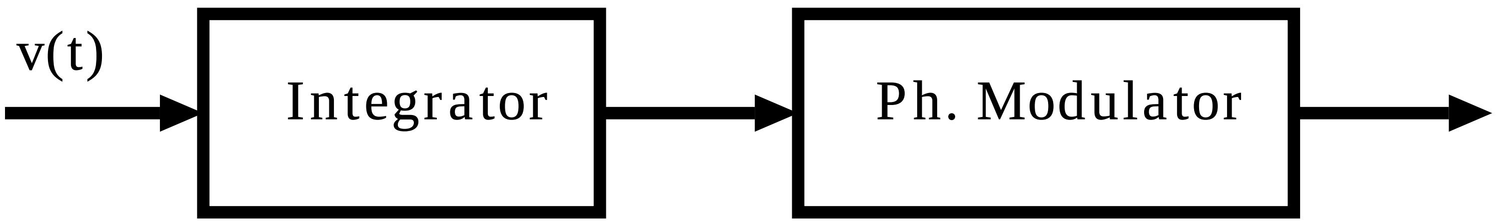
where k_f is the frequency deviation constant (rad/sec/volt).

With $t_0 = -\infty$ and $\Phi(t_0) = 0$, we have

$$x(t) = A\cos[\omega_c t + k_p m(t)] \qquad \text{(PM)}$$

$$x(t) = A\cos[\omega_c t + k_f \int_{-\infty}^{t} m(s)ds] \qquad \text{(FM)}$$

FM using integrator and phase modulator



If modulating signal is a sinusoid, $m(t) = A_m \cos \omega_m t$, then

$$x(t) = A \cos[\omega_c t + \beta \sin \omega_m t]$$

where $\beta = \frac{k_f A_m}{\omega_m}$, the *modulation index* (defined for single-tone modulation only). In this case, it can be shown that $\frac{x(t)}{A}$ is

$$J_0(\beta) \cos \omega_c t + \sum_{n=1}^{\infty} (-1)^n J_n(\beta) [\cos(\omega_c - n\omega_m)t + (-1)^n \cos(\omega_c + n\omega_m)t]$$

For small β, we have

$$J_0(\beta) \approx 1 - \left(\frac{\beta}{2}\right)^2$$

$$J_n(\beta) \approx \frac{1}{n!} \left(\frac{\beta}{2}\right)^n, n \neq 0$$

This implies

$$\frac{x(t)}{A} \approx \cos \omega_c t - \frac{\beta}{2} \cos(\omega_c - \omega_m)t + \frac{\beta}{2} \cos(\omega_c + \omega_m)t$$

or (using a trig identity)

$$\frac{x(t)}{A} \approx \cos \omega_c t - \beta \sin \omega_m t \sin \omega_c t$$

General rule: if $\beta < 0.3$, the bandwidth of the modulated signal is approx. $2\omega_m$, and we have narrow-band FM (NBFM). This is the modulation scheme used in AMPS.

FM Demodulation Methods

- Limiter-discriminator
- FM feedback (FMFB)
- **Phase-locked loop** (PLL)

FM Performance

Characterized by signal-to-noise ratio (SNR): the demodulator input CNR (carrier-to-noise ratio) for AMPS is specified to be 18 dB, resulting in an output SNR of 40 dB.

Digital Modulation

Criteria for selection:

- BER performance
  - Mobile/personal channel – severe fading
  - Cellular architecture – interference
  - Typically, req't is 10^{-2} or better (speech)
- Spectral efficiency
- Adjacent channel interference
- Power efficiency (esp. at mobile)
- Implementation complexity/cost (may require dual-mode mobile)

Digital Modulation — Classification

Constant-envelope methods: Allow use of less expensive amplification (not dependent on signal amplitude) at the expense of out-of-band emissions. Limited to a spectral efficiency of about 1 bit/sec/Hz.

Examples: MSK, GMSK

Linear methods: Higher spectral efficiency, but must use linear amplifiers to maintain performance and to limit out-of-band emissions.

Examples: PSK, QAM

Spectral Efficiency

Spectral occupancy (per channel) is roughly

$$S_O = B + 2\Delta f$$

where $B =$ bandwidth occupied of RF signal power spectrum and Δf is the maximum (one-way) carrier frequency (oscillator) drift.

Remark: Per-channel spectral efficiency for narrowband systems only

We can express the bandwidth as

$$B = \frac{R_d}{n}$$

where R_d is the channel data rate and n is the spectral efficiency (in bits/sec/Hz).

Combining,

$$S_O = \frac{R_d}{n} + 2\Delta f$$

Thus, to minimize spectral occupancy (thus maximizing capacity in number of users) we can:

1. Lower speech encoder rate (trade: cost, fidelity), or
2. Improve spectral efficiency of modulation (trade: complexity), or
3. Improve transmitter/receiver oscillators (trade: cost).

State of the technology:

Bandwidth efficiency: $1 < n < 2$

Speech encoder rate: $R_d \approx 4 - 8$ kb/sec

Oscillator stability: $\approx 1 \times 10^{-6}$/year implying $\Delta f \leq 1$ kHz at 900 MHz (long-term)

Examples:

- NADC (TDMA): 48.6 kbps in 30 kHz
- GSM: 34 kbps in 25 kHz