Frequency and Phase Modulation

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Overview

- History
- Why FM? Noise problems with linear modulation systems: AM/SSB/DSB
- Definitions: Deviation, WBFM, NBFM
- Very popular for VHF voice

Definition of an FM Signal

- For a baseband signal, x(t):

$$x_{FM}(t) = A_c \cos\left[2\pi f_c t + 2\pi k_f \int_{-\infty}^{t} x(\tau) d\tau\right]$$

  - k_f is the frequency deviation constant in Hz/volt
  - A constant envelope signal with varying frequency/phase
  - The instantaneous frequency is:

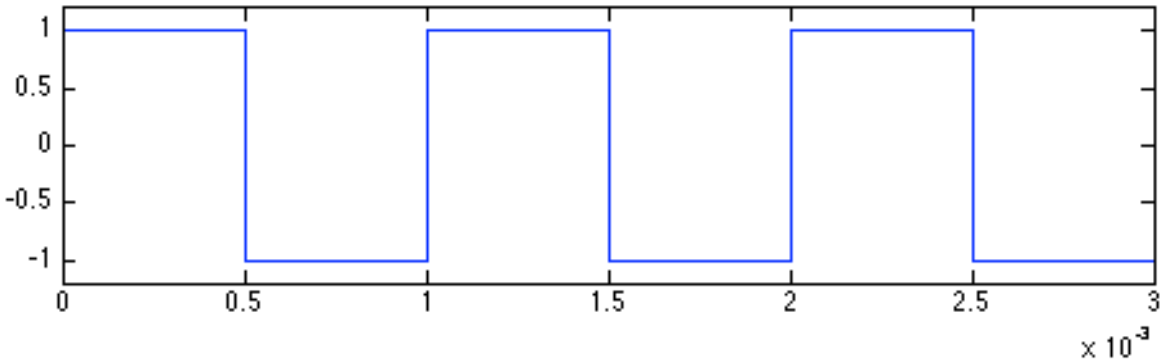
$$f_i(t) = f_c + k_f x(t)$$

  - Maximum frequency deviation =$\Delta f = k_f |x(t)|_{max}$

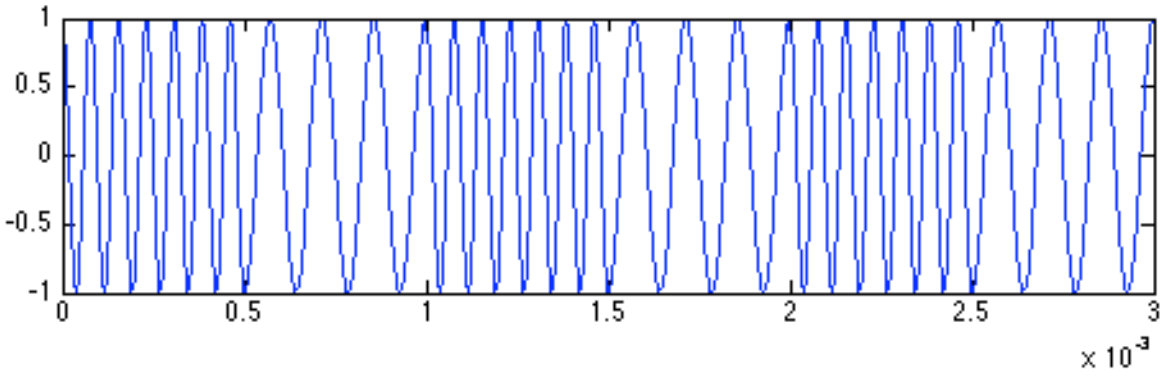
FM Signal - Time Domain

- For a pulse train baseband signal:

Baseband signal, x(t)



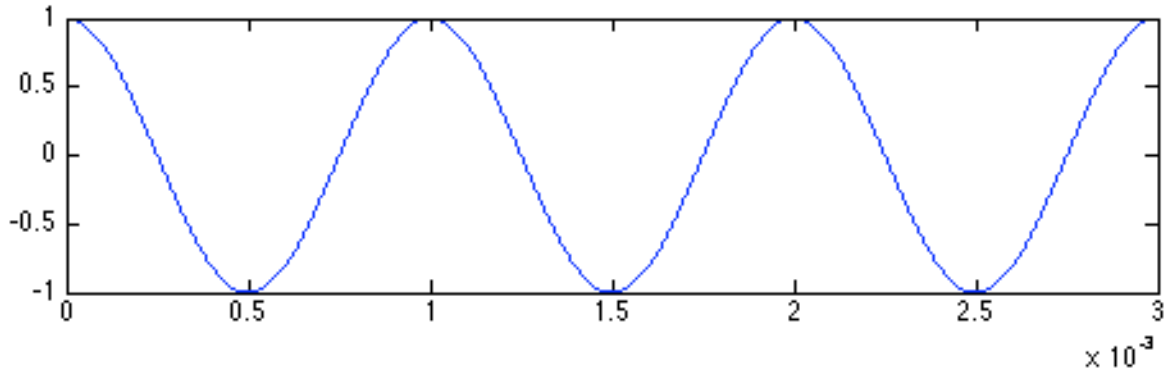
FM signal



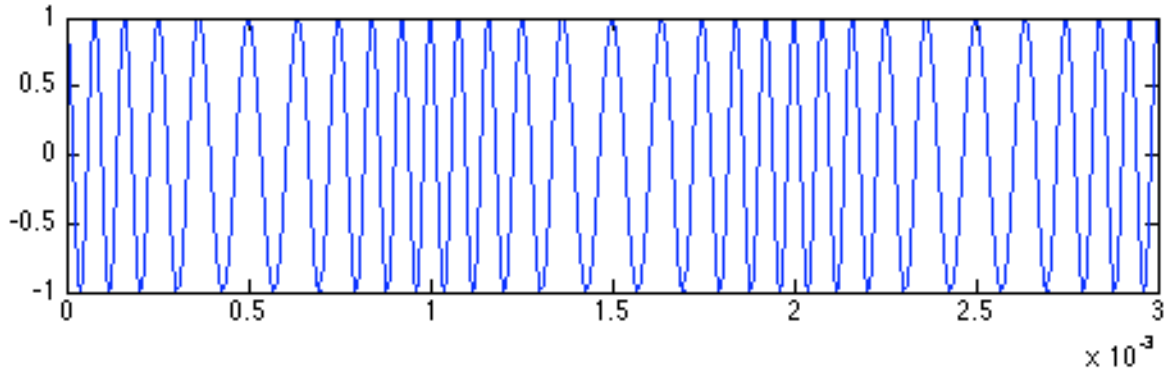
FM Signal - Time Domain

- For a sinusoidal baseband signal:

Baseband signal, x(t)

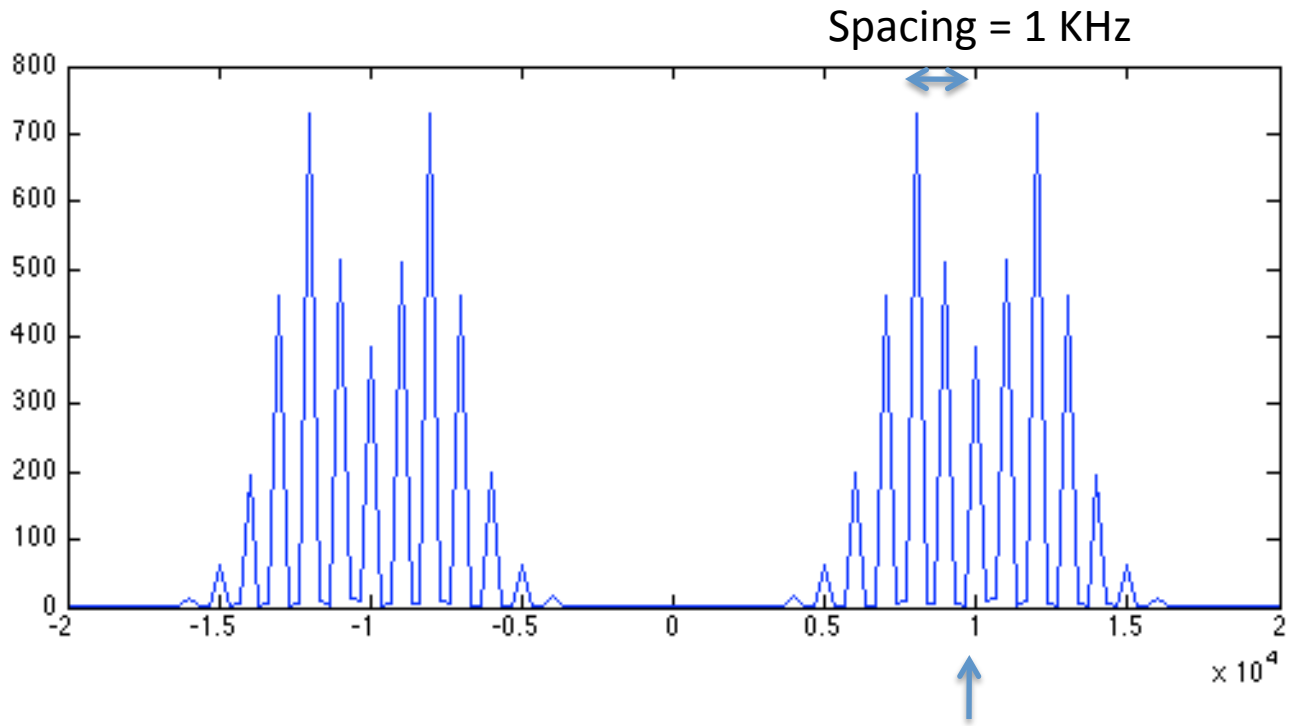


FM signal



FM Signal – Frequency Domain

- For a 1 KHz sinusoidal baseband signal (tone modulation) and 10 KHz carrier



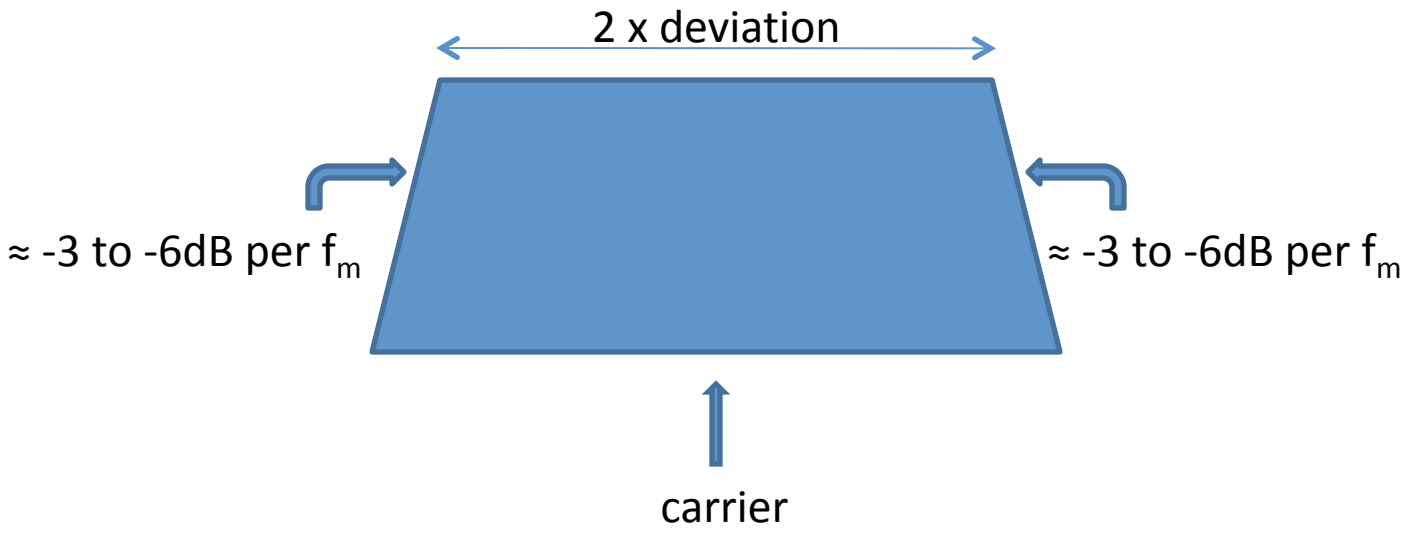
Wider than an AM or DSB signal

Deviation and Bandwidth

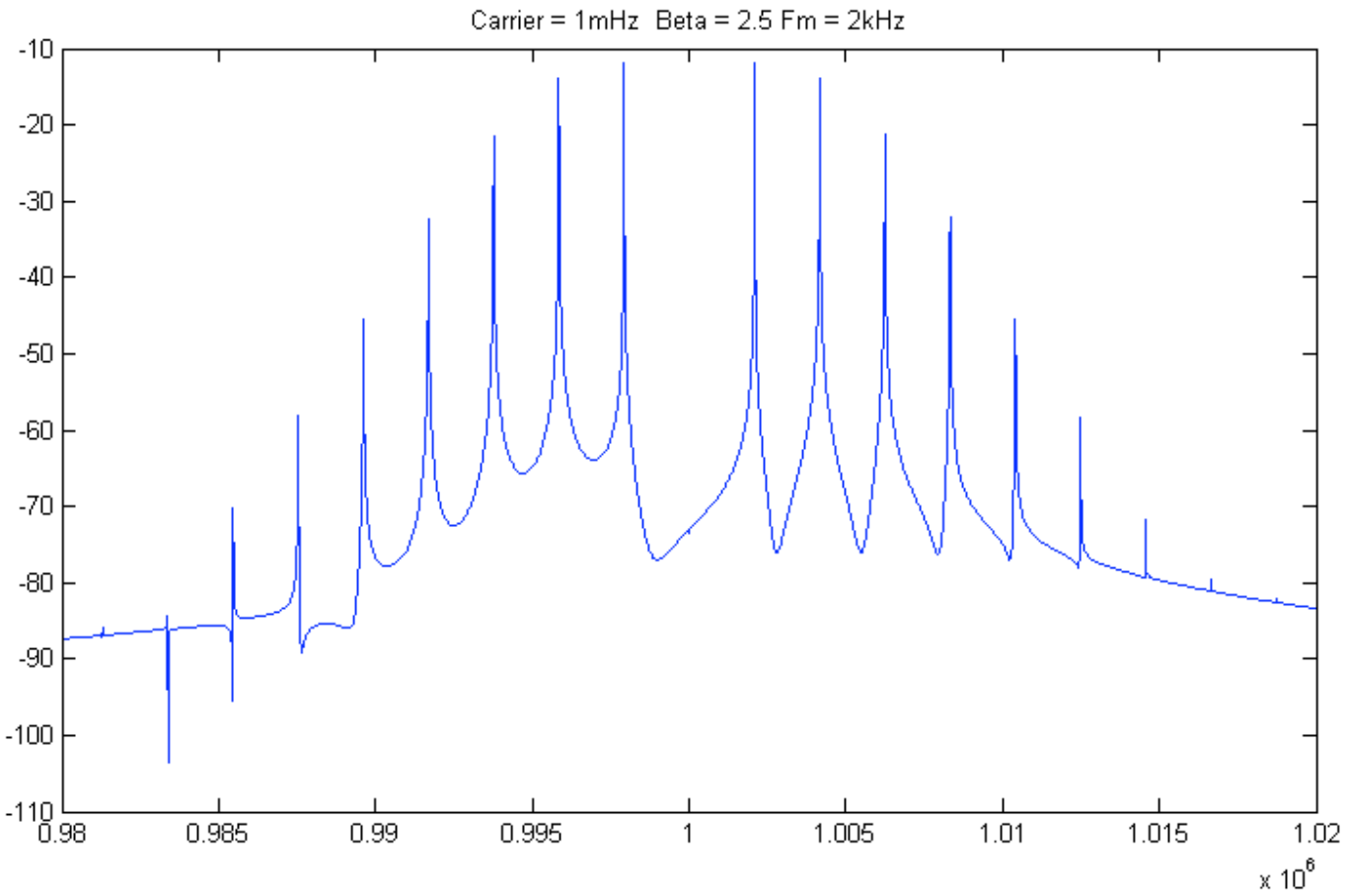
- Instantaneous Frequency: $f_c + k_f x(t)$
- Frequency deviation: $\Delta f = k_f x(t)$
- Maximum frequency deviation, $\Delta f = k_f |x(t)|_{max}$
  - For tone modulation: $\Delta f = k_f A_m$
- Deviation Ratio, $D = \Delta f / W$
  - For tone modulation: Modulation index, $b = Df/f_m$
  - $b << 1$: narrowband FM, NBFM
  - $b >> 1$: wideband FM, WBFM
- Bandwidth, $BW = 2(D+1)W$, or $BW = 2(b+1)f_m$

FM MODULATION

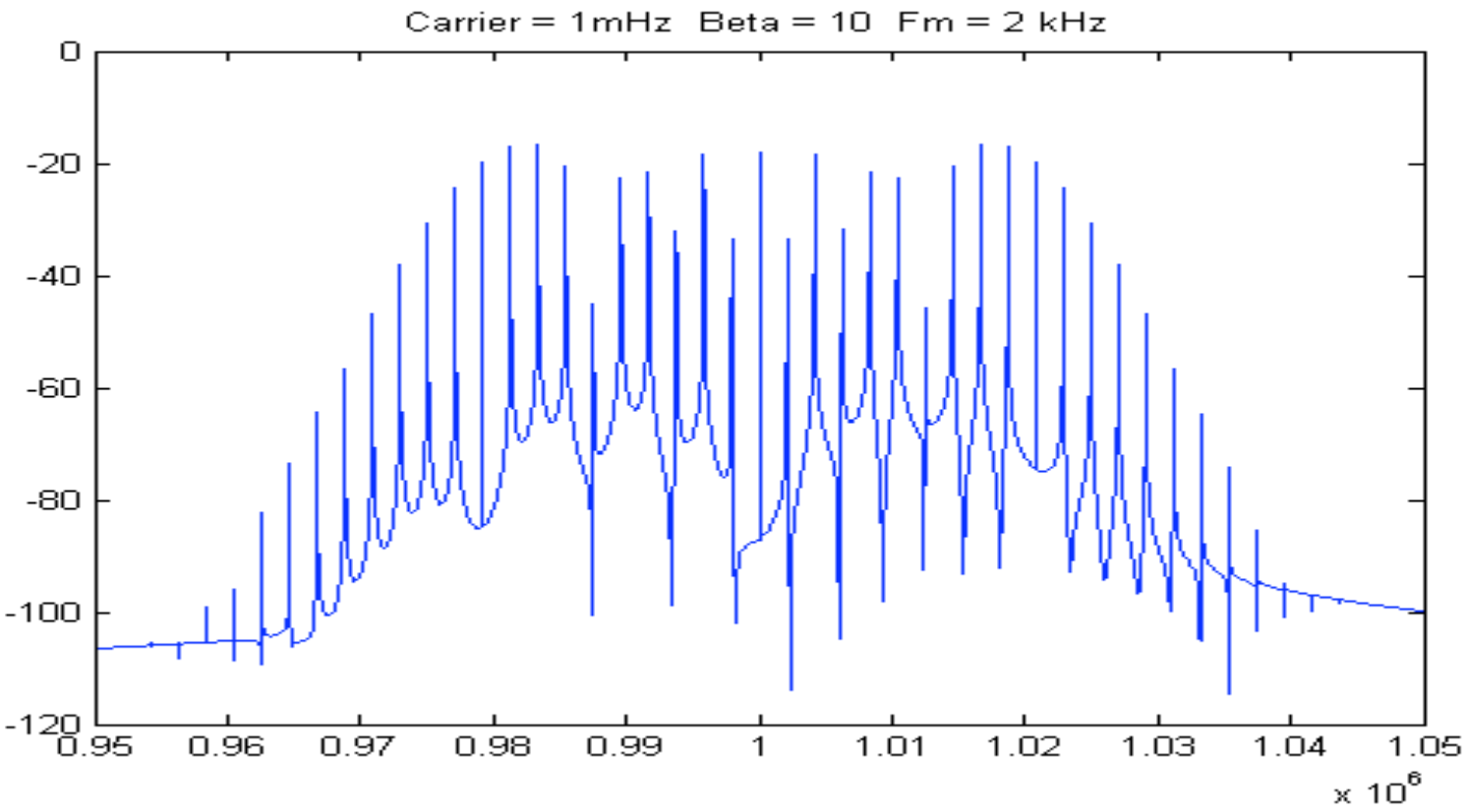
- Spectrum vs. modulation index, β
  - Spectra have a typical trapezoidal shape in linear frequency and amplitude in decibels.



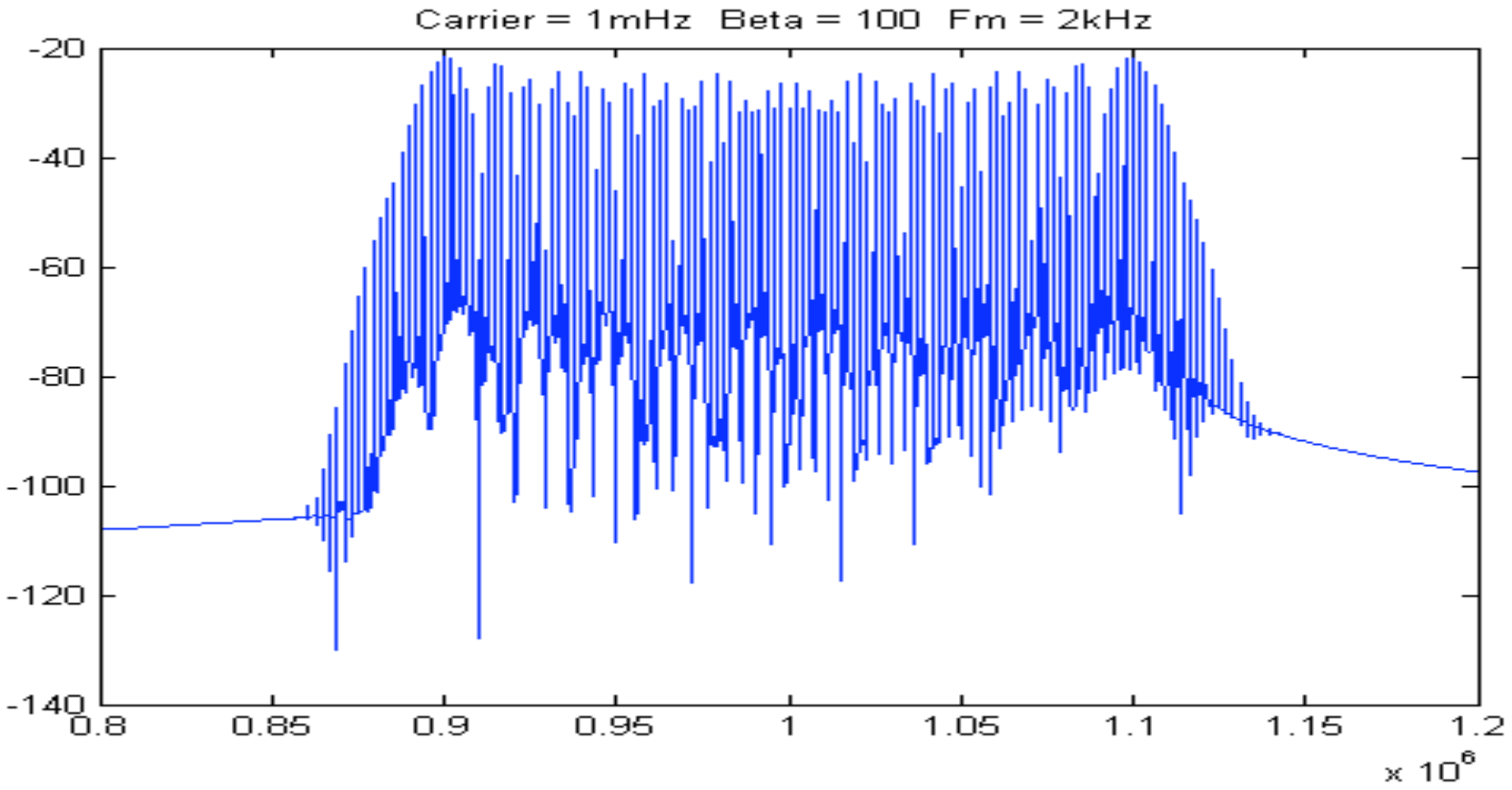
FM MODULATION



FM MODULATION



FM MODULATION



demos

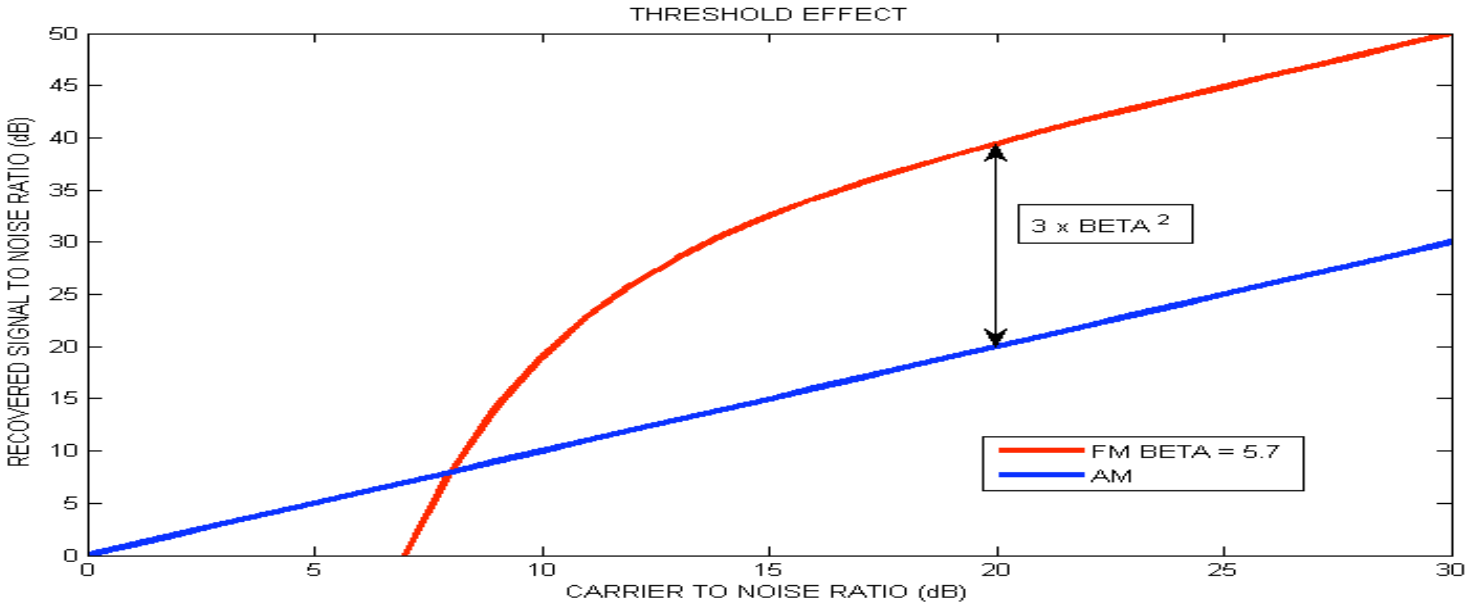
FM MODULATION

- Comparison to AM/SSB/DSB

	AM	DSB	SSB	FM
BANDWIDTH	$2 f_m$	$2 f_m$	f_m	$2 (\beta+1) f_m$
SNR	LINEAR	LINEAR	LINEAR	NON-LINEAR
EFFICIENCY	33%	50%	100%	$\leq 100\%$*
COMPLEXITY	LOW	MODERATE	MODERATE	HIGH

FM MODULATION

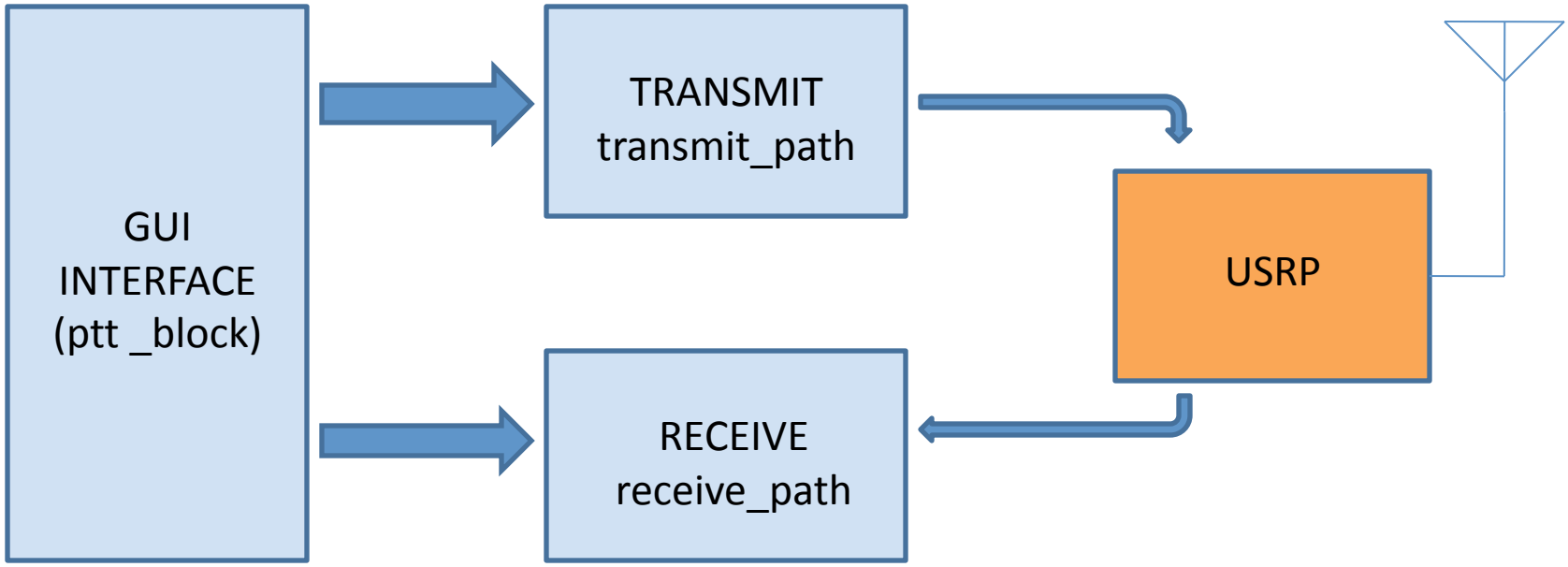
- Threshold Effect



- Capture effect: Signals more than 6dB down will not interfere.

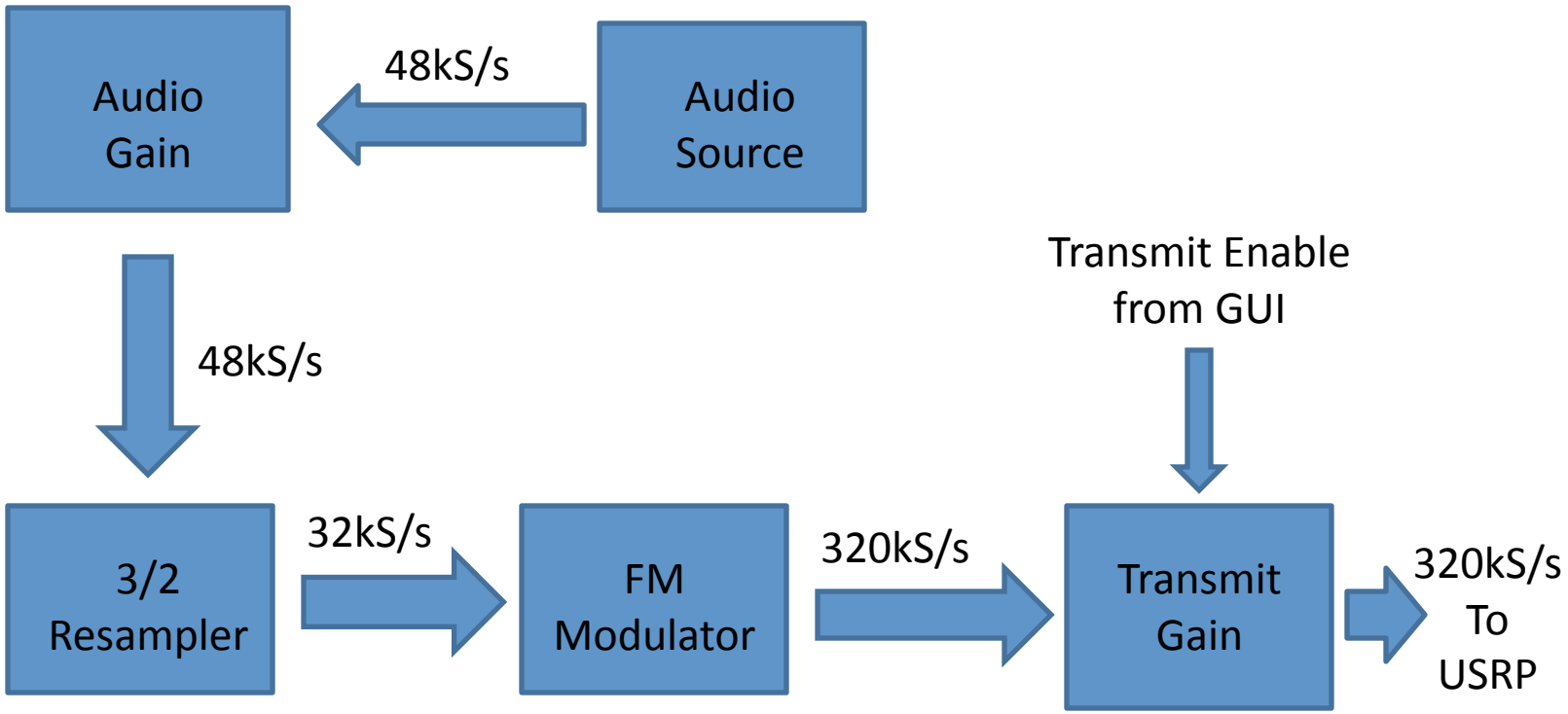
FM MODULATION

- SDR Program for NBFM



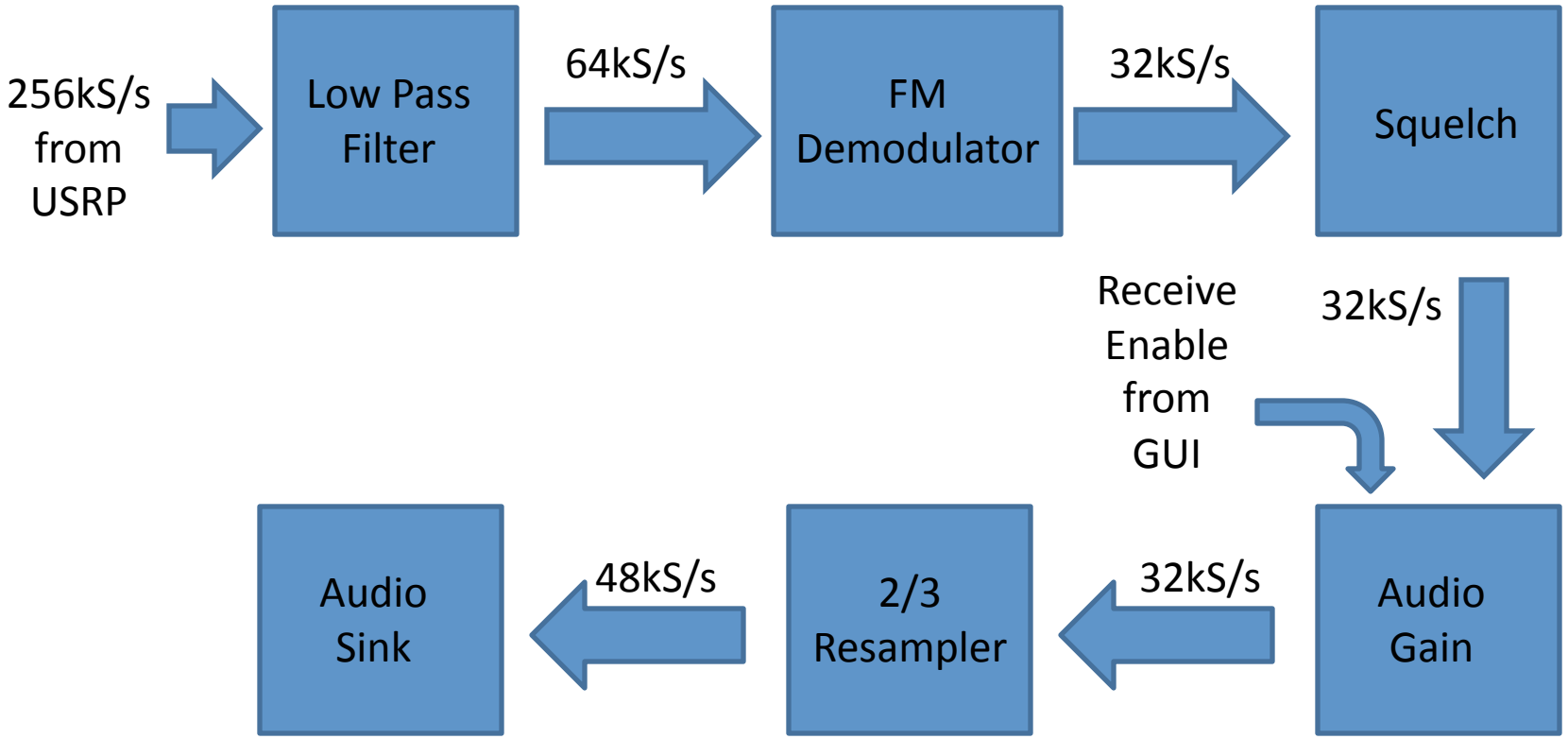
FM MODULATION

- TRANSMIT PATH (always running)



FM MODULATION

- RECEIVE PATH (always running)



Definition of a PM Signal

- For a baseband signal, x(t):

$$x_{PM}(t) = A_c \cos\left[2\pi f_c t + k_p x(t)\right]$$

  - k_p is the frequency deviation constant in rad/volt
  - A constant envelope signal with varying frequency/phase
  - The instantaneous phase is:

$$\theta_i(t) = 2\pi f_c t + k_p x(t)$$

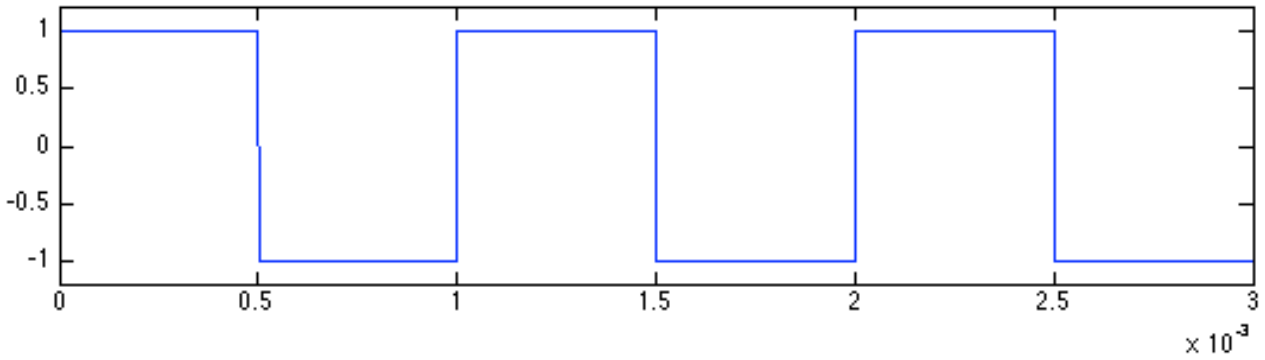
  - The instantaneous frequency is:

$$f_i(t) = f_c + \frac{k_p}{2\pi}\frac{dx(t)}{dt}$$

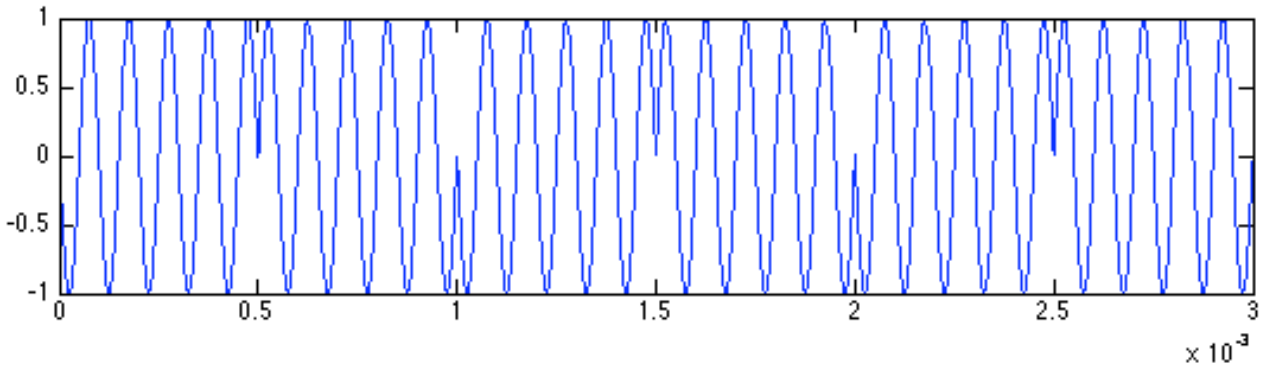
PM Signal - Time Domain

- For a pulse train baseband signal:

Baseband signal, x(t)



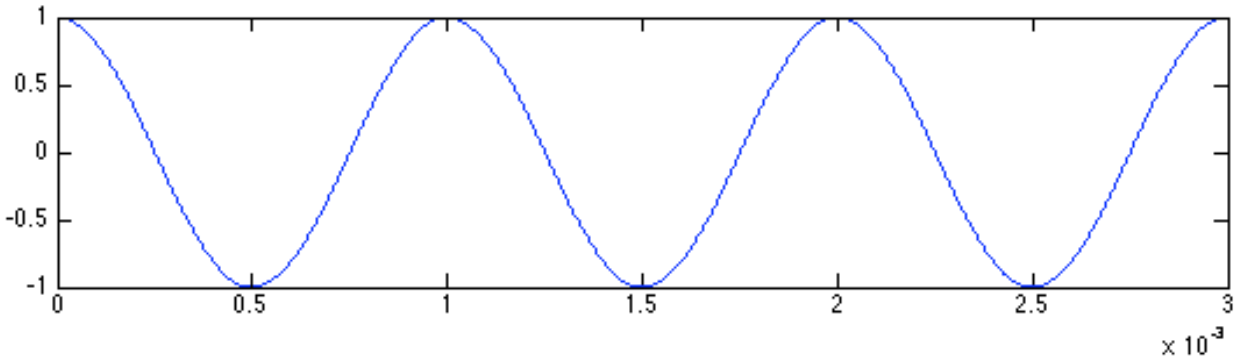
PM signal



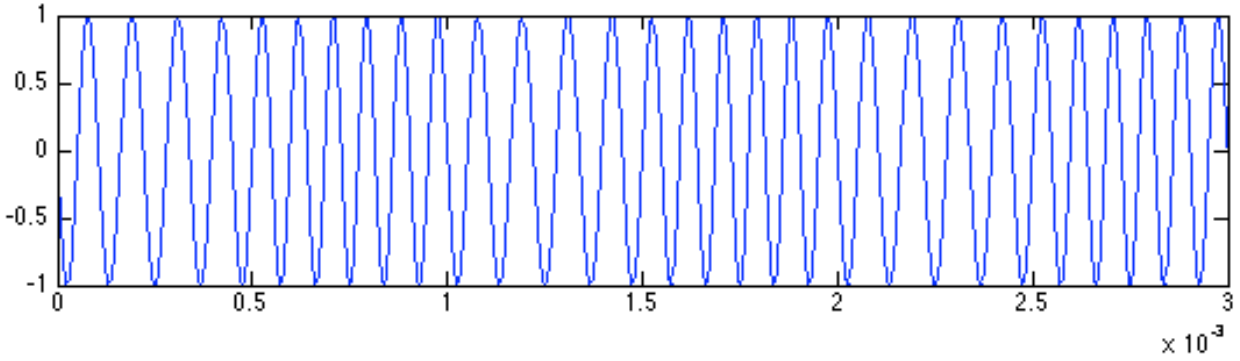
PM Signal - Time Domain

- For a sinusoidal baseband signal:

Baseband signal, x(t)



PM signal



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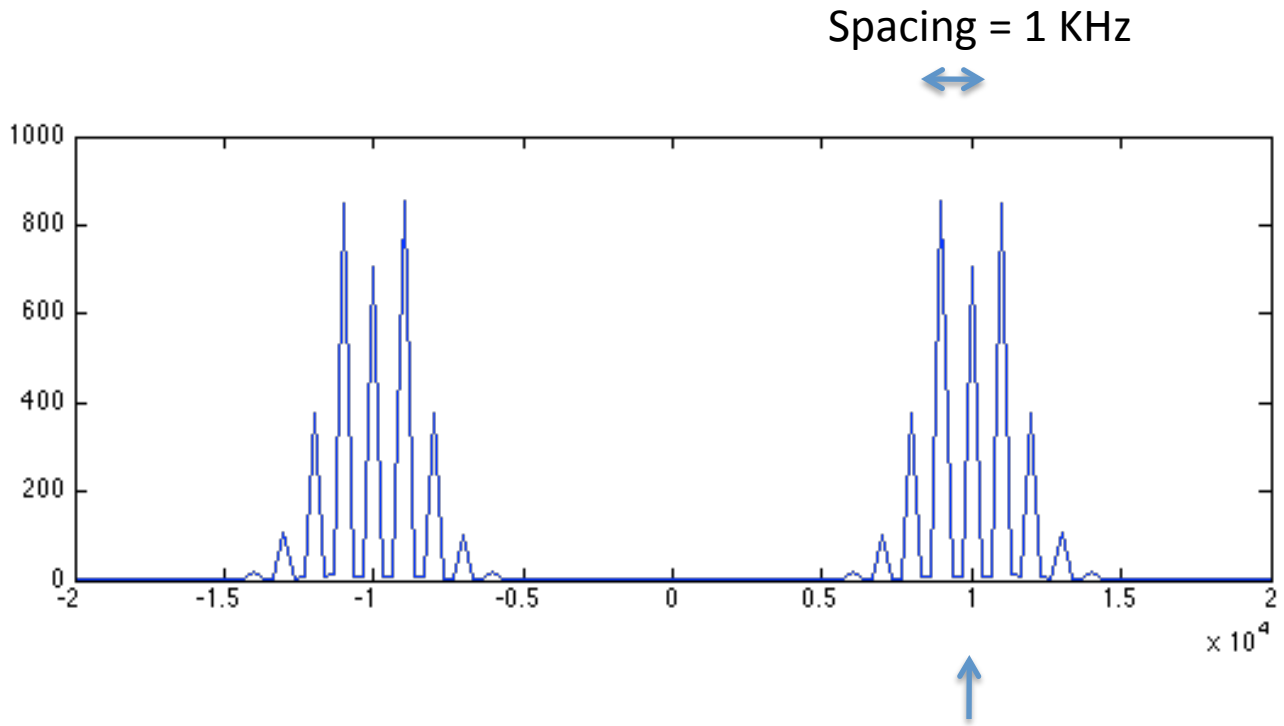

Wider than an AM or DSB signal

Bandwidth Comparison for FM/PM

- Bandwidth, BW = 2(D+1)W, or BW = 2(b+1)f_m
- FM:
  - For tone modulation: Modulation index, b = Df/ f_m
  - BW = $2(k_f A_m + f_m)$
- PM:
  - For tone modulation: Modulation index, b = $k_p A_m$
  - BW = $2(k_p A_m + 1)f_m$
- Increasing frequency has a more profound effect on the BW of PM