FM - Modulation

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Recall: AM/FM

- Analog modulation - applied continuously in response to the analog information signal (first 4 lectures)
  - AM (Amplitude Modulation): amplitude of carrier signal is varied in accordance to instantaneous amplitude of modulating signal
    - Double-sideband modulation (DSB) [including DSB with unsuppressed carrier (DSB-WC), DSB suppressed-carrier transmission (DSB-SC), DSB reduced carrier transmission (DSB-RC)]
    - Single-sideband modulation (SSB, or SSB-AM) [including SSB with carrier (SSB-WC), SSB suppressed carrier modulation (SSB-SC)]
    - Vestigial sideband modulation (VSB, or VSB-AM)
    - Quadrature amplitude modulation (QAM)
  - Angle modulation
    - Frequency modulation (FM): frequency of carrier signal is varied in accordance to instantaneous value of modulating signal
    - Phase modulation (PM): phase shift of the carrier signal is varied in accordance to the instantaneous phase shift of the modulating signal)
- Digital modulation - analog carrier signal is modulated by a digital bit stream.

More detail,

- Message signal: $x_m(t)$
- Carrier: $x_c(t) = A_c \cos(2\pi f_c t)$
- So that: $y(t) = A_c \cos\left(2\pi \int_0^t \boxed{f(\tau)} d\tau\right)$

Instantaneous frequency

frequency deviation

$$= A_c \cos\left(2\pi \int_0^t [f_c + \boxed{f_\Delta} x_m(\tau)] d\tau\right)$$

$$= A_c \cos\left(2\pi f_c t + 2\pi f_\Delta \int_0^t x_m(\tau) d\tau\right)$$

→ difference between instantaneous and base frequency of the carrier is directly proportional to instantaneous value of input signal amplitude.

Let's look step by step

$$f_c + \alpha x_m(t)$$

or

$$2\pi(f_c + \alpha x_m(t))$$

$$\Big\downarrow \int_0^t d\tau$$

$$\int_0^t 2\pi(f_c + \alpha x_m(\tau))d\tau$$

$$= 2\pi f_c t + 2\pi\alpha \int_0^t x_m(\tau)d\tau$$

By definition of FM, the carrier frequency is changed by a message signal - "instantaneous frequency deviation"

Frequency deviation at time t

Take cosine, making FM!

Sinusoidal Message Signal

- Message signal: $\int_0^t x_m(t)dt = \frac{A_m \cos(2\pi f_m t)}{2\pi f_m}$
- The corresponding FM signal:

$$y(t) = A_c \cos\left(2\pi f_c t + \frac{f_\Delta}{f_m}\cos(2\pi f_m t)\right)$$

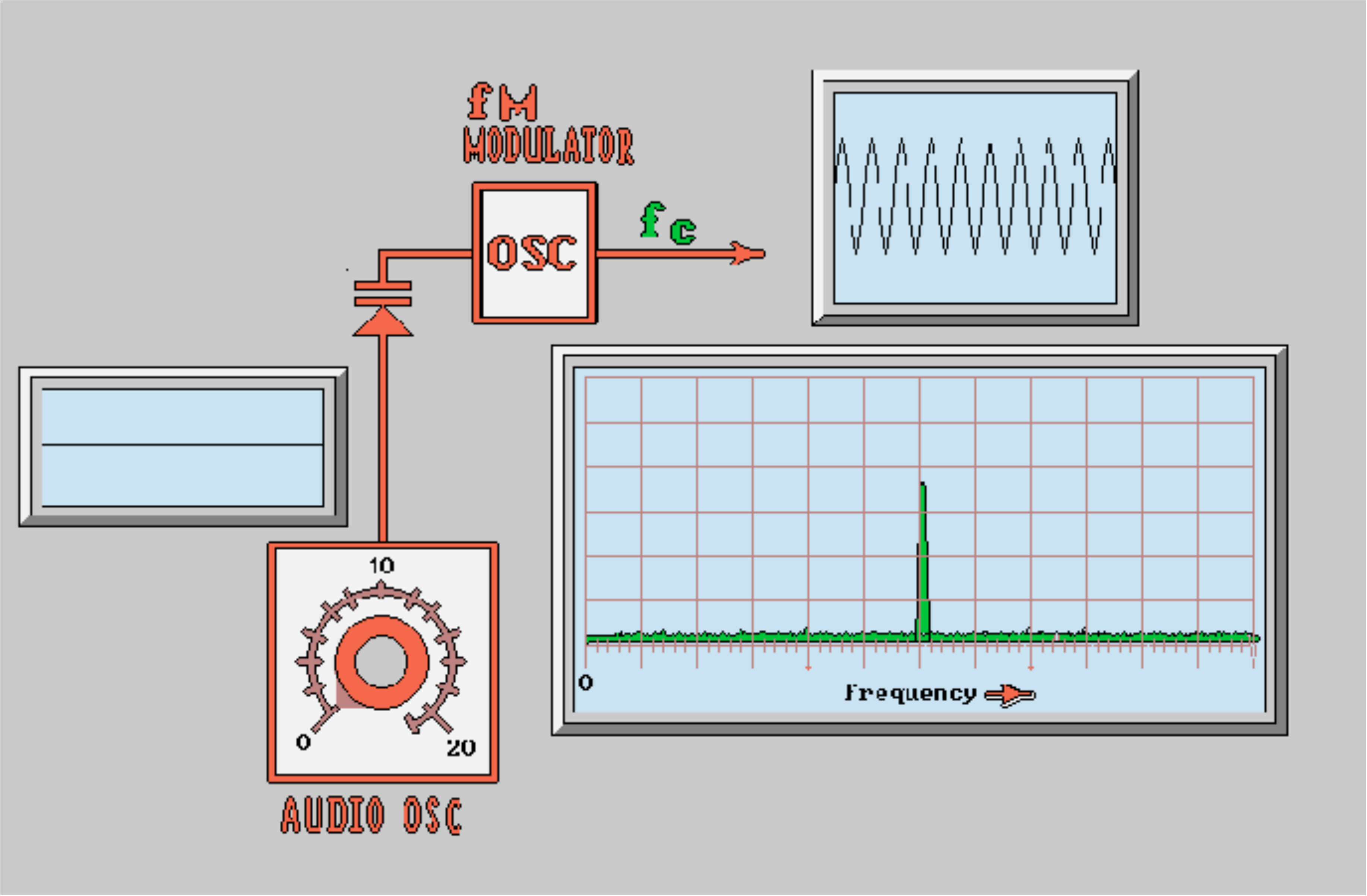
- Here we define modulation index for FM:

$$h = \frac{\text{Peak frequency - deviation}}{\text{highest frequency component in } \mathrm{x}_m(t)} = \frac{\Delta f}{f_m} = \frac{f_\Delta |x_m(t)|}{f_m}$$

- If $h << 1$: narrow band FM, BW $\approx 2f_m$ (+/- 3kHz, P-P comm.)
- If $h >> 1$: wideband FM, BW $\approx 2f_\Delta$ (+/-75kHz, broadcasting)

$\rightarrow$ Wideband FM: use more BW, but better SNR

Animation



- Modulating wave, f_a, varies the rate of change of f_c (from http://www.williamson-labs.com)
- See local file, FM_animation.gif

Demodulation

- AM demodulators:
  - cannot be used due to the constant amplitude of FM signals
- FM dedicated demodulator
  - Phase detector
  - The Foster-Seeley discriminator
  - Ratio detector
  - Quadrature detector

Illustrative Results: