ENSC327
Communications Systems
11: FM Modulation

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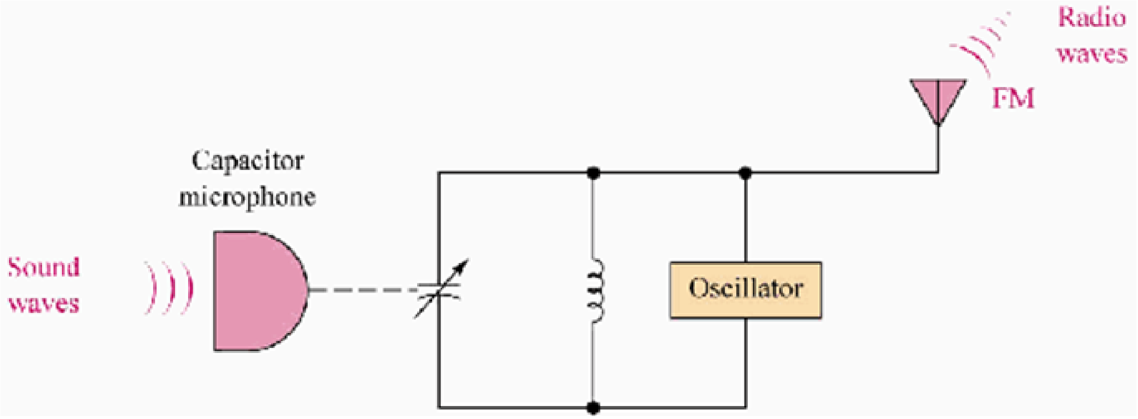
Outline

- Required Background
  - Narrowband FM
  - Frequency mixing
  - Trigonometric identities (the usual!)
- Two methods of generating FM waves:
  - Direct method
  - Indirect Method: Armstrong's wideband frequency modulator

Direct FM generator

- The carrier freq is directly varied by the input signal
- Can be accomplished by Voltage-Controlled Oscillator (VCO), whose output frequency is proportional to the voltage of the input signal.
- A VCO example: implemented by variable capacitor

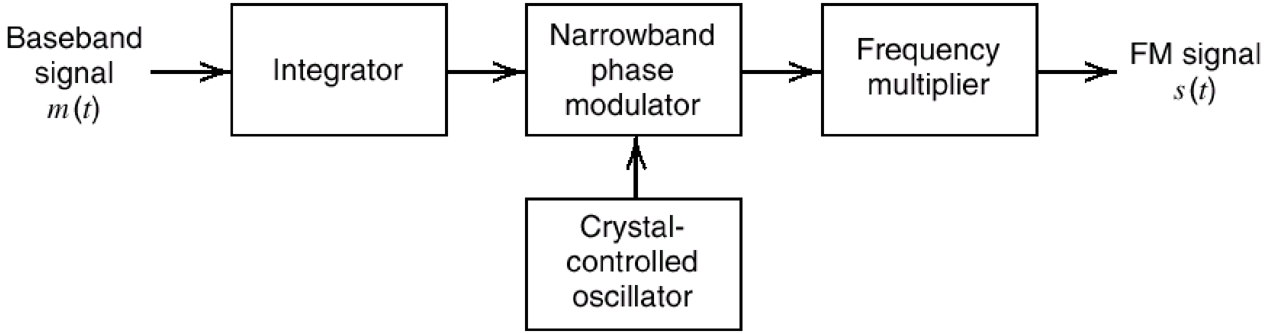


- Advantage: Conceptually very simple.
- Disadvantage: The carrier frequency tends to drift away => requires expensive and complicated feedback circuit for stabilizing the frequency.

Indirect Method: Armstrong Modulator

- Indirect FM is preferred when the stability of carrier frequency is of major concern (e.g., in commercial FM broadcasting)

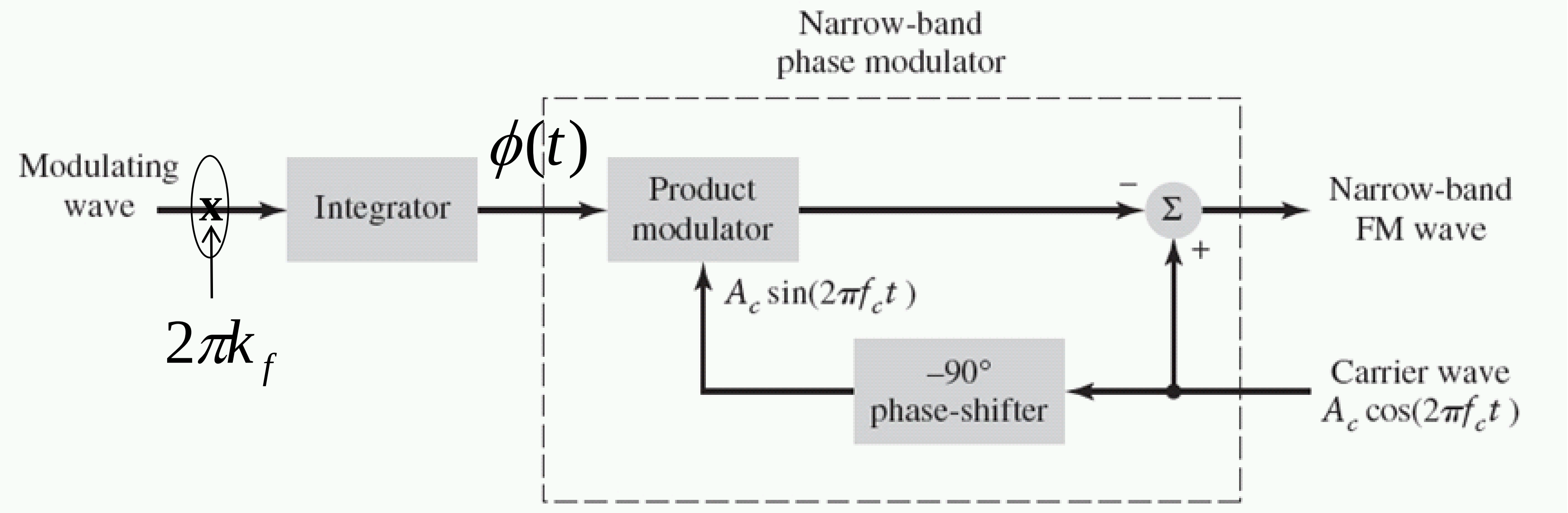
- 1. First obtain NBFM via a NBPM circuit with crystal oscillator
- 2. Apply frequency multiplier
  - Increases both the carrier frequency and the frequency deviation
- 3. If necessary, use mixer to concatenate multiple multipliers
  - Mixer only changes the carrier frequency, but not the frequency deviation.



Recall: Narrow-band FM

- If Δf is small: $s(t) = A_c \cos(2\pi f_c t + \phi(t))$

$$\Longrightarrow \quad s(t) \approx A_c \cos(2\pi f_c t) - A_c \phi(t) \sin(2\pi f_c t)$$



Crystal oscillator can be used to get stable frequency (prevent drifting)

But frequency deviation of NBFM is small.

To get a larger frequency deviation, use frequency multiplier…

Frequency Multiplier

- Frequency multiplier is constructed of a module that raises the signal to the power of n, followed by a band pass signal.
- Let's first look at the case of $n = 2$:

$$s(t) = A_c \cos(2\pi f_c t + 2\pi k_f \int_0^t m(\tau) d\tau)$$

$$\Rightarrow \ s^2(\mathrm{t}) =$$

- Now use a BPF with center frequency $2f_c$:

Frequency Multipliers (Cont.)

- The case of raising to the power of 3 ($n = 3$):

$$s^3(t) = s^2(t)s(t)$$

$$= \frac{A_c^3}{2}\left[1 + \cos\left(2\pi(2f_c)t + 2\pi(2k_f)\int_0^t m(\tau)d\tau\right)\right]\cos\left(2\pi f_c t + 2\pi k_f \int_0^t m(\tau)d\tau\right)$$

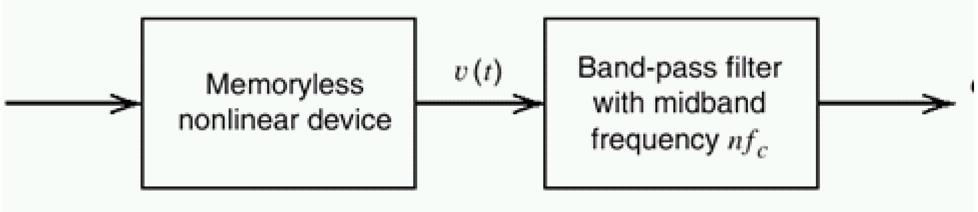
$$= \frac{A_c^3}{2}\cos\left(2\pi f_c t + 2\pi k_f \int_0^t m(\tau)d\tau\right)$$

$$+ \frac{A_c^3}{4}\left[\cos\left(2\pi(3f_c)t + 2\pi(3k_f)\int_0^t m(\tau)d\tau\right) + \cos\left(2\pi f_c t + 2\pi k_f \int_0^t m(\tau)d\tau\right)\right]$$

- BPF at $3f_c$:

Frequency Multipliers (Cont.)

FM signal with f_c and k_f



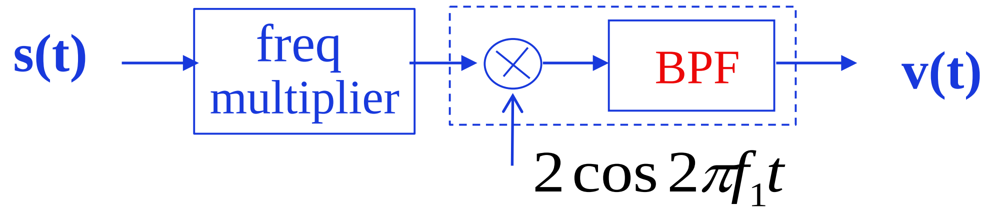
FM signal with mf_c and mk_f

- A general nonlinear circuit produces $v(t) = a_1 s(t) + a_2 s^2(t) + \ldots + a_n s^n(t)$
- This results in several FM signals with carrier frequencies, mf_c, and frequency sensitivity factors, mk_f, for $m = 1, 2, \ldots, n$.
- The BPF is then centered at the desired carrier frequency.
- In practice: n = 2, or 3. Larger n is not efficient.
- But we can concatenate multiple stages to obtain higher orders

Mixer & Frequency Multiplier

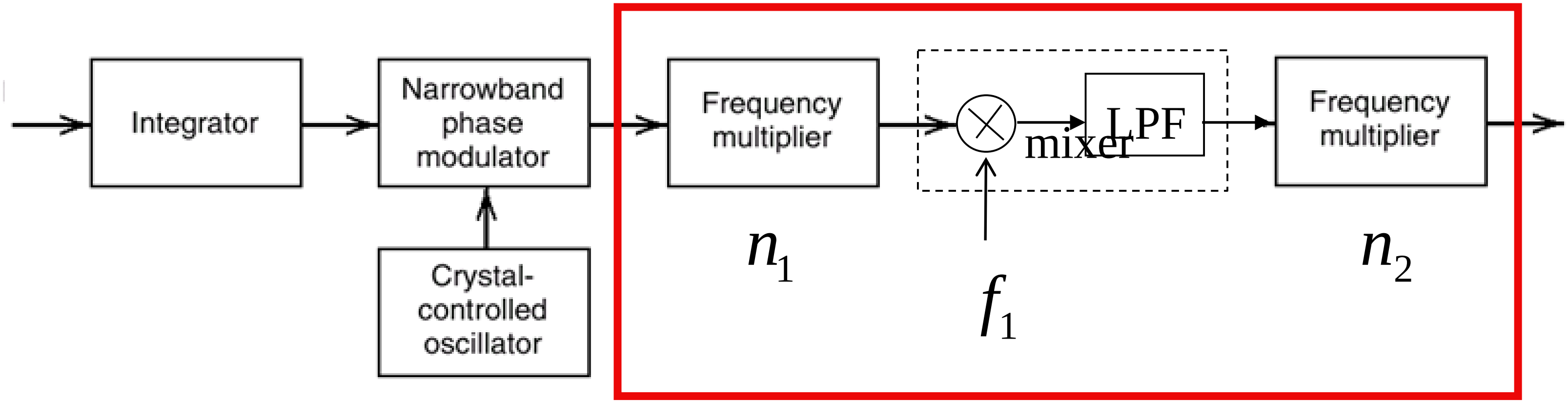
- Frequency multiplier increases both the carrier frequency and frequency deviation of the FM signal.
- By combining a mixer and a frequency multiplier we can adjust them separately.

$$s(t) = A_c \cos(2\pi f_c t + \phi(t)),$$



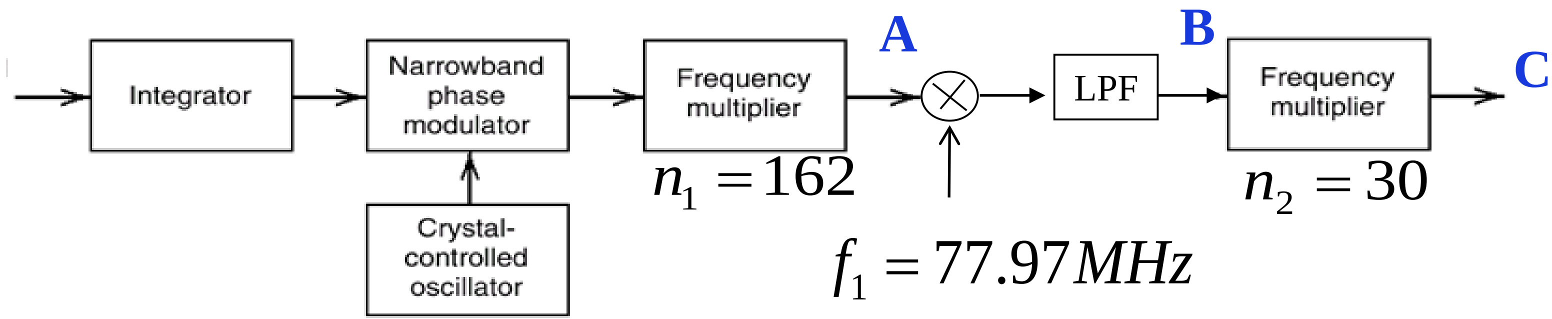
- After the frequency multiplier:
- After multiplying (mixing) with frequency f_1:
- After BPF: freq:

Armstrong's Indirect FM Generator



- Two multipliers and one mixer are used.
  - Allows flexible choices of carrier frequency and frequency deviation.
  - The first stage multiplier increases both fc and Δf.
  - The mixer brings down the carrier frequency.
  - The second frequency multiplier amplifies fc and Δf again.

Example



$$\text{NBPM output}: \ f = 500 kHz, \ \Delta f = 15.432 Hz$$

Find f and Δf at A, B, C.

Point A:

Point B:

Point C:

Summary

- Direct FM generation:
  - The carrier freq is directly varied by the input signal
  - Frequency drifting is a problem
  - Freq deviation < 5KHz
- Indirect FM generation:
  - NBFM followed by freq multiplier
    - Use nonlinear circuit to get multiplier
  - Can use mixer to change the carrier freq
  - Combination of mixer and multiplier provides flexibility.