Two methods of generating FM waves:

- Direct method
- Indirect Method: Armstrong’s wideband frequency modulator

Review of frequency deviation:

Angle modulation: \[ s(t) = A_c \cos(2\pi f_c t + \phi(t)) \]

Instantaneous frequency \[ f_i(t) = \frac{1}{2\pi} \frac{d\theta_i(t)}{dt} = f_c + \frac{1}{2\pi} \frac{d\phi(t)}{dt} \]

Frequency deviation \[ \Delta f = \max \left| \frac{1}{2\pi} \frac{d\phi(t)}{dt} \right|. \]

Frequency deviation for FM signals: \[ \Delta f = k_f \max |m(t)|. \]

For example, FM radio allows 75kHz deviation to each side of the carrier.
Direct FM Generation

- 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.
Problems of direct FM generator

- The carrier freq of VCO tends to drift away.
  - (Crystal oscillator cannot be used in direct FM: its freq is too stable, and is difficult to change.)
  - Feedback freq stabilization circuit is required:
    - The complexity is increased.
- The frequency deviation with direct FM is only about 5 KHz, too small for wideband FM:
  - Recall: the max frequency deviation in commercial FM radio is 75kHz.
Indirect Method: Armstrong Modulator

- First obtain **NBFM** via a NBPM circuit with crystal oscillator
- Then apply **frequency multiplier**
  - Increase both the **carrier frequency** and the **freq deviation**
- If necessary, use **mixer** to concatenate multiple multipliers
  - Mixer only changes the **carrier frequency**, but not the **frequency deviation**.
- Indirect FM is preferred when the stability of carrier frequency is of major concern (e.g., in commercial FM broadcasting)
Recall: Narrow-band FM

- if $\Delta f$ is small: \[ s(t) = A_c \cos(2\pi f_c t + \phi(t)) \]

Crystal oscillator can be used to get stable frequency (prevent drifting)
But frequency deviation of NBFM is small.
To get larger one, use freq multiplier…
Frequency Multipliers

How to increase the frequency deviation?

Answer: trigonometric identity!

From

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

If we can get the squared signal:
Frequency Multipliers

If we can get $s^3(t)$:
A general **nonlinear circuit** produces

\[ v(t) = a_1 s(t) + a_2 s^2(t) + \ldots + a_n s^n(t) \]

- The highest carrier frequency:
- The highest freq sensitivity factor:
- The bandpass filter:
  - Center:
  - Passband width:
  - In practice: \( n = 2, \) or 3. Larger \( n \) is not efficient.
  - But can concatenate multiple stages to obtain higher orders.
Mixer & Frequency Multiplier

- Frequency multiplier increases the freq and deviation together.
- How to adjust them separately to get more flexibilities?

\[ s(t) \rightarrow \text{freq multiplier} \]

- Input: \( s(t) = A_c \cos(2\pi f_c t + \phi(t)) \), with freq deviation \( \Delta f \).
- After freq multiplier:
- After multiplying with local freq \( f_1 \):
- After BPF:
Armstrong’s Indirect FM

- Two stages of multiplier and one mixer are used.
  - Allow flexible choices of carrier freq and freq deviation.
  - The first stage multiplier amplifies both $f_c$ and $\Delta f$.
  - The mixer brings down the central freq.
  - The second stage amplifies $f_c$ and $\Delta f$ again.
Example

NBPM output: \( f = 500kHz, \; \Delta f = 15.432Hz \)

Find \( f \) and \( \Delta f \) at A, B, C.
Example

Total multiplier for $\Delta f$:

$\Delta f = \Delta f_n = f_1 - f_{out} = 97.77 MHz$

$n_1 = 162$

$n_2 = 30$

$f_1 = 77.97 MHz$
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 flexibilities.
Reference

- **Direct FM generation:**
  http://www.ycars.org/EFRA/Module%20B/directfm.htm

- **Indirect FM generation:**
  http://www.ycars.org/EFRA/Module%20B/indirectfm.htm