EE1 and ISE1 Communications I

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Lecture fifteen

Lecture Aims

- To identify how resilient FM is to non-linear distortion
- To outline FM modulators and demodulators

Angle Modulation and non-linearities

- FM signals are constant envelope signals, therefore they are less susceptible to non-linearities
- Example: a non linear device whose input $x(t)$ and output $y(t)$ are related by

$$y(t) = a_1 x(t) + a_2 x^2(t)$$

- if $x(t) = \cos[\omega_c t + \psi(t)]$
- Then

$$\begin{aligned} y(t) &= a_1 \cos[\omega_c t + \psi(t)] + a_2 \cos^2[\omega_c t + \psi(t)] \\ &= \tfrac{a_2}{2} + a_1 \cos[\omega_c t + \psi(t)] + \tfrac{a_2}{2} \cos[2\omega_c t + 2\psi(t)] \end{aligned}$$

Angle Modulation and non-linearities

- For FM wave

$$\psi(t) = k_f \int m(\alpha)d\alpha$$

- The output waveform is

$$y(t) = \frac{a_2}{2} + a_1 \cos[\omega_c t + k_f \int m(\alpha)d\alpha] + \frac{a_2}{2}\cos[2\omega_c t + 2k_f \int m(\alpha)d\alpha]$$

- Unwanted signals can be removed by means of a bandbass filter

Higher order non-linearities

- Consider higher order non-linearities

$$y(t) = a_0 + a_1 x(t) + a_2 x^2(t) + \cdots + a_n x^n(t)$$

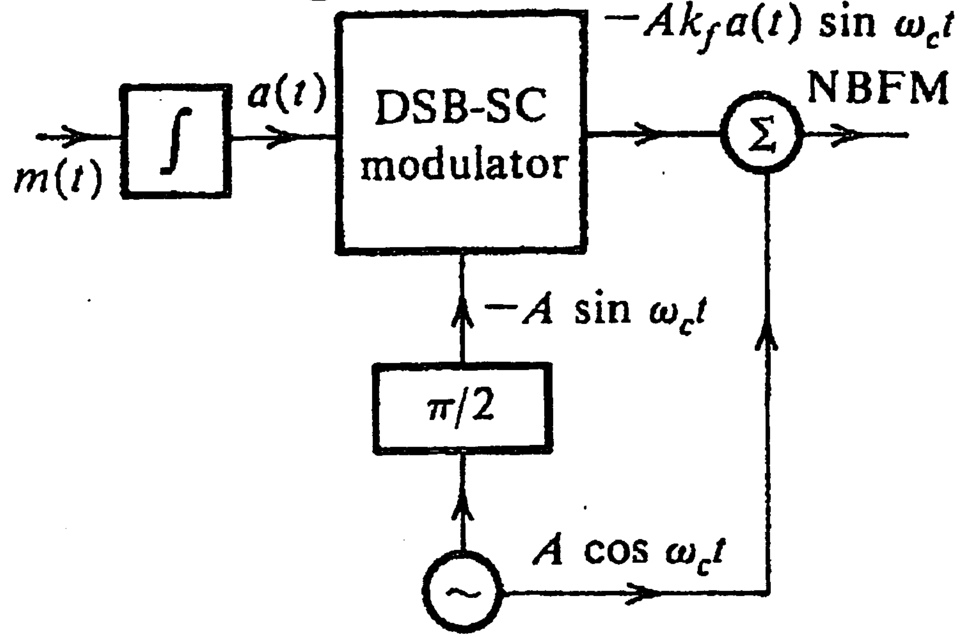
- If the input signal is an FM wave, $y(t)$ will have the form

$$\begin{aligned} y(t) &= c_0 + c_1 \cos\left[\omega_c t + k_f \int m(\alpha)d\alpha\right] + c_2 \cos\left[2\omega_c t + 2k_f \int m(\alpha)d\alpha\right] \\ &+ \cdots + c_n \cos\left[n\omega_c t + nk_f \int m(\alpha)d\alpha\right] \end{aligned}$$

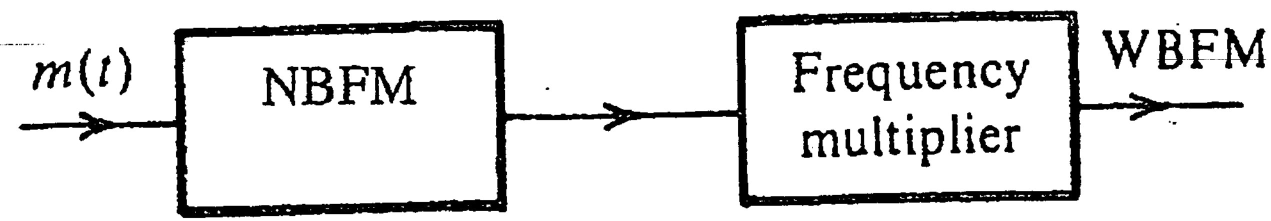
- The deviations are $\Delta f, 2\Delta f, ..., n\Delta f$

Armstrong's Indirect Method of FM Generation

- **Narrowband signal is generated using**



- **NBFM signal is then converted to WBFM using**



Direct Method of FM Generation

- The modulating signal $m(t)$ can control a voltage controlled oscillator to produce instantaneous frequency

$$\omega_i(t) = \omega_c + k_f m(t)$$

- A voltage controlled oscillator can be implemented using an LC parallel resonant circuit with centre frequency

$$\omega_o = \frac{1}{\sqrt{LC}}$$

- If the capacitance is varied by $m(t)$

$$C = C_0 - km(t)$$

Direct Method of FM Generation

- The oscillator frequency is given by

$$\omega_i(t) = \frac{1}{\sqrt{LC_0\left[1 - \frac{km(t)}{C_0}\right]}} = \frac{1}{\sqrt{LC_0}\left[1 - \frac{km(t)}{C_0}\right]^{1/2}}$$

- If $\frac{km(t)}{C_0} \ll 1$, the binomial series expansion gives

$$\omega_i(t) \simeq \frac{1}{\sqrt{LC_0}}\left[1 + \frac{km(t)}{2C_0}\right]$$

- This gives the instantaneous frequency as a function of the modulating signal.

Demodulation of FM signals

- The FM demodulator is given by a differentiator followed by an envelope detector
- Output of the ideal differentiator

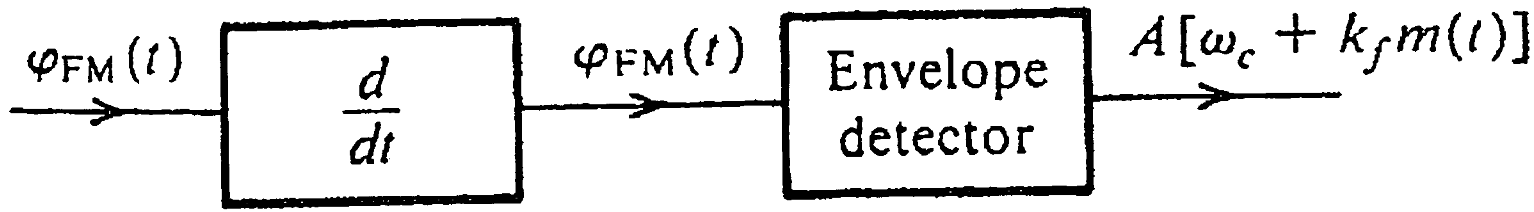
$$\begin{aligned}\dot{\phi}_{FM}(t) &= \frac{d}{dt}\left\{A\cos\left[\omega_c t + k_f \int_{-\infty}^{t} m(\alpha)d\alpha\right]\right\} \\ &= A[\omega_c + k_f m(t)]\sin\left[\omega_c t + k_f \int_{-\infty}^{t} m(\alpha)d\alpha\right]\end{aligned}$$

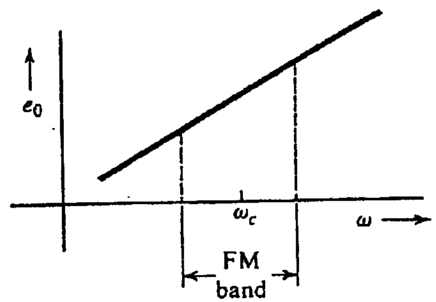
- The above signal is both amplitude and frequency modulated. Hence, an envelope detector with input $\dot{\phi}_{FM}(t)$ yields an output proportional to

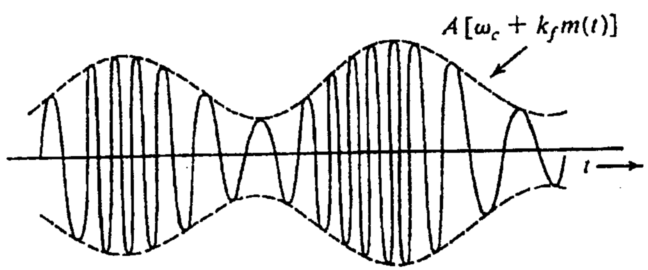
$$A[\omega_c + k_f m(t)]$$

Demodulation of FM signals

- As $\Delta\omega = k_f m_p < \omega_c$ and $\omega_c + k_f m(t) > 0$ for all t. The modulating signal $m(t)$ can be obtained using an envelope detector.

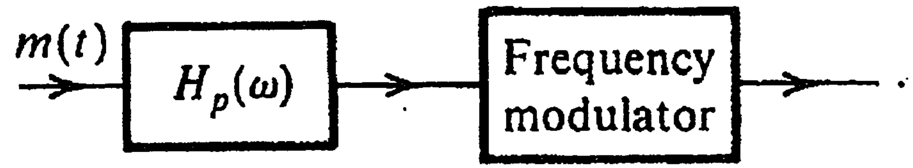




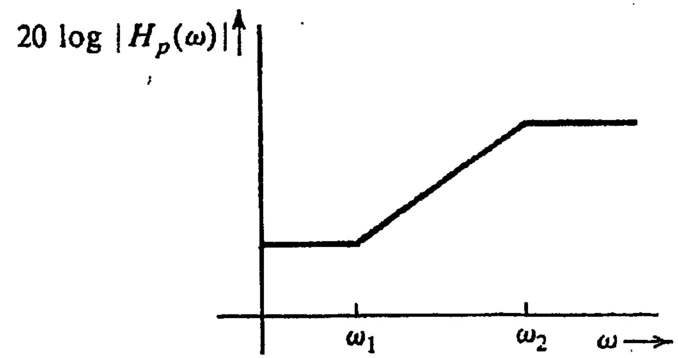


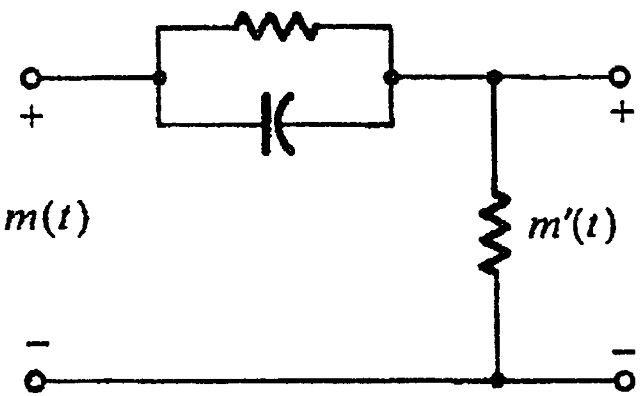
Pre-emphasis and de-emphasis circuits

- **To improve noise immunity of FM signals we use a pre-emphasis circuit at transmitter**



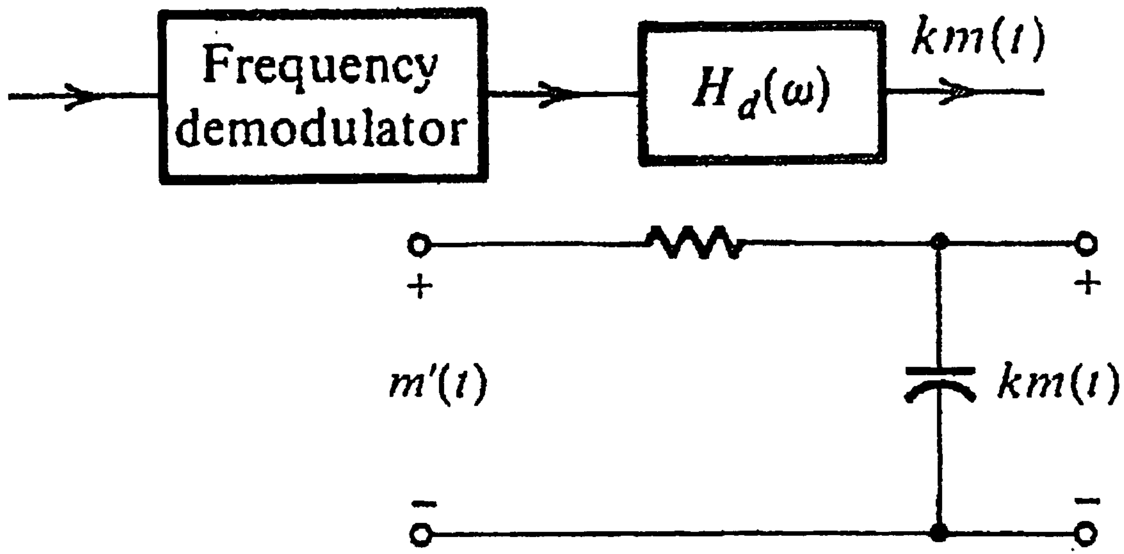
$$H_p(\omega) = K\frac{j\omega + \omega_1}{j\omega + \omega_2}$$

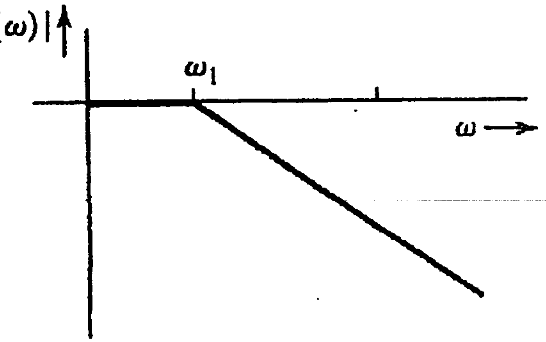




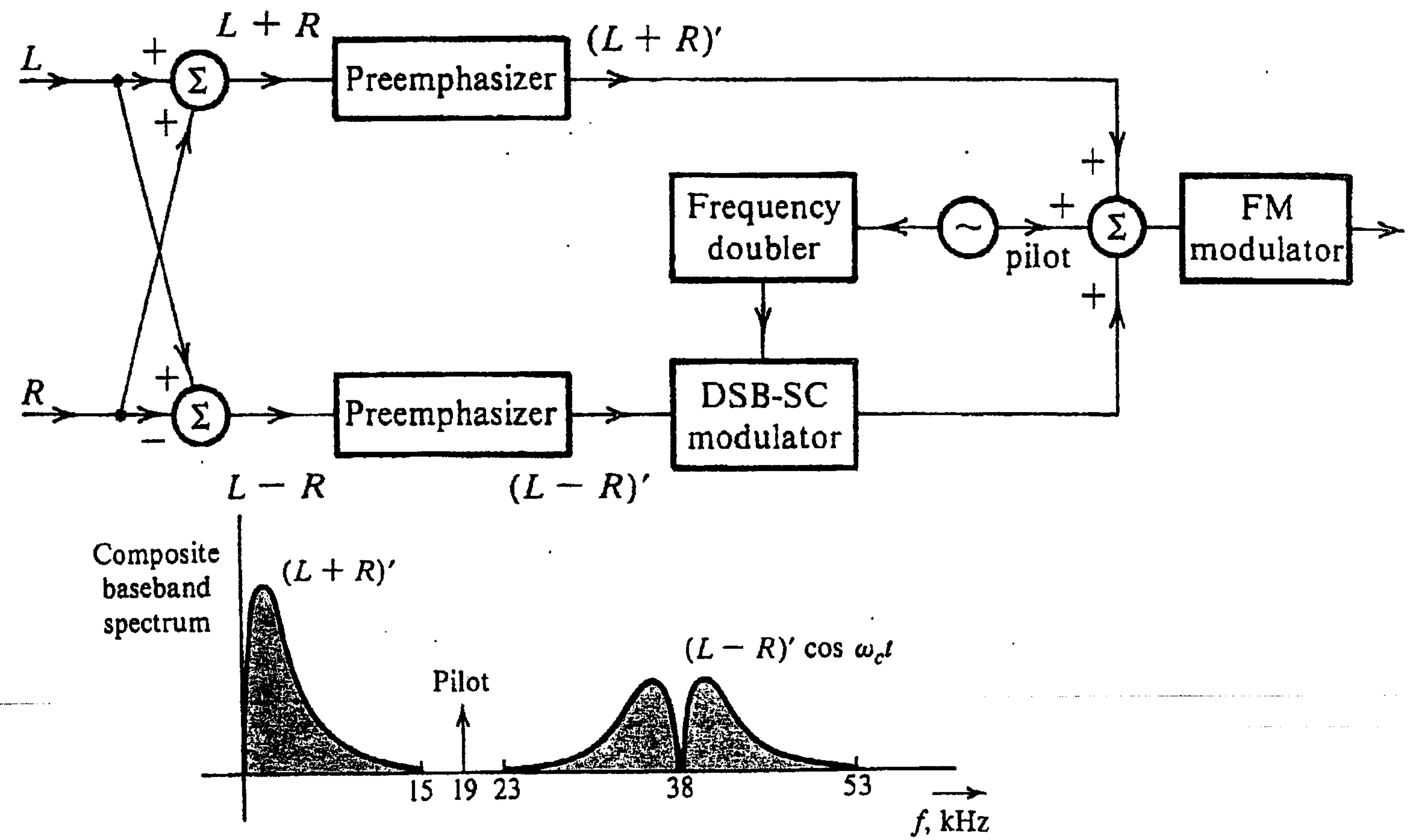
De-emphasis circuit for receiver

- **Receiver de-emphasis circuit**

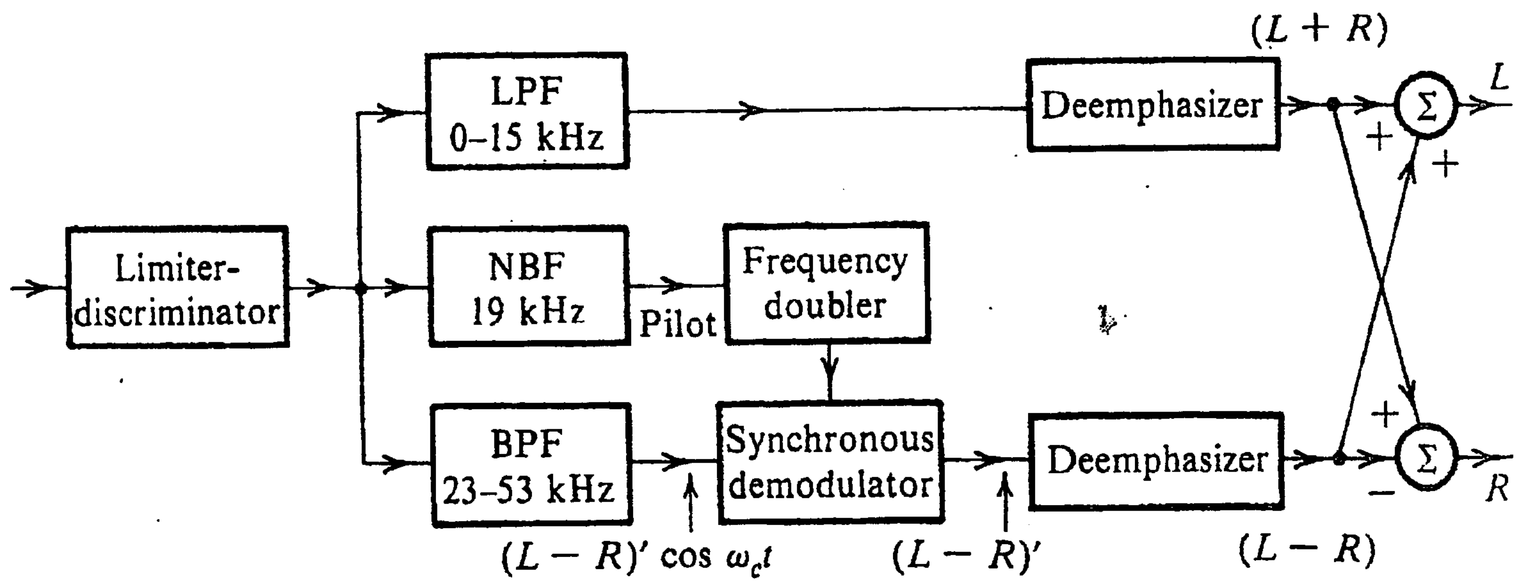




- **Transmitter**



- **Receiver**


Limiter-
discriminator
LPF
0–15 kHz
NBF
19 kHz
Pilot
Frequency
doubler
BPF
23–53 kHz
Synchronous
demodulator
Deemphasizer
Deemphasizer
(L + R)
(L − R)' cos ω_c t
(L − R)'
(L − R)
L
R
Σ
Σ
+
+
+
−

Conclusions

- FM modulators: direct and indirect methods
- FM demodulator
- Pre-emphasis and de-emphasis circuits to improve noise immunity of signals
- FM stereo transmitter and receiver