\[ i_d = i_D (e^{\frac{v_D}{V_T}} - 1) \]

\[ I_D = \text{Reverse Saturation Current} \]

(Harley, Colpitts oscillators)

Let \( C' \) be varied by \( w(t) \)

\[ C = C_0 - K w(t) \]

oscillating or resonant freq.

\[ \frac{1}{\sqrt{L_C}} = \omega_0 = \frac{1}{\sqrt{L C_0 \left[ 1 - K \frac{w(t)}{C_0} \right]}} \]

\[ = \frac{1}{\sqrt{L C_0}} \left[ 1 - K \frac{w(t)}{C_0} \right]^{-1/2} \]

\[ = \frac{1}{\sqrt{L C_0}} \left[ 1 + \frac{K w(t)}{2 C_0} + \frac{3}{8} \frac{K^2 w^2(t)}{C_0^2} + \ldots \right] \]

\[ (a + b)^n = a^n + n a^{n-1} b + \frac{n(n-1)}{2!} a^{n-2} b^2 + \ldots + b^n \]
\[ \omega_0 = \frac{1}{\sqrt{LC_0}} \left[ 1 + \frac{K w(t)}{2 C_0} \right] \]

when \( \frac{K w(t)}{C_0} \ll 1 \)

\[ \omega_0 = \omega_c \left[ 1 + \frac{K w(t)}{2 C_0} \right], \quad \omega_c = \frac{1}{\sqrt{LC_0}} \]

\[ = \omega_c + K_f w(t) \]

\[ K_f = \frac{K \omega_c}{2 C_0} \]

\[ C = C_0 - K w(t), \text{ max capacitance deviation } (\Delta C) = K w_p \]

\[ (\Delta C)_{\text{max}} = 2 \frac{K_f C_0}{\omega_c} w_p \mid w_p = |w(t)|_{\text{max}} \]

\[ \frac{\Delta C_{\text{max}}}{C_0} = 2 \frac{K_f w_p}{\omega_c} = 2 \frac{\Delta f}{f_c} \]

\[ \left( \frac{\Delta f}{f_c} \right) \ll 1, \quad (\Delta C)_{\text{max}} \ll 1 \]

\[ \Delta f = \text{max freq., deviation} \]
5.4 Demodulation of FM

Figure 5.11 (a) FM demodulator frequency response. (b) Output of a differentiator to the input FM wave. (c) FM demodulation by direct differentiation.

FM signal
\[ \omega_i = \omega_c + K_f m(t) \]

Freq. deviation
\[ \omega_c + K_f m(t) \]

\[ \frac{d}{dt} \Phi_{FM}(t) = \frac{d}{dt} \left( A \cos \left[ \omega_c t + K_f \int m(t) dt \right] \right) \]

\[ = -A \left[ \omega_c + K_f m(t) \right] \sin \left[ \omega_c t + K_f \int m(t) dt \right] \]

Envelope of \( \frac{d}{dt} \Phi_{FM}(t) \) is
\[ A \left[ \omega_c + K_f m(t) \right] \]

Freq. deviation \( \Delta \omega = K_f m_p < \omega_c \)

\( m_p \) is max value of \( m(t) \).

\( \Rightarrow \omega_c + K_f m(t) > 0 \)

Envelope detection of \( \frac{d}{dt} \Phi_{FM}(t) \) yields \( m(t) \).
FM Demodulation

Implementation of a Simple Discriminator

\[ H(f) = \frac{j2\pi f Rc}{R + j(2\pi f Rc)} \]

\[ H(f) = \frac{j f}{\left(\frac{1}{2\pi Rc}\right) + j f} \quad \text{when} \quad f \leq \frac{1}{2\pi Rc} \]

\[ H(f) \approx j2\pi f Rc, \quad H(f) \sim f \quad (3.110) \]

**FIGURE:** Implementation of a simple discriminator. (a) RC network. (b) Transfer function. (c) Simple discriminator.

\[ \left| \frac{J}{1 + j} \right| = 0.7 \Omega \]

**See** Fig. 5.11

\[ (\text{freq. deviation from } \omega_c) \sim m(t) \]

**See** Fig. 4.12

\[ \text{Freq. discriminator} \]

\[ \text{Envelope detector} \]

\[ J_d(t) \]
FIGURE: Derivation of balanced discriminator. (a) Bandpass filter. (b) Stagger-tuned bandpass filters. (c) Amplitude response $H(f)$ of balanced discriminator. (d) Balanced discriminator.

$\frac{f_1}{f_2} = \frac{1}{2\pi \sqrt{L_1 C_1}} \frac{1}{2\pi \sqrt{L_2 C_2}}$

$M(f) = |H_1(f)| - |H_2(f)|$

Center frequency:

$f_c = \frac{1}{2\pi \sqrt{L_2 C_2}}$

$x = 1, 2$
**Bandpass Limiter**

\[
\frac{A(t) \cos [\omega_0 t + \theta(t)]}{\nu_i} \xrightarrow{\nu_o} \frac{4}{\pi} \cos [\omega_0 t + \theta(t)]
\]

**Figure 5.12** (a) Hard limiter and bandpass filter used to remove amplitude variations in FM wave. (b) Hard limiter input-output characteristic. (c) Hard limiter input and the corresponding output. (d) Hard limiter output as a function of \(\theta\).

**FM Signal**

\[
\nu_i(t) = A(t) \cos [\omega_0 t + \kappa \int m(x) \, dx]
\]

\[
= A(t) \cos \theta(t)
\]

**Hard Limiter output**

\[
\nu_o(\theta) = \begin{cases} 
1 & \text{for } \cos \theta > 0 \\
-1 & \text{for } \cos \theta < 1
\end{cases}
\]
Bandpass Limiter (cont'd.)

\[ r_0 (\theta) = \frac{4}{\pi} \left( \cos \theta - \frac{1}{3} \cos 3\theta + \frac{1}{5} \cos 5\theta - \cdots \right) \]

F.S. of Square Wave

( Eq. 2.76 / p. 52 )

\[ r_0 [\theta(t)] = \frac{4}{\pi} \left(\cos \left[\omega_c t + k \frac{\pi}{2} \sin (\omega_c t) \, d\omega \right] \right. \]
\[ - \frac{1}{3} \cos \left(3 \left[\omega_c t + k \frac{\pi}{2} \sin (\omega_c t) \, d\omega \right] \right) \]
\[ + \frac{1}{5} \cos \left(5 \left[\omega_c t + k \frac{\pi}{2} \sin (\omega_c t) \, d\omega \right] \right) \]
\[ \cdots \]

BPF output

\[ e_0(t) = \frac{4}{\pi} \cos \left[\omega_c t + k \frac{\pi}{2} \sin (\omega_c t) \, d\omega \right] \]

Amplitude variation of FM signal is eliminated.
PLL is most widely used as a FM demodulator.

\[ \omega_c = \text{Free running or quartz freq. of VCO} \]

\[ \omega_{VCO} = \omega_c + c e_0(t) \]

VCO output = B cos(\(\omega_c t + \theta(t)\))

\[ \frac{d}{dt} [\theta(t)] = c e_0(t) \quad (5.29) \]

Input to PLL = A sin(\(\omega_c t + \theta(t)\))

Multiplier output

= AB sin(\(\omega_c t + \theta(t)\)) cos(\(\omega_c t + \theta(t)\))

= \frac{AB}{2} [\sin(\theta_s - \theta_0) + \sin(2\omega_c t + \theta + \theta_0)]]

Suppressed by loop filter
FM Demodulator (PLL) 5-30

Loop filter output: $L(h(t) = \frac{\omega}{2}[\theta(t) - \theta_e(t)]$

$\theta(t) = \omega \cdot \frac{AB}{2} \sin[\theta(t) - \theta_e(t)]$

$= \frac{AB}{2} \int_0^t h(t-x) \sin[\theta_e(x) - \theta_e(x)] dx \quad (5.25)$

$\frac{d}{dt}[\theta(t)] = C \theta(t) = \frac{CAB}{2} \int_0^t h(t-x) \cdot \sin \theta_e(x) dx \quad (5.26)$

$\theta(t) - \theta_e(t) = \theta_e(t) = \text{Phase error}$

For an FM signal,

$\sin[\omega_c t + \theta_e(t)]$ where

$\theta_e(t) = K_f \int_0^t w(\alpha) d\alpha \quad (5.27)$

$\theta(t) = \theta(t) - \theta_e(t)$

$\theta(t) = K_f \int_0^t w(\alpha) d\alpha - \theta_e(t)$
For small phase error $\theta_e$

$$\theta_e(t) = \frac{1}{c} \frac{d}{dt} [\theta_0(t)] = \frac{k_p}{c} w(t) \quad (5.28)$$

**PM Signal**

$$A \cos[\omega_c t + K_p w(t)]$$

Freq. deviation in $K_p \frac{d}{dt}[w(t)]$.

For the PLL to act as a **PM demodulator**, concatenate an integrator at the end

$$\int K_p \left[ \frac{d}{dt} w(t) \right] dt = \left[ k_p w(t) \right]$$
Phase error $\theta_e = \theta_\omega - \theta_0$

$\sin\theta_e \approx \theta_e$, when $\theta_e \ll 1$

$\theta_\omega(n) - \theta_0(n) = \theta_e(n)$

$\theta_0(n) = \frac{AKH(n)}{\nu} \theta_e(n)$

$\theta_\omega(n) - \theta_0(n) = \frac{\nu}{AKH(n)} \theta_0(n)$

$\frac{\theta_0(n)}{\theta_\omega(n)} = \frac{AKH(n)}{\nu + AKH(n)} \quad (5.29)$

$\theta_e(n) = \left[ \frac{\nu}{\nu + AKH(n)} \right] \theta_\omega(n) \quad (5.30)$

PLL as a carrier generator (coherent detection) at the receiver.
A \sin (\omega s t + \phi_0) \rightarrow \text{PLL} \rightarrow \text{output}

\text{freq.} = \omega_0
\text{phase} = \phi_0

\text{Quiescent freq. of VCO} = \omega_c

\text{Incoming Signal} = A \sin [\omega_c t + \Theta(t)]

\Theta_0 (t) = (\omega_0 - \omega_c) t + \phi_0

\Theta_0 (\lambda) = \frac{\omega_0 - \omega_c}{\lambda^2} + \frac{\phi_0}{\lambda}

\text{Let } H(t) = 1, \text{ I order PLL}

\text{From (5.30)}

\Theta_e (\lambda) = \left[ \frac{\lambda}{\lambda + AK} \right] \left[ \frac{\omega_0 - \omega_c}{\lambda^2} + \frac{\phi_0}{\lambda} \right]

= \frac{(\omega_0 - \omega_c)/AK}{\lambda} - \frac{(\omega_0 - \omega_c)/AK}{\lambda + AK} + \frac{\phi_0}{\lambda + AK}

\Theta_e (\lambda) = \left[ \frac{\omega_0 - \omega_c}{AK} \right] (1 - e^{-AK\lambda}) + \phi_0 e^{-AK\lambda}

(5.31)
\[
\lim_{t \to \infty} \theta_e(t) = \frac{\omega_0 - \omega_c}{AK} \]

= constant phase error

PLL output:

\[
B \cos \left[ \omega_0 t + \phi_0 - \frac{\omega_0 - \omega_c}{AK} \right]
\]

Let \( H(\lambda) = \frac{\lambda + a}{\lambda} \), \( \lambda \) order PLL

Substitute \( \lambda \) (5.30) to get

\[
\theta_e(\lambda) = \frac{\lambda^2}{\lambda^2 + AK(\lambda + a)} \left[ \frac{\omega_0 - \omega_c}{\lambda^2} + \frac{\phi_0}{a} \right]
\]

Apply Final Value Theorem

(FVT) \( \lim_{t \to \infty} x(t) = \lim_{\lambda \to 0} [\Lambda X(\lambda)] \)

\[
\therefore \lim_{t \to \infty} \theta_e(t) = 0
\]

i.e., phase error is zero.

Both freq. & phase synchronism.
In Fig 5.13b, let $H(W) = 1$

From (5.26)

$$\frac{d}{dt} \left[ \theta_e(t) \right] = AK \sin \theta_e(t)$$

$$\theta_e = \theta_i - \theta_0 = \text{phase error}$$

$$\dot{\theta}_e = \dot{\theta}_i - \dot{\theta}_0$$

$$\frac{d}{dt} (\theta_e) = \frac{d}{dt} (\theta_i) - AK \sin [\theta_e(t)]$$

(5.34)

Input to PLL be $A \sin (\omega_c t + \phi_0)$

$$\omega_c = \text{VCO quiescent freq.}$$

$$= A \sin \left[ \omega_c t + (\omega_0 - \omega_c) t + \phi_0 \right]$$

$$= A \sin \left[ \omega_c t + \theta_e(t) \right]$$

$$\therefore \frac{d}{dt} [\theta_e] = (\omega_0 - \omega_c) - AK \sin \theta_e(t)$$

(5.35)
Overall Architecture

Fig. 3 shows the major functional units of the codec. These units include: the RSC microcontroller, the video interface unit (VIU), the audio interface unit (AUI), the video engine unit (VEU), the audio engine (DSP), the host interface unit (HIU), and the SDRAM control unit (DCU). All blocks intercommunicate using two major buses: a 64-bit wide data bus (D-Bus) and a 16-bit wide register bus (R-Bus). In addition to the above seven major blocks, the PIC CTRL block provides control for external NTSC/PAL video encoders and decoders. The PLL block provides clocking for all internal blocks and also external memory. Given an input 27-MHz clock, all internal components operate at 108 MHz. A separate audio PLL can be used to provide an output master clock to external audio A/D and D/A converters.

Application of PLL in MPEG-2 A/V Codec
5.5 Interference in Angle modulated Systems

Consider only the carrier $A \cos \omega_c t$ with interference $I \cos (\omega_c + \omega) t$, i.e.,

$$v(t) = A \cos \omega_c t + I \cos (\omega_c + \omega) t$$

$$= (A + I \cos \omega t) \cos \omega_c t - I \sin \omega t$$

$$= \sqrt{(A + I \cos \omega t)^2 + I^2 \sin^2 \omega t} \cdot \sin \omega_c t$$

$$= \sqrt{\frac{(A + I \cos \omega t)^2 + I^2 \sin^2 \omega t}{(A + I \cos \omega t) \cos \omega_c t - I \sin \omega_c t}}$$

$$E_v(t) = \cos \left[ \omega_c t + \psi_d(t) \right]$$

$$E_v(t) = \sqrt{\frac{I \sin \omega t}{A + I \cos \omega t}}$$

$$\tan \psi_d(t) = \frac{I \sin \omega t}{A + I \cos \omega t}$$

$$\psi_d(t) = \tan^{-1} \left[ \frac{I \sin \omega t}{A + I \cos \omega t} \right]$$
when \( I \ll A \) (small interference)
\[
\tan \psi_d(t) \approx \frac{I}{A} \sin \omega t
\]
\[
\Psi_d(t) \approx \frac{I}{A} \sin \omega t
\]
\[
\nu(t) = E_v(t) \cos [\omega_m t + \Psi_d(t)]
\]

**FM:** freq. deviation \( \frac{1}{A} \) \[\psi_d(t)\]

**FM demodulator**
\[
\nu_d(t) = \frac{I}{A} \cos \omega t \quad (5.38)
\]

**Phase deviation** = \( \Psi_d(t) \)

**PM demodulator**
\[
\nu_d(t) = \frac{I}{A} \sin \omega t \quad (5.37)
\]
Interference in PM & FM

\[ \sim \frac{1}{A}, \quad A = \text{Amplitude of Carrier} \]

In AM signals, interference output is independent of \( A \). PM & FM systems suppress weak interference (\( I << A \)) better than AM systems.

Consider an AM system with interference

\[ v(t) = [A + m(t)] \cos \omega t + [I \cos (\omega_c + \omega) t] \]

\[ = [A + m(t) + I \cos \omega_c t] \cos \omega_c t ] \]

\[ - [I \sin \omega_c t] \sin \omega_c t \]

\[ = \left[ B_1 \right] \cos \omega_c t - \left[ B_2 \right] \sin \omega_c t \]

\[ = \sqrt{B_1^2 + B_2^2} \left[ \frac{B_1}{\sqrt{B_1^2 + B_2^2}} \cos \omega_c t - \frac{B_2}{\sqrt{B_1^2 + B_2^2}} \sin \omega_c t \right] \]
Envelope of $v(t)$ is

$$E(t) = \frac{1}{2} \left[ (A + m(t) + I \cos \omega_1 t)^2 + (I \sin \omega_1 t)^2 \right]$$

$$\approx \left[ A + m(t) + I \cos \omega_1 t \right]^2 \quad I \ll A$$

Interference 'I cos \omega_1 t' is independent of $A$, carrier amplitude.

Interference in PM & FM systems (consider 2 interfering tone signals)

$$v(t) = A \cos \omega_c t + I_1 \cos (\omega_c + \omega_1) t$$
$$+ I_2 \cos (\omega_c + \omega_2) t$$

$$= (A + I_1 \cos \omega_1 t + I_2 \cos \omega_2 t) \cos \omega_c t$$
$$- (I_1 \sin \omega_1 t + I_2 \sin \omega_2 t) \sin \omega_c t$$

$$= K_1 \cos \omega_c t - K_2 \sin \omega_c t$$
\[
\nu(t) = E_\nu(t) \left[ \cos \left( \omega_c t + \psi_\nu(t) \right) \right]^{5.40}
\]

\[
= \sqrt{K_1^2 + K_2^2} \left[ \frac{K_1}{\sqrt{2}} \cos \omega c t - \frac{K_2}{\sqrt{2}} \sin \omega c t \right]
\]

\[
\psi_\nu(t) = \tan^{-1} \left[ \frac{I_1 \sin \omega_1 t + I_2 \sin \omega_2 t}{A + I_1 \cos \omega_1 t + I_2 \cos \omega_2 t} \right]
\]

(For \( A \gg I_1 \) & \( A \gg I_2 \))

\[
\psi_\nu(t) \approx \tan^{-1} \left[ \frac{I_1 \sin \omega_1 t + I_2 \sin \omega_2 t}{A} \right]
\]

\[
\approx \frac{I_1}{A} \sin \omega_1 t + \frac{I_2}{A} \sin \omega_2 t
\]

= Phase deviation PM

Freq. deviation

\[
= \left[ \frac{I_1 \omega_1}{A} \cos \omega_1 t + \frac{I_2 \omega_2}{A} \cos \omega_2 t \right]
\]

Compare with (5.37) & (5.38)
PDE in FM Broadcasting 5-41

Figure 5.16 Effect of interference in PM, FM, and FM with preemphasis-deemphasis.

\[
PDE = \text{(preemphasis-)}
\]

\[
\text{DEemphasis}
\]

\[
\frac{f_1}{2.1 \text{ kHz}}
\]

Figure 4.19 Relative power spectrum of speech signal and the corresponding USB spectrum.

PSD of an audio signal \( w(t) \) is concentrated at lower freqs. below 2.1 kHz. Noise PSD is concentrated at higher freqs.

Preemphasis filter: Boosts high freq. components (\( >2.1 \text{ kHz} \)) of audio signal.
Figure 5.17 Preemphasis-deemphasis in an FM system.

\[ H_3(w) \]

\[ H_4(w) \]

Figure 5.18 (a) Preemphasis filter. (b) Its frequency response. (c) Deemphasis filter. (d) Its frequency response.

\[ H_p(w) = \frac{R_2}{\left[ \frac{1}{j \omega C} \right] \left( \frac{1}{R_1 + \frac{1}{j \omega C}} \right) + \left[ \frac{R_1}{j \omega C} \right]} + R_2 \]

\[ = \frac{R_2}{\left[ \frac{1}{1 + j \omega R_1 R_2 C} \right]} \]

\[ = R_2 \left[ 1 + j \omega R_1 R_2 C \right] \left[ \frac{1}{R_1 + R_2 + j \omega R_1 R_2 C} \right] \]

\[ = \frac{R_2 \left[ R_1 + R_2 + j \omega R_1 R_2 C \right]}{\left( R_1 + R_2 \right) + j \omega R_1 R_2 C} \]

\[ \sim \frac{1}{\omega} \]

\[ \sim \frac{km(t)}{\omega} \]
Deemphasizing filter: Attenuates both high freq. components of audio signal and that of noise
\[ \frac{R}{\sqrt{C}} \quad H_d(w) = \frac{1}{j\omega C} \]
\[ H_d(w) = \frac{1}{R + 1/j\omega C} \]
\[ H_d(w) = \left| \frac{\omega = \frac{1}{RC}, \quad 3dB \text{ point}}{1 + j\omega RC} \right| \]
For \( \frac{w}{RC} \gg 1 \), \( H_d(w) \approx \frac{1}{j\omega RC} \)
\[ H_d(w) \sim \frac{1}{w}, \text{ Integrator} \]

Preemphasis filter
\[ H_p(w) = k \quad \frac{(j\omega + \sqrt{R_1C})}{\sqrt{\frac{R_1 + R_2}{R_1R_2C}}} \]
\[ = \left( \frac{w_2}{w_1} \right) \left( \frac{j\omega + w_1}{j\omega + w_2} \right) \quad (5.39) \]
\[ \omega_1 = \frac{1}{R_1 c} \]

\[ \omega_2 = \frac{(R_1 + R_2)}{R_1 R_2 c} \]

Set \( K = \frac{\omega_2}{\omega_1} = \frac{(R_1 + R_2)}{R_2} \)

Hence

\[ H_p(w) = \frac{\omega_2}{\omega_1} \left( \frac{jw + \omega_1}{jw + \omega_2} \right) \]

For \( \omega \ll \omega_1 \)

\[ H_p(w) \approx \left( \frac{\omega_2}{\omega_1} \right) \left( \frac{\omega_1}{\omega_2} \right) = 1 \]

For \( \omega_1 \ll \omega \ll \omega_2 \)

\[ H_p(w) \approx \left( \frac{\omega_2}{\omega_1} \right) \left( \frac{jw}{\omega_2} \right) = \frac{jw}{\omega_1} \]

For \( \omega >> \omega_2 \)

\[ H_p(w) \approx \left( \frac{\omega_2}{\omega_1} \right) \left( \frac{jw}{\omega_1} \right) = \frac{M}{R_1 C} \]

Choose \( f_1 = 2.1 \text{ kHz} \), \( f_2 = 30 \text{ kHz} \)
<table>
<thead>
<tr>
<th>BAND NAME</th>
<th>FREQUENCY RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF (High Frequency)</td>
<td>3-30MHz</td>
</tr>
<tr>
<td>VHF (Very High Frequency)</td>
<td>30-300MHz</td>
</tr>
<tr>
<td>UHF (Ultra High Frequency)</td>
<td>300MHz-1000MHz</td>
</tr>
<tr>
<td>L-Band</td>
<td>1GHz-2GHz</td>
</tr>
<tr>
<td>S-Band</td>
<td>2GHz-4GHz</td>
</tr>
<tr>
<td>C-Band</td>
<td>4GHz-8GHz</td>
</tr>
<tr>
<td>X-Band</td>
<td>8GHz-12GHz</td>
</tr>
<tr>
<td>Ku-Band</td>
<td>12GHz-18GHz</td>
</tr>
<tr>
<td>K-Band</td>
<td>18GHz-27GHz</td>
</tr>
<tr>
<td>Ka-Band</td>
<td>27GHz-40GHz</td>
</tr>
<tr>
<td>V-Band</td>
<td>40GHz-75GHz</td>
</tr>
<tr>
<td>W-Band</td>
<td>75GHz-110GHz</td>
</tr>
<tr>
<td>Mm-Band (millimeter)</td>
<td>110GHz-300GHz</td>
</tr>
<tr>
<td>AM radio</td>
<td>535KHz-1605KHz</td>
</tr>
<tr>
<td>FM radio/VHF TV</td>
<td>88MHz-108MHz</td>
</tr>
<tr>
<td>UHF TV</td>
<td>470MHz-890MHz</td>
</tr>
<tr>
<td>Microwaves</td>
<td>3GHz-300GHz</td>
</tr>
</tbody>
</table>
Table 5-4  FCC FM STANDARDS

<table>
<thead>
<tr>
<th>Class of Service</th>
<th>Item</th>
<th>FCC Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>FM broadcasting</td>
<td>Assigned frequency, ( f_c )</td>
<td>In 200-kHz increments from 88.1 MHz (FM Channel 201) to 107.9 MHz (FM Channel 300)</td>
</tr>
<tr>
<td></td>
<td>Channel bandwidth</td>
<td>200 kHz</td>
</tr>
<tr>
<td></td>
<td>Noncommercial stations</td>
<td>88.1 MHz (Channel 201) to 91.9 MHz (Channel 220)</td>
</tr>
<tr>
<td></td>
<td>Commercial stations</td>
<td>92.1 MHz (Channel 221) to 107.9 MHz (Channel 300)</td>
</tr>
<tr>
<td></td>
<td>Carrier frequency stability</td>
<td>±2,000 Hz of the assigned frequency</td>
</tr>
<tr>
<td></td>
<td>100% modulation(^a)</td>
<td>( \Delta F = 75 ) kHz</td>
</tr>
<tr>
<td></td>
<td>Audio frequency response(^b)</td>
<td>50 Hz to 15 kHz, following a 75-( \mu )s preemphasis curve</td>
</tr>
<tr>
<td></td>
<td>Modulation index</td>
<td>5 (for ( \Delta F = 75 ) kHz and ( B = 15 ) kHz)</td>
</tr>
<tr>
<td></td>
<td>% harmonic distortion(^b)</td>
<td>&lt;3.5% (50–100 Hz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;2.5% (100–7500 Hz)</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>1.67 (for ( \Delta F = 25 ) kHz and ( B = 15 ) kHz)</td>
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Figure 5.19  (a) FM stereo transmitter. (b) Spectrum of a baseband stereo signal. (c) FM stereo receiver.

FM Broadcasting  
FCC  
88 - 108 MHz  
Separation between adjacent stations 200 KHz  
Peak freq. deviation \( \Delta f = 75 \text{ KHz} \)  
SHD Receiver  \( f_F = 10.7 \text{ MHz} \)
FM Receiver (contd.)

Output of FM demodulator

$$f_c = 38 \text{KHz}$$

Pilot

$$\begin{array}{c}
(L+R)' \\
(L-R)' \cos \omega_c t \\
15 & 19 & 23 & 38 & 53 & f \\
\end{array}$$

Receiver

$$\begin{array}{c}
\text{LPF} \quad 0-15 \\
\text{BPF} \quad 23-53 \\
\end{array}$$

$$\begin{array}{c}
(L+R)' \\
(L-R)' \cos \omega_c t \\
0 & 15 & 61 & 76 & 91 & f \\
\end{array}$$

$$\begin{array}{c}
(-38) \\
(-53) \\
-23 & 23 & 38 & 53 & f \\
\end{array}$$

$$\begin{array}{c}
\text{LPF} \quad 0-15 \\
\text{BPF} \quad 23-53 \\
\times \quad \cos \omega_c t \\
\end{array}$$

$$f_c = 38 \text{KHz}$$
Problem 5.1.1. Use \( \omega_c = 2\pi \times 10^7 \) 
\( f_c = 10^7 \text{ Hz} = 10 \text{ MHz} \) 
\( K_f = 2\pi \times 10^5, \ K_p = 2\pi \times 25 \) 
\( F_M = A \cos \left[ \omega_c t + K_f \int_0^t m(x) \, dx \right] \) 
\( \omega_2 = \omega_c + K_f m(t) \) 
Freq. deviation \( = K_f m(t) \) 

![Graph of \( m(t) \)]

\( m_p = 1, \ \left| \frac{d}{dt} m(t) \right| = \frac{2}{(10^{-3}/4)} \) 
\( F_M = 8000 \) 
\( f_2 = f_c + \frac{K_f}{2\pi} m(t) \) 
\( = 10^7 + 10^5 m(t) \) \( \text{Hz} \) 
Freq. deviation \( = 10^5 m(t) \)
\( \text{Prob. 5.1.1 (Cont.)) } \)

\( (f_z)_{\text{max}} = 10^7 + 10^5 = 10.1 \text{ MHz} \)

\( (f_z)_{\text{min}} = 10^7 - 10^5 = 9.9 \text{ MHz} \)

PM: \( A \cos \left[ \omega_c t + \kappa_p m(t) \right] \)

\( \omega_z = (\omega_c + \kappa_p \frac{d}{dt} [m(t)]) \)

\( f_z = \left[ f_c + \frac{\kappa_p}{2\pi} \frac{d}{dt} [m(t)] \right] \text{ Hz} \)

\( \Delta f = \frac{2\pi \times 25 \times 8000}{2\pi} = 2 \times 10^5 \text{ Hz} \)

\( (f_z)_{\text{max}} = 10^7 + 2 \times 10^5 = 10.2 \text{ MHz} \)

\( (f_z)_{\text{min}} = 10^7 - 2 \times 10^5 = 9.8 \text{ MHz} \)

I \text{ Quarter Cycle} \quad f_z = 10.2 \text{ MHz}

II \quad f_z = 10 \text{ MHz}

III \quad f_z = 9.8 \text{ MHz}

IV \quad f_z = 10 \text{ MHz}
Problem 5.4-2

\[ A \rightarrow \frac{\pi}{4} + \frac{\pi}{4} \rightarrow \theta \]

\[ f_\xi = 101 \text{kHz}, \quad \Delta f = 1 \text{kHz} \]

\[ (f_\xi)_{\text{max}} = 11 \text{kHz}, \quad (f_\xi)_{\text{min}} = 9 \text{kHz} \]

\[ \rightarrow \frac{\pi}{4} + \frac{\pi}{4} \rightarrow \theta \]

\[ \text{At } (\theta) \]

\[ \text{FM: } A \cos \left[ \omega_c t + K_f \int w(\alpha) \, d\alpha \right] \]

\[ \text{Fig. 5.5.4-2} \]

\[ \left( \frac{d}{dt} \left[ x(t) \right] \right)_{\text{FM}} = -A \left[ \omega_c + K_f w(t) \right] \sin \left[ \omega_c t + K_f \int w(\alpha) \, d\alpha \right] \]

Envelope is: \(-A \left[ \omega_c + K_f w(t) \right] \]

Remove DC component \( A w_c \) from the envelope.

\[ w_c >> K_f w_p \]
<table>
<thead>
<tr>
<th>Class of Service</th>
<th>Item</th>
<th>FCC Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>FM broadcasting</td>
<td>Assigned frequency, $f_c$</td>
<td>In 200-kHz increments from 88.1 MHz (FM Channel 201) to 107.9 MHz (FM Channel 300)</td>
</tr>
<tr>
<td>Channel bandwidth</td>
<td>200 kHz</td>
<td></td>
</tr>
<tr>
<td>Noncommercial stations</td>
<td>88.1 MHz (Channel 201) to 91.9 MHz</td>
<td></td>
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<tr>
<td>Commercial stations</td>
<td>92.1 MHz (Channel 221) to 107.9 MHz</td>
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<td>Carrier frequency stability</td>
<td>$\pm 2,000$ Hz of the assigned frequency</td>
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<td>100% modulation$^a$</td>
<td>$\Delta F = 75$ kHz</td>
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<tr>
<td>Audio frequency response$^b$</td>
<td>50 Hz to 15 kHz, following a 75-µs preemphasis curve</td>
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<td>% harmonic distortion$^c$</td>
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2. www.fcc.gov