HW 10
Electronic Communication Systems
Fall 2008
California State University, Fullerson

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Contents

1 Problem 3.24

3.24 Consider a composite wave obtained by adding a noncoherent carrier $A_c \cos(2\pi f_c t + \phi)$ to a DSB-SC wave $\cos(2\pi f_c t)m(t)$. This composite wave is applied to an ideal envelope detector. Find the resulting detector output for

(a) $\phi = 0$

(b) $\phi \neq 0$ and $|m(t)| \ll A_c/2$

Figure 1: the Problem statement

$$s_1(t) = A_c \cos(\omega_c t + \phi)$$

DSB-SC signal is

$$s_2(t) = m(t) \cos(\omega_c t)$$

Hence by adding the above, we obtain

$$s(t) = m(t) \cos(\omega_c t) + A_c \cos(\omega_c t + \phi)$$

The above signal is applied to an ideal envelope detector. The output of an envelope detector is given by

$$a(t) = \sqrt{s_I^2(t) + s_Q^2(t)}$$

Since $s(t)$ is a bandpass signal, we need to first write it in the canonical form $s_I(t) \cos(\omega_c t) - s_Q(t) \sin(\omega_c t)$

Using $\cos(A + B) = \cos A \cos B - \sin A \sin B$, then we have

$$\begin{aligned} s(t) &= m(t) \cos(\omega_c t) + A_c [\cos \omega_c t \cos \phi - \sin \omega_c t \sin \phi] \\ &= [m(t) + A_c \cos \phi] \cos(\omega_c t) - A_c \sin \omega_c t \sin \phi \end{aligned}$$

Hence we see that

$$\begin{aligned} s_I(t) &= m(t) + A_c \cos \phi \\ s_Q(t) &= A_c \sin \phi \end{aligned}$$

Now we can start answering parts (a) and (b)

1.1 Part(a)

When $\phi = 0$, then

$$
\begin{aligned}
s_I(t) &= m(t) + A_c \\
s_Q(t) &= 0
\end{aligned}
$$

Hence

$$
\begin{aligned}
a(t) &= \sqrt{[m(t) + A_c]^2 + 0^2} \\
&= m(t) + A_c
\end{aligned}
$$

2 Part(b)

When $\phi \neq 0$ and $|m(t)| << \frac{A_c}{2}$

$$
\begin{aligned}
a(t) &= \sqrt{[m(t) + A_c]^2 + [A_c \sin\phi]^2} \\
&= \sqrt{[m^2(t) + A_c^2 + 2A_c m(t)] + [A_c^2 \sin^2\phi]}
\end{aligned}
$$

Since $|m(t)| << \frac{A_c}{2}$, then $m^2(t) + A_c^2 + 2A_c m(t) \simeq A_c^2$ hence

$$
\begin{aligned}
a(t) &\simeq \sqrt{A_c^2 + A_c^2 \sin^2\phi} \\
&= A_c\sqrt{1 + \sin^2\phi}
\end{aligned}
$$

3 Problem 5.20

5–20 A modulated signal is described by the equation

$$s(t) = 10\cos[(2\pi \times 10^8)t + 10\cos(2\pi \times 10^3 t)]$$

Find each of the following:

(a) Percentage of AM.
(b) Normalized power of the modulated signal.
(c) Maximum phase deviation.
(d) Maximum frequency deviation.

Figure 2: the Problem statement

3.1 Part(a)

An AM signal is $s(t) = A_c [1 + \mu\, m(t)] \cos(2\pi f_c t + \theta(t))$. Now compare this form with the one given above, which is $s(t) = A_c \cos(2\pi f_c t + \theta(t))$. We see that $\mu = 0$, i.e. no message source exist. Hence percentage of modulation is zero.

3.2 Part(b)

$$P_{av} = \frac{1}{2} A_c^2$$

But $A_c = 10$, hence

$$\begin{aligned} P_{av} &= \frac{100}{2} \\ &= 50\text{watt} \end{aligned}$$

3.3 Part(c)

From the general form for angle modulated signal

$$s(t) = \cos(\omega_c t + \theta(t))$$

Looking at

$$s(t) = A_c \cos\left(\overbrace{\overbrace{\left(2\pi \times 10^8\right)}^{2\pi f_c} t + \overbrace{10 \cos\left(2\pi \times 10^3 t\right)}^{\theta(t)}}^{Total\ \ Phase} \right)$$

Phase deviation is

$$\theta(t) = 10 \cos\left(2\pi \times 10^3 t\right)$$

Which is maximum when $\cos(2\pi \times 10^3 t) = 1$Hence maximum Phase deviation is 10 radians.

3.4 part(d)

Now, we know that the instantenouse frequency f_i is given by

$$\begin{aligned} f_i(t) &= \frac{1}{2\pi} \frac{d}{dt} (\text{total phase}) \\ &= \frac{1}{2\pi} \frac{d}{dt} [\omega_c t + \theta(t)] \\ &= \frac{1}{2\pi} \frac{d}{dt} \left[2\pi f_c t + 10 \cos\left(2\pi \times 10^3 t\right)\right] \\ &= f_c - 10\left(10^3\right) \sin\left(2\pi \times 10^3 t\right) \end{aligned}$$

The deviation of frequency is the difference between f_i and the carrier frequency f_c. Hence from the above we see that the frequency deviation is

$$\begin{aligned}\Delta f &= f_i - f_c \\ &= -10\left(10^3\right)\sin\left(2\pi\times 10^3 t\right)\end{aligned}$$

So, maximum Δf occures when $\sin\left(2\pi\times 10^3 t\right) = -1$, hence

$$\max\left(\Delta f\right) = 10^4 \text{ Hz}$$

4 Problem 5.22

5–22 A sinusoidal modulating waveform of amplitude 4 V and frequency 1 kHz is applied to an FM exciter that has a modulator gain of 50 Hz/V.
(a) What is the peak frequency deviation?
(b) What is the modulation index?

Figure 3: the Problem statement

The modulating waveform is $m(t)$ Hence (I am assuming it is cos since it said sinusoidal)

$$\begin{aligned}m(t) &= A_m\cos\left(2\pi f_m t\right) \\ &= 4\cos\left(2000\pi t\right)\end{aligned}$$

Since it is an FM signal, then

$$s(t) = A_c\cos\left[\overbrace{\omega_c t + 2\pi k_f\int_0^t m(x)\,dx}^{\theta(t)}\right]$$

Where k_f is the frequency deviation constant in cycle per volt-second. The gain here means the frequency gain, which is the frequency deviation (deviation from the f_c frequency). Let Δf be the frequency deviation in Hz, then

$$\begin{aligned}\Delta f &= f_i - f_c \\ &= \frac{1}{2\pi}\frac{d}{dt}\theta(t) \\ &= k_f m(t) \\ &= k_f\left[4\cos\left(2000\pi t\right)\right]\end{aligned}$$

4.1 Part(a)

max Δf is

$$(\Delta f)_{\max} = 4k_f$$

But $k_f = 50$ hz/volt, hence

$$\begin{aligned}(\Delta f)_{\max} &= 4 \times 50\\ &= 200\text{hz}\end{aligned}$$

4.2 Part(b)

Modulation index

$$\begin{aligned}\beta &= \frac{(\Delta f)_{\max}}{f_m}\\ &= \frac{200}{1000}\\ &= 0.2\end{aligned}$$

5 Problem 5.24

5–24 An FM transmitter has the block diagram shown in Fig. P5–24. The audio frequency response is flat over the 20-Hz-to-15-kHz audio band. The FM output signal is to have a carrier frequency of 103.7 MHz and a peak deviation of 75 kHz.
(a) Find the bandwidth and center frequency required for the bandpass filter.
(b) Calculate the frequency f_0 of the oscillator.
(c) What is the required peak deviation capability of the FM exciter?

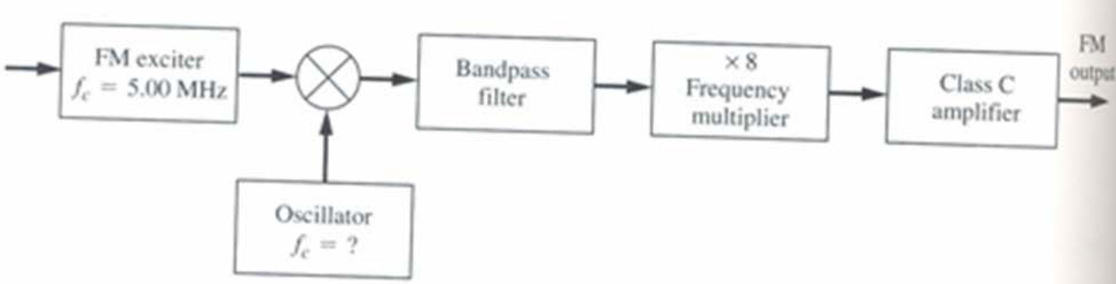

Figure P5–24

Figure 4: the Problem statement

$$s\left(t\right) = A_c \cos\left(2\pi f_c t + 2\pi k_f \int_0^t m\left(x\right) dx\right)$$

We are told the carrier frequency has $f_c = 103.7$ Mhz, but there is a multiplier of 8, and hence the center frequency of the bandpass filter must be $\frac{1}{8}$ of the carrier frequency. i.e.

center frequency of the bandpass filter is $\frac{1}{8}103.7 = \frac{103.7}{8} = 12.963$

Since peak deviation is $75khz$, which means the deviation from the central frequency has maximum of $75khz$, then

$$\frac{75}{8} = 9.375 \text{ khz}$$

Hence bandwidth from center of frequency of bandwidth filter is 9.375 but we need to add frequency width of the audio which is $15000 - 20 = 14980$ Hz on both side, hence

Bandwidth of BPF is $9.375 \times 10^3 \pm 14980$

5.1 Part (b)

To do

6 Problem 5.26

> **5–26** A modulated RF waveform is given by $500 \cos[\omega_c t + 20 \cos \omega_1 t]$, where $\omega_1 = 2\pi f_1$, $f_1 = 1$ kHz, and $f_c = 100$ MHz.
>
> **(a)** If the phase deviation constant is 100 rad/V, find the mathematical expression for the corresponding phase modulation voltage $m(t)$. What is its peak value and its frequency?
>
> **(b)** If the frequency deviation constant is 1×10^6 rad/V-s, find the mathematical expression for the corresponding FM voltage $m(t)$. What is its peak value and its frequency?
>
> **(c)** If the RF waveform appears across a 50-Ω load, determine the average power and the PEP.

Figure 5: the Problem statement

$$s\left(t\right) = A_c \cos\left(\omega_c t + 20 \cos \omega_1 t\right)$$

where $A_c = 500, f_1 = 1khz, f_c = 100Mhz$

6.1 Part(a)

The general form of the above PM signal is

$$s(t) = A_c \cos\left(\omega_c t + \overbrace{k_p m(t)}^{\text{phase deviation}}\right)$$

Where $k_p m(t)$ is the phase deviation, and k_p is the phase deviation constant in radians per volt. Hence we write

$$k_p m(t) = 20 \cos \omega_1 t$$

Then

$$m(t) = \frac{20 \cos \omega_1 t}{k_p}$$

But we are given that $k_p = 100$ rad/voltage and $f_1 = 1000hz$, then the above becomes

$$\begin{aligned} m(t) &= \frac{20 \cos(2000\pi t)}{100} \\ &= 0.2 \cos(2000\pi t) \end{aligned}$$

its frequency is 1 khz and its peak value is 0.2 volts

6.2 Part(b)

The general form of the above FM signal is

$$s(t) = A_c \cos\left(\omega_c t + k_f \int_0^t m(x)\, dx\right)$$

Where k_f is the frequency deviation constant in radians per volt-second

Hence

$$k_f \int_0^t m(x)\, dx = 20 \cos \omega_1 t$$

Solve for $m(t)$ in the above, given that $k_f = 10^6$radians per volt-second, hence

$$\begin{aligned} k_f \int_0^t m(x)\, dx &= 20 \cos \omega_1 t \\ \int_0^t m(x)\, dx &= \frac{20 \cos(2000\pi t)}{10^6} \end{aligned}$$

Take derivative of both sides, we obtain

$$\begin{aligned} m(t) &= \frac{20}{10^6}\left[-\sin(2000\pi t)\times 2000\pi\right] \\ &= -\frac{20\times 2000\pi}{10^6}\sin(2000\pi t) \\ &= -0.126\sin(2000\pi t) \end{aligned}$$

Hence its peak value is 0.126 and its frequency is 1 khz

6.3 Part(c)

$$\begin{aligned} P_{av} &= \frac{\langle s^2(t)\rangle}{50} \\ &= \frac{\frac{1}{2}A_c^2}{50} \\ &= \frac{500^2}{100} \\ &= 2500\text{watt} \end{aligned}$$

PEP is average power obtained if the complex envelope is held constant at its maximum values. i.e. (the normalized PEP) is

$$PEP = \frac{1}{2}\left[\max\left(|\tilde{s}(t)|\right)\right]^2$$

Since

$$\begin{aligned} s(t) &= A_c\cos(\omega_c t + 20\cos\omega_1 t) \\ &= A_c\left[\cos\omega_c t\cos(20\cos\omega_1 t) - \sin\omega_c t\sin(20\cos\omega_1 t)\right] \\ &= \overbrace{A_c\cos(20\cos\omega_1 t)}^{s_I(t)}\cos\omega_c t - \overbrace{A_c\sin(20\cos\omega_1 t)}^{s_Q(t)}\sin\omega_c t \end{aligned}$$

Hence

$$\begin{aligned} \tilde{s}(t) &= s_I(t) + js_Q(t) \\ &= A_c\cos(20\cos\omega_1 t) + jA_c\sin(20\cos\omega_1 t) \end{aligned}$$

Then

$$\begin{aligned} |\tilde{s}(t)| &= \sqrt{\left[A_c\cos(20\cos\omega_1 t)\right]^2 + \left[A_c\sin(20\cos\omega_1 t)\right]^2} \\ &= A_c\sqrt{\cos^2(20\cos\omega_1 t) + \sin^2(20\cos\omega_1 t)} \\ &= A_c \end{aligned}$$

Hence the non-normalized PEP is

$$\begin{aligned} PEP &= \frac{\frac{1}{2}\left[A_c\right]^2}{50} \\ &= \frac{500^2}{100} \\ &= 2500\text{watt} \end{aligned}$$

ps. is there an easier or more direct way to find PEP than what I did? (assuming it is correct)

7 Key solution

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and part of 9

5-18. (a.)

(A) $v_A(t) = m(t)\cos\omega_{if}t \mp \hat{m}(t)\sin\omega_{if}t$ (− ← USSB, + ← LSSB)

(D) $v_D(t) = \cos\omega_{if}t$

(B) $v_B(t) = v_A(t)v_D(t) = m(t)\cos^2\omega_{if}t \mp \hat{m}(t)\sin\omega_{if}t\cos\omega_{if}t$

$= \frac{m(t)}{2}(1+\cos 2\omega_{if}t) \mp \frac{\hat{m}(t)}{2}\sin 2\omega_{if}t$

(C) $v_C(t) = \frac{m(t)}{2}$

(E) $v_E(t) = \sin\omega_{IF}t$

(F) $v_F(t) = v_A(t)\,v_E(t)$

$= m(t)\sin\omega_{IF}t\cos\omega_{IF}t \mp \hat{m}(t)\sin^2\omega_{IF}t$

$= \frac{m(t)}{2}\sin 2\omega_{IF}t \mp \frac{\hat{m}(t)}{2}\left(1-\cos 2\omega_{IF}t\right)$

(G) $v_G(t) = \mp\frac{\hat{m}(t)}{2}$

(H) $v_H(t) = \pm\frac{m(t)}{2}$

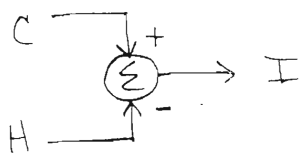
(I) $v_I(t) = v_C(t) + v_H(t)$

$= \frac{m(t)}{2} \pm \frac{m(t)}{2}$

$$v_I(t) = \begin{cases} m(t), & \text{USSB} \\ 0, & \text{LSSB} \end{cases}$$

EE 443 Hw # page 2

5.18 Cont'd) To receive LSSB signals, <u>subtract</u> $v_H(t)$ from $v_C(t)$ at the summer.



(b.) see part (a.)

(c.) see part (a.)

(d.) IF should be centered at $f_c \pm 1.5KHz$ (+ USSB, − LSSB), have 3KHz BW and as small a roll-off factor as is economically feasible.

LPF should have 3KHz BW and as small a roll-off factor as is feasible, also.

√ 5-2a (a.) <u>0% AM</u>

(b.) $P_{norm} = A_c^2/2 = 10^2/2 = \underline{50W}$

(c.) $\Delta\theta_{max} = \underline{10 \text{ radians}}$

(d.) $\omega_d(t) = \frac{d\theta(t)}{dt} = -10(2000\pi)\sin(2000\pi t)$

$\Delta F = \frac{\Delta\omega_d}{2\pi} = \frac{10(2000\pi)}{2\pi} = 10^4 = \underline{10\,kHz}$

EE 443 HW # page 3

5-22. $m(t) = A_m \cos(2\pi f_m t) = 4\cos(2\pi \times 10^3 t)$

(a.) $f_i(t) = f_c + \Delta F \cos(2\pi \times 10^3 t)$

$\Delta F = k_f A_m = \left(\frac{50\,Hz}{V}\right)(4V) = \underline{200\,Hz}$

(b.) $\beta = \frac{\Delta F}{f_m} = \frac{200\,Hz}{1\,kHz} = \underline{\underline{0.2}}$

✓ 5-24. (a.) $f_{BPF} = \frac{103.7}{8}\,MHz = \underline{\underline{12.96\,MHz}}$

$\Delta F_{BPF} = \frac{75\,KHz}{8} = 9.375\,KHz$

$BW_{BPF} = 2(\Delta F + f_m) = 2(9.375 + 15)\,KHz$

$= \underline{\underline{48.75\,KHz}}$

(b.) $f_{BPF} = f_c + f_o \Rightarrow f_o = 12.96 - 5 = \underline{\underline{7.96\,MHz}}$

$f_{BPF} = f_c - f_o \Rightarrow f_o = 12.96 + 5 = \underline{\underline{17.96\,MHz}}$

↑ $f_c = 5\,MHz$

(c.) $\Delta F_{FME} = \frac{75\,KHz}{8} = \underline{\underline{9.38\,KHz}}$

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✓ **5-26.** (a.) $\Theta(t) = D_p m_p(t) = 20 \cos \omega_1 t$

$$\Rightarrow m_p(t) = \frac{20}{D_p} \cos \omega_1 t = \underline{\underline{0.2 \cos(2000\pi t)}}$$

$$m_p(t)_{peak} = \underline{\underline{0.2\ V}} \quad ; \quad f_m = \underline{\underline{1\ KHz}}$$

(b.) $\Theta(t) = D_f \int_{-\infty}^{t} m_f(\lambda)\, d\lambda = 20 \cos \omega_1 t$

$$\Rightarrow m_f(t) = \frac{20}{D_f} \frac{d}{dt}\left[\cos \omega_1 t\right]$$

$$= \frac{-20}{10^6}(2000\pi) \sin \omega_1 t$$

$$m_f(t) = \underline{\underline{-.1257 \sin \omega_1 t}}$$

$$m_f(t)_{peak} = \underline{\underline{.1257\ V}} \quad ; \quad f_m = \underline{\underline{1\ KHz}}$$

(c.) $P_{AV} = \frac{V_{rms}^2}{R} = \frac{(500)^2}{2(50)} = \underline{\underline{2.5\ KW}}$

$$PEP = \underline{\underline{2.5\ KW}}$$

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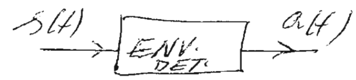
3.24)



$$s(t) = m(t)\cos 2\pi f_c t + A_c \cos(2\pi f_c t + \varphi)$$

$$= m(t)\cos 2\pi f_c t + A_c \cos\phi \cos 2\pi f_c t - A_c \sin\phi \sin 2\pi f_c t$$

$$= \underbrace{(m(t) + A_c \cos\varphi)}_{\text{In phase Comp.}} \cos 2\pi f_c t - \underbrace{A_c \sin\phi}_{\text{quadrature Component}} \sin 2\pi f_c t$$

$$a(t) = \sqrt{(m(t) + A_c\cos\phi)^2 + A_c^2 \sin^2\phi}$$

$$= \sqrt{m^2(t) + A_c^2\cos^2\phi + 2A_c\cos\phi\, m(t) + A_c^2\sin^2\phi}$$

$$= \sqrt{m^2(t) + A_c^2 + 2A_c\cos\phi\, m(t)} \qquad (1)$$

a) If $\varphi = 0 \Rightarrow a(t) = \sqrt{m^2(t) + A_c^2 + 2A_c m(t)} = \sqrt{(m(t) + A_c)^2}$

$\Rightarrow a(t) = |m(t) + A_c| = m(t) + A_c$ if $|m(t)| < A_c$

b) For $\phi \neq 0$ and $|m(t)| << A_c/2$ using eq (1)

$$a(t) = A_c\sqrt{1 + \frac{2}{A_c}\cos\phi\, m(t) + \frac{m^2(t)}{A_c^2}}$$

$$\simeq A_c\sqrt{1 + \frac{2}{A_c}\cos\phi\, m(t)}$$ we can neglect $\frac{m^2(t)}{A_c^2}$ since $|m(t)| << A_c/2$

$$= A_c\left[1 + \frac{1}{2}\cdot\frac{2}{A_c}\cos\phi\, m(t)\right]$$ using $(1+x)^\alpha \simeq 1 + \alpha x$ if $x << 1$

$$= A_c + \cos\phi\, m(t)$$

8 my graded HW

HW10, EGEE 443. CSUF, Fall 2008 (3.24, 5-20,5-22,5-24,5-26)

Nasser Abbasi

December 4, 2008

18/20

1 Problem 3.24

3.24 Consider a composite wave obtained by adding a noncoherent carrier $A_c \cos(2\pi f_c t + \phi)$ to a DSB-SC wave $\cos(2\pi f_c t) m(t)$. This composite wave is applied to an ideal envelope detector. Find the resulting detector output for

(a) $\phi = 0$

(b) $\phi \neq 0$ and $|m(t)| \ll A_c/2$

$$s_1(t) = A_c \cos(\omega_c t + \phi)$$

DSB-SC signal is

$$s_2(t) = m(t) \cos(\omega_c t)$$

Hence by adding the above, we obtain

$$s(t) = m(t) \cos(\omega_c t) + A_c \cos(\omega_c t + \phi)$$

The above signal is applied to an ideal envelope detector. The output of an envelope detector is given by

$$a(t) = \sqrt{s_I^2(t) + s_Q^2(t)}$$

Since $s(t)$ is a bandpass signal, we need to first write it in the canonical form $s_I(t)\cos(\omega_c t) - s_Q(t)\sin(\omega_c t)$

Using $\cos(A+B) = \cos A \cos B - \sin A \sin B$, then we have

$$\begin{aligned} s(t) &= m(t)\cos(\omega_c t) + A_c[\cos\omega_c t \cos\phi - \sin\omega_c t \sin\phi] \\ &= [m(t) + A_c\cos\phi]\cos(\omega_c t) + A_c \sin\omega_c t \sin\phi \end{aligned}$$

Hence we see that

$$\begin{aligned} s_I(t) &= m(t) + A_c\cos\phi \\ s_Q(t) &= A_c \sin\phi \end{aligned}$$

Now we can start answering parts (a) and (b)

1.1 Part(a)

When $\phi = 0$, then

$$s_I(t) = m(t) + A_c$$
$$s_Q(t) = 0$$

Hence

$$a(t) = \sqrt{[m(t) + A_c]^2 + 0^2}$$
$$= |m(t) + A_c| \leftarrow \text{don't miss the absolute value}$$
$$= m(t) + A_c, \text{ if } |m(t)| < A_c$$

− 0.5

1.2 Part(b)

When $\phi \neq 0$ and $|m(t)| << \frac{A_c}{2}$

$$a(t) = \sqrt{[m(t) + A_c]^2 + [A_c \sin\phi]^2}$$
$$= \sqrt{[m^2(t) + A_c^2 + 2A_c m(t)] + [A_c^2 \sin^2\phi]}$$

Since $|m(t)| << \frac{A_c}{2}$, then $m^2(t) + A_c^2 + 2A_c m(t) \simeq A_c^2$ hence

$$a(t) \simeq \sqrt{A_c^2 + A_c^2 \sin^2\phi}$$
$$= A_c\sqrt{1 + \sin^2\phi}$$

ok. See sol.

2 Problem 5.20

5–20 A modulated signal is described by the equation

$$s(t) = 10\cos[(2\pi \times 10^8)t + 10\cos(2\pi \times 10^3 t)]$$

Find each of the following:
(a) Percentage of AM.
(b) Normalized power of the modulated signal.
(c) Maximum phase deviation.
(d) Maximum frequency deviation.

2.1 Part(a)

An AM signal is $s(t) = A_c[1 + \mu\, m(t)]\cos(2\pi f_c t + \theta(t))$. Now compare this form with the one given above, which is $s(t) = A_c \cos(2\pi f_c t + \theta(t))$. We see that $\mu = 0$, i.e. no message source exist. Hence $\boxed{\text{percentage of modulation is zero}}$.

2.2 Part(b)

$$P_{av} = \frac{1}{2}A_c^2$$

But $A_c = 10$, hence

$$P_{av} = \frac{100}{2} = \boxed{50\ \text{watt}}$$

2.3 Part(c)

From the general form for angle modulated signal

$$s(t) = \cos(\omega_c t + \theta(t))$$

Looking at

$$s(t) = A_c \cos\left(\overbrace{\overbrace{(2\pi \times 10^8)t}^{2\pi f_c} + \overbrace{10\cos(2\pi \times 10^3 t)}^{\theta(t)}}^{Total\ Phase}\right)$$

Phase deviation is

$$\theta(t) = 10\cos(2\pi \times 10^3 t)$$

Which is maxinnum when $\cos(2\pi \times 10^3 t) = 1$Hence maximum Phase deviation is $\boxed{10\ \text{radians}}$.

2.4 part(d)

Now, we know that the instantenouse frequency f_i is given by

$$\begin{aligned}
f_i(t) &= \frac{1}{2\pi}\frac{d}{dt}(\text{total phase}) \\
&= \frac{1}{2\pi}\frac{d}{dt}\left[\omega_c t + \theta(t)\right] \\
&= \frac{1}{2\pi}\frac{d}{dt}\left[2\pi f_c t + 10\cos\left(2\pi \times 10^3 t\right)\right] \\
&= f_c - 10\left(10^3\right)\sin\left(2\pi \times 10^3 t\right)
\end{aligned}$$

The deviation of frequency is the difference between f_i and the carrier frequency f_c. Hence from the above we see that the frequency deviation is

$$\begin{aligned}
\Delta f &= f_i - f_c \\
&= -10\left(10^3\right)\sin\left(2\pi \times 10^3 t\right)
\end{aligned}$$

So, maximum Δf occures when $\sin\left(2\pi \times 10^3 t\right) = -1$, hence

$$\max(\Delta f) = 10^4 \text{ Hz}$$

3 Problem 5.22

> **5–22** A sinusoidal modulating waveform of amplitude 4 V and frequency 1 kHz is applied to an FM exciter that has a modulator gain of 50 Hz/V.
> **(a)** What is the peak frequency deviation?
> **(b)** What is the modulation index?

The modulating waveform is $m(t)$ Hence (I am assuming it is cos since it said sinusoidal)

$$\begin{aligned} m(t) &= A_m \cos(2\pi f_m t) \\ &= 4\cos(2000\pi t) \end{aligned}$$

Since it is an FM signal, then

$$s(t) = A_c \cos\left[\overbrace{\omega_c t + 2\pi k_f \int_0^t m(x)\,dx}^{\theta(t)}\right]$$

Where k_f is the frequency deviation constant in cycle per volt-second. The gain here means the frequency gain, which is the frequency deviation (deviation from the f_c frequency). Let Δf be the frequency deviation in Hz, then

$$\begin{aligned} \Delta f &= f_i - f_c \\ &= \frac{1}{2\pi}\frac{d}{dt}\theta(t) \\ &= k_f m(t) \\ &= k_f\left[4\cos(2000\pi t)\right]_{max} \\ &= \frac{50}{V} \times 4V = 200 \text{ Hz} \end{aligned}$$

3.1 Part(a)

max Δf is

$$(\Delta f)_{\max} = 4k_f$$

But $k_f = 50$ hz/volt, hence

$$\begin{aligned} (\Delta f)_{\max} &= 4 \times 50 \\ &= \boxed{200 \text{ hz}} \end{aligned}$$

3.2 Part(b)

Modulation index

$$\beta = \frac{(\Delta f)_{\text{max}}}{f_m} = \frac{200}{1000} = \boxed{0.2}$$

4 Problem 5.24

5–24 An FM transmitter has the block diagram shown in Fig. P5–24. The audio frequency response is flat over the 20-Hz-to-15-kHz audio band. The FM output signal is to have a carrier frequency of 103.7 MHz and a peak deviation of 75 kHz.
(a) Find the bandwidth and center frequency required for the bandpass filter.
(b) Calculate the frequency f_0 of the oscillator.
(c) What is the required peak deviation capability of the FM exciter?

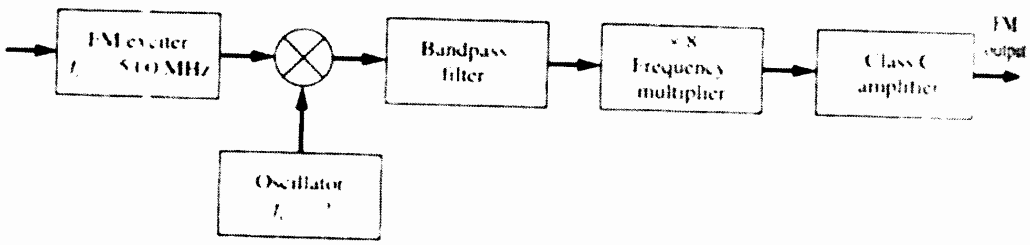


Figure P5–24

$$s(t) = A_c \cos\left(2\pi f_c t + 2\pi k_f \int_0^t m(x)\,dx\right)$$

We are told the carrier frequency has $f_c = 103.7$ Mhz, but there is a multiplier of 8, and hence the center frequency of the bandpass filter must be $\frac{1}{8}$ of the carrier frequency. i.e.

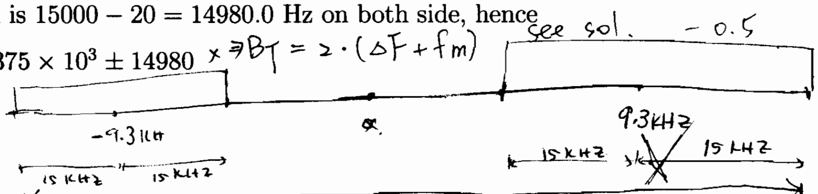
center frequency of the bandpass filter is $\frac{1}{8}103.7 = \frac{103.7}{8} = \boxed{12.963 \text{ Mhz}}$

Since peak deviation is $75khz$, which means the deviation from the central frequency has maximum of $75khz$, then

$$\frac{75}{8} = 9.375 \text{ khz}$$

Hence bandwidth from center of frequency of bandwidth filter is 9.375 but we need to add frequency width of the audio which is $15000 - 20 = 14980.0$ Hz on both side, hence

Bandwidth of BPF is $9.375 \times 10^3 \pm 14980$ × ∋ $B_T = 2 \cdot (\Delta F + f_m)$ see sol. − 0.5



4.1 Part (b)

~~need more time. sorry, I run out of time to finish. not sure how to finish now.~~

$f_o = \frac{f_c}{2} = 2.5$ MHz ?

~~$f_0 = f_c \pm f_{BPF}$~~

−1 $f_0 = f_{BPF} \pm f_c$

$= 12.963 \pm 5$ (MHz)

Part (c)

5 Problem 5.26

5-26 A modulated RF waveform is given by $500\cos[\omega_c t + 20\cos\omega_1 t]$, where $\omega_1 = 2\pi f_1$, $f_1 = 1$ kHz, and $f_c = 100$ MHz.

(a) If the phase deviation constant is 100 rad/V, find the mathematical expression for the corresponding phase modulation voltage $m(t)$. What is its peak value and its frequency?

(b) If the frequency deviation constant is 1×10^6 rad/V-s, find the mathematical expression for the corresponding FM voltage $m(t)$. What is its peak value and its frequency?

(c) If the RF waveform appears across a 50-Ω load, determine the average power and the PEP.

$$s(t) = A_c \cos(\omega_c t + 20\cos\omega_1 t)$$

where $A_c = 500, f_1 = 1khz, f_c = 100Mhz$

5.1 Part(a)

The general form of the above PM signal is

$$s(t) = A_c \cos\left(\omega_c t + \overbrace{k_p m(t)}^{\text{phase deviation}}\right)$$

Where $k_p m(t)$ is the phase deviation, and k_p is the phase deviation constant in radians per volt. Hence we write

$$k_p m(t) = 20\cos\omega_1 t$$

Then

$$m(t) = \frac{20\cos\omega_1 t}{k_p}$$

But we are given that $k_p = 100$ rad/voltage and $f_1 = 1000hz$, then the above becomes

$$\begin{aligned} m(t) &= \frac{20\cos(2000\pi t)}{100} \\ &= \boxed{0.2\cos(2000\pi t)} \end{aligned}$$

its frequency is $1khz$ and its peak value is 0.2 volts

5.2 Part(b)

The general form of the above FM signal is

$$s(t) = A_c \cos\left(\omega_c t + k_f \int_0^t m(x)\,dx\right)$$

Where k_f is the frequency deviation constant in radians per volt-second

Hence

$$k_f \int_0^t m(x)\,dx = 20\cos\omega_1 t$$

Solve for $m(t)$ in the above, given that $k_f = 10^6$radians per volt-second, hence

$$\begin{aligned} k_f \int_0^t m(x)\,dx &= 20\cos\omega_1 t \\ \int_0^t m(x)\,dx &= \frac{20\cos(2000\pi t)}{10^6} \end{aligned}$$

Take derivative of both sides, we obtain

$$\begin{aligned} m(t) &= \frac{20}{10^6}\left[-\sin(2000\pi t) \times 2000\pi\right] \\ &= -\frac{20 \times 2000\pi}{10^6}\sin(2000\pi t) \\ &= \boxed{-0.125\,66\sin(2000\pi t)} \end{aligned}$$

Hence its peak value is 0.12566 and its frequency is 1 khz

5.3 Part(c)

$$\begin{aligned} P_{av} &= \frac{\langle s^2(t)\rangle}{50} \\ &= \frac{\frac{1}{2}A_c^2}{50} \\ &= \frac{500^2}{100} \\ &= \boxed{2500 \text{ watt}} \end{aligned}$$

PEP is average power obtained if the complex envelope is held constant at its maximum values. i.e. (the normalized PEP) is

$$PEP = \frac{1}{2}\left[\max\left(\left|\tilde{s}\left(t\right)\right|\right)\right]^2$$

Since

$$\begin{aligned} s\left(t\right) &= A_c \cos\left(\omega_c t + 20\cos\omega_1 t\right) \\ &= A_c\left[\cos\omega_c t \cos\left(20\cos\omega_1 t\right) - \sin\omega_c t \sin\left(20\cos\omega_1 t\right)\right] \\ &= \overbrace{A_c \cos\left(20\cos\omega_1 t\right)}^{s_I(t)} \cos\omega_c t - \overbrace{A_c \sin\left(20\cos\omega_1 t\right)}^{s_Q(t)} \sin\omega_c t \end{aligned}$$

Hence

$$\begin{aligned} \tilde{s}\left(t\right) &= s_I\left(t\right) + j s_Q\left(t\right) \\ &= A_c \cos\left(20\cos\omega_1 t\right) + j A_c \sin\left(20\cos\omega_1 t\right) \end{aligned}$$

Then

$$\begin{aligned} \left|\tilde{s}\left(t\right)\right| &= \sqrt{\left[A_c\cos\left(20\cos\omega_1 t\right)\right]^2 + \left[A_c\sin\left(20\cos\omega_1 t\right)\right]^2} \\ &= A_c\sqrt{\cos^2\left(20\cos\omega_1 t\right) + \sin^2\left(20\cos\omega_1 t\right)} \\ &= A_c \end{aligned}$$

Hence the non-normalized PEP is

$$\begin{aligned} PEP &= \frac{\frac{1}{2}\left[A_c\right]^2}{50} \\ &= \frac{500^2}{100} \\ &= \boxed{2500\text{ watt}} \end{aligned}$$

ps. is there an easier or more direct way to find PEP than what I did? (assuming it is correct)

It's good !

* In angle Mod, $a(t) = A_c$ * $\therefore PEP = \frac{(A_c)^2}{2R}$