5.1-1 Sketch \( \varphi_M(t) \) and \( \varphi_{PM}(t) \) for the modulating signal \( m(t) \) shown in Fig. P5.1-1, given \( 10^6, k_f = 10^3 \), and \( k_p = 25 \).

![Figure P5.1-1](image)

5.1-2 A baseband signal \( m(t) \) is the periodic sawtooth signal shown in Fig. P5.1-2. Sketch \( \varphi_{PM}(t) \) and \( \varphi_{PM}(t) \) for this signal \( m(t) \) if \( \omega_c = 2\pi \times 10^6, k_f = 2000\pi, \) and \( k_p = \pi / 2 \). Explain why it is necessary to use \( k_p < \pi \) in this case.

![Figure P5.1-2](image)

5.1-3 Over an interval \( |t| \leq 1 \), an angle modulated signal is given by

\[
\varphi_{PM}(t) = 10 \cos 13,000t
\]

It is known that the carrier frequency \( \omega_c = 10,000 \).

(a) If this were a PM signal with \( k_p = 1000 \), determine \( m(t) \) over the interval \( |t| \leq 1 \).

(b) If this were an FM signal with \( k_f = 1000 \), determine \( m(t) \) over the interval \( |t| \leq 1 \).

5.2-1 For a modulating signal

\[
m(t) = 2 \cos 100t + 18 \cos 2000\pi t
\]

(a) Write expressions (do not sketch) for \( \varphi_{PM}(t) \) and \( \varphi_{PM}(t) \) when \( A = 10, \omega_c = 10^6, k_f = 1000\pi, \) and \( k_p = 1 \). For determining \( \varphi_{PM}(t) \), use the indefinite integral of \( m(t) \), that is, take the value of the integral at \( t = -\infty \) to be 0.

(b) Estimate the bandwidths of \( \varphi_{PM}(t) \) and \( \varphi_{PM}(t) \).
5.2-2 An angle-modulated signal with carrier frequency \( \omega_c = 2\pi \times 10^6 \) is described by the equation

\[
\varphi_{PM}(t) = 10 \cos (\omega_c t + 0.1 \sin 2000\pi t)
\]

(a) Find the power of the modulated signal.
(b) Find the frequency deviation \( \Delta f \).
(c) Find the phase deviation \( \Delta \phi \).
(d) Estimate the bandwidth of \( \varphi_{PM}(t) \).

5.2-3 Repeat Prob. 5.2-2 if

\[
\varphi_{PM}(t) = 5 \cos (\omega_c t + 20 \sin 1000\pi t + 10 \sin 2000\pi t)
\]

5.2-4 Estimate the bandwidth for \( \varphi_{PM}(t) \) and \( \varphi_{PM}(t) \) in Prob. 5.1-1. Assume the bandwidth of \( m(t) \) in Fig. P5.1-1 to be the third-harmonic frequency of \( m(t) \).

5.2-5 Estimate the bandwidth of \( \varphi_{PM}(t) \) and \( \varphi_{PM}(t) \) in Prob. 5.1-2. Assume the bandwidth of \( m(t) \) to be the fifth harmonic frequency of \( m(t) \).

5.2-6 Given \( m(t) = \sin 2000\pi t \), \( k_f = 200,000\pi \), and \( k_p = 10 \).

(a) Estimate the bandwiths of \( \varphi_{PM}(t) \) and \( \varphi_{PM}(t) \).
(b) Repeat part (a) if the message signal amplitude is doubled.
(c) Repeat part (a) if the message signal frequency is doubled.
(d) Comment on the sensitivity of FM and PM bandwidths to the spectrum of \( m(t) \).

5.2-7 Given \( m(t) = e^{-t^2} \), \( f_c = 10^4 \) Hz, \( k_f = 6000\pi \), and \( k_p = 8000\pi \).

(a) Find \( \Delta f \), the frequency deviation for FM and PM.
(b) Estimate the bandwidths of the FM and PM waves. Hint: Find \( M(\omega) \) and observe the rapid decay of this spectrum. Its 3-dB bandwidth is even smaller than 1 Hz (\( B \ll \Delta f \)).

5.3-1 Design (only the block diagram) an Armstrong indirect FM modulator to generate an FM carrier with a carrier frequency of 98.1 MHz and \( \Delta f = 75 \) kHz. A narrow-band FM generator is available at a carrier frequency of 100 kHz and a frequency deviation \( \Delta f = 10 \) Hz. The stock room also has an oscillator with an adjustable frequency in the range of 10 to 11 MHz. There are also plenty of frequency doublers, triplers, and quintuplers.

5.3-2 Design (only the block diagram) an Armstrong indirect FM modulator to generate an FM carrier with a carrier frequency of 96 MHz and \( \Delta f = 20 \) kHz. A narrow-band FM generator with \( f_c = 200 \) kHz and adjustable \( \Delta f \) in the range of 9 to 10 Hz is available. The stock room also has an oscillator with adjustable frequency in the range of 9 to 10 MHz. There is a bandpass filter with any center frequency, and only frequency doublers are available.

5.4-1 Show that when \( m(t) \) has no jump discontinuities, an FM demodulator followed by an integrator (Fig. P5.4-1a) acts as a PM demodulator, and a PM demodulator followed by a differentiator (Fig. P5.4-1b) serves as an FM demodulator even if \( m(t) \) has jump discontinuities. Hint: For an input \( A \cos (\omega_c t + \psi(t)) \), the output of an ideal FM demodulator is \( \psi(t) \) and that of an ideal PM demodulator is \( \psi(t) \).
5.4-2 A periodic square wave $m(t)$ (Fig. P5.4-2a) frequency-modulates a carrier of frequency 10 kHz with $\Delta f = 1$ kHz. The carrier amplitude is $A$. The resulting FM signal is demodulated as shown in Fig. P5.4-2b by the method discussed in Sec. 5.4 (Fig. 5.11). Sketch the waveforms at points $b$, $c$, $d$, and $e$.

![Figure P5.4-2](image)

5.4-3 Using small-error analysis, show that a first-order loop [$H(s) = 1$] cannot track an incoming signal whose instantaneous frequency is varying linearly with time [$\theta(t) = kt^2$]. This signal can be tracked within a constant phase if $H(s) = (s + a)/s$. It can be tracked with a zero phase error if $H(s) = (s^2 + as + b)/s^2$. 