1. [18%] Consider the following FM signal:

\[ \hat{\lambda}_{FM}(t) = 10 \cos(2 \pi 94 \times 10^6 t + 2 \sin(2 \pi 30 \times 10^3 t)) \text{ V} \]

(a) [3%] What is the carrier frequency, \( f_c \), of this FM signal?

\[ f_c = \] 

(b) [3%] What is the frequency deviation, \( \Delta f \), of this FM signal?

\[ \Delta f = \] 

(c) [3%] What is the maximum frequency, \( f_m \), in the message?

\[ f_m = \] 

(d) [3%] What is the difference between the maximum and minimum instantaneous frequencies of this FM signal?

\[ f_{i(max)} - f_{i(min)} = \] 

(e) [3%] What is the difference between the maximum and minimum frequencies in the spectrum of this FM signal? (The bandwidth of the signal.)

\[ BW = \] 

(f) [3%] What is the power in this FM signal?

\[ P_{FM} = \]
2. [28%] An FM transmission system transmits at a carrier frequency of \( f_c = 100 \) MHz. The modulating signal has a maximum frequency of \( f_m = 20 \) kHz. The frequency deviation of the transmitted signal is required to be \( \Delta f = 80 \) kHz. The indirect FM system shown in Figure PR-2 is used to generate the transmitted signal. The narrowband FM (NBFM) component uses a carrier frequency of \( f_{c_1} = 400 \) kHz and has a maximum frequency deviation of \( \Delta f = 400 \) Hz. (The NBFM frequency deviation is adjustable.)

(a) [5%] What is the bandwidth of the transmitted signal \( y(t) \).

(b) [10%] How many frequency doublers are needed in the multiplier stage?

(c) [5%] To what value should the frequency deviation of the NBFM component be adjusted?

(d) [8%] What value of \( f_{LO} \) is required?

\[
\begin{align*}
\text{Figure PR-2: Indirect FM Generation System}
\end{align*}
\]

\[\text{Narrowband frequency modulator} \quad \text{Phase Modulator} \quad \text{Frequency Multipliers} \quad \text{\( f_{LO} \)} \quad \text{\( f_{FM}(t) \)} \]
3. [28%] The superheterodyne FM receiver shown in Figure PR-3 is tuned to receive an FM radio signal at a carrier frequency of 91.5 MHz. Assume the received FM waveform has the following parameters: $f_m = 20$ kHz and $\Delta f = 40$ kHz. The receiver uses an intermediate frequency (IF) of 10.7 MHz. Find the following.

(a) [8%] The local oscillator frequency, $f_{LO}$ (assume high-side conversion is being used).

\[ f_{LO} = \] _________________

(b) [8%] The image frequency corresponding to the carrier frequency of $f_c = 91.5$ MHz.

\[ f'c = \] _________________

(c) [6%] The bandwidth of the IF amplifier/filter.

\[ BW_{IF} = \] _________________

(d) [6%] The bandwidth of the Audio amplifier/filter.

\[ BW_{Audio} = \] _________________

![Figure PR-3: Superheterodyne FM Receiver](image-url)
4. [26%] Consider the following situations concerning the performance of FM systems.

(a) [10%] A received analog FM waveform with $A = 50$ mV, $f_c = 80$ MHz, $f_m = 20$ kHz, $P_s = 10$ W and $k_f = 800$ Hz/V is received in white noise with power spectral density level $N_o = 10^{-10}$ W/Hz. Find the SNR in dB at the output of an FM receiver.

$$\text{SNR}_{(dB)} = \text{________________________}$$

(b) [8%] A received binary FM waveform with $A = 50$ mV, $f_c = 80$ MHz, and $T_b = 1$ $\mu$s is received in white noise with power spectral density level $N_o = 10^{-10}$ W/Hz. Orthogonal tone spacing is used. Find the bit error rate for coherent detection.

$$P_e = \text{________________________}$$

(c) [8%] For the same scenario as in part (b), find the bit error rate if incoherent detection is used.

$$P_e = \text{________________________}$$