In the Name of God

Communication Systems (25751-4)

Problem Set 05

Fall Semester 1402-03

Department of Electrical Engineering

Sharif University of Technology

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Due on Azar 4, 1402 at 16:00

(∗) starred problems are optional and have a bonus mark!

1 FM Bandwidth and Demodulation

Consider the following signal

$$v(t) = A\cos\left(2\pi f_c t + \frac{\pi}{2}p(t)\right),$$

where $f_c = 100$ kHz.

which $p(t)$ is a periodic triangular signal between $-A$ and A with $A = 1$ and period $T_p = 1$ ms.

1. Find $f(t)$, the instant frequency.
2. Draw approximately $v(t)$ using $f(t)$ found in part 1.
3. We give this signal to an ideal FM demodulator and denote the output signal with $m(t)$. Write an expression for $m(t)$.
4. Find the bandwidth of $m(t)$ using the first three terms of fourier series and then use Carson's rule to find the bandwidth of $v(t)$.

2 FM Modulator

Figure 1 shows an FM modulator. If the message has a bandwidth of ~~15~~ 10 kHz and the output frequency from the oscillator is $f_0 = 100$ kHz. The narrow-band FM signal has a maximum angular deviation of 0.10 radians in order to keep distortion under control. Assume that the maximum amplitude of $m(t)$ is 1.

1. Determine the frequency multiplications (M_1 and M_2) that are necessary to generate an FM signal at a carrier frequency of $f_c = 120$MHz (for the upper side-band) and a frequency deviation of $f = 70$ kHz.
2. Repeat the last part for the lower side-band.
3. If the carrier frequency for the wideband FM signal is to be within 2 Hz, determine the maximum allowable drift of the 100 kHz oscillator.

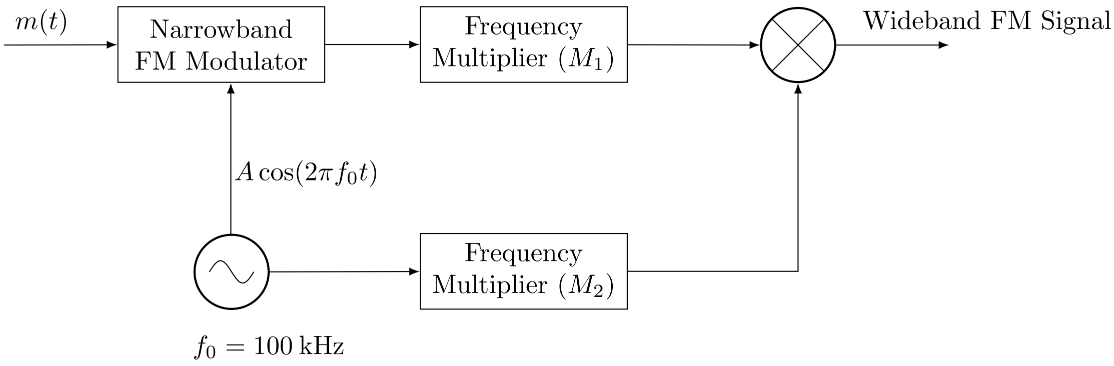

Figure 1: An FM Modulator

3 (∗) Power of FM Signal

We use the previous question's modulator (Figure 1) on the signal $m(t) = \cos(200\pi t)$ with $A = 2$, $M_1 = 60$ and $M_2 = 800$. The narrow-band FM signal has a maximum angular deviation of 0.1 radians. We want to put an ideal band-pass filter at the end to make the output signal have the maximum power possible but also less then 1.8 Watts.

1. What is the best choice for the central frequency and bandwidth of the filter?
2. If there are multiple choices, which one is better? Explain the reason.

4 FM Demodulator

The FM signal

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

is applied to the system shown in 2 consisting of a high-pass RC filter and an envelope detector. Assume that (a) the resistance R is small compared with the reactance of the capacitor C for all significant frequency components of $s(t)$, and (b) the envelope detector doesn't load the filter. Determine the resulting signal at the envelope detector output, assuming that $k_f|m(t)| < f_c$ for all t.

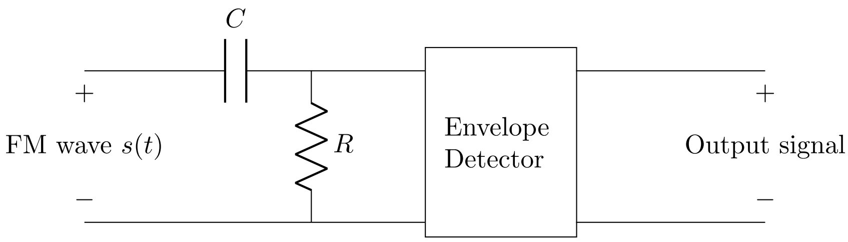

Figure 2: An FM Demodulator

5 (∗) Mixed Modulation

Suppose that the received signal in an FM system contains some residual amplitude modulation of positive amplitude $a(t)$, as shown by

$$s(t) = a(t)\cos\left(2\pi f_c t + \phi(t)\right)$$

where f_c is the carrier frequency. The phase $\phi(t)$ is related to the modulating signal $m(t)$ by

$$\phi(t) = 2\pi k_f \int_0^t m(\tau)\, d\tau$$

where k_f is a constant. Assume that the signal $s(t)$ is restricted to a frequency band of width B_T, centered at f_c, where B_T is the transmission bandwidth of the FM signal in the absence of amplitude modulation, and that the amplitude modulation is slowly varying compared with $\phi(t)$. Show that the output of an ideal frequency discriminator (consisting of a differentiator followed by an envelope detector and a DC block) produced by $s(t)$ is proportional to $a(t)m(t)$. *Hint:* You may take the complex envelope of $s(t)$ into consideration.

6 Superheterodyne Receiver

1. Consider a superhet intended for USSB modulation with W = 4 KHz and f_c = 3.57-3.63 MHz. Take $f_{LO} = f_c + f_{IF}$ and choose the receiver parameters so that all bandpass stages have $\frac{B}{f_0}$= 0.02. Then sketch $|H_{RF}(f)|$ to show that the RF stage can be fixed-tuned. Also sketch $|H_{IF}(f)|$, accounting for sideband reversal.

2. Do (1) for LSSB modulation with W = 6 kHz and f_c = 7.14 - 7.26 MHz.

7 Double Conversion Superhetrodyne Receiver

A receiver designer is given the task of designing a receiver for signals with carrier frequencies in the band from $f_{c1} = 50$ MHz to $f_{c2} = 100$ MHz and bandwidth of $B = 5$ kHz. To achieve good selectivity at reasonable cost, the designer wants to use a particular standard IF filter with a center frequency of $f_{IF} = 455$ kHz. The designer first contemplates using a simple superhetrodyne receiver as discussed in the class.

1. If such a system is used,

   (a) Find the range of frequencies that the local oscillator should generate. (Assume that $f_{LO} > f_c$.)

   (b) How wide should the transition region of the RF filter be to eliminate the image frequency problem.

2. A better design that is used when high selectivity and wide RF frequency range is desired (such as spectrum analyzers) is shown in Figure 3.

   (a) What should the frequency f_{LO2} be? (Assume that $f_{LO2} > f_{c,\text{IF1}}$.)

   (b) What should be the maximum transition region of the first IF filter be to reject all image frequencies of the second IF filter?

   (c) What range of frequencies the first local oscillator should be capable of generating? (Assume that $f_{LO1} > f_c$.)

   (d) What is the maximum width of the transition region of the RF filter?

   (e) Compare the requirements for IF filters of this design with that of the IF filter in the superhetrodyne receiver (Assume the index of difficulty in building a band-pass filter is the ratio of the center frequency of the filter to its pass-band bandwidth)

   (f) Compare the difficulty of building the RF filter in this design with that of the regular superhetrodyne receiver.

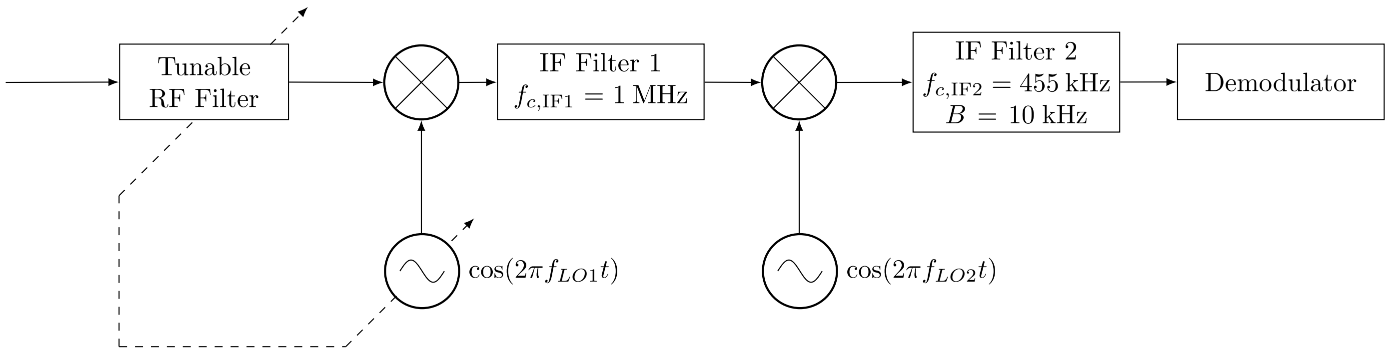

Figure 3: Problem 7