In the Name of God

Communication Systems (25751-4)

Problem Set 05

Fall Semester 1401-02

Department of Electrical Engineering

Sharif University of Technology

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Due on Azar 9, 1401 at 23:55

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

1 FM Bandwidth and Demodulation

Consider the following signal

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

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 Bandwidth of FM Signal

The carrier $c(t) = A\cos(2\pi\times 10^6 t)$ is FM modulated by the sinusoid signal $m(t) = 2\cos(2000\pi t)$ with a modulation index factor $k_f = 3000\ \frac{\text{Hz}}{\text{V}}$

1. Determine the amplitude and frequency of all signal components that have a power level of at least 10% of the power of unmodulated carrier wave and plot the Fourier transform of the signal (include only these components)
2. Determine the bandwidth using Carsons rule
3. Answer parts (1) and (2) if the amplitude of $m(t)$ is decreased by a factor of two.
4. Answer parts (1) and (2) if the amplitude of $m(t)$ is increased by a factor of two.

3 FM Modulator

Figure 1 shows an FM modulator. If the message has a bandwidth of 15 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 multiplication that is necessary to generate an FM signal at a carrier frequency of $f_c = 104$ MHz and a frequency deviation of $f = 75$ kHz.
2. 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.

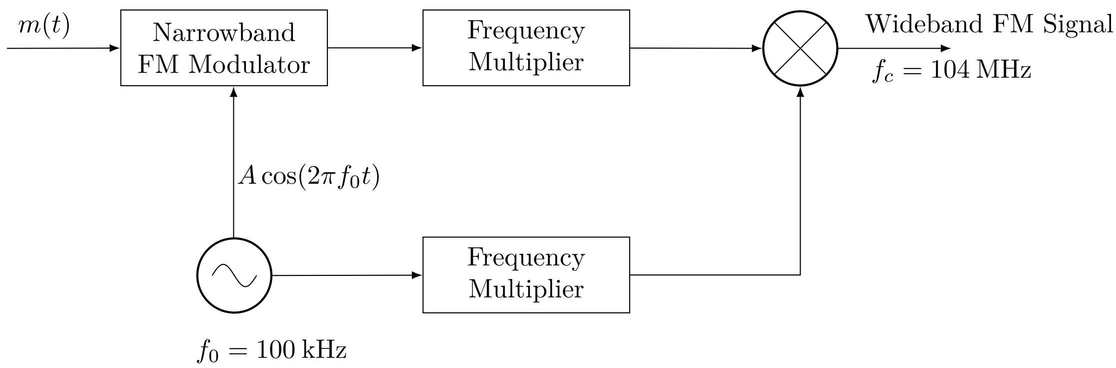

Figure 1: An FM Modulator

4 FM Demodulator

An FM demodulator is shown in Figure 2. The envelope detector is assumed to be ideal and has an infinite input impedance. Select the values of L and C (in terms of R) to demodulate an FM signal at carrier f_c and a peak frequency deviation of Δf.
Note that if the center frequency of the transfer function $H(f)$ of the LC circuit is f_0 you can assume that the slope of $H(f)$ is almost constant from f_1 to f_2, where f_1 is the frequency such that $|H(f_1)| = 0.1|H(f_0)|$ and f_2 is the frequency such that $|H(f_2)| = 0.9|H(f_0)|$.

1. Give your answer in terms of R, f_1, and f_2.
2. Assume that $f_c = 80$ MHz, $\Delta f = 6$ MHz, $R = 10$ kΩ. Find the values of L and C.

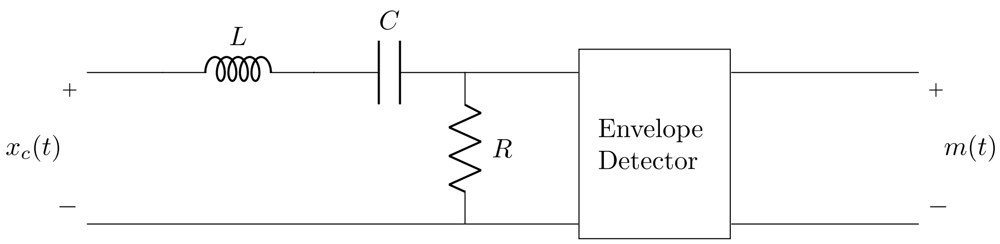

Figure 2: An FM Demodulator

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

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

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 Commercial AM and FM

The parameters for commercial broadcast AM and FM receivers are given in Table 1.

parameter	AM	FM
Carrier Frequency (f_c)	540 - 1600 kHz	88.1 - 107.9 MHz
Carrier Spacing	10 kHz	200 kHz

Table 1: Problem 6

1. Suppose a commercial AM superhetrodyne receiver has been designed such that the image frequency always falls above the broadcast band. Find the minimum value of f_{IF}, the corresponding range of f_{LO}, and the bounds on B_{RF} (the bandwidth of RF filter).
2. Suppose a commercial FM superhetrodyne receiver has been designed such that the image frequency always falls below the broadcast band. Find the minimum value of f_{IF}, the corresponding range of f_{LO}, and the bounds on B_{RF} (the bandwidth of RF filter).

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 $f_{LO2} > f_{c,\mathrm{IF1}}$.)

(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.

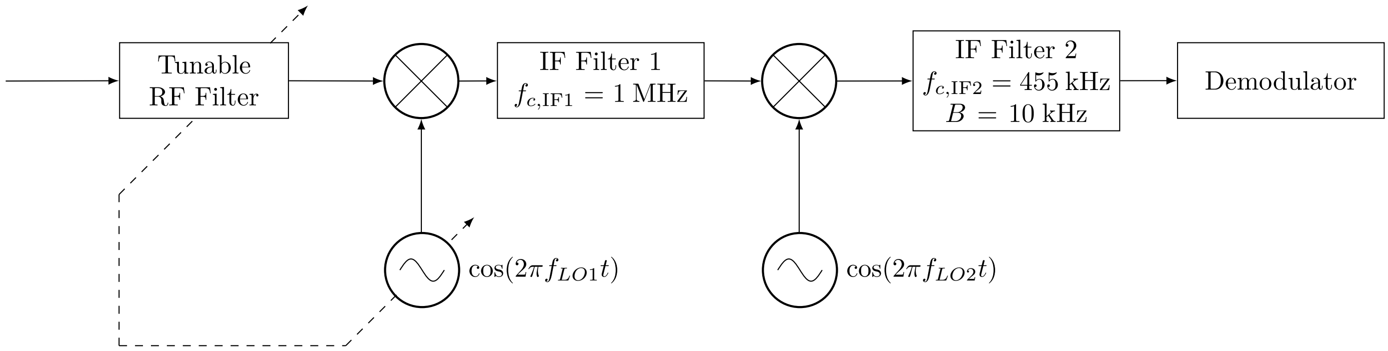

Figure 3: Problem 7