End-Semester Examination

Communication Systems (EE 308), Autumn'19

Nov. 11, 2019; Total: 50 marks; Time: 3 hours

- *You are allowed to use ONE A4 sheet with handwritten notes on BOTH sides.*
- *You are allowed to use any result discussed in class without proof. For all other results, a proof needs to be provided.*

QUESTION 1 (4 MARKS)

An FM signal generated using a tone message signal $A_m \cos(2\pi f_m t)$, where $f_m = 5$ kHz, has a frequency deviation of 10 kHz, and is applied to two frequency multipliers connected in cascade. The first multiplier doubles the frequency and the second multiplier triples the frequency. Determine the frequency deviation and the modulation index of the FM signal obtained at the second multiplier output. What is the frequency separation of the adjacent side frequencies of this FM signal?

QUESTION 2 (1.5 + 1.5 = 3 MARKS)

Consider a sine wave of frequency f_m and amplitude A_m, applied to a delta modulator of step-size Δ. Show that slope-overload distortion will occur if:

$$A_m > \frac{\Delta}{2\pi f_m T_s},$$

where T_s is the sampling period. What is the maximum power of a sine wave that may be transmitted without slope-overload distortion?

QUESTION 3 (3 MARKS)

A message signal with bandwidth W is transmitted using FM. Suppose pre-emphasis and de-emphasis are used with the pre-emphasis filter having a transfer function of:

$$H(f) = c + \frac{jf}{f_0},$$

where c and f_0 are positive constants. Find the ratio of the output SNR achieved in the above FM system to that in the above FM system with the change that no pre-emphasis and de-emphasis are used.

QUESTION 4 (2 + 2 = 4 MARKS)

A dual-band radio operates at 900 MHz and 1.8 GHz. There are several bands around each of the above frequencies. Each band has bandwidth 1 MHz; also, the guard band between adjacent bands is of width 1 MHz. We wish to design a superheterodyne receiver with an IF of 250 MHz. The LO is built using a frequency synthesizer that is tunable from 1.9 to 2.35 GHz, and frequency divider circuits if needed (assume that you can only implement frequency division by an integer).

(a) How would you design a superheterodyne receiver to receive a passband signal restricted to the band $1800 - 1801$ MHz? Specify the characteristics of the RF and IF filters, and how you would choose and synthesize the LO frequency.

(b) Repeat part (a) for when the signal to be received lies in the band $900 - 901$ MHz.

QUESTION 5 (1.5 + 1.5 = 3 MARKS)

A PCM system uses a uniform quantizer and represents each quantized value using 7 bits. The bit rate of the system is equal to 50×10^6 bps.

(a) What is the maximum message bandwidth for which the system operates satisfactorily?

(b) Determine the output signal-to-quantization noise ratio when a sinusoidal modulating wave of amplitude A_m and frequency 1 MHz is applied to the input. Assume that the quantizer divides the range $[-A_m, A_m]$ into intervals of equal sizes.

QUESTION 6 (1 + 1 + 1 + 2 = 5 MARKS)

A noise process has a power-spectral density given by:

$$S_n(f) = \begin{cases} 10^{-8}\left(1 - \frac{|f|}{10^8}\right), & |f| < 10^8, \\ 0, & |f| > 10^8. \end{cases}$$

This noise is passed through an ideal bandpass filter with a bandwidth of 2 MHz centred at 50 MHz.

(a) Find the power content of the output process.

(b) Write the output process in terms of the in-phase and quadrature components and find the power in each component. Assume that $f_c = 50$ MHz.

(c) Find the power-spectral density of the in-phase and quadrature components.

(d) Now assume that the filter is not an ideal filter and is described by:

$$|H(f)|^2 = \begin{cases} |f| - 49 \times 10^6, & 49 \text{ MHz } < |f| < 51 \text{ MHz}, \\ 0, & \text{otherwise.} \end{cases}$$

Repeat parts (a), (b) and (c) with this assumption.

QUESTION 7 (2.5 + 2.5 = 5 MARKS)

Suppose $X(t)$ is a WSS Gaussian process with mean function $E(X(t)) = 0$ and autocorrelation function $R_X(\tau) = 4e^{-2|\tau|}$.

(a) Find $P(X(t) \leq 3)$.

(b) Find $E\left\{[X(t+1) - X(t-1)]^2\right\}$.

QUESTION 8 (4 MARKS)

Consider the random process:

$$X(t) = \cos(\omega t),$$

where ω is a random variable that is uniformly distributed in $[0, \omega_{max}]$, and ω_{max} is a positive constant. Show that $X(t)$ is *not* WSS.

QUESTION 9 (4 MARKS)

In *natural sampling*, an analog signal $g(t)$ is multiplied by a periodic train of rectangular pulses $c(t)$. Given that the pulse repetition frequency of this periodic train is f_s and the duration of each rectangular pulse is T, do the following. Find the spectrum of the signal $s(t)$ that results from the use of natural sampling. You may assume that time $t = 0$ corresponds to the midpoint of a rectangular pulse in $c(t)$. Show that the original signal $g(t)$ may be recovered exactly from its naturally sampled version, provided that the conditions embodied in the sampling theorem are satisfied.

QUESTION 10 (2 + 2 + 1 = 5 MARKS)

An input signal $m(t)$ takes values in $[-m_p, m_p]$, where $m_p = 10$ V. Its samples are non-uniformly quantized by first passing them through a μ-law compressor with $\mu = 255$ and applying the compressed samples to a uniform quantizer that uses 8-bits to represent each quantized sample. For the above non-uniform quantizer, find the smallest and largest step-size. Also, if no compander is used, so that the above input signal is uniformly quantized, then find the step-size.

QUESTION 11 (2.5 + 2.5 = 5 MARKS)

Consider passband modulation using the bandlimited pulse shown in Fig. 1. For each of the following statements, state whether it is true or false, clearly stating your reasoning.

(a) The pulse $p(t)$ can be used for Nyquist signaling at a bit rate of 56 Mbps using a 16QAM constellation.

(b) The pulse $p(t)$ can be used for Nyquist signaling at a bit rate of 25 Mbps using a QPSK constellation.

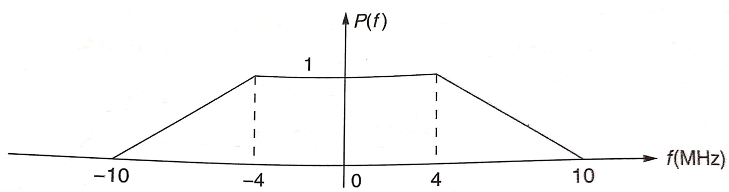

Fig. 1. The figure for Question 11.

QUESTION 12 (5 MARKS)

Weaver's SSB modulator is illustrated in Fig. 2. By taking the input signal as $m(t) = \cos(2\pi f_m t)$, where $f_m < W$, demonstrate that by proper choice of f_1 and f_2, the output is an SSB signal.

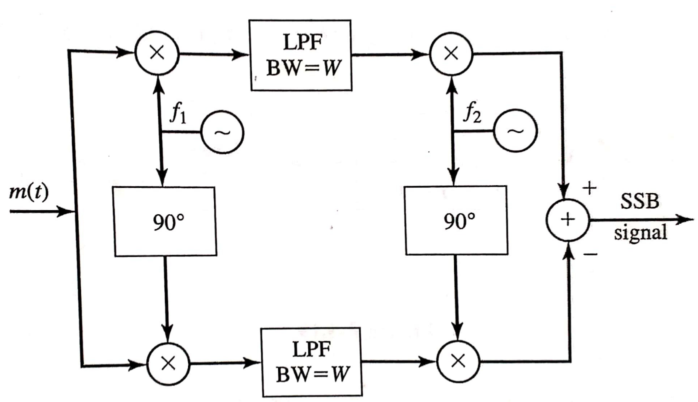

Fig. 2. The figure for Question 12.