Instructions:

A. *You have the entire class time to answer these questions.*
B. *This is a closed note/book exam.*
C. *Please write within the area provided under each question.*
D. *Please turn off your cell phone, laptop, and all other electronic/transmitting devices.*
E. *Each question is worth 20 points.*
F. *Nyquist's result:* $C = 2B \log_2 M$ *Shannon result:* $C = B \log_2(1 + S/N)$ $dB = 10 \log_{10} S/N$
G. *There is no need for a calculator, all numbers are power of 2 or 10.*
H. $\log_2 11 = 3.45, \log_2 101 = 6.65, \log_2 1001 = 9.96, \log_2 10001 = 13.28$

1. Define the following:
   (a) Attenuation.
      i. Is it a problem? If yes, how do we fix it?
      ii. Does it matter whether the signal is analog or digital?
   (b) Delay distortion.
   (c) Thermal noise.
   (d) Inter-modulation noise.

   See lecture notes

2. (a) Consider a 10 KHz noiseless channel that transmits signals. Each signal carries 3 bits of data. What is maximum channel capacity in bits/s?

$$C = 2B \log_2 M = 2 \times 10,000 \log_2 8 = 60,000 = 60\ Kbps$$

   (b) Now, consider a 10 KHz noisy channel with signal-to-noise ratio of 20 dB. What is maximum channel capacity in bits/s?

$$20dB = 10 \log_{10} S/N \quad S/N = 100$$

$$C = B \log_2(1 + S/N) = 10,000 \log_2(1 + 100) = 10,000 \times 6.65 = 60.65\ Kbps$$

3. When we send a packet from one computer to another over the Internet, it suffers four types of delays.
   (a) Discuss each delay type and why it exists.
   (b) Explain which delay type is deterministic or non-deterministic (probabilistic).
   (c) Give an example.

   See lecture notes

4. Consider a 1 Mbps point-to-point connection between a computer in NY and a computer in LA which are 4096 = 2^{12} Km apart. Assume the signal travels at the speed of $2.6 \times 10^5 \approx 2^{18}$ Km/s in the cable.
   (a) What is the length of a bit (in time) in the cable? 1 Mb = 2^{20} bits

$$\frac{1}{2^{20}} = 2^{-20}\ s$$

   (b) What is the length of a bit (in meters) in the cable?

$$2^{-20} s \times 2^{18}\ Km/s = 2^{-2} = 0.25\ Km = 250\ m$$

   (c) Assume that we are sending packets that are 2 KB (2×2^{10} bytes) long,
      i. How long does it take before the first bit of the packet arrives to the destination?

$$\text{Propagation delay of 1 bit} \frac{2^{12}\ Km}{2^{18}\ Km/s} = 2^{-6} = 15.6\ ms$$

ii. How long does it take before the transmission of the packet is completed?

$$2^{-6} + 2^{14}/2^{20} = 2^{-6} + 2^{-6} = 2^{-5}\ s$$

(d) How many packets can fill the $1Mbps \times 4,096$ Km pipe (RTT)?

$$2^{20}\ bps \times 2 \times 2^{-6}\ s(RTT) = 2^{15}\ bits = 2^{12}\ bytes = 2^{2}\ KB = 2\ packets$$

5. For the following bit streams, sketch the digital signal for each encoding technique. form for the following formats.

   (a) Non-return-to-Zero (NRZ).

   (b) Manchester coding.

   (c) Differential Manchester coding.