Introduction to Baseband Communications

Communication System: Transfers info from a source to a destination through a transmission medium (channel).

Example: Telephone System

You talking → telephone network → telephone → Your buddy listening

We are interested in those communication systems that utilize electromagnetic (EM) signals as the means of conveying info.

Q: The question we will address (very briefly) in this course is "how to design the Tx & Rx so that we can convey info efficiently through a channel?"
To preview the "answer" to the question, let's look at the simplest possible comm. system (if interest):

E.g.: The Tx is connected directly to the Rx and the whole circuit is submerged in liquid helium!

In this case, we can assume that the channel does nothing to the signal from the Tx and hence the Rx sees exactly the same signal.

Q: The next question to ask is what kind of info we'd like to convey through this comm. system?

A: There are basically 2 types of info:
   1. Analog info: e.g. voice
   2. Digital info: e.g. a stream of bits with values "0" or "1"

Q: So how should we send these two types of info from the Tx to the Rx by means of EM signals (we only electric signal for simplicity)?

A: 1. Analog info:
   - Convert analog info to electrical signal and send the signal to Rx → Analog communications
   e.g. Telephone handset converts voice to voltage signal.
Analog info (cont.)

(11) "digitize" analog info into digital info, then....
I will talk about this process later.

2. Digital info
Represent "0" by a voltage pulse and "1" by another voltage pulse.
Tx sends a sequence of pulses to convey a stream of bits.
Rx maps seq. of pulses back to bit stream.
This method is usually called line coding.
The resulting system is called a digital communication system.

Summary:

- Analog communications - convey analog info
- Digital communications - convey digital info (or digitized analog info)

- We're interesting mainly in digital comm.
- Some commonly used line coding techniques are given on the following page.
Common line codes:

(a) Punched Tape

(b) Unipolar NRZ

(c) Polar NRZ

(d) Unipolar RZ

(e) Bipolar RZ

(f) Manchester NRZ

$N = \text{Non}$, $R = \text{Return}$, $Z = \text{Zero}$
Thermal noise

Next, we look at a little bit more realistic case:

Q: What happens if the circuit is not submerged in liquid helium?

A: The electrons in the circuit will have enough energy to move around (jitter), adding a random signal, called thermal noise, to the transmitted signal. Hence the signal received by the RX would be:

\[ r(t) = s(t) + n(t) \]

\[ \text{received signal \quad transmitted signal \quad thermal noise} \]

* Usually, the thermal noise \( n(t) \) is modelled by a white Gaussian random process. We will not go deep into defining what a white Gaussian process is. It suffices to mention some properties of the process:

1. If we sample \( n(t) \) at time \( t \), the \( n(t) \) is a Gaussian random variable with zero mean and infinite variance.

2. The samples \( n(t_1), n(t_2), \ldots, n(t_k) \) are jointly Gaussian and independent for any \( k \).

3. Define \( N = \int_{T_s}^{T_e} n(t) \, dt \) is a Gaussian random variable with zero mean and variance \( \frac{N_0}{2}(T_e - T_s) \) for all \( T_e > T_s \).
White Gaussian process (cont.)

The parameter $\frac{N_0}{2}$ is crucial in specifying the thermal noise. It is usually referred to as the two-sided power spectral density of the noise.

Remark: To say $n$ is a Gaussian random variable with zero mean and variance $\sigma^2$, it means that the value taken by $n$ is random (can range from $-\infty$ to $+\infty$) with $P(n \leq a) = \frac{1}{\sqrt{2\pi}\sigma} \int_{-\infty}^{a} e^{-\frac{x^2}{2\sigma^2}} dx$.

Example: Suppose we use unipolar NRZ.

$$s(t) = \begin{cases} 1 & 0 \leq t < \frac{1}{2} \\ 0 & \frac{1}{2} \leq t < 1 \\ -1 & 1 \leq t < \frac{3}{2} \\ 0 & \frac{3}{2} \leq t < 2 \\ \vdots & \vdots \\ \end{cases}$$

$$n(t) = \begin{cases} \text{random} & \text{continuous} \\ \text{voltage fluctuations} & \text{discrete} \\ \text{magnitude} -0.1V, 0V, 0.1V, 0.2V, 0.3V, 0.4V, 0.5V \\ \end{cases}$$

$$r(t) = \begin{cases} \text{random} & \text{continuous} \\ \text{voltage fluctuations} & \text{discrete} \\ \text{magnitude} -0.1V, 0V, 0.1V, 0.2V, 0.3V, 0.4V, 0.5V \\ \end{cases}$$

Rx samples $r(t)$ at these pts. to determine whether the tx bits are "0" or "1" by the following rule:

If $r > 0.5V$, then decide "1".
If $r < -0.5V$, then decide "0".

Wrong decisions (errors)!

Conclusion: Noise causes errors!

Question: Can we do better? How?