[10:30] Channel Impairments (Lecture 12)

- Goal: develop different models for physical communication channels
  - Wire
  - Air
  - Underwater
  - Optical
- Several steps occur between baseband processing at transmitter and receiver
  - Carrier circuits at transmitter
  - Physical channel
  - Carrier circuits at receiver
- Propagating signal quality degrades with distance traveled
- Physical channel can be modeled as a convolution
  - Leads to spreading over time
  - Leads to attenuation over distance
- Repeaters can be used to control the reduction in signal quality

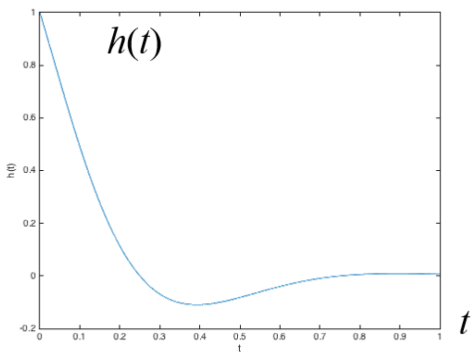
[10:40] Impairment #1: Additive thermal noise

- Use central limit theorem to model random motion of elections as Gaussian
- At each point in time t_0 the noise is a random variable $n(t_0)$
- Many particles contribute to the noise. Model each particle as a RV $V_0, V_1, \dots$
$$n(t_0) = C_0(V_0 + V_1 + V_2 + \cdots)$$
- Distribution of each particle is modeled as statistically independent, zero mean.
- As number of particles goes to infinity → sum of random variables tends to Gaussian
- Result: $n(t_0) \sim N(0, \sigma^2)$
- Variance σ^2 is the noise power

[10:55] Impairment #2: LTI effects

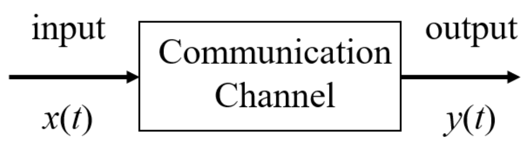
- Example: wire has resistance, capacitance, and inductance per meter
  - Model as second order IIR filter, or truncate and model as FIR
- Alternative example: modeling wave propagation
  - Received signal consists of direct and reflected paths
  - Radiated energy also affected by absorption and scattering
  - Impulse response can be modeled as set of shifted delta functions
  - Generally modeled as FIR (ignore most attenuated paths)
- LTI model captures distortion in frequency and spreading in time

Wireline

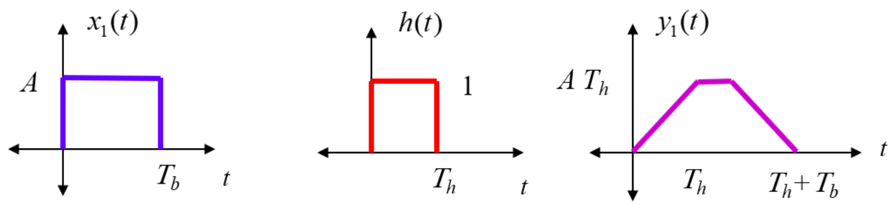


Wireless

- Simplified model to understand effect on PAM transmission:
  - Model channel as LTI
  - Truncate IIR response as FIR to capture effects in time and frequency
  - Approximate impulse response as rectangular pulse for timing analysis



Pulse amplitude is
+A for '1' bit or
-A for '0' bit



Bit of '0' or '1'   Assume $T_h < T_b$ 12 - 7

[11:25] Impairment: Phase Jitter

- Time-varying linear system can be modeled as phase shift
- Example: sinusoidal signal

$$x(t) = \cos(2\pi f_c t) \xrightarrow{\text{Time varying linear system}} y(t) = \cos\big(2\pi f_c t + \Theta(t)\big)$$

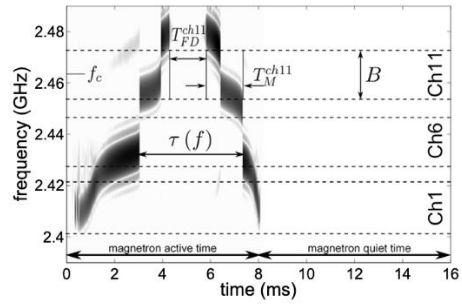
- Example #1: Visualize phase jitter in $y(t)$ by superimposing the second period on the first period, third period on the first period, etc. Matlab demo on Slide 12-9.
- Example #2: 2-PAM example: $x(t) = \underbrace{a_n}_{\substack{+1 \text{ for 0 bit} \\ -1 \text{ for 1 bit}}} \cos(2\pi f_c t)$.
- Visualize phase jitter in $y(t) = a_n \cos\big(2\pi f_c t + \Theta(t)\big)$ by superimposing the second period on the first, third period on the first, etc. Matlab demo on Slide 12-10

[11:35] Additive interference

http://users.ece.utexas.edu/~bevans/courses/realtime/lectures/12_Channel_Impairments/announcements.html

- Nonlinear effects: Harmonics, additive noise, interference, and can be time-varying
- Interference can be narrowband or broadband, periodic or asynchronous
- Microwave oven can interfere with Wi-Fi and other transmissions in 2.4 GHz band:

Spectrogram of emissions from a microwave oven in unlicensed 2.4 GHz band sweeping across IEEE 802.11g Wi-Fi channels 1, 6, 11
[Nassar, Lin & Evans, 2011]



- Powerline background noise is often spectrally shaped (1/frequency)
- Periodic impulsive noise in power lines
  - Synchronous to the main powerline frequency (50 Hz or 60 Hz)
    - Appear at the same instant of the AC cycle.
    - Example sources: silicon-controlled rectifiers and diodes that switch on and off with the AC cycle while generating abrupt switching transients.
  - Asynchronous to the main powerline frequency (50 Hz or 60 Hz)
    - Impulsive interference (high-amplitude impulse trains) with repetition rates unrelated to the main powerline frequency.
    - Primarily injected by switching mode power supplies that operate at frequencies above 10 kHz.

[11:50] Full model of channel impairments

- Fading is a time-varying effect due to changes in the electromagnetic environment, e.g. from motion of transmitter and/or receiver.