• **Information on WWW**
  - url is http://silicon.phys.washington.edu/lubatti
  - This page contains general information, lecture notes and experiments

• **Laboratories meet on Thursday and Friday from 1:30 to 4:30 PM.**
  - To arrange lab make-up days contact Henry Lubatti, your TA'S David Ventura (dventura@u) and M. Luzum (mluzum@u) and/or David Pengra, lab manager
  - The first two labs provide the opportunity for you to become acquainted with lab equipment you will use this quarter
    • Transmission lines – coaxial cables
    • Analogue oscilloscopes
    • NIM logic units
Physics 433 - Lecture 1

• Pulse Signals (W. Leo chapt. 11, read before first lab)
  - Detectors currently employed in Nuclear and Particle physics provide information in *voltage or current pulses* that must be processed and recorded if the experimenters selection criteria are met
  - Pulse signal terminology: base line, Pulse-height/amplitude, leading edge, falling edge, rise time, fall time, unipolar or bipolar (figs. Below from W. R. Leo, Chapter 11)
Physics 433 - Lecture 1

- Transmission lines (read Leo p. 263-272)
  - Used to propagate signals from one point to another
    - Signal source (pulse generator, scintillator, logic units such as discriminators, coincidence circuits, fan-outs, etc.) to other logic units or an oscilloscope
    - Transmit with minimum signal distortion—broad band width
  - Coaxial cables widely used in Nuclear and Elementary Particle Physics so we will discuss those in some detail
    - Coaxial cable has outer non-conducting sheath, a braided shield or screen that forms a return path, a dielectric and a center conductor
  - Outer conductor shields the central wire from stray EM fields and provides a return path for the signal
Physics 433 - Lecture 1

- Cable properties
  - For an ideal lossless cable the velocity of propagation is given by $v = 1/(\mu\varepsilon)^{1/2}$
  - Most cables use a solid dielectric and have velocities about 2/3 the speed of light in vacuum but cables with air dielectric having transmission speeds approaching the speed of light in vacuum are available (NB In vacuum light travels about 1 foot in 1 ns.)
  - Cables are usually specified by an RG/U designation (Radio Guide) that insures certain quality standards - we will make use of RG58 cable quite frequently in the lab (see W. R. Leo Table 13.1)
  - All real cables have some resistance from the center conductor, and imperfect dielectrics that result in attenuation and distortion of the signal
• Lossless cable with no resistance in the conductor or conductance in the dielectric – not real life but close
  - Can show that \( \frac{d^2V}{dz^2} = L \frac{d^2V}{dt^2} \) where \( L \) and \( C \) are the inductance and capacitance per unit length
    • Wave equation of a wave traveling with speed \( v = \frac{1}{(LC)^{1/2}} \)
    • Time of signal propagation per unit cable length \( T = (LC)^{1/2} \) is a useful parameter and needs to be taken into account
    • For a coaxial cable the propagation speed is determined by the permeability and permittivity of the dielectric because \( LC = \mu \varepsilon \)

- Characteristic Impedance
  • Expressed as \( Z_0 = V/I \), which for a coaxial cable can be shown to be \( Z_0 = (L/C)^{1/2} \) for a lossless cable (if cable lossless, \( Z_0 \) is purely resistive)
  • Note that \( Z_0 = (L/C)^{1/2} = 60(K_m/K_e)\ln(a/b) \), where \( a(b) \), inner (outer) diameter of conductors and \( K_m(K_e) \) the permeability (permittivity) of the dielectric (your text uses \( K_m \) & \( K_e \))
  • \( Z_0 \) is independent of the length of cable-only depends on geometry and material (dielectric)
  • Two standard cables widely used have characteristic impedances of 50 \( \Omega \) and 93 \( \Omega \) (we will use 50 \( \Omega \) in lab)
Reflections

- A signal propagating in a coaxial cable satisfies the wave equation which has as a general solution a superposition of waves propagating in \(+z\) and \(-z\) direction (\(z\)-along length of cable)

\[ V = f(x-\nu t) + g(x+\nu t), \text{ where } V \text{ is voltage.} \]

- Reflections will overlap and interfere with the original signal and result in incorrect data
- Reflections are result of changes in characteristic impedance of the line, such as an open-ended or shorted line

By matching the impedance of the load to the characteristic impedance of the line, reflections can be avoided

- In the lab you will find 50 \(\Omega\) terminators used for this purpose.
- In lab 0 you will explore the effects of properly and improperly terminated cables.
Physics 433 - Lecture 1

- Transmission lines
  • We will use coaxial cables for all of our work
  • In the first lab you will compare 50 ohm and 70 ohm cable and look at signals with proper and improper termination and observe reflections from cables that are open and shorted at the opposite end
  • We will use both BNC and Limo cables in the lab; both have a 50 \( \Omega \) characteristic impedance
  • Various connectors that are used in the lab

Various BNC connectors

Various Limo and BNC to Limo connectors
- Analogue scopes (read W. R. Leo Appendix A, pg 353)
  - Best to use external trigger unless instructed otherwise
  - Terminate in characteristic impedance of the cable
  - In general it is best to use DC input mode
Physics 433 - Lecture 1

- **Pulse shaping** – used in all commercial amplifiers
  - Basic pulse shaping done with RC circuits
    - High pass filter – often used on drift tube read out
    - Low pass filters – often needed also for RF noise rejection
  - RC filters

- CR differentiating circuit (RC time important)
  - For a negative input pulse what would the output pulse look like?
  - Is the second pulse a problem

- RC integrating circuit (has a lower cut-off frequency)
  - Lower cut off frequency is $\omega > 1/RC$ (output from a fast input pulse will reach 0.63 of peak in a time $t = RC$)
  - What will this circuit do a a negative pulse that is noisy, that is one that has a lot of high frequency riding on the pulse?

- CR-RC Pulse shaping provides both low frequency (differentiation) and high-frequency (integration) filtering which improves signal to noise
In the lab you will encounter other equipment

- **Preamplifiers and amplifiers**
  - Used for amplifying a low level signal; often two stages
    - Preamplification
    - Amplification
  - Amplifiers also include a pulse shaping function
    - Shorten timer duration of pulse to avoid overlap of sequential pulses
    - Optimize signal to noise (filter out frequencies where noise is the largest.

- **Pulse stretchers lengthen pulse**
  - Necessary for some multichannel analyzers

- **Fan-in and fan-outs**
  - used to distribute a signal to several logic units

- **Discriminators**
  - Provide output only if input pulse is above some preset value