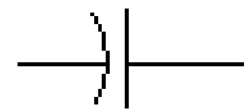
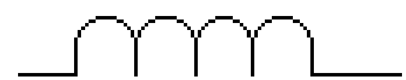
Transient DC Circuits

- Lab #4 examines inductors and capacitors and their influence on DC circuits.
- As R is the symbol for a resistor, C and L are the symbols for capacitors and inductors.
- Capacitors and inductors are the other two passive circuits components.
- In a circuit with capacitors and inductors (and normally, also resistors), turning a DC power source on or off causes a brief, non-linear behavior of current in the circuit.
- Such circuits (usually referred to as RL, RC, or RLC circuits) are of great interest in electrical engineering, as is their transient behavior.



Capacitor (C)

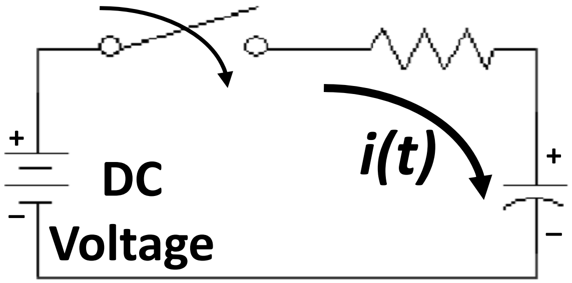


Inductor (L)

The Capacitor

- A capacitor consists of two conducting surfaces separated by a dielectric, or insulator.
- A capacitor stores electric charge when current flows due to an applied voltage, just as a water tank stores water.
- The capacitor develops an equal and opposite voltage as it collects charge.
- When the voltage on the capacitor = the applied voltage, current flow ceases.
- Charge cannot cross the dielectric barrier of a capacitor.
- Voltage cannot appear instantaneously across a capacitor.

Water Tower

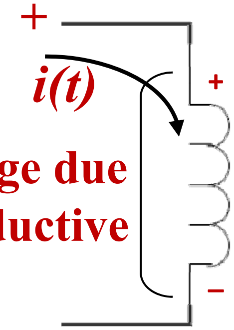


Charging a Capacitor

The Inductor

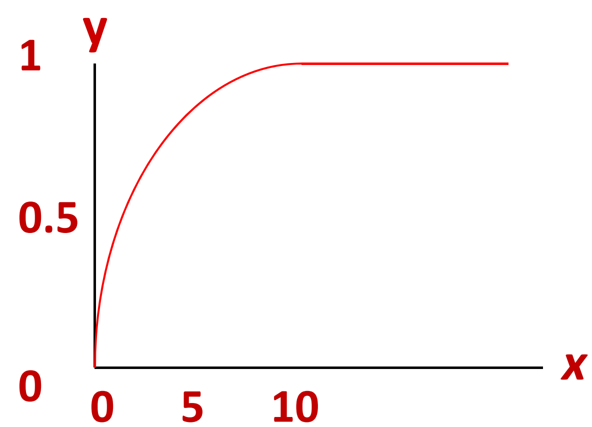
- The inductor has the property of electrical inertia.
- Physical inertia is the property of mass that resists a change in motion (acceleration). If at rest, an object resists moving; if moving, it resists a change in speed.
- Similarly, an inductor resists a change in current. If no current flows, it resists the start of current. If current is flowing, it resists a change in current.
- Just as a voltage cannot instantaneously appear across a capacitor, current cannot flow instantaneously in an inductor.

A massive truck would have high resistance to rapid acceleration or braking.



Exponential Behavior

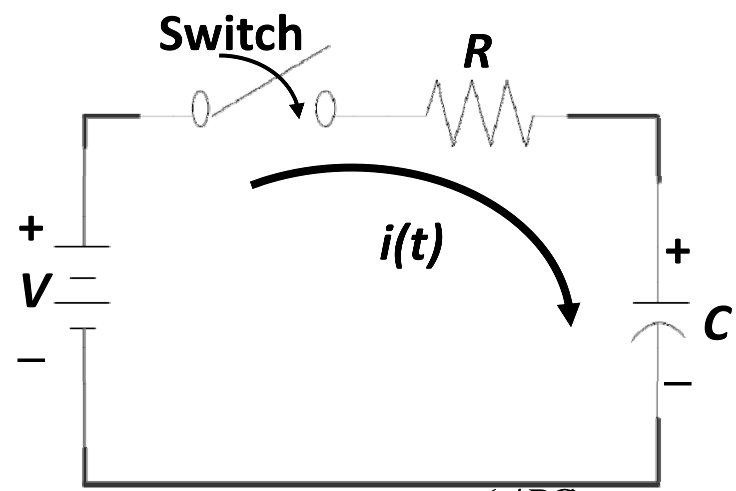
- **Exponential behavior is mathematical behavior such that one of the variables is an exponent.**
- **Some functions have an exponential behavior that involves *e*, the base of natural logarithms.**
- **Some exponential behavior is asymptotic; it approaches a value but never reaches it. Such a behavior is exhibited in the equation to the right.**
- **DC transient circuit behavior is characterized by this mathematical description.**



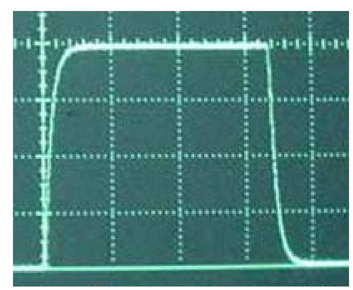
Plot of $1-e^{-x}$

Behavior of an RC Circuit

- **Asymptotic, transient behavior is exhibited in an RC circuit.**
- **When the switch is closed, current flows into the capacitor.**
- **Current flow ceases when charge collected on the capacitor produces a voltage equal and opposite to *V*.**
- **An equation describing the behavior is shown; it is both exponential and asymptotic.**



$$v_C(t) = V(1 - e^{-(t/RC)})$$



The Time Constant τ

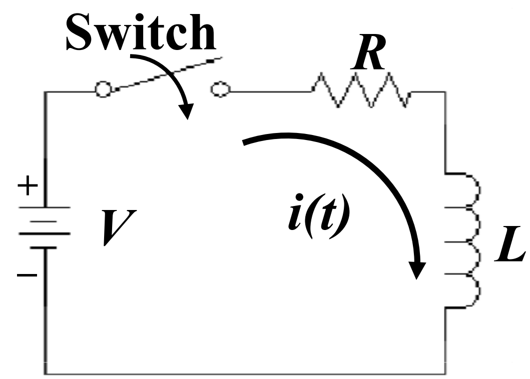
- **In the equation shown, as time passes, $v_c(t) \rightarrow V$, as the value of $e^{-t/RC} \rightarrow 0$.**
- **In the equation, the value *RC* is called τ.**
- **Clearly, as τ grows smaller, transient behavior disappears much faster.**
- **Since τ determines how quickly the transient response of the circuit dies, it is called the time constant.**
- **Note: For R = 1000 Ω, C= 0.05 µF, then $\tau \approx$ 0.00005 sec. Transient effects last a very short time.**

$$v_C(t) = V(1 - e^{-(t/RC)})$$

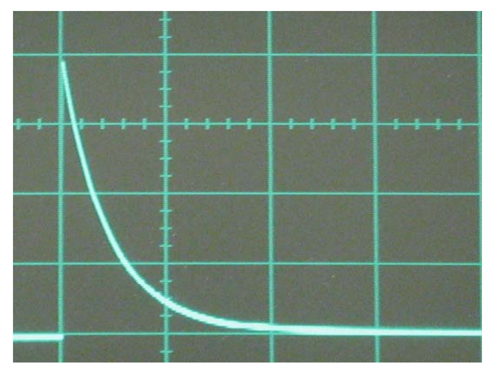
The time constant in an RC circuit is sometimes referred to as "the RC time constant."

A Transient RL Circuit

- **We also see <u>asymptotic</u>, <u>transient</u> behavior in an RL circuit.**
- **When the switch is closed, current flow is inhibited as the inductor develops <u>an opposite voltage to the one applied</u>.**
- **Current slowly begins to flow, as the inductor voltage falls toward 0.**
- **As the transient effect dies, current flow approaches *V/R*.**
- **An equation describing the behavior is shown.**



$$v_L(t) = Ve^{-(t/[L/R])} = Ve^{-(R/L)t}$$



τ in an RL Circuit

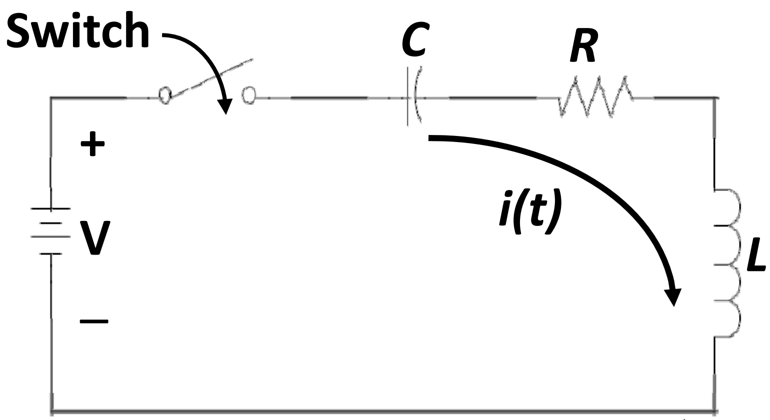
- The time constant τ in an *RL* circuit is defined as $\tau = L/R$.
- In the equation shown, as time passes, $v_L(t) \rightarrow 0$, as the value of $e^{-t/L/R} = e^{-(R/L)t} \rightarrow 0$.
- As τ grows smaller, transient behavior disappears much faster, as in the *RC* case.

$$v_L(t) = Ve^{-(t/[L/R])} = Ve^{-(R/L)t}$$

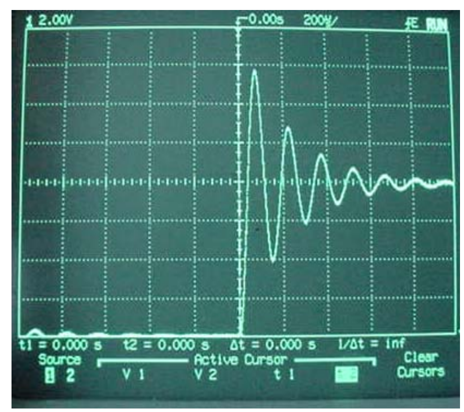
The time constant in an RL circuit is often referred to as "the RL time constant."

Odd Behavior of an RLC Circuit

- A circuit with *R*, *L*, and *C* can exhibit oscillatory behavior if the components are chosen properly.
- For many values of *R-L-C*, there will be no oscillation.
- The expression that describes this behavior is shown at right.
- The parameter ω_d is the radian frequency ($\omega_d = 2\pi f$, f the frequency in Hz), which depends on the values of *R* and *C*.
- α is the damping factor, which determines the rate at which the oscillation dies out.



$$v_c(t) = V(1 - [\cos \omega_d t]e^{-\alpha t})$$



Behavioral Parameters in the RLC Circuit

- In the formula for $v_C(t)$, the radian frequency of oscillation, ω depends on R, L, and C.
- Note that in general, the smaller L and C, the higher frequency the oscillation. Also, if R is too large the quantity under the square root is negative, which means there is no oscillation.
- Note that α is very similar to τ. In fact the value of α is exactly ½ the value of τ for an RL circuit.

$$v_c(t) = V(1 - [\cos \omega_d t] e^{-\alpha t})$$

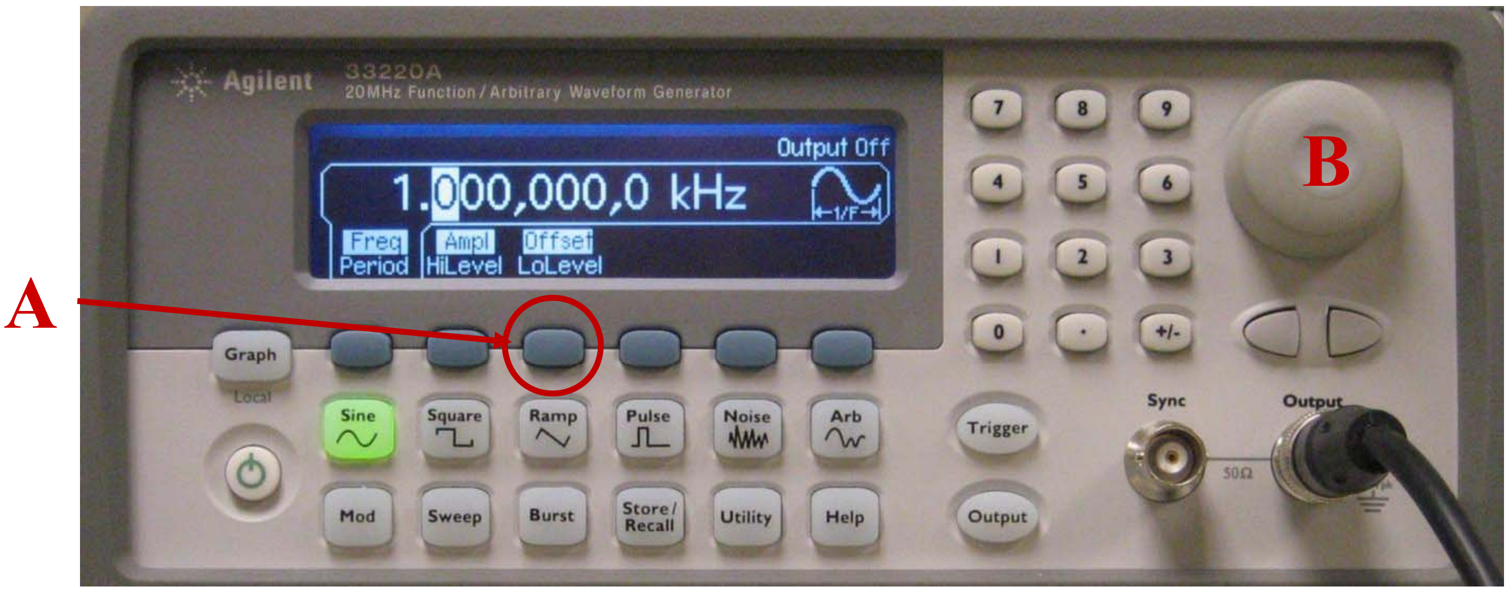
$$\alpha = R / 2L$$

$$\omega_d = \sqrt{(1/LC) - (R/2L)^2}$$

Using the Signal Generator as a "DC Power Source"

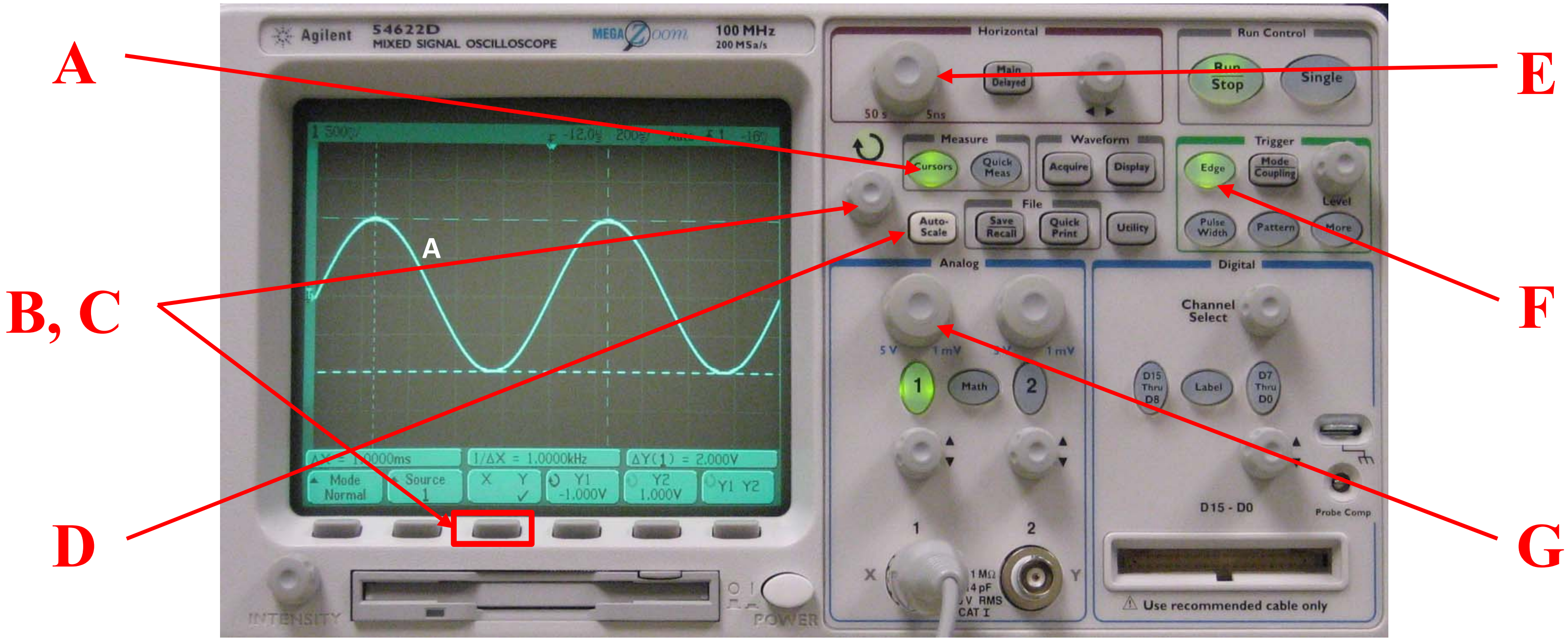
- For our RC transient circuit, as mentioned on a previous slide, $\tau = RC \approx 1000 \times 0.05\ 10^{-6} = 0.00005$ seconds, or 50µsec. Then 10 τ = ½ msec.
- That is a <u>very short time</u>.
- <u>We will need to use the oscilloscope to observe transient behavior</u>.
- It is not very convenient to try to rapidly turn the DC power supply on and off to evoke the transient signals we want to watch.
- Instead, why not use the signal generator square wave pattern as a "rapidly switching DC power source?"
- One hitch: the normal square wave pattern is equally above and below 0V. We need a varying voltage level from 0 to a positive voltage (say 5V).
- Solution: The signal generator will let us "dial in" a DC level to algebraically add to the AC voltage. Thus, dial in +2.5 V to a 5 V p-p AC signal to get a voltage that varies 0-5 VDC.

Adding a DC Level to an AC Signal



- **Dialing in an offset: Press the "offset" soft button (A) and use the dial (B) to add in the desired DC level.**

Review of the Oscilloscope



- **Important controls: Cursor on (A), cursor control (B, C), autoscale (D), manual sweep (E), trigger (F), manual sensitivity (G).**

Oscilloscope (2)

- We will be using the oscilloscope to view transient signals as shown.
- Note that the oscilloscope must be switched to "DC coupling" to register the DC signal value; otherwise it is stripped away and ignored.
- Use controls mentioned on the previous slide to get the right voltage sensitivity and time base to view the transient signals as shown.