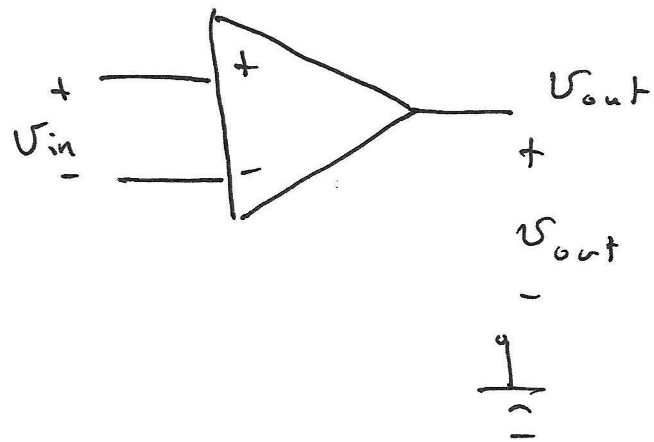
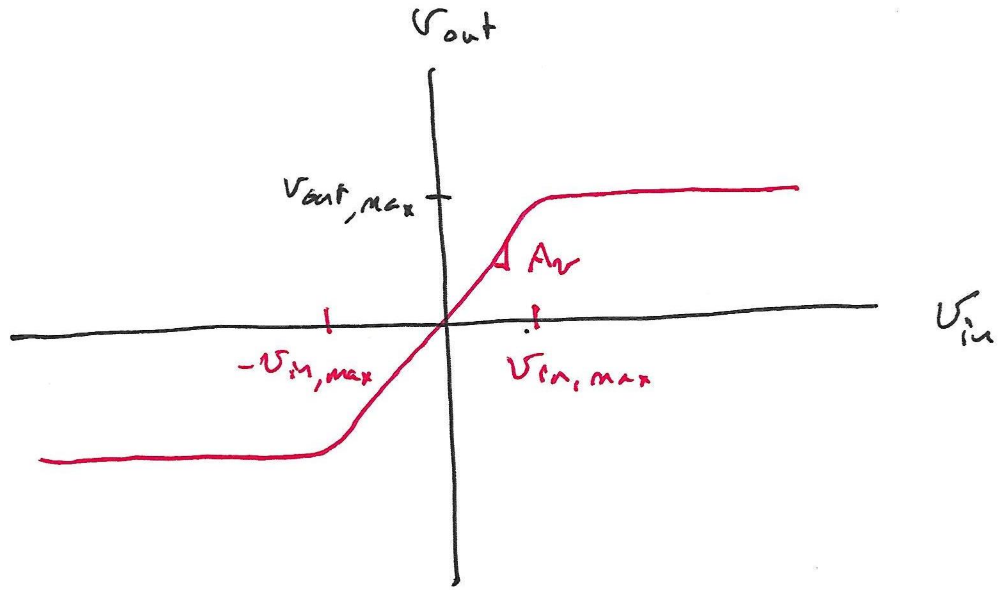
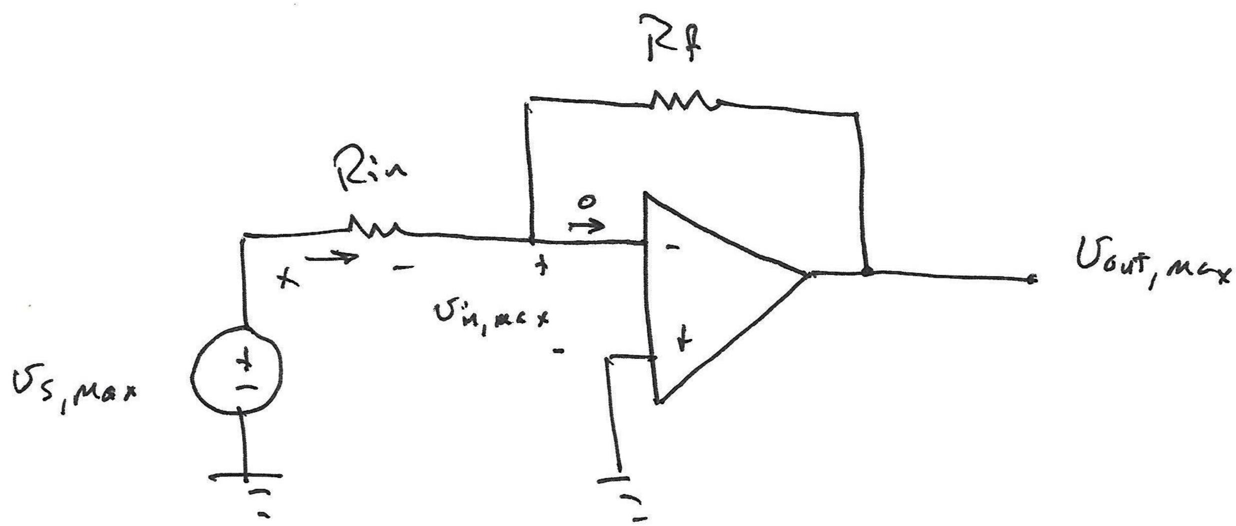


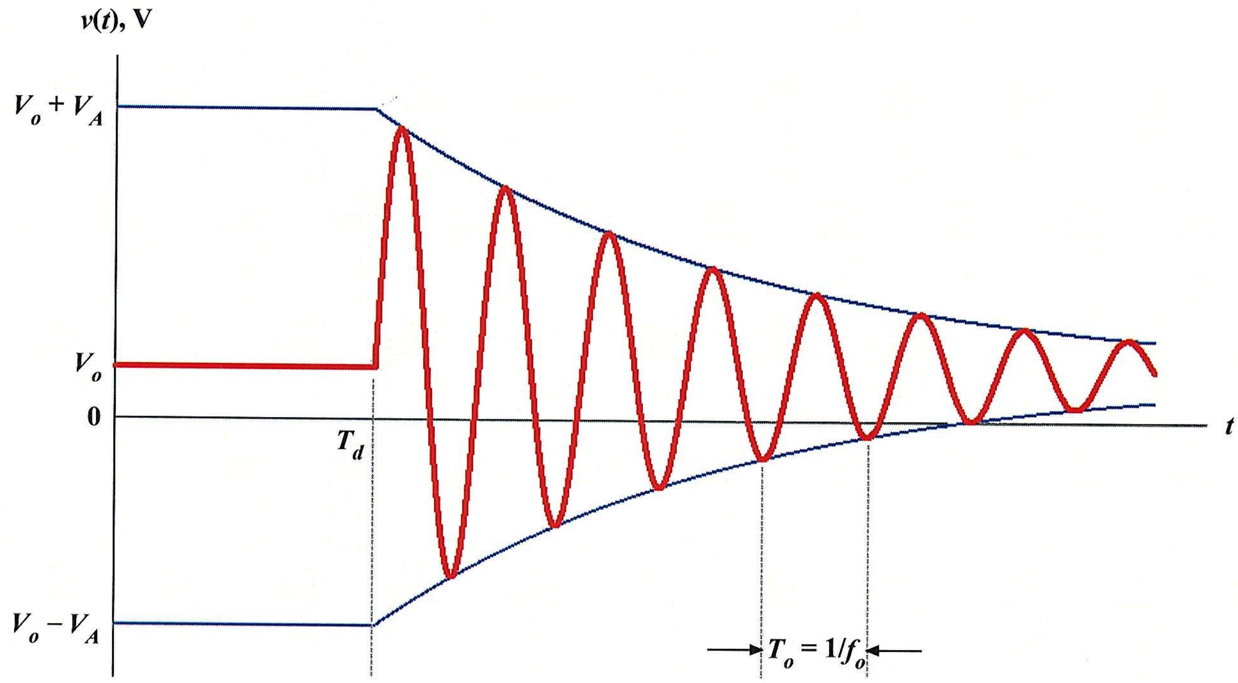
$$A_v = \frac{v_{out}}{v_{in}}$$



v_{out}
$v_{out,max}$
A_v
v_{in}
$-v_{in,max}$
$v_{in,max}$


Rf
Rin
0
x
-
+
$v_{in,max}$
-
$v_{s,max}$
+
-
+
$v_{out,max}$

Sinusoidal Source for Transient Analysis



Vname N+ N– SIN(V_o V_A f_o T_d α θ)

$$Vname = V_o + V_A e^{-\alpha(t-T_d)} \sin\left\{2\pi\left[f_0\left(t-T_d\right)+\theta/360\right]\right\}$$

where:

$V_0 = offset\ voltage\ (V)$

$V_A = amplitude\ (V)$

$f_o = frequency\ (Hz)$

$T_d = delay\ (s)$

$\alpha = damping\ \ factor\ (s^{-1})$

$\theta = phase\ angle\ (°)$

Transient Analysis with LTspice

This is a time domain analysis. Selected circuit signals may be displayed in the Waveform viewer as they are simulated, much like an oscilloscope on the bench. It basically computes what happens when the circuit is powered up and runs. Test signals are often applied as independent sources or may be taken from captured data stored on file.

Syntax: `.tran <Tstep> <Tstop> [Tstart [dTmax]] [modifiers]`
or `.tran <Tstop> [modifiers]`

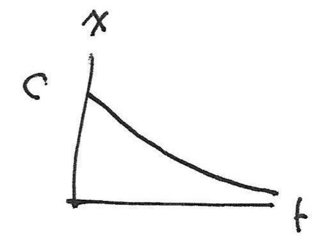
The first form is the traditional `.tran` SPICE command. `Tstep` is the plotting increment for the waveforms but is also used as an initial step-size guess. LTspice uses waveform compression, so this parameter is of little value and can be omitted or set to zero. `Tstop` is the duration of the simulation. Transient analyses always start at time equal to zero. However, if `Tstart` is specified, the waveform data between zero and `Tstart` is not saved. This is a means of managing the size of waveform files by allowing startup transients to be ignored. The final parameter `dTmax`, is the maximum time step to take while integrating the circuit equations. If `Tstart` or `dTmax` is specified, `Tstep` must be specified.

Several *modifiers* can be placed on the `.tran` line.

- **`UIC`:** Use Initial Conditions. Skip the D.C. operating solution and use user-specified initial conditions. Normally, a dc operating point analysis is performed before starting the transient analysis. This directive suppresses this initialization. The initial conditions of some circuit elements can be can be specified on a per-instance basis.
- **`steady`:** Stop the simulation when steady state has been reached.
- **`nodiscard`:** Don't delete the part of the transient simulation before steady state is reached.
- **`startup`:** Solve the initial operating point with independent voltage and current sources turned off (but using any constraints specified by a .ic directive). Then start the transient analysis and linearly ramp on these sources during the first 20 us of the simulation.
- **`step`:** Compute the step response of the circuit.

Transient Analysis

$$A\dot{x} + Bx = 0$$



$$\dot{x} = -\frac{B}{A}x$$

$$x(t) = C e^{-\frac{B}{A}t}$$

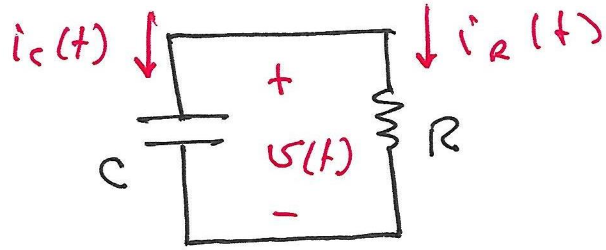
If $x(t)$ has an initial value

$$x(0)$$

then

$$x(t) = x(0)\, e^{-\frac{B}{A}t}$$

RC circuit:



$$i_c(t) = C\dot{v}(t)$$

$$i_R(t) = \frac{1}{R}v(t)$$

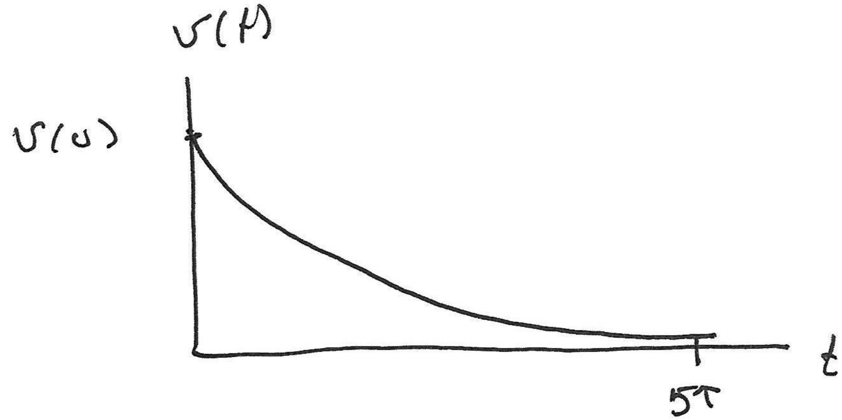
KCL: $i_c(t) + i_R(t) = 0$

$$C\dot{v}(t) + \frac{1}{R}v(t) = 0$$

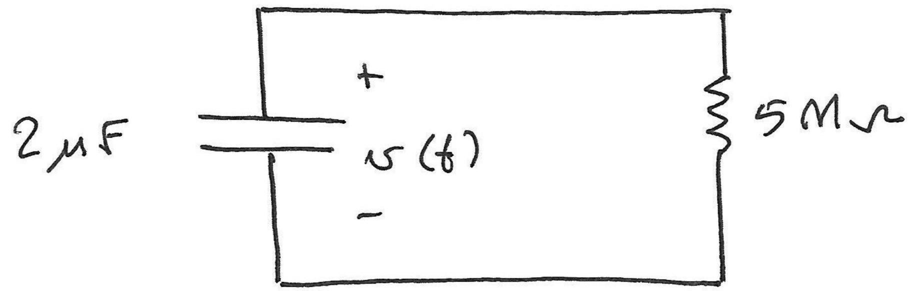
$$\dot{v}(t) = -\frac{1}{RC}v(t)$$

$$\Rightarrow \quad v(t) = v(0)\, e^{-t/RC} \quad V, \; t \geq 0$$

RC is called the "time constant", τ



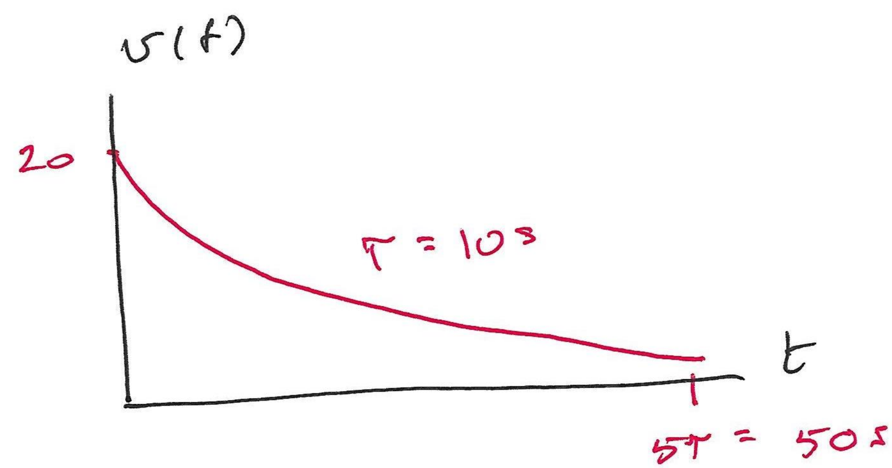
$v(t)$ is $\approx$ $v(\infty)$

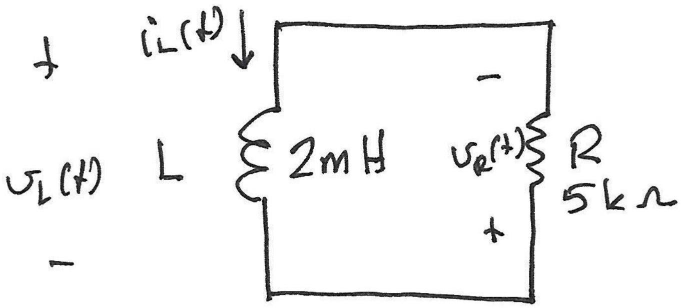


$v(0) = 20\,V$

$$\tau = RC = 5\times10^{6} \times 2\times10^{-6} = 10$$

$$v(t) = 20\, e^{-t/10}\ V, \quad t \geq 0$$





$$i_L(0) = 25\ mA$$

$$v_L(t) = L\frac{di_L}{dt}$$

$$v_R(t) = R\, i_L(t)$$

KVL: $v_L(t) + v_R(t) = 0$

$$L\frac{di_L}{dt} + R\, i_L = 0 \quad \Rightarrow \quad \frac{di_L}{dt} = -\frac{R}{L}\, i_L$$

$$i_L(0) = i_L(0)\, e^{-t/(L/R)}$$

The time constant for an RL circuit is $\frac{L}{R}$

$$\boxed{\tau = \frac{L}{R} \text{ seconds}}$$

For this example,

$$\tau = \frac{L}{R} = \frac{2 \times 10^{-3}}{5 \times 10^{3}} = .4 \times 10^{-6} = 0.4\,\mu s$$

$$i_L(t) = 25\, e^{-t/0.4\mu s} \quad mA, \quad t \geq 0$$

$$A\ddot{x} + B\dot{x} + Cx = 0$$

Assume $x = x(0)e^{-t/\tau}$

$$\dot{x} = -\frac{x(0)}{\tau} e^{-t/\tau}$$

$$\ddot{x} = \frac{x(0)}{\tau^2} e^{-t/\tau}$$

$$A\frac{x(0)}{\tau^2} e^{-t/\tau} - B\frac{x(0)}{\tau} e^{-t/\tau} + C\,x(0)\,e^{-t/\tau} = 0$$

$$\frac{A}{\tau^2} - \frac{B}{\tau} + C = 0$$

Define $\alpha = \frac{1}{\tau}$

Then

$$A\alpha^2 - B\alpha + C = 0$$

$$\alpha = \frac{B \pm \sqrt{B^2 - 4AC}}{2A}$$

There are two possible values of α.

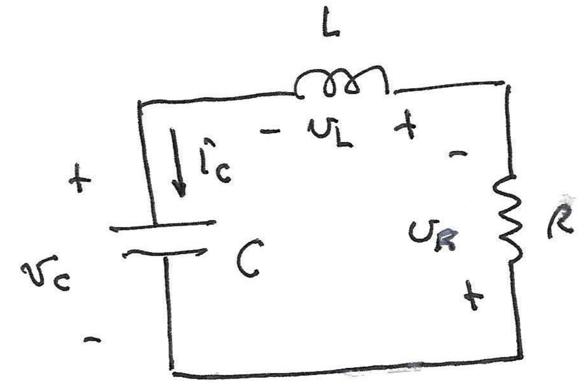
$$\therefore \quad x = K_1 e^{-\alpha_1 t} + K_2 e^{-\alpha_2 t}$$

where

$$\alpha_1 = \frac{B + \sqrt{B^2 - 4AC}}{2A}$$

$$\alpha_2 = \frac{B - \sqrt{B^2 - 4AC}}{2A}$$

Series RLC circuit:



$$i_c = C\dot{v}_c$$

$$v_R = R i_c = RC\dot{v}_c$$

$$v_L = L\frac{di_c}{dt} = LC\frac{d^2 v_c}{dt^2} \quad \text{or} \quad LC\ddot{v}_c$$

KVL: $$v_c + v_R + v_L = 0$$

$$v_c + RC\dot{v}_c + LC\ddot{v}_c = 0$$

$$LC\ddot{v}_c + RC\dot{v}_c + v_c = 0$$

$$\boxed{\ddot{v}_c + \frac{R}{L}\dot{v}_c + \frac{1}{LC}v_c = 0}$$