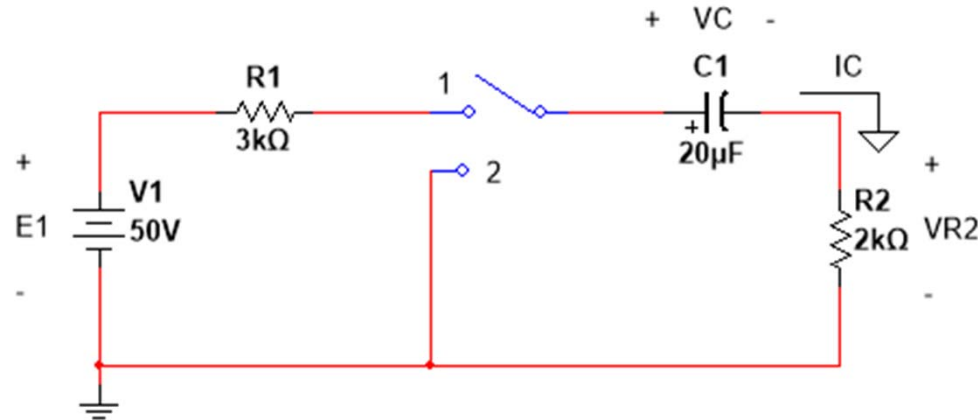


Example – Charge and Discharge

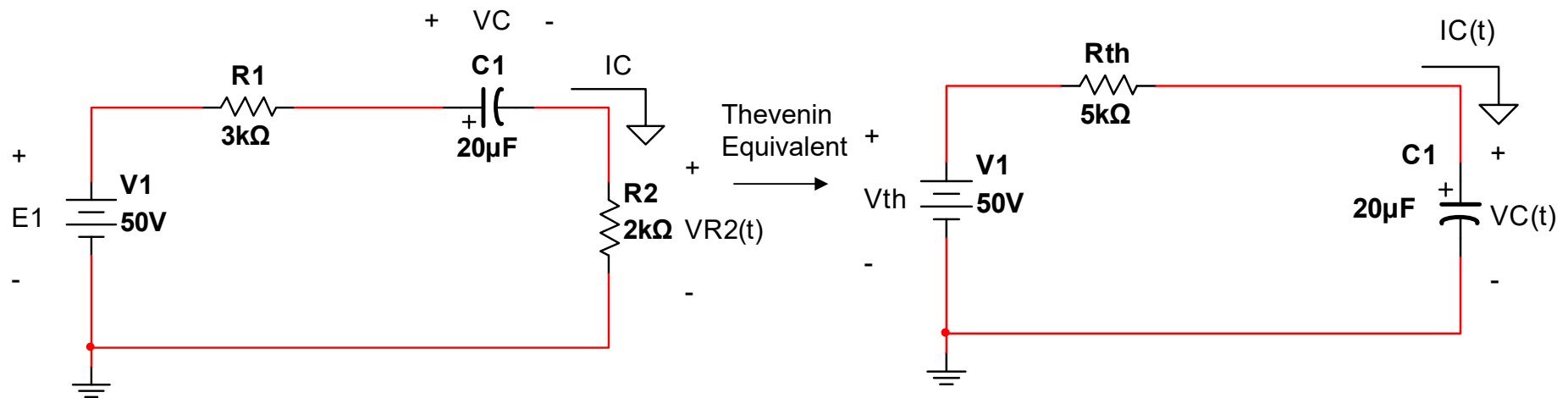


No initial charge
 $V_C = 0 \text{ V}, t < 0$

Position 1: C_1 **charges** through R_1 and R_2

Position 2: C_1 **discharges** through R_2

Circuit for Position 1

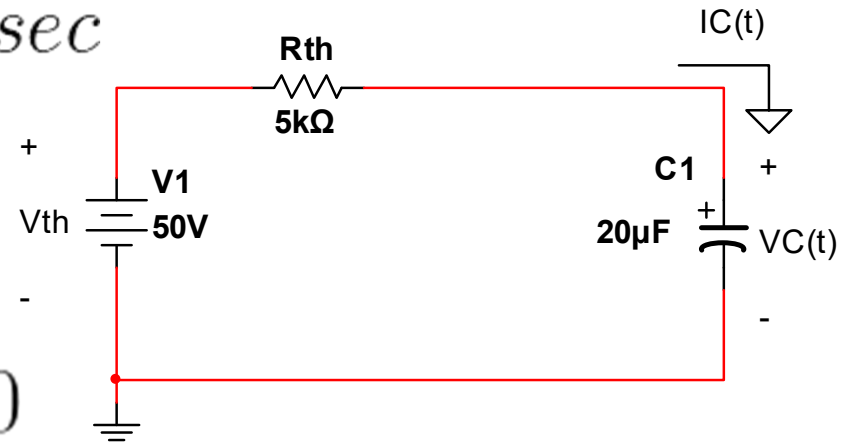


Example – Charge and Discharge

$$\tau = RC = 5k\Omega \cdot 20\mu F = 0.1sec$$

$$i_c(t) = \left(\frac{E}{R}\right)e^{\frac{-t}{\tau}} A, t > 0$$

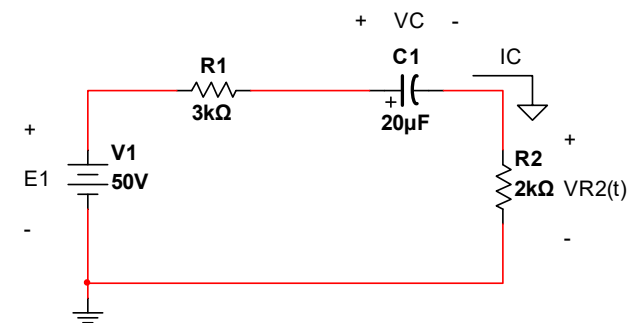
$$i_c(t) = \left(\frac{50V}{5k\Omega}\right)e^{\frac{-t}{0.1sec}} A, t > 0$$



$$v_c(t) = E(1 - e^{\frac{-t}{\tau}}) V, t \geq 0$$

$$v_c(t) = 50(1 - e^{\frac{-t}{0.1sec}}) V, t \geq 0$$

$$V_{R2}(t) = i_C(t) \cdot R_2 = 20e^{\frac{-t}{0.1}} V, t > 0$$



Example – Charge and Discharge

At $t = 1 \text{ sec}$ ($1 \text{ sec} > 5 \tau$), switch moves to position 2

□ $V_C(t = 1 \text{ sec}) = 50\text{V}$, final $V_C(t)$ from charge phase

- V_C cannot change instantaneously
- V_C will decrease exponentially to 0 V
 - Depends on τ value for timing
- The capacitor acts like a battery during discharge

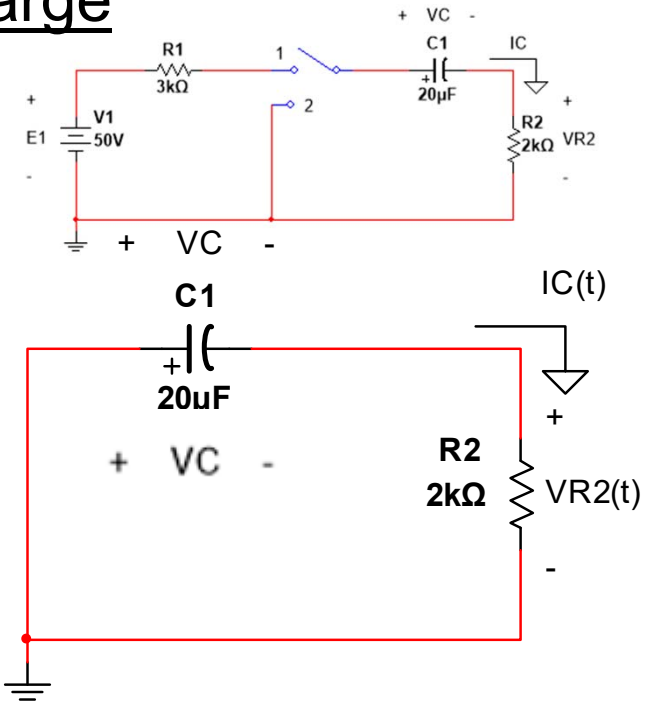
$$v_c(t) = \underset{\substack{\text{Initial Charge} \\ \nearrow}}{E} e^{\underset{\substack{\text{Assumes } E \text{ at } t=0 \\ \nwarrow}}{-\frac{t}{\tau}}} V$$

$$E = 50\text{V} \quad \tau = R \cdot C = 2\text{k}\Omega \cdot 20\mu\text{F} = 40\text{ms}$$

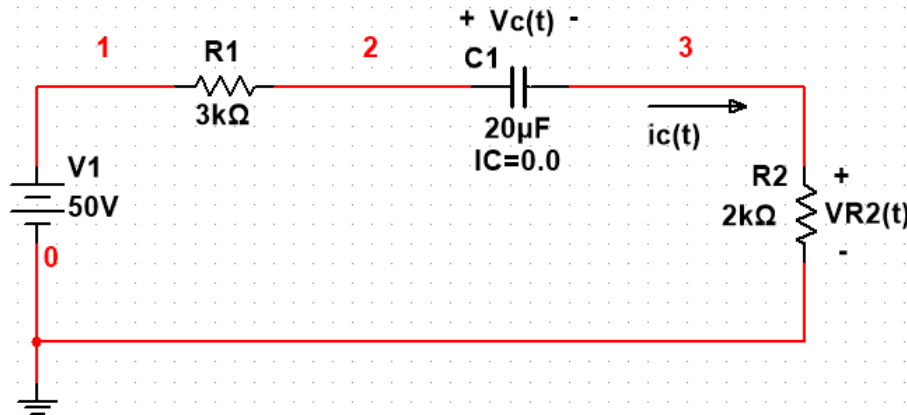
$$v_c(t) = 50e^{\frac{-(t-1)}{.04\text{sec}}} \text{V}, t \geq 1\text{sec} \quad \text{Note: } t_{\text{initial}} = 1 \text{ sec (not 0 sec)}$$

$$v_{R_2}(t) = -v_c(t) = -50e^{\frac{-(t-1)}{0.04}} \text{V}, t > 1\text{sec}$$

$$i_c(t) = \frac{v_{R_2}(t)}{R_2} = -25 \cdot 10^{-3} e^{\frac{-(t-1)}{0.04}} \text{A}, t > 1\text{sec}$$



Simulation – Charge and Discharge



Analyses and Simulation

Active Analysis:

- Interactive Simulation
- DC Operating Point
- AC Sweep
- Transient
- DC Sweep
- Single Frequency AC
- Parameter Sweep
- Noise
- Monte Carlo
- Fourier
- Temperature Sweep
- Distortion
- Sensitivity
- Worst Case
- Noise Figure
- Pole Zero
- Transfer Function
- Trace Width
- Batched

Transient

Analysis parameters Output Analysis options Summary

Variables in circuit:

All variables

I(C1)
I(R1)
I(R2)
I(V1)
P(C1)
P(R1)
P(R2)
P(V1)
V(1)
V(2)
V(3)

Selected variables for analysis:

All variables

V(2)-V(3)
V(3)

Add Remove Edit expression... Add expression...

Filter unse

More options

$$v_c(t) = V2 - V3,$$

$$v_{R2}(t) = V3$$

Analyses and Simulation

Active Analysis:

- Interactive Simulation
- DC Operating Point
- AC Sweep
- Transient
- DC Sweep
- Single Frequency AC
- Parameter Sweep
- Noise
- Monte Carlo
- Fourier
- Temperature Sweep
- Distortion

Transient

Analysis parameters Output Analysis options Summary

Initial conditions: User-defined

Start time (TSTART): 0 s

End time (TSTOP): 0.5 s

☐ Maximum time step (TMAX): Determine automatically s

Setting a small TMAX value will improve accuracy, however the simulation time will increase.

☐ Initial time step (TSTEP): Determine automatically s

Analyses and Simulation

Active Analysis:

- Interactive Simulation
- DC Operating Point
- AC Sweep
- Transient
- DC Sweep
- Single Frequency AC
- Parameter Sweep
- Noise
- Monte Carlo
- Fourier
- Temperature Sweep
- Distortion
- Sensitivity

Transient

Analysis parameters Output Analysis options Summary

Variables in circuit:

All variables

I(C1)
I(R1)
I(R2)
I(V1)
P(C1)
P(R1)
P(R2)
P(V1)
V(1)
V(2)
V(3)

Selected variables for analysis:

All variables

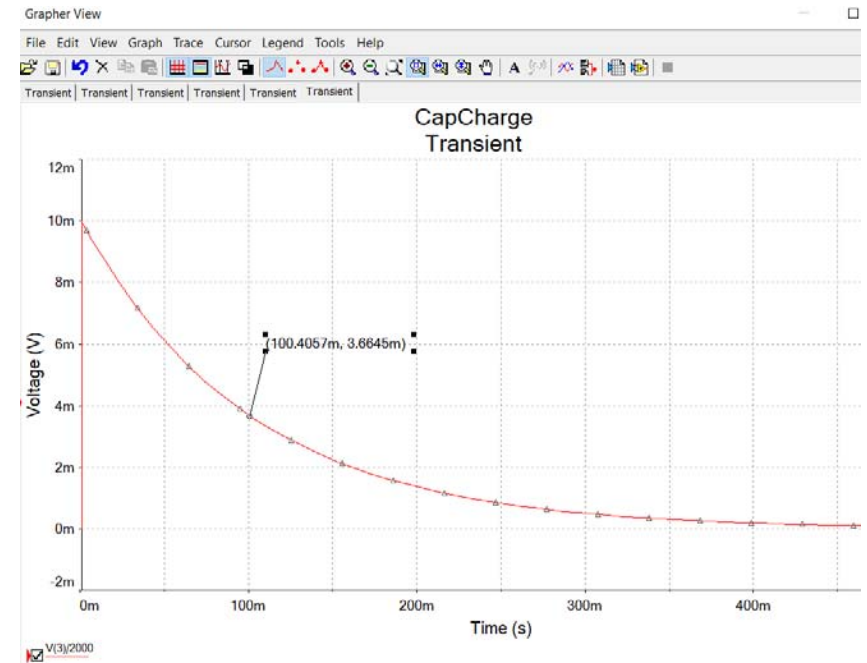
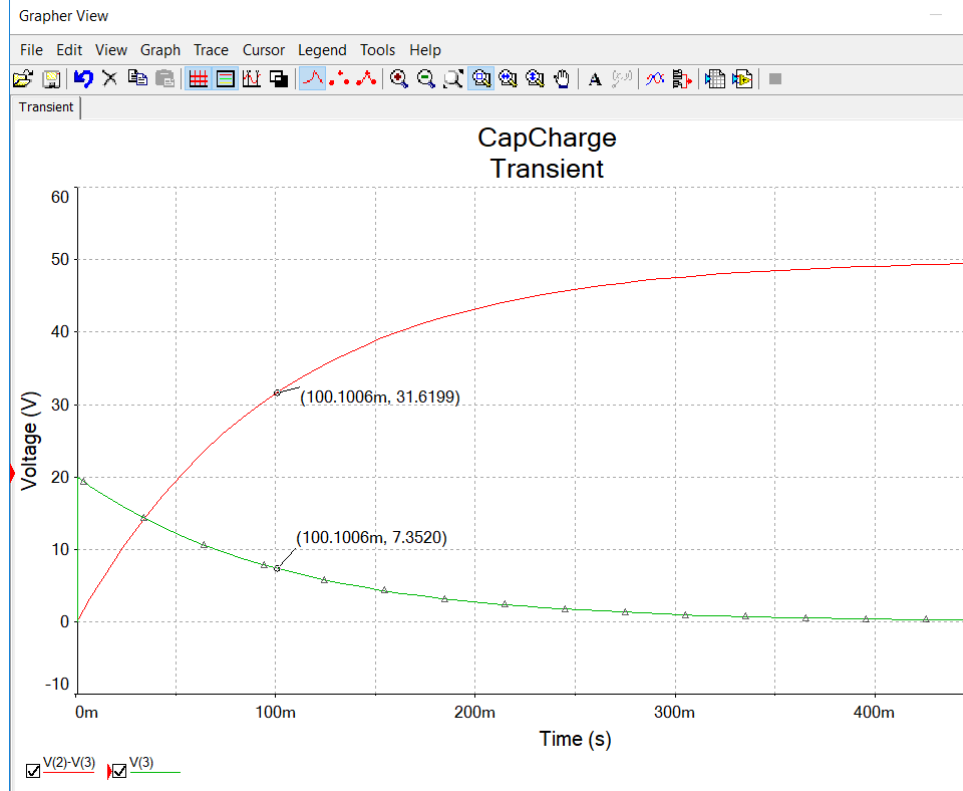
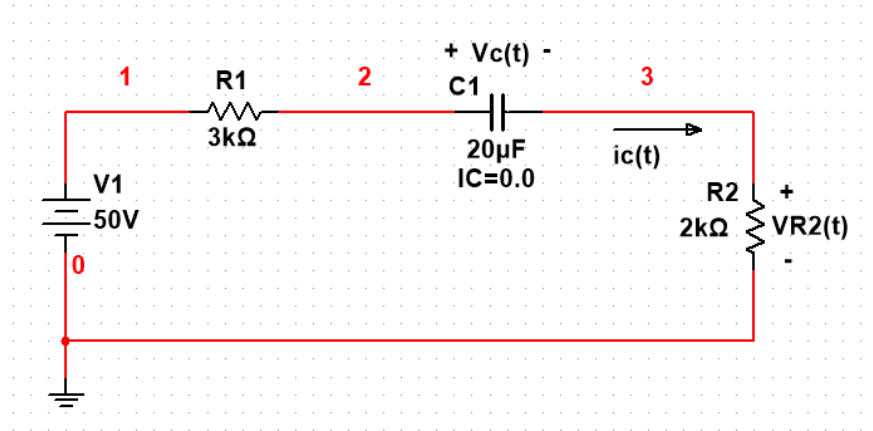
V(3)/2000

Add Remove

Recall: $\tau_{\text{charge}} = 0.1 \text{ sec}$
Simulate for 5τ

$$i_c(t) = v_3(t)/R_2$$

Simulation – Charge and Discharge



At one time constant (0.1 sec):

$$v_c(0.1\text{sec}) = 31.6\text{V}$$

$$v_{R2}(0.1\text{sec}) = 7.35\text{V}$$

$$i_c(0.1\text{sec}) = 3.66\text{mA}$$

Example – Charge and Discharge

Checking the charge phase results (theory and simulation):

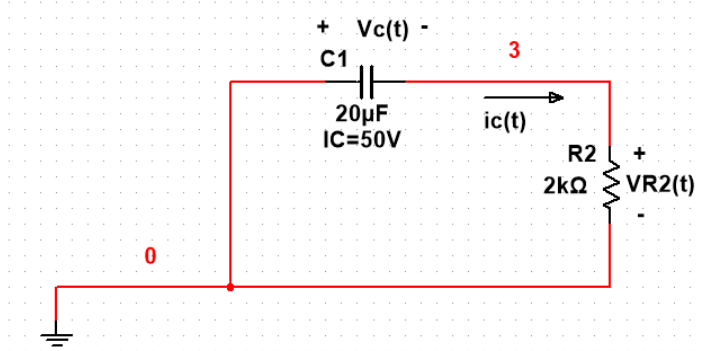
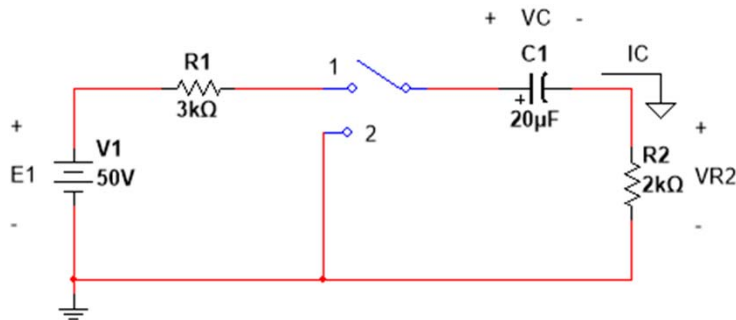
$$i_c(t) = 10 \cdot 10^{-3} \cdot e^{\frac{-t}{0.1}} A, t > 0$$

$$v_c(t) = 50(1 - e^{\frac{-t}{0.1}}) V, t \geq 0$$

$$v_{R2}(t) = i_c(t) \cdot R_2 = 20e^{\frac{-t}{0.1}} V, t > 0$$

t (sec)	i _c (t)		v _c (t)		v _{R2} (t)	
	Calc	Multisim	Calc	Multisim	Calc	Multisim
0 ⁺	10 mA	9.9 mA	0 V	0V	20 V	19.9 V
0.1 (\mathcal{T})	3.68 mA	3.66 mA	31.6 V	31.6 V	7.36 V	7.35 V
0.25	0.82 mA	0.82 mA	45.9 V	45.8 V	1.64 V	1.63 V
0.5 (5 \mathcal{T})	67.4 μ A	66.7 μ A	49.7 V	49.6 V	0.13 V	0.13 V
1	0.45 μ A	0.45 μ A	49.98 V	49.85 V	0.91 mV	0 V

Simulation – Charge and Discharge



Analyses and Simulation

Active Analysis:

Interactive Simulation
DC Operating Point
AC Sweep
Transient
DC Sweep
Single Frequency AC
Parameter Sweep
Noise
Monte Carlo
Fourier
Temperature Sweep
Distortion
Sensitivity

Transient

Analysis parameters Output Analysis options Summary

Variables in circuit:

All variables
I(C1)
I(R2)
P(C1)
P(R2)

Selected variables for analysis:

All variables
0-V(3)
V(3)

$$v_c(t) = 0 - V3,$$

$$v_{R2}(t) = V3$$

Analyses and Simulation

Active Analysis:

Interactive Simulation
DC Operating Point
AC Sweep
Transient
DC Sweep
Single Frequency AC
Parameter Sweep
Noise

Transient

Analysis parameters Output Analysis options Summary

Initial conditions: User-defined
Start time (TSTART): 0 s
End time (TSTOP): 0.2 s

Analyses and Simulation

Active Analysis:

Interactive Simulation
DC Operating Point
AC Sweep
Transient
DC Sweep
Single Frequency AC
Parameter Sweep
Noise
Monte Carlo
Fourier
Temperature Sweep
Distortion
Sensitivity

Transient

Analysis parameters Output Analysis options Summary

Variables in circuit:

All variables
I(C1)
I(R2)
P(C1)
P(R2)
V(3)

Selected variables for analysis:

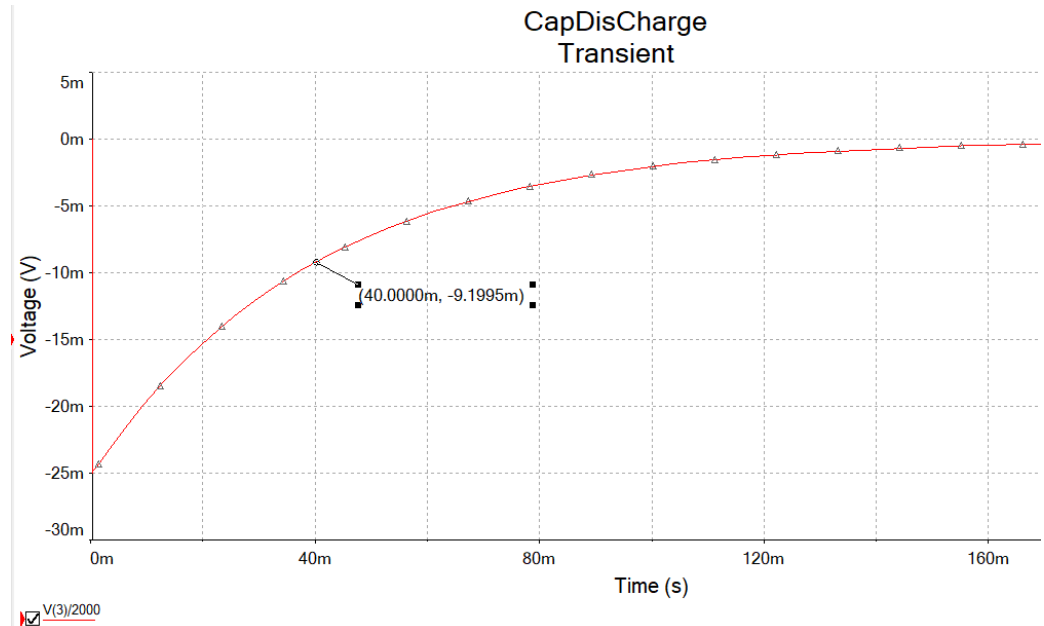
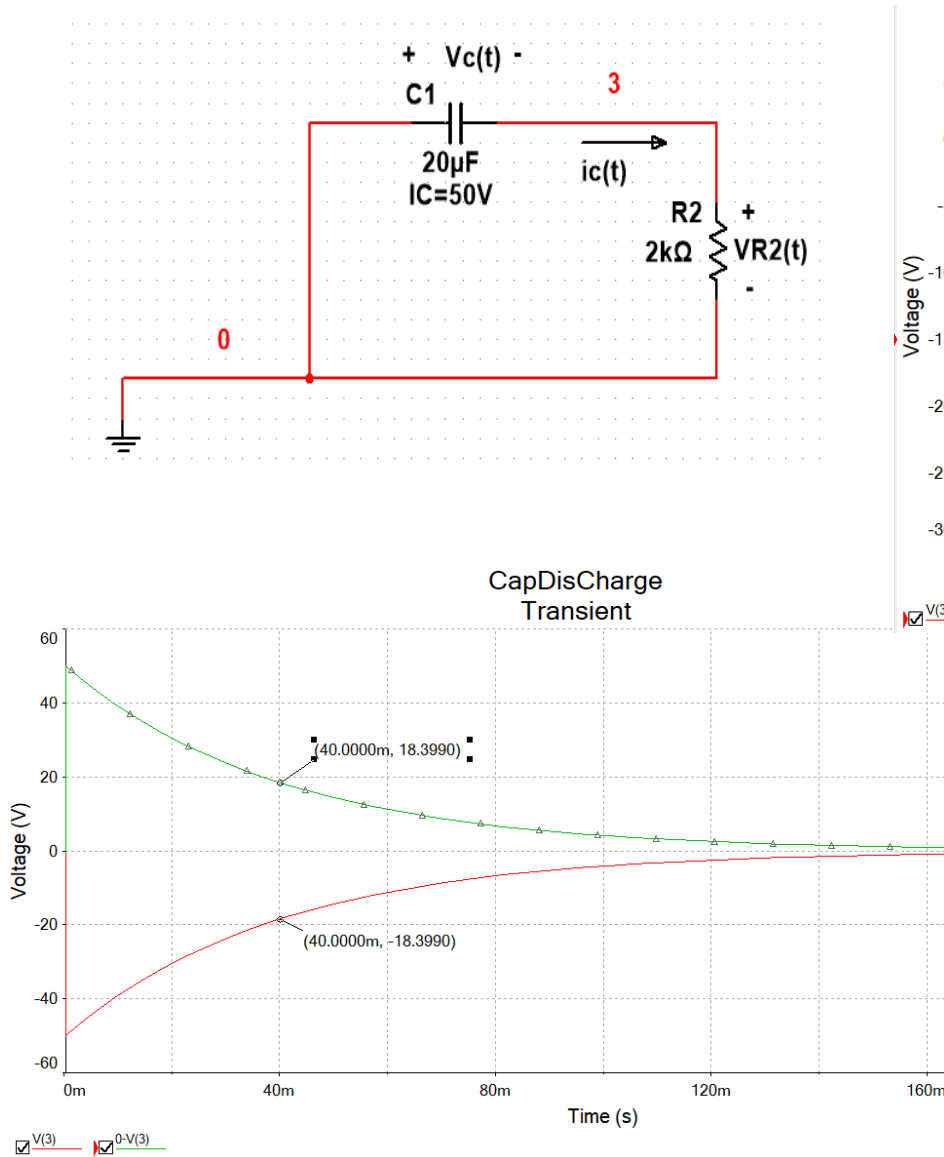
All variables
V(3)/2000

$$i_c(t) = v_3(t)/R2$$

Recall: $\tau_{\text{discharge}} = 40\text{msec}$

Simulate for 5τ (Simulation starts at $t=0$ sec, actual time is $t=1$ sec)

Simulation – Charge and Discharge



At one time constant into discharge (40ms, actual problem time of 1.04 sec):

$$v_c(1.04\text{sec}) = 18.4\text{V}$$

$$v_{R2}(1.04\text{sec}) = -18.4\text{V}$$

$$i_c(1.04\text{sec}) = -9.2\text{mA}$$

Example – Charge and Discharge

Checking the discharge phase results (theory and simulation):

$$v_c(t) = 50e^{\frac{-(t-1)}{0.04}} V, t \geq 1$$

$$v_{R_2}(t) = -50e^{\frac{-(t-1)}{0.04}} V, t > 1$$

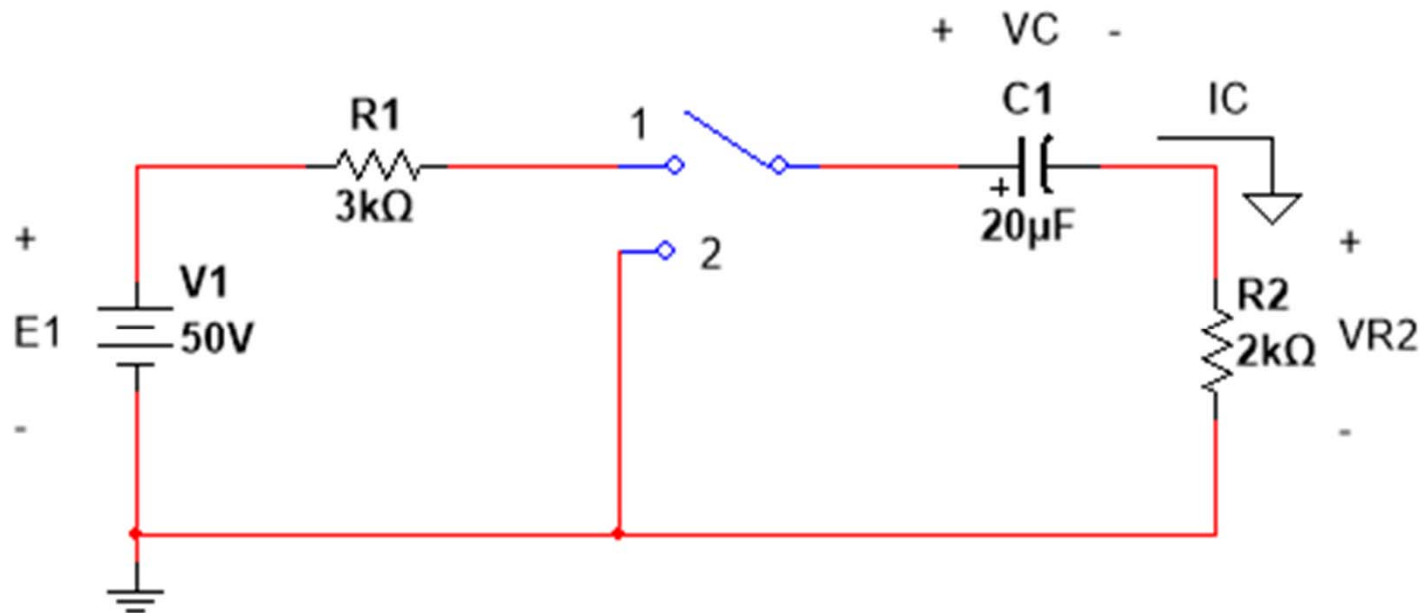
$$i_c(t) = -25 \cdot 10^{-3} \cdot e^{\frac{-(t-1)}{0.04}} A, t > 1$$

t (sec)	i _c (t)		v _c (t)		v _{R2} (t)	
	Calc	Multsim	Calc	Multisim	Calc	Multisim
1 ⁺	-25 mA	-24.93 mA	50 V	49.85 V	-50 V	-50 V
1.04 (T)	-9.20 mA	-9.2 mA	18.39 V	18.4 V	-18.39 V	-18.4 V
1.12 (3T)	-1.24 mA	-1.23 mA	2.49 V	2.47 V	-2.49	-2.47 V

In Class Problem

Find t for $V_C(t) = 25 \text{ V}$ for charge and discharge

- No initial charge on $C1$
- Switch to pos 1 at $t = 0$
- Switch to pos 2 at $t = 1 \text{ sec}$



Same circuit as earlier