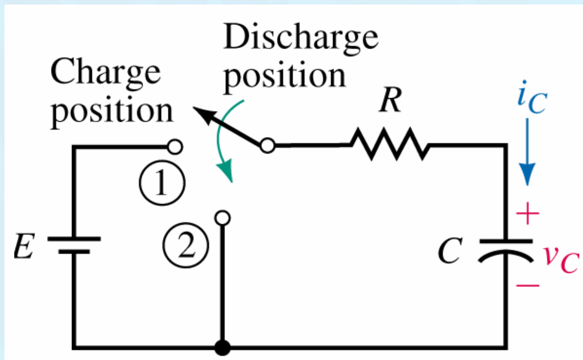
Chapter 11

Capacitive Charging, Discharging, and Simple Waveshaping Circuits

Introduction

- Circuit
  - Capacitor charging and discharging
  - Transient voltages and currents result when circuit is switched

Introduction



Capacitor Charging

- Charging a capacitor that is discharged
  - When switch is closed, the current instantaneously jumps to *E*/*R*
  - Exponentially decays to zero
- When switching, the capacitor looks like a short circuit

Circuit Analysis with Devices: Theory and Practice

Capacitor Charging

- Voltage begins at zero and exponentially increases to *E* volts
- Capacitor voltage cannot change instantaneously

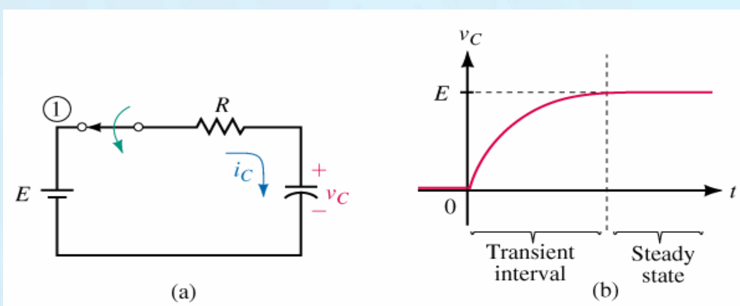
5

Robbins and Miller

Circuit Analysis with Devices: Theory and Practice

Capacitor Charging

- Capacitor voltage has shape shown:



6

Robbins and Miller

Steady State Conditions

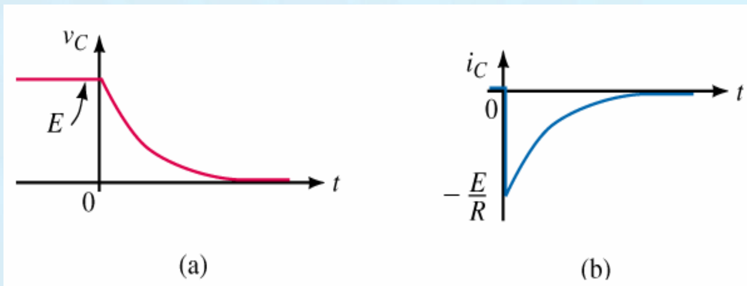
- Circuit is at steady state
  - When voltage and current reach their final values and stop changing
- Capacitor has voltage across it, but no current flows through the circuit
- Capacitor looks like an open circuit

Capacitor Discharging

- Assume capacitor has *E* volts across it when it begins to discharge
- Current will instantly jump to $-E/R$
- Both voltage and current will decay exponentially to zero

Capacitor Discharging

- Here are the decay waveforms:



Capacitor Charging Equations

- Voltages and currents in a charging circuit do not change instantaneously
- These changes over time are exponential changes

Capacitor Charging Equations

- Equation for voltage across the capacitor as a function of time is

$$v_C = E\left(1 - e^{-t/RC}\right)$$

Capacitor Charging Equations

- Voltage across resistor is found from KVL: E - v_C

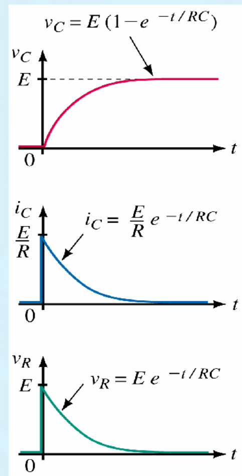
$$V_R = Ee^{-t/RC}$$

- The current in the circuit is

$$i_C = \frac{E}{R}e^{-t/RC}$$

Capacitor Charging Equations

- Values may be determined from these equations
- Waveforms are shown to right



13

Circuit Analysis with Devices:
Theory and Practice
THOMSON DELMAR LEARNING

The Time Constant

- Rate at which a capacitor charges depends on product of *R* and *C*
- Product known as time constant
- $\tau = RC$
- τ (Greek letter tau) has units of seconds

14

Robbins and Miller
Copyright © 2007 Thomson Delmar Learning

Duration of a Transient

- Length of time that a transient lasts depends on exponential function $e^{-t/\tau}$
- As *t* increases
  - Function decreases
  - When the *t* reaches infinity, the function decays to zero

Circuit Analysis with Devices:
Theory and Practice
THOMSON DELMAR LEARNING

Duration of a Transient

- For all practical purposes, transients can be considered to last for only five time constants

Robbins and Miller
Copyright © 2007 Thomson Delmar Learning

Capacitor with an Initial Voltage

- Voltage denoted as V_0
  - Capacitor has a voltage on it
- Voltage and current in a circuit will be affected by initial voltage

Circuit Analysis with Devices:
Theory and Practice

THOMSON
DELMAR LEARNING

Capacitor with an Initial Voltage

$$v_C = E + (V_0 - E)e^{-t/\tau}$$

$$i_C = \frac{E - V_0}{R} e^{-t/\tau}$$

Robbins and Miller

Copyright © 2007 Thomson Delmar Learning

Circuit Analysis with Devices: Theory and Practice

Capacitor Discharging Equations

- If a capacitor is charged to voltage V_0 and then discharged, the equations become

$$v_C = V_0 e^{-t/\tau}$$

$$v_R = -V_0 e^{-t/\tau}$$

$$i_C = -\frac{V_0}{R} e^{-t/\tau}$$

19

Robbins and Miller

Circuit Analysis with Devices: Theory and Practice

Capacitor Discharge Equations

- Current is negative because it flows opposite to reference direction
- Discharge transients last five time constants
- All voltages and currents are at zero when capacitor has fully discharged

20

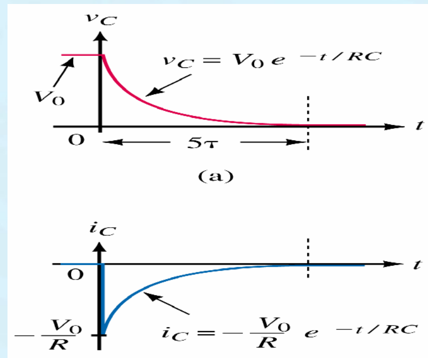
Robbins and Miller

Circuit Analysis with Devices: Theory and Practice

THOMSON DELMAR LEARNING

Capacitor Discharge Equations

- Curves shown represent voltage and current during discharge



(b) During discharge, i_C is negative as determined in Figure 11–18

21

Robbins and Miller

Circuit Analysis with Devices: Theory and Practice

THOMSON DELMAR LEARNING

More Complex Circuits

- You may have to use Thévenin's theorem (those with multiple resistors)
- Remove capacitor as the load and determine Thévenin equivalent circuit

22

Robbins and Miller

Copyright © 2007 Thomson Delmar Learning

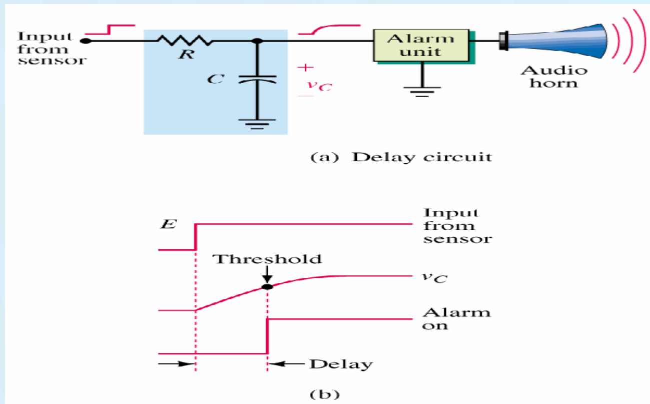
More Complex Circuits

- Use R_{Th} to determine τ
- $\tau = R_{Th} \cdot C$
- Use E_{Th} as the equivalent source voltage

An *RC* Timing Application

- *RC* circuits
  - Used to create delays for alarm, motor control, and timing applications
- Alarm unit shown contains a threshold detector
  - When input to this detector exceeds a preset value, the alarm is turned on

An *RC* Timing Application



Circuit Analysis with Devices:
Theory and Practice
THOMSON
DELMAR LEARNING

Pulse Response of *RC* Circuits

- Pulse
  - Voltage or current that changes from one level to another and back again
- Periodic waveform
  - Pulse train is a repetitive stream of pulses

Circuit Analysis with Devices: Theory and Practice

THOMSON DELMAR LEARNING

Pulse Response of *RC* Circuits

- Square wave
  - Waveform's time high equals its time low
- Length of each cycle of a pulse train is its period

27

Robbins and Miller

Circuit Analysis with Devices: Theory and Practice

THOMSON DELMAR LEARNING

Pulse Response of *RC* Circuits

- Number of pulses per second is its pulse repetition frequency
- Width of pulse compared to its period is its duty cycle
- Usually given as a percentage

28

Robbins and Miller

Copyright © 2007 Thomson Delmar Learning

Circuit Analysis with Devices:
Theory and Practice

THOMSON DELMAR LEARNING

Pulse Response of *RC* Circuits

- Pulses have a rise and fall time
  - Because they do not rise and fall instantaneously
- Rise and fall times are measured between the 10% and 90% points

29

Robbins and Miller

Circuit Analysis with Devices:
Theory and Practice

THOMSON DELMAR LEARNING

The Effect of Pulse Width

- Width of pulse relative to a circuit's time constant
  - Determines how it is affected by an *RC* circuit
- If pulse width >> 5τ
  - Capacitor charges and discharges fully
  - With the output taken across the resistor, this is a differentiator circuit

30

Robbins and Miller

The Effect of Pulse Width

- If pulse width = 5τ
  - Capacitor fully charges and discharges during each pulse
- If the pulse width << 5τ
  - Capacitor cannot fully charge and discharge
  - This is an integrator circuit

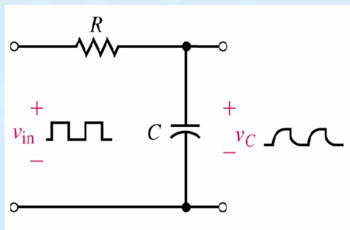
Circuit Analysis with Devices:
Theory and Practice
THOMSON
DELMAR LEARNING

Simple Waveshaping Circuits

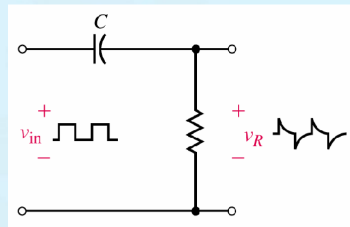
- Circuit (a) provides approximate integration if $5\tau >> T$
- Circuit (b) provides approximate differentiation if $T >> 5\tau$

Robbins and Miller
Copyright © 2007 Thomson Delmar Learning

Simple Waveshaping Circuits



(a) Output across *C*



(b) Output across *R*

Capacitive Loading

- Capacitance
  - Occurs when conductors are separated by insulating material
  - Leads to stray capacitance
  - In high-speed circuits this can cause problems