Chapter 15

Time Response of Reactive Circuits

Objectives

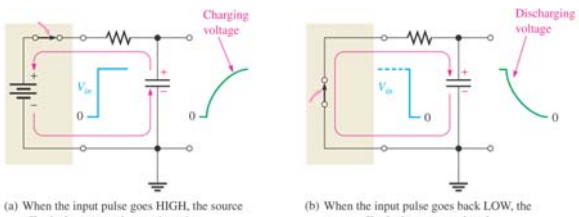
- Explain the operation of an RC integrator
- Analyze an RC integrator with a single input pulse
- Analyze an RC integrator with repetitive input pulses
- Analyze an RC differentiator with a single input pulse

Objectives

- Analyze an RC differentiator with repetitive input pulses
- Analyze the operation of an RL integrator
- Analyze the operation of an RL differentiator

The RC Integrator

- When a pulse generator is connected to the input of an RC integrator, the capacitor will charge and discharge in response to the pulses



(a) When the input pulse goes HIGH, the source effectively acts as a battery in series with a closed switch, thereby charging the capacitor.

(b) When the input pulse goes back LOW, the source effectively acts as a closed switch, providing a discharge path for the capacitor.

The RC Integrator

- The rate of charging and discharging depends on the RC time constant

$$\tau = RC$$

- For an ideal pulse, both edges are considered to be instantaneous
  - The capacitor appears as a short to an instantaneous change in current and as an open to dc
  - The voltage across the capacitor cannot change instantaneously - it can change only exponentially

Capacitor Voltage

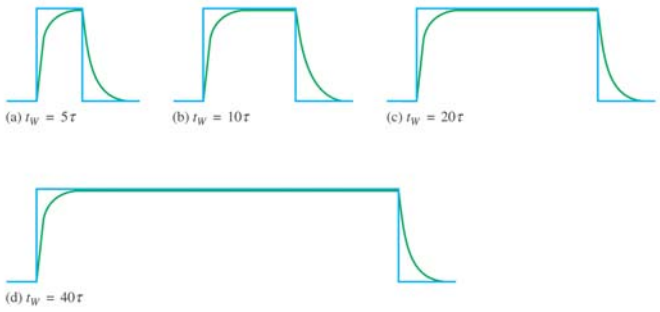
- In an RC integrator, the output is the capacitor voltage
- The capacitor charges during the time that the pulse is high
- If the pulse is at its high level long enough, the capacitor will fully charge to the voltage amplitude of the pulse
- The capacitor discharges during the time that the pulse is low

Response of RC Integrators to Single-Pulse Inputs

- A capacitor will fully charge if the pulse width is equal to or greater than 5 time constants (5τ)
- At the end of the pulse, the capacitor fully discharges back through the source

When the Pulse Width is Equal to or Greater than 5 Time Constants

- As the pulse width is increased, the shape of the output pulse approaches that of the input



When the Pulse Width is Less Than 5 Time Constants

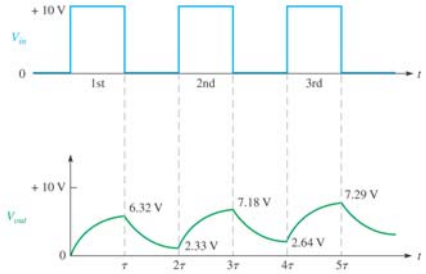
- The output voltage will not reach the full input voltage before the end of the pulse
- The capacitor only partially charges
- As the pulse width is reduced, the output voltage becomes smaller because the capacitor has less time to charge
- However, it takes the capacitor approximately the same length of time (5τ) to discharge back to zero after the pulse is removed

Repetitive-Pulse Response of RC Integrators

- If a periodic pulse waveform is applied to an RC integrator, the output waveshape depends on the relationship of the circuit time constant and the frequency (period) of the input pulses
- If the pulse width and the time between pulses are each equal to or greater than five time constants ($T>5\tau$), the capacitor will fully charge and fully discharge during each period of the input waveform

When a Capacitor Does Not Fully Charge and Discharge

- When the pulse width and the time between pulses are shorter than five time constants, the capacitor will not completely charge or discharge



When a Capacitor Does Not Fully Charge and Discharge

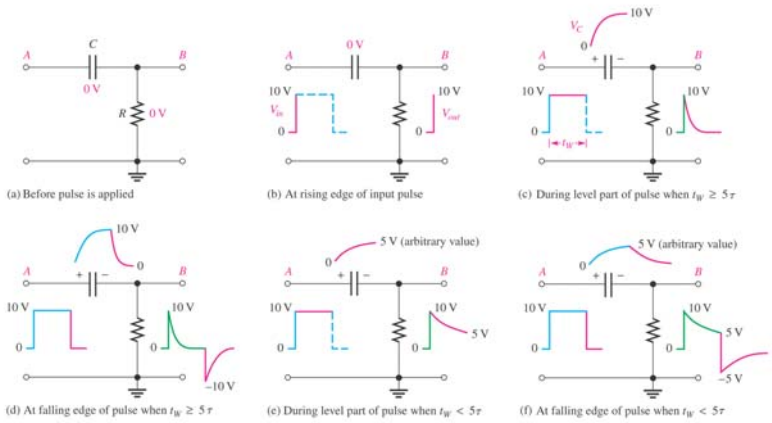
- During the first pulse, the capacitor charges, the output voltage reaches 63.5%
- Between the first and second pulses, the capacitor discharges, and the voltage decreases to (100% - 63.2%) = 36.8% of the voltage at the beginning of this interval
- On the second pulse, the capacitor voltage increases another 63.2% of its full value, added to the value it started with

Steady-State Response

- The output voltage will build up to a steady-state average value in five time constants (5τ)
- If the time constant is extremely long compared to the pulse width, the output voltage approaches a constant dc voltage. This value is the average value of the input
- For a square wave, the steady-state value is one-half of the input voltage

Single-Pulse Response of RC Differentiators

- A series RC circuit in which the output voltage is taken across the resistor is known as a differentiator. In terms of frequency response, it is a high-pass filter
- The shape of the differentiator's resistor voltage is determined by the charging and discharging action of the capacitor
- The next slide shows the pulse response of a differentiator for: $t_W \geq 5\ \tau$, and $t_W < 5\tau$

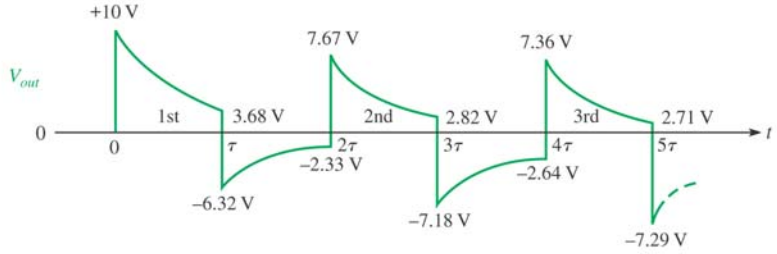


Repetitive-Pulse Response of RC Differentiators

- As the time constant is reduced ($t_W<5\tau$), both positive and negative portions of the output become narrower
- The average value of the output is zero
- For a very long time constant, the output approaches the shape of the input, but with an average value of zero
- The average value of a waveform is its dc component

Analysis of a Repetitive Waveform

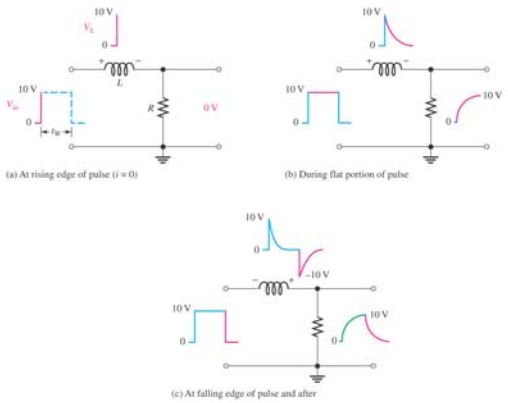
- Consider an RC differentiator with $\tau = t_W$, and an input waveform of 0 to +10V



Pulse Response of RL Integrators

- The output waveform is taken across the resistor, and under equivalent conditions, is the same shape as that for the RC integrator
- When a pulse generator is connected to the input of the integrator and the voltage pulse goes from its low level to its high level, the inductor prevents a sudden change in current
- The inductor acts as an open, and all of the input voltage is across it at the instant of the rising edge

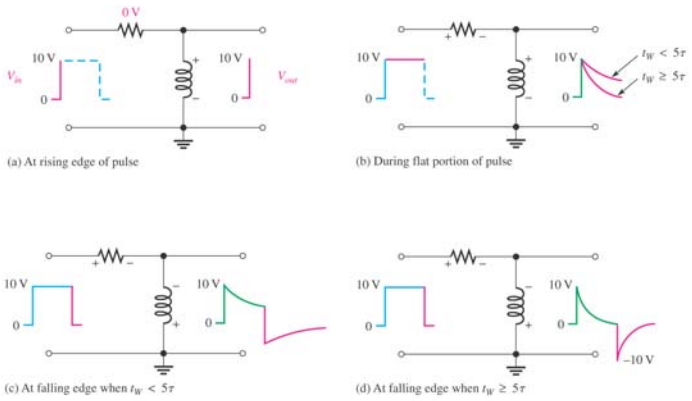
Response of the Integrator to a Single Pulse



Pulse Response of an RL Differentiator

- A series RL circuit in which the output voltage is taken across the inductor is known as a differentiator
- When the input pulse goes from its low level to its high level, L looks like an open, and all of the input voltage appears across it at the instant of the rising edge
- Shown in the next slide are the responses of an RL differentiator for both time constant conditions

Pulse Response of an RL Differentiator



Summary

- In an RC integrating circuit, the output voltage is taken across the capacitor
- In an RC differentiating circuit, the output voltage is taken across the resistor
- In an RL integrating circuit, the output voltage is taken across the resistor
- In an RL differentiating circuit, the output voltage is taken across the inductor

Summary

- In an integrator, when the pulse width (t_W) of the input is much less than the transient time, the output voltage approaches a constant level equal to the average value of the input
- In an integrator, when the pulse width of the input is much greater than the transient time, the output voltage approaches the shape of the input

Summary

- In a differentiator, when the pulse width of the input is much less than the transient time, the output voltage approaches the shape of the input but with an average value of zero

Summary

- In a differentiator , when the pulse width of the input is much greater than the transient time, the output voltage consists of narrow, positive-going and negative-going spikes occurring on the leading and trailing edges of the input pulses