EELE 250: Circuits, Devices, and Motors

Lecture 15

Assignment Reminder

- Read 5.5-5.6, 6.2, AND 10.1 – 10.6 (diodes)
- Practice problems:
  - P5.63, P5.68, P5.77, P5.85
  - P6.23, P6.26
  - P10.7, P10.8, P10.37

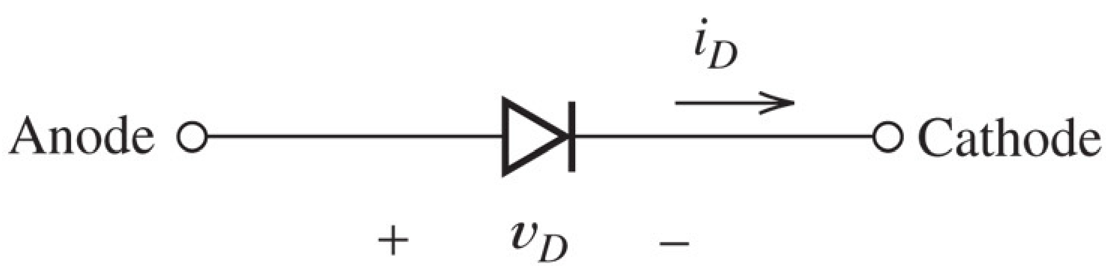
- D2L Quiz #7 will be posted this week. It is due by 11AM on Monday 14 Oct.

- REMINDER: Lab #5 will be performed this week—be sure to do the pre-lab assignment calculations!
  There will be no EELE 250 labs *next* week.

- Exam #2: in class on Wednesday 23 Oct.

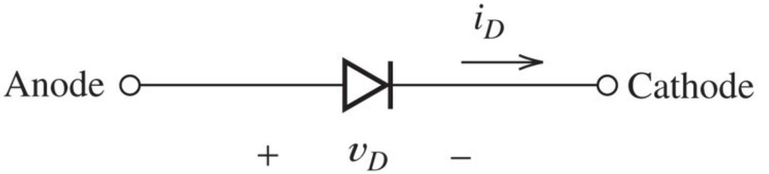
Diodes

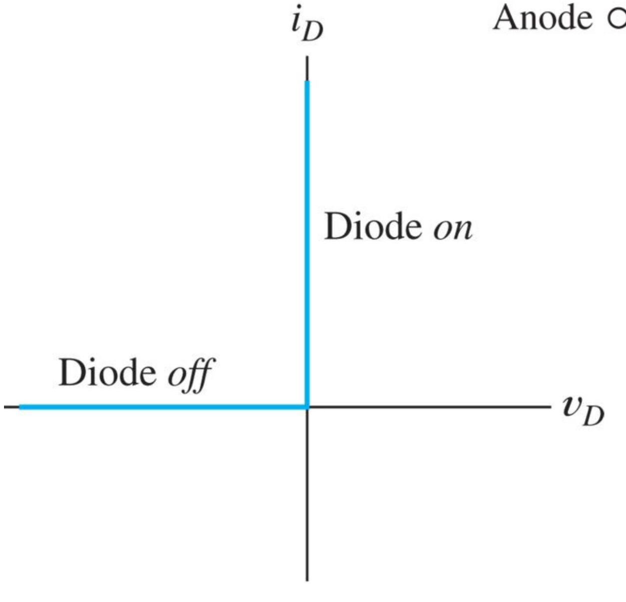
- Conceptually, a *diode* is an element that allows current to flow in one direction, but blocks current in the other direction.
- The fluid analogy: the diode is like a flapper valve in a pipe.
- Diode symbol:



The “ideal” diode model

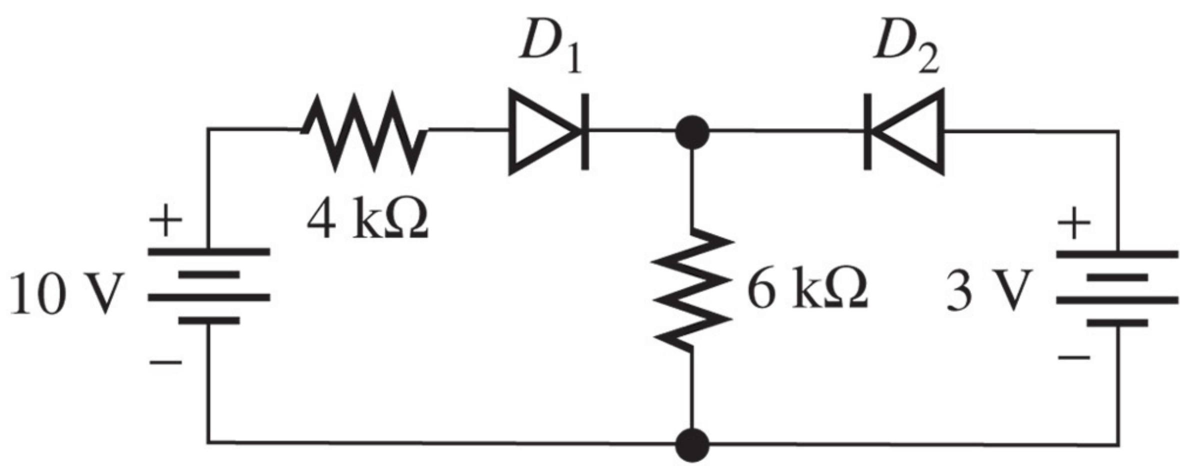
- If a perfect diode could be made, it would act like a *short circuit* for one current direction and an *open circuit* for the other current direction.



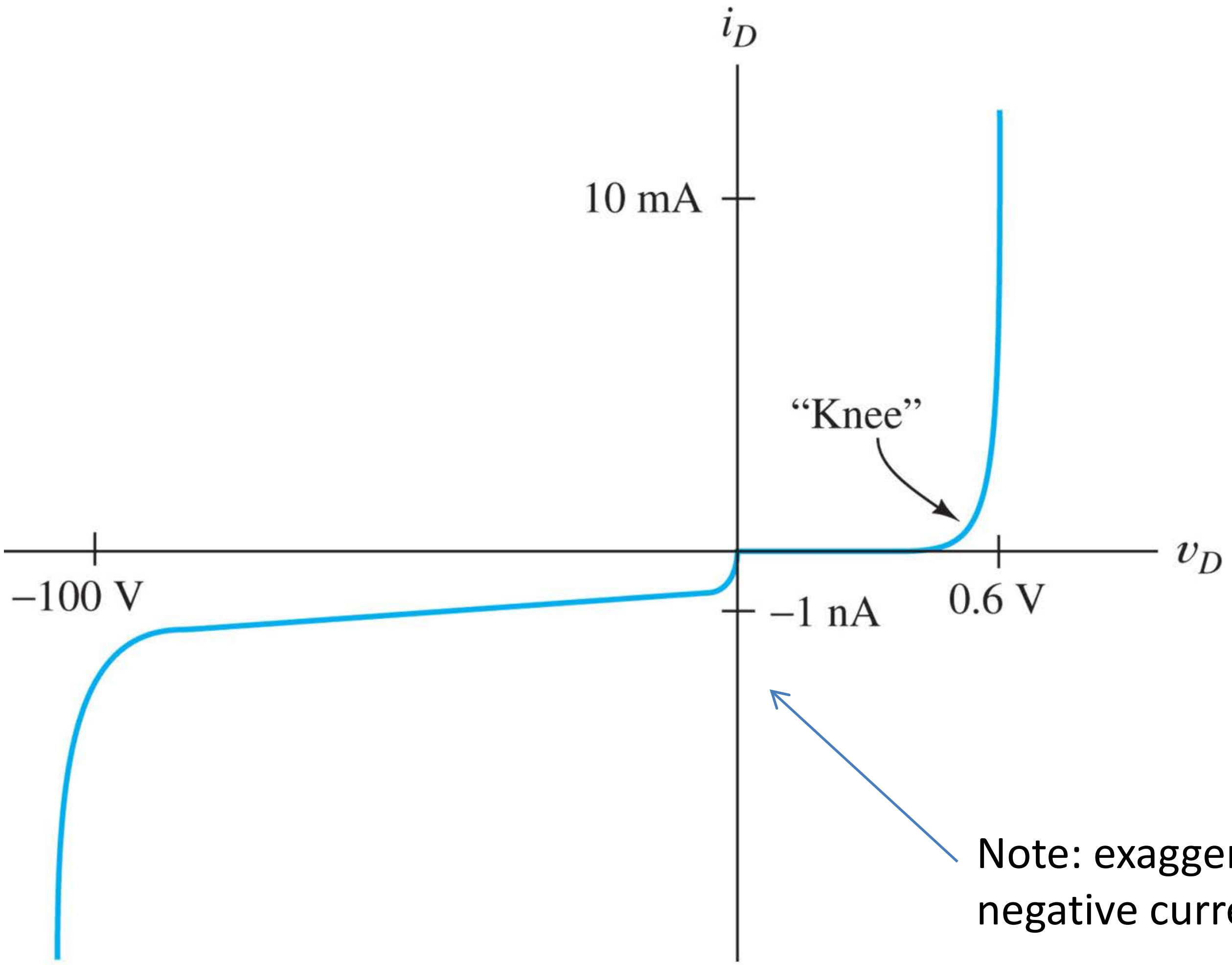


Ideal diode model (cont.)

- We often use the ideal diode model to do a quick circuit assessment of whether a diode is "on" or "off" in a circuit. This is because diodes are *nonlinear* and therefore we cannot use linearity, superposition, etc.!



The real diode model



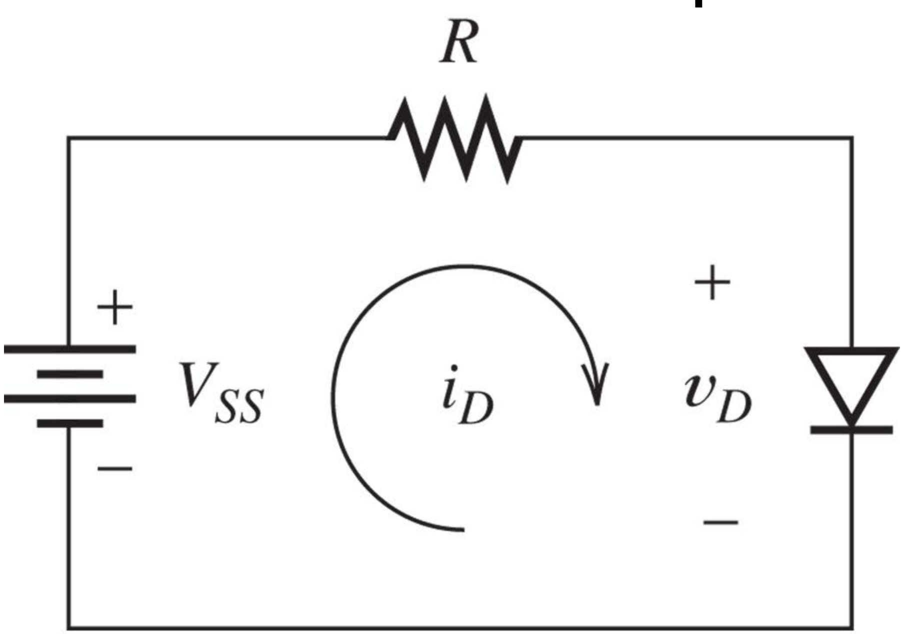
Note: exaggerated negative current axis

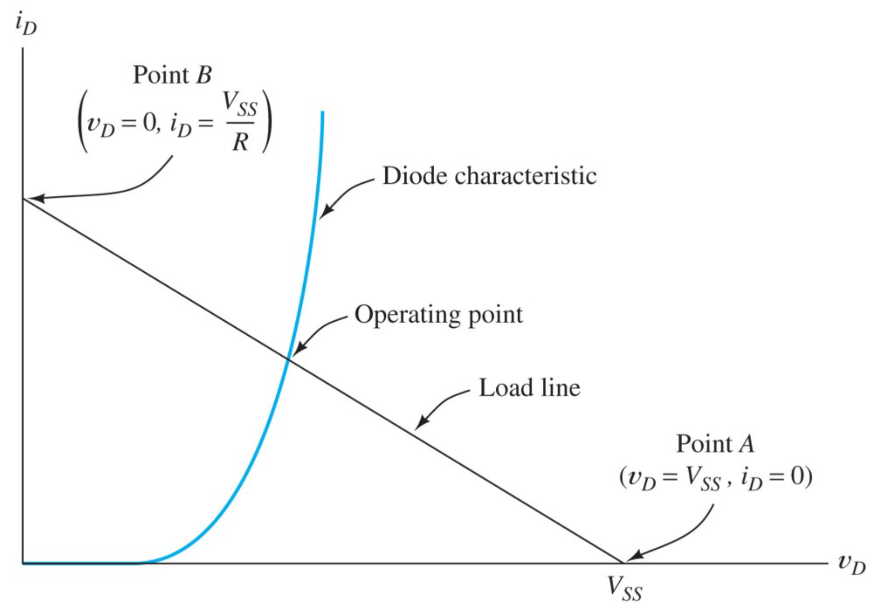
Shockley Equation

- William Shockley, one of the inventors of the transistor, developed a mathematical model for semiconductor diodes.
- $i_D = I_S\left(e^{\frac{v_D}{nV_T}} - 1\right)$
  - I_s is the *saturation current*
  - *n* is a coefficient ($1 < n < 2$) that depends on the diode's design
  - V_t is the thermal voltage (kT/q), about 26mV

Diode circuit analysis

- Diodes are nonlinear, as is clear from the Shockley equation.
- Equation solutions require nonlinear or iterative techniques.





Frequency Response

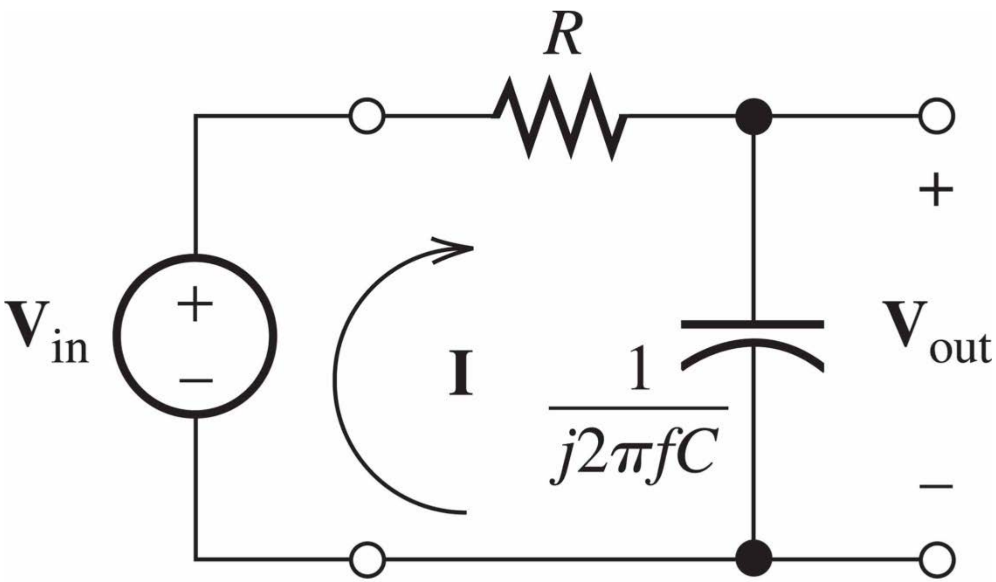
- Recall:

$$Z_L = j\omega L \qquad\qquad Z_c = 1/\, j\omega C$$

- Low frequency, $|Z_L| \rightarrow$ zero, $|Z_c| \rightarrow$ infinity
- High frequency, $|Z_L| \rightarrow$ infinity, $|Z_c| \rightarrow$ zero

“Low Pass” Filter

- A circuit that allows low frequencies to pass through and attenuates high frequencies



- $\mathbf{V_{out}} = \mathbf{V_{in}} \cdot \mathbf{Z_c}/(R+\mathbf{Z_c}) = \mathbf{V_{in}}\,/(1 + j2\pi f RC)$

Low Pass (cont.)

- $V_{out} = \frac{V_{in}}{(1+j2\pi fRC)}$
- As $f \rightarrow$ zero, $V_{out} \approx V_{in}$
- As $f \rightarrow$ big, $V_{out} \approx V_{in}/j2\pi fRC \approx$ zero

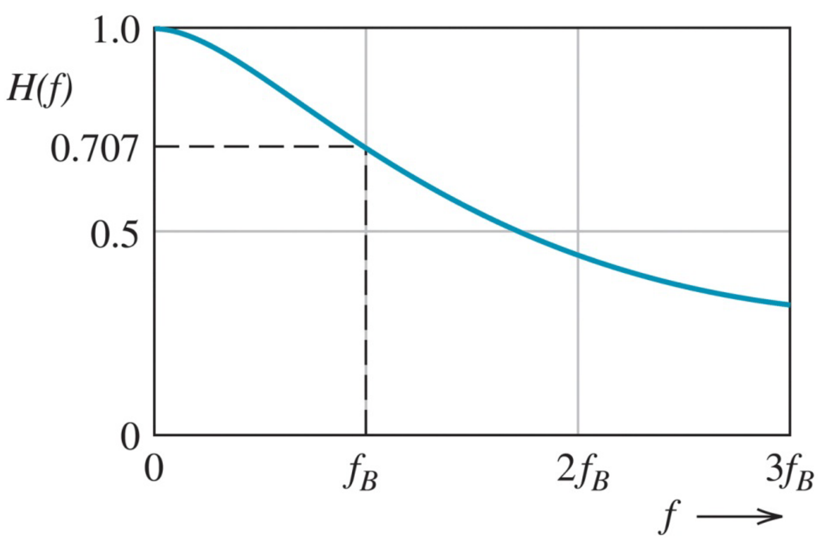
- $|V_{out}| = \frac{|V_{in}|}{\sqrt{1+(2\pi fRC)^2}}$
- $\angle V_{out}$ = -arctan($2\pi f$RC)

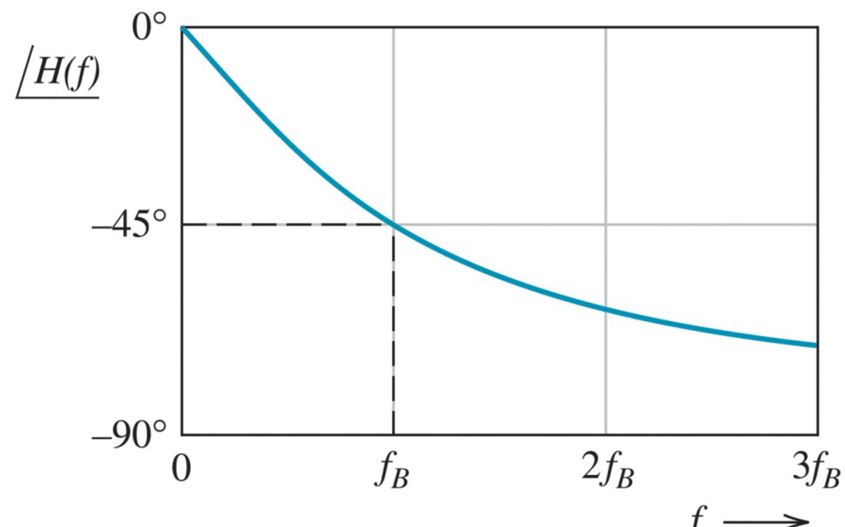
Where have we seen $R \cdot C$ before?

- The *time constant* came up when we looked at RC transient analysis: $t_c = R \cdot C$
- If we define $\omega_b = 1/(RC)$, or $f_b = 1/(2\pi RC)$, then $RC = 1/(2\pi f_b)$
- $V_{out} = \dfrac{V_{in}}{(1+j2\pi fRC)} = \dfrac{V_{in}}{1+j(2\pi f/2\pi f_b)} = \dfrac{V_{in}}{1+j(f/f_b)}$
- When $f = f_b$, $V_{out} = V_{in}/(1+j1) = V_{in}/(0.707\angle 45°)$

Magnitude and Phase

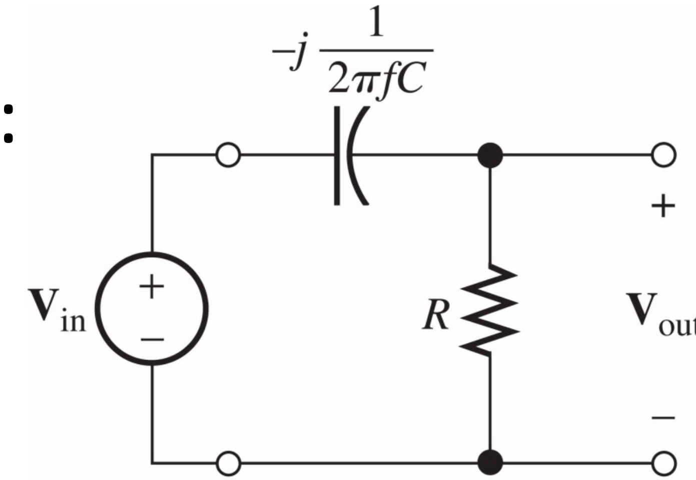
- $V_{out} = \frac{V_{in}}{(1+j2\pi fRC)} = \frac{V_{in}}{1+j(2\pi f/2\pi f_b)} = \frac{V_{in}}{1+j(f/f_b)}$
- When $f = f_b$, $V_{out} = V_{in}/(1+j1) = V_{in}/(0.707\angle 45$
- $|V_{out}| = \frac{|V_{in}|}{\sqrt{1+(f/f_b)^2}}$, $\angle V_{out}$ = -arctan(f/f_b)





High Pass Filter

- Interchange R and C:

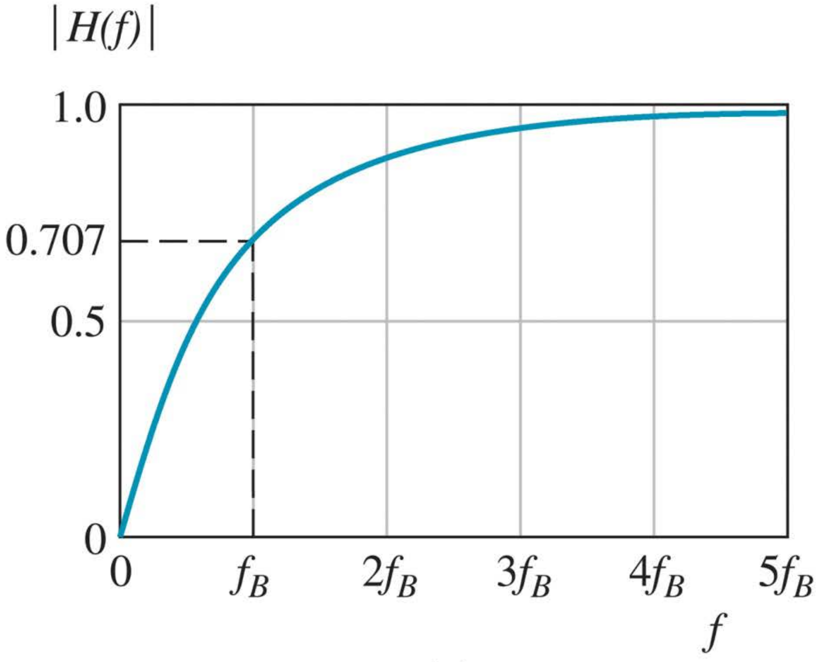


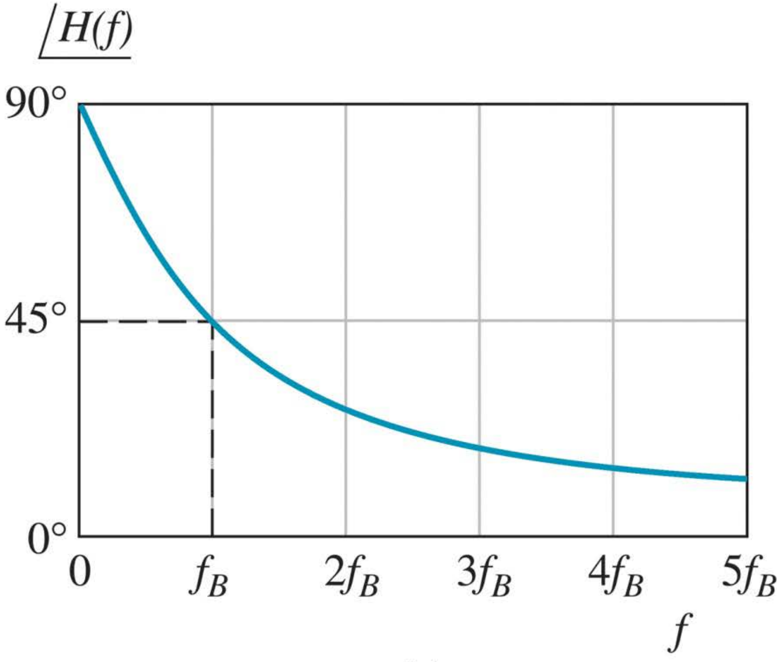
- Low frequencies are blocked, high frequencies are passed through to v_{out}

High Pass (cont.)

- As we did for Low Pass, we can define

  $f_b = 1/(2\pi RC)$





Frequency-selective Filters

- Bass/Treble control for a stereo
- Remove high frequency or low frequency noise
- Smooth out (low pass) or accentuate (high pass) variations in a signal
- Signal processing: high pass acts like a *differentiator* (*d/dt*), while low pass acts like an *integrator* ($\int dt$)