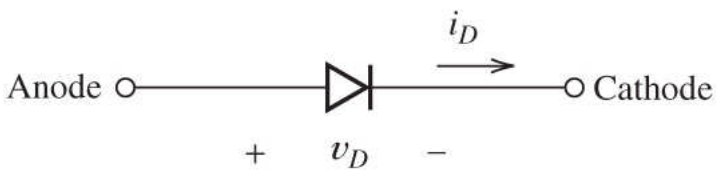
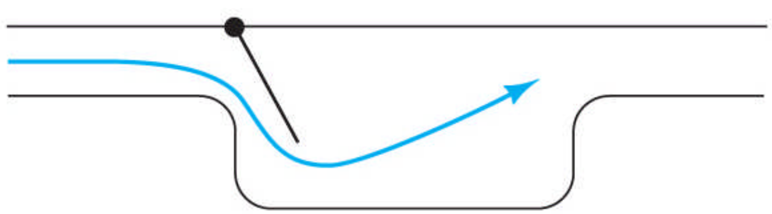
Lesson 32: Diodes

Diode

- A diode is an electrical check (flapper) valve.
  - It allows current to flow in one direction.
  - It blocks current flow in the opposite direction.
- Current flows from positive terminal (anode) to negative terminal (cathode).

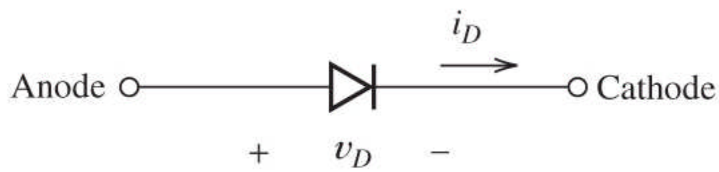


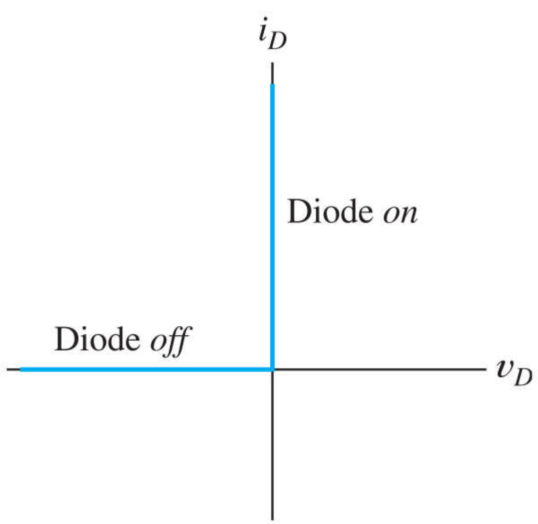
circuit symbol


flapper (check) valve

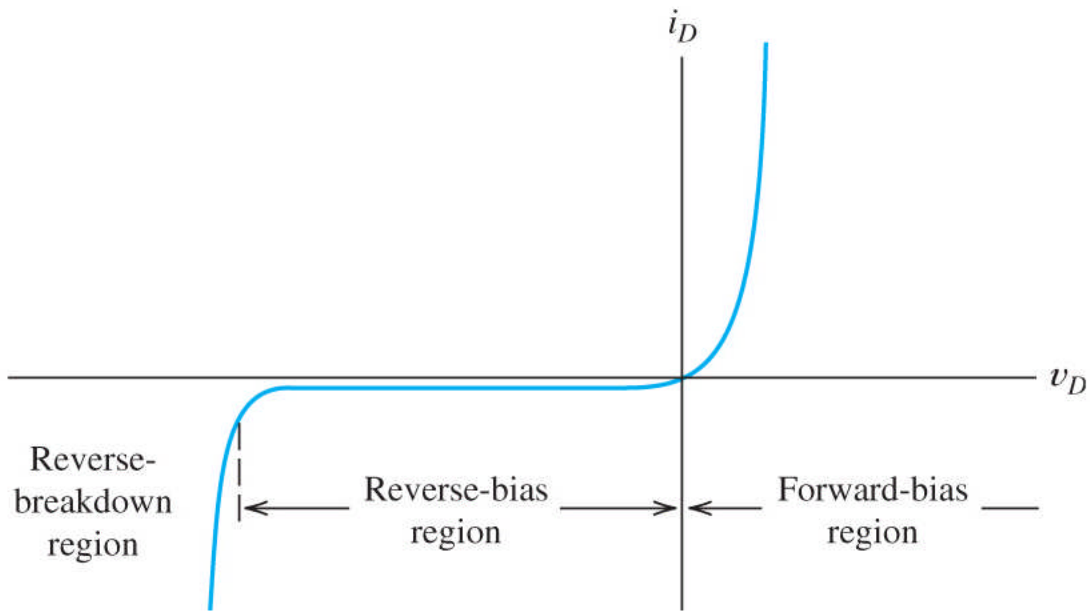

physical diode

Diode characteristic





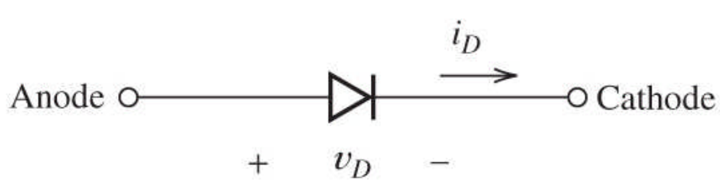
ideal diode volt-ampere characteristic



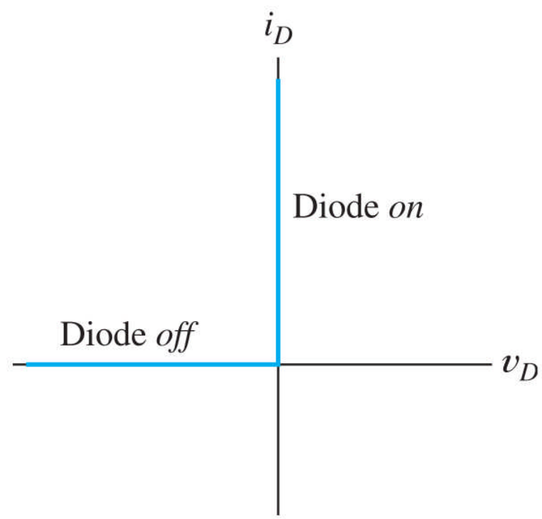
realistic diode volt-ampere characteristic

Ideal diode

- An ideal diode is a simplification for analysis.
  - With a positive voltage, the diode acts as a short circuit.
  - With a negative voltage, the diode acts as an open circuit.



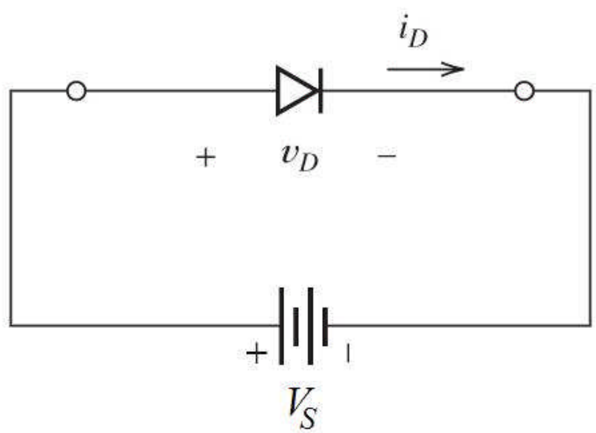
circuit symbol

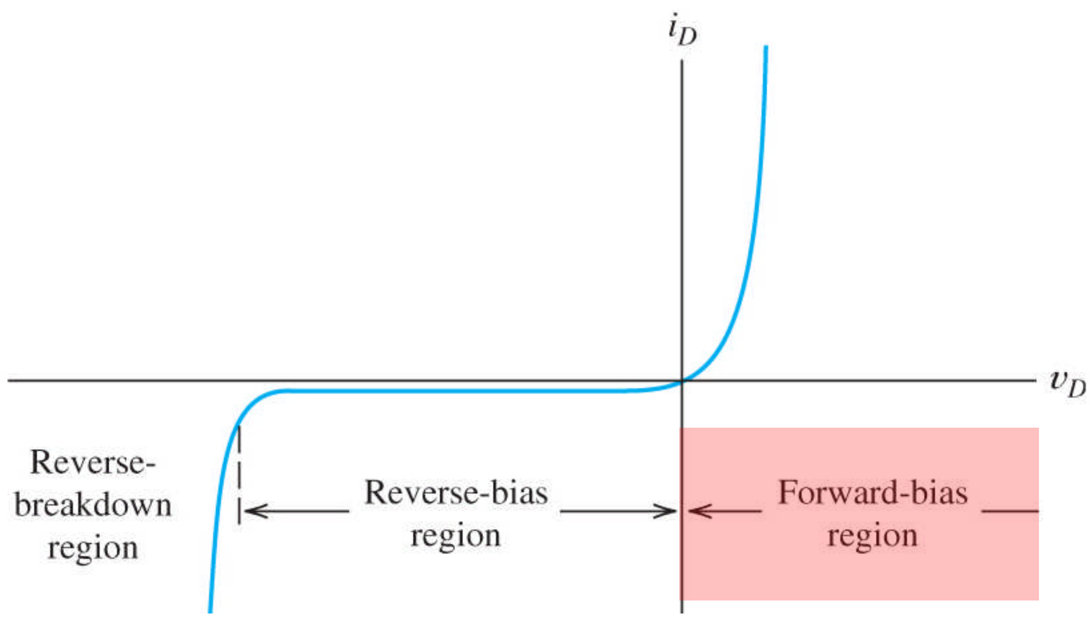


ideal diode volt-ampere characteristic

Diode characteristic

- If a positive voltage is applied to a diode, large amounts of current can flow with very little voltage drop.
- This condition is called **forward bias**.

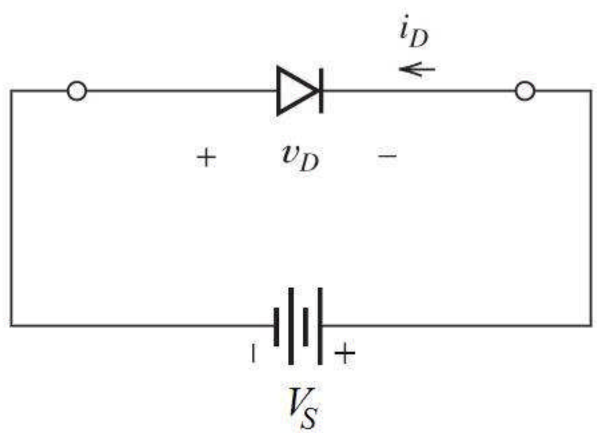


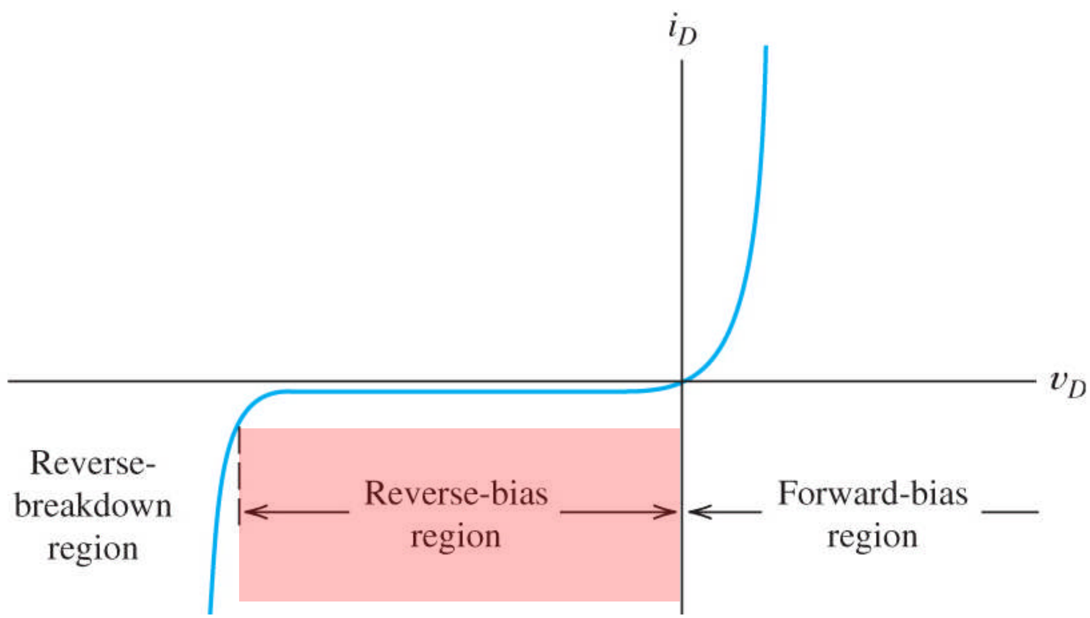


diode volt-ampere characteristic

Diode characteristic

- If a negative voltage is applied to a diode, very little current can flow.
- This condition is called **reverse bias**.

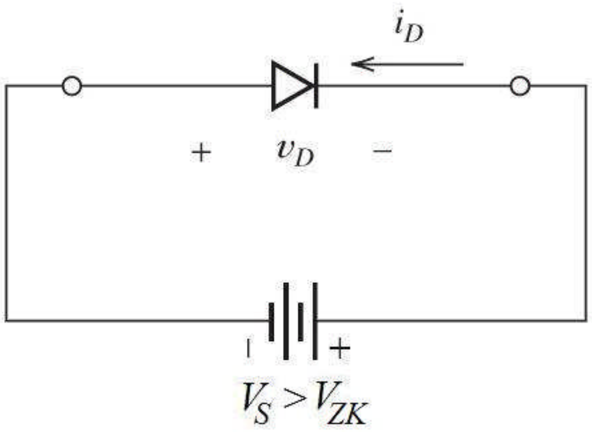


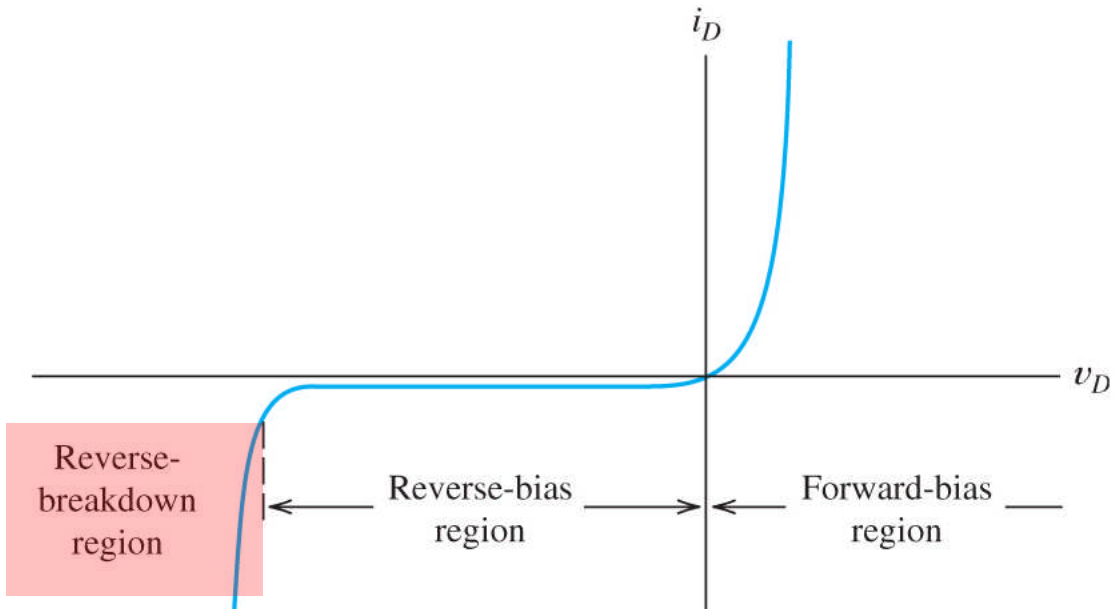


diode volt-ampere characteristic

Diode characteristic

- If the negative voltage is sufficiently large, the diode enters the **reverse-breakdown** region allowing large, negative currents to flow.
- This may or may not be destructive.





diode volt-ampere characteristic

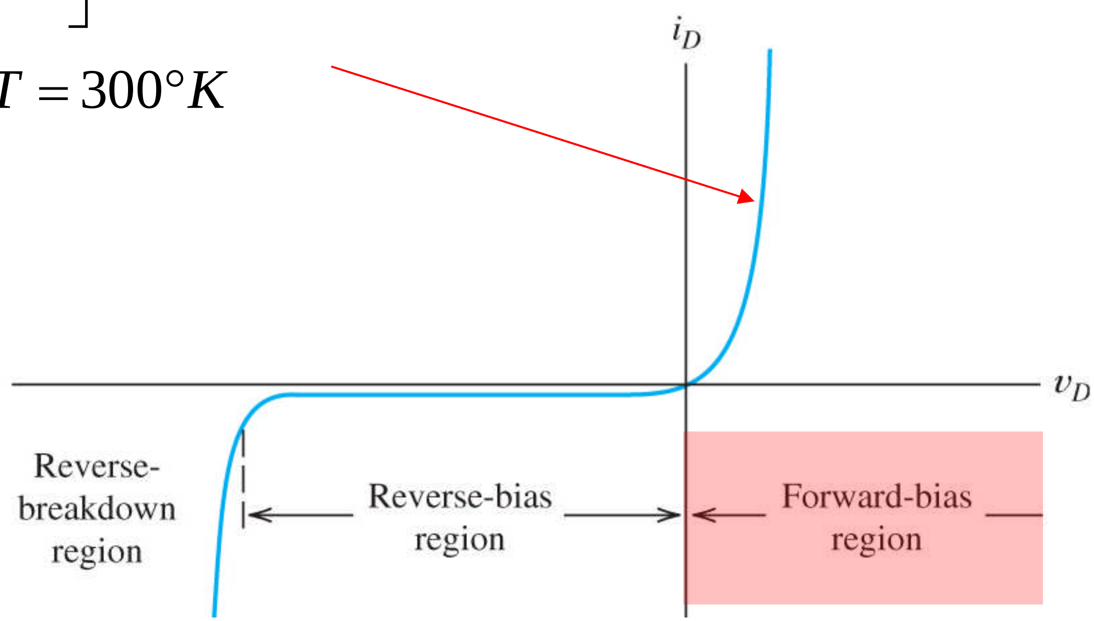
Diode in forward bias

- Current flow in a forward biased diode can be closely approximated by the Shockley equation given

$$i_D = I_s\left[e^{(v_D/nV_T)} - 1\right]$$ where

$$I_S \approx 10^{-14} \text{ A at } T = 300°K$$

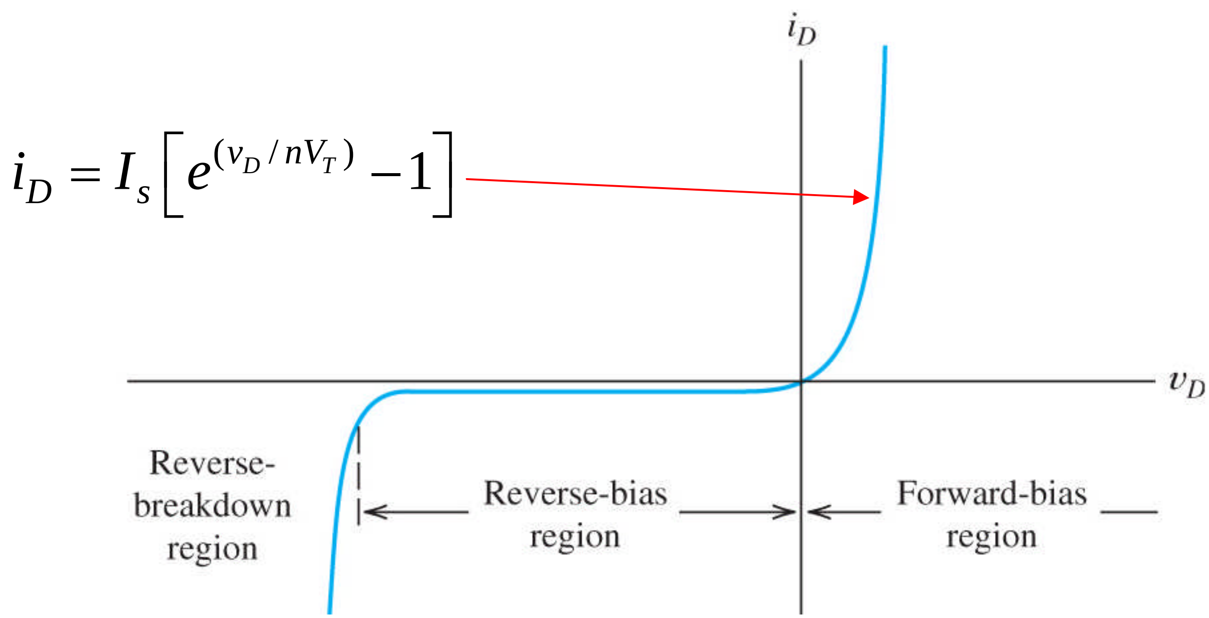
$$nV_T = 0.0259 \text{ V}$$



diode volt-ampere characteristic

Circuit analysis with diodes

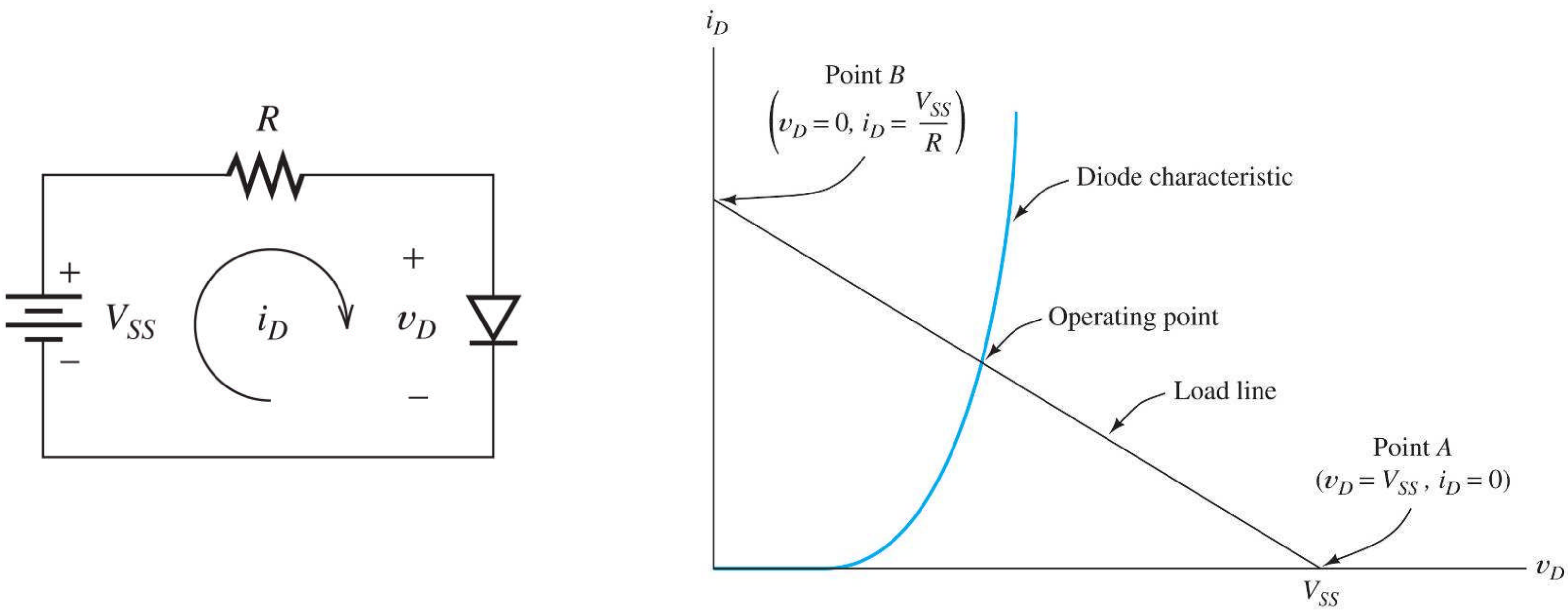
- The volt-ampere characteristic of diodes is **non-linear**, therefore many of the circuit analysis techniques we've learned do not apply.



diode volt-ampere characteristic

Graphical (load-line) analysis

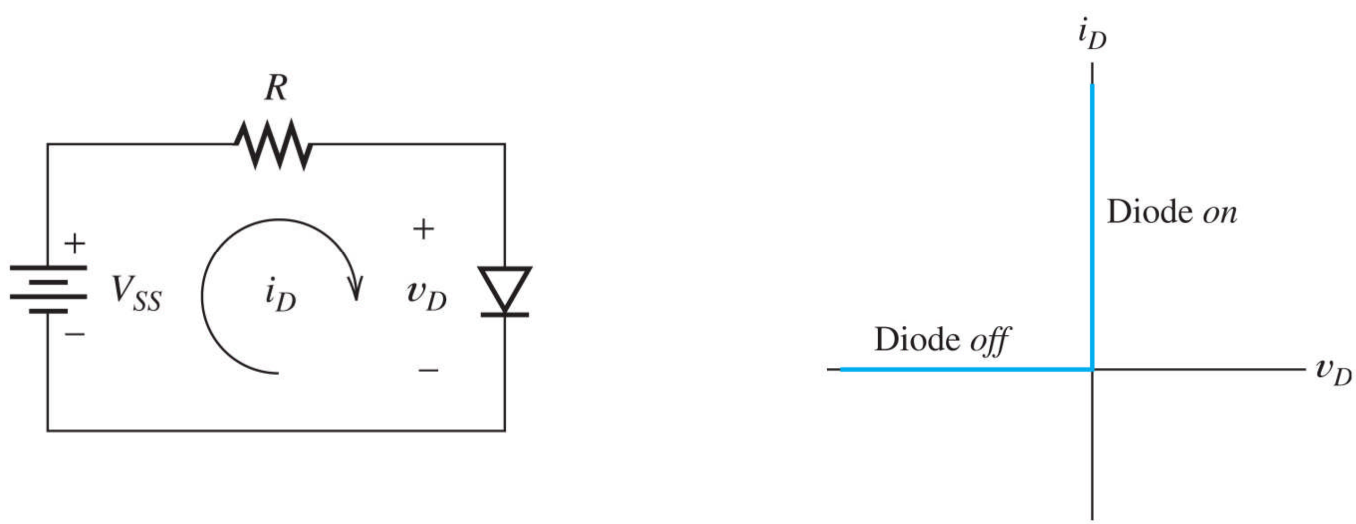
- As we did in dc motors, one way of determining an operating point is by plotting characteristic equations and locating an intersection.
- This method is called **load-line analysis**.



Determining operating point using load-line analysis

Analysis by assumed diode states

- Load-line analysis is often too cumbersome for complex circuits.
- An alternative method utilizes the ideal diode model.



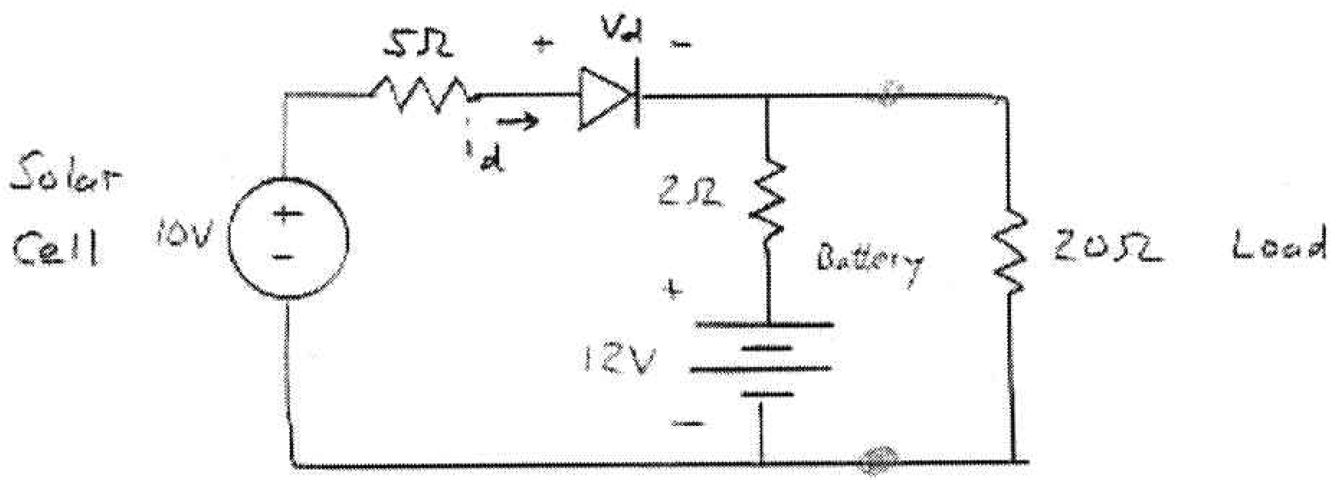
Determining operating point using ideal-diode model

Assumed diode states analysis procedure

1. Assume a state for each diode, either **on** (short-circuit) or **off** (open-circuit).
2. Analyze the circuit to determine current through diodes assumed to be on and voltage across diodes assumed to be off.
3. Verify results from (2) are consistent with assumed states.
    1. Positive current flow in diodes assumed **on** ($i_D > 0$ A).
    2. Diodes assumed **off** must be reverse biased ($v_D < 0$ V).
4. If not consistent, repeat from (1) with a different combination of diode states.

Example Problem 1

Determine the diode states for the following circuit.



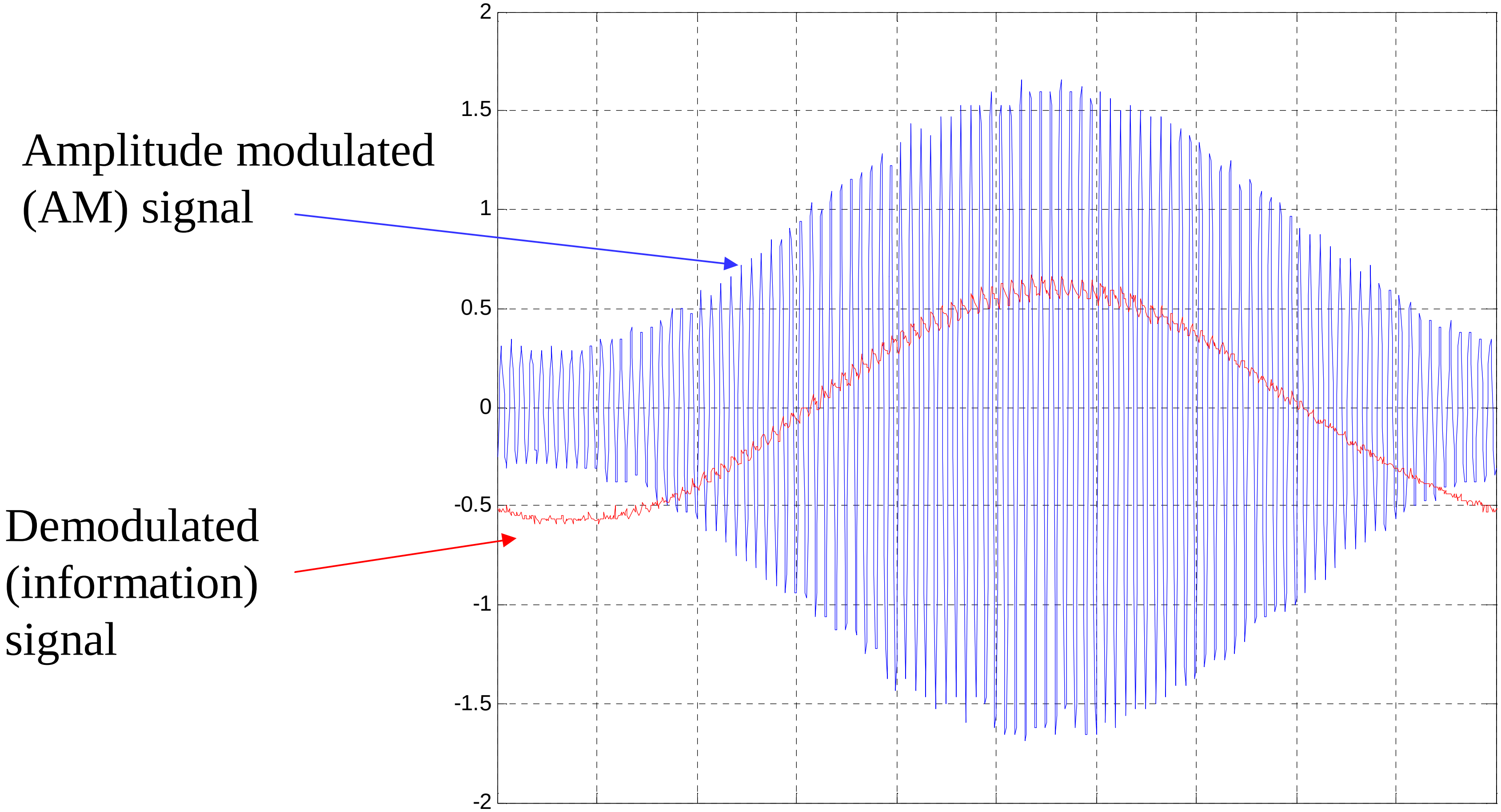
Rectifier

- Rectifiers are devices that transform ac power into dc power.
- Rectifiers form the basis for electronic power supplies and battery charging circuits.

Bosch alternator

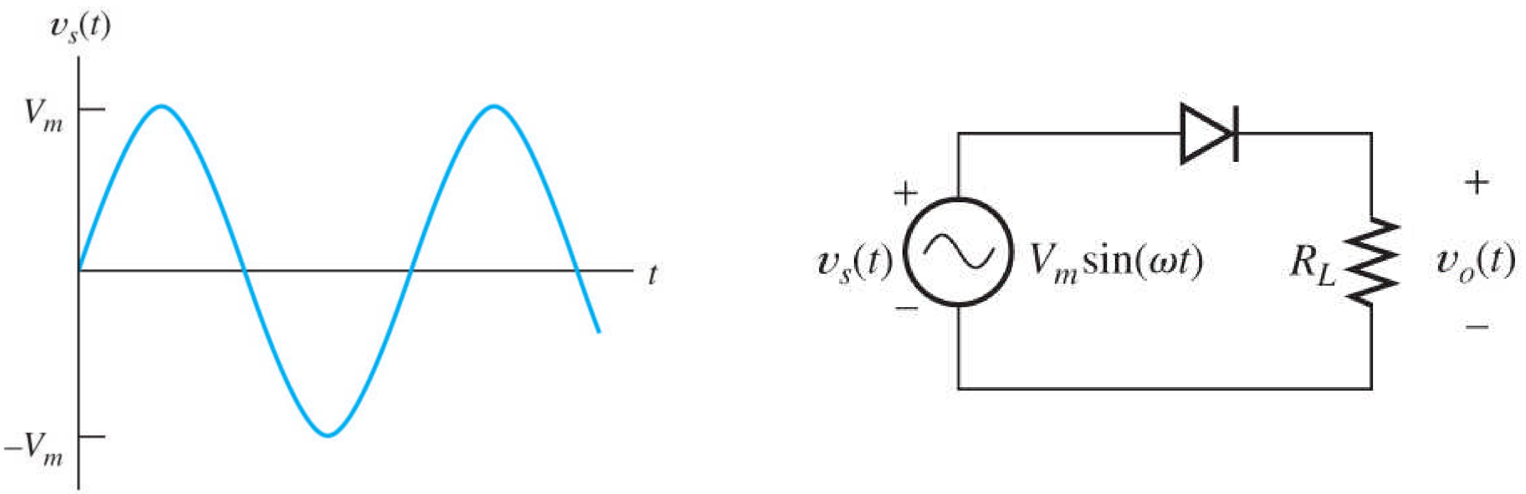
Rectifier used as diode detector

- Another application of rectifiers is in demodulation of radio signals.



Analysis of half-wave rectifier

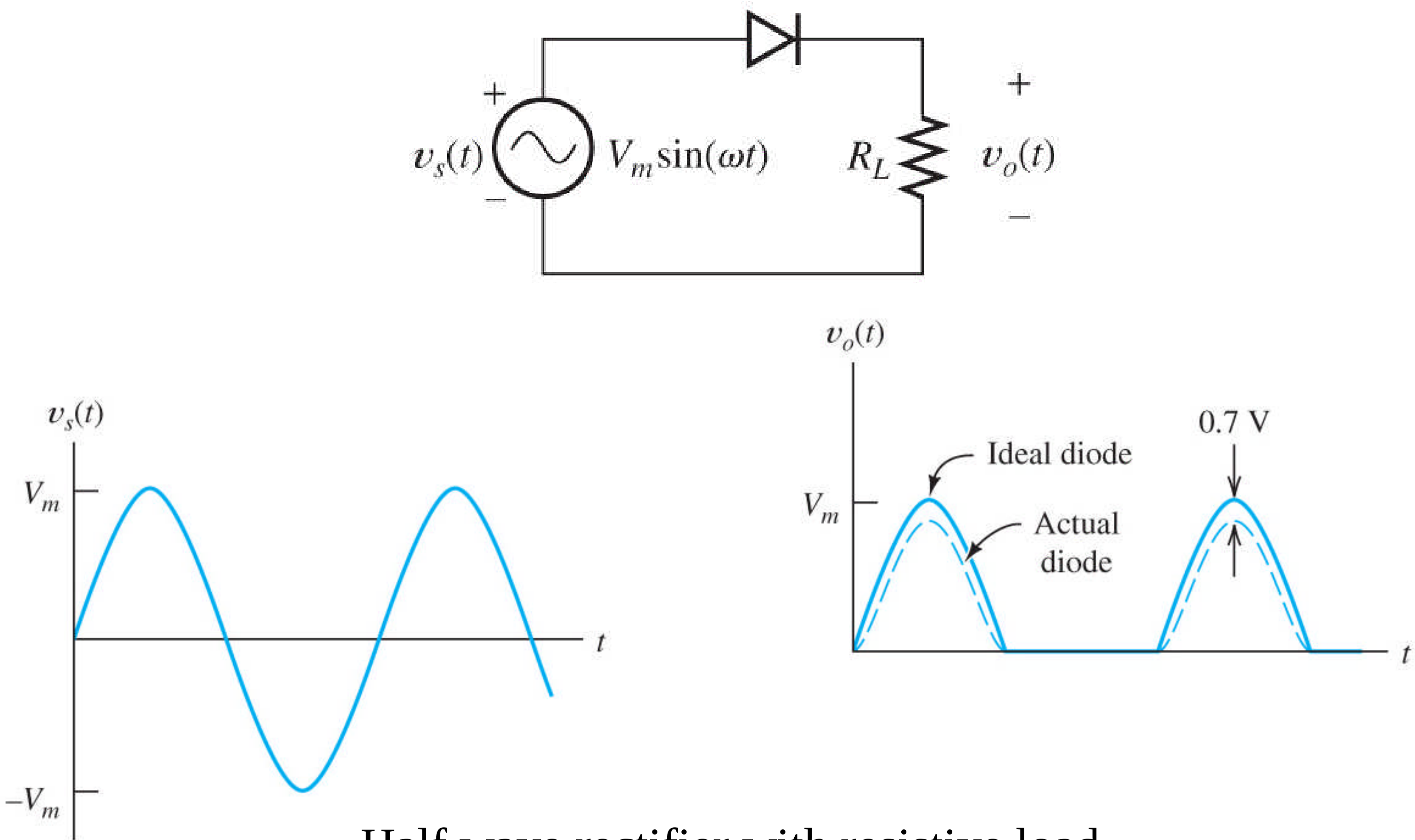
- What is the output (v_o) of the half-wave rectifier below?



Half wave rectifier with resistive load.

Analysis of half-wave rectifier

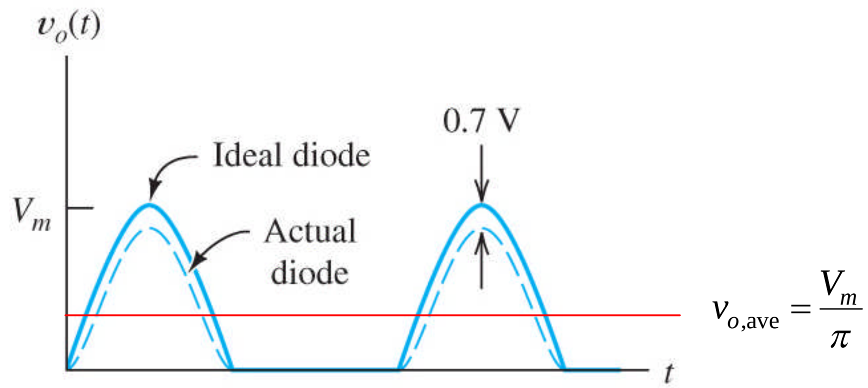
- What is the **average value** of v_o?



Half wave rectifier with resistive load.

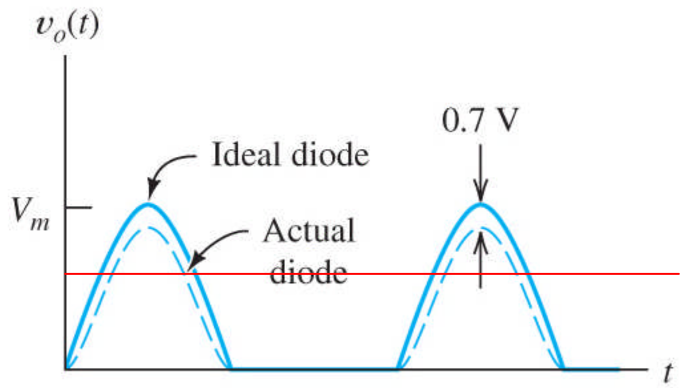
Average value of half-wave rectified sinusoid

$$v_{o,\text{ave}} = \frac{1}{2\pi}\int_0^{2\pi} V_m \sin\theta\, d\theta$$
$$= \frac{V_m}{2\pi}\left(-\cos\theta\right)\Big|_0^{\pi}$$
$$= \frac{V_m}{2\pi}\left(1+1\right)$$
$$= \frac{V_m}{\pi}$$



- What is the **rms value** of v_o?

RMS value of half-wave rectified sinusoid



$$v_{o,\text{rms}} = \frac{V_m}{2}$$

$$v_{o,\text{rms}} = \sqrt{\frac{1}{T}\int_0^T v_o^2(t)\,dt} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} \left(V_m \sin\theta\right)^2 d\theta}$$

$$= \sqrt{\frac{V_m^2}{2\pi}\int_0^{\pi} \frac{1}{2}\left(1+\cos 2\theta\right)d\theta} = \sqrt{\frac{V_m^2}{4\pi}\int_0^{\pi}\left(1+\cos 2\theta\right)d\theta}$$

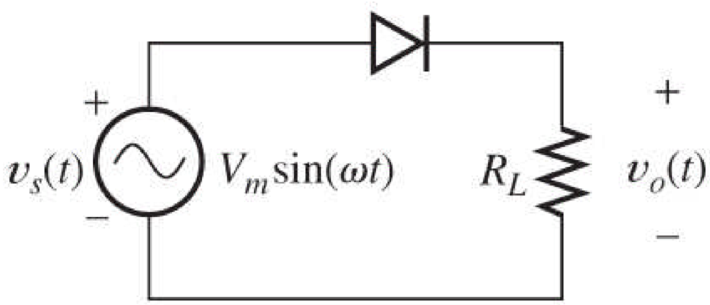
$$= \sqrt{\frac{V_m^2}{4\pi}\left(\theta + \frac{1}{2}\sin 2\theta\right)\Bigg|_0^{\pi}} = \sqrt{\frac{V_m^2}{4\pi}(\pi - 0)}$$

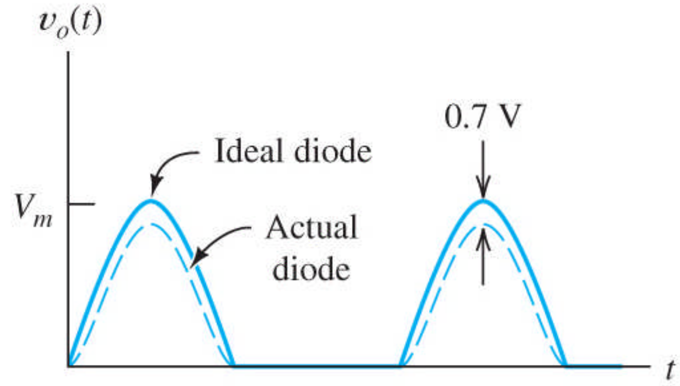
$$= \frac{V_m}{2}$$

Average power

- Because the rms value of v_o is $V_m/2$, the average power dissipated by R_L is given

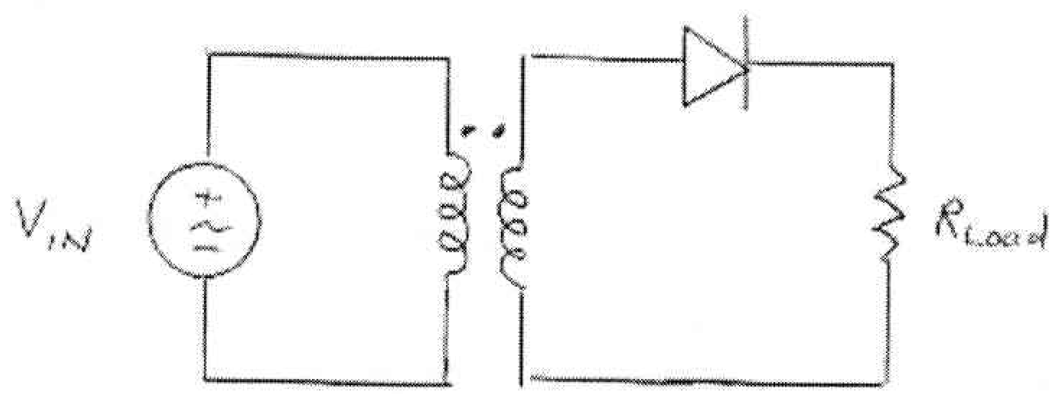
$$P_{L,\text{ave}} = \frac{v_{o,\text{rms}}^2}{R_L} = \frac{V_m^2}{4R_L}$$





Non-ideal effects

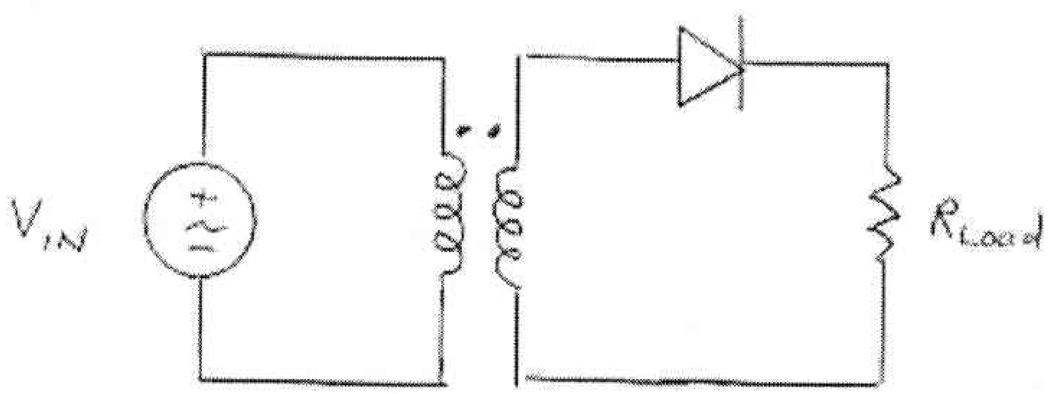
- In power supplies, the desired dc voltage is often much lower than the 120 V ac supply.
- To efficiently scale the voltage, transformers are employed.



Half wave rectifier with transformer

Non-ideal effects

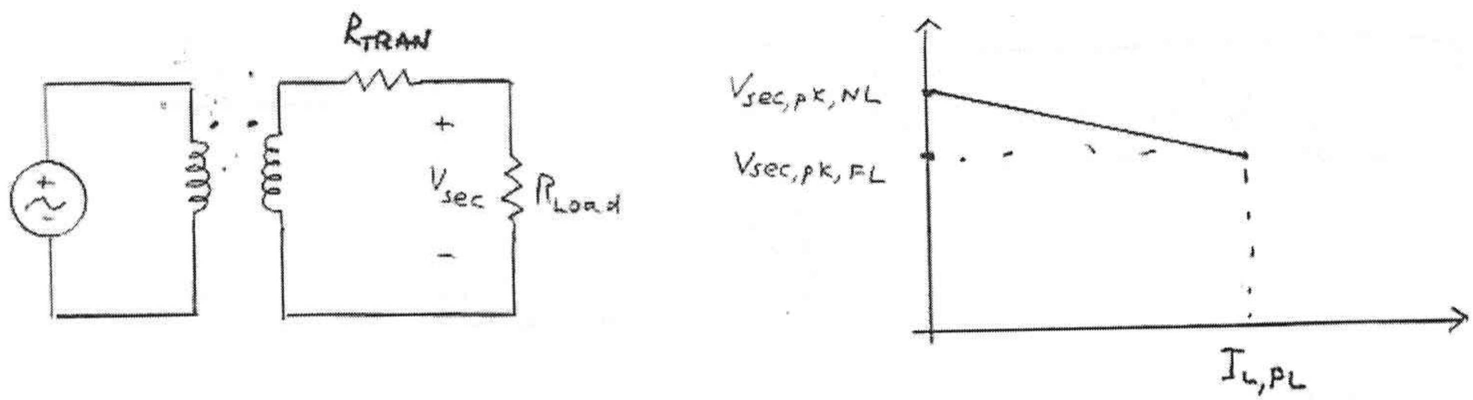
- A more accurate model should include
  - Voltage drop of the conducting diode (~0.7 V)
  - Output resistance of transformer coils.
- These two factors reduce the peak secondary voltage ($V_{sec,pk}$) from that of the ideal case.



Half wave rectifier with transformer

Transformer resistance effect

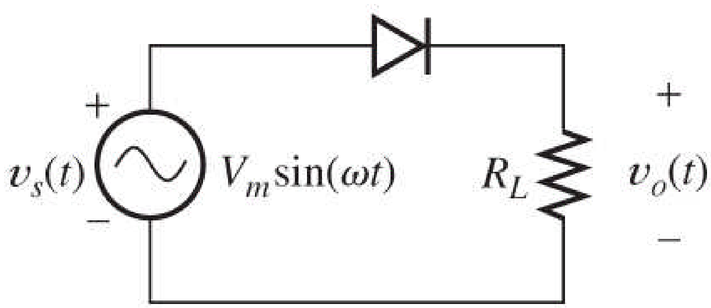
- The voltage loss due to resistance of the transformer output coils is a function of current.
  - At no load ($R_{L,\mathrm{NL}} = \infty$), $i_L = 0$ resulting in no loss.
  - At full load (minimum $R_L = R_{L,\mathrm{FL}}$), $i_L \rightarrow \max$ resulting in maximum voltage drop.

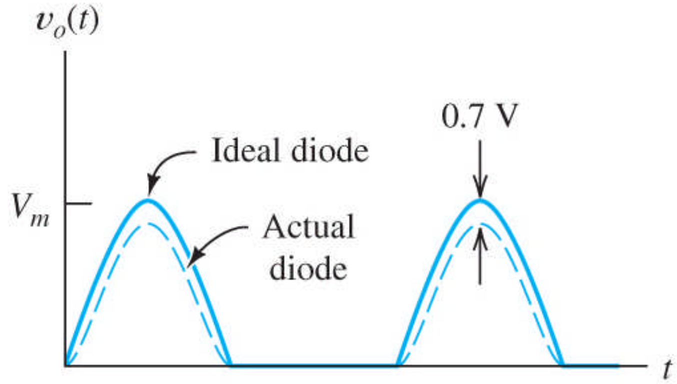


Transformer resistance loss

Voltage drop of conducting diode

- The output voltage is also reduce by ~0.7 V drop across the diode then it is conducting.





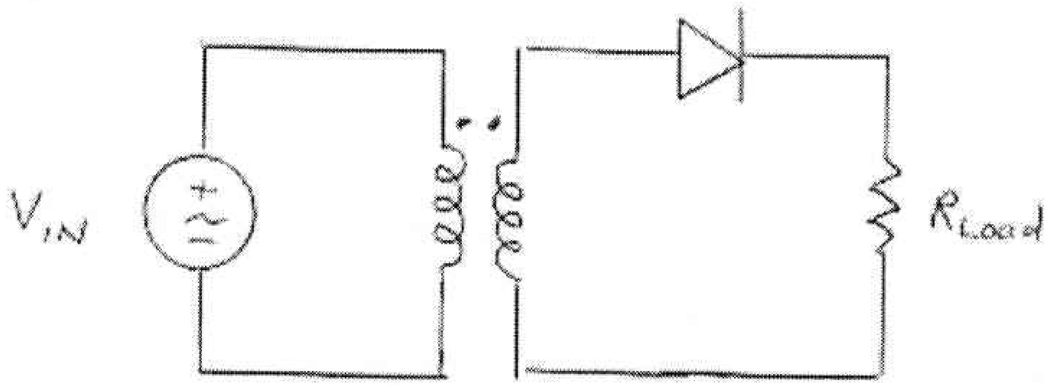
- Combining both effects, we find

$$V_{\text{sec,pk}} = \left(V_{\text{sec,pk,NL}} - 0.7\right)\frac{R_{\text{Load}}}{R_{\text{Load}} + R_{\text{Tran}}}$$

Non-ideal effects

- This peak value can be used to predict the average and rms out voltages.

$$V_{\mathrm{sec,pk}} = \left(V_{\mathrm{sec,pk,NL}} - 0.7\right)\frac{R_{\mathrm{Load}}}{R_{\mathrm{Load}} + R_{\mathrm{Tran}}} \Rightarrow \begin{matrix} V_{out,\mathrm{ave}} = \dfrac{V_{\mathrm{sec,pk}}}{\pi} \\ V_{out,\mathrm{rms}} = \dfrac{V_{\mathrm{sec,pk}}}{2} \end{matrix}$$



Half wave rectifier with transformer