Instantaneous Power (Anlık Güç)

Instantaneous power for a 2-terminal element:

$$p(t) \triangleq v(t)i(t)$$

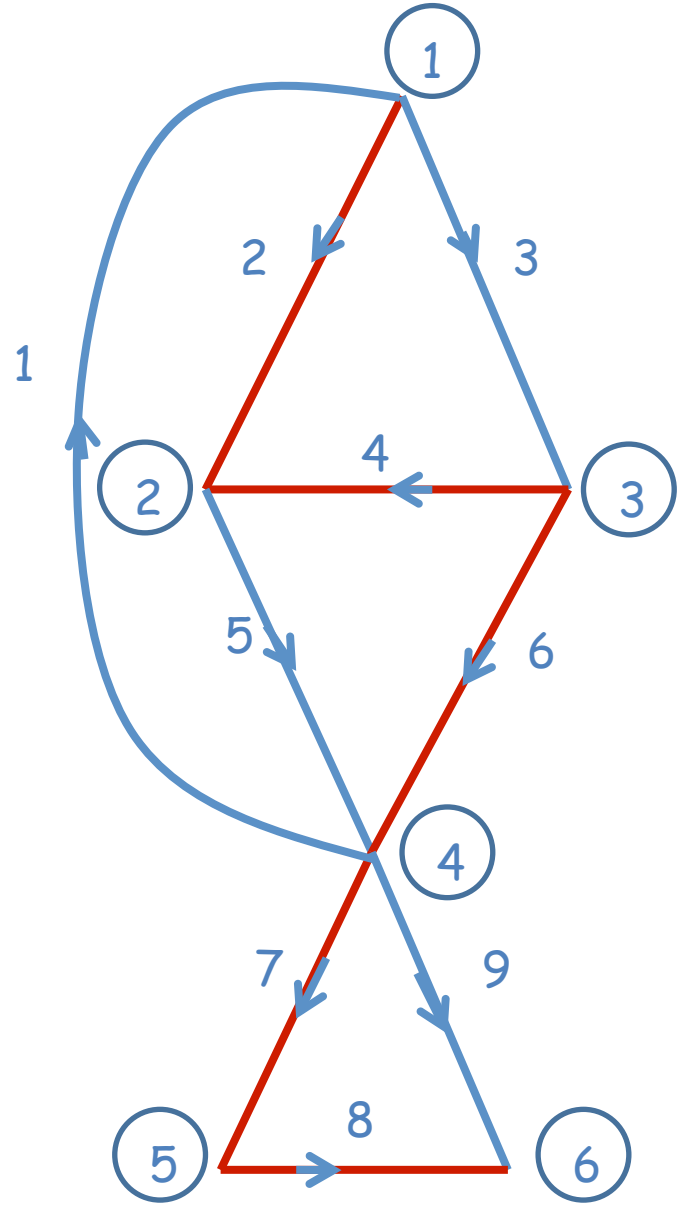
= *power* delivered at time *t to* the two-terminal element *by* the remainder of the circuit to which it is connected

- Unit of power is Watt.
- $p(t)>0$ means that the element is consuming energy.
- $p(t)<0$ means that the element is producing energy.

Instantaneous power for an (n+1)-terminal or n-port element: $$p(t) = \sum_{k=1}^{n} i_k v_k$$

Total instantaneous power for a circuit: $$p(t) = \sum_{k=1}^{n_e} i_k v_k = 0$$

Tellegen's Theorem



a) $v_2=2V$, $v_4=4V$, $v_6=6V$, $v_7=7V$, $v_8=8V$ are given. Find the other voltages.

b) $i_1=1A$, $i_3=3A$, $i_5=5A$, $i_9=9A$ are given. Find the other currents.

c) Show that Tellegen's Theorem is satisfied for this circuit.

How many linearly independent equation can we obtain from KVL and KCL?

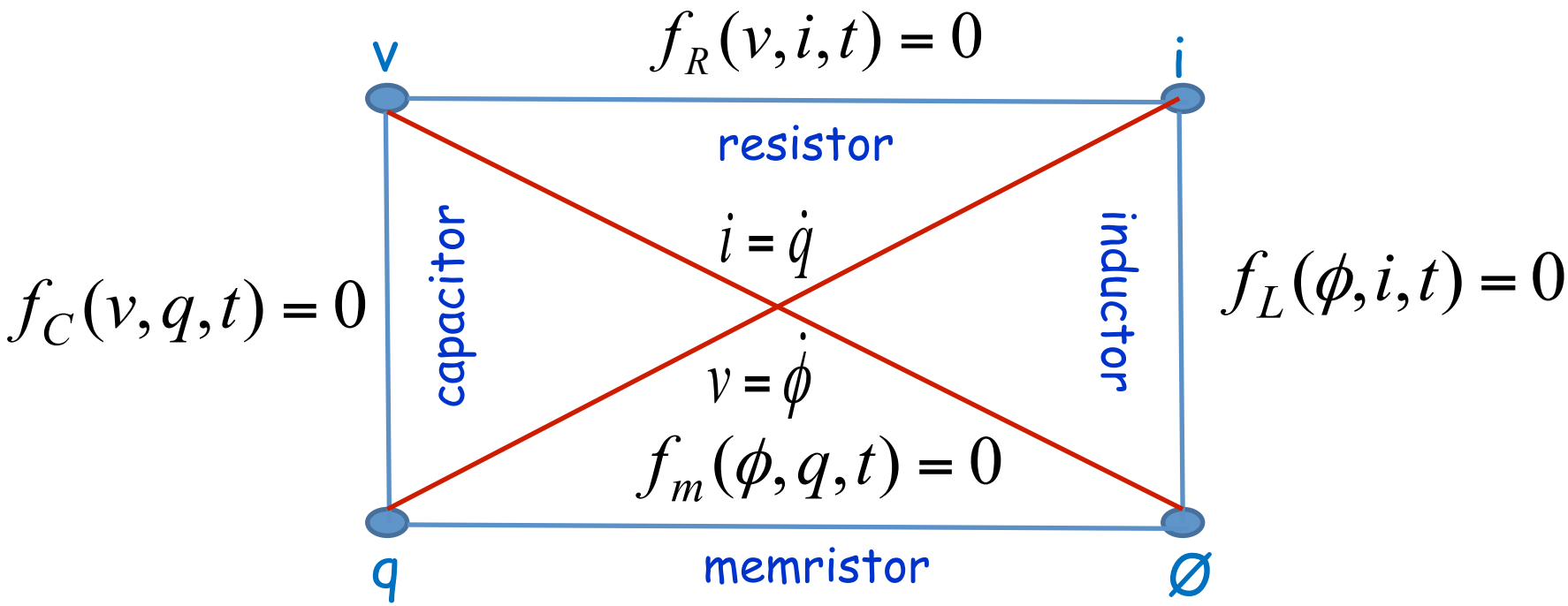
How many unknowns are there?

How many equations do we need?

How can we obtain the other ..... equations?

Element Equations

for 2-terminal elements



<u>Resistor:</u> An element that has an algebraic equation between v and i.

<u>Inductor:</u> An element that has an algebraic equation between Ø and i.

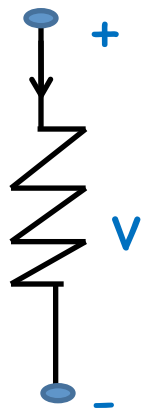
<u>Capacitor:</u> An element that has an algebraic equation between v and q.

<u>Memristor:</u> An element that has an algebraic equation between Ø and q.

Algebraic equation: .....

2-Terminal Resistors

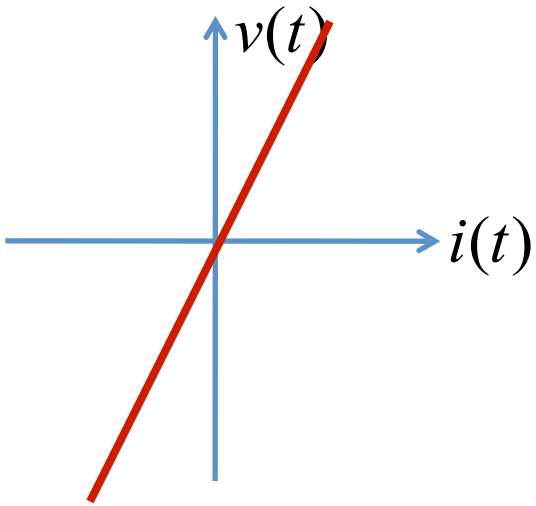
Linear Resistor



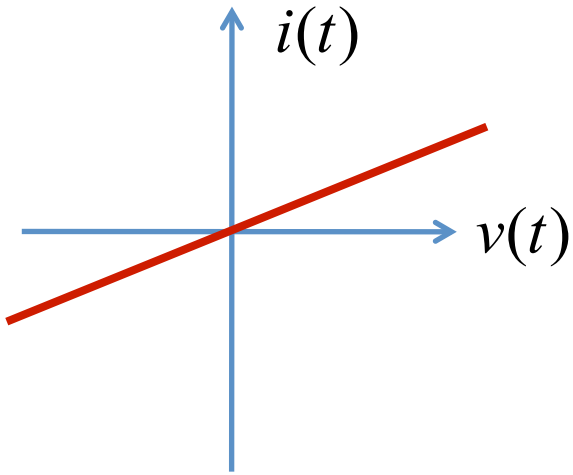
$v(t) = Ri(t)$ resistance, ohm (Ω)

$i(t) = Gv(t)$ conductance, siemens (S)

mho $(\mho)$



i-v characteristic



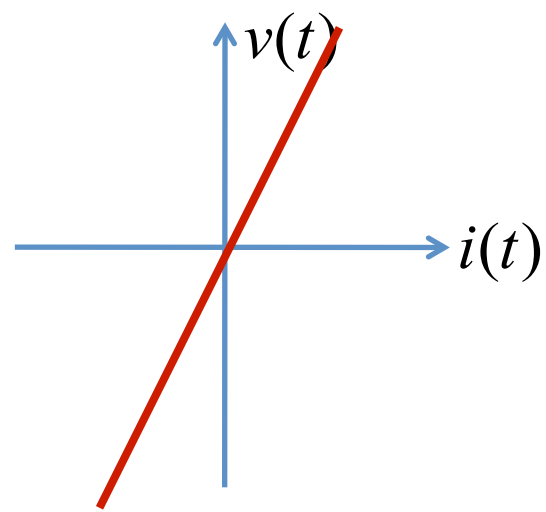
v-i characteristic

Instantaneous power of a linear resistor: $p(t) = v(t)i(t) = Ri^2(t) > 0$

2-Terminal Resistors

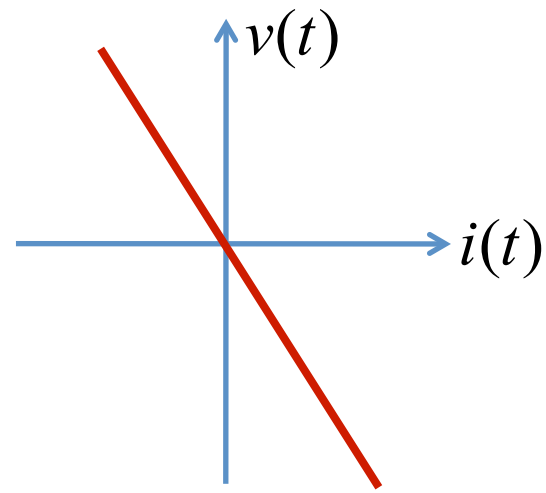
If R>0, then $p(t) = v(t)i(t) = Ri^2(t) > 0$, passive resistor, consumes energy.

If R<0, then $p(t) = v(t)i(t) = Ri^2(t) < 0$, active resistor, produces energy.



i-v characteristic

passive resistor



i-v characteristic

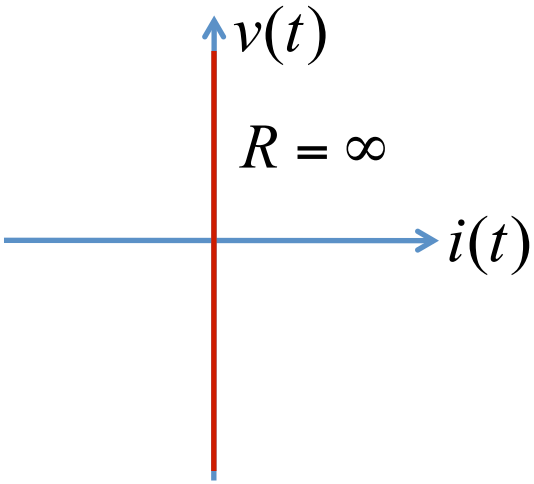
active resistor

Linearity

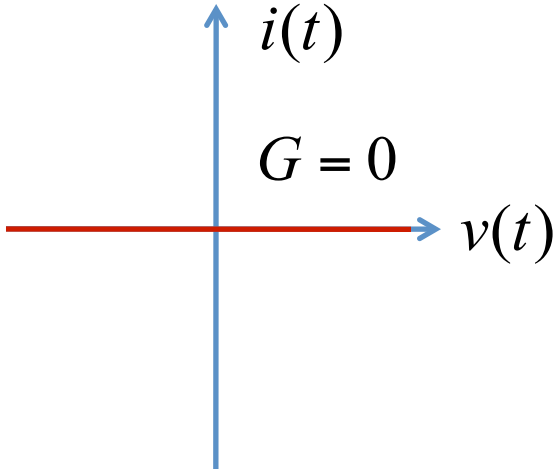
$$f(x_1) = y_1 \qquad f(x_2) = y_2 \xrightarrow{f(.)\ \text{linear}} f(\alpha x_1 + \beta x_2) = \alpha f(x_1) + \beta f(x_2)$$
$$= \alpha y_1 + \beta y_2$$

Special Linear Resistors:

Open circuit element: $f(i,v) = i = 0$

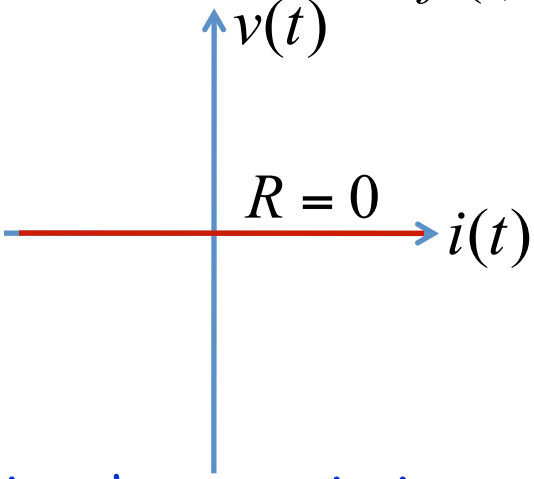


i-v characteristic

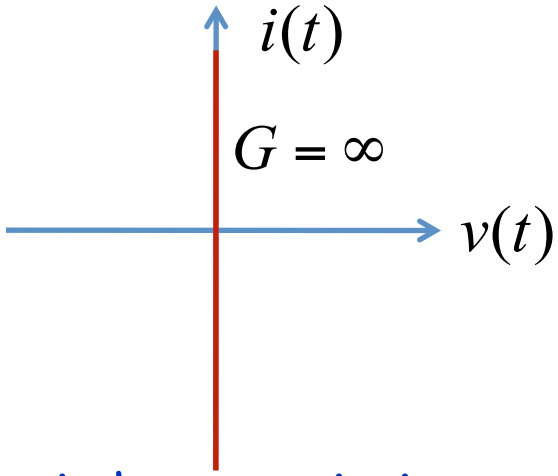


v-i characteristic

Short circuit element: $f(i,v) = v = 0$



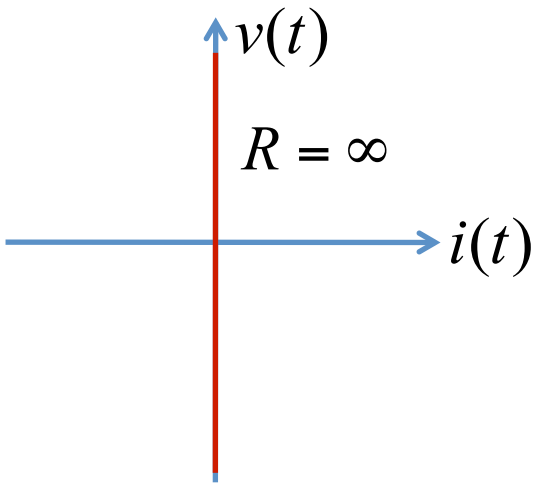
i-v characteristic



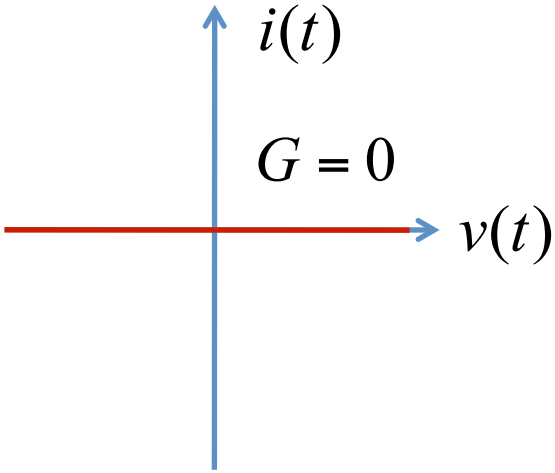
v-i characteristic

Is there any relation between the characteristics of these two elements?

Open circuit element: $f(i,v) = i = 0$



i-v characteristic



v-i characteristic

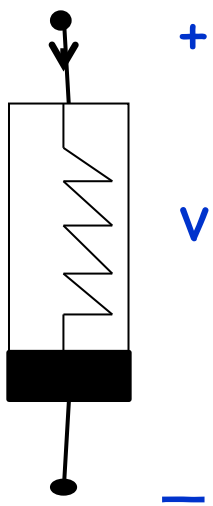
Definition: (Dual Resistors)

v-i characteristics of resistor A = i-v characteristics of resistor B

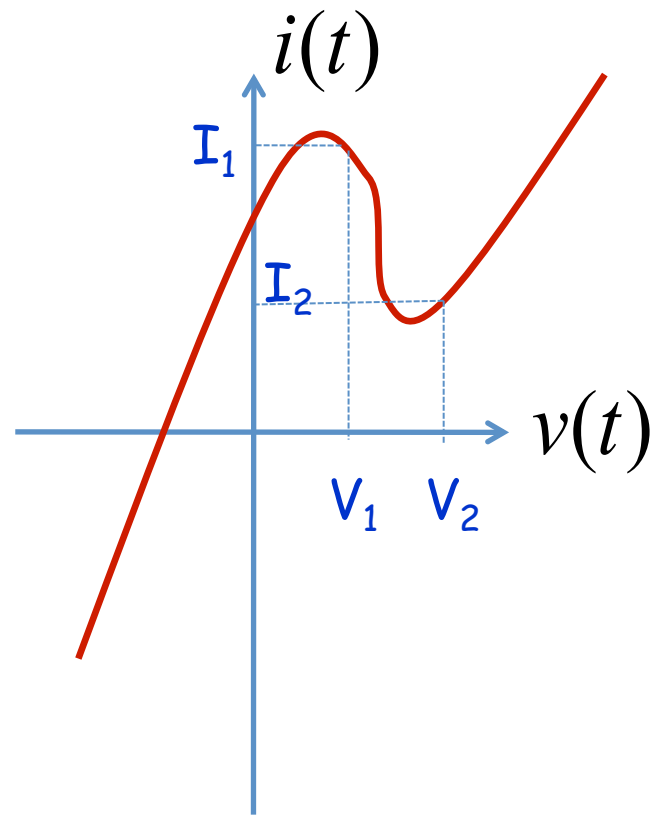
$\Longleftrightarrow$

Resistor A and B are dual resistors.

Nonlinear Resistor

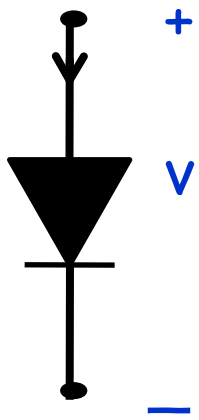


$$f(v,i)=0$$



Some Special Nonlinear Resistor

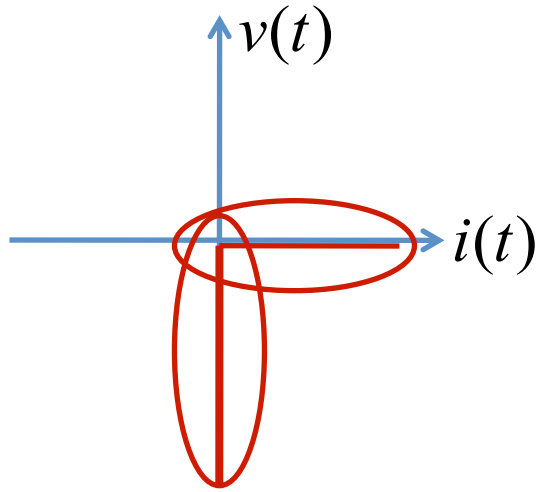
Ideal Diodes



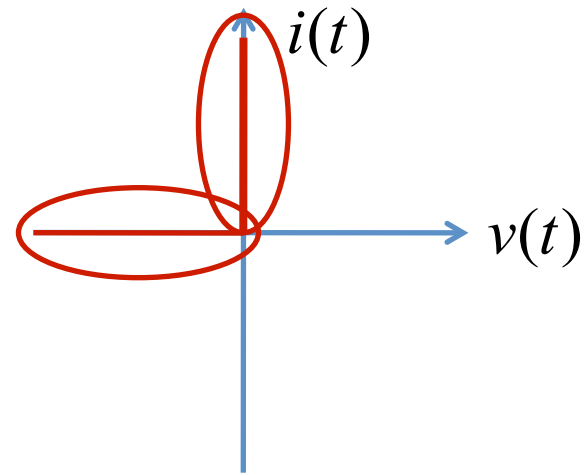
$$R_{ID} = \{(v,i) : vi = 0, i = 0, v < 0 \text{ ve } v = 0, i > 0\}$$

Diode is conductiong: $(i > 0), \quad v = 0$

Diode is reverse biased: $(v < 0), \quad i = 0$



i-v characteristic

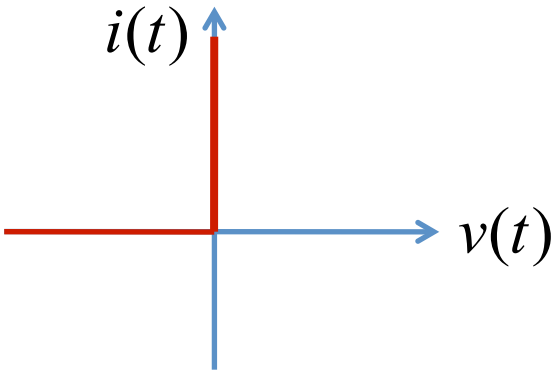


v-i characteristic

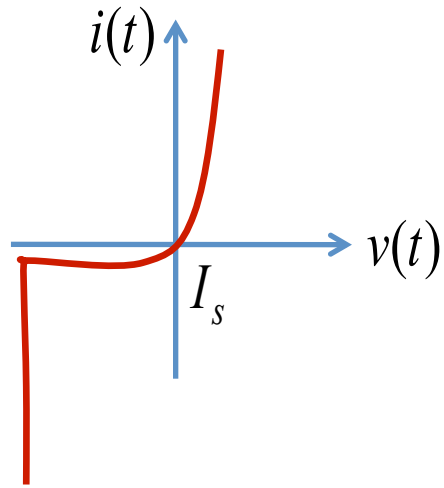
How does a diode behave when it is conducting?

How does a diode behave when it is reverse biased?

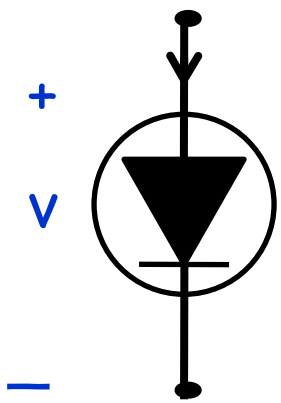
Ideal Diode



A more realistic diode



p-n Junction Diode (a model that is valid for low frequencies)



current and voltage of the diode

$$R_D = \{(v,i) : i = I_s[\exp(\frac{v}{v_T}) - 1], I_s, v_T \text{ sabit}\}$$

I_s reverse saturation current

$$V_T = \frac{kT}{q}$$

$$V_T = 0{,}026V$$

q electron charge

k Boltzman constant

T Temparature (Kelvin)

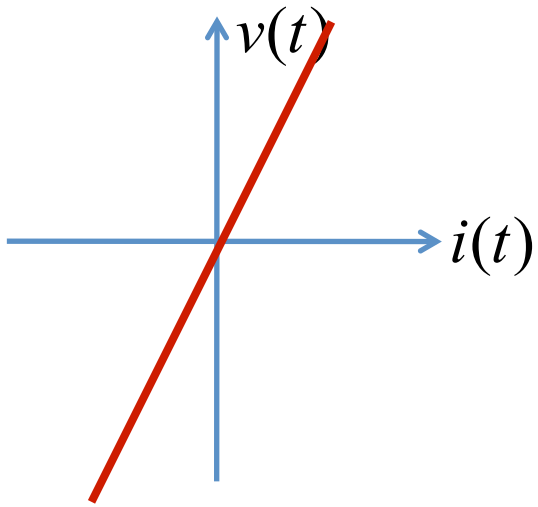
Is the p-n junction diode an active or passive element?

Active and Passive Elements

(definitions for linear resistors)

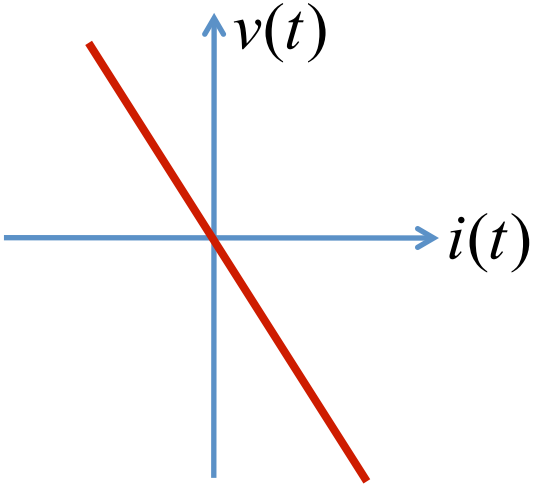
If R>0, then $p(t) = v(t)i(t) = Ri^2(t) > 0$, passive resistor, consumes energy.

If R<0, then $p(t) = v(t)i(t) = Ri^2(t) < 0$, active resistor, produces energy.



i-v characteristic

passive resistor



i-v characteristic

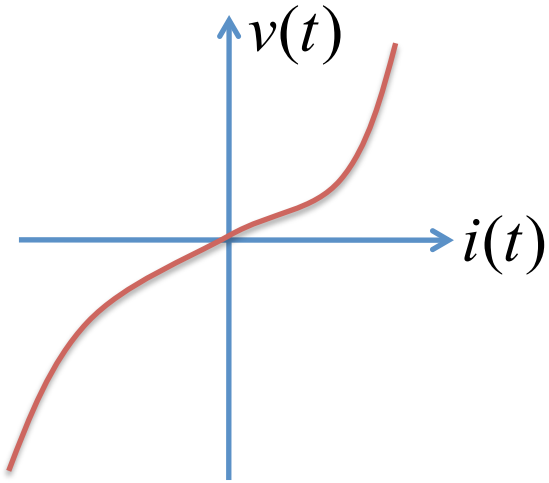
active resistor

Active and Passive Elements

(definitions for nonlinear resistors)

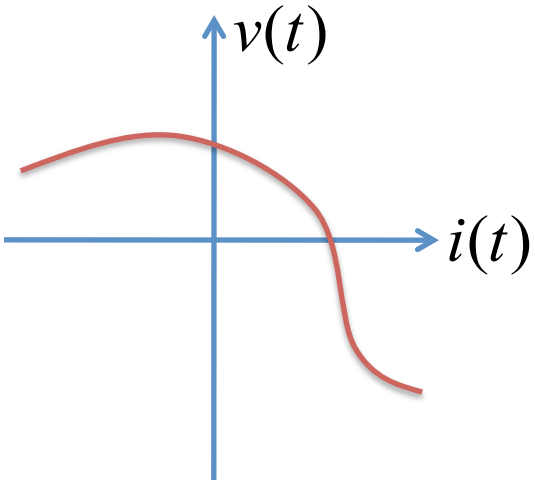
Passive resistor: $p(t) = v(t)i(t) > 0 \quad \text{for all} \quad t > 0$

Active resistor: $p(t) = v(t)i(t) < 0 \quad \text{for some} \quad t > 0$



i-v characteristic

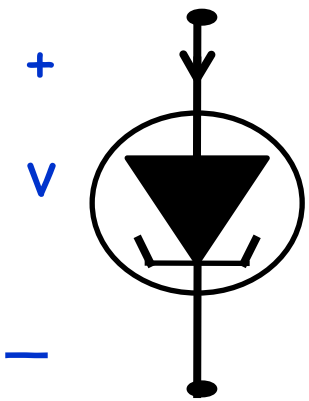
passive resistor



i-v characteristic

active resistor

Tunel Diode



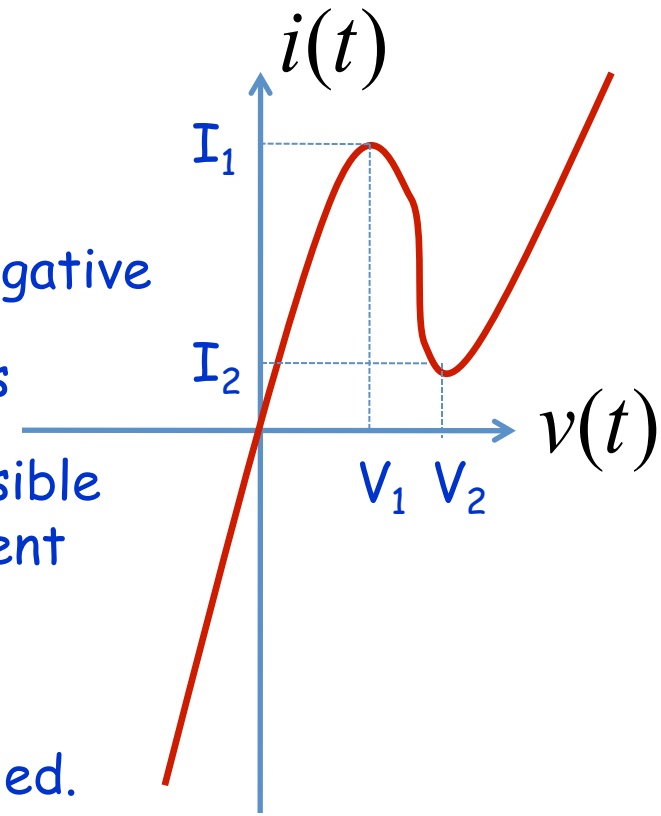
$$R_{TD} = \{(v,i) : i = \hat{i}(v)\}$$

$v_1 < v < v_2$ slope is negative

→ oscillators, amplifiers

$I_2 < i < I_1$ three possible voltages for one current

→ memory, switching



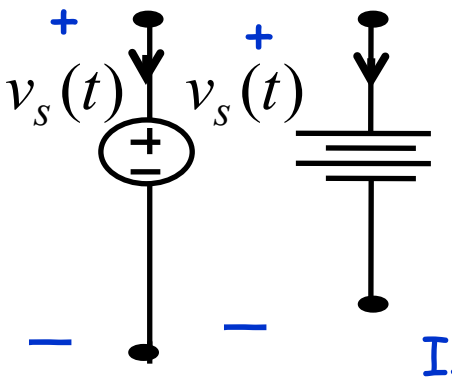
It is voltage-controlled, not current-controlled.

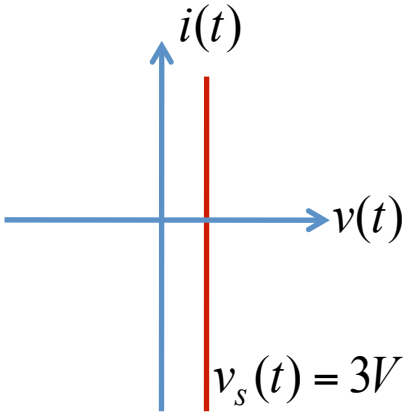
Voltage-controlled element:

Current-controlled element:

Independent Source

Independent voltage source





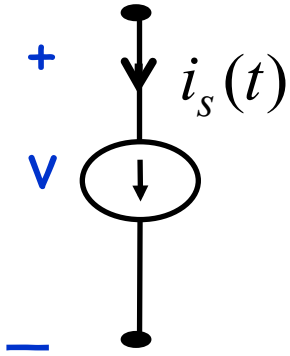
$$R_{v_s} = \{(v,i) : v = v_s(t), -\infty < i < \infty\}$$

Is the independent voltage source linear?

Is the independent voltage source voltage-controlled?

Is the independent voltage source current-controlled?

Independent current source



$$R_{i_s} = \{(v,i) : i = i_s(t), -\infty < v < \infty\}$$