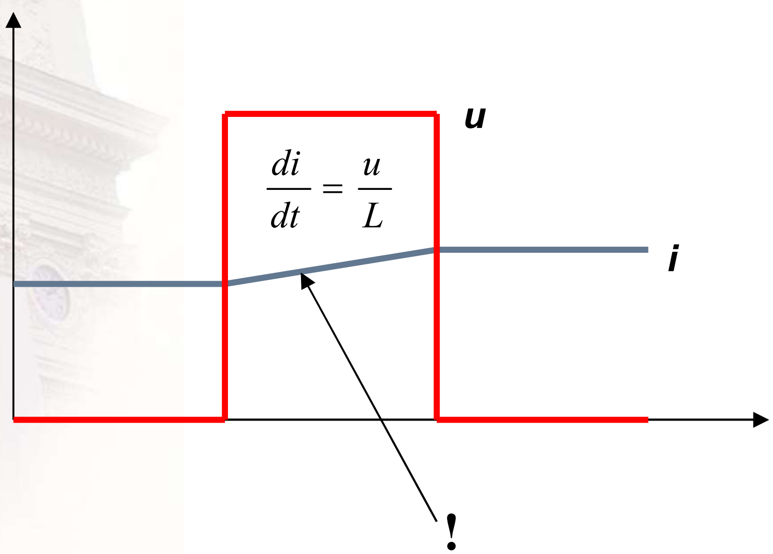
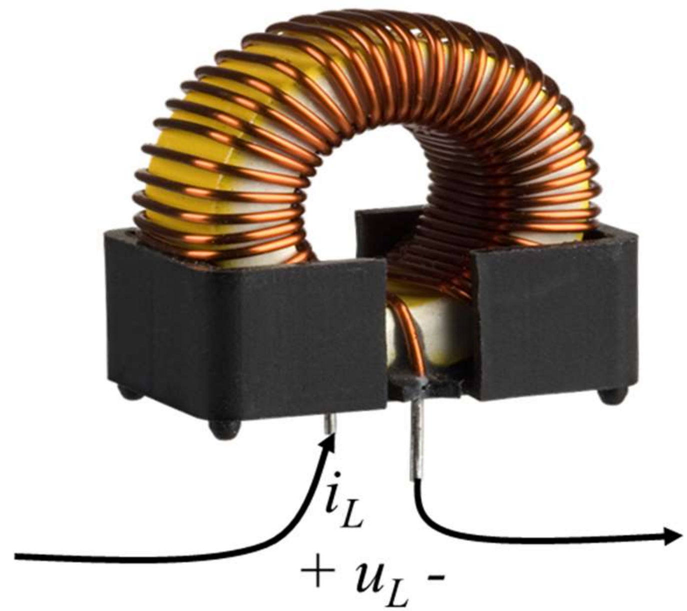
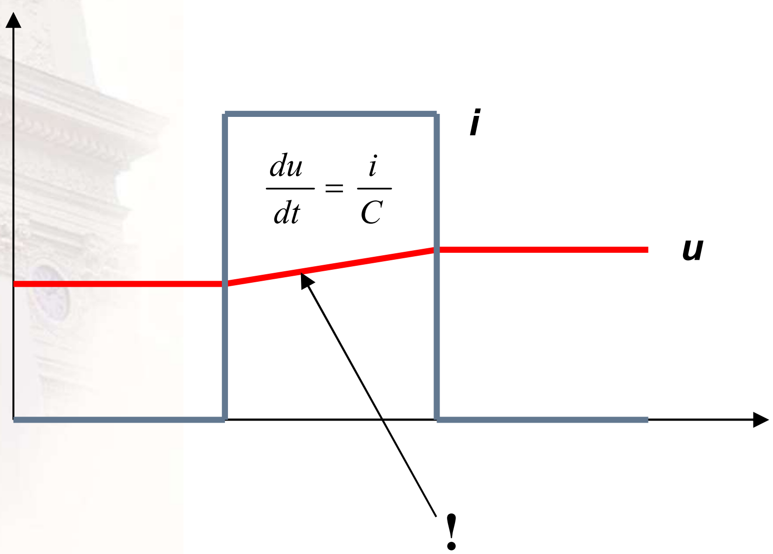
Lecture 3 – Modulation

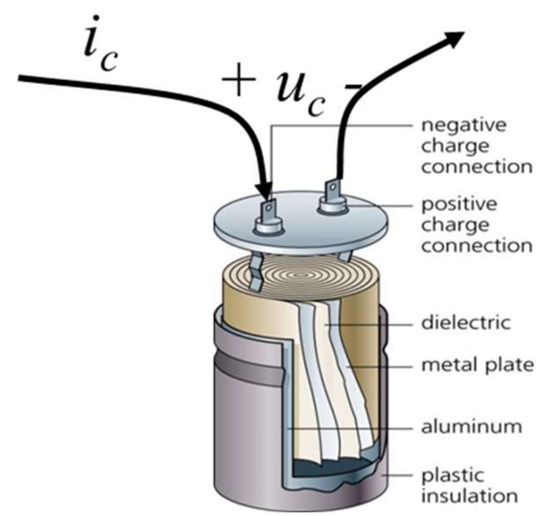
Summary
An inductance keeps a current ”constant”





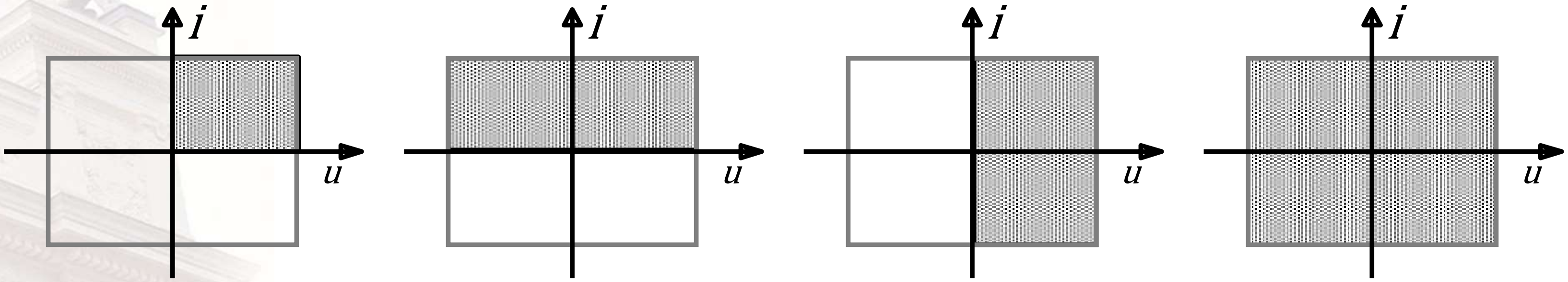
Summary
A capacitance keeps a voltage ”constant”



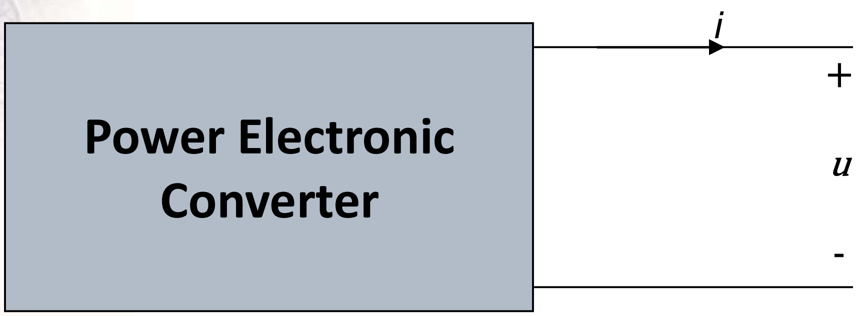


Some fundamental topologies

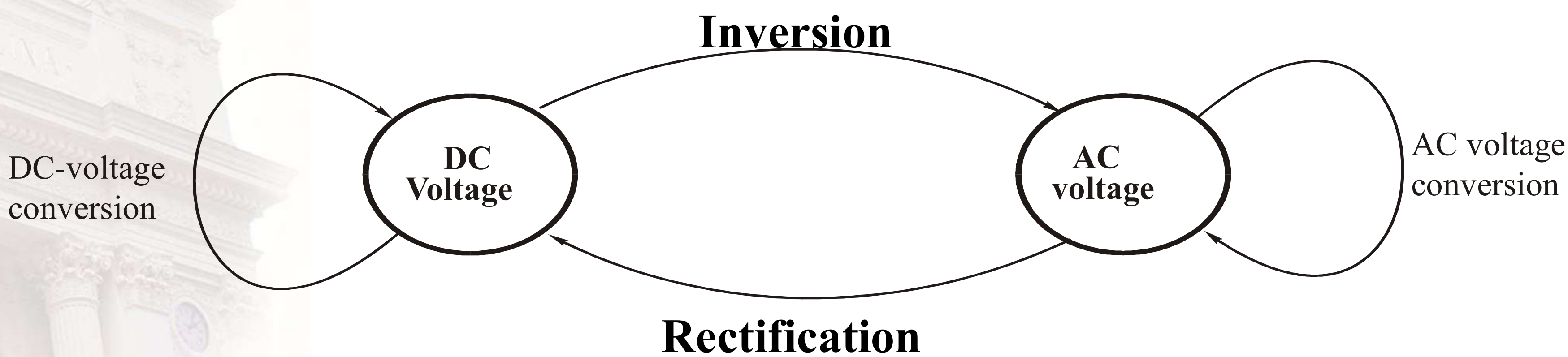
Quadrants



1-quadrant 2-quadrant 2-quadrant 4-quadrant



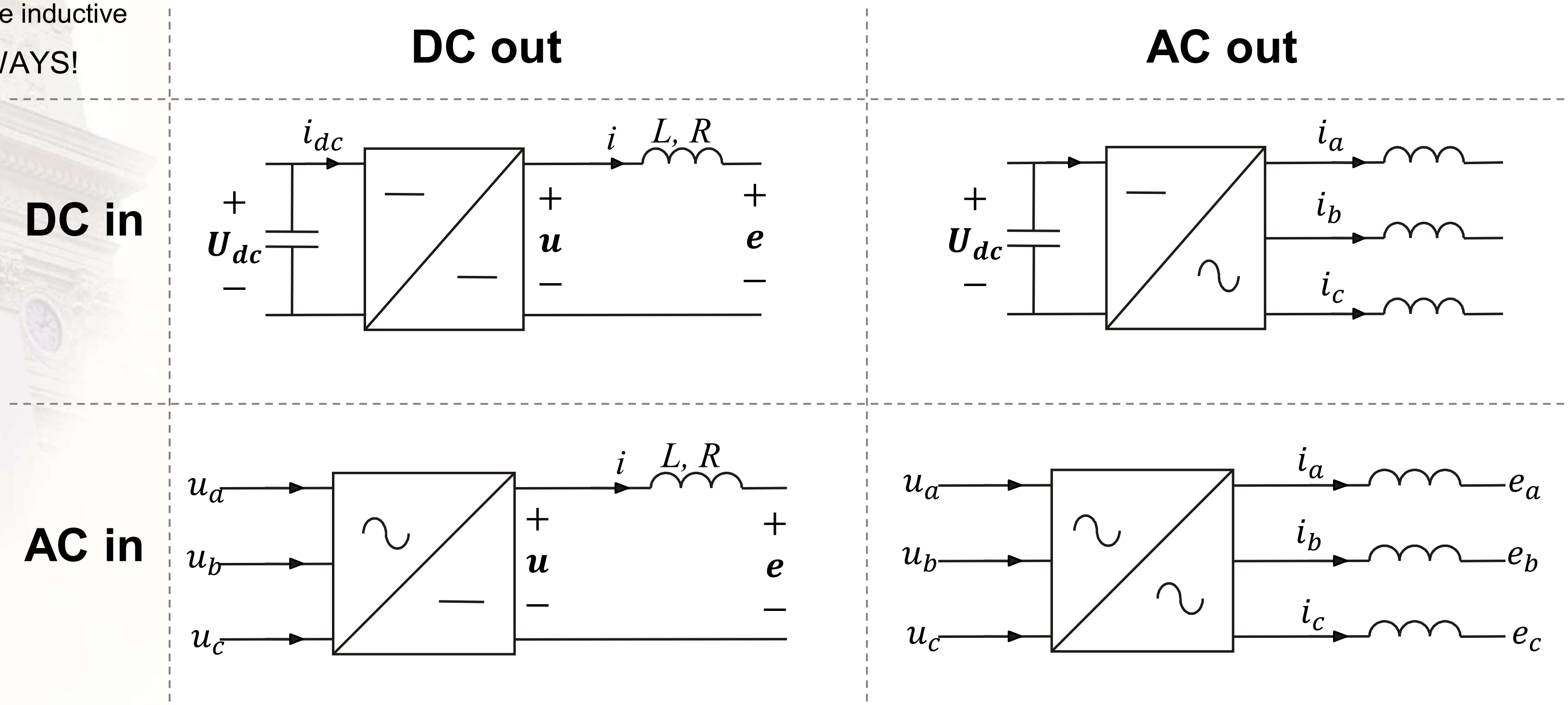
Classification



Converter topologies

Remember:

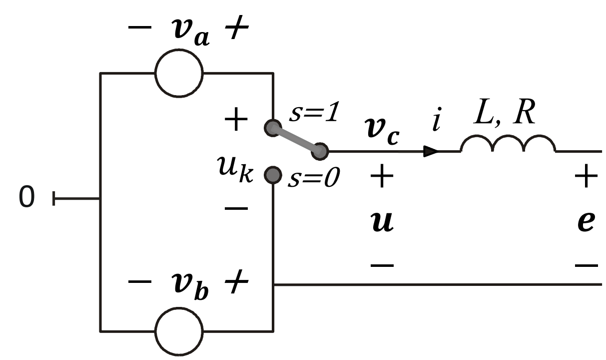
- 1 side capacitive
- 1 side inductive
- ALWAYS!



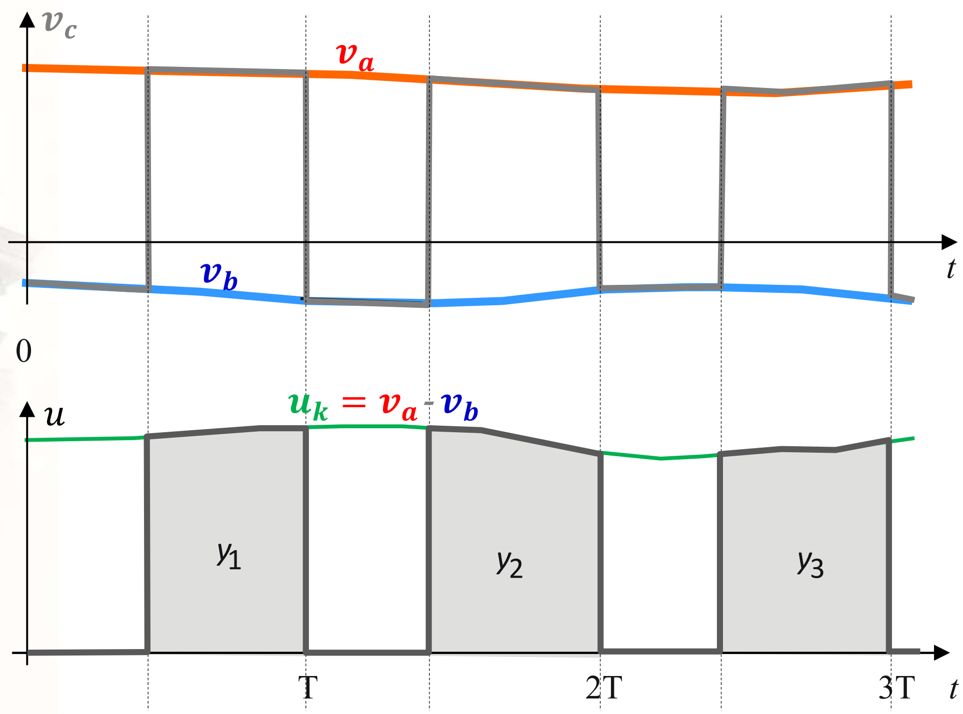
Modulation - Control of voltage time area

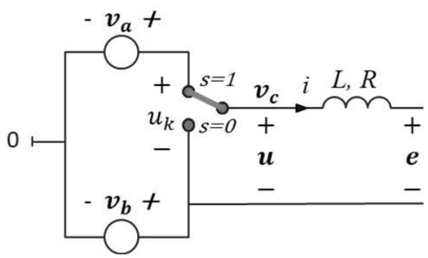
$$v_c = \begin{cases} v_a \text{when } s = 1 \\ v_b \text{when } s = 0 \end{cases}$$

$$u = s \cdot (v_a - v_b) = s \cdot u_k = \begin{cases} u_k \text{ when } s = 1 \\ 0 \text{ when } s = 0 \end{cases}$$



Output voltage





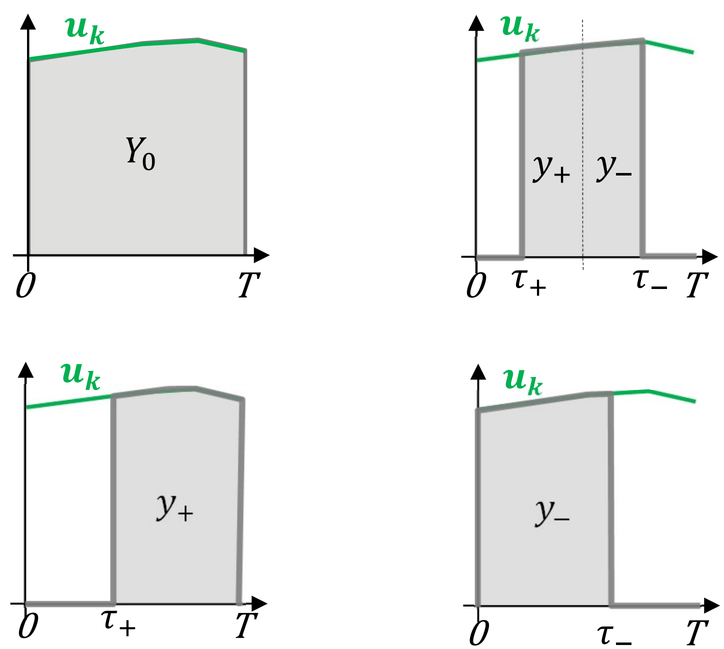
Voltage control options

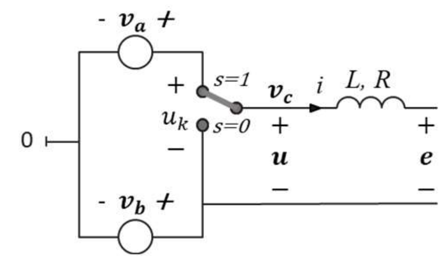
Assume a limited pulse interval T and a slowly varying switching voltage u_k

$$Y_0 = \int_0^T u_k \cdot dt$$

$$u_k(\tau_+) = -\frac{dy(\tau_+)}{d\tau_+}$$

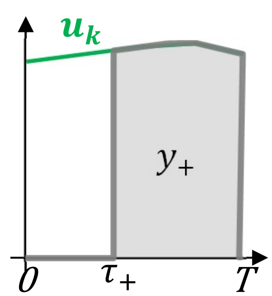
$$u_k(\tau_-) = \frac{dy(\tau_-)}{d\tau_-}$$





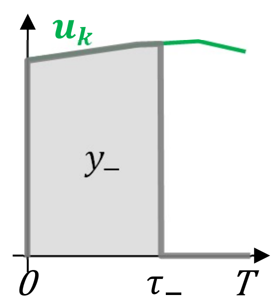
Control with positive flank

$$y(\tau_+) = \int_{\tau_+}^{T} u_k \cdot dt = Y_0 - \int_{0}^{\tau_+} u_k \cdot dt$$



Control with negative flank

$$y(\tau_-) = \int_0^{\tau_-} u_k \cdot dt$$



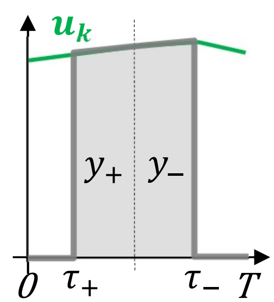
Control with both flanks

$$Y_0 = \int_0^{T/2} u_k \cdot dt$$

$$y(\tau_+, \tau_-) = y_+ + y_-$$

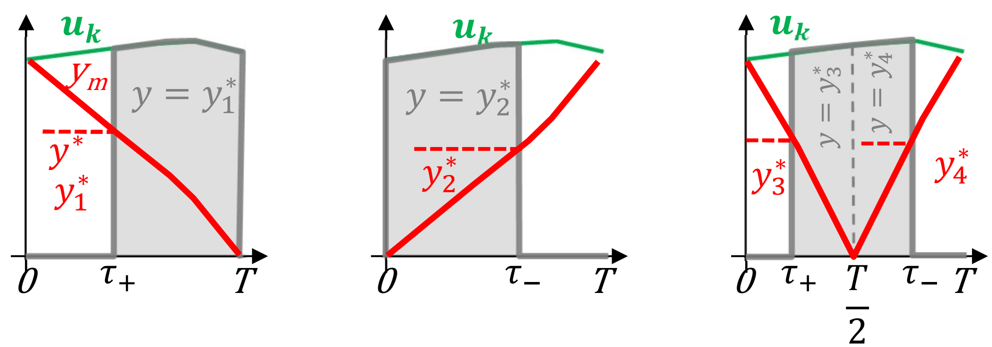
$$y_+ = \int_{\tau_+}^{T/2} u_k \cdot dt = Y_0 - \int_0^{\tau_+} u_k \cdot dt$$

$$y_- = \int_{T/2}^{T/2+\tau_-} u_k \cdot dt$$



Carrier wave modulation

- A reference value y^* for the desired average voltage over one switching period is calculated by an external control system
- A modulation signal y_m is generated, such that $y(t)=y_m(t)$
- The reference is compared to the modulation signal to determine the switching instants.



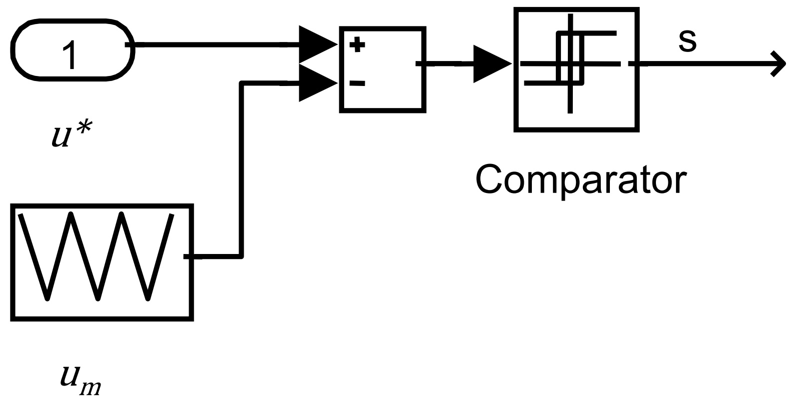
Voltage time area vs. average voltage

- *This far the modulation has been described with voltage time areas, both regarding the estimate of the output voltage time area as a function of the switching time instant, i.e. the modulating wave y_m, and the references for the output voltage time areas y^*.*
- *In the following sections and chapters, voltage time area is replaced with average voltages.*

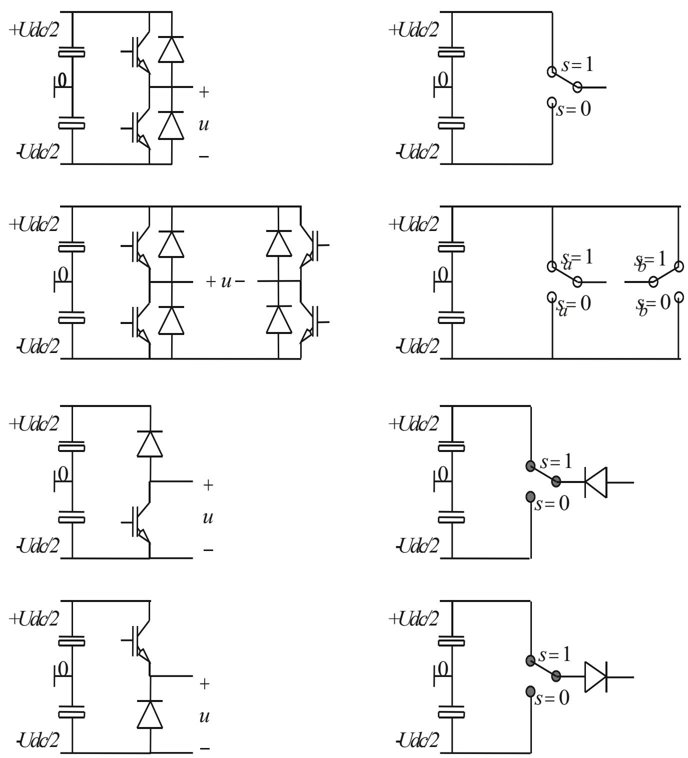
$$u_m = \frac{y_m}{T_s}$$

$$u* = \frac{y*}{T_s}$$

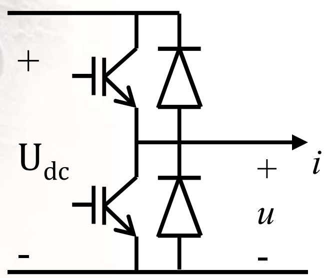
The modulator

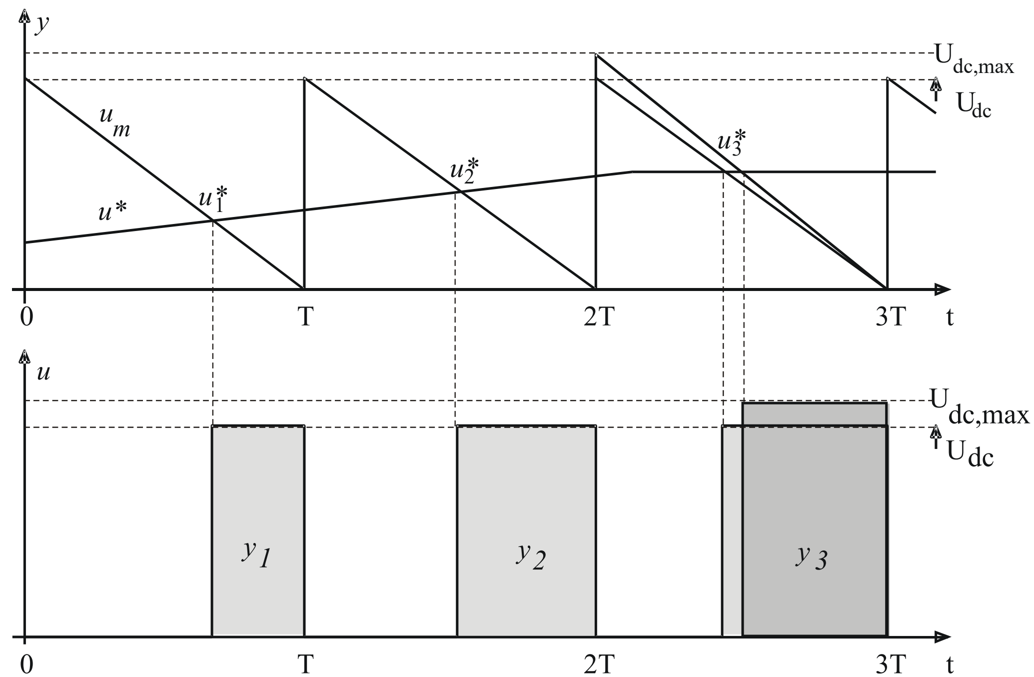


PWM-controlled dc converters

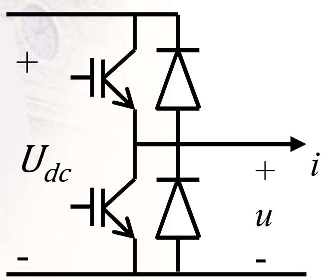


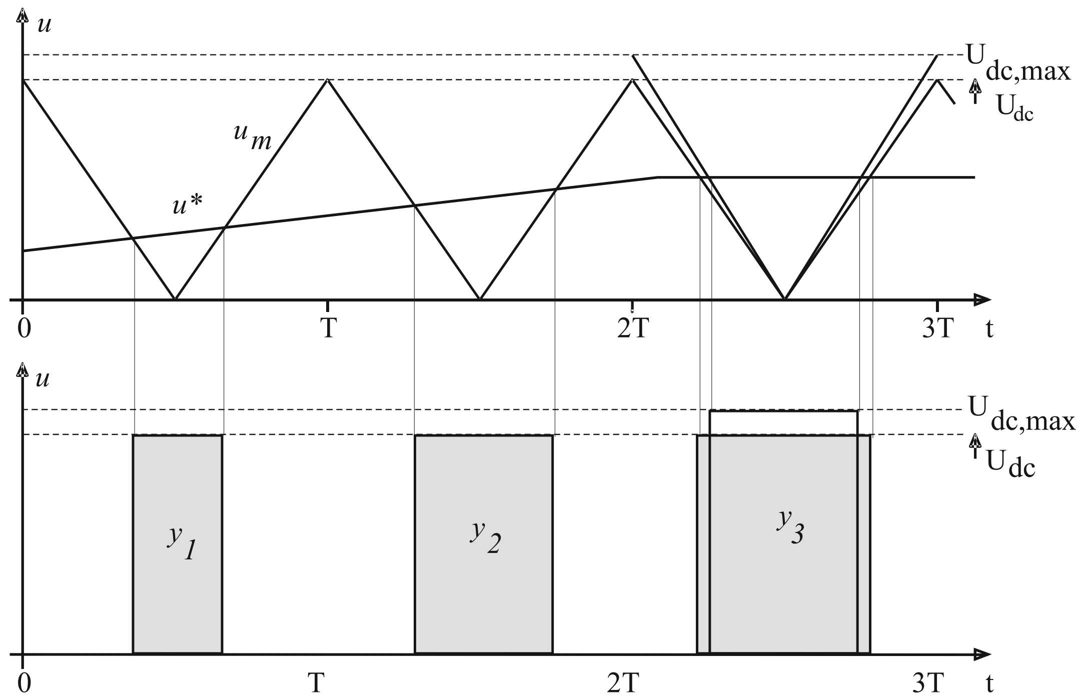
Two quadrant DC converters : I





Two quadrant DC converters : II

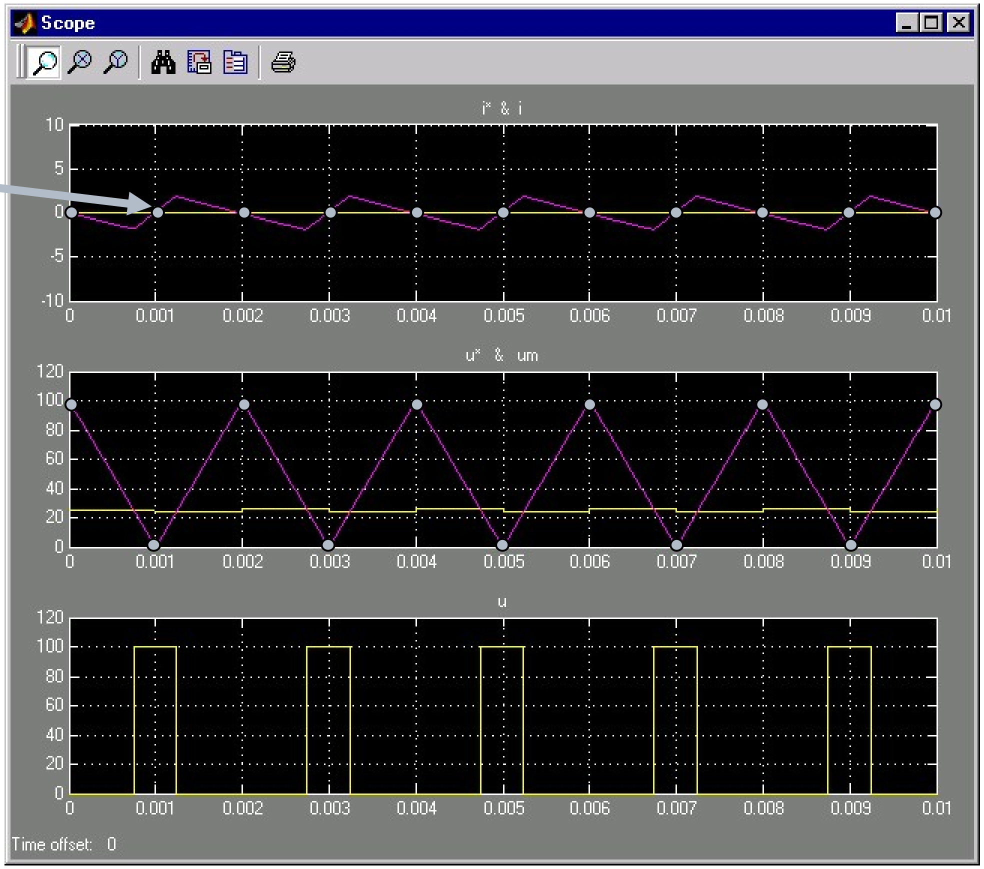




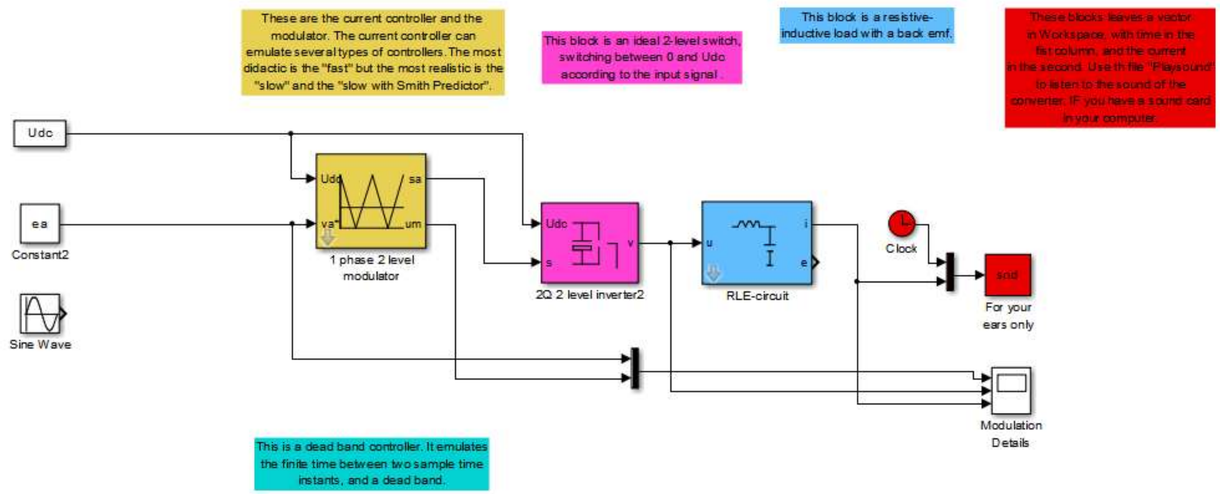
2-quadrant DC converters : III

Current sampling – how often?

- When the carrier turns, i.e. With twice the switching frequency!

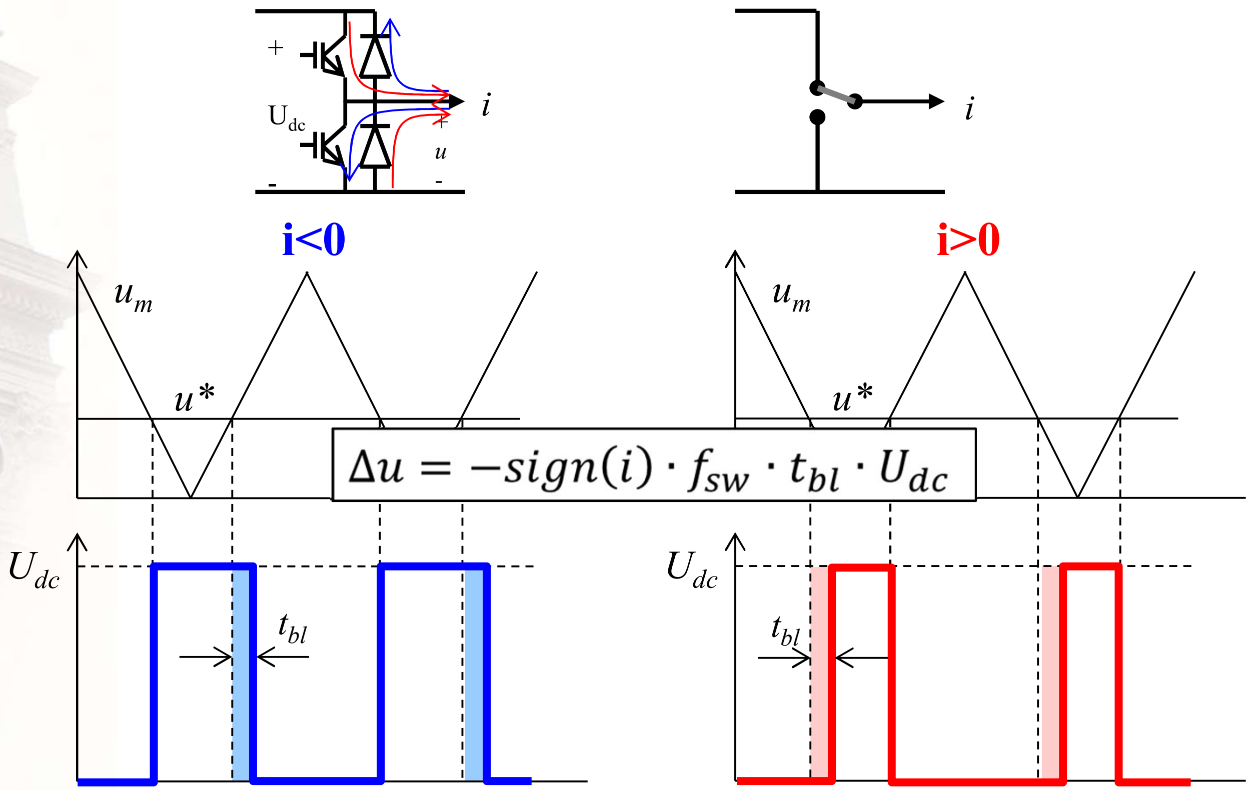


Example



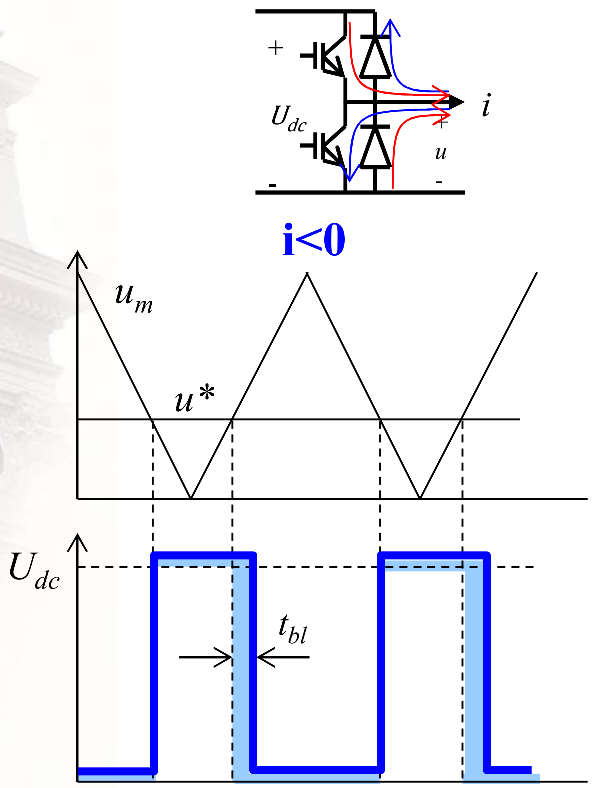
These are the current controller and the modulator. The current controller can emulate several types of controllers. The most didactic is the "fast" but the most realistic is the "slow" and the "slow with Smith Predictor".
This block is an ideal 2-level switch, switching between 0 and Udc according to the input signal.
This block is a resistive-inductive load with a back emf.
These blocks leaves a vector in Workspace, with time in the fist column, and the current in the second. Use th file "Playsound" to listen to the sound of the converter. IF you have a sound card in your computer.
Udc
ea
Constant2
Sine Wave
Udc
va
sa
um
1 phase 2 level modulator
Udc
s
v
2Q 2 level inverter2
u
i
e
RLE-circuit
Clock
snd
For your ears only
Modulation Details
This is a dead band controller. It emulates the finite time between two sample time instants, and a dead band.

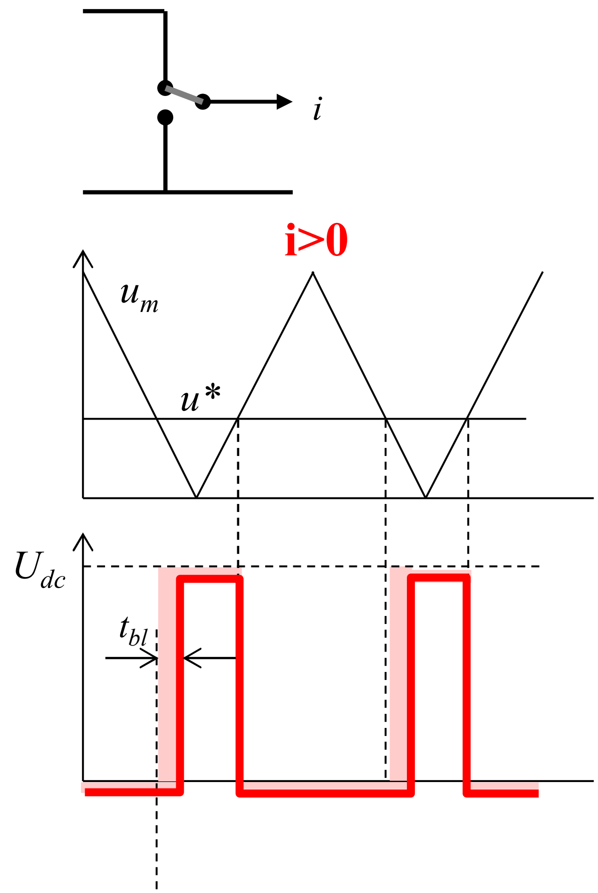
Blanking Time



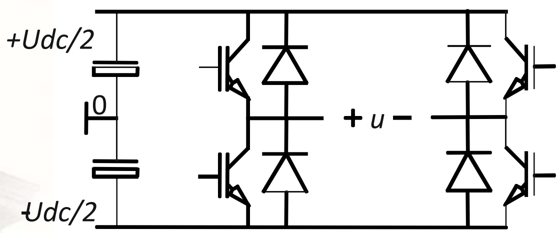
$$\Delta u = -sign(i) \cdot f_{sw} \cdot t_{bl} \cdot U_{dc}$$

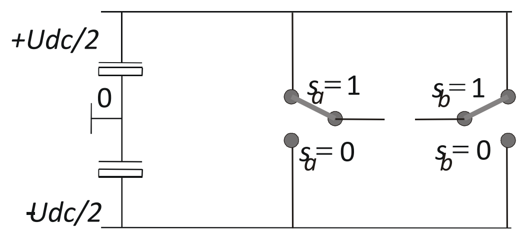
Blanking Time + Voltage Drops





4 – quadrant DC converters





- Bridge connected
- 2 phase potentials:
  - *Only 1 output voltage = 1 degree of freedom to be used for other purposes.*

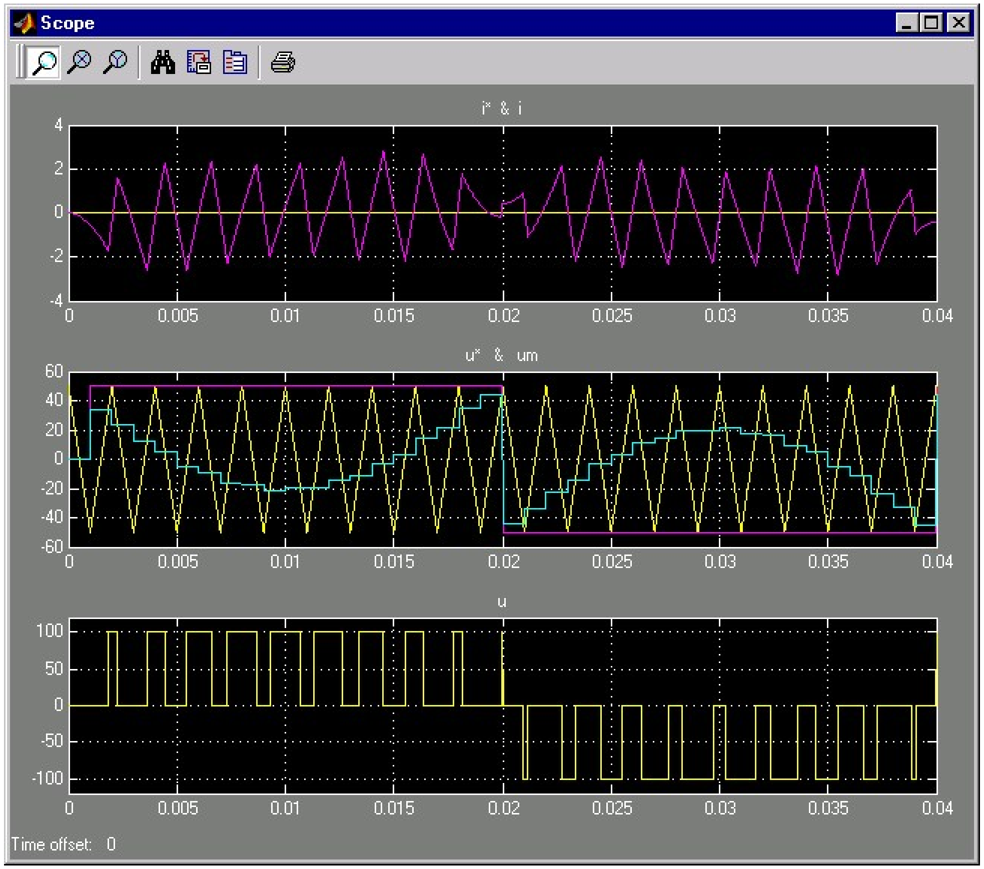
4-quadrant DC converters

$$u* = v_a^* - v_b^*$$

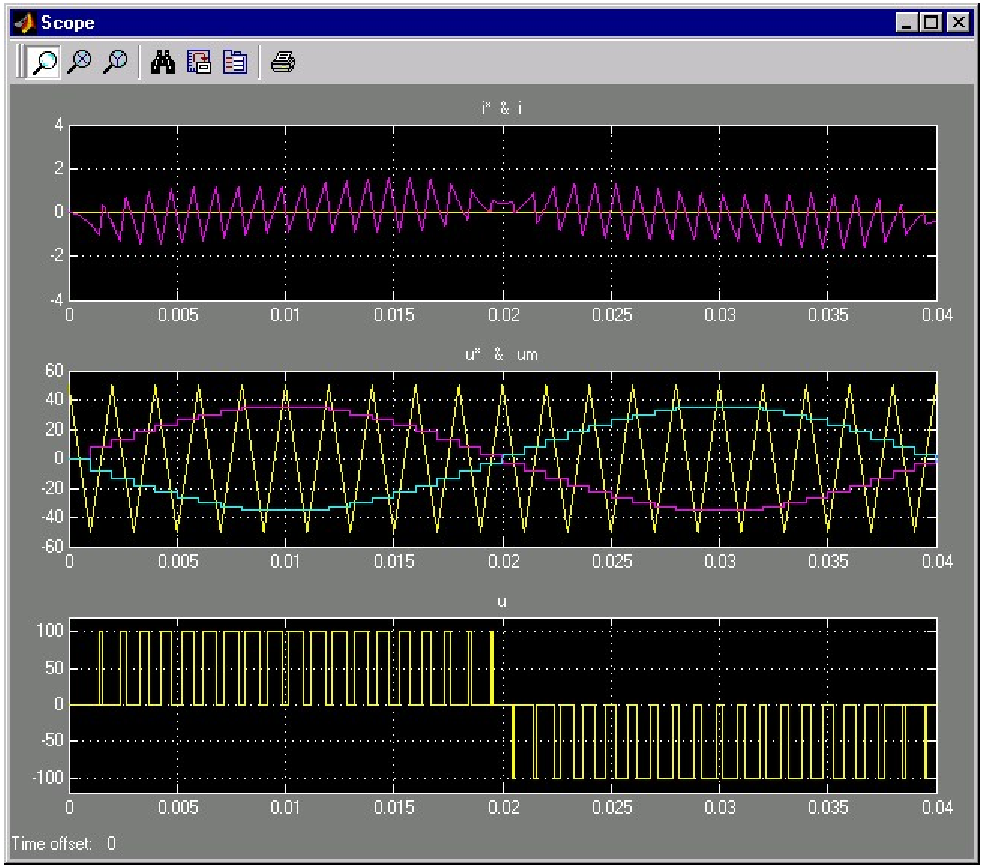
$$alt1: v_a^* = sign(u*) \cdot \frac{U_{dc}}{2} \Rightarrow v_b^* = v_a^* - u* = sign(u*) \cdot \frac{U_{dc}}{2} - u*$$

$$alt2: v_a^* = -v_b^* \Rightarrow v_a^* - v_b^* = 2 \cdot v_a^* \Rightarrow \begin{cases} v_a^* = \frac{u*}{2} \\ v_b^* = -\frac{u*}{2} \end{cases}$$

4-quadrant DC converters – alt 1

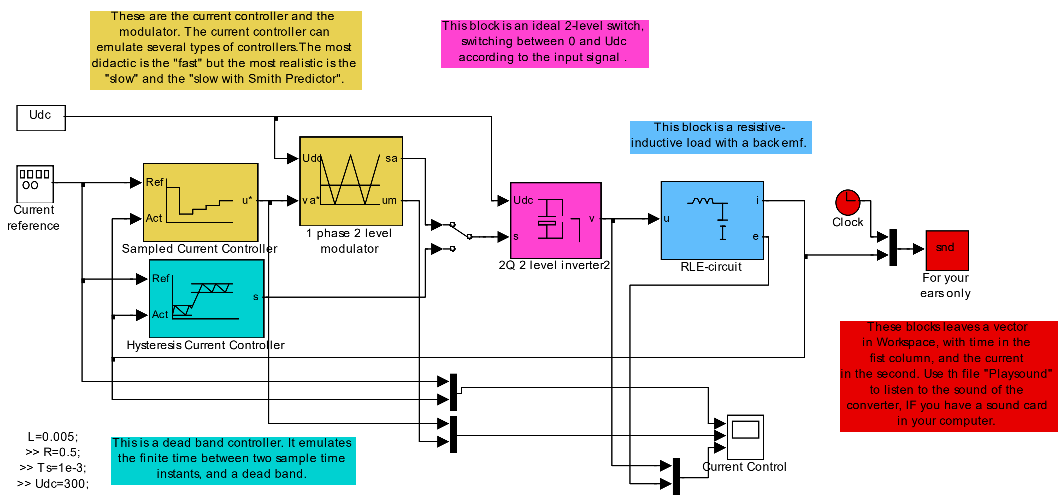


4-quadrant DC converters – alt 2



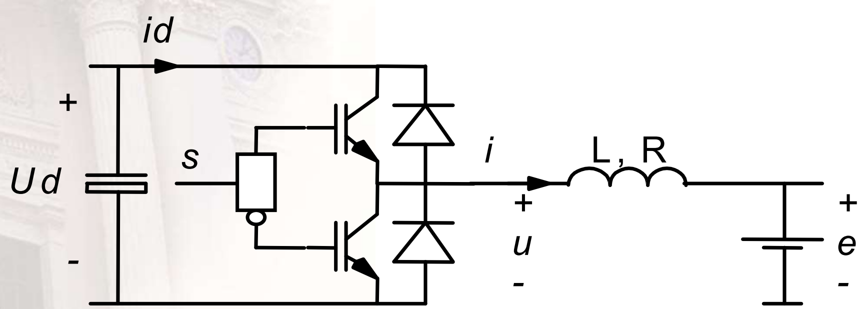
Example

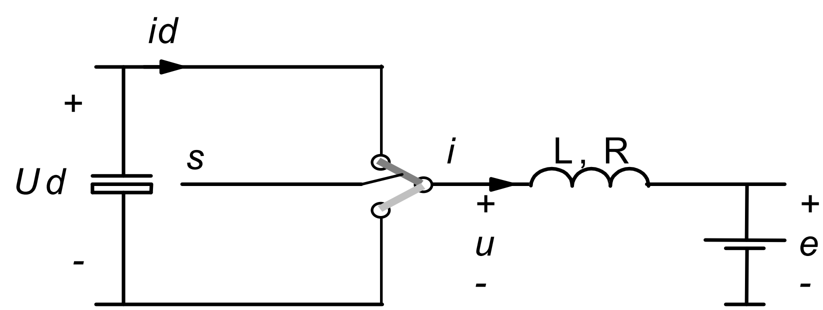
- Sampling and symmetry ...



2-Q DC converters

- Bidirectional power
  - *u*>0, *i* bidirectional
- Equivalent switch:

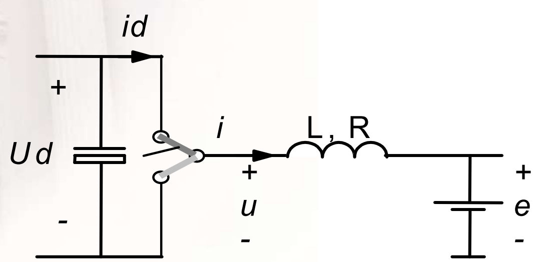


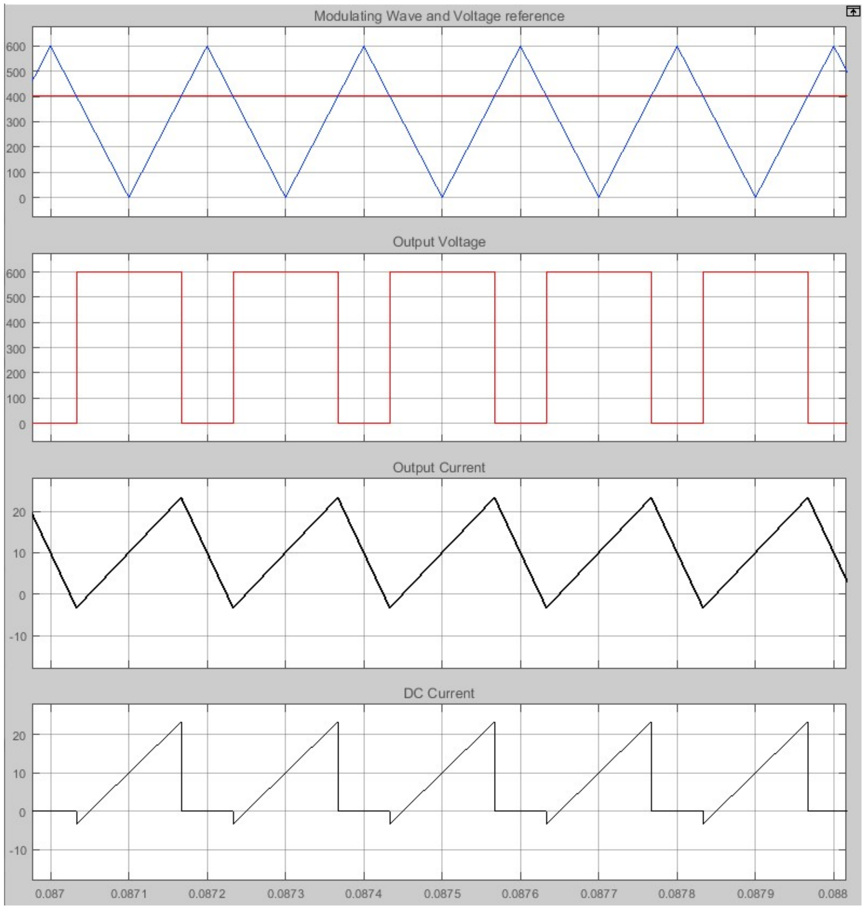


Modulation of a 2Q DC converter

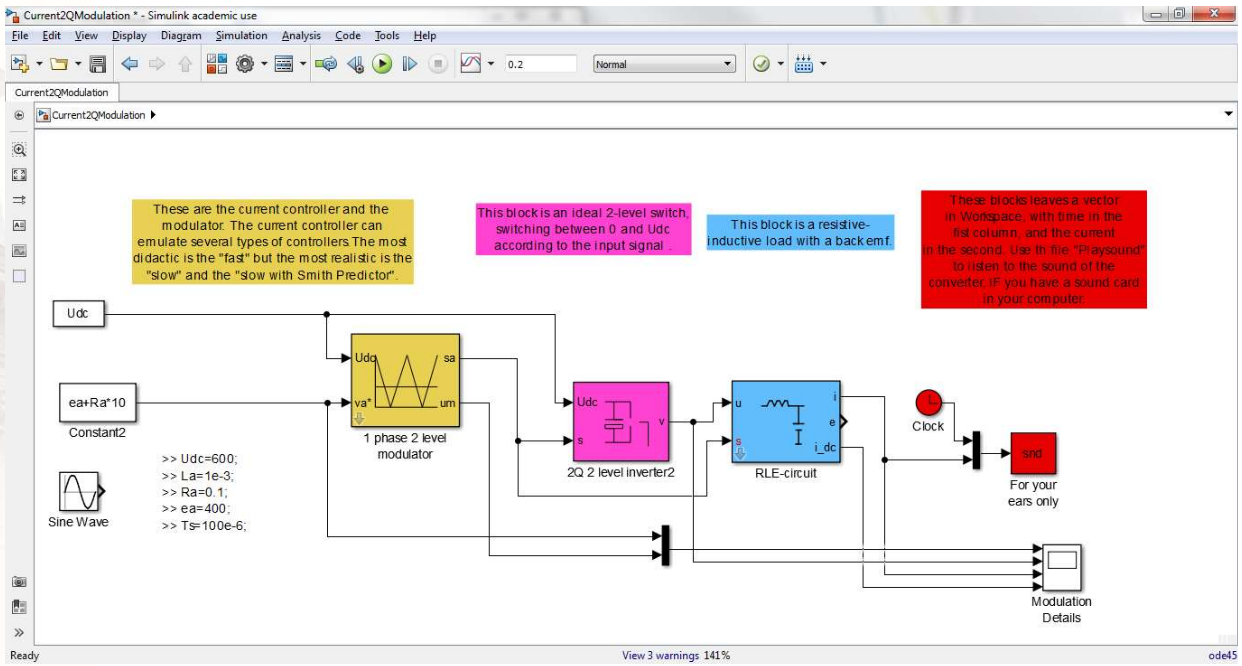
- Only positive output voltages
- Currents both positive and negative
- Example:
  - Udc=600;
  - La=1e-3;
  - Ra=0.1;
  - ea=400;
  - Ts=100e-6
  - u* = 400 + Ra*10

$$\frac{di}{dt} = \frac{(u - e - R \cdot i)}{L}$$





To Simulink


Current2QModulation * - Simulink academic use
File Edit View Display Diagram Simulation Analysis Code Tools Help
0.2
Normal
Current2QModulation
These are the current controller and the modulator. The current controller can emulate several types of controllers. The most didactic is the "fast" but the most realistic is the "slow" and the "slow with Smith Predictor".
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Udc
ea+Ra*10
Constant2
Sine Wave
Udc
va*
sa
um
1 phase 2 level modulator
>> Udc=600;
>> La=1e-3;
>> Ra=0.1;
>> ea=400;
>> Ts=100e-6;
Udc
s
v
2Q 2 level inverter2
u
s
i
e
i_dc
RLE-circuit
Clock
snd
For your ears only
Modulation Details
Ready
View 3 warnings 141%
ode45

One more 2Q example

- To reduce current ripple
- Example:
  - Udc=600;
  - La=1e-3;
  - Ra=0.1;
  - ea=400;
  - Ts=25e-6 (much higher switching frequency)
  - u* = 400 + Ra*10
- DC side: PWM current
- AC side: PWM voltage

$$\frac{di}{dt} = \frac{(u - e - R \cdot i)}{L}$$