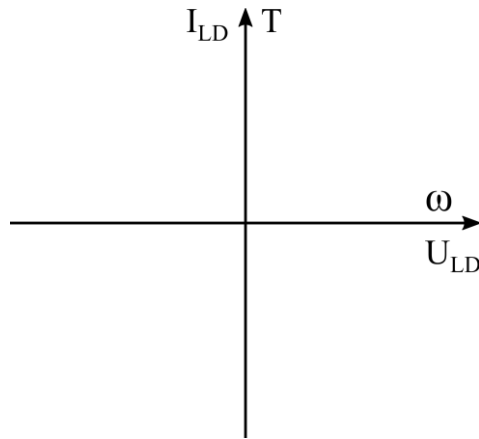
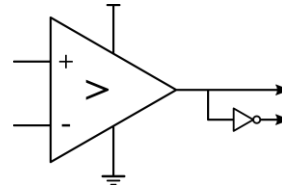
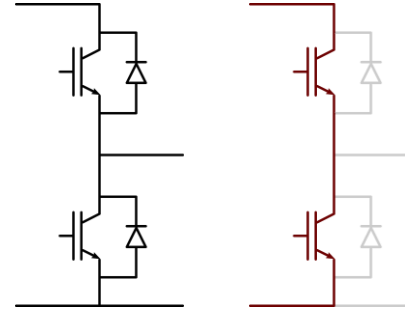
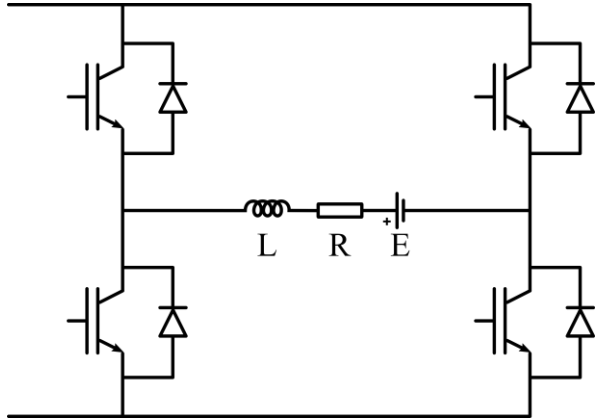


FOUR-QUADRANT CHOPPER

- Possible/correct switches' states.
- Relevant waveforms.
- DC-machine model.
- Details on all four quadrants operation.

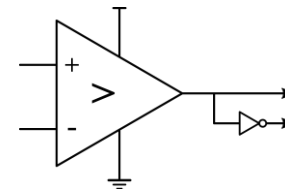
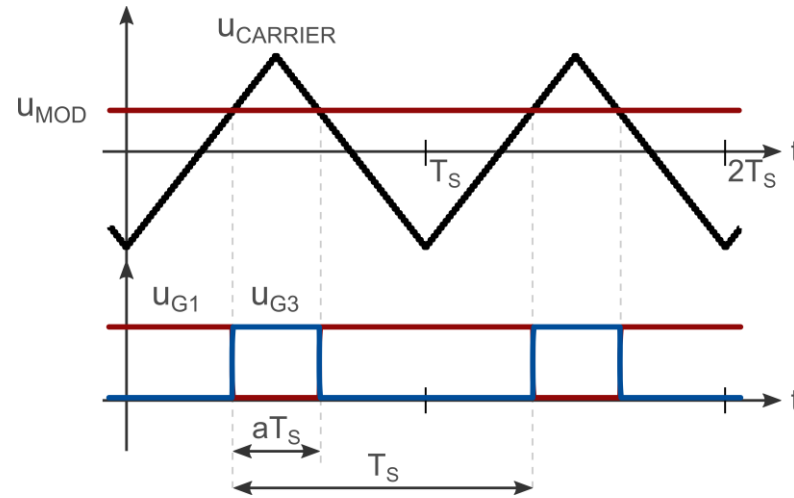
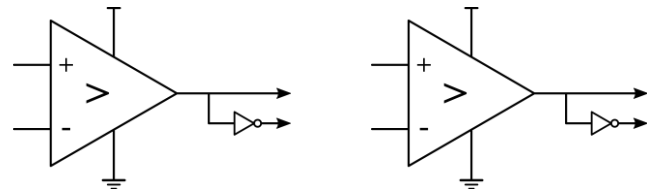
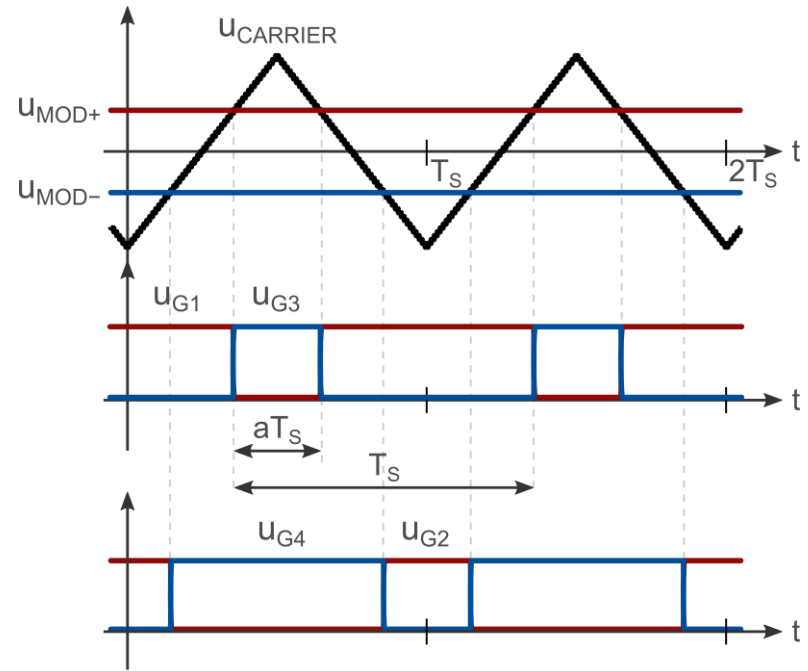
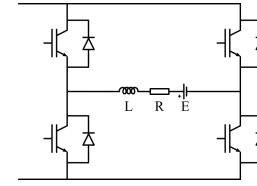
CHOPPERS

Four-quadrant chopper



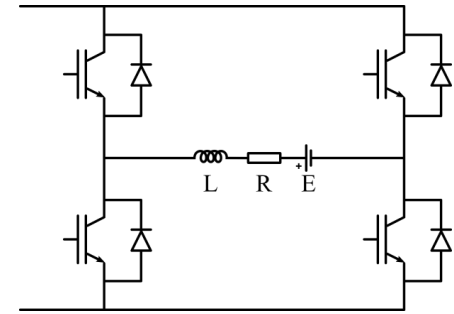
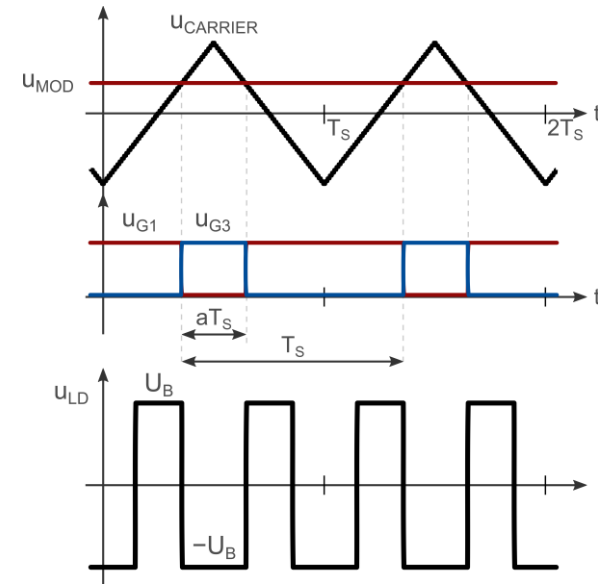
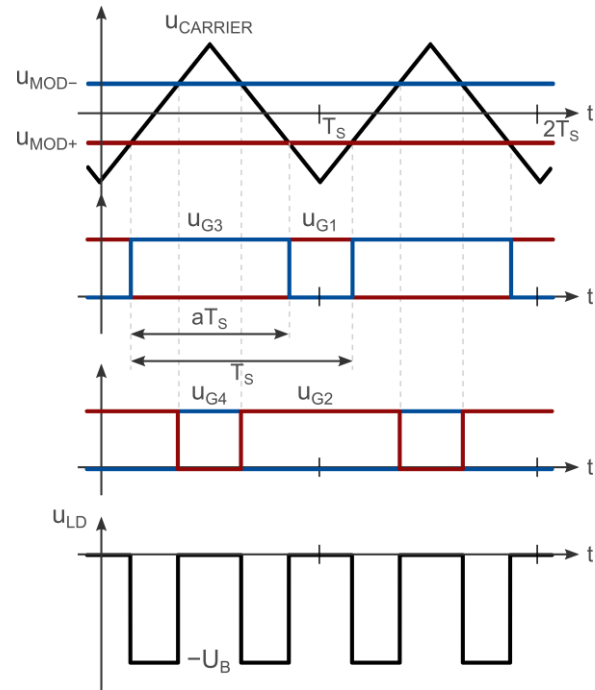
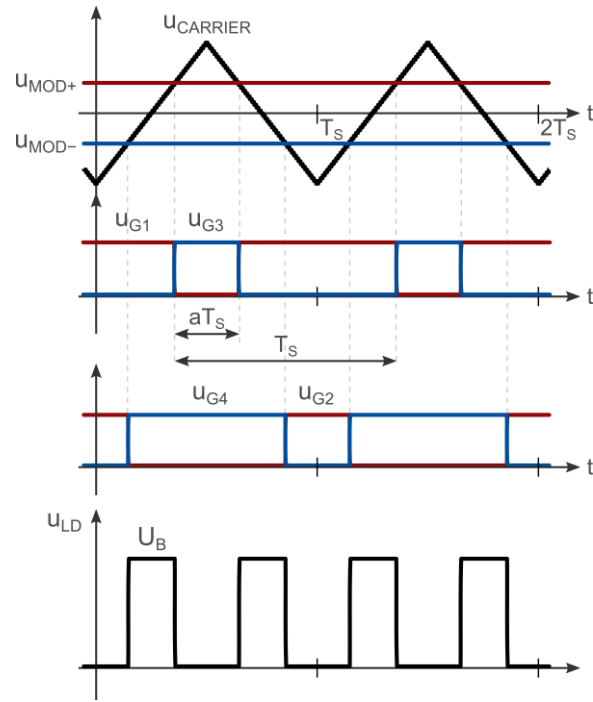
CHOPPERS

Four-quadrant copper - modulation



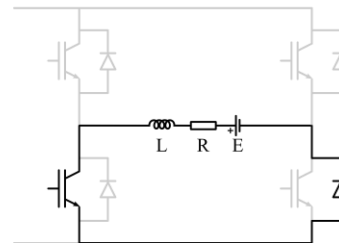
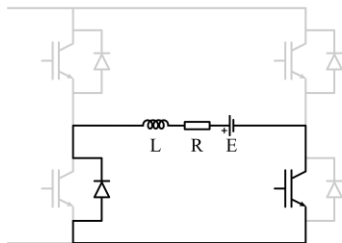
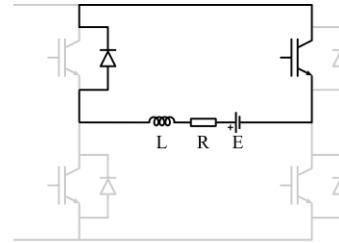
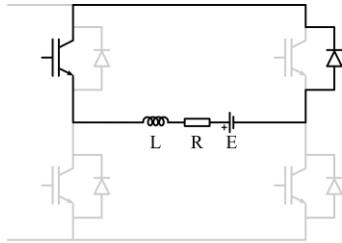
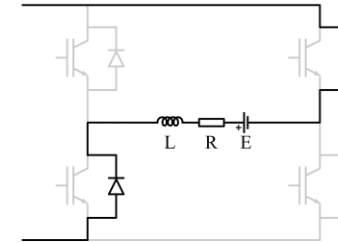
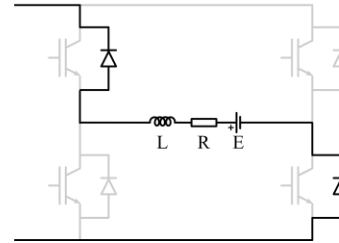
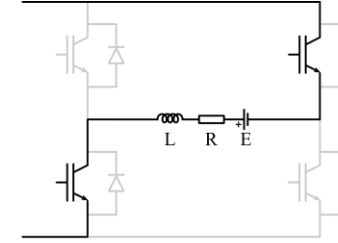
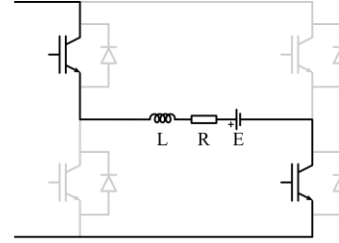
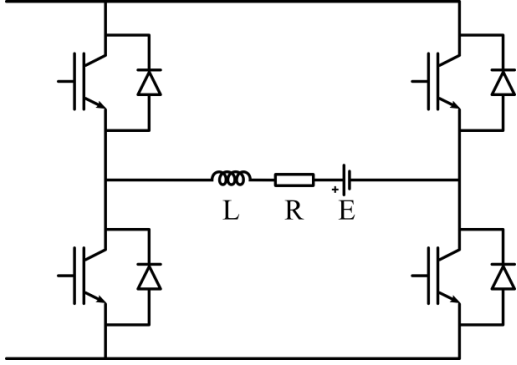
CHOPPERS

Four-quadrant copper - modulation



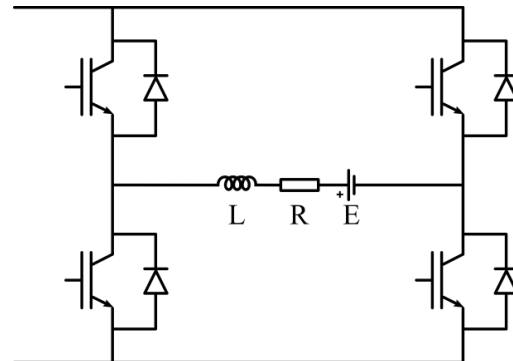
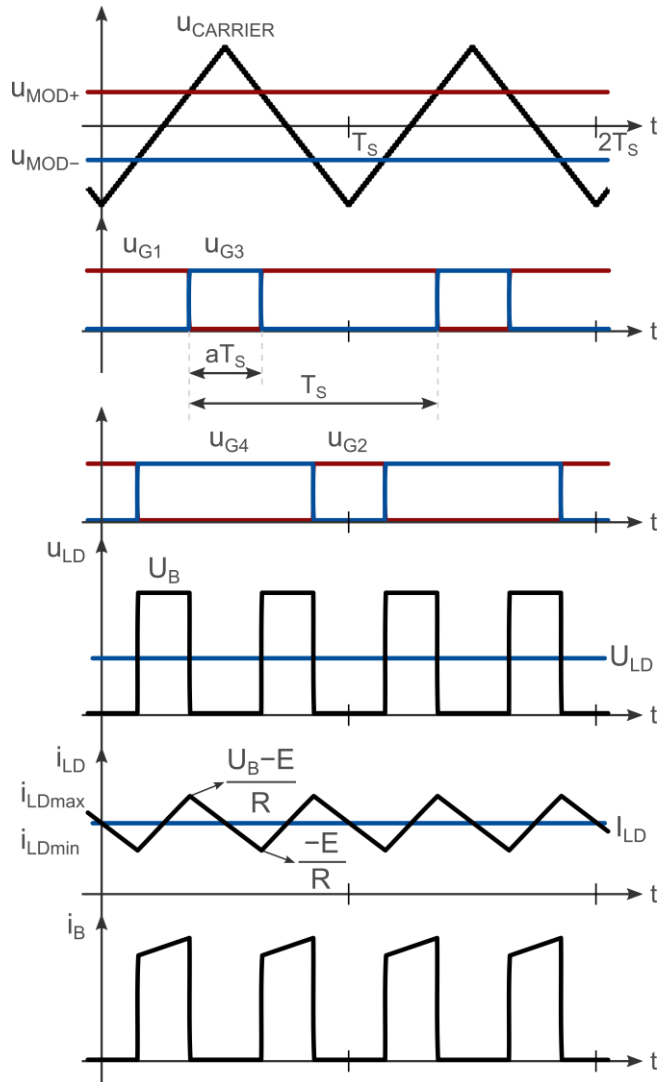
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Four-quadrant copper - possible converter states



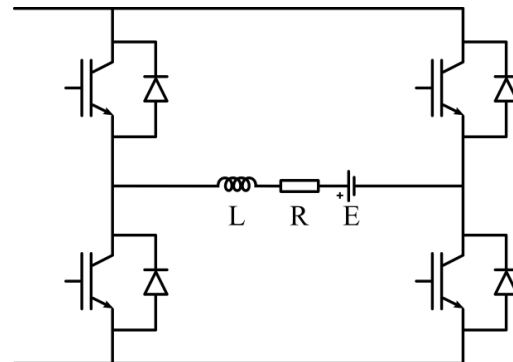
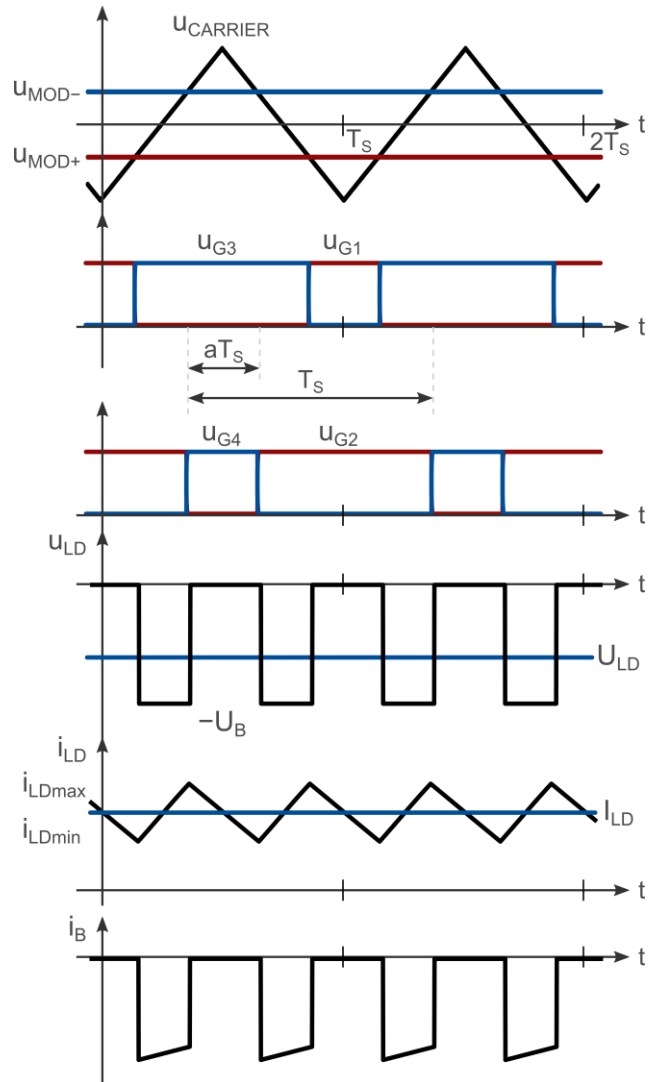
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Four-quadrant copper - the first quadrant



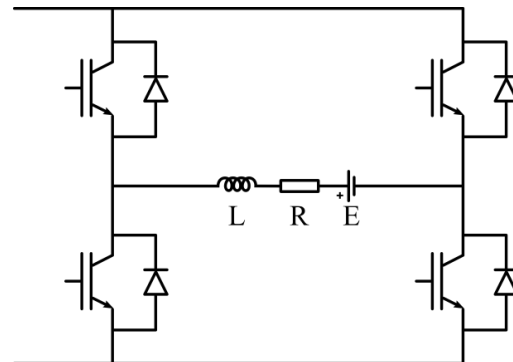
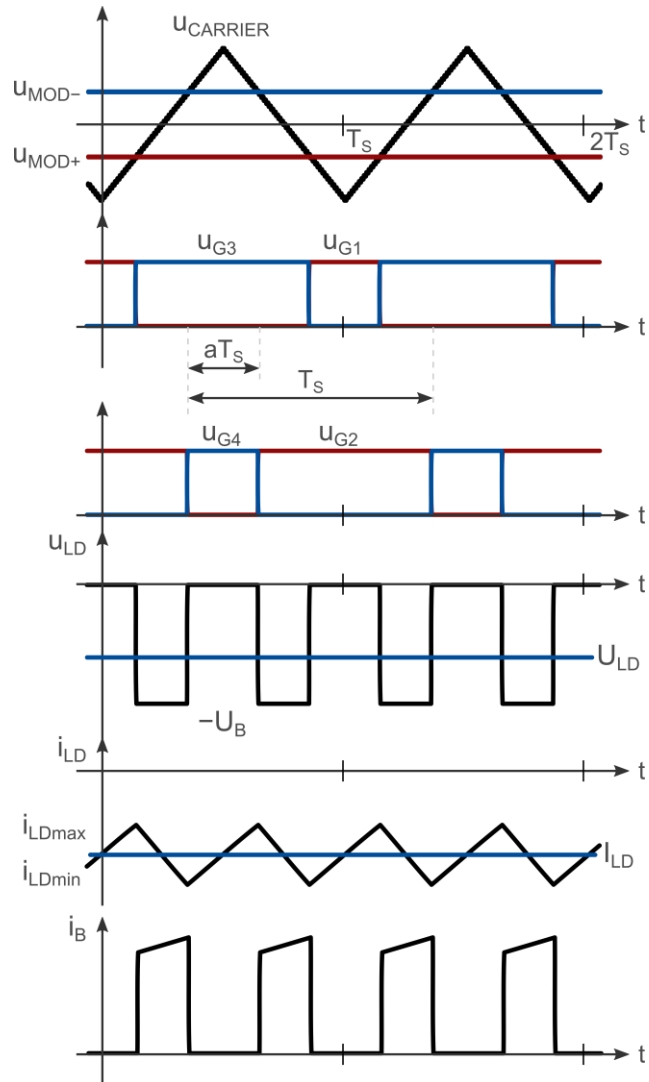
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Four-quadrant copper - the second quadrant



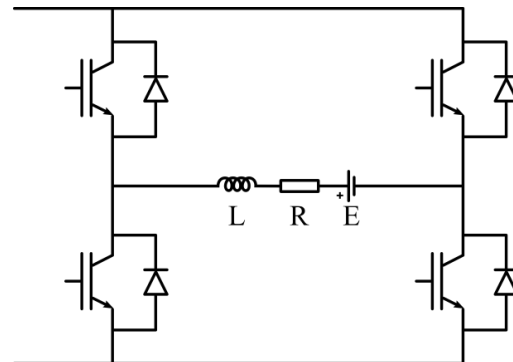
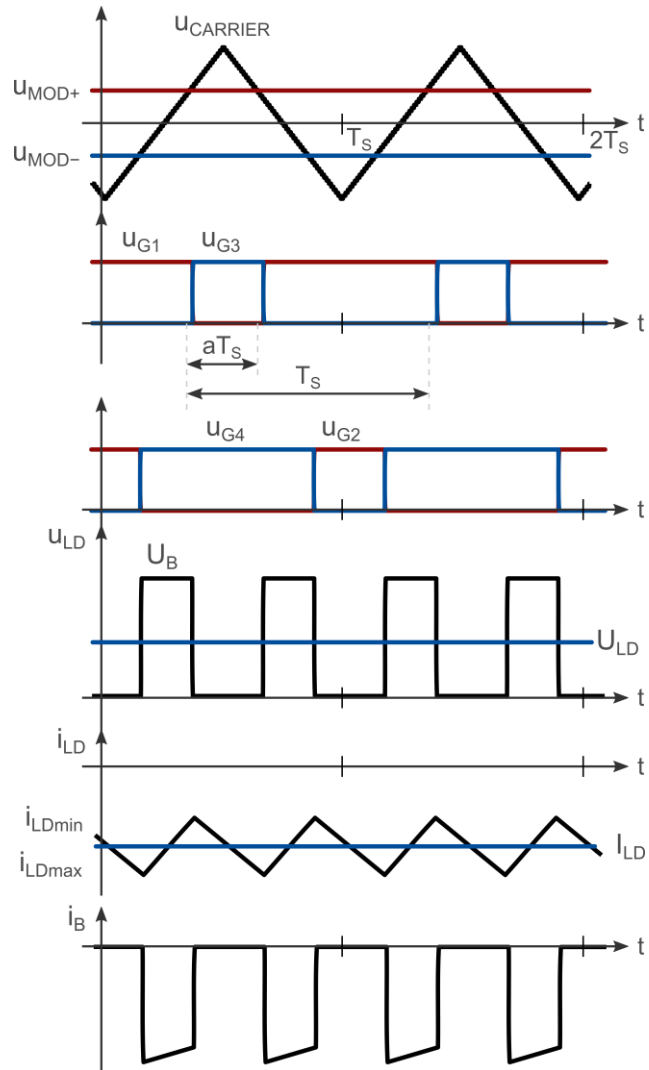
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Four-quadrant copper - the third quadrant



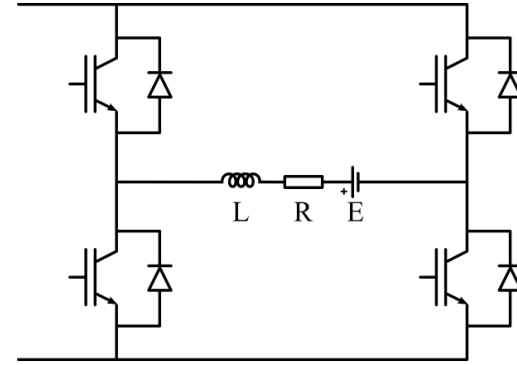
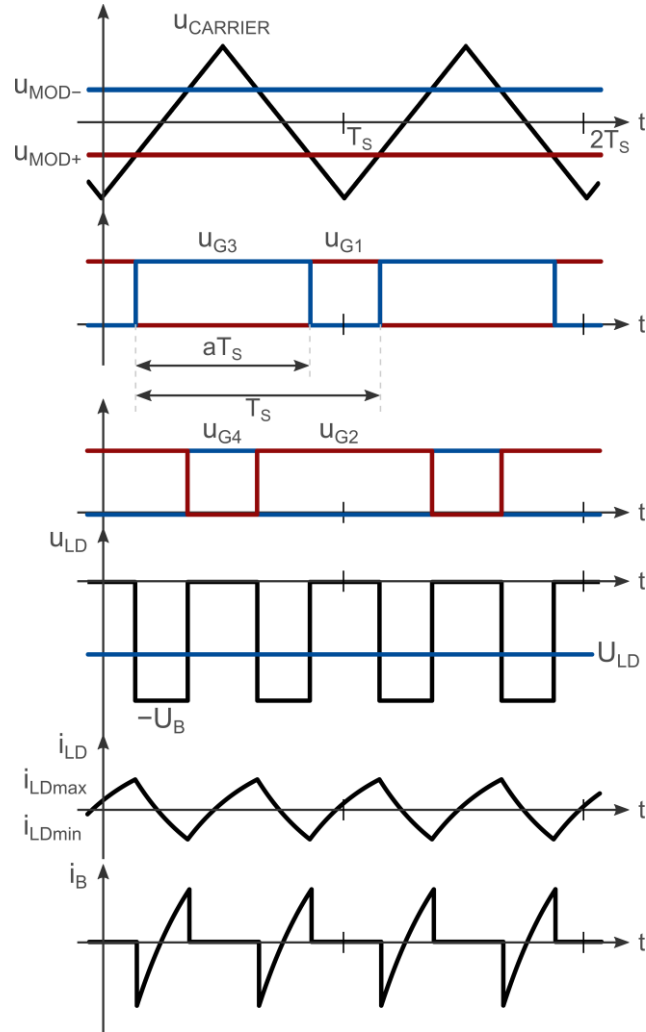
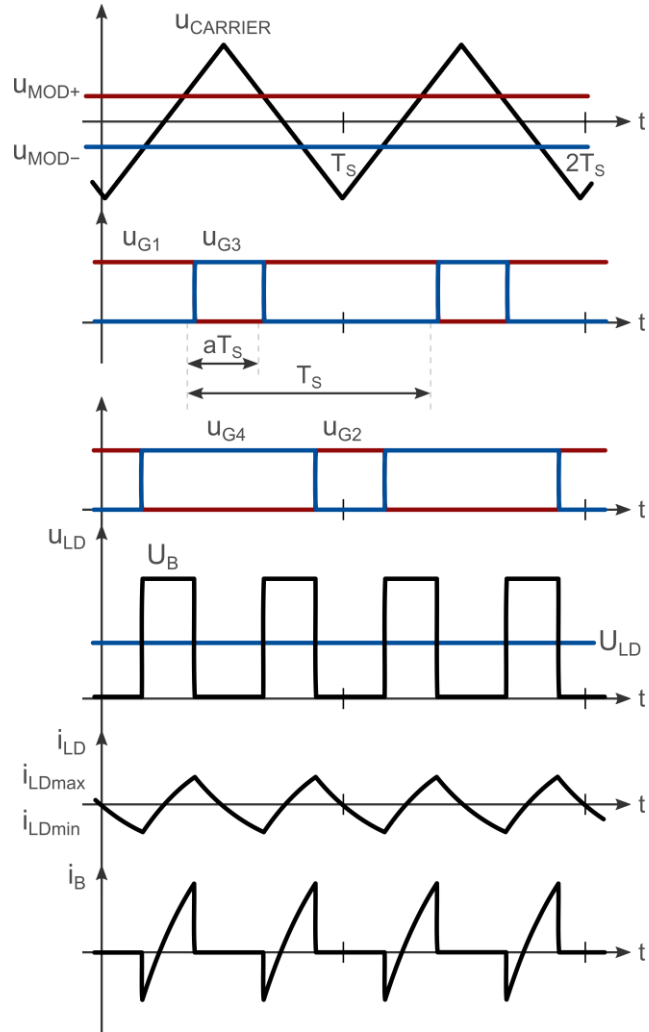
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Four-quadrant copper - the fourth quadrant



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Four-quadrant copper - small f_s



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DC machine model

Instantaneous DC machine model:

$$u_a = R_a \cdot i_a + L_a \cdot \frac{di_a}{dt} + e_a$$

$$e_a = \omega \cdot \psi_f$$

$$\psi_f = M_{af} \cdot i_f$$

$$t_e = i_a \cdot \psi_f$$

$$J \frac{d\omega}{dt} = t_e - t_m$$

Averaged DC machine model (steady state):

$$U_a = R_a \cdot I_a + E_a$$

$$E_a = \omega \cdot \psi_f$$

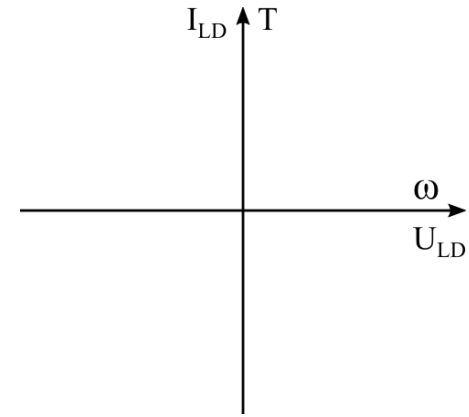
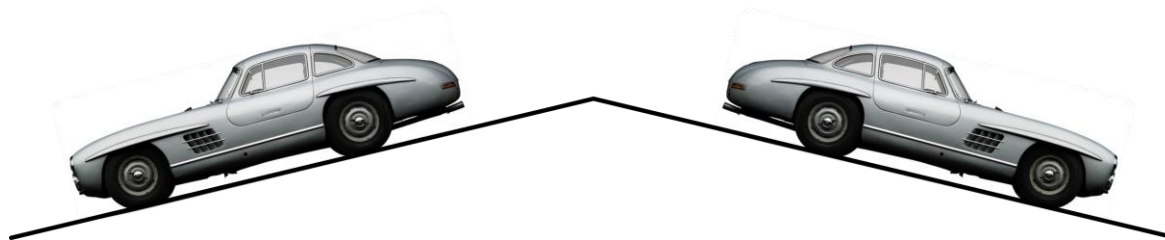
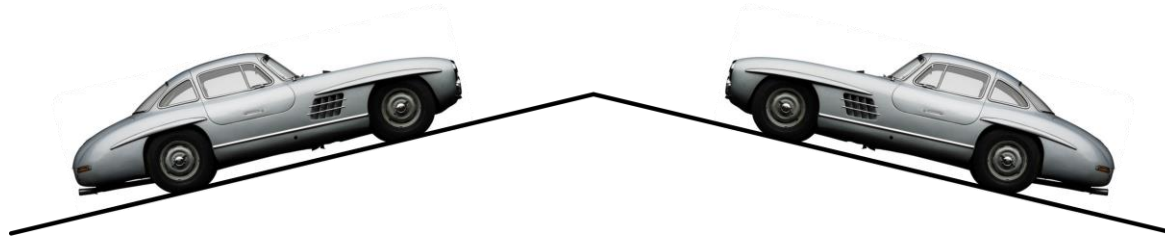
$$\psi_f = M_{af} \cdot I_f$$

$$T_e = I_a \cdot \psi_f$$

$$T_e = T_m$$

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Four quadrant operation



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Four-quadrant copper - important notes

- Unipolar PWM,
- (Eight) operating 'modes' of the converter,
- Maximum, instantaneous and average variables' values,
- DC-machine model vs four quadrant operation.

