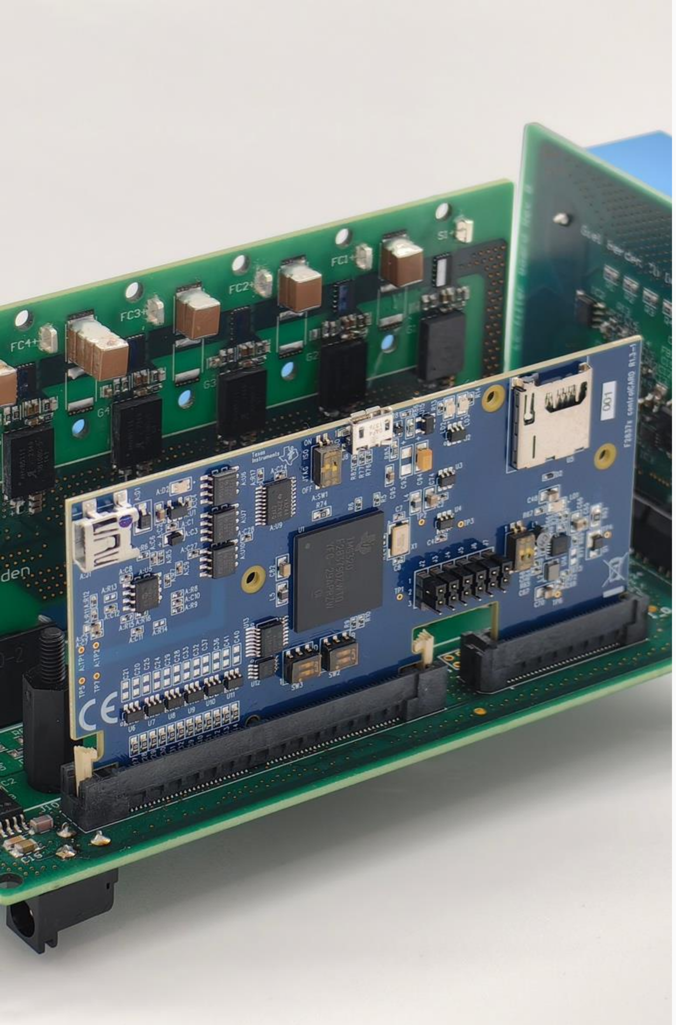
Power converters in motor drives

Components, topology and modulation

Prof. dr. ir. Pavol Bauer


Power converter, Photo by Jianning Dong, CC-BY-4.0

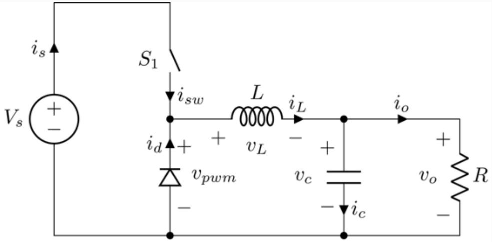
Lecture Outline

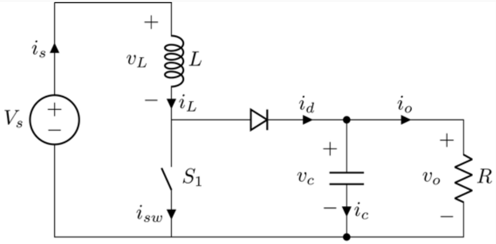
1. Types of power converters
2. Power converter components
3. Power semiconductors
4. Basic building block: half-bridge
5. H-bridge converter and its modulation

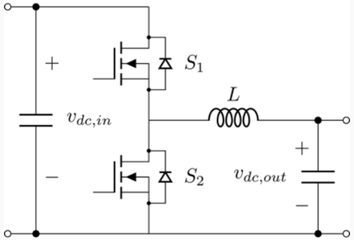
What power converters you may see in motor drives?

Power converter types

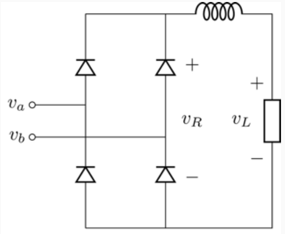
DC-DC

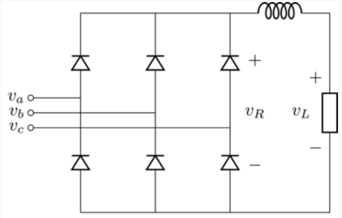




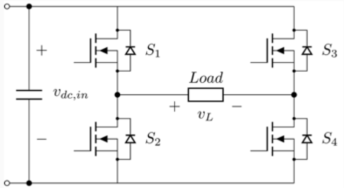


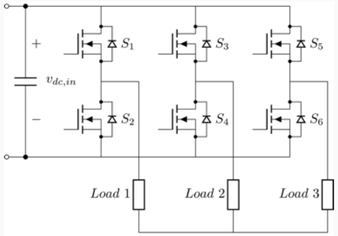
AC-DC (rectifier)





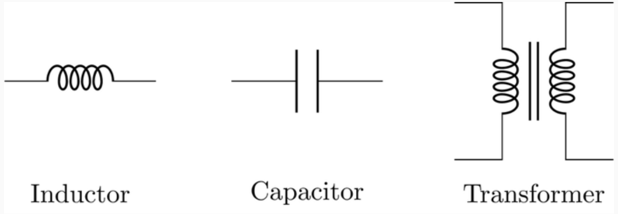
DC-AC (inverter)





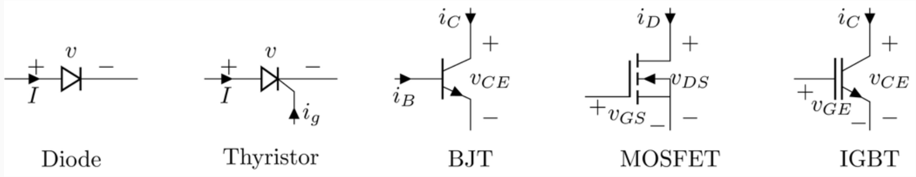
What components are there inside power converters?

Passive components



- Inductor: store energy and stabilize current (di/dt limiter)
- Capacitor: store energy and stabilize voltage (dv/dt limiter)
- Transformer: introduce a conversion ratio or galvanic isolation

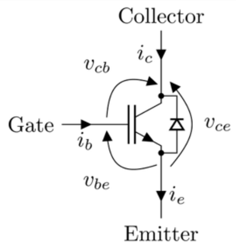
Switching components

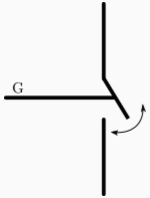


- Diode: only let go forward current, no gate operable
- Thyristor/BJT: gate current controlled
- MOSFET/IGBT: gate voltage controlled (mainstream in motor drive)

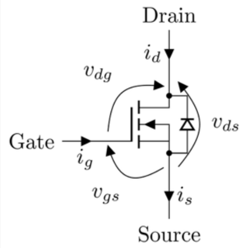
Power semiconductors: IGBT and MOSFET

Power IGBT (with antiparallel diode)





Power MOSFET



- Insulated-gate bipolar transistor

  $v_G > v_E$ (v_{be} > threshold): on, $i_c \approx i_e$

  $v_{ce} \approx$ small constant

  $v_G < v_E$ (v_{be} < threshold): off, $i_c \approx 0$
- Antiparallel diode needed for reverse current flow
- Medium switching speed (ns-us)
- Very high rated voltage and current

- Metal-oxide-semiconductor field-effect transistor

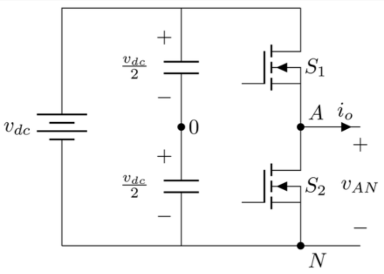
  $v_G > v_s$ (v_{gs} > threshold): on, $i_d \approx i_s$

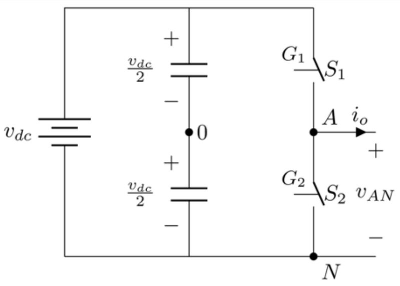
  $v_{ce} \approx i_d R_{\text{ds,on}}$, $R_{\text{ds,on}} \approx$ small constant

  $v_G < v_S$ (v_{gs} < threshold): off, $R_{\text{ds,off}} \approx \infty$
- Internal body diode
- Fast switching speed (ns)
- Lower rated voltage and current

How to construct power converters from these components?

Half bridge: a basic building block





S1 on, S2 off:

- $v_{AN} = v_{dc}$; $v_{A0} = v_{dc}/2$

S1 off, S2 on:

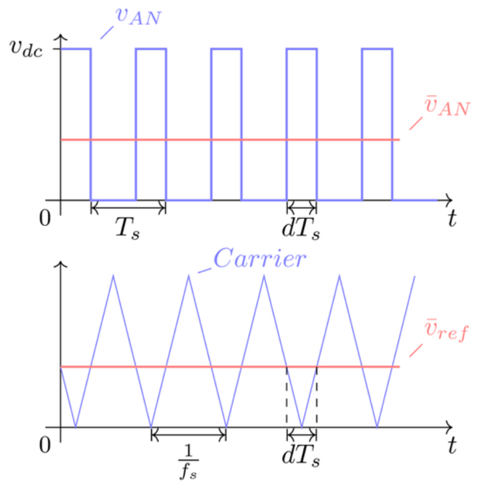
- $v_{an} = 0$; $v_{A0} = -v_{dc}/2$

In one switching period $T_s = 1/f_s$:

- S1 on, S2 off for 0~dT_s interval
- S1 off, S2 on for dT_s~T_s interval

To achieve the wanted average voltage:

- Pulse width modulation (PWM)
- Reference voltage v_{ref}
- Triangular carrier waveform
- v_{ref} > carrier: S1 on, S2 off
  v_{ref} < carrier: S1 off, S2 on

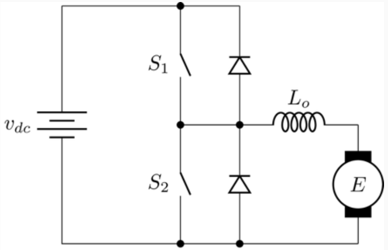


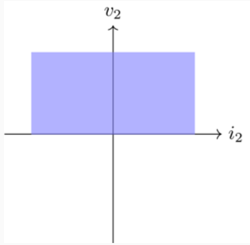
Average output:

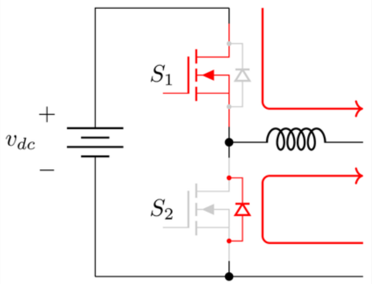
$$\bar{v}_{AN} = dv_{dc}$$

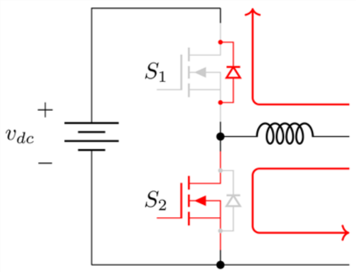
$$\bar{v}_{A0} = (d - 0.5)v_{dc}$$

Half bridge: two-quadrant operation





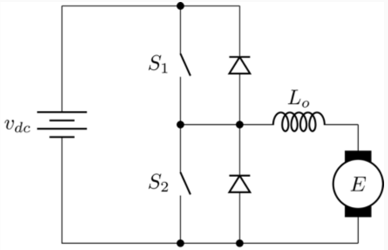




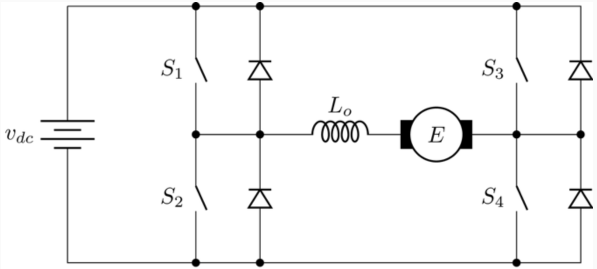
DC motor drive for 2 quadrant operation

- Turn in forward direction: motor and generator operation.
- Not able to turn backward, because the voltage polarity is not able to be reversed.

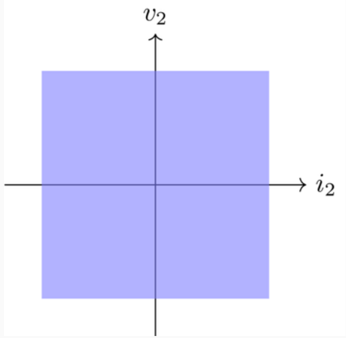
H-bridge: four-quadrant operation



Two-quadrant half-bridge

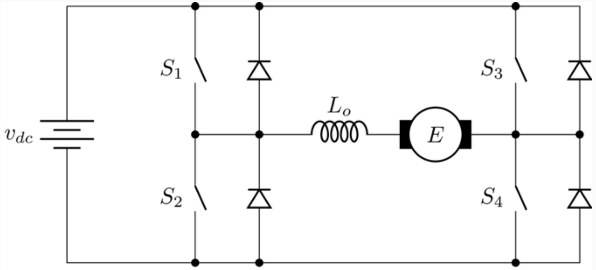


Two half-bridges form a four-quadrant H-bridge



- Voltage polarity reversible
- Can make a DC machine rotate backward
- How to realize the PWM (pulse-width-modulation)?

H-bridge: bipolar modulation



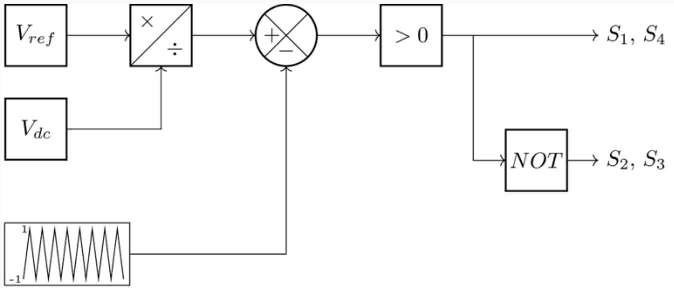
- S1, S4 and S2, S3 are switched in pairs, complementarily
- output V_o is switching between $+V_{dc}$ and $-V_{dc}$ (bi-polar PWM).
- Therefore negative V_o is possible.

d_1: duty cycle of S1, S4
d_2: duty cycle of S2, S3

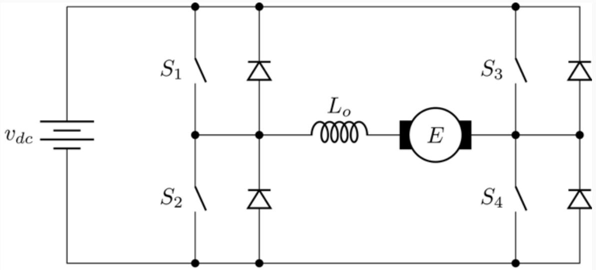
- Complementary switching: $d_1+d_2 = 1$
- Averaged output voltage:

$$v_o = d_1 V_{dc} - d_2 V_{dc} = (2d_1 - 1)V_{dc}$$

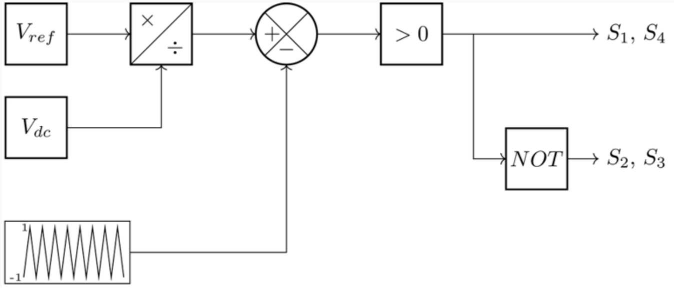
- Modulation:

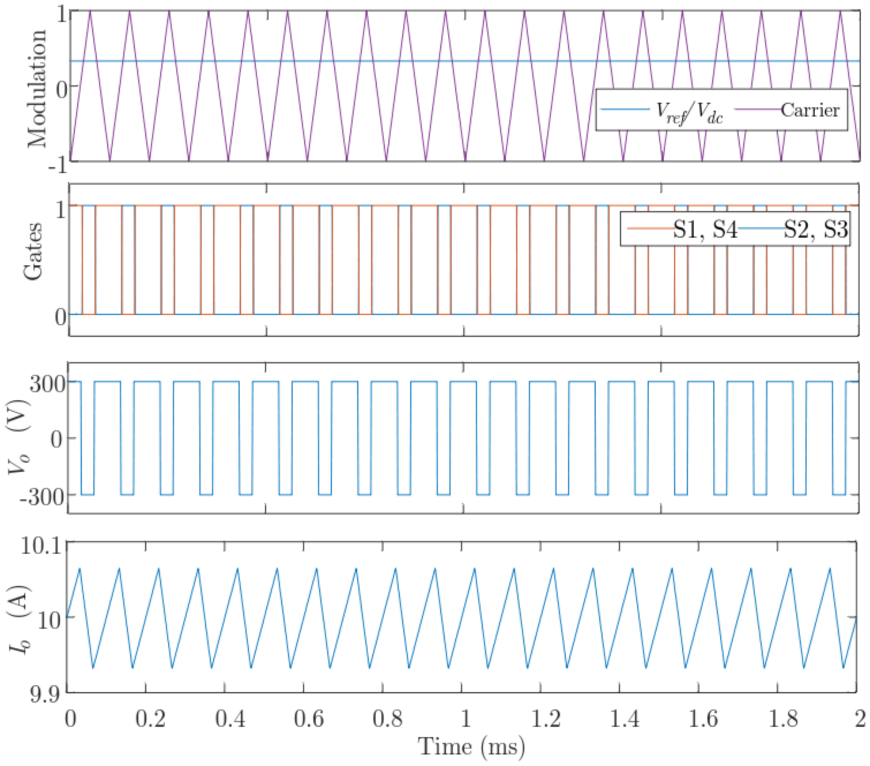


H-bridge bipolar modulation waveforms

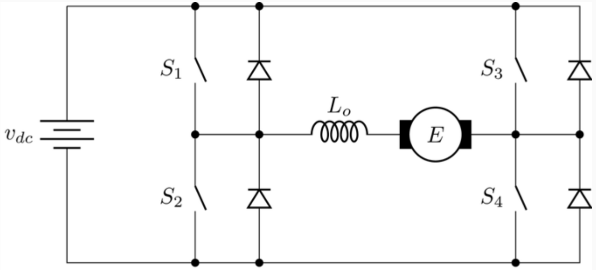


- S1, S3 and S2, S4 are switched in pairs, complementarily
- output V_o is switching between $+V_{dc}$ and $-V_{dc}$ (bi-polar PWM).





H-bridge: unipolar modulation



- S1, S2 switch complementary, so are S3, S4.
- V_o is switching either between $+V_{dc}$ and 0 or between $-V_{dc}$ and 0 (uni-polar PWM)
- Less current ripple compared to bi-polar switching

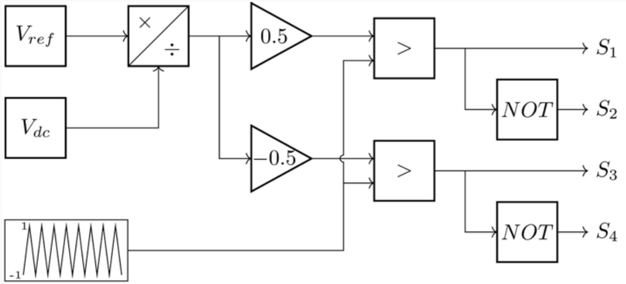
d_1: duty cycle of S_1

d_3: duty cycle of S_3

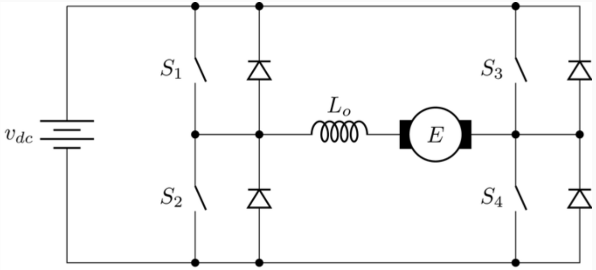
- Complementary switching: $d_1+d_2 = 1$, $d_3+d_4=1$
- Averaged output voltage:

$$v_o = d_1 V_{dc} - d_3 V_{dc}$$

- Modulation:



H-bridge unipolar modulation waveforms



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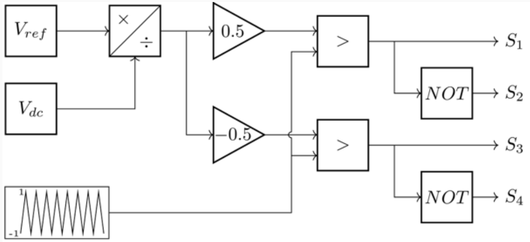
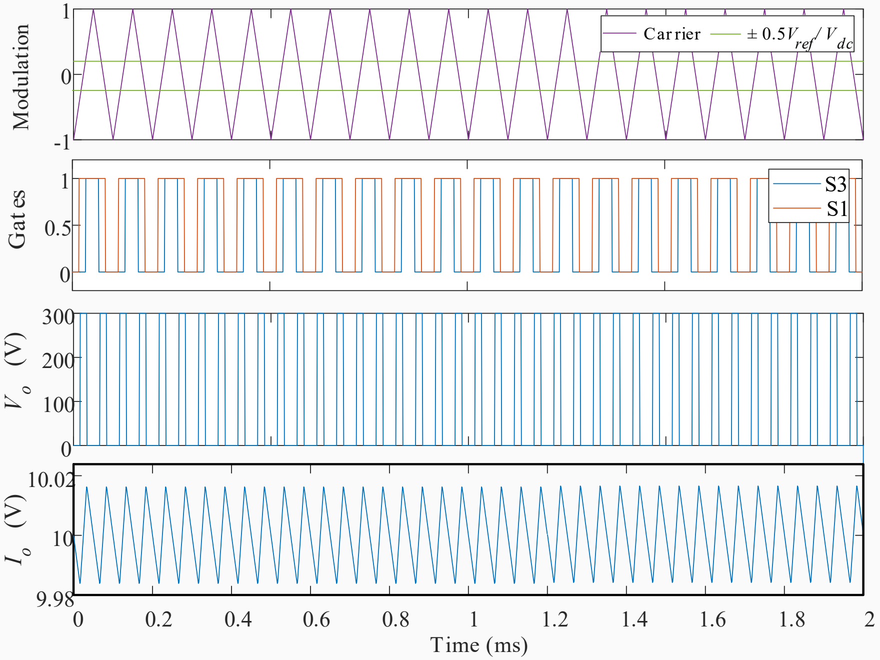
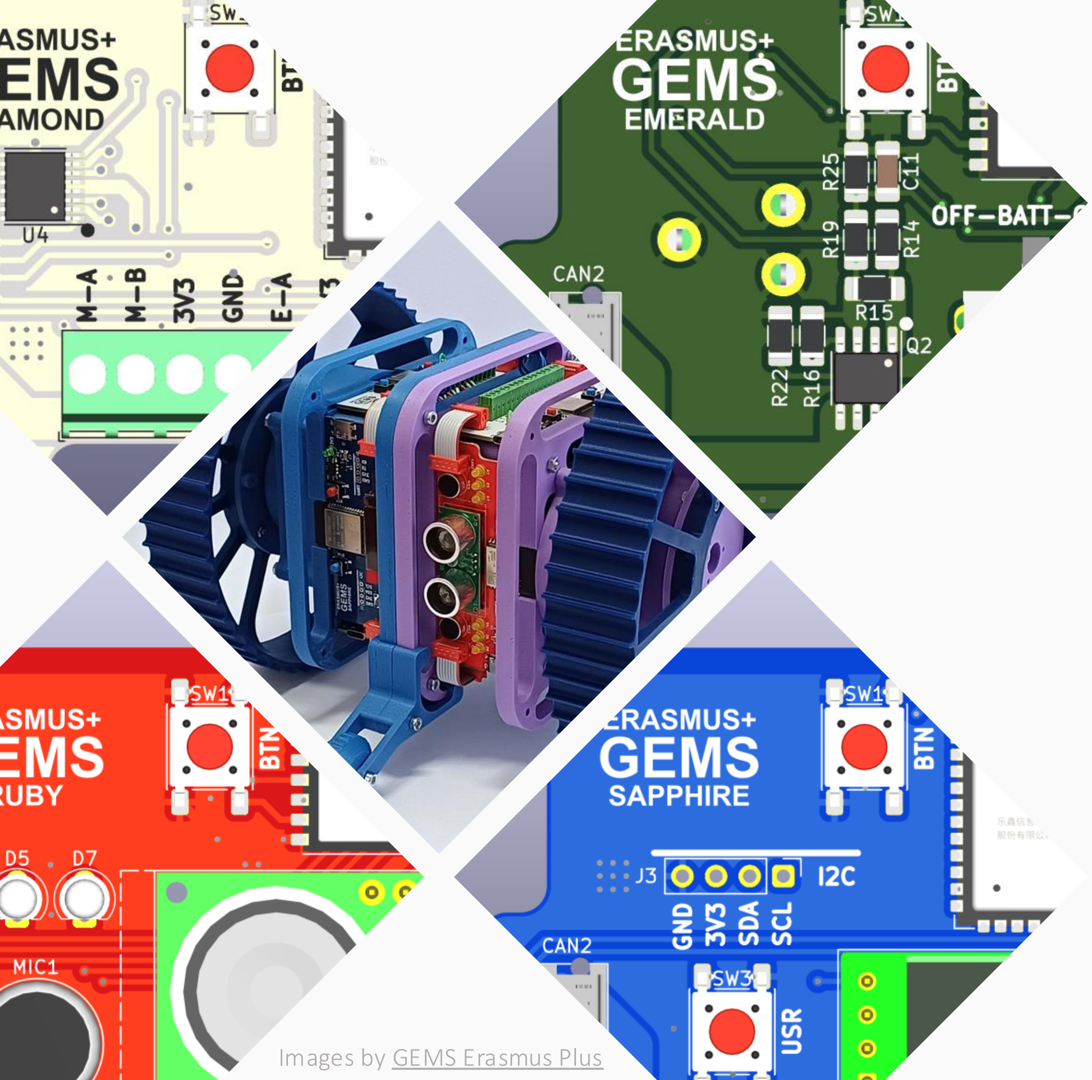




Conclusions

- Power converters are built based on passive components (LC) and power semiconductors (IGBT, MOSFET, diode etc.)
- Voltage controlled devices (Power MOSFET and IGBT) are commonly used in modern drives.
- A half-bridge is able to drive a DC motor in two quadrants, but without ability to reverse rotation.
- A full-bridge (H-bridge) is able to drive DC motor in four quadrants.
- H-bridge can be modulated in either bipolar or unipolar modes.



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