Driver Magnetorquer

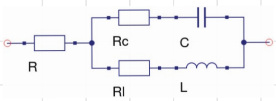
Como Funciona?

3 axis control system
3 magnetorquers x, y, z

Sensor :

H bridge and filtering components

Similar to inductors → Higher Resistance
// Parasitic Capacitance (more turns?)
Possible Lower Inductance



↑V → ↑I → ↑μ (Am^2)
↳ Controlled by its resistance

Resistance determines the voltage
Voltage Controls the current on the magnetorquer

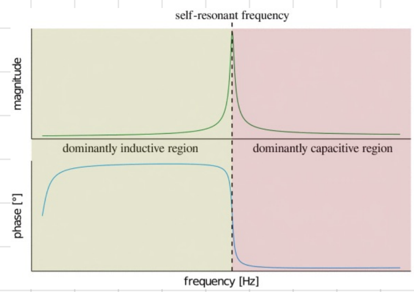
Resistance → Varies with size and temperature

$$\text{time constant} = \frac{\text{inductance}}{\text{resistance}} = \frac{\Phi(i)}{i} : R = \frac{\Phi(i)}{R \cdot i}$$

inductance → $\frac{V \cdot s}{A}$
Φ → magnetic flux
time constant → smaller is better

Ondulação Residual (Ripple)

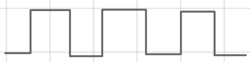
↳ depends on the circuit → ripple voltage < impedance, frequency



Digital Controll Stage

- receive commands
- Store parameters
- responds w/ housekeeping data

→ Output signal value calculated ← output mode + time since reception
↓
transformed into a PWM signal



\+ Direction Selection output → Power conversion Stage

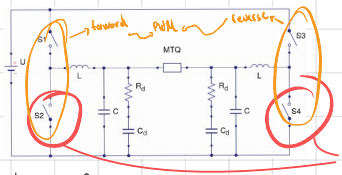
More formulas
Calculations
& strategies
for the control itself

Power conversion Stage

μ depends linearly on the I passing

- Current Control
  - Operational Amplifiers with negative feedback loop → output stability + dissipation of excess energy
  - Switched power converters } highly efficient → use energy storage capabilities of inductors → magnetorquers!! (if sufficient inductance) ↓ Convert pulsed voltage source with controllable duty cycles to continuous current flow

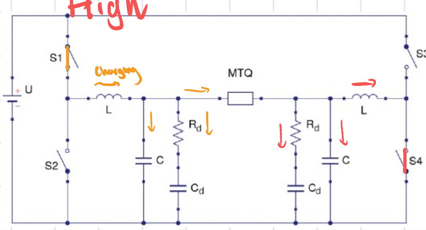
FORESAIL → Switching pwr converter + buck converter
↓
Full H-bridge
↳ 4 N channeled Mosfets → operated by digital control stage ≈ synchronous continuous-mode buck converter operation



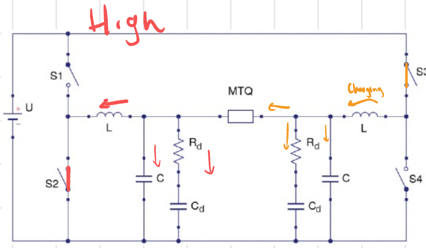
two RLC circuits
↳ third-order low pass filters on output terminals

3 power converters → symmetrical

Forward High



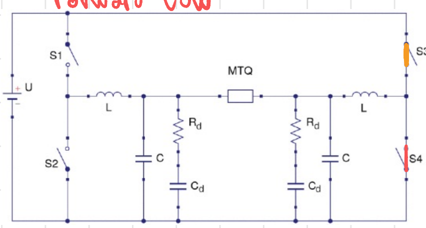
Reverse High



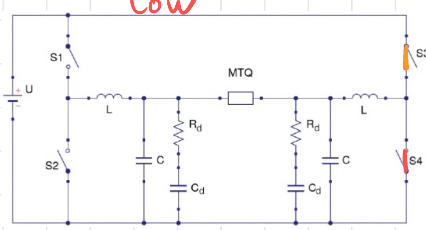
Mode	PWM	S1	S2	S3	S4
Forward	HIGH	ON	OFF	OFF	ON
	LOW	OFF	OFF	ON	ON
Reverse	HIGH	OFF	ON	ON	OFF
	LOW	OFF	OFF	ON	ON

12,6 e 7,5V

Forward Low



Reverse Low



Simulate on LT Spice

However, it is also possible to leave the lower MOSFET of the driving side switched off if they incorporate the body diode.

Not efficient enough for lower power consumption → use pwm from the digital control stage

Lt Spice Simulation

Mosfet → Voltage Controlled Switch

Depletion : NC → only "N" type

Enhancement : NO → "P" or "N" type
↓ PMOS ↓ NMOS

Research past Drivers
Try - Copy & pasting

TABLE IV Magnetorquers' Model Values

coils	long	short
R [Ω]	0.0	41.61
R_c [Ω]	106.51	689.56
C [pF]	115.34	68
R_l [Ω]	33.92	0.0
L [mH]	5.56	28.8
f_0 [kHz]	198.74	113.73
t_c [μs]	164.01	692.14
Effective area [m^2]	2.145	2.045
Resistance @0 °C [Ω]	28.45	36.2
Resistance @20 °C [Ω]	30.7	39.08
Resistance @80 °C [Ω]	37.5	47.72
Power @20 °C, 0.15 A m^2 [mW]	149.64	208.75
Power @20 °C, 3.6 V [mW]	423.26	334.08
Dipole moment @20 °C, 3.6 V [A m^2]	0.304	0.188

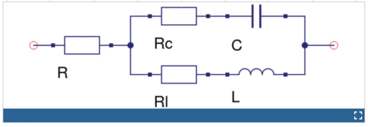
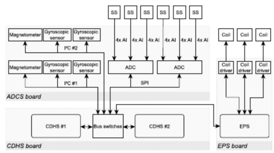


Fig. 2.
Equivalent circuit model for magnetorquer.

https://www.researchgate.net/publication/262822004_Attitude_determination_and_control_for_centrifugal_tether_deployment_on_the_ESTCube-1_nanosatellite

"Coil Driver" → Alegro A3901 motor driver
→ Maxim MAX 319CSA Analog Switch → Clock 32kHz
Linear Technology LT6105 current Sensor



http://www.raumfahrt.fh-aachen.de/compass-1/download/Development%20of%20an%20Active%20Magnetic%20Attitude%20Determination%20and%20Control%20System%20for%20Picosatellites%20on%20highly%20inclined%20circular%20Low%20Earth%20Orbits.pdf

"Coil Driver" →

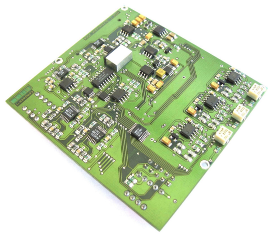


Figure 4.19: Bottom view of the ADCS flight spare model main board with complete component mount. The circuitry on the left is the analog section of the three-axis magnetometer; the three circuits on the right are the coil current drivers.

ORESAT - ACS - board repo (github)

Controller_rev5.0_flat ~> Main?

Processor → STM32G473V

Blocks? →

1st → ???
- 2nd → Magnetorquer → File: reactionwheel.kicad_sch
- 3rd → LEDs → File: LEDs.kicad_sch
- ~~4th → Reaction Wheel → BLDC.kicad_sch~~ → USELESS for now
- 5th → LED RGB + resistors → Commutation Sequence motor driver
- 6th → ADDR Conector Pin Header
- ~~7th → Encoder → File: encoder.kicad_sch~~
- 8th → Debug_Sig Conector Pin Header
- 9th → Prog Conector Pin Header
- 10th → UART Conector Pin Header
- 11th → Mezanine Plug ~ Mzz Breakout ~ Resistor Array ~ TCAN330
- 12th → Samtec - TFM-120-x1-xx8-D-RA
- 13th → crystal 16MHz
- 14th → Power → File: power.kicad_sch

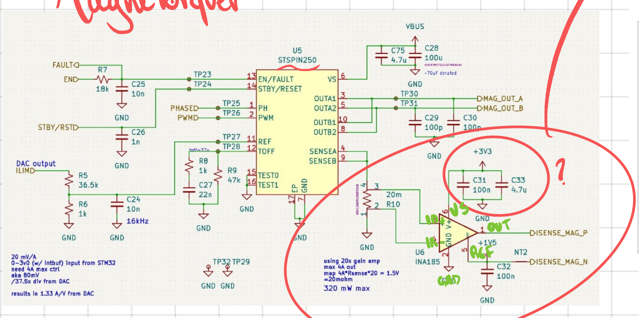
Magnetorquer Block:

Inputs:
- EN (Mag_EN) ~> logic input 5V
- STBY/RST (Mag_STBY) ~> Logic input 5V ~> Low = low consumption mode
- ILIM ~> Analog Input ~> Reference voltage 4 current limiter circuitry
- Phase ~> Logic input ~> phase input
- PWM ~> // ~> Pwm input

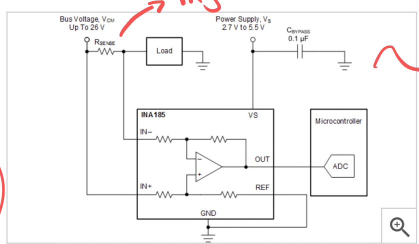
Outputs:
- Fault (Mag_Fault) ~> open drain output
- ISENSE_MAG_P ~> Power output
- ISENSE_MAG_N ~> //
- Mag_out_A (Mag_1) ~> Power bridge output
- Mag_out_B (Mag_2) ~> //

Understanding the circuit:

Magnetorquer:



→ Current Shunt monitor high-side



→ Difference Amplifier

STSPIN250:

Single low voltage DC motor driver integrating a Rds(on) power stage in a 3x3 mm package ?

Designed to be operated with batteries, thus can be forced into a zero consumption state.
80nA

Protections:

- Over current
- Overtemperature
- Short Circuit

What is $R_{DS(on)}$?

Resistance → Drain-Source ON

- It's the total resistance between the drain and source in a Metal Oxide field Effect transistor, or Mosfet.
  Basis for a maximum current rating
  See more in microcontrollertips.com/mosfets-what-is-rdson-faq/

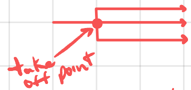
STSPIN250 Block Diagram → Rabit Hole

- Representation of a control system
- Used to calculate the transfer function of the system
  block

What's a transfer function?
Math function that models the system output based on the input

- Summing point ⇝ add two or more signals

- Take off Point / Pick-off Point / Branch point ⇝ Distributes signals



Reduction of Multiple Subsystems (controller systems are complex in nature)

- Get the overall transfer function
- Reduce Complexity = Reduce blocks

Block Diagram Algebra → Bound by Block Diagram Reduction Rules

PWM current control
The device implements a current controller.
The voltage on the sense pins (VSENSE) is compared to the reference voltage applied on the REF pin (VREF).
When VSENSE > VREF, the current limiter is triggered, the OFF time counter is started, and the decay sequence is performed.
The decay sequence starts turning on all the low sides of the full-bridge. After the programmed OFF time the system returns to the ON state.

Current Shunt Monitor

+ Easy and cheap ⇝ no more than just an op-amp
+ Precise
- Add Resistance in gnd
- May require additional wire to the load that could be omitted

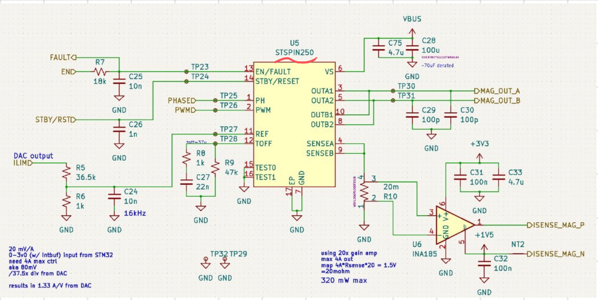
High Side Current Sensing

- between Supply and Load
- \+ Directly to the Source → detect downstream failure
- \+ No gnd disturbance
- \- Requires careful Resistor Matching to obtain common-mode rejection ratio
- \- Must withstand very high and dynamic common-mode voltages

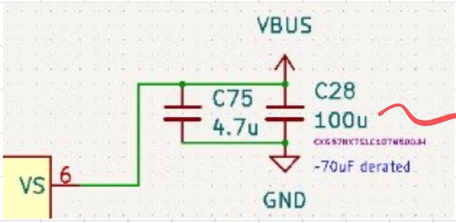
Current Shunt Monitor (family)

- Measure voltage across a Shunt Resistor ⇝ mV range ⇝ need amplification

STSPIN250 pin by pin



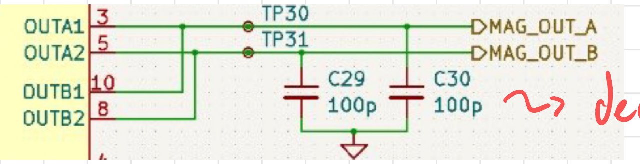
Pin 6 → VS → Voltage Supply



⇝ decoupling capacitors

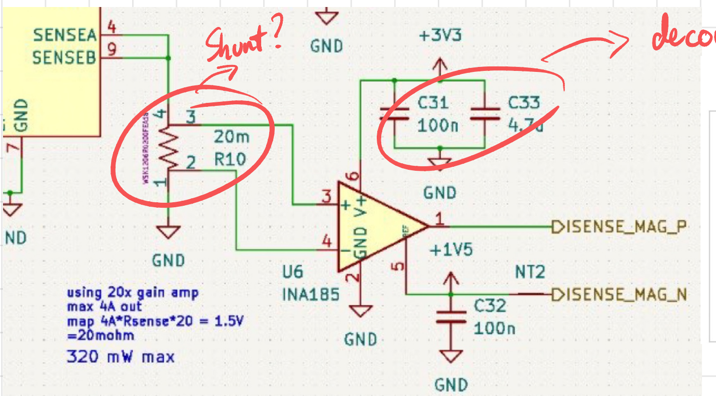
typical values: 2.2µ/16V & 22µ/16V

Pin 3, 5, 8, 10 → Output



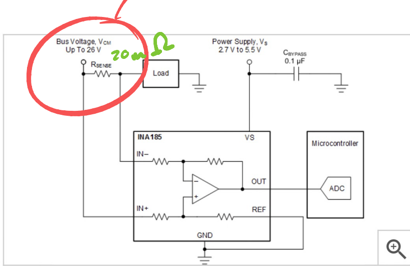
⇝ decoupling } typical application

Pin 4, 9 → Sense Pins



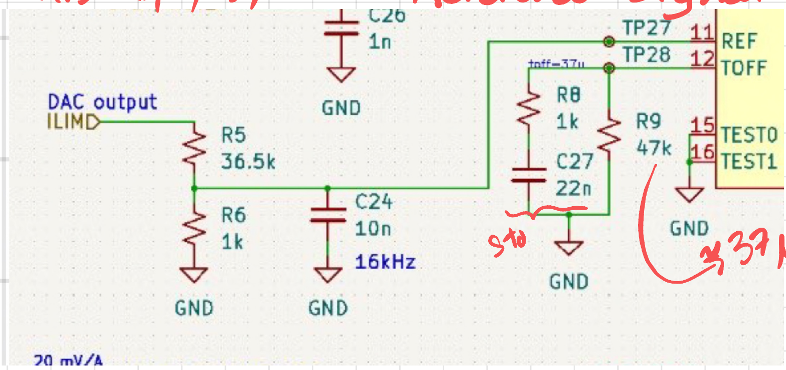
→ decoupling

HS → between supply and load



→ compare to sense voltage

Pins 11, 12, 15, 16 → Reference Signal and Decay time




```
if (Sense Voltage > Reference Voltage){
    Shutdown(){
        LSx1 && LSx2 = High;
    }
}
```