PRPL - Acceleration of discharge repeatability on the tokamak GOLEM

Czech Technical University in Prague

Faculty of Nuclear Sciences and Physical Engineering

Department of Physics

Field of Plasma Physics and Thermonuclear Fusion

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Year: 2024

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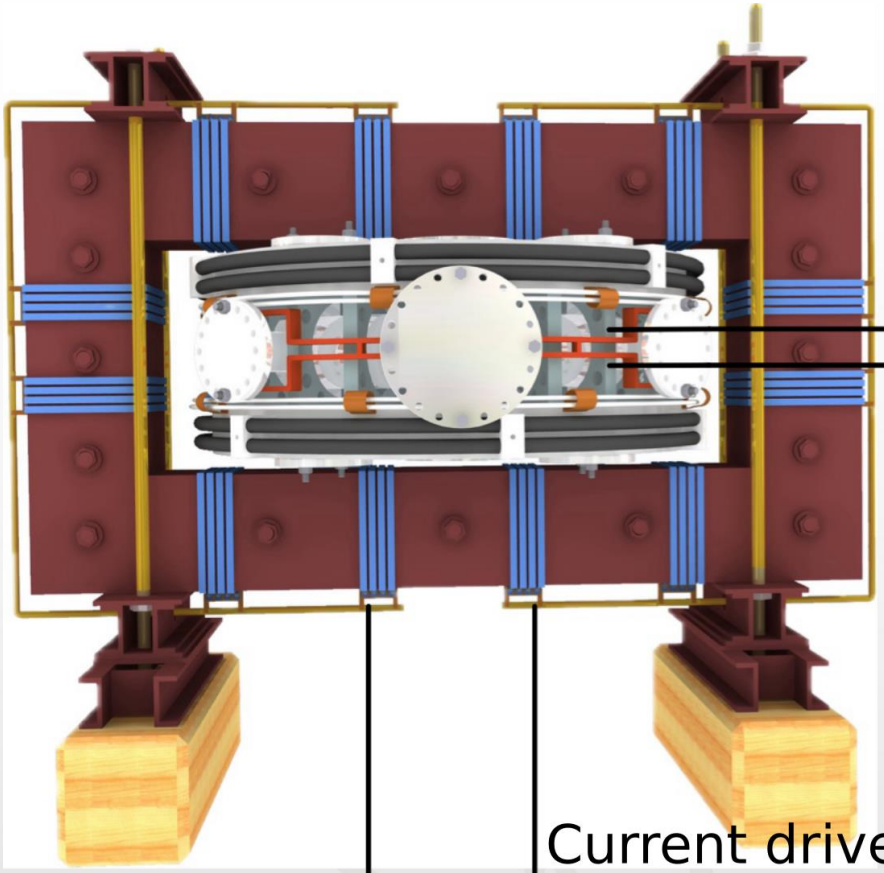
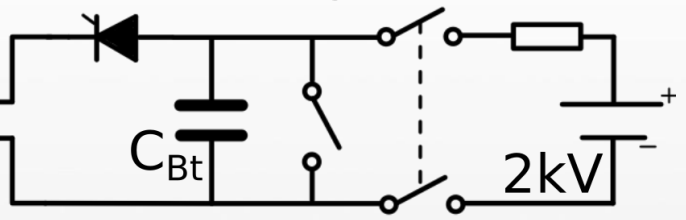
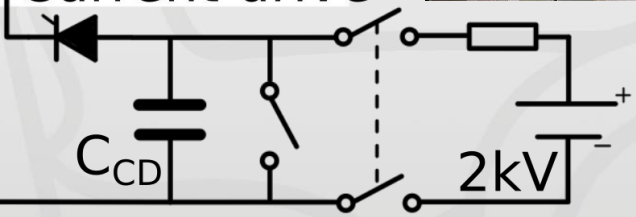
1. Introduction to the current discharge regime



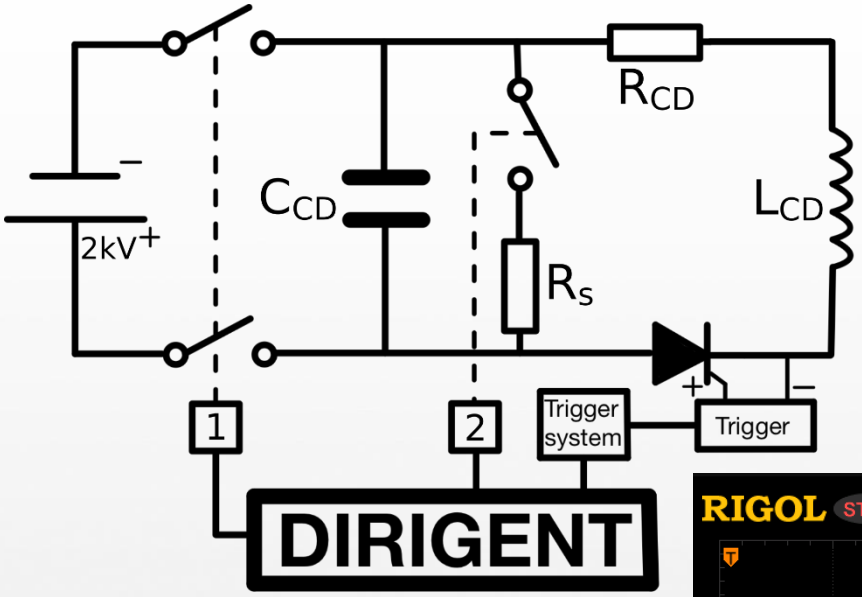
Torodial magnetic field



Current drive



Discharging of the capacitors during the discharge



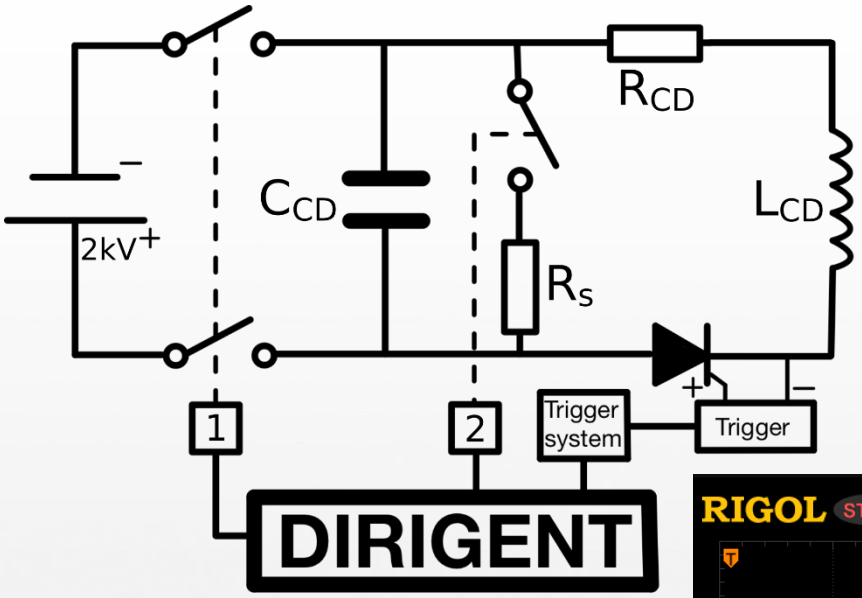
Current drive of the tokamak GOLEM

- **Blue signal** – Current drive
- **Purple signal** – Torodial magnetic field
- **Yellow signal** – 2kV single-pole power source

- Reversal of capacitor polarity

Shot #45100

Discharging of the capacitors during the discharge



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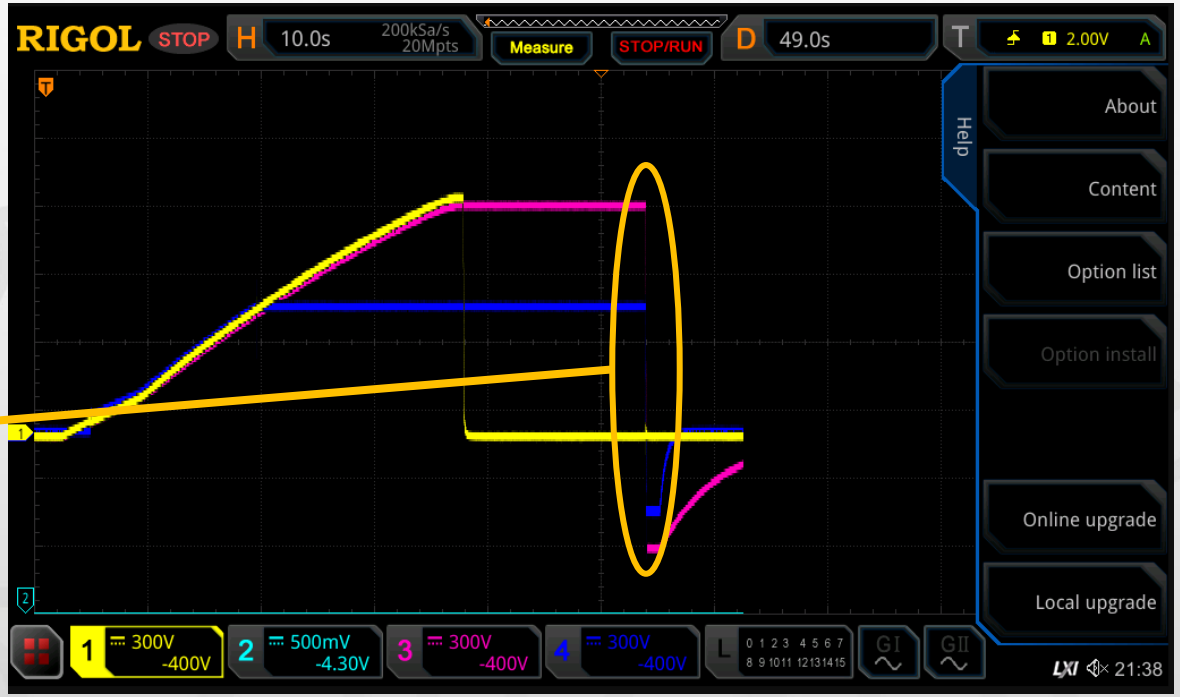
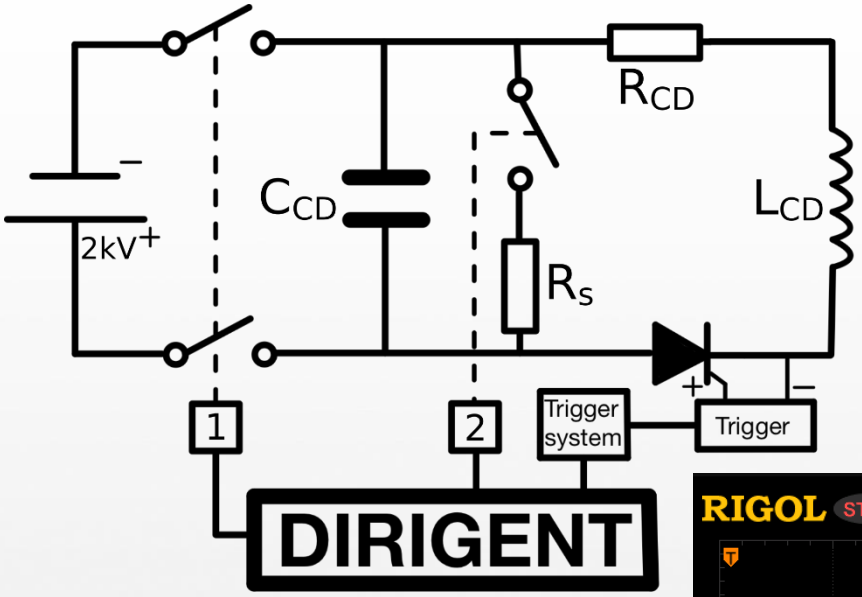
Discharging of capacitors



Discharging of the capacitors during the discharge



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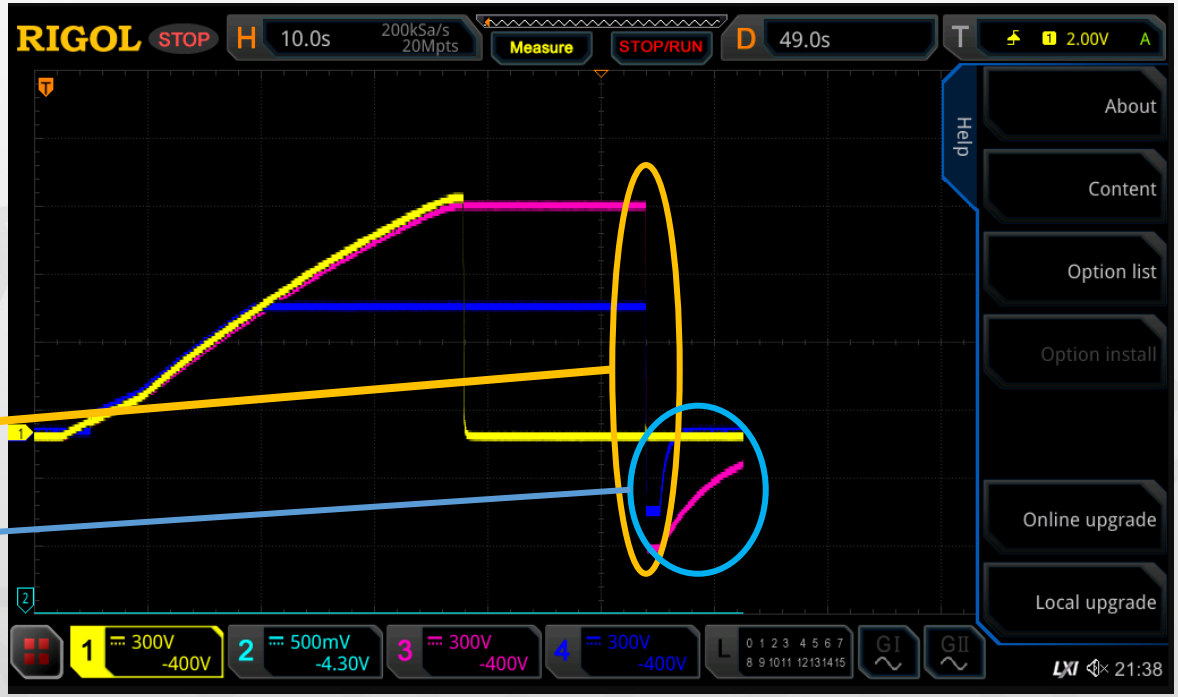
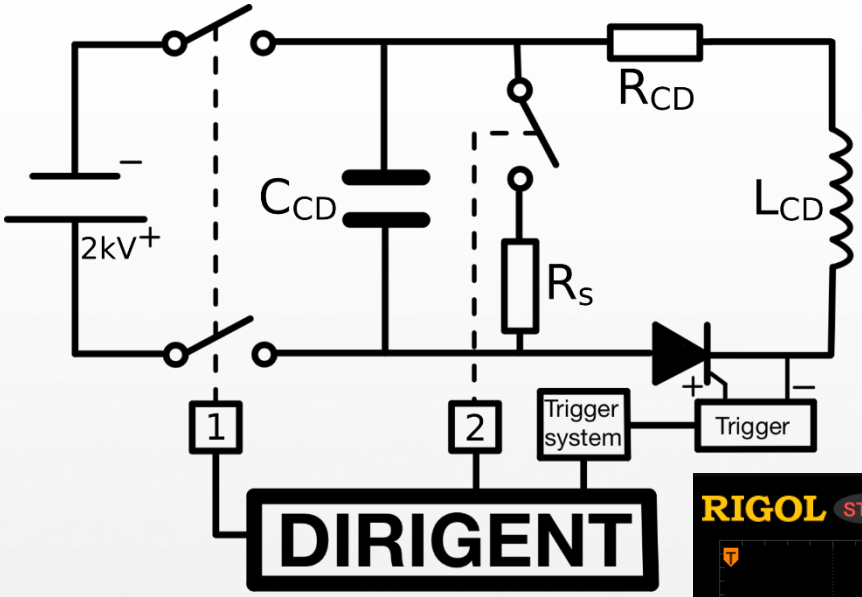


Discharging of capacitors

Short-circuiting of capacitors

Discharging of the capacitors during the discharge



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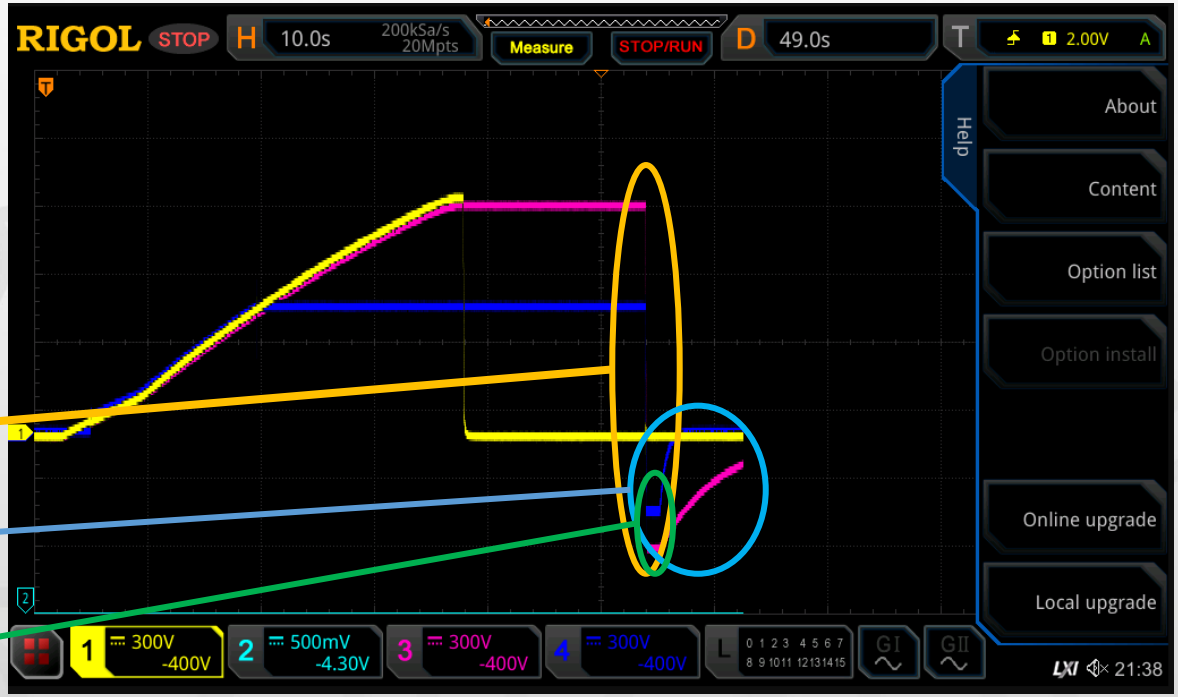


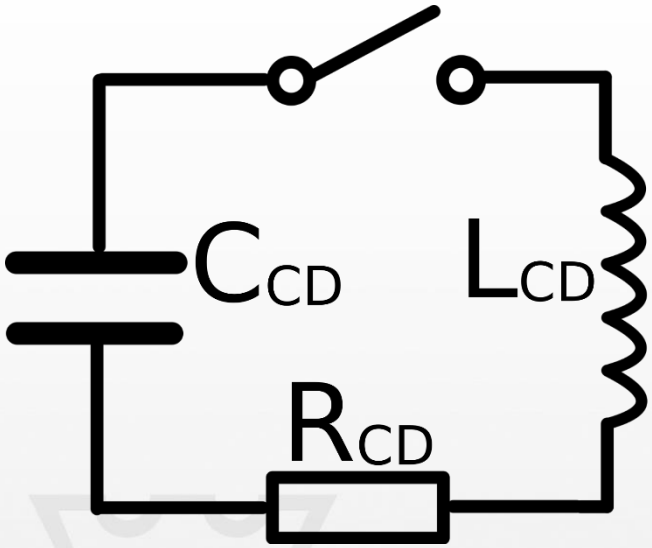
Discharging of capacitors

Short-circuiting of capacitors

Capacitor hold reversed voltage

2. Discharge characteristics of capacitors on the tokamak GOLEM

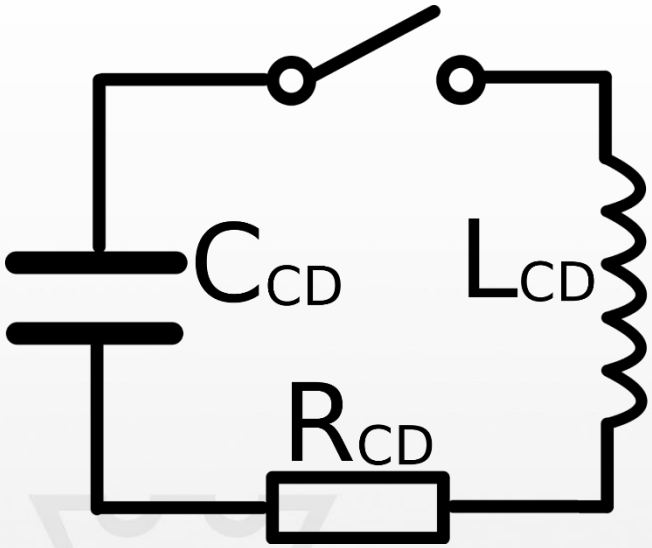
$$U_{total} = U_R + U_L + U_C$$



Approximation by an RLC circuit

$$U_{total} = U_R + U_L + U_C$$

$$R \cdot I(t) + L \cdot \frac{dI(t)}{dt} + \frac{1}{C} \int_0^t I(\tau)\, d\tau + U_C(0) = 0$$



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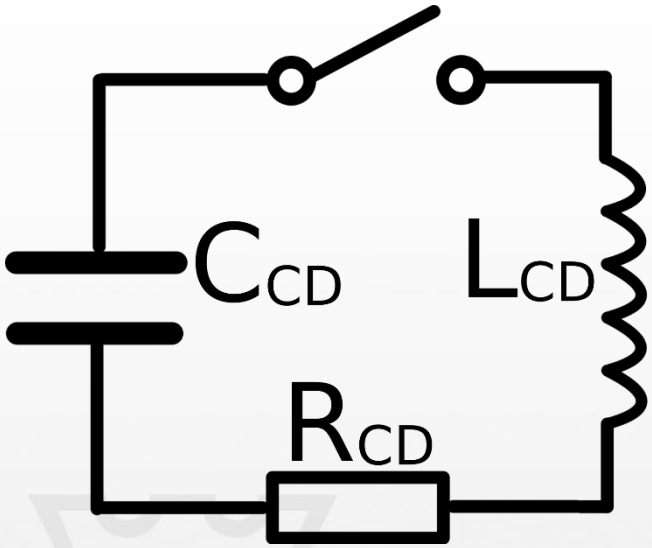
Laplace transform



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Laplace transform

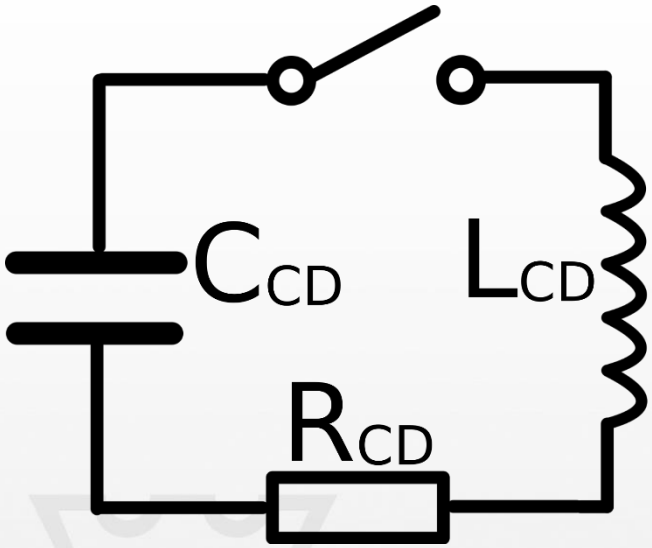
$$U_C(t) = U_C(0) \cdot e^{-\delta t} \cdot \left(\cos \omega t + \frac{\delta}{\omega} \sin \omega t\right)$$

$$I(t) = -U_C(0) C \frac{\omega^2 + \delta^2}{\omega} \cdot e^{-\delta t} \sin \omega t$$

$$\delta = \frac{R}{2L}$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$\omega = \sqrt{\omega_0^2 - \delta^2}$$



Resulting waveforms of the RLC circuit approximation

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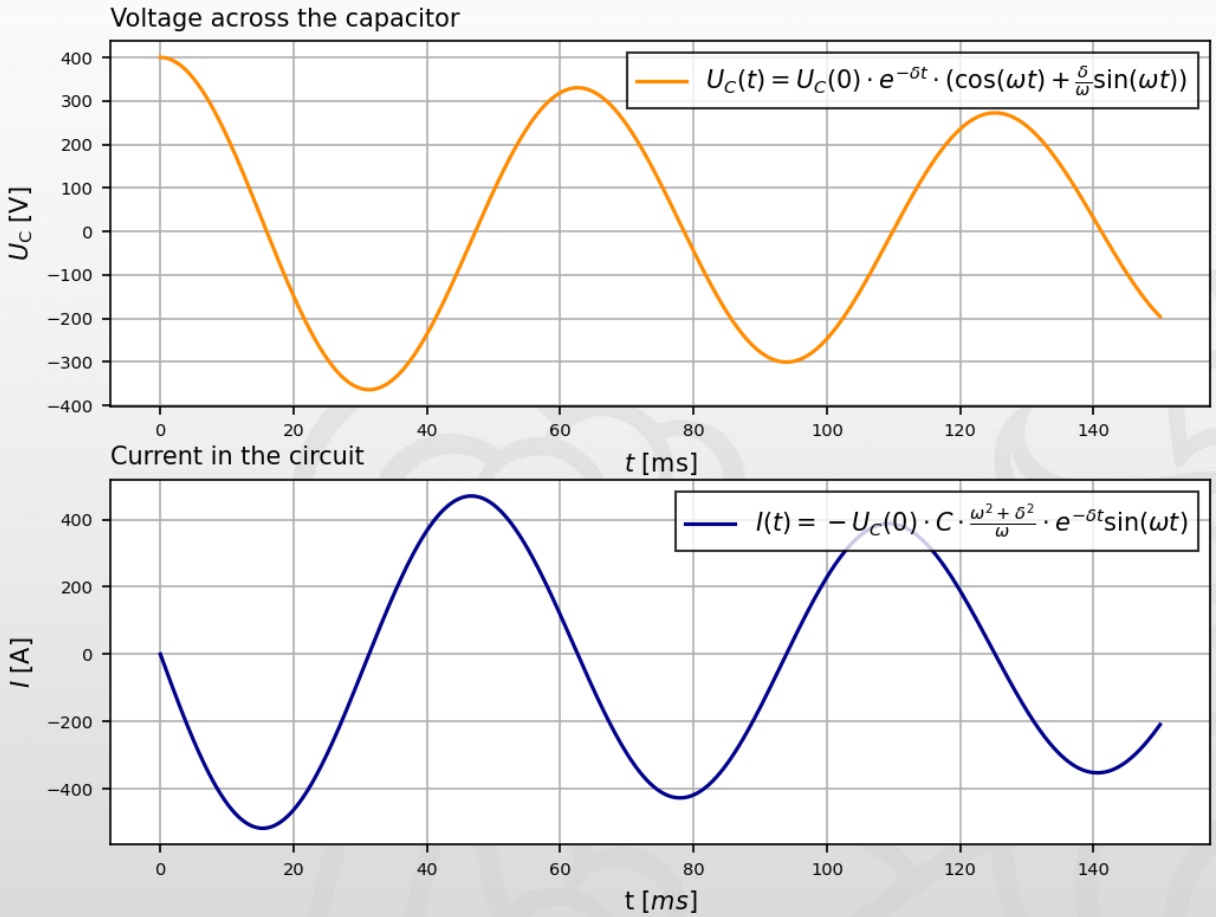
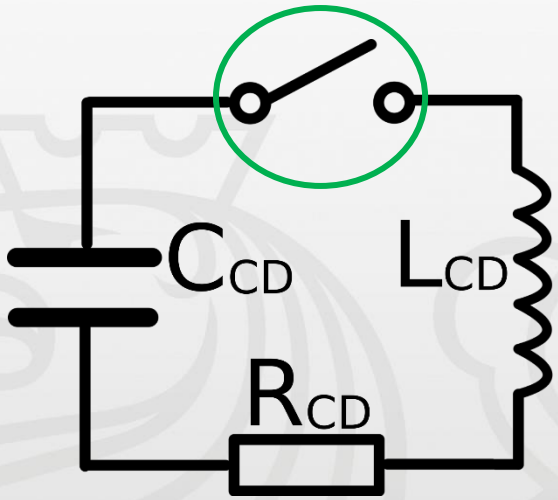


A classic switch, such as a relay



Difference compared to a circuit with a thyristor

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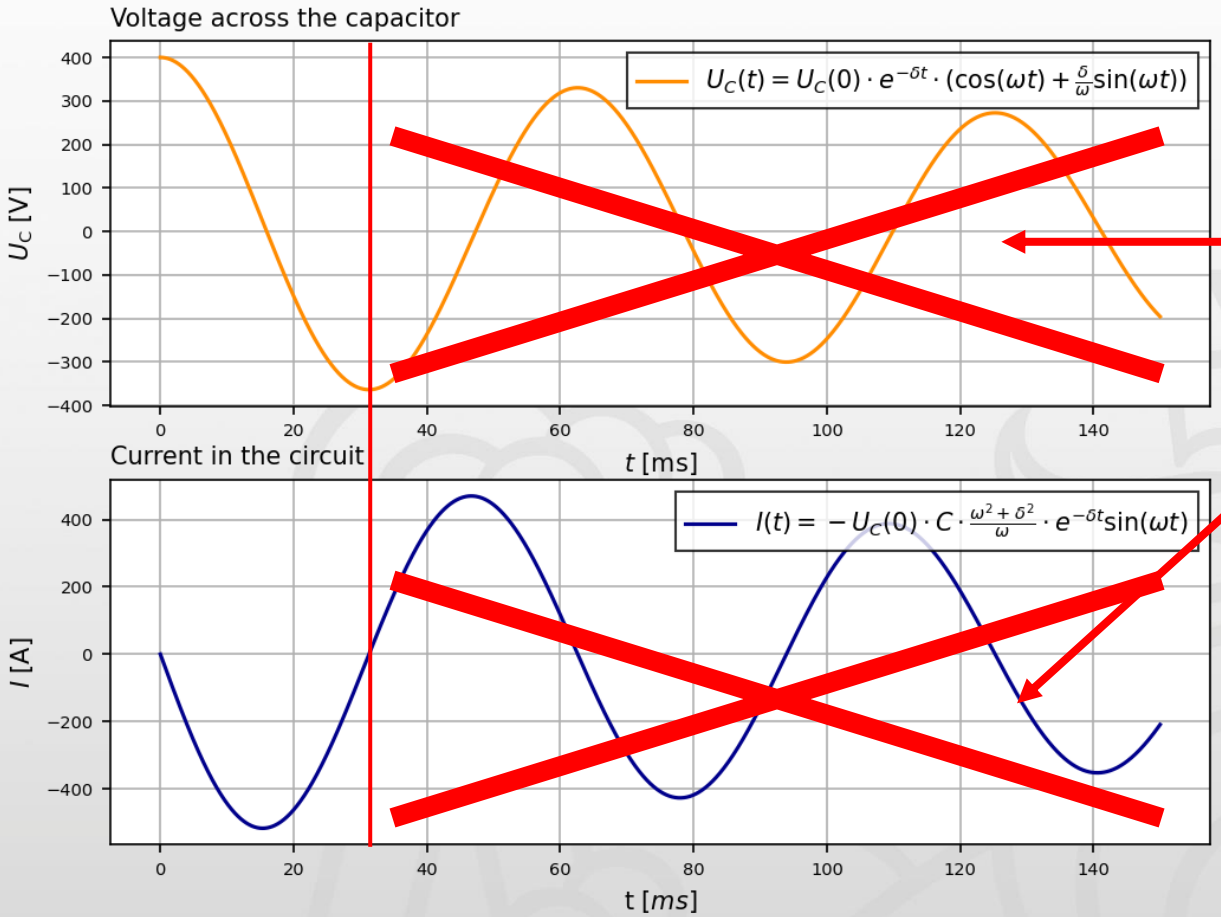
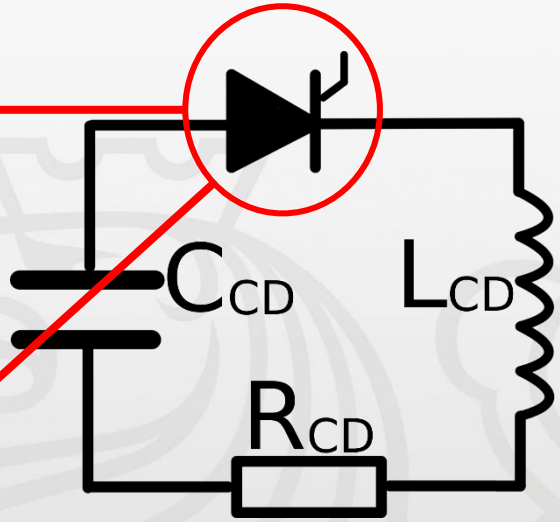


A thyristor does not allow reverse polarity



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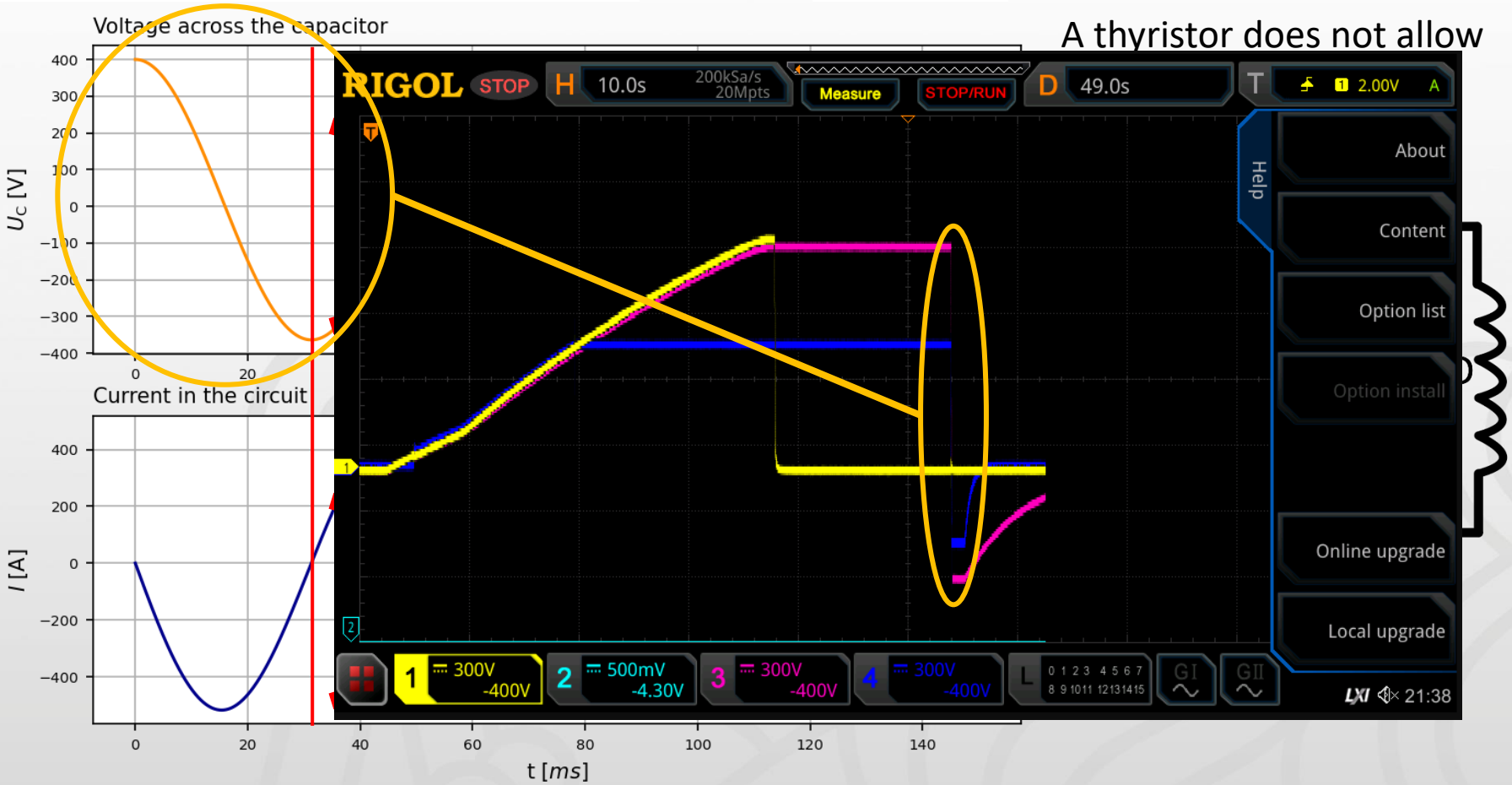
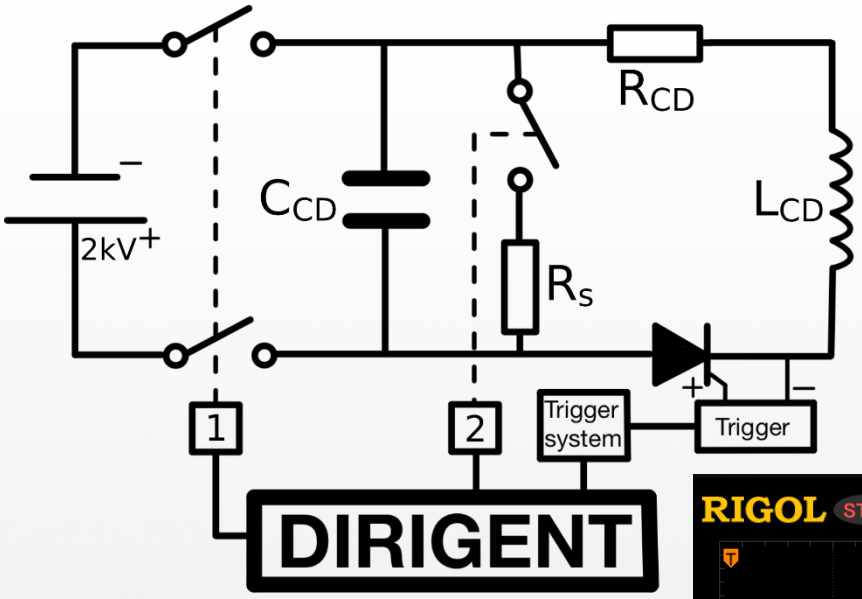


A thyristor does not allow

3. Possible improvement of discharge repeatability

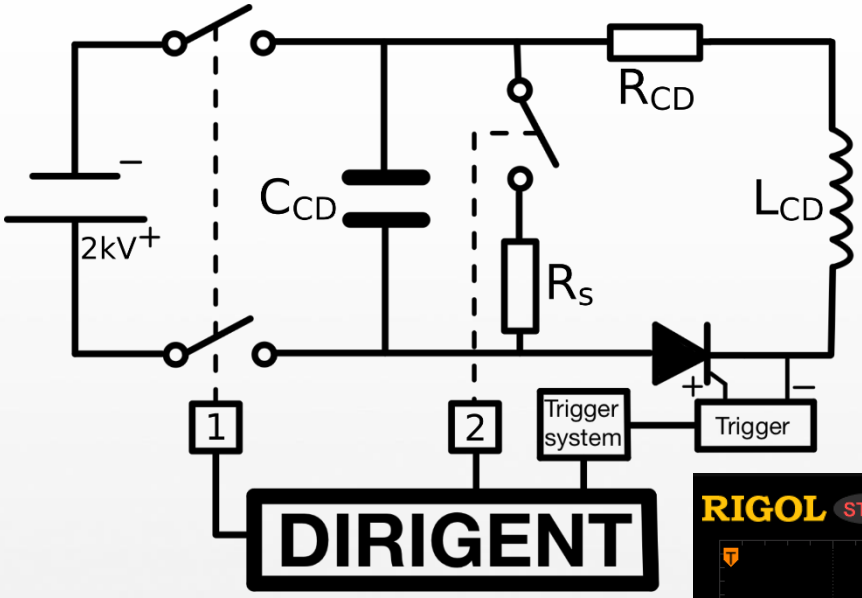


Could the energy in reversed-polarity capacitors be utilized?

Reversed-polarity capacitors

- The capacitors already hold the voltage due to the thyristor used in the circuit.

3. Possible improvement of discharge repeatability



Could the energy in reversed-polarity capacitors be utilized?

Problems that need to be resolved!

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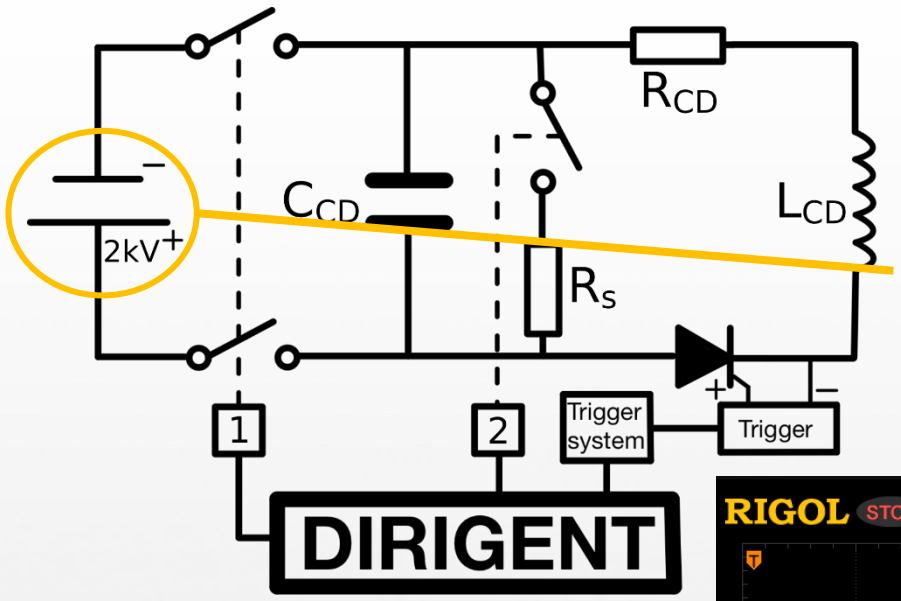

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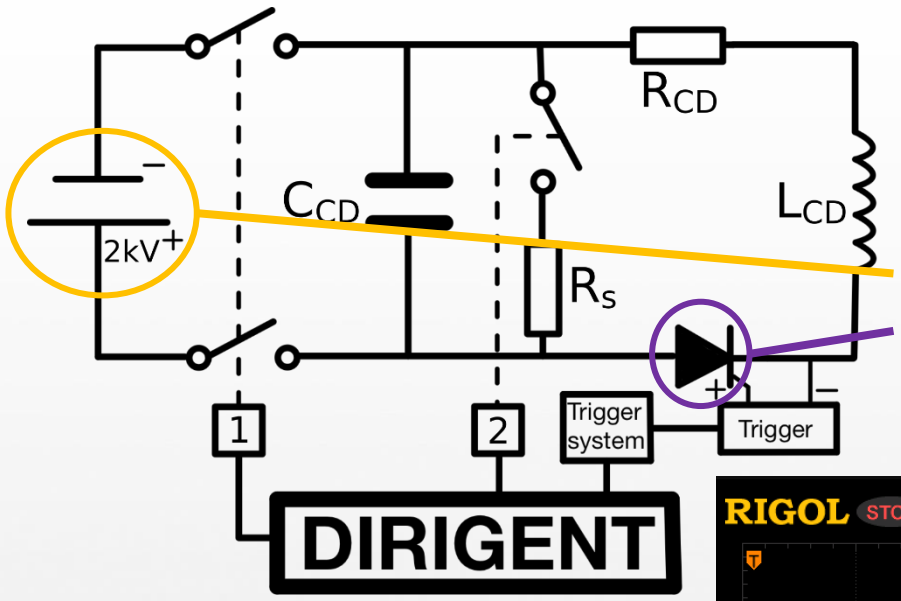
Problems that need to be resolved!

1. **Single-pole power source**

Reversed-polarity capacitors

- The capacitors already hold the voltage due to the thyristor used in the circuit.

3. Possible improvement of discharge repeatability



Could the energy in reversed-polarity capacitors be utilized?

Problems that need to be resolved!

1. **Single-pole power source**
2. **Thyristor orientation**

Reversed-polarity capacitors

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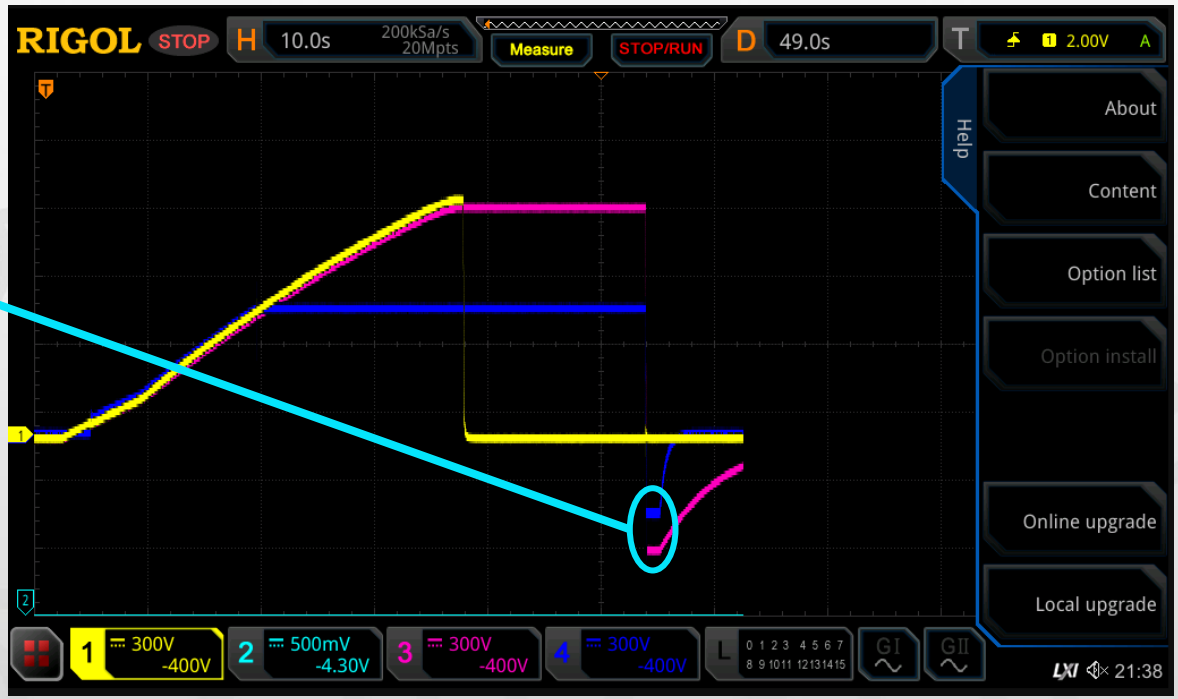

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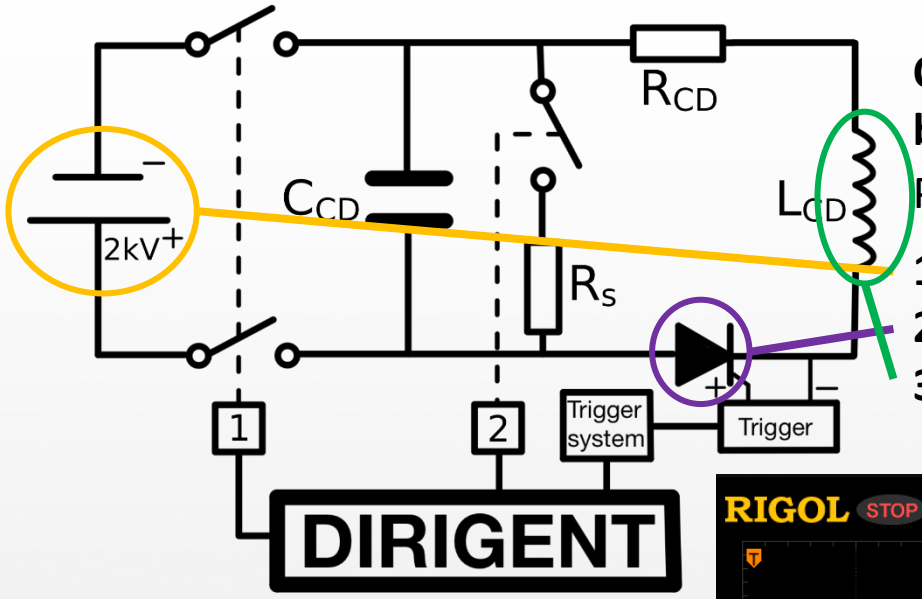


Could the energy in reversed-polarity capacitors be utilized?

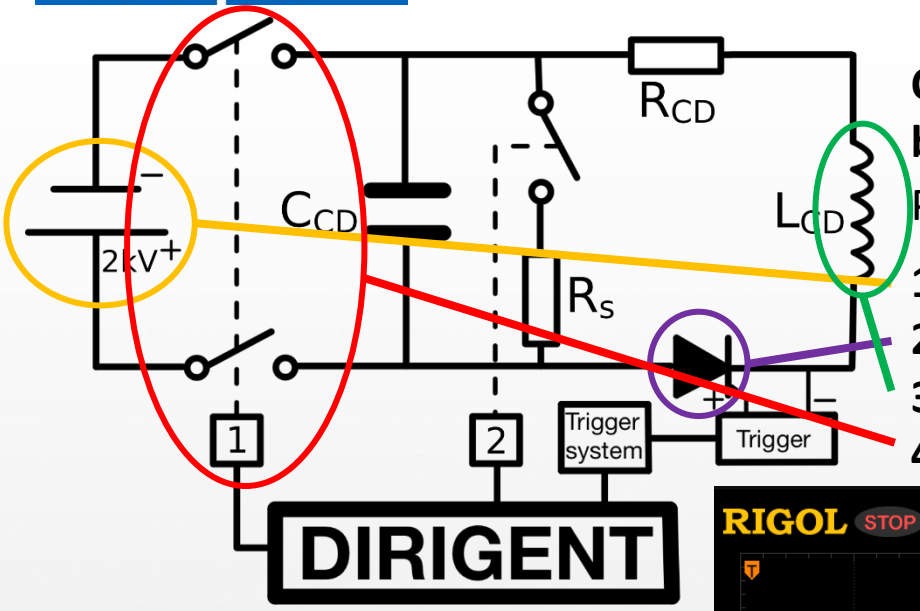
Problems that need to be resolved!

1. **Single-pole power source**
2. **Thyristor orientation**
3. **Discharge orientation into the coil**

Reversed-polarity capacitors

- The capacitors already hold the voltage due to the thyristor used in the circuit.

3. Possible improvement of discharge repeatability



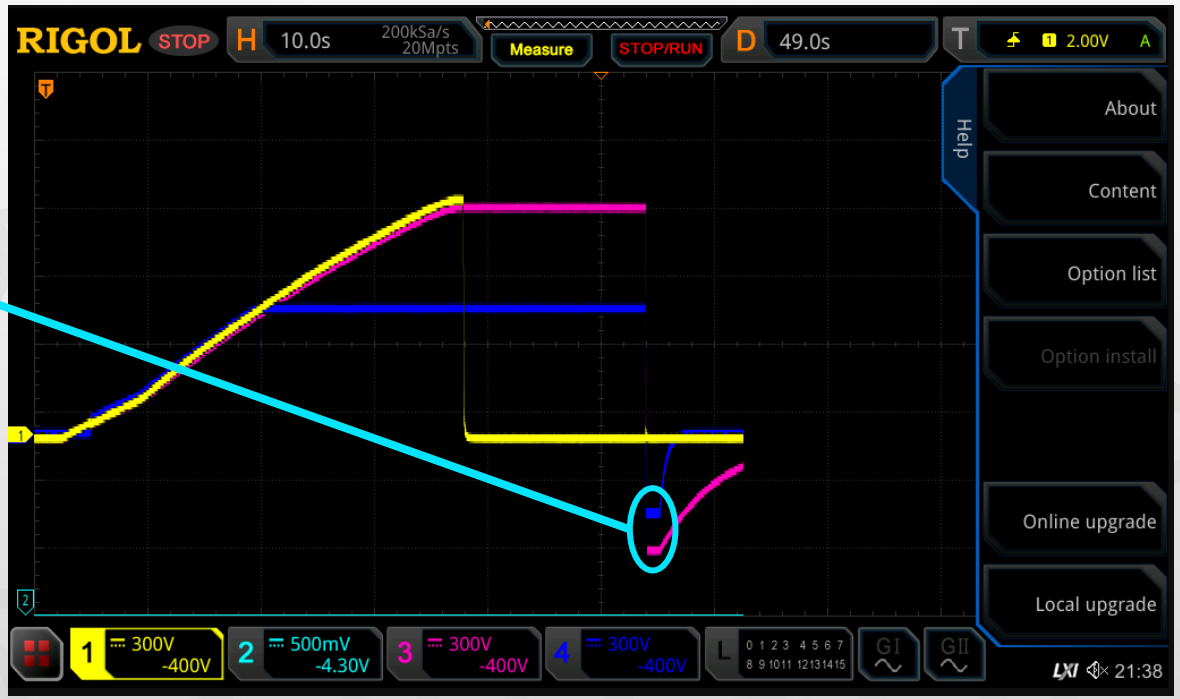
Could the energy in reversed-polarity capacitors be utilized?

Problems that need to be resolved!

1. **Single-pole power source**
2. **Thyristor orientation**
3. **Discharge orientation into the coil**
4. **Charging of the capacitor**

Reversed-polarity capacitors

- The capacitors already hold the voltage due to the thyristor used in the circuit.



The voltage value after reversing the polarity of the capacitor

U_Bt = 1000V, C_Bt = 67,5mF -> U_Bt(reverse) = -500V
U_CD = 500V, C_CD = 13,5mF -> U_CD(reverse) = -300V

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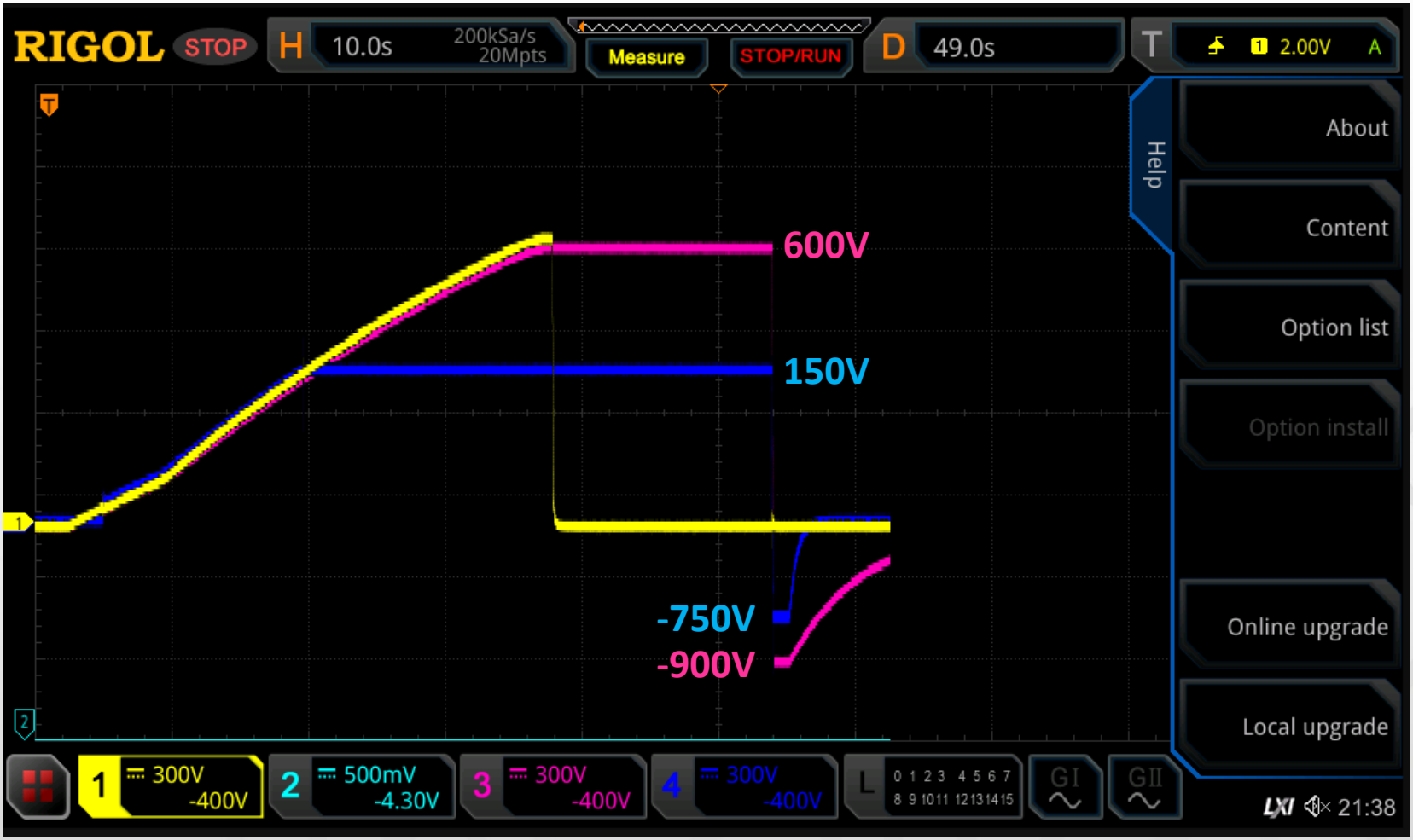
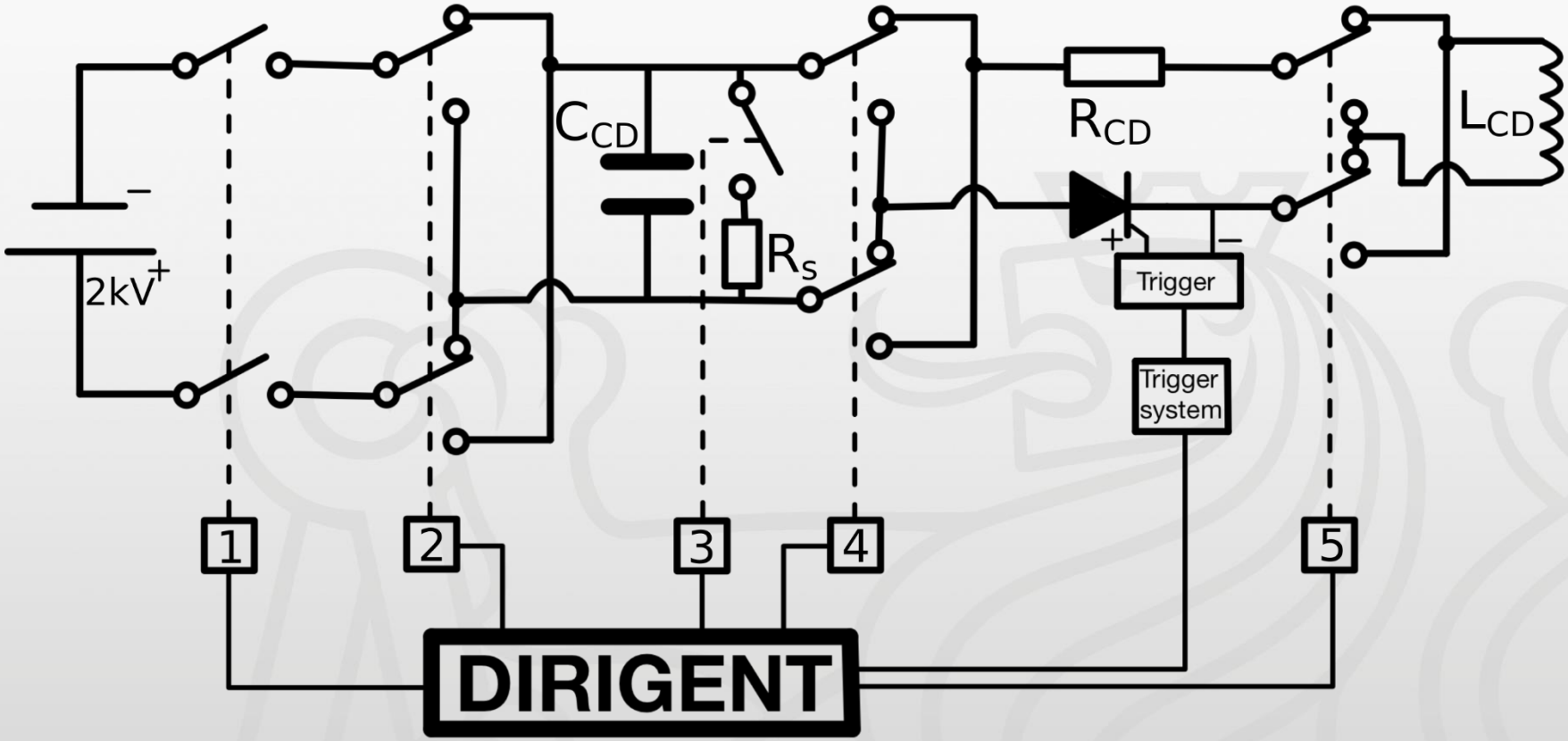


Solutions to problems 1 – 3

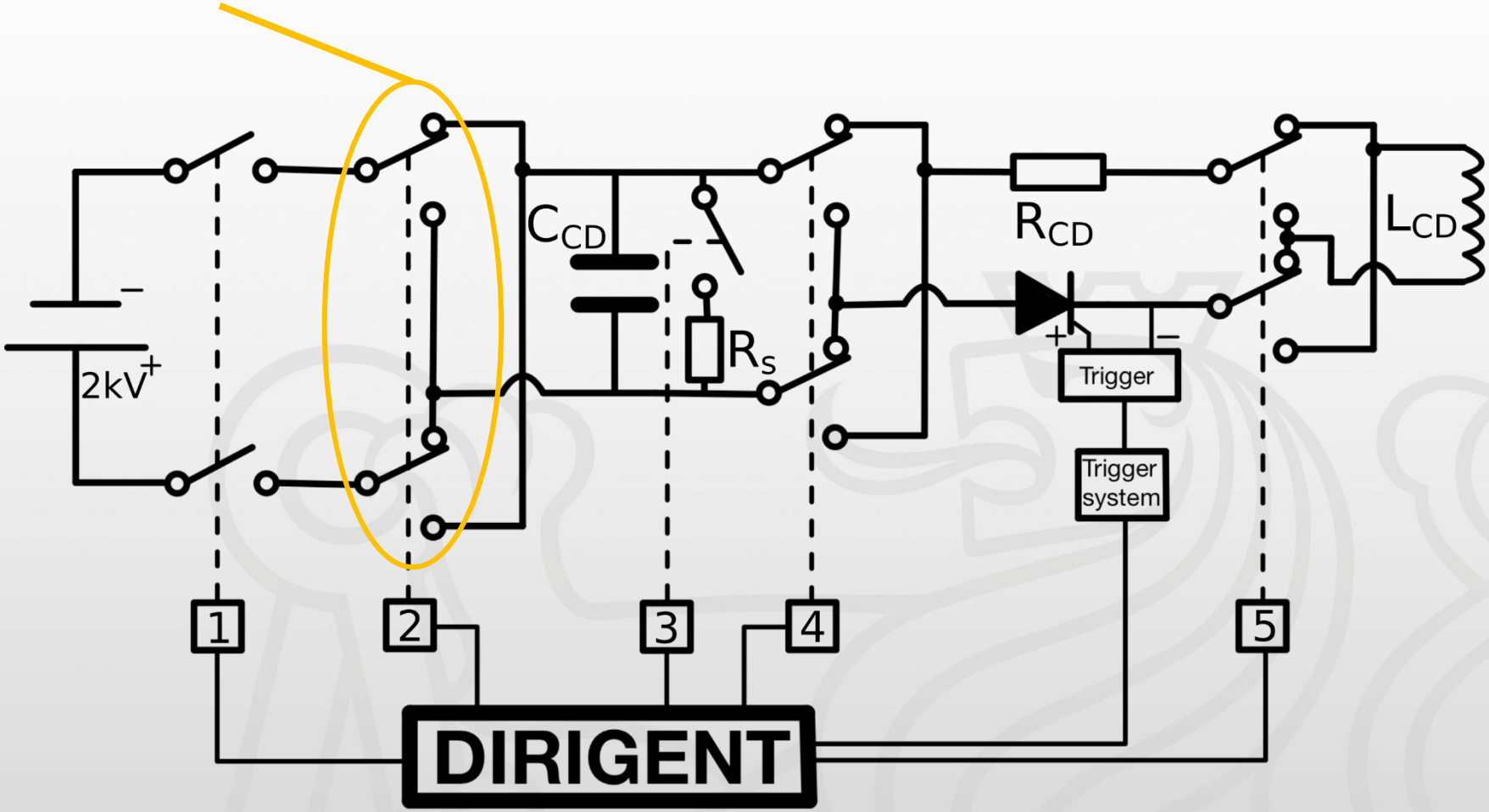
Use of commutators for specific circuit areas



Solutions to problems 1 – 3

Use of commutators for specific circuit areas

1. Solution to the problem with the single-pole power source



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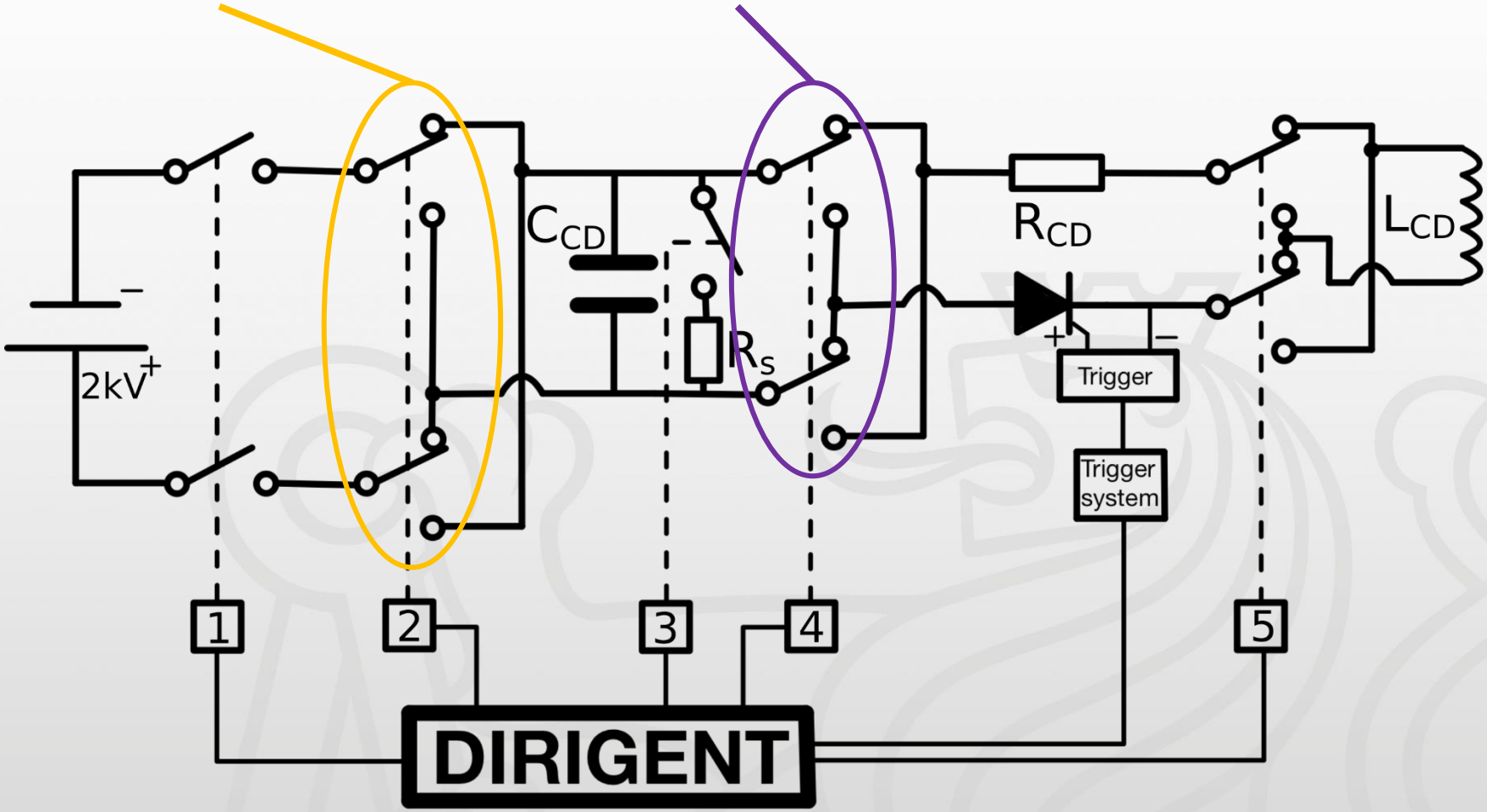
Use of commutators for specific circuit areas

1. Solution to the problem with the single-pole power source

2. Solution to the problem with thyristor orientation



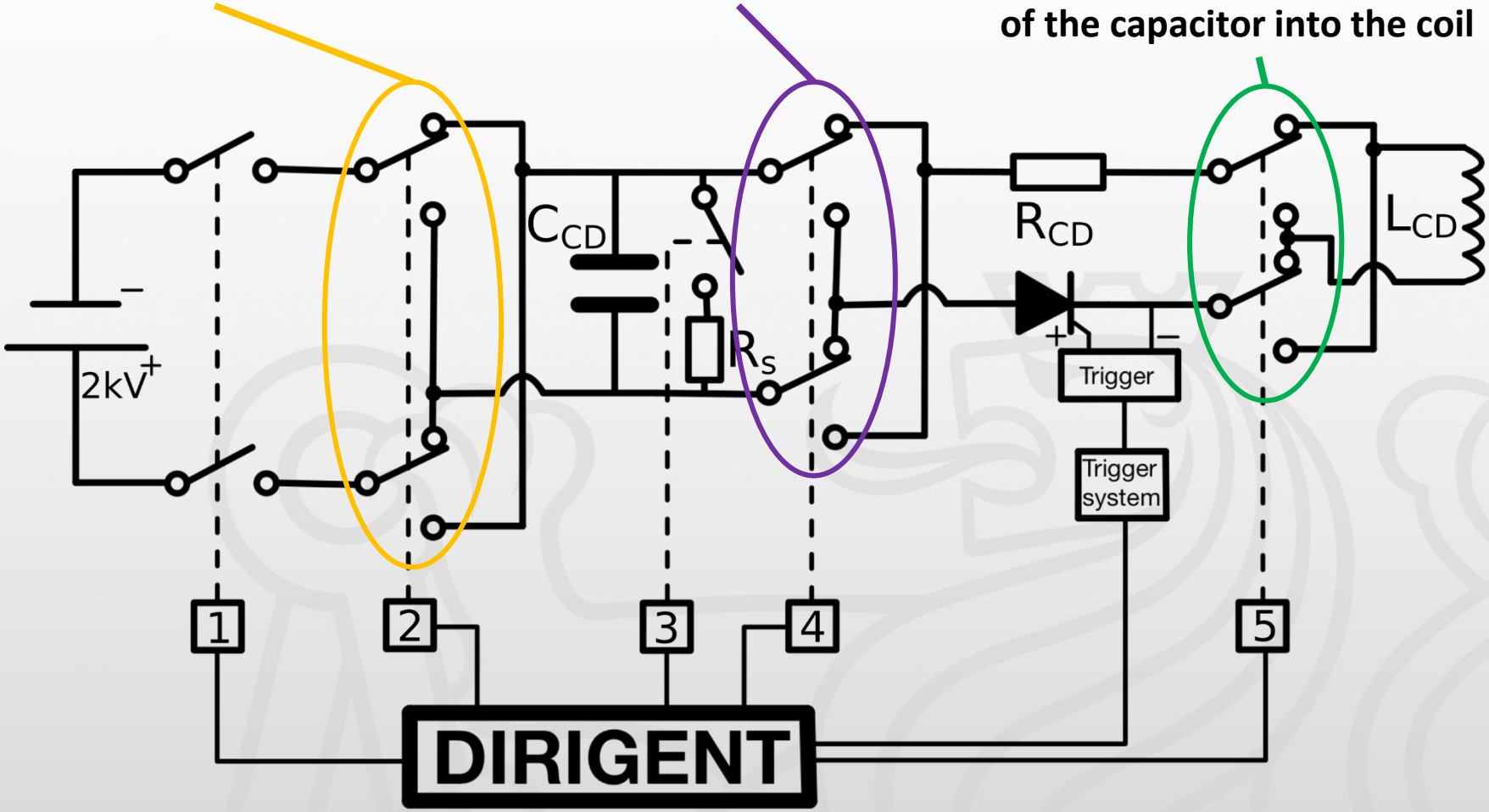
Solutions to problems 1 – 3

Use of commutators for specific circuit areas

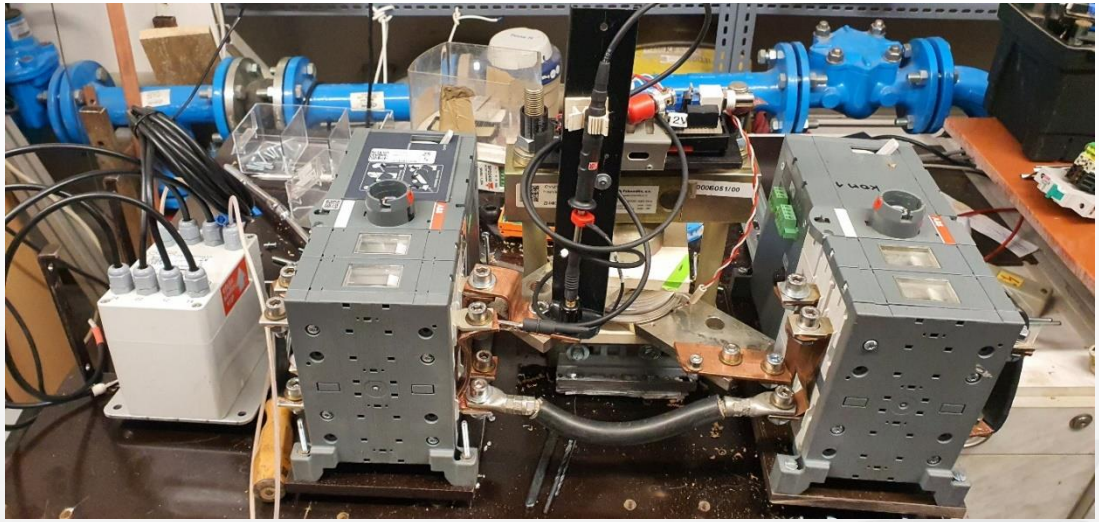
1. Solution to the problem with the single-pole power source

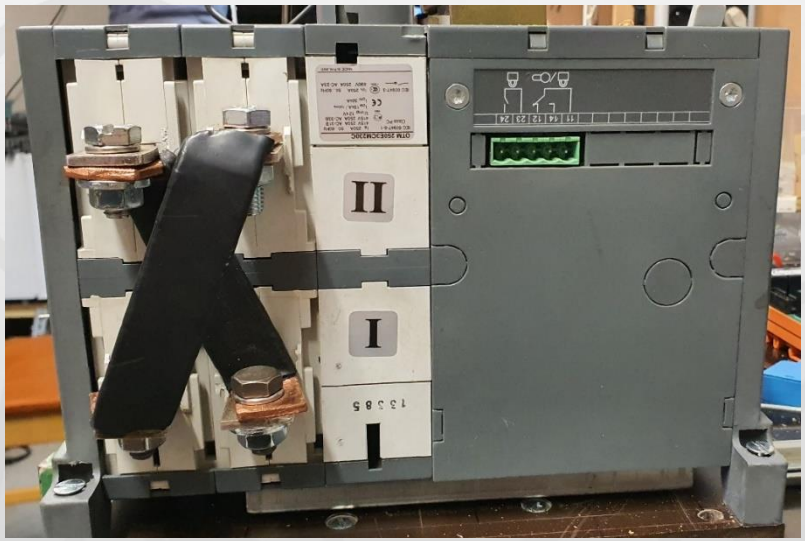
2. Solution to the problem with thyristor orientation

3. Solution to the problem with the discharge orientation of the capacitor into the coil

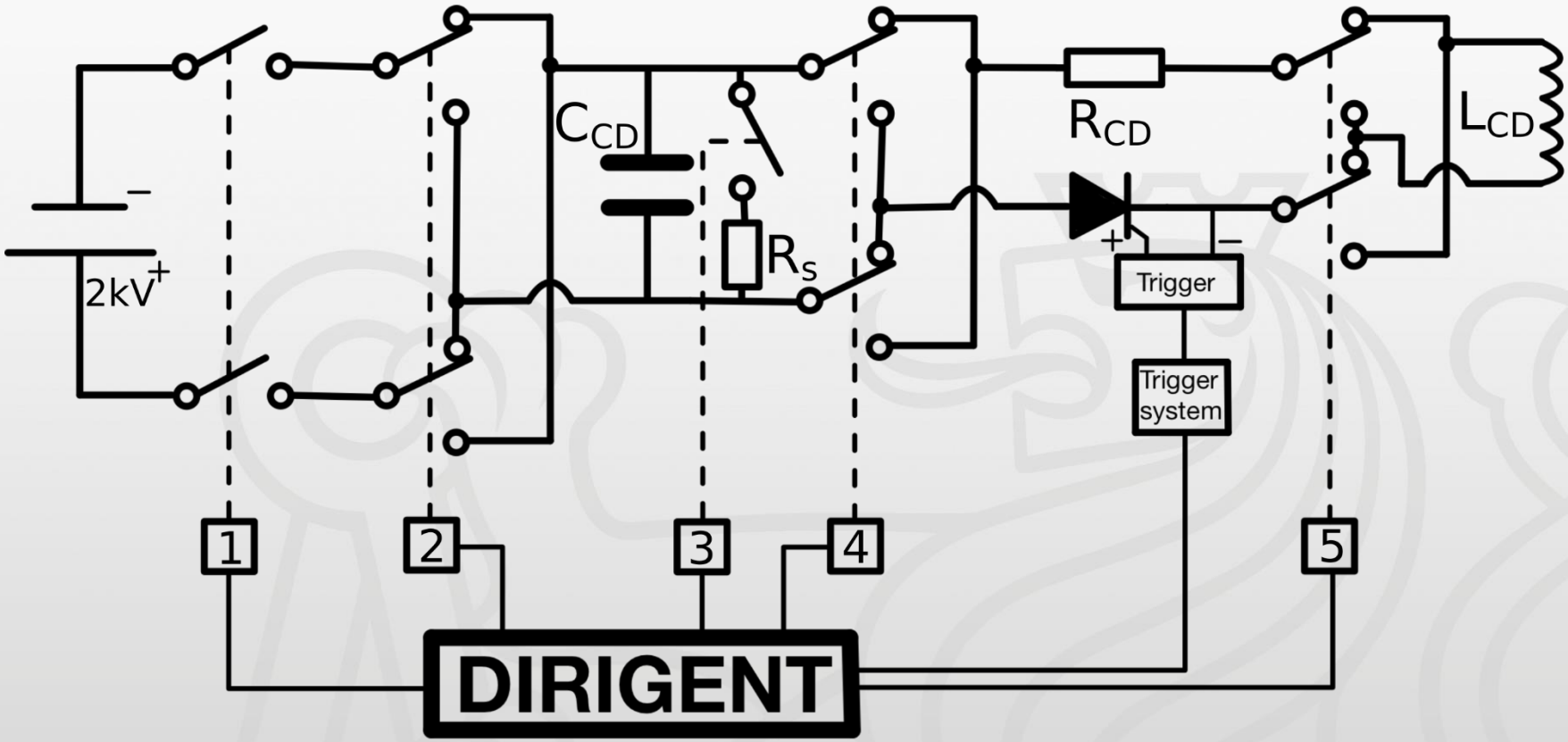


Current implementation of commutators for the given electrical circuit



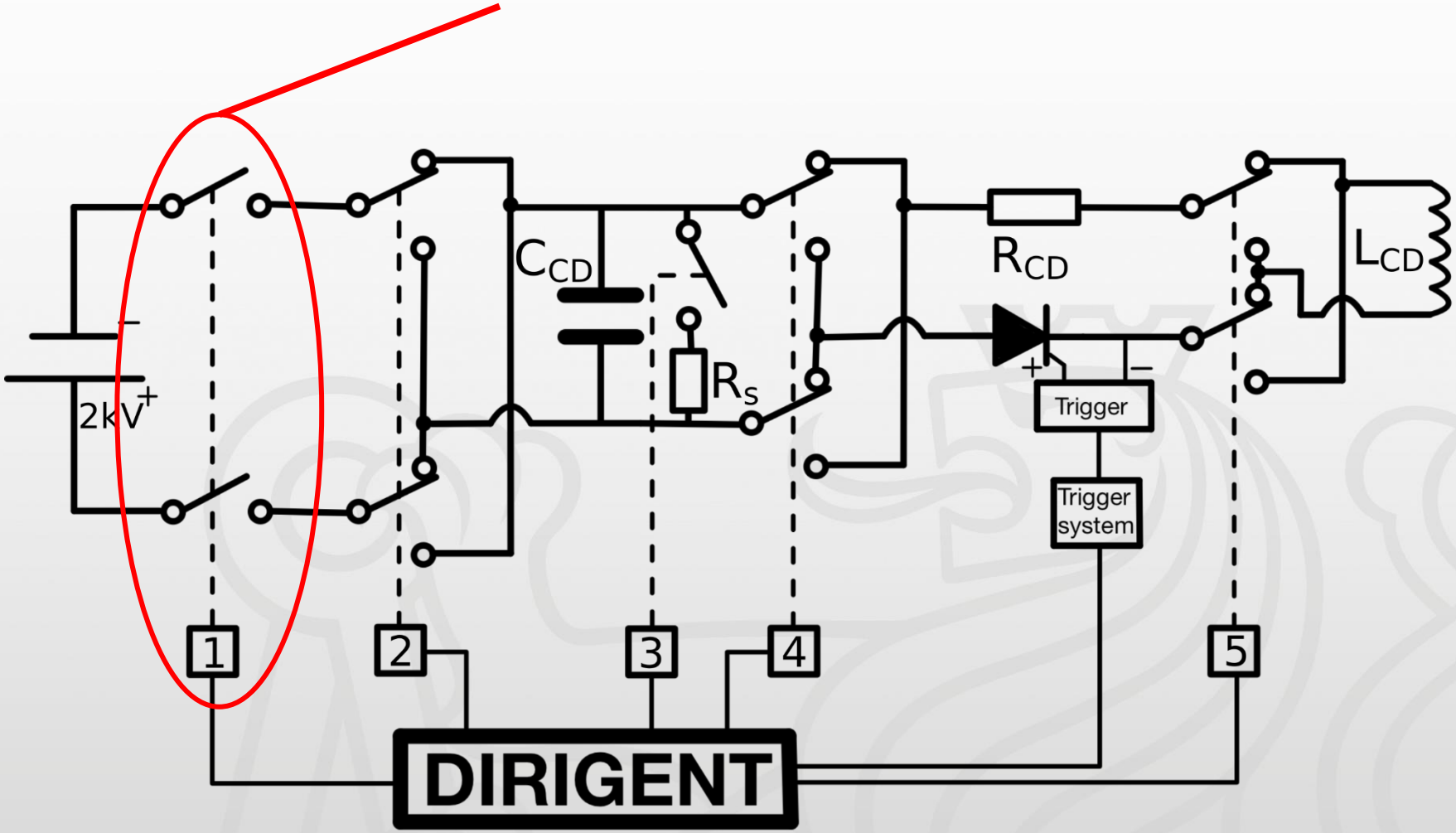


Solution to problem 4



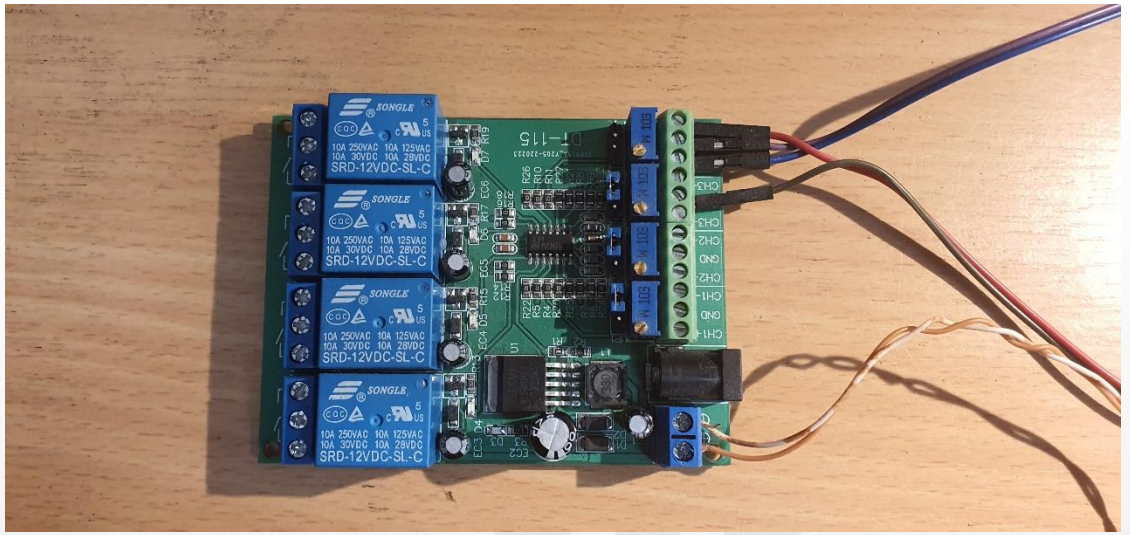
Solution to problem 4

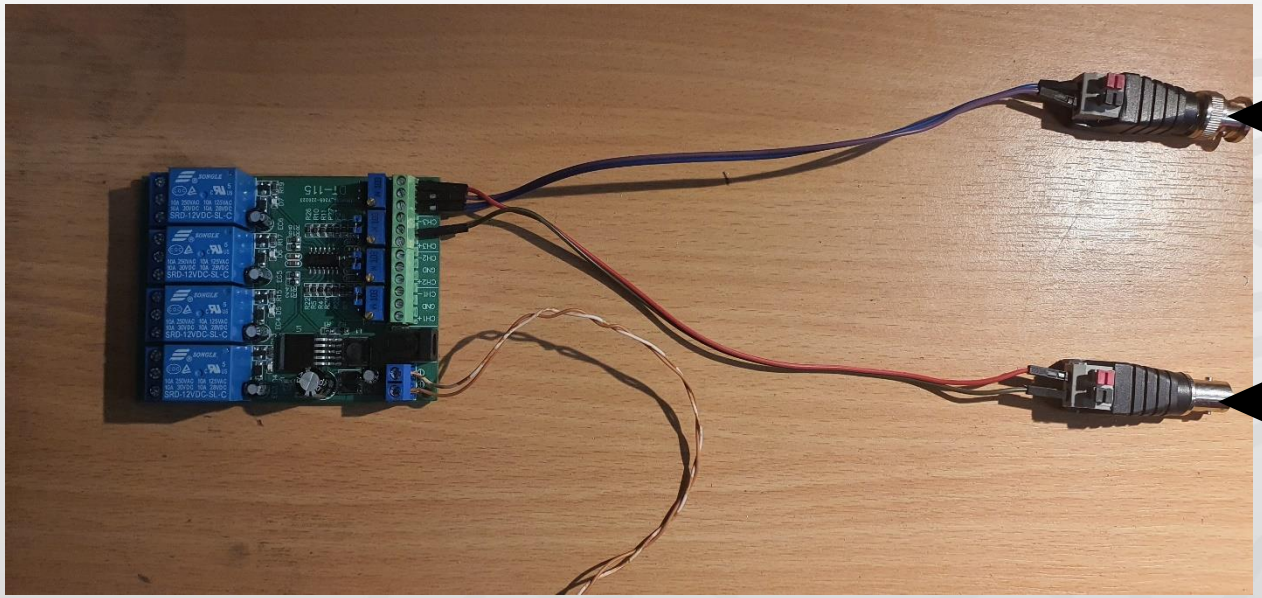
4. Solution for capacitor charging by applying a comparator instead of charging via an oscilloscope



Example of a comparator designed for capacitor charging

- When the voltage on both inputs is equalized, the relay is activated, disconnecting the power source.
- This method of monitoring the current value on the capacitor is much faster than using an oscilloscope and an ethernet conection (Approximately 1-second response time).





Reference input set to a voltage corresponding to the desired voltage on the capacitor

Input of the current voltage value on the capacitor converted into a value suitable for computers

4. Project timeline

1. Introduction to the comparator for capacitor charging

- Study the proper operation and configuration of the comparator
- Test the operation within a table-top experiment

2. Assist with completing the commutator technology

- Fully understand the assembled technology and their components
- Programing the control system for managing the commutators and the neccesary relays used in the circuit
- Test the operation and functionality of the technological solution in a table-top experiment

3. Implementation of the technology on the tokamak GOLEM

- Integration of the technology into operation
- Conducting functionality tests
- Drawing conclusions and fine-tuning technology

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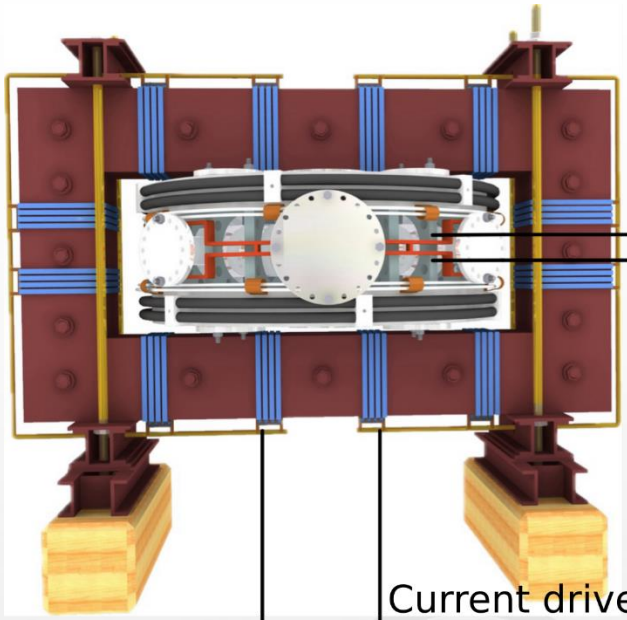
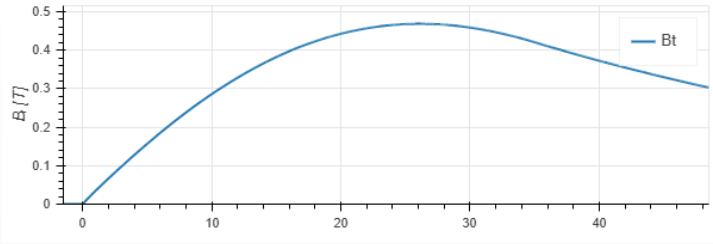
Thank you for your attention

Application of an additional diode in the discharge part of the circuit





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