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Applications of Transistor Switches

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III. Objectives:

In this experiment, our main objectives were to learn how to use transistors as power switches for controlling DC devices and gain experience in interpreting manufacturer's data sheets. We aimed to apply this knowledge in designing and building circuits using transistor switches to control various electronic devices, such as DC motors, electromagnets, lamps or LEDs, relays, and mechanical actuators.

IV. Equipment Used:

- Breadboard
- Various Electronic Components
- Power supply
- Function generator

- Oscilloscope

V. Preliminary Calculations:

A. For the first part of the preliminary, we used **Figure 1** shown below. We calculated the maximum collector current (ICmax) to be 0.33 A, and the base current (IB) to be 11.1 mA. This was required to saturate the transistor. Next, we determined the maximum value for resistor R1 to be 375 Ω and then divided that value by about 4 to overdrive the transistor switch for added safety and faster switching, this values ended up being, 100 Ω. The necessary parameters were obtained from the 2N3904 data sheet. The full calculations can be observed at the end of the report within **Appendix 1.**

B. We then calculated the power dissipated in the relay coil to be 9.6 W and the power dissipated in the transistor when the switch was in the ON state to be 66.7 W. This information was crucial for determining if the transistor would operate within its limits and if a heat sink was needed. We determined that that the transistor would beagle to operate within its limits, and a heat sink would not be necessary because the calculated power was lower than the rating. These calculations can be observed within **Appendix 2.**

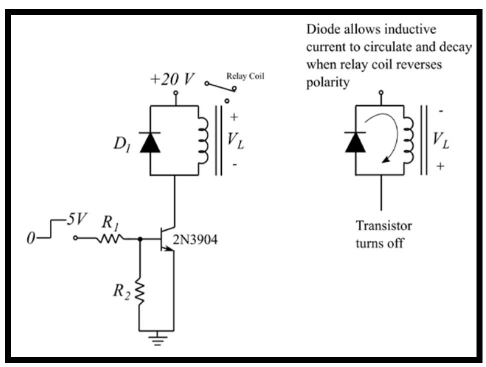

Figure 1: Using a BJT to control a relay.

VI. Procedure/Result/Analysis:

01. Procedure:

a. Construct the circuit on the breadboard using the designed switching circuit from the preliminary calculations (based on **Figure 1**), ensuring that the relay's freewheeling diode, D1, is correctly placed.

b. Apply VCC to the circuit and verify that the relay does not close when VCC is applied. If the relay closes, recheck the circuit.

c. Connect the function generator to the oscilloscope and set the output to a 0 to +5 V square wave with a frequency of about 1 Hz. Connect the generator output to the circuit and observe the relay turning on and off reliably.

d. Use the oscilloscope to observe the collector voltage and confirm that the diode is suppressing any inductive overshoot on turn-off. Sketch the waveform.
e. Allow the circuit to operate for a few minutes and carefully feel the transistor to detect any temperature rise.
f. Construct the circuit shown in **Figure 4** using an RFP14N05 MOSFET. Be cautious when handling the MOSFET and ensure that the gate is properly terminated before applying power.
g. Calculate the power dissipation in the load resistor and the power dissipation expected in the MOSFET.
h. Apply a +/-10 Vp-p square wave as the drive signal (starting at 1 Hz). Use the oscilloscope to observe VDS, ensuring that the MOSFET is switching the load as intended. Increase the frequency and observe the waveform during turn-off (when VDS goes HIGH).
i. Allow the circuit to operate for a few minutes. Carefully feel the MOSFET and resistive load for any temperature rise and note your observations.

02. Experiment:

a. We carefully breadboarded our circuit, making sure that the relay's freewheeling diode, D1, was configured with its polarity correct. When we applied VCC, the relay did not close, which was the expected outcome. We then connected the function generator to the oscilloscope and carefully set the output for a 0 to +5 V square wave with a frequency of about 1 Hz. After connecting the generator output to the circuit, the relay began turning on and off reliably which can be observed below within **Figure 2**. We then observed the collector voltage with the scope which can be observed below within **Figure 3.** This confirmed that the diode was doing its job of suppressing any inductive overshoot on turn-off. We let the circuit operate for a few minutes and then carefully felt the transistor. We did not detect any temperature rise, which was a positive sign.

   In response to Q3, if we had been required to specify the diode, we would have chosen a diode that can withstand transient voltage for nanoseconds and is capable of handling a non-repetitive peak surge current. The 1N4007 diode, for example, can withstand 1200V non-repetitive peak reverse voltage and a non-repetitive peak surge current of 30A.

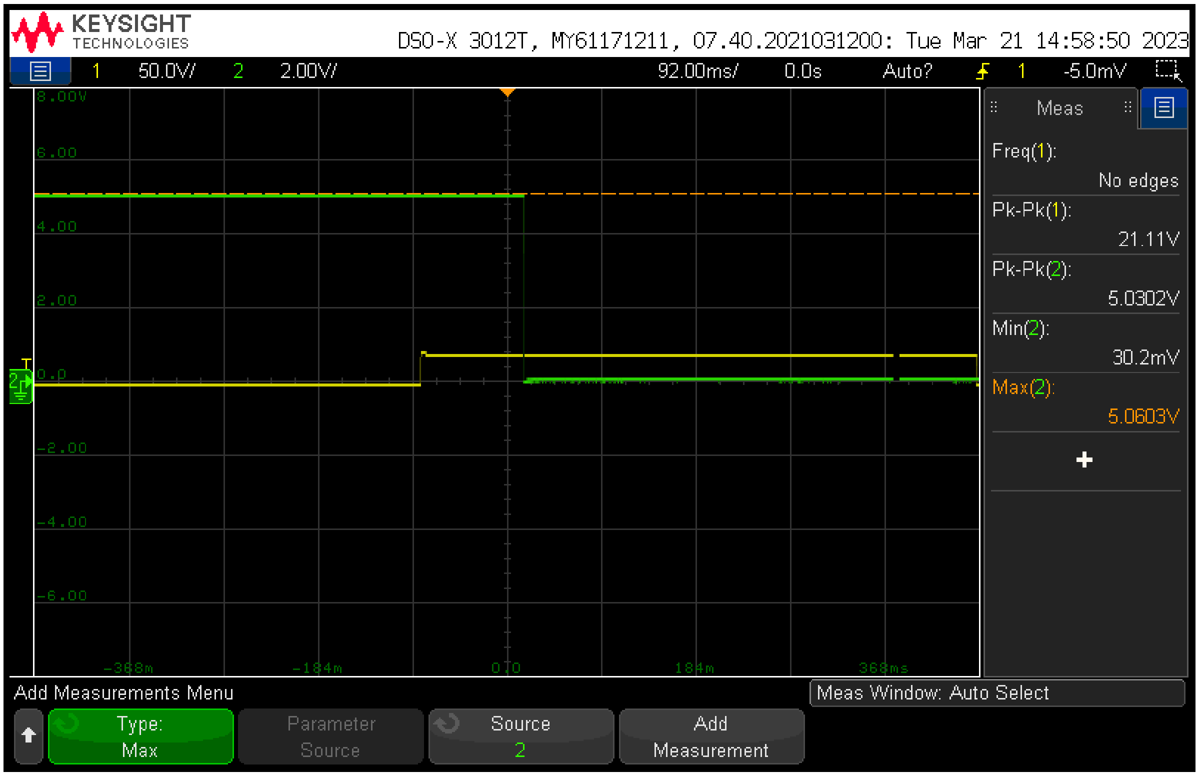

Figure 2: Oscilloscope Reading for the Relay Functioning

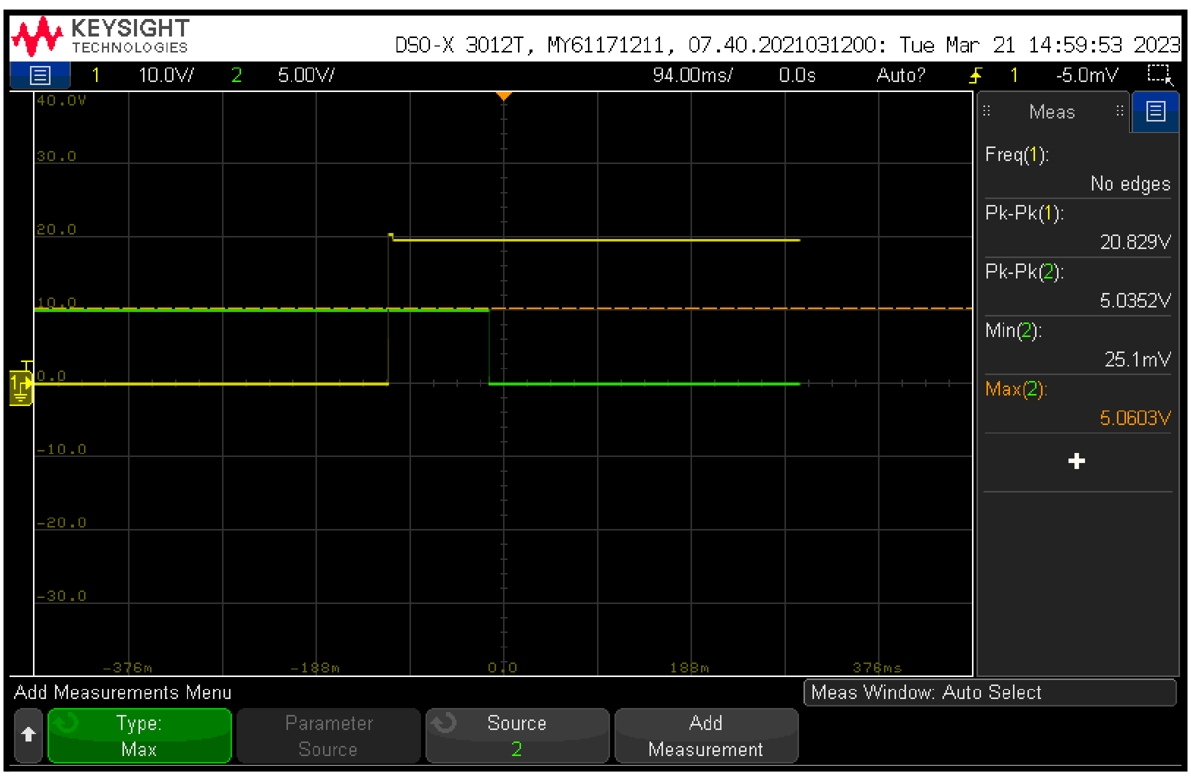

Figure 3: Collector Voltage Measurement with Oscilloscope

b. For Part B, we used an RFP14N05 MOSFET to construct the circuit of **Figure 4** shown below, following the necessary precautions regarding static charges and proper gate termination. Before energizing the circuit, we calculated the expected power dissipation in the MOSFET using the provided equations to be 19.84 W, inferring that we must use ratings over 20 W. We applied a +/-10 Vp-p square wave as the drive signal at 1 Hz and used the oscilloscope to observe VDS, ensuring that the MOSFET was switching the load as intended. This can be seen in **Figure 5**. We increased the frequency and looked at the waveform during turn-off when VDS went HIGH, as shown in **Figure 6**. In response to Q4, there was a turn-off transient present in the waveform. For Q5, this transient was present with a resistive load because of the inherent capacitance of the breadboard, the MOSFET, and the inductance from the wires. The capacitance was responsible for the slow discharge of voltage rather than an instant drop, as shown in **Figure 7**. As for Q6, the particular peak voltage might have been due to frequency-induced capacitance, which increased the voltage beyond the power supply voltage, as depicted in **Figure 8**. We allowed the circuit to operate for a few minutes and then carefully felt the MOSFET and resistive load for any temperature rise. The MOSFET was hot, while the load was warm(above room temp). In response to Q7, this observation tells us that the MOSFET was dissipating more power than the resistive load. However, the MOSFET did not need a heat sink, as it could withstand up to 235W of power dissipation.

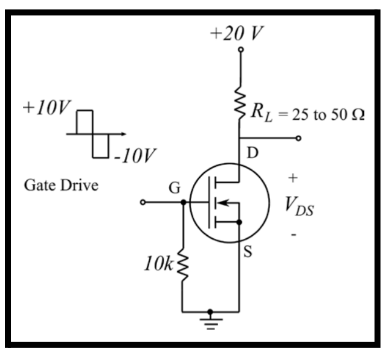

Figure 4: Driving a resistive load with a power MOSFET.

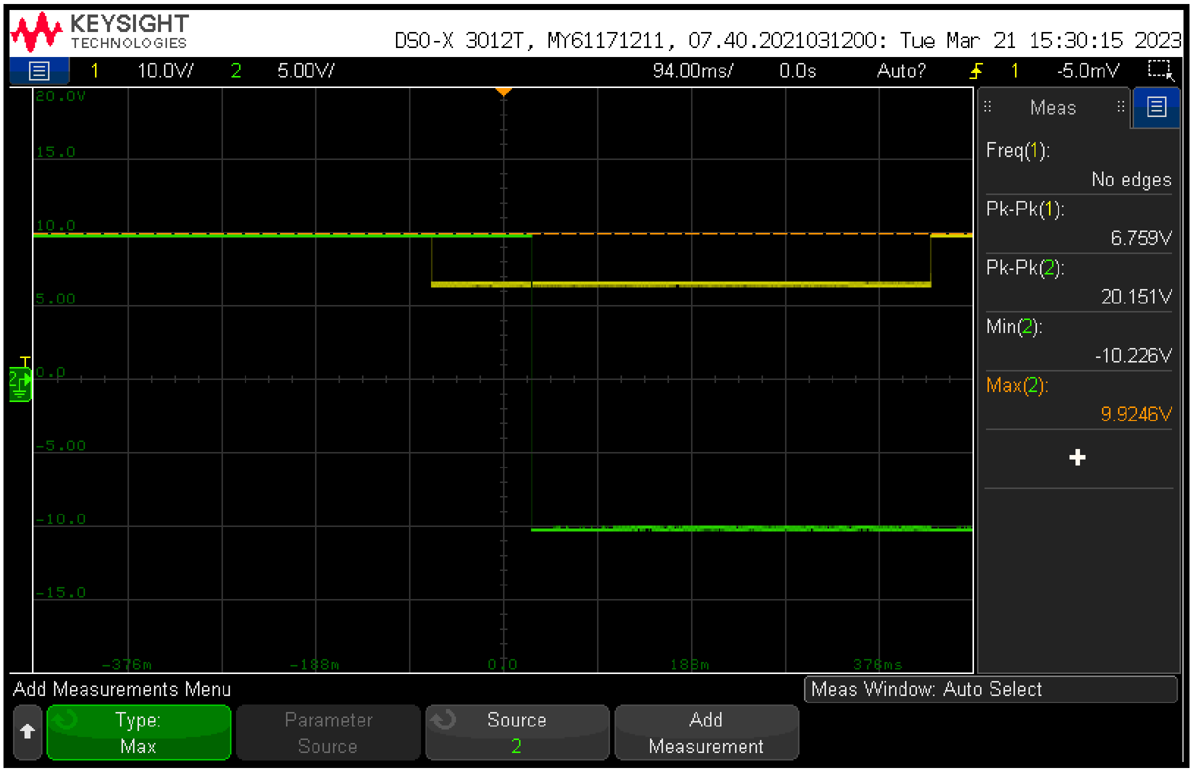

Figure 5: Oscilloscope Reading for VDS during Switching

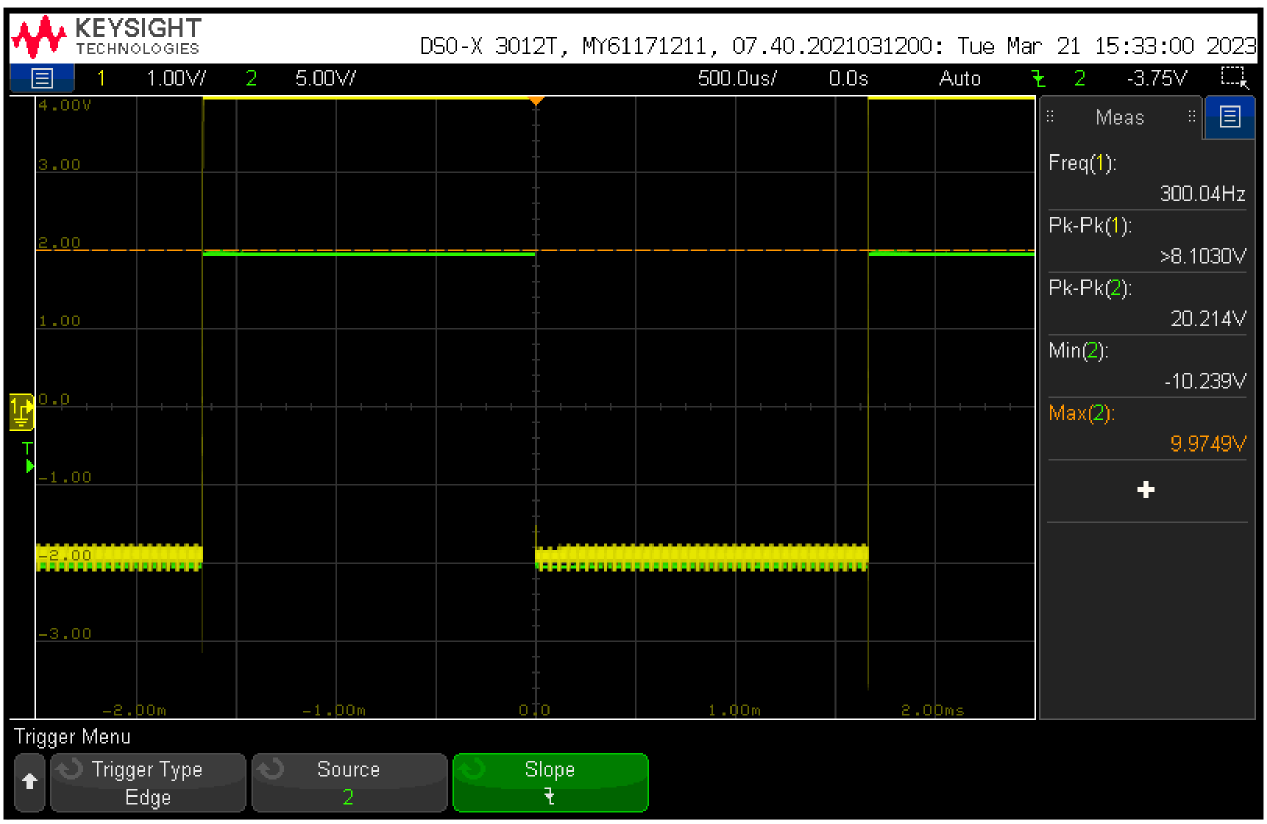

Figure 6: Waveform during Turn-off when VDS goes HIGH

VII. Conclusion:

In conclusion, this lab provided us with valuable insights into the behavior of transistors and MOSFETs when driving inductive and resistive loads. We successfully built two separate circuits, one using a relay and a diode to suppress inductive overshoot, and the other using a power MOSFET to drive a resistive load. Throughout the experiment, we carefully observed and analyzed the waveforms, transient voltages, and temperature changes in various components. Our findings demonstrated the importance of properly configuring and designing circuits to ensure the efficient and safe operation of electronic components. The diode in the first circuit effectively suppressed inductive overshoot, while the MOSFET in the second circuit switched the load as intended, despite the presence of a turn-off transient. The temperature observations provided us with a better understanding of power dissipation in the components and helped us determine that, in our specific case, a heat sink was not required for the MOSFET.

VIII. References:

Not applicable

IX. Appendix:

Appendix 1:

$$I_{c(Max)} = \frac{V_{cc}}{R_{coil}} = \frac{20}{60} = 0.33\ A$$

$$I_{B(Max)} = \frac{I_{c(Max)}}{h_{fe(min)}} = \frac{0.33}{100} = 11.1\ mA$$

$$R_{1(Max)} = \frac{V_{in} - V_{BE(ON)}}{I_{B(Max)} + I_2} = \frac{5-0.7}{(11.1\times10^{-3}) + \frac{0.7}{2000}} = 375\Omega$$

Appendix 2:

$$P_{Coil} = \frac{V_{Coil}^{\ 2}}{R_{Coil}} = \frac{24^2}{60} 9.6\ W$$

$$P_{transistor} = V_{CE(Sat)} I_c = 0.2 \times 0.33 = 66.7\ mW$$