Digital Outputs and Relays

Many control tasks require only a binary type of output, i.e. turning on or off a switch, light, motor or other device. Examples would be turning on or off a conveyor, a gas valve to your furnace, a fan or pump. You can think of many more, I'm sure.

Inherent in the control task is the idea of power amplification. The Analog outputs of the DAQ can only supply 5 mA. The Digital outputs can instead supply 32 mA, which is a little bit more but still not enough to control processes that may require large forces or power flows. Think about the positioning of the control surfaces for a commercial aircraft, or raising the landing gear for such a machine. Think about turning on or off a conveyor that transports steel slabs weighing 30 tons each. Your computer has the brains to do such jobs, but not the brawn. In this lab, we will see how to turn micro-level “thoughts” into macro-level actions.

Digital Outputs

The DAQ board has 32 digital IO lines, of which 16 are configured as digital outputs, and 16 as digital inputs.

The Matlab command line for digital output is called “digital_out”, and it takes two input argument, the channel, which can assume values from 1 to 16 and the value, which can be either 1 (High) or 0 (Low).

Try “help digital_out” from the Matlab command line and look for yourself.

The first 8 outputs are connected to both the relays and the red LEDs on the side. By giving 1 as a value to a certain channel (from 1 to 8), the LED lights up and current flows into the corresponding relay, therefore switching the relay on. But what does it exactly mean “to switch a relay on”?, Read on.

Relays

The digital outputs of the DAQ are capable of sourcing only about 32 mA each. Many digital outputs can provide even less current to drive external devices. That current is not enough to drive Lego motors, let alone turning your air conditioner on/off or controlling a conveyor in a robotic workcell.

Last week we learned about using pneumatic and hydraulic valves to somehow amplify the power of the DAQ board. This week we will see how we can use a small amount of electric current to control magnetic switches called
relays. Relays can take a small signal from a computer and use it to control electrical machinery of virtually any size.

A relay is an electrical switch that opens and closes under control of another electrical circuit. In the original form, the switch is operated by an electromagnet to open or close one or many sets of contacts. Joseph Henry invented it in 1835. Relays operate much like an ordinary mechanical switch. The only difference is that instead of “throwing the switch” by hand a relay uses an electrical signal to operate the switching.

Relays come in a variety of sizes, shapes and operating principles. The traditional old electromechanical relays are the easiest to understand.

![Electromechanical relay schematic](image)

**Figure 1 Electromechanical relay schematic**

In electromechanical relays, when a current flows through the coil, the resulting magnetic field attracts an armature that is mechanically linked to a moving contact. The movement either makes or breaks a connection with a fixed contact. When the current to the coil is switched off, the armature is returned by a force that is half as strong as the magnetic force to its relaxed position. Usually this force is supplied by a spring, but gravity is also used commonly in industrial motor starters.

The relay schematic in Figure L4.1 is one of the simplest; it has only four terminals and is called Normally Open (NO), Single Pole Single Throw (SPST). The term “Pole” stands for “Switching Circuit”, which in this case is only one.
Single Throw means that the internal switch has only one contact on one side of the common pole.

In General, the contacts of the switching circuit can be either Normally Open (NO), Normally Closed (NC), or change-over:

- **Normally-open** contacts connect the circuit when the relay is activated; the circuit is disconnected when the relay is inactive. It is also called Form A contact or "make" contact. Form A contact is ideal for applications that require to switch a high-current power source from a remote device.

- **Normally-closed** contacts disconnect the circuit when the relay is activated; the circuit is connected when the relay is inactive. It is also called Form B contact or "break" contact. Form B contact is ideal for applications that require the circuit to remain closed until the relay is activated.

- **Change-over** contacts control two circuits: one normally-open contact and one normally-closed contact with a common terminal. It is also called Form C contact.

Regarding the number of poles and throws, relays (as well as switches in general), can be of the following types, as described in the next figure:

- **SPST** - Single Pole Single Throw. These have two terminals which can be switched on/off. In total, four terminals when the coil is also included.

- **SPDT** - Single Pole Double Throw. These have one row of three terminals. One terminal (common) switches between the other two poles. It is the same as a single change-over switch. In total, five terminals when the coil is also included.

- **DPST** - Double Pole Single Throw. These have two pairs of terminals. Equivalent to two SPST switches or relays actuated by a single coil. In total, six terminals when the coil is also included. This configuration may also be referred to as DPNO.

- **DPDT** - Double Pole Double Throw. These have two rows of change-over terminals. Equivalent to two SPDT switches or relays actuated by a single coil. In total, eight terminals when the coil is also included.

- **QPDT** - Quadruple Pole Double Throw. Often referred to as Quad Pole Double Throw, or 4PDT. These have four rows of change-over terminals. Equivalent to four SPDT switches or relays actuated by a single coil or two DPDT relays. In total, fourteen terminals when the coil is also included.
The relay in the next figure is an electromechanical double pole, double throw relay. All the contacts (Eight) can be connected to a separate device in each position. The contacts of this relay can carry up to 30 Amps of current and can switch a 2 hp motor on and off. The coil operates on 12 VDC and requires only a few tenths of an Amp to operate.
The following Figure shows the inside of the above electromechanical relay:

This relay is shown in the Normally Closed (NC) position, i.e. there is no current supplied to the relay coil. A separate power source connected to the Common (C) terminal would supply power to a load connected to the NC terminal. If a small current is sent through the coil, it creates an electromagnet, which attracts the “common” terminal down, connecting (C) with Normally Open (NO). Power would then be removed from the load on the NC terminal and
applied to the NO terminal. The contacts of this relay can carry up to 30 Amps of current and can switch a 2 hp motor on and off. The coil operates on 12 VDC and requires only a few tenths of an Amp to operate. When the coil current is removed, the spring on top of the relay pulls the common conductor back up so the connection between C and NC is re-established.

Figures 5: Schematic of relay connection.

Figure 5 is a schematic diagram of the relay connections.

The pin numbers are as seen from the bottom of the relay and are marked on the base of the relay. The socket (right) has numbers by each of the screw terminals that correspond to the relay pin numbers, making connections easy for those with eyes good enough to see the tiny little buggers. Note that the relay is "keyed" so it only fits in the socket one way.

Terminal 1 on the relay socket is connected to the little circle marked 1 on the relay schematic above—the common terminal for pole 1. Screw terminal 4 is connected to the NC terminal of pole 1 and screw terminal 3 is connected to the NO terminal of pole 1. Screw terminals 2 and 7 connect to the relay coil. Putting 12V across pins 2 and 7 causes the relay to switch from the NC to the NO position, i.e. pin 1 is now connected to pin 3 and pin 8 is now connected to pin 6. Even though they are shown backwards here, both poles switch at the same time.

A solid-state relay (SSR) is a solid-state electronic component that provides a similar function to an electromechanical relay but does not have any moving components, increasing long-term reliability. As transistors improved, SSR's, capable of handling 100 to 1,200 amps, have become commercially available.
The Solid State relays in the following pictures are SPST – Normally Open relays as you can tell by the fact that they have 4 terminals.

![Solid State Relays](image)

**Figure 6: Solid State Relays**

![Internal circuitry of a Solid State Relay](image)

**Figure 7: Internal circuitry of a Solid State Relay**

You are not expected to understand the above circuit, but note that the two sides of the relay are actually separated from each other, and the switching happens whenever the light emitted by a diode on the left side hits the phototransistor on the other side. Both diode and phototransistor are inside the element “TIL 111”.

To choose a relay for a particular application, one needs to know/specify the following basic parameters:

1. What will the control voltage and current be? Relays typically come with coil voltages of 5V, 6V, 12V, 24V, or 48V DC or 115VAC. The coil current required depends on how massive the contacts and springs are. Big
Relays may require 250 mA of coil current or more. Smaller ones and solid state relays may only require 10 to 30 mA.

2. What "contact rating" is needed? The contact rating is the amount of current and/or power that can be handled by the high-power side of the relay. Contact ratings are most often printed on the cover of the relay. The contact rating always includes a current rating, which may be from one Amp up to thousands of Amps. The rating may also include a voltage and may or may not specify a "horsepower" rating for the largest motor that can be served. The voltage and horsepower ratings are determined by the ability of the relay contacts to resist arc welding them together when a load is switched off.

3. What configuration of "poles" and "throws" is needed? The diagrams below explain the idea of poles and throws.

4. Other minor factors like the mounting configuration or "form factor". Pull one of your relays out of the plastic socket and you will see a circle with pins sticking out of it that fit into the socket. Other form factors have flat contacts arranged in rows, or solder terminals or screw connections.

The relays we will use is called ODC 5A (Figure L4.8).

![Figure 8: ODC5A Solid State Relay](image)

It has the following features:

- Load Voltage: 0 to 200V
- Load Current Max: 1 Amp
- Max Power Dissipation: 1.5 W/Amp
- Blocking Voltage: 360 VDC
- Turn On Time: 75uS
- Turn Off Time: 750uS
- Off Leakage Current: 10 uA
- On Voltage Drop: 1.6VDC
- Logic Supply Current: 11mA
The relay is connected to the project board so that the output side is accessible through the screw terminals, and that the input switch is activated by the Matlab command “digital_out”(channel,1), where channel is a number from 1 to 8.

**Motor (Forward On/Off Only):**
Try connecting a motor to the relay so that you can turn it on and off using the digital_out command. Follow the scheme in Figure 9

![Figure 9: Forward On/Off Motor Connection](image)

**Motor (On/Off and Forward/Reverse):**
A DC motor can run forward or backward by changing the direction of current flow through the motor. You can connect two digital output terminals on the Project Board to a DPDT relay to effect motor on/off and direction control. You will need two digital outputs to control the system. One output will choose on/off and one will choose forward/reverse. Figure 10 is a schematic of how can connect the relays and motor together.
Figure 10: Forward On/Off Motor Connection

Construct this system. Trace the connections so you can completely understand how the logic works.