Mechatronics & Embedded Microcomputer Control
ME E4058   Fall 2018

Case Study #3: Digital On/Off Control

Feedback control involves the measuring of a sensor signal and deriving an input to the system to produce a required response in real time. While feedback control often involves the measurement and use of continuous (analog) signals, a very large number of embedded control applications require simply measuring a discrete (digital) source such as a switch and turning a device on or off. These applications include the use of high power sources. Large motors, for example, often use alternating current (ac) rather than direct current (dc) and derive their speed control from the frequency of the power grid (60 Hz in the United States). To start these motors, a signal is sent to a triac, solid-state switch or relay which applies the ac power to the motor. Chemical processes often use solenoid (on/off) valves to control the flow of reactants. Safety systems are often on/off where the power to the system can be shutdown by opening the main breaker. What differentiates on/off control from simple on/off switching is the use of sensors. When an actuator is turned on, a sensor determines if the process really turns on. When an actuator is turned off, a sensor determines if the process really turns off.

The microcomputer is a very effective device for sophisticated on/off control applications. While some microcomputers have A/D converter inputs to read analog signals and pulse width modulated (PWM) outputs to produce analog signals, all have digital (on/off) input and output ports for interfacing to the system. Programming the microcomputer involves setting the properties on the port for the desired operation (reading or writing) and setting internal registers for the desired control. Considerations for turning power devices on or off can involve simple timing (open loop) or the state of digital sensors (closed loop feedback).

The goal in the third case study is to provide an understanding of the issues and techniques for on/off control using an embedded microcontroller.

Introduction:

This lab will investigate on/off control with a microcomputer using a simple laboratory test fixture. The test fixture, illustrated in Figure 1 below, includes a 12 Volt solenoid and an optical sensor. When a 12 Volt signal is applied across the solenoid coil, the armature retracts. When the 12 Volt signal is removed, the armature returns to the open position by the coil spring. We will operate the solenoid using the high current 12 Volt supply (MPJA).

The optical sensor is shown schematically in Figure 2. One leg of the sensor encloses an infrared light emitting diode (LED). When current flows through the LED, it emits an infrared light which is directed outward from the sensor. The other leg of the sensor encloses a phototransistor.

The diagonal arrows from the LED are meant to represent the light path. A photo transistor, similar to the device used for the Magnetic Levitation system, is a transistor that is controlled by the amount of light (photons) rather than by a current (electrons).

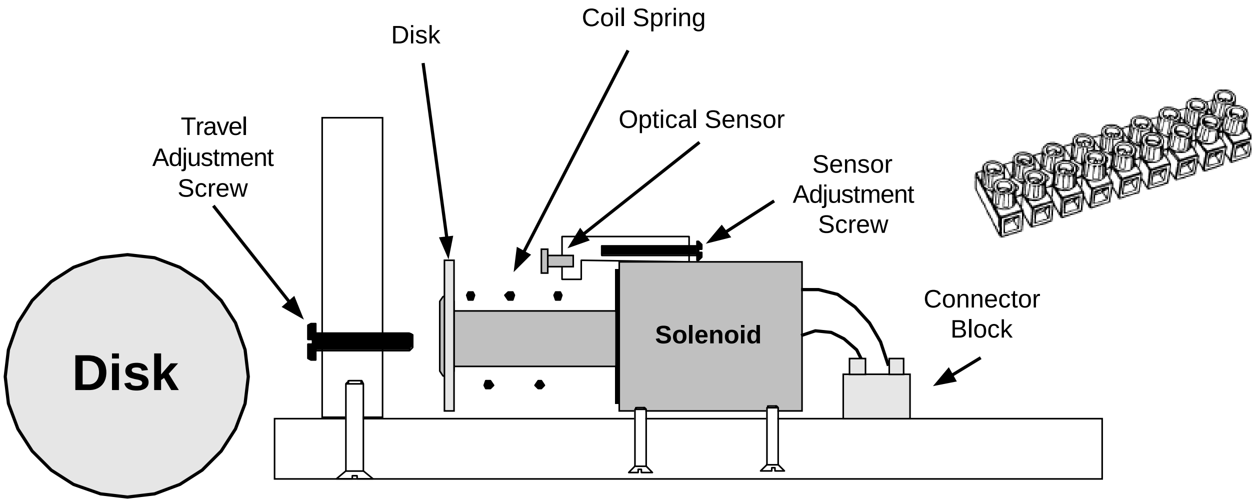


Figure 1. Solenoid Test Stand

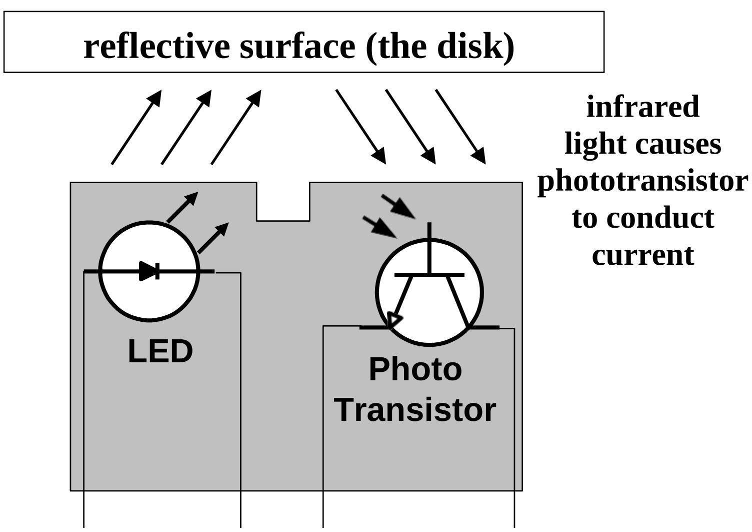


Figure 2. Optical Sensor

When light enters the base of the phototransistor (indicated by the diagonal arrows), the device conducts current between the collector (on the right) and the emitter (on the left). The direction of current flow in the device is indicated by the arrow on the device terminal. Since the arrow points away from the device, the device is called an npn phototransistor. The terminology npn says that the collector and emitter of the device are fabricated from a silicon doped with a material which gives it an excess of electrons (negative current carriers – n) and the base of the device is fabricated from a silicon doped with a material which gives it a shortage of electrons (therefore making it effectively a carrier of positive charge particles – p). The alternate device, a pnp phototransistor (which is typically not used) would have an arrow pointing into the emitter.

To use the sensor, a reflective surface is brought into the path of the light from the LED to the phototransistor. This is indicated in Figure 2. When the surface is far from the sensor, no light enters and therefore no current passes through the phototransistor; when the surface is brought close, light enters the phototransistor and current flows. The sensor will operate with 5 Volts (so that it is compatible with the microcomputer which operates on 5 Volts) and requires 2 resistors. A resistor is placed in series with the LED to limit the current flowing through what is effectively a diode. The resistor is chosen to give a sufficient amount of current (and thus a sufficient amount of light) to operate the device. A second resistor is placed in series with the phototransistor. This also limits the current through that device which is effectively a transistor. That resistor is chosen to provide enough current to drive any device that is attached to the phototransistor. The voltage across that resistor determines if the solenoid is retracted or not. Both resistors are to be connected on the protobord.

The "user interface" for the program will be the white octal switch on the microcomputer board. The program will read the switches and determine the required mode of operation. Three different modes will be programmed. In addition, two pushbutton switches (the green and red ones) on the microcomputer board base, the bank of 4 visible (red) LED's (along the top of the board) and the precision potentiometer connected to Port A pin 0 will be used.

Laboratory Procedure:

General procedure:

- Assume nothing
- Using the multimeter, measure all resistors and capacitors. Note values. Note tolerances.
- Using the multimeter, check +12 V and +5 V on the power supplies.
- Using the multimeter, check the connectivity on the protoboard.

The user interface to the microcomputer will consist of a white octal IC switch block on the lower right hand side of the microcomputer board. The outputs of the switches are pulled up to the 5 Volt supply with 4.7 K resistors as shown below in the figure. As in the digital logic case study, this is done so that we do not short the power supply to ground when the switches are closed. These resistors also limit potential currents to the microcomputer when the switches are open. The schematic for the interface is shown below. The switches are connected to **Port E pins**

0, 1 and 2 on the microcomputer. Note that when the switch is "on" (or closed), the resistor is shorted to ground and the signal to the port is a digital 0. When the switch is "off" (or open), the 5 Volt signal is connected to the microcomputer through the resistor and the signal to the port is a digital 1. Thus when the switch reads octal 6 (as illustrated), the switch connected to Port E pins 2 and 1 will be digital 0 and the switch connected to Port E pin 0 will be digital 1 (i.e. the combination 001 on Port E). What you might find easiest to do is to read Port E and then complement the bits so that the digital value is the same as the position indicated on the switch. The assembler complement command is "**comf**". In other words, for the illustrated case, you would read in 0 0 1 on Port E and then complement the bits to read 1 1 0 which is binary for 6 (the switch position). If this is not clear, please ask. (Note: what does the **comf** command do to the upper bits in the 8 bit register associated with Port E ?)

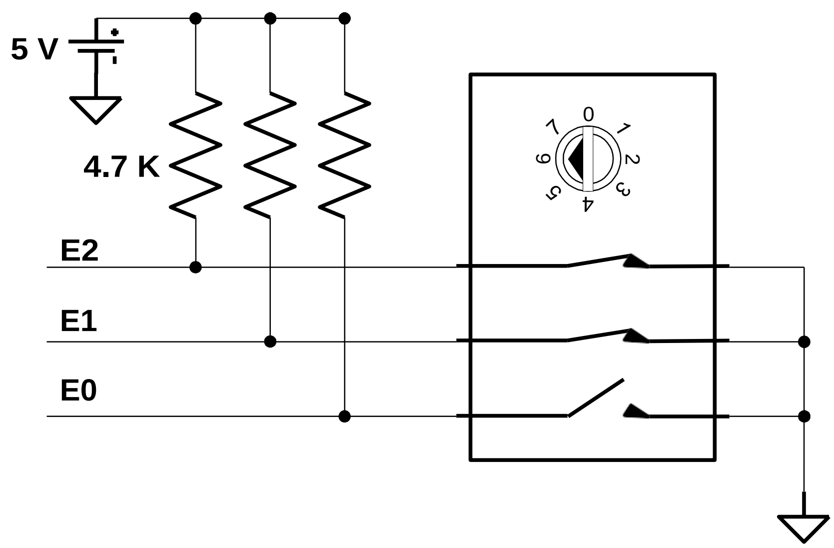


Figure 3. Octal Switch User Interface.

In addition to the octal switch, the green pushbutton switch connected to Port C pin 0 and the red pushbutton switch connected to Port C pin 1 will be used for the user interface. The red LEDs connected to Port B pins 0 – 3 along the top of the microcomputer board will be used to indicate the operating mode as explained below (called the indicator LEDs). The precision potentiometer on the microcomputer board base connected to Port A pin 0 will be used to control the operation (called the control pot).

The following circuits have to be constructed on the protoboard. Remember, for protoboard circuits, try to keep the wires neat and short so that it is easy to see problems and wires will not be inadvertently disconnected when operating the circuit. Use different colored wires to represent different signals. Leads to the higher power components (which use the 12 Volt supply) should use adjacent holes on the protoboard whenever possible.

The 5 volt power supply should be bypassed with capacitors both where it enters the protoboard and near the chip. Use a polarized 10.0 μF and a non-polarized 0.1 μF capacitor near the terminals and a 0.01 μF capacitor near the chip. **Be careful of the polarization of the 10.0 μF capacitor.**

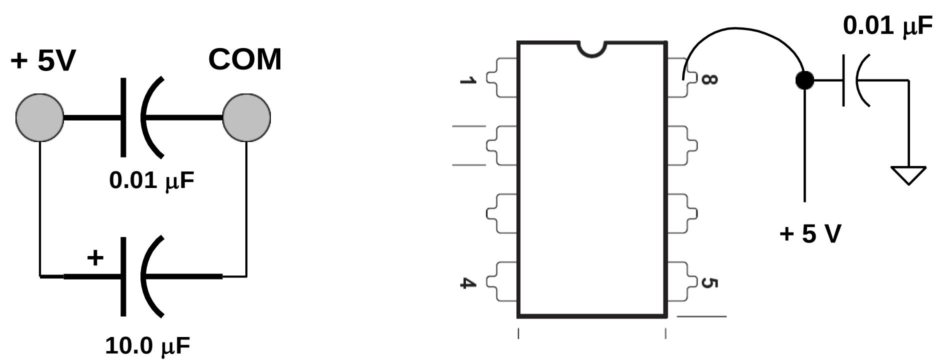


Figure 4. Power Supply ByPass Capacitors

The grounds for the two supplies (COM on the 5 volt supply and – on the 13.5 volt supply) should be connected to a common point. This is done on the system. Power must also be supplied to the solenoid test stand (both 12 V and 5 V) and the microcomputer board. The microcomputer board requires 5 V only. The red wire is connected to 5 V (the 6 V terminal on the Agilent power supply) and the black wire to the COM terminal. **The microcomputer is damaged if the supply voltage exceeds 5.5 V so please insure that the voltage is set correctly.**

Circuits Required

The connection for the solenoid is shown in Figure 6. Two of the same transistor will be used to energize the solenoid. The transistor used (TIP 122) is actually two transistors in a configuration called a "Darlington" (an equivalent circuit is shown below in Figure 5). It is treated like a common transistor. The Darlington configuration is done to increase the effective current gain of the transistor so that very little current into the base of the transistor from the microcomputer will cause the transistor to switch on.

It is a property of solenoids that they require a large current to engage them but that once the armature is seated, very little current is needed to hold them in the seated position. For applications where the solenoid is to be engaged for long periods of time (called continuous duty), a common practice is to switch to a second driver where the current (and thus the power) will be reduced. The transistor connected directly to the solenoid (called the main transistor below) provides the high current required to engage the solenoid. The second transistor and the

100 Ω 1 Watt resistor are for reduced current after the solenoid is engaged. This will be called the reduced transistor below. The two 100 Ω (normal ¼ Watt) resistors that connect the circuit to the microcomputer are to limit the current drawn from the microcomputer port. Finally, the FES16JT diode is added to provide a path for the current from the solenoid when the device is to be switched off. Recall that the voltage across an inductor is proportional to the derivative of the current. If we switch the transistor off, we cannot interrupt this current instantly without the voltage on the device approaching infinity. This high voltage will damage the transistor. The diode is back biased meaning that normally no current flows through it from the power supply. When we try to interrupt the current to the solenoid by turning the transistor off, the current actually flows from the inductor through the diode back to the power supply where it absorbed. The best place to connect the diode is in the connector block on the solenoid test stand and this was done. You will note that the 100 Ω 1 Watt resistor is also mounted on the connector block.

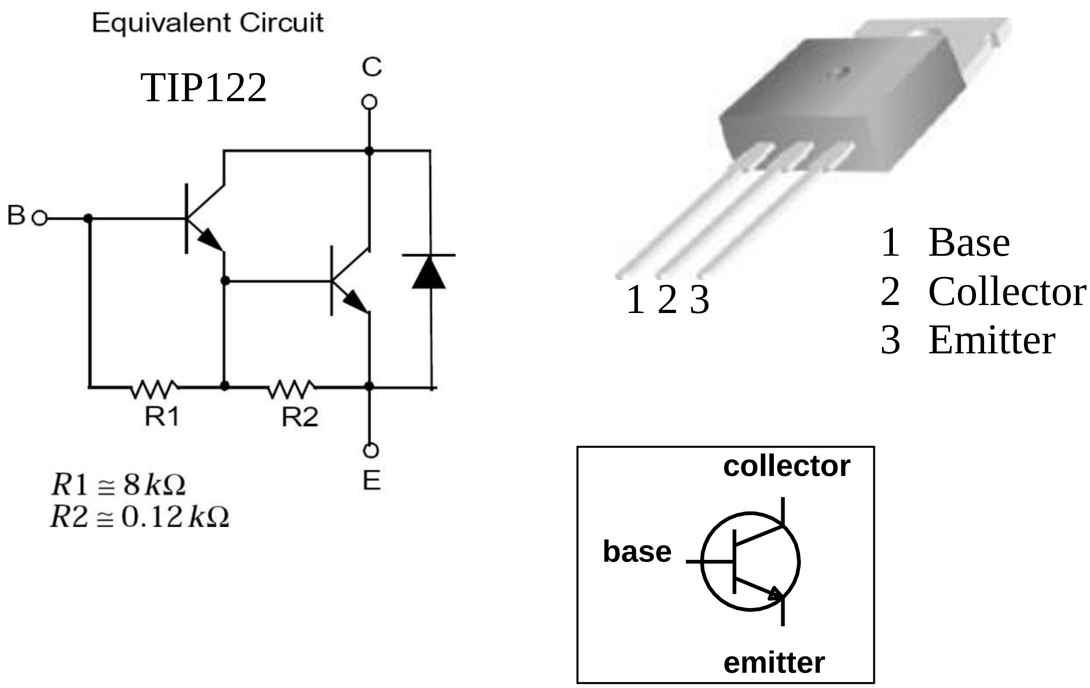


Figure 5. TIP122 Darlington Transistor

The solenoid will be connected to two output pins on **Port D** of the microcomputer. You will decide which pins to use. **Note: you should set unused pins to be inputs.** Port D can be easily connected to the protoboard with a ribbon cable from connector JP1. You will build up the transistor circuit on the protoboard. Please connect the wires which come directly from the solenoid to the holes adjacent to the transistors. You do not want the relatively high currents for the solenoid to pass through the protoboard traces. Pins 1 to 8 of a ribbon cable connected to connector JP1 on the microcomputer board connects to Port D pins 0 to 7, respectively.

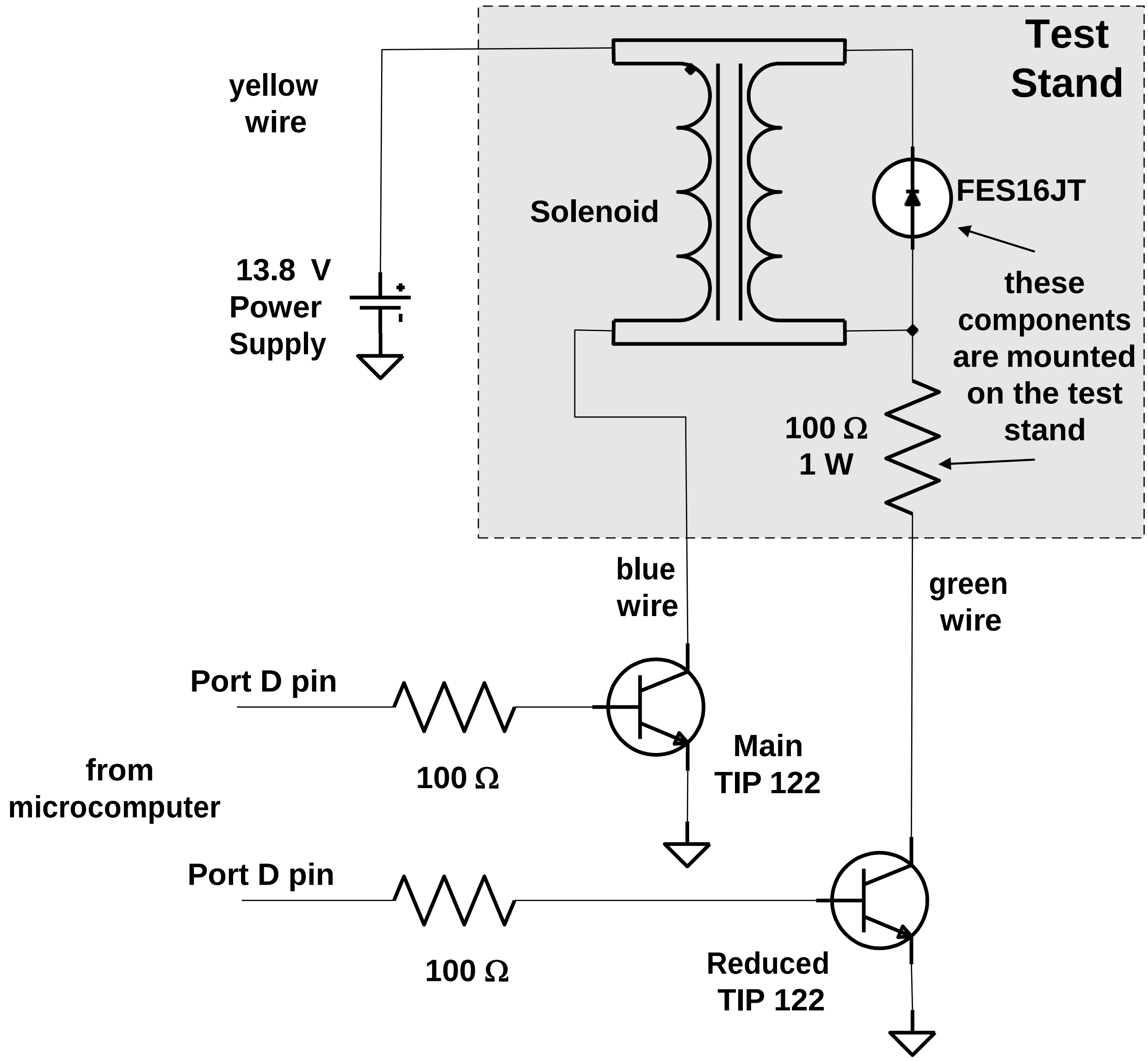


Figure 6. Solenoid Driver.

The final circuit that is needed is for the sensor. It is shown in Figure 7. The need for the two resistors was described above. The comparator (LM311) is the same device that was used for the digital logic case study and the laboratory equipment exercise so you should be aware how it will operate. It is added to give a digital indication when the armature of the solenoid has retracted.

The voltage level on the potentiometer is adjusted so that the output of the comparator is a logical high when the solenoid is engaged. This will be adjusted after the first mode of operation is programmed. An input on **Port D** of the microcomputer will be used for the sensor. Again, you will decide which pin to use for the input. Note that this means that Port D of the microcomputer will have to be configured for both input and output. This is done with the TRISD register. Also, the Port D pins that you use for input and output should be described in the general comments in your program.

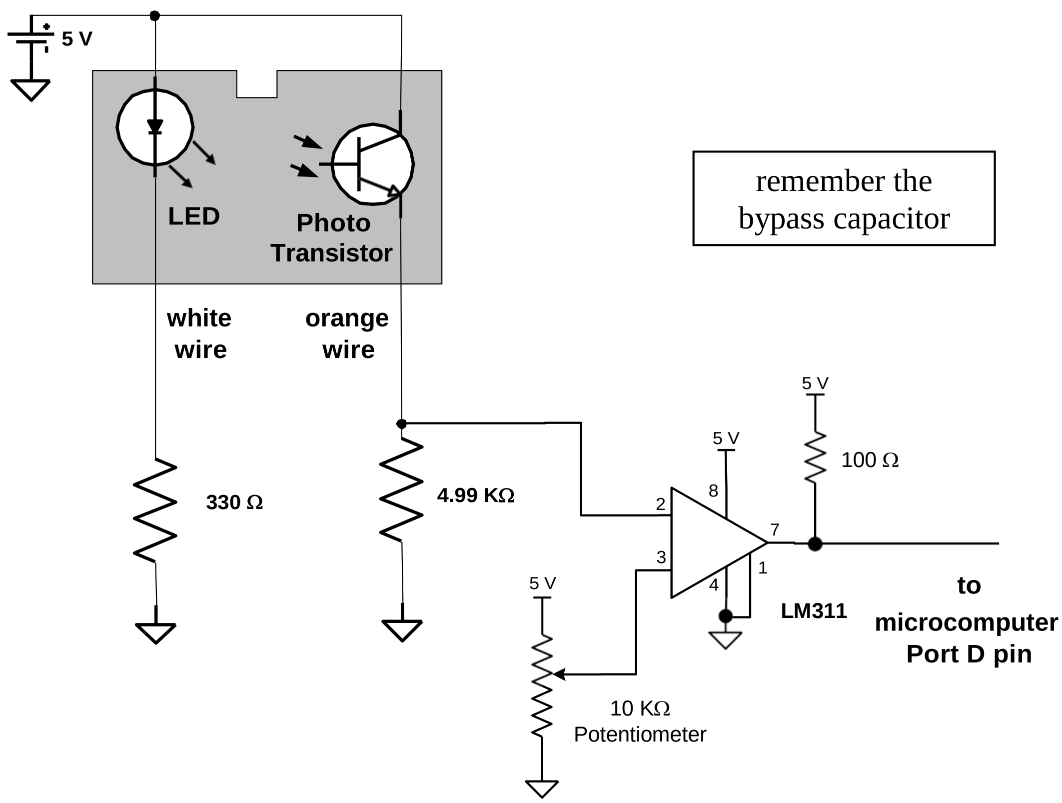


Figure 7. Optical Sensor Interface.

Microcomputer Board Setup

For proper operation, the following changes should be made to the microcomputer board:

- Jumper J6 should be connected.
- Jumper J7 should be disconnected (open).
- Jumper J9 should be disconnected (open).
- All DIP-4 switches (1 – 4 on both the red and blue sets) should be open (off).

- Ribbon cable should be connected from the microcomputer board connector JP1 to the protoboard.

General Programming Considerations

In general, the embedded program will operate as follows:

- At least two memory addresses have to be set up. One will hold the state of the program and will be called "**State**". You could use this to save the mode (for example) or something else useful in your program. You can also setup another register called "**Octal"** for example. In lecture, the idea of setting up another register called "**Mode"** where individual bits determine the mode was discussed. Another will hold the count for modes 2 and 4 and be called "**Count**" (for example Count0, Count1, etc.). You will probably also want a register to hold the value from the A/D converter.

- The 4 LED's connected to Port B will be used to display the mode of the program operation and any errors (the indicator LEDs).

- Upon reset, the program will jump to an initialization routine (starting with the letters "**init**" in the label). Ports will be configured and set for input or output as required. Internal special function registers will be set up as required. The program will then wait until the green button (the pushbutton connected to Port C pin 0) is pressed. The indicator LEDs (connected to Port B pins 0 - 3) will indicate 0h (or 0000 in binary).

- The octal switch connected to Port E can be changed. The bits (bits 0, 1 and 2) will indicate the mode. These will be read when the green button is pressed and released and that mode of operation will be started. The indicator LEDs will indicate the mode. Note that for 3 modes, only 2 switches are needed. If the upper switch is on or no switches are on, this will be indicated by a fault. An incorrect mode fault will be indicated by the LED connected to Port B pin 3 being on. Thus mode 0 and modes 4 through 7 are all mode faults.

- At any time when there is no fault after the previous operation has completed, when the green button is pressed, the mode bits are read and that mode of operation is engaged. This means that you can switch between different modes after an operation. (Remember to display the correct code on the LED's and to turn off the transistors before starting any mode.) For correct modes, the fault LED will be off. Thus a fault will be indicated by the highest order bit on the LED's, i.e. bit 3. After any fault (including a mode fault), pressing the green button will not cause the bits to be read. The processor must be reset with the black reset switch. (Note: for extra credit, make the code on Port B flash on and off every second for faults.)

- The three lower bits of the indicator LEDs (bits 0, 1 and 2) are used to indicate the mode.

- The state of the program, including the current mode, should be stored in the "State" internal register. While this is not required for operation, it makes debugging easier.

Embedded Program Requirements:

The following describes the different modes of operation:

1. **Mode 1 – Basic Test (Process Checking Application)**

In mode 1, the microcomputer will basically test the operation of the solenoid interface circuit and the sensor. For this mode, when the red button (the pushbutton connected to Port C pin 1) is pressed and released, the main transistor (connected to a Port D output pin) will toggle on and off. The solenoid should engage and the sensor should indicate the engagement. Use this test circuit to adjust the screw on the solenoid test stand (the travel adjustment screw in Figure 1) for armature travel and the screw which sets the position of the sensor (the sensor adjustment screw in Figure 1) for a usable signal. The travel adjustment screw has to be set so that the solenoid has the maximum possible travel and still is able to engage when the main transistor is on. The solenoid only has so much force to overcome the return spring but the force increases inversely with the square of the air gap in the armature magnetic circuit. If the travel is too large, it will not engage. The sensor adjustment screw has to be set so that the sensor produces a change in voltage as the solenoid is engaged and disengaged. This mode is also used to set the potentiometer in the sensor circuit. The potentiometer should be adjusted so that the output of the comparator is low when the solenoid is off (disengaged) and high when the solenoid is on (engaged). It is probably easier to set the potentiometer by measuring the voltages with the oscilloscope. Try to set the voltage level of the potentiometer near the middle of the range of the sensor.

2. **Mode 2 – Basic Timing Control (Toaster Oven Application)**

In mode 2, the microcomputer basically controls the solenoid in an open loop fashion with timing. When the red button is pressed and released, the main transistor will turn on and remain on for a period of seconds when measured with a watch (in other words, with limited precision). The microcomputer will complete this timing every time the pushbutton is pressed and released. If the pushbutton is pressed and released in the middle of the timeout, the timer will be restarted from that point.

The timing will be obtained from the control pot (the precision potentiometer connected to Port A pin 0 on the microcomputer board). When the red button is pressed and released, the A/D converter is read and converted to a binary value. The main transistor will turn on and remain on for ¼ (one-quarter) that number of seconds (again when measured with a watch). For example, if the A/D indicates a 16, the transistor will remain on for 4 seconds, if the A/D indicates a 140, the transistor will remain on for 35 seconds, etc. The microcomputer will complete this timing every time the pushbutton is pressed and released. If the pushbutton is pressed and released in the middle of the timeout, the count will be restarted from that point. The count will also be stored in the user "Count" registers. Note that for maximum travel of the control pot (maximum clockwise), the solenoid will stay on for 64 seconds or over 1 minute. For minimum travel of the control pot (maximum counterclockwise), the solenoid will stay on for 0 sec and will indicate an error. Since the control pot has a precision readout, you should be able to determine the timing for values between the minimum and maximum readings.

Note: the mode cannot be changed by pressing the red button. If the octal switch is changed, the processor will continue in mode 2. Modes can only be changed with the green button after the timing cycle has finished.

You need to check for one fault in mode 2. If the potentiometer is turned fully counterclockwise (so the reading in the A/D is zero), this would say you want to turn on the system for zero time. This is a fault. Recall that a fault is indicated by bit 3 of the indicator LEDs. In a fault, additional presses of the red and green buttons are ignored. Operation is only restored with a processor reset.

3. Mode 3 – Basic Feedback Control (Air Conditioning Application)

In mode 3, the microcomputer basically controls the solenoid in a simple closed loop fashion. When the red button is pressed and released, the control starts. When you press and release the red button again, control stops. To indicate that the control is active, an LED connected to a PORTD pin (not used for anything else) is turned on. When the control is inactive, the LED will be off.

The feedback signal will be obtained from the control pot (the precision potentiometer connected to Port A pin 0 on the microcomputer board). When the red button is pressed and released making control active, the A/D converter is read and converted to a digital binary value. This value will be compared to 70 hex (112 decimal). If the A/D converter value is greater than 70 hex, the main transistor will turn on and remain on and the solenoid will engage. The A/D converter is read again (it will be read continuously while control is active). If the value on the A/D falls below 70 hex, the main transistor will be turned off and the solenoid will disengage. Pressing the red button again will make the control inactive and the A/D converter is not read. The solenoid should be disengaged while control is inactive.

Note: the mode cannot be changed by pressing the red button. If the octal switch is changed, the processor will continue in mode 3. Modes can only be changed with the green button when control is inactive.

You need to check for one fault in mode 3. If the potentiometer is turned fully counterclockwise (so the reading in the A/D is zero), this could say that the feedback sensor is broken. This is a fault. Recall that a fault is indicated by bit 3 of the indicator LEDs. In a fault, additional presses of the red and green buttons are ignored. Operation is only restored with a processor reset.

4. **Mode 4 – Feedback, Backup Circuit, Fault Detection, Fault Recovery (Sump Pump Application)**

In mode 4, the microcomputer controls the backup transistor (connected to another Port D output pin). Again, as discussed above, this is used to limit the current for essentially continuous operation. When the red button is pressed and released, the control pot is read. The main transistor will turn on and remain on until the optical sensor (connected to a Port D input pin) indicates that the solenoid has retracted. (Note: you may also have to wait several milliseconds after the sensor goes high to insure that the armature has truly retracted. It may bounce a little on the spring.) After that time, the backup transistor will be turned on and the main transistor will be turned off. (Note: it has to happen in this order. Both transistors have to be on for a short period to make the transition otherwise the armature may move.)

After that, the backup transistor will remain on ¼ the number of seconds on the control pot as the main transistor did in Mode 2. After that time, the backup transistor will be turned off.

In this mode, additional presses of the red button are ignored until the timing is finished. Note that this is a difference from mode 2. Of course, after the timing is completed, pressing the mode pushbutton (the green button) is recognized. Once the timing has finished, the operation can be repeated by pressing and releasing the red button again.

As in mode 2, if the potentiometer is turned fully counterclockwise (so the reading in the A/D is zero), this would say you want to turn on the system for zero time. This is again a fault and should be indicated as a fault in mode 4. Recall that a fault is indicated by bit 3 of the indicator LEDs. In a fault, additional presses of the red and green buttons are ignored. Operation is only restored with a processor reset.

If the optical sensor is not detected in approximately 10 seconds, a fault is indicated and the transistors are turned off. Operation is only restored with a processor reset.

In addition, if the sensor goes low when the backup transistor is on (indicating that the solenoid had disengaged under the low power) the microcomputer will try to re-engage the solenoid by repeating the sequence (i.e. by turning on the main transistor again). It will only do this one more additional time (i.e. two tries total). If it goes low after the 2nd restart, it will indicate a fault with bit 3. **(Note: if after 1 restart, the timing finishes, the process is successful and you need to reset the bit that counts these faults.)**

Finally, if the solenoid is turned off and the optical sensor remains on for approximately 10 seconds, a fault is also indicated.

Additional Faults

The 4 modes listed above are the only modes allowed. If the octal switch is set to any other number, this is an incorrect mode. This is indicated on the indicator LEDs by having the bit 3 (FAULT) on and the (incorrect) mode indicated in the lower 3 LEDs. Again, returning from any fault (including mode faults) requires a processor reset.

Summary of the Operation

- On processor reset, nothing happens until the green button is pressed. (indicator LEDs 0000)

- The octal switch is changed and the green button is pressed.

- Mode 1 (indicator LEDs 0001)
    - Press the red button, the solenoid engages.
    - Press the red button again, the solenoid disengages.
    - Repeats on and off with the red button.
    - Press the green button and a new mode is entered.

- Mode 2 (indicator LEDs 0010)
    - Read the value on the control pot
    - Press the red button, the solenoid engages for ¼ the value of the control pot in seconds.
    - Press the red button again before the timing finishes, the timing sequence restarts.
    - After finishing, press the red button again to repeat the process.
    - After finishing, press the green button to switch to a new mode.
    - If the reading of the A/D converter is 0, a fault is indicated.

- Mode 3 (indicator LEDs 0011)
    - Read the value on the control pot
    - Press the red button, the control becomes active.
    - If the value on the A/D converter is greater than 70 hex, the solenoid engages
    - The A/D is read continuously. When the value is greater than 70 hex, the solenoid engages. When the value is less than 70 hex, the solenoid retracts.
    - Press the red button again to stop the control.
    - When control is active, the indicator flashes.
    - With control inactive, press the green button to switch to a new mode.
    - If the reading of the A/D converter is 0, a fault is indicated.

- Mode 4 (indicator LEDs 0100)
    - Read the value on the control pot
    - Press the red button, the solenoid engages with the main transistor.
    - As soon as the optical sensor indicates that the solenoid has retracted, turn on the reduced transistor and turn off the main transistor.
    - The reduced transistor stays on for ¼ the value of the control pot in seconds.

    - Pressing the red button again before the timing finishes does not restart the timing sequence.
    - If the reading of the A/D converter is 0, a fault is indicated.
    - If the optical sensor does not indicate that the solenoid has retracted in 10 seconds, turn off the main transistor and indicate a fault.   (indicator LEDs 1011)
    - If the optical sensor indicates that the solenoid has disengaged when the reduced transistor in on, restart the whole sequence again (one time). If the optical sensor indicates that the solenoid has disengaged a second time when the reduced transistor in on, indicate a fault.   (indicator LEDs 1011)
    - If the solenoid is turned off and the optical sensor indicates that the solenoid is still retracted in 10 seconds, also indicate a fault.   (indicator LEDs 1011)
    - After finishing successfully, press the red button again to repeat the process.
    - After finishing successfully, press the green button to switch to a new mode.
    - If a fault, the microcomputer has to be reset with the black reset switch (green and red buttons are ignored).

- Mode 0 and 5 to 7   (indicator LEDs 1xxx where xxx is the mode number)
    - These modes are errors (they do not exist). The solenoid is disengaged (if it is engaged) and the microcomputer has to be reset with the reset switch (green and red buttons are ignored).

Requirements

The design of the embedded code is completely under your control. You should give some thought as to what you want to do before you start coding. Try to understand the different modes, what they have in common and how they are different. You should consider using subroutines for the common parts.

Successful completion of this case study involves:

- **Programming and successfully demonstrating each of the modes.**

- **Submitting successful Assembly code which adheres to the "Software Standard", is efficient and uses comments liberally. Grading specifics will be given with the "Software Standard". Elegance of the program, its efficiency in program size and execution time, will be considered.**

- **Answering the following questions.**

Questions:

a) Why should the solenoid require time to retract? Think in terms both of the mechanical system and the equivalent electric circuit for the solenoid (which is an inductor in series with a resistor). The force on a solenoid is typically proportional to the current squared but is typically inversely proportional to the magnetic gap (i.e. for a constant current, the force goes up as it retracts).

b) Assuming that the equivalent circuit for the solenoid is simply an inductor and resistor in series, write the differential equation which relates the current to the applied voltage (i.e. assume that the voltage is the input and the current is the output). Write the transfer function for this (i.e. derive the admittance, the inverse of impedance) and the frequency response.

c) With the discussion of the solenoid given in part a and b, approximately sketch the step response of the solenoid using what you learned for lag circuits. Assume that you apply a step in the applied voltage and roughly sketch the current and force assuming no motion of the armature.

d) List 3 other faults that perhaps should be detected. (Hint: this may require measuring other parameters, for example, the current through the solenoid or the force on the bumper using a force transducer.)

e) Discuss how you might use a keypad to enter the time that the solenoid would retract rather than using the potentiometer. (For example, they way that you typically set cook time on a microwave oven.) What would be the advantages of using a keypad for potential users of the system (or why do you think toaster ovens have knobs and microwave ovens have keypads)?

f) If there was a 2-line LCD display connected to the microcomputer, what 2 things might you want to display?

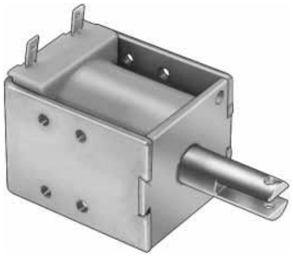
g) Give an example of an on/off consumer product or industrial process which behaves like the solenoid in Mode 2 (except the light control discussed in lecture).

h) Give an example of an on/off consumer product or industrial process which behaves like the solenoid in Mode 3 (except the home heater control discussed in lecture).

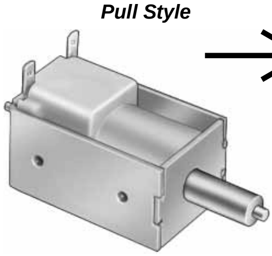
i) Give an example of an on/off consumer product or industrial process which behaves like the solenoid in Mode 4 (except the motor starter discussed in lecture). (Hint: either think of a system which is typically turned on, draws a lot of power and remains on for a very long time before being turned off or a system which might automatically restart.)

j) List two other examples of on/off applications in a consumer product or industrial process. List one that does not involve control (i.e. where something is turned on and off but the system gets no feedback on whether or not this actually happens). List a second that involves control (i.e. where there is feedback on whether or not the system actually turned on or off).

More About Linear Solenoids



Pull Style

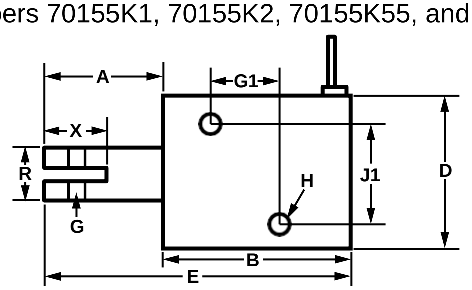


Push Style

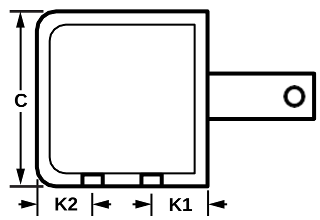
MCM Part No.	Input Voltage	Max. Stroke	Force, oz. @ ⅛" Stroke	Power Rating (Watts)	Coil Resistance (Ohms) 12V Model	24V Model	120 VAC Model
***Pull Style**—Intermittent Duty*							
70155K1	DC	½"	20	11.5	12.5	50.1	—
70155K3	DC	½"	43	19.0	7.6	30.3	—
70155K5	DC	1"	120	38.0	3.8	15.2	—
70155K72	120 VAC	½"	14	22	—	—	232.1
70156K47	120 VAC	⅞"	24	40	—	—	85
70155K41	120 VAC	⅞"	45	60	—	—	32.2
***Pull Style**—Continuous Duty*							
70155K2	DC	½"	11	5.0	28.8	115.0	—
70155K4	DC	½"	29	8.0	18.0	72.0	
70155K6	DC	1"	76	11.0	13.1	52.4	—
70155K55	120 VAC	½"	12	8	—	—	400
70155K48	120 VAC	⅞"	12	12	—	—	200
70155K42	120 VAC	⅞"	14	10	—	—	133
***Push Style**—Intermittent Duty*							
70155K11	DC	½"	42	19.0	7.6	30.3	—
70155K13	DC	1"	40	30.0	7.4	30.3	—
70155K65	120 VAC	½"	14	22	—	—	220
70155K61	120 VAC	⅞"	20	40	—	—	85
***Push Style**—Continuous Duty*							
70155K12	DC	½"	16	8.0	18.0	72.0	—
70155K14	DC	1"	20	29.0	30.3	117.0	—
70155K66	120 VAC	½"	9	8	—	—	400
70155K62	120 VAC	⅞"	10	12	—	—	200

Pull Style

For part numbers 70155K1, 70155K2, 70155K55, and 70155K72.



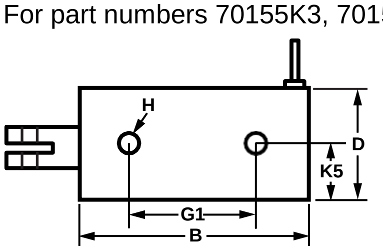
Side View



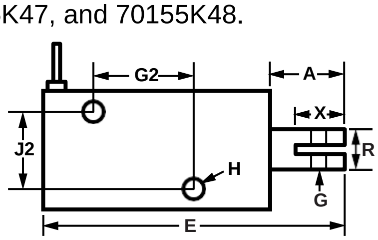
Top View

Retracted Rod Lg. (A)	Frame Lg. (B)	Frame Wd. (C)	Frame Ht. (D)	Overall Lg., Rod Retracted (E)	Rod Cutaway Depth (X)	Rod Hole Dia. (G)	Rod Dia. (R)	Mounting Hole Size (H)	Mounting Holes, Center-to-Center (G1)	(J1)	Mounting Holes, Center-to-Frame Edge (K1)	(K2)
.612"	1.13"	1.19"	.94"	1.74"	.41"	.096"	.31"	6-32	.406"	.625"	.41"	.31"

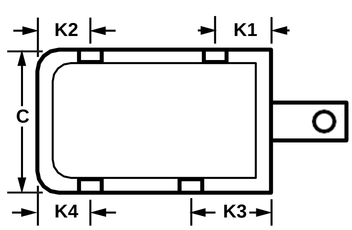
For part numbers 70155K3, 70155K4, 70155K47, and 70155K48.



Side View



Side View



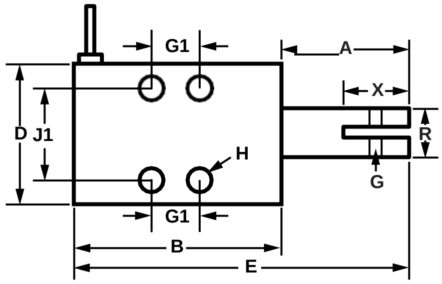
Top View

Retracted Rod Lg. (A)	Frame Lg. (B)	Frame Wd. (C)	Frame Ht. (D)	Overall Lg., Rod Retracted (E)	Rod Cutaway Depth (X)	Rod Hole Dia. (G)	Rod Dia. (R)	Mounting Hole Size (H)	Mounting Holes, Center-to-Center (G1)	(G2)	(J2)	Mounting Holes, Center-to-Frame Edge (K1)	(K2)	(K3)	(K4)	(K5)
.62"	1.846"	1.189"	.94"	2.466"	.41"	.096"	.31"	6-32	1"	.81"	.63"	.42"	.426"	.63"	.41"	.47"

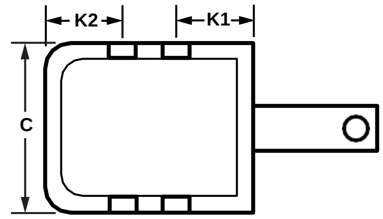
More About Linear Solenoids

Pull Style *(Cont.)*

For part numbers 70155K5, 70155K6, 70155K41, and 70155K42.



Side View

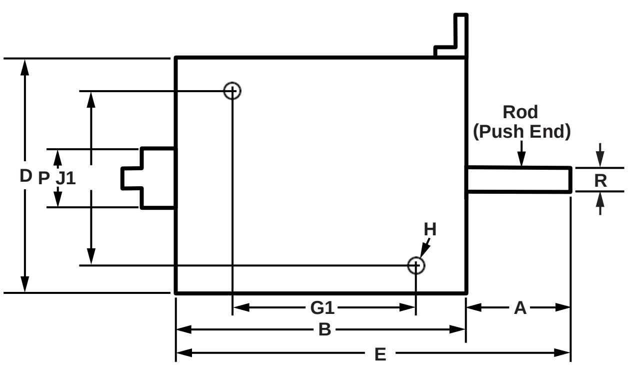


Top View

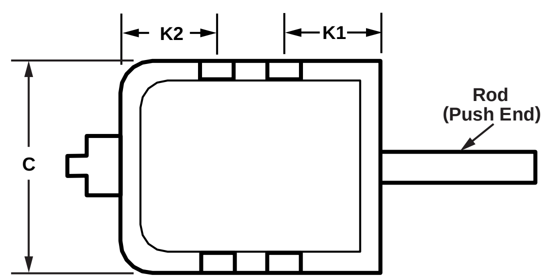
Retracted Rod Lg. (A)	Frame Lg. (B)	Frame Wd. (C)	Frame Ht. (D)	Overall Lg., Rod Retracted (E)	Rod Cutaway Depth (X)	Rod Hole Dia. (G)	Rod Dia. (R)	Mounting Hole Size (H)	Mounting Holes, Center-to-Center (G1)	Mounting Holes, Center-to-Center (J1)	Mounting Holes, Center-to-Frame Edge (K1)	Mounting Holes, Center-to-Frame Edge (K2)
1.165"	2"	1.63"	1.44"	3.165"	.69"	.128"	.437"	8-32	.5"	.936"	.87"	.63"

Push Style

For part numbers 70155K65 and 70155K66.



Side View



Top View

Extended Push End Lg. (A)	Frame Lg. (B)	Frame Wd. (C)	Frame Ht. (D)	Overall Lg., Push End Extended (E)	Rod (Push End) Dia. (R)	(P)	Mounting Hole Size (H)	Mounting Holes, Center-to-Center (G1)	Mounting Holes, Center-to-Center (J1)	Mounting Holes, Center-to-Frame Edge (K1)	Mounting Holes, Center-to-Frame Edge (K2)
.5"	1.13"	1.19"	.94"	1.63"	.093"	.31"	6-32	.406"	.625"	.32"	.41"

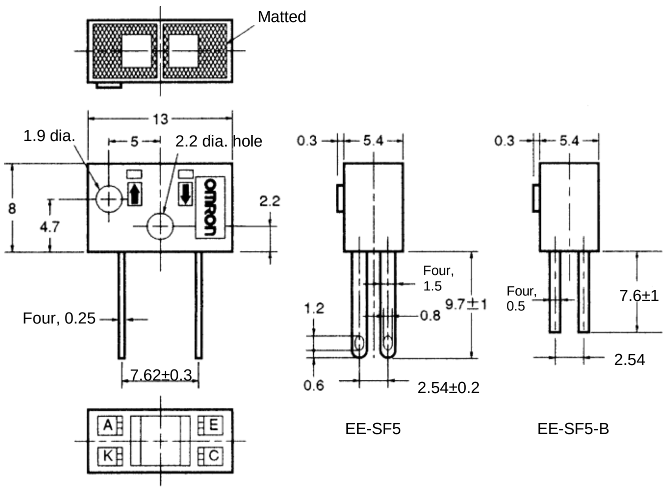
OMRON

EE-SF5(-B)

Photomicrosensor (Reflective)

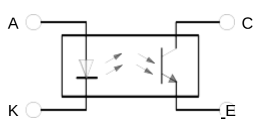
■ Dimensions

Note: All units are in millimeters unless otherwise indicated.



EE-SF5 EE-SF5-B

Internal Circuit



Terminal No.	Name
A	Anode
K	Cathode
C	Collector
E	Emitter

Unless otherwise specified, the tolerances are as shown below.

Dimensions	Tolerance
3 mm max.	±0.3
$3 < mm \leq 6$	±0.375
$6 < mm \leq 10$	±0.45
$10 < mm \leq 18$	±0.55
$18 < mm \leq 30$	±0.65

■ Features

- Dust-tight model with a 5 mm sensing distance.
- With a visible-light intercepting filter which allows objects to be sensed without being greatly influenced by the light radiated from fluorescent lamps.
- Mounted with M2 screws.
- Model with soldering terminals (EE-SF5).
- Model with PCB terminals (EE-SF5-B).

■ Absolute Maximum Ratings (Ta = 25°C)

Item		Symbol	Rated value
Emitter	**Forward current**	I_F	50 mA (see note 1)
	Pulse forward current	I_{FP}	1A (see note 2)
	Reverse voltage	V_R	4V
Detector	**Collector- Emitter voltage**	V_{CEO}	30 V
	Emitter- Collector voltage	V_{ECO}	---
	Collector current	I_C	20 mA
	Collector dissipation	P_C	100 mW (see note 1)
Ambient temperature	**Operating**	Topr	--25°C to 80°C
	Storage	Tstg	--30°C to 80°C
Soldering temperature		Tsol	260°C (see note 3)

Note: 1. Refer to the temperature rating chart if the ambient temperature exceeds 25°C.

2. The pulse width is 10 µs maximum with a frequency of 100 Hz.

3. Complete soldering within 10 seconds.

■ Ordering Information

Description	Part number
Photomicrosensor (Reflective)	**EE-SF5(-B)**

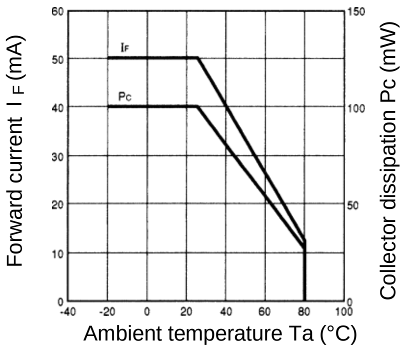
■ Electrical and Optical Characteristics (Ta = 25°C)

Item		Symbol	Value	Condition
Emitter	**Forward voltage**	V_F	1.2 V typ., 1.5 V max.	I_F = 30 mA
	Reverse current	I_R	0.01 µA typ., 10 µA max.	V_R = 4 V
	Peak emission wavelength	λ_P	940 nm typ.	I_F = 20 mA
Detector	**Light current**	I_L	200 µA min., 2,000 µA max.	I_F = 20 mA, V_{CE} = 10 V White paper with a reflection ratio of 90%, d = 5 mm (see note)
	Dark current	I_D	2 nA typ., 200 nA max.	V_{CE} = 10 V, 0 ℓx
	Leakage current	I_{LEAK}	2 µA max.	I_F = 20 mA, V_{CE} = 10 V with no reflection
	Collector- Emitter saturated voltage	V_{CE} (sat)	---	---
	Peak spectral sensitivity wavelength	λ_P	850 nm typ.	V_{CE} = 10 V
Rising time		tr	30 µs typ.	V_{CC} = 5 V, R_L = 1 kΩ, I_L = 1 mA
Falling time		tf	30 µs typ.	V_{CC} = 5 V, R_L = 1 kΩ, I_L = 1 mA

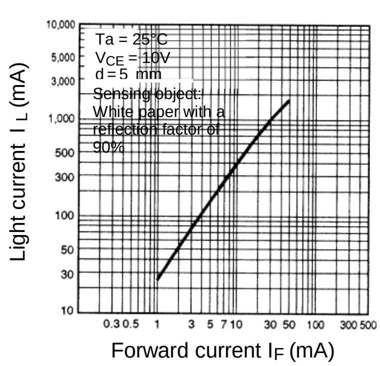
Note: The letter “d” indicates the distance between the top surface of the sensor and the sensing object.

■ Engineering Data

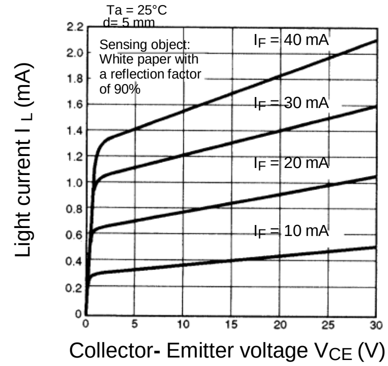
Forward Current vs. Collector Dissipation Temperature Rating



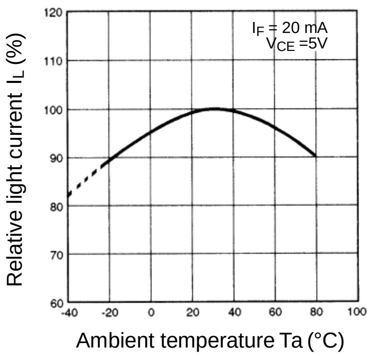
Light Current vs. Forward Current Characteristics (Typical)



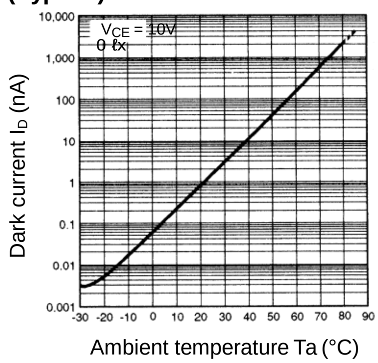
Light Current vs. Collector- Emitter Voltage Characteristics (Typical)



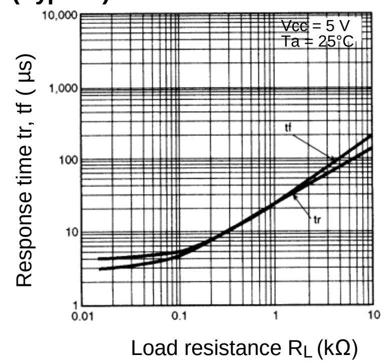
Relative Light Current vs. Ambient Temperature Characteristics (Typical)



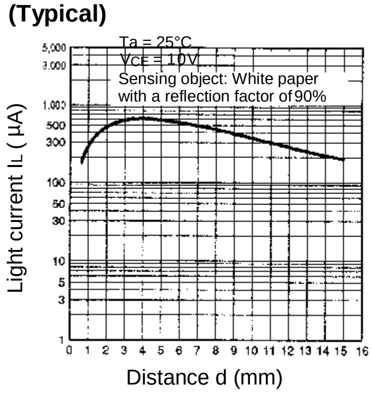
Dark Current vs. Ambient Temperature Characteristics (Typical)



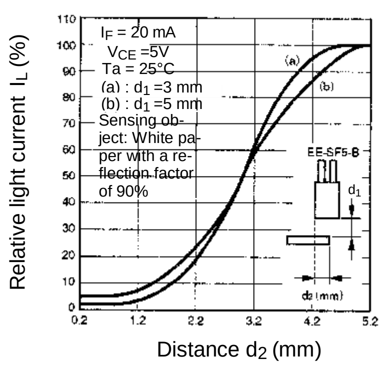
Response Time vs. Load Resistance Characteristics (Typical)



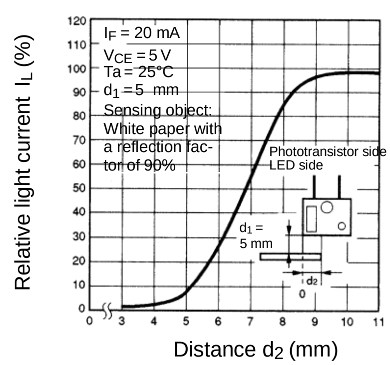
Sensing Distance Characteristics (Typical)



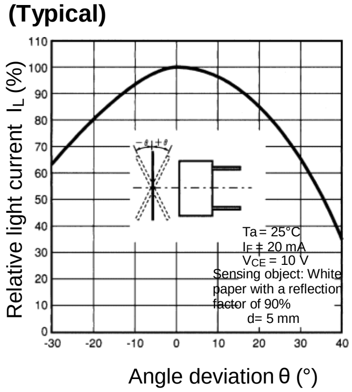
Sensing Position Characteristics (Typical)



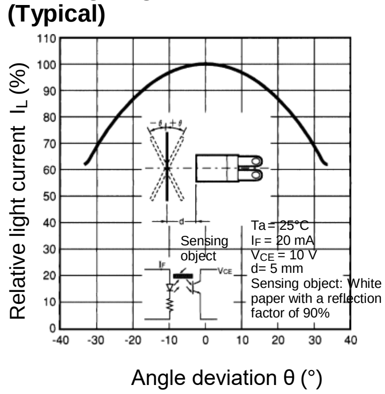
Sensing Position Characteristics (Typical)



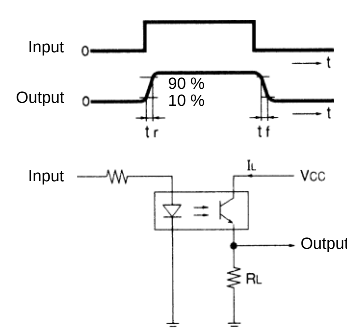
Sensing Angle Characteristics (Typical)



Sensing Angle Characteristics (Typical)



Response Time Measurement Circuit

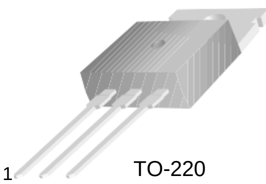


FAIRCHILD SEMICONDUCTOR®

TIP120/121/122

Medium Power Linear Switching Applications

- Complementary to TIP125/126/127

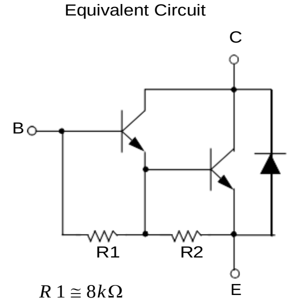


1 TO-220

1. Base 2.Collector 3.Emitter

NPN Epitaxial Darlington Transistor

Equivalent Circuit



$R1 \cong 8k\Omega$
$R2 \cong 0.12\ k\Omega$

Absolute Maximum Ratings T_C=25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CBO}	Collector-Base Voltage : TIP120 : TIP121 : TIP122	60 80 100	V V V
V_{CEO}	Collector-Emitter Voltage : TIP120 : TIP121 : TIP122	60 80 100	V V V
V_{EBO}	Emitter-Base Voltage	5	V
I_C	Collector Current (DC)	5	A
I_{CP}	Collector Current (Pulse)	8	A
I_B	Base Current (DC)	120	mA
P_C	Collector Dissipation (T_a=25°C)	2	W
	Collector Dissipation (T_C=25°C)	65	W
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	- 65 ~ 150	°C

Electrical Characteristics T_C=25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Max.	Units
V_{CEO}(sus)	Collector-Emitter Sustaining Voltage : TIP120 : TIP121 : TIP122	I_C = 100mA, I_B = 0	 60 80 100		 V V V
I_{CEO}	Collector Cut-off Current : TIP120 : TIP121 : TIP122	 V_{CE} = 30V, I_B = 0 V_{CE} = 40V, I_B = 0 V_{CE} = 50V, I_B = 0		 0.5 0.5 0.5	 mA mA mA
I_{CBO}	Collector Cut-off Current : TIP120 : TIP121 : TIP122	 V_{CB} = 60V, I_E = 0 V_{CB} = 80V, I_E = 0 V_{CB} = 100V, I_E = 0		 0.2 0.2 0.2	 mA mA mA
I_{EBO}	Emitter Cut-off Current	V_{BE} = 5V, I_C = 0		2	mA
h_{FE}	* DC Current Gain	V_{CE} = 3V,I_C = 0.5A V_{CE} = 3V, I_C = 3A	1000 1000		
V_{CE}(sat)	* Collector-Emitter Saturation Voltage	I_C = 3A, I_B = 12mA I_C = 5A, I_B = 20mA		2.0 4.0	V V
V_{BE}(on)	* Base-Emitter ON Voltage	V_{CE} = 3V, I_C = 3A		2.5	V
C_{ob}	Output Capacitance	V_{CB} = 10V, I_E = 0, f = 0.1MHz		200	pF

* Pulse Test : PW≤300μs, Duty cycle ≤2%

Typical characteristics

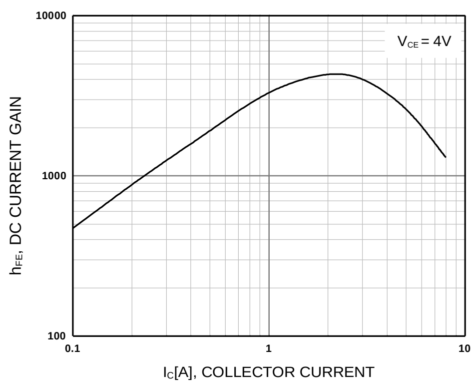


Figure 1. DC current Gain

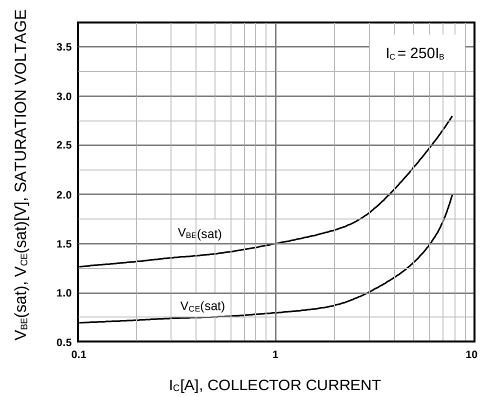


Figure 2. Base-Emitter Saturation Voltage Collector-Emitter Saturation Voltage

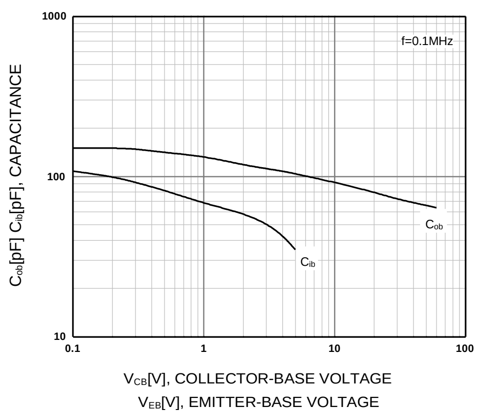


Figure 3. Output and Input Capacitance vs. Reverse Voltage

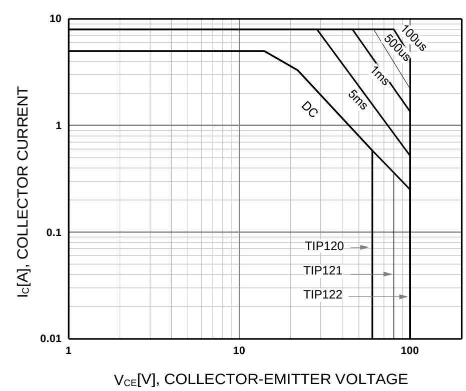


Figure 4. Safe Operating Area

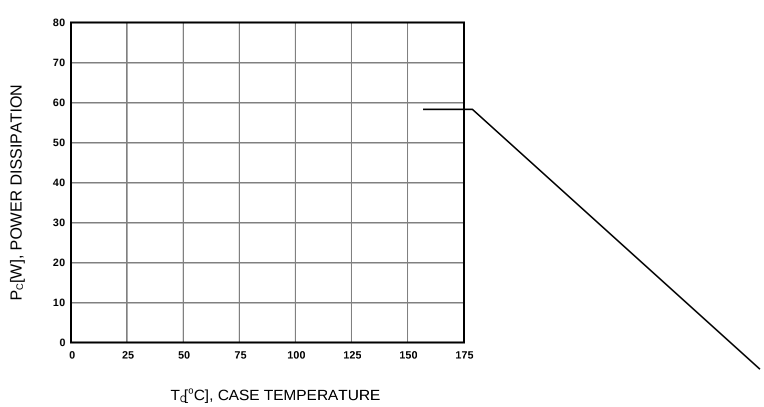
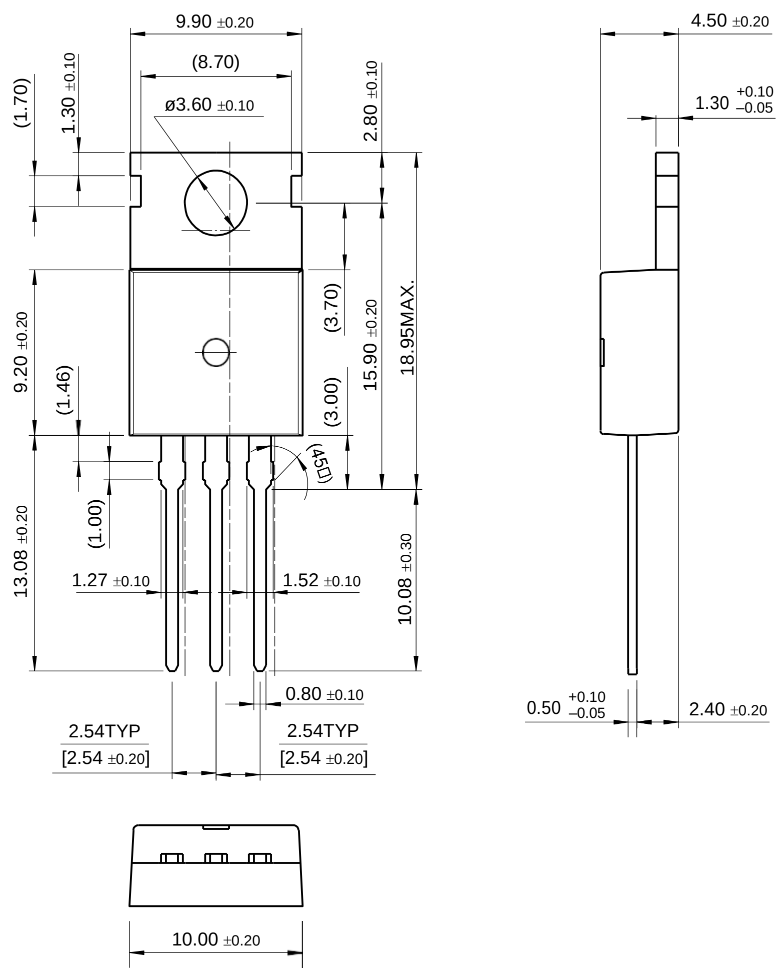


Figure 5. Power Derating

Package Demensions

TO-220



Dimensions in Millimeters

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DenseTrench™	GTO™	PowerTrench®	SuperSOT™-8
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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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Datasheet Identification	Product Status	Definition
Advance Information	Formative or In Design	This datasheet contains the design specifications for product development. Specifications may change in any manner without notice.
Preliminary	First Production	This datasheet contains preliminary data, and supplementary data will be published at a later date. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
No Identification Needed	Full Production	This datasheet contains final specifications. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
Obsolete	Not In Production	This datasheet contains specifications on a product that has been discontinued by Fairchild semiconductor. The datasheet is printed for reference information only.

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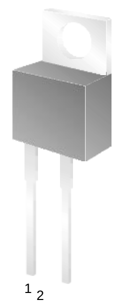
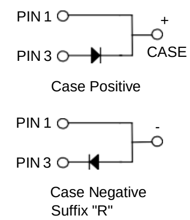
FES16AT - FES16JT

Features

- Low forward voltage drop.
- High surge current capacity.
- High current capability.
- High reliability.



TO-220AC



Fast Rectifiers (Glass Passivated)

Absolute Maximum Ratings*

T_A = 25°C unless otherwise noted

Symbol	Parameter	Value								Units
		16AT	16BT	16CT	16DT	16FT	16GT	16HT	16JT	
V_{RRM}	Maximum Repetitive Reverse Voltage	50	100	150	200	300	400	500	600	V
$I_{F(AV)}$	Average Rectified Forward Current, .375 " lead length @ T_A= 100°C	16								A
I_{FSM}	Non-repetitive Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave	250								A
T_{stg}	Storage Temperature Range	-65 to +150								V
T_J	Operating Junction Temperature	-65 to +150								pF

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	7.81	W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	16	°C/W
$R_{\theta JL}$	Thermal Resistance, Junction to Lead	1.2	°C/W

Electrical Characteristics

T_A = 25°C unless otherwise noted

Symbol	Parameter	Device								Units
		16AT	16BT	16CT	16DT	16FT	16GT	16HT	16JT	
V_F	Forward Voltage @ 8.0A	0.95				1.3		1.5		V
t_{rr}	Reverse Recovery Time I_F = 0.5 A, I_R = 1.0 A, I_{RR} = 0.25 A	35				50				ns
I_R	Reverse Current @ rated V_R T_A = 25°C T_A = 100°C	10 500								µA µA
C_T	Total Capacitance V_R = 4.0. f = 1.0 MHz	170						145		pF

Typical Characteristics

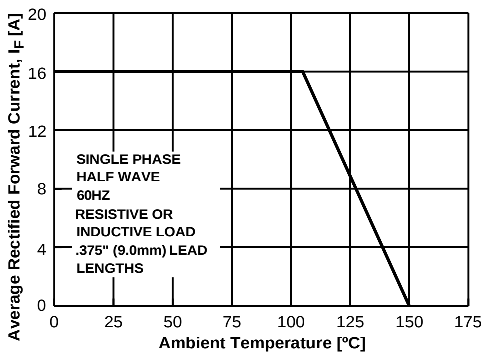


Figure 1. Forward Current Derating Curve

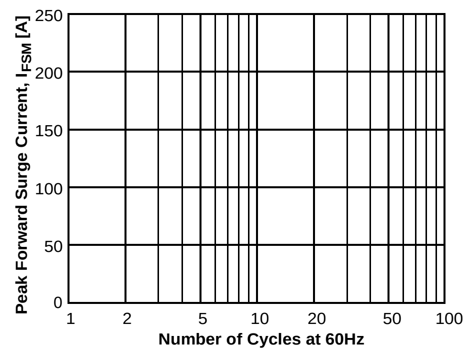


Figure 2. Non-Repetitive Surge Current

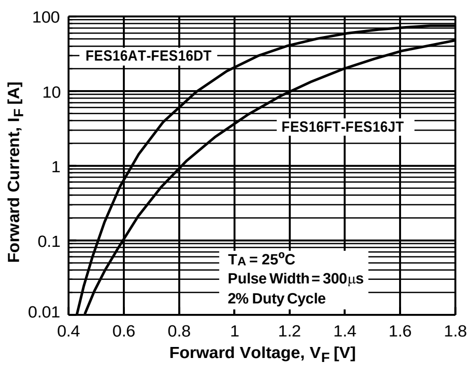


Figure 3. Forward Voltage Characteristics

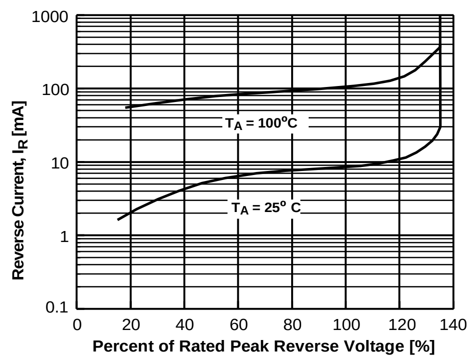


Figure 4. Reverse Current vs Reverse Voltage

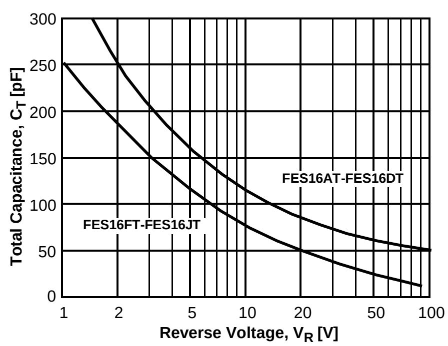
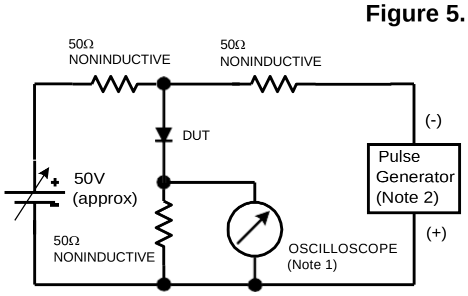
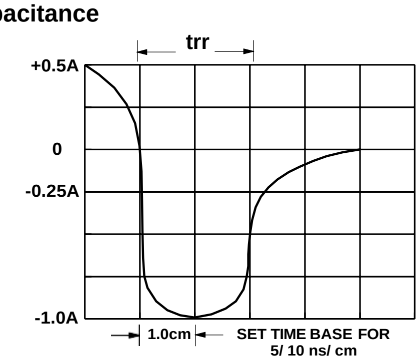


Figure 5. Total Capacitance





Reverse Recovery Time Characterstic and Test Circuit Diagram