School of Electronic &
Electrical Engineering
FACULTY OF ENGINEERING

UNIVERSITY OF LEEDS

ELEC2130 *Case Study Assignment*

Template for the Case Study Assignment Report

For your ELEC2130 case study assignment, you are required to complete and submit the template report below. The 'answer boxes' in the template will expand as required. For steps (1) and (2) circuit diagrams should be included in your report. You may use Multisim or any other suitable means to draw circuit diagrams. Scanned hand-drawn diagrams are acceptable, providing they are legible. **All other text *must* be machine-readable.**

The file size limit for your submission is 20 Mb. Please take care to ensure that your report file does not exceed this limit by creating unnecessarily large bitmaps/image files for your circuit diagrams.

Important! The Case Study Assignment is an individual exercise. You may have worked with a partner during the laboratory sessions, but this assignment must be completed *individually.*

Do not reproduce any text or diagrams directly from the ELEC2130 module resources (lecture handouts, lab notes, case study examples, etc). Marks will not be awarded for reprinting the module resources!

Please be aware that every submission is automatically checked for similarity to every other submission, internet resources and a repository of all previously submitted work.

Case Study Reports should be completed electronically and then submitted via the VLE.

You should receive an e-mail receipt from the Turnitin system to confirm that your work has been properly submitted.

Name and SID:

PIERRE TABET

Step 1: Signal conditioning for the Doppler signal

The nominal output from the Doppler unit is a low-level (≈ 100 mV) sinusoidal AC signal. Two main frequency components are present at the output: the sum frequency (≈ 100 kHz) and the difference frequency (≈ 0..500 Hz). There is also the original ultrasonic transmitted frequency of 50 kHz. The difference frequency is proportional to the speed of moving objects (people).

The original transmitted frequency and the sum frequency need to be filtered out. It is suggested that these signals should be attenuated by around 80 dB relative to a nominal difference frequency of about 500 Hz.

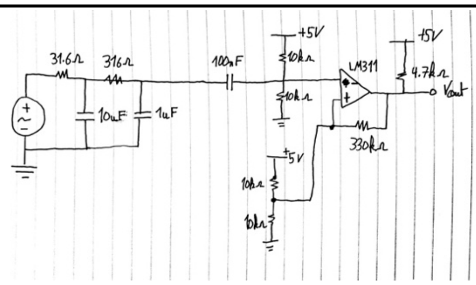
The microcontroller will need to measure the remaining difference frequency using one of the frequency counting techniques discussed in the course notes (Section 5.3).

Propose a suitable signal conditioning circuit that will (a) filter and (b) prepare the Doppler signal for the microcontroller by converting it to a suitable 5 V logic-compatible signal.

- Provide a circuit diagram.
- State any assumptions you have made.
- Explain *how* your circuit is intended to work and justify your component values.

NB – this section will be the most complex in your design, so pay particular attention to it!

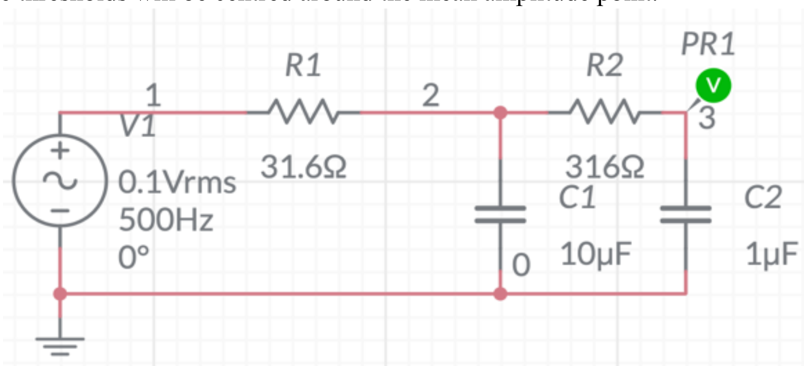
[Hint: for the filter, think about the roll-off required between (a) the nominal signal frequency and (b) the original transmitted signal of 50 kHz.]



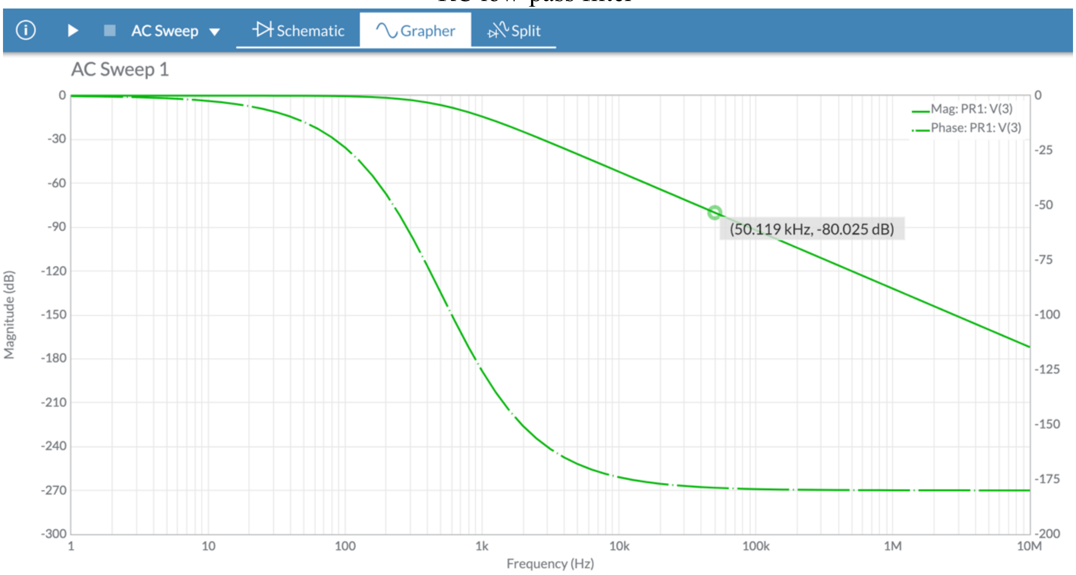
LM311 is powered by a 5V power supply.

"Typically, a walking person will have a speed in the region of 3mph", I am assuming movement of the approaching people will be perpendicular to the Doppler radar. So at this speed we will get a difference frequency around 391Hz. The specification also requests that it be made possible to decide in the software "whether the measurement indicates a real movement or not" therefore analysing 0-500Hz range allows for flexibility.

Filter (How it works and assumptions):
I have chosen to use a passive (RC) low-pass filter, because it is simple to use and does not need to be additionally powered. It works because at frequencies above the cut off frequency the capacitors impedances start to drop significantly meaning less voltage is dropped across them relatively to the resistors. However in order to achieve 80 dB of attenuation relative to the nominal difference frequency of 500Hz, I need 40dB/decade (maths below). This means it would have to be a two pole filter. A consequence of this is that the gain at the cut off frequency (fc) will be 0.5Vin (0.7071 x 0.7071=0.5), however the sine wave is still large enough to cross the upper and lower thresholds of the Schmitt trigger as those thresholds will be centred around the mean amplitude point.

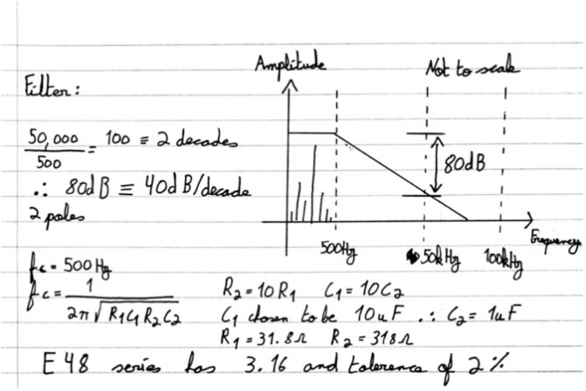


RC low-pass filter



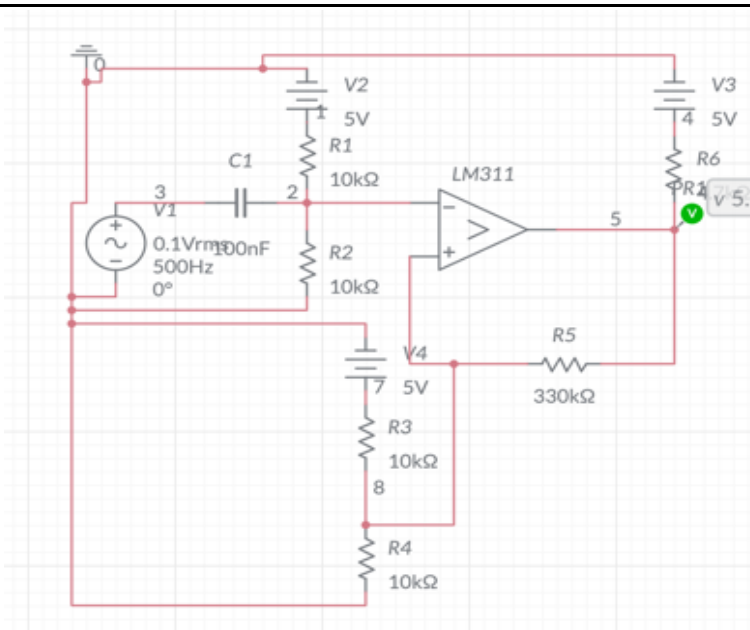
AC sweep graph with Magnitude (full line) and Phase (dotted line)

Filter (Justification of component values):
I chose initial values of capacitors and calculated values for resistors as this was more convenient. As you can see in the bode plot at -80dB the frequency is 50,000 Hz. Also in order to reduce the loading effect of the first stage on the second stage, I made the impedance of the second stage 10 times greater then the first. So R_2=10R_1 and C_1=10C_2. I am choosing resistors from the E48 series as it has a lower tolerance (2%) then the E12 (10%) series which is important in insuring the actual cut off frequency is accurate.



Preparing the Doppler signal for the microcontroller (How it works and assumptions):
In order to satisfy the ability to decide in software, I have decided to use a zero-crossing detection (where ‘zero’ is set at mean amplitude point of the voltage that comes out of the filter). This allows the sine wave to be converted into a digital (square-wave) signal which can then be fed into the microcontroller. It works because if the input signal is larger than the reference the output will be low and if it is greater it will be high. The microcontroller will then use frequency counting, where it counts the number of periods in the square-wave in a given time and compares it to an arbitrary ‘actual movement’ frequency.

There are several potential issues we have to deal with in preparation. In order to deal with slew rate limitations, saturation and possible limitation in the differential input range I will use a comparator IC (LM311). Another issue is noise in the signal causing multiple transitions; this is why I have chosen a Schmitt trigger which allows for two thresholds separated by a small distance around the reference. And because it is of equal distance from the reference voltage, the frequency of the square wave will still be the same of the sine wave, it will just have shifted slightly which is not important. The third issue is that microcontrollers can typically only work with positive voltages, therefore I will introduce a DC voltage bias to insure the frequency can be counted properly.



LM311 is powered by a 5V power supply.

Preparing the Doppler signal for the microcontroller (Justification of component values):
I used a pull up resistor of 4.7 k Ω because the LM311 has an open-collector output circuit. I used a high impedance potential divider (two 10k Ω resistors) to make sure that the DC bias current was small. I used a 100nF capacitor (C1) to insure the cut off frequency of the inevitable high-pass network was very low (less then 90Hz) and that there is no DC current flowing towards my filter from the pull up power supply. I used a relatively large feedback resistor (330k Ω) and my calculated thresholds will be 2.5 +_ 0.037V. This allows the digital signal to be produced in the passband up until 500Hz (even though at this point it is -6dB from the filter). But beyond this the digital signal stops oscillating as you can see in diagram 2.

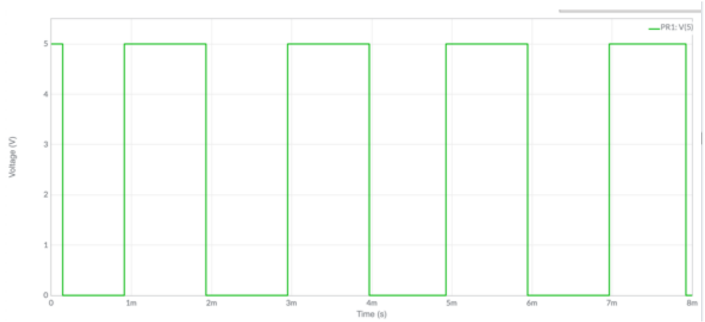


Diagram 1

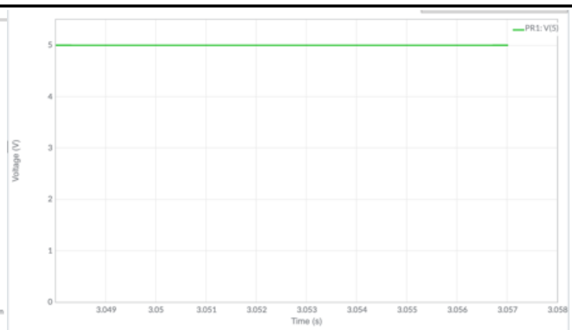


Diagram 2

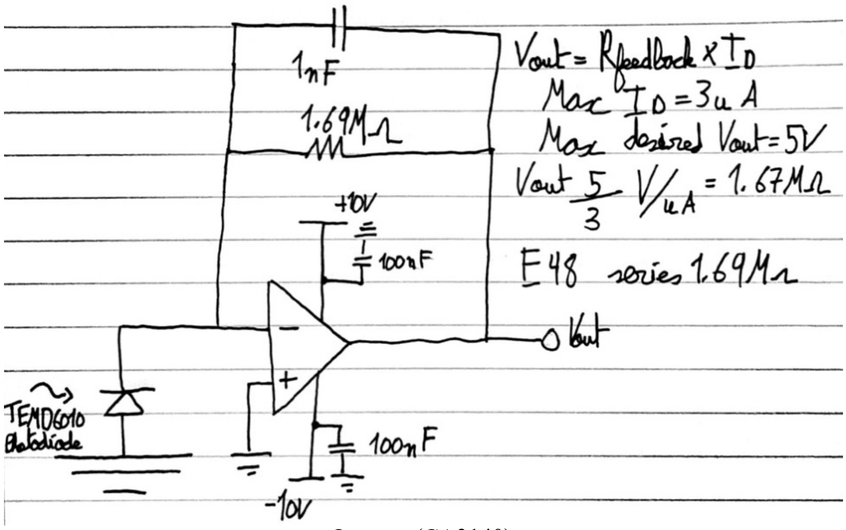
Step 2: Signal conditioning for the ambient light sensor

Using the data sheet, propose a suitable signal conditioning circuit that will allow the photodiode to produce a DC signal proportional to the ambient light, so that it can be digitised by the microcontroller.

Assume that daytime ambient light produces an incident power on the photodiode equivalent to 20 mW/cm^2. Design your circuit to produce an output voltage equal to the full scale value (FSV) of the microcontroller's ADC under these light conditions.

- Provide a circuit diagram.
- State any assumptions you have made.
- Explain *how* your circuit is intended to work.
- What might be the output of your circuit if the ambient light conditions were completely dark?

Circuit diagram:



Op-amp (CA3140)

Assumptions:
I chose to use the unbiased (photovoltaic) mode because it is more suitable in this application. More specifically in this case we are concerned on whether or not external lighting is needed. This is because the time that it takes lighting conditions to change is usually over hours and therefore speed is not a priority, precision is (at least more than speed). Also the photovoltaic mode has a few additional benefits, less voltage across diode means less current though the resistor within the diode. This means there will be less dark current compared to the biased mode, there will be less noise and the output will be more linear. There still will be a dark current though due to background radiation.
Micro-controller- A specific microcontroller is not identified in this specification, but the ADC channels will have a FSV of 5V. Most microcontrollers ADCs are 10 bit. This is equivalent to 0.098% resolution, which is definitely adequate enough for the purpose of determining when additional illumination is required or not.
TEMD6010FX01 photodiode- There is no single conversion factor between lx and W/m^2 ; it depends on the wavelength. For a light source with a mixture of wavelengths such as sunlight we can assume 130 lm/W[1]. The radiant sensitive area of the photodiode is $0.0027cm^2$ meaning $5.4*10^{-5}$ W is incident. 130* $5.4*10^{-5} = 7.02*10^{-3}$ lm . 1 lx = 1 lm/m^2 so we have $7.02*10^{-3}$ lm / $2.7*10^{-7}$ m = 26,000 lx. From the datasheet table we can then deduce that 26,000 lx results in the reverse light current of 3μA as it surpasses the maximum reading on the graph.

[1] https://journals.sagepub.com/doi/abs/10.1177/14771535850170040401

How circuit is intended to work:
The incident radiation induces a current and because there is a current path provided the interaction behaves as a current source that is proportional to the incident radiation. The photodiode is connected so that the cathode is placed at ground. The anode is connected to the inverting pin of the Op-amp (CA3140E). The non inverting pin is grounded. This creates a low impedance load (because of the virtual ground principle) for the input of the op-amp. This keeps the photodiode voltage low. As mentioned above the photodiode is operating in the unbiased mode. The high gain insures that the current is equal to the current going through the feedback resistor. $-I_D=V_{out}/R_f$ where I_D is the current flowing from the photodiode towards the op amp. The capacitor in parallel with R_f is there to improve stability at higher frequencies, and the bypass capacitors at both power supplies short circuit high frequency noise and prevent internal power supply instability.

Ambient light conditions are completely dark:
The photodiode produces a maximum dark current of 5 nA due to background radiation (outside the visible spectrum). This would output a voltage of 8.45mV, we can digitally set what is defined as dark (requiring external lighting) on the microcontroller, it will probably be necessary to set “dark” at levels significantly above this as the camera needs to be able to capture the subjects in good lighting.

Step 3: Connecting the real time clock (RTC) IC

Using the data sheet, propose a suitable connection scheme for the RTC chip.

- Explain *briefly* (four or five sentences) *how* you would connect this device to the microcontroller.
- State any assumptions you have made.
- Mention which pins (on the RTC) need to be connected to the microcontroller.
- Comment on the manufacturer's provision for hardware read/write address *selection* and state which addresses are available for 'read' and which addresses are available for 'write'.
- *You do not need to supply a circuit diagram.*

Clock and calendar to Microcontroller connection:
I am only connecting two ports from the RTC to the microcontroller as the specification does not require setting alarms and data is going to be saved onto an SD card. SDA and SCL lines will be connected with two separate pull up resistors to a common +5V supply and there will be a capacitor between the power supply and ground. Both the SDA and SCL pins from the microcontroller and the RTC will be connected to their respective line. I have chosen a value of 4.7kΩ (E12 series) for the pull up resistors because the RTC works on a frequency of 100kbit/s.

Assumptions:
I chose 4.7kΩ because it will keep the rise time within 10% of the bit period and the sink current will be 1.1mA which is small enough for this standard mode device to sink. The microcontroller will be the bus master and control the clock line.

RTC Pins:
SDA: pin 5 SCL : pin 6

Read/Write:
Reading (in Hex): A1 or A3
Writing (in Hex): A0 or A2
It is the last select bit that decides if it is read or write.

Step 4: Connecting the keypad

Using the data sheet, propose a suitable connection scheme for the keypad.

- Explain *briefly* (four or five sentences) *how* you would connect this device to the microcontroller.
- *You do not need to supply a circuit diagram.*

The keypad is a 4 by 4 matrix and when one button is pressed it shorts the row to a column. I am going to make the assumption that the microcontroller does not have internal pull up resistors, so I will attach a 10kΩ pull up resistor between each row and a common +3.3V supply. Because I am assuming the input impedance at each port of the microcontroller to be around 100kΩ, the microcontroller will register a high state across the 4 input channels when none of the buttons are pressed. I will use 4 output ports and set them to a high in their default state (+3.3V). Each output will be connected to its own column. Then one by one relatively low frequency of a 10Hz I will scan through the four outputs and make one of them low at a time. By knowing which input was low when one of the outputs was set to zero you can identify the correct button. This is done using a simple if statements in software.

Step 5: Connecting the SD card

Using the data sheet for the SD card, and assuming a suitable card socket is used, propose a suitable connection scheme between the SD card and the microcontroller based on SPI mode.

- Explain *briefly* (four or five sentences) *how* you would connect this device to the microcontroller.
- Mention which pins (on the SD card) need to be connected to the microcontroller. State the *function* of each of these connections for the SPI mode.
- *You do not need to supply a circuit diagram.*

Firstly I will assume that the SD card socket is attached to a data logging shield. This is a buffer that protects the SD card from damage and is needed because I do not know if the output of the microcontroller has the same voltage level of the SD card (2V, max 3.6V). SPI uses a four-wire serial bus. In the case of this SD card, Pin 1 is Data Line 2, which is unused. Pin 2 is Data Line 3 which is used as a Chip select and will be connected to the SS port of the microcontroller. This is used so that the master (microcontroller) can select a slave device by selecting a logic zero. Pin 3- Command / Response is connected to the MOSI port. Pin 7 is connected to the MISO port. SPI takes advantage of these two pins by being a full duplex system. Every clock cycle (even when one-direction data is transferred over) the master sends a bit on the MOSI line and the slave reads it, and the slave sends one bit on the MISO for the master to read. Pin 4 will supply 2V, and Pin 6 supply a ground source. Pin 5 is the clock, and will be connected to an assigned SCK port on the microcontroller .Pin 8 is unused.

Step 6: Connecting the LCD

Using the data sheet for the LCD, propose a suitable connection scheme.

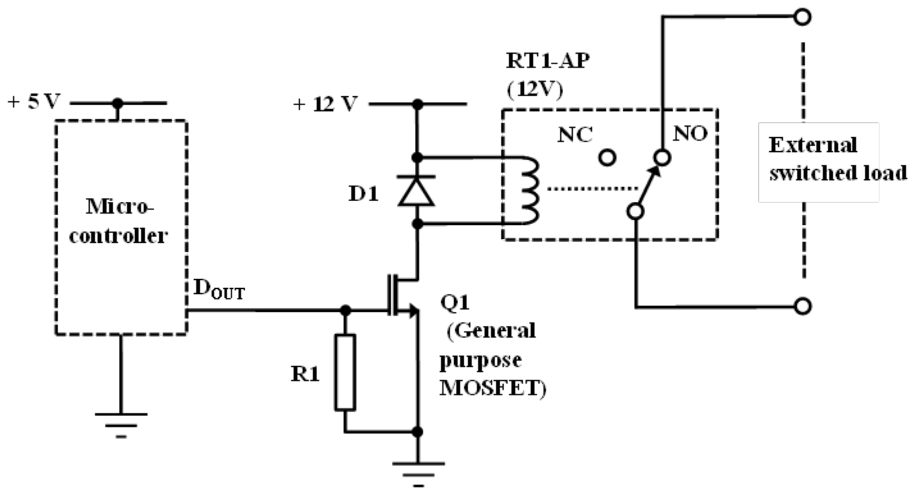
- Explain *briefly* (four or five sentences) *how* you would connect this device to a 5 V microcontroller.
- What does the information on Page 7 of the datasheet imply for connecting this device to a microcontroller based on 5 V logic levels?
- *You do not need to supply a circuit diagram.*

Cholesteric Display Module is SPI compatible. To power the device I will provide a 5V to V_{PWR} pin and ground source to V_{SS}. For the logic levels it ideally requires a 3.3V for a high logic supply. Since we have a 5V microcontroller, I will just use a simple potential divider. A 1kΩ and a 2kΩ will be placed between the digital output pins and ground and the connection for the display port will be between the two resistors so that Vout = 3.3V. In case the microcontroller outputs more current then the display can sink the resistors will also reduce the current. The output high minimum of the LCD will be V_{CC}-0.6V, I will therefore I will program the microcontroller to recognise to recognise V_{CC}-1V (i.e. 2.3V) to be a high. The same tolerance applies on the low, so I will program in a V_{SS}+1V (i.e. 1V) to be a low. If the microcontroller can't be programmed to do this, I will use n-channel transistor as a switch to turn on off a 5V path to the microcontroller. A pull down resistor (1kΩ) from the 5V supply will be allowed to flow from the drain to source if the V_{GS} (of 2.7V) is exceeded. (3.3V-0.6V = 2.7V, IXFP34N65X2 transistor has such V_{GS}).

I will use 6 GPIO ports for this LCD display, 4 of which are used for the standard SPI interfacing, whist the additional two ports I have optionally chosen to use for added functionality. The 4 SPI pins: SI pin used for transferring data from the microcontroller to the display. SO to shift data out of the display into the microcontroller. Clock will be linked to a pin on the microcontroller so that we can digitally match clock rate to 250KHz. Chip select, is used to select a display module (only one in our case). Finally the two additional pins gives the added functionality of: Reset- terminating any operation in progress and entering the sleep mode. Busy- to monitor module status.

Step 7: Provision of a switched output for an infrared light source

The client wants the ability to connect an externally-powered light source to help provide extra illumination for the separate camera-recording system. Using the datasheet for the RT1-AP relay, consider how the circuit below can be used to switch the external load with the microcontroller:



- Explain the *purpose* of R1 and D1 in the circuit.
- Why is transistor Q1 necessary?
- Suggest two advantages provided by using a relay to switch the external load.

R1 is a safety pull down resistor, it is useful in case that the microcontroller is disconnected or put in a high impedance state, it prevents the transistor from behaving in an unpredictable fashion.
D1 insures that when inductor is switched off abruptly the back EMF cannot flow into the microcontroller. This would most likely destroy the microcontroller as it is likely that the back EMF voltage is significantly higher than the microcontroller can handle. But with the diode here the maximum voltage would be 12.7 V which the transistor should be able to handle.
Q1 is needed in order to control the relay switch ON or OFF. Additionally the relay requires +12V to operate which the microcontroller is unable to provide directly from its output. Therefore the transistor enables a smaller voltage (the Voltage High of the microcontroller) to switch ON the relay.
One advantage of the relay switch is it can provide galvanic isolation. So for instance if there was a short in the microcontroller circuit the system would not be exposed to the voltage or current of the external load. Another advantage is it can be made a fail safe system by allowing the external load to receive power if there was a failure in the microcontroller or the circuit preventing it from staying off. If a thief had managed to damage the circuitry of the microcontroller for example it can be made so that the light switches on.

Step 8: 5 V power supply

The system needs a 5 V supply, capable of delivering 300 mA, which will be derived from the + 12 V (which is already available from the switched-mode supply). This will be provided from a linear voltage regulator (LM78M05) in a TO-220 package. Assume that the ambient temperature in the system enclosure *could* reach 50°C and that the junction temperature in the regulator should be kept below 90°C.

Using the data sheet for the regulator, determine the size of heatsink required (in °C/W) in order to keep the junction temperature below 90°C when the circuit draws the full-load current of 300 mA.

- Explain *how* you arrived at you answer.
- Also, explain the significance of the 'dropout voltage' mentioned in the datasheet.
- *You do not need to supply a circuit diagram.*

16 °C/W (1SF) will keep it below 90°C

$T_{j\,(max)}$ = 90 °C , V_{IN}= 12V, V_{out}=5V I_{Load}= 300mA, R_{JC}=2.5 °C/W, R_{JA}=66 °C/W, R_{CA}=63.5 °C/W

P_{reg}= (12-5)(0.3)= 2.1W

T_j = (2.1)(2.5 + x)+ 50 T_j < 90°C

X= 16.55 roughly 16 °C/W will keep it below 90°C

Dropout Voltage (V_D) is the minimum voltage that the transistor requires to maintain its +5V output, in this case it is 2V, which means we would want at least 7V, so it is adequate regulator to use.