

Electronic I Assignment 1 - Adam Cross

by Adam Cross

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Electronics I

Introduction

This report is based upon a smart rear bicycle light that is controlled by a PIC microcontroller. It consists of background research into existing market leading LED bike lights and the core technologies utilised within them, along with a personal design and accompanying documentation to support the design.

Background Research

Existing market leading products:

Garmin Varia RTL515 Smart Rear Bike Light



Figure 1 [1]

This smart bike light, made by market leading company Garmin contains many of the smart features that one desires in a smart rear bike light design. One of the smartest features that this light has is a built-in radar sensor that can detect vehicles up to 140 metres behind the rider, it can alert the rider of an approaching car in three ways, either via a connected smartwatch, smartphone or a connected Garmin Edge computer. To allow it to connect to these devices, the light will contain a Bluetooth module with IoT (Internet of Things) functionality, such as the Microchip RN4871.

Price: £169.99 [1]

This light has a simplistic design, with just one button and one status LED. To change light modes the user must hold the button for 1 second to turn the device on and enter active mode, the user can then cycle through the different light modes by pressing the button. To turn the device off the button must be pressed for 2 seconds.

Mode	Light Intensity	Default Flash Behavior	Flash Behavior when Vehicle Approaches
Solid (default)	High	None	Light flashes
Peloton (group ride)	Moderate	None	Light flashes softly
Night Flash	High	Slow	Light flashes quickly
Day Flash	Maximum	Occasional	Light flashes quickly
Standby	None	None	The device does not detect vehicles.

Figure 2 [2]

The LED status light incorporates 6 different states as shown in the table below.

LED State	Status
Flashing purple	The device is in active pairing mode.
Flashing blue	The device is in smart mode and can be controlled by a paired Varia RDU or compatible Garmin device.
Flashing green	The device is charging.
Solid green	The device is fully charged.
Flashing red	The device has approximately 60 or fewer minutes of battery life remaining.
Solid red	An error occurred. You may need to restart the device.

Figure 3 [2]

Charges via 5V USB-C connection to a rechargeable built-in lithium-ion battery which suggests that the battery may not be easy to replace like an 18650 lithium-ion battery would be for example.

Battery type	Rechargeable, built-in lithium-ion battery
RTL515 battery life	Up to 6 hr. in solid mode Up to 8 hr. in peloton mode Up to 6 hr. in night flash mode Up to 16 hr. in day flash mode Up to 3 mo. in standby mode
RTL516 battery life	Up to 9 hr. in solid mode Up to 3 mo. in standby mode
Operating temperature range	From -20° to 50°C (from -4° to 122°F)
Charging temperature range	From 0° to 45°C (from 32° to 113°F)
Wireless frequencies	2.4 GHz @ 0 dBm nominal; 2.4 GHz @ 13.6 dBm nominal
Water rating	IEC 60529 IPX7 ¹
RTL515 LED luminous flux	20 lm (solid mode) 8 lm (peloton mode) 29 lm (night flash mode) 65 lm (day flash mode)
RTL516 LED luminous flux	5 lm (solid mode only) Certified for use in Germany

Figure 4 [2]

This table taken from the Garmin RTL515 datasheet shows the typical battery life of the rear bike light in its different modes. What is interesting is the LED luminous flux ratings, as you can see in day flash mode, the light is brighter, 65 lumens compared to night flash mode of 29 lumens, this shows that the light has a daylight maximum power mode and a night-time reduced power mode, this is necessary to attract drivers' attention in the daylight when the bike light is less likely to be noticed. Although in the day flash mode, the battery life is 16 hours, compared to 6 hours in night flash mode, this suggests that the light is on for a longer period of time in night mode compared to the day mode.

Exposure TraceR MK2 ReAKT Peloton



Figure 5 [4]

This rear bike light is another very popular light in the cycling community, it incorporates a single CREE XPE-RED LED that has a typical forward voltage drop @700mAh of 2.3V [3] and uses a special lens to maximise the light output providing 75 lumens of light intensity at 180 degrees. The light contains a 700 mAh Lithium-ion battery that is rechargeable via micro-USB and provides a run time of 3-24 hours depending on the mode used. The light uses one "function" button to allow the user to select between 6 modes

Price: £55 [6]

Smart technology:

- ReAKT – As the rider brakes, the light utilises an accelerometer to increase light intensity to a maximum brightness of 120 lumens. The light also adapts to ambient lighting by using a photoresistor to alter the amount of current provided to the LED, the brighter the ambient light, the brighter the LED output.
- ITM – Built in temperature monitoring
- LED display – Provides run time, mode selection and battery percentage to the user
- OMS – Optimised mode selector that allows the user to select different programs [4]

Bontrager Flare RT

A compact rear bike light made by Bontrager that can be seen from up to 2km away.

Price: £44.99. [7]

As you can see in the table below (figure 7), the Flare RT has 5 modes, all with varying levels of brightness. The device has a simple design, of one power/mode button and a status LED. The light uses CREE LED technology to output a maximum light intensity of 90 lumens and has a rechargeable battery charged via



Figure 6 [8]

USB. This provides a runtime of 6 – 13.5 hours from a 420mAh 3.7Vdc 1.6Wh lithium-ion battery. [8] All three bike lights contain lithium-ion battery packs as taillights don't draw as much power as a headlight, therefore allowing the manufacturers to make smaller, flatter battery packs to fit into their devices, as opposed to the readily used cylindrical 18650 lithium-ion rechargeable and user-replaceable batteries found in most bike headlights.

Smart features:

- Low battery feature – When the remaining battery percentage is below 5%, the light incorporates battery monitoring that automatically reduces the output brightness and begins to flash the LED, this provides the user with an additional 30 minutes of runtime.
- Auto brightness – The device contains an ambient light sensor, such as a LDR (light dependant resistor) that allows the device to automatically change modes to optimise light output and battery life.
- Wireless communication - ANT+ Protocol and Bluetooth wireless technology that allows the device to communicate to other smart devices. This gives the user to option to wirelessly control the device and view the battery status.

Model	Power Button/Status LED	Mode	Max Output (lumens)	Runtime (hours) ²	Power Button/Status LED Color	Battery Life, %
Ion Pro RT		High	1200	1.5	Green Steady	25 to 100%
		Medium	800	3	Green Steady	25 to 100%
		Low	400	6	Red Steady	5 to 25%
		Night Flash	200	26	Red Flashing	Less than 5%
		Day Flash	300	22	Red Flashing	Less than 5%
		Day Flash	300	22	Red Flashing	Less than 5%
Ion 200 RT		High	200	1.5	Green Steady	25 to 100%
		Medium	100	3	Green Steady	25 to 100%
		Low	5	14.5	Red Steady	5 to 25%
		Night Flash	5	30	Red Steady	5 to 25%
		Day Flash	100	12	Red Flashing	Less than 5%
		Day Flash	100	12	Red Flashing	Less than 5%
Flare RT		Day Flash ¹	90	6	Green Steady	25 to 100%
		All Day Flash ¹	45	12	Green Steady	25 to 100%
		Night Flash	5	15	Red Steady	5 to 25%
		Day Steady ¹	25	4.5	Red Steady	5 to 25%
		Night Steady	5	13.5	Red Flashing	Less than 5%
		Night Steady	5	13.5	Red Flashing	Less than 5%

Figure 7 [8]

Light pattern research

Research carried out over a 12-month period by Aalborg University, Denmark in 2004/05 consisting of 3845 cyclists, 1845 of which had permanent running lights/daytime running lights mounted to their bike, concluded that a cyclist who uses lights to attract motorists' attention is 19% less likely to be involved in an accident. [9]

Further research carried out by Clemson University in 2017, concluded that using a flashing rear bike light during the day, increased the rider's chances of being seen by up to 140% when compared to a cyclist using a steady mode light setting and 240% more noticeable when compared to a rider using no lights at all. [10]

Their study also tested an older version of the Bontrager Flare RT that was researched in the section above. They tested the steady mode, which produces a fixed LED light output of 3.5 lumens against the night-time flash mode which produced 9 lumens of light at a frequency of 2.6Hz (2.6 flashes per second) for two flashes and a third flash at 65 lumens at a frequency of 0.87Hz (0.87 flashes per second). The light also has a steady background light that is always on at an intensity of 0.4 lumens.

The diagram shows the utilisation of an irregular pulsing light pattern. The study found that an irregular light flash pattern significantly increases visibility to other road users. They carried out this test by allowing

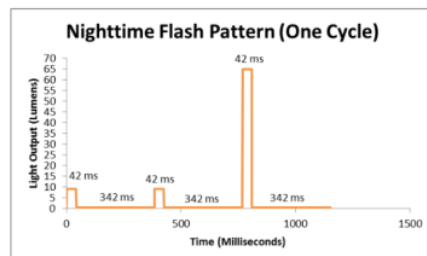


Figure 8 [10]

235 participants to drive a closed loop circuit, containing two bicycles mounted with static and flashing seat post lights at a constant speed and measured the distances in which the volunteer noticed each cyclist.

The mean response distance of the flashing seat post light was 3 times greater than that of a static seat post light, 123.1m compared to 40.8m.

A similar irregular light pattern can also be found in many other bicycle lights, such as the Exposure TraceR MK2 ReAKT Peloton that was researched in the section above. The video, showcasing their light pattern

The bike light laws in the UK covered under the BS6102/3 standard if the light has a steady light output, state that a flashing bike light must “must only flash between 60 and 240 times per minute (1 to 4Hz) [13].” I will therefore have to take this into account when designing my smart rear bicycle light.

Lithium-ion batteries can be found in three forms, cylindrical, brick shaped or flat rectangular shape. The two main forms used in bicycle lighting are cylindrical, 18650 batteries or flat lithium-polymer cells such as the ones used in smartphones. 18650 batteries have a standard footprint whereas lithium-polymer batteries can be made in all shapes and sizes to suit the manufacturer.

In order to charge an 18650 battery, one would first need to convert 230VAC to a smooth DC voltage. This is achieved via a full bridge rectifier circuit, like the one below. The circuit contains a step-down transformer that converts 230VAC to approximately 12VAC, to achieve this there will be more turns on the primary coil of the transformer than the secondary coil. The AC voltage then passes through a bridge rectifier circuit containing 4 diodes or a dedicated IC could be used, each set of diodes conduct during every half cycle of the AC waveform, allowing the positive voltage to flow through the circuit although this creates an average DC voltage output with a large AC ripple. Smoothing capacitors are then connected in parallel across the output of the bridge rectifier, the larger generally polarised 470 μ F capacitor acts as a reservoir, smoothing out the low frequency AC ripple and large transients caused by mains supply noise, the smaller non-polarised capacitor has very good high frequency response and can deal with fast transients to further smooth the signal to create a smooth DC output. The smooth DC signal then passes through the 7805 IC which produces a constant, regulated 5V DC output. Capacitor C3 is placed in the circuit to remove residual noise in the output. [14]

[illegible]

Figure 10 [16]

The IC has 8 pins, as shown in figure 10. The chip monitors battery temperature to ensure its charged above a minimum ambient temperature and to prevent overheating while charging. Some Li-ion batteries have an internal NTC thermistor, this is connected to the battery's negative terminal along with an external series resistor to create a simple voltage divider circuit, this is then connected to the TEMP pin, the TP4056 can monitor the temperature by measuring the voltage on TEMP pin, as the NTC resistance increases as temperature decreases, producing a temperature related output voltage. If the voltage is below 45% of VCC (5V) the battery temperature is too low (thermistor is causing a larger voltage drop due to an increase in resistance) or if it is more than 80% of VCC for 0.15 seconds it is too high.

Pin 2 is PROG, this allows the charge current to be controlled by altering the resistance value to GND, varying from 130mA to 1000mA.

Pin 3 is connected directly to ground.

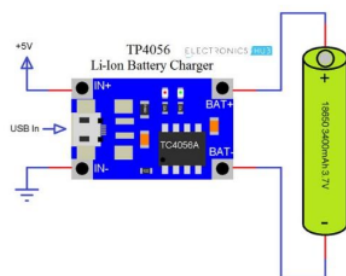
Pin 4 is VCC, the output of the 7805 IC circuit above could be connected to this via USB to provide 5VDC.

Pin 5 is the BAT pin, connected to the positive terminal of the 18650 lithium-ion battery.

Pin 6 is an inverted standby pin that has a high impedance when not activated. When the battery is fully charged, this pin is pulled low and subsequently illuminates an LED to inform the user that the battery is charged.

Pin 7 is an inverted charge pin with a high input impedance. When the TP4056 is connected to a USB power source, an internal switch pulls the pin low and activates the red LED to inform the user that the battery is charging.

Pin 8 is a chip enable pin, when a voltage is applied, the input is 'HIGH,' when the power is removed the input goes LOW and disables the chip. [15]



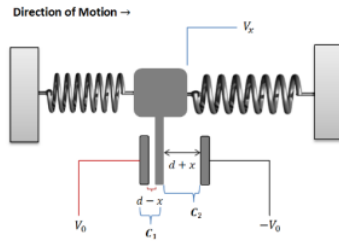
Example diagram showing the TP4056 chip being used to charge an 18650 lithium-ion battery.

Figure 11 [16]

Movement detection/MEMS accelerometer research

Movement detection could be incorporated into the bicycle light to measure velocity and position and/or to simply turn the LED light on/off when motion is detected. MEMS stands for micro-electrical-mechanical systems and is a device that provides an output proportional to the amount of force applied. There are two main types of MEMS accelerometers, capacitive and piezoresistive. As shown in Figure 13 below, capacitive accelerometers contain a seismic mass suspended on springs, with one end of each spring connected to capacitive plate and the other to the mass, an acceleration force causes the spring to deform, changing the distance between the mass and plates, resulting in a change in capacitance. Piezoresistive accelerometers contain piezoresistive material that deforms due to force, resulting in a change in resistance. This change in resistance is converted into a voltage output that is proportional to acceleration forces and can be used to

illustrate that the cyclist has started to move and therefore turn on the LED. When no changes in forces are measured for a set period, the microcontroller can turn the light off to save power. [18], [19].



Selection of MEMS PICs on the market:

MPU6050 6 axis - InvenSense

MM7150 9 axis sensor - Microchip

ADXL335 triple axis – Analog Devices

Figure 12 [20]

CREE LED Research

While carrying out research into existing high power rear bicycle lights, it became apparent that CREE LED technology is used throughout the market. There are two market leading LEDs used, these are the CREE XP-E and the updated CREE XP-E2.

CREE XP-E RED (620-630nm) LED Specifications:

Power - Max 3.5W

Maximum DC forward current - 700mA

Typical forward voltage at 350mA – 2.1V

Typical forward voltage at 700mA – 2.3V

Luminous flux at 350mA – 73.9lm

Maximum LED junction temperature - 150°C

RELATIVE FLUX VS. CURRENT ($T_j = 25^\circ\text{C}$) - CONTINUED

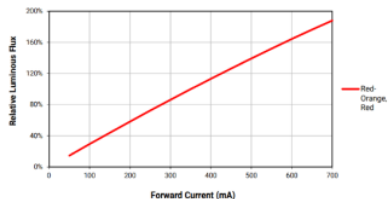


Figure 13 [3]

The graph opposite taken from the CREE datasheet depicts the relationship between LED drive current and light output and shows how the LED will perform when subjected to varying drive currents. This graph suggests that the XP-E RED LED could reach a brightness of almost twice the stated 73.9lm of minimum brightness listed at 350mA, in the region of 120lm at 700mA. [3]

CREE XP-E2 RED (620-630nm) LED Specifications:

Power - Max 3W

Maximum DC forward current - 1000mA

Typical forward voltage at 350mA – 2.18V

Typical forward voltage at 1000mA – 2.6V

Luminous flux at 350mA – 80.6lm

Maximum LED junction temperature - 150°C [21]

The graph below shows that the new generation XP-E2 RED LED can achieve greater levels of brightness although this will obviously come at a cost of reduced battery life. Maximum brightness is in the region of 210lm. Comparing data with the original XP-E LED, it is clear to see that the XP-E2 is more efficient, providing a brighter light at 350mA and superior peak brightness.

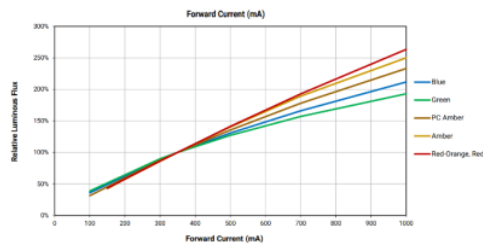


Figure 14 [21]

Core technologies used in creating LED bike lights

The theory behind PWM to perform power control:

In a simple flashlight circuit, the battery power is controlled by a switch and a single resistor is used to limit the current to the LED. This is the cheapest way to create the circuit but is inefficient as the resistor turns the extra power into wasted heat energy. The voltage required to power an LED varies between 2V-2.6V, whereas a single cell 18650 lithium ion battery has a voltage range of 2.5V-4.7V, the battery would overload the LED without regulation, switch mode drivers, containing buck-boost converters are used to step up or step down the battery voltage, they also serve the purpose of averaging out current efficiently by providing a constant current power source to maintain the LED output brightness throughout the battery range, even as the battery voltage starts to drain, this is very important when it comes to bicycle lighting. It does this by adjusting the amount of time a transistor is turned on, this amount of time is known as the duty cycle (on/off switching cycle) of the PWM output and controls the average LED current, the duty cycle is equal to the time on divided by the period, this type of circuit is far more efficient than trying to partially restrict current flow to the LED using resistance.

Built into the microcontroller is a clock oscillator that acts as a timer module to generate the Pulse Width Modulation (PWM) signal, this can also be achieved using a dedicated 555 timer chip. PWM controls the average output current via a fast on/off switching cycle. The longer each pulse stays in the 'ON' state, the brighter the LED will be, as the average output current will rise. The on/off switching happens so quickly that the human eye cannot detect the flickering. Analysing the diagrams below, for example a 50% PWM duty cycle would mean that the LED is on for 50% of the time and off for 50% of the time, meaning the average current is halved, making the device more efficient while providing the functionality to dim the light output to provide different output brightness options to the user.

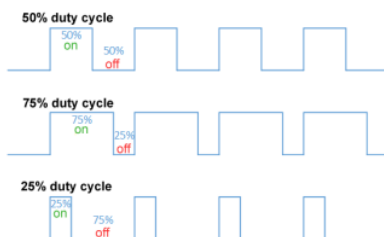


Figure 16 [17]

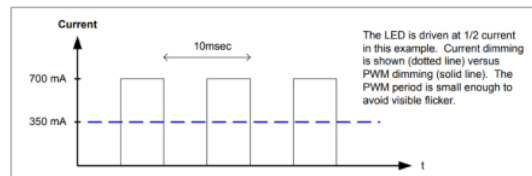


Figure 15 [22]

A buck converter contains 6 key elements. A voltage source, switch, diode, inductor, capacitor and a load as shown in figure 17 below. When the switch is ON, current cannot flow through the diode as it is reversed bias, current therefore flows through the inductor taking a time to charge up and store energy, voltage is also limited as the voltage across the capacitor cannot rise instantly, this leads to a reduced output voltage across the load. When the switch is OFF, the current flowing through the inductor will decrease, thus the magnetic field of the inductor will begin to collapse, inducing a voltage with reversed polarity. The inductor then becomes a current source to feed the load or charge up the capacitor and the diode then becomes in forward bias mode, allowing current to flow around the circuit and back to the inductor. Therefore, a lower duty cycle will mean that the circuit is switched off for a longer period, thus reducing the output voltage.

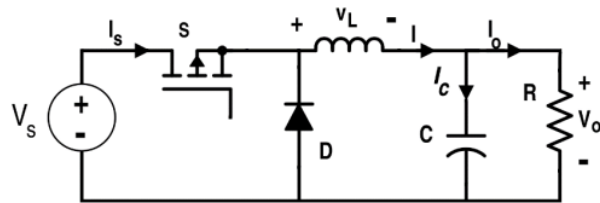


Figure 17 [28]

A boost converter circuit is similar to a buck converter circuit but is arranged slightly differently. When the switch is open, current will flow from the source, through the inductor and diode, charging the capacitor and feeding the load. When the switch is closed, it creates a short circuit to ground, this increasing the amount of current flowing through the inductor and as a result increasing the magnetic field it produces, in this state the inductor will continue to store energy. When the switch is opened back up, the current ' I_s ' starts to decrease, reducing the magnetic field of the inductor and its polarity. This then puts the inductor in series with the battery, it therefore acts as a secondary source as it releases its stored energy, increasing the voltage across the load.

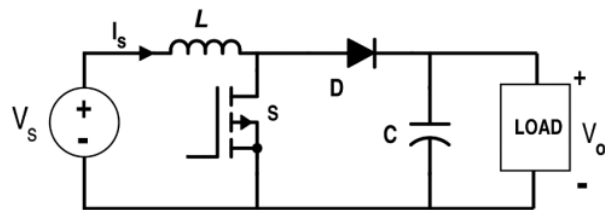
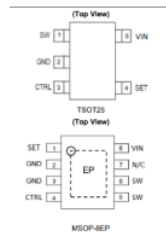


Figure 18 [28]

LED Driver Examples

As the forward voltage drop of the LED is at the lower end of the battery voltage, a buck (step-down) converter is required.

Al8860 - DC/DC buck (step-down) convertor



Features:

1A output current

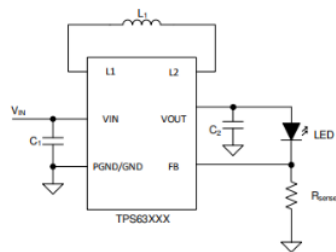
4.5V-40V input range – This may pose an issue when using a single 18650 cell

PWM signal – Analog LED dimming

Over temperature protection (OTP)

Figure 19 [23]

TPS63xxx buck-boost converter



Features:

Input voltage range - 1.8V-5.5V

Fixed/adjustable output voltage range – 1.2V-5.5V

Up to 1200mA output current

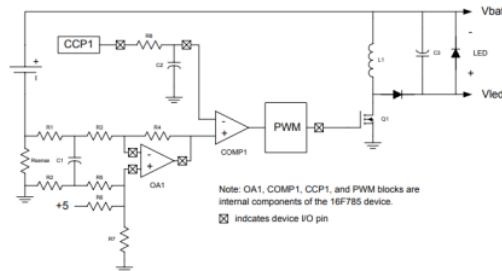
PWM signal

Over temperature protection via built in temperature sensor (OTP) [25]

Figure 20 [24]

Figure 20 shows a simple configuration of the TPS63000 family chip. A resistor 'Rsense' is used to operate the chip as a constant current source, measuring the voltage drop across the resistor, converting this signal into a digital signal via an analog-to-digital converter inside the chip, the duty cycle is then adjusted to maintain current output and LED brightness as the battery voltage decreases.

PIC16F785 8-Bit Buck-Boost Microcontroller



Features:

Input voltage range 2V-5.5V

EEPROM – Useful for saving data when power will be lost

PWM Output

Over temperature protection via built in temperature sensor (OTP)

Analog-to-digital converter [26]

Figure 21 [22]

Figure 21 shows a simplified schematic diagram of the PIC16F785 chip. 'Rsense' in this case is connected to the negative terminal of the battery, the voltage drop is amplified using an op amp and fed into the internal PWM module to maintain output current. [22]

PIC16(L)F1764 8 bit Microcontroller

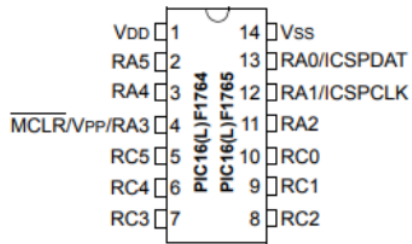


Figure 22 [27]

Input voltage range 1.8V-3.6V

PWM module

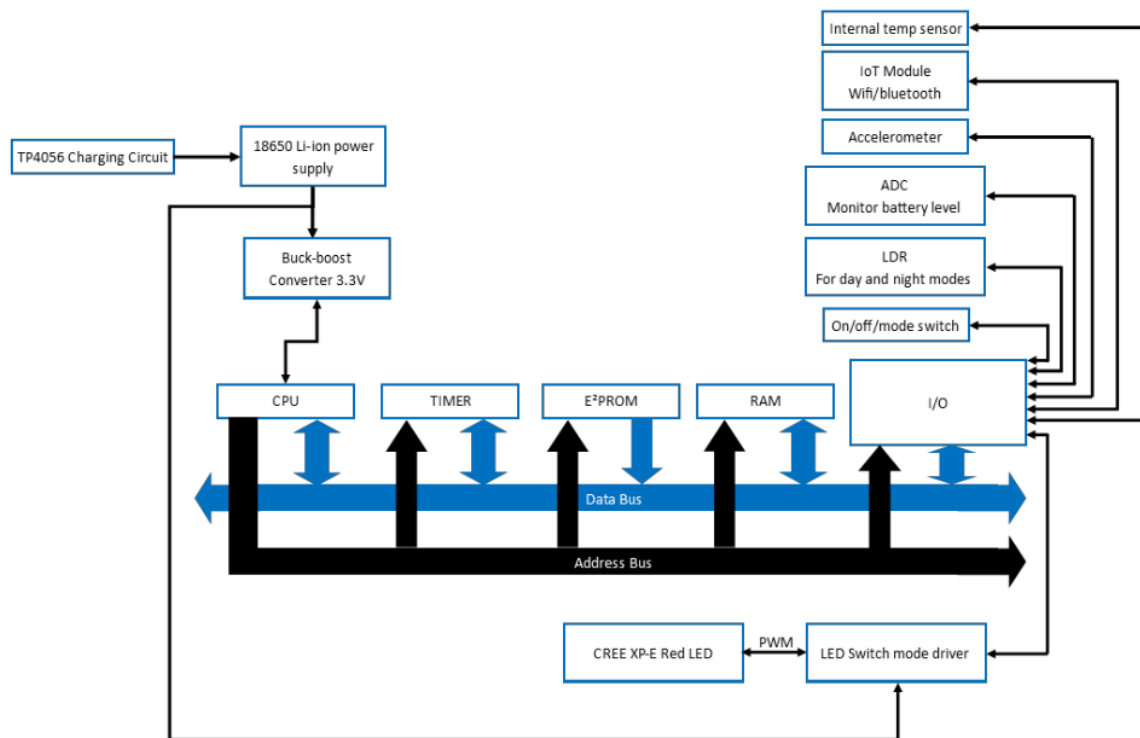
Over temperature protection via built in temperature sensor (OTP)

Analog-to-digital converter

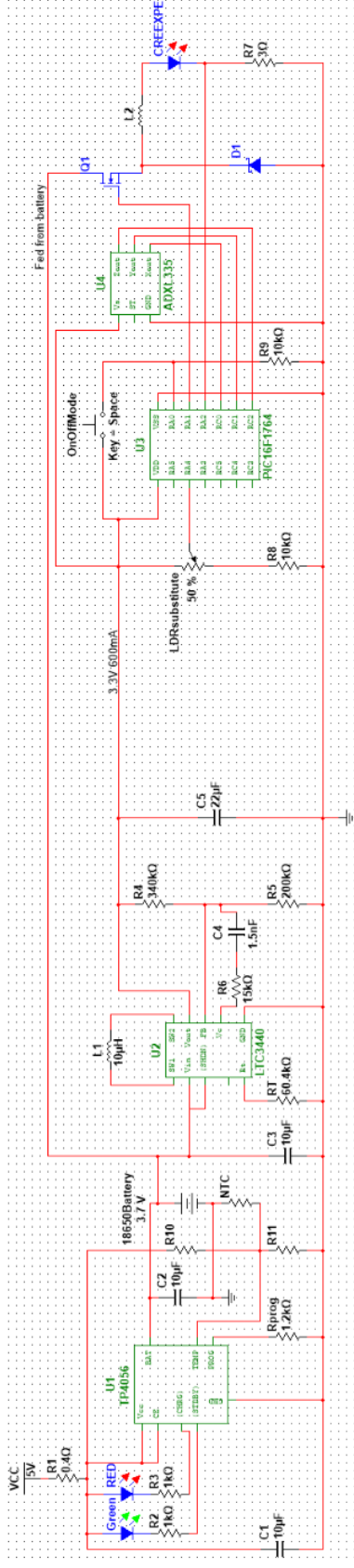
Digital to analog converter

8-bit timers [27]

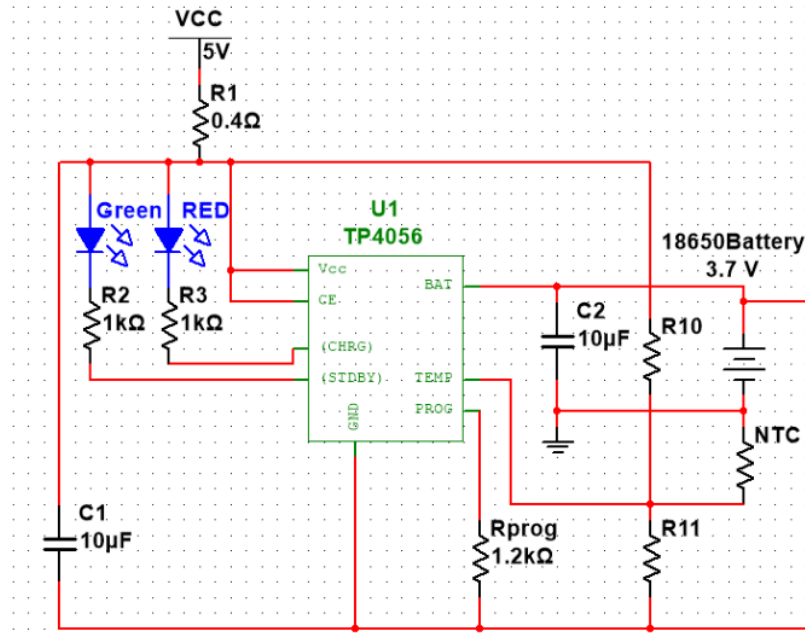
System (block) diagram



Circuit Diagram



TP4056 Charging Circuit



The first part of the circuit consists of a TP4056 IC lithium-ion constant-current/constant-voltage (CC/CV) charging circuit, they are readily available and ideal for charging single cell 18650 batteries as they have a pre-set output charge voltage of 4.2V during constant voltage mode, the upper voltage threshold of an 18650 battery. It is powered by a USB connection, such as USB-C with a voltage input range of 4-8V. This is supplied to the circuit by an external rectifier and linear voltage regulator circuit such as the 7805 IC explained previously in this report.

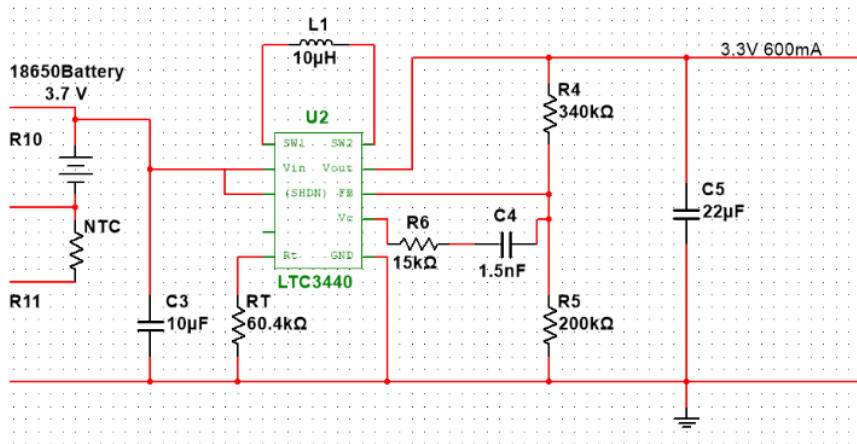
For 18650 batteries with built in thermal protection via an NTC thermistor, this can be used to provide automatic thermal feedback to the chip to monitor the thermal state of the battery and ambient temperature during charging. If the battery does not have thermal feedback, the temperature sensing element (pin 1) of the TP4056 is connected to ground. For batteries with a NTC thermistor, as stated previously in the research section above, resistor 'R11' is placed in series with the NTC to create a simple voltage divider circuit for means of voltage feedback to pin 1. As the resistance of the NTC increases as temperature decreases, it produces a temperature related output voltage. If the voltage measured on pin 1 is below 45% of VCC (5V) the battery temperature is too low, as the thermistor is causing a larger voltage drop due to an increase in resistance or if it is more than 80% of VCC for 0.15 seconds it is too high. In either case, the TP4056 module will terminate the charging cycle.

The charge current is set by an external resistor, 'Rprog,' to set the output charging capacity to a maximum of 1000mA, this resistor must be 1.2kΩ. The 1.2kΩ resistor is connected between pin 2 (PROG) and ground. The calculation used to calculate the charge current is included in the datasheet and is $I_{bat} = \frac{V_{prog}}{R_{Prog}} \times 1200$, where 'Vprog' is a predetermined 1V. Therefore, there is 1:1 relationship between the voltage on this pin and charge current, i.e., if 1V is measured on pin 2, the current charging the battery is 1A. The TP4056 constantly measures the voltage on pin 2 to determine the battery charge state, as the charge rate will start to fall as the battery charges to 100%. When the charge rate falls below C/10 (where C is the mAh capacity of the battery) during constant current charge mode towards the end of the charging cycle, charging of the battery is terminated.

The 10 μ F capacitor is placed in parallel with the battery to act as a voltage filter, to smooth ripple voltage and store charge.

There are two indicator LEDs incorporated into the circuit, a red LED to indicate that the battery is charging and a green LED to indicate that charging is complete, both have 1k Ω resistors placed in series to limit current through the LED's. To indicate to the user that the charging cycle has stopped, pin 6 an inverted standby pin is pulled low by an internal switch, allowing current to flow through the green LED to illuminate it, when not switched, this pin along with pin 7, has a very high impedance when not switched to limit current flow to prevent the LED's from illuminating. During the charging cycle pin 7 also an inverted pin, is pulled low by an internal switch, this allows current to flow through the red LED to indicate to the user that the battery is charging. [16].

LTC3440 Buck-Boost Converter Circuit



The second part of the circuit contains a LTC3440 buck-boost voltage converter. This is in place to regulate the output voltage of the 18650 battery to 3.3V at a maximum output current of 600mA when the battery charge is equal to, above or below this value. The upper and lower voltage range of the 18650 cell is 2.5 – 4.2V, the LTC3440 will continue to function throughout this range as it has an input voltage range of 2.5 – 5.5V. This powers the PIC and external components such as the accelerometer and LDR. Rt is the timing pin, the value of the series resistor to ground, Rt controls the internal oscillator frequency between 300kHz and 2MHz, according to the datasheet formula, a value of 60.4k Ω sets the oscillator frequency to 1MHz [20]. Switching is controlled within the chip via two N-channel and two P-channel MOSFET's with low on resistances of 0.19 Ω and 0.22 Ω respectively and require a low gate charge to conduct. C1 capacitor is placed in parallel with the battery supply and will store charge therefore reducing noise in the circuit, C5 plays a similar role, acting as an output filter to smooth possible voltage transients. [30]

Inductor L1 is placed across pins 'SW1' and 'SW2.' The inductor's purpose is to store charge during the switching cycle, when current passes through it, a magnetic field is formed, the inductor will then begin to release energy back into the circuit as the supply current to it decreases, as the magnetic field will begin to collapse, producing a voltage in the opposite polarity to feed back into the circuit during the off cycle.

FB is an analog voltage feedback pin and is connected to the voltage divider network of R4 and R5. As you can see in figure 23 below, extracted from the datasheet, FB is connected to the inverted input pin of an error op amp and the device is fed by a reference voltage of 1.22V on its non-inverting pin, a large difference in the inverting and non-inverting voltage will see the op amp amplify this output to adjust the PWM switching and therefore control the output voltage to the desired 3.3V.

Vc pin, with its RC network is used to provide frequency compensation. As you can see in the block diagram below, 'Vc' pin is connected to the output of the error op amp and is fed to the 'Fb' pin to compensate the feedback to the inverting input of the op amp.

Spare pin, 'mode/sync' is not used in this application. This offers a user controlled burst mode option that isn't required in this circuit as 'Rt' is being used to set a fixed frequency output.

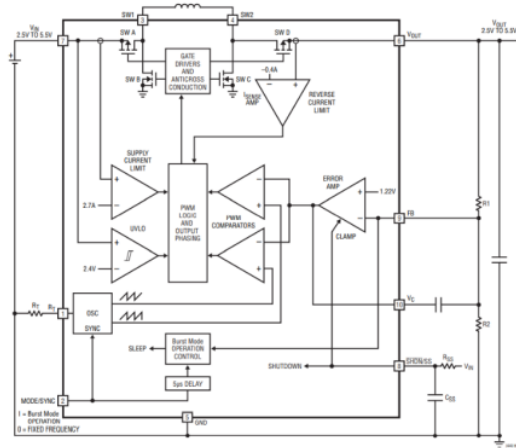
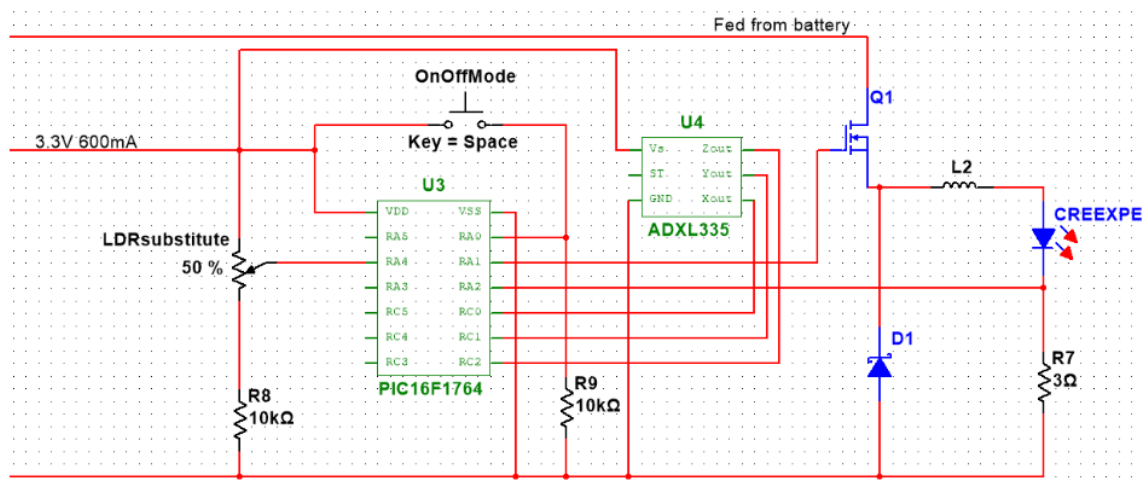


Figure 23 [29]

Microcontroller – PIC16F1764



This microcontroller was chosen to control the LED switch mode driver circuit and interface with other peripherals such as the accelerometer, push button and light dependant resistor due to the number of I/O pins and analog to digital converter pins available, its in-built timers, the low input voltage range and crucially it is capable of providing a PWM output using a built-in oscillator. When powered on and not in sleep mode, the timer will begin a count that keeps track of seconds, minutes and hours. The device is powered by the LTC3440 voltage output of 3.3v to pin 'Vdd.' Power is also fed directly to the push button; the design incorporates one single push button to turn on/off the device as well as switch modes. To turn on the device the user must press the button for more than 2 seconds, the button is connected to a pin that can be configured as a digital input pin, therefore, if the pin is driven 'high,' for more than 2 seconds, the device will receive a pulse wake up command that will be configured in the programming. Once on, to switch modes the user will simply press the button to cycle between the 5 pre-set modes, driving the input

pin high and low will initiate mode switching within the microcontroller programming. The device is also capable of remembering the user's choice of mode when switched off, the mode selection is stored in the E2PROM memory location of the microcontroller and is read from, upon start-up of the device so that the microcontroller can output the correct PWM and/or delay setting. To power down the device, again the programming will be waiting for if the user presses and holds the button, driving pin 'RA0' high for more than 2 seconds. A series resistor of 10k Ω is used as a pull-down resistor to ensure the pin is pulled down to ground (low) when the switch isn't being pressed to prevent an undefined state on the input pin.

LDR

The design above shows a potentiometer as an LDR substitute, as the design program does not include LDR's. The LDR input is used to control the PWM output and therefore the power on the LED. This is a separate selectable mode (mode 5) and is controlled by ambient light. In daylight, we want the light luminous output to be at its maximum to attract road users to the cyclist in bright conditions, while at night-time we can afford to dim the light output somewhat to save power while still being more than bright enough to be visible to other road users. The LDR being used in this design has an off/dark resistance of 1M Ω , a resistance of 10k Ω at 10 lux and 2k Ω at 100 lux. [31] A typical overcast day has a lux rating of 1000 lux or more, therefore any form of daylight will essentially mean that the LDR resistance is less than 2k Ω . If it is dark, the input pin will be virtually grounded. The LDR is connected to an analog to digital input pin that will convert the voltage on the input pin to a digital value to determine a switching point. Again, a series resistor of 10k Ω is used as a pull-down resistor to ensure the pin is pulled down to ground (low). It is fed by 3.3V, therefore we would expect the voltage on the pin to be 1.65V or more when it is light outside, as the voltage across the 2k Ω resistance will be half of the supply voltage and will continue to rise as the resistance of the LDR decreases with increasing light intensity. The switch point from low power mode of a 50% duty cycle to a high-power daytime mode of 100% PWM duty cycle would therefore need to be set somewhere in the region of 10% lower than this, 1.485V. Likewise, the switching point from high power daylight mode to low power night mode would need to be set 10% higher than the threshold to prevent unwanted switching, i.e., 1.815V.

Led Driver Circuit

Q1, L2, CREE LED, R7 and D1 make up the LED driver circuit. Q1 is a PMV16XNR logic level N-channel MOSFET, this means it has a low gate threshold switching voltage (V_{gs}) ideal for use with a microcontroller PWM output and has a low on resistance of 0.016 Ω . [32] The gate-source voltage controls the drain-source resistance, no voltage on the gate means the drain-source resistance is very high and no current will flow, when a voltage is applied to the gate, the drain-source resistance reduces somewhat allowing current to flow. The MOSFET is connected directly to the battery to provide sufficient current to drive the LED, as the microcontroller is not capable of driving the LED due to its output current limitations. To drive the LED, an internal 10-bit (providing 1024 discrete duty cycles for a given period) timer module is available and will operate at a fixed frequency controlled by the internal clock oscillator (20MHz), the output frequency will be configured at approximately 4.88kHz [27]. The PWM output of the microcontroller to the gate of the MOSFET controls the gate to source current flow to the LED and thus the LED brightness. Therefore, a PWM output of 100% would mean that the MOSFET is always switched on and the LED will be at its maximum brightness, whereas a PWM output of 0% duty cycle would totally remove current flow to the LED and it will therefore be off. A PWM output consisting of a 50% duty cycle means that the MOSFET is switched on for half the time and off for half the time, providing an average power by switching on and off extremely quickly. The LED will therefore be at half brightness; due to the speed in which the MOSFET switches on and off, the human eye cannot detect the flickering of the LED, as explained previously in the research section of this report.

The inductor acts as a filter between the fast-switching MOSFET and the LED. When a current is applied to the inductor it will begin to set up a magnetic field, storing charge, during the off cycle and when current flowing to the inductor reduces, its magnetic field will begin to collapse, releasing its stored charge into the circuit to maintain LED power and smooth out sharp voltage transients during switching. When switched ON, the diode, a Schottky diode is in reverse bias mode and therefore blocks current flow, sending it across the inductor, when the gate transistor is closed, as explained previously the inductor discharges from the LED, to R7 and back through the now forward bias D1 Schottky diode. A Schottky diode is best suited to this application as it has a low ohmic resistance producing a smaller forward voltage drop compared to standard diodes and has fast recovery times making them good for high-speed switching applications. R7 is placed in series with the LED to create a voltage divider circuit that connects to pin RA2 on the microcontroller. Pin RA2 has an ADC function that is used to measure and provide voltage feedback to control the current flow through the LED using a simple ohm's law calculation. A resistor value of 3Ω was chosen as this will provide approximately a 1V drop across the resistor at maximum LED current, as the forward voltage of the LED is 2.1V and the maximum resistance flowing through it will be 700mA. The internal ADC converts the measured voltage drop into a digital value which is proportional to the current flowing through the LED, therefore allowing the microcontroller to constantly adjust the timer module PWM duty cycle to maintain LED current and therefore brightness. This is especially important to ensure LED brightness is maintained as the battery charge decreases, increasing the amount of time that the MOSFET is switched ON as the battery charge decreases.

The LED chosen in this design is a CREE XP-E Red LED. Market research showed that CREE are the market leading LED producer and are a very reputable company. It has an extremely small footprint and produces a high luminous flux output which is important on a bicycle light. It was also an obvious choice to choose the XP-E over the XP-E2 as it draws less current, at 700mA compared to the XP-E2's 1000mA and therefore has a smaller forward voltage drop which will allow the battery to last longer before needing to be recharged. The XP-E is also more than bright enough for the application and as its red in colour it saves having to add a red filter to a white LED. The LED is mounted on a PCB board containing a thermal pad that acts as a heat sink to dissipate heat away from the LED and current flow and therefore heat is measured and limited via the feedback loop to the microcontroller to prevent overheating as the LED will get rather hot during operation.

ADXL335 Accelerometer

As stated previously in the research section of this report, an accelerometer provides a triple axis analog voltage proportional to acceleration via its 3 output voltage pins on its circuit board. The ADXL335 is fed by 3.3V via its Vs pin and its 3-axis output is connected to 3 separate ADC pins on the microcontroller. The microcontroller is looking for a change in voltage on these pins in order to know if the cyclist is moving. If acceleration is detected by this module, the cyclist is moving, therefore the LED will always remain on. If the accelerometer doesn't detect any movement for a set period, such as 2 minutes, the PWM output of the microcontroller will be set to 0% duty cycle and the LED will turn off to save battery. At this point the microcontroller will enter a sleep mode but can be woken if/when a voltage change is detected on the 3 axis input pins to reactivate the light output if movement is detected. The accelerometer has a zero-gravity output voltage of approximately half the input voltage supplied to the Vs pin, therefore the zero-gravity voltage will be approximately 1.65V, this will be the voltage setpoint. If the accelerometer detects movement in any of its 3-axis, the voltage on the ADC pins will increase above the setpoint, providing feedback to the microcontroller to tell it that the cyclist is moving. The ADXL335 sensitivity is typically 300mV/g and has measurement range of +/- 3.6g. [33]

Modes

This design will incorporate 5 user selectable modes that can be toggled using the single push button on the device, these modes are:

Mode 1 – 50% PWM duty cycle output. This will provide a solid half brightness light mode

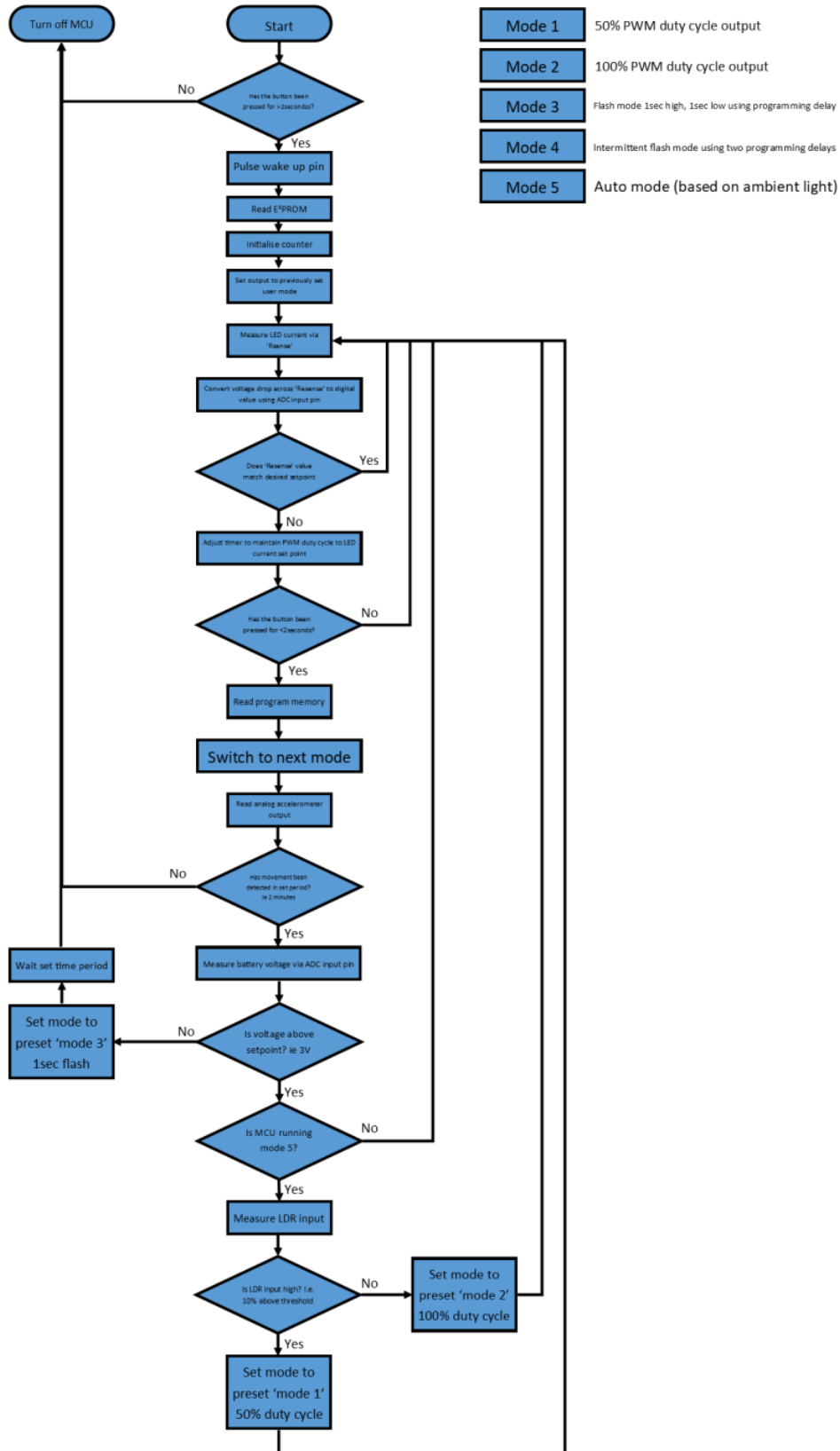
Mode 2 – 100% PWM duty cycle output. This will provide a solid light at maximum brightness, particularly useful to the user in bright daylight conditions.

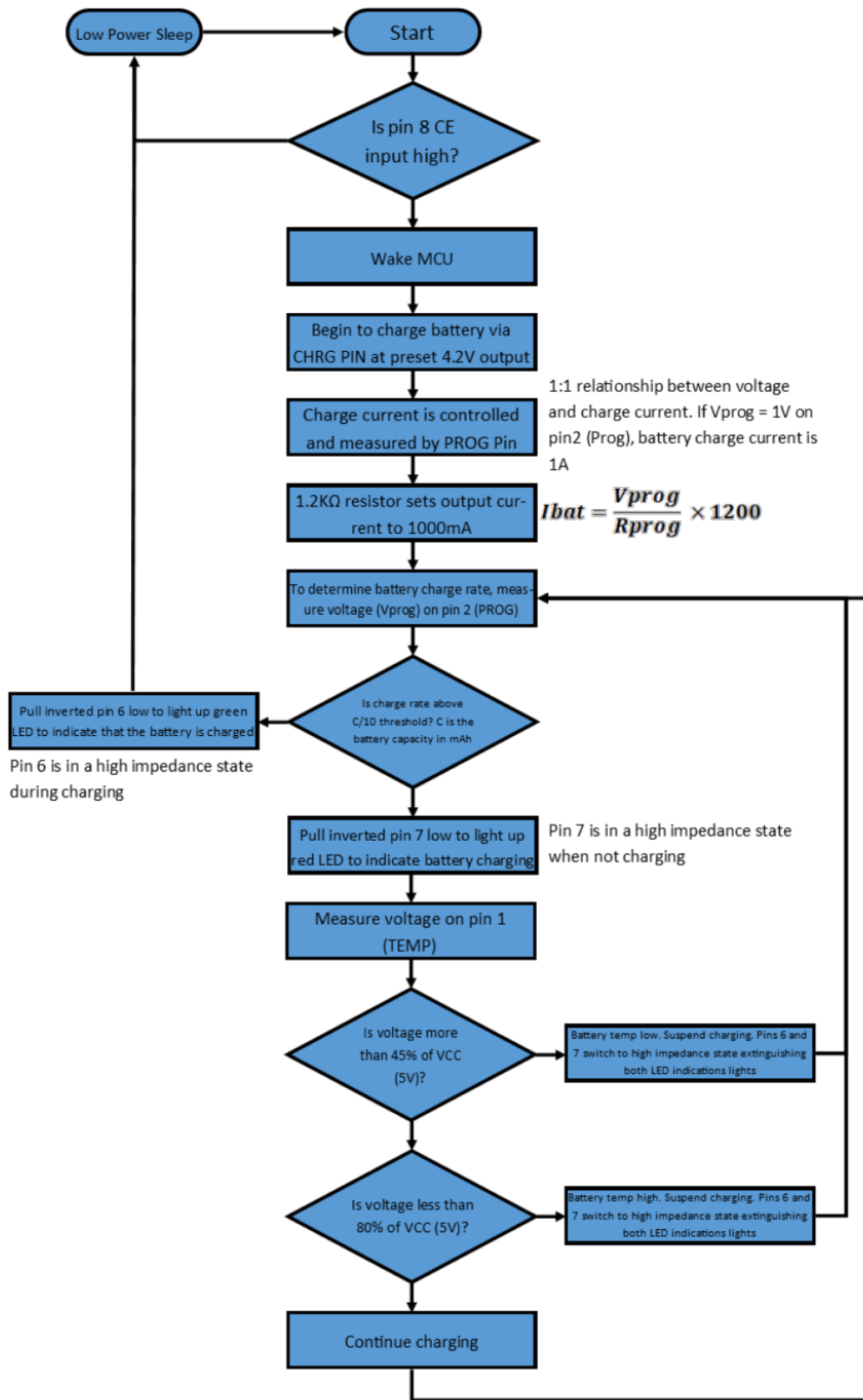
Mode 3 – Flash mode, 1 second on, 1 second off using a programming delay. The PWM duty cycle of this mode will be 100% for maximum brightness.

Mode 4 – Intermittent flash mode using several programming delays, e.g., on for 300ms, off for 100ms, on for 400ms and off again for 200ms on a constant loop. This mode again will be at 100% PWM duty cycle for maximum brightness. This mode is particularly useful to the user as market research shown previously in this report illustrated that an intermittent flashing light is more likely to catch the attention of the human eye when compared to a solid or simple flashing light mode.

Mode 5 – Automatic brightness mode, based upon the light dependant resistor input to the microcontroller. In daylight conditions, this mode will set the PWM output to 100% duty cycle for maximum visibility, while at night-time the PWM output duty cycle will be set to 50%, this will aid battery life and still be more than bright enough to visible at night.

Flowchart Microcontroller & Charging Circuit





TP4056 charging circuit flowchart

Parts list and estimate of costing

LDR (price per unit) - £0.40 [31]

PMV16XNR N-Channel MOSFET (price per unit) – £0.63 - Low threshold voltage compatible with 3.3Vgs, low on resistance of 0.016Ω [32]

CREE XP-E RED LED - £1.82 [34]

TP4056 Charging Module - £6.49 [35]

18650 2.6Ah Battery - £6.89 [36]

ADXL335 Accelerometer - £11.24 [37]

PIC16(L)F1764 - £1.03 [38]

Inductor DR1030 – £0.83 - Inductance range from $1.1\mu\text{H}$ to $155\mu\text{H}$ and current range of 0.23A-9.5A [39]

LTC3440 Buck-Boost Converter - £6.26 [40]

Cost set aside for other small components required such as resistors and capacitors - £10

Total cost estimate - £45.59

Conclusion, recommendation on future work etc.

The final design incorporates a rechargeable 18650 lithium-ion cell, charged via a TP4056 USB-C charging module, this 18650-cell output is regulated via a LTC3440 buck-boost converter, powering the main microcontroller of the design, a PIC16F1764. This microcontroller controls the LED via a PWM output and LED driver circuit to a high-power CREE XP-E Red LED. The microcontroller contains 5 user selectable modes, controlled via a single on/off and mode button. External components connected to the microcontroller add some additional features to the bicycle light, such as the ADXL335 accelerometer, which provides functionality to auto switch off when there is no movement or auto reactivate the light when movement is detected. An external light dependent resistor also provides feedback to the microcontroller for it to know if the light is being used in daylight or at night-time to adjust output brightness accordingly to maximise cyclist visibility in changing light conditions as well as optimising power usage. The 5 modes also include a series of flashing and a pulsing mode, that are designed to maximise the cyclist's visibility on the road.

During further research, it became apparent that a means of isolation may need to be included between the TP4056 charging circuit to the battery and the rest of the circuit. The load should be isolated from the charging unit during charging as it can affect the way in which the TP4056 measures the charge rate, which could mean that it doesn't terminate the charging process when it needed. To overcome this issue, a MOSFET could be used to form the isolation, acting as a switch when a power source is connected to the battery charger module, disconnecting the battery from the load.

The original design concept incorporated an Internet of things (IoT) module for the bicycle light to have Bluetooth and Wi-Fi capability, research was carried out into the RN4870/1 Microchip module, but I was not confident in interfacing this module with the microcontroller or how the Bluetooth and Wi-Fi capabilities would be set up. I believe it can be connected via UART Rx and Tx serial communication, which the PIC microcontroller chosen in this design indeed does support. If I was to design another circuit similar to this bicycle light in the future, I would ensure that an IoT module is added to the circuit.

To further enhance the design in the future, battery level indication could be added. The design created simply incorporates a feature whereby the light output switches to the pre-set, user selectable mode 3

that flashes the main LED on and off for 1 second at a time when the battery voltage is low, this will prolong the remaining battery capacity but if the user is already in this mode, they may not be aware that the battery is running low. If the user is in any other mode, such as constant light mode, they would notice that the light has automatically switched to a flashing mode and will know to charge the battery when they finish their ride, as the battery should last a minimum of 30 minutes in this flash mode to allow the user to get to their destination. Although in hindsight and if I was to design a similar circuit in the future, I would ensure that a battery level indicator with multiple LED's is incorporated into the design to allow the user to visually check the battery charge.

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Electronic I Assignment 1 - Adam Cross

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

80/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17

GRADING FORM: GJ_2019

ADAM CROSS

400

ENGAGEMENT WITH LITERATURE



Excellent level and range of research sources - good to see things like the studies on flash mode effectiveness!

90

KNOWLEDGE AND UNDERSTANDING



Generally very competent in all areas.

87

COGNITIVE AND INTELLECTUAL



As above. A couple of areas (such as the 230vac to DC converter) irrelevant to this application, but generally this section is also a good piece of work

83

PRACTICAL APPLICATION



The circuit looks fairly straightforward but very sensible. Very good work on thinking about the flowchart as well (although how exactly will the flash modes get implemented?)

80

TRANSFERABLE SKILLS



Report needs a neat, cover page. with students name and number, title etc. No table of contents provided. Other than that, it reads well and is reasonably presented.

60