

Toby CO2 assignment

by Thorbjorn Ravnaas Kristiansen

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University of Wales, Trinity St. David

A Design Investigation: Measuring Concentrations of CO₂ in Ambient Air Utilising Two PIC-based Platforms

Module: Embedded Microcontrollers (M3X8529)

Author: Thorbjørn Ravnaas Kristiansen
Course: BEng Computer Systems and Electronics (L6)
Lecturer: Mr. Gareth Jones
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Abstract

A CO₂ detection system based on vintage electronic parts was emulated utilising modern digital components, proving the superiority of embedded microcontrollers over discrete logic and external electronic components. A second system was designed from the ground up, based on the PIC18F25K50 microcontroller from Microchip. Microcontrollers were deemed a practical, efficient and cost-effective approach for this application.

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Background research

Measuring CO₂ is an important aspect of the modern world. Atmospheric CO₂ concentrations affect global warming, room concentrations affect human alertness and wellbeing. Industrial applications include measuring the CO₂ content of automobile exhaust and industrial processes. Very high concentrations can induce loss of consciousness and death due to oxygen deprivation[1]. CO₂ is not a toxic gas, it merely replaces oxygen in the air mixture.

Measuring CO₂ can be accomplished in several ways. Laser spectroscopy have been proposed[2], along with smaller more efficient systems such as anode reduction techniques[3].

An NDIR (Non-Dispersive Infrared) sensor is the most common approach. They can exhibit an accuracy of 0.5%, making them reliable for room concentration measurements[4].

Possible applications for this product are areas with a risk of high concentrations of CO₂ such as pub cellars and hospitals.

System Analysis and MCU selection

A previously designed system for detecting CO₂ levels was implemented utilising a modular approach, with a 6502 processor at its core. The modular nature of this system is a product of technological limitations at the time. Components like RAM (random access memory), ADC-modules (analogue to digital converter) and counters were individual components as opposed to the all-in-one nature of a modern MCU (microcontroller unit). As seen in figure 1, the original system was designed utilising a Von Neumann architecture. The system had 8KB of RAM and used an external oscillator (presumably a quartz crystal) as a clock source. See table 1 for reference table.

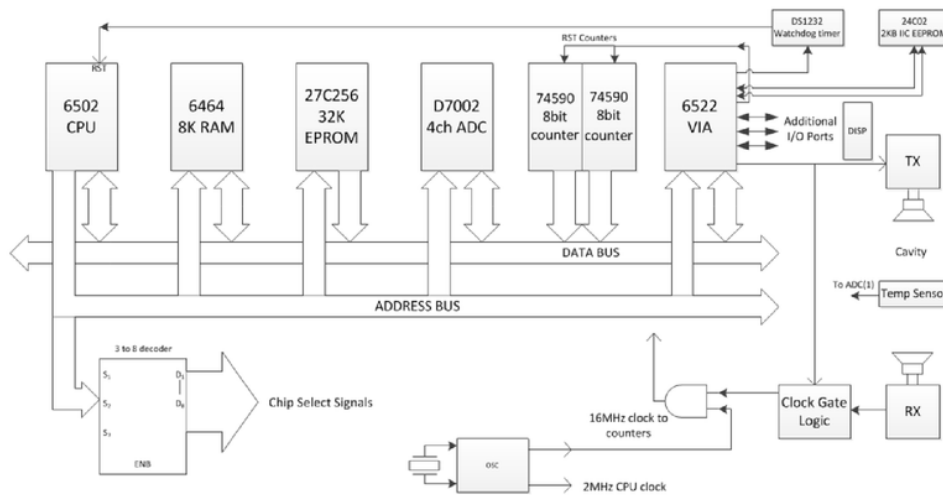


Figure 1 - Original system architecture block diagram

Module	Relevant details	Purpose
6502 CPU[5]	3MHz max clock speed	Central processing unit
6464 8K RAM[6]	8-bit RAM module	Random access memory
27C256 EPROM[7]	32K light-erasable non-volatile memory	Program memory
D7002 4ch ADC[8]	12-bit resolution	Analogue to digital conversion
74590 8bit counter[9]	-	Counter for time of flight measurement
6522 VIA[10]	2 8-channel peripheral ports (16 I/O channels)	Interface adapter. Allows for I/O expansion.
DS1232 Watchdog timer[11]	-	Restarts CPU in the event of errors/hanging system
24C02 2KB IIC EEPROM[12]	Electrically erasable, securing calibration data	Calibration memory
3 to 8 decoder	-	Chip selector system
OSC	Divides the raw crystal output frequency to usable frequencies	Oscillator circuit (generates 16/2MHz)
Clock Gate Logic	-	Logic for ultrasonic pulse detection and synchronisation

Table 1 - Original system overview table

Choosing a microcontroller for redesigning this system was accomplished utilising Microchip's parametric search function for 8-bit PICs (Microchip's brand name for MCUs; Programmable Interface Controller). The parametric search function reveals that 8KB RAM the largest capacity Microchip is currently offering (figure 3). Since the potential complexity of both purpose and software for MCUs has increased since the initial design of this system, it can be argued that 8K RAM is excessive. Only 7 PICs offer this capacity, and they are comparably expensive relative to other options explored in this report.

Product	Buy	Status	Documents	5K Pricing	Program Memory Size (KB)	SRAM (Bytes)
[Reset] PIC10F320 PIC10F322 PIC12F1501 PIC12F1571 PIC12F1572 PIC12F1612 PIC16F1454 PIC16F1455 PIC16F1459 PIC16F1503				[Reset] \$0.36 \$0.39 \$0.43 \$0.46 \$0.50 \$0.53 \$0.55 \$0.56 \$0.57 \$0.60	[Reset] 0.448 0.896 1.75 3.5 7 8 14 16 28 32	64 128 256 512 768 1024 2048 3562 3728 4096 8192
 PIC18F25K42		In Production		\$1.15	32	8192
 PIC18F27K42		In Production		\$1.37	128	8192
 PIC18F47K42		In Production		\$1.54	128	8192
 PIC18F57K42		In Production		\$1.58	128	8192
 PIC18F27Q43		Future Product		Call for pricing	128	8192
 PIC18F47Q43		Future Product		Call for pricing	128	8192
 PIC18F57Q43		Future Product		Call for pricing	128	8192

Figure 2 - Microchip selection of 8K RAM PICs

As seen in figure 2, the PIC18F25K42 mirrors the original system in terms of RAM and program memory size. It is also a 28-pin device, which is desirable for future upgrades.

The PIC16F18345

The chosen microcontroller for this application is the PIC16F18345. It was chosen with the following search parameters:

- Pin count: 20
- Watchdog timer: Yes
- ADC modules: >0
- Program memory: <=16KB
- EEPROM: >0

This yielded a result of 2 microcontrollers, as seen in table 2 on the next page.

PIC	PIC16F18344	PIC16F18345
Status	In Production	In Production
5K Pricing	\$0.70	\$0.77
Family	Enhanced Mid-Range	Enhanced Mid-Range
Program Memory Size (KB)	7	14
Program Memory Size (KWords)	4	8
SRAM (Bytes)	512	1024
Emulated EEPROM in Flash	256	256
Max I/O Pins	18	18
Pin count	20	20
Max CPU Speed (MHz)	32	32
Brown-Out Reset	BOR	BOR
Low Voltage Detection	LVD	LVD
Power On Reset	Yes	Yes
Internal Oscillator	32 MHz, 32 kHz	32 MHz, 32 kHz
Watch Dog Timer	Yes	Yes
Number of ADCs	1	1
ADC Input	17	17
Max ADC Resolution (Bits)	10	10
Max ADC Sampling Rate (ksps)	100	100
Max 8-Bit Digital Timers	4	4
Max 16-Bit Digital Timers	3	3
Capture / Compare/PWM (CCP)	4	4
UART	1	1
SPI	1	2
I ² C	1	2

Table 2 - Comparison between PIC16F18344 and PIC16F18345

Although both PICs could conceivably be used to fulfil the intended purpose, the PIC16F18345 was chosen for its larger program memory capacity and RAM size. This provides some margin in terms of software development, as these requirements are extremely difficult to accurately predict. It also has extra I²C and SPI channels allowing for extended serial interfacing.

Packaging Options

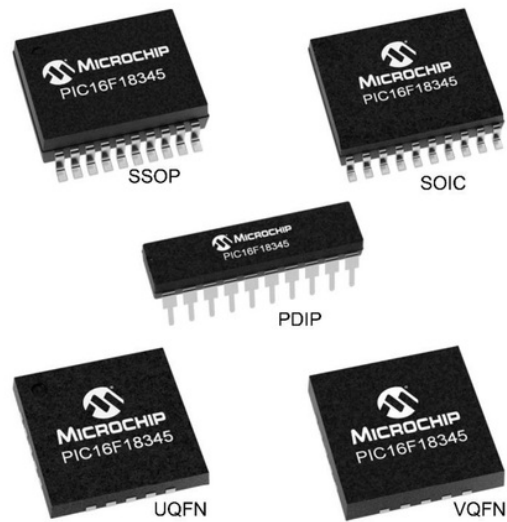


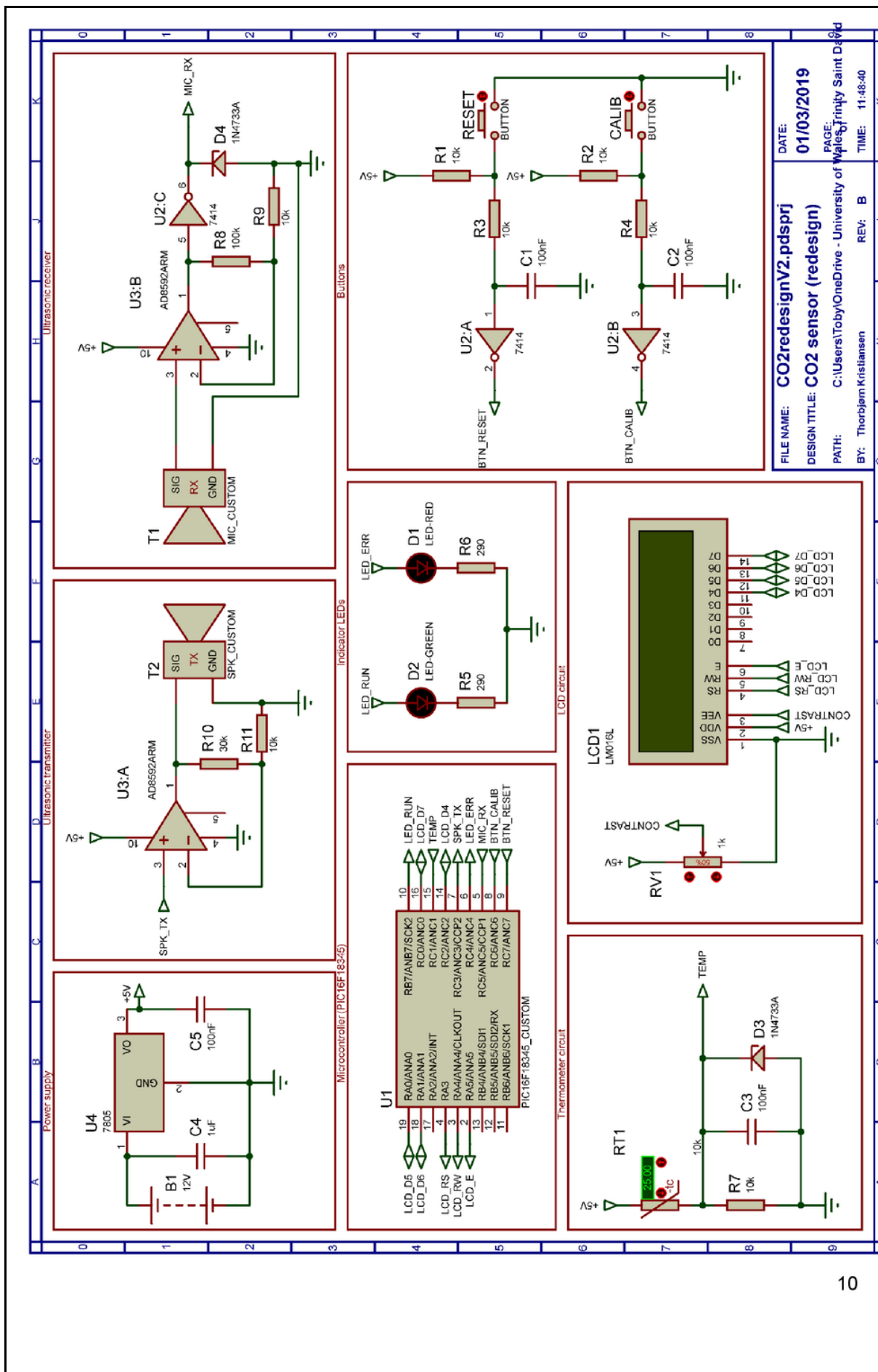
Figure 3 - PIC16F18345 packaging options

The chosen packaging for the initial prototype is the PDIP version (plastic dual in-line package). This was done to accommodate simple prototyping, as through-hole components are unproblematic to manually manipulate. The other alternatives are surface mounted components (figure 3), making them ideal for production runs as they occupy less PCB space. They are also marginally less expensive.

Redesigning the Original System

Since a microcontroller contains all the digital circuitry in figure 1, the design requirements for a microcontroller-based system change substantially. As seen in figure 4 on the next page, the only necessary auxiliary components are analogue system blocks such as buttons, operational amplifiers and LEDs (disregarding the digital LCD). Noise mitigation was accomplished primarily using 100nF capacitors. These values could be subject to change, as the circuit will need real life testing to tune the system to a satisfactory level.

In figure 4, the system is broken down into 8 blocks, where each block has its own connections to the PIC.



Electrical Details

The redesigned circuit is simplistic by nature, in that a microcontroller is performing all digital control operations except for the internal LCD controller. This renders the circuit design minimalistic, so a brief explanation for each block will suffice, where necessary. The power supply is included as an example, as no power supply was specified in the original block diagram.

All operational amplifiers have the negative supply rail grounded, as all signals are on a DC level.

Ultrasonic Transmitter and Receiver

The datasheet for the ultrasonic transmitter does not specify power consumption, only maximum peak to peak input voltage[13]. However, it is reasonable to assume that the transmitter requires some form of amplification, as the PIC has a limited current drive. Amplification was accomplished through the use of a AD8532 dual operational amplifier, chosen for its high current drive capability (250mA)[14].

Gain was calculated by:

$$K = \left(\frac{R10}{R11} \right) + 1$$

Since the rail voltage of the amplifier is only 5V, amplification does not make much difference, and the op-amps main purpose is to act as a buffer to provide current drive and a sharper transition due to overloading the amplifier.

The receiver has a gain of 101, which is a preliminary setting as the transmitter/receiver system has not been tested in real life. In the prototyping stage, R8 would be temporarily replaced with a potentiometer to accurately adjust and verify the necessary gain. The output is clamped at 5V, and Schmitt-triggered to provide an adequate edge trigger for the PIC.

Thermometer Circuit

An NTC thermistor was chosen since the resistance decreases as the temperature rises. This gives it a desirable attribute, in that the on-current is relatively low in cold rooms (cellars, refrigerators, etc). The circuit is a simple potential divider with the 5V clamped output feeding directly to the on-chip ADC unit.

Button Inputs

The button system consists of 5V pull-up resistors (R1, R2), debouncing capacitors (C1, C2) and a Schmitt trigger system to provide hysteresis for the debouncing operation. The resistors R3 and R4 provide current limiting when the capacitor discharges, to prevent arcing at the switch point.

Operational Details

As explained in the background research, the speed of sound through air is directly affected by the CO₂ content and temperature. The system is comprised of a transmitter and a receiver placed apart in a passively ventilated chamber. The separation distance is predetermined and must be included in the calibration phase.

When the system starts up, a temperature reading is taken from the thermistor and stored in memory. A 40KHz square wave is outputted from the PWM generator within the chip and sent to the ultrasonic transmitter. At the same time, the timer1 value is reset. When the first ultrasonic pulse reaches the ultrasonic receiver, the signal is amplified and squared. The output of the receiver is coupled to the capture/compare module of the PIC, which saves the value of timer1 to a holding register when the first edge is detected.

This value is therefore the time of flight it takes for the ultrasonic signal to travel from the transmitter to the receiver. Together with the temperature level, a floating-point calculation can be performed to accurately determine the CO₂ content of the air in the chamber.

Calibration can be accomplished by placing the unit in an environment where the exact temperature and CO₂ content are known variables. The calibration button is then pressed, and the unit self-calibrates to these values. The calibration settings can be stored in the internal EEPROM of the PIC.

Flowchart

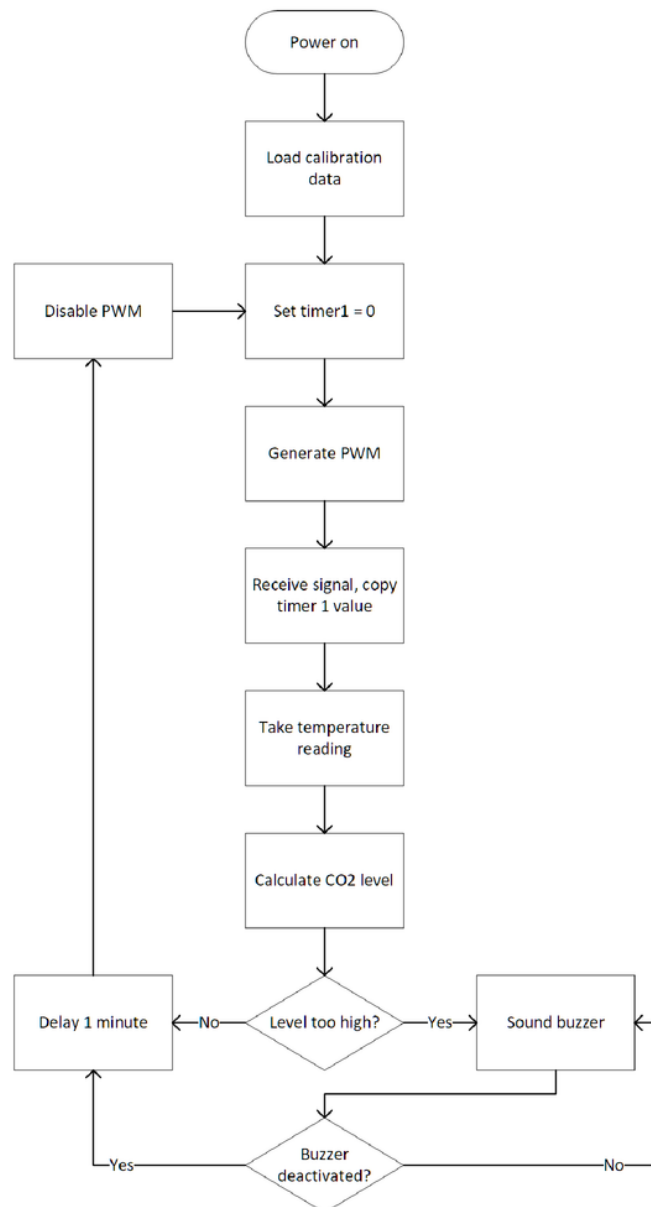


Figure 5 - Ultrasonic system flowchart

Parts List

Component	Manufacturer	Manufacturer part number	DigiKey part number	Price	Notes
Microcontroller	Microchip	PIC16F18345-I/P	PIC16F18345-I/P-ND	£1.07	-
Ultrasonic transmitter	Murata	MA40S4S	490-7707-ND	£5.73	20v Pk-Pk
Ultrasonic receiver	Murata	MA40S4R	490-7706-ND	£5.73	-
Voltage regulator	Texas Instruments	UA7805CKCS	296-13996-5-ND	£0.58	5V
Thermistor	Littelfuse	PS103J2	615-1003-ND	£2.39	10kOhm
Operational amplifier	Analog Devices	AD8532ARMZ	AD8532ARMZ-REELCT-ND	£0.95	-
Schmitt trigger/inverter	Texas Instruments	SN7414N	296-33604-5-ND	£1.84	6 channel
LCD	Lumex Opto/Components Inc.	LCM-S01602DTR/M	67-1781-ND	£7.23	No backlight
Casing	Bud Industries	CU-3011-A	377-1098-ND	£22.47	Aluminium 1' long
Sum:				£47.99	

Table 3 - Parts list for redesigned system

Contemporary System

Designing a system based on current technology allows for greater flexibility when implementing more functionality than the original system. Microcontrollers have great toolsets built in, completely accessible by software alone.

The PIC18F45K50

When choosing a microcontroller for this task, pin count is paramount. This allows all peripherals to be connected without the need for multiplexers or other external components for I/O expansion. Table 4 is a simple input/output table:

I/O					
	Digital	I2C	UART	Other	SPI
Sensor	1	2			
VCC				1	
GND				1	
USB				4	
Buttons	6				
LCD	7				
Bluetooth	8		2		
SD card					3
Buzzer	1				
				Sum:	36

Table 4 - Input/output table for modern system

As seen above, a PIC with at least 36 pins is required. This perfectly coincides with Microchip's selection, as the closest PIC has 40 pins. A Bluetooth unit is the largest occupier of pins, as it needs a minimum of 7 pins to function satisfactory. In the parametric search function, 5 attributes were specified:

- UART: >0
- SPI: >0
- I2C: >0
- USB: >0
- Pin count: 40

This yielded a result of only 1 PIC, the PIC18F45K50.



Figure 6 - PIC18F45K50

Circuit Details

Since a requirement for this system was USB charging and data passthrough, a choice to lower the supply voltage to 3.3V was made. This was not a problem, as all the components in the schematic have at least 3.3V minimum voltage requirements. The reasoning behind this choice was to remove the need for DC-DC boost converters, as single-cell lithium batteries have a potential of between 3V-4.2V, depending on charge level. USB standard voltage is 5V, which makes single-cell lithium ideal for USB charging.

Schematic Sheet 1

In sheet 1 (figure 7), we find the button array, SD-card interface, warning buzzer, the LCD screen and the sensor module itself. The button array design is identical to the previously discussed circuit. The only changes are a lower supply voltage and more buttons.

The SD-card interface is a simple SPI-based unit, with 2 data lines and 1 clock line. The PIC generates the clock signal, and the SD-card acts as an SPI slave.

The LCD screen was chosen for its lower supply voltage as the circuit is now running on 3.3V.

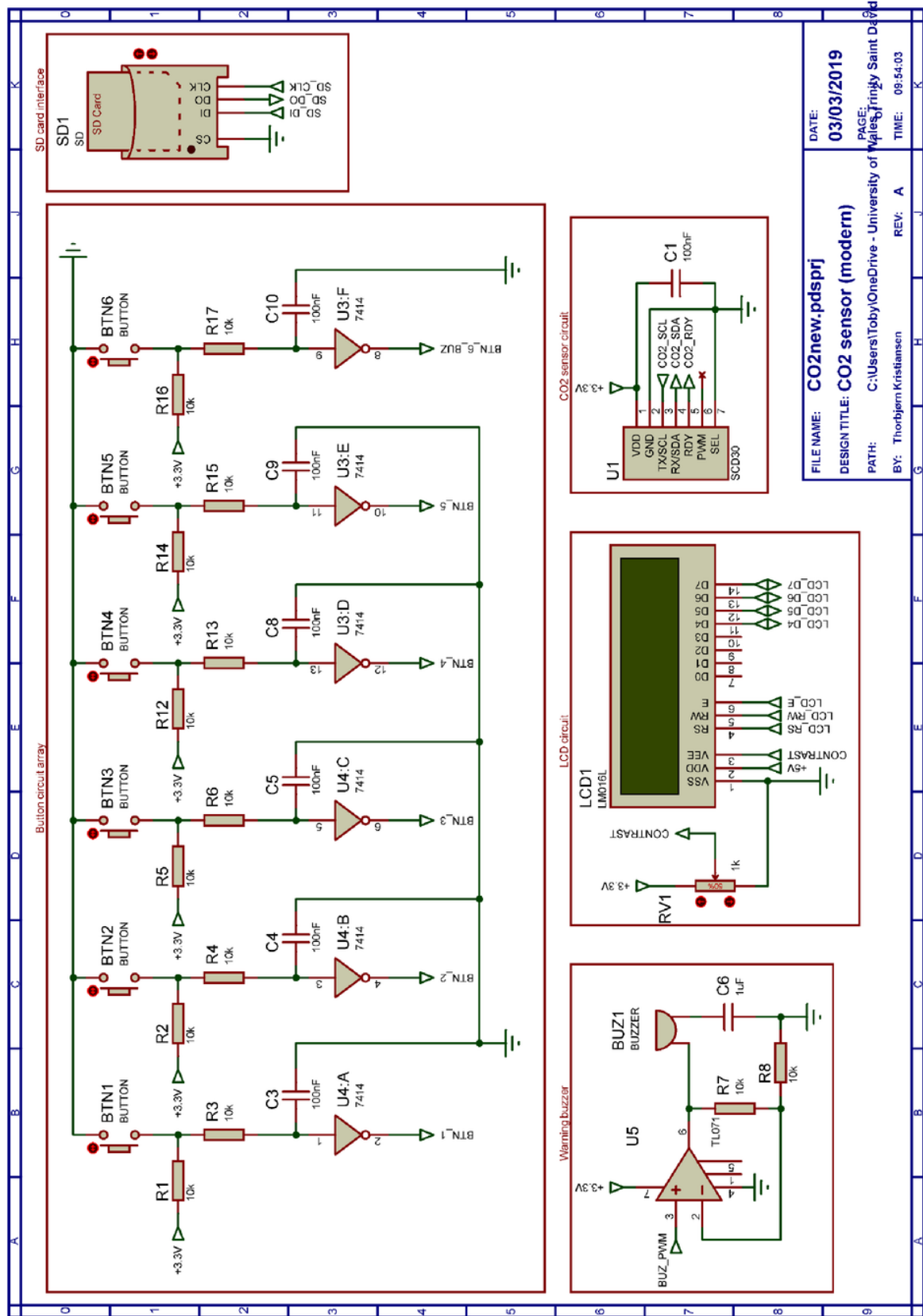


Figure 7 - Modern system circuit diagram (sheet 1/2)

Schematic Sheet 2

Sheet 2 (figure 8, next page) contains the microcontroller itself, the power supply and the Bluetooth module. The RN4020 Bluetooth module from Microchip offers MLDP (Microchip Low-energy Data Profile), which can transmit data at a lower power consumption than standard Bluetooth modems. If a baud rate of 2400 is selected, the module does not need to be fully awake for data transmission to happen. The three LEDs provides information on connection status, on-status and transmission status.

The power supply is sourced from 2 lithium cells in parallel. This offers higher capacity, but the cells need to be closely matched to prevent short cell life or dangerous situations such as high quiescent currents between the cells due to differing internal resistances and charges. A 3.3V voltage regulator regulates and supplies the entire system. The charger (LTC4053) can supply up to 500mA, which is the limit for most USB hosts. A 10k NTC thermistor monitors the battery temperature, offering safer charge control in case of overheating. The charge current is also selectable, with options of 100mA and 500mA. In the current configuration, the charge current is set to max (500mA). Since the voltage regulator can supply a maximum of 200mA and the batteries have a 6700mAh capacity, the worst-case battery life can be calculated:

$$\frac{6700mAh}{200mA} \times 0.7 = 23.45h$$

In this equation, the 0.7 is a “consumption rate” factor (provided by Digi-Key[15]), which attempts to correct the equation for real-life factors such as battery wear and temperature changes. Since the system will never reach 200mA, a more sensible approach would be to halve the current consumption. This is still a very conservative approach, as most of the components in the circuit draw less than 100mA. The unit can therefore comfortably operate for 24 hours on a single charge.

$$\frac{6700mAh}{100} \times 0.7 = 46.9h$$

The PIC itself has 3 available I/O ports for future expansion. The power supply and ground pins are not visible in this schematic. Pin 18 (VUSB3v3) is coupled to ground through a ceramic low-ESR capacitor, as per the datasheet instructions.

Principle of Operation

This sensor system is based on an I2C protocol between the sensor module and microcontroller. The sensor module itself is an NDIR sensor, which is not reliant on a chamber of a certain size like the ultrasonic version.

On the next page, in figure 9, the flowchart explains the operation of the program during normal use. At first, the user is prompted with a voluntary setup routine. If declined, the system will run as normal but without Bluetooth or SD-card capabilities. The setup routine also prompts the user with inputting the date/time.

When the normal program flow starts, a CO₂ measurement is taken. If the level is too high, the program sets a flag. The purpose of this flag is to create a different time interval so the user can temporarily disable the buzzer. The buzzer only gets permanently deactivated if the CO₂ level drops to a safe level.

The interrupt routine handles both the silencing of the buzzer and a system-wide reset if necessary. It accomplishes this by recording the button depression time and executing a system reset and SD-card wipe if the button is depressed for more than 5 seconds. If the button is pressed in rapid succession, the PIC records this, and if it reaches 5 depressions, it takes the user into setup mode without the user having to power off beforehand.

Flowchart

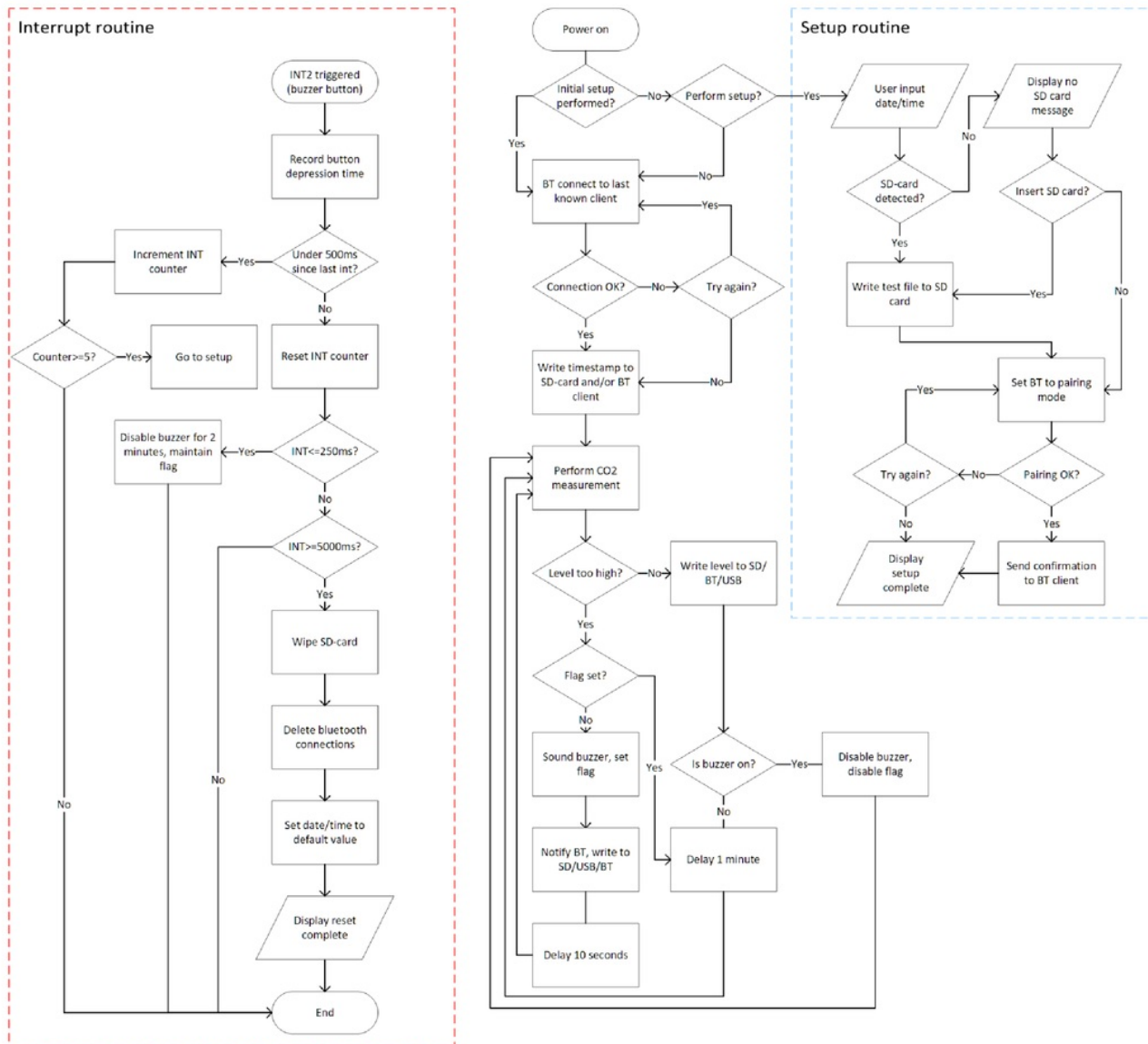


Figure 9 - Modem system flowchart

Parts List

Component	Manufacturer	Manufacturer part number	Vendor	Vendor part number	Price	Notes
PIC[16]	Microchip	PIC18F45K50-I/P	DigiKey	PIC18F45K50-I/P-ND	£2.26	
Bluetooth module[17]	Microchip	RN4020-V/RM120	DigiKey	RN4020-V/RM120-ND	£6.81	
Charging IC[18]	Linear Technology	LTC4053EDD-4.2#PBF	DigiKey	LTC4053EDD-4.2#PBF-ND	£2.88	500mA
Voltage regulator[19]	Texas Instruments	TLV70033DDCR	DigiKey	296-27937-1-ND	£0.36	200mA
Batteries[20]	Panasonic	PICPAULLNB46	Farnell	2819211	£39.73	1S2P configuration
Thermistor[21]	Littelfuse	PS103J2	DigiKey	615-1003-ND	£2.39	10kOhm
CO2 sensor[22]	Sensirion AG	SCD30	DigiKey	1649-1098-ND	£43.06	NDIR
LCD[23]	FORDATA	FC1602N04-NSWBBW-91*E	Farnell	2674135	£12.47	Transmissive
Op amp[24]	Texas Instruments	TL071IP	DigiKey	296-7188-5-ND	£0.42	
Schmitt trigger/inverter[25]	Texas Instruments	SN7414N	DigiKey	296-33604-5-ND	£1.84	6 channel
Casing[26]	Hammond	1554DGY	Farnell	4080828	£9.76	IP66
Buttons[27]	Grayhill	87HC3-201	DigiKey	87HC3-201-ND	£11.80	6x1 matrix
Buzzer[28]	Pro Signal	ABI-042-RC	Farnell	1827949	£1.96	80dB
Sum:					£135.74	

Table 5 - Modern system parts list

Conclusion

Embedded microcontrollers are very practical for purpose-specific applications such as CO₂ detection. Eliminating the need for full size computers proves very practical when size and portability is desirable. Older systems utilised discreet logic and modular digital chips, rendering the PCB complex and expensive. Collecting all digital circuitry on a small microcontroller makes the system smaller, more efficient and more portable. With the high energy density of lithium battery packs, the system can be designed to last for days without human intervention or charging.

User Manual

Contents:

- Device overview
- Initial setup
- Changing default values
- Data logging on SD-card
- USB connection
- Bluetooth connection

Device Overview

The CO₂ detector has been crafted with usability, stability and safety in mind. The system consists of a splash-proof case with the sensor opening on top and an LCD display moulded into the casing. The female USB connector is located to the side of the unit. To access the SD-card tray, simply unscrew the 4 screws holding the lid of the unit in place.

To navigate the different menus, 4 arrow keys and an "OK" button is placed on the top of the unit. A button to deactivate the buzzer is also present.

The unit has an internal rechargeable battery pack which is guaranteed to last at least 36 hours for logging purposes.

Initial Setup

To start using the device, power it on by connecting the battery pack to the connector on the printed circuit board and flip the main switch on the side of the unit. The LCD screen will then display "Perform setup?".

The setup is not mandatory for operating the device but is necessary if logging and connective capabilities are required.

Perform the setup by first entering the date and time with the arrow keys. Press OK to confirm. The next screen will show "Insert SD-card?" if the card is not already present. Insert the SD-card if applicable. To skip this step, press the right arrow. When the SD-card is inserted, the device will write a test file in the .txt format to the SD-card. Please ensure proper operation by inserting the SD-card into a computer and confirming the output.

The device will now go into Bluetooth pairing mode. To connect, simply select the "EasyCO2" unit in the device list of your Bluetooth device. If the pairing is successful, the display will show "Setup complete" and automatically start its normal sequence of operations. If pairing is unsuccessful, an option to try again or skip appears.

Setup can be easily accessed at any time by pressing the buzzer button 5 times in rapid succession.

Normal Operation

The device requires no maintenance or user intervention during normal operation. If the CO₂ level should rise to an unsafe level, a buzzer will sound. A notification will also be sent to any connected Bluetooth devices, displaying the current CO₂ content and urging the user to investigate the cause of the problem.

Pressing the buzzer button will deactivate the buzzer for 2 minutes. The unit will now start taking readings every 10 seconds as opposed to every minute. This is designed to aid with troubleshooting, as ventilating the room will have an immediate effect on the CO₂ level of the room.

Resetting the Unit to Factory Settings

To reset all values and delete the list of Bluetooth clients, hold down the buzzer button for 5 seconds. This will display the message "reset complete" on the LCD screen.

Note: Resetting the device to factory settings also deletes all information stored on the SD-card. Proceed with caution.

Appendix: Datasheet Snippets

FC1602N04-NSWBBW-91LE

3

GENERAL SPECIFICATIONS

FEATURES

AVAILABLE OPTIONS	CHARACTERISTICS	CODE	No.
DISPLAY FORMAT	16 Characters by 2 Lines	FC1602N04	1~6
POLARIZER OPTIONS	Negative Transmissive	N	7
BACKLIGHT TYPE OPTIONS	Edge Type LED Backlight (Standard version)	S	8
BACKLIGHT COLOR OPTIONS	White color	W	9
LCD PANEL OPTIONS	Blue STN	B	10
VIEWING ANGLE OPTIONS	6:00 (Bottom)	B	11
TEMPERATURE RANGE OPTIONS	-20°C ~ 70°C, Single Supply Voltage	W	12
SUGGESTED DRIVING VOLTAGE	V _{icm} = 3.0V V _{led} = 3.0V	9	13
SUGGESTED LED DRIVING MODE	PIN15: LED+, PIN16: LED-	1	14
CONTROLLER ▲1	SPLC780D+SPLC100A	L	15
FONT MAP CODE	E Version	E	16
DRIVING DUTY	1/16	—	—
DRIVING BIAS	1/5	—	—

▲1 Please ask for datasheet of the mentioned controller from FORDATA or FORDATA's authorized distributors. You can find the related information including AC & DC characteristics, Write & Read Timing diagram, Instruction table and descriptions, DDRAM & CGRAM, Rest Function and so on from the datasheet of controller.

▲1 You can ask for the example of software program (C language) from FORDATA or FORDATA's authorized distributors.

MECHANICAL SPECIFICATIONS

OVERALL SIZE	80.0W x 36.0H	mm	THICKNESS	max 13.5	mm
VIEWING AREA	64.5W x 13.8H	mm	HOLE-HOLE	75.0W x 31.0H	mm
CHARACTER SIZE	2.95W x 4.35H	mm	CHARACTER PITCH	0.7W x 0.7H	mm
DOT SIZE	0.55W x 0.50H	mm	DOT PITCH	0.05W x 0.05H	mm

ABSOLUTE MAXIMUM RATINGS

ITEM	SYMBOL	CONDITION	MIN	TYP	MAX	UNIT
POWER SUPPLY (LOGIC)	V _{dd}	25°C	-0.3	—	7.0	V
POWER SUPPLY (LCD)	V ₀	25°C	V _{dd} -13.5	—	V _{dd} +0.3	V
INPUT VOLTAGE	V _{in}	25°C	-0.3	—	V _{dd} +0.3	V
OPERATING TEMPERATURE	V _{opr}	—	-20	—	70	°C
STORAGE TEMPERATURE	V _{stg}	—	-30	—	80	°C

ELECTRONIC CHARACTERISTICS*

ICONS	ITEM	SYMBOL	CONDITION	MIN	TYP	MAX	UNIT
	INPUT VOLTAGE	V _{icm} = V _{dd}	—	—	3.0	—	V
	SUPPLY CURRENT	I _{dd}	V _{dd} =3V	—	1.5	—	mA
	DRIVING VOLTAGE FOR LCD PANEL	V _{lcd} = (V _{dd} - V ₀)	-20°C	—	—	—	V
			0°C	—	—	—	
			25°C	—	—	—	
			50°C	—	—	—	
			70°C	—	—	—	

* All data are recorded from TEST REPORT #FSYP000700079



classic LEDs & LEDS

Figure 10 - 3V LCD datasheet snip

TLV700

SLVSA00E – SEPTEMBER 2009 – REVISED APRIL 2015

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6.5 Electrical Characteristics

At $V_{IN} = V_{OUT(nom)} + 0.3 \text{ V}$ or 2 V (whichever is greater); $I_{OUT} = 10 \text{ mA}$, $V_{EN} = 0.9 \text{ V}$, $C_{OUT} = 1 \mu\text{F}$, and $T_J = -40^\circ\text{C}$ to $+125^\circ\text{C}$, unless otherwise noted. Typical values are at $T_J = 25^\circ\text{C}$.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{IN}	Input voltage range		2	5.5	V
V_{OUT}	DC output accuracy	$-40^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$	-2%	2%	
$\Delta V_{OUT(\Delta V_{IN})}$	Line regulation	$V_{OUT(nom)} + 0.3 \text{ V} \leq V_{IN} \leq 5.5 \text{ V}$, $I_{OUT} = 10 \text{ mA}$	1	5	mV
$\Delta V_{OUT(\Delta I_{OUT})}$	Load regulation	$0 \text{ mA} \leq I_{OUT} \leq 200 \text{ mA}$	1	15	mV
V_{DO}	Dropout voltage ⁽¹⁾	$V_{IN} = 0.98 \times V_{OUT(nom)}$, $I_{OUT} = 50 \text{ mA}$, $V_{OUT} = 2.8 \text{ V}$	43		mV
		$V_{IN} = 0.98 \times V_{OUT(nom)}$, $I_{OUT} = 100 \text{ mA}$, $V_{OUT} = 2.8 \text{ V}$	85		
		$V_{IN} = 0.98 \times V_{OUT(nom)}$, $I_{OUT} = 200 \text{ mA}$, $V_{OUT} = 2.35 \text{ V}$	175	250	
I_{CL}	Output current limit	$V_{OUT} = 0.9 \times V_{OUT(nom)}$	220	860	mA
I_{GND}	Ground pin current	$I_{OUT} = 0 \text{ mA}$	31	55	μA
		$I_{OUT} = 200 \text{ mA}$, $V_{IN} = V_{OUT} + 0.5 \text{ V}$	270		
I_{SHDN}	Ground pin current (shutdown)	$V_{EN} \leq 0.4 \text{ V}$, $V_{IN} = 2 \text{ V}$	400		nA
		$V_{EN} \leq 0.4 \text{ V}$, $2 \text{ V} \leq V_{IN} \leq 4.5 \text{ V}$	1	2	
PSRR	Power-supply rejection ratio	$V_{IN} = 2.3 \text{ V}$, $V_{OUT} = 1.8 \text{ V}$, $I_{OUT} = 10 \text{ mA}$, $f = 1 \text{ kHz}$	68		dB
V_n	Output noise voltage	$BW = 100 \text{ Hz to } 100 \text{ kHz}$, $V_{IN} = 2.3 \text{ V}$, $V_{OUT} = 1.8 \text{ V}$, $I_{OUT} = 10 \text{ mA}$	48		μV_{RMS}
t_{STR}	Start-up time ⁽²⁾	$C_{OUT} = 1 \mu\text{F}$, $I_{OUT} = 200 \text{ mA}$	100		μs
$V_{EN(high)}$	Enable pin high (enabled)		0.9	V_{IN}	V
$V_{EN(low)}$	Enable pin low (disabled)		0	0.4	V
I_{EN}	Enable pin current	$V_{IN} = V_{EN} = 5.5 \text{ V}$	0.04	0.5	μA
UVLO	Undervoltage lockout	V_{IN} rising	1.9		V
T_{sd}	Thermal shutdown temperature	Shutdown, temperature increasing	160		$^\circ\text{C}$
		Reset, temperature decreasing	140		
T_J	Operating junction temperature		-40	125	$^\circ\text{C}$

(1) V_{DO} is measured for devices with $V_{OUT(nom)} \geq 2.35 \text{ V}$.

(2) Start-up time = time from EN assertion to $0.98 \times V_{OUT(nom)}$.

Figure 12 - 3v3 voltage regulator datasheet snip

Six Button Module

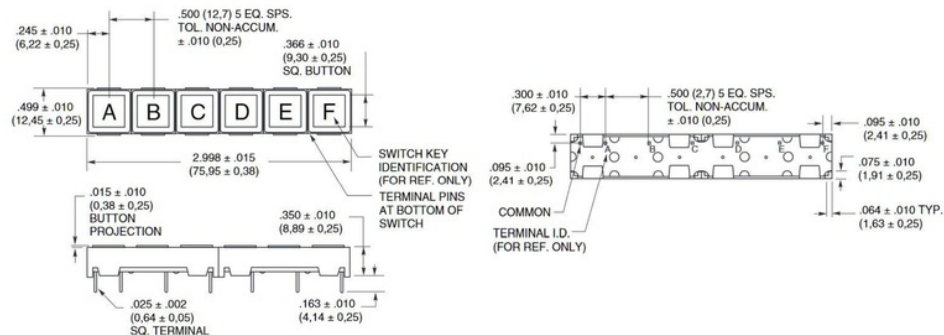


Figure 11 - Button matrix datasheet snip

PICPAULLNB46 – 3.6V / 6700 mAh



Dimensions

length: 66 ± 1mm
width: 19 ± 1mm
height: 41 ± 1mm

 UL recognized MH45979, IEC62133 2nd ed. CB Report available

Data for pack

Nominal Voltage	3.6V	2.5V - 4.2V
Nominal capacity	6700mAh	typical
Used cell in Pack	2 pcs	Panasonic NCR-18650BF
Internal resistance pack	115mΩ	103mΩ - 127mΩ
Max charge voltage	4.2V	
Charge current	standard	1625mA 10°C < T < 45°C
	rapid	3000mA 10°C < T < 45°C (limited by connector)
Discharge	standard	1300mA -20°C < T < 60°C
	max.cont.	3000mA -20°C < T < 60°C (limited by connector)
	max.peak	3000mA -20°C < T < 60°C
Short circuit current	≤ 34.5A	< 320μs
NTC	10 kΩ	
Connector	JST	XHP-3
		Pin 1: GND black
		Pin 2: NTC yellow
Cable length	45mm	±5mm
		Weight
		125g ±5g
Watt-hour rating	24Wh	acc. to UN38.3 Certificate Rev. 5.1

Limitations by Safety Unit (SU)

over voltage (per cell)	cut off	4.215V	±25mV
over voltage (per cell)	release	4.1V	±25mV
under voltage (per cell)	cut off	2.3V	±50mV
under voltage (per cell)	release	2.4V	±50mV
Current limit 1 by SU		< 3A	continuous (typical)
Current limit 2 by SU		≥ 14.5A	< 2.24ms (typical)
Current limit 3 by SU		≥ 34.5A	< 320μs (typical)
Power consumption	active	≤35μA	@4.2V ±5μA
	power down	10μA	±2μA

Figure 13 - Battery datasheet snip

Audio Indicator

pro-SIGNAL



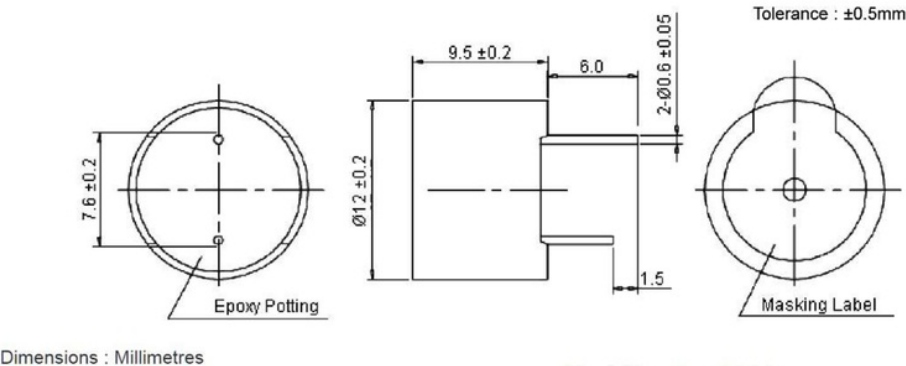
Features:

- Colour : Black
- Housing material : Noryl
- Wave solderable and washable
- All data at 25°C unless otherwise specified

RoHS
Compliant

Specifications:

Operating Voltage	: 2V DC to 3V DC
Rated Voltage	: 1.5V DC
Maximum Rated Current at Rated Voltage	: 20mA
Sound Output at 20cm, at Rated Voltage	: ≥80dB
Resonant Frequency	: 2,300 ±400Hz
Tone	: Single
Operating Temperature	: -30°C to +70°C
Storage Temperature	: -40°C to +85°C
Weight	: 2g
Transducer Function	: Buzzer
External Depth	: 9.5mm
Outer Dia	: 12mm



Part Number Table

Description	Part Number
Indicator, Audio	ABI-042-RC

Figure 14 - Buzzer datasheet snip

LTC4053-4.2

ABSOLUTE MAXIMUM RATINGS (Note 1)

Input Supply Voltage (V_{CC})	7V	Junction Temperature	125°C
BAT	7V	Operating Temperature Range (Note 3)	–40°C to 85°C
NTC, SHDN, TIMER, PROG	–0.3V to $V_{CC} + 0.3V$	Storage Temperature Range	
CHRG, FAULT, ACPR	–0.3V to 7V	MSE	–65°C to 150°C
BAT Short-Circuit Duration	Continuous	DD	–65°C to 125°C
BAT Current (Note 2)	1.3A	Lead Temperature (Soldering, 10 sec)	
PROG Current (Note 2)	1.3mA	MSE	300°C

PACKAGE/ORDER INFORMATION

DD PACKAGE 10-LEAD (3mm × 3mm) PLASTIC DFN $T_{JMAX} = 125^{\circ}\text{C}$, $\theta_{JA} = 40^{\circ}\text{C/W}$ (NOTE 4) EXPOSED PAD (PIN 11) IS GND (MUST BE SOLDERED TO PCB)	ORDER PART NUMBER	MSE EXPOSED PAD PACKAGE 10-LEAD PLASTIC MSOP $T_{JMAX} = 125^{\circ}\text{C}$, $\theta_{JA} = 40^{\circ}\text{C/W}$ (NOTE 4) EXPOSED PAD (PIN 11) IS GND (MUST BE SOLDERED TO PCB)	ORDER PART NUMBER
	LTC4053EDD-4.2		LTC4053EMSE-4.2
	DD PART MARKING		MSE PART MARKING
	LBQC		LTZT

Order Options Tape and Reel: Add #TR
Lead Free: Add #PBF Lead Free Tape and Reel: Add #TRPBF
Lead Free Part Marking: <http://www.linear.com/leadfree/>

Consult LTC Marketing for parts specified with wider operating temperature ranges.

ELECTRICAL CHARACTERISTICS The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at $T_A = 25^{\circ}\text{C}$, $V_{CC} = 5V$

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
V_{CC}	V_{CC} Supply Voltage	●	4.25		6.5	V
I_{CC}	V_{CC} Supply Current	Charger On; Current Mode; $R_{PROG} = 30k$ (Note 5) Shutdown Mode; $V_{SHDN} = 0V$ Sleep Mode $V_{CC} < V_{BAT}$ or $V_{CC} \leq 4V$	●	1 25 25	2 50 50	mA μA μA
V_{BAT}	V_{BAT} Regulated Float Voltage	●	4.158	4.2	4.242	V
I_{BAT}	Battery Pin Current	$R_{PROG} = 3k$; Current Mode $R_{PROG} = 15k$; Current Mode Shutdown Mode; $V_{SHDN} = 0V$ Sleep Mode $V_{CC} < V_{BAT}$ or $V_{CC} < (V_{UV} - \Delta V_{UV})$	●	465 93	500 100	535 107 ± 1 ± 3 μA
I_{TRIKL}	Trickle Charge Current	$V_{BAT} < 2V$; $R_{PROG} = 3k$	●	35	50	65 mA
V_{TRIKL}	Trickle Charge Trip Threshold	V_{BAT} Rising		2.48		V
ΔV_{TRIKL}	Trickle Charge Trip Hysteresis			100		mV
V_{UV}	V_{CC} Undervoltage Lockout Voltage	V_{CC} Rising	●	4	4.25	V
ΔV_{UV}	V_{CC} Undervoltage Lockout Hysteresis			200		mV
V_{MSD}	Manual Shutdown Threshold Voltage	SHDN Pin Voltage		0.6	1.3	V
V_{ASD}	Automatic Shutdown Threshold Voltage	$(V_{CC} - V_{BAT})$ High to Low $(V_{CC} - V_{BAT})$ Low to High		35 70		mV mV

4053fa

2



Figure 15 - Charging IC datasheet snip

RN4020

2.0 GENERAL SPECIFICATIONS

Table 2-1 provides the general specifications of the module. Table 2-2 and Table 2-3 shows the weight and dimensions, and electrical characteristics of the module. Table 2-4 and Table 2-5 specify the current consumption of the module.

TABLE 2-1: GENERAL SPECIFICATIONS

Specification	Description
Standard	Bluetooth 4.1
Frequency Band	2.4 ~ 2.48 GHz
Modulation Method	GFSK
Maximum Data Rate	1 Mbps
Antenna	PCB
Interface	UART, PIO, AIO, SPI
Operation Range	100 meters ⁽¹⁾
Sensitivity	-92.5 dBm at 0.1% BER
RF TX Power	-19.0 dBm to +7.5 dBm
Temperature (operating)	-30°C to +85°C
Temperature (storage)	-40°C to +85°C
Humidity	10% ~ 90% non-condensing

Note 1: Maximum range under ideal conditions such as RF matching, line of sight, maximum power. Actual results may vary depending on the customer's design.

TABLE 2-2: WEIGHT AND DIMENSIONS

Specification	Description
Dimensions	11.5 x 19.5 x 2.5 mm
Weight	1.2g

TABLE 2-3: ELECTRICAL CHARACTERISTICS

Specification	Description
Supply Voltage	1.8 to 3.6V DC
Working current	Depends on profiles, 12 mA typical

TABLE 2-4: CURRENT CONSUMPTION

Mode	Typical Current at 3V
Dormant	<900 nA
Deep Sleep	<5.0 μ A
Idle	<1.5 mA
TX/RX active	16 mA

TABLE 2-5: CURRENT CONSUMPTION VS RF TX POWER

RN4020, V _{DD} = 3.3V, 25°C	
TX Power (dBm)	I _d (mA)
-19.1	14.0
-15.1	14.4
-10.9	15.0
-6.9	15.9
-2.5	17.6
1.6	20.7
5.8	26.9
7.5	33.6

Figure 17 - Bluetooth module datasheet snip

1 Sensor Specifications¹

CO₂ Sensor Specifications

Parameter	Conditions	Value
CO ₂ measurement range	-	0 – 40'000 ppm
Accuracy ²	400 ppm – 10'000 ppm	± (30 ppm + 3%MV)
Repeatability ³	400 ppm – 10'000 ppm	± 10 ppm
Temperature stability ⁴	T = 0 ... 50°C	± 2.5 ppm / °C
Response time ⁵	τ _{63%}	20 s
Accuracy drift over lifetime ⁶	400 ppm – 10'000 ppm ASC field-calibration algorithm activated and SCD30 in environment allowing for ASC, or FRC field-calibration algorithm applied.	± 50 ppm

Table 1: SCD30 CO₂ sensor specifications

Humidity Sensor Specifications⁷

Parameter	Conditions	Value
Humidity measurement range	-	0 %RH – 100 %RH
Accuracy ⁸	25°C, 0 – 100 %RH	± 3 %RH
Repeatability ³	-	± 0.1 %RH
Response time ⁵	τ _{63%}	8 s
Accuracy drift	-	< 0.25 %RH / year

Table 2: SCD30 humidity sensor specifications

Temperature Sensor Specifications⁷

Parameter	Conditions	Value
Temperature measurement range ⁹	-	- 40°C – 70°C
Accuracy ⁸	0 – 50°C	± (0.4°C + 0.023 × (T [°C] – 25°C))
Repeatability ³	-	± 0.1°C
Response time ⁵	τ _{63%}	> 10 s
Accuracy drift	-	< 0.03 °C / year

Table 3: SCD30 temperature sensor specifications

Figure 18 – CO₂ sensor datasheet snip

6.5 Electrical Characteristics

over operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS ⁽¹⁾		MIN	TYP ⁽²⁾	MAX	UNIT
V_{T+}	$V_{CC} = 5\text{ V}$	SNx414	1.5	1.7	2	V
		SNx4LS14	1.4	1.6	1.9	
V_{T-}	$V_{CC} = 5\text{ V}$	SNx414	0.6	0.9	1.1	V
		SNx4LS14	0.5	0.8	1	
Hysteresis ($V_{T+} - V_{T-}$)	$V_{CC} = 5\text{ V}$		0.4	0.8		V
V_{IK}	$V_{CC} = \text{MIN}, I_I = -12\text{ mA}, \text{SNx414}$				-1.5	V
	$V_{CC} = \text{MIN}, I_I = -18\text{ mA}, \text{SNx4LS14}$				-1.5	
V_{OH}	$V_{CC} = \text{MIN}, V_I = 0.6\text{ V}, I_{OH} = -0.8\text{ mA}, \text{SNx414}$		2.4	3.4		V
	$V_{CC} = \text{MIN}, V_I = 0.5\text{ V}, I_{OH} = -0.4\text{ mA}, \text{SNx4LS14}$		2.4	3.4		
V_{OL}	$V_{CC} = \text{MIN}, V_I = 2\text{ V}, I_{OL} = 16\text{ mA}, \text{SNx414}$			0.2	0.4	V
	$V_{CC} = \text{MIN}, V_I = 1.9\text{ V}$	$I_{OL} = 4\text{ mA}, \text{SNx4LS14}$		0.25	0.4	
		$I_{OL} = 8\text{ mA}, \text{SN74LS14}$		0.35	0.5	
I_{T+}	$V_{CC} = 5\text{ V}, V_I = V_{T+}$	SNx414		-0.43		mA
		SNx4LS14		-0.14		
I_{T-}	$V_{CC} = 5\text{ V}, V_I = V_{T-}$	SNx414		-0.56		mA
		SNx4LS14		-0.18		
I_I	$V_{CC} = \text{MAX}, V_I = 5.5\text{ V}, \text{SNx414}$				1	mA
	$V_{CC} = \text{MAX}, V_I = 7\text{ V}, \text{SNx4LS14}$				0.1	
I_{IH}	$V_{CC} = \text{MAX}, V_{IH} = 2.4\text{ V}, \text{SNx414}$				40	μA
	$V_{CC} = \text{MAX}, V_{IH} = 2.7\text{ V}, \text{SNx4LS14}$				20	
I_{IL}	$V_{CC} = \text{MAX}, V_{IL} = 0.4\text{ V}$	SNx414		-0.8	-1.2	mA
		SNx4LS14			-0.4	
$I_{OS}^{(3)}$	$V_{CC} = \text{MAX}$	SNx414	-18		-55	mA
		SNx4LS14	-20		-100	
I_{CCH}	$V_{CC} = \text{MAX}$	SNx414		22	36	mA
		SNx4LS14		8.6	16	
I_{CCL}	$V_{CC} = \text{MAX}$	SNx414		39	60	mA
		SNx4LS14		12	21	

(1) For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.

(2) All typical values are at $V_{CC} = 5\text{ V}$ and $T_A = 25^\circ\text{C}$.

(3) Not more than one output should be shorted at a time.

Figure 19 - Schmitt trigger/inverter datasheet snip

Leaded Thermistors
Interchangeable Thermistor



PS Series Standard Precision Interchangeable Thermistors

Specifications

Part Number	Resistance Ohms @ 25°C	Accuracy (±°C) 0-70°C	R-T Curve	Temperature Coefficient (% / °C) @ 25°C	Beta (K) 0-50°C	Max. Power Rating (mW)	Dissipation Constant, Nominal (mW/°C)	Thermal Time Constant, Max. - Still Air (seconds)	Thermal Time Constant, Max. - Well Stirred Oil (seconds)	Temperature Rating (°C)	Storage & Operation Temp for Best L/T Stability (°C)
PS102J2	1000	± 0.1°C	J	-4.4	3892	30	1	10	1	-80 to +150	-80 to +75
PS222J2	2252	± 0.1°C	J	-4.4	3892	30	1	10	1	-80 to +150	-80 to +75
PS302J2	3000	± 0.1°C	J	-4.4	3892	30	1	10	1	-80 to +150	-80 to +75
PS502J2	5000	± 0.1°C	J	-4.4	3892	30	1	10	1	-80 to +150	-80 to +75
PS602J2	6000	± 0.1°C	J	-4.4	3892	30	1	10	1	-80 to +150	-80 to +75
PS103G2	10000	± 0.1°C	G	-4.04	3575	30	1	10	1	-80 to +150	-80 to +75
PS103J2	10000	± 0.1°C	J	-4.4	3892	30	1	10	1	-80 to +150	-80 to +75
PS203J2	20000	± 0.1°C	J	-4.4	3892	30	1	10	1	-80 to +150	-80 to +75
PS303J2	30000	± 0.1°C	J	-4.4	3892	30	1	10	1	-80 to +150	-80 to +75
PS503J2	50000	± 0.1°C	J	-4.4	3892	30	1	10	1	-80 to +150	-80 to +75
PS503R2	50000	± 0.1°C	R	-4.68	4140	30	1	10	1	-80 to +150	-80 to +75
PS104J2	100000	± 0.1°C	J	-4.4	3892	30	1	10	1	-80 to +150	-80 to +75
PS104R2	100000	± 0.1°C	R	-4.68	4140	30	1	10	1	-80 to +150	-80 to +75

Figure 20 - Thermocouple datasheet snip (see red mark)

6.13 Electrical Characteristics: TL071I, TL072I, TL074I

$V_{CC\pm} = \pm 15$ V (unless otherwise noted)

PARAMETER		TEST CONDITIONS ⁽¹⁾ ⁽²⁾		MIN	TYP	MAX	UNIT
V _{IO}	Input offset voltage	V _O = 0 R _S = 50 Ω	T _A = 25°C T _A = Full range		3	6 8	mV
α	Temperature coefficient of input offset voltage	V _O = 0 R _S = 50 Ω	T _A = Full range		18		μV/°C
I _{IO}	Input offset current	V _O = 0	T _A = 25°C T _A = Full range		5	100 2	pA nA
I _{IB}	Input bias current ⁽³⁾	V _O = 0	T _A = 25°C T _A = Full range		65	200 7	pA nA
V _{ICR}	Common-mode input voltage range	T _A = 25°C		±11	–12 to 15		V
V _{OM}	Maximum peak output voltage swing	R _L = 10 kΩ	T _A = 25°C	±12	±13.5		V
		R _L ≥ 10 kΩ	T _A = Full range	±12			
		R _L ≥ 2 kΩ		±10			
A _{VD}	Large-signal differential voltage amplification	V _O = ±10 V R _L ≥ 2 kΩ	T _A = 25°C T _A = Full range	50 25	200		V/mV
B ₁	Unity-gain bandwidth	T _A = 25°C			3		MHz
r _i	Input resistance	T _A = 25°C			10 ¹²		Ω
CMRR	Common-mode rejection ratio	V _{IC} = V _{ICR(min)} V _O = 0 R _S = 50 Ω	T _A = 25°C	75	100		dB
k _{SVR}	Supply-voltage rejection ratio (ΔV _{CC±} /ΔV _{IO})	V _{CC} = ±9 V to ±15 V V _O = 0 R _S = 50 Ω	T _A = 25°C	80	100		dB
I _{CC}	Supply current (each amplifier)	V _O = 0; no load	T _A = 25°C		1.4	2.5	mA
V _{O1} / V _{O2}	Crosstalk attenuation	A _{VD} = 100	T _A = 25°C		120		dB

(1) All characteristics are measured under open-loop conditions with zero common-mode voltage, unless otherwise specified.

(2) $T_A = -40^\circ\text{C}$ to 85°C .

(3) Input bias currents of an FET-input operational amplifier are normal junction reverse currents, which are temperature sensitive, as shown in Figure 1. Pulse techniques must be used that maintain the junction temperature as close to the ambient temperature as possible.

Figure 21 - TL071 Opamp datasheet snip

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Toby CO2 assignment

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

67/100

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ENGAGEMENT WITH LITERATURE



Generally very comprehensive research and referencing into the practical aspects of the electronic components. The first page also has first class use of in line citations for the background research, however things then peter out a little! Its imperative you include research material to show you understand ALL aspects of the project. This includes things like competitors products, previous research done in the relevant areas etc.

60

KNOWLEDGE AND UNDERSTANDING



Excellent knowledge demonstrated in all aspects of the electronic design. Remember the brief also stated: "Marks will be awarded for a thorough understanding of: What the product/market requirements are...." This section would have been 1st class, but you have lost marks here for lack of alternative product/market research.

67

COGNITIVE AND INTELLECTUAL



Excellent work in this section on the design decided on, but again: This section would have been 1st class, but you have lost marks here for lack of alternative product/market research and then subsequent analysis and discussion before coming to conclusions as to how to proceed in your own design.

67

PRACTICAL APPLICATION



Solid design. Good level of detail and thought demonstrated in the flowcharting. Parts list/costing included and ok.

75

TRANSFERABLE SKILLS



As most/all assignments are now read electronically, putting circuit diagrams in portrait orientation isn't a good idea. If you do want to include the whole thing, then ALSO provide rotated version (maybe need to break down into sections and magnify?). Most large assignments (major project!) benefit from having the various sections numbered 1.1 1.2 etc Otherwise, very well laid out and presented.

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