Detailed Development Specification
for the
Function Generator and I2C Frequency Oscillator Circuits

Document Stakeholders (THESE NAMES ARE FOR INFORMATION ONLY)	
Author	**Chase Griswold**
Design Engineer	**Chase Griswold**
Approver	**Fernando Araujo**
Approver	**Vincent Banh**
Approver	**Alex Baret**

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M.S. ECE: Embedded Systems 6780

University of Utah

201 Presidents' Cir

Salt Lake City, Utah 84112

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1 [-] INTRODUCTION

1.1 [-] Identification

This is a Detailed Development Specification document for the two PCBs/Circuits designed for the 6780 Embedded Systems final Project.

1) Function Generator Circuit Utilizing LM741 Operational Amplifiers.
2) Square Wave Function Generator Using LM324N and DS18030 Digital Potentiometer

1.2 [-] Function Generator (Overview)

This technical specification details the construction and operation of a function generator circuit that employs three LM741 operational amplifiers to produce square, triangle, and sine waveforms. The LM741 operational amplifier is a single, versatile, and reliable component used in various analog circuits, replacing the LM324 for this specific design. The circuit is capable of generating multiple waveforms with adjustments for frequency and amplitude, making it suitable for a wide range of applications. A schematic of the Function Generator can be seen in Figure 1.

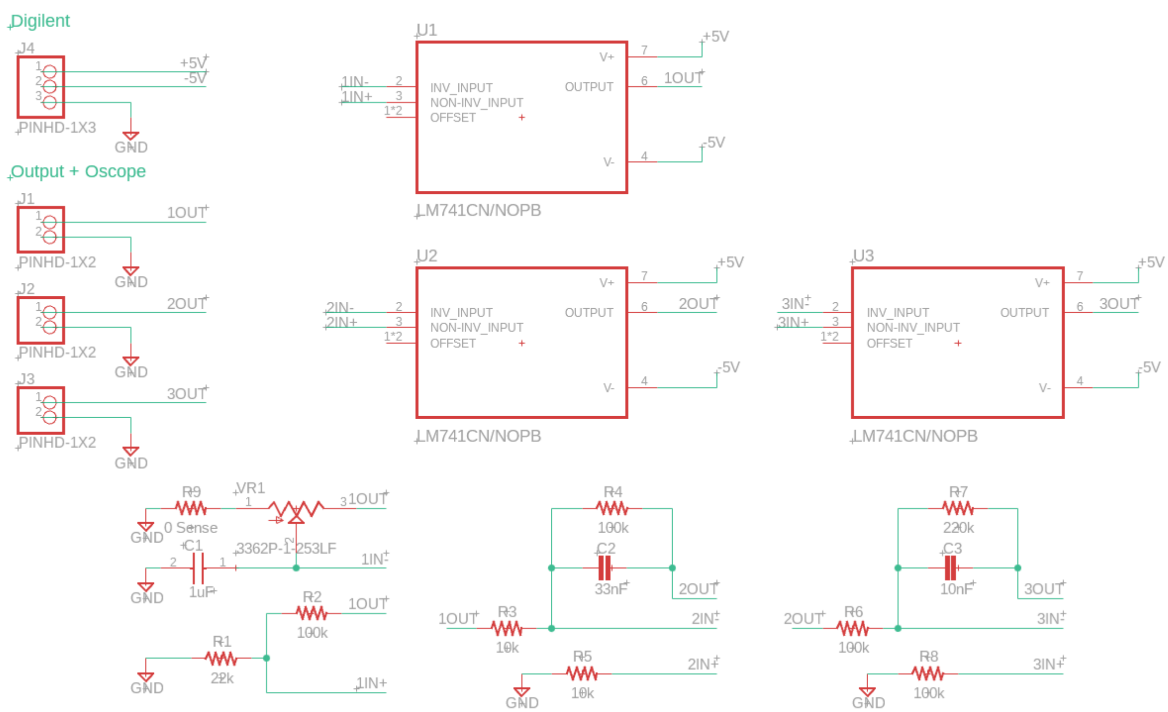


Figure 1 [-] Function Generator Circuit Utilizing LM741 Operational Amplifier

1.2.1 [-] External Interface Definition (Function Generator)

The PCB is shown in Figure 2, and the electrical interfaces are outlined in Table 1.

Table 1 [-] Function Generator Electrical Interface

Module/CCA Ref Des	Connector Name	Connector Type	Mating Connector Type
J1	Square Wave Output / GND	PINH Male	PINH Female
J2	Triangle Wave Output / GND	PINH Male	PINH Female
J3	Sine Wave Output / GND	PINH Male	PINH Female
J4	±5V Power Supply / GND	PINH Male	PINH Female

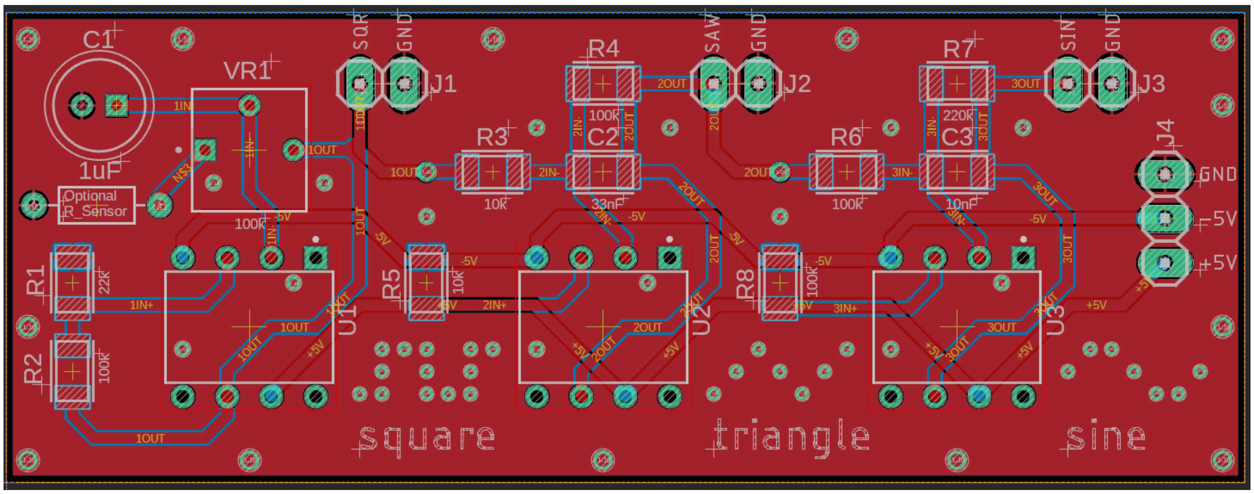


Figure 2 [-] Function Generator PCB

1.2.2 [-] Function Generator Operational Definitons

The LM741 operational amplifiers are biased with a dual-supply voltage of +5V and -5V, ensuring a broad signal swing range. The offset null pin of the LM741 is not utilized in this configuration. The first LM741 operational amplifier is configured to generate a square wave, which is then fed into a second LM741 configured as an integrator circuit to produce a triangle wave. This triangle wave is subsequently processed by another LM741 configured as an integrator circuit to output a sine wave. (Technically, the sine wave is formed of a parabolic voltage rise and fall, and then that parabolic voltage output is inverted, so it’s not truly a continuous sine wave).

Power is supplied to the circuit through the LM741’s power supply pins, accommodating a range from +5V to +15V for the positive supply and -5V to -15V for the negative supply. This power configuration ensures sufficient operation of the circuit across its functionalities.

Frequency modulation is achieved through a 100KΩ potentiometer, allowing for user control over the output signal's frequency. This potentiometer, in conjunction with the specific resistor and capacitor values, provides a wide range of frequency adjustments, emulating the flexibility of a standard function generator.

Amplitude adjustment can be easily implemented by varying the voltage from the DC power supply or, if powered by batteries, by adding a small-valued potentiometer (200Ω-500Ω) for voltage adjustment. This feature enhances the circuit's utility by allowing for precise control over the signal amplitude, accommodating various testing and measurement needs.

In summary, this function generator circuit, designed with LM741 operational amplifiers, offers the generation of square, triangle, and sine waveforms with adjustable frequency and amplitude. The circuit's design and component selection cater to a an excellent educational tool when considering the addition of probing points for each waveform, whereby they can be output onto an oscilloscope or sampled with an ADC.

1.2.3 [A] Function Generator BOM

Table 2 [A] Function Generator BOM

Value	Type	QTY	NOTES
LM741	IC (Amplifier)	3	
10KΩ	Resistor SMD	2	
100KΩ	Resistor SMD	4	
22KΩ	Resistor SMD	1	
220KΩ	Resistor SMD	1	
1μF	Capacitor Polarized Through-Hole	1	
1uF (REV A CHANGE)	Capacitor SMD	1	
100nF (REV A CHANGE)	Capacitor SMD	1	
N/A	PINHEADER	10	
100KΩ	Potentiometer	1	

1.3 [-] I2C Frequency Oscillator Overview

This technical specification details the construction and operation of an I2C controlled frequency oscillator circuit that employs an LM324N operational amplifier to produce a square waveform whose frequency can be adjusted via an I2C interfaced Digital Potentiometer (DS18030-100+). This is ostensibly a simpler take on the Function Generator circuit described in Section 1.2, where the potentiometer on that circuit is replaced with the DS18030-100+ I2C digital potentiometer and only the square wave is generated. A schematic of the I2C Frequency Oscillator can be seen in Figure 3.

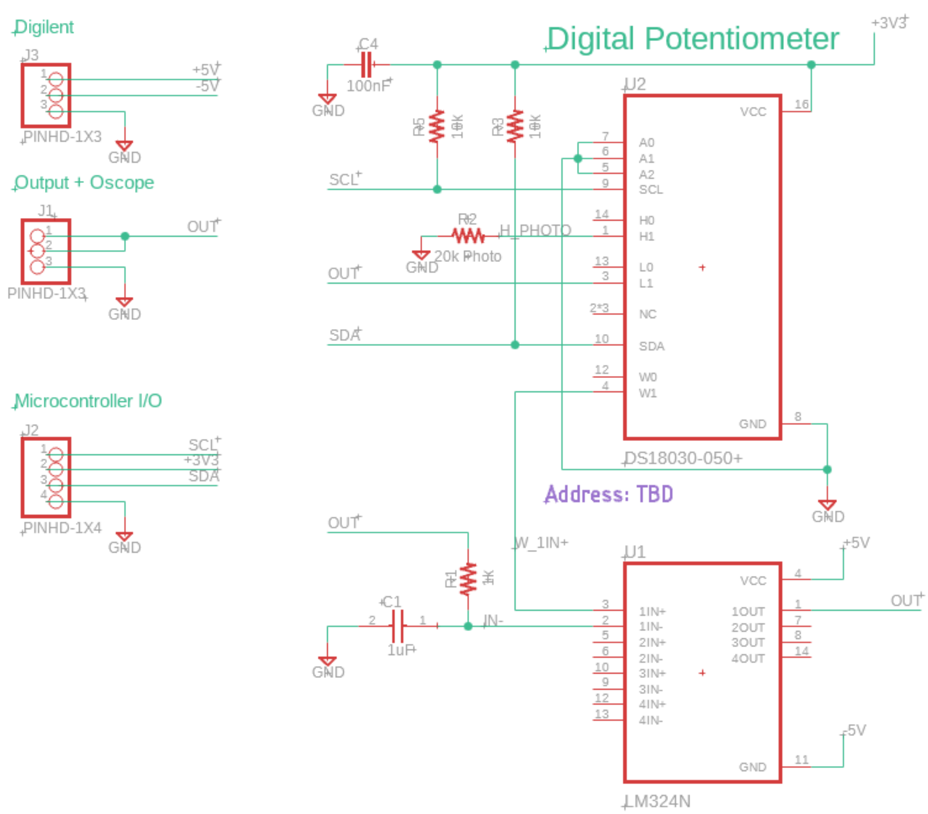


Figure 3 [-] I2C Frequency Oscillator Schematic

1.3.1 [-] External Interface Definition (I2C Frequency Oscillator)

The I2C Frequency Oscillator PCB is shown in Figure 4, and the electrical interfaces are outlined in .

Table 3 [-] I2C Frequency Oscillator Electrical Interfae

Module/CCA Ref Des	Connector Name	Connector Type	Mating Connector Type
J1	Square Wave Output / GND	PINH Male	PINH Female
J2	I2C CMD/STS – V / GND	PINH Male	PINH Female
J3	±5V Power Supply / GND	PINH Male	PINH Female

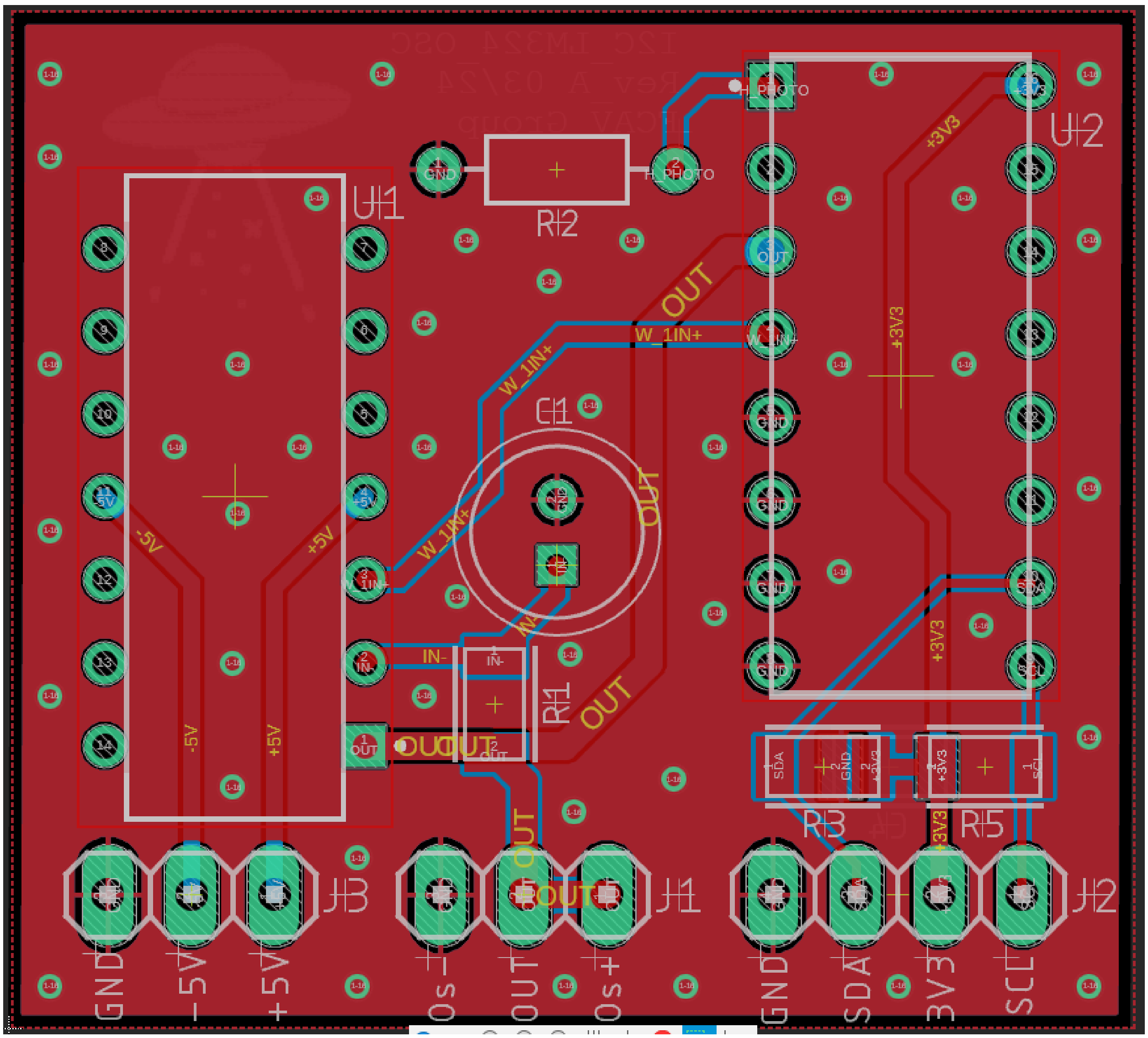


Figure 4 [-] I2C Frequency Oscillator PCB

1.3.2 I2C Frequency Oscillator Operational Definitons

The circuit employs one operational amplifier within the LM324N chip to generate the square wave. Power is supplied to the LM324N with +5V and -5V to ensure a broad output swing. The frequency adjustment is facilitated by the DS18030-100+ digital potentiometer, which offers 256 tap points over a 100KΩ range, allowing for fine-tuning of the square wave's frequency. This digital potentiometer is controlled via an I2C interface, providing a way to adjust the function generator's output without manual intervention.

1.3.3 [-] I2C Frequency Oscillator BOM

Table 4 [-] I2C Frequency Oscillator BOM

Value	Type	QTY	NOTES
LM324N	IC/Amplifier	1	
DS18030-100+	IC/ Digital Potentiometer	1	
10KΩ	Resistor	2	
1KΩ	Resistor	1	
20KΩ	Photo Resistor	1	optional
220KΩ	Resistor	1	
1µF	Capacitor / Polarized Through-Hole	1	
100nF	Capacitor / SMD	1	
100KΩ	Potentiometer	1	

1.4 [-] Referenced Items

Table 5 [-] Referenced Items

Document	Title
LM324N	Datasheet
LM741	Datasheet
DS18030-100+	Datasheet

2 [-] TEST RESOURCES AND SETUP

2.1 [-] Test Resources

Table 6 lists the needed resources (or equivalent) for completing the design and scope of this part of the project. An STM32 Discovery Kit provides a versatile development platform for prototyping and testing the designs. Keil µVision IDE is an essential tool for writing, compiling, and debugging the microcontroller code, offering a user-friendly interface and powerful features that streamline the development process. To complement these resources, the Digilent Analog Discovery 2 serves as an invaluable tool for analyzing the electrical characteristics of the circuits. This multi-function instrument can act as an oscilloscope, function generator, power supply, and more.

Table 6 [-] Test Resources

Name	Model	Description	Qty	Manufacturer	Notes
Digilent Analog Discovery 2	2	Signal/Logic Analyzer, Power Supply	1	Digilent	
STM32 discovery kit STM32F072x8/xB	STM32F072x8/xB	Embedded Systems Application Development Board	1	STMicroelectronics	
Keil µVision IDE		IDE for programming the microcontroller		Keil	
PC		Standard Issue Lab PC	1		
Misc. Cables	Various	Power/CMD/STS/Oscilloscope			Cables as needed
Misc. Hardware	Various	Multi-meter, etc…			General lab items as needed

2.2 [A] Test Setup

Connect the PCBs to the STM32 and Digilent AD2 in accordance with (IAW) Figure 5.

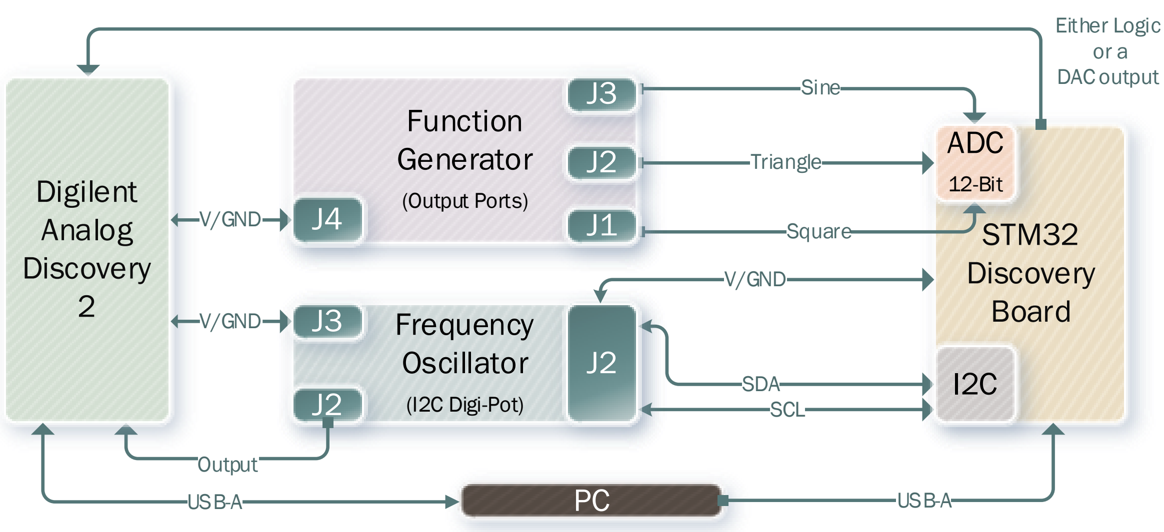


Figure 5 [-] Test Setup for the Circuit Design Portion

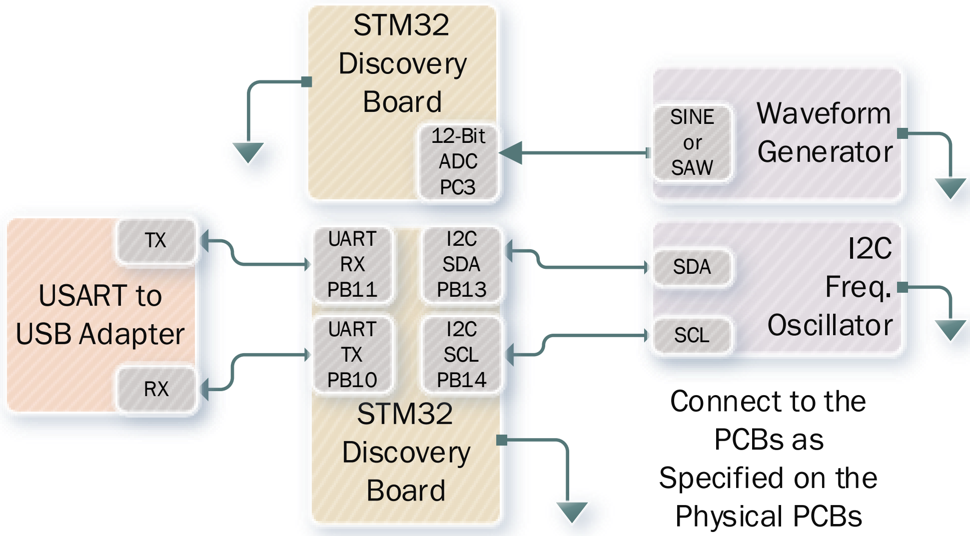


Figure 6 [A] Wire Diagram for the STM32 Peripheral Connections

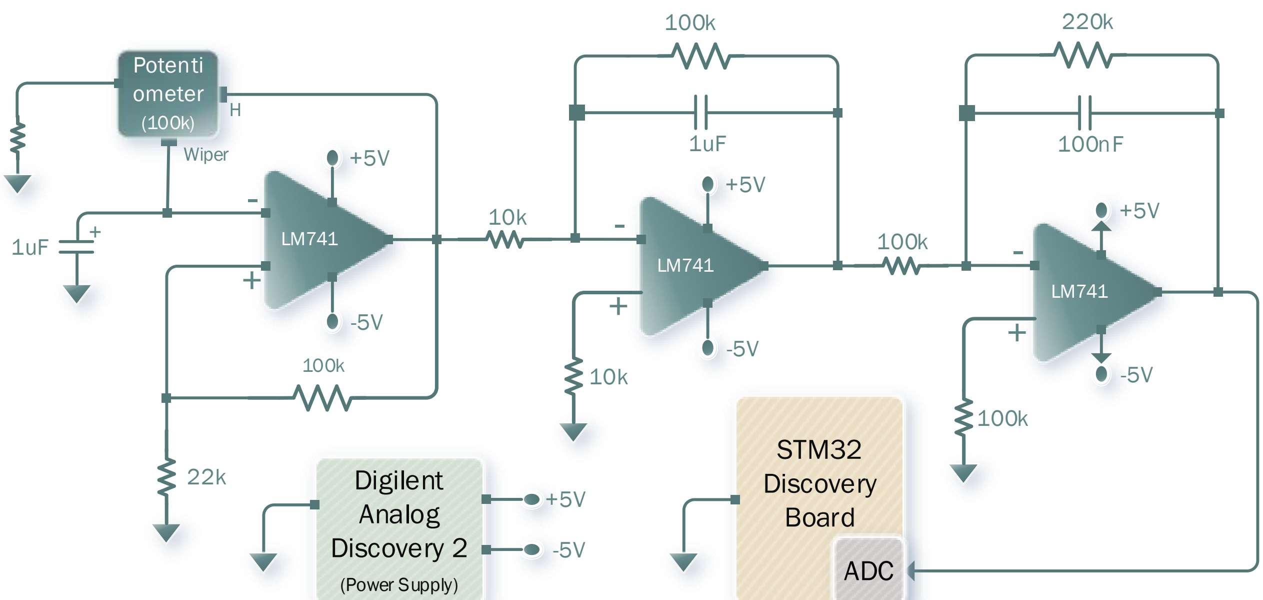


Figure 7 [A] Function Generator Schematic and Setup

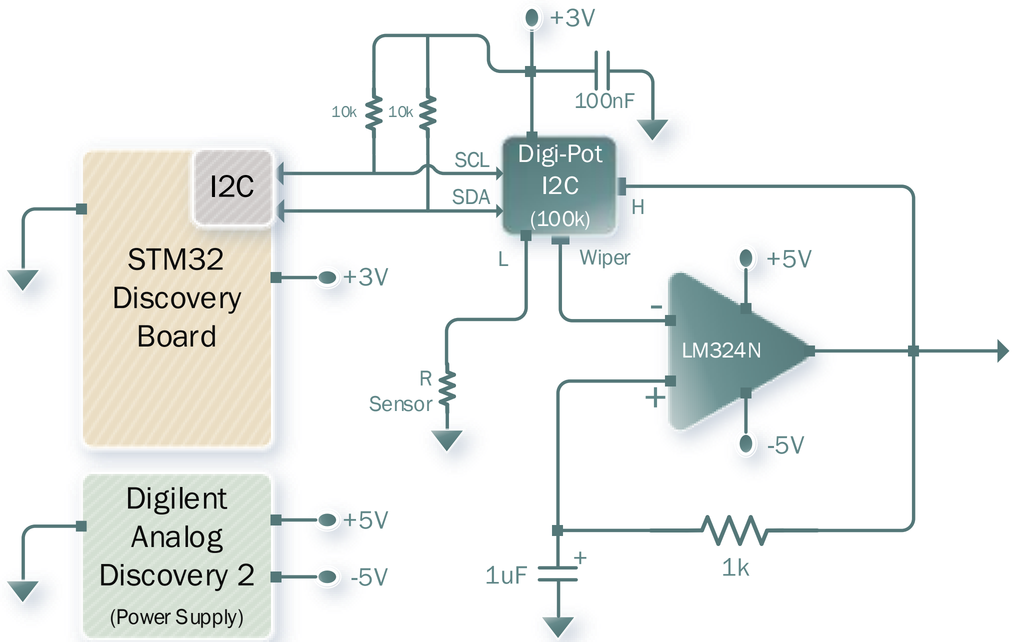


Figure 8 [-] I2C Frequency Oscillator Schematic and Setup

2.3 [A] Function Generator: Connecting to the STM32 and sampling

Input the analog signal into PC3 of the STM32.

```
/* Private function prototypes -----------------------------------------------*/
void SystemClock_Config(void);

/**
  * @brief  The application entry point.
  * @retval int
  */
int main(void)
{

  /* MCU Configuration--------------------------------------------------------*/
  /* Reset of all peripherals, Initializes the Flash interface and the Systick. */
  HAL_Init();
  SystemClock_Config();

        RCC->AHBENR |=  RCC_AHBENR_GPIOCEN;

        //LED RESET
        GPIOC->MODER = 0;
        GPIOC->PUPDR = 0;
        GPIOC->OSPEEDR = 0;
        GPIOC->OTYPER = 0;

        //LED SETUP
        GPIOC->MODER |= (1 << 12);
        GPIOC->MODER |= (1 << 14);
        GPIOC->MODER |= (1 << 16);
```

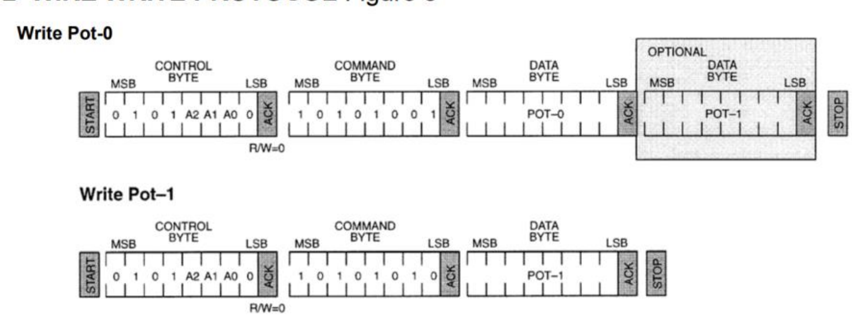
```
        GPIOC->MODER |= (1 << 18);

        //Set GPIOC low
        GPIOC->ODR = 0;

        //Set PC3 to Analog mode. (Connects to ADC_IN13)
        GPIOC->MODER |= (3 << 6);

        // Enable the ADC1 in the RCC peripheral.
        RCC->APB2ENR |= RCC_APB2ENR_ADCEN;

        //Configure the ADC to 8-bit resolution, continuous conversion mode, hardware triggers
        //disabled (software trigger only).
        ADC1->CFGR1 = 0; //Clear: Also Disables Hardware Triggers
        ADC1->CFGR1 |= (1 << 13); //Continuous Conversion Mode
        ADC1->CFGR1 |= (0 << 3);
        ADC1->CFGR1 |= (0 << 4); //12-Bit Resolution

        // Select/enable the input pin s channel for ADC conversion
        ADC1->CHSELR = 0; //Clear
        ADC1->CHSELR |= (1 << 13); //Set Channel to ADC_IN13

        // Perform a self-calibration, enable, and start the ADC.
        ADC1->CR = 0; //Cal
        ADC1->CR |= (1 << 31); //Enable

        //Wait:  ADCAL: ADC calibration bit 31 = 0
        while (((ADC1->CR)>>31) != 0){

        }

        //Zero out the ADEN
        ADC1->CR |= (1 << 0); //Set ADEN

        //Wait ADRDY Flag
        while((ADC1->ISR && 0x1) != 1){ //ISR Bit 0: ADRDY
        }

        //Set ADSTART: Start Conversion
        ADC1->CR |= (1 << 2);

        uint16_t reso = 0;

/* Infinite loop */
while (1)
{
                //12-bit ADC - 4096 bits of resolution/4 LEDs = 1024
                //RED 6, BLUE 7, ORANGE 8, GREEN 9
                //Apply the DR stored value to a variable that can be used in the loop.
                reso = ADC1->DR;
                if (reso < 1024){
```

```
                GPIOC->ODR |= (1 << 6); //Red High
                GPIOC->ODR &= ~((1 << 7) | (1 << 8) | (1 << 9));
            }
            else if (reso >= 1024 && reso < 2048){
                GPIOC->ODR |= (1 << 7); // Blue High
                GPIOC->ODR &= ~((1 << 8) | (1 << 9));
            }
            else if (reso >= 2048 && reso < 3072){
                GPIOC->ODR |= (1 << 8); //Orange High
                GPIOC->ODR &= ~(1 << 9);
            }
            else {
                GPIOC->ODR |= (1 << 9); //Green High
            }

            //Wait: End Sequence
            while((ADC1->ISR & 0x4) != 4){

            }
            //Reset: FLAG after each loop
            ADC1->ISR |= (1 << 2);
        }
}
```

2.4 [A] I2C Frequency Oscillator: I2C Control with STM32

NOTE: The code below uses PB11 and PB13 for SDA and SCL respectively, versus the USART version in the wire diagram where PB11 is changed to PB14.

2–WIRE WRITE PROTOCOL Figure 5



The PCB is hooked up to Pot-1,
USART TX from PUTTY sets the DATA BYTE values when performing the write command.

Below is a simple implementation of writing to the i2c controlled Digi-Pot.

```
/* Includes ------------------------------------------------------------------*/
#include "main.h"

/* Private function prototypes -----------------------------------------------*/
void SystemClock_Config(void);
/* USER CODE BEGIN */

//void init_digiPot(void); //For hardcode Data Byte Version
void init_digiPot(int c);
uint8_t resist_val_data;
volatile uint8_t data;

/**
  * @brief  The application entry point.
  * @retval int
  */
int main(void)
{
  /* Reset of all peripherals, Initializes the Flash interface and the Systick. */
  HAL_Init();
  SystemClock_Config();

  /* USER CODE BEGIN SysInit */
	//Enable GPIOB and GPIOC
	RCC->AHBENR |= RCC_AHBENR_GPIOCEN;
	RCC->AHBENR |= RCC_AHBENR_GPIOBEN; //Needed for I2C stuff

	//Initialize (Clear) the GPIOB/C registers
	GPIOB->OTYPER = 0;
	GPIOB->MODER = 0;

	//SDA Setup --------
	//Initialize PB11
	GPIOB->MODER |= (1 << 23); //Enable AF Mode
	GPIOB->OTYPER |= (1 << 11); //Open-drain

	//PB11 Alternate Function AF1 select: I2C2_SDA -> AF1 of PB11
	//Bits [15:12] correspond to PB11 in the register -> AF1 is 0001.
	GPIOB->AFR[1] |= (1 << 12);

	//SCL Setup --------
	// Initialize PB13
	GPIOB->MODER |= (1 << 27); //Enable AF Mode
	GPIOB->OTYPER |= (1 << 13); //Open-drain

	//PB13 Alternate Function AF5 select: I2C2_SCL -> AF5 of PB13
	//Bits [23:20] correspond to PB13 in the register, -> AF5 is 0101.
	GPIOB->AFR[1] |= (5 << 20);

	//Initialize PC0 and PB14
	GPIOB->MODER |= (1 << 28); //General-Purpose Output
	GPIOC->MODER |= (1 << 0);
	GPIOC->OTYPER = 0; //Push-pull mode.
	GPIOB->ODR |= (1 << 14); //PB14 set High
```

```
	GPIOC->ODR |= (1 << 0);  //PC0 set High

	//I2C2 Peripheral RCC Enable (I2C)
	RCC->APB1ENR |= RCC_APB1ENR_I2C2EN; //Clock enable

	//Setting up the I2C2 Peripheral timing for SDA and SCL
	//Set to 100kHz operation
	I2C2->TIMINGR |= (1 << 28); //PSC = 1
	I2C2->TIMINGR |= (0x4 << 20); //[23:20] SCLDEL (Data Setup Time)
	I2C2->TIMINGR |=  (0x2 << 16); //[19:16] SDADEL (Data Hold Time)
	I2C2->TIMINGR |= (0xF << 8); //[15:8] SCLH (SCL High Period)
	I2C2->TIMINGR |= (0x13 << 0); //[7:0] SCLL (SCL Low Period)

	//Enable the I2C2 Peripheral
	I2C2->CR1 |= (1 << 0); //Enable (PE Bit in CR1 Register)

	// Hardcodede version
	//resist_val_data = 0b00010000; //Data Byte (256-bit resolution number, ~396 ohms per bit).

		data = 0;

//  /* Infinite loop */ //Used to loop through all 0-255 Data Byte Values for simple visual results on an oscope.
		while (1)
			{

					init_digiPot(data);
					if(data<255) {
						data++;
					}
					else {
						data = 0;
					}
					HAL_Delay(25); // Delay 25ms
					GPIOC->ODR ^= (1 << 6);

	}
}


//void write_digiPot() //If using the hardcoded version.
void write_digiPot(int resist_val_data){
		I2C2->CR2 = 0; //Clear to start.

		//Setup: Digi-pot Address 0x28
		I2C2->CR2 |= (0x28 << 1); //Digi-pot address is [7:1]

		//Set # of bytes = 2 (Address + Register value).
		I2C2->CR2 |= (2 << 16);

		//Set the RD_WRN bit to 'WRITE' operation.
		//Set the START bit
		I2C2->CR2 &= ~(1 << 10); //Ensure 0 for write
		I2C2->CR2 |= (1 << 13);

		//Wait until either of the TXIS (Transmit Register Empty/Ready)
		//or NACKF (Slave NotAcknowledge) flags are set.
```

```
        //----//If the NACKF flag is set, the slave did not respond to the address frame.
        //----//Continue if the TXIS flag is set
        while(((I2C2->ISR & 0x2) >> 1) != 1){
                if((I2C2->ISR & 0x10) >> 4){ //NACFK flag check
                        //Turn on LED to indicate config error
                        GPIOC->ODR |= (1 << 6);
                }
        }

        //Set command_byte for digi-pot TX
        I2C2->TXDR = 0b10101010; // Command Byte to write to potentiometer 1.

        //Wait for TXIS flag
        while(((I2C2->ISR & 0x2) >> 1) != 1){
                if((I2C2->ISR & 0x10) >> 4){ //NACFK flag check
                        //Turn on LED to indicate config error
                        GPIOC->ODR |= (1 << 6);
                }
        }

        //Set data_byte for digi-pot TX
        I2C2->TXDR = resist_val_data;

        //Wait for TC flag
        while(((I2C2->ISR & 0x40) >> 6) != 1){

        }

        //STOP bit: Release the I2C bus
        I2C2->CR2 |= (1 << 14);
}
```

Where resist_val_data is some 8-bit value written to the Data Byte of the digital potentiometer, with each 0-255 step value corresponding to ~390 ohms out of 100k ohms.

3 [-] COMPONENT DESCRIPTIONS

3.1 [-] Amplifiers

3.1.1 [-] LM741

The LM741 is a classic operational amplifier (op-amp) integrated circuit known for its versatile performance in analog circuit applications. Featuring a single op-amp configuration, it offers reliable amplification and signal processing capabilities. With its wide supply voltage range and compatibility with both single and dual power supplies, the LM741 is suitable for a variety of voltage requirements in different circuit designs. This IC comes in an 8-pin DIP package, making it easy to incorporate into various electronic projects. Its straightforward pinout and simple configuration make it a popular choice for amplification, filtering, and signal conditioning tasks in electronics.

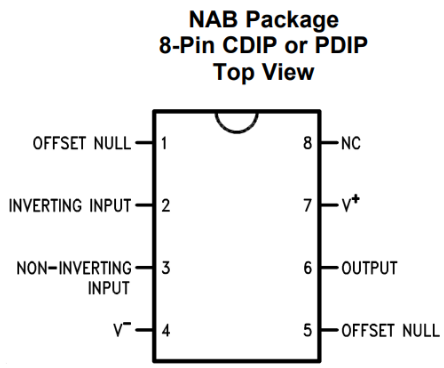


Figure 9 [-] LM741 Package

3.1.2 [-] LM324N

The LM324N is a widely used quad operational amplifier (op-amp) integrated circuit renowned for its versatility and reliability in analog circuit designs. With four independent op-amps housed within a single chip, it offers convenience and space-saving benefits for circuit integration. The LM324N operates over a wide range of supply voltages and is compatible with both single and dual power supplies, making it suitable for diverse voltage requirements. Its simple pinout and standard 14-pin DIP package facilitate easy incorporation into various electronic projects. Renowned for its low cost and robust performance, the LM324N is commonly utilized in amplification, filtering, signal conditioning, and other analog applications across industries.

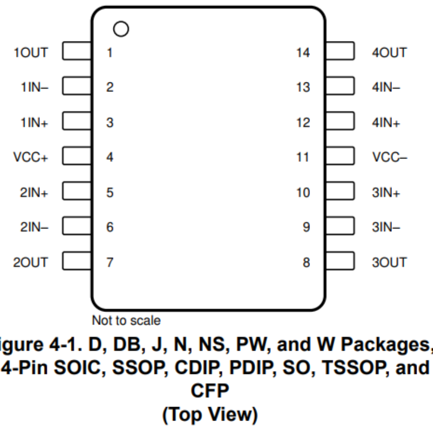


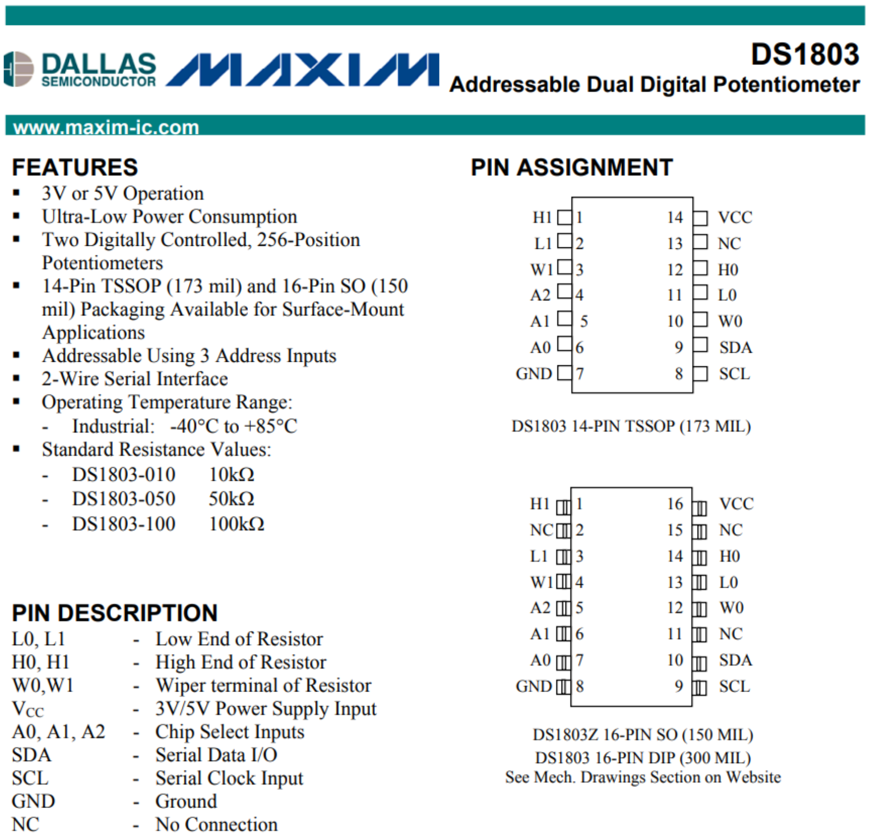
Figure 10 [-] LM324N Package

3.2 [-] I2C

3.2.1 [-] Digital Potentiometer

Address: 0101000 (A2, A1, A0 tied to ground for the 000) - Hex: 0x28

The DS18030 is a digital potentiometer integrated circuit designed for electronic control applications. It features a 100 kΩ resistance with 256-tap resolution, allowing for precise adjustment in various circuits. This device utilizes a 2-wire serial interface, compatible with I2C communication protocols, facilitating easy integration with microcontrollers like the STM32. With its compact 16-pin DIP package, the DS18030 offers versatility and flexibility in analog circuit designs, providing a convenient solution for applications requiring digital potentiometer functionality.


DALLAS SEMICONDUCTOR MAXIM

DS1803
Addressable Dual Digital Potentiometer

www.maxim-ic.com

FEATURES
- 3V or 5V Operation
- Ultra-Low Power Consumption
- Two Digitally Controlled, 256-Position Potentiometers
- 14-Pin TSSOP (173 mil) and 16-Pin SO (150 mil) Packaging Available for Surface-Mount Applications
- Addressable Using 3 Address Inputs
- 2-Wire Serial Interface
- Operating Temperature Range:
  - Industrial: -40°C to +85°C
- Standard Resistance Values:
  - DS1803-010 10kΩ
  - DS1803-050 50kΩ
  - DS1803-100 100kΩ

PIN ASSIGNMENT

DS1803 14-PIN TSSOP (173 MIL)

DS1803Z 16-PIN SO (150 MIL)
DS1803 16-PIN DIP (300 MIL)
See Mech. Drawings Section on Website

PIN DESCRIPTION

L0, L1	- Low End of Resistor
H0, H1	- High End of Resistor
W0,W1	- Wiper terminal of Resistor
V_{CC}	- 3V/5V Power Supply Input
A0, A1, A2	- Chip Select Inputs
SDA	- Serial Data I/O
SCL	- Serial Clock Input
GND	- Ground
NC	- No Connection

4 [A] NOTES

We implemented an additional protocol to transmit the i2c Data Byte 8-bit digital potentiometer value over USART via PuTTY, essentially creating a GUI for us to change resistor values from.

We attached a photoresistor to the i2c Frequency Oscillator circuit to showcase how a resistive sensor can be applied to change the analog frequency, where different frequencies could correspond to different operations of a larger system. See “R-Sensor” in circuit diagram in the “setup” section.

5 [-] REVISION HISTORY

Table 7 [-] Revision Table for DDS

Rev	Date	Engineer	Description
-	Mar 2023	Chase Griswold	Initial Release
A	April 2023	Chase Griswold	Revision A (changes to waveform generator capacitors, new schematic included in setup)