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

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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.

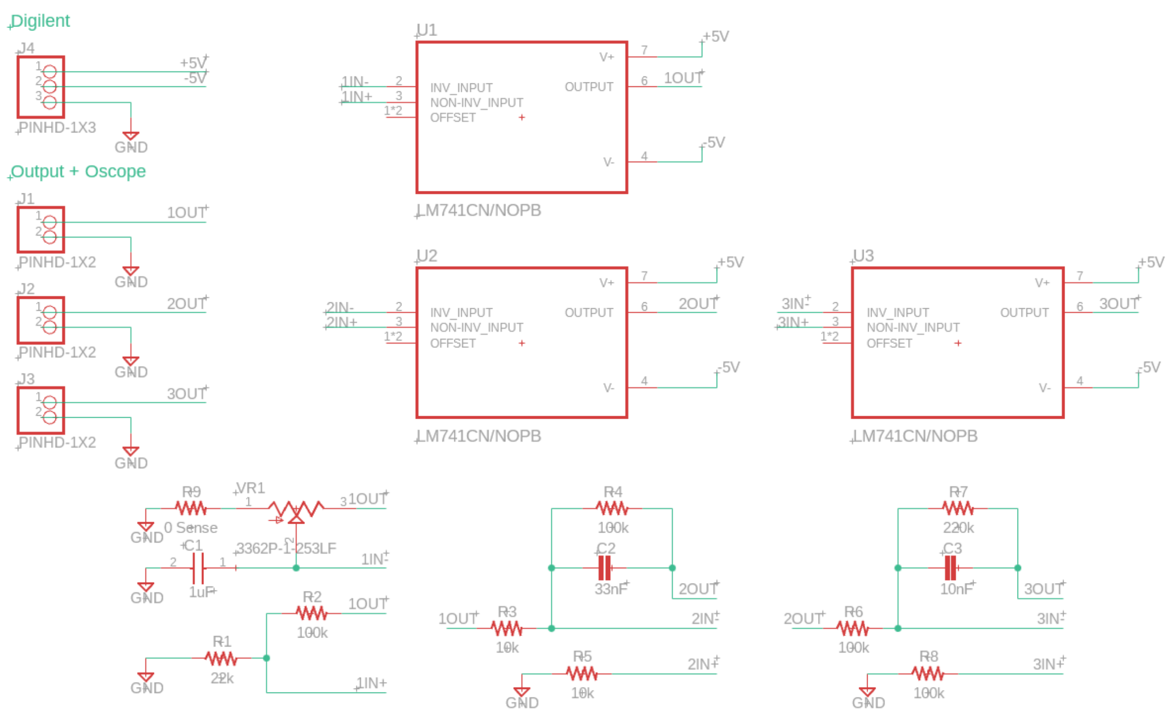


Figure 1 [-] Function Generator Circuit Utilizing LM741 Operational Amplifier

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

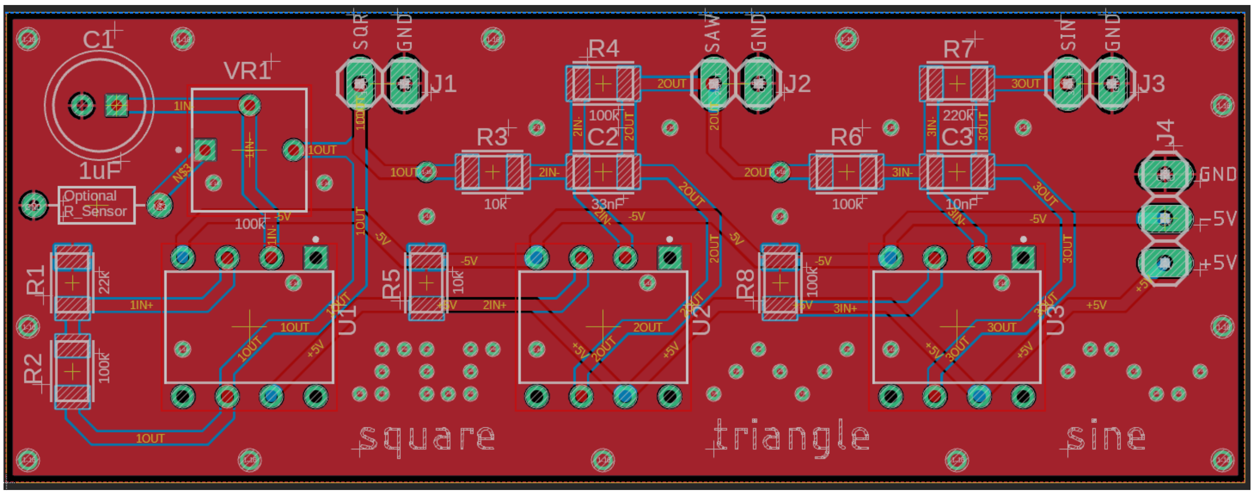


Figure 2 [-] Function Generator PCB

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 [-] Function Generator BOM

Table 2 [-] 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	
33nF	Capacitor SMD	1	
10nF	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.

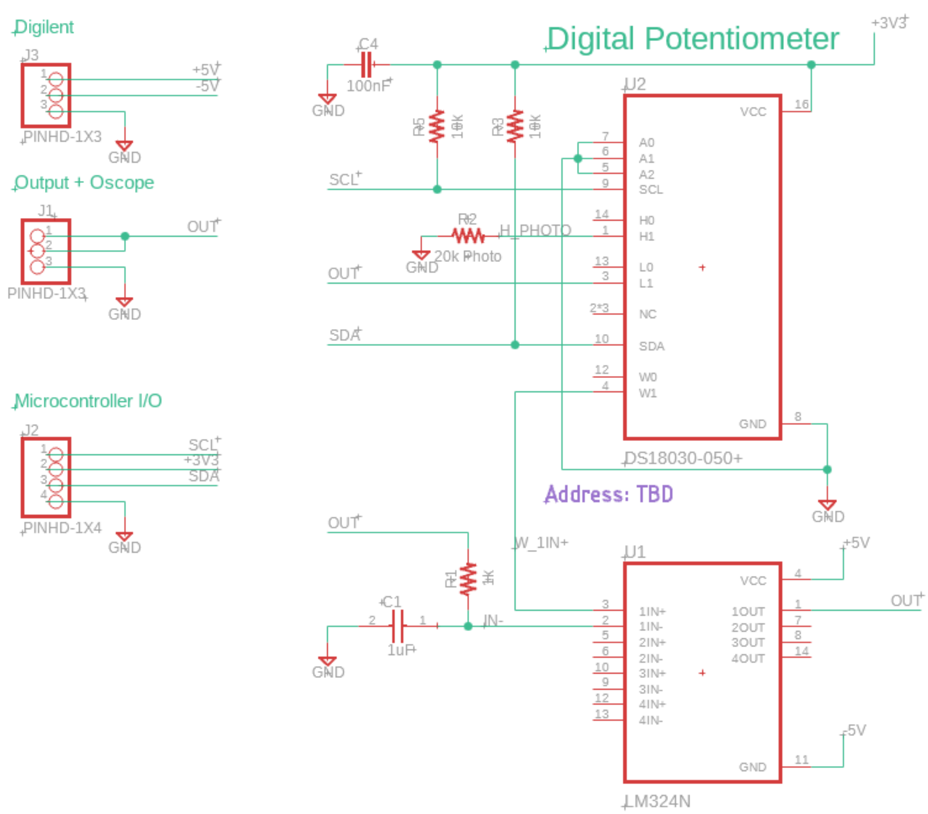


Figure 3 [-] I2C Frequency Oscillator Schematic

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

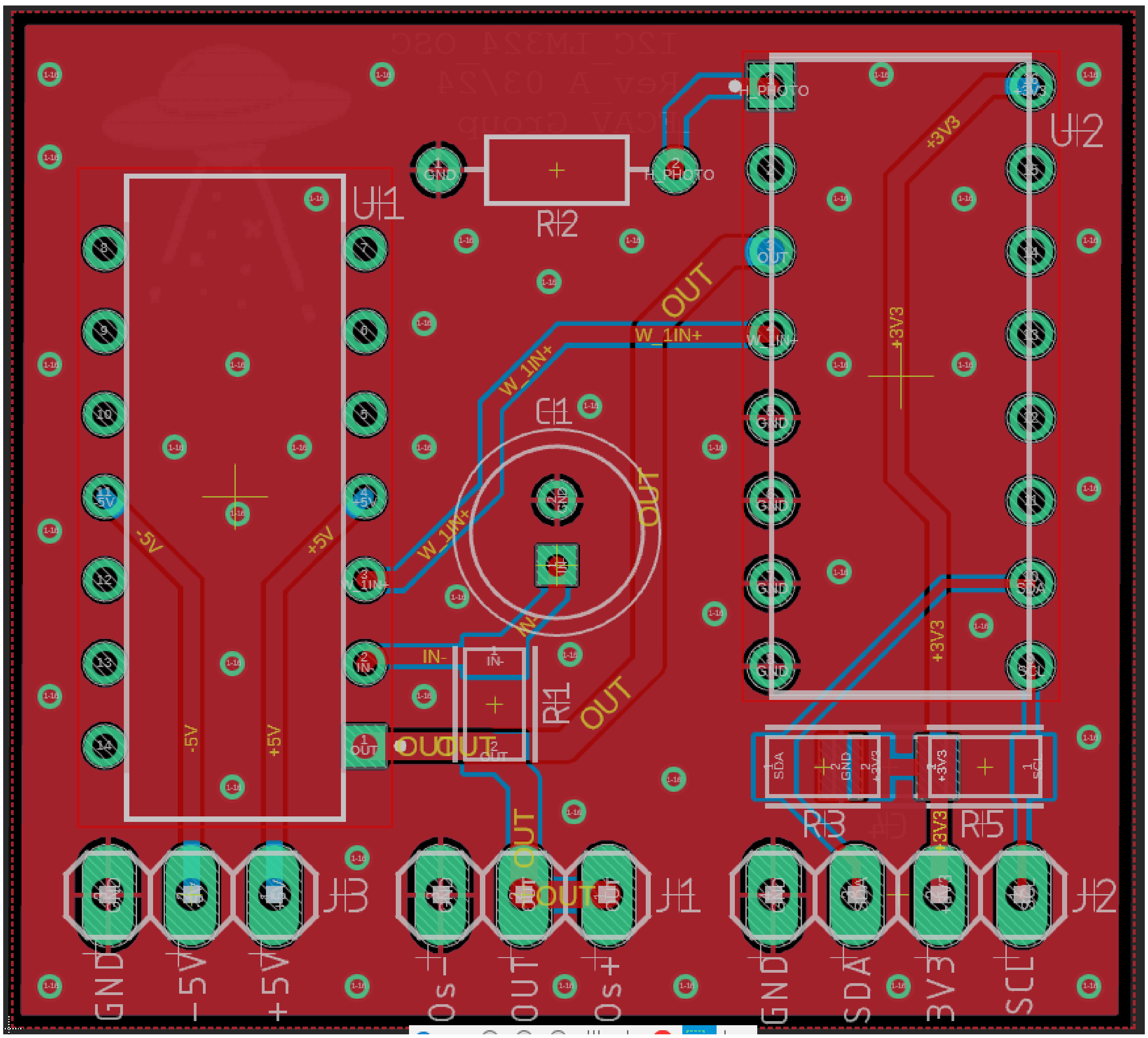


Figure 4 [-] I2C Frequency Oscillator PCB

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	Look up later	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 [-] Test Setup

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

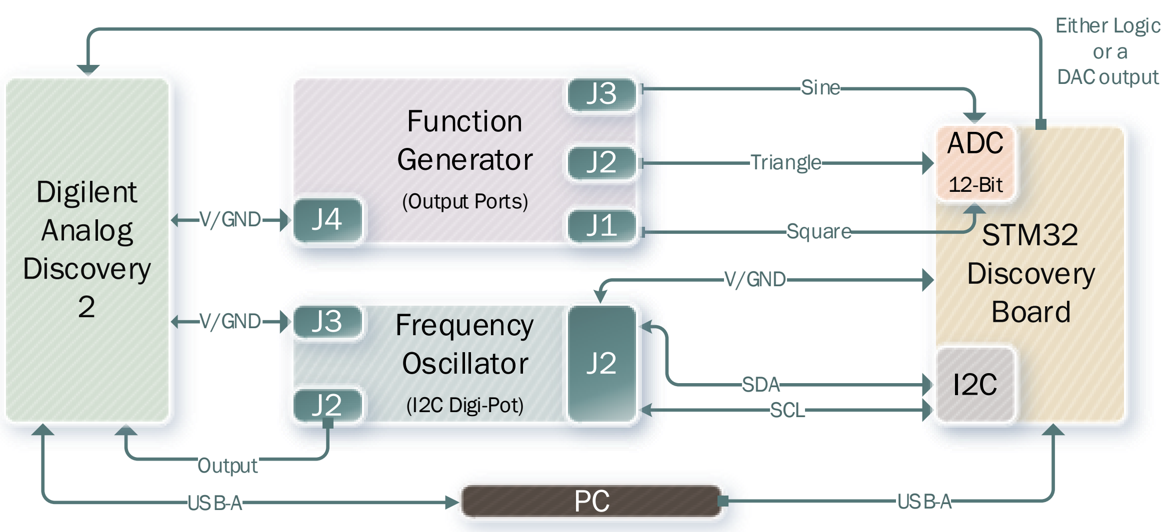


Figure 5 [-] Test Setup for the Circuit Design Portion

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

Connecting the function generator circuit to an STM32 microcontroller for sampling involves configuring one of the GPIO pins (GPIOx) to analog mode, enabling the capture of analog data generated by the function generator. The STM32's onboard 12-bit ADC (Analog to Digital Converter) can then digitize this analog signal for further processing or analysis. To ensure accurate digitization and minimize aliasing, the sampling rate must adhere to the Nyquist criterion, which states that the sampling frequency should be at least twice the maximum frequency of the input signal. Given the versatility of the described function generator circuit, let's assume an expected high output frequency in the tens of kilohertz range, potentially up to 20 kHz based on common operational amplifier response limits and circuit design. Therefore, to adequately sample signals up to this frequency, the STM32 should be configured to sample at a minimum rate of 40 kHz (twice the highest frequency component of the signal), ensuring that the captured digital representation accurately reflects the generated analog waveforms.

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

To control the DS18030 digital potentiometer from the STM32 Discovery Kit, follow these steps:

1. Peripheral Configuration: Begin by configuring the I2C peripheral in your STM32. This involves setting up I2C speed (standard mode up to 100kHz or fast mode up to 400kHz), slave address of the DS18030-100+ (consult the datasheet for the device's address), and enabling the I2C peripheral clock.
2. GPIO Configuration: Assign GPIO pins for SDA (Serial Data) and SCL (Serial Clock) lines. These pins must be configured as open-drain with pull-up resistors. In STM32CubeMX or STM32CubeIDE, this can be easily done by selecting the I2C function for the corresponding pins.
3. Communication Setup: Implement the I2C communication protocol in your firmware, ensuring that start conditions, the slave address (with write bit), register addresses within the DS18030-100+, and data bytes for the desired resistance value are correctly sequenced.
4. Frequency Adjustment: To change the frequency of the square wave, calculate the desired resistance value that corresponds to the frequency change. Write this value to the DS18030-100+ via I2C by sending the appropriate commands and data to the device.
5. Error Handling: Implement error handling for I2C communication to ensure reliable operation. This includes monitoring the ACK/NACK responses from the DS18030-100+ and handling bus errors.

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.

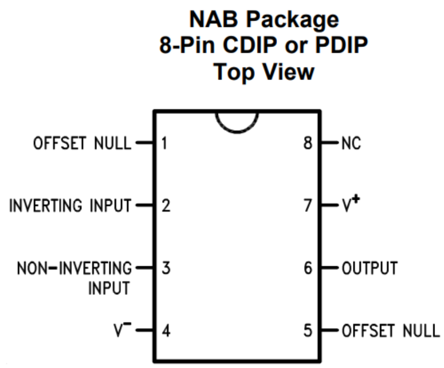


Figure 6 [-] LM741 Package

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.

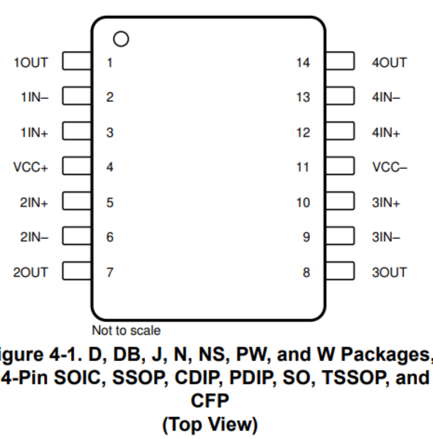


Figure 7 [-] LM324N Package

3.2 [-] I2C

3.2.1 [-] Digital Potentiometer

Address: TBD

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.

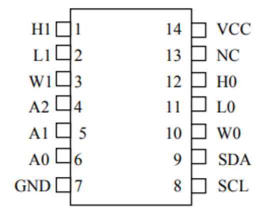
DALLAS SEMICONDUCTOR MAXIM

DS1803
Addressable Dual Digital Potentiometer

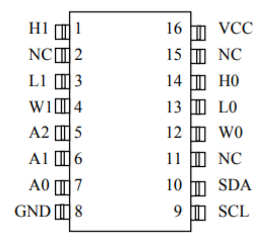
www.maxim-ic.com

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 [-] NOTES

5 [-] REVISION HISTORY

Table 7 [-] Revision Table for DDS

Rev	Date	Engineer	Description
-	Mar 2023	Chase Griswold	Initial Release