



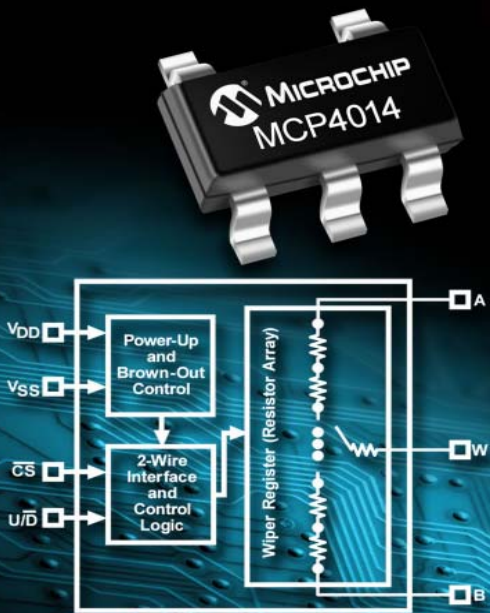
Digital Potentiometers Design Guide

Supporting digital potentiometer applications, including: mechanical potentiometer replacement, amplifiers with offset and trimming, band pass filtering with offset and gain trimming, programmable filter, Whetstone bridge trimming and general embedded system design techniques.

Small Package

Low Power

Low Cost



Design ideas in this guide use the following devices. A complete device list and corresponding data sheets for these products can be found at www.microchip.com.

MCP4011	MCP4021	MCP41010
MCP4012	MCP4022	MCP41050
MCP4013	MCP4023	MCP41100
MCP4014	MCP4024	MCP42010
		MCP42050
		MCP42100

Microchip's Family of Digital Potentiometers

Microchip offers a range of devices that allow the customer to select a device that is a best fit for their application. Some of the selection options include:

- A wide range of resistor values
 - R_{AB} resistance (typical) from 2.1 k Ω to 100 k Ω
- Step resolution
 - 6-bit
 - 8-bit
- Serial Interfaces
 - Up/Down
 - SPI
- Memory Types
 - Volatile
 - Non-volatile
- Resistor Network Configurations
 - Potentiometer (Resistor divider)
 - Rheostat (Variable resistor)
- Single/dual Potentiometer Options
- Package Options
- Special Features
 - Shutdown Mode
 - WiperLock™ Technology
- Low Voltage, Low Power Options

Resistor sizes and resolutions allow the designer to select the step resistance and number of steps. For the device with the resistance (R_{AB}) equal to 2.1 k Ω , there are 64 steps (63 resistors), so the step resistance (R_s) equals $R_{AB}/63$ (or 33.33 Ω). Now at the other end of the spectrum, for the device with the resistance (R_{AB}) equal to 50 k Ω , there are 64 steps (63 resistors), so the step resistance (R_s) equals $R_{AB}/63$ (or 793.65 Ω).

The serial interface options allow the designer to easily integrate the device into the application. For some applications the simple Up/Down interface will be adequate, while for other applications the SPI interface will better meet their system requirements.

The availability of both volatile and non-volatile devices allows the designer flexibility in optimizing the application. Some applications may use the digital potentiometer as a replacement for a mechanical potentiometer. In this case, a non-volatile device with the serial interface connecting to the test hardware interface allows a low cost device with low cost manufacturing.

Resistor Network configurations allow the package size/cost to be minimized for the desired functionality. If a variable resistor (rheostat) with one terminal tied to ground is desired, then only one resistor terminal (the wiper) needs to be implemented. In the MCP402X family, this configuration is shown in the MCP4024 and allows the functionality to be achieved in the low-cost SOT-23-5 package. The potentiometer pinout with all terminals available requires an 8-pin package.

Dual potentiometer options allow the customer to have potentiometers/variable resistors that are closely matched in the system, since the two devices are on the same device die.

Packaging options allow customers to address their system requirement trade-offs including device cost, board area, and manufacturing sites (surface mount vs. thru-hole). Packages include tiny 3x3 SOT-23 and 3x2 DFN packages.

Low Power Applications

Many applications are very power sensitive. Typically, these are battery powered applications. Microchip Technology's MCP401X, MCP402X, MCP41XXX and MCP42XXX have a maximum I_{DD} of 1 μ A when the serial interface is inactive. The non-volatile memory is also not being programmed for the MCP402X device.

Low power devices include: MCP4011, MCP4012, MCP4013, MCP4014, MCP4021, MCP4022, MCP4023 and MCP4024.

Low Voltage Applications

Some applications require a low operating voltage. Microchip offers devices that operate down to 1.8V, which are useful for many battery applications. At these lower voltages (below 2.7V), the analog performance of the device is not specified, but is characterized. For many applications this may be acceptable.

1.8V operational devices include: MCP4011, MCP4012, MCP4013 and MCP4014.

Product Specifications

Device		R _{AB} (k Ω) (typ.)	Serial Interface	Volatile Non-Volatile	Resolution	# RS Resistors	R _S (Ω) (typ.)	Zero-Scale/ Full-Scale(1)	# of Channels	WiperLock™ Technology	Shutdown Mode	Configuration	Voltage Range	# of Pins	Packages	I _{DD} max (μ A)(3)
MCP4011	-202	2.1	Up/Down	V	6-bit	63	33.33	Y/Y	1	N	N	Pot	1.8V to 5.5V ⁽⁴⁾	8	DFN, MSOP, SOIC	1
	-502	5.0	Up/Down	V	6-bit	63	79.37	Y/Y	1	N	N	Pot	1.8V to 5.5V ⁽⁴⁾	8	DFN, MSOP, SOIC	1
	-103	10.0	Up/Down	V	6-bit	63	158.73	Y/Y	1	N	N	Pot	1.8V to 5.5V ⁽⁴⁾	8	DFN, MSOP, SOIC	1
	-503	50.0	Up/Down	V	6-bit	63	793.65	Y/Y	1	N	N	Pot	1.8V to 5.5V ⁽⁴⁾	8	DFN, MSOP, SOIC	1
MCP4012	-202	2.1	Up/Down	V	6-bit	63	33.33	Y/Y	1	N	N	Rheo	1.8V to 5.5V ⁽⁴⁾	6	SOT-23	1
	-502	5.0	Up/Down	V	6-bit	63	79.37	Y/Y	1	N	N	Rheo	1.8V to 5.5V ⁽⁴⁾	6	SOT-23	1
	-103	10.0	Up/Down	V	6-bit	63	158.73	Y/Y	1	N	N	Rheo	1.8V to 5.5V ⁽⁴⁾	6	SOT-23	1
	-503	50.0	Up/Down	V	6-bit	63	793.65	Y/Y	1	N	N	Rheo	1.8V to 5.5V ⁽⁴⁾	6	SOT-23	1
MCP4013	-202	2.1	Up/Down	V	6-bit	63	33.33	Y/Y	1	N	N	Pot	1.8V to 5.5V ⁽⁴⁾	6	SOT-23	1
	-502	5.0	Up/Down	V	6-bit	63	79.37	Y/Y	1	N	N	Pot	1.8V to 5.5V ⁽⁴⁾	6	SOT-23	1
	-103	10.0	Up/Down	V	6-bit	63	158.73	Y/Y	1	N	N	Pot	1.8V to 5.5V ⁽⁴⁾	6	SOT-23	1
	-503	50.0	Up/Down	V	6-bit	63	793.65	Y/Y	1	N	N	Pot	1.8V to 5.5V ⁽⁴⁾	6	SOT-23	1
MCP4014	-202	2.1	Up/Down	V	6-bit	63	33.33	Y/Y	1	N	N	Rheo	1.8V to 5.5V ⁽⁴⁾	5	SOT-23	1
	-502	5.0	Up/Down	V	6-bit	63	79.37	Y/Y	1	N	N	Rheo	1.8V to 5.5V ⁽⁴⁾	5	SOT-23	1
	-103	10.0	Up/Down	V	6-bit	63	158.73	Y/Y	1	N	N	Rheo	1.8V to 5.5V ⁽⁴⁾	5	SOT-23	1
	-503	50.0	Up/Down	V	6-bit	63	793.65	Y/Y	1	N	N	Rheo	1.8V to 5.5V ⁽⁴⁾	5	SOT-23	1
MCP4021	-202	2.1	Up/Down	NV	6-bit	63	33.33	Y/Y	1	Y	N	Pot	2.7V to 5.5V	8	DFN, MSOP, SOIC	1
	-502	5.0	Up/Down	NV	6-bit	63	79.37	Y/Y	1	Y	N	Pot	2.7V to 5.5V	8	DFN, MSOP, SOIC	1
	-103	10.0	Up/Down	NV	6-bit	63	158.73	Y/Y	1	Y	N	Pot	2.7V to 5.5V	8	DFN, MSOP, SOIC	1
	-503	50.0	Up/Down	NV	6-bit	63	793.65	Y/Y	1	Y	N	Pot	2.7V to 5.5V	8	DFN, MSOP, SOIC	1
MCP4022	-202	2.1	Up/Down	NV	6-bit	63	33.33	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	6	SOT-23	1
	-502	5.0	Up/Down	NV	6-bit	63	79.37	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	6	SOT-23	1
	-103	10.0	Up/Down	NV	6-bit	63	158.73	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	6	SOT-23	1
	-503	50.0	Up/Down	NV	6-bit	63	793.65	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	6	SOT-23	1
MCP4023	-202	2.1	Up/Down	NV	6-bit	63	33.33	Y/Y	1	Y	N	Pot	2.7V to 5.5V	6	SOT-23	1
	-502	5.0	Up/Down	NV	6-bit	63	79.37	Y/Y	1	Y	N	Pot	2.7V to 5.5V	6	SOT-23	1
	-103	10.0	Up/Down	NV	6-bit	63	158.73	Y/Y	1	Y	N	Pot	2.7V to 5.5V	6	SOT-23	1
	-503	50.0	Up/Down	NV	6-bit	63	793.65	Y/Y	1	Y	N	Pot	2.7V to 5.5V	6	SOT-23	1
MCP4024	-202	2.1	Up/Down	NV	6-bit	63	33.33	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	5	SOT-23	1
	-502	5.0	Up/Down	NV	6-bit	63	79.37	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	5	SOT-23	1
	-103	10.0	Up/Down	NV	6-bit	63	158.73	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	5	SOT-23	1
	-503	50.0	Up/Down	NV	6-bit	63	793.65	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	5	SOT-23	1

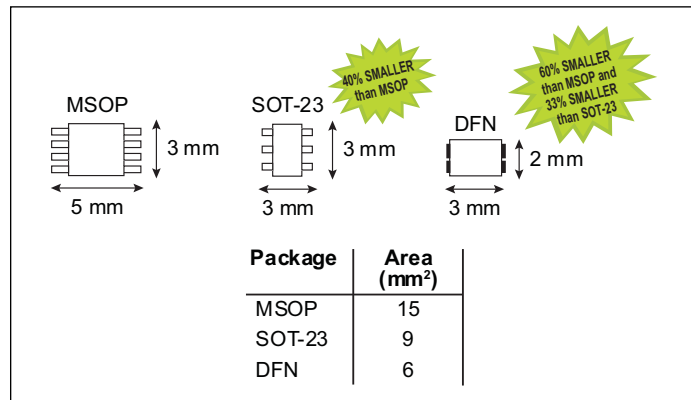
- Note 1:** Zero-scale allows the wiper to "directly" connect to Terminal B, while full-scale allows the wiper to "directly" connect to Terminal A.
2: There is one RS resistor between the maximum wiper value and Terminal A.
3: This current is with the serial interface inactive, and not during an EEPROM write cycle (for non-volatile devices).
4: The serial interface has been tested to 1.8V, the device's analog characteristics (resistor) have been tested from 2.7V to 5.5V. Review the device's characterization graphs for information on analog performance between 1.8V and 2.7V.

Small Footprint Applications

Some applications require devices with tiny footprints. Microchip offers several devices in very small form factor packages.

Small footprint devices include: MCP4011, MCP4012, MCP4013, MCP4014, MCP4021, MCP4022, MCP4023 and MCP4024.

Small Footprint Devices



Product Specifications

Device		R _{AB} (k Ω) (typ.)	Serial Interface	Volatile Non-Volatile	Resolution	# R _s Resistors	R _s (Ω) (typ.)	Zero-Scale/ Full-Scale(1)	# of Channels	WiperLock™ Technology	Shutdown Mode	Configuration	Voltage Range	# of Pins	Packages	I _{DD} max (μ A)(3)
MCP4011	-202	2.1	Up/Down	V	6-bit	63	33.33	Y/Y	1	N	N	Pot	1.8V to 5.5V ⁽⁴⁾	8	DFN, MSOP, SOIC	1
	-502	5.0	Up/Down	V	6-bit	63	79.37	Y/Y	1	N	N	Pot	1.8V to 5.5V ⁽⁴⁾	8	DFN, MSOP, SOIC	1
	-103	10.0	Up/Down	V	6-bit	63	158.73	Y/Y	1	N	N	Pot	1.8V to 5.5V ⁽⁴⁾	8	DFN, MSOP, SOIC	1
	-503	50.0	Up/Down	V	6-bit	63	793.65	Y/Y	1	N	N	Pot	1.8V to 5.5V ⁽⁴⁾	8	DFN, MSOP, SOIC	1
MCP4012	-202	2.1	Up/Down	V	6-bit	63	33.33	Y/Y	1	N	N	Rheo	1.8V to 5.5V ⁽⁴⁾	6	SOT-23	1
	-502	5.0	Up/Down	V	6-bit	63	79.37	Y/Y	1	N	N	Rheo	1.8V to 5.5V ⁽⁴⁾	6	SOT-23	1
	-103	10.0	Up/Down	V	6-bit	63	158.73	Y/Y	1	N	N	Rheo	1.8V to 5.5V ⁽⁴⁾	6	SOT-23	1
	-503	50.0	Up/Down	V	6-bit	63	793.65	Y/Y	1	N	N	Rheo	1.8V to 5.5V ⁽⁴⁾	6	SOT-23	1
MCP4013	-202	2.1	Up/Down	V	6-bit	63	33.33	Y/Y	1	N	N	Pot	1.8V to 5.5V ⁽⁴⁾	6	SOT-23	1
	-502	5.0	Up/Down	V	6-bit	63	79.37	Y/Y	1	N	N	Pot	1.8V to 5.5V ⁽⁴⁾	6	SOT-23	1
	-103	10.0	Up/Down	V	6-bit	63	158.73	Y/Y	1	N	N	Pot	1.8V to 5.5V ⁽⁴⁾	6	SOT-23	1
	-503	50.0	Up/Down	V	6-bit	63	793.65	Y/Y	1	N	N	Pot	1.8V to 5.5V ⁽⁴⁾	6	SOT-23	1
MCP4014	-202	2.1	Up/Down	V	6-bit	63	33.33	Y/Y	1	N	N	Rheo	1.8V to 5.5V ⁽⁴⁾	5	SOT-23	1
	-502	5.0	Up/Down	V	6-bit	63	79.37	Y/Y	1	N	N	Rheo	1.8V to 5.5V ⁽⁴⁾	5	SOT-23	1
	-103	10.0	Up/Down	V	6-bit	63	158.73	Y/Y	1	N	N	Rheo	1.8V to 5.5V ⁽⁴⁾	5	SOT-23	1
	-503	50.0	Up/Down	V	6-bit	63	793.65	Y/Y	1	N	N	Rheo	1.8V to 5.5V ⁽⁴⁾	5	SOT-23	1
MCP4021	-202	2.1	Up/Down	NV	6-bit	63	33.33	Y/Y	1	Y	N	Pot	2.7V to 5.5V	8	DFN, MSOP, SOIC	1
	-502	5.0	Up/Down	NV	6-bit	63	79.37	Y/Y	1	Y	N	Pot	2.7V to 5.5V	8	DFN, MSOP, SOIC	1
	-103	10.0	Up/Down	NV	6-bit	63	158.73	Y/Y	1	Y	N	Pot	2.7V to 5.5V	8	DFN, MSOP, SOIC	1
	-503	50.0	Up/Down	NV	6-bit	63	793.65	Y/Y	1	Y	N	Pot	2.7V to 5.5V	8	DFN, MSOP, SOIC	1
MCP4022	-202	2.1	Up/Down	NV	6-bit	63	33.33	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	6	SOT-23	1
	-502	5.0	Up/Down	NV	6-bit	63	79.37	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	6	SOT-23	1
	-103	10.0	Up/Down	NV	6-bit	63	158.73	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	6	SOT-23	1
	-503	50.0	Up/Down	NV	6-bit	63	793.65	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	6	SOT-23	1
MCP4023	-202	2.1	Up/Down	NV	6-bit	63	33.33	Y/Y	1	Y	N	Pot	2.7V to 5.5V	6	SOT-23	1
	-502	5.0	Up/Down	NV	6-bit	63	79.37	Y/Y	1	Y	N	Pot	2.7V to 5.5V	6	SOT-23	1
	-103	10.0	Up/Down	NV	6-bit	63	158.73	Y/Y	1	Y	N	Pot	2.7V to 5.5V	6	SOT-23	1
	-503	50.0	Up/Down	NV	6-bit	63	793.65	Y/Y	1	Y	N	Pot	2.7V to 5.5V	6	SOT-23	1
MCP4024	-202	2.1	Up/Down	NV	6-bit	63	33.33	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	5	SOT-23	1
	-502	5.0	Up/Down	NV	6-bit	63	79.37	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	5	SOT-23	1
	-103	10.0	Up/Down	NV	6-bit	63	158.73	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	5	SOT-23	1
	-503	50.0	Up/Down	NV	6-bit	63	793.65	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	5	SOT-23	1

Note 1: Zero-scale allows the wiper to “directly” connect to Terminal B, while full-scale allows the wiper to “directly” connect to Terminal A.

2: There is one R_S resistor between the maximum wiper value and Terminal A.

3: This current is with the serial interface inactive, and not during an EEPROM write cycle (for non-volatile devices).

4: The serial interface has been tested to 1.8V, the device’s analog characteristics (resistor) have been tested from 2.7V to 5.5V. Review the device’s characterization graphs for information on analog performance between 1.8V and 2.7V.

Non-Volatile Applications

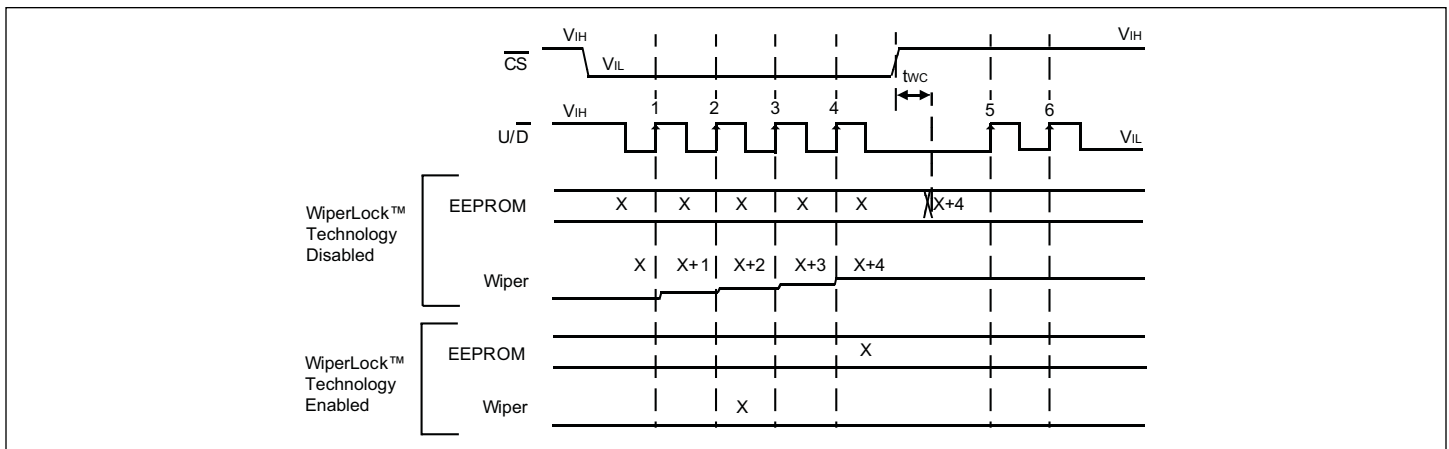
Non-volatile devices allow the desired wiper position to be saved through a device power down or brown-out condition. When the device power is restored, the wiper value is loaded with the wiper value stored in the non-volatile register.

This is useful for both applications where the wiper value is programmed once and never changed (system calibration) as well as applications where the last user setting is saved on system powerdown (such as a volume setting).

Many applications require the use of a mechanical trim pot for the calibration of the system to optimize system performance. This may be done to calibrate the characteristics of some other component on the board (such as a sensor). Mechanical trim pots are not as reliable as a semiconductor implementation (susceptible to vibration, humidity, ...) and have higher manufacturing costs, due to the manual requirements for tuning and the gluing the setting into position.

WiperLock™ Technology is the method that allows Microchips non-volatile devices to ensure that once the non-volatile wiper is “locked” the wiper setting (volatile and non-volatile) can not be modified except with “High Voltage” commands. This inhibits accidental modification of the wiper setting, as long as the high voltage is not present to the digital potentiometer during normal operation.

WiperLock™ Technology Operation Example



Product Specifications

Device	R _{AB} (k Ω) (typ.)	Serial Interface	Volatile Non-Volatile	Resolution	# RS Resistors	R _S (Ω) (typ.)	Zero-Scale/ Full-Scale(1)	# of Channels	WiperLock™ Technology	Shutdown Mode	Configuration	Voltage Range	# of Pins	Packages	I _{DD} max (μ A)(3)	
MCP4021	-202	2.1	Up/Down	NV	6-bit	63	33.33	Y/Y	1	Y	N	Pot	2.7V to 5.5V	8	DFN, MSOP, SOIC	1
	-502	5.0	Up/Down	NV	6-bit	63	79.37	Y/Y	1	Y	N	Pot	2.7V to 5.5V	8	DFN, MSOP, SOIC	1
	-103	10.0	Up/Down	NV	6-bit	63	158.73	Y/Y	1	Y	N	Pot	2.7V to 5.5V	8	DFN, MSOP, SOIC	1
	-503	50.0	Up/Down	NV	6-bit	63	793.65	Y/Y	1	Y	N	Pot	2.7V to 5.5V	8	DFN, MSOP, SOIC	1
MCP4022	-202	2.1	Up/Down	NV	6-bit	63	33.33	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	6	SOT-23	1
	-502	5.0	Up/Down	NV	6-bit	63	79.37	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	6	SOT-23	1
	-103	10.0	Up/Down	NV	6-bit	63	158.73	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	6	SOT-23	1
	-503	50.0	Up/Down	NV	6-bit	63	793.65	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	6	SOT-23	1
MCP4023	-202	2.1	Up/Down	NV	6-bit	63	33.33	Y/Y	1	Y	N	Pot	2.7V to 5.5V	6	SOT-23	1
	-502	5.0	Up/Down	NV	6-bit	63	79.37	Y/Y	1	Y	N	Pot	2.7V to 5.5V	6	SOT-23	1
	-103	10.0	Up/Down	NV	6-bit	63	158.73	Y/Y	1	Y	N	Pot	2.7V to 5.5V	6	SOT-23	1
	-503	50.0	Up/Down	NV	6-bit	63	793.65	Y/Y	1	Y	N	Pot	2.7V to 5.5V	6	SOT-23	1
MCP4024	-202	2.1	Up/Down	NV	6-bit	63	33.33	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	5	SOT-23	1
	-502	5.0	Up/Down	NV	6-bit	63	79.37	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	5	SOT-23	1
	-103	10.0	Up/Down	NV	6-bit	63	158.73	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	5	SOT-23	1
	-503	50.0	Up/Down	NV	6-bit	63	793.65	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	5	SOT-23	1

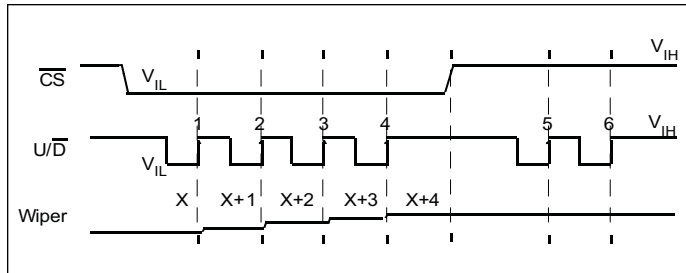
- Note 1:** Zero-scale allows the wiper to “directly” connect to Terminal B, while full-scale allows the wiper to “directly” connect to Terminal A.
Note 2: There is one RS resistor between the maximum wiper value and Terminal A.
Note 3: This current is with the serial interface inactive, and not during an EEPROM write cycle (for non-volatile devices).
Note 4: The serial interface has been tested to 1.8V, the device’s analog characteristics (resistor) have been tested from 2.7V to 5.5V. Review the device’s characterization graphs for information on analog performance between 1.8V and 2.7V.

Serial Interfaces

Microchip currently offers two serial interfaces:

- An Up/Down interface
- An SPI interface

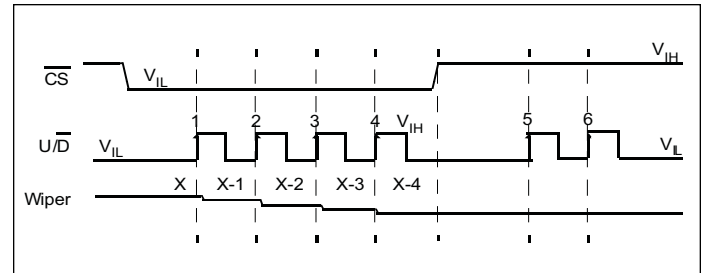
Increment



Up/Down

This is an easy to implement interface that requires two pins and can be implemented with minimal software overhead. This interface is also easy for test systems when using the non-volatile devices as replacements for mechanical potentiometers.

Decrement



Product Specifications

Device	R _{AB} (k Ω) (typ.)	Serial Interface	Volatile Non-Volatile	Resolution	# Rs Resistors	Rs (2) (typ.)	Zero-Scale/ Full-Scale(1)	# of Channels	WiperLock™ Technology	Shutdown Mode	Configuration	Voltage Range	# of Pins	Packages	I _{DD} max (μA)(3)	
MCP4011	-202	2.1	Up/Down	V	6-bit	63	33.33	Y/Y	1	N	N	Pot	1.8V to 5.5V(4)	8	DFN, MSOP, SOIC	1
	-502	5.0	Up/Down	V	6-bit	63	79.37	Y/Y	1	N	N	Pot	1.8V to 5.5V(4)	8	DFN, MSOP, SOIC	1
	-103	10.0	Up/Down	V	6-bit	63	158.73	Y/Y	1	N	N	Pot	1.8V to 5.5V(4)	8	DFN, MSOP, SOIC	1
	-503	50.0	Up/Down	V	6-bit	63	793.65	Y/Y	1	N	N	Pot	1.8V to 5.5V(4)	8	DFN, MSOP, SOIC	1
MCP4012	-202	2.1	Up/Down	V	6-bit	63	33.33	Y/Y	1	N	N	Rheo	1.8V to 5.5V(4)	6	SOT-23	1
	-502	5.0	Up/Down	V	6-bit	63	79.37	Y/Y	1	N	N	Rheo	1.8V to 5.5V(4)	6	SOT-23	1
	-103	10.0	Up/Down	V	6-bit	63	158.73	Y/Y	1	N	N	Rheo	1.8V to 5.5V(4)	6	SOT-23	1
	-503	50.0	Up/Down	V	6-bit	63	793.65	Y/Y	1	N	N	Rheo	1.8V to 5.5V(4)	6	SOT-23	1
MCP4013	-202	2.1	Up/Down	V	6-bit	63	33.33	Y/Y	1	N	N	Pot	1.8V to 5.5V(4)	6	SOT-23	1
	-502	5.0	Up/Down	V	6-bit	63	79.37	Y/Y	1	N	N	Pot	1.8V to 5.5V(4)	6	SOT-23	1
	-103	10.0	Up/Down	V	6-bit	63	158.73	Y/Y	1	N	N	Pot	1.8V to 5.5V(4)	6	SOT-23	1
	-503	50.0	Up/Down	V	6-bit	63	793.65	Y/Y	1	N	N	Pot	1.8V to 5.5V(4)	6	SOT-23	1
MCP4014	-202	2.1	Up/Down	V	6-bit	63	33.33	Y/Y	1	N	N	Rheo	1.8V to 5.5V(4)	5	SOT-23	1
	-502	5.0	Up/Down	V	6-bit	63	79.37	Y/Y	1	N	N	Rheo	1.8V to 5.5V(4)	5	SOT-23	1
	-103	10.0	Up/Down	V	6-bit	63	158.73	Y/Y	1	N	N	Rheo	1.8V to 5.5V(4)	5	SOT-23	1
	-503	50.0	Up/Down	V	6-bit	63	793.65	Y/Y	1	N	N	Rheo	1.8V to 5.5V(4)	5	SOT-23	1
MCP4021	-202	2.1	Up/Down	NV	6-bit	63	33.33	Y/Y	1	Y	N	Pot	2.7V to 5.5V	8	DFN, MSOP, SOIC	1
	-502	5.0	Up/Down	NV	6-bit	63	79.37	Y/Y	1	Y	N	Pot	2.7V to 5.5V	8	DFN, MSOP, SOIC	1
	-103	10.0	Up/Down	NV	6-bit	63	158.73	Y/Y	1	Y	N	Pot	2.7V to 5.5V	8	DFN, MSOP, SOIC	1
	-503	50.0	Up/Down	NV	6-bit	63	793.65	Y/Y	1	Y	N	Pot	2.7V to 5.5V	8	DFN, MSOP, SOIC	1
MCP4022	-202	2.1	Up/Down	NV	6-bit	63	33.33	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	6	SOT-23	1
	-502	5.0	Up/Down	NV	6-bit	63	79.37	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	6	SOT-23	1
	-103	10.0	Up/Down	NV	6-bit	63	158.73	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	6	SOT-23	1
	-503	50.0	Up/Down	NV	6-bit	63	793.65	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	6	SOT-23	1
MCP4023	-202	2.1	Up/Down	NV	6-bit	63	33.33	Y/Y	1	Y	N	Pot	2.7V to 5.5V	6	SOT-23	1
	-502	5.0	Up/Down	NV	6-bit	63	79.37	Y/Y	1	Y	N	Pot	2.7V to 5.5V	6	SOT-23	1
	-103	10.0	Up/Down	NV	6-bit	63	158.73	Y/Y	1	Y	N	Pot	2.7V to 5.5V	6	SOT-23	1
	-503	50.0	Up/Down	NV	6-bit	63	793.65	Y/Y	1	Y	N	Pot	2.7V to 5.5V	6	SOT-23	1
MCP4024	-202	2.1	Up/Down	NV	6-bit	63	33.33	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	5	SOT-23	1
	-502	5.0	Up/Down	NV	6-bit	63	79.37	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	5	SOT-23	1
	-103	10.0	Up/Down	NV	6-bit	63	158.73	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	5	SOT-23	1
	-503	50.0	Up/Down	NV	6-bit	63	793.65	Y/Y	1	Y	N	Rheo	2.7V to 5.5V	5	SOT-23	1

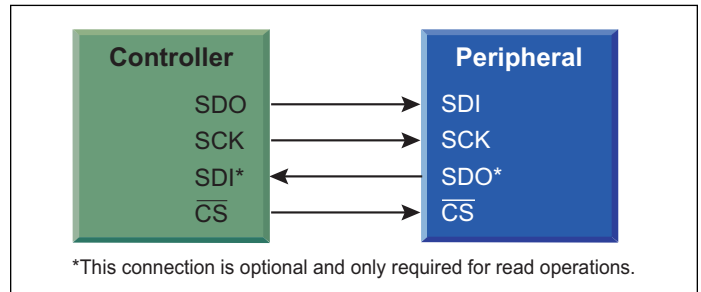
- Note 1:** Zero-scale allows the wiper to “directly” connect to Terminal B, while full-scale allows the wiper to “directly” connect to Terminal A.
Note 2: There is one RS resistor between the maximum wiper value and Terminal A.
Note 3: This current is with the serial interface inactive, and not during an EEPROM write cycle (for non-volatile devices).
Note 4: The serial interface has been tested to 1.8V, the device’s analog characteristics (resistor) have been tested from 2.7V to 5.5V. Review the device’s characterization graphs for information on analog performance between 1.8V and 2.7V.

SPI

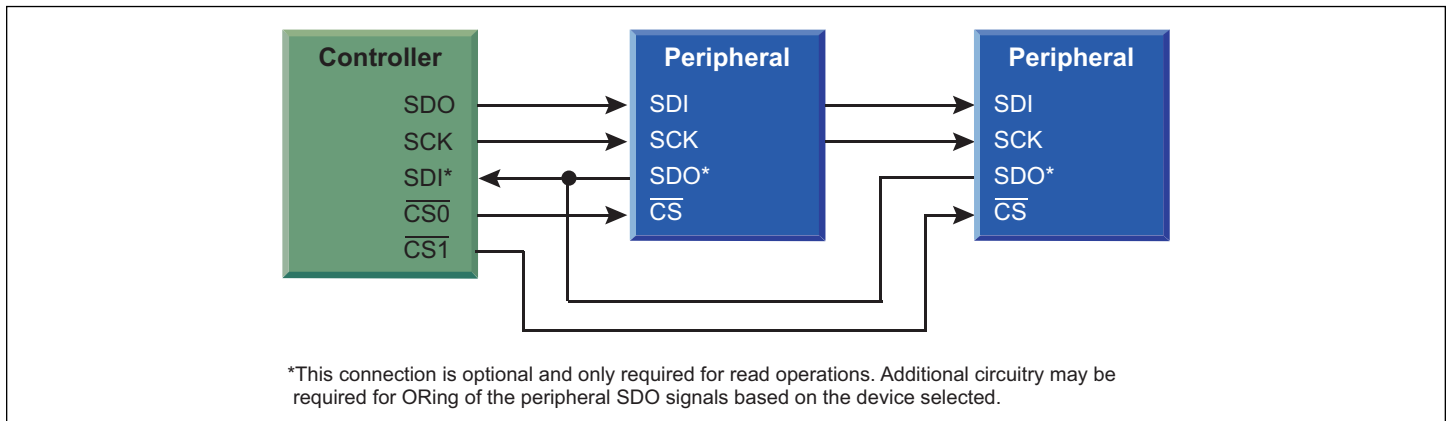
This is also an easy to implement interface, that requires three or four I/O pins. The additional pins allow data to be read back from the device or to allow device daisy chaining. Daisy chaining allows the SPI interface to update all devices in that chain at the same time.

Many microcontrollers offer this interface as a hardware module, further simplifying the code development.

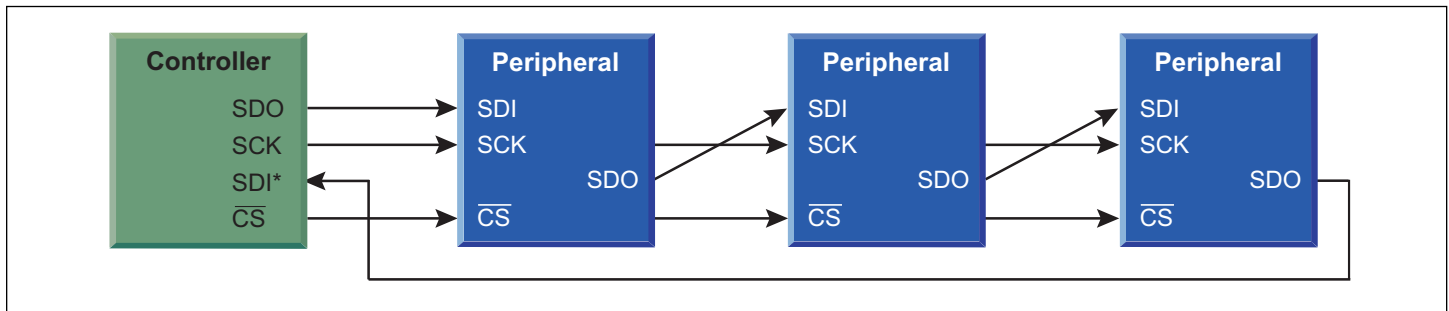
Controller to Single Peripheral



Controller to Multiple Peripherals (Multiple Chip Selects)



Controller to Multiple Peripherals (Daisy Chaining)



Product Specifications

Device	R _{AB} (kΩ) (typ.)	Serial Interface	Volatile Non-Volatile	Resolution	# R _S Resistors	R _S (Ω) (typ.)	Zero-Scale/ Full-Scale ⁽¹⁾	# of Channels	WiperLock™ Technology	Shutdown Mode	Configuration	Voltage Range	# of Pins	Packages	I _{DD} max (μA) ⁽³⁾
MCP41010	10.0	SPI	V	8-bit	256	39.06	Y/N ⁽²⁾	1	N	Y	Pot	2.7V to 5.5V	8	SOIC, PDIP	1
MCP41050	50.0	SPI	V	8-bit	256	195.31	Y/N ⁽²⁾	1	N	Y	Pot	2.7V to 5.5V	8	SOIC, PDIP	1
MCP41100	100.0	SPI	V	8-bit	256	390.625	Y/N ⁽²⁾	1	N	Y	Pot	2.7V to 5.5V	8	SOIC, PDIP	1
MCP42010	10.0	SPI	V	8-bit	256	39.06	Y/N ⁽²⁾	2	N	Y	Pot	2.7V to 5.5V	14	TSSOP, SOIC, PDIP	1
MCP42050	50.0	SPI	V	8-bit	256	195.31	Y/N ⁽²⁾	2	N	Y	Pot	2.7V to 5.5V	14	TSSOP, SOIC, PDIP	1
MCP42100	100.0	SPI	V	8-bit	256	390.625	Y/N ⁽²⁾	2	N	Y	Pot	2.7V to 5.5V	14	TSSOP, SOIC, PDIP	1

- Note 1:** Zero-scale allows the wiper to “directly” connect to Terminal B, while full-scale allows the wiper to “directly” connect to Terminal A.
2: There is one R_S resistor between the maximum wiper value and Terminal A.
3: This current is with the serial interface inactive, and not during an EEPROM write cycle (for non-volatile devices).
4: The serial interface has been tested to 1.8V, the device’s analog characteristics (resistor) have been tested from 2.7V to 5.5V. Review the device’s characterization graphs for information on analog performance between 1.8V and 2.7V.

Dual Potentiometer Options

Some devices offer two potentiometers in a single package. These are often referred to as Potentiometer 0 and Potentiometer 1. Having multiple potentiometers on the same device offers several advantages, including:

- Cost per potentiometer
- Layout area per potentiometer
- Variation between potentiometers

In some applications, the RAB resistance variation between potentiometers is important for the application circuit. When these potentiometers are on the same silicon, the RAB resistance variation is small compared to the possible variation of the RAB resistance on different devices. ≤

Product Specifications

Device	RAB (kΩ) (typ.)	Serial Interface	Volatile Non-Volatile	Resolution	# Rs Resistors	Rs (Ω) (typ.)	RAB0 (to RAB1) Resistance Variation (max.)	Zero-Scale/ Full-Scale ⁽¹⁾	# of Channels	WiperLock™ Technology	Shutdown Mode	Configuration	Voltage Range	# of Pins	Packages	I _{DD} max (μA) ⁽³⁾
MCP41010	10.0	SPI	V	8-bit	256	39.06	≤ 1%	Y/N ⁽²⁾	1	N	Y	Pot	2.7V to 5.5V	8	SOIC, PDIP	1
MCP41050	50.0	SPI	V	8-bit	256	195.31	≤ 1%	Y/N ⁽²⁾	1	N	Y	Pot	2.7V to 5.5V	8	SOIC, PDIP	1
MCP42100	100.0	SPI	V	8-bit	256	390.625	≤ 1%	Y/N ⁽²⁾	2	N	Y	Pot	2.7V to 5.5V	14	TSSOP, SOIC, PDIP	1

- Note 1:** Zero-scale allows the wiper to “directly” connect to Terminal B, while full-scale allows the wiper to “directly” connect to Terminal A.
2: There is one RS resistor between the maximum wiper value and Terminal A.
3: This current is with the serial interface inactive, and not during an EEPROM write cycle (for non-volatile devices).
4: The serial interface has been tested to 1.8V, the device’s analog characteristics (resistor) have been tested from 2.7V to 5.5V. Review the device’s characterization graphs for information on analog performance between 1.8V and 2.7V.

Resistance Options and Resolutions

Microchip offers Digital Potentiometer devices with typical R_{AB} resistances of 2.1 K Ω , 5 K Ω , 10 K Ω , 50 K Ω and 100 K Ω . The devices offer either 6- or 8-bits of resolution. The step resistance (R_s) is the R_{AB} resistances divided by the number of wiper steps.

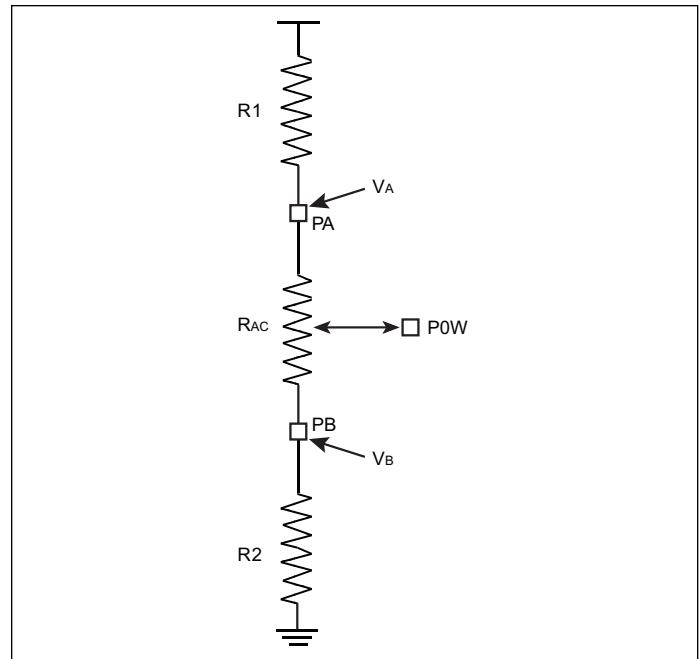
The step resistance is important to understand when you are using the device in a rheostat mode, or the potentiometer is being windowed by resistors on the Terminal A and/or on the Terminal B.

Voltage Windowing

Terminal A and Terminal B may for example be any voltage within the device specification limits. Let's call the voltages at these nodes V_A and V_B . So the voltage across the resistor R_{AB} (V_{AB}) is $|V_A - V_B|$. The V_{AB} voltage is determined by the values of the R_1 , R_2 and R_{AB} resistors. As the V_{AB} voltage becomes smaller relative to the voltage range, the effective resolution of the device increases, though the resolution is limited to between the V_A and V_B voltages.

This allows a less precise device to be used for more precise circuit tuning over a narrower range. When replacing a mechanical potentiometer, this configuration can be used and R_1 and R_2 may be any resistance (including 0).

Voltage Windowing



Resistance Options

R_{AB} Resistance (K Ω - typ.)	Step Resistance (R_s) (Ω - typ.)		Comment
	6-bit Device (63 resistors)	8-bit Device (256 resistors)	
2.1	33.33	–	Smallest Step Resistance available
5.0	79.37	–	
10.0	158.73	39.06	Can trade off between cost and Step Resistance (resolution).
50.0	793.65	195.31	Can trade off between cost and Step Resistance (resolution).
100.0	–	390.63	

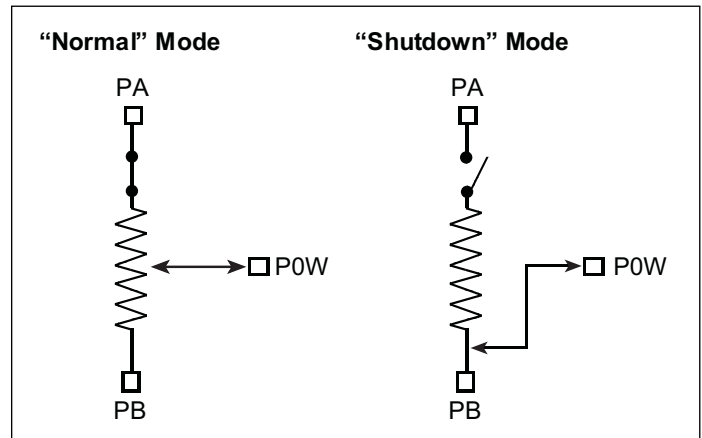
How the V_{AB} Voltage Effects the Effective Resolution

V_{AB}	Step Voltage (V_s) (mV)		Effective Resolution		Comment
	6-bit Device (63 resistors)	8-bit Device (256 resistors)	6-bit Device (63 resistors)	8-bit Device (256 resistors)	
5.0	79.4	19.5	6-bits	8-bits	$V_{AB} = V_{DD}$
2.5	39.7	9.8	7-bits	9-bits	$V_{DD} = 5.0V$
1.25	1.98	4.9	8-bits	10-bits	$V_{DD} = 5.0V$

Shutdown

Shutdown allows the resistor network to be disconnected from the circuit. This can substantially reduce the current of the system. In the MCP42XXX devices, when the SHDN pin is low, Terminal A is disconnected from the resistor network and Terminal W is connected to Terminal B. When the device enters “Shutdown” mode, the current path from Terminal A to Terminal B is opened. This minimizes the system current. Also the wiper is forced to be connected to Terminal B. This is to force that node to a known state so that system power consumption can be minimized.

Normal vs. Shutdown Mode



Product Specifications

Device	R _{AB} (k Ω) (typ.)	Serial Interface	Volatile Non-Volatile	Resolution	# R _s Resistors	R _s (Ω) (typ.)	Zero-Scale/ Full-Scale ⁽¹⁾	# of Channels	WiperLock™ Technology	Shutdown Mode	Configuration	Voltage Range	# of Pins	Packages	I _{DD} max (μ A) ⁽³⁾
MCP41010	10.0	SPI	V	8-bit	256	39.06	Y/N ⁽²⁾	1	N	Y	Pot	2.7V to 5.5V	8	SOIC, PDIP	1
MCP41050	50.0	SPI	V	8-bit	256	195.31	Y/N ⁽²⁾	1	N	Y	Pot	2.7V to 5.5V	8	SOIC, PDIP	1
MCP42100	100.0	SPI	V	8-bit	256	390.625	Y/N ⁽²⁾	2	N	Y	Pot	2.7V to 5.5V	14	TSSOP, SOIC, PDIP	1

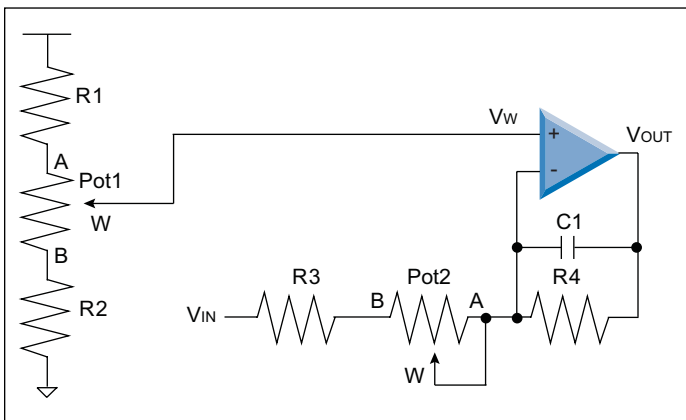
- Note 1:** Zero-scale allows the wiper to “directly” connect to Terminal B, while full-scale allows the wiper to “directly” connect to Terminal A.
Note 2: There is one R_S resistor between the maximum wiper value and Terminal A.
Note 3: This current is with the serial interface inactive, and not during an EEPROM write cycle (for non-volatile devices).
Note 4: The serial interface has been tested to 1.8V, the device’s analog characteristics (resistor) have been tested from 2.7V to 5.5V. Review the device’s characterization graphs for information on analog performance between 1.8V and 2.7V.

Application Circuits and Techniques

Digital potentiometers are a good fit for applications to trim offset and gain in amplifier circuits. In this following circuit, a resistor ladder is used to create a voltage window where Pot1 is used to trim the desired offset for the inverting amplifier. A second potentiometer (Pot2) is used in a rheostat mode along with resistor R3 to control the gain of the amplifier. The step resistance of Pot2 relative to resistor R3 determines if the gain trimming is a fine adjustment or a course adjustment. Capacitor C1 is for compensation of the op amp and to inhibit the output from oscillating.

In this circuit, there is no interaction between the offset trimming and the gain trimming, but the input signal (V_{IN}) is loaded by the resistance of R3 plus Pot2's R_{BW} value.

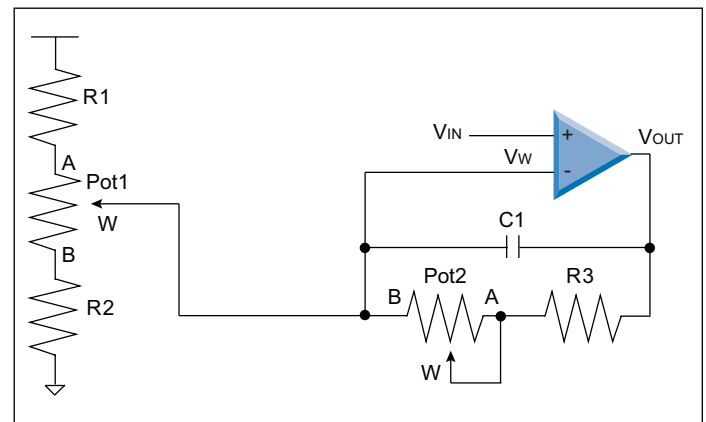
Inverting Amplifier with Offset and Gain Trimming



In the following circuit, a resistor ladder is used to create a voltage window where Pot1 is used to trim the desired offset for the non-inverting amplifier. A second potentiometer is used in a rheostat mode to control the gain of the amplifier. The step resistance of Pot2 relative to resistor R3 determines if the gain trimming is a fine adjustment or a course adjustment. Capacitor C1 is for compensation of the op amp and to inhibit the output from oscillating.

In this circuit, there is an interaction between the offset trimming and the gain trimming. To minimize this interaction, Pot2 should be small compared to resistor R3 and Pot1 should be small relative to the sum of R1 and R2. But the input signal (V_{IN}) is not loaded.

Non-Inverting Amplifier with Offset and Gain Trimming



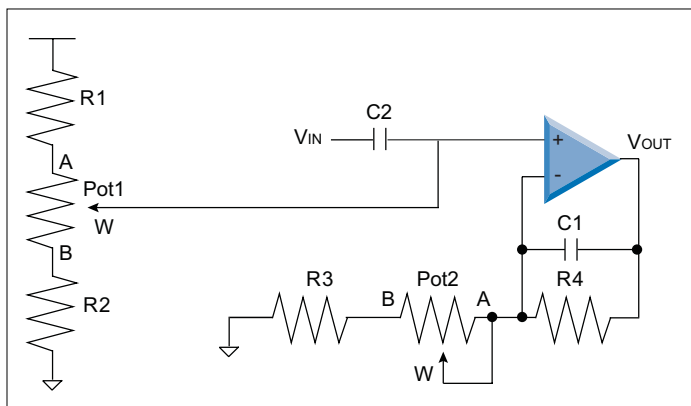
In the following circuit, a resistor ladder is used to create a voltage window where Pot1 is used to trim the desired offset for the band pass filter. This resistor ladder setting also works with capacitor C2 to set the high pass filter frequency.

A second potentiometer (Pot2) is used in a rheostat mode along with R3 and R4 to control the gain of the amplifier. The step resistance of Pot2 relative to resistors R3 and R4 determines if the gain trimming is a fine adjustment or a course adjustment. Capacitor C1 along with Pot2, R3 and R4 is used to set the low pass filter.

Capacitor C1 is also used for compensation of the Op Amp and to inhibit the output from oscillating.

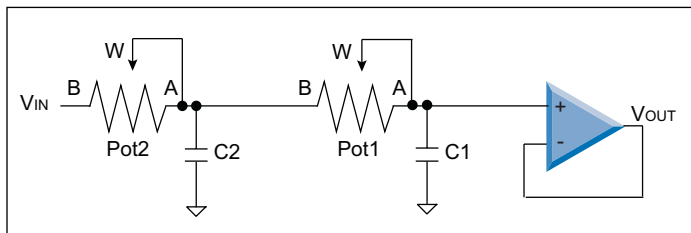
If capacitor C1 is not present, then the circuit is a high pass filter, while if capacitor C2 is not present then the circuit is a low pass filter.

Band Pass Filter with Offset and Gain Trimming



The following circuit will use the use of an RC filter (Potx and Cx) will filter at the selected frequency. that frequency is determined by the rheostat value (R_{BW}) of the Pot and the capacitor value (Cx). each additional stage of the RC filter is used to enhance the roll-off characteristics for the filter. The capacitors Cx should be the same, while the wiper values of the Pots should be similar. The differences would be to compensate for the slight variations of the R_{AB} values of each Pot and the variations of the capacitors.

Programmable Filter



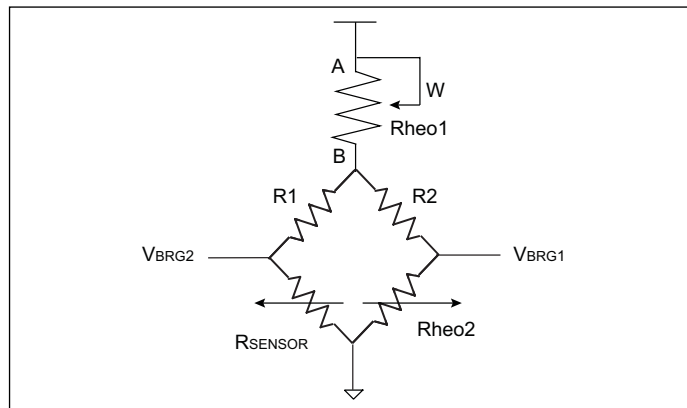
The following circuit shows a Wheatstone Bridge with current limiting. In a Wheatstone Bridge, there are four resistive elements. In this example, two are fixed value (R1 and R2), there is a resistive sensor (R_{SENSOR}) and then there is the digital potentiometer in rheostat configuration to calibrate the circuit due to variations of the resistive sensor. This sensor could be for temperature or weight measurement.

At a default condition the sensor should be a given value, but this value will change from device to device. To compensate for the resistive changes in the R1 plus R_{SENSOR} leg of the bridge, the Rheo2 would be modified for the R2 plus Rheo2 leg of the bridge. This would be done so that the voltages of V_{BRG1} and V_{BRG2} are at their desired levels. Many times this is $V_{BRG1} = V_{BRG2}$.

Now as the conditions on the sensor change, the resistance of the sensor will change, causing the V_{BRG2} voltage to change. The delta voltage between V_{BRG1} and V_{BRG2} can then be used to determine the state of the system (temperature, weight, etc.).

Rheo 1 is used in a rheostat mode to limit the current or trim the current through the Wheatstone Bridge.

Wheatstone Bridge Trimming



Implementing a More Precise Rheostat

The R_{AB} value of a typical digital potentiometer can vary as much as $\pm 20\%$, so a device with a 10 k Ω R_{AB} value could have an R_{AB} value as small as 8 k Ω , as large as 12 k Ω . In a system, this variation for the rheostat value may not be desirable. This variation can be calibrated out to make a precise rheostat, at a cost of the resolution of the device.

If we design the application circuit where this rheostat only operates from 0 Ω to 8 k Ω , all digital potentiometer devices (over process) will meet this requirement. Now with calibration, we will need to ensure that the wiper value is limited to a value where the rheostat value is the closest resistance value to the desired rheostat target value of 8 k Ω . The worst case (lowest) wiper value occurs when the R_{AB} value is 12 k Ω . In this case, a wiper value of 171. results in a resistance of 8016 Ω . This results in a resolution of approximately 7.4 bits, or 0.58%.

In potentiometer mode, the process variation of the R_{AB} value may not be an application issue since the device is operating as a voltage divider.

Demo/Evaluation Support

Microchip Technology offers several boards that support the demonstration and evaluation of the digital potentiometer devices. These boards fall into two categories:

- Populated boards to demonstrate/evaluate the specific device(s)
- Blank printed circuit boards (PCBs)

The blank PCBs allow customers to populate the device and supporting circuit to best evaluate the performance and characteristics of the desired device configuration.

The following boards are available on the Microchip web site at: www.microchip.com/analogtools.

Name	Part Number	Package Supported	
		# Pins	Types
MCP4XXX Demo Daughter Board	MCP4XXXDM-DB	–	MCP42XXX (DIP) and MCP40X1 (SOIC)
MCP401X/2X Evaluation Board	MCP402XEV	–	MCP40X1 (SOT-23)
MCP4XXX MXDEV® Daughter Board	DV42XXX	–	MCP42XXX
14-pin SOIC/TSSOP/DIP Evaluation Board	SOIC14EV	14	DIP, SOIC and TSSOP
8-pin SOIC/MSOP/TSSOP/DIP Evaluation Board	SOIC8EV	8	DIP, MSOP, SOIC and TSSOP
SOT-23-5/6 Evaluation Board	VSUPEV2	5 and 6	SOT-23

MCP4XXX Digital Potentiometer Daughter Board



Part Number: MCP4XXXDM-DB

This board allows evaluation of the MCP42XXX and MCP402X Digital Potentiometers. The MCP42XXX are dual digital potentiometer devices that have the same characteristics as the single digital potentiometer devices (MCP41XXX). The MCP402X devices are non-volatile and have similar characteristics to their volatile memory versions (MCP401X). The board supports two MCP42XXX devices to allow the resistor networks to be “stacked” and form a programmable windowed digital potentiometer. The board also has a voltage doubler device (TC1240A), which can be used to show the WiperLock™ Technology feature of the MCP4021.

MCP402X Non-Volatile Digital Potentiometer Evaluation Board



Part Number: MCP402XEV

This low-cost board enables user's to exercise all of the features of the MCP401X and MCP402X devices. Kit includes one populated and one unpopulated PCB. The populated board has an MCP4021-103E/SN digital potentiometer configured as a “windowed” potentiometer using a 2.5 kΩ pull-up and a 2.5 kΩ pull-down resistor. The PCB supports the 8-pin SOIC, SOT-23-6 and SOT-23-5 package variations. The unpopulated PCB allows user's to build the exact combination of components their application requires.

MCP42XXX Digital Potentiometer Evaluation Board



Part Number: DV42XXX

Includes an evaluation board, prototype board, RS-232 cable, 9V DC power supply, MXLAB® software, digital potentiometers and PIC® microcontroller. Used with the MXDEV® Driver Board (available separately).

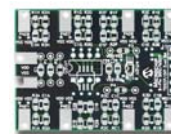
SOT-23-5/6 Voltage Supervisor Evaluation Board



Part Number: VSUPEV2

This blank PCB allows quick evaluation of voltage supervisors and voltage detectors in the SOT-23-5 and SOT-23-6 packages. This PCB supports many Microchip devices, including the non-volatile Digital Potentiometer and PIC10F2XX devices.

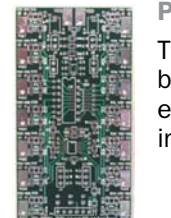
SOIC 8-Lead Evaluation Board



Part Number: SOIC8EV

A blank PCB to easily evaluate Microchip's 8-pin devices (in SOIC, DIP, MSOP and TSSOP packages). Each device pin is connected to a pull-up resistor, a pull-down resistor, an in-line resistor and a loading capacitor. The PCB pads allow through hole or surface mount connectors to be installed to ease connection to the board. Additional passive component footprints are on the board, to allow simple circuits to be implemented.

14-Pin SOIC/TSSOP/DIP Evaluation Board



Part Number: SOIC14EV

This 14-lead SOIC/TSSOP/DIP evaluation board allows system designers to quickly evaluate the operation of Microchip's devices in either SOIC, DIP or TSSOP packages.

The following Application Notes are available on the Microchip web site: www.microchip.com.

AN219: *Comparing Digital Potentiometers to Mechanical Potentiometers*

This application note compares two types of potentiometers – the mechanical potentiometer (also called a trimmer potentiometer) and the digital potentiometer. Resistor potentiometers can be found in electronic circuits across a wide spectrum of applications. Most typically, they function in a voltage divider configuration in order to execute various types of tasks, such as offset or gain adjust.

AN691: *Optimizing Digital Potentiometer Circuits to Reduce Absolute Temperature Variations*

Circuit ideas are presented that use the necessary design techniques to mitigate errors, consequently optimizing the performance of the digital potentiometer.

AN692: *Using Digital Potentiometers to Optimize a Precision Single-Supply Photo Detect Circuit*

This application note shows how the adjustability of the digital potentiometer can be used to an advantage in photosensing circuits.

AN737: *Using Digital Potentiometers to Design Low-Pass Adjustable Filters*

A programmable, second-order, low-pass filter is presented in four different scenarios. The first three scenarios will illustrate how a dual digital potentiometer and a single amplifier can be configured for low-pass second-order Butterworth, Bessel and Chebyshev responses with a programmable corner frequency range of 1:100. An example of the digital potentiometer setting for these designs is summarized. The fourth scenario will show the same circuit design, where all three approximation methods (Butterworth, Bessel and Chebyshev) can coexist with a programmable corner frequency range of 1:10.

AN746: *Interfacing Microchip's MCP41XXX/MCP4XXX Digital Potentiometer to a PIC® Microcontroller*

Communications between the MCP41XXX and MCP42XXX family of digital potentiometers and a PIC16F876 microcontroller is discussed. These devices communicate using a standard 3-wire SPI compatible interface. The code supplied with this application note will include both absolute and relocatable assembly code, written for both hardware SPI and firmware SPI implementations.

AN747: *Communicating with Daisy Chained MCP42XXX Digital Potentiometers*

The MCP41XXX and MCP42XXX family of digital potentiometers allow for daisy chaining of multiple devices on a single SPI bus. It is possible to communicate to multiple devices using one 3-wire data bus (CS, CLK and DATA), by connecting the SO pin on one device to the SI pin of the next device in the chain. This application note details one example of source code that is used to communicate with eight daisy chained devices.

AN757: *Interfacing Microchip's MCP41XXX/MCP4XXX Digital Potentiometer to the Motorola 68HC12 Microcontroller*

Communication between the MCP41XXX and MCP42XXX family of digital potentiometers and the Motorola 68HC12 family of microcontrollers is discussed. These devices communicate using a standard 3-wire SPI compatible interface. Specifically, the MC68HC912B32 evaluation board was used.

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