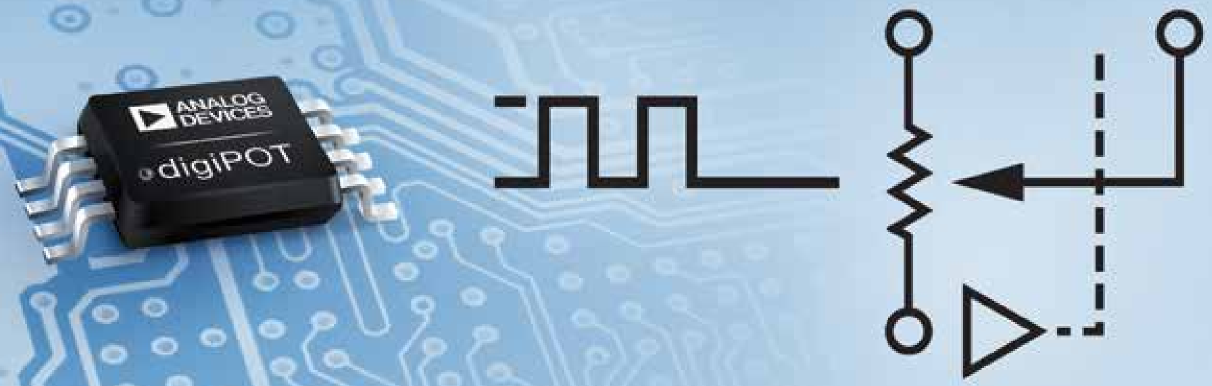
Choosing the Correct digiPOT for Your Application



Analog Devices offers a wide range of digital potentiometer (digiPOT) options, including different memory technologies, single and dual supply, a variety of digital interfaces, high resolution devices, and the industry's broadest end-to-end resistance options.

What Is a digiPOT?

A digiPOT is a digitally controlled device that can be used to adjust voltage or current and offers the same analog functions as a mechanical potentiometer or rheostat. This allows an automatic calibration process that is more accurate, more robust, and faster, with smaller voltage glitches. digiPOTs are often used for digital trimming and calibration of analog signals and are typically controlled by digital protocols, such as I²C and SPI, as well as more basic up/down and push-button protocols.

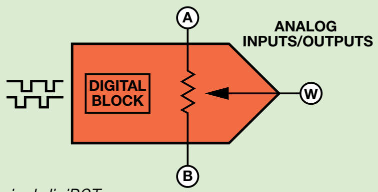


Figure 1. 3-terminal digiPOT.

Architecture

A digiPOT is a 3-terminal device (see Figure 1), with an internal architecture that is comprised of an array of resistances and switches. Each digiPOT consists of passive resistors in series between Terminals A and B. The wiper terminal, W, is digitally programmable to access any one of the 2^n tap points on the resistor string.

The resistance between Terminals A and B, R_{AB}, is commonly called the end-to-end resistance. ADI offers a wide range of end-to-end resistor options spanning from 1 kΩ to 1 MΩ.

The resistance between Terminals A and W, R_{AW}, and the resistance between Terminals B and W, R_{WB}, are complementary. That is, if R_{AW} increases, then R_{WB} will decrease in the same proportion.

There is no restriction on the voltage polarity applied to Terminals A, B, or W. Voltage across the Terminals A to B, W to A, and W to B can be at either polarity—the only requirement is to ensure that the signal does not exceed the power supply rails. Similarly, there is no limitation in the current flow direction; the only restriction is that the maximum current does not exceed the current density specification, typically on the order of a few mA.

Which digiPOT to Use?

When choosing the correct digital potentiometer for your application, the key parameters to consider are

I. Resistor configuration
II. Digital interface
III. Internal memory
IV. Supply voltage
V. End-to-end resistance
VI. Resolution
VII. Performance
VIII. Package

I. Resistor Configuration

A digiPOT can be configured as a potentiometer or as a rheostat.

Potentiometer Mode

In this configuration, there are three terminals available: A, B, and W (see Figure 2).

The digiPOT operates as a voltage divider, and the wiper terminal voltage is proportional to the voltage applied between the A and B terminals and the resistance at R_{AW} and R_{WB}.

In Figure 3, a reference voltage is connected to Terminal A, and Terminal B is grounded. The voltage at the wiper pin can be calculated as

$$V_{OUT} = \frac{CODE}{2^n} \times V_{REF}$$

Typical Applications

- DAC
- LCD V_{COM} adjustment
- Analog signal attenuation

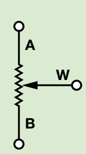


Figure 2. Potentiometer.

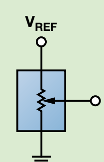


Figure 3. DAC mode.

Rheostat Mode

The digiPOT can operate as a digitally controlled rheostat where only two terminals are used. The unused terminal can be left floating or tied to the W terminal, as shown in Figure 4.

The nominal end-to-end resistance (R_{AB}) of the digiPOT has 2^n contact points accessible by the wiper terminal, and the resulting resistance can be measured either across the wiper and B terminals (R_{WB}) or across the wiper and A terminals (R_{AW}).

The minimum wiper resistance is at the wiper's first connection at the B terminal for zero scale. This B terminal connection has a minimum wiper contact resistance, R_W, of typically 70 Ω.

The rheostat resistance can be calculated by

$$R_{AW} = \frac{2^n - CODE}{2^n} \times R_{AB} + R_W \quad \text{or} \quad R_{WB} = \frac{CODE}{2^n} \times R_{AB} + R_W$$

Typical Applications

- Wheatstone bridge calibration
- Op amp gain control (see Figure 5)
- Analog filter tuning

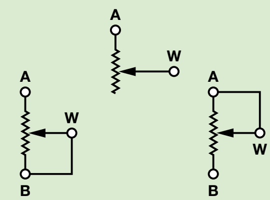


Figure 4. Rheostat.

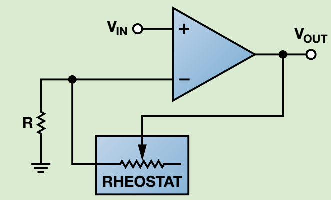


Figure 5. Noninverting amplifier.

II. Digital Interface

ADI's large digiPOT portfolio supports a wide range of digital interfaces:

- **SPI—**ADI offers SPI-compatible interfaces that can be operated at speeds up to 50 MHz clock rate.
- **I²C—**ADI offers I²C-compatible interfaces that support standard and fast mode, up to a 400 kHz clock rate. Address pins are typically available, which allow the user to configure the slave address so that multiple devices can be operated on the same bus.
- **Push-Button—**the user can interact directly with the system by just adding two push-button switches. Press the UP button to increment the resistance and DOWN to decrement resistance (see Figure 6).
- **Up/Down—**this is a simple interface, which can be operated by any host controller or discrete logic or manually with a rotary encoder or push buttons. With a single edge, resistance can be increased or decreased.

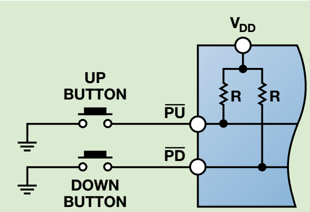


Figure 6. Push-button interface.

III. Internal Memory

ADI's wide portfolio supports four different options of integrated memory, allowing the user the flexibility to select the ideal digiPOT for the end application. Internal memory allows the user to set the wiper's power-on reset (POR) position to a user programmed value. The wiper position can be reprogrammed multiple times but always returns to the programmed position on power-up. This function is ideal for calibration or for applications that require a fast power-on time.

- Volatile memory only: digiPOT typically powers up to midscale.
- One-time programmable (OTP): allows user to program the wiper power-up position once—ideal for factory calibration.
- Multitime programmable (MTP): ADI has product offerings that support 2×, 20×, or 50× programmable wiper memory.
- EEPROM: ADI's integrated EEPROM offers endurance up to 1M programming cycles and data retention of 50 years at 125°C.

IV. Supply Voltage

Before selecting a digiPOT for an application, it is important to understand the maximum signal voltage that will be applied to the A, B, or W terminals. The positive, V_{DD}, and negative, V_{SS} (or GND for a unipolar digiPOT), power supplies define the voltage signal boundary conditions. Signals that exceed V_{DD} or V_{SS} are typically clamped by internal forward-biased diodes.

ADI's large portfolio supports a wide range of supply options:

- Single supply: 2.3 V to 33 V (see Figure 7)
- Dual supply: ±2.25 V to ±16.5 V (see Figure 8)

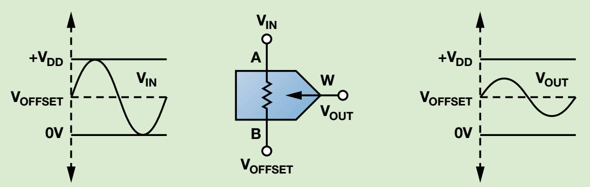


Figure 7. AC signal, single-supply mode.

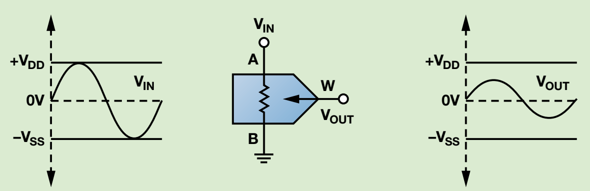


Figure 8. AC signal, dual-supply mode.

V. End-to-End Resistance

ADI offers a wide range of end-to-end resistor options, from 1 kΩ to 1 MΩ. This simplifies the task of achieving the optimum impedance, power dissipation, bandwidth, and noise performance combination.

VI. Resolution

ADI has offerings ranging from 5-bit to 10-bit resolution offering LSB step sizes as low as 4 Ω. If more resolution is required, then a cascade, serial, or parallel combination of digiPOTs can be implemented (see Table 1).

Table 1. Quick Reference Resistance Options

	Resistance (Ω)											
Resolution (Taps)	1k	2.5k	5k	10k	20k	25k	50k	80k	100k	200k	250k	1M
32				•			•	•	•			
64	•		•	•				•	•			
128				•			•	•	•			
256	•	•	•	•	•		•		•	•		•
1024				•	•	•	•		•		•	

VII. Key Performance Parameters

Resistor Tolerance Error—digiPOT resistor tolerance error is the absolute end-to-end resistance error. This error is typically ±20% and can be a critical parameter if matching to an external discrete resistor or sensor in an open-loop application.

Reducing the Impact of Resistor Tolerance Error

- ADI offers digiPOTs, for example, the AD5272 and AD5292, with industry-leading maximum ±1% variable resistor performance. These devices enable designers to digitally program accurate resistor values, simplifying the process of determining the system error budget (see Figure 9).
- Low resistor tolerance, for example, the AD5110, with a ±1% typical and ±8% maximum resistor tolerance.
- Products such as the AD5259 and AD5235 have the resistor tolerance error stored in the EEPROM memory. This allows the user to calculate the actual end-to-end resistance to an accuracy of 0.01%.
- The new patented linear gain setting mode allows controlling the potentiometer as two independent rheostats, R_{AW} and R_{WB}, connected in a single point, W terminal (see Figure 10). This mode is ideal in equations where the output depends on the ratio of two resistors, G = R1/R2, for example, in an inverting amplifier. This mode can be found in the AD5141, offering a maximum ratio error below ±1%.

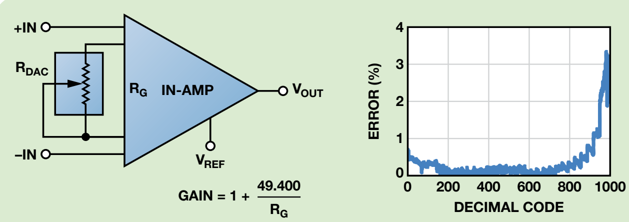


Figure 9. Instrumentation amplifier.

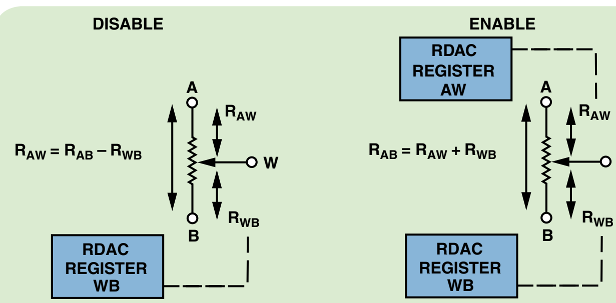


Figure 10. Linear gain setting mode.

digiPOT Temperature Coefficient—ADI's digiPOTs leverage proprietary thin film resistor technology, leading to the lowest temperature coefficient performance available on the market (for example, AD5292):

- 5 ppm/°C in potentiometer mode
- 35 ppm/°C in rheostat mode

Bandwidth—the digiPOT architecture is comprised of resistors and switches (see Figure 11). The resistance of the resistors in the path of a particular code, combined with the switch parasitic, pin, and board capacitances, creates an RC low-pass filter, which determines the maximum ac frequency that can be passed through the digiPOT before it is attenuated by more than –3 dB. Choosing a low end-to-end resistor option will support a higher –3 dB bandwidth (see Table 2).

Table 2. Typical –3 dB Bandwidth vs. Resistor Option

Resistance	1 kΩ	5 kΩ	10 kΩ	50 kΩ	100 kΩ	1 MΩ
Frequency	5 MHz	2 MHz	1 MHz	120 kHz	70 kHz	6 kHz

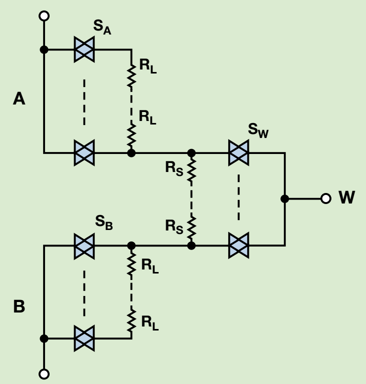


Figure 11. Internal architecture.

THD—an ac signal applied to the terminals of a digiPOT will cause variation in the internal switch, R_{ON}, leading to some nonsymmetrical attenuation and, therefore, signal distortion (see Figure 12). Choosing a high end-to-end resistor option reduces the contribution of the internal switches' resistance vs. the total resistance, leading to better THD performance. Table 3 shows some typical THD performance values.

Table 3. Typical THD Performance of the AD5292

Resistance	20 kΩ	50 kΩ	100 kΩ
THD	–93 dB	–101 dB	–106 dB

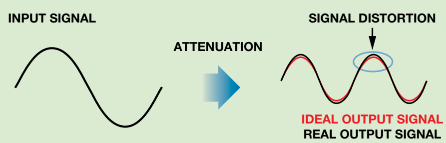


Figure 12. Total harmonic distortion.

VIII. Packages

ADI digiPOTs are available in a wide range of packages:

- SC70
- LFCSP
- SOT-23
- MSOP
- TSSOP
- SOIC

Applications

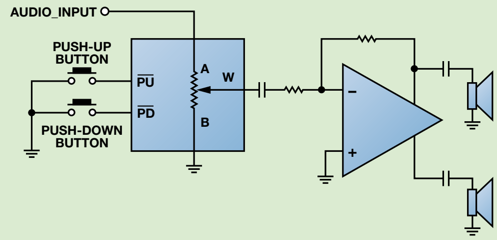


Figure 13. Audio volume control with an amplifier and push-button interface.

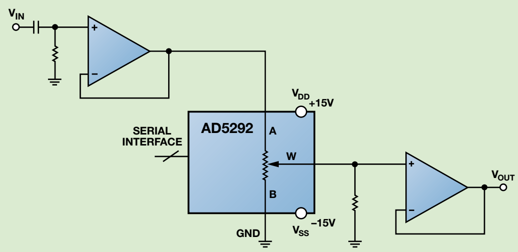


Figure 14. Logarithmic pro audio volume control.

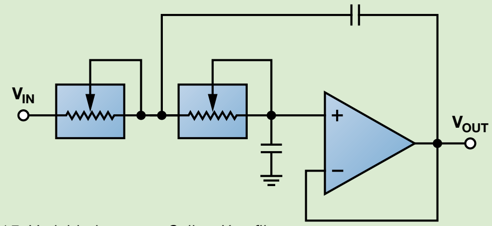


Figure 15. Variable low-pass Sallen-Key filter.

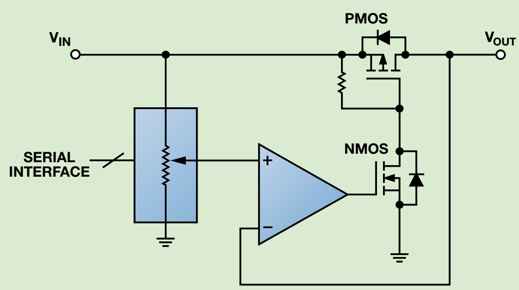


Figure 16. Programmable voltage source with current booster.

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Nonvolatile Memory Digital Potentiometers

Part Number	Resolution (Number of Wiper Steps)	Number of Channels	Maximum Terminal Voltage Range (V)	Interface	Nominal Resistance (kΩ)	Absolute Tempco (ppm/°C)	Package Leads	Price @ 1k ($U.S.)	Comments
One Time Programmable Memory (OTP)									
AD5273	64	1	5.5	I^{2}C	1, 10, 50, 100	300	8-lead SOT-23	0.69	1 kΩ option has high bandwidth
AD5171	64		5.5	I^{2}C	5, 10, 50, 100	35	8-lead SOT-23	0.72	Tempco is 5 ppm/°C in potentiometer mode
AD5172	256	2	5.5	I^{2}C	2.5, 10, 50, 100	35	10-lead MSOP	1.32	Tempco is 15 ppm/°C in potentiometer mode
AD5173	256		5.5	I^{2}C	2.5, 10, 50, 100	35	10-lead MSOP	1.32	Additional address pins (AD0 and AD1)
Multitime Programmable Memory (MTP)									
AD5271	256		±2.75, +5.5	SPI	20, 100	35	10-lead LFCSP, 10-lead MSOP	0.95	1% R-tol, 50 TP,† internal fuse programming supply
AD5291	256		±16.5, +33	SPI	20, 50, 100	35	14-lead TSSOP	2.29	High voltage, 1% R-tol, 20 TP,† internal fuse programming supply, low THD
AD5170	256		5.5	I^{2}C	2.5, 10, 50, 100	35	10-lead MSOP	1.00	2-TP†
AD5274	256		±2.75, +5.5	I^{2}C	20, 100	35	10-lead LFCSP, 10-lead MSOP	0.95	1% R-tol, 50 TP,† internal fuse programming supply
AD5270	1024	1	±2.75, +5.5	SPI	20, 50, 100	35	10-lead LFCSP, 10-lead MSOP	1.59	1% R-tol, 50 TP,† internal fuse programming supply
AD5174	1024		±2.75, +5.5	SPI	10	35	10-lead LFCSP, 10-lead MSOP	1.45	50 TP,† internal fuse programming supply
AD5292	1024		±16.5, +33	SPI	20, 50, 100	35	14-lead TSSOP	2.62	High voltage, 1% R-tol, 20 TP,† internal fuse programming supply, low THD
AD5272	1024		±2.75, +5.5	I^{2}C	20, 50, 100	35	10-lead LFCSP, 10-lead MSOP	1.59	1% R-tol, 50 TP,† internal fuse programming supply
AD5175	1024		±2.75, +5.5	I^{2}C	10	35	10-lead LFCSP, 10-lead MSOP	1.45	50 TP,† internal fuse programming supply
EEPROM									
AD5114 ***New***	32		5.5	I^{2}C	10, 80	35	8-lead LFCSP	0.60	8% R-tol; 2.3 V supply operation, low power consumption
AD5115 ***New***	32		5.5	Up/down	10, 80	35	8-lead LFCSP	0.60	8% R-tol; 2.3 V supply operation, low power consumption
AD5112 ***New***	64		5.5	I^{2}C	5, 10, 80	35	8-lead LFCSP	0.68	8% R-tol; 2.3 V supply operation, low power consumption
AD5113 ***New***	64		5.5	Up/down	5, 10, 80	35	8-lead LFCSP	0.68	8% R-tol; tempco is 5 ppm/°C in potentiometer mode
AD5116 ***New***	64		5.5	Push-button	5, 10, 80	35	8-lead LFCSP	0.66	8% R-tol; 2.3 V supply operation, low power consumption
AD5258	64	1	5.5	I^{2}C	1, 10, 50, 100	300	10-lead MSOP	0.59	% R-tol error stored in NVM
AD5110 ***New***	128		5.5	I^{2}C	10, 80	35	8-lead LFCSP	0.76	8% R-tol; 2.3 V supply operation, low power consumption
AD5111 ***New***	128		5.5	Up/down	10, 80	35	8-lead LFCSP	0.76	8% R-tol; 2.3 V supply operation, low power consumption
AD5121 ***New***	128		±2.75, +5.5	SPI/I^{2}C	10, 100	35	16-lead LFCSP	0.70	LGST,* 8% R-tol; 2.3 V supply operation
AD5259	256		5.5	I^{2}C	5, 10, 50, 100	300	10-lead LFCSP, 10-lead MSOP	0.9	% R-tol error stored in NVM
AD5141 ***New***	256		±2.75, +5.5	SPI/I^{2}C	10, 100	35	16-lead LFCSP	0.90	LGST,* 8% R-tol; 2.3 V supply operation
AD5231	1024		±2.75, +5.5	SPI	10, 50, 100	600	16-lead TSSOP	1.97	28 bytes of user-programmable NVM
AD5251	64		±2.75, +5.5	I^{2}C	1, 10, 50, 100	600	14-lead TSSOP	1.97	% R-tol error stored in NVM, 12 bytes of user-programmable NVM
AD5122A ***New***	128		±2.75, +5.5	I^{2}C	10, 100	35	16-lead LFCSP, 16-lead TSSOP	1.45	LGST,* 8% R-tol; 2.3 V supply operation
AD5122 ***New***	128		±2.75, +5.5	SPI	10, 100	35	16-lead LFCSP, 16-lead TSSOP	1.45	LGST,* 8% R-tol; 2.3 V supply operation
AD5232	256		±2.75, +5.5	SPI	10, 50, 100	300	16-lead TSSOP	2.40	14 bytes of user-programmable NVM
AD5252	256	2	±2.75, +5.5	I^{2}C	1, 10, 50, 100	300	14-lead TSSOP	1.61	% R-tol error stored in NVM, 12 bytes of user-programmable NVM
AD5142A ***New***	256		±2.75, +5.5	I^{2}C	10, 100	35	16-lead LFCSP, 16-lead TSSOP	1.65	LGST,* 8% R-tol; 2.3 V supply operation
AD5142 ***New***	256		±2.75, +5.5	SPI	10, 100	35	16-lead LFCSP, 16-lead TSSOP	1.65	LGST,* 8% R-tol; 2.3 V supply operation
AD5235	1024		±2.75, +5.5	SPI	25, 250	35	16-lead TSSOP	3.52	% R-tol error stored in NVM, 26 bytes of user-programmable NVM
ADN2850	1024		±2.75, +5.5	SPI	25, 250	35	16-lead LFCSP, 16-lead TSSOP	3.52	% R-tol error stored in NVM, 26 bytes of user-programmable NVM
AD5233	64		±2.75, +5.5	SPI	10, 50, 100	600	24-lead TSSOP	2.50	11 bytes of user-programmable NVM
AD5253	64		±2.75, +5.5	I^{2}C	1, 10, 50, 100	300	20-lead TSSOP	2.49	% R-tol error stored in NVM, 12 bytes of user-programmable NVM
AD5123 ***New***	128		±2.75, +5.5	I^{2}C	10, 100	35	16-lead LFCSP	2.45	LGST,* 8% R-tol; 2.3 V supply operation
AD5124 ***New***	128	4	±2.75, +5.5	SPI/I^{2}C	10, 100	35	24-lead LFCSP, 20-lead TSSOP	2.50	LGST,* 8% R-tol; 2.3 V supply operation
AD5254	256		±2.75, +5.5	I^{2}C	1, 10, 50, 100	300	20-lead TSSOP	2.58	% R-tol error stored in NVM, 12 bytes of user-programmable NVM
AD5143 ***New***	256		±2.75, +5.5	I^{2}C	10, 100	35	16-lead LFCSP	2.85	LGST,* 8% R-tol; 2.3 V supply operation
AD5144A ***New***	256		±2.75, +5.5	I^{2}C	10, 100	35	20-lead TSSOP	2.90	LGST,* 8% R-tol; 2.3 V supply operation
AD5144 ***New***	256		±2.75, +5.5	SPI/I^{2}C	10, 100	35	24-lead LFCSP, 20-lead TSSOP	2.90	LGST,* 8% R-tol; 2.3 V supply operation

†TP = times programmable
*Linear gain setting mode

Volatile Digital Potentiometers

Part Number	Resolution (Number of Wiper Steps)	Number of Channels	Maximum Terminal Voltage Range (V)	Interface	Nominal Resistance (kΩ)	Absolute Tempco (ppm/°C)	Package Leads	Price @ 1k ($U.S.)	Comments
AD5228	32	1	5.5	Push-button	10, 50, 100	35	8-lead TSOT	0.34	Manual with built-in debouncer
AD5201	33		±2.75, +5.5	SPI	10, 50	500	10-lead MSOP	0.50	Low wiper resistance
AD5227	64		5.5	Up/down	10, 50, 100	35	8-lead TSOT	0.36	Tempco is 10 ppm/°C in potentiometer mode
AD5246	128		5.5	I²C	5, 10, 50, 100	35	6-lead SC70	0.45	Ultracompact, rheostat only
AD5247	128		5.5	I²C	5, 10, 50, 100	35	6-lead SC70	0.45	Ultracompact
AD5220	128		5.5	Up/down	10, 50, 100	800	8-lead MSOP, 8-lead SOIC	0.90	
AD7376	128		±16.5, +33	SPI	10, 50, 100	300	14-lead TSSOP, 16-lead SOIC	2.86	High voltage
AD5160	256		5.5	SPI	5, 10, 50, 100	35	8-lead SOT-23	0.64	
AD5165	256		5.5	SPI	100	35	8-lead TSOT	0.58	Low power: 0.05 µA
AD5245	256		5.5	I²C	5, 10, 50, 100	35	8-lead SOT-23	0.64	
AD5161	256		5.5	SPI	5, 10, 50, 100	35	10-lead MSOP	0.65	
AD5241	256		±2.75, +5.5	I²C	10, 100, 1000	30	14-lead TSSOP, 14-lead SOIC	0.93	
AD5200	256		±2.75, +5.5	SPI	10, 50	500	10-lead MSOP	0.89	
AD8400	256		5.5	SPI	1, 10, 50, 100	500	8-lead SOIC	1.13	1 kΩ option has high bandwidth
AD5260	256		±5.5, +16.5	SPI	20, 50, 200	35	14-lead TSSOP	1.80	
AD5280	256		±5.5, +16.5	I²C	20, 50, 200	35	14-lead TSSOP	1.80	
AD5290	256		±16.5, +33	SPI	10, 50, 100	35	10-lead MSOP	1.97	High voltage
AD5293	1024		±16.5, +33	SPI	20, 50, 100	35	14-lead TSSOP	2.55	High voltage, 1% R-tol, low THD
AD5222	128	2	±2.75, +5.5	Up/down	10, 50, 100, 1000	35	14-lead TSSOP, 14-lead SOIC	0.80	
AD5162	256		5.5	SPI	2.5, 10, 50, 100	35	10-lead MSOP	1.00	1 rheostat, 1 potentiometer
AD5207	256		±2.75, +5.5	SPI	10, 50, 100	500	14-lead TSSOP	1.06	AD8402 replacement
AD8402	256		5.5	SPI	1, 10, 50, 100	500	14-lead TSSOP, 14-lead SOIC	1.68	1 kΩ option has high bandwidth
AD5262	256		±5.5, +16.5	SPI	20, 50, 200	35	16-lead TSSOP	1.97	
AD5243	256		5.5	I²C	2.5, 10, 50, 100	35	10-lead MSOP	1.00	Rheostat/potentiometer
AD5248	256		5.5	I²C	2.5, 10, 50, 100	35	10-lead MSOP	1.00	Rheostats only
AD5242	256		±2.75, +5.5	I²C	10, 100, 1000	30	16-lead TSSOP, 16-lead SOIC	1.27	
AD5282	256		±5.5, +16.5	I²C	20, 50, 200	35	16-lead TSSOP	1.97	
AD5203	64	4	5.5	SPI	10, 100	700	24-lead TSSOP, 24-lead SOIC	1.47	
AD5204	256		±2.75, +5.5	SPI	10, 50, 100	700	32-lead LFCSP, 24-lead TSSOP, 24-lead SOIC	1.52	Preset to midscale/zero-scale pin
AD8403	256		5.5	SPI	1, 10, 50, 100	500	24-lead TSSOP, 24-lead SOIC	2.79	1 kΩ option has high bandwidth
AD5263	256		±7.5, +16.5	SPI/I²C	20, 50, 200	30	24-lead TSSOP	2.58	Additional I²C address pins (AD0 and AD1)
AD5206	256	6	±2.75, +5.5	SPI	10, 50, 100	700	24-lead TSSOP, 24-lead SOIC	1.94	Preset to midscale/zero-scale pin

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