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TND6010/D

Understanding Digitally Programmable Potentiometers

This White Paper presents the fundamentals of Digitally Programmable Potentiometers (DPP), and provides design ideas for applying DPP in adjustable gain circuits, programmable instrumentation amplifiers, positive LCD bias controls, programmable voltage regulators, and programmable band-pass filters.

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REFERENCE DESIGN

Description

The digital potentiometer is a mixed signal device designed as an electronic replacement for mechanical potentiometers. The function of the potentiometer section of the digital potentiometer is the same as the mechanical version. In both cases, the potentiometer or pot is a three terminal device.

Between two of the terminals there is a resistive element. The third terminal called the wiper is connected to various points along this resistive element. The big difference between the two potentiometer technologies (Figure 1) is in the control section. In the mechanical version (Figure 1a), the connection is physical or mechanical while in the electronic version (Figure 1b) the connection is electrical. The wiper of the mechanical potentiometer is physically moved by one's hand while the electronic version is digitally controlled, typically by a computer or microcontroller. The most common terminal designations for the digital potentiometer are R_L, R_H, and R_W.

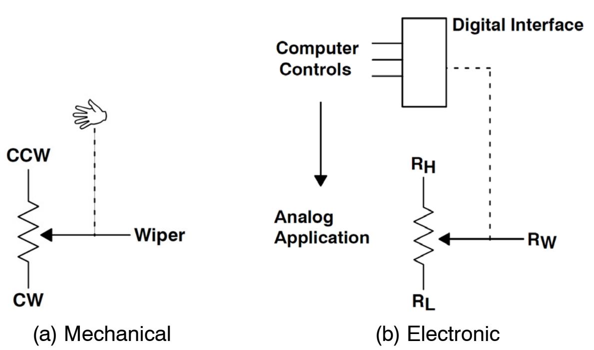


Figure 1. Potentiometers

The digital portion of a digital potentiometer circuit contains the interface, control, and registers associated with the potentiometer. The input signals to the digital section are the external control signals from the serial bus. The outputs of the digital section are internal signals that move the wiper, stored in internal volatile and/or nonvolatile registers. In the below example (Figure 2) a typical analog portion of a digital potentiometer is shown.

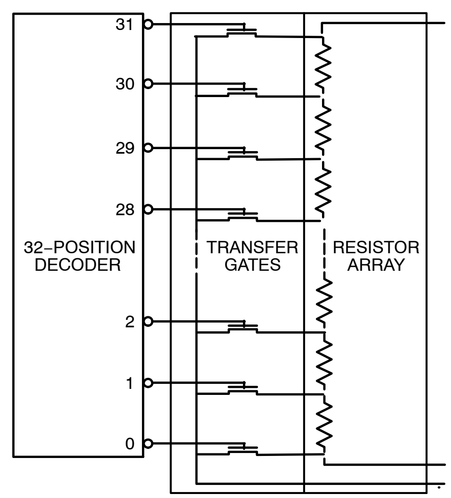


Figure 2. Example of Digital Potentiometer Architecture

Ideal for automated adjustments on high volume production lines, the digital potentiometers are also well suited for applications where equipment requiring periodic adjustment is either difficult to access or located in a hazardous or remote environment.

Digital potentiometers are suitable for any application requiring trimming or calibration:

- Instrumentation and medical
- Base stations

- Security systems
- Frequency trimming

They have many advantages over mechanical potentiometers:

- No drift over time
- No drift over temperature
- No changes due to mechanical stress/shock
- Systems can be calibrated real−time in the field

The Basic Ways of Using a Digital Potentiometer

The digital potentiometer is a three terminal device and has two fundamental modes or configurations; (1) three terminals and (2) two terminals. As a three terminal device, the pot is a resistive divider and as a two terminal device (called the rheostat mode) the pot is a variable resistance.

Figure 3 illustrates the two basic modes and basic applications.

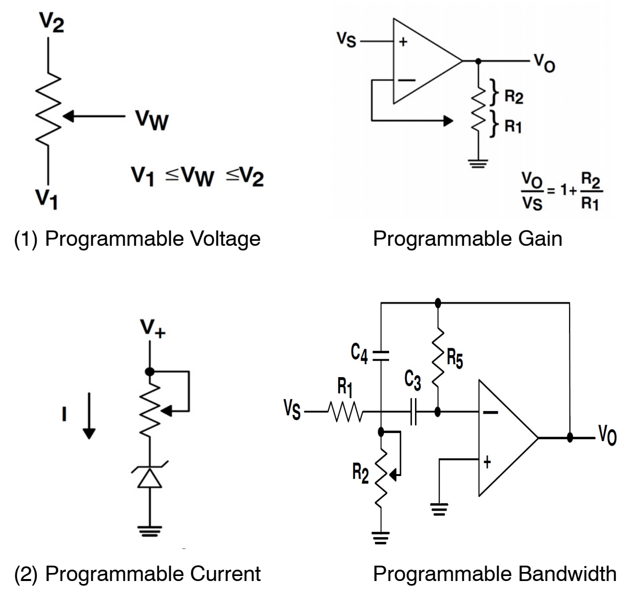


Figure 3. Basic Potentiometer Applications

DPP Memory Types

Depending on their type of memory, there are volatile DPP and non−volatile DPP, providing the designer with the possibility of choosing the most suitable solution for a specific application.

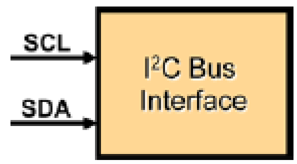
The volatile DPP resets the wiper at mid−scale on power−on. Although they don't have internal non−volatile storage, volatile DPP provides a cost−effective solution by using the storage capability already existent within the application.

The non−volatile DPP has an EEPROM for wiper storage, thus recalling the wiper position at power−on. This feature simplifies applications that require the wiper position to be automatically saved (for example, saving the last user setting).

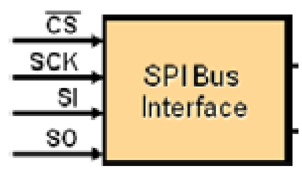
Control Interface

Most digital potentiometers are controlled through a serial bus. The three most popular options are I2C, SPI, and the UP/Down interface.

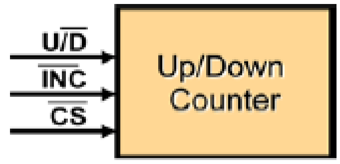
The I2C bus offers the advantage of using the fewest lines – SDA and SCL. Multiple devices can be controlled via the same bus. Clock speed, however, is limited to 400 kHz or 1 MHz, depending on the device.



The SPI protocol is faster, with speeds of up to 25 MHz. However, each device requires its own Chip Select signal, and the data bus uses three lines – SI, SO, and SCK.



The Up/Down interface requires three lines (CS, INC, and U/D), and allows incrementation and decrementation of the current wiper position, as opposed to the other two which require the whole data byte to be sent. If the device is selected, the device will increment its position on the negative edge of INC when U/D is high, and it will decrement its position when U/D is low. This interface is suitable for adjustments to the position, but does not allow the master to read back the digital potentiometer's current settings. The Up/Down interface is well suited to use with incremental rotary encoders.



Application Circuits

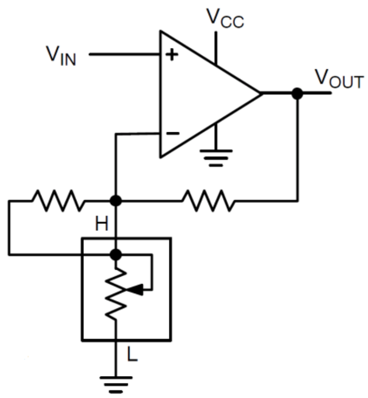


Figure 4. Adjustable Gain Circuit with Rheostat

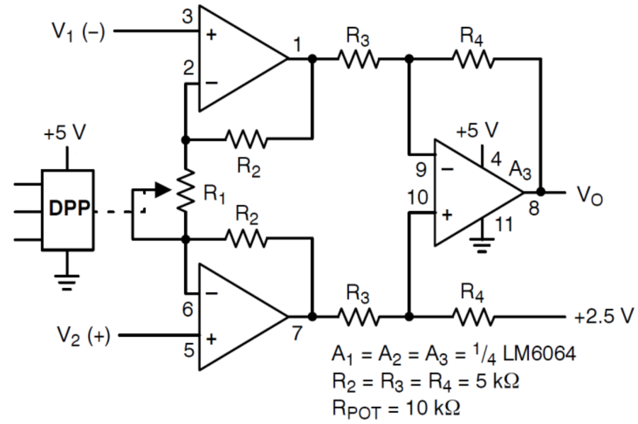


Figure 5. Programmable Instrumentation Amplifier

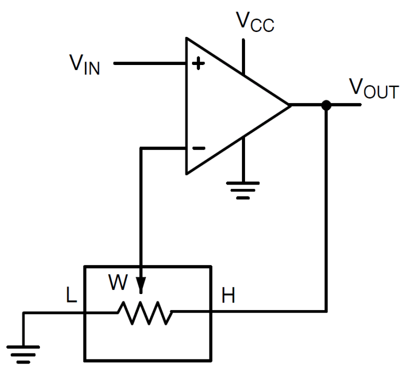


Figure 6. Adjustable Gain Circuit with Voltage Divider

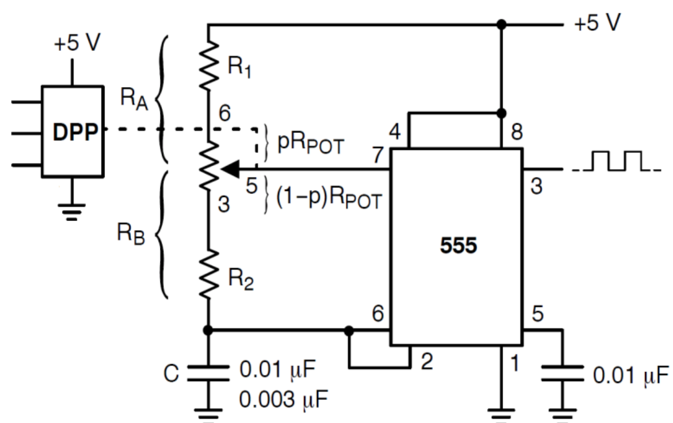


Figure 7. Programmable Square Wave Oscillator (555)

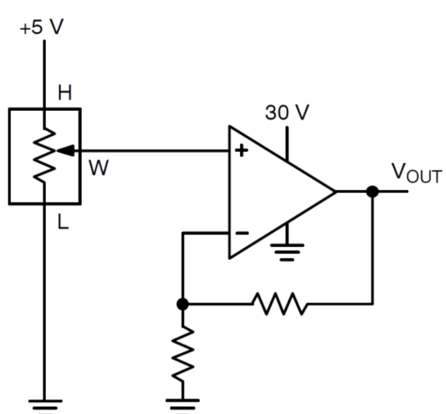


Figure 8. Positive LCD Bias Control

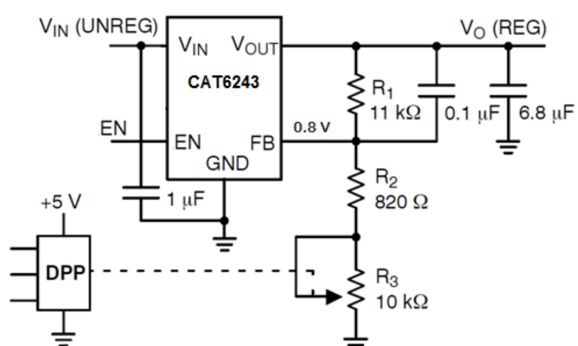


Figure 9. Programmable Voltage Regulator

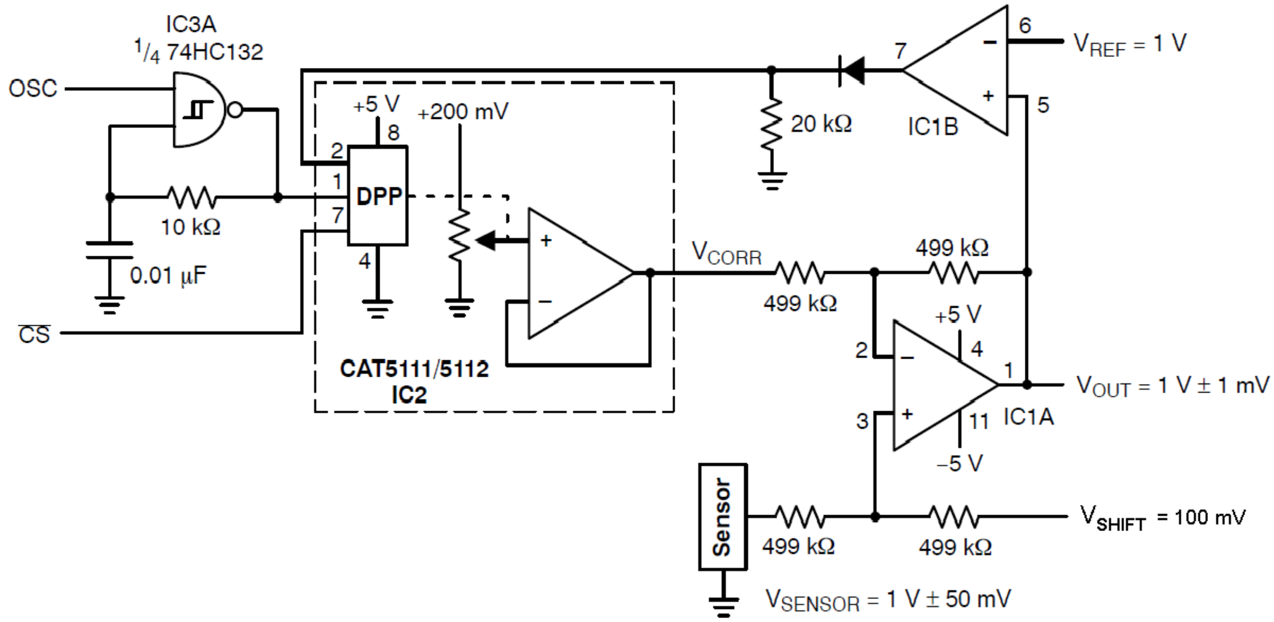


Figure 10. Sensor Auto Referencing Circuit

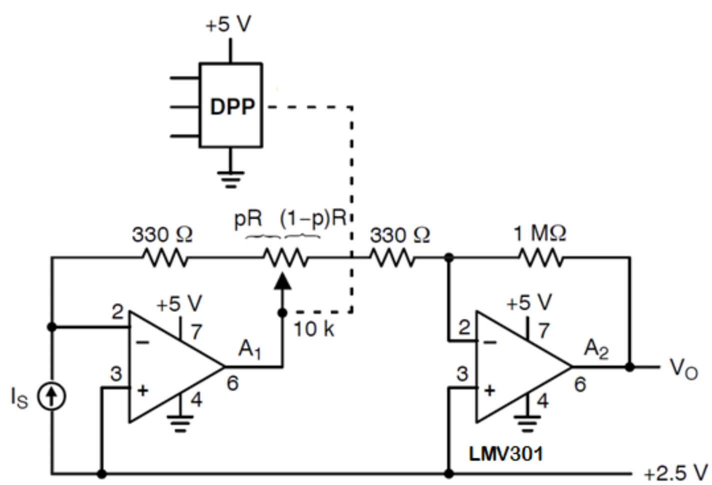


Figure 11. Programmable I to V Converter

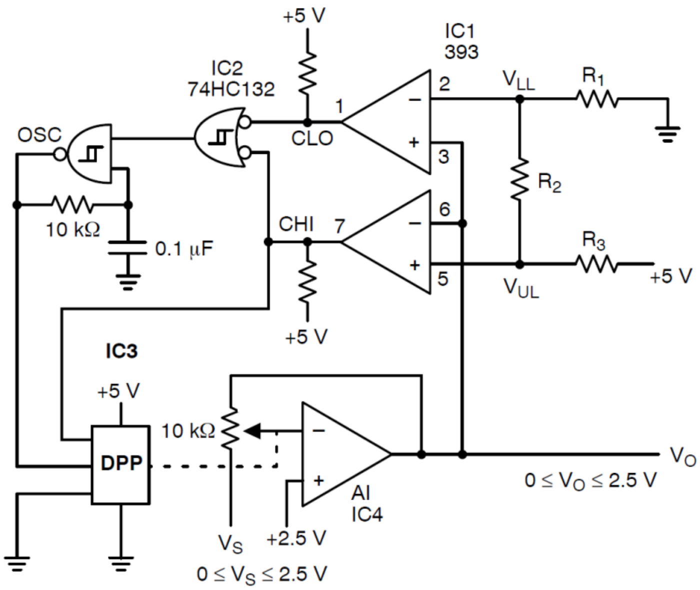


Figure 12. Automatic Gain Control

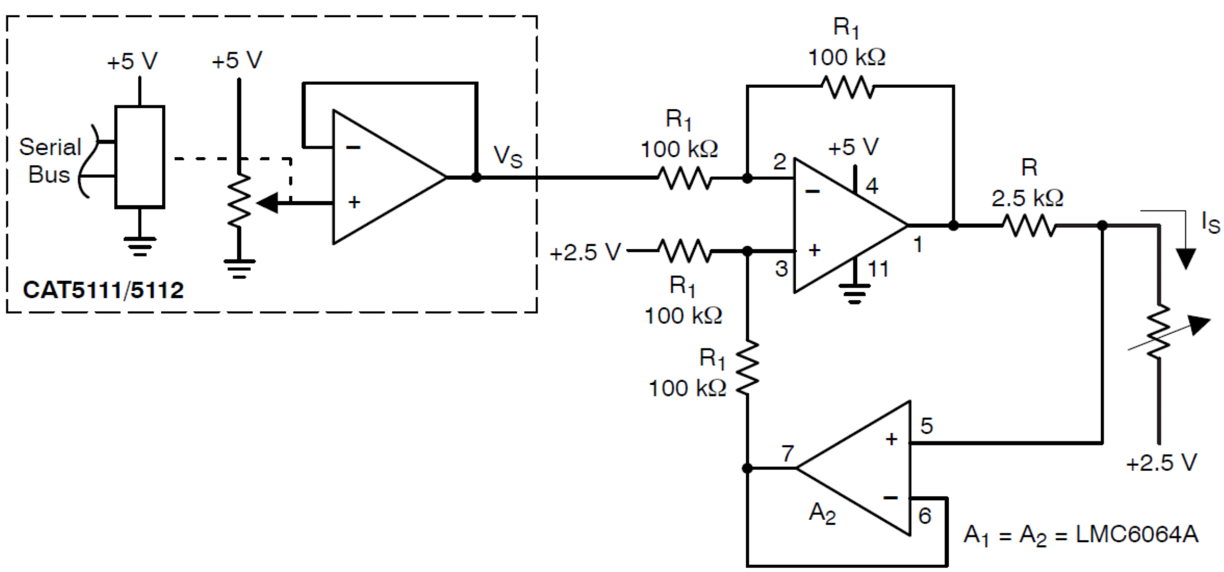


Figure 13. Programmable Current Source/Sink

Related Application Notes

Application notes can be found at www.onsemi.com.

AND8412/D DPP to Control LED Brightness

This application note shows a DPP circuit used in combination with the CAT32 white LED driver. A digitally programmable Potentiometer replaces a discrete resistor with the advantage of providing an adjustable value allowing the LED brightness to dynamically change.

AND8414/D Everything You Wanted to Know About Digitally Potentiometers

This application note answers frequently asked questions about the fundamentals of electronic or digitally programmable potentiometers (DPP).

AND8420/D Improving the Resolution of Digitally Programmable Potentiometer Applications

The objective of this application note is to illustrate a few basic device and circuit ideas on resolution. This application note focuses on resolving voltage.

AND8421/D Making a Stop−less Digitally Programmable Potentiometer

This application note contains a reference design to take the stops out of the digitally programmable potentiometer (DPP) in an application circuit.

AND8415/D Minimizing the Temperature Dependence of Digitally Programmable Potentiometers

The temperature dependence of the parameters of an analog circuit using a digitally programmable potentiometer is reduced if the performance of the circuit is shifted from the TC of the end−to−end resistance of the pot to the ratiometric TC.

AND8419/D Operating Speeds of Digitally Programmable Potentiometers

This application note lists the dominant operating time and frequency characteristics of digitally programmable potentiometers.

AND8422/D Power−Up and Power−Down Characteristics for Digitally Programmable Potentiometers

This application note discusses what happens when power (V_{CC}) is applied or removed from a digitally programmable potentiometer in an application circuit.

AND8413/D Programmable Analog Functions

This application note provides the analog design engineer with basic reference designs and circuit ideas for controlling the key parameters of analog circuits using digitally programmable potentiometers connected to a computer bus or microcontroller.

AND8417/D Push Button Control of Digitally Programmable Potentiometers with an Increment/Decrement Interface

This application note discusses the push button control of DPP which has an increment/decrement interface in applications where there is no embedded processor.

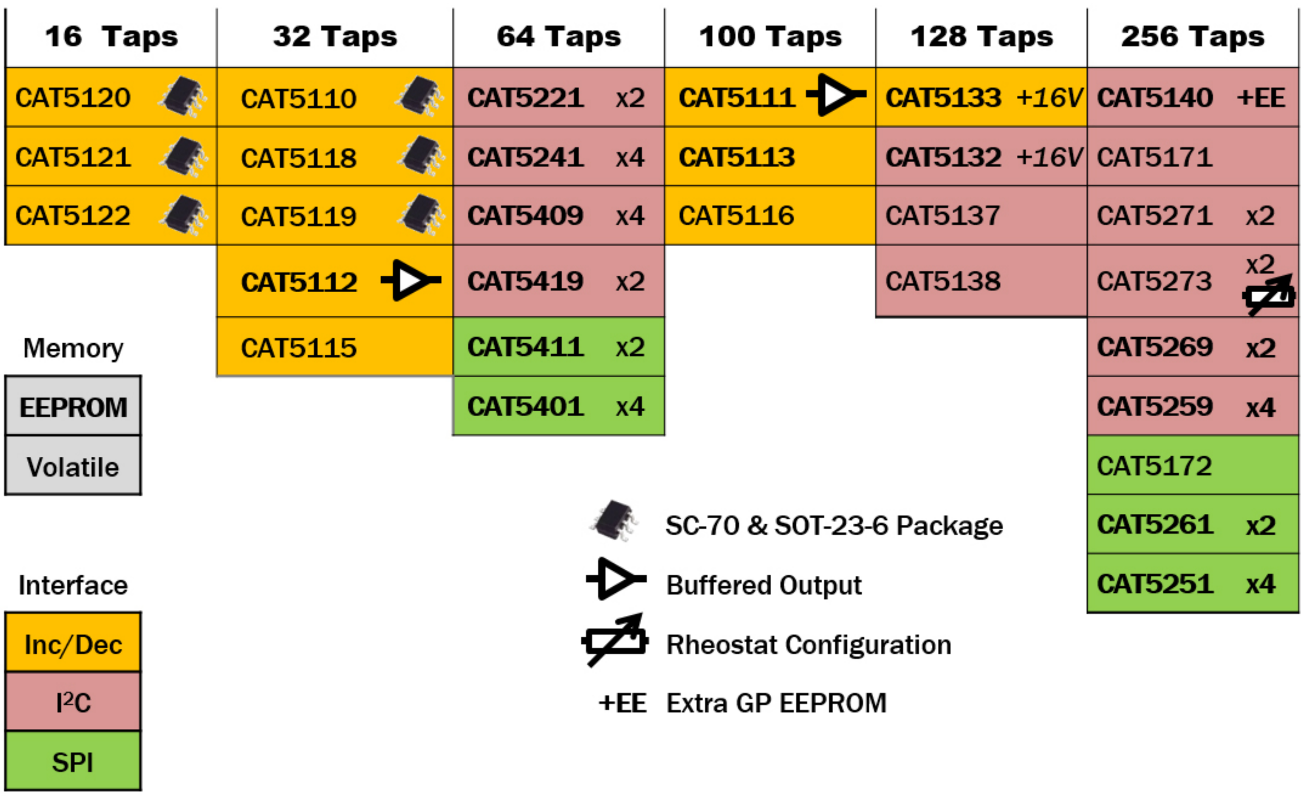
AND8416/D The CAT5132 Used for V_{COM} Buffer Control in a TFT LCD Display

The CAT5132 is a 7 bit (128 positions) DPP with a nonvolatile memory and capable of resistor terminal voltages as high as 16 V. It maintains the simplicity of the mechanical potentiometer solution while providing the versatility and reliability of the DAC solution at a much lower cost.

Product Portfolio

ON Semiconductor’s offers a broad portfolio of digitally programmable potentiometers:

- Resolution: 16 to 256 taps (4 to 8−bit)
- Resistance (full scale): 2.5 kΩ to 100 kΩ
- Log or Linear
- Memory Types:
    - Volatile
    - Non−volatile
- Resistor Network Configuration:
    - Potentiometer (resistive divider)
    - Rheostat (variable resistance)
- Control Interface:
    - UP−DOWN
    - I²C
    - SPI
- Single, dual, quad potentiometer options



Product	# of Pots	# of Taps	Type	Control Interface	End−to−End Resistance (kΩ)	Wiper Position Memory
CAT5111	1	100	Potentiometer	Up/Down	10, 50, 100	Yes
CAT5113	1	100	Potentiometer	Up/Down	1, 10, 50, 100	Yes
CAT5116	1	100	Potentiometer	Up/Down	32	Yes
CAT5110	1	32	Potentiometer	Up/Down	10, 50, 100	No
CAT5112	1	32	Potentiometer	Up/Down	10, 50, 100	Yes
CAT5114	1	32	Potentiometer	Up/Down	10, 50, 100	Yes
CAT5115	1	32	Potentiometer	Up/Down	10, 50, 100	No
CAT5118	1	32	Rheostat	Up/Down	10, 50, 100	No
CAT5119	1	32	Rheostat	Up/Down	10, 50, 100	No
CAT5123	1	32	Rheostat	Up/Down	10	No
CAT5124	1	32	Rheostat	Up/Down	50	No
CAT5125	1	32	Rheostat	Up/Down	10	No
CAT5126	1	32	Potentiometer	Up/Down	10	OTP
CAT5127	1	32	Rheostat	Up/Down	10	Yes
CAT5128	1	32	Potentiometer	Up/Down	10, 50	No
CAT5129	1	32	Rheostat	Up/Down	10	Yes
CAT5120	1	16	Potentiometer	Up/Down	10, 50	No

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