TND6010/D
Rev. 0, AUG − 2011

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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.

Digitally Programmable Potentiometers (DPP)

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 electronic 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 electronic potentiometer are R_L, R_H, and R_W.

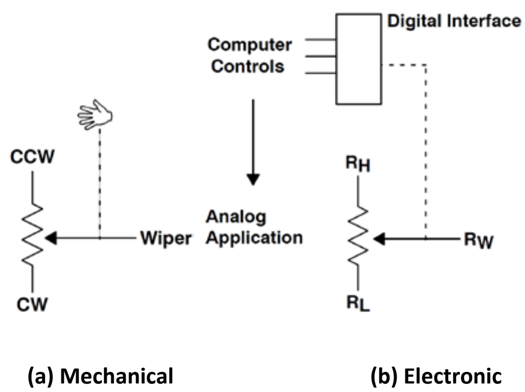


Figure 1. Potentiometers

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.

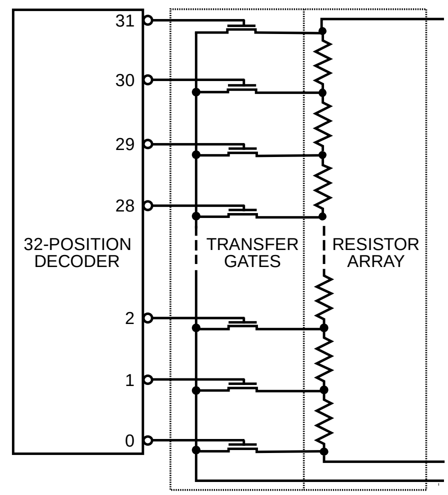


Figure 2. Example of digital potentiometer architecture

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

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 electronic 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.

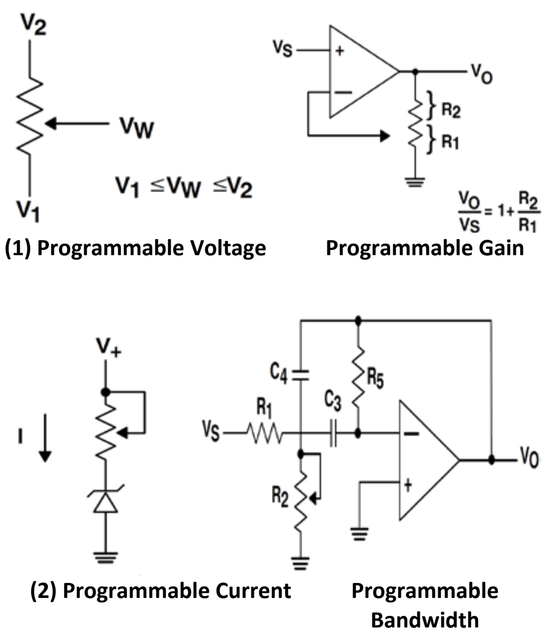


Figure 3. Basic Potentiometer Applications

DPP Memory Types

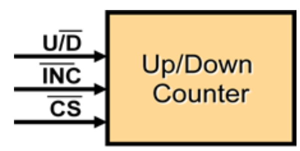
Depending on their type of memory, there are volatile DPP and non-volatile DPP, providing the designer with the possibility of choosing the most suitable solution for a specific application.
The volatile DPP resets the wiper at mid-scale on power-on. Although they don't have internal non-volatile storage, 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

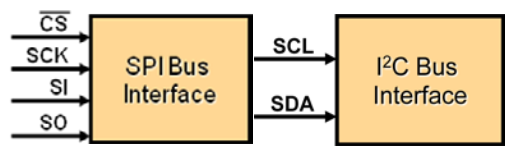
Most electronic potentiometers are controlled through a serial bus. There are, however, a few potentiometers designed to be controlled by control logic or front panel switches. The serial buses can be asynchronous or synchronous.

The most common asynchronous bus is the increment/decrement interface:



- U/D̄ – pin sets direction (up or down)
- $\overline{\text{INC}}$ – pin increments wiper

The most common synchronous buses are SPI and I²C.



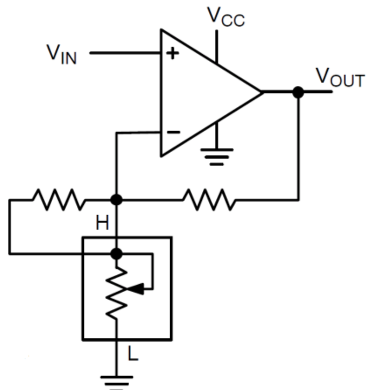
The typical synchronous serial interface signals are:

- clock, called SCL or SCK
- a bidirectional data line SDA or separate input/output data lines, SO and SI
- chip select $\overline{\text{CS}}$
- one or more address lines, ADDRx.

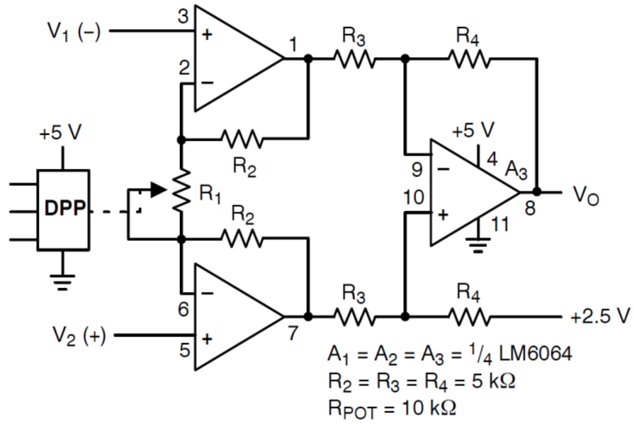
The clock, data, and address signals along with a protocol move information in and out of the DPP.

Application circuits

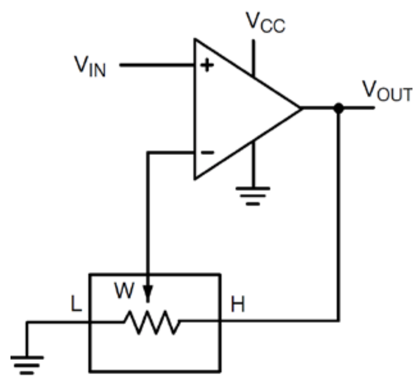
1) Adjustable Gain Circuit with Rheostat



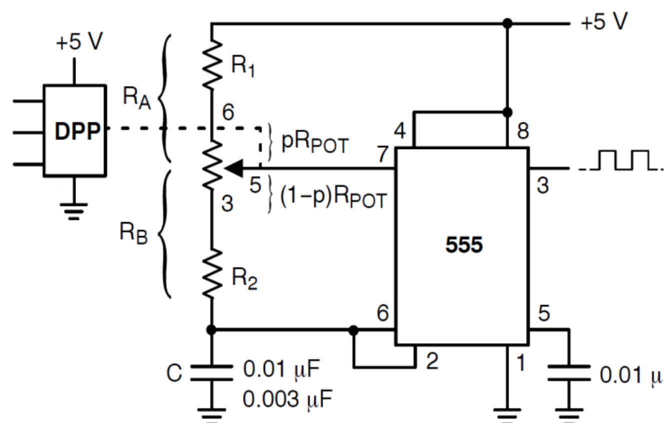
4) Programmable Instrumentation Amplifier



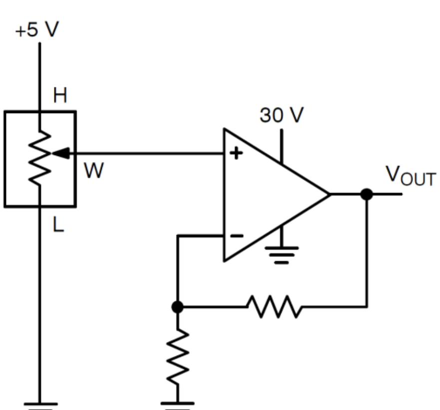
2) Adjustable Gain Circuit with Voltage Divider



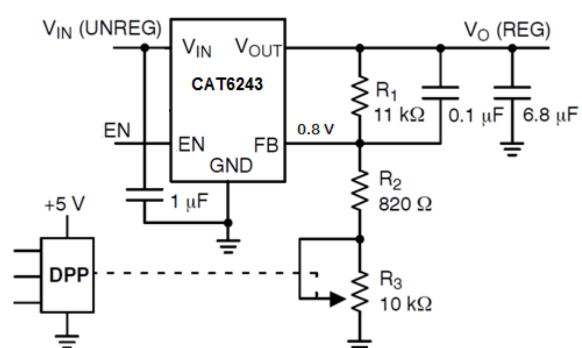
5) Programmable Square Wave Oscillator (555)



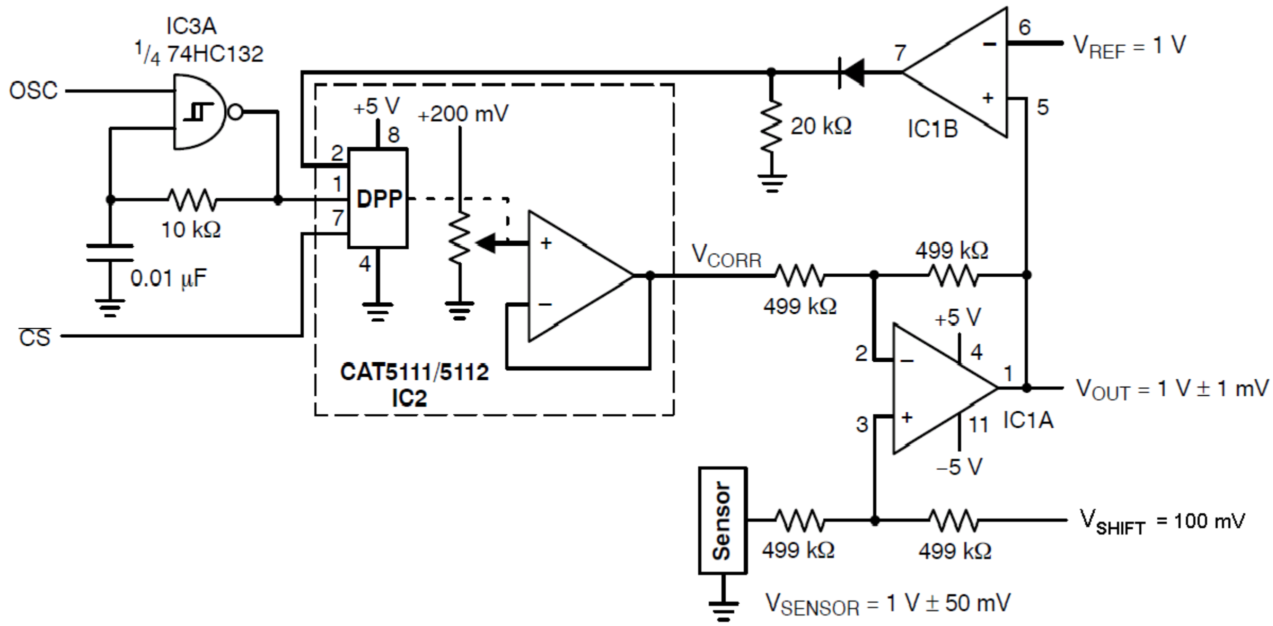
3) Positive LCD Bias Control



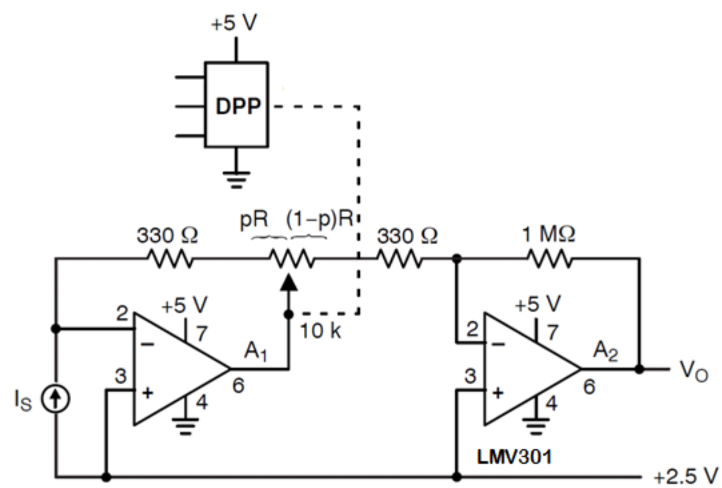
6) Programmable Voltage Regulator



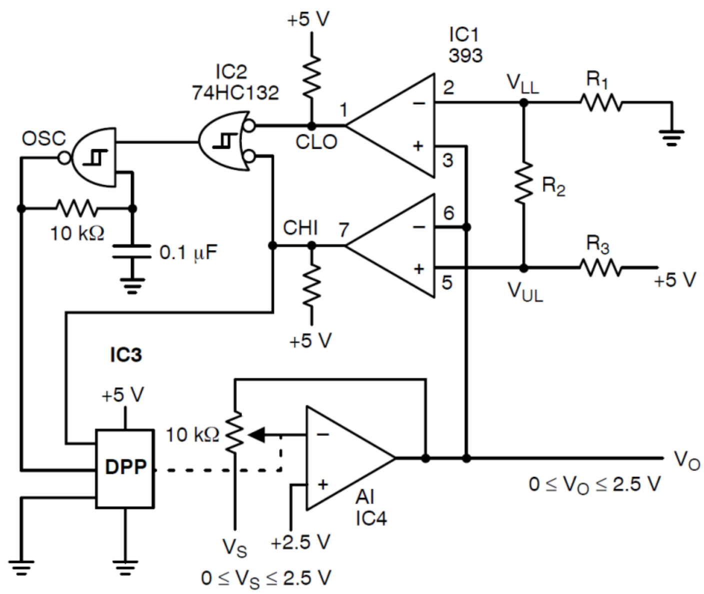
7) Sensor Auto Referencing Circuit



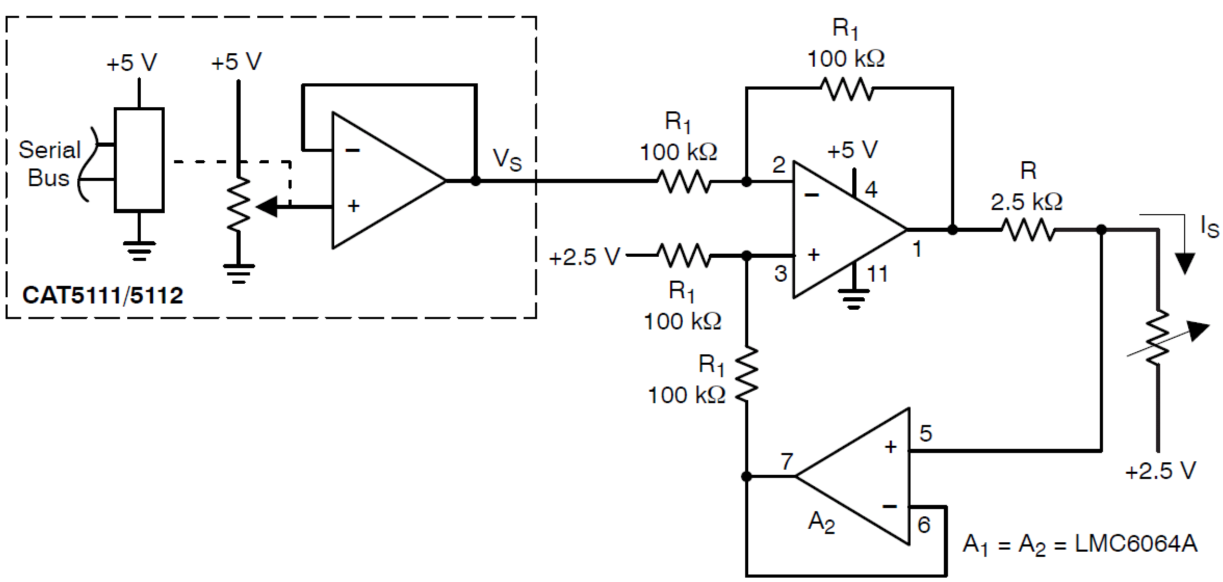
8) Programmable I to V Converter



9) Automatic Gain Control



10) 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
  - OTP
- Resistor Network Configuration:
  - Potentiometer (resistive divider)
  - Rheostat (variable resistance)
- Control Interface:
  - UP-DOWN
  - I^2C
  - SPI
- Single, dual, quad potentiometer options

Product	# of Pots	# of Taps	Type	Control Interface	End-to-End Resistance (kΩ)	Wiper Position Memory
CAT5259	4	256	Potentiometer	I2C	50, 100	Yes
CAT5251	4	256	Potentiometer	SPI	50, 100	Yes
CAT5241	4	64	Potentiometer	I2C	2.5, 10, 50, 100	Yes
CAT5409	4	64	Potentiometer	I2C	2.5, 10, 50, 100	Yes
CAT5401	4	64	Potentiometer	SPI	2.5, 10, 50, 100	Yes
CAT5269	2	256	Potentiometer	I2C	10, 50, 100	Yes
CAT5271	2	256	Potentiometer	I2C	50, 100	No
CAT5273	2	256	Rheostat	I2C	50	No
CAT5261	2	256	Potentiometer	SPI	50, 100	Yes
CAT5221	2	64	Potentiometer	I2C	2.5, 10, 50, 100	Yes
CAT5419	2	64	Potentiometer	I2C	2.5, 10, 50, 100	Yes
CAT5411	2	64	Potentiometer	SPI	2.5, 10, 50, 100	Yes
CAT5140	1	256	Potentiometer	I2C	50, 100	Yes
CAT5171	1	256	Potentiometer	I2C	50, 100	No
CAT5172	1	256	Potentiometer	SPI	50	No
CAT5132	1	128	Potentiometer	I2C	10, 50, 100	Yes
CAT5133	1	128	Potentiometer	Up/Down	10	Yes

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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