

General Digitally Controlled Potentiometers

This application note provides a better understanding of how Digitally Controlled Potentiometers (DCPs) operate and their application solutions.

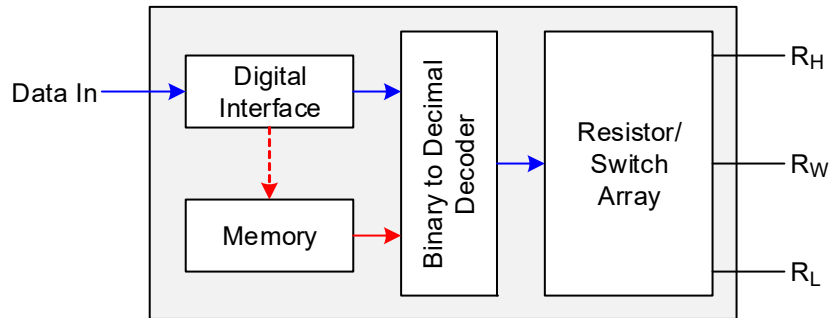


Figure 1. Block Diagram of Non-Volatile DCP

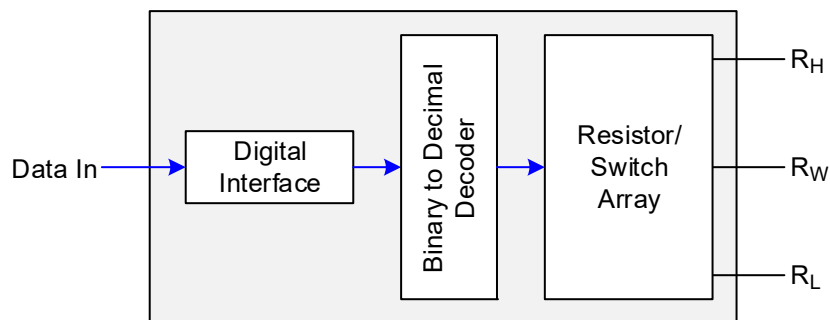


Figure 2. Block Diagram of Volatile DCP

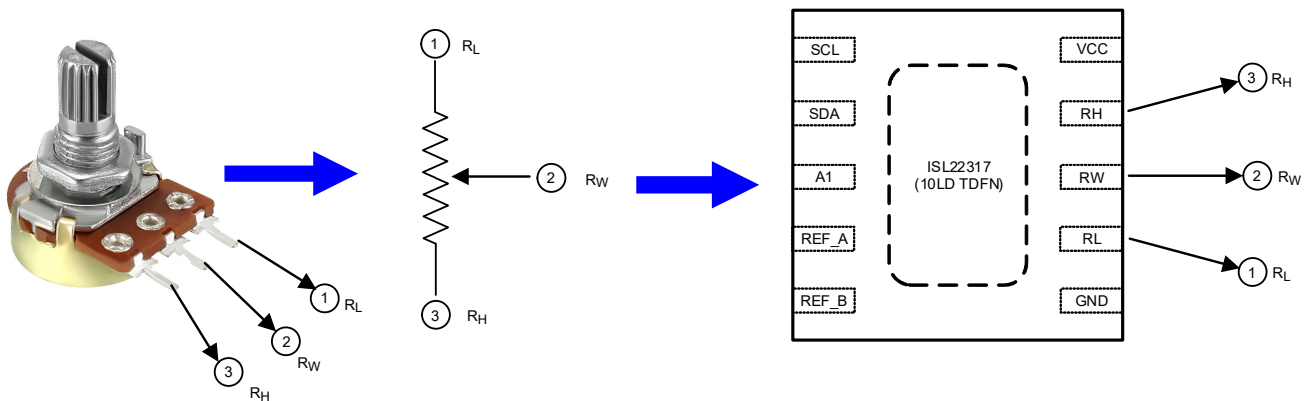
Contents

- 1. Overview ..... 2
- 2. Operation ..... 3
- 3. Setting Up Resistance ..... 4
  - 3.1 Potentiometer Configuration ..... 4
  - 3.2 Rheostat Configuration ..... 4
- 4. Revision History ..... 5

# 1. Overview

Digitally Controlled Potentiometers (DCPs) brought about a new way to adjust resistance in analog circuitry. Mechanical Potentiometers were replaced by DCPs because of their ability to control resistance digitally using interfaces such as I<sup>2</sup>C, SPI, Pushbutton, 2-wire, and 3-wire (up/down). Unlike mechanical potentiometers where resistance is set by hand or a tool, the resistance of a DCP is communicated by an interface. This interface receives a value that is translated by the decoder from a binary to a decimal number, which sets the wiper into a corresponding position.

Internally, DCPs consist of a serial string of resistors and CMOS transistor switches (taps). The number of taps is important in choosing which DCP to use in application. Tap positions range from 32, 64, 100, 128, and 256. A higher number of taps increases the ability to fine-tune the resistance of the DCP. The physical upper and lower ends of the DCP ( $R_H$  and  $R_L$ ) are the same as the fixed terminals in mechanical potentiometers. Similarly, the wiper terminal  $R_W$  of the DCP is the same as the wiper position in mechanical potentiometers. The  $R_{TOTAL}$  is the total resistance that is measured between  $V_H/R_H$  and  $V_L/R_L$ . DCPs can be differentiated from one another based on the maximum value of the total resistance, which can range from 1k $\Omega$ , 2k $\Omega$ , 10k $\Omega$ , 50k $\Omega$ , or 100k $\Omega$ .



**Figure 3. Potentiometer Terminal Assignments**

The DCP tap position is controlled by the wiper register, which can have volatile or non-volatile memory. DCPs are seeing wide usage in applications today because of their ability to fine-tune the tap setting for higher accuracy and precision than a mechanical potentiometer, in addition to being much more robust because there is no degrading of the resistive film.

## 2. Operation

DCPs operate the same way as mechanical potentiometers, except there is no screw or knob to twist for a change in resistance. Instead, a DCP's resistance is changed by a digital interface, which increases or decreases the tap position that determines the resistance of the DCP.

To change the tap position, the user provides an input value, which is then stored in the wiper register. The value goes through a binary-to-decimal decoder, which converts the address into a logic high state that closes the corresponding transistor switch. This is the wiper position,  $R_W$ .

For DCPs that have volatile wiper registers, after power cycling, the tap resets to a default position, which is usually the center of the resistor array, ideally giving  $\frac{1}{2}$  of  $R_{TOTAL}$ . For DCPs that have non-volatile (EEPROM) wiper registers, after power cycling, the previous tap position is retained.

The tap positioning happens in the Resistor/Switch Array block, which is made up of a resistor ladder and their corresponding transistor switches (taps) that are at the junction of each resistor. The wiper is a common node to all resistors. The  $R_{TOTAL}$  is the sum of the resistor array and gives you the total resistance of the DCP. Resistance is measured from the rail terminals ( $R_H$  and  $R_L$ ) regarding  $R_W$ . The first tap ( $Tap_0$ ) position has ideally a resistance of  $0\Omega$ , and the last ( $Tap_{n-1}$ ) of  $R_{TOTAL}$ .

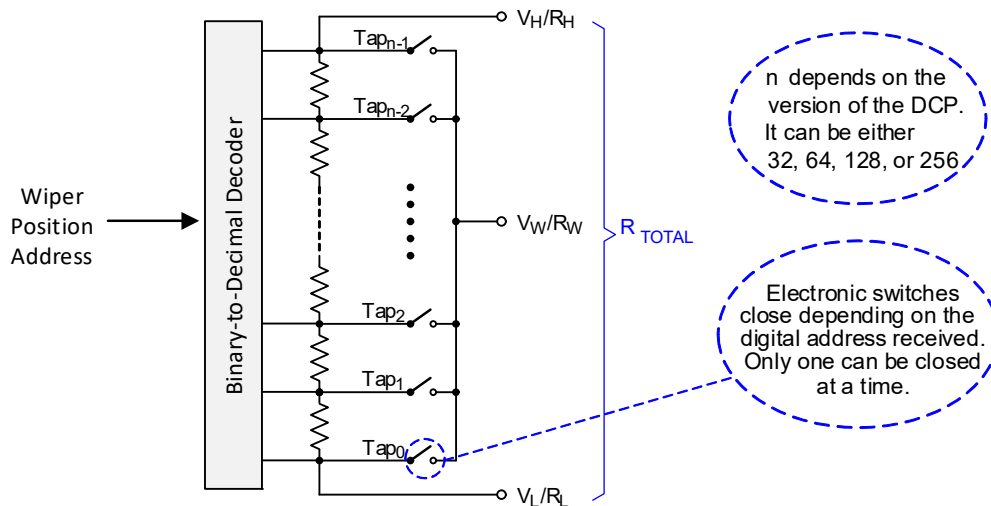


Figure 4. Switching Array with Resistor Ladder

### 3. Setting Up Resistance

The resistance of the DCP can be set up in two ways, Potentiometer and Rheostat configuration.

#### 3.1 Potentiometer Configuration

DCPs connected in a Potentiometer configuration or voltage divider mode use all three terminals. The resistance between  $R_H$  and  $R_W$ , and between  $R_W$  and  $R_L$  can be viewed as two resistors in series. Therefore, a change in  $R_W$  determines the ratio between these two resistors. If the output voltage is measured across  $R_{RW-RL}$ , and a reference voltage is applied to  $V_H/R_H$ , the resistors in the voltage divider configuration have a scale factor (SF) that is determined by using Equation 1:

$$(EQ. 1) \quad SF = \frac{R_{RW-RL}}{R_{RH-RW} + R_{RW-RL}}$$

Scaling down the reference voltage by the scaling factor, the output voltage across the  $R_{RW-RL}$  is determined by using Equation 2:

$$(EQ. 2) \quad V_{OUT} = \frac{R_{RW-RL}}{R_{RH-RW} + R_{RW-RL}} \cdot V_{REF}$$

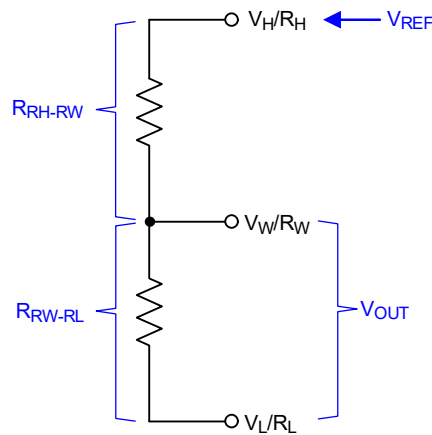


Figure 5. Potentiometer Configuration

#### 3.2 Rheostat Configuration

DCPs configured in Rheostat mode, or as single variable resistor, have one of the end terminals tied to the wiper. For example,  $R_W$  is tied to  $R_L$ . The output resistance ( $R_{OUT}$ ) in this configuration can be measured from  $R_H$  to  $R_W$  and is determined by the position of the wiper. It is also determined by the following equations:

$$R_{OUT} = R_{RW-RW}$$

$$R_{TOTAL} = R_{RW-RW} + R_{RW-RL}$$

$$R_{OUT} = R_{TOTAL} - R_{RW-RL}$$

Figure 6 demonstrates the best way of setting up the DCP. If the electronic switch loses contact,  $R_W$  being tied to  $R_L$  prevents the total resistance from spiking to infinity.

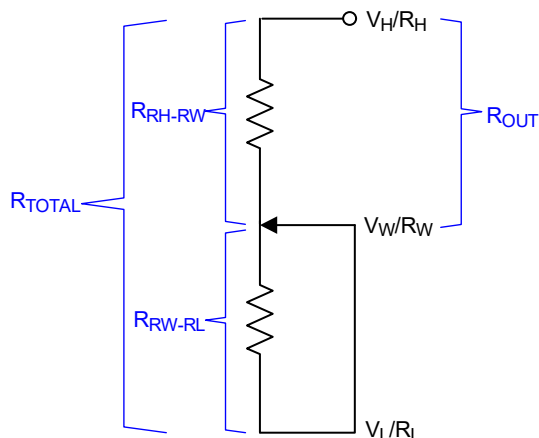


Figure 6. Rheostat Configuration

## 4. Revision History

Revision	Date	Description
1.00	Jul 5, 2022	Initial release.

## IMPORTANT NOTICE AND DISCLAIMER

RENESAS ELECTRONICS CORPORATION AND ITS SUBSIDIARIES (“RENESAS”) PROVIDES TECHNICAL SPECIFICATIONS AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS OR IMPLIED, INCLUDING, WITHOUT LIMITATION, ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for developers skilled in the art designing with Renesas products. You are solely responsible for (1) selecting the appropriate products for your application, (2) designing, validating, and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. Renesas grants you permission to use these resources only for development of an application that uses Renesas products. Other reproduction or use of these resources is strictly prohibited. No license is granted to any other Renesas intellectual property or to any third party intellectual property. Renesas disclaims responsibility for, and you will fully indemnify Renesas and its representatives against, any claims, damages, costs, losses, or liabilities arising out of your use of these resources. Renesas' products are provided only subject to Renesas' Terms and Conditions of Sale or other applicable terms agreed to in writing. No use of any Renesas resources expands or otherwise alters any applicable warranties or warranty disclaimers for these products.

(Rev.1.0 Mar 2020)

### Corporate Headquarters

TOYOSU FORESIA, 3-2-24 Toyosu,  
Koto-ku, Tokyo 135-0061, Japan  
[www.renesas.com](http://www.renesas.com)

### Contact Information

For further information on a product, technology, the most up-to-date version of a document, or your nearest sales office, please visit:  
[www.renesas.com/contact/](http://www.renesas.com/contact/)

### Trademarks

Renesas and the Renesas logo are trademarks of Renesas Electronics Corporation. All trademarks and registered trademarks are the property of their respective owners.