General Digitally Controlled Potentiometers

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

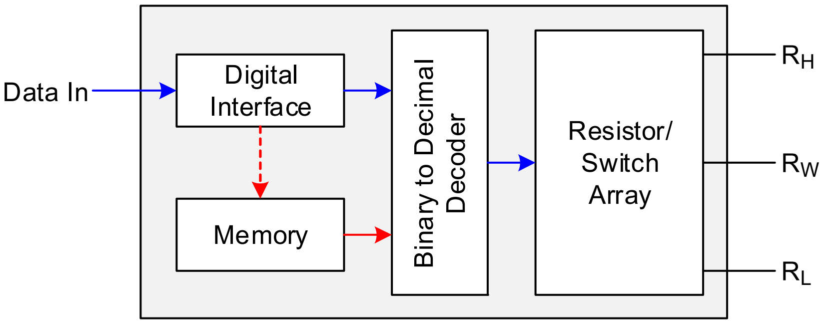

Figure 1. Block Diagram of Non-Volatile DCP

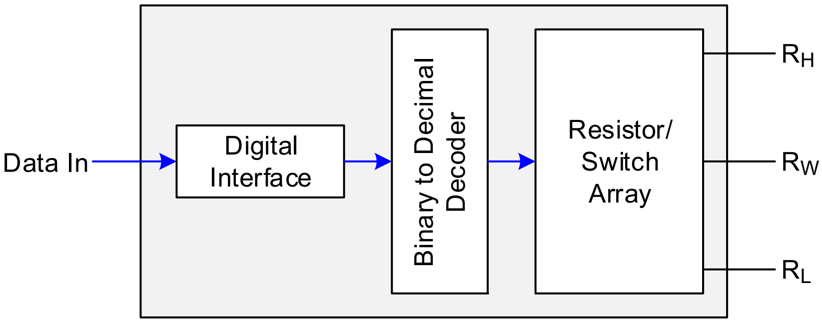

Figure 2. Block Diagram of Volatile DCP

Contents

1. Overview

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^2C, 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 1kΩ, 2kΩ, 10kΩ, 50kΩ, or 100kΩ.

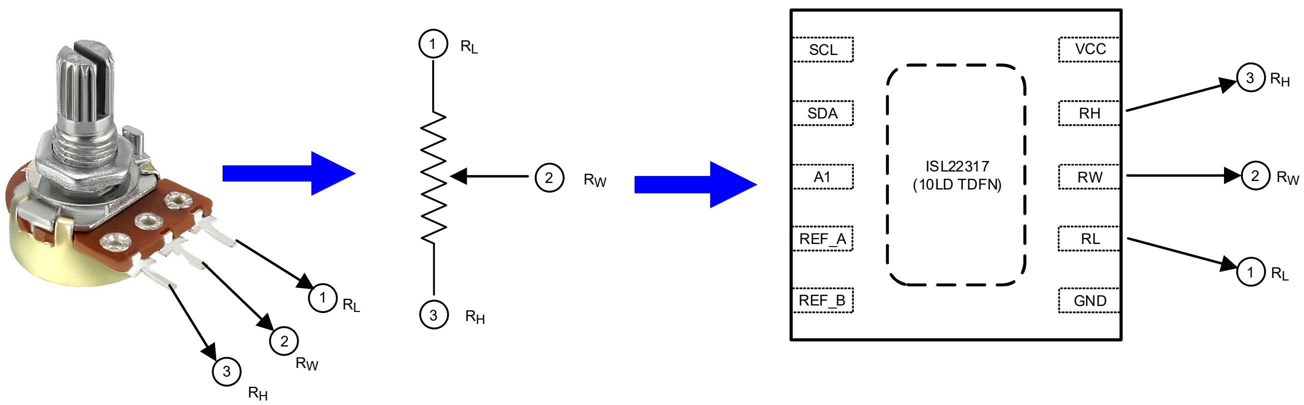

Figure 3. Potentiometer Terminal Assignments

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 nob to twist for a change in resistance. Instead, a DCPs 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 ½ 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 0Ω, and the last (Tap_{n-1}) of R_{TOTAL}.

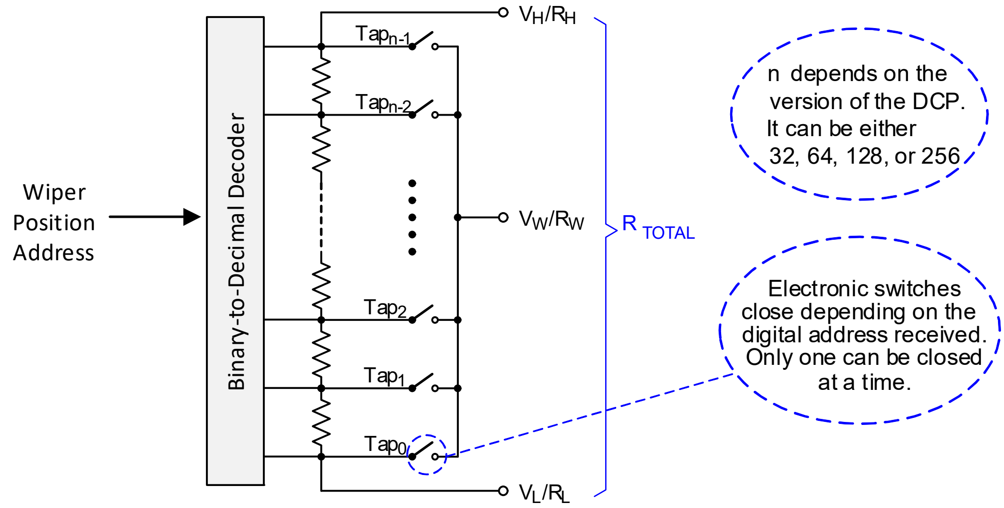

Figure 4. Switching Array with Resistor Ladder

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 $R_{RW\text{-}RL}$, 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) $$SF = \frac{R_{RW\text{-}RL}}{R_{RH\text{-}RW} + R_{RW\text{-}RL}}$$

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

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

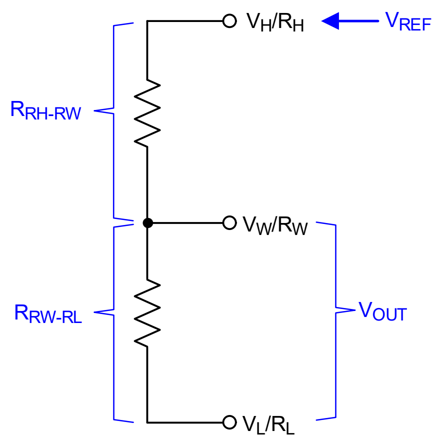

Figure 5. Potentiometer Configuration

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:

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

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

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

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.

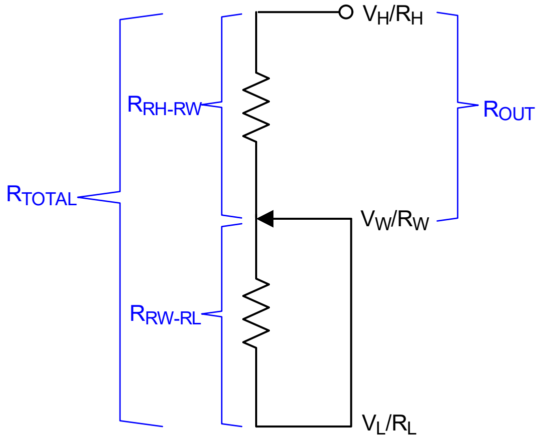

Figure 6. Rheostat Configuration

4. Revision History

Revision	Date	Description
1.00	Jul 5, 2022	Initial release.

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