11065 DGP

Hands-on with Digital Potentiometers

Class Objective

- **When you finish this class you will:**
  - Understand the Operation of a Digital Potentiometer
  - Understand how the Characteristics of a Digital Potentiometer’s Resistor Network are affected in your application circuit
  - Know some of the applications that are a good fit for Digital Potentiometers

Agenda

- Discussion of Digital Potentiometers
- The Resistor Network
- The Tools
(Evaluation Board, PICkit™ Serial ,
DMM, Oscilloscope, Power Supply, …)
- Labs
- Summary

Why Use a Digital Potentiometer?

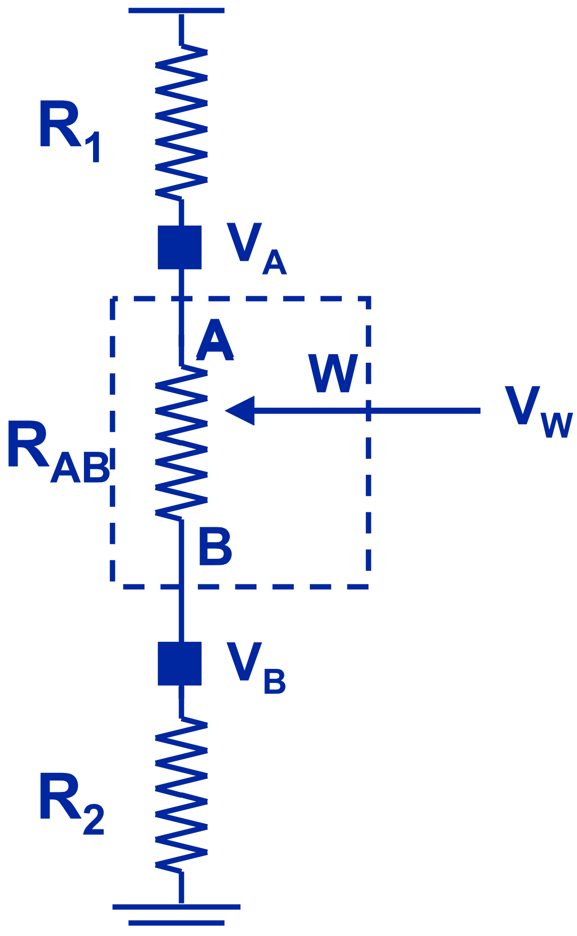
- **Why would one use a Digital Potentiometer?**
  - Replacement of Mechanical Pots
  - Calibration of “other” device/circuits
  - “Real time” tuning of analog circuits
  - Programmable reference voltage
  - Programmable current limiter

Replacement of Mechanical Pots

- Mechanical Pots are used to set voltage thresholds and to tune circuit operation
- Digital Potentiometers can replace Mechanical Pots

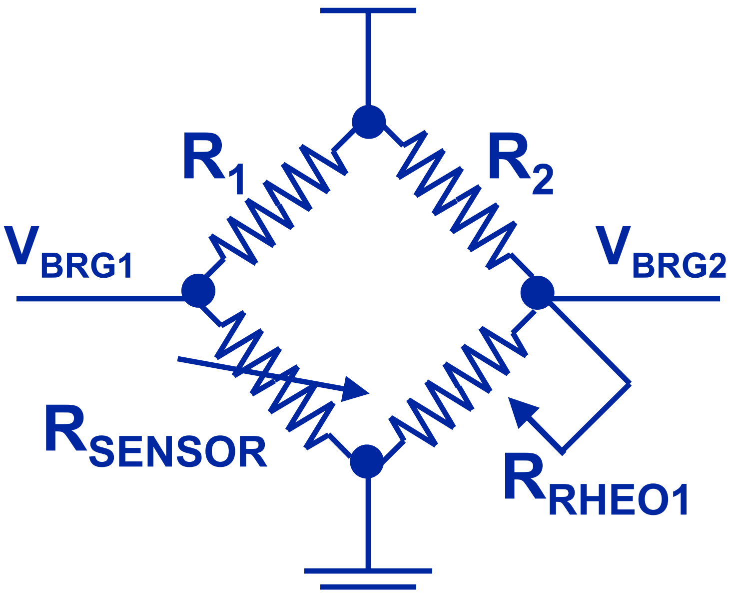
	Digital Potentiometer	Mechanical Potentiometer
Component Cost		✓
Total System Cost	✓	
System Reliability	✓	
Vibration Reliability/Characteristics	✓	
Ease of System Recalibration	✓	

Replacement of Mechanical Pots



- Typically, Mechanical Pots are tuned to a given voltage range
- Digital Pots can be configured to output the desired voltage (P0W)
- Non-Volatile Digital Pots can store this “configured” value
- The use of R1 and R2 may allow a cheaper Digital Pot to be used for the desired resolution

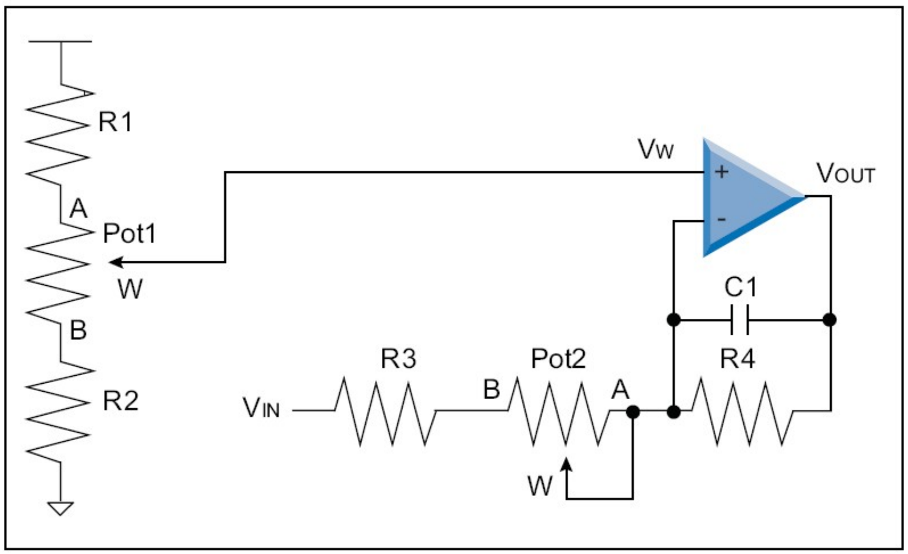
Calibration of “other” device/circuits



- Rheo1 is used to calibrate the sensor in the Wheatstone Bridge
- At the “default” condition, Rheo1 is programmed to balance V_{BRG1} and V_{BRG2}

“Real time” tuning of analog circuits

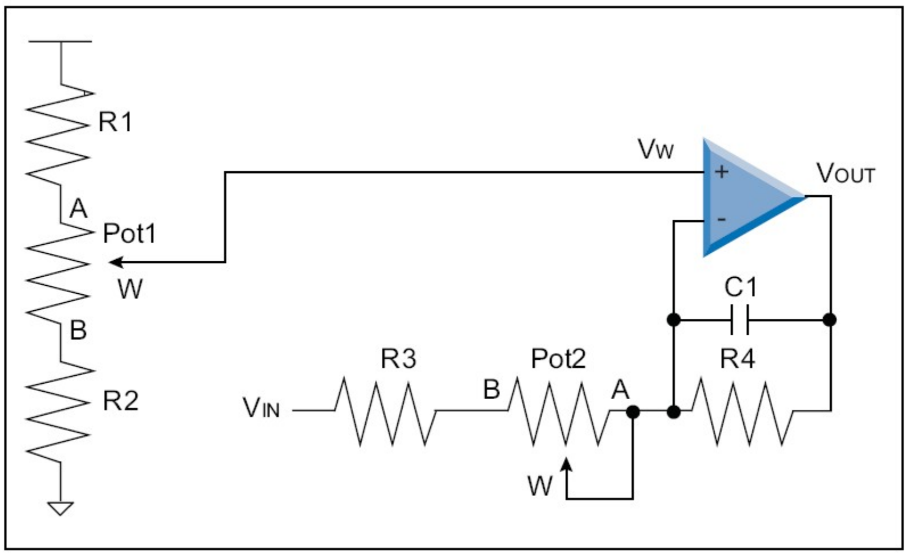
Inverting Amplifier with Offset and Gain Trimming



- Pot1 and Pot2 can be corrected in real time to compensate for changes in temperature and component characteristics over time

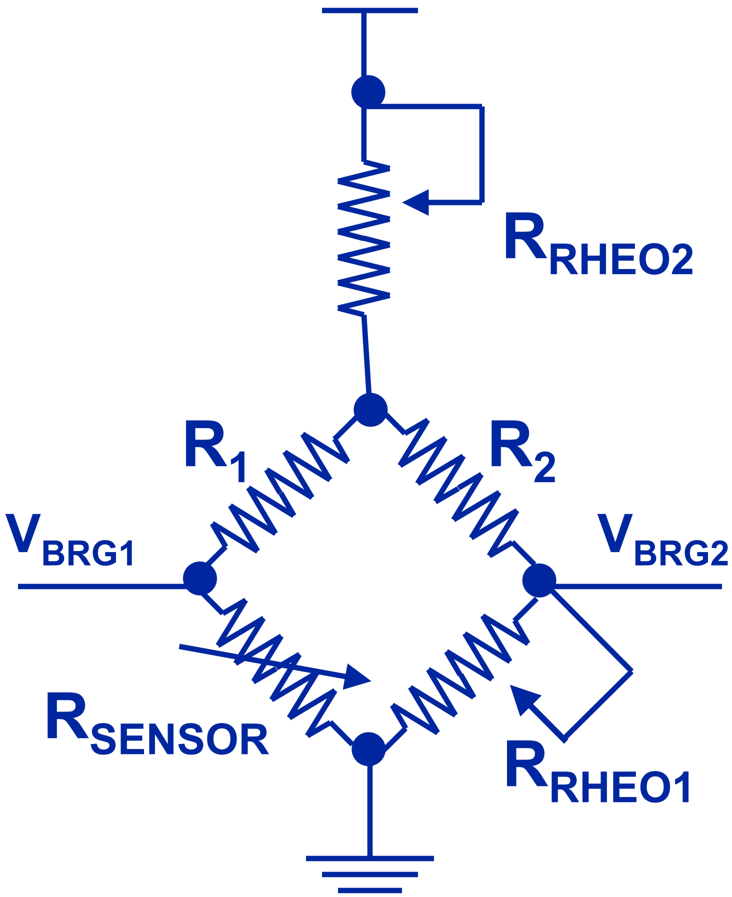
Programmable reference voltage

Inverting Amplifier with Offset and Gain Trimming



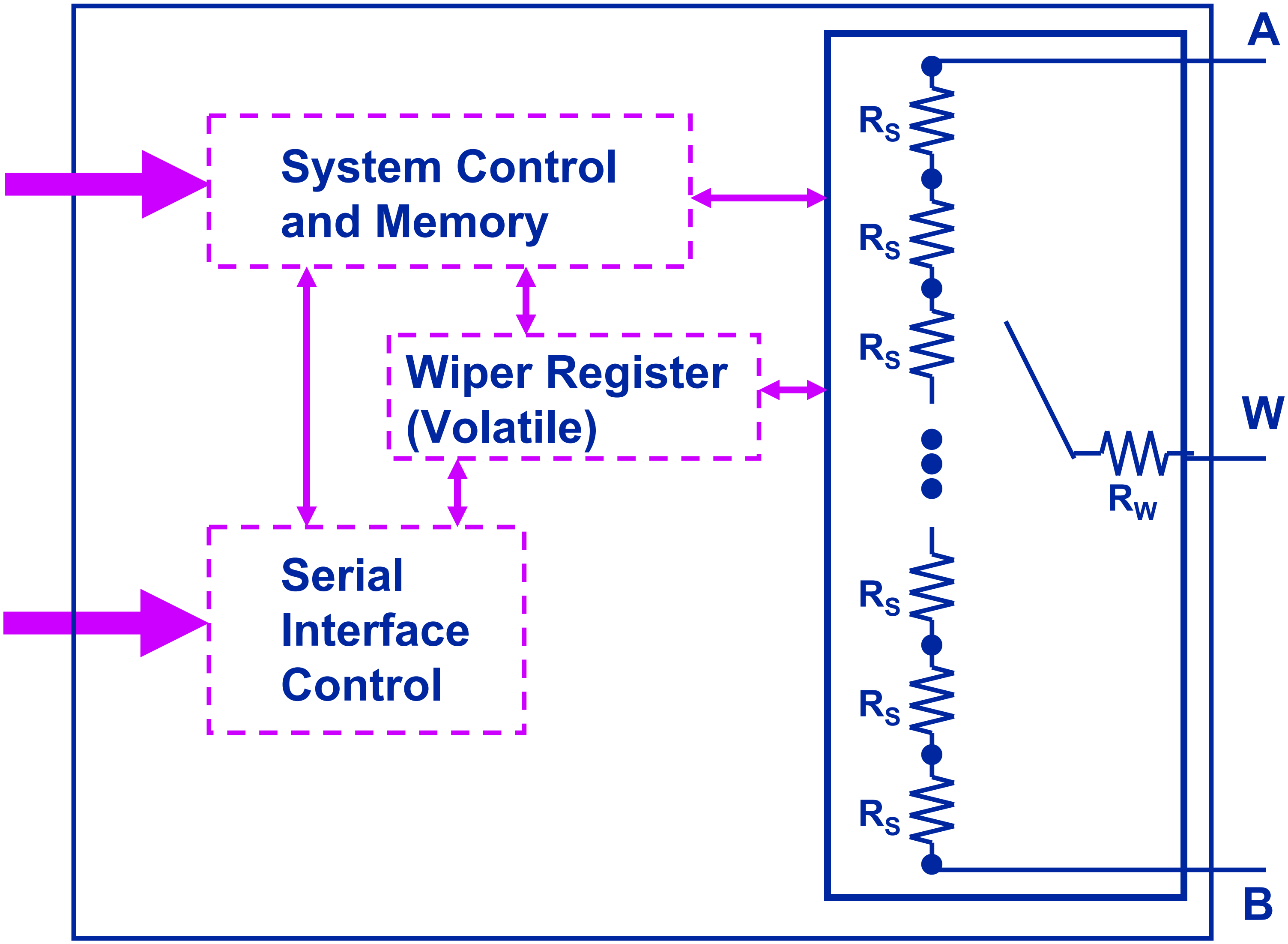
- **Pot1 is used as a programmable voltage reference which sets the offset of the amplifier**

Programmable current limiter



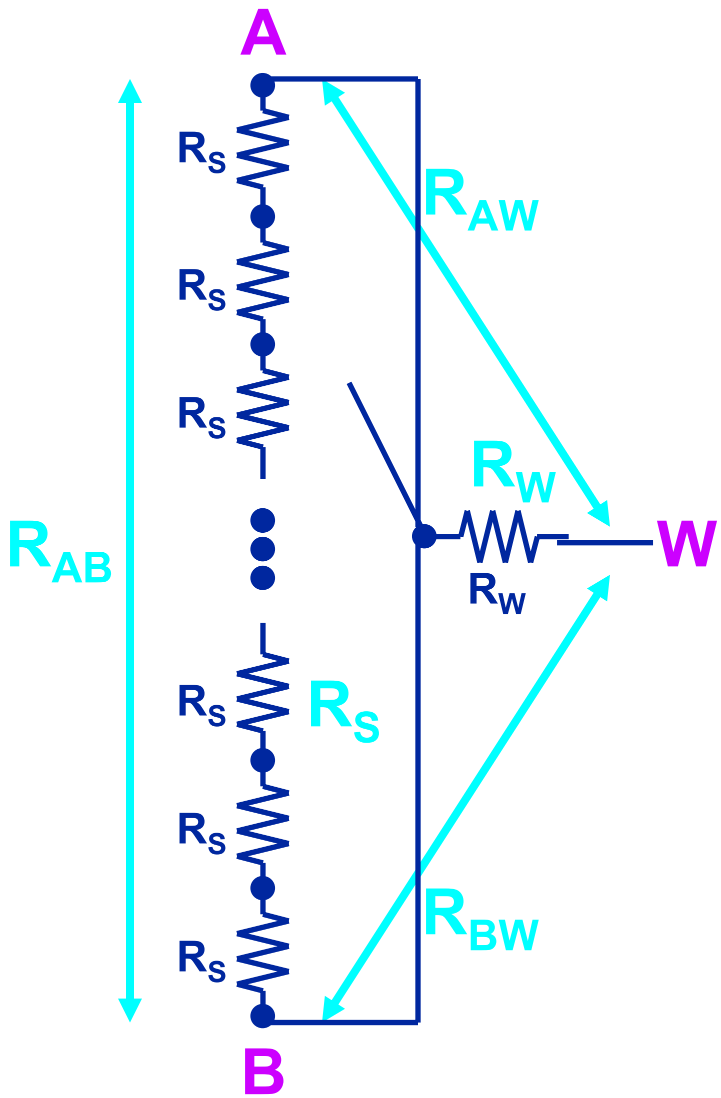
- Rheo2 is used as a programmable current limiter

Digital Potentiometer – Block Diagram



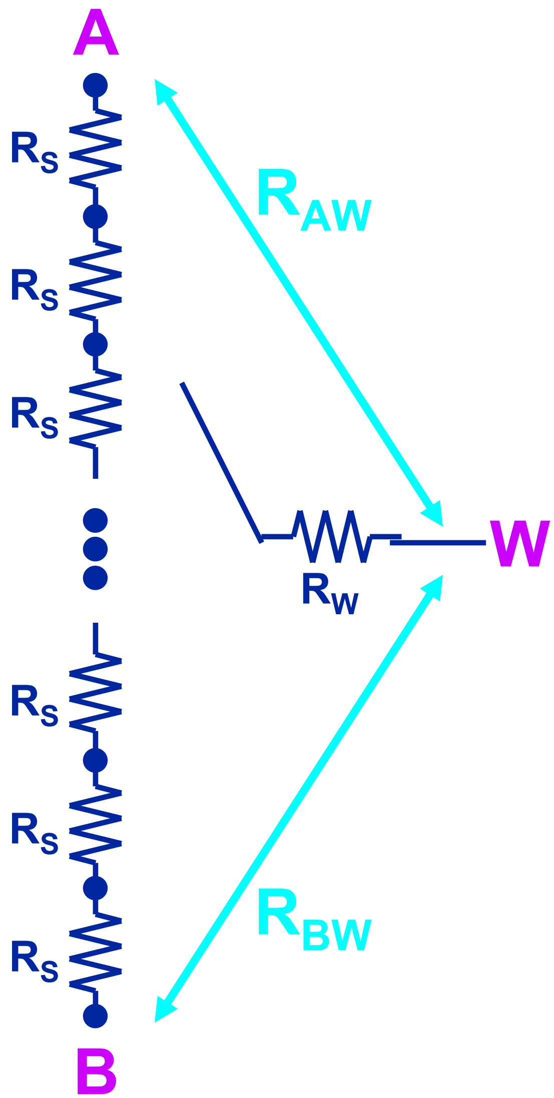
The Resistor Network of the Digital Potentiometer

Digital Potentiometer – Terms



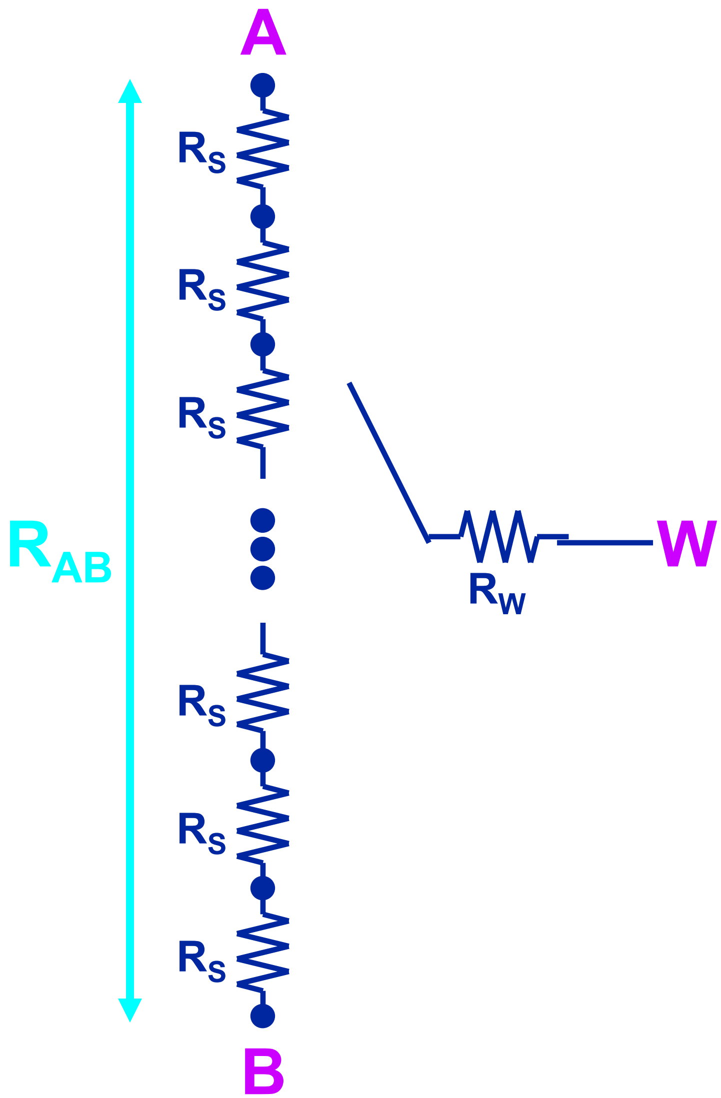
- **Three Terminals A, B, and W**
- R_{AB} is the total resistance Terminal A and Terminal B
- R_S is the Step Resistance
- R_W is the Wiper resistance
- R_{BW} is the total resistance between Terminal B and the Wiper Terminal
- R_{AW} is the total resistance between Terminal A and the Wiper Terminal
- Zero-Scale is when the Wiper Terminal is connected to Terminal B
- Full-Scale is when the Wiper Terminal is connected to Terminal A

Digital Potentiometer – Terms



- **Two Device Configurations:**
  - Potentiometer (Voltage Divider)
  - Rheostat (Variable Resistor)
- **Voltage Divider requires all three Terminals (A, B, and W)**
  - $V_W = (((V_A - V_B) * WREG)/RES) + V_B$
- **Variable Resistor requires only two Terminals (W and either A or B)**
  - $R_{BW} = R_S * WREG + R_W$
  - $R_{AW} = R_S * (RES - WREG) + R_W$

Resistor Network – Step Resistance

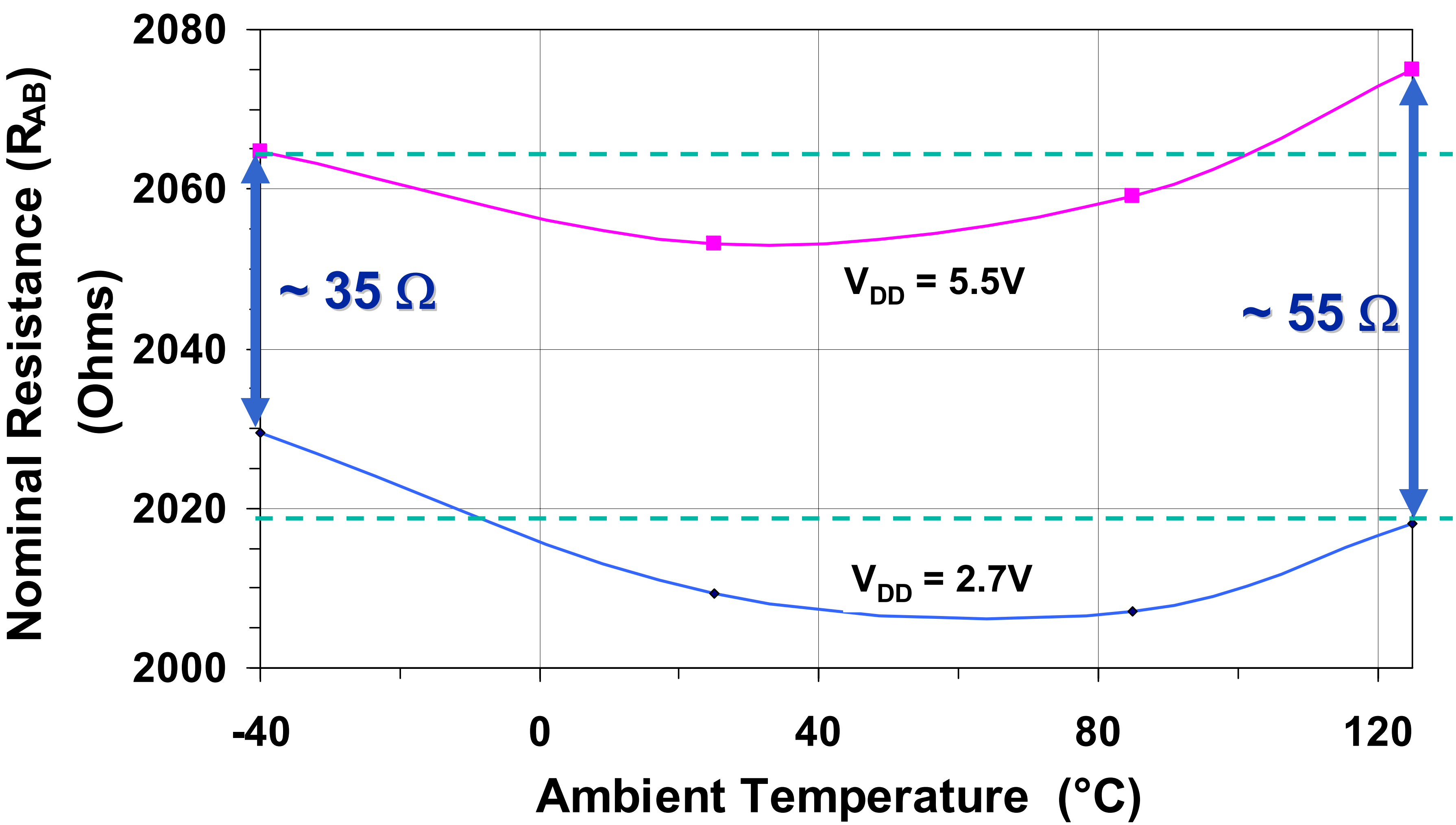


- R_{AB} range is ± 20% of Typical (Over Process)
- R_{AB} (⇨ R_S) resistance has minor variations over voltage and temperature
- The step resistance (R_S) is R_{AB} divided by the number of steps
  - R_S's "track" each other

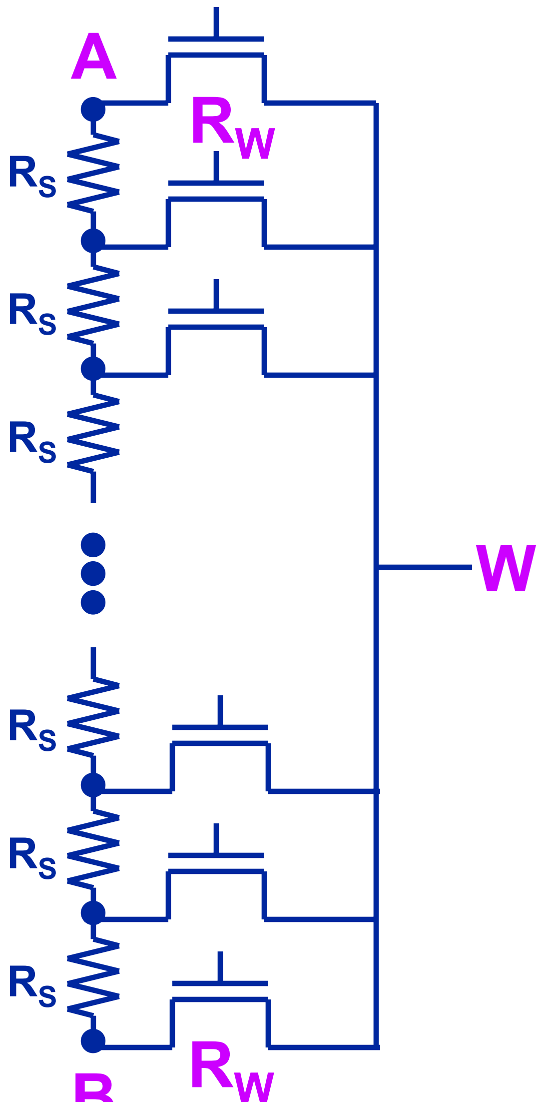
Resistor Network – Dual Potentiometer Devices and R_{AB}

- **Dual Potentiometer Devices have two Independent Potentiometers**
- **It is common to have a specification for the R_{AB} variation between Pot 0 and Pot 1**
  - This variation is typically relatively small, ~1% (for the same conditions)
  - The R_{AB} values will track each other due to changes in supply voltage and temperature

R_{AB} Characteristics - 2.1KΩ

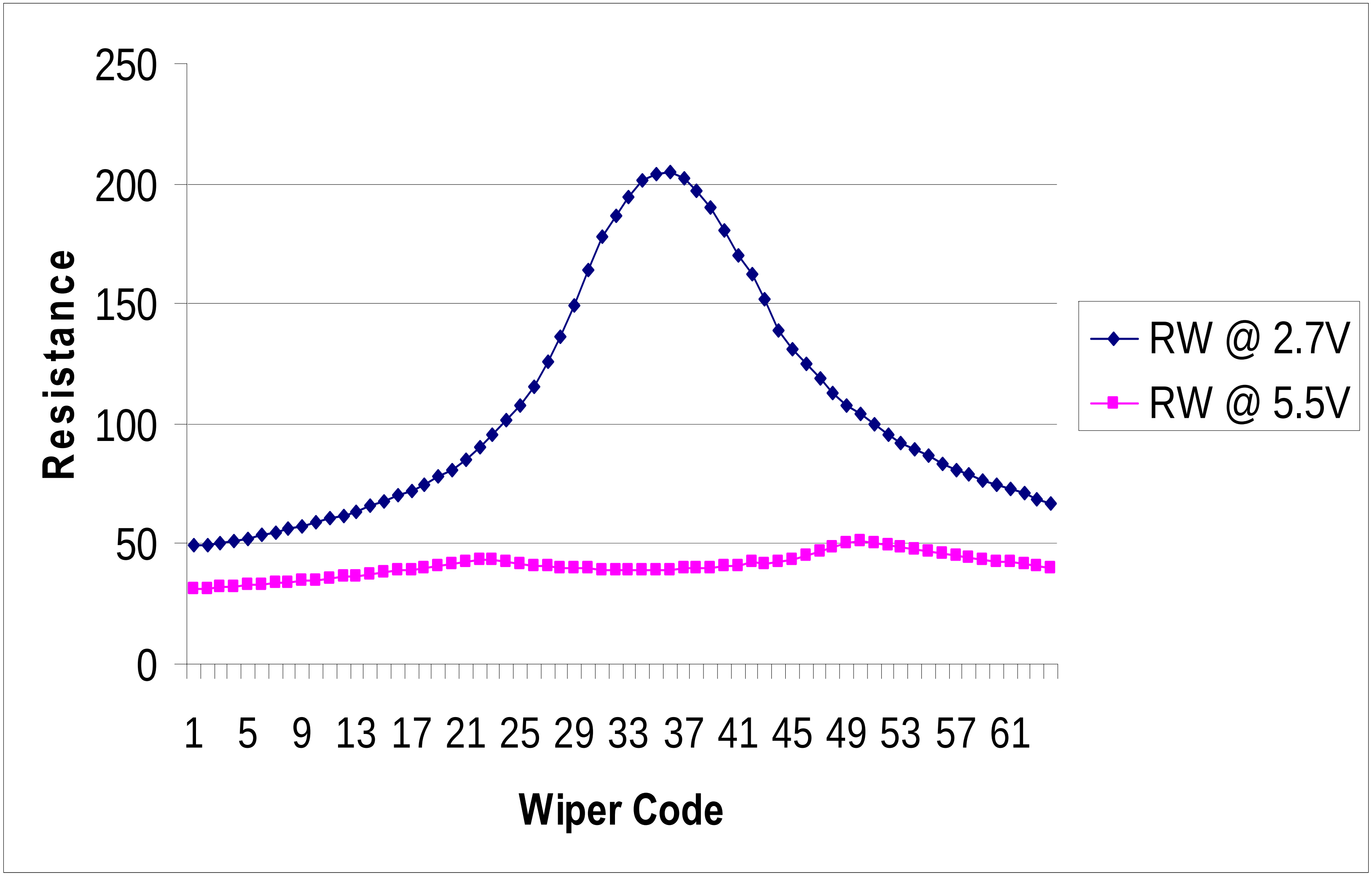


Resistor Network - Wiper

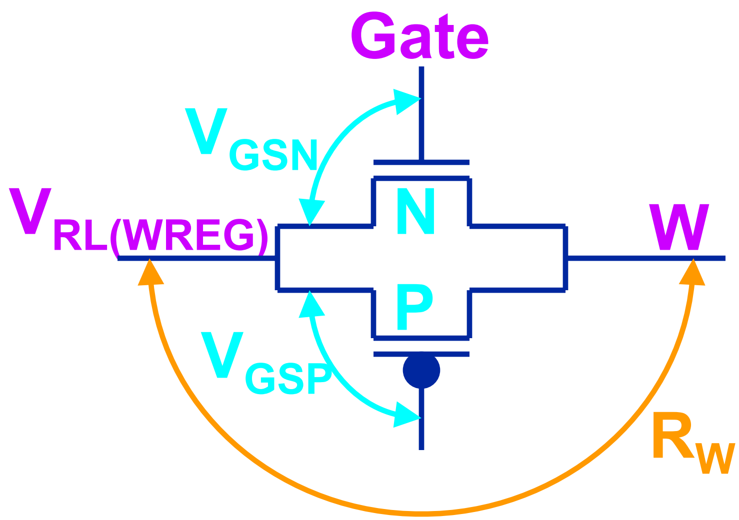


- Wiper can go from Zero-Scale (W=B) to Full-Scale (W=A)
- Wiper Switch resistances (R_W) are "independent" of each other
- R_W has variations over voltage (supply and Terminal) and temperature
  - R_W's "track" each other

R_W Characteristics - 2.1KΩ



The Wiper Switch

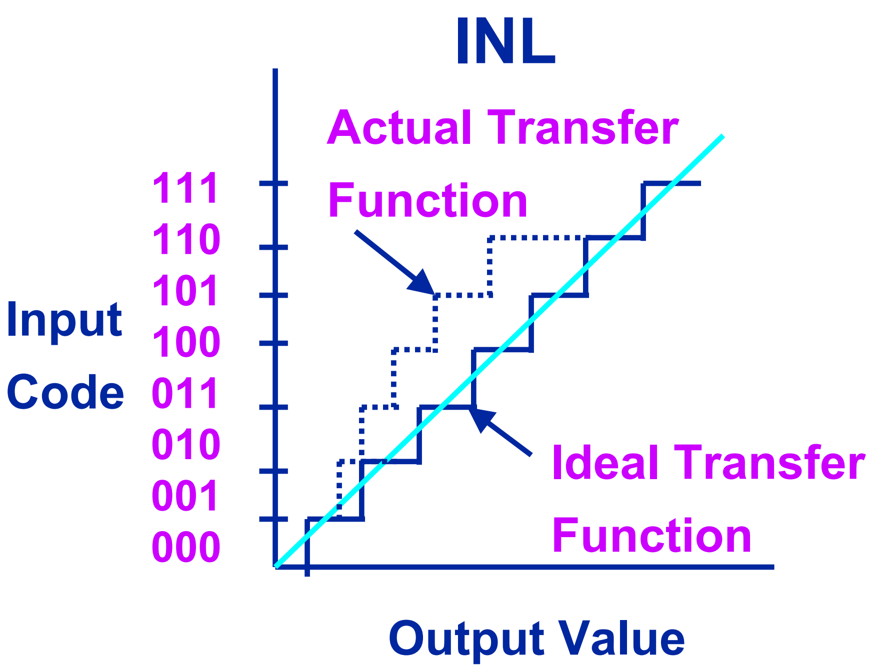


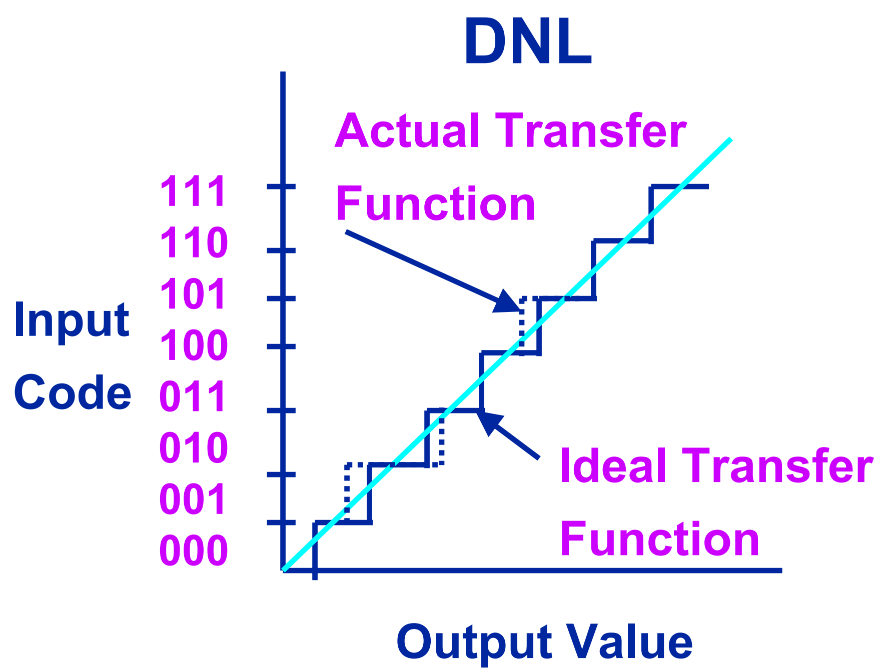
Near Transistor turn-on Threshold (V_T) ⇨ R_W is very high

		V_{DD}					
		5.5V		2.7V		1.8V	
		N	P	N	P	N	P
V_{GS}	FS	0V	5.5V	0V	2.7V	0V	1.8V
	MS	2.75V	2.75V	1.35V	1.35V	0.9V	0.9V
	ZS	5.0V	0V	2.7V	0V	1.8V	0V

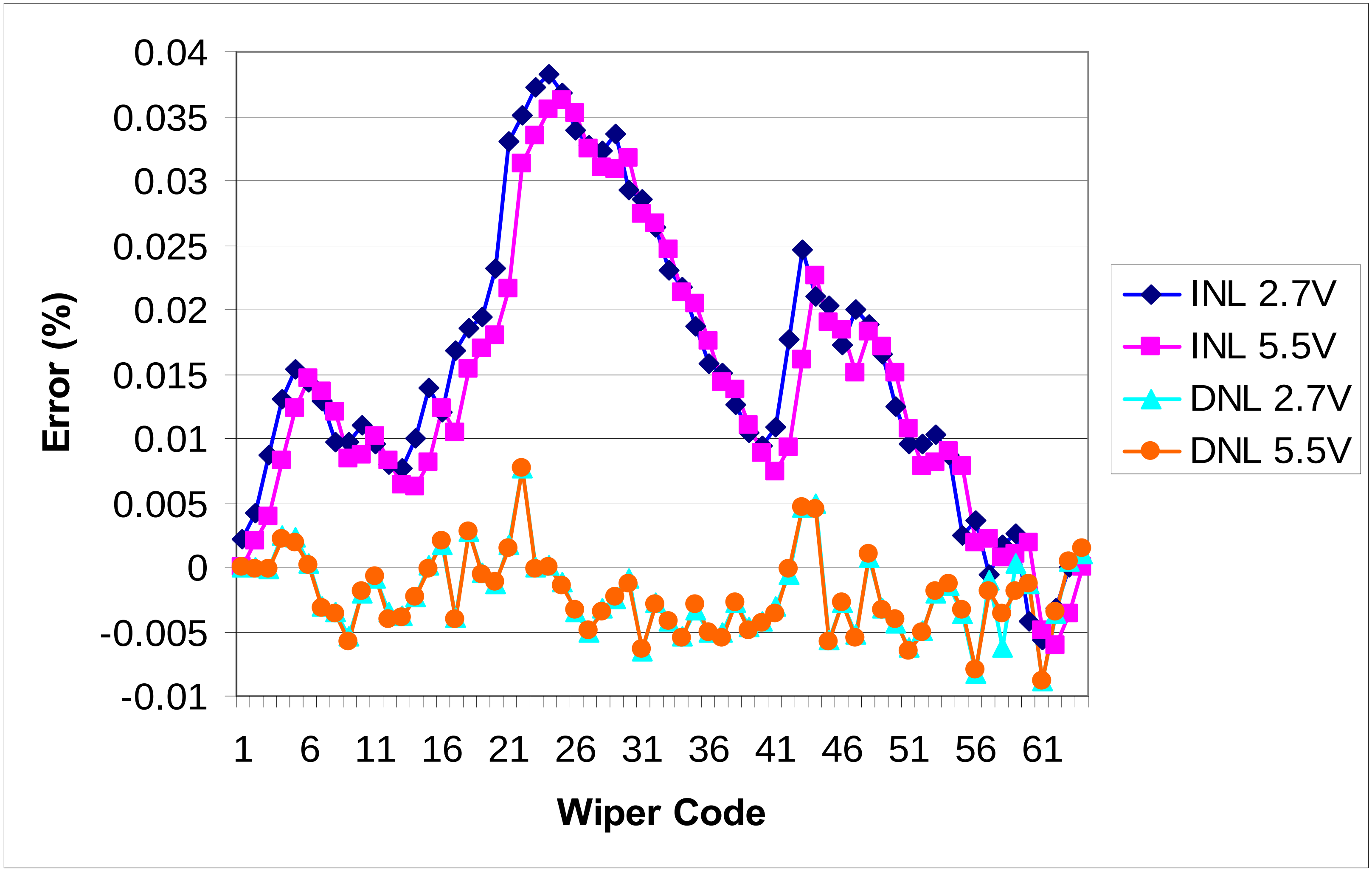
INL and DNL

- **INL =** Δ Actual Code Transition and Ideal Code Transition (less offset & gain)
- **DNL =** Δ Actual Code Width and Ideal Code Width

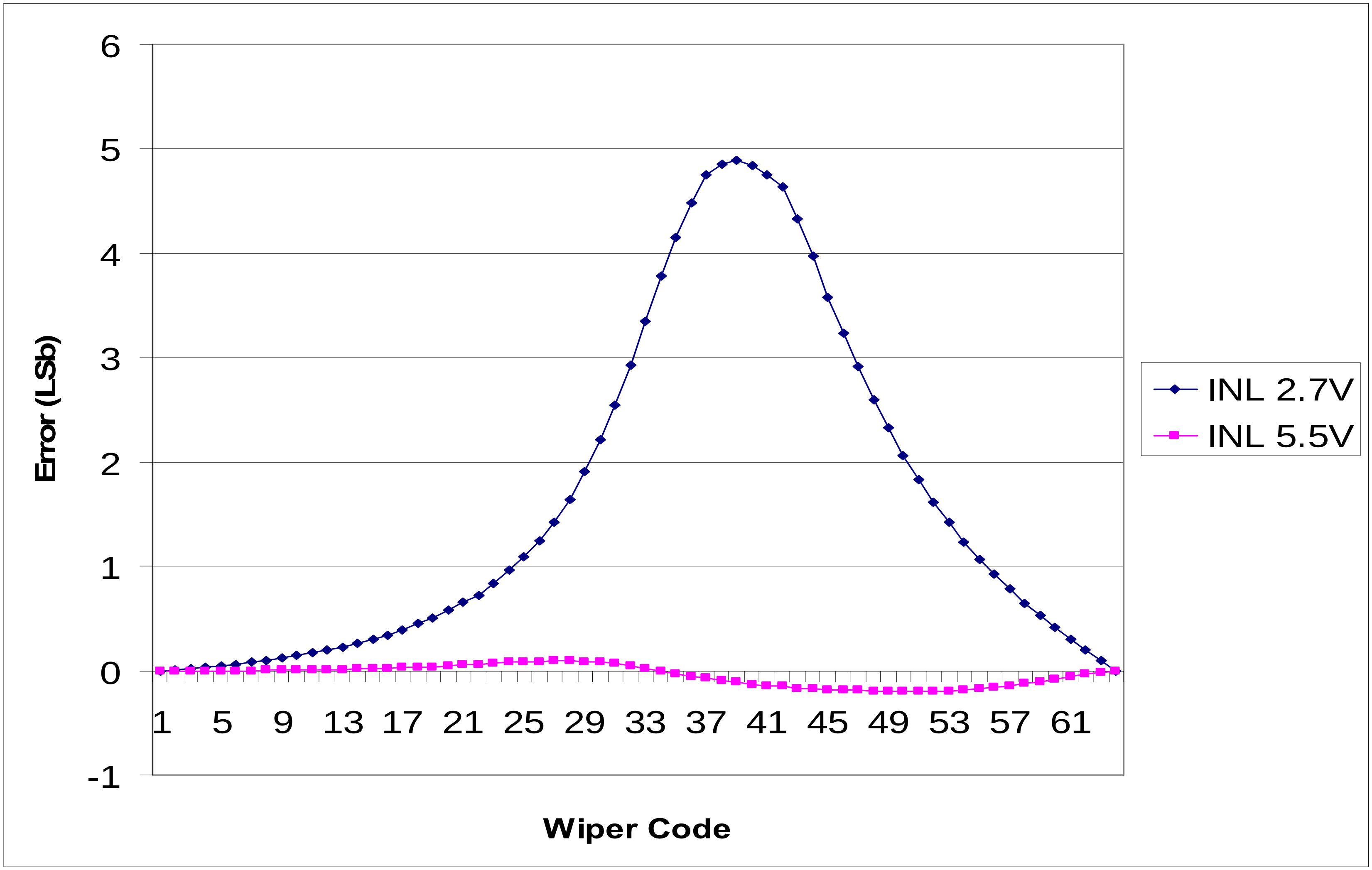




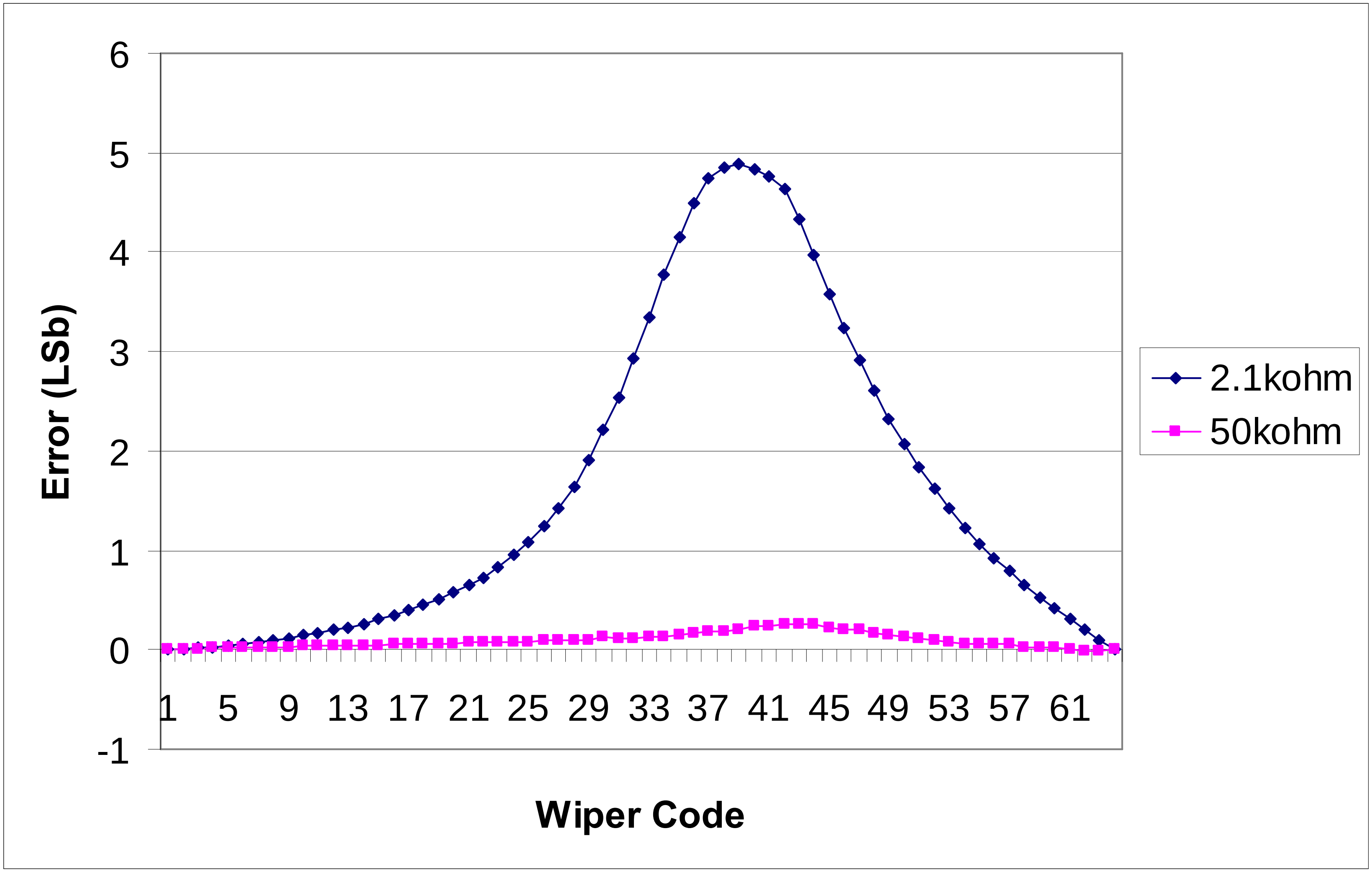
Pot Mode INL & DNL Error @ 25°C (2.1KΩ Device)



Rheostat Mode INL @ 25°C (2.1KΩ Device)



Rheostat Mode INL Comparison @ 25°C and 2.7V

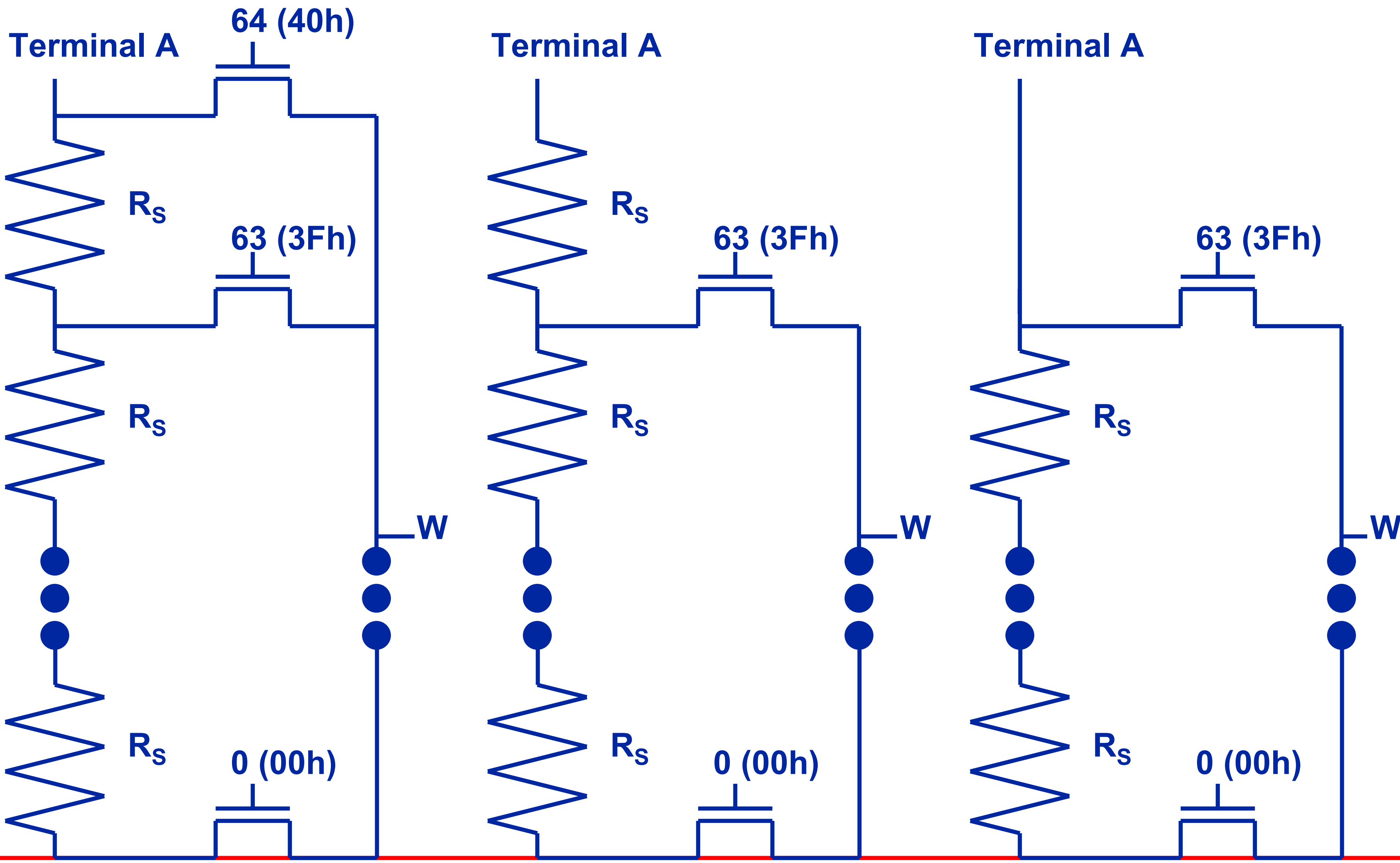


Effects of R_W in Rheostat Mode

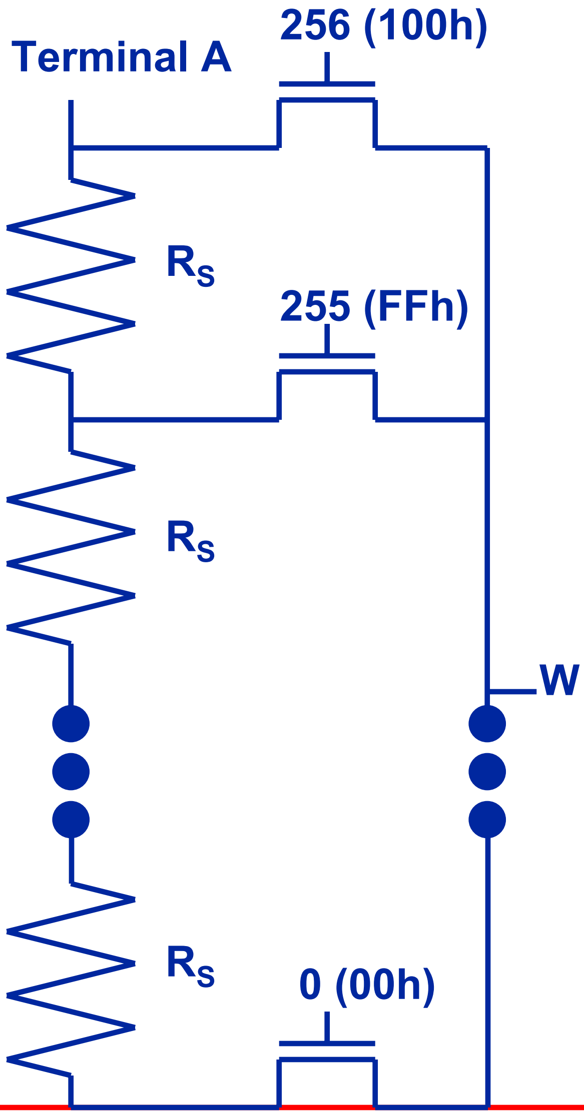
$R_{AB}(\Omega)$	R_S (Ω)	R_W (Ω)			R_W/R_S (%)		
Typ	Typ (6-bit)	Typ	Max @ 5.5V	Max @ 2.7V	Typ	Max @ 5.5V	Max @ 2.7V
2100	33.33	75	125	325	225%	375%	975%
50000	793.7	75	125	325	9.5%	15.8%	41%

- R_W variations affect devices with "small" step resistance (2.1kΩ device ⇨ R_S = 33.3ohm) more then devices with larger step resistance devices (50kΩ devices ⇨ R_S = 793.7ohm)
- Worst case R_W is almost 10x R_S for 2.1kΩ device
- Application may need to account for the R_W variation in the R_{BW} or R_{AW} resistance
- In Potentiometer (voltage divider) mode, variation of R_W does not change output (V_W)

Resistor Network – Wiper Range

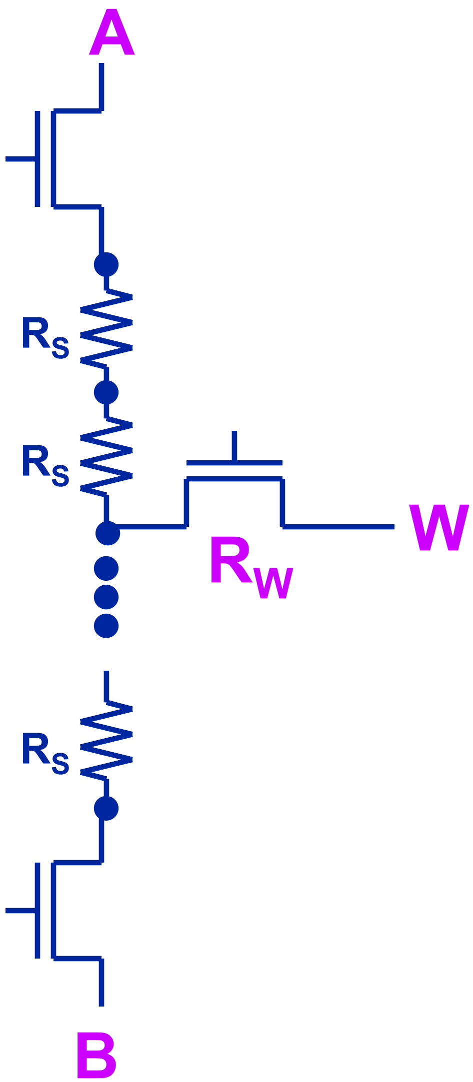


Resistor Network – Wiper Range



- **MCP4xxx Devices are 8-bit and 7-bit digital potentiometers**
  – 8-bit = 257 taps (100h)
  – 7-bit = 128 taps (80h)
- **Offered in Non-Volatile and Volatile versions (Volatile versions to be released shortly)**

Resistor Network – Terminal Disconnect



- **Terminal Disconnect allows any terminal to be disconnected from the Resistor Network**
- **Useful to reduce system current through the digital potentiometer**
- **Switches at Terminal A and Terminal B have similar characteristics as Wiper switch**

MCP4XXX TCON Register

FIGURE 6-2: TCON BITS (1)

R-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
D8	R1HW	R1A	R1W	R1B	R0HW	R0A	R0W	R0B

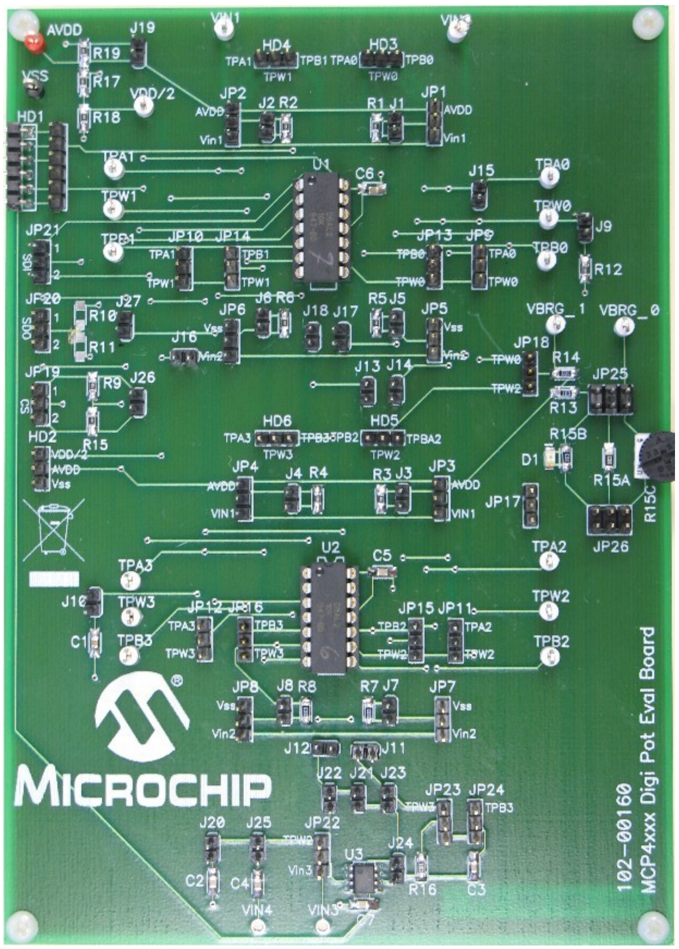
- **Bit = 1, Terminal connected to Resistor Network**
- **Bit = 0, Terminal NOT connected to Resistor Network**

The Tools

PICkit™ Serial Analyzer

- USB Interface to PC
- SPI or I^2C™ Communications to Board
- PC GUI Interface

MCP4XXX Digital Potentiometer Evaluation Board

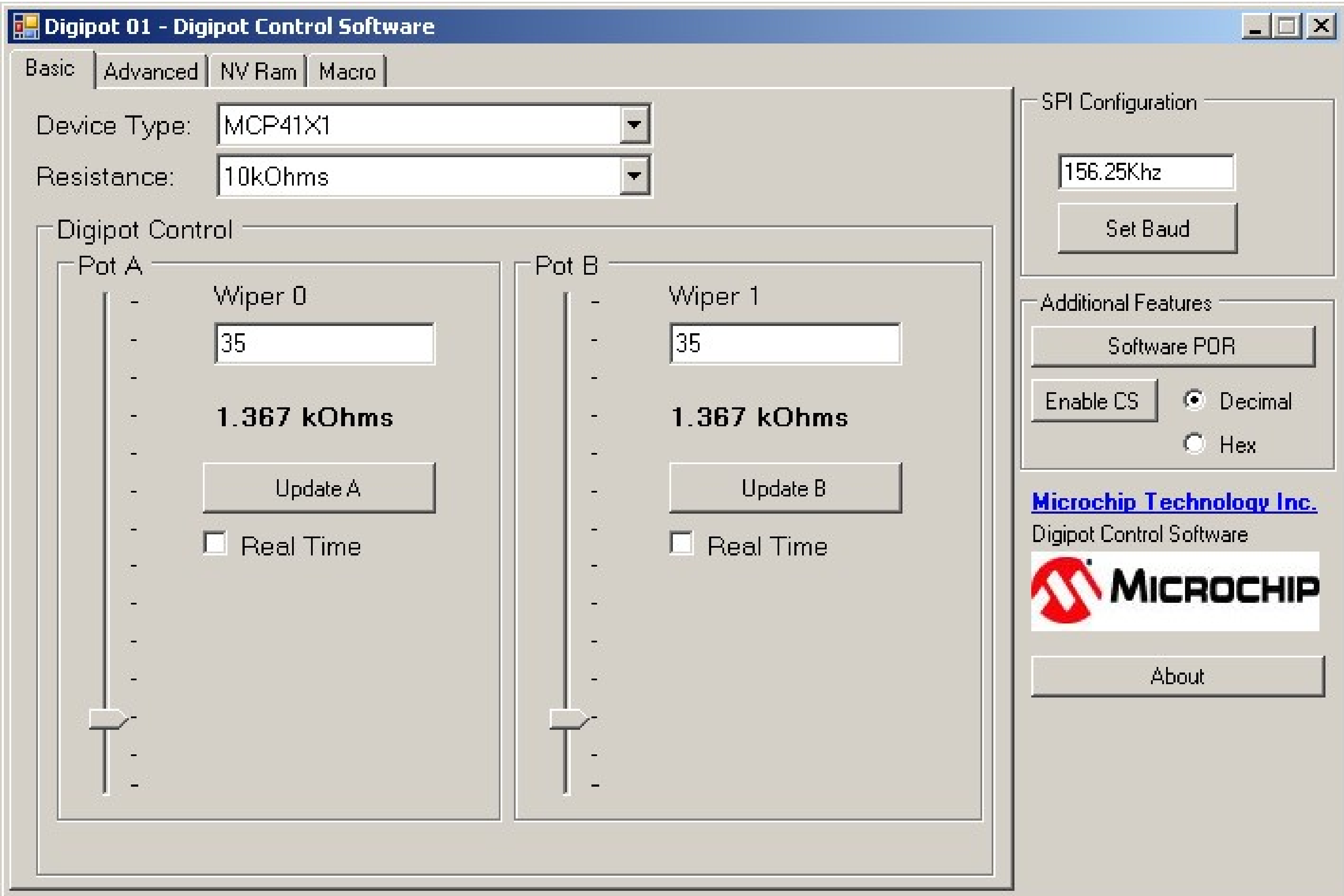


- SPI Communications Interface to PICkit™ Serial Analyzer
- Jumpers to configure demo circuit
- Custom PC GUI Interface

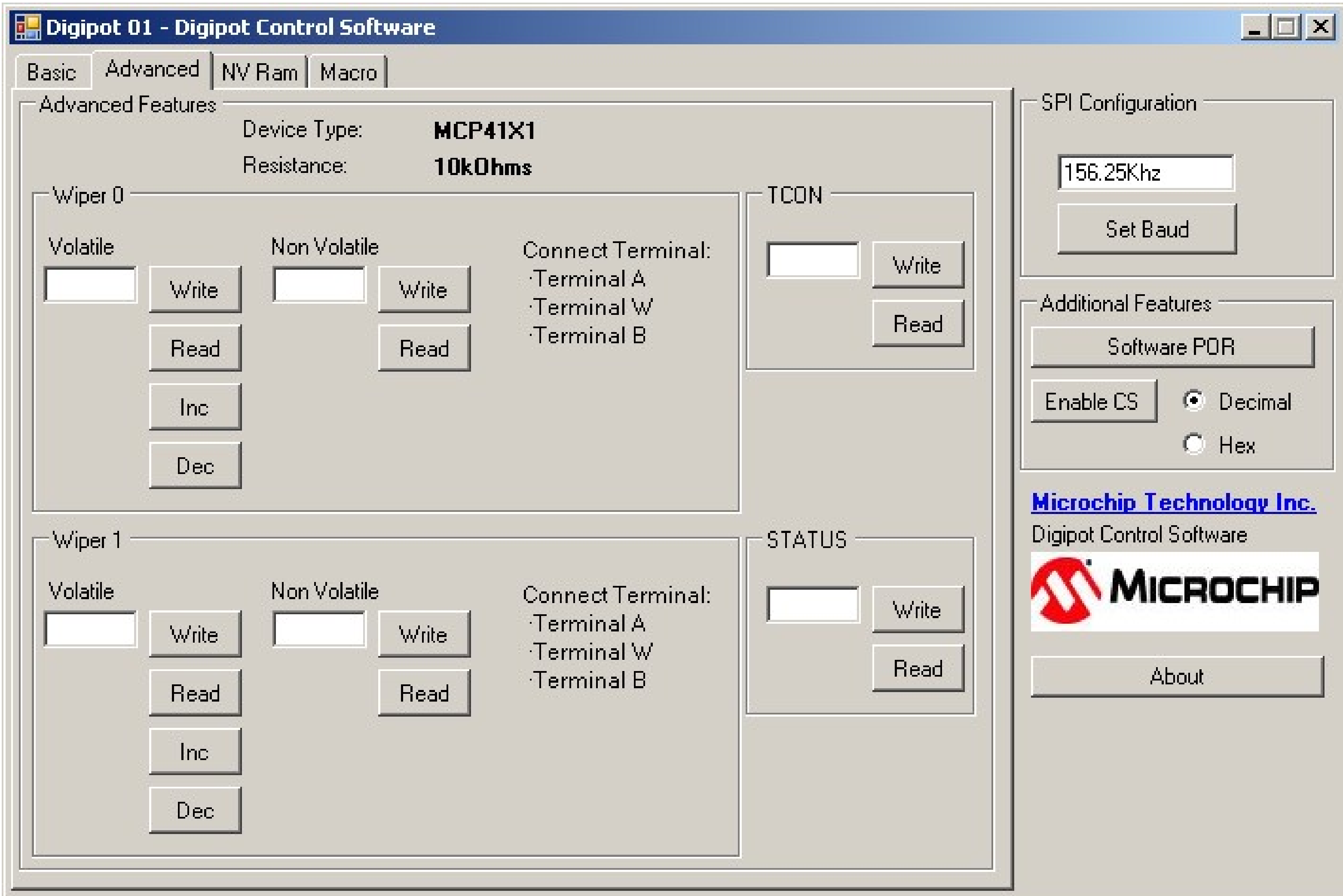
Bench Tools

- **The following bench tools will be used throughout these labs**
  - Oscilloscope
  - Digital Multi-Meter
  - Variable Power Supply
  - Arbitrary Waveform Generator/Frequency Generator

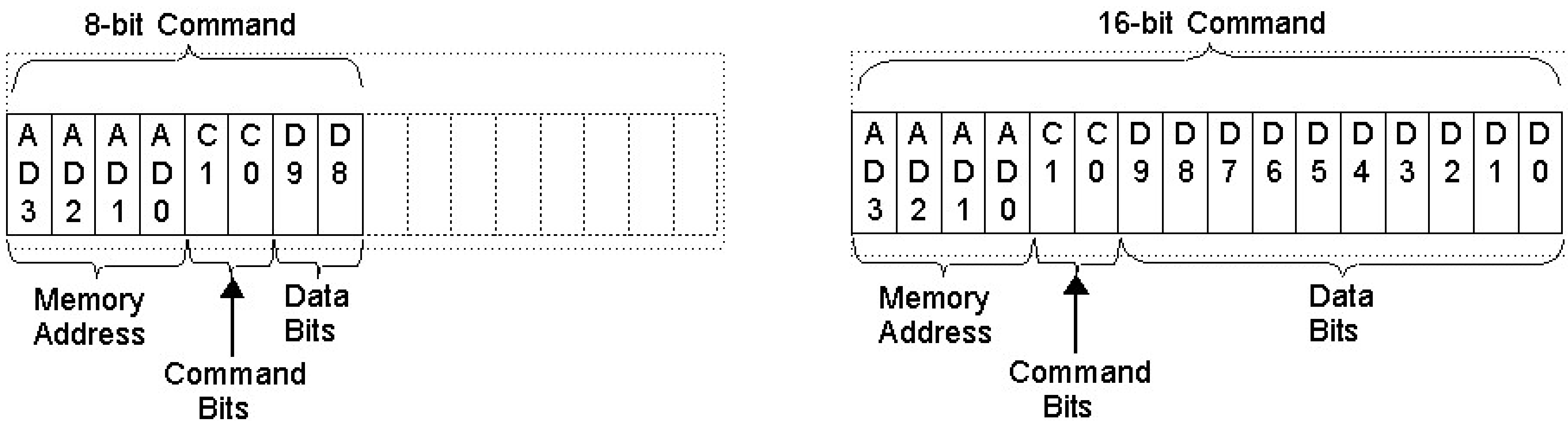
GUI – Basic Mode



GUI – Advance Mode



MCP4xxx SPI Commands



- **C1:C0**
  0 0 = Write Data
  0 1 = Increment Register Value
  1 0 = Decrement Register Value
  1 1 = Read Data

MCP4xxx SPI Commands

Address		Command	Data (9-bits)	SPI String (Binary)	
Value	Function			MOSI (SDI pin)	MISO (SDO pin)
00h	Volatile Wiper 0	Write	x xxxx xxxx	0000 000x xxxx xxxx	1111 1111 1111 1111
		Read	x xxxx xxxx	0000 110x xxxx xxxx	1111 111x xxxx xxxx
		Increment	—	0000 0100	1111 1111
		Decrement	—	0000 1000	1111 1111
01h	Volatile Wiper 1	Write	x xxxx xxxx	0001 000x xxxx xxxx	1111 1111 1111 1111
		Read	x xxxx xxxx	0001 110x xxxx xxxx	1111 111x xxxx xxxx
		Increment	—	0001 0100	1111 1111
		Decrement	—	0001 1000	1111 1111
02h	NV Wiper 0	Write	x xxxx xxxx	0010 000x xxxx xxxx	1111 1111 1111 1111
		Read	x xxxx xxxx	0010 110x xxxx xxxx	1111 111x xxxx xxxx
03h	NV Wiper 1	Write	x xxxx xxxx	0011 000x xxxx xxxx	1111 1111 1111 1111
		Read	x xxxx xxxx	0011 110x xxxx xxxx	1111 111x xxxx xxxx
04h	Volatile TCON Register	Write	x xxxx xxxx	0100 000x xxxx xxxx	1111 1111 1111 1111
		Read	x xxxx xxxx	0100 110x xxxx xxxx	1111 111x xxxx xxxx
05h	Status Register	Read	x xxxx xxxx	0101 110x xxxx xxxx	1111 111x xxxx xxxx

- **MCP4XXX Register – Command SPI String**
  - MOSI = Master Out – Slave In
  - MISO = Master In – Slave Out

MCP4XXX STATUS Register

FIGURE 6-1: STATUS RESISTER

R-1	R-1	R-1	R-1	R-1	R-1
D8:D5	EEWA	WL1 (1)	WL0 (1)	SHDN	WP (1)

Labs

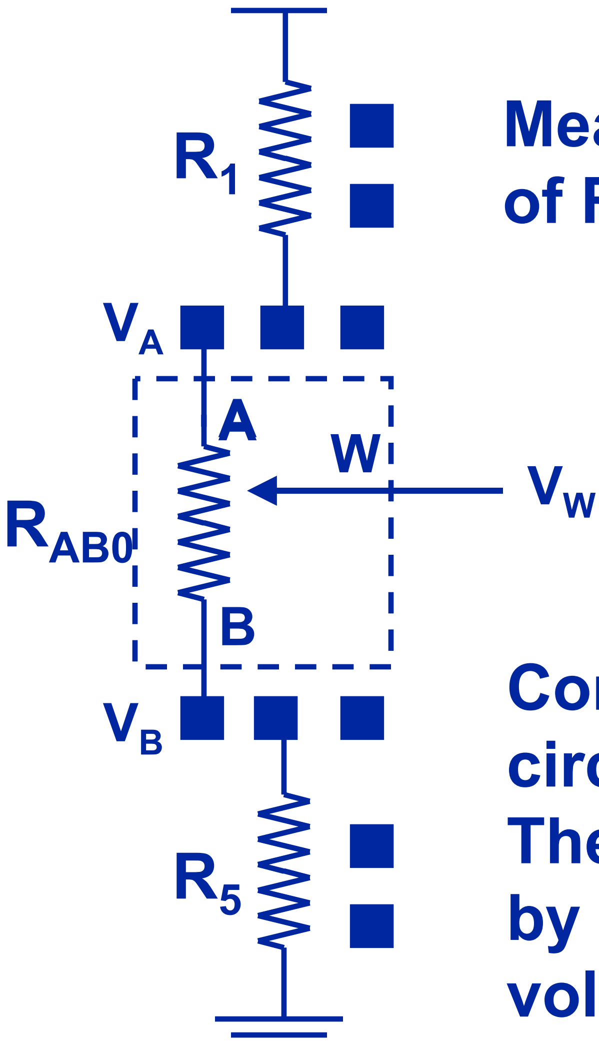
- **Handout sheets show:**
  - Jumper connections required for each lab configuration
  - Lab Equipment settings
  - Hints
  - Optional things to look at after you complete the lab

Lab #1
Measuring R_{AB} Resistance

Lab #1

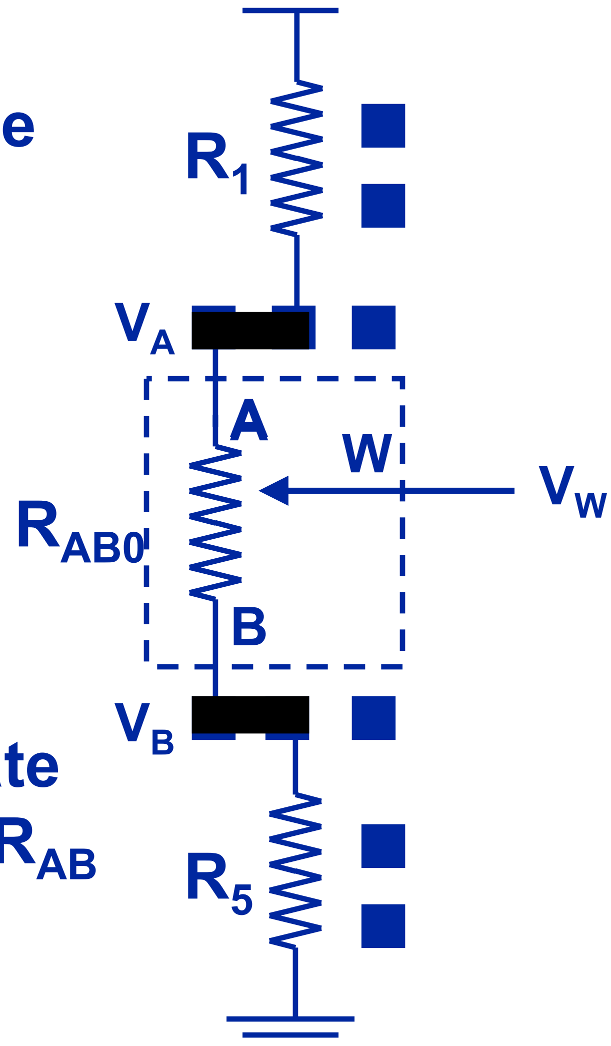
- **In this lab the R_{AB} resistance of one Resistor Network is measured and then compared to the R_{AB} resistance on a second device**
  - How do the resistances compare ?
- **Equipment Used:**
  - Oscilloscope
  - Digital Multi-Meter

Lab #1 Circuit



Measure resistance of R_1 and R_5

Connect R_{AB} to circuit and calculate The resistance of R_{AB} by the V_A and V_B voltages

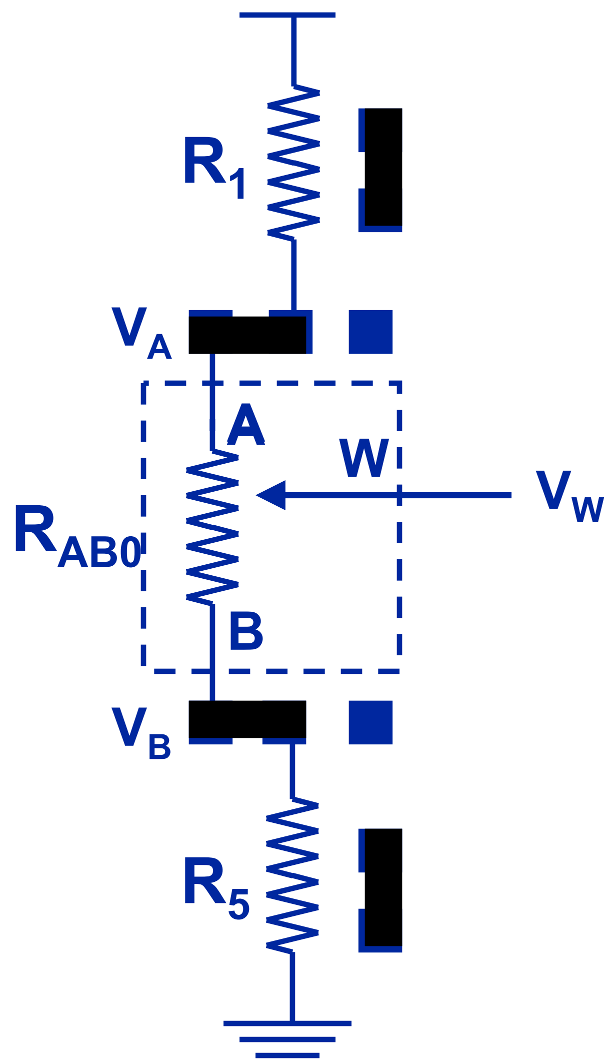


Lab #2
TCON Register Operation

Lab #2

- **In this lab the effects of the TCON register are observed**
  - With a value of 0x80 in the Wiper 0 register, write to the TCON register the following values 0xFE, 0xFF, 0xFB, 0xFF, 0xFD, and 0xFF
  - What do you observe
- **Equipment Used:**
  - Oscilloscope

Lab #2 Circuit

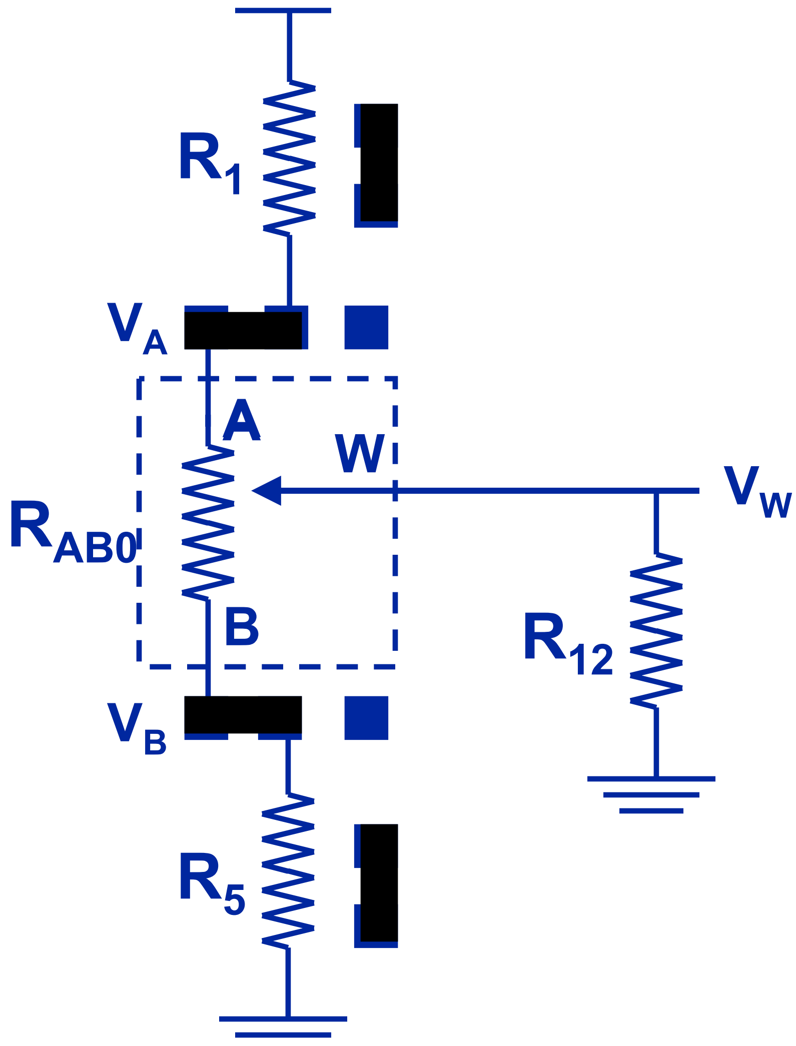


Lab #3
Wiper Loading

Lab #3

- **This lab demonstrates that the Wiper output of the resistor network is not buffered**
  - Measure Wiper voltage with and without resistive loading
- **Equipment Used:**
  - Oscilloscope
  - Digital Multi-Meter

Lab #3 Circuit

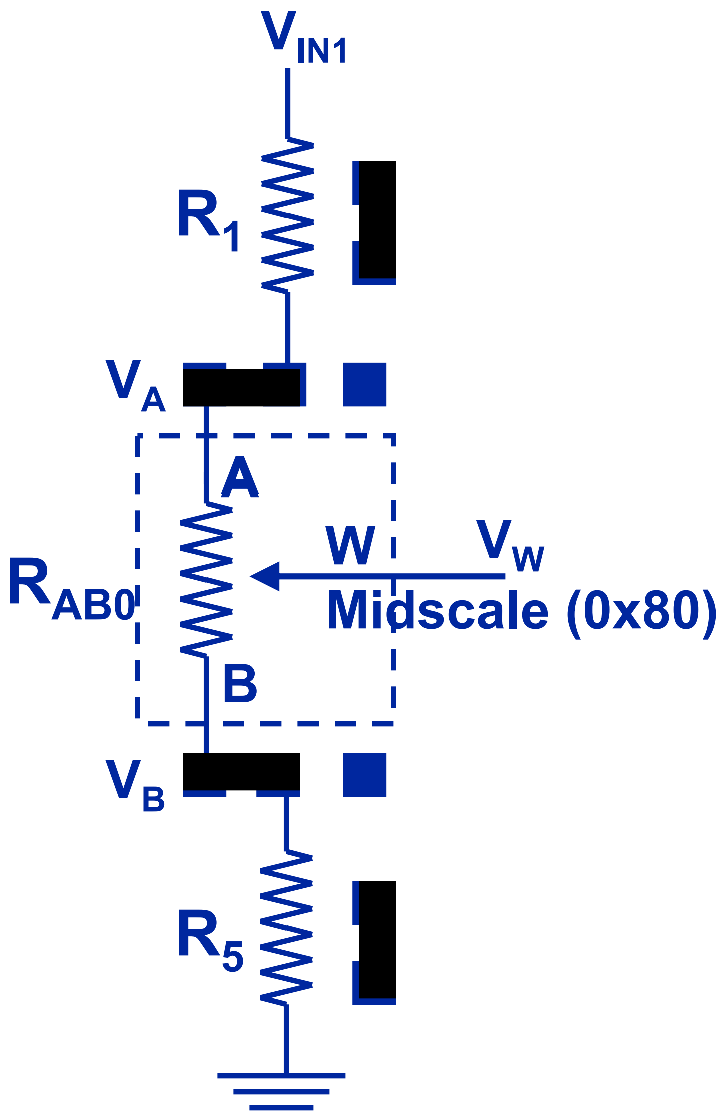


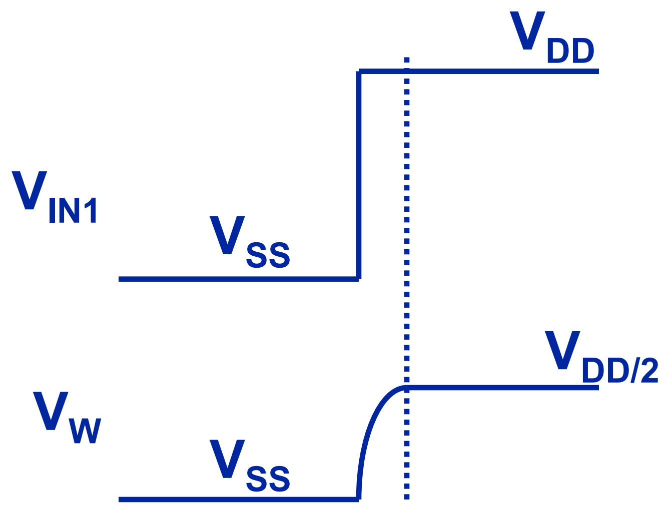
Lab #4
Resistor Network Capacitance

Lab #4

- **This lab demonstrates the capacitance of the Resistor Network**
  - Terminal A has a square wave from VSS to VDD and the time is measured for the W Terminal to arrive at its expected voltage; this allows the capacitance to be measured
- **Equipment Used:**
  - Oscilloscope
  - Excel

Lab #4 Circuit





T (s) = R (Ω) * C (F)

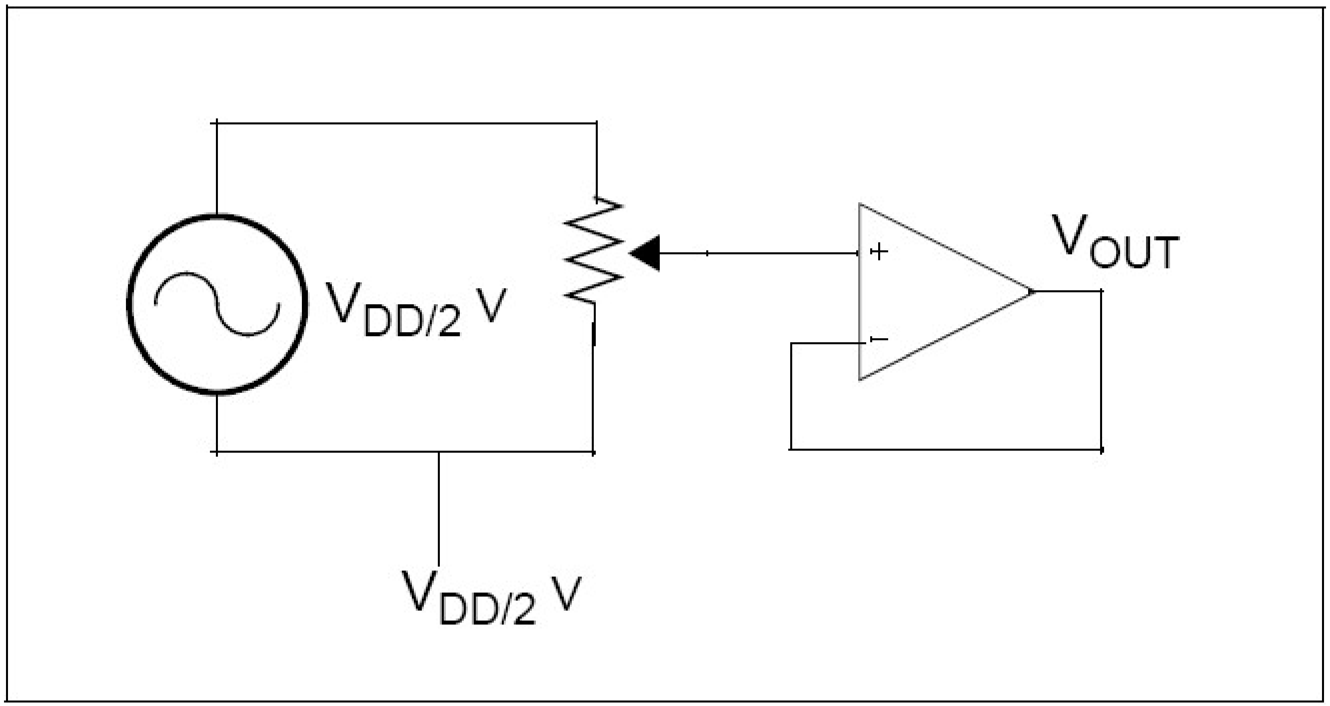
C = T / R

Lab #5
-3dB Bandwidth Measurement

Lab #5

- **This lab shows the technique to measure the -3dB bandwidth of the digital potentiometer Resistor Network**
- **-3dB Voltage Ratio = $\sqrt{1 / 2}$ = 0.7071**
- **Equipment Used:**
  – Oscilloscope
  – Digital Multi-Meter

Lab #5 Circuit



Lab #6
Programmable Filter

Lab #6

- **This lab demonstrates how a digital potentiometer can be used in a programmable filter application**
- **Equipment Used:**
  - Oscilloscope
  - Digital Multi-Meter

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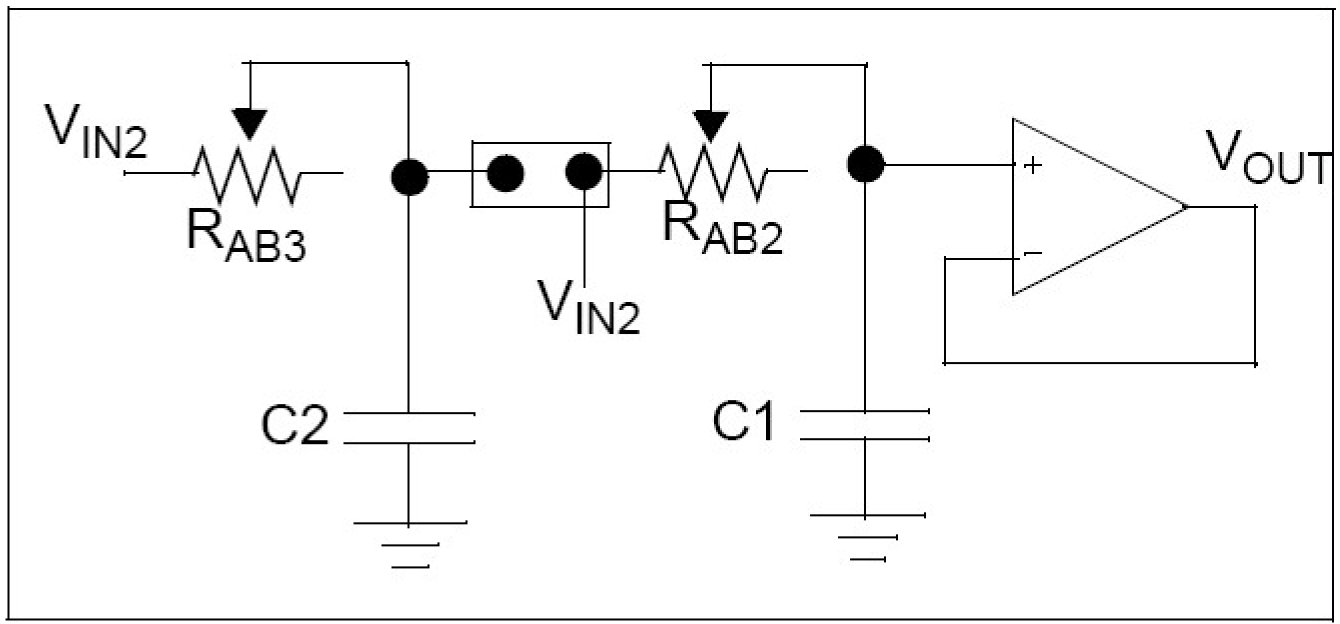
Lab #6 Circuit

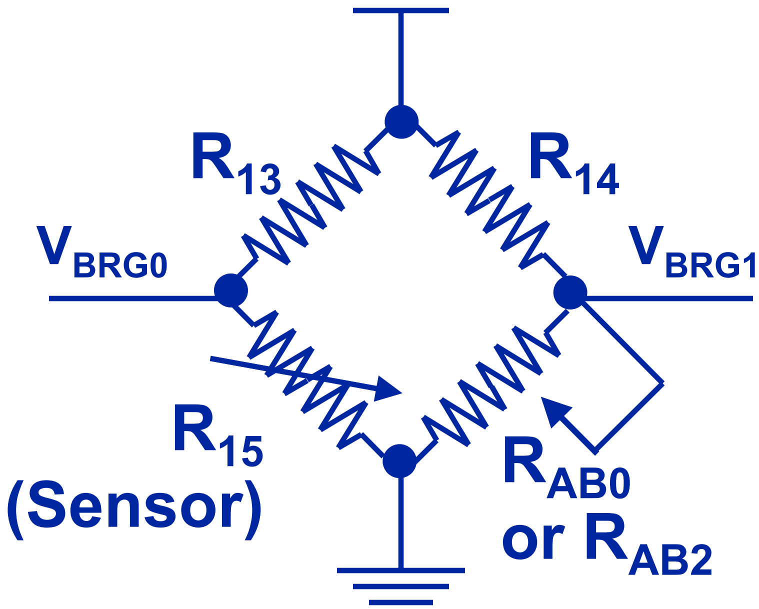


Lab #7
Calibrating the Wheatstone Bridge R_{AB} Resistance

Lab #7

- **This lab demonstrates how a Digital Potentiometer can be used to calibrate a sensor used in a Wheatstone Bridge**
- **Equipment Used:**
  - Oscilloscope
  - Digital Multi-Meter

Lab #7 Circuit



Summary

- **Operation of the Resistor Network and Serial Interface**
  - Easy to implement in applications
- **Characteristics of the Resistor Network**
  - Better understanding of Digital Potentiometer characteristics with respect to system conditions; including device voltage, signal characteristics on terminals, and system temperature (also see AN1080)
- **Applications**
  - Operated a digital potentiometer in some application circuits

Microchip Tools Used In Labs

- **PICkit™ Serial Analyzer (DV164122)**
- **MCP4xxx Digital Potentiometer Evaluation Board kit (not yet released – expected order # MCP4XXXEV)**
  - MCP4xxx Digital Potentiometer Evaluation Board
  - Custom PC GUI

Lab Equipment

- **Oscilloscope:**
  LeCroy waveJet 314
- **Power Supply:**
  Extech Instruments 382213
- **DMM: Extech Instruments MN36**
- **Function Generator:**
  GW Instek SFG- 2010

Thank you for your time

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