MAX5391/MAX5393

Dual 256-Tap, Volatile, Low-Voltage Linear Taper Digital Potentiometers

General Description

The MAX5391/MAX5393 dual 256-tap, volatile, low-voltage linear taper digital potentiometers offer three end-to-end resistance values of 10kΩ, 50kΩ, and 100kΩ. Operating from a single +1.7V to +5.5V power supply, these devices provide a low 35ppm/°C end-to-end temperature coefficient. The devices feature an SPI interface.

The small package size, low supply voltage, low supply current, and automotive temperature range of the MAX5391/MAX5393 make the devices uniquely suitable for the portable consumer market and battery backup industrial applications.

The MAX5391/MAX5393 include two digital potentiometers in a voltage-divider configuration. The MAX5391/MAX5393 are specified over the -40°C to +125°C automotive temperature range and are available in a 16-pin, 3mm x 3mm TQFN and a 14-pin TSSOP package, respectively.

Applications

- Low-Voltage Battery Applications
- Portable Electronics
- Mechanical Potentiometer Replacement
- Offset and Gain Control
- Adjustable Voltage References/Linear Regulators

Features

- Dual 256-Tap Linear Taper Positions
- Single +1.7V to +5.5V Supply Operation
- Low 12µA Quiescent Supply Current
- 10kΩ, 50kΩ, and 100kΩ End-to-End Resistance Values
- SPI-Compatible Interface
- Wiper Set to Midscale on Power-Up
- -40°C to +125°C Operating Temperature Range

Ordering Information

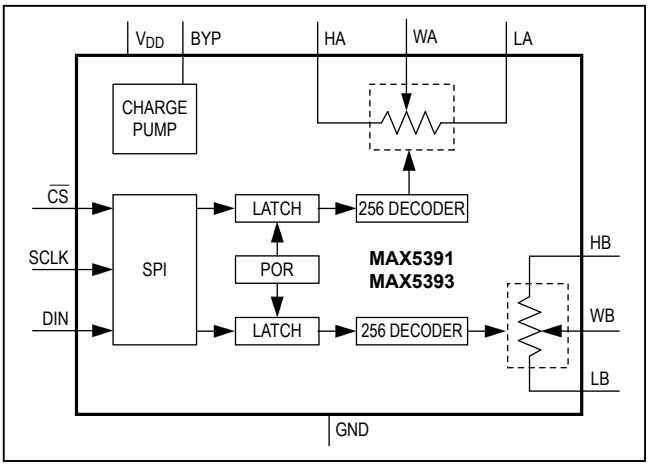
PART	PIN-PACKAGE	END-TO-END RESISTANCE (kΩ)
MAX5391LATE+	16 TQFN-EP*	10
MAX5391MATE+	16 TQFN-EP*	50
MAX5391NATE+	16 TQFN-EP*	100
MAX5393LAUD+	14 TSSOP	10
MAX5393MAUD+	14 TSSOP	50
MAX5393NAUD+	14 TSSOP	100

Note: *All devices are specified in the -40°C to +125°C temperature range.*

+Denotes lead(Pb)-free/RoHS-compliant package.

**EP = Exposed paddle.*

Functional Diagram



maxim integrated™

Absolute Maximum Ratings

V_{DD} to GND .....-0.3V to +6V
H_, W_, L_ to GND ..... -0.3V to the lower of (V_{DD} + 0.3V) or +6V
All Other Pins to GND .....-0.3V to +6V
Continuous Current into H_, W_, and L_
MAX5391L/MAX5393L .....±5mA
MAX5391M/MAX5393M .....±2mA
MAX5391N/MAX5393N.....±1mA

Continuous Power Dissipation (T_A = +70°C)
14-Pin TSSOP (derate 10mW/°C above +70°C).....796.8mW
16-Pin TQFN (derate 14.7mW/°C above +70°C)...1176.5mW
Operating Temperature Range..... -40°C to +125°C
Junction Temperature.....+150°C
Storage Temperature Range..... -65°C to +150°C
Lead Temperature (soldering, 10s) .....+300°C
Soldering Temperature (reflow).....+260°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Electrical Characteristics

(V_{DD} = +1.7V to +5.5V, $V_{H_}$ = V_{DD}, $V_{L_}$ = 0V, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at V_{DD} = +1.8V, T_A = +25°C.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Resolution	N			256			Tap
DC PERFORMANCE (Voltage-Divider Mode)							
Integral Nonlinearity	INL	(Note 2)		-0.5		+0.5	LSB
Differential Nonlinearity	DNL	(Note 2)		-0.5		+0.5	LSB
Dual-Code Matching		Register A = Register B		-0.5		+0.5	LSB
Ratiometric Resistor Tempco		$(\Delta V_W/V_W)/\Delta T$, no load			5		ppm/°C
Full-Scale Error		Code = FFh	MAX5391L/MAX5393L	-3	-2.2		LSB
			MAX5391M/MAX5393M	-1	-0.6		
			MAX5391N/MAX5393N	-0.5	-0.3		
Zero-Scale Error		Code = 00h	MAX5391L/MAX5393L		2.2	3	LSB
			MAX5391M/MAX5393M		0.6	1	
			MAX5391N/MAX5393N		0.3	0.5	
DC PERFORMANCE (Variable Resistor Mode)							
Integral Nonlinearity (Note 3)	R-INL	MAX5391L/MAX5393L		-1.5		+1.5	LSB
		MAX5391M/MAX5393M		-0.75		+0.75	
		MAX5391N/MAX5393N		-0.5		+0.5	
Differential Nonlinearity	R-DNL	(Note 3)		-0.5		+0.5	LSB
DC PERFORMANCE (Resistor Characteristics)							
Wiper Resistance	R_{WL}	(Note 4)				200	Ω
Terminal Capacitance	$C_{H_}$, $C_{L_}$	Measured to GND			10		pF
Wiper Capacitance	$C_{W_}$	Measured to GND			50		pF
End-to-End Resistor Tempco	TC_R	No load			35		ppm/°C
End-to-End Resistor Tolerance	ΔR_{HL}	Wiper not connected		-25		+25	%
AC PERFORMANCE							
Crosstalk		(Note 5)			-90		dB
-3dB Bandwidth	BW	Code = 80H, 10pF load, V_{DD} = 1.8V	MAX5391L/MAX5393L		600		kHz
			MAX5391M/MAX5393M		100		
			MAX5391N/MAX5393N		50		
Total Harmonic Distortion Plus Noise	THD+N	Measured at W, $V_{H_}$ = $1V_{RMS}$ at 1kHz			0.02		%

Electrical Characteristics (continued)

(V_{DD} = +1.7V to +5.5V, $V_{H_}$ = V_{DD}, $V_{L_}$ = 0V, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at V_{DD} = +1.8V, T_A = +25°C.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Wiper Settling Time (Note 6)	t_S	MAX5391L/MAX5393L		400		ns
		MAX5391M/MAX5393M		1200		
		MAX5391N/MAX5393N		2200		
Charge-Pump Feedthrough at W_	V_{RW}	f_{CLK} = 600kHz, C_{OUT} = 0nF		200		nV_{P-P}
POWER SUPPLIES						
Supply Voltage Range	V_{DD}		1.7		5.5	V
Standby Current		V_{DD} = 5.5V	27			µA
		V_{DD} = 1.7V	12			
DIGITAL INPUTS						
Minimum Input High Voltage	V_{IH}	V_{DD} = 2.6V to 5.5V	70			% x V_{DD}
		V_{DD} = 1.7V to 2.6V	75			
Maximum Input Low Voltage	V_{IL}	V_{DD} = 2.6V to 5.5V			30	% x V_{DD}
		V_{DD} = 1.7V to 2.6V			25	
Input Leakage Current			-1		+1	µA
Input Capacitance				5		pF
TIMING CHARACTERISTICS—SPI (Note 7)						
SCLK Frequency	f_{MAX}				10	MHz
SCLK Clock Period	t_{CP}		100			ns
SCLK Pulse-Width High	t_{CH}		40			ns
SCLK Pulse-Width Low	t_{CL}		40			ns
$\overline{CS}$ Fall to SCK Rise Setup Time	t_{CSS}		40			ns
SCLK Rise to $\overline{CS}$ Rise Hold Time	t_{CSH}		0			ns
DIN Setup Time	t_{DS}		40			ns
DIN Hold Time	t_{DH}		0			ns
SCLK Rise to $\overline{CS}$ Fall Delay	t_{CS0}		10			ns
SCLK Rise to SCLK Rise Hold Time	t_{CS1}		40			ns
CS Pulse-Width High	t_{CSW}		100			ns

Note 1: All devices are 100% production tested at T_A = +25°C. Specifications over temperature limits are guaranteed by design and characterization.

Note 2: DNL and INL are measured with the potentiometer configured as a voltage-divider (Figure 1) with H_ = V_{DD} and L_ = GND. The wiper terminal is unloaded and measured with a high-input-impedance voltmeter.

Note 3: R-DNL and R-INL are measured with the potentiometer configured as a variable resistor (Figure 1). DNL and INL are measured with the potentiometer configured as a variable resistor. H_ is unconnected and L_ = GND. For V_{DD} = +5V, the wiper terminal is driven with a source current of 400µA for the 10kΩ configuration, 80µA for the 50kΩ configuration, and 40µA for the 100kΩ configuration. For V_{DD} = +1.7V, the wiper terminal is driven with a source current of 150µA for the 10kΩ configuration, 30µA for the 50kΩ configuration, and 15µA for the 100kΩ configuration.

Note 4: The wiper resistance is the value measured by injecting the currents given in Note 3 into W_ with L_ = GND. $R_{W_} = (V_{W_} - V_{H_})/I_{W_}$.

Note 5: Drive HA with a 1kHz GND to V_{DD} amplitude tone. LA = LB = GND. No load. WB is at midscale with a 10pF load. Measure WB.

Note 6: The wiper-settling time is the worst-case 0 to 50% rise time, measured between tap 0 and tap 127. H_ = V_{DD}, L_ = GND, and the wiper terminal is loaded with 10pF capacitance to ground.

Note 7: Digital timing is guaranteed by design and characterization, not production tested.

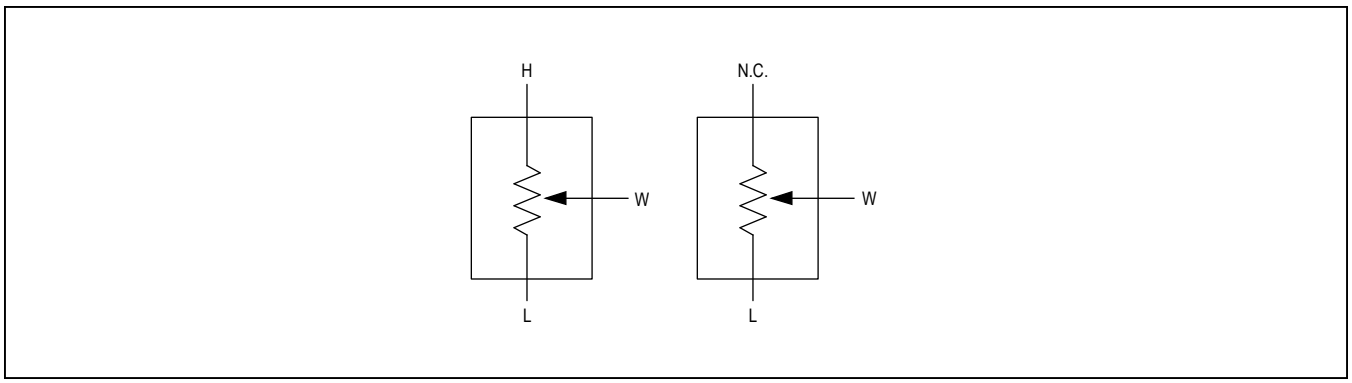
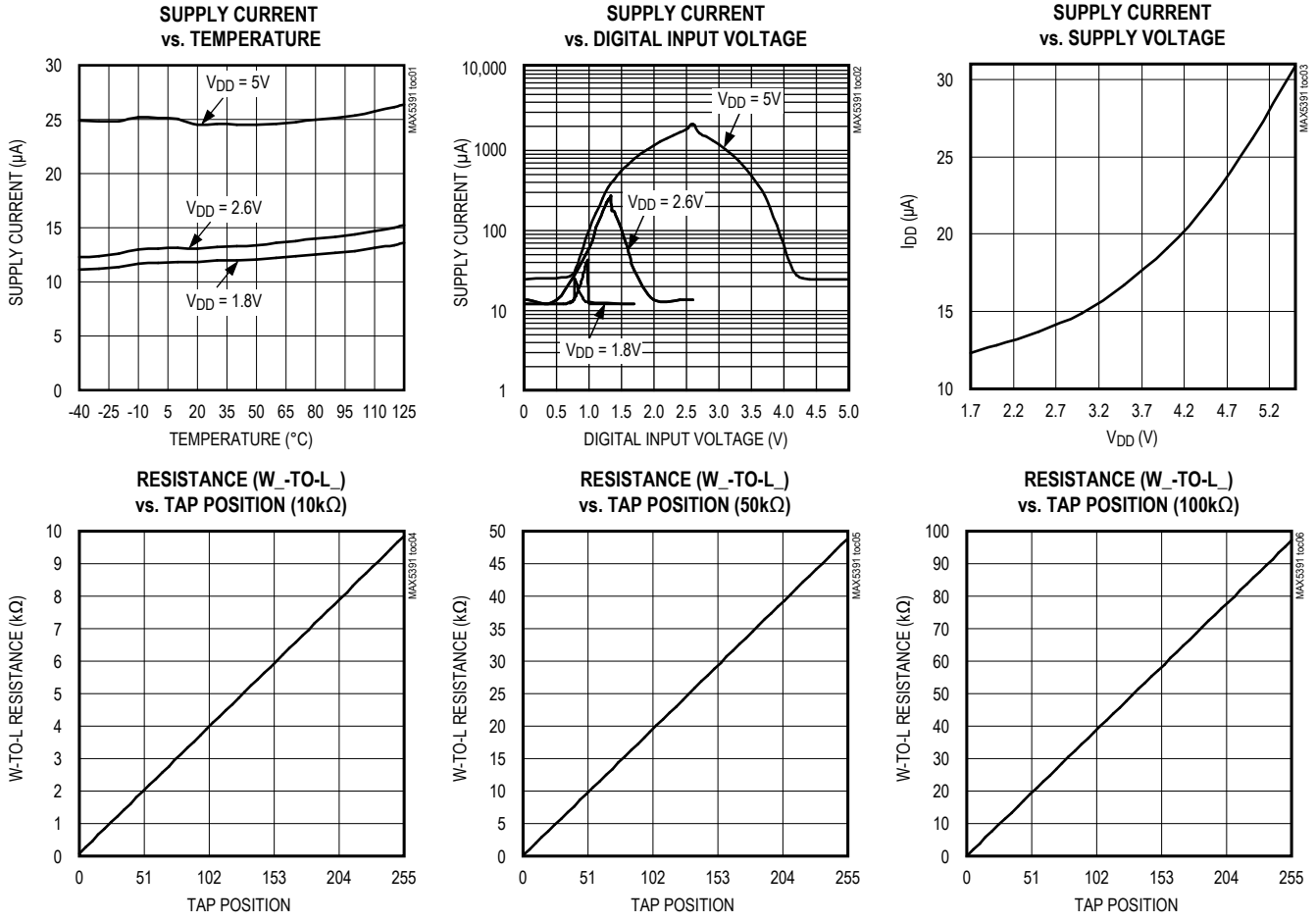


Figure 1. Voltage-Divider and Variable Resistor Configurations

Typical Operating Characteristics

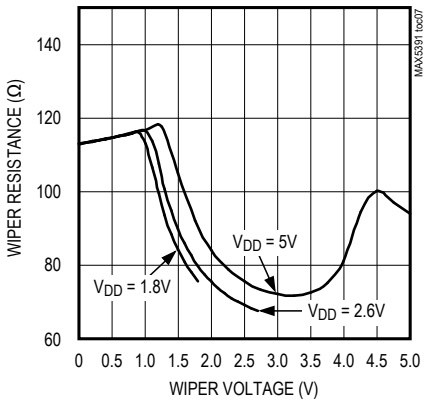
(V_{DD} = 1.8V, T_A = +25°C, unless otherwise noted.)



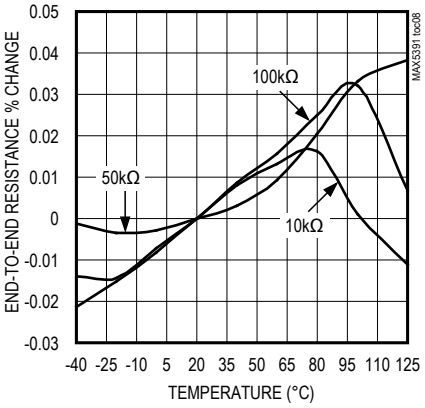
Typical Operating Characteristics (continued)

(V_{DD} = 1.8V, T_A = +25°C, unless otherwise noted.)

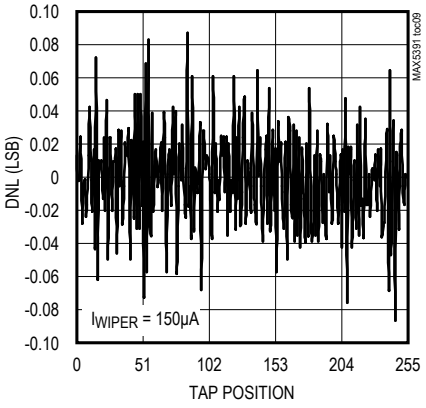
WIPER RESISTANCE vs. WIPER VOLTAGE



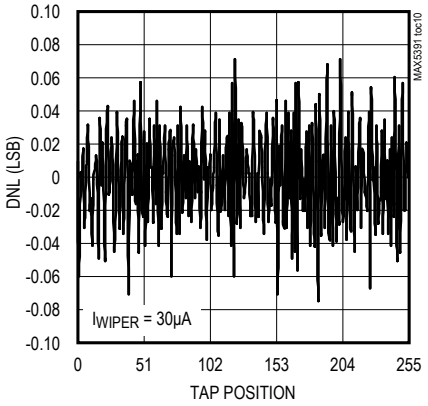
END-TO-END RESISTANCE PERCENTAGE CHANGE vs. TEMPERATURE



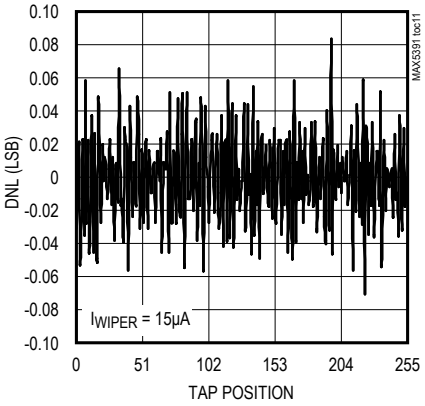
VARIABLE RESISTOR DNL vs. TAP POSITION (10kΩ)



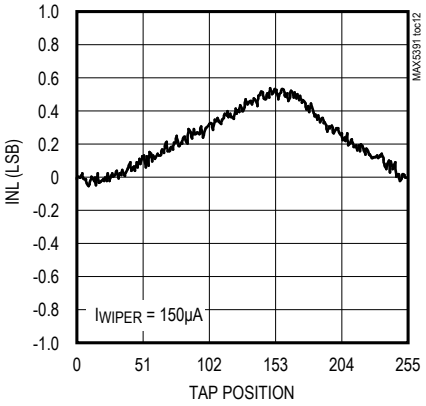
VARIABLE RESISTOR DNL vs. TAP POSITION (50kΩ)



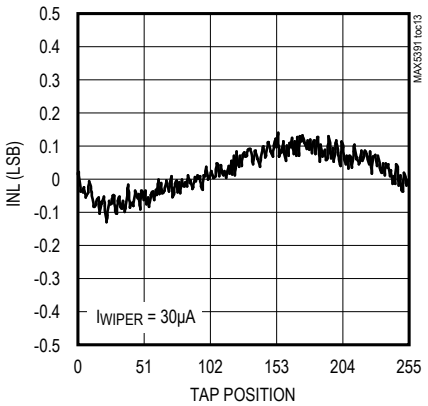
VARIABLE RESISTOR DNL vs. TAP POSITION (100kΩ)



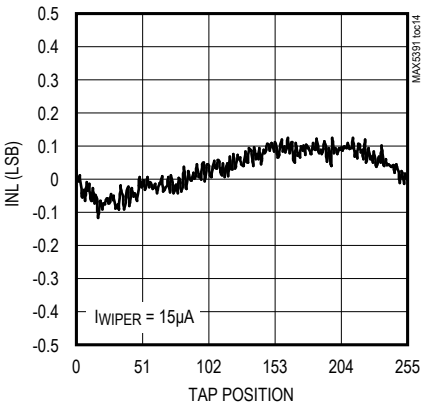
VARIABLE RESISTOR INL vs. TAP POSITION (10kΩ)



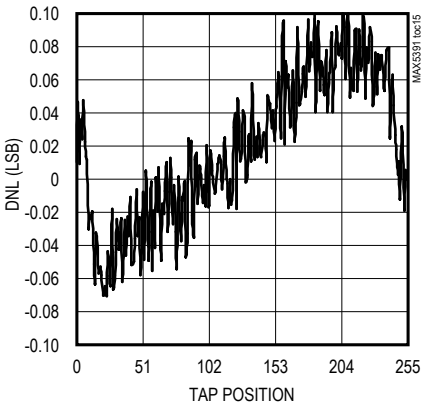
VARIABLE RESISTOR INL vs. TAP POSITION (50kΩ)



VARIABLE RESISTOR INL vs. TAP POSITION (100kΩ)



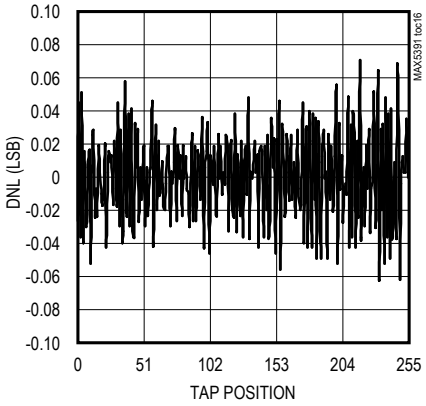
VOLTAGE-DIVIDER DNL vs. TAP POSITION (10kΩ)



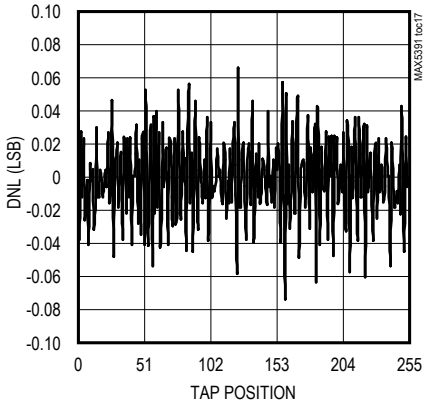
Typical Operating Characteristics (continued)

(V_{DD} = 1.8V, T_A = +25°C, unless otherwise noted.)

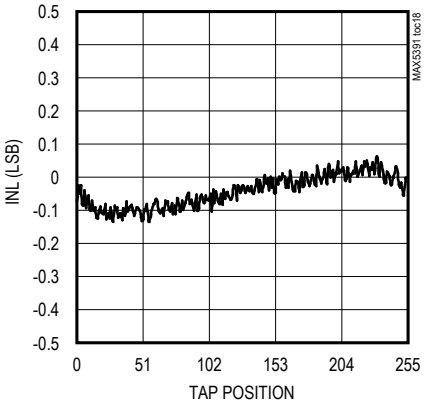
VOLTAGE-DIVIDER DNL vs. TAP POSITION (50kΩ)



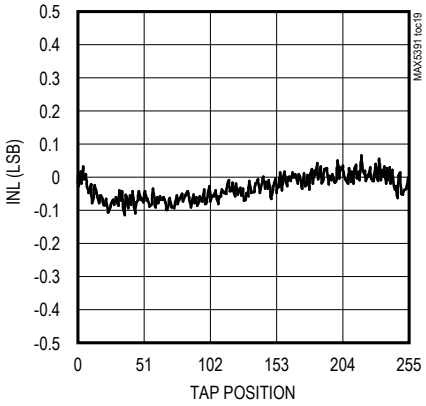
VOLTAGE-DIVIDER DNL vs. TAP POSITION (100kΩ)



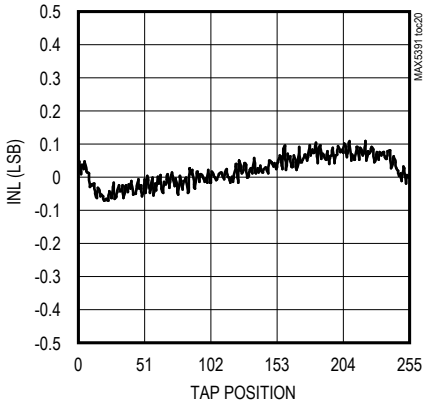
VOLTAGE-DIVIDER INL vs. TAP POSITION (10kΩ)



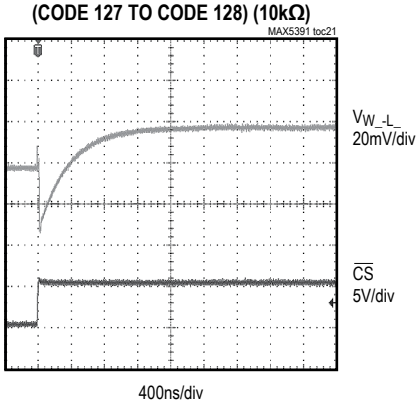
VOLTAGE-DIVIDER INL vs. TAP POSITION (50kΩ)



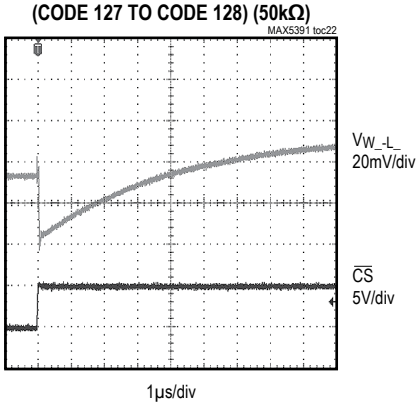
VOLTAGE-DIVIDER INL vs. TAP POSITION (100kΩ)



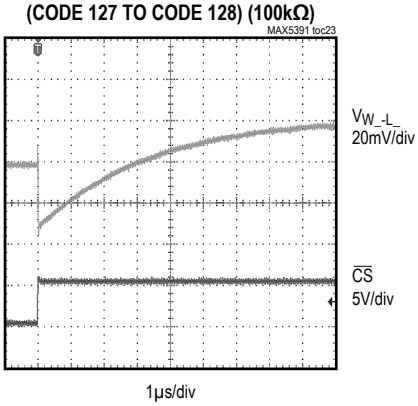
TAP-TO-TAP SWITCHING TRANSIENT (CODE 127 TO CODE 128) (10kΩ)



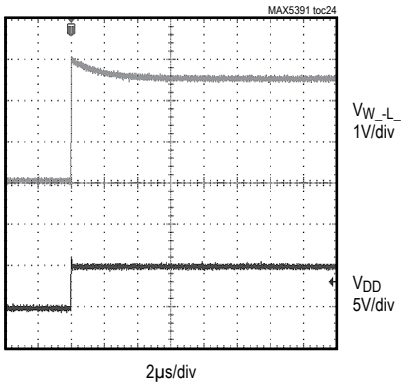
TAP-TO-TAP SWITCHING TRANSIENT (CODE 127 TO CODE 128) (50kΩ)



TAP-TO-TAP SWITCHING TRANSIENT (CODE 127 TO CODE 128) (100kΩ)



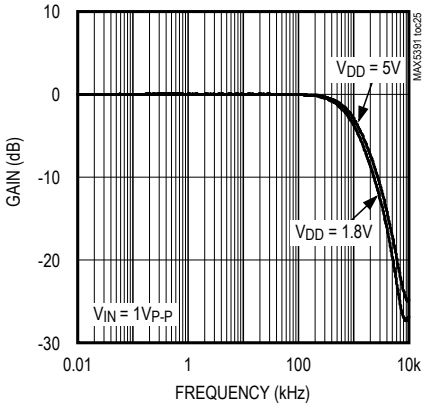
MAX5391M POWER-ON TRANSIENT



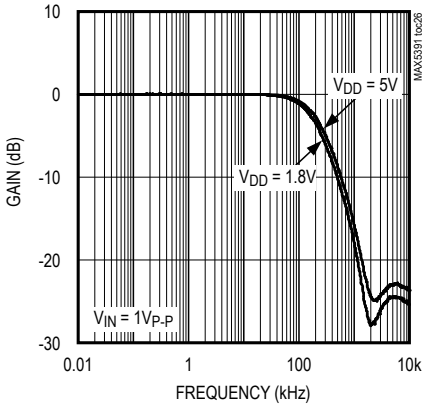
Typical Operating Characteristics (continued)

(V_{DD} = 1.8V, T_A = +25°C, unless otherwise noted.)

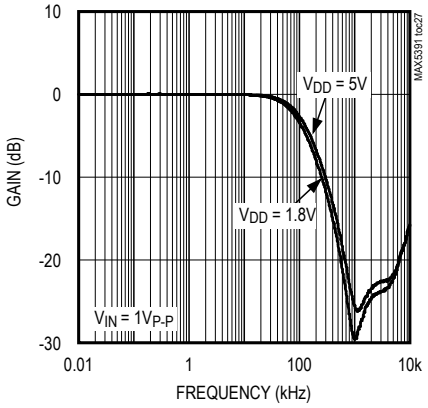
MIDSCALE FREQUENCY RESPONSE (10kΩ)



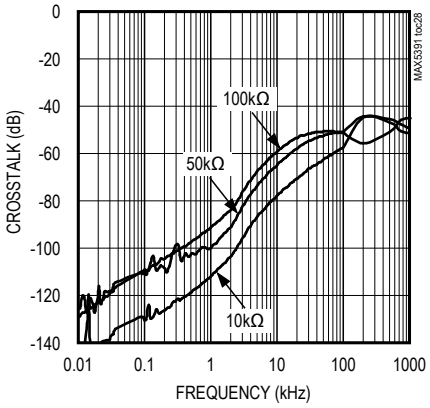
MIDSCALE FREQUENCY RESPONSE (50kΩ)



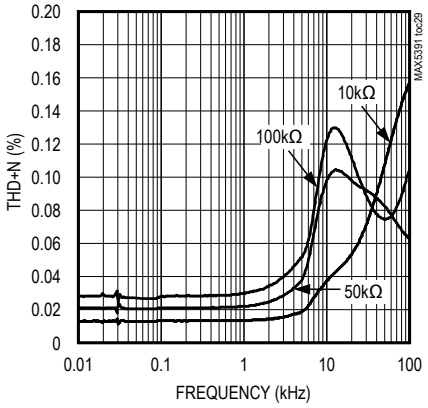
MIDSCALE FREQUENCY RESPONSE (100kΩ)



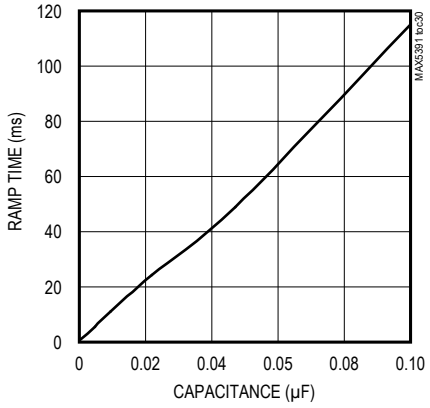
CROSSTALK vs. FREQUENCY



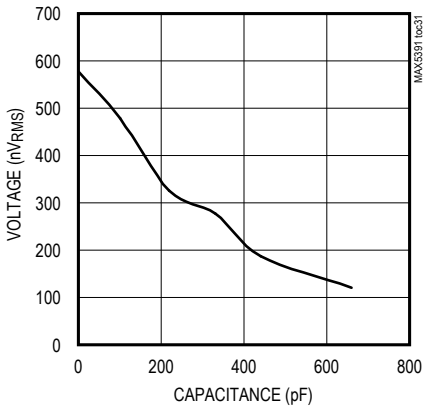
TOTAL HARMONIC DISTORTION PLUS NOISE vs. FREQUENCY



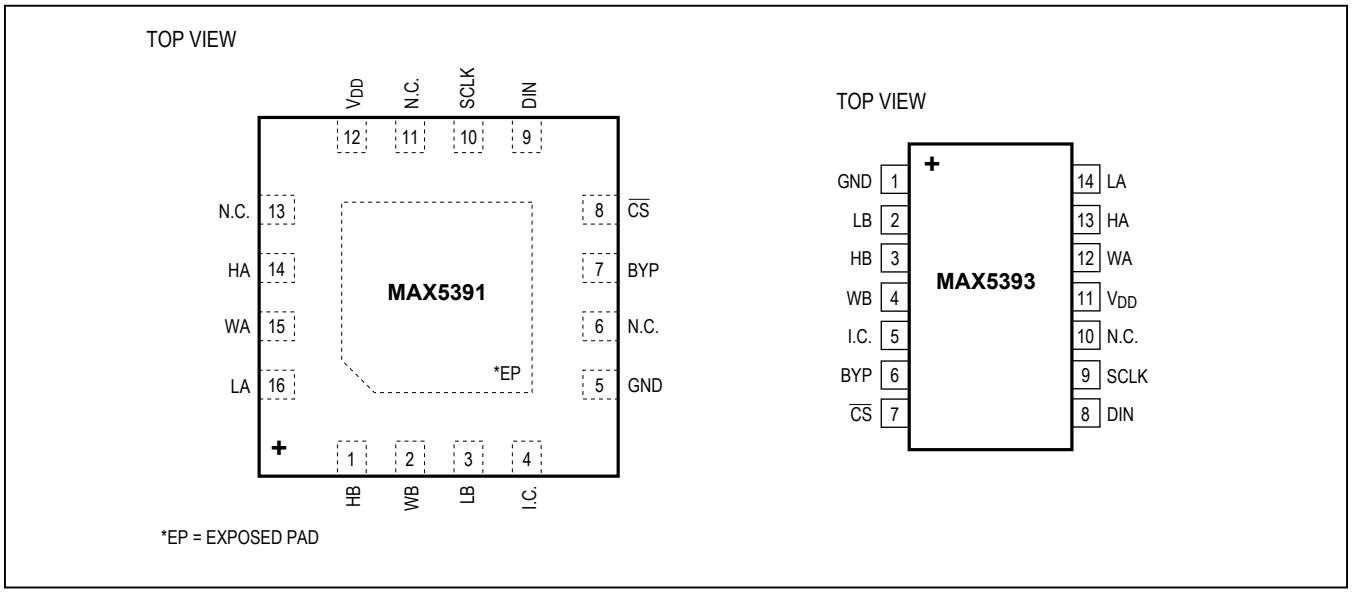
BYP RAMP vs. C_{BYP}



CHARGE-PUMP FEEDTHROUGH AT W_ vs. C_{BYP}



Pin Configurations



Pin Description

PIN		NAME	FUNCTION
MAX5391 (TQFN-EP)	MAX5393 (TSSOP)		
1	3	HB	Resistor B High Terminal. The voltage at HB can be higher or lower than the voltage at LB. Current can flow into or out of HB.
2	4	WB	Resistor B Wiper Terminal
3	2	LB	Resistor B Low Terminal. The voltage at LB can be higher or lower than the voltage at HB. Current can flow into or out of LB.
4	5	I.C.	Internally Connected. Connect to GND.
5	1	GND	Ground
6, 11, 13	10	N.C.	No Connection. Not internally connected.
7	6	BYP	Internal Power-Supply Bypass. For additional charge-pump filtering, bypass to GND with a capacitor close to the device.
8	7	$\overline{CS}$	Active-Low Chip-Select Input
9	8	DIN	Serial-Interface Data Input
10	9	SCLK	Serial-Interface Clock Input
12	11	V_{DD}	Power-Supply Input. Bypass V_{DD} to GND with a 0.1µF capacitor close to the device.
14	13	HA	Resistor A High Terminal. The voltage at HA can be higher or lower than the voltage at LA. Current can flow into or out of HA.
15	12	WA	Resistor A Wiper Terminal
16	14	LA	Resistor A Low Terminal. The voltage at LA can be higher or lower than the voltage at HA. Current can flow into or out of LA.
—	—	EP	Exposed Pad (MAX5391 Only). Connect to GND.

Detailed Description

The MAX5391/MAX5393 dual 256-tap, volatile, low-voltage linear taper digital potentiometers offer three end-to-end resistance values of 10kΩ, 50kΩ, and 100kΩ. Each potentiometer consists of 255 fixed resistors in series between terminals H_ and L_. The potentiometer wiper, W_, is programmable to access any one of the 256 tap points on the resistor string.

The potentiometers in each device are programmable independently of each other. The MAX5391/MAX5393 feature an SPI interface.

Charge Pump

The MAX5391/MAX5393 contain an internal charge pump that guarantees the maximum wiper resistance, R_{WL}, to be less then 200Ω for supply voltages down to 1.7V. Pins H_, W_, and L_ are still required to be less than V_{DD} + 0.3V. A bypass input, BYP, is provided to allow additional filtering of the charge-pump output, further reducing clock feed through that may occur on H_, W_, or L_. The nominal clock rate of the charge pump is 600kHz. BYP should remain resistively unloaded as any additional load would produce a ripple of approximately $I_{BYP}/(600kHz \times C_{BYP})$ volts. See the Charge-Pump Feedthrough at W_ vs. C_{BYP} graph in the *Typical Operating Characteristics* for C_{BYP} sizing guidelines with respect to clock feedthrough to the wiper. The value of C_{BYP} does affect the startup time of the charge pump; however, C_{BYP} does not impact the ability to communicate with the device, nor is there a minimum C_{BYP} requirement. The maximum wiper impedance specification is not guaranteed until the charge pump is fully settled. See the BYP Ramp vs. C_{BYP} graph in the *Typical Operating Characteristics* for C_{BYP} impact on charge-pump settling time.

SPI Digital Interface

The MAX5391/MAX5393 include a SPI interface that provides a 3-wire write-only serial-data interface to control the wiper tap position through inputs chip select ($\overline{CS}$), data in (DIN), and data clock (SCLK). Drive $\overline{CS}$ low to load data from DIN synchronously into the serial shift register on the rising edge of each SCLK pulse. The MAX5391/MAX5393 load the last 10 bits of clocked data into the appropriate potentiometer control register once $\overline{CS}$ transitions high. See Figures 2 and 3. Data written to a memory register immediately updates the wiper position. Keep $\overline{CS}$ low during the entire data stream to prevent the data from being terminated.

The first two bits A1:A0 (address bits) address one of the two potentiometers. See Table 1. The power-on reset (POR) circuitry sets the wiper to midscale.

Table 1. SPI Register Map

Bit Number	1	2	3	4	5	6	7	8	9	10
Bit Name	A1	A0	D7	D6	D5	D4	D3	D2	D1	D0
Write Wiper Register A	0	0	D7	D6	D5	D4	D3	D2	D1	D0
Write Wiper Register B	0	1	D7	D6	D5	D4	D3	D2	D1	D0
Write to Both A and B	1	1	D7	D6	D5	D4	D3	D2	D1	D0

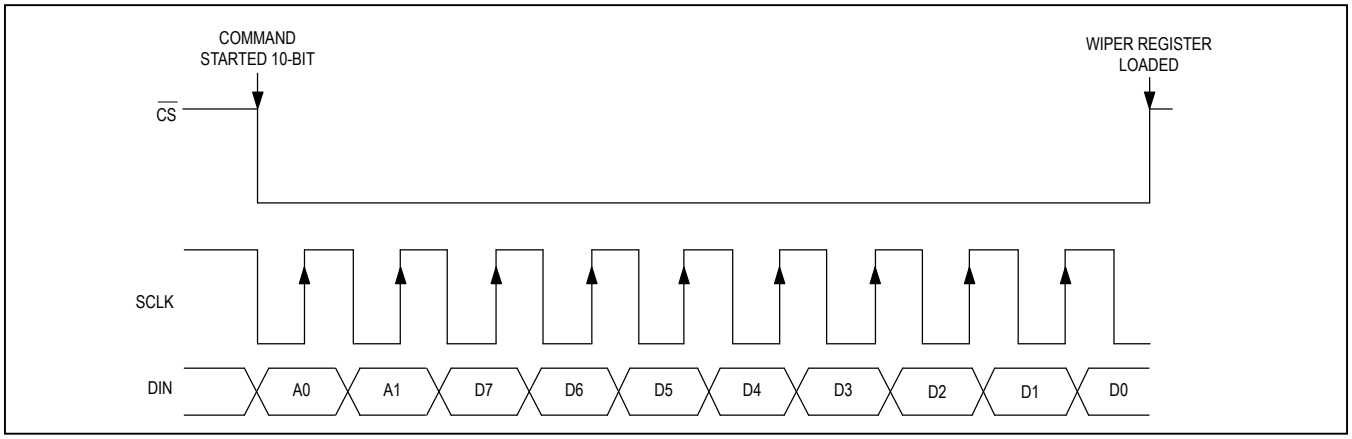


Figure 2. SPI Digital Interface Format

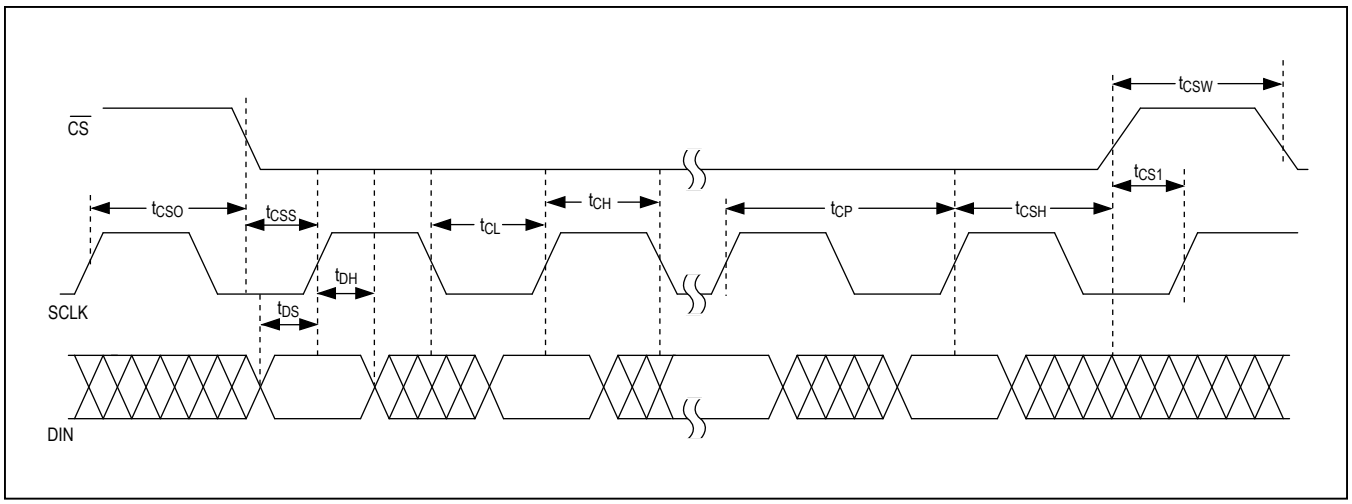


Figure 3. SPI Timing Diagram

REG A: The data byte writes to register A, and the wiper of potentiometer A moves to the appropriate position at the rising edge of $\overline{CS}$. D[7:0] indicates the position of the wiper. D[7:0] = 00h moves the wiper to the position closest to LA. D[7:0] = FFh moves the wiper closest to HA. D[7:0] is 80h following power-on.

REG B: The data byte writes to register B, and the wiper of potentiometer B moves to the appropriate position at the rising edge of $\overline{CS}$. D[7:0] indicates the position of the wiper. D[7:0] = 00h moves the wiper to the position closest to LB. D[7:0] = FFh moves the wiper to the position closest to HB. D[7:0] is 80h following power-on.

REG A and B: The data byte writes to registers A and B, and the wipers of potentiometers A and B move to the appropriate position. D[7:0] indicates the position of the wiper. D[7:0] = 00h moves the wiper to the position closest to L_. D[7:0] = FFh moves the wiper to the position closest to H_. D[7:0] is 80h following power-on.

Applications Information

Variable Gain Amplifier

Figure 4 shows a potentiometer adjusting the gain of a noninverting amplifier. Figure 5 shows a potentiometer adjusting the gain of an inverting amplifier.

Adjustable Dual Regulator

Figure 6 shows an adjustable dual linear regulator using a dual potentiometer as two variable resistors.

Adjustable Voltage Reference

Figure 7 shows an adjustable voltage reference circuit using a potentiometer as a voltage divider.

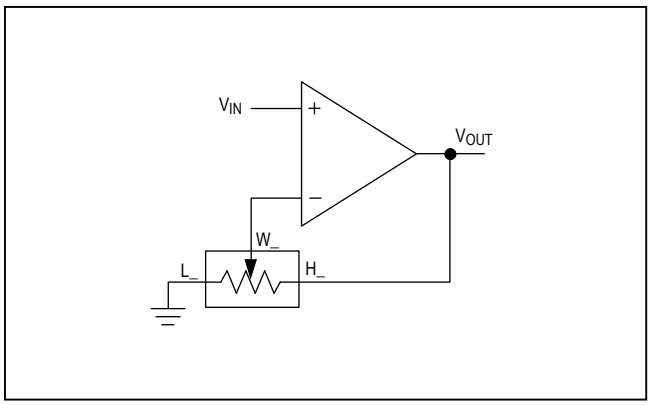


Figure 4. Variable-Gain Noninverting Amplifier

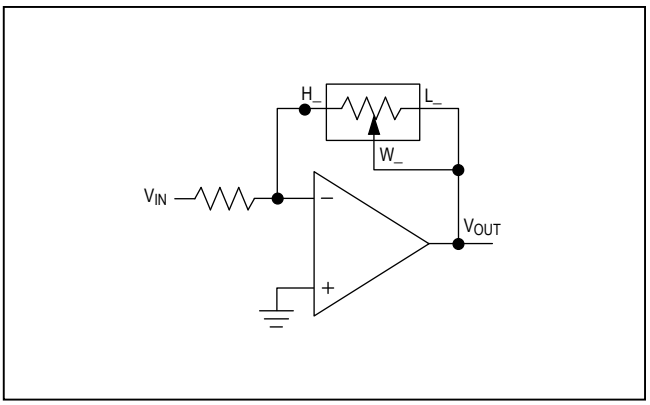


Figure 4. Variable-Gain Noninverting Amplifier

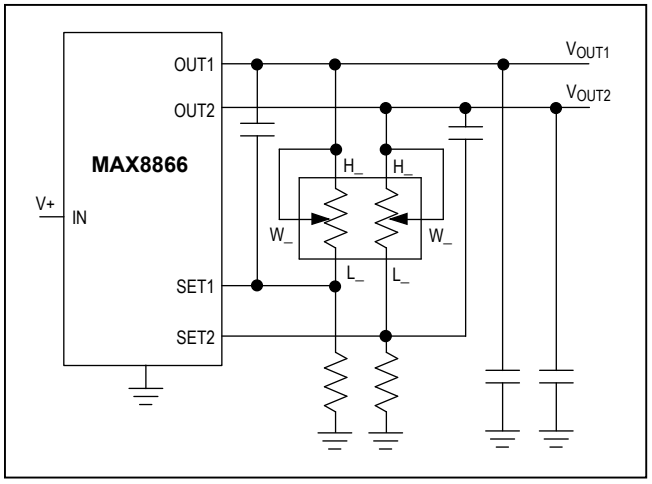


Figure 6. Adjustable Dual Linear Regulator

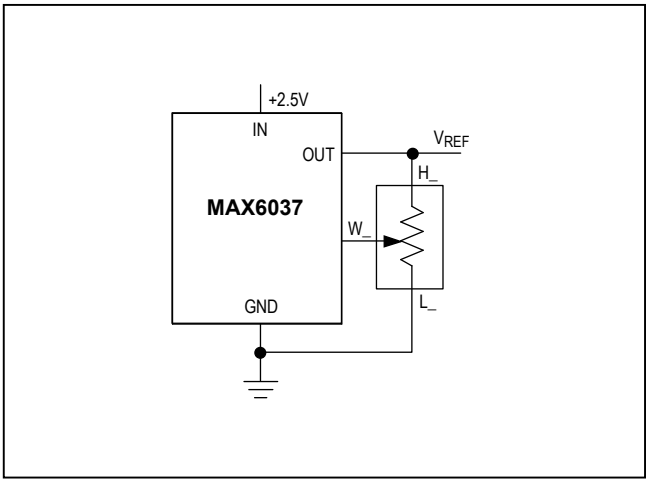


Figure 7. Adjustable Voltage Reference

Variable-Gain Current-to-Voltage Converter

Figure 8 shows a variable-gain current-to-voltage converter using a potentiometer as a variable resistor.

LCD Bias Control

Figure 9 shows a positive LCD bias control circuit using a potentiometer as a voltage-divider.

Programmable Filter

Figure 10 shows a programmable filter using a dual potentiometer.

Offset Voltage Adjustment Circuit

Figure 11 shows an offset voltage adjustment circuit using a dual potentiometer.

Chip Information

PROCESS: BiCMOS

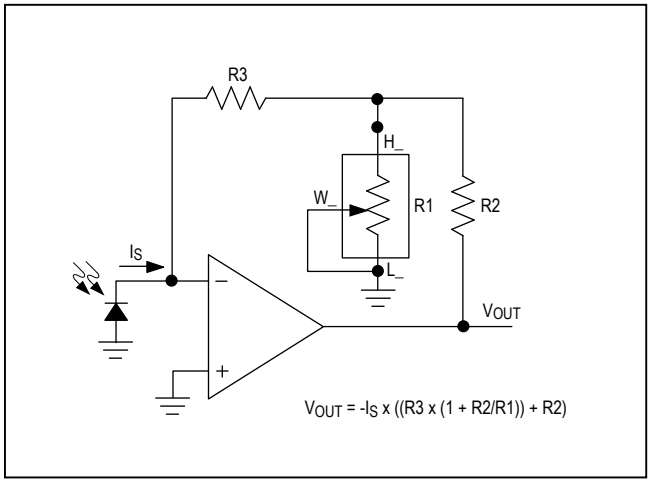


Figure 8. Variable Gain I-to-V Converter

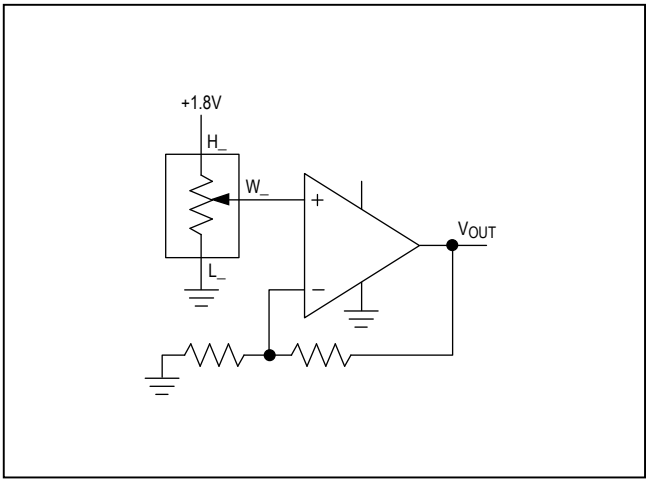


Figure 9. Positive LCD Bias Control Using a Voltage-Divider

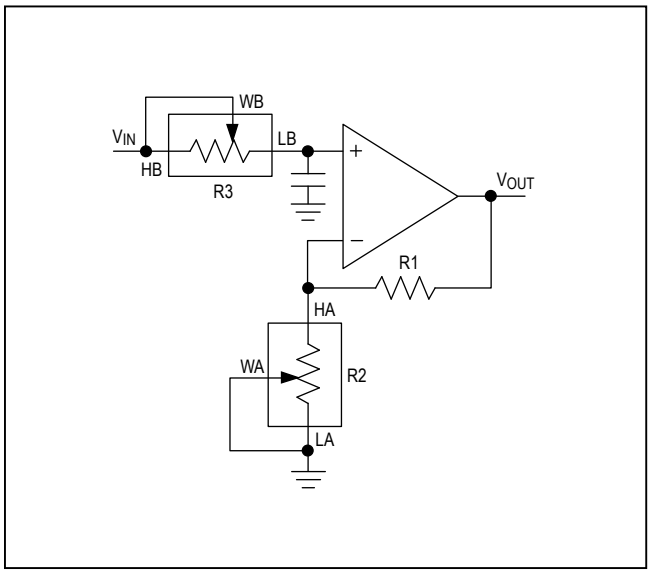


Figure 10. Programmable Filter

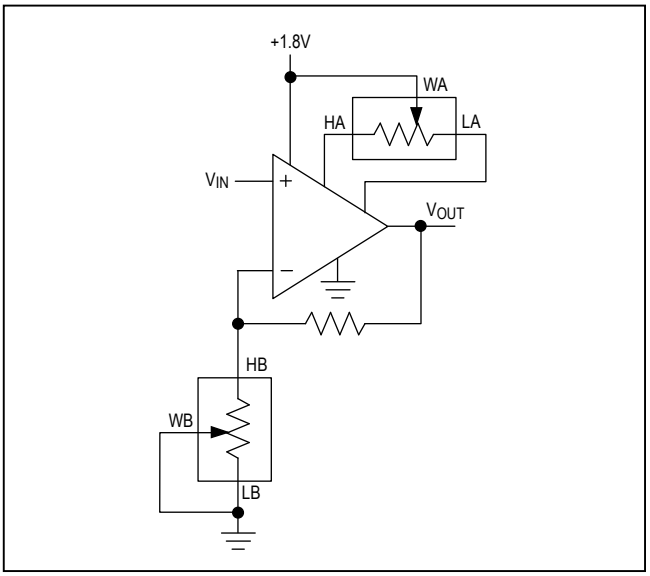


Figure 11. Offset Voltage Adjustment Circuit

Package Information

For the latest package outline information and land patterns (footprints), go to **www.maximintegrated.com/packages**. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

PACKAGE TYPE	PACKAGE CODE	OUTLINE NO.	LAND PATTERN NO.
14 TSSOP	U14+1	21-0066	90-0113
16 TQFN-EP	T1633+5	21-0136	90-0032

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	10/09	Initial release	—
1	4/10	Added Soldering Temperature in *Absolute Maximum Ratings*; corrected code in Conditions of -3dB Bandwidth specification and corrected Integral Nonlinearity specifications in *Electrical Characteristics*	2
2	11/10	Changed *Electrical Characteristics* heading and changed Figures 5, 8, 10, 11	2, 3, 11, 12
3	10/14	Removed automotive reference from *Applications* and *General Description*	1

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