19-0200; Rev. 1; 11/94

MAXIM

Calibrated, Low-Drift, +4.096V/+5V/+10V Precision Voltage References

General Description

The MAX676/MAX677/MAX678 precision +4.096V, +5V, and +10V voltage references feature a factory-programmed on-chip ROM that calibrates each reference at specific temperatures, and reduces the temperature drift to less than 1ppm/°C over temperature—the lowest in the industry.

The MAX676/MAX677/MAX678 have excellent line and load regulation: 30ppm/V and 3ppm/mA, respectively. Load regulation specifications are guaranteed for source currents up to 5mA and sink currents up to 500µA. The 4.096V MAX676 operates from a supply voltage as low as 4.75V, making it an ideal reference for single 5V, high resolution ADCs.

Applications

High Resolution 16-Bit ADCs and DACs

Precision Test and Measurement Systems

Precision, Calibrated Voltage-Reference Standard

High-Accuracy Transducers

Features

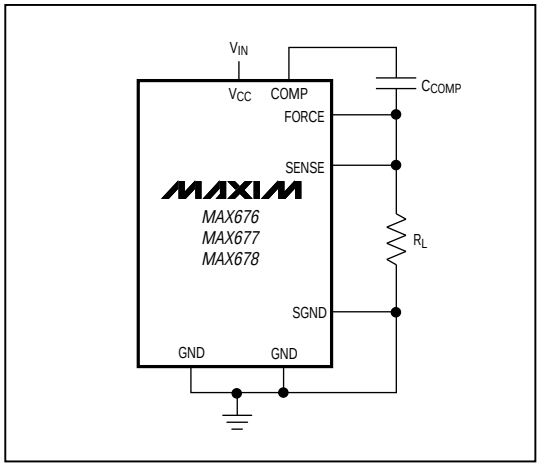
- ♦ **Lowest Temperature Drift:**
  1ppm/°C Max Over -40°C to +85°C
  1.5ppm/°C Max Over -55°C to +125°C
- ♦ **0.02% Initial Accuracy**
- ♦ **3ppm/mA Max Load Regulation**
- ♦ **30ppm/V Max Line Regulation**
- ♦ **4.096V Reference Operates from 5V ±5% Supply**
- ♦ **Available in Surface-Mount Package**

Ordering Information

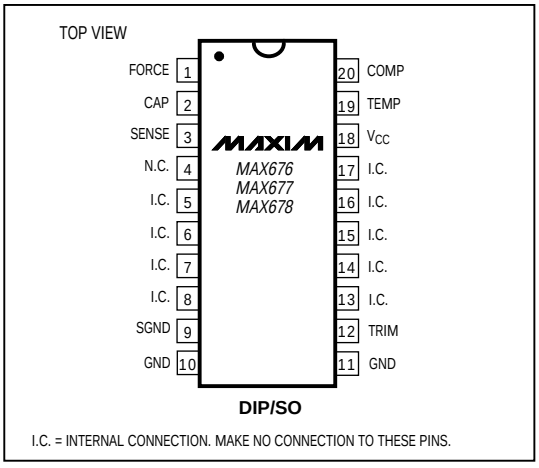
PART	TEMP. RANGE	PIN-PACKAGE	MAX DRIFT (ppm/°C)
MAX676ACPP	0°C to +70°C	20 Plastic DIP	1.0
MAX676BCPP	0°C to +70°C	20 Plastic DIP	2.0
MAX676ACWP	0°C to +70°C	20 Wide SO	1.0
MAX676BCWP	0°C to +70°C	20 Wide SO	2.0
MAX676ACJP	0°C to +70°C	20 CERDIP	1.0
MAX676AEPP	-40°C to +85°C	20 Plastic DIP	1.0
MAX676BEPP	-40°C to +85°C	20 Plastic DIP	2.0
MAX676AEWP	-40°C to +85°C	20 Wide SO	1.0
MAX676BEWP	-40°C to +85°C	20 Wide SO	2.0
MAX676AEJP	-40°C to +85°C	20 CERDIP	1.0
MAX676AMJP	-55°C to +125°C	20 CERDIP	1.5
MAX676BMJP	-55°C to +125°C	20 CERDIP	3.0

Ordering Information continued on last page.

Typical Operating Circuit



Pin Configuration



DIP/SO

I.C. = INTERNAL CONNECTION. MAKE NO CONNECTION TO THESE PINS.

Calibrated, Low-Drift, +4.096V/+5V/+10V Precision Voltage References

ABSOLUTE MAXIMUM RATINGS

V_{CC} to GND .....-0.3V, +20V
Output Short-Circuit Duration (to GND or V_{CC}) .....Continuous
Voltage at Any Pin .....(GND - 0.3V), (V_{CC} + 0.3V)
Current into Any Pin.....±50mA
Continuous Power Dissipation (T_A = +70°C)
Plastic DIP (derate 11.11mW/°C above +70°C) 889mW
SO (derate 10.00mW/°C above +70°C).....800mW
CERDIP (derate 11.11mW/°C above +70°C).....889mW

Operating Temperature Ranges:
MAX67_ _C_P .....0°C to +70°C
MAX67_ _E_P .....-40°C to +85°C
MAX67_ _MJP .....-55°C to +125°C
Storage Temperature Range.....-65°C to +160°C
Lead Temperature (soldering, 10sec).....+300°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—MAX676

(V_{CC} = +5V, I_L = 0mA, T_A = +25°C, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS			MIN	TYP	MAX	UNITS
Output Voltage	V_{OUT}	T_A = +25°C			4.0952	4.0960	4.0968	V
		$T_A = T_{MIN}$ to T_{MAX}		MAX676AC	4.09491		4.09709	
				MAX676BC	4.09463		4.09737	
				MAX676AE	4.09469		4.09731	
				MAX676BE	4.09418		4.09782	
				MAX676AM	4.09409		4.09791	
				MAX676BM	4.09299		4.09901	
Output Voltage Drift (Note 1)	TCV_{OUT}	$T_A = T_{MIN}$ to T_{MAX}		MAX676AC/AE		0.6	1.0	ppm/°C
				MAX676BC/BE		1.2	2.0	
				MAX676AM		0.8	1.5	
				MAX676BM		1.5	3.0	
Long-Term Output Drift		MAX676A_JP (CERDIP only)				5	20	ppm/khrs
		MAX676 (all other packages)				25		
Load Regulation		T_A = +25°C		I_L = 0mA to 2mA		1	3	ppm/mA
				I_L = 0mA to 5mA		5	10	
				I_L = 0mA to -0.5mA		5	20	
		$T_A = T_{MIN}$ to T_{MAX}	MAX676_C	I_L = 0mA to 2mA			10	
				I_L = 0mA to -0.5mA			30	
			MAX676_E	I_L = 0mA to 2mA			10	
				I_L = 0mA to -0.5mA			30	
			MAX676_M	I_L = 0mA to 2mA			15	
				I_L = 0mA to -0.5mA			50	
Line Regulation		T_A = +25°C, 4.75V ≤ V_{CC} ≤ 18V				8	30	ppm/V
		$T_A = T_{MIN}$ to T_{MAX}, 4.75V ≤ V_{CC} ≤ 18V		MAX676_C			35	
				MAX676_E			35	
				MAX676_M			35	
Quiescent Supply Current	I_Q	T_A = +25°C				5	10	mA
		$T_A = T_{MIN}$ to T_{MAX}		MAX676_C			12	
				MAX676_E			12	
				MAX676_M			14	
Output Noise Voltage	e_n	0.1Hz to 10Hz				1.2		µVp-p
		10Hz to 1kHz (CAP pin open)				4		μV_{RMS}
Short-Circuit Output Current	I_{SC}	Output shorted to GND				15		mA
Turn-On Settling Time		To 0.01%				100		µs
Output Voltage Adjust Range							±2	mV
TEMP PIN								
Voltage Output						1.8		V
Temperature Sensitivity						6.0		mV/°C

ELECTRICAL CHARACTERISTICS—MAX677

(V_{CC} = +15V, I_L = 0mA, T_A = +25°C, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS			MIN	TYP	MAX	UNITS
Output Voltage	V_{OUT}	T_A = +25°C			4.9990	5.0000	5.0010	V
		$T_A = T_{MIN}$ to T_{MAX}		MAX677AC	4.99865		5.00135	
				MAX677BC	4.99830		5.00170	
				MAX677AE	4.99837		5.00163	
				MAX677BE	4.99775		5.00225	
				MAX677AM	4.99765		5.00235	
				MAX677BM	4.99630		5.00370	
Output Voltage Drift (Note 1)	TCV_{OUT}	$T_A = T_{MIN}$ to T_{MAX}		MAX677AC/AE		0.6	1.0	ppm/°C
				MAX677BC/BE		1.2	2.0	
				MAX677AM		0.8	1.5	
				MAX677BM		1.5	3.0	
Long-Term Output Drift		MAX677A_JP (CERDIP only)				5	20	ppm/khr
		MAX677 (all other packages)				25		
Load Regulation		T_A = +25°C		I_L = 0mA to 2mA		1	3	ppm/mA
				I_L = 0mA to 5mA		5.6	10	
				I_L = 0mA to -0.5mA		5	20	
		$T_A = T_{MIN}$ to T_{MAX}	MAX677_C	I_L = 0mA to 2mA			10	
				I_L = 0mA to -0.5mA			30	
			MAX677_E	I_L = 0mA to 2mA			10	
				I_L = 0mA to -0.5mA			30	
			MAX677_M	I_L = 0mA to 2mA			15	
				I_L = 0mA to -0.5mA			50	
Line Regulation		T_A = +25°C, 8V ≤ V_{CC} ≤ 18V				8	30	ppm/V
		$T_A = T_{MIN}$ to T_{MAX}		MAX677_C			35	
				MAX677_E			35	
				MAX677_M			35	
Quiescent Supply Current	I_Q	T_A = +25°C				6.5	10	mA
		$T_A = T_{MIN}$ to T_{MAX}		MAX677_C			12	
				MAX677_E			12	
				MAX677_M			14	
Output Noise Voltage	e_n	0.1Hz to 10Hz				1.5		µVp-p
		10Hz to 1kHz (CAP pin open)				5		$µV_{RMS}$
Short-Circuit Output Current	I_{SC}	Output shorted to GND				15		mA
Turn-On Settling Time		To 0.01%				100		µs
Output Voltage Adjust Range							±2.5	mV
TEMP PIN								
Voltage Output						1.8		V
Temperature Sensitivity						6.0		mV/°C

ELECTRICAL CHARACTERISTICS—MAX678

(V_{CC} = +15V, I_L = 0mA, T_A = +25°C, unless otherwise noted.)

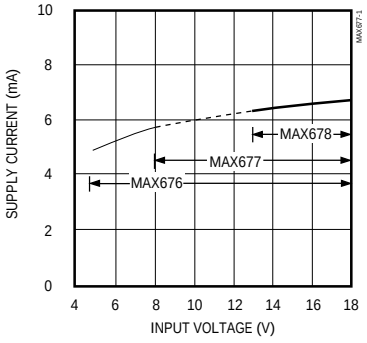
PARAMETER	SYMBOL	CONDITIONS			MIN	TYP	MAX	UNITS
Output Voltage	V_{OUT}	T_A = +25°C			9.9980	10.0000	10.0020	V
		T_A = T_{MIN} to T_{MAX}		MAX678AC	9.9973		10.0027	
				MAX678BC	9.9966		10.0034	
				MAX678AE	9.9967		10.0033	
				MAX678BE	9.9955		10.0045	
				MAX678AM	9.9953		10.0047	
				MAX678BM	9.9926		10.0074	
Output Voltage Drift (Note 1)	TCV_{OUT}	T_A = T_{MIN} to T_{MAX}		MAX678AC/AE		0.6	1.0	ppm/°C
				MAX678BC/BE		1.2	2.0	
				MAX678AM		0.8	1.5	
				MAX678BM		1.5	3.0	
Long-Term Output Drift		MAX678A_JP (CERDIP only)				5	20	ppm/khrs
		MAX678 (all other packages)				25		
Load Regulation		T_A = +25°C		I_L = 0mA to 2mA		1	3	ppm/mA
				I_L = 0mA to 5mA		5.6	10	
				I_L = 0mA to -0.5mA		5	20	
		T_A = T_{MIN} to T_{MAX}	MAX678_C	I_L = 0mA to 2mA			10	
				I_L = 0mA to -0.5mA			30	
			MAX678_E	I_L = 0mA to 2mA			10	
				I_L = 0mA to -0.5mA			30	
			MAX678_M	I_L = 0mA to 2mA			20	
				I_L = 0mA to -0.5mA			100	
Line Regulation		T_A = +25°C, 13V ≤ V_{CC} ≤ 18V				8	35	ppm/V
		T_A = T_{MIN} to T_{MAX}		MAX678_C			40	
				MAX678_E			40	
				MAX678_M			45	
Quiescent Supply Current	I_Q	T_A = +25°C				6.5	10	mA
		T_A = T_{MIN} to T_{MAX}		MAX678_C			12	
				MAX678_E			12	
				MAX678_M			14	
Output Noise Voltage	e_n	0.1Hz to 10Hz				3		µVp-p
		10Hz to 1kHz (CAP pin open)				10		$µV_{RMS}$
Short-Circuit Output Current	I_{SC}	Output shorted to GND				15		mA
Turn-On Settling Time		To 0.01%				100		µs
Output Voltage Adjust Range							±5	mV
TEMP PIN								
Voltage Output						1.8		V
Temperature Sensitivity						6.0		mV/°C

Note 1: Temperature coefficient is determined by the "box" method using the following formula: $\frac{V_{MAX} - V_{MIN}}{V_{NOMINAL} \times (T_{MAX} - T_{MIN})}$

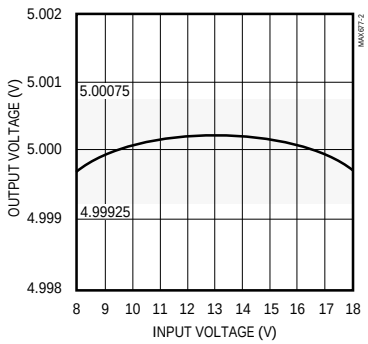
Typical Operating Characteristics

(V_{CC} = +5V (MAX676), V_{CC} = +15V (MAX677/MAX678), I_L = 0mA, C_L < 100pF, T_A = +25°C, unless otherwise noted.)

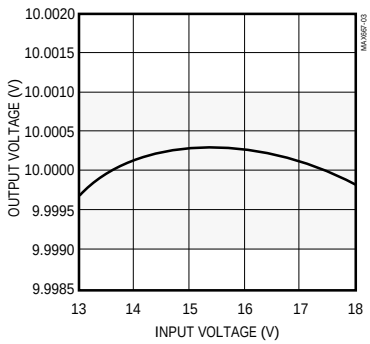
SUPPLY CURRENT vs. INPUT VOLTAGE



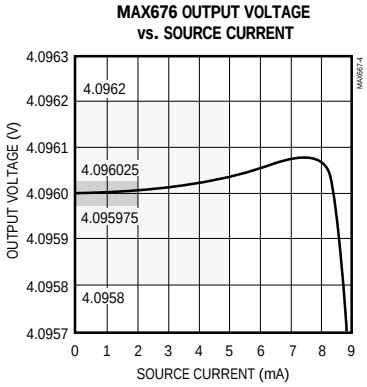
MAX677 OUTPUT VOLTAGE vs. INPUT VOLTAGE



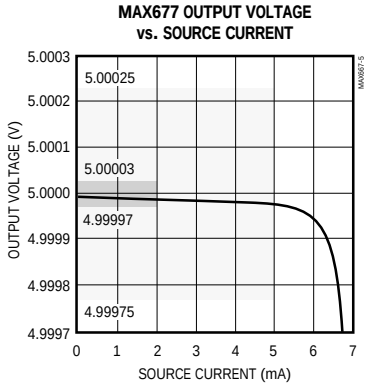
MAX678 OUTPUT VOLTAGE vs. INPUT VOLTAGE



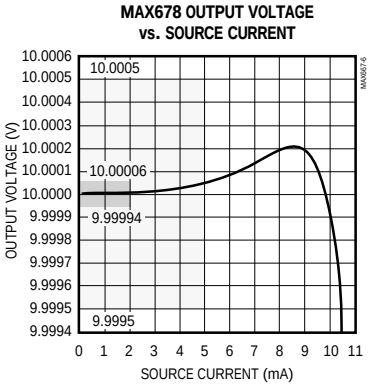
MAX676 OUTPUT VOLTAGE vs. SOURCE CURRENT



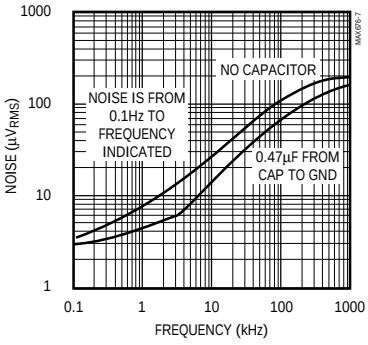
MAX677 OUTPUT VOLTAGE vs. SOURCE CURRENT



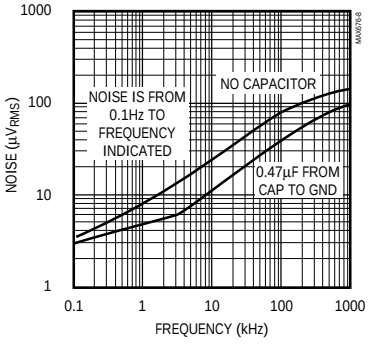
MAX678 OUTPUT VOLTAGE vs. SOURCE CURRENT



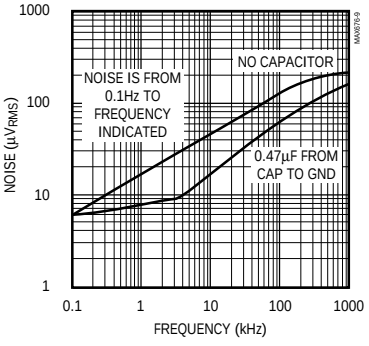
MAX676 WIDEBAND OUTPUT NOISE vs. BANDWIDTH



MAX677 WIDEBAND OUTPUT NOISE vs. BANDWIDTH



MAX678 WIDEBAND OUTPUT NOISE vs. BANDWIDTH

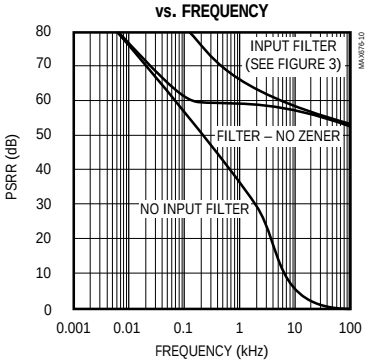


Calibrated, Low-Drift, +4.096V/+5V/+10V Precision Voltage References

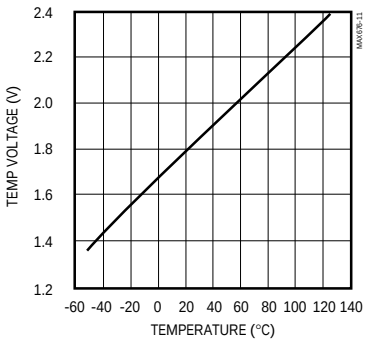
Typical Operating Characteristics (continued)

(V_{CC} = +5V (MAX676), V_{CC} = +15V (MAX677/MAX678), I_L = 0mA, C_L < 100pF, T_A = +25°C, unless otherwise noted.)

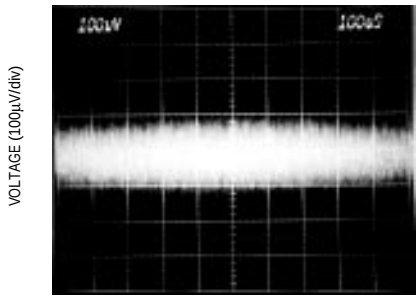
POWER-SUPPLY REJECTION RATIO vs. FREQUENCY



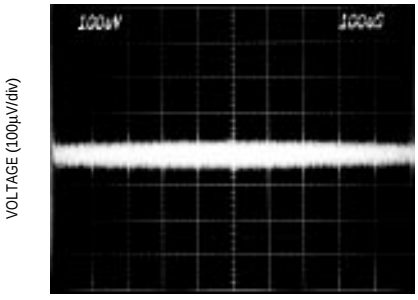
TEMP PIN VOLTAGE vs. TEMPERATURE



WIDEBAND OUTPUT NOISE (CAP PIN OPEN)



WIDEBAND OUTPUT NOISE (CAP PIN = 0.47µF)



Pin Description

PIN	NAME	FUNCTION
1	FORCE	Output voltage force connection. This pin drives the load.
2	CAP	Optional capacitor connection for wideband noise reduction. Leave open if unused.
3	SENSE	Output voltage sense is connected at the load and maintains the voltage to the load at the reference voltage.
4	N.C.	No Connect. Not internally connected.
5, 6, 7, 8, 13, 14, 15, 16, 17	I.C.	Internal Connection. Make no connection to these pins.
9	SGND	Ground sense for the bandgap reference. The reference voltage is calibrated between SENSE and SGND.
10, 11	GND	Main ground pins. Connect both pins to ground.
12	TRIM	Used for trimming the reference voltage to a value slightly higher or lower than the nominal value. The output can be adjusted ±0.05% without affecting the drift specification. Leave open if unused.
18	V_{CC}	Supply-voltage connection
19	TEMP	Temperature voltage output. This pin provides a voltage proportional to ambient temperature. The nominal value is 1.8V at +25°C, with a typical temperature coefficient of 6mV/°C. Leave open if unused.
20	COMP	A compensation capacitor is required at this pin to compensate the output amplifier of the reference. The recommended value is 4.7nF.

Detailed Description

The MAX676/MAX677/MAX678 include a 1.2V bandgap reference and an amplifier, and provide outputs of 4.096V, 5V, and 10V. Ideally, the bandgap reference does not vary with temperature. In practice, however, some temperature coefficient exists. The MAX676/MAX677/MAX678 significantly reduce this remaining variation using an “analog ROM” that adds or subtracts a small voltage from the reference, depending on the device’s temperature. During production, each device is tested and calibrated at 16 temperatures to minimize the output error over the entire operating temperature range.

A conventional voltage reference may have a linear, bow-shaped, or S-shaped temperature characteristic. Due to the internal ROM’s action, the MAX676/MAX677/MAX678 can have a distinctly different temperature characteristic from that of other references. The calibration algorithm, which minimizes the output error over temperature, gives each device a unique voltage profile over temperature, always staying close to the desired output voltage. A graph of output voltage vs. temperature for a MAX677, along with the pre-calibration performance, is given in Figure 1. The pre-calibration performance is seen at the factory, and cannot be observed on finished units.

Calibrated, Low-Drift, +4.096V/+5V/+10V Precision Voltage References

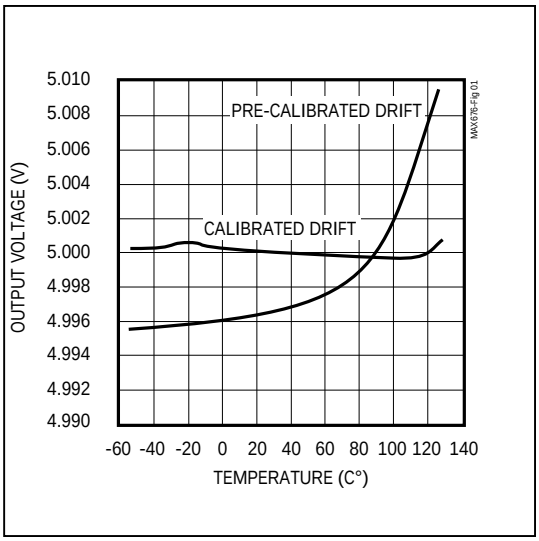


Figure 1. MAX677 Temperature Drift

Applications Information

Input Bypassing

For best transient performance, decouple the input using a 4.7µF to 10µF tantalum or electrolytic capacitor in parallel with a 0.01µF to 0.1µF ceramic capacitor as shown in Figure 2. Where transient performance is less important, a single 0.1µF ceramic suffices.

Input Filter for High-Frequency Noise

Typically, the MAX676/MAX677/MAX678 references will be used with other sensitive analog components and will have a high-quality, low-noise power supply. However, it may be necessary or desirable to use these references with a noisy switching power supply or a supply contaminated with switching noise from digital components. In this situation, Figure 3's circuit provides excellent noise rejection, at the expense of some input voltage headroom and supply current.

If the load does not vary, the zener, which prevents load variations from causing additional impact as line variations, may be omitted. The Power-Supply Rejection Ratio vs. Frequency graph in the *Typical Operating Characteristics* shows how the zener provides better low-frequency rejection than the same filter without the zener. The zener voltage (V_Z) should be less than the minimum level of the input voltage without the zener present. This voltage is given by:

$$V_Z \le V_{IN}(min) - (I_Q + I_{LOAD})(R_S).$$

Output Bypassing

These devices function well without output bypassing, but the output should be bypassed if there are rapid changes in load current, such as those caused by sampling ADCs. A 0.1µF ceramic capacitor may be used alone or in parallel with up to a 10µF tantalum or electrolytic capacitor for improved load-transient performance.

Output-Voltage Trimming

With the addition of a potentiometer as shown in Figure 4, the TRIM input can be used to adjust the output voltage. The trim range is ±2mV for the MAX676, ±2.5mV for the MAX677, and ±5mV for the MAX678. The reference temperature coefficient is unaffected by trimming within these ranges.

Compensation

The MAX676/MAX677/MAX678's output amplifier requires a compensation capacitor for stable operation. 4.7nF is recommended, although any value from 2.2nF through 100nF may be used. Values smaller than 2.2nF can result in instability at very cold temperatures, while large values may decrease high-frequency power-supply noise rejection.

CAP Pin Noise Filter

The CAP input connects to an internal node located between the bandgap reference and the output amplifier (Figure 5). Connecting a capacitor to this pin effectively forms a low-pass filter with the internal 1.5kΩ resistor, reducing noise from the bandgap reference (see the Wideband Output Noise vs. Bandwidth graph in the *Typical Operating Characteristics*.) A low-leakage capacitor must be used. Leave unconnected if unused.

Temperature Measurement with TEMP Output

The TEMP output provides a voltage proportional to ambient temperature. This information may be used to control LCD contrast, or to provide ADC gain compensation or thermal out-of-range indication. TEMP must be buffered or connected to a high-impedance input. Leave unconnected if unused.

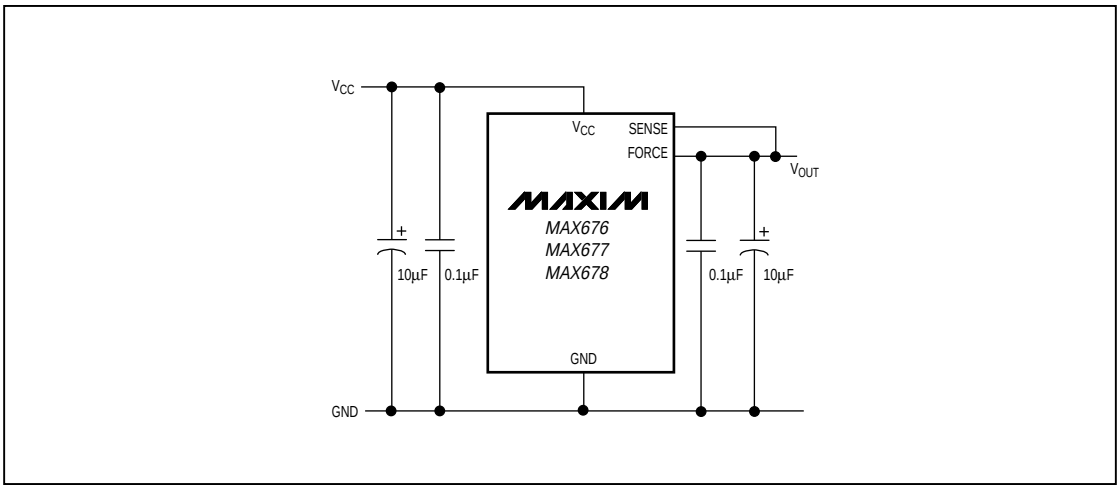


Figure 2. Recommended Input and Output Bypassing (other pin connections omitted for clarity)

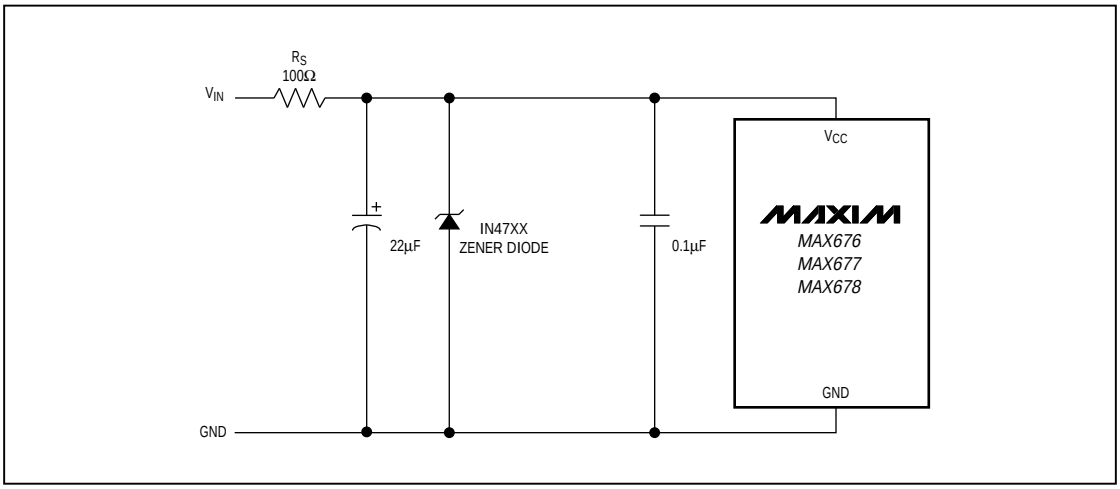
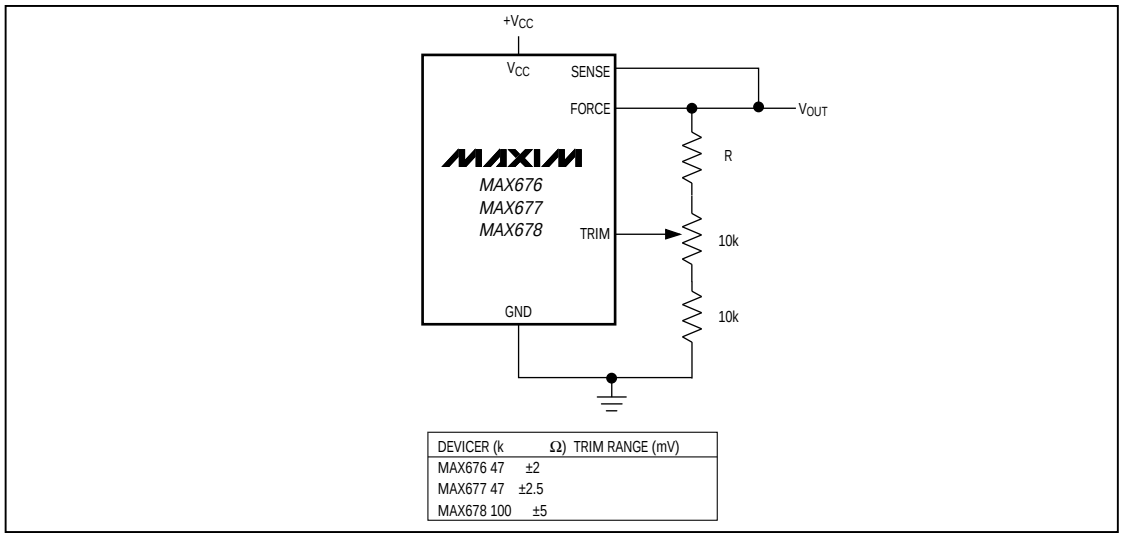


Figure 3. Input Filter for Improved High-Frequency Supply Rejection

Calibrated, Low-Drift, +4.096V/+5V/+10V Precision Voltage References



DEVICER (k	Ω) TRIM RANGE (mV)
MAX676 47	±2
MAX677 47	±2.5
MAX678 100	±5

Figure 4. Adjusting V_{OUT} with the TRIM input (other pin connections omitted for clarity)

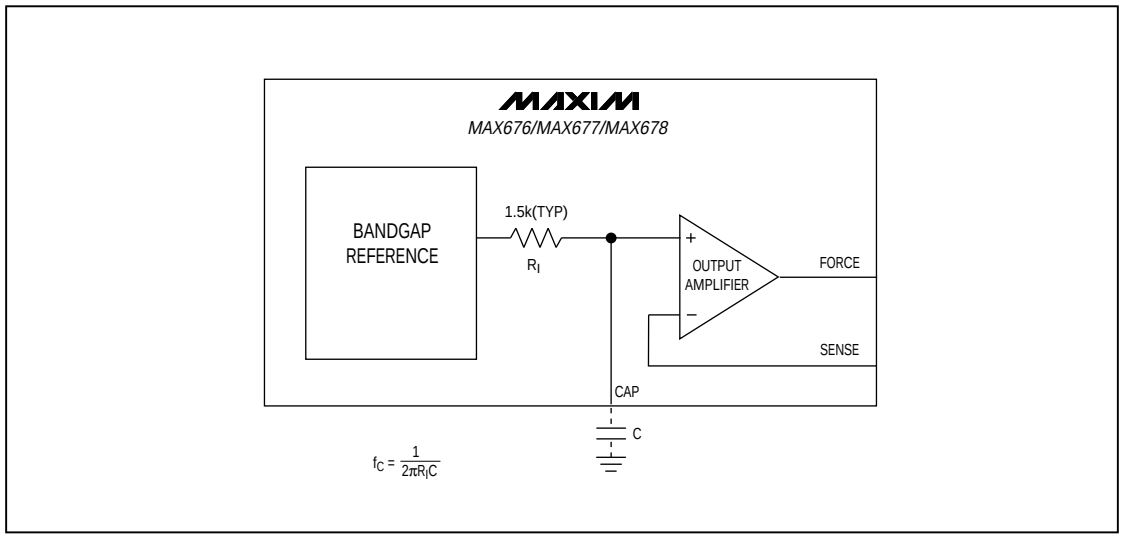


Figure 5. External Capacitor for Reference Noise Reduction

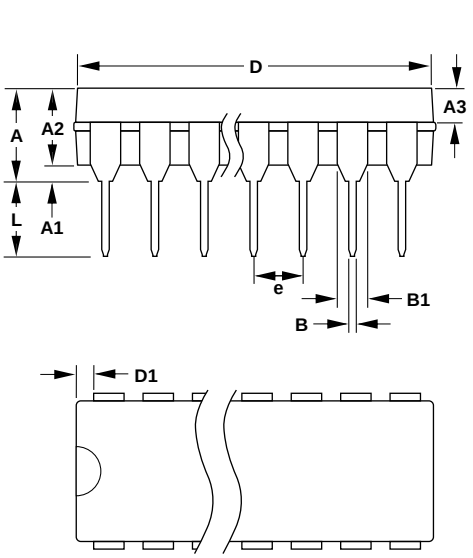
Ordering Information (continued)

PART	TEMP. RANGE	PIN-PACKAGE	MAX DRIFT (ppm/°C)
MAX677ACPP	0°C to +70°C	20 Plastic DIP	1.0
MAX677BCPP	0°C to +70°C	20 Plastic DIP	2.0
MAX677ACWP	0°C to +70°C	20 Wide SO	1.0
MAX677BCWP	0°C to +70°C	20 Wide SO	2.0
MAX677ACJP	0°C to +70°C	20 CERDIP	1.0
MAX677AEPP	-40°C to +85°C	20 Plastic DIP	1.0
MAX677BEPP	-40°C to +85°C	20 Plastic DIP	2.0
MAX677AEWP	-40°C to +85°C	20 Wide SO	1.0
MAX677BEWP	-40°C to +85°C	20 Wide SO	2.0
MAX677AEJP	-40°C to +85°C	20 CERDIP	1.0
MAX677AMJP	-55°C to +125°C	20 CERDIP	1.5
MAX677BMJP	-55°C to +125°C	20 CERDIP	3.0
MAX678ACPP	0°C to +70°C	20 Plastic DIP	1.0
MAX678BCPP	0°C to +70°C	20 Plastic DIP	2.0
MAX678ACWP	0°C to +70°C	20 Wide SO	1.0
MAX678BCWP	0°C to +70°C	20 Wide SO	2.0
MAX678ACJP	0°C to +70°C	20 CERDIP	1.0
MAX678AEPP	-40°C to +85°C	20 Plastic DIP	1.0
MAX678BEPP	-40°C to +85°C	20 Plastic DIP	2.0
MAX678AEWP	-40°C to +85°C	20 Wide SO	1.0
MAX678BEWP	-40°C to +85°C	20 Wide SO	2.0
MAX678AEJP	-40°C to +85°C	20 CERDIP	1.0
MAX678AMJP	-55°C to +125°C	20 CERDIP	1.5
MAX678BMJP	-55°C to +125°C	20 CERDIP	3.0

TRANSISTOR COUNT: 1465

Calibrated, Low-Drift, +4.096V/+5V/+10V Precision Voltage References

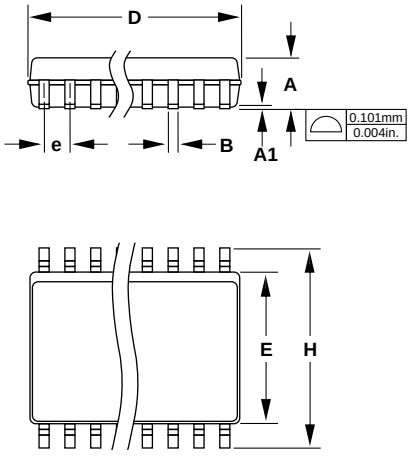
Package Information



Plastic DIP
PLASTIC
DUAL-IN-LINE
PACKAGE
(0.300 in.)

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	–	0.200	–	5.08
A1	0.015	–	0.38	–
A2	0.125	0.175	3.18	4.45
A3	0.055	0.080	1.40	2.03
B	0.016	0.022	0.41	0.56
B1	0.045	0.065	1.14	1.65
C	0.008	0.012	0.20	0.30
D1	0.005	0.080	0.13	2.03
E	0.300	0.325	7.62	8.26
E1	0.240	0.310	6.10	7.87
e	0.100	–	2.54	–
eA	0.300	–	7.62	–
eB	–	0.400	–	10.16
L	0.115	0.150	2.92	3.81

DIM	PINS	INCHES		MILLIMETERS	
		MIN	MAX	MIN	MAX
D	8	0.348	0.390	8.84	9.91
D	14	0.735	0.765	18.67	19.43
D	16	0.745	0.765	18.92	19.43
D	18	0.885	0.915	22.48	23.24
D	20	1.015	1.045	25.78	26.54
D	24	1.14	1.265	28.96	32.13



Wide SO
SMALL OUTLINE
PACKAGE
(0.300 in.)

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.093	0.104	2.35	2.65
A1	0.004	0.012	0.10	0.30
B	0.014	0.019	0.35	0.49
C	0.009	0.013	0.23	0.32
E	0.291	0.299	7.40	7.60
e	0.050		1.27	
H	0.394	0.419	10.00	10.65
L	0.016	0.050	0.40	1.27

DIM	PINS	INCHES		MILLIMETERS	
		MIN	MAX	MIN	MAX
D	16	0.398	0.413	10.10	10.50
D	18	0.447	0.463	11.35	11.75
D	20	0.496	0.512	12.60	13.00
D	24	0.598	0.614	15.20	15.60
D	28	0.697	0.713	17.70	18.10

21-0042A