19-0020; Rev 0; 6/92

MAXIM

8th-Order, Lowpass, Elliptic, Switched-Capacitor Filters

MAX293/MAX294/MAX297

General Description

The MAX293/MAX294/MAX297 are easy-to-use, 8th-order, lowpass, elliptic, switched-capacitor filters that can be set up with corner frequencies from 0.1Hz to 25kHz (MAX293/MAX294) or from 0.1Hz to 50kHz (MAX297).

The MAX293/MAX297's 1.5 transition ratio provides sharp rolloff and -80dB of stopband rejection. The MAX294's 1.2 transition ratio provides the steepest rolloff and -58dB of stopband rejection. All three filters have fixed responses, so the design task is limited to selecting the clock frequency that controls the filter's corner frequency.

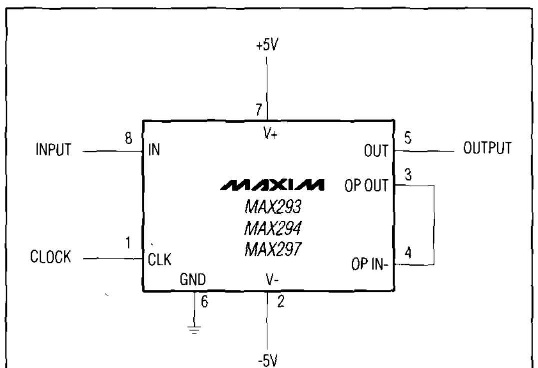
An external capacitor is used to generate a clock using the internal oscillator, or an external clock signal can be used. An uncommitted op amp (noninverting input grounded) is provided for building a continuous-time lowpass filter for post-filtering or anti-aliasing. Steep rolloff and high order make these filters ideal for anti-aliasing applications that require maximum bandwidth, and for communication applications that require filtering signals in close proximity within the frequency domain.

The MAX293/MAX294/MAX297 are available in 8-pin DIP and 16-pin wide SO packages, delivering aggressive performance from a tiny area.

Applications

Data-Acquisition Systems
Anti-Aliasing
DAC Post-Filtering
Voice/Data Signal Filtering

Typical Operating Circuit



PIN CONFIGURATION IS 8-PIN DIP.

Features

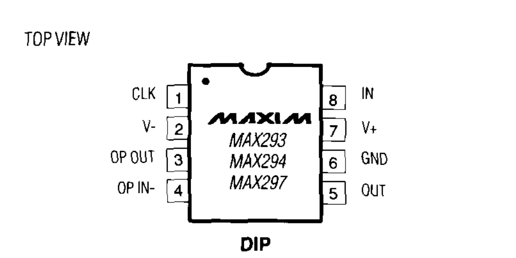
- ♦ **8th-Order Lowpass Elliptic Filters**
- ♦ **Clock-Tunable Corner-Frequency Range:**
  0.1Hz to 25kHz (MAX293/MAX294)
  0.1Hz to 50kHz (MAX297)
- ♦ **No External Resistors or Capacitors Required**
- ♦ **Internal or External Clock**
- ♦ **Clock to Corner Frequency Ratio:**
  100:1 (MAX293/294)
  50:1 (MAX297)
- ♦ **Operate with a Single +5V Supply or Dual ±5V Supplies**
- ♦ **Uncommitted Op Amp for Anti-Aliasing or Clock-Noise Filtering**
- ♦ **8-Pin DIP and 16-Pin Wide SO Packages**

Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX293CPA	0°C to +70°C	8 Plastic DIP
MAX293CWE	0°C to +70°C	16 Wide SO
MAX293C/D	0°C to +70°C	Dice*
MAX293EPA	-40°C to +85°C	8 Plastic DIP
MAX293EWE	-40°C to +85°C	16 Wide SO
MAX293MJA	-55°C to +125°C	8 CERDIP**
MAX294CPA	0°C to +70°C	8 Plastic DIP
MAX294CWE	0°C to +70°C	16 Wide SO
MAX294C/D	0°C to +70°C	Dice*

Ordering Information continued on last page.
* *Contact factory for dice specifications.*
** *Contact factory for availability and processing to MIL-STD-883.*

Pin Configurations



Wide SO on last page

8th-Order, Lowpass, Elliptic, Switched-Capacitor Filters

ABSOLUTE MAXIMUM RATINGS

Supply Voltage (V+ to V-) 12V
Input Voltage at Any Pin . . . . (V- - 0.3V) ≤ V_{IN} ≤ (V+ + 0.3V)
Continuous Power Dissipation
8-Pin Plastic DIP (derate 9.09mW/°C above +70°C) . . .727mW
16-Pin Wide SO (derate 9.52mW/°C above +70°C) . . .762mW
8-Pin CERDIP (derate 8.00mW/°C above +70°C) 640mW

Operating Temperature Ranges:
MAX29_C_ . . . . 0°C to +70°C
MAX29_E_ . . . . -40°C to +85°C
MAX29_MJA . . . . -55°C to +125°C
Storage Temperature Range . . . . -65°C to +160°C
Lead Temperature (soldering, 10 sec) . . . . +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

(V+ = 5V, V- = -5V, filter output measured at OUT pin, 20kΩ load resistor to ground at OUT, f_{CLK} = 100kHz (MAX293/MAX294) or f_{CLK} = 50kHz (MAX297) T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
FILTER CHARACTERISTICS						
Corner-Frequency Range	MAX293/MAX294			0.1-25k		Hz
	MAX297			0.1-50k		
Clock to Corner Frequency Ratio	MAX293/MAX294			100:1		
	MAX297			50:1		
Clock to Corner Frequency Tempco	MAX293			8		ppm/°C
	MAX294			7		
	MAX297			4		
Insertion Gain Relative to DC Gain (Note 1)	MAX293	$f_{IN} = 0.381F_O$	0.12	-0.10	-0.17	dB
		$f_{IN} = 0.594F_O$	0.12	0.02	-0.17	
		$f_{IN} = 0.759F_O$	0.12	-0.11	-0.17	
		$f_{IN} = 0.866F_O$	0.12	-0.03	-0.17	
		$f_{IN} = 0.939F_O$	0.12	-0.11	-0.17	
		$f_{IN} = 0.993F_O$	0.12	0.04	-0.17	
		$f_{IN} = 1.000F_O$	0.12	0.01	-0.17	
		$f_{IN} = 1.500F_O$	-75	-78		
		$f_{IN} = 1.610F_O$	-80	-87		
		$f_{IN} = 2.020F_O$	-80	-84		
		$f_{IN} = 4.020F_O$	-80	-84		
	MAX294	$f_{IN} = 0.425F_O$	0.10	-0.11	-0.17	
		$f_{IN} = 0.644F_O$	0.10	0.02	-0.17	
		$f_{IN} = 0.802F_O$	0.10	-0.10	-0.17	
		$f_{IN} = 0.895F_O$	0.10	-0.03	-0.17	
		$f_{IN} = 0.946F_O$	0.10	-0.07	-0.17	
		$f_{IN} = 0.994F_O$	0.26	0.16	-0.17	
		$f_{IN} = 1.000F_O$	0.26	0.13	-0.17	
		$f_{IN} = 1.200F_O$	-51	-54		
		$f_{IN} = 1.270F_O$	-57	-62		
		$f_{IN} = 1.530F_O$	-57	-60		
		$f_{IN} = 2.840F_O$	-57	-60		

ELECTRICAL CHARACTERISTICS (continued)

(V+ = 5V, V- = -5V, filter output measured at OUT pin, 20kΩ load resistor to ground at OUT, f_{CLK} = 100kHz (MAX293/MAX294) or f_{CLK} = 50kHz (MAX297) T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

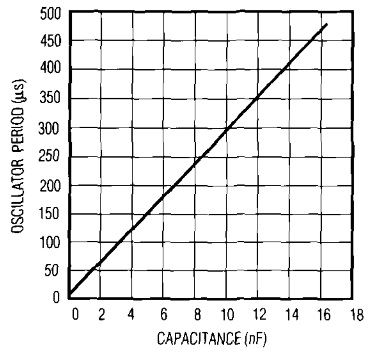
PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Insertion Gain Relative to DC Gain (Note 1) (continued)	MAX297	$f_{IN} = 0.377F_O$	0.10	-0.11	-0.17	dB
		$f_{IN} = 0.591F_O$	0.10	0.03	-0.17	
		$f_{IN} = 0.754F_O$	0.10	-0.12	-0.17	
		$f_{IN} = 0.873F_O$	0.10	0.02	-0.17	
		$f_{IN} = 0.944F_O$	0.10	-0.07	-0.17	
		$f_{IN} = 0.996F_O$	0.20	0.11	-0.17	
		$f_{IN} = 1.000F_O$	0.20	0.10	-0.17	
		$f_{IN} = 1.500F_O$	-75	-79		
		$f_{IN} = 1.610F_O$	-80	-87		
		$f_{IN} = 2.020F_O$	-80	-84		
		$f_{IN} = 4.000F_O$	-80	-85		
Passband Ripple	MAX293			0.15		dB
	MAX294			0.27		
	MAX297			0.23		
Output DC Swing			±4			V
Output Offset Voltage	IN = GND			±150	±400	mV
DC Insertion Gain with Output Offset Removed			-0.15	±0.01	0.15	dB
Total Harmonic Distortion plus Noise	T_A = +25°C	MAX293		-71		dB
		MAX294		-69		
		MAX297		-77		
Clock Feedthrough	T_A = +25°C			5.0		mVp-p
Output Drive Capability			20	10		kΩ
CLOCK						
Internal Oscillator Frequency	C_{OSC} = 1000pF		29	35	43	kHz
Internal Oscillator Current Source/Sink	V_{CLK} = 0V or 5V			±70	±120	µA
Clock Input (Note 2) High			4.0			V
Low					1.0	
UNCOMMITTED OP AMP						
Input Offset Voltage				±10	±50	mV
Output Drive Capability			20	10		kΩ
Output DC Swing			±4			V
Gain-Bandwidth Product				4		MHz
POWER REQUIREMENTS						
Supply Voltage Dual Supply			±2.375		±5.5	V
Single Supply	V- = 0V, GND = V+/2		4.75		11.0	
Supply Current	V+ = 5V, V- = -5V, V_{CLK} = 0V to 5V			15.0	22.0	mA
	V+ = 2.375V, V- = -2.375V, V_{CLK} = -2V to 2V			7.0	12.0	

Note 1: Test frequencies selected at ripple peaks and troughs.
Note 2: Guaranteed by design.

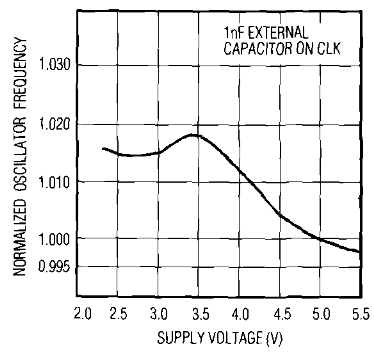
Typical Operating Characteristics

(V+ = 5V, V- = -5V, f_{CLK} = 100kHz (MAX293/MAX294) or f_{CLK} = 50kHz (MAX297), T_A = +25°C, unless otherwise noted.)

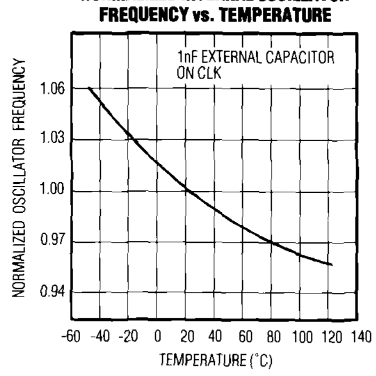
INTERNAL OSCILLATOR PERIOD vs. CAPACITANCE VALUE



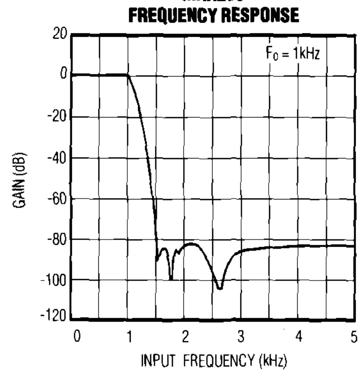
NORMALIZED INTERNAL OSCILLATOR FREQUENCY vs. SUPPLY VOLTAGE



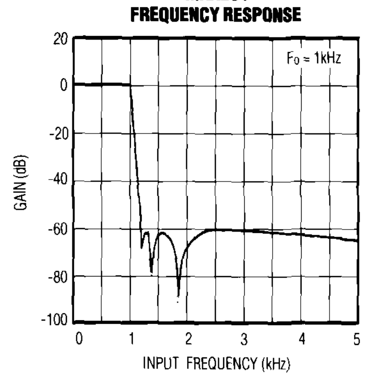
NORMALIZED INTERNAL OSCILLATOR FREQUENCY vs. TEMPERATURE



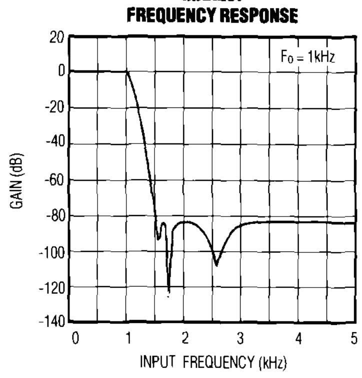
MAX293 FREQUENCY RESPONSE



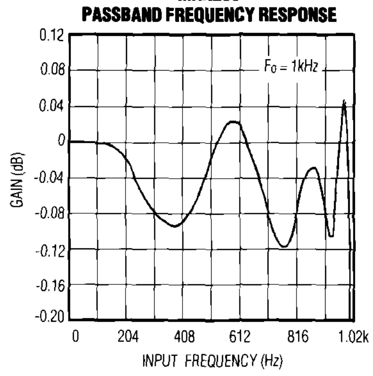
MAX294 FREQUENCY RESPONSE



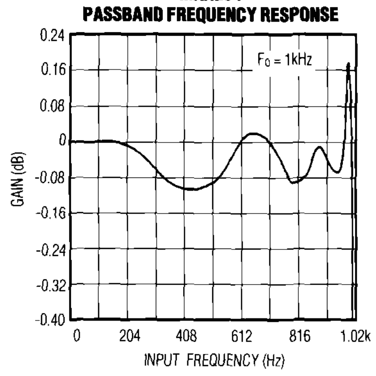
MAX297 FREQUENCY RESPONSE



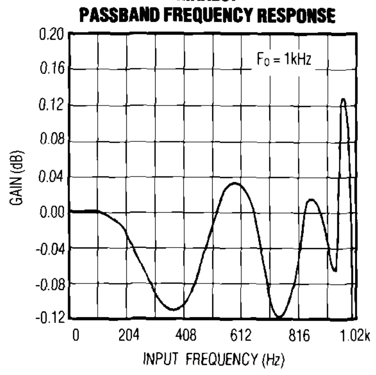
MAX293 PASSBAND FREQUENCY RESPONSE



MAX294 PASSBAND FREQUENCY RESPONSE



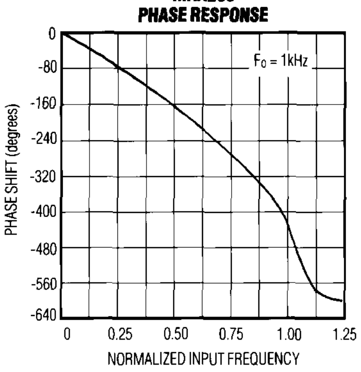
MAX297 PASSBAND FREQUENCY RESPONSE



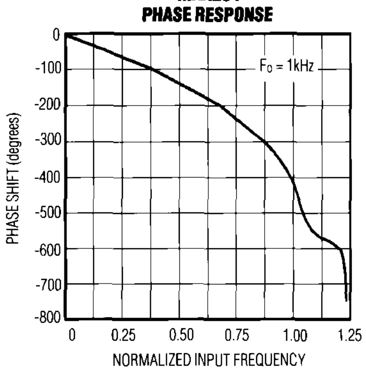
Typical Operating Characteristics (continued)

(V+ = 5V, V- = -5V, f_{CLK} = 100kHz (MAX293/MAX294) or f_{CLK} = 50kHz (MAX297), T_A = +25°C, unless otherwise noted.)

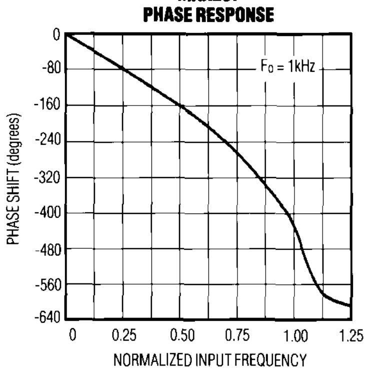
MAX293 PHASE RESPONSE



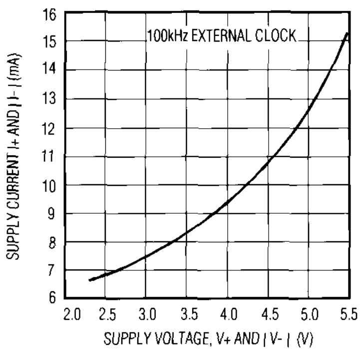
MAX294 PHASE RESPONSE



MAX297 PHASE RESPONSE



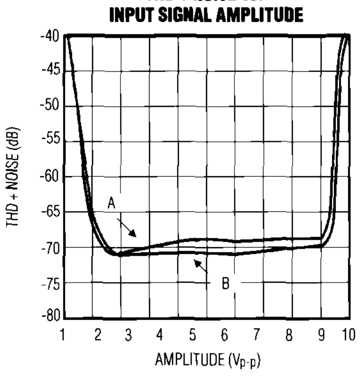
SUPPLY CURRENT vs. SUPPLY VOLTAGE



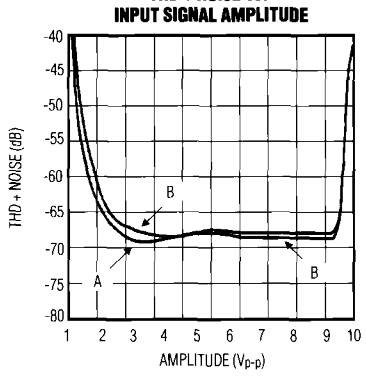
LABEL	f_{CLK} (Hz)	F_0 (kHz)	INPUT FREQ. (Hz)	MEASUREMENT BANDWIDTH (kHz)
A	200k	2	200	30
B	1M	10	1k	80
C	200k	4	400	30
D	1M	20	2k	80

(V+ = 5V, V- = -5V, R_{LOAD} = 20kΩ, T_A = +25°C, unless otherwise noted.)

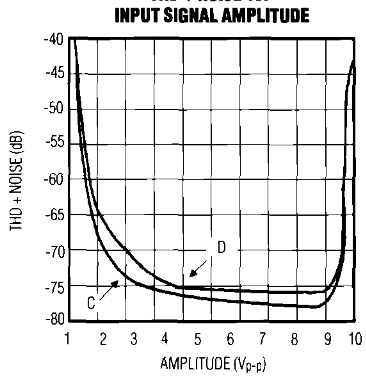
MAX293 THD + NOISE vs. INPUT SIGNAL AMPLITUDE



MAX294 THD + NOISE vs. INPUT SIGNAL AMPLITUDE



MAX297 THD + NOISE vs. INPUT SIGNAL AMPLITUDE



Pin Description

PIN		NAME	FUNCTION
8-PIN DIP	16-PIN SO		
	1,2,7,8,9, 10,15,16	N.C.	No Connect—not internally connected
1	3	CLK	Clock Input—use internal or external clock.
2	4	V-	Negative Supply pin. Dual supplies: -2.375V to -5.5V. Single supply: V- = 0V.
3	5	OP OUT	Uncommitted Op-Amp Output
4	6	OP IN-	Inverting Input to the uncommitted op amp. The noninverting op amp is internally tied to GND.
5	11	OUT	Filter Output
6	12	GND	Ground. In single-supply operation, GND must be biased to the mid-supply voltage level.
7	13	V+	Positive Supply pin. Dual supplies: +2.375V to +5.5V. Single supply: +4.75V to +11.0V.
8	14	IN	Filter Input

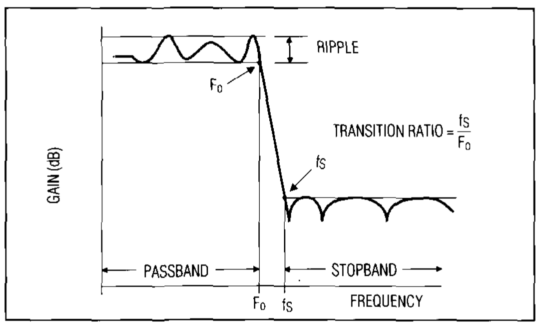


Figure 1. Elliptic Filter Response

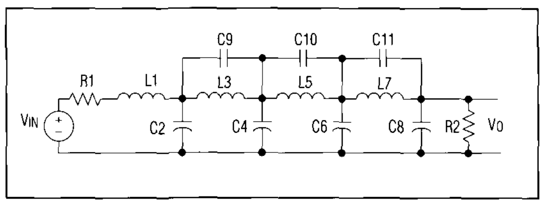


Figure 2. 8th-Order Ladder Filter Network

Detailed Description

The MAX293/MAX294/MAX297 8th-order (eight-pole), elliptic, switched-capacitor, lowpass filters provide the steepest possible rolloff with frequency of the four common filter types (Butterworth, Bessel, Chebyshev, elliptic). The high Q value of the poles near the passband edge combined with stopband zeros allows for the sharp attenuation characteristic of elliptic filters. The MAX293/MAX297 have a 1.5 transition ratio and typically -78dB and -79dB of stopband rejection, respectively; the MAX294 has a 1.2 transition ratio (providing the steepest rolloff) and typically -58dB of stopband rejection.

Passband Ripple and Corner Frequency

The MAX293/MAX294 operate with a 100:1 clock to corner frequency ratio and a 25kHz maximum corner frequency, with corner frequency defined as the point where the filter output attenuation falls just below the passband ripple (Figure 1). The passband ripple is typically 0.15dB (MAX293) and 0.27dB (MAX294). The MAX297 operates with a 50:1 clock to corner frequency ratio and a 50kHz maximum corner frequency. Its passband ripple is typically 0.23dB.

Transition Ratio and Stopband Response

In the frequency domain, the first transmission zero causes the filter's amplitude to drop to a minimum level. Beyond this zero, the response rises as the frequency increases until the next transmission zero. Several repetitions of this response create the filter's stopband comb shape (Figure 1). The stopband begins at f_S. At frequencies above f_S, the filter's gain does not exceed the gain at f_S. The transition ratio is defined as the ratio of the stopband frequency to the corner frequency.

Background Information

Most switched-capacitor filters are designed with biquadratic sections. Each section implements two filtering poles, and the sections can be cascaded to produce higher-order filters. The advantage to this approach is ease of design. However, this type of design is highly sensitive to component variations if any section's Q is high.

An alternative approach is to emulate a passive network using switched-capacitor integrators with summing and scaling. The passive network can be synthesized using CAD programs, or can be found in many filter books. Figure 2 shows the basic ladder filter structure.

A switched-capacitor filter that emulates a passive ladder filter retains many of its advantages. The filter's component sensitivity is low when compared to a cascaded biquad design because each component affects the entire filter shape, not just one pole pair. That is, a mismatched component in a biquad design will have a concentrated error on its respective poles, while the

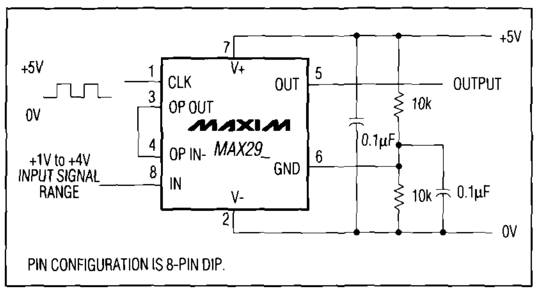


Figure 3. +5V Single-Supply Operation

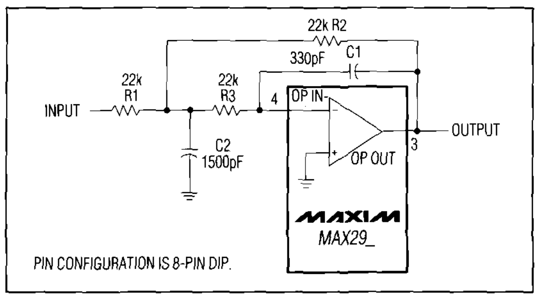


Figure 4. Uncommitted Op Amp Configured as a 2nd-Order Butterworth Lowpass Filter (F_0 = 10kHz)

same mismatch in a ladder filter design will spread its error over all poles.

Clock-Signal Requirements

The MAX293/MAX294/MAX297 maximum recommended clock frequency is 2.5MHz, producing a cutoff frequency of 25kHz for the MAX293/MAX294 and 50kHz for the MAX297. The CLK pin can be driven by an external clock or by the internal oscillator with an external capacitor. For external clock applications, the clock circuitry has been designed to interface with +5V CMOS logic. Drive the CLK pin with a CMOS gate powered from 0V and +5V when using either a single supply or dual ±5V supplies. Varying the rate of an external clock will dynamically adjust the filter's corner frequency.

When using the internal oscillator, the capacitance (C_{OSC}) on the CLK pin determines the oscillator frequency:

$$f_{OSC(kHz)} = \frac{10^5}{3C_{OSC(pF)}}$$

The stray capacitance at CLK should be minimized, since it will affect the internal oscillator frequency.

Applications Information

Power Supplies

The MAX293/MAX294/MAX297 operate from either dual or single power supplies. The dual-supply voltage range is ±2.375V to ±5.5V (0.1µF bypass capacitors from each supply to GND are recommended). When using a single supply, tie the V- pin to ground and bias the GND pin to the mid-supply point using a resistor-divider network, as shown in Figure 3.

Input-Signal Amplitude Range

The ideal input-signal range is determined by observing at what voltage level the signal-to-noise plus distortion (SINAD) ratio is maximized for a given corner frequency. The *Typical Operating Characteristics* show the MAX293/MAX294/MAX297 THD + Noise response as the input signal's peak-to-peak amplitude is varied.

Uncommitted Op Amp

The uncommitted op amp has its noninverting input connected to the GND pin, and can be used to build a 1st- or 2nd-order continuous-time lowpass filter. This filter is intended for anti-aliasing applications preceding the switched-capacitor filter, but it can be used as a post-filter to reduce clock noise. Figure 4 shows one of many filters that can be built with this op amp: a 2nd-order Butterworth filter with a 10kHz corner frequency and an input impedance greater than 22kΩ. Table 1 gives alternative component values for different corner frequencies of the same Butterworth filter.

Table 1. Component Values for Figure 4's Filter

Corner Freq. (Hz)	R1 (kΩ)	R2 (kΩ)	R3 (kΩ)	C1 (F)	C2 (F)
100k	10	10	10	68p	330p
50k	20	20	20	68p	330p
25k	20	20	20	150p	680p
10k	22	22	22	330p	1.5n
1k	22	22	22	3.3p	15n
100	22	22	22	33n	150n
10	22	22	22	330n	1.5µ

NOTE: Some approximations have been made in selecting preferred component values.

The passband error caused by a 2nd-order Butterworth can be calculated using the formula:

$$\text{Gain error} = -10\log\left[1 + \left(\frac{f}{f_c}\right)^4\right] \text{ dB}$$

8th-Order, Lowpass, Elliptic, Switched-Capacitor Filters

As the passband ripple of the MAX293/MAX294/MAX297 elliptic filters is of the order of ±0.1dB, it is normally appropriate to keep the passband errors of any anti-aliasing filter at or below this level. This is achieved by choosing the corner frequency of Figure 4's Butterworth filter (f_{CB}) to be higher than the corner frequency of the elliptic switched-capacitor filter (f_{CE}) by a factor of 2.5 or more. A factor of 5 or more is recommended to avoid problems with component tolerances, i.e. $f_{CB} > (5)(f_{CE})$.

When using the uncommitted op amp as a post-filter to reduce clock noise, keep the filter's input impedance above 20kΩ to avoid excessive loading of the switched-capacitor filter. Note that the op amp experiences some clock feedthrough, so it is generally more useful for anti-aliasing than for clock-noise attenuation.

DAC Post-Filtering

When using the MAX293/MAX294/MAX297 for DAC post-filtering, synchronize the DAC and the filter clocks. If clocks are not synchronized, beat frequencies will alias into the desired passband. The DAC's clock should be generated by dividing down the switched-capacitor filter's clock.

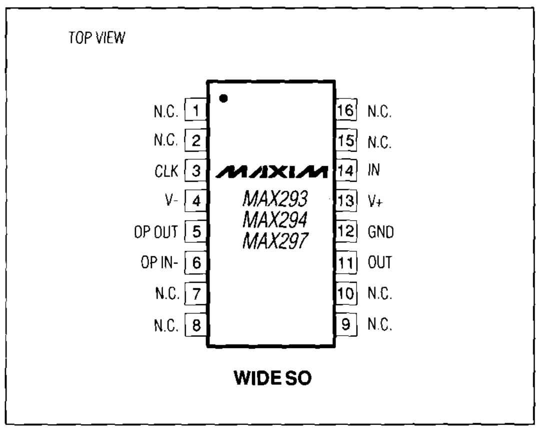
Harmonic Distortion

Harmonic distortion arises from nonlinearities within the filter. These nonlinearities generate harmonics when a pure sine wave is applied to the filter input. Table 2 lists typical harmonic distortion values for the MAX293/MAX294/MAX297 with a 1kHz 5Vp-p sine wave input signal, a 1MHz clock frequency, and a 20kΩ load.

Table 2. Typical Harmonic Distortion (dB)

FILTER	HARMONIC			
	2nd	3rd	4th	5th
MAX293	70	90	88	92
MAX294	67	90	92	94
MAX297	84	89	93	99

Pin Configurations (continued)



Ordering Information (continued)

PART	TEMP. RANGE	PIN-PACKAGE
MAX294EPA	-40°C to +85°C	8 Plastic DIP
MAX294EWE	-40°C to +85°C	16 Wide SO
MAX294MJA	-55°C to +125°C	8 CERDIP**
MAX297CPA	0°C to +70°C	8 Plastic DIP
MAX297CWE	0°C to +70°C	16 Wide SO
MAX297C/D	0°C to +70°C	Dice*
MAX297EPA	-40°C to +85°C	8 Plastic DIP
MAX297EWE	-40°C to +85°C	16 Wide SO
MAX297MJA	-55°C to +125°C	8 CERDIP**

** Contact factory for dice specifications.*
*** Contact factory for availability and processing to MIL-STD-883.*