

General Description

The MAX293/MAX294/MAX297 are easy-to-use, 8thorder, 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.

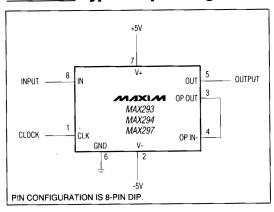
An external capacitor is used to generate a clock using the internal oscillator, or an external clock signal can be used. An uncommitted op amp (noninverting input grounded) is provided for building a continuous-time lowpass filter for post-filtering or anti-aliasing. Steep rolloff and high order make these filters ideal for antialiasing 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



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

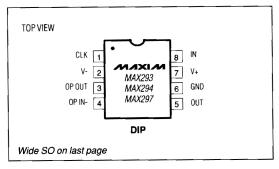
Ordering Information

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



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For pricing, delivery, and ordering information, please contact Maxim Direct at 1-888-629-4642, or visit Maxim's website at www.maxim-ic.com.

ABSOLUTE MAXIMUM RATINGS

Supply Voltage (V+ to V-)	2V
Input Voltage at Any Pin $(V0.3V) \le V_{IN} \le (V++0.3V)$	3V)
Continuous Power Dissipation	
8-Pin Plastic DIP (derate 9.09mW/°C above +70°C)727r	nW
16-Pin Wide SO (derate 9.52mW/°C above +70°C) 762r	nW
8-Pin CERDIP (derate 8.00mW/°C above +70°C) 640r	nW

Operating Temperature Ranges:
MAX29_C0°C to +70°C
MAX29_E
MAX29_MJA55°C to +125°C
Storage Temperature Range65°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

 $(V+=5V, V-=-5V, \text{filter output measured at OUT pin, } 20 \text{k}\Omega$ load resistor to ground at OUT, fCLK = 100kHz (MAX293/MAX294) or fCLK = 50kHz (MAX297) Ta = TMIN to TMAX, unless otherwise noted.)

PARAMETER	CONI	DITIONS	MIN	TYP	MAX	UNITS
FILTER CHARACTERISTIC	cs					
Corner-Frequency Range	MAX293/MAX294			0.1-25k		Hz
Comer-mequency mange	MAX297			0.1-50k		
Clock to Corner	MAX293/MAX294	ļ		100:1	-	
Frequency Ratio	MAX297			50:1		
Clock to Corner	MAX293	-		8	-	
Frequency Tempco	MAX294	_		7		ppm/°C
	MAX297			4		
		$f_{IN} = 0.381F_{O}$	0.12	-0.10	-0.17	
		$f_{IN} = 0.594F_{O}$	0.12	0.02	-0.17	
		$f_{IN} = 0.759F_0$	0.12	-0.11	-0.17	
		$f_{IN} = 0.866F_{o}$	0.12	-0.03	-0.17	
	MAX293	$f_{IN} = 0.939F_0$	0.12	-0.11	-0.17	
		$f_{IN} = 0.993F_0$	0.22	0.04	-0.17	
		$f_{IN} = 1.000F_0$	0.22	0.01	-0.17	
		$f_{IN} = 1.500F_0$	-73	-78		
Insertion Gain Relative to		$f_{IN} = 1.610F_0$	-80	-87	-	
DC Gain (Note 1)		$f_{IN} = 2.020F_0$	-80	-84		
		f _{IN} =4.020F ₀	-80	-84		dB
		$f_{IN} = 0.425F_0$	0.10	-0.11	-0.17	
		$f_{IN} = 0.644F_0$	0.10	0.02	-0.17	
		$f_{IN} = 0.802F_0$	0.10	-0.10	-0.17	
		$f_{IN} = 0.895F_0$	0.10	-0.03	-0.17	
		$f_{IN} = 0.946F_0$	0.10	-0.07	-0.17	
	MAX294	$f_{IN} = 0.994F_0$	0.36	0.16	-0.17	
		$f_{IN} = 1.000F_0$	0.36	0.13	-0.17	
		$f_{IN} = 1.200F_0$	-49	-54		
		$f_{IN} = 1.270F_0$	-57	-62		
		$f_{IN} = 1.530F_0$	-57	-60		
=-		$f_{IN} = 2.840F_0$	-57	-60		

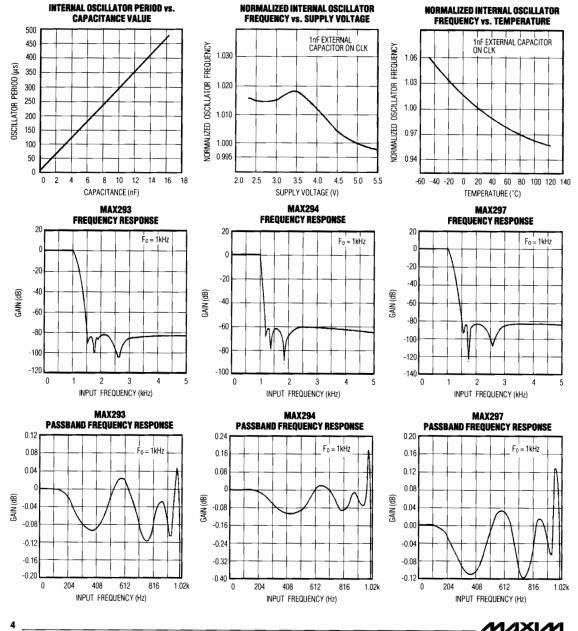
ELECTRICAL CHARACTERISTICS (continued) (V+ = 5V, V- = -5V, filter output measured at OUT pin, 20k Ω load resistor to ground at OUT, f_{CLK} = 100kHz (MAX293/MAX294) or f_{CLK} = 50kHz (MAX297) T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

PARAMETER	CONI	DITIONS	MIN	TYP	MAX	UNITS	
		$f_{IN} = 0.377F_0$	0.10	-0.11	-0.17		
		$f_{IN} = 0.591F_0$	0.10	0.03	-0.17		
		$f_{IN} = 0.754F_0$	0.10	-0.12	-0.17	dB	
		$f_{IN} = 0.873F_{o}$	0.10	0.02	-0.17		
Insertion Gain Relative to		$f_{IN} = 0.944F_0$	0.10	-0.07	-0.17		
DC Gain (Note 1) (continued)	MAX297	$f_{IN} = 0.996F_0$	0.30	0.11	-0.17		
(Continued)		$f_{IN} = 1.000F_{O}$	0.30	0.10	-0.17		
		$f_{1N} = 1.500F_0$	-73	-79			
		$f_{IN} = 1.610F_0$	-80	-87		1	
		$f_{IN} = 2.020F_0$	-80	-84			
		$f_{IN} = 4.000F_0$	-80	-85			
	MAX293			0.15			
Passband Ripple	MAX294			0.27		dB	
	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	
Table 1 Distant		MAX293		-71		dB	
Total Harmonic Distortion plus Noise	$T_A = +25^{\circ}C$	MAX294		-69			
piasitions	MAX297			-77			
Clock Feedthrough	T _A = +25°C			5.0		mVp-p	
Output Drive Capability			20	10		kΩ	
CLOCK							
Internal Oscillator Frequency	Cosc = 1000pF		29	35	43	kHz	
Internal Oscillator Current Source/Sink	V _{CLK} = 0V or 5V			±70	±120	μА	
Clock Input (Note 2) High			4.0			V	
Low					1.0		
UNCOMMITTED OF AMP						T	
Input Offset Voltage	 			±10	±50	mV	
Output Drive Capability			20	10		kΩ	
Output DC Swing			±4			V	
Gain-Bandwidth Product				4		MHz	
POWER REQUIREMENTS	<u> </u>						
Supply Voltage Dual Supply			±2.375		±5.5	V	
Single Supply	V- = 0V, GND = V		4.75		11.0		
		, VCLK = 0V to 5V		15.0	22.0	mA	
Supply Current	V+ = 2.375V, V- = V _{CLK} = -2V to 2V			7.0	12.0	InA	

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

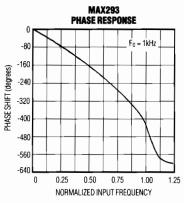
Typical Operating Characteristics

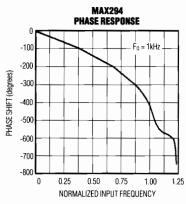
(V+ = 5V, V- = -5V, fclk = 100kHz (MAX293/MAX294) or fclk = 50kHz (MAX297), TA = +25°C, unless otherwise noted.)

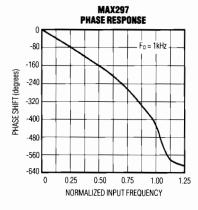


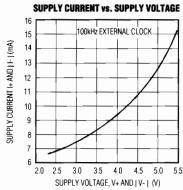
Typical Operating Characteristics (continued)

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



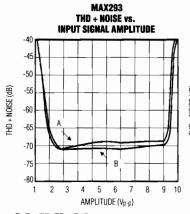


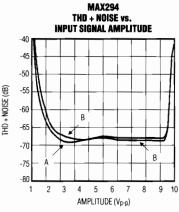


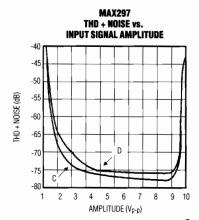


LABEL	f _{CLK} (Hz)	Fo (kHz)	INPUT FREQ. (Hz)	MEASUREMENT BANDWIDTH (kHz)
Α	200k	2	200	30
В	1M	10	1k	80
C	200k	4	400	30
_ D _	1M	20	2k	80

(V+ = 5V, V- = -5V, R_{LOAD} = $20k\Omega$, T_A = $+25^{\circ}C$, unless otherwise noted.)







MAX293/MAX294/MAX297

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

Pin Description

PIN		NAME	
8-PIN DIP	16-PIN SO	NAME	FUNCTION
	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

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.

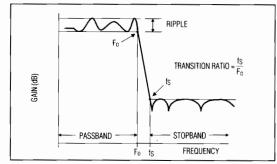


Figure 1. Elliptic Filter Response

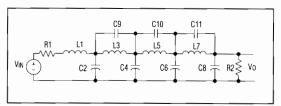


Figure 2. 8th-Order Ladder Filter Network

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 fs. At frequencies above fs, the filter's gain does not exceed the gain at fs. 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

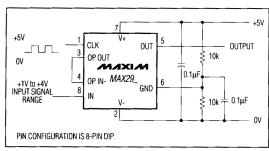


Figure 3. +5V Single-Supply Operation

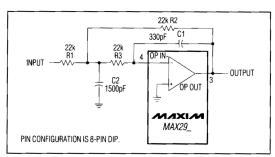


Figure 4. Uncommitted Op Amp Configured as a 2nd-Order Butterworth Lowpass Filter ($F_o = 10 \text{kHz}$)

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 (Cosc) on the CLK pin determines the oscillator frequency:

$$fOSC(kHz) = \frac{10^5}{3COSC(pF)}$$

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 $\pm 2.375 V$ to $\pm 5.5 V$ (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 $22k\Omega$. 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	3.3n	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:

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

As the passband ripple of the MAX293/MAX294/MAX297 elliptic filters is of the order of ± 0.1 dB, 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 (fcB) to be higher than the corner frequency of the elliptic switched-capacitor filter (fcE) by a factor of 2.5 or more. A factor of 5 or more is recommended to avoid problems with component tolerances, i.e. fcB > (5)(fcE).

When using the uncommitted op amp as a post-filter to reduce clock noise, keep the filter's input impedance above $20 \mathrm{k}\Omega$ 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 postfiltering, 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.

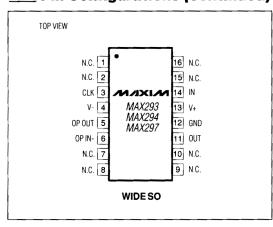
Harmonic Distortion

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 $20k\Omega$ load.

Table 2. Typical Harmonic Distortion (dB)

FILTER		HARMONIC					
FILTER	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.

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