19-4191; Rev. 2; 12/92

MAXIM

4th- and 8th-Order Continuous-Time Active Filters

MAX274/MAX275

General Description

The MAX274 and MAX275 are continuous-time active filters consisting of independent cascadable 2nd-order sections. Each section can implement any all-pole bandpass or lowpass filter response, such as Butterworth, Bessel, and Chebyshev, and is programmed by four external resistors. The MAX274/MAX275 provide lower noise than switched-capacitor filters, as well as superior dynamic performance - both due to the continuous-time design. Since continuous-time filters do not require a clock, aliased and clock noise are eliminated with the MAX274/MAX275.

The MAX274 comprises four 2nd-order sections, permitting 8th-order filters to be realized. Center frequencies range up to 150kHz, and are accurate to within ±1% over the full operating temperature range. Total harmonic distortion (THD) is typically better than -89dB

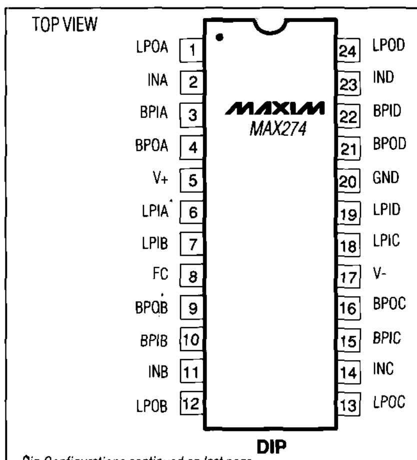
The MAX275 comprises two 2nd-order sections, permitting 4th-order filters to be realized. Center frequencies range up to 300kHz, and are accurate to within ±0.9% over the full operating temperature range. Total harmonic distortion (THD) is typically better than -86dB

Both filters operate from a single +5V supply or from dual ±5V supplies

Applications

Low-Distortion Anti-Aliasing Filters
DAC Output Smoothing Filters
Modems
Audio/Sonar/Avionics Frequency Filtering
Vibration Analysis

Pin Configurations



DIP

Pin Configurations continued on last page

Features

- ♦ **Continuous-Time Filter - No Clock, No Clock Noise**
- ♦ **Implement Butterworth, Chebyshev, Bessel and Other Filter Responses**
- ♦ **Lowpass, Bandpass Outputs**
- ♦ **Operate from a Single +5V Supply or Dual ±5V Supplies**
- ♦ **Design Software Available**
- ♦ **MAX274 Evaluation Kit Available**
- ♦ **8th-Order – Four 2nd-Order Sections (MAX274) 4th-Order – Two 2nd-Order Sections (MAX275)**
- ♦ **Center-Frequency Range: 150kHz for MAX274 300kHz for MAX275**
- ♦ **Low Noise: -86dB THD Typical for MAX274 -89dB THD Typical for MAX275**
- ♦ **Center-Frequency Accurate Over Temp: within ±1% for MAX274 within ±0.9% for MAX275**

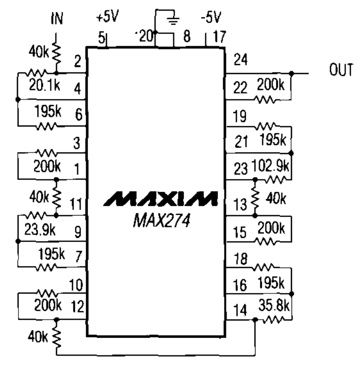
Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX274ACNG	0°C to +70°C	24 Narrow Plastic DIP
MAX274BCNG	0°C to +70°C	24 Narrow Plastic DIP
MAX274ACWI	0°C to +70°C	28 Wide SO
MAX274BCWI	0°C to +70°C	28 Wide SO
MAX274BC/D	0°C to +70°C	Dice*

Ordering Information continued on last page

* *Contact factory for dice specifications.*

Typical Operating Circuits



10kHz 8TH-ORDER BUTTERWORTH LOWPASS FILTER

PIN NUMBERS ARE FOR DIP.

Typical Operating Circuits continued on last page

ABSOLUTE MAXIMUM RATINGS

V+ to V- .... -0.3V, 12V
Input Voltage to GND (any input) .... V- - 0.3V, V+ + 0.3V
Continuous Power Dissipation (T_A = +70°C)
MAX274
24-Pin Narrow Plastic DIP (derate 13.33mW/°C above +70°C) ... 1067mW
28-Pin Wide SO (derate 12.50mW/°C above +70°) . 1000mW
24-Pin CERDIP (derate 12.50mW/°C above +70°C) . 1000mW
MAX275
20-Pin Plastic DIP(derate 11.11mW/°C above +70°C) 889mW
20-Pin Wide SO (derate 10.00mW/°C above +70°) .. 800mW
20-Pin CERDIP (derate 11.11mW/°C above +70°C) .. 889mW

Operating Temperature Ranges:
MAX27_ _C_ _ .... 0°C to +70°C
MAX27_ _E_ _ .... -40°C to +85°C
MAX27_ _MRG .... -55°C to +125°C
Storage Temperature Range .... -65°C to +165°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 – MAX274

(V+ = 5V, V- = -5V, test circuit A of Figure 1a, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
FILTER CHARACTERISTICS							
Maximum Operating Frequency					10		MHz
Center-Frequency Range	F_O	(Note 1)			100 to 150k		Hz
Center-Frequency Accuracy	F_O		MAX274A	-1.0		1.0	%
			MAX274B	-1.4		1.4	
Q Accuracy - Unadjusted			MAX274A	-10		10	%
			MAX274B	-15		15	
Q Accuracy - Adjusted		Scaled for bandwidth compensation			±2.8		%
F_O Temperature Coefficient	$\Delta F_O/\Delta T$	(Note 2)			-28		ppm/°C
Q Temperature Coefficient	$\Delta Q/\Delta T$	(Note 2)			160		ppm/°C
Wideband Noise	V_{NOISE}	LPO_, Figure 1a, test circuit B	1Hz to 10Hz		23		μV_{RMS}
			10Hz to 10kHz		120		
DC CHARACTERISTICS							
DC Lowpass Gain Accuracy	H_{OLP}	Assume ideal resistors	MAX274A	-2		2	%
			MAX274B	-3		3	
Offset Voltage at Outputs	V_{OS}	LPO_	MAX274A	-200		200	mV
			MAX274B	-300		300	
		BPO_	MAX274A	-40		40	
			MAX274B	-80		80	
Offset Voltage Drift	$\Delta V_{OS}/\Delta T$				20		µV/°C
Leakage Current at FC Pin	I_{FC}			-10		10	µA
DYNAMIC FILTER CHARACTERISTICS							
Signal-to-Noise plus Distortion	SINAD	F_{TEST} = 1kHz, Figure 1a, test circuit B	LPO_, V_{LPO} = 8Vp-p		-86		dB
		F_{TEST} = 10kHz, Figure 1a, test circuit C			-82		

ELECTRICAL CHARACTERISTICS (continued) – MAX274

($V+ = 5V$, $V- = -5V$, test circuit A of Figure 1a, $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Output Voltage Swing	V_{OUT}	LPO_, BPO_, $R_{LOAD} = 5k\Omega$	±3.25	±4.50		V
Slew Rate	SR			10		V/µs
Gain-Bandwidth Product	GBW			7.5		MHz
POWER REQUIREMENTS						
Supply Voltage Range	V_{SUPP}	(Note 3)	±2.37		±5.50	V
Supply Current	I_C	For V+, V-		20	30	mA
Power-Supply Rejection Ratio	PSRR	V+ = 5V + 100mVp-p at 1kHz, V- = -5V		-30		dB

Note 1: Center frequencies ($F_{O}s$) below 100Hz are possible at reduced dynamic range.
Note 2: Assume no drift for external resistors.
Note 3: See Figure 9 for single-supply operation.

ELECTRICAL CHARACTERISTICS – MAX275

($V+ = 5V$, $V- = -5V$, test circuit A of Figure 1b, $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
FILTER CHARACTERISTICS							
Maximum Operating Frequency					10		MHz
Center-Frequency Range	F_O	(Note 1)			100 to 300k		Hz
Center-Frequency Accuracy	F_O		MAX275A	-0.9		0.9	%
			MAX275B	-1.4		1.4	%
Q Accuracy – Unadjusted			MAX275A	-8		8	%
			MAX275B	-12		12	%
Q Accuracy – Adjusted		Scaled for bandwidth compensation			±1		%
F_O Temperature Coefficient	$\Delta F_O/\Delta T$	(Note 2)			-24		ppm/°C
Q Temperature Coefficient	$\Delta Q/\Delta T$	(Note 2)			38		ppm/°C
Wideband Noise	V_{NOISE}	LPO_, test circuit B of Figure 1b	1Hz to 10Hz		6		µV_{RMS}
			10Hz to 10kHz		42		µV_{RMS}
DC CHARACTERISTICS							
DC Lowpass Gain Accuracy	H_{OLP}	Assume ideal resistors	MAX275A	-1		1	%
			MAX275B	-2		2	%
Offset Voltage at Outputs	V_{OS}	LPO_	MAX275A	-125		125	mV
			MAX275B	-250		250	mV
		BPO_	MAX275A	-50		50	mV
			MAX275B	-100		100	mV
Offset Voltage Drift	$\Delta V_{OS}/\Delta T$				20		µV/°C
Leakage Current at FC Pin	I_{FC}			-10		10	µA
DYNAMIC FILTER CHARACTERISTICS							
Signal-to-Noise plus Distortion	SINAD	F_{TEST} = 1kHz, test circuit B of Figure 1b	LPO_, V_{LPO} = 8Vp-p		-89		dB
		F_{TEST} = 10kHz, test circuit C of Figure 1b			-83		dB

ELECTRICAL CHARACTERISTICS (continued) – MAX275

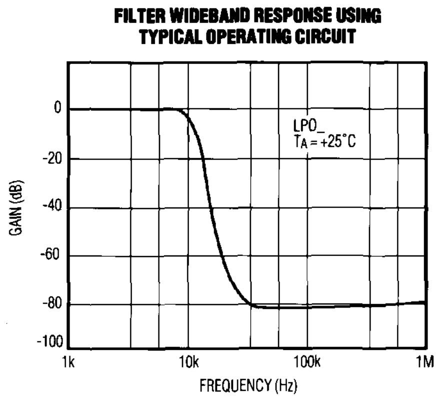
($V+ = 5V$, $V- = -5V$, test circuit A of Figure 1b, $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Output Voltage Swing	V_{OUT}	LPO_, BPO_, R_{LOAD} = 5kΩ	±3.25	±4.50		V
Internal Amplifier Slew Rate	SR			10		V/µs
Gain-Bandwidth Product	GBW			15		MHz
POWER REQUIREMENTS						
Supply Voltage Range	V_{SUPP}	(Note 3)	±2.37		±5.50	V
Supply Current	I_C	For V+, V-		10	24	mA
Power-Supply Rejection Ratio	PSRR	V+ = 5V + 100mVp-p at 1kHz, V- = -5V		-35		dB

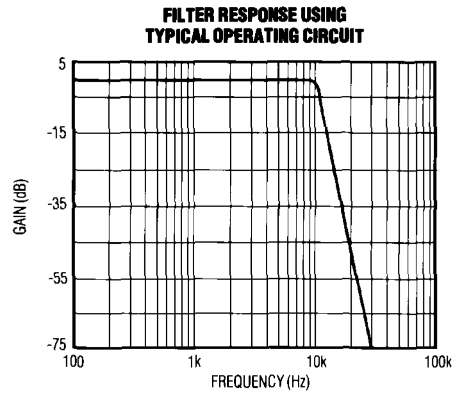
Note 1: Center frequencies (F_{OS}) below 100Hz are possible at reduced dynamic range.
Note 2: Assume no drift for external resistors.
Note 3: See Figure 9 for single-supply operation.

Typical Operating Characteristics–MAX274

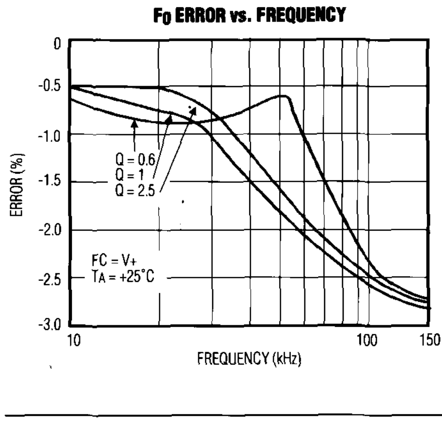
FILTER WIDEBAND RESPONSE USING TYPICAL OPERATING CIRCUIT



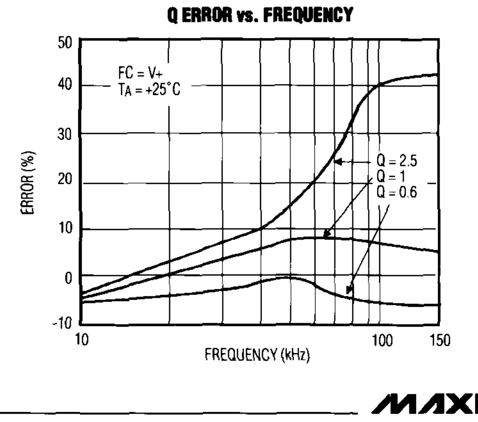
FILTER RESPONSE USING TYPICAL OPERATING CIRCUIT



F0 ERROR vs. FREQUENCY

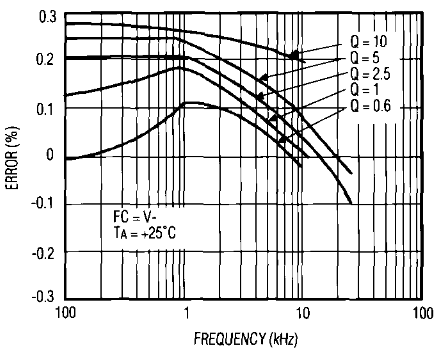


Q ERROR vs. FREQUENCY

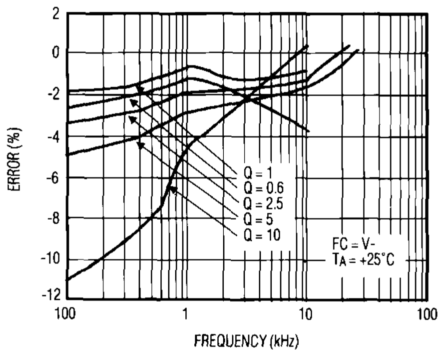


Typical Operating Characteristics–MAX274 (continued)

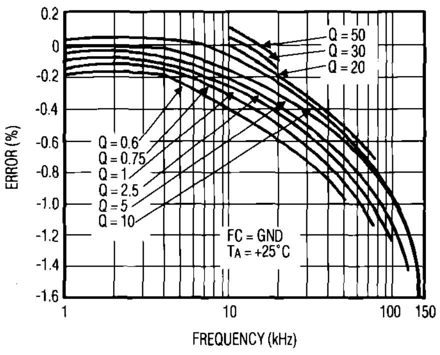
F_0 ERROR vs. FREQUENCY



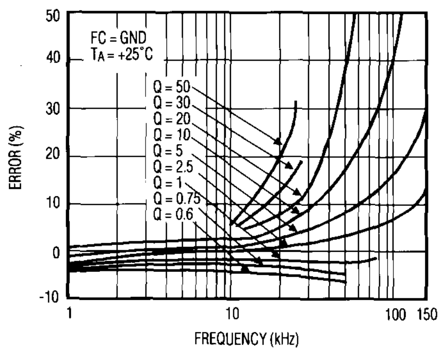
Q ERROR vs. FREQUENCY



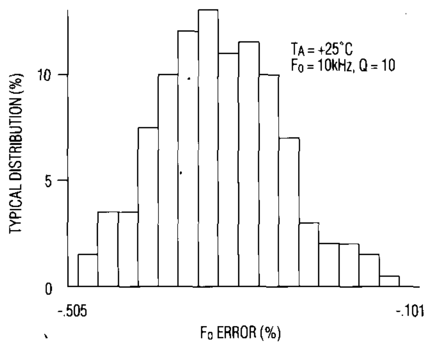
F_0 ERROR vs. FREQUENCY



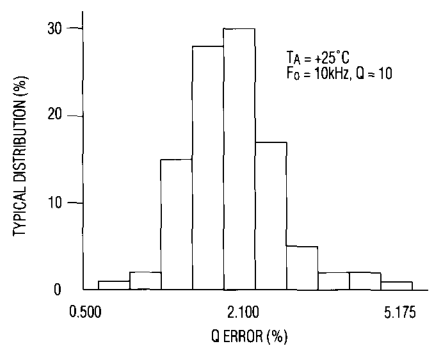
Q ERROR vs. FREQUENCY



TYPICAL DISTRIBUTION OF CENTER-FREQUENCY ERRORS



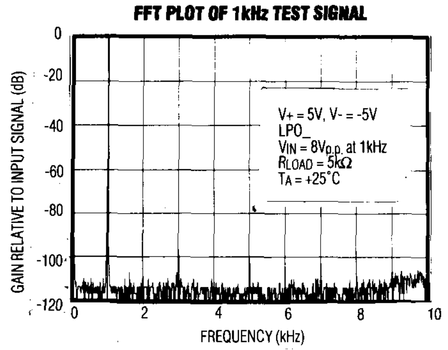
TYPICAL DISTRIBUTION OF Q ERRORS



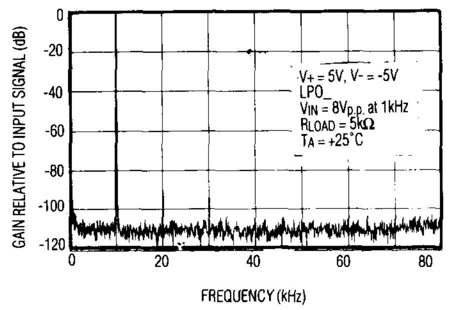
4th- and 8th-Order Continuous-Time Active Filters

Typical Operating Characteristics–MAX274 (continued)

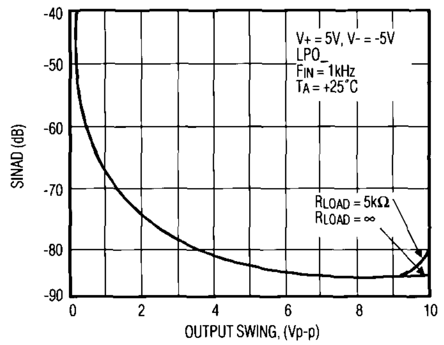
FFT PLOT OF 1kHz TEST SIGNAL



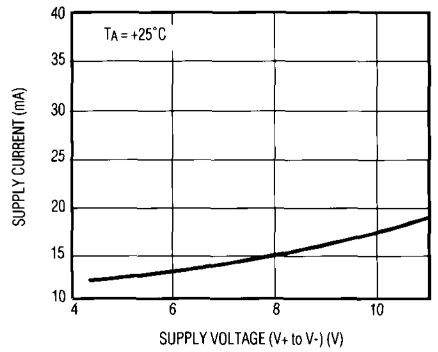
FFT PLOT OF 10kHz TEST SIGNAL



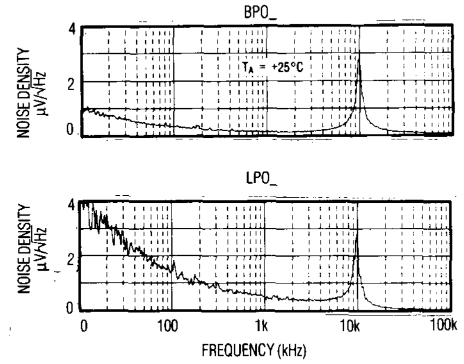
SIGNAL TO NOISE + DISTORTION (SINAD) vs. OUTPUT SWING



SUPPLY CURRENT vs. SUPPLY VOLTAGE

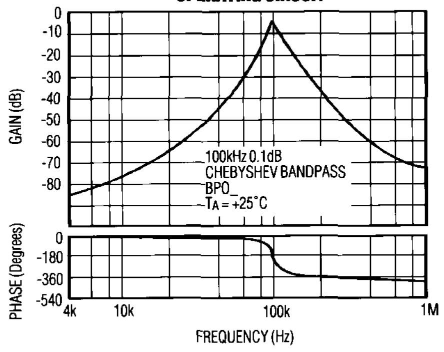


SPECTRAL NOISE DENSITY vs. FREQUENCY

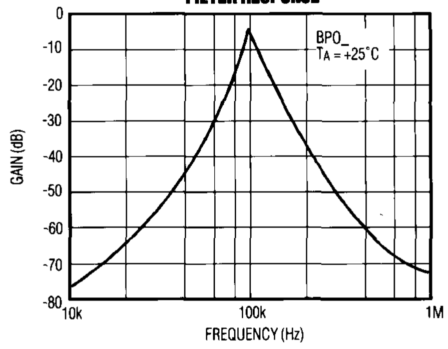


Typical Operating Characteristics—MAX275

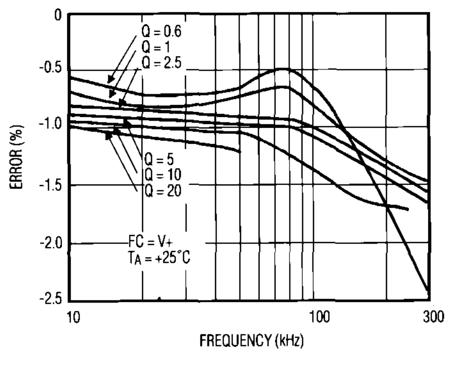
FILTER WIDEBAND RESPONSE USING TYPICAL OPERATING CIRCUIT



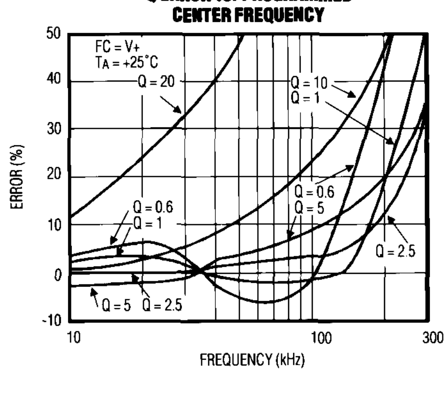
FILTER RESPONSE



CENTER-FREQUENCY ERROR vs. PROGRAMMED CENTER FREQUENCY



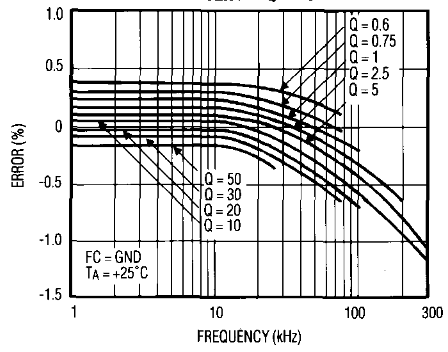
Q ERROR vs. PROGRAMMED CENTER FREQUENCY



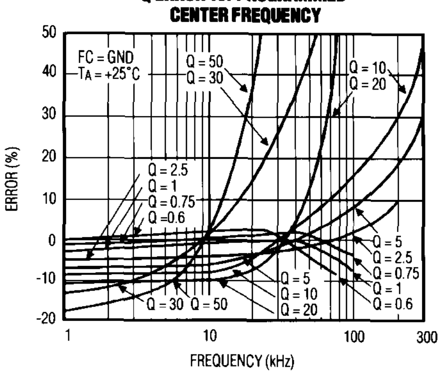
4th- and 8th-Order Continuous-Time Active Filters

Typical Operating Characteristics–MAX275 (continued)

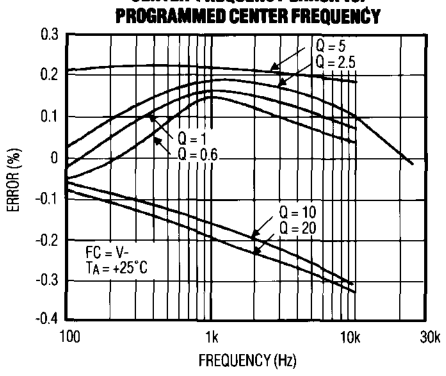
CENTER-FREQUENCY ERROR vs. PROGRAMMED CENTER FREQUENCY



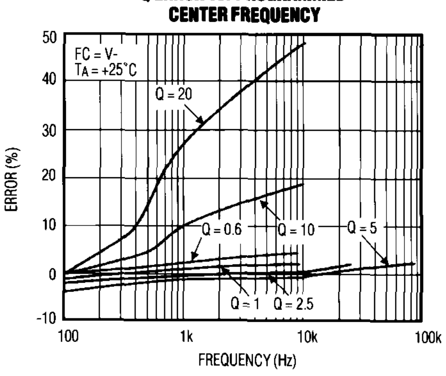
Q ERROR vs. PROGRAMMED CENTER FREQUENCY



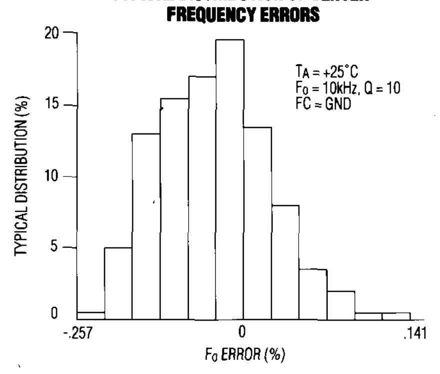
CENTER-FREQUENCY ERROR vs. PROGRAMMED CENTER FREQUENCY



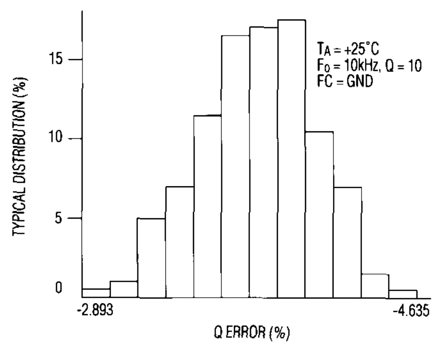
Q ERROR vs. PROGRAMMED CENTER FREQUENCY

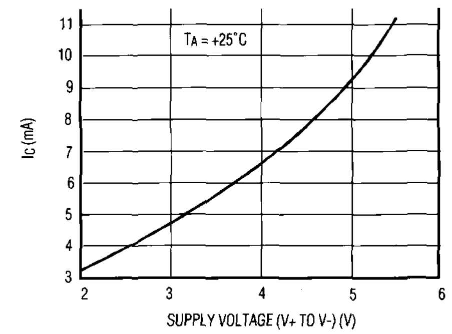


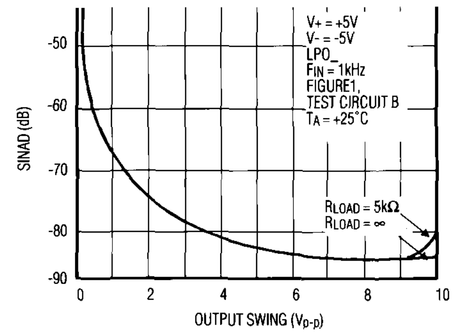
TYPICAL DISTRIBUTION OF CENTER-FREQUENCY ERRORS



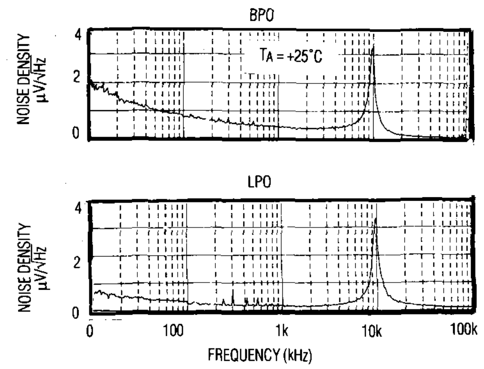
TYPICAL DISTRIBUTION OF Q ERRORS





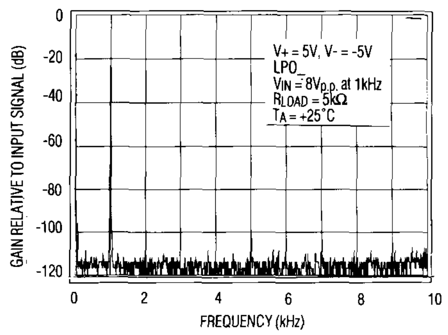


NOISE-SPECTRAL DENSITY vs. FREQUENCY

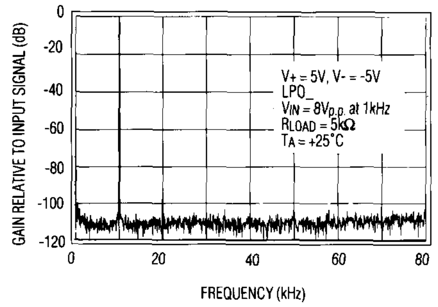


Typical Operating Characteristics—MAX275 (continued)

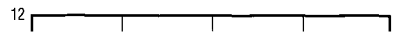
FFT PLOT OF 1kHz TEST SIGNAL



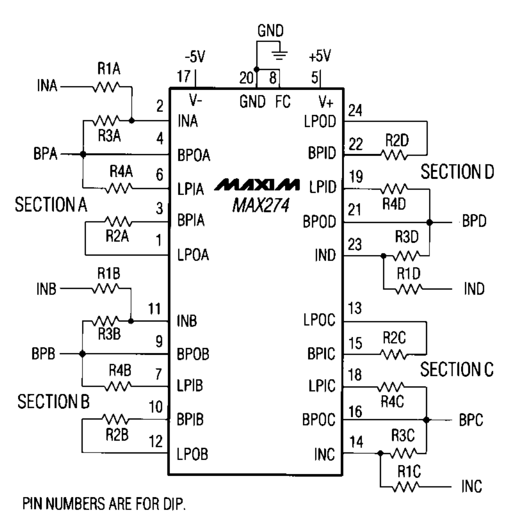
FFT PLOT OF 10kHz TEST SIGNAL



SUPPLY CURRENT vs. SUPPLY VOLTAGE

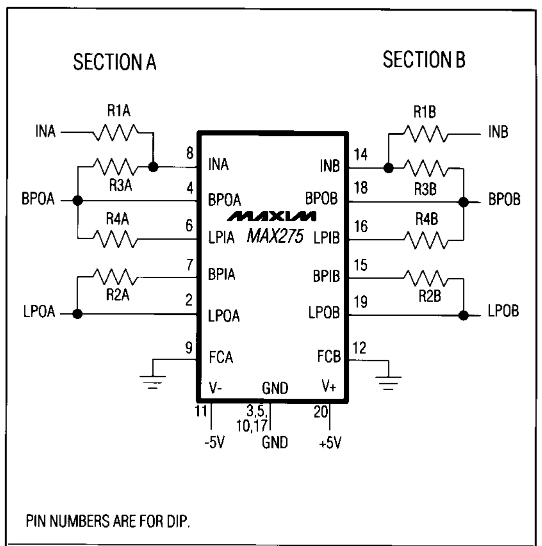


SIGNAL-TO-NOISE + DISTORTION (SINAD) vs. OUTPUT SWING



TEST CIRCUIT	F_o (kHz)	Q	R1X (kΩ)	R2X (kΩ)	R3X (kΩ)	R4X (kΩ)	FC PIN
A	10	10	80	200	400	195	GND
B	10	0.707	40	200	28	195	GND
C	100	0.707	40	20	48	15	V+

Figure 1a. MAX274 Connection Diagram and Test Circuit



TEST CIRCUIT	F_o (kHz)	Q	R1X (kΩ)	R2X (kΩ)	R3X (kΩ)	R4X (kΩ)	FC PIN
A	10	10	80	200	400	195	GND
B	10	0.707	40	200	28	195	GND
C	100	0.707	40	20	48	14	V+

Figure 1b. MAX275 Connection Diagram and Test Circuit

Detailed Description

The MAX274 contains four identical 2nd-order filter sections while the MAX275 contains two sections. Figure 2 shows the state-variable topography employed in each filter section. This topography allows simultaneous lowpass and bandpass functions at separate outputs.

The MAX274/MAX275 employ a four-amplifier design, chosen for its relative insensitivity to parasitic capacitances and high bandwidth. The built-in capacitors and amplifiers, together with external resistors, form cascaded integrators with feedback to provide simultaneous lowpass and bandpass filtered outputs. To maximize bandwidth, the highpass (HP) node is not accessible. A 5kΩ resistor is connected in series with the input of the last stage amplifier to isolate the integration capacitor from external parasitic capacitances that could alter the filter's pole accuracy.

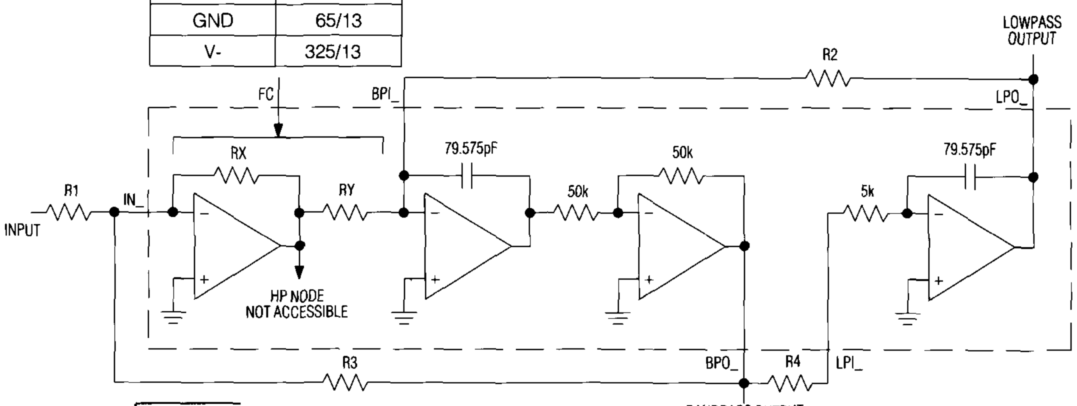
Although a notch output pin is not available, a notch can be created at the pole frequency by summing the input and bandpass output. See Creating a Notch Output Section

Filter Design Procedure

Figure 3 outlines the overall filter design procedure. Maxim's Filter Design Software is highly recommended. This software automatically calculates filter order, poles, and Qs based on the required filter shape, so no manual calculations are necessary. Menu-driven commands and on-screen filter response graphs take the user through the complete design process, including the selection of resistor values for implementing a filter with the MAX274/MAX275. See *Maxim Filter Design Software* section.

If designing without the filter software, see the filter design references listed at the end of this data sheet. These references provide numerical tables and equations needed to translate a desired filter response into order, poles, and Q. Once these three parameters have been calculated, see the next section, *Translating F_o/Q Pairs into MAX274/MAX275 Hardware (Resistor Selection).*

CONNECT FC TO:	RY/RX* (kΩ)
V+	13/52
GND	65/13
V-	325/13



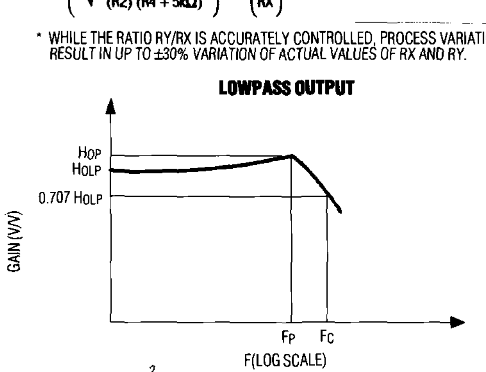
$$F_0(Hz) = \left(\sqrt{\frac{1}{(R2)(R4 + 5k\Omega)}}\right)(2 \times 10^9) \qquad H_{OBP} = \text{BP GAIN AT } F_0 = \frac{R3}{R1}$$

$$Q = \left(\sqrt{\frac{1}{(R2)(R4 + 5k\Omega)}}\right)(R3)\left(\frac{RY}{RX}\right) \qquad H_{OLP} = \text{LP GAIN AT DC} = \left(\frac{R2}{R1}\right)\left(\frac{RX}{RY}\right)$$

EQUATIONS DO NOT INCLUDE COMPENSATION FACTORS THAT CORRECT SMALL ERRORS IN F_0 AND Q DUE TO AMPLIFIER BANDWIDTH LIMITATIONS. SEE *TYPICAL OPERATING CHARACTERISTICS* FOR CORRECTION FACTORS.

* WHILE THE RATIO RY/RX IS ACCURATELY CONTROLLED, PROCESS VARIATIONS AND TEMPERATURE DRIFT *RESULT IN UP TO ±30% VARIATION OF ACTUAL VALUES OF RX AND RY.*

LOWPASS OUTPUT



$$G(S) = H_{OLP}\frac{\omega_0^2}{S^2 + S(\omega_0/Q) + \omega_0^2}$$

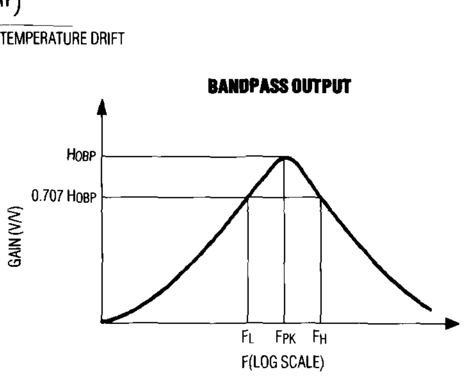
H_{OLP} = LOWPASS OUTPUT GAIN AT DC

$F_0 = \omega_0/2\pi$ = POLE FREQUENCY

$$(F_C) = (F_0)\sqrt{\left(1 - \frac{1}{2Q^2}\right) + \sqrt{\left(1 - \frac{1}{2Q^2}\right)^2 + 1}}$$

$$F_P = F_0\sqrt{1 - \frac{1}{2Q^2}} \qquad H_{OP} = (H_{OLP})\frac{1}{\frac{1}{Q}\sqrt{1 - \frac{1}{4Q^2}}}$$

BANDPASS OUTPUT



$$G(S) = H_{OBP}\frac{S(\omega_0/Q)}{S^2 + S(\omega_0/Q) + \omega_0^2}$$

H_{OBP} = BP GAIN AT $\omega = \omega_0$

$F_0 = \omega_0/2\pi$ = THE CENTER FREQUENCY OF THE COMPLEX POLE PAIR. INPUT-OUTPUT PHASE SHIFT IS - 180° AT F_0.

F_{PK} = THE FREQUENCY AT WHICH BPO_ GAIN IS THE GREATEST (MAY NOT BE EQUAL TO F_0).

Q = THE QUALITY FACTOR OF THE COMPLEX POLE PAIR. ALSO THE RATIO OF F_0, TO -3dB (0.707) BANDWIDTH OF THE SECOND-ORDER BANDPASS RESPONSE.

$$Q = \frac{F_{PK}}{F_H - F_L}$$

Figure 2. Single 2nd-Order Filter Section

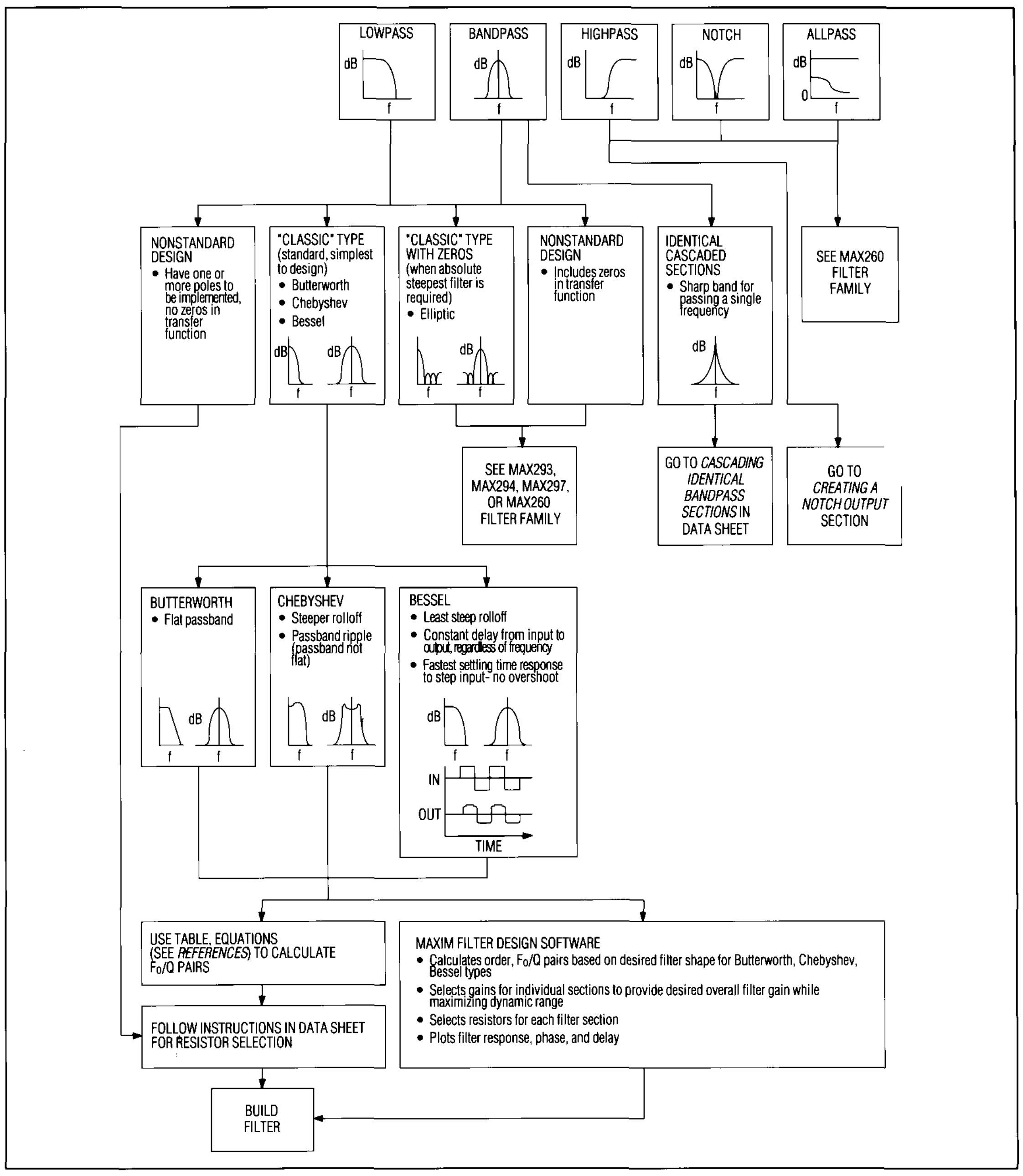


Figure 3. General Filter Design Flowchart

Translating Calculated F_O/Q Pairs into MAX274/MAX275 Hardware (Resistor Selection)

If the filter design procedure has been completed as outlined in Figure 3, with the exception of external resistor selection, follow these steps:

1. Check all F_O/Q pairs for realizability. The MAX274/MAX275 have limits on which F_O/Q values can be implemented. These limits are bound by finite amplifier gain-bandwidth and amplifier load drive capability (which limit the highest frequency F_O/highest Qs) as well as amplifier noise pickup and susceptibility to errors caused by stray capacitance (which sets a low-frequency limit on the poles). Refer to Figure 4 to be sure each F_O/Q pair is within the "realizable" portion of the graph. If filter Qs are too high, reduce them by increasing the filter order (that is, increase the number of poles in the overall filter).

High-frequency F_Os (up to 400kHz) and high Qs outside of Figure 4's limits are also realizable, but F_O and Q will deviate significantly from the ideal. Adjust resistor values by prototyping.

To implement F_Os less than 100Hz, see *High-Value Resistor Transformation* section.

2. Calculate resistor values for each section (F_O/Q pair). Calculate resistor values using graphs and equations in steps A through D of this section. Begin by estimating required values according to the graphs; then use the given equations to derive a precise value.

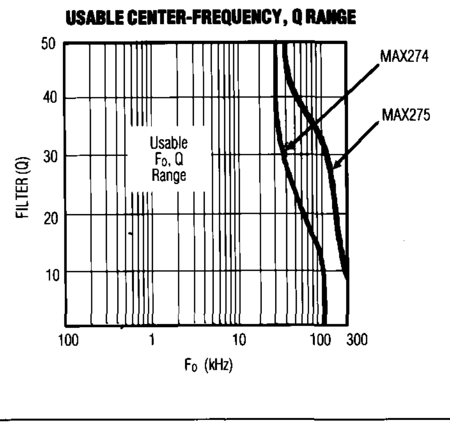


Figure 4. Usable F_O, Q Range. See Translating Fo/Q Pairs into Hardware (Resistor Selection).

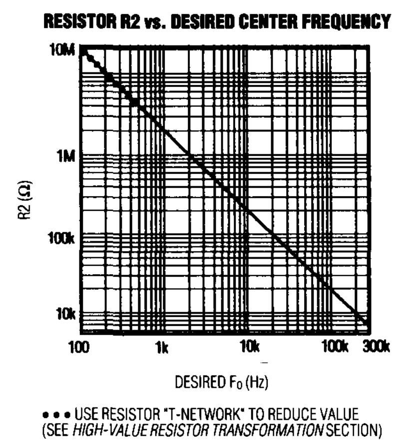
Resistor values should not exceed 4MΩ because parasitic capacitances shunting such high values cause excessive F_O/Q errors. Values lower than 5kΩ for R2 and R3 are not recommended due to limited amplifier output drive capability. For cases where larger values are unavoidable (as in low-frequency sections) refer to the *High-Value Resistor Transformation* section.

The Frequency Control (FC) pin is connected to V+, GND, or V- and scales R3 and R1 to accomodate a wide range of gains and Q values. Different FC settings may be chosen for each section. Refer to the *FC Pin Connection* section.

The steps for calculating resistor values are given below.

STEP A. CALCULATE R2.

$$R2 = \frac{(2 \times 10^9)}{F_O}$$



Resistors R2 and R4 set the center frequency.

STEP B. CALCULATE R4.

$$R4 = R2 - 5k\Omega$$

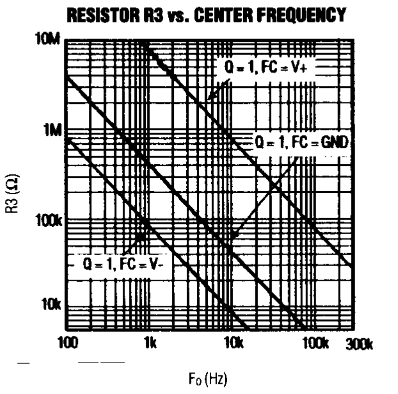
R4 may be less than 5kΩ because an internal series 5kΩ resistor limits BPO_ loading

STEP C. CALCULATE R3.

R3 sets the Q for the section. R3 values are plotted assuming Q = 1; since R3 is proportional to Q, multiply the graph's value by the desired Q.

Given Q, three choices exist for R3, depending on the FC setting. Choose a setting that provides a reasonable resistor value (5kΩ < R3 < 4MΩ). R3 > 4MΩ may be used if unavoidable – refer to the *High-Value Resistor Transformation* section for an explanation of resistor "Ts."

RESISTOR R3 vs. CENTER FREQUENCY



• • • USE RESISTOR "T-NETWORK" TO REDUCE VALUE (SEE *HIGH-VALUE RESISTOR TRANSFORMATION* SECTION)

Scale R3 to desired Q

$$R3 = \frac{(Q)\,(2X10^9)}{F_O} \times \left(\frac{RX}{RY}\right)$$

CONNECT FC TO:	RX/RY
V+	4/1
GND	1/5
V-	1/25

STEP D. CALCULATE R1.

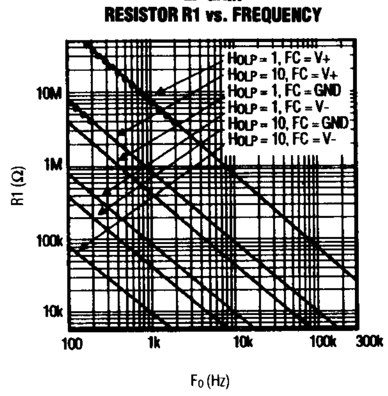
R1 sets the gain. If individual section gains have not yet been calculated, refer to *Cascaded Filter Gain Optimization, Ordering of Sections.*

R1 is inversely proportional to LP gain. R1 values for gains of 1 and 10 are plotted; scale R1 according to desired gain.

Lowpass Filters:

The FC pin setting was chosen in Step C (or from previous section calculations).

LP GAIN
RESISTOR R1 vs. FREQUENCY



• • • USE RESISTOR "T-NETWORK" TO REDUCE VALUE (SEE *HIGH-VALUE RESISTOR TRANSFORMATION* SECTION)

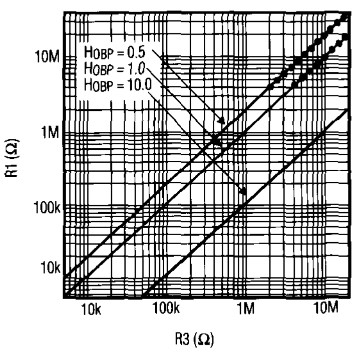
$$R1 = \frac{(2)\,(10^9)}{(F_O)\,(H_{OLP})} \times \left(\frac{RX}{RY}\right)$$

CONNECT FC TO:	RX/RY
V+	4/1
GND	1/5
V-	1/25

where H_{OLP} is the gain at LPO_ at DC.

Bandpass Filters:

BP GAIN
RESISTOR R1 vs. RESISTOR R3



• • • USE RESISTOR "T-NETWORK" TO REDUCE VALUE (SEE *HIGH-VALUE RESISTOR TRANSFORMATION* SECTION)

$$R1 = \frac{R3}{H_{OBP}}$$

where H_{OBP} is the gain at BPO_ at F_O.

3. Recalculate resistor values to compensate for filter amplifier bandwidth errors. Some of the *Typical Operating Characteristics* graphs show deviations in F_O and Q compared with expected values, due to gain rolloff of the internal amplifiers. If desired, correct these deviations by recalculating values R1- R4.

4. Build a filter prototype. Build and test all filter designs! Refer to the Prototyping, PC-Board Layout section of this data sheet.

For applications that require high accuracy (for example, those with filter sections containing Qs greater than 10) or those that use a ground plane, a final prototype tuning procedure is recommended. Build a prototype filter; then adjust resistor values of each section until desired accuracy is achieved.

High-Value Resistor Transformation

High-value resistors (greater than 4MΩ) used in the MAX274/MAX275 filter circuit introduce excessive F_O and Q errors. To reduce the impedance of these feedback paths while maintaining equivalent feedback current, use the resistor "T" method shown in Figure 5.

F_Os less than 100Hz can be realized using T-networks. T-networks provide the equivalent of large resistor values for R2, R3, and R4, necessary for low-frequency filters; however, T-networks reduce dynamic range by attenuating the input signal level. Note that parasitic capacitances across these high resistor values affect the filter response at high frequencies. For best results, build a prototype and check its performance thoroughly.

Odd Number of Poles

For lowpass designs containing an odd number of poles, add an RC lowpass filter after the final filter section. The value of RC should be:

$$RC = 1/2\pi F_O$$

where F_O is the desired real pole frequency. If required, buffer the RC with an op amp.

In many cases it may be advantageous to simply increase the filter order by 1, and implement it with an additional 2nd-order section.

FC Pin Connection

Connect FC to GND for all applications, except where resistor values fall below 5kΩ (at high F_Os, low Qs). In these cases connect FC to V+. For low F_Os and high Qs, connect FC to V- to keep the value of R1 and R3 below 4MΩ.

F_O and Q errors are significantly higher when FC is connected to V+ or V- (see Typical Operating Characteristics). Adjusting resistor values compensates for these errors, since the errors are repeatable from part to part. Note that noise increases threefold when FC is connected to V+.

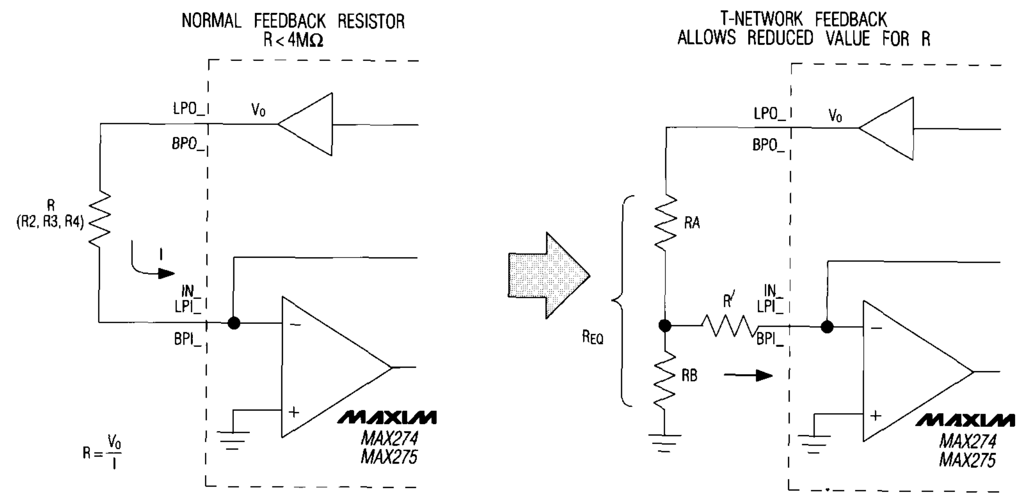
Cascading Identical Sections for Simplest Bandpass

If designing a bandpass filter where a single frequency (or a very narrow band of frequencies) must be passed, several 2nd-order sections with identical F_Os and Qs may be cascaded. The resulting Q (selectivity) of the filter is a function of the individual sections' Qs and the number of sections cascaded:

$$Q_t = \frac{Q}{\sqrt{2^{1/n} - 1}}$$

where Qt is the overall cascaded filter Q, Q is the Q of each individual section, and N is the number of sections.

4th- and 8th-Order Continuous-Time Active Filters



USE THE T-NETWORK FEEDBACK METHOD WHENEVER THE CALCULATED VALUE FOR R2, R3, OR R4 IS GREATER THAN 4MΩ.

A VOLTAGE DIVIDER CONSISTING OF RA AND RB DROPS THE VOLTAGE ACROSS RESISTOR R', PERMITTING A LOWER VALUE FOR R' WHILE MAINTAINING AN EQUIVALENT CURRENT INTO THE SUMMING NODE (I).

$R_{EQ} = \frac{V_O}{I}$

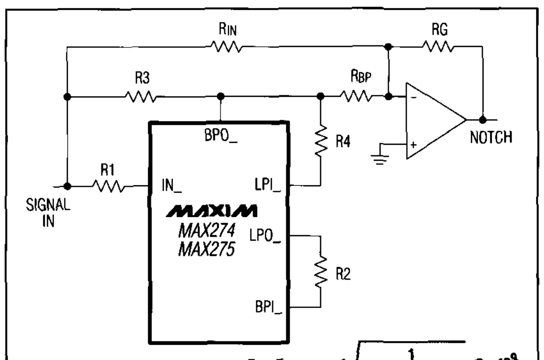
LET $R' < 4M\Omega$

$R_{EQ} = R' + \frac{RA}{RB}(RB + R')$

LET $\frac{(RA)(RB)}{RA + RB} = 10k\Omega$

SOLVE FOR RA AND RB

Figure 5. Resistor T-Networks Reduce Resistor Values



$$G(S) = H_{ON}\frac{S^2 + \omega_0^2}{S^2 + S(\omega_0/Q) + \omega_0^2}$$

WHERE $\omega_0 = 2\pi F_0$

$$F_0 = F_{NOTCH} = \sqrt{\frac{1}{(R2)(R4 + 5k\Omega)}}\,(2 \times 10^9)$$

$$Q = \sqrt{\frac{1}{(R2)(R4 + 5k\Omega)}}\,(R3)\left(\frac{RY}{RX}\right)$$

$$H_{ON} = GAIN = \frac{RG}{R_{IN}}$$

Figure 6a. Creating a Notch Output

Creating a Notch Output

A notch (zero) can be created in the filter response by summing the input signal with BPO_ using an external op amp (Figure 6a). The notch will have the poles and Q characteristics of the 2nd-order section, as well as a zero at the pole frequency (transfer function given in Figure 6a). H_{OBP} (BP gain at F_0) must be accurately set to unity so the input signal summed with BPO_ cancels precisely at the pole frequency. The notch's maximum attenuation is therefore a function of the accuracy of R1, R3, R_{IN}, and R_{BP}.

A notch can be used to create a null within the passband of a lowpass filter to reject specific frequencies (see *Applications* section).

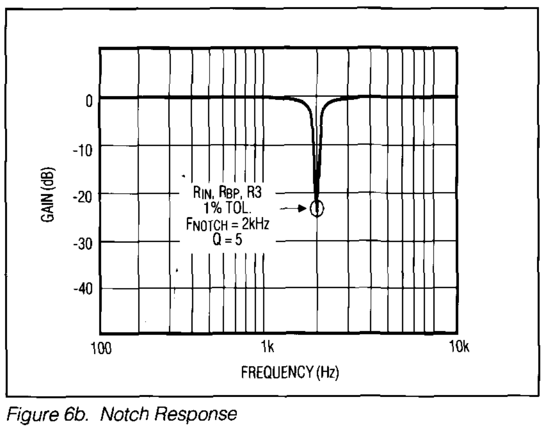


Figure 6b. Notch Response

Cascaded Filter Gain Optimization, Ordering of Sections

Gains across the individual sections in a filter may be set an infinite number of ways, as long as the total gain from filter input to output is correct. Often, gains cannot be equally divided among sections, since different F_0s and Qs create gain peaks and valleys at different frequencies for each section.

The goal in choosing gains is to prevent section outputs from swinging beyond the ±3.25V limit (using ±5V supplies) while the full input signal is applied. On the other hand, if section gains are set too low and only a small proportion of output range is used, the noise factor increases. An optimal gain distribution between sections allows each section to swing as close to ±3.25V as possible in a wide range of frequencies.

Check the unused output (BPO_ or LPO_), and the internal HP node for overvoltage, since clipping at any node will cause distortion at the outputs. The HP node is not available for probing (Figure 2); however, its gain may approach RX / R1. Low R1 values and connecting FC to V+ (which sets RX as high as 64kΩ) may cause this node to clip.

Maxim's Filter Design Software allows optimum gain by plotting output gains of each successive cascaded filter section, including the internal node. Gains may be adjusted manually and sections reordered for the best overall dynamic range.

To optimize gain without the help of software, begin by ordering the sections from lowest Q to highest Q. Divide gains equally between sections, setting each section gain to:

$$H_O = A^{(1/N)}$$

where A = overall filter gain

$H_O = H_{OBP}$ for bandpass designs (gain at F_0)

$H_O = H_{OLP}$ for lowpass designs (gain at DC)

N = total number of sections

This approach offers a good first-pass solution to clipping problems in the high Q sections by keeping gains low in the first (low Q) sections. The gains may then be adjusted in hardware to maximize overall dynamic range.

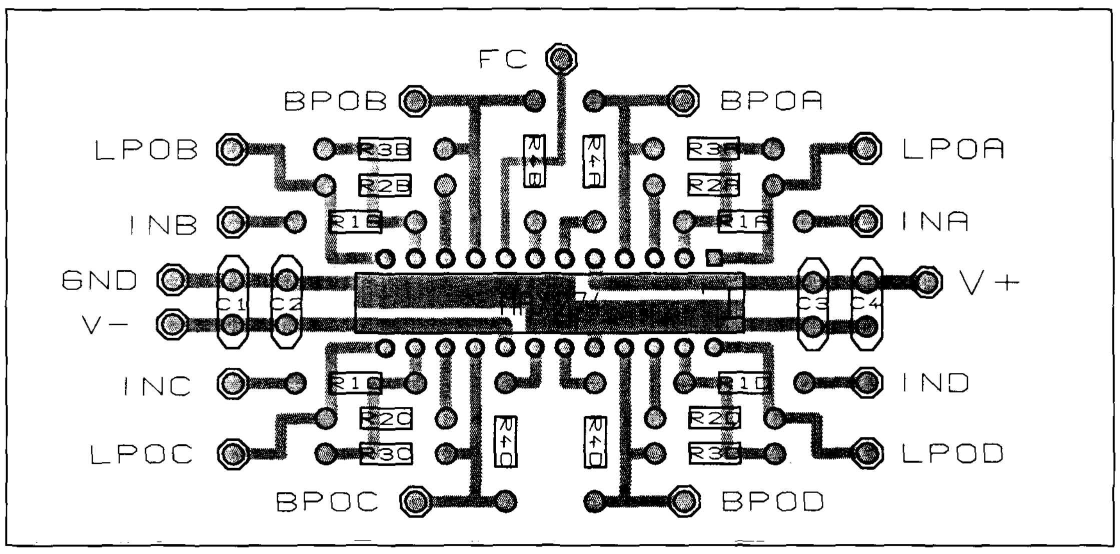


Figure 7a. MAX274 Suggested PC-Board Layout for DIP

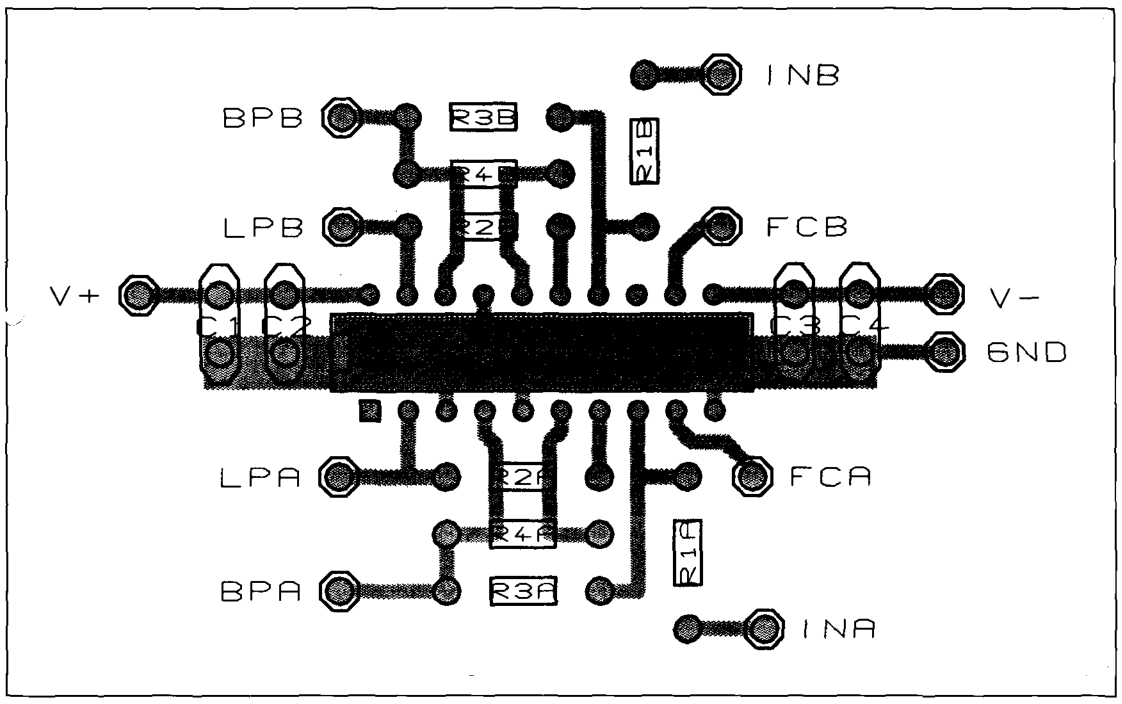


Figure 7b. MAX275 Suggested PC-Board Layout for DIP

Resistors

Aside from accuracy, the most important criterion for resistor selection is parasitic capacitance across the resistor. Typical capacitance should be less than 1pF. Precision wire-wound resistors exhibit several picofarads, as well as unacceptable inductance – DO NOT USE THESE. Capacitance effectively reduces the resistance at high frequencies (especially when using high-value resistors), and causes phase shifts in feedback loops. Do not mount resistors in sockets. Socket capacitance appearing across resistors is often several picofarads, and will cause significant errors in F_O and Q. Metal-film resistors minimize noise better than carbon types.

Prototyping, PC-Board Layout

For highest accuracy filters, build the filter prototype on a PC board with a layout as similar as possible to the final production circuit. If a ground plane will be used in production, build prototype filters on a copper board. Do not use push-in type breadboards for prototyping – pin-to-pin capacitance is too high. For faster prototyping, the MAX274 evaluation kit includes a PC-board circuit to test designs.

Layout-sensitive errors, though repeatable from part to part, vary according to resistor placement, trace routing, and ground-plane layout. For highest accuracy, use the recommended layout provided in Figures 7a and 7b. Keep all traces, especially LPI_ and BPI_ , as short as possible. LPI_ and BPI_ are particularly sensitive to ground capacitance, and may cause errors in Q. If a ground plane is used, tune the prototype filter by adjusting resistor values to cancel errors caused by ground capacitance.

Prevent capacitive coupling between pins. Coupling between BPI_ and BPO_ can cause F_O errors; capacitance across resistors connecting IN and BPO_ (R3), BPI_ and LPO_ (R2), and BPO_ and LPI_ (R4) cause F_O and Q errors. Minimize these errors with "tight" (shortest trace) layout practices.

Measuring F_o and Q

For multiple-order filters, measure each section individually, before cascading, to verify correct F_O and Q. For best results, measure BPO_ with a spectrum analyzer. F_O is the frequency at which the input and BPO_ are 180° out of phase. Q is the ratio of F_{PK} to BPO_'s - 3dB bandwidth (Figure.2), where F_{PK} is the frequency at which BPO_ gain is the greatest (which may not be equal to F_O).

Filter F_o and Q Accuracy

F_O sensitivity to external resistor tolerance is 1:1 – for example, use of 1% tolerant resistors for R2 and R4 adds ±1% error to F_O (which should be added to the ±1% tolerance of the MAX274/MAX275, guaranteed over temperature). Q errors are of greater magnitude, since they are a function of the internal resistor divider (controlled by the FC pin) and also involve R3. Typical Q error distributions are given in the *Typical Operating Characteristics*; additional Q errors associated with resistor tolerances are a function of R2, R3, and R4, and must be calculated according to the values used.

DC Offset Removal

Figures 8a and 8b show methods for removing the DC offset voltage at LPO_. The first method shows adjustable DC nulling signals injected into either BPI_ or the filter input. R_{TRIM} must be adjusted until DC offset is nulled at the LPO_ (Figure 8a). Figure 8b shows a trimless solution for lowpass filters that removes DC offset by AC coupling the LPO_ output, while allowing a DC path through R from the input. At DC and low frequencies, the output is equal to the prefiltered signal input (across R); at higher frequencies, C conducts and the output equals the signal at LPO_. The external RC pole should be set at least one frequency decade lower than the overall filter F_O. A low offset amplifier can buffer the output signal, if desired. For bandpass filters, a simple buffered RC highpass filter at the output removes DC offset.

Noise and Distortion

Noise-spectral density is shown in the *Typical Operating Characteristics*. The noise frequency distribution is shaped by the filter gain and response (higher Q section will have a proportionally higher noise peak around the pole frequency), as well as by amplifier 1/f noise. With FC set to V+, noise is 3 times greater than if set to GND or V-; therefore, avoid this setting for noise-sensitive applications. The noise density graphs from the *Typical Operating Characteristics* can be scaled to any gain or Q for an accurate noise estimation.

The MAX274/MAX275 can drive 5kΩ loads to typically within ±500mV of the supply rails with negligible distortion. The outputs can drive up to 100pF; however, filters with high F_Os and Qs will undergo some phase shift (1° at 100kHz driving 130pF, F_O = 100kHz, Q = 10 section).

4th- and 8th-Order Continuous-Time Active Filters

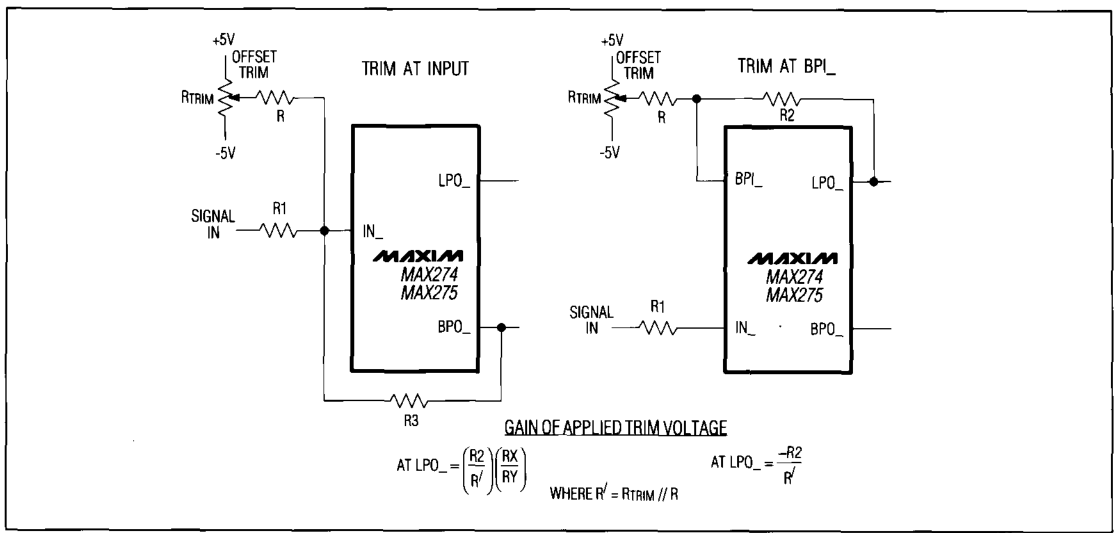


Figure 8a. Trimmed Offset Removal

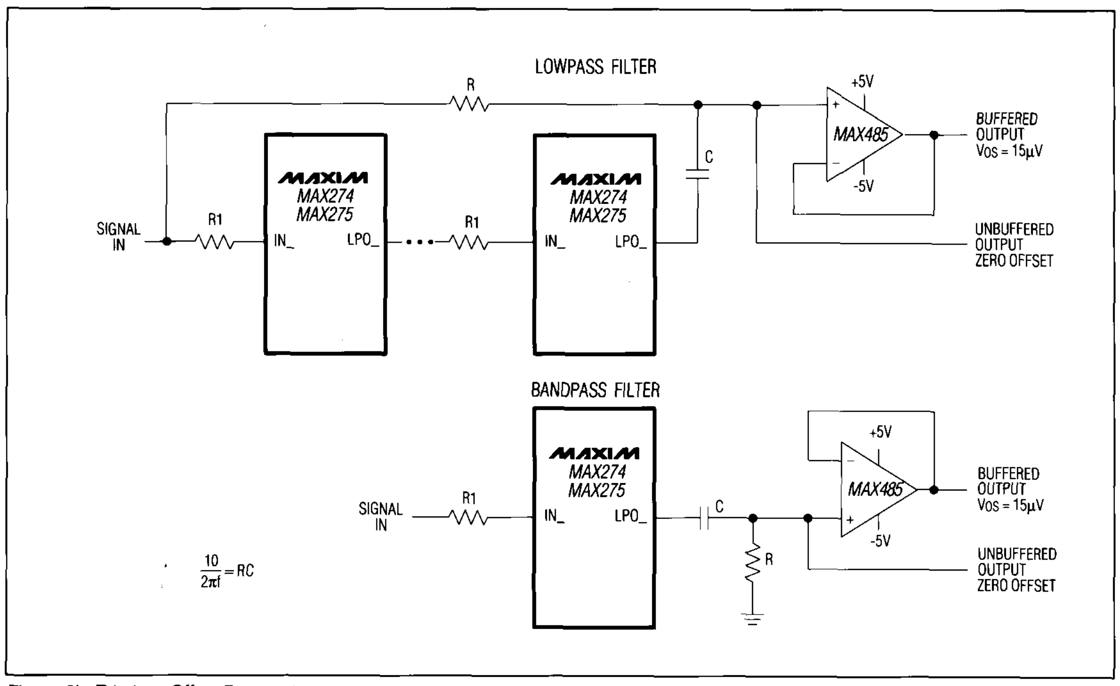


Figure 8b. Trimless Offset Removal

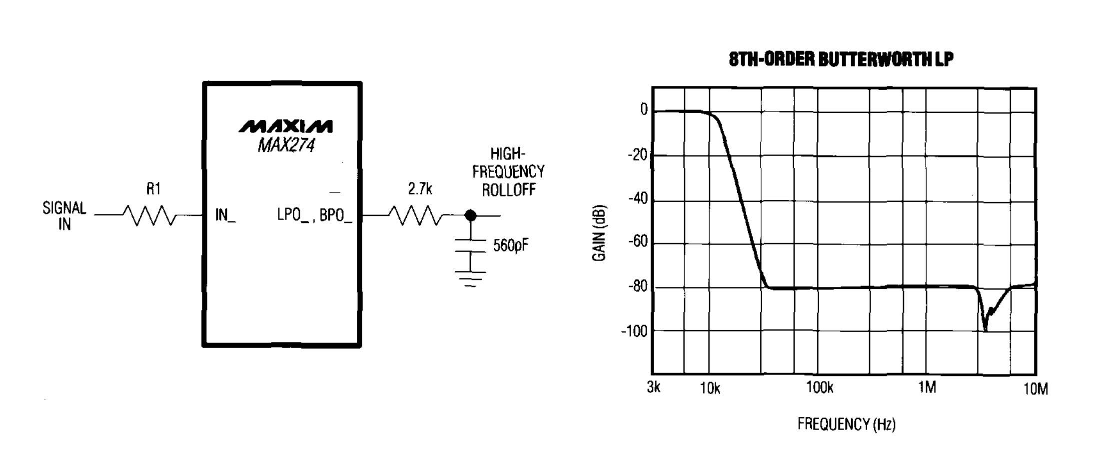


Figure 10. External RC Lowpass for High-Frequency Rolloff

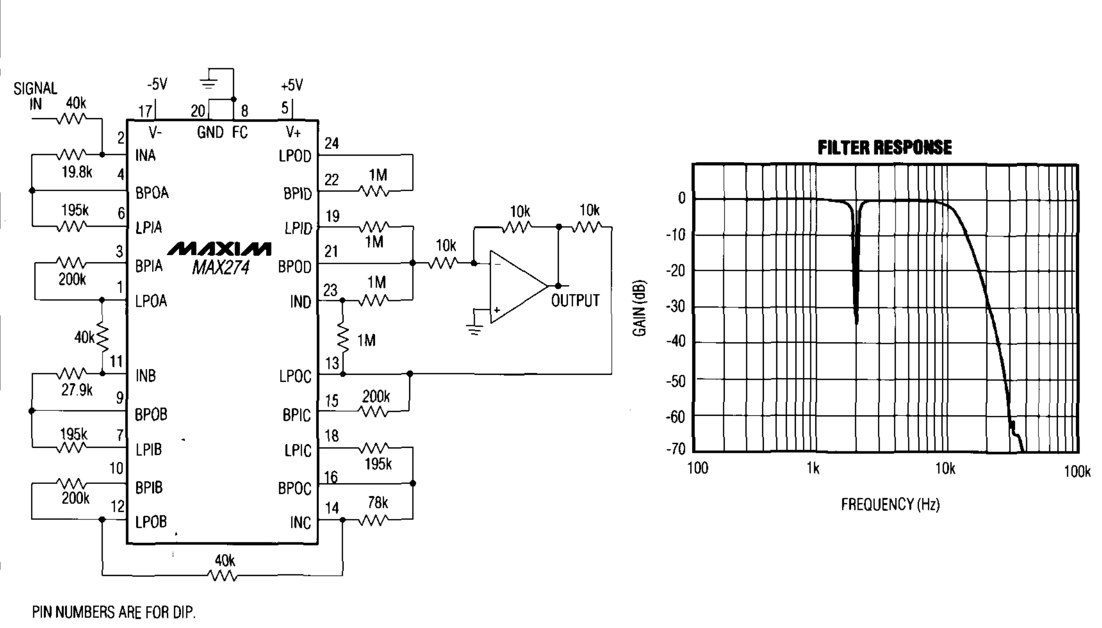


Figure 11. 10kHz 6th-Order Butterworth Lowpass Filter with 2kHz Notch (MAX274)

Applications (continued)

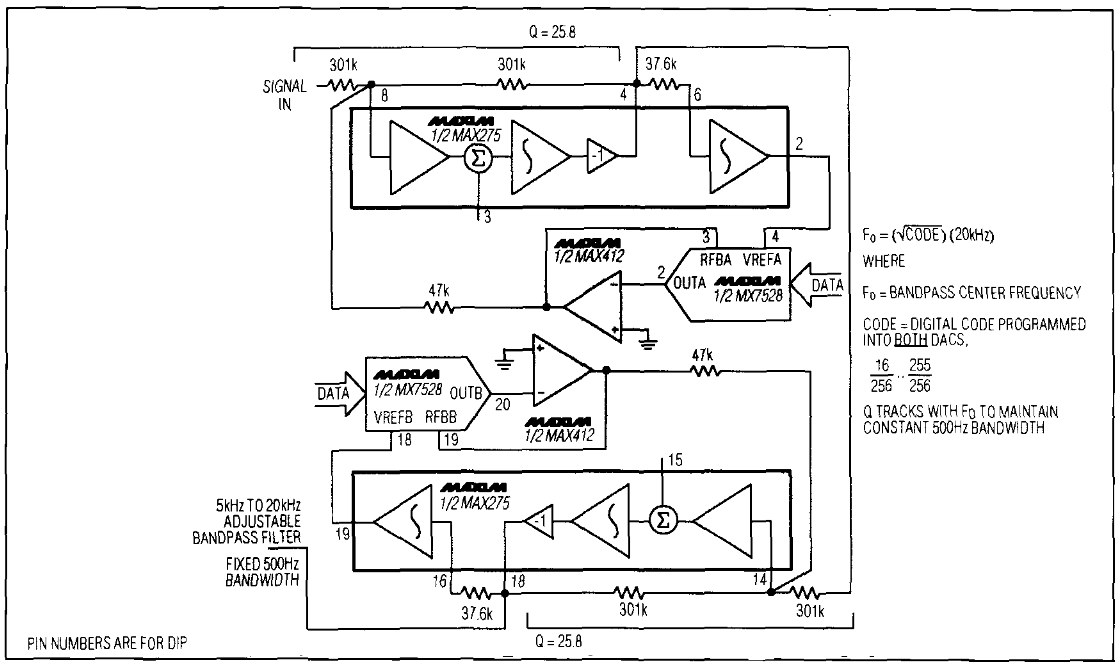
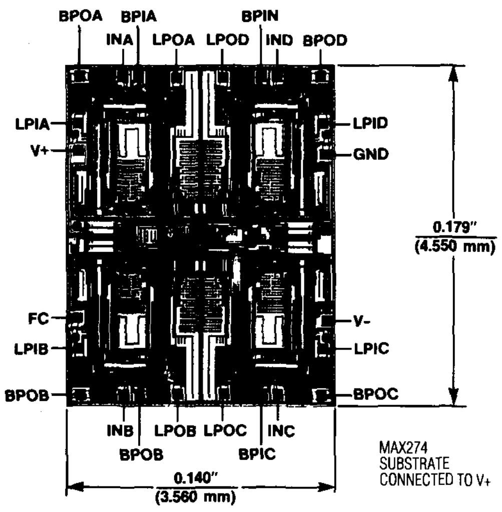
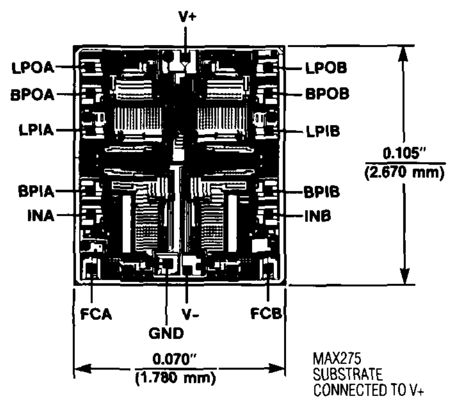


Figure 12. Programmable Bandpass Filter (MAX275)

Chip Topographies





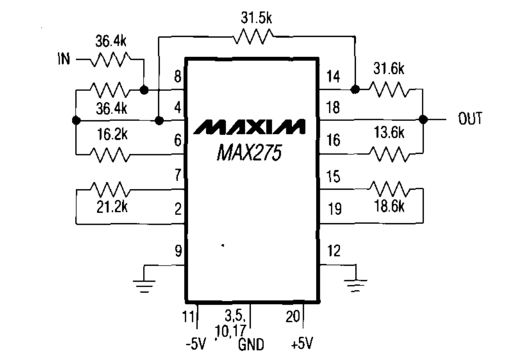
Ordering Information (continued)

PART	TEMP. RANGE	PIN-PACKAGE
MAX274AENG	-40°C to +85°C	24 Narrow Plastic DIP
MAX274BENG	-40°C to +85°C	24 Narrow Plastic DIP
MAX274AEWI	-40°C to +85°C	28 Wide SO
MAX274BEWI	-40°C to +85°C	28 Wide SO
MAX274AMRG	-55°C to +125°C	24 CERDIP**
MAX274BMRG	-55°C to +125°C	24 CERDIP**
MAX274EV KIT-DIP	0°C to +70°C	Plastic DIP – Through Hole
MAX274_SOFT	—	MAX274/MAX275 Design Software
MAX275ACPP	0°C to +70°C	20 Plastic DIP
MAX275BCPP	0°C to +70°C	20 Plastic DIP
MAX275ACWP	0°C to +70°C	20 Wide SO
MAX275BCWP	0°C to +70°C	20 Wide SO
MAX275BC/D	0°C to +70°C	Dice*
MAX275AEPP	-40°C to +85°C	20 Plastic DIP
MAX275BEPP	-40°C to +85°C	20 Plastic DIP
MAX275AEWP	-40°C to +85°C	20 Wide SO
MAX275BEWP	-40°C to +85°C	20 Wide SO
MAX275AMJP	-55°C to +125°C	20 CERDIP**
MAX275BMJP	-55°C to +125°C	20 CERDIP**
MAX274_SOFT	—	MAX274/MAX275 Design Software

* *Contact factory for dice specifications.*

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

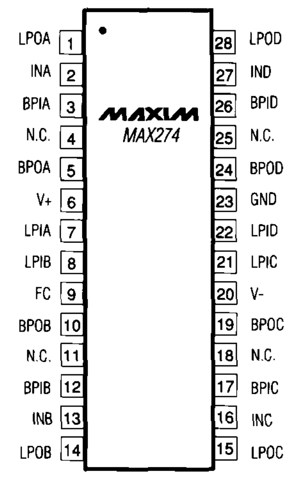
Typical Operating Circuits (continued)



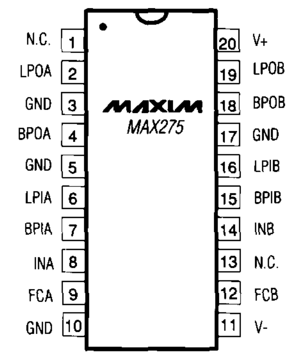
100kHz 4TH-ORDER 0.1dB CHEBYSHEV BANDPASS FILTER
PIN NUMBERS ARE FOR DIP

Pin Configurations (continued)

TOP VIEW



WIDE SO



DIP/SO

Power Supplies

The MAX274/MAX275 can be operated from a single power supply or dual supplies (Figure 9). V+ and V- pins must be properly bypassed to GND with 4.7µF electrolytic (tantalum preferred) and 0.1µF ceramic capacitors in parallel. These should be as close as possible to the chip supply pins.

For single-supply applications, GND must be centered between V+ and V- voltages so signals remain in the common-mode range of the internal amplifiers.

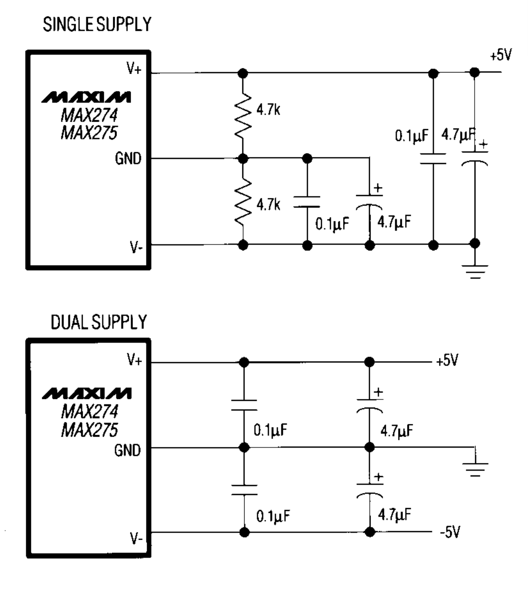


Figure 9. Power-Supply Configurations

Design Software General Description

Maxim's filter software reduces the time required to design a continuous-time lowpass or bandpass filter using the MAX274 or MAX275. Starting from your basic filter requirements, using a "spreadsheet-style" format, the software calculates order, poles and Qs of classic filter types (Butterworth, Chebyshev, or Bessel), and resistor values required to implement the desired filter response.

For hardware prototyping with the MAX274, the MAX274 evaluation kit is recommended, which includes a PC board and a MAX274 IC.

Features

- **Calculates filter order, poles, and Qs from your filter requirements.**
- **Plots filter responses – gain, phase, and group delay – for inspection BEFORE you build the filter.**
- **Calculates resistor values used to obtain desired filter response using the MAX274 or MAX275.**

Ordering Information

PART	DISK TYPE
MAX274SOFT	5¼" Floppy
MAX275SOFT	5¼" Floppy

In the USA and Canada, order directly from Maxim (1-800-998-8800). In other countries, call your local Maxim representative.

Software Operation

NOTE: CHECK FILE "README.DOC" FOR IMPORTANT CHANGES.

Installation

You will need an IBM-compatible PC, DOS version 2.0 or later with a 5¼" floppy disk drive, and one of the following video displays: Hercules graphics, CGA, EGA, VGA, or compatible. Either a hard drive or an additional floppy drive is also required.

To install the program, insert the floppy into your disk drive and type "A: INSTALL" (or B:INSTALL). Follow the instructions on the screen. After installation, type "FILTER" to start the program. Be sure you are in the drive/directory where the software is installed.

Help

After installing the software, print a hard copy of the file FILTER.HLP by entering "TYPE FILTER.HLP > PRN" from DOS. This collection of help screens serves as the instruction manual for operating the software. Individual help screens may be printed while running the software by pressing F1, then following the instructions on the screen.

References

The following references contain information and tables to aid in filter designs:

Carson, Chen. *Active Filter Design*, Hayden, 1982.

Tedeschi, Franck. *Active Filter Cookbook*, Tab Books No 1133, 1979.

Hilburn, Johnson. *Manual of Active Filter Design*, McGraw Hill, 1973.

German Language:

U. Tietze; Ch. Schenk. *Halbleiter-Schaltungstecknik Springer-Verlag*, Berlin Heidelberg, New York/Tokyo 1991.