



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

MAX7401/MAX7405

General Description

The MAX7401/MAX7405 8th-order, lowpass, Bessel, switched-capacitor filters (SCFs) operate from a single +5V (MAX7401) or +3V (MAX7405) supply. These devices draw only 2mA of supply current and allow corner frequencies from 1Hz to 5kHz, making them ideal for low-power post-DAC filtering and anti-aliasing applications. They feature a shutdown mode that reduces supply current to 0.2μA.

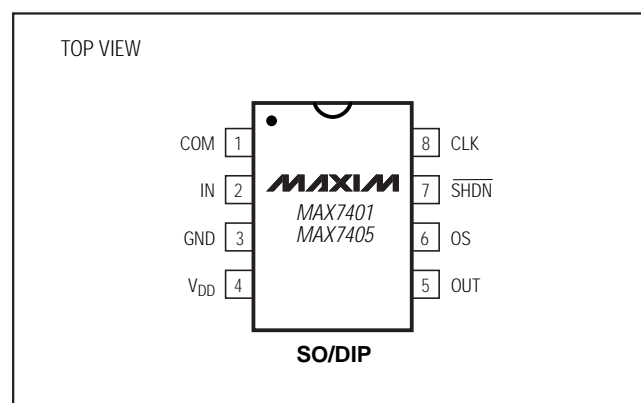
Two clocking options are available on these devices: self-clocking (through the use of an external capacitor) or external clocking for tighter corner-frequency control. An offset adjust pin allows for adjustment of the DC output level.

The MAX7401/MAX7405 Bessel filters provide low overshoot and fast settling. Their fixed response simplifies the design task to selecting a clock frequency.

Applications

ADC Anti-Aliasing
Post-DAC Filtering
Air-Bag Electronics
CT2 Base Stations
Speech Processing

Pin Configuration



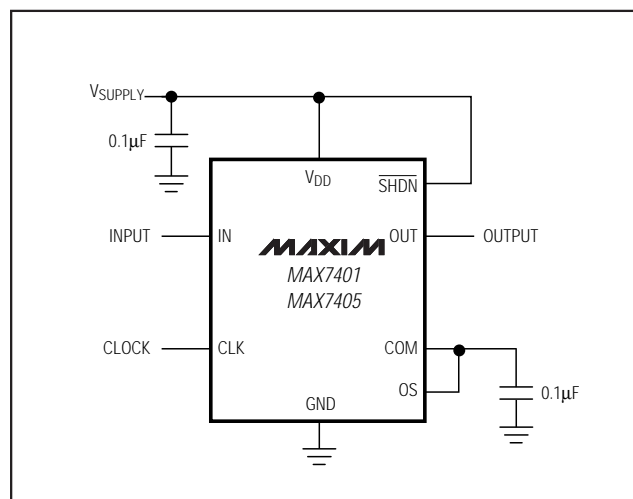
Features

- ◆ 8th-Order, Lowpass Bessel Filters
- ◆ Low Noise and Distortion: -82dB THD + Noise
- ◆ Clock-Tunable Corner Frequency (1Hz to 5kHz)
- ◆ 100:1 Clock-to-Corner Ratio
- ◆ Single-Supply Operation
 - +5V (MAX7401)
 - +3V (MAX7405)
- ◆ Low Power
 - 2mA (Operating Mode)
 - 0.2μA (Shutdown Mode)
- ◆ Available in 8-Pin SO/DIP Packages
- ◆ Low Output Offset: ±5mV

Ordering Information

| PART | TEMP. RANGE | PIN-PACKAGE |
|------------|----------------|---------------|
| MAX7401CSA | 0°C to +70°C | 8 SO |
| MAX7401CPA | 0°C to +70°C | 8 Plastic DIP |
| MAX7401ESA | -40°C to +85°C | 8 SO |
| MAX7401EPA | -40°C to +85°C | 8 Plastic DIP |
| MAX7405CSA | 0°C to +70°C | 8 SO |
| MAX7405CPA | 0°C to +70°C | 8 Plastic DIP |
| MAX7405ESA | -40°C to +85°C | 8 SO |
| MAX7405EPA | -40°C to +85°C | 8 Plastic DIP |

Typical Operating Circuit



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ABSOLUTE MAXIMUM RATINGS

| | |
|----------------------------|-----------------------------------|
| V _{DD} to GND | |
| MAX7401 | -0.3V to +6V |
| MAX7405 | -0.3V to +4V |
| IN, OUT, COM, OS, CLK | -0.3V to (V _{DD} + 0.3V) |
| SHDN | -0.3V to +6V |
| OUT Short-Circuit Duration | 1sec |

| | |
|---|-----------------|
| Continuous Power Dissipation (T _A = +70°C) | |
| 8-Pin SO (derate 5.88mW/°C above +70°C) | 471mW |
| 8-Pin DIP (derate 9.09mW/°C above +70°C) | 727mW |
| Operating Temperature Ranges | |
| MAX740 _C_A | 0°C to +70°C |
| MAX740 _E_A | -40°C to +85°C |
| Storage Temperature Range | -65°C to +150°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—MAX7401

(V_{DD} = +5V, filter output measured at OUT, 10k Ω || 50pF load to GND at OUT, OS = COM, 0.1 μ F from COM to GND, SHDN = V_{DD}, f_{CLK} = 100kHz, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|--|-----------------------------------|---|---------------------------|------------------------|---------------------------|------------|
| FILTER CHARACTERISTICS | | | | | | |
| Corner Frequency | f _C | (Note 1) | | 0.001 to 5 | | kHz |
| Clock-to-Corner Ratio | f _{CLK} / f _C | | | 100:1 | | |
| Clock-to-Corner Tempco | | | | 10 | | ppm/°C |
| Output Voltage Range | | | 0.25 | V _{DD} - 0.25 | | V |
| Output Offset Voltage | V _{OFFSET} | V _{IN} = V _{COM} = V _{DD} / 2 | | ±5 | ±25 | mV |
| DC Insertion Gain with Output Offset Removed | | V _{COM} = V _{DD} / 2 (Note 2) | -0.1 | 0.15 | 0.3 | dB |
| Total Harmonic Distortion plus Noise | THD+N | f _{IN} = 200Hz, V _{IN} = 4Vp-p, measurement bandwidth = 22kHz | | -82 | | dB |
| OS Voltage Gain to OUT | A _{OS} | | | 1 | | V/V |
| Input Voltage Range at OS | V _{OS} | | | V _{COM} ±0.1 | | V |
| COM Voltage Range | V _{COM} | Input, COM externally driven | V _{DD} / 2 - 0.5 | V _{DD} / 2 | V _{DD} / 2 + 0.5 | V |
| | | Output, COM internally biased | V _{DD} / 2 - 0.2 | V _{DD} / 2 | V _{DD} / 2 + 0.2 | |
| Input Resistance at COM | R _{COM} | | 75 | 125 | | k Ω |
| Clock Feedthrough | | | | 10 | | mVp-p |
| Resistive Output Load Drive | R _L | | 10 | 1 | | k Ω |
| Maximum Capacitive Load at OUT | C _L | | 50 | 500 | | pF |
| Input Leakage Current at COM | | SHDN = GND, V _{COM} = 0 to V _{DD} | | ±0.1 | ±10 | μ A |
| Input Leakage Current at OS | | V _{OS} = 0 to (V _{DD} - 1V) (Note 3) | | ±0.1 | ±10 | μ A |
| CLOCK | | | | | | |
| Internal Oscillator Frequency | f _{OSC} | C _{OSC} = 1000pF (Note 4) | 29 | 38 | 48 | kHz |
| Clock Input Current | I _{CLK} | V _{CLK} = 0 or 5V | | ±15 | ±30 | μ A |
| Clock Input High | V _{IH} | | V _{DD} - 0.5 | | | V |
| Clock Input Low | V _{IL} | | | | 0.5 | V |

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ELECTRICAL CHARACTERISTICS—MAX7401 (continued)

($V_{DD} = +5V$, filter output measured at OUT, $10k\Omega \parallel 50pF$ load to GND at OUT, OS = COM, $0.1\mu F$ from COM to GND, $\overline{SHDN} = V_{DD}$, $f_{CLK} = 100kHz$, $T_A = T_{MIN}$ to T_{MAX} , unless otherwise noted. Typical values are at $T_A = +25^\circ C$.)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|-----------------------|---|----------------|-----------|----------|---------|
| POWER REQUIREMENTS | | | | | | |
| Supply Voltage | V_{DD} | | 4.5 | | 5.5 | V |
| Supply Current | I_{DD} | Operating mode, no load, IN = OS = COM | | 2 | 3.5 | mA |
| Shutdown Current | $I_{\overline{SHDN}}$ | $\overline{SHDN} = GND$, CLK driven from 0 to V_{DD} | | 0.2 | 1 | μA |
| Power-Supply Rejection Ratio | PSRR | Measured at DC | | 60 | | dB |
| SHUTDOWN | | | | | | |
| \overline{SHDN} Input High | V_{SDH} | | $V_{DD} - 0.5$ | | | V |
| \overline{SHDN} Input Low | V_{SDL} | | | | 0.5 | V |
| \overline{SHDN} Input Leakage Current | | $V_{\overline{SHDN}} = 0$ to V_{DD} | | ± 0.1 | ± 10 | μA |

ELECTRICAL CHARACTERISTICS—MAX7405

($V_{DD} = +3V$, filter output measured at OUT, $10k\Omega \parallel 50pF$ load to GND at OUT, OS = COM, $0.1\mu F$ from COM to GND, $\overline{SHDN} = V_{DD}$, $f_{CLK} = 100kHz$, $T_A = T_{MIN}$ to T_{MAX} , unless otherwise noted. Typical values are at $T_A = +25^\circ C$.)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|--|---------------|--|--------------------|-------------------|--------------------|-----------------|
| FILTER CHARACTERISTICS | | | | | | |
| Corner Frequency | f_C | (Note 1) | | 0.001 to 5 | | kHz |
| Clock-to-Corner Ratio | f_{CLK}/f_C | | | 100:1 | | |
| Clock-to-Corner Tempco | | | | 10 | | ppm/ $^\circ C$ |
| Output Voltage Range | | | 0.25 | $V_{DD} - 0.25$ | | V |
| Output Offset Voltage | V_{OFFSET} | $V_{IN} = V_{COM} = V_{DD} / 2$ | | ± 5 | ± 25 | mV |
| DC Insertion Gain with Output Offset Removed | | $V_{COM} = V_{DD} / 2$ (Note 2) | -0.1 | 0.03 | 0.3 | dB |
| Total Harmonic Distortion plus Noise | THD+N | $f_{IN} = 200Hz$, $V_{IN} = 2.5V_{p-p}$, measurement bandwidth = 22kHz | | -84 | | dB |
| OS Voltage Gain to OUT | A_{OS} | | | 1 | | V/V |
| Input Voltage Range at OS | V_{OS} | | | $V_{COM} \pm 0.1$ | | V |
| COM Voltage Range | V_{COM} | COM internally biased or externally driven | $V_{DD} / 2 - 0.1$ | $V_{DD} / 2$ | $V_{DD} / 2 + 0.1$ | V |
| Input Resistance at COM | R_{COM} | | 75 | 125 | | $k\Omega$ |
| Clock Feedthrough | | | | 10 | | mVp-p |
| Resistance Output Load Drive | R_L | | 10 | 1 | | $k\Omega$ |
| Maximum Capacitive Load at OUT | C_L | | 50 | 500 | | pF |
| Input Leakage Current at COM | | $\overline{SHDN} = GND$, $V_{COM} = 0$ to V_{DD} | | ± 0.1 | ± 10 | μA |
| Input Leakage Current at OS | | $V_{OS} = 0$ to $(V_{DD} - 1V)$ (Note 3) | | ± 0.1 | ± 10 | μA |

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ELECTRICAL CHARACTERISTICS—MAX7405 (continued)

($V_{DD} = +3V$, filter output measured at OUT, $10k\Omega \parallel 50pF$ load to GND at OUT, OS = COM, $0.1\mu F$ from COM to GND, $\overline{SHDN} = V_{DD}$, $f_{CLK} = 100kHz$, $T_A = T_{MIN}$ to T_{MAX} , unless otherwise noted. Typical values are at $T_A = +25^\circ C$.)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|-------------------------------------|-------------------|--|-----------------------|------|-----|-------|
| CLOCK | | | | | | |
| Internal Oscillator Frequency | f _{OSC} | C _{OSC} = 1000pF (Note 4) | 26 | 34 | 43 | kHz |
| Clock Input Current | I _{CLK} | V _{CLK} = 0 or 3V | | ±15 | ±30 | µA |
| Clock Input High | V _{IH} | | V _{DD} - 0.5 | | | V |
| Clock Input Low | V _{IL} | | 0.5 | | | V |
| POWER REQUIREMENTS | | | | | | |
| Supply Voltage | V _{DD} | | 2.7 | | 3.6 | V |
| Supply Current | I _{DD} | Operating mode, no load, IN = OS = COM | | 2 | 3.5 | mA |
| Shutdown Current | I _{SHDN} | $\overline{\text{SHDN}}$ = GND, CLK driven from 0 to V _{DD} | | 0.2 | 1 | µA |
| Power-Supply Rejection Ratio | PSRR | Measured at DC | | 60 | | dB |
| SHUTDOWN | | | | | | |
| $\overline{\text{SHDN}}$ Input High | V _{SDH} | | V _{DD} - 0.5 | | | V |
| $\overline{\text{SHDN}}$ Input Low | V _{SDL} | | 0.5 | | | V |
| SHDN Input Leakage Current | | V $\overline{\text{SHDN}}$ = 0 to V _{DD} | | ±0.1 | ±10 | µA |

FILTER CHARACTERISTICS—MAX7401/MAX7405

($V_{DD} = +5V$ for MAX7401, $V_{DD} = +3V$ for MAX7405; filter output measured at OUT; $10k\Omega \parallel 50pF$ load to GND at OUT; $\overline{SHDN} = V_{DD}$; $V_{COM} = V_{OS} = V_{DD}/2$; $f_{CLK} = 100kHz$; $T_A = T_{MIN}$ to T_{MAX} ; unless otherwise noted. Typical values are at $T_A = +25^\circ C$.)

| PARAMETER | CONDITIONS | MIN | TYP | MAX | UNITS |
|------------------------------------|-------------------|------|------|------|-------|
| Insertion Gain Relative to DC Gain | $f_{IN} = 0.5f_C$ | -1.0 | -0.8 | -0.6 | dB |
| | $f_{IN} = f_C$ | -3.3 | -3.0 | -2.7 | |
| | $f_{IN} = 3f_C$ | | -33 | -29 | |
| | $f_{IN} = 6f_C$ | | -79 | -74 | |

Note 1: The maximum f_C is defined as the clock frequency, $f_{CLK} = 100 \cdot f_C$, at which the peak SINAD drops to 68dB with a sinusoidal input at $0.2f_C$.

Note 2: DC insertion gain is defined as $\Delta V_{OUT} / \Delta V_{IN}$.

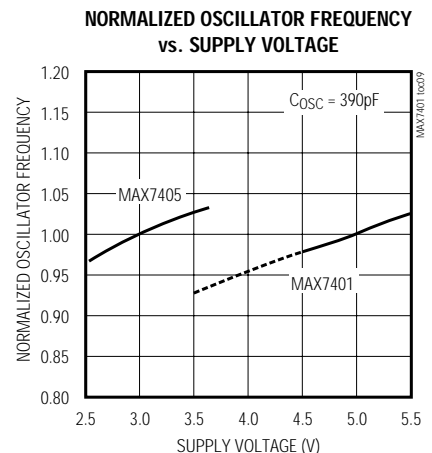
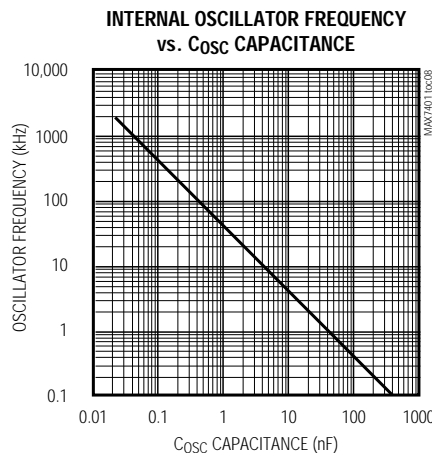
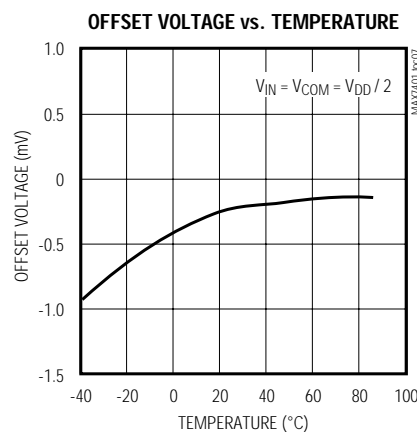
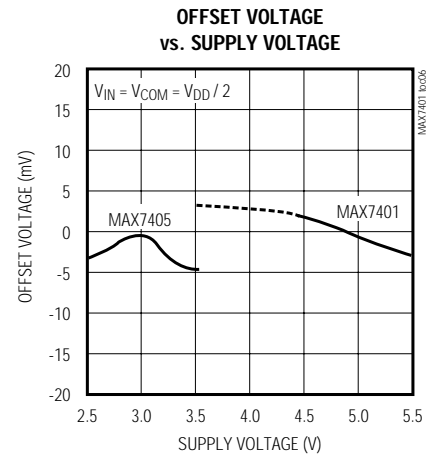
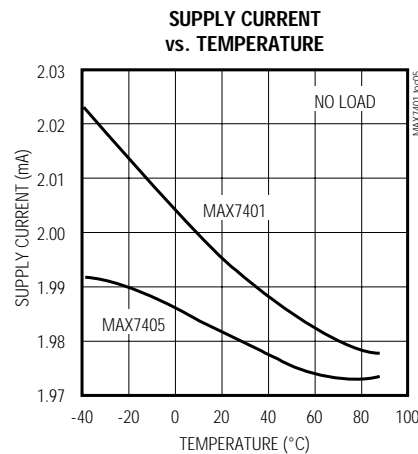
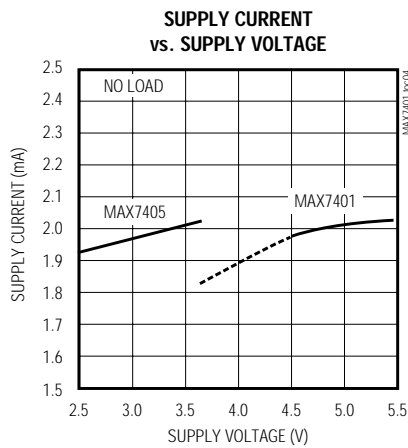
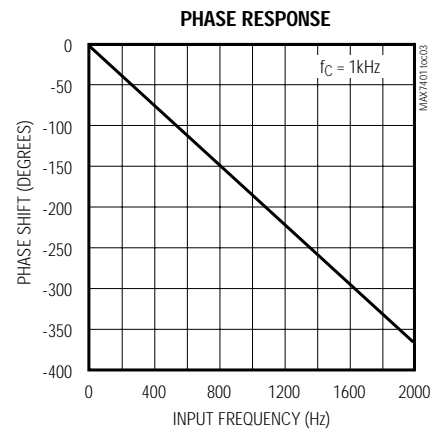
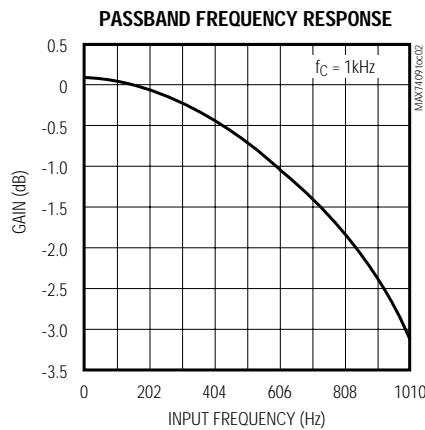
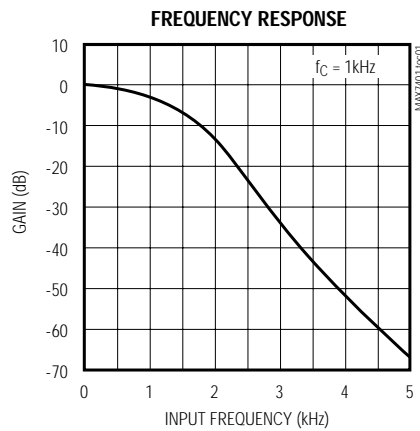
Note 3: OS voltages above $V_{DD} - 1V$ saturate the input and result in a $75\mu A$ typical input leakage current.

Note 4: For MAX7401, $f_{OSC} (kHz) \approx 38 \cdot 10^3 / C_{OSC} (pF)$. For MAX7405, $f_{OSC} (kHz) \approx 34 \cdot 10^3 / C_{OSC} (pF)$.

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Typical Operating Characteristics

($V_{DD} = +5V$ for MAX7401, $V_{DD} = +3V$ for MAX7405; $f_{CLK} = 100kHz$; $\overline{SHDN} = V_{DD}$; $V_{COM} = V_{OS} = V_{DD} / 2$; $T_A = +25^\circ C$; unless otherwise noted.)



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

Typical Operating Characteristics (continued)

($V_{DD} = +5V$ for MAX7401, $V_{DD} = +3V$ for MAX7405; $f_{CLK} = 100kHz$; $\overline{SHDN} = V_{DD}$; $V_{COM} = V_{OS} = V_{DD} / 2$; $T_A = +25^\circ C$; unless otherwise noted.)

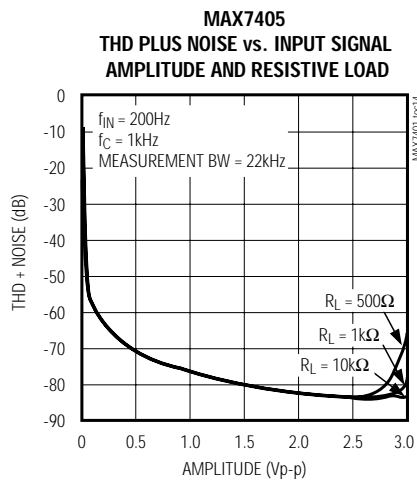
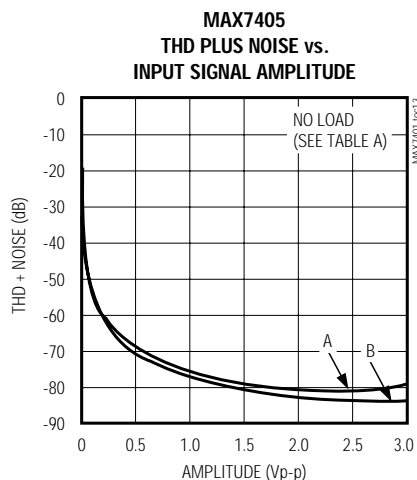
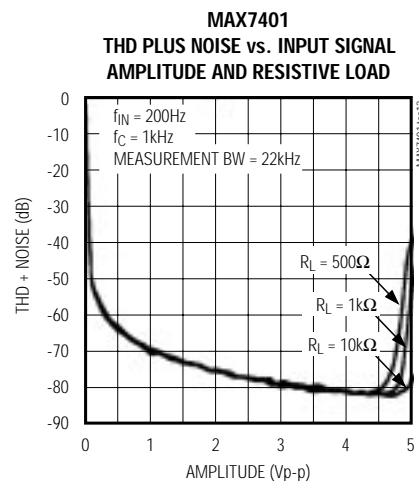
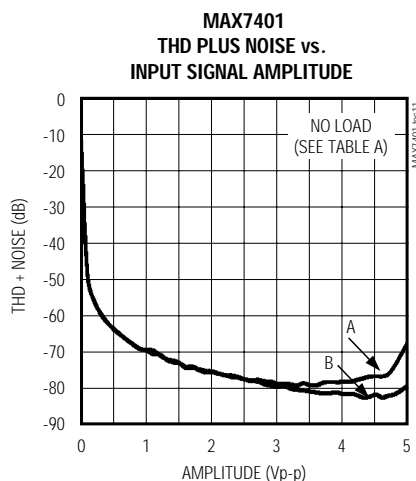
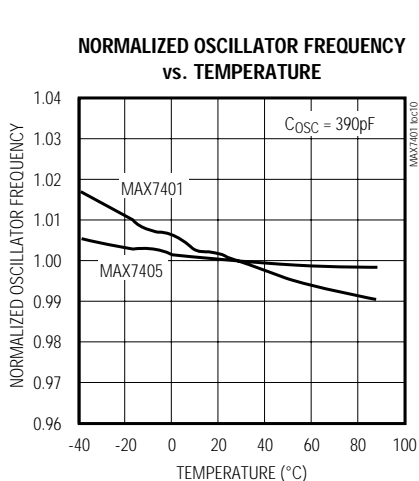


Table A. THD Plus Noise vs. Input Signal Amplitude Test Conditions

| TRACE | f_{IN} (Hz) | f_C (kHz) | f_{CLK} (kHz) | MEASUREMENT BANDWIDTH (kHz) |
|-------|------------------|----------------|--------------------|--------------------------------|
| A | 1000 | 5 | 500 | 80 |
| B | 200 | 1 | 100 | 22 |

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

Pin Description

| PIN | NAME | FUNCTION |
|-----|--------------------------|--|
| 1 | COM | Common Input. Biased internally at mid-supply. Bypass externally to GND with a 0.1 μ F capacitor. To override internal biasing, drive with an external supply. |
| 2 | IN | Filter Input |
| 3 | GND | Ground |
| 4 | V _{DD} | Positive Supply Input: +5V for MAX7401, +3V for MAX7405 |
| 5 | OUT | Filter Output |
| 6 | OS | Offset Adjust Input. To adjust output offset, bias OS externally. Connect OS to COM if no offset adjustment is needed. Refer to <i>Offset and Common-Mode Input Adjustment</i> section. |
| 7 | $\overline{\text{SHDN}}$ | Shutdown Input. Drive low to enable shutdown mode; drive high or connect to V _{DD} for normal operation. |
| 8 | CLK | Clock Input. To override the internal oscillator, connect to an external clock; otherwise, connect an external capacitor (C _{OSC}) from CLK to GND to set the internal oscillator frequency. |

Detailed Description

The MAX7401/MAX7405 Bessel filters provide low overshoot and fast settling responses. Both parts operate with a 100:1 clock-to-corner frequency ratio and a 5kHz maximum corner frequency.

Lowpass Bessel filters such as the MAX7401/MAX7405 delay all frequency components equally, preserving the shape of step inputs (subject to the attenuation of the higher frequencies). Bessel filters settle quickly—an important characteristic in applications that use a multiplexer (mux) to select an input signal for an analog-to-digital converter (ADC). An anti-aliasing filter placed between the mux and the ADC must settle quickly after a new channel is selected.

Figure 1 shows the difference between Bessel and Butterworth filters when a 1kHz square wave is applied to the filter input. With the filter cutoff frequencies set at 5kHz, trace B shows the Bessel filter response and trace C shows the Butterworth filter response.

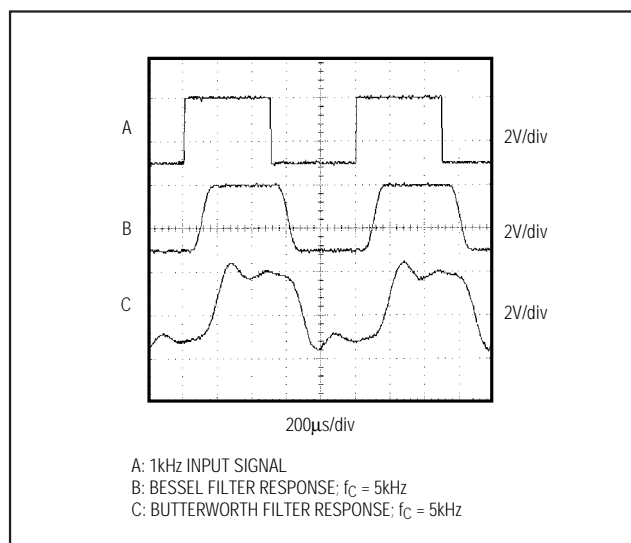


Figure 1. Bessel vs. Butterworth Filter Response

Background Information

Most switched-capacitor filters (SCFs) are designed with biquadratic sections. Each section implements two filtering poles, and the sections are 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. Figure 2 shows a basic 8th-order ladder filter structure.

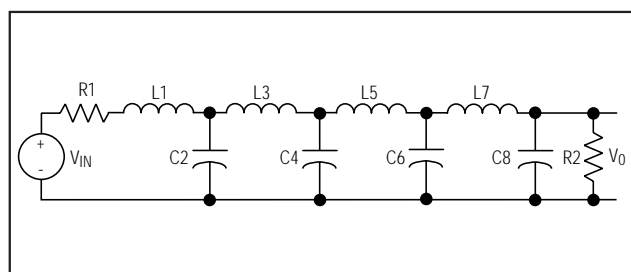
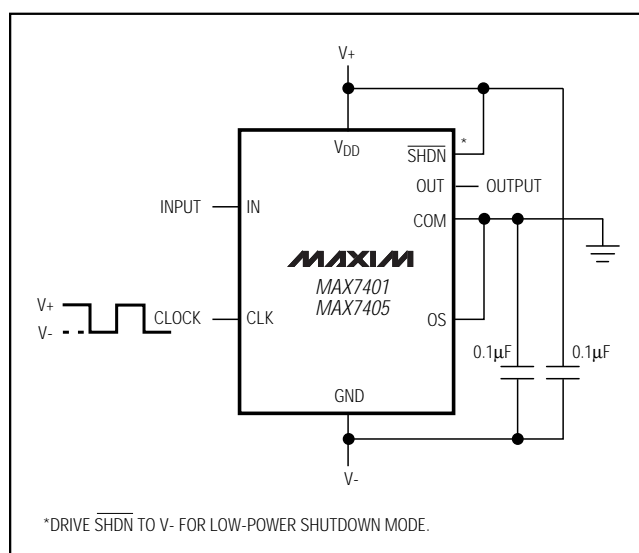


Figure 2. 8th-Order Ladder Filter Network

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

Table 1. Typical Harmonic Distortion

| FILTER | f _{CLK} (kHz) | f _c (kHz) | f _{IN} (Hz) | V _{IN} (V _{p-p}) | TYPICAL HARMONIC DISTORTION (dB) | | | |
|---------|---------------------------|-------------------------|-------------------------|--|----------------------------------|-----|-----|-----|
| | | | | | 2nd | 3rd | 4th | 5th |
| MAX7401 | 100 | 1 | 200 | 4 | -91 | -83 | -90 | -93 |
| | 500 | 5 | 1000 | | -89 | -79 | -92 | -92 |
| MAX7405 | 100 | 1 | 200 | 2 | -87 | -83 | -87 | -88 |
| | 500 | 5 | 1000 | | -83 | -82 | -88 | -88 |


Figure 4. Dual-Supply Operation

GND to the negative supply. Figure 4 shows an example of dual-supply operation. Single- and dual-supply performance are equivalent. For either single- or dual-supply operation, drive CLK and SHDN from GND (V₋ in dual-supply operation) to V_{DD}. For $\pm 5V$ dual-supply applications, use the MAX291–MAX297.

Input Signal Amplitude Range

The optimal input signal range is determined by observing the voltage level at which the total harmonic distortion plus noise (THD+N) is minimized for a given corner frequency. The *Typical Operating Characteristics* show graphs of the devices' THD+N response as the input signal's peak-to-peak amplitude is varied. These measurements are made with OS and COM biased at mid-supply.

Anti-Aliasing and Post-DAC Filtering

When using the MAX7401/MAX7405 for anti-aliasing or post-DAC filtering, synchronize the DAC and the filter clocks. If the clocks are not synchronized, beat frequencies may alias into the passband.

The high clock-to-corner frequency ratio (100:1) also eases the requirements of pre- and post-SCF filtering. At the input, a lowpass filter prevents the aliasing of frequencies around the clock frequency into the passband. At the output, a lowpass filter attenuates the clock feedthrough.

A high clock-to-corner frequency ratio allows a simple RC lowpass filter, with the cutoff frequency set above the SCF corner frequency, to provide input anti-aliasing and reasonable output clock attenuation.

Harmonic Distortion

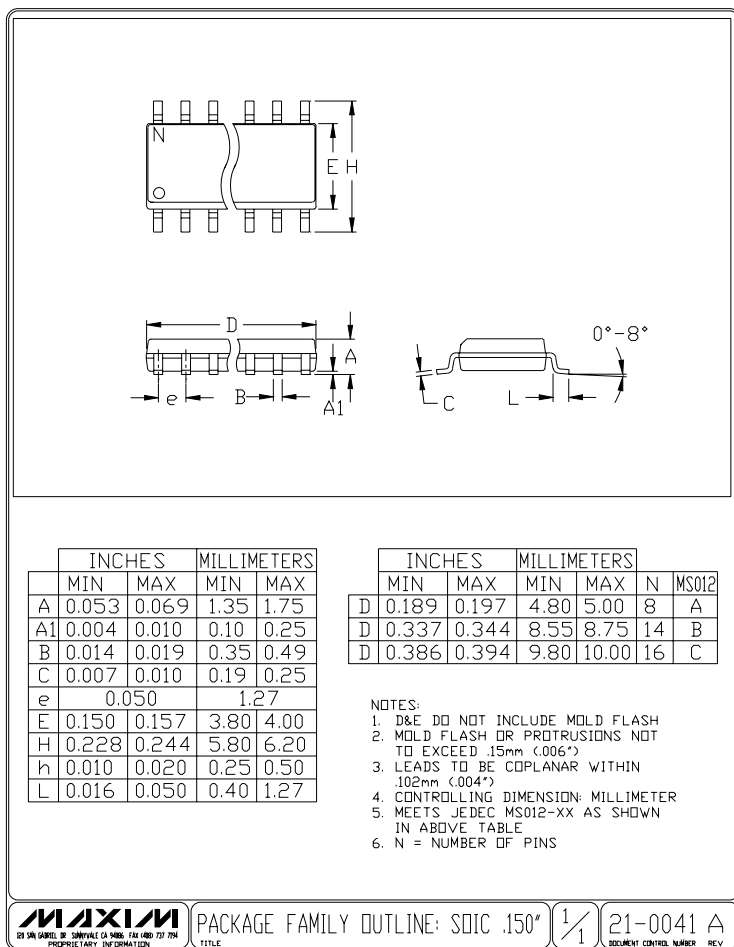
Harmonic distortion arises from nonlinearities within the filter. These nonlinearities generate harmonics when a pure sine wave is applied to the filter input. Table 1 lists the MAX7401/MAX7405's typical harmonic-distortion values with a 10k Ω load at T_A = +25°C.

Chip Information

TRANSISTOR COUNT: 1116

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

Package Information



Package Information (continued)

Figure 1: Package Family Outline (PFO) for the PDIP package. The figure includes three views: a top view showing the package width D1 and pin pitch D; a side view showing the package height A, lead height A2, lead length L, lead thickness e, and pin diameter B1; and a front view showing the package width E, lead height E1, lead length L, lead thickness eA, eB, and pin diameter C. The front view also indicates a 0°-15° lead angle. The package is labeled with 'N' for the number of pins.

| 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 | |

| INCHES | | MILLIMETERS | | N | MS001 |
|--------|-------------|-------------|-------|---|-------|
| MIN | MAX | MIN | MAX | | |
| D | 0.348 0.390 | 8.84 9.91 | 8 AB | | |
| D | 0.735 0.765 | 18.67 19.43 | 14 AC | | |
| D | 0.745 0.765 | 18.92 19.43 | 16 AA | | |
| D | 0.885 0.915 | 22.48 23.24 | 18 AD | | |
| D | 1.015 1.045 | 25.78 26.54 | 20 AE | | |
| D | 1.14 1.265 | 28.96 32.13 | 24 AF | | |
| D | 1.360 1.380 | 34.54 35.05 | 28 *5 | | |

NOTES:

1. D&E DO NOT INCLUDE MOLD FLASH
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .15mm (.006")
3. CONTROLLING DIMENSION: MILLIMETER
4. MEETS JEDEC MS001-XX AS SHOWN IN ABOVE TABLE
5. SIMILAR TO JEDEC MO-058AB
6. N = NUMBER OF PINS

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PACKAGE FAMILY OUTLINE: PDIP .300" TITLE

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DOCUMENT CONTROL NUMBER 85

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

NOTES

Maxim cannot assume responsibility for use of any circuitry other than circuitry entirely embodied in a Maxim product. No circuit patent licenses are implied. Maxim reserves the right to change the circuitry and specifications without notice at any time.

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