



10 Hz to 102.4 kHz 4-Bit Programmable

32-Pin DIP 4-Pole Filters

Description

The 424 Series are 4-pole digitally programmable low-pass and high-pass active filters. These new filters take advantage of the company's proprietary designs using surface-mount technology to provide a low profile, compact package in minimal board space. 424 filters are factory tuned to one of ten preset 4-bit binary ranges from 10 Hz to 102.4 kHz. Contact the factory for custom discrete tuning ranges, maximum span 1000:1.

All 424 Series models are easy to use fully finished filters which require no external components or adjustment. They feature low harmonic distortion, near theoretical phase and amplitude characteristics and operate over a dynamic input voltage range from non-critical ±12V to ±18V power supplies.

Features/Benefits:

- Low harmonic distortion and wide signal-to-noise ratio to 16-bit resolution.
- Compact 1.8"L x 0.8"W x 0.3"H min. (32-pin DIP footprint) minimizes board space requirements.
- Digitally programmable corner frequency allows selecting cut-off frequencies specific to each application.
- Plug-in ready-to-use, reducing engineering design and manufacturing cycle time.
- Factory tuned, no external clocks or adjustments needed
- Broad range of transfer characteristics and corner frequencies to meet a wide range of applications.

Applications

- Anti-alias filtering
- Data acquisition systems
- Communication systems and electronics
- Medical electronics equipment and research
- Aerospace, navigation and sonar applications
- Acoustic and vibration analysis and control
- Real and compressed time data analysis
- Noise elimination
- Signal reconstruction



| | |
|--|------|
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| Available Low-Pass Models: | |
| 424L4B 4-pole Butterworth | 3 |
| 424L4L 4-pole Bessel | 3 |
| 424L4Y2 4-pole Cheby (0.2 dB Ripple) | 3 |
| 424L4Y5 4-pole Cheby (0.5 dB Ripple) | 3 |
| Available High-Pass Models: | |
| 424H4B 4-pole Butterworth | 4 |
| 424H4Y2 4-pole Cheby (0.2 dB Ripple) | 4 |
| 424H4Y5 4-pole Cheby (0.5 dB Ripple) | 4 |
| General Specifications: | |
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Digital Tuning & Control Characteristics

4-Bit Programmable Filters

Digital Tuning Characteristics

The digital tuning interface circuits are a parallel set of CMOS switches which accept CMOS compatible inputs for the four tuning bits ($D_0 - D_3$).

Binary Tuning Range

| MSB | --- | --- | LSB | Bit Weight |
|-------|-------|-------|-------|-----------------------|
| 2^3 | 2^2 | 2^1 | 2^0 | fc - corner frequency |
| D_3 | D_2 | D_1 | D_0 | |
| 0 | 0 | 0 | 0 | $f_{max}/16$ |
| 0 | 0 | 0 | 1 | $f_{max}/8$ |
| 0 | 0 | 1 | 1 | $f_{max}/4$ |
| 0 | 1 | 1 | 1 | $f_{max}/2$ |
| 1 | 1 | 1 | 1 | f_{max} |

Binary Tuning Equation:

$$fc = (f_{max}/16) [1 + D_3 \times 2^3 + D_2 \times 2^2 + D_1 \times 2^1 + D_0 \times 2^0]$$

where $D_1 - D_3 = "0"$ or $"1"$, and

f_{max} = Maximum tuning frequency

fc = Corner frequency;

Minimum tunable frequency = $f_{max}/16$ (D_0 thru $D_3 = 0$);

Minimum frequency step (Resolution) = $f_{max}/16$

Discrete Frequencies

| F | D_0 | D_1 | D_2 | D_3 |
|-------|-------|-------|-------|-------|
| F_B | 0 | 0 | 0 | 0 |
| F_1 | 1 | 0 | 0 | 0 |
| F_2 | 1 | 1 | 0 | 0 |
| F_3 | 1 | 1 | 1 | 0 |
| F_4 | 1 | 1 | 1 | 1 |

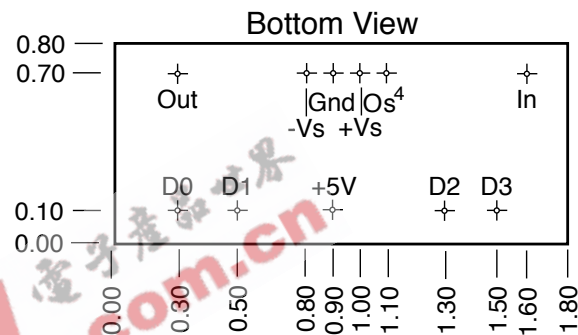
Discrete Tuning Equation:

$$fc = F_B + D_0[\Delta f_0] + D_1[\Delta f_1] + D_2[\Delta f_2] + D_3[\Delta f_3]$$

$\Delta f_0, \Delta f_1, \Delta f_2, \Delta f_3$ are the incremental frequency shifts for the data bits D_0, D_1, D_2 and D_3 . They are selected to realize the five customer specified programming frequencies $F_B \Rightarrow F_4$. Other programming codes produce valid fc's between F_B and F_4 .

Pin-Out Key

| | | | |
|-----|--------------------------|-------|--------------------|
| IN | Analog Input Signal | D_3 | Tuning Bit 3 (MSB) |
| OUT | Analog Output Signal | D_2 | Tuning Bit 2 |
| GND | Power and Signal Return | D_1 | Tuning Bit 1 |
| +Vs | Supply Voltage, Positive | D_0 | Tuning Bit 0 (LSB) |
| -Vs | Supply Voltage, Negative | +5V | Logic Power |
| Os | Offset Adjustment | | |



Data Input Specifications

Input Data Levels

(+5Vdc CMOS Logic)

Input Voltage ($V_{S=15}$ Vdc)

| | | |
|---------------|--------------|--------------|
| Low Level In | 0 Vdc min. | 0.5 Vdc max. |
| High Level In | 3.5 Vdc min. | 5.0 Vdc max. |

Input Current

| | | |
|---------------|-------------------|-------------------|
| High Level In | -0.4 μ A typ. | -2.0 μ A max. |
| Low Level In | +0.4 μ A typ. | +2.0 μ A max. |

Input Capacitance

| | |
|------------|------------|
| 20 pF typ. | 30 pF max. |
|------------|------------|

Input Data Format

Positive Logic

Frequency Select Bits

Logic "1" = (+5Vdc)
Logic "0" = Gnd

Bit Weight

(Binary-Coded)

D_0

LSB (least significant bit)

D_3

MSB (most significant bit)

Frequency Range 16:1 Binary Weighted



4-Bit Programmable

4-Pole Low-Pass Filters

| Model | 424L4B | 424L4L | 424L4Y2 | 424L4Y5 |
|--|--|--|---|---|
| Product Specifications | | | | |
| Transfer Function | 4-Pole, Butterworth | 4-Pole, Bessel | 4-Pole, Chebychev, 0.2 dB Ripple | 4-Pole, Chebychev, 0.5 dB Ripple |
| Size | 0.8" x 1.8" x 0.3" | 0.8" x 1.8" x 0.3" | 0.8" x 1.8" x 0.3" | 0.8" x 1.8" x 0.3" |
| Range fc | 10.0 Hz to 102.4 kHz | 10.0 Hz to 102.4 kHz | 10.0 Hz to 102.4 kHz | 10.0 Hz to 102.4 kHz |
| Theoretical Transfer Characteristics | Appendix A Page 7 | Appendix A Page 2 | Appendix A Page 12 | Appendix A Page 15 |
| Passband Ripple (theoretical) | 0.0 dB | 0.0 dB | 0.20 dB | 0.50 dB |
| DC Voltage Gain (non-inverting) | 0 ± 0.1 dB max. 0 ± 0.05 dB typ. | 0 ± 0.1 dB max. 0 ± 0.05 dB typ. | 0 ± 0.1 dB max. 0 ± 0.05 dB typ. | 0 ± 0.1 dB max. 0 ± 0.05 dB typ. |
| Stopband Attenuation Rate | 24 dB/octave | 24 dB/octave | 24 dB/octave | 24 dB min. |
| Cutoff Frequency Stability | fc ± 2% max. ± 0.01% /°C | fc ± 2% max. ± 0.01% /°C | fc ± 2% max. ± 0.01% /°C | fc ± 2% max. ± 0.01% /°C |
| Amplitude Phase | -3 dB -180° | -3 dB -121° | -3 dB -231° | -3 dB -245° |
| Filter Attenuation (theoretical) | 0.67 dB 0.80 fc 3.01 dB 1.00 fc 30.0 dB 2.37 fc 40.0 dB 3.16 fc | 1.86 dB 0.80 fc 3.01 dB 1.00 fc 30.0 dB 3.50 fc 40.0 dB 4.72 fc | -0.20 dB 0.80 fc 3.01 dB 1.00 fc 30.0 dB 1.89 fc 40.0 dB 2.46 fc | -0.43 dB 0.80 fc 3.01 dB 1.00 fc 30.0 dB 1.80 fc 40.0 dB 2.33 fc |
| Phase Match¹ | 0 - 0.8 fc ± 2° max. ± 1° typ. 0.8 fc - 1.0 fc ± 3° max. ± 1.5° typ. | 0 - fc ± 2° max. ± 1° typ. | 0 - 0.8 fc ± 2° max. ± 1° typ. 0.8 fc - 1.0 fc ± 3° max. ± 1.5° typ. | 0 - 0.8 fc ± 2° max. ± 1° typ. 0.8 fc - 1.0 fc ± 3° max. ± 1.5° typ. |
| Amplitude Accuracy (theoretical) | 0 - 0.8 fc ± 0.2 dB max. ± 0.1 dB typ. 0.8 fc - 1.0 fc ± 0.3 dB max. ± 0.15 dB typ. | 0 - fc ± 0.2 dB max. ± 0.1 dB typ. | 0 - 0.8 fc ± 0.2 dB max. ± 0.1 dB typ. 0.8 fc - 1.0 fc ± 0.3 dB max. ± 0.15 dB typ. | 0 - 0.8 fc ± 0.2 dB max. ± 0.1 dB typ. 0.8 fc - 1.0 fc ± 0.3 dB max. ± 0.15 dB typ. |
| Total Harmonic Distortion @ 1 kHz | < - 100 dB typ. | < - 100 dB typ. | < - 88 dB typ. | < - 88 dB typ. |
| Wide Band Noise (5 Hz - 2 MHz) | 200 µVrms typ. | 200 µVrms typ. | 200 µVrms typ. | 200 µVrms typ. |
| Narrow Band Noise (5 Hz - 100 kHz) | 50 µVrms typ. | 50 µVrms typ. | 50 µVrms typ. | 50 µVrms typ. |
| Filter Mounting Assembly | FMA-02A | FMA-02A | FMA-02A | FMA-02A |

1. Unit to unit match for the same transfer function, set to the same frequency and operating configuration, and from the same manufacturing lot.



4-Bit Programmable

4-Pole High-Pass Filters

| Model | 424H4B | 424H4Y2 | 424H4Y5 |
|---|---|---|---|
| Product Specifications | | | |
| Transfer Function | 4-Pole, Butterworth | 4-Pole, Chebychev, 0.2 dB Ripple | 4-Pole, Chebychev, 0.5 dB Ripple |
| Size | 0.8" x 1.8" x 0.3" | 0.8" x 1.8" x 0.3" | 0.8" x 1.8" x 0.3" |
| Range f_c | 10.0 Hz to 102.4 kHz | 10.0 Hz to 102.4 kHz | 10.0 Hz to 102.4 kHz |
| Theoretical Transfer Characteristics | Appendix A Page 27 | Appendix A Page 31 | Appendix A Page 33 |
| Passband Ripple (theoretical) | 0.0 dB | 0.20 dB | 0.50 dB |
| Voltage Gain (non-inverting) | 0 ± 0.2 dB to 100 kHz 0 ± 0.5 dB to 120 kHz | 0 ± 0.2 dB to 100 kHz 0 ± 0.5 dB to 120 kHz | 0 ± 0.2 dB to 100 kHz 0 ± 0.5 dB to 120 kHz |
| Power Bandwidth | 120 kHz | 120 kHz | 120 kHz |
| Small Signal Bandwidth | (-6 dB) 1 MHz | (-6 dB) 1 MHz | (-6 dB) 1 MHz |
| Stopband Attenuation Rate | 24 dB/octave | 24 dB/octave | 24 dB/octave |
| Cutoff Frequency Stability Amplitude Phase | f_c ± 2% max. ± 0.01% /°C -3 dB -180° | f_c ± 2% max. ± 0.01% /°C -3 dB -231° | f_c ± 2% max. ± 0.01% /°C -3 dB -245° |
| Filter Attenuation (theoretical) | 40 dB 0.31 f_c 30 dB 0.42 f_c 3.01 dB 1.00 f_c 0.02 dB 2.00 f_c | 40.0 dB 0.41 f_c 30.0 dB 0.53 f_c 3.01 dB 1.00 f_c -0.07 dB 2.00 f_c | 40.0 dB 0.43 f_c 30.0 dB 0.56 f_c 3.01 dB 1.00 f_c -0.25 dB 2.00 f_c |
| Phase Match¹ | f_c - 100 kHz ± 3° max. ± 1.5° typ. | f_c - 100 kHz ± 3° max. ± 1.5° typ. | f_c - 100 kHz ± 3° max. ± 1.5° typ. |
| Amplitude Accuracy (theoretical) | 1.0 - 1.25 f_c ± 0.3 dB max. ± 0.15 dB typ. 1.25 f_c - 100 kHz ± 0.2 dB max. ± 0.1 dB max. | 1.0 - 1.25 f_c ± 0.3 dB max. ± 0.15 dB typ. 1.25 f_c - 100 kHz ± 0.2 dB max. ± 0.1 dB typ. | 1.0 - 1.25 f_c ± 0.3 dB max. ± 0.15 dB typ. 1.25 f_c - 100 kHz ± 0.2 dB max. ± 0.1 dB typ. |
| Total Harmonic Distortion @ 1kHz | < - 100 dB typ. | < - 88 dB typ. | < - 88 dB typ. |
| Wide Band Noise (5 Hz - 2 MHz) | 400 μ Vrms typ. | 400 μ Vrms typ. | 400 μ Vrms typ. |
| Narrow Band Noise (5 Hz - 100 kHz) | 100 μ Vrms typ. | 100 μ Vrms typ. | 100 μ Vrms typ. |
| Filter Mounting Assembly | FMA-02A | FMA-02A | FMA-02A |

1. Unit to unit match for the same transfer function, set to the same frequency and operating configuration, and from the same manufacturing lot.



Specification (25°C and Vs ± 15 Vdc)

Pin-Out and Package Data Ordering Information

Analog Input Characteristics¹

| | |
|-------------------|-------------|
| Impedance | 10 k Ω min. |
| Voltage Range | ± 10 Vpeak |
| Max. Safe Voltage | ±Vs |

Analog Output Characteristics

| | |
|------------------------------|-------------------------|
| Impedance (Closed Loop) | 1 Ω typ. 10 Ω max. |
| Linear Operating Range | ±10V |
| Maximum Current ² | ±2 mA |
| Offset Voltage ³ | 2 mV typ. 20 mV max. |
| Offset Temp. Coeff. | 50 μV/°C |

Power Supply (±V)

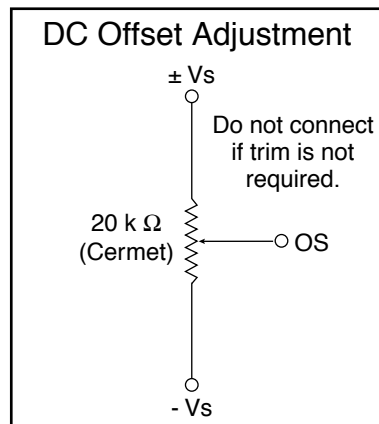
| | |
|----------------------|----------------------------|
| Rated Voltage | ±15 Vdc |
| Operating Range | ±12 to ±18 Vdc |
| Maximum Safe Voltage | ±18 Vdc |
| Quiescent Current | |
| 4-Pole | ±13 mA typ. ±20 mA max. |

Temperature

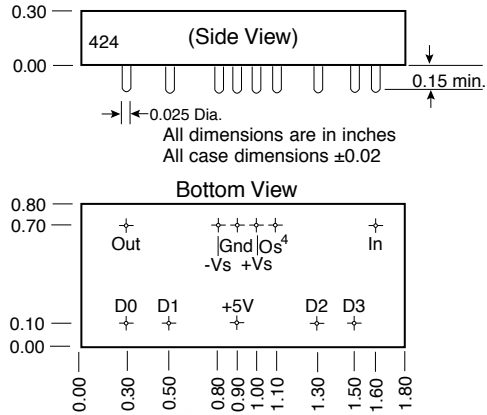
| | |
|-----------|--------------|
| Operating | 0 to +70°C |
| Storage | -25 to +85°C |

Notes:

- Input and output signal voltage referenced to supply common.
- Output is short circuit protected to common.
DO NOT CONNECT TO ±Vs.
- Adjustable to zero.
- Units operate with or without offset pin connected.



Pin-Out & Package Data



Filter Mounting Assembly-See FMA-02A

Ordering Information

Filter Type

- L - Low Pass
- H - High Pass

424 Transfer Function

- B - Butterworth
- L - Bessel
- Y2 - 0.2 Ripple Chebychev
- Y5 - 0.5 Ripple Chebychev

424 L4L-7

Model Number

Binary Tuning Ranges

| Model Number | Tuning Range (Hz) | *Minimum Step (Hz) |
|--------------|-------------------|--------------------|
| 1 | 10-160 | 10 |
| 2 | 25-400 | 25 |
| 3 | 50-800 | 50 |
| 4 | 100-1.60k | 100 |
| 5 | 250-4.00k | 250 |
| 6 | 500-8.00k | 500 |
| 7 | 1.00k-16.0k | 1.00k |
| 8 | 2.50k-40.0k | 2.50k |
| 9 | 5.00k-80.0k | 5.00k |
| 10 | 6.40k-102.4k | 6.40k |

*Contact factory for custom step frequency. Maximum step 6.40 kHz.

Discrete Frequency's

Customer must specify f₁, f₂, f₃, f₄, f₅. Maximum span f₁ ⇒ f₅ 1,000:1.

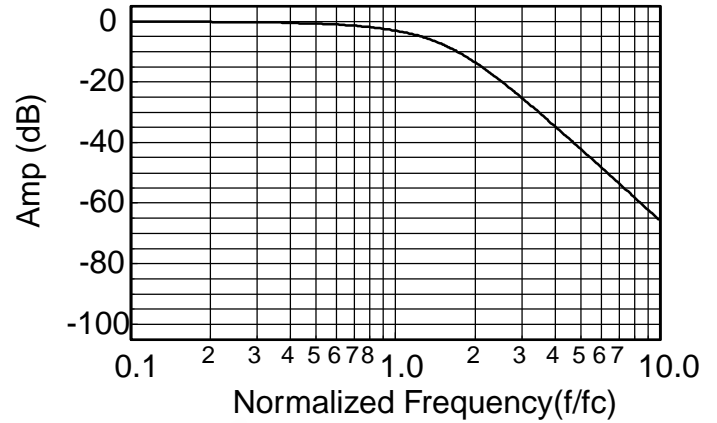


Appendix A

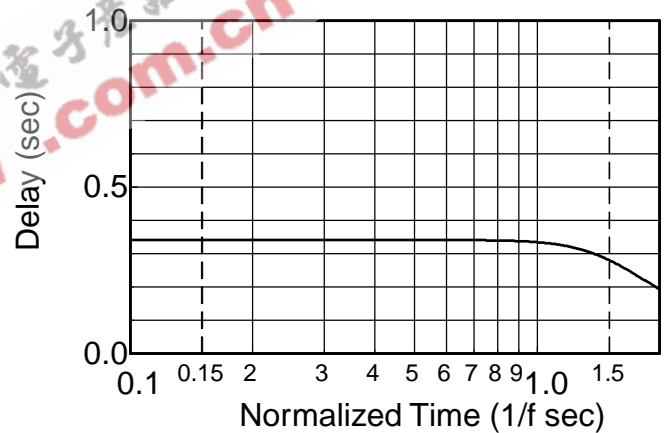
Theoretical Transfer Characteristics

| f/fc (Hz) | Amp (dB) | Phase (deg) | Delay ¹ (sec) |
|--------------|-------------|----------------|-----------------------------|
| 0.00 | 0.00 | 0.00 | .336 |
| 0.10 | -0.028 | -12.1 | .336 |
| 0.20 | -0.111 | -24.2 | .336 |
| 0.30 | -0.251 | -36.3 | .336 |
| 0.40 | -0.448 | -48.4 | .336 |
| 0.50 | -0.705 | -60.6 | .336 |
| 0.60 | -1.02 | -72.7 | .336 |
| 0.70 | -1.41 | -84.8 | .336 |
| 0.80 | -1.86 | -96.8 | .335 |
| 0.85 | -2.11 | -103 | .334 |
| 0.90 | -2.40 | -109 | .333 |
| 0.95 | -2.69 | -115 | .332 |
| 1.00 | -3.01 | -121 | .330 |
| 1.10 | -3.71 | -133 | .325 |
| 1.20 | -4.51 | -144 | .318 |
| 1.30 | -5.39 | -156 | .308 |
| 1.40 | -6.37 | -166 | .295 |
| 1.50 | -7.42 | -177 | .280 |
| 1.60 | -8.54 | -187 | .263 |
| 1.70 | -9.71 | -195 | .246 |
| 1.80 | -10.9 | -204 | .228 |
| 1.90 | -12.2 | -212 | .211 |
| 2.00 | -13.4 | -219 | .194 |
| 2.25 | -16.5 | -235 | .158 |
| 2.50 | -19.5 | -248 | .129 |
| 2.75 | -22.4 | -259 | .107 |
| 3.00 | -25.1 | -267 | .089 |
| 3.25 | -27.6 | -275 | .076 |
| 3.50 | -30.0 | -281 | .065 |
| 4.00 | -34.4 | -291 | .049 |
| 5.00 | -41.9 | -305 | .031 |
| 6.00 | -48.1 | -315 | .021 |
| 7.00 | -53.4 | -321 | .016 |
| 8.00 | -58.0 | -326 | .012 |
| 9.00 | -62.0 | -330 | .009 |
| 10.0 | -65.7 | -333 | .008 |

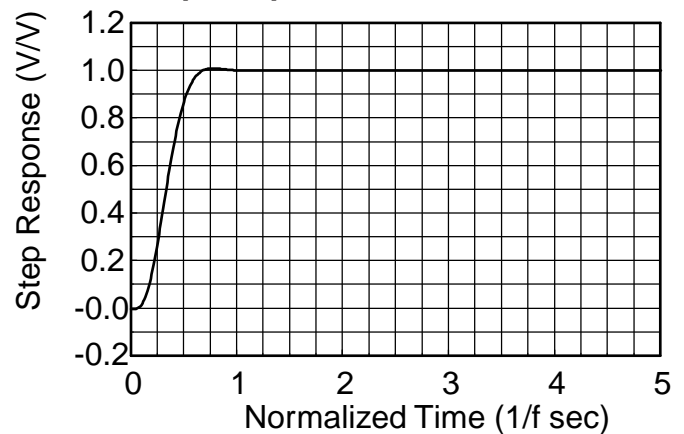
Frequency Response



Delay (Normalized)



Step Response



1. Normalized Group Delay:

The above delay data is normalized to a corner frequency of 1.0Hz. The actual delay is the normalized delay divided by the actual corner frequency (fc).

$$\text{Actual Delay} = \frac{\text{Normalized Delay}}{\text{Actual Corner Frequency (fc) in Hz}}$$

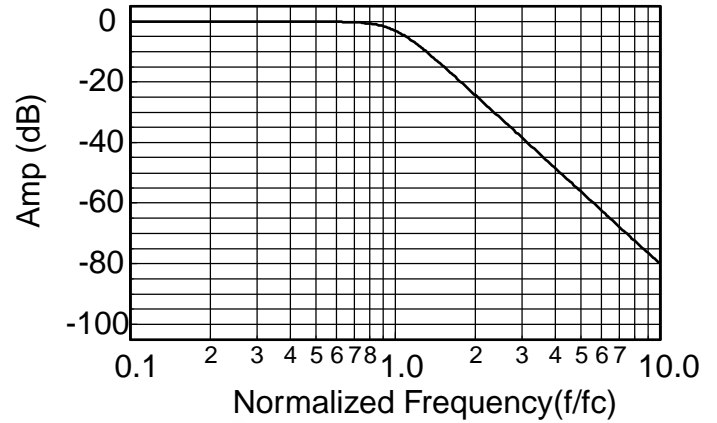


Appendix A

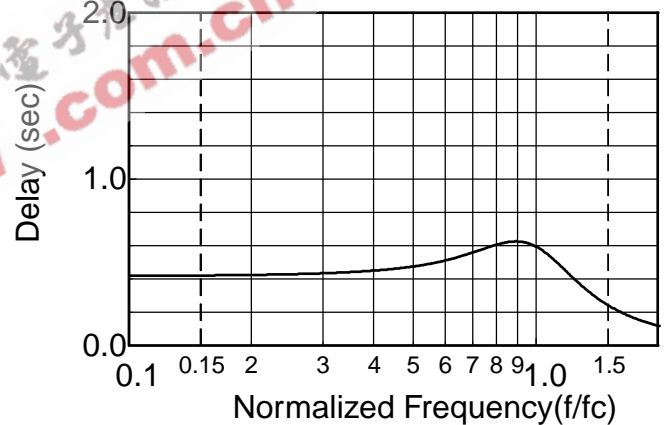
Theoretical Transfer Characteristics

| f/fc (Hz) | Amp (dB) | Phase (deg) | Delay ¹ (sec) |
|--------------|-------------|----------------|-----------------------------|
| 0.00 | 0.00 | 0.00 | .416 |
| 0.10 | 0.00 | -15.0 | .418 |
| 0.20 | 0.00 | -30.1 | .423 |
| 0.30 | -0.00 | -45.5 | .433 |
| 0.40 | -0.003 | -61.4 | .449 |
| 0.50 | -0.017 | -78.0 | .474 |
| 0.60 | -0.072 | -95.7 | .511 |
| 0.70 | -0.243 | -115 | .558 |
| 0.80 | -0.674 | -136 | .604 |
| 0.85 | -1.047 | -147 | .619 |
| 0.90 | -1.555 | -158 | .622 |
| 0.95 | -2.21 | -169 | .612 |
| 1.00 | -3.01 | -180 | .588 |
| 1.10 | -4.97 | -200 | .513 |
| 1.20 | -7.24 | -217 | .427 |
| 1.30 | -9.62 | -231 | .350 |
| 1.40 | -12.0 | -242 | .289 |
| 1.50 | -14.3 | -252 | .241 |
| 1.60 | -16.4 | -260 | .204 |
| 1.70 | -18.5 | -266 | .175 |
| 1.80 | -20.5 | -272 | .152 |
| 1.90 | -22.3 | -277 | .134 |
| 2.00 | -24.1 | -282 | .119 |
| 2.25 | -28.2 | -291 | .091 |
| 2.50 | -31.8 | -299 | .072 |
| 2.75 | -35.1 | -304 | .059 |
| 3.00 | -38.2 | -309 | .049 |
| 3.25 | -41.0 | -313 | .041 |
| 3.50 | -43.5 | -317 | .035 |
| 4.00 | -48.2 | -322 | .027 |
| 5.00 | -55.9 | -330 | .017 |
| 6.00 | -62.3 | -335 | .012 |
| 7.00 | -67.6 | -339 | .009 |
| 8.00 | -72.2 | -341 | .007 |
| 9.00 | -76.3 | -343 | .005 |
| 10.0 | -80.0 | -345 | .004 |

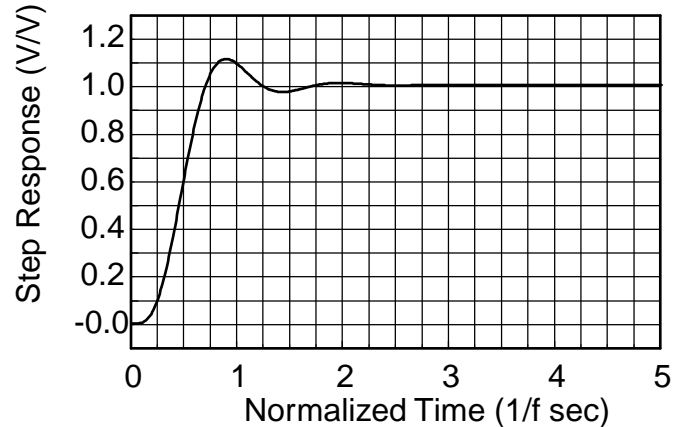
Frequency Response



Delay (Normalized)



Step Response



1. Normalized Group Delay:

The above delay data is normalized to a corner frequency of 1.0Hz. The actual delay is the normalized delay divided by the actual corner frequency (fc).

$$\text{Actual Delay} = \frac{\text{Normalized Delay}}{\text{Actual Corner Frequency (fc) in Hz}}$$

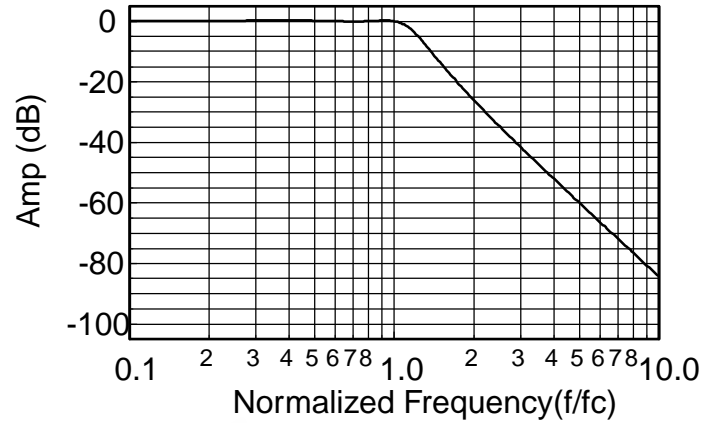


Appendix A

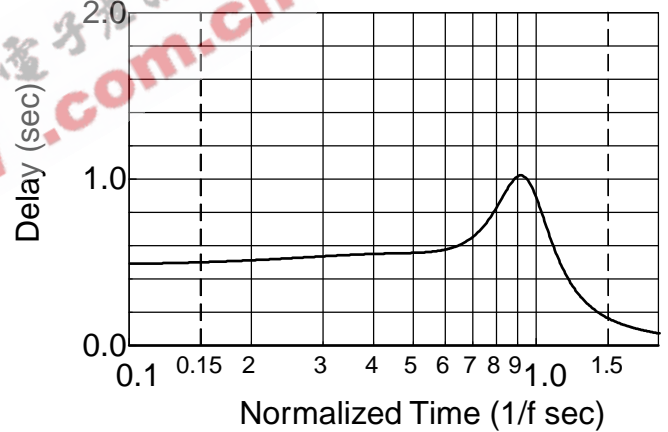
Theoretical Transfer Characteristics

| f/fc (Hz) | Amp (dB) | Phase (deg) | Delay ¹ (sec) |
|--------------|-------------|----------------|-----------------------------|
| 0.00 | 0.000 | 0.00 | .478 |
| 0.10 | 0.039 | -17.3 | .487 |
| 0.20 | 0.129 | -35.2 | .509 |
| 0.30 | 0.195 | -54.0 | .533 |
| 0.40 | 0.174 | -73.4 | .547 |
| 0.50 | 0.074 | -93.2 | .553 |
| 0.60 | 0.000 | -113 | .575 |
| 0.70 | 0.074 | -135 | .654 |
| 0.80 | 0.199 | -162 | .836 |
| 0.85 | 0.063 | -178 | .947 |
| 0.90 | -0.443 | -196 | 1.02 |
| 0.95 | -1.47 | -214 | .989 |
| 1.00 | -3.01 | -231 | .873 |
| 1.10 | -6.89 | -257 | .583 |
| 1.20 | -10.8 | -274 | .385 |
| 1.30 | -14.5 | -286 | .271 |
| 1.40 | -17.7 | -294 | .202 |
| 1.50 | -20.7 | -300 | .158 |
| 1.60 | -23.4 | -306 | .128 |
| 1.70 | -25.8 | -310 | .107 |
| 1.80 | -28.1 | -313 | .090 |
| 1.90 | -30.2 | -316 | .078 |
| 2.00 | -32.2 | -319 | .068 |
| 2.25 | -36.7 | -324 | .051 |
| 2.50 | -40.6 | -328 | .039 |
| 2.75 | -44.1 | -331 | .032 |
| 3.00 | -47.3 | -334 | .026 |
| 3.25 | -50.2 | -336 | .022 |
| 3.50 | -52.8 | -338 | .018 |
| 4.00 | -57.6 | -341 | .014 |
| 5.00 | -65.5 | -345 | .009 |
| 6.00 | -71.9 | -347 | .006 |
| 7.00 | -77.3 | -349 | .004 |
| 8.00 | -82.0 | -351 | .003 |
| 9.00 | -86.1 | -352 | .003 |
| 10.0 | -89.8 | -352 | .002 |

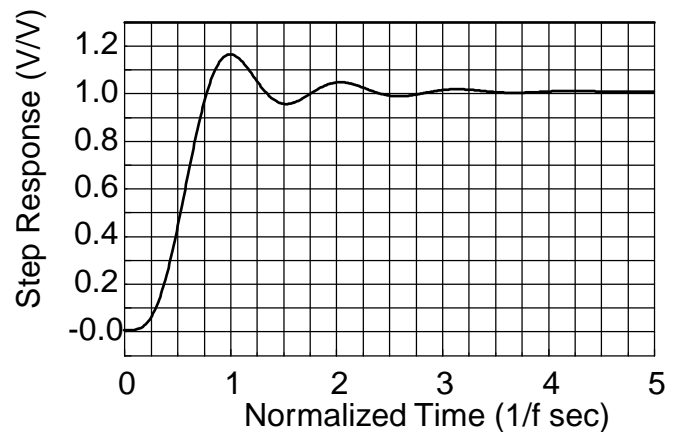
Frequency Response



Delay (Normalized)



Step Response



1. Normalized Group Delay:

The above delay data is normalized to a corner frequency of 1.0Hz. The actual delay is the normalized delay divided by the actual corner frequency (fc).

$$\text{Actual Delay} = \frac{\text{Normalized Delay}}{\text{Actual Corner Frequency (fc) in Hz}}$$

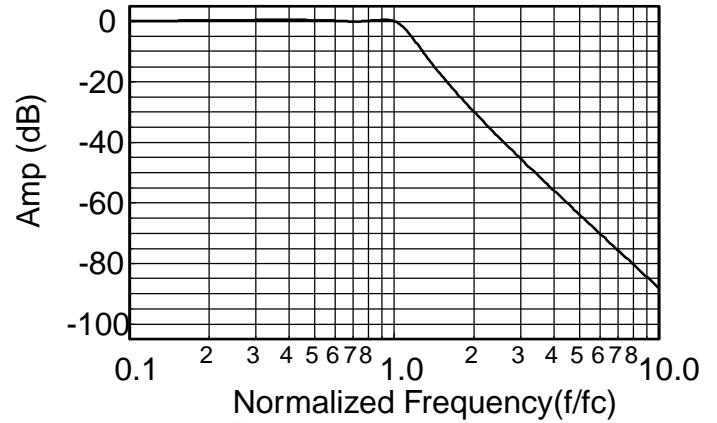


Appendix A

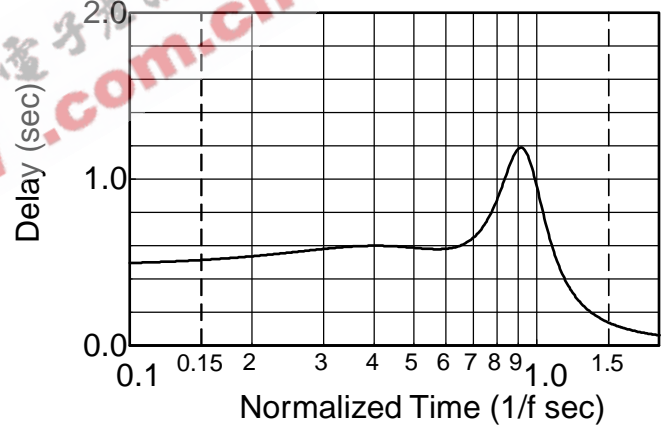
Theoretical Transfer Characteristics

| f/fc (Hz) | Amp (dB) | Phase (deg) | Delay ¹ (sec) |
|--------------|-------------|----------------|-----------------------------|
| 0.00 | 0.00 | 0.00 | .476 |
| 0.10 | 0.087 | -17.3 | .492 |
| 0.20 | 0.295 | -35.7 | .533 |
| 0.30 | 0.474 | -55.7 | .577 |
| 0.40 | 0.463 | -76.9 | .596 |
| 0.50 | 0.248 | -98.2 | .583 |
| 0.60 | 0.025 | -119 | .578 |
| 0.70 | 0.072 | -141 | .647 |
| 0.80 | 0.432 | -168 | .881 |
| 0.85 | 0.482 | -185 | 1.06 |
| 0.90 | 0.062 | -205 | 1.18 |
| 0.95 | -1.12 | -226 | 1.13 |
| 1.00 | -3.01 | -245 | .946 |
| 1.10 | -7.61 | -272 | .559 |
| 1.20 | -12.0 | -288 | .345 |
| 1.30 | -15.9 | -298 | .235 |
| 1.40 | -19.3 | -305 | .173 |
| 1.50 | -22.4 | -311 | .134 |
| 1.60 | -25.1 | -315 | .108 |
| 1.70 | -27.6 | -318 | .089 |
| 1.80 | -29.9 | -321 | .075 |
| 1.90 | -32.1 | -324 | .065 |
| 2.00 | -34.1 | -326 | .057 |
| 2.25 | -38.6 | -301 | .042 |
| 2.50 | -42.6 | -334 | .033 |
| 2.75 | -46.1 | -336 | .026 |
| 3.00 | -49.3 | -339 | .021 |
| 3.25 | -52.2 | -340 | .018 |
| 3.50 | -54.9 | -342 | .015 |
| 4.00 | -59.7 | -344 | .011 |
| 5.00 | -67.6 | -347 | .007 |
| 6.00 | -74.0 | -350 | .005 |
| 7.00 | -79.4 | -351 | .004 |
| 8.00 | -84.1 | -352 | .003 |
| 9.00 | -88.2 | -353 | .002 |
| 10.0 | -91.9 | -354 | .002 |

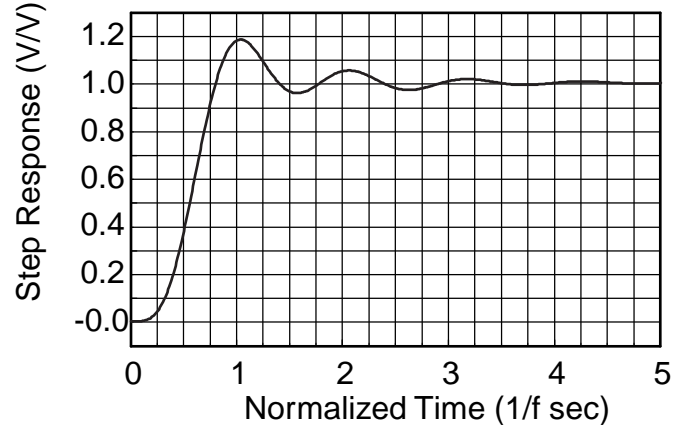
Frequency Response



Delay (Normalized)



Step Response



1. Normalized Group Delay:

The above delay data is normalized to a corner frequency of 1.0Hz. The actual delay is the normalized delay divided by the actual corner frequency (fc).

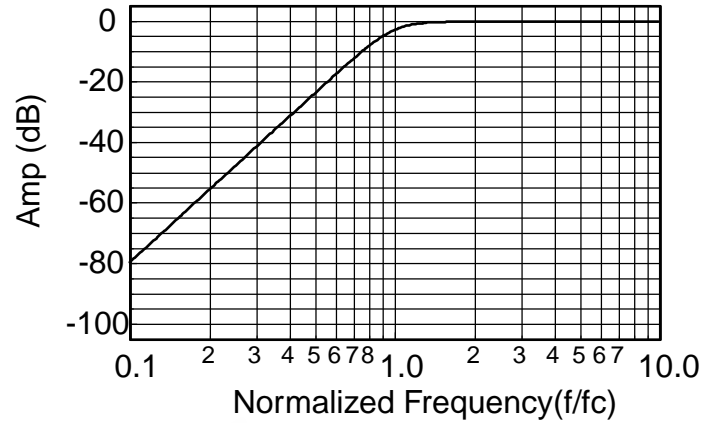
$$\text{Actual Delay} = \frac{\text{Normalized Delay}}{\text{Actual Corner Frequency (fc) in Hz}}$$



Theoretical Transfer Characteristics

| f/fc (Hz) | Amp (dB) | Phase (deg) | Delay ¹ (sec) |
|--------------|-------------|----------------|-----------------------------|
| 0.10 | -80.0 | 345 | .418 |
| 0.20 | -55.9 | 330 | .423 |
| 0.30 | -41.8 | 314 | .433 |
| 0.40 | -31.8 | 299 | .449 |
| 0.50 | -24.1 | 282 | .474 |
| 0.60 | -17.8 | 264 | .511 |
| 0.70 | -12.6 | 245 | .558 |
| 0.80 | -8.43 | 224 | .604 |
| 0.85 | -6.69 | 213 | .619 |
| 0.90 | -5.22 | 202 | .622 |
| 0.95 | -3.99 | 191 | .612 |
| 1.00 | -3.01 | 180 | .588 |
| 1.20 | -0.908 | 143 | .427 |
| 1.40 | -0.285 | 118 | .289 |
| 1.60 | -0.100 | 100 | .204 |
| 1.80 | -0.039 | 87.6 | .152 |
| 2.00 | -0.017 | 78.0 | .119 |
| 2.50 | -0.003 | 61.4 | .072 |
| 3.00 | -0.001 | 50.7 | .049 |
| 4.00 | 0.00 | 37.8 | .027 |
| 5.00 | 0.00 | 30.1 | .017 |
| 6.00 | 0.00 | 25.1 | .012 |
| 7.00 | 0.00 | 21.4 | .009 |
| 8.00 | 0.00 | 18.8 | .007 |
| 9.00 | 0.00 | 16.7 | .005 |
| 10.0 | 0.00 | 15.0 | .004 |

Frequency Response



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1. Normalized Group Delay:

The above delay data is normalized to a corner frequency of 1.0Hz. The actual delay is the normalized delay divided by the actual corner frequency (fc).

$$\text{Actual Delay} = \frac{\text{Normalized Delay}}{\text{Actual Corner Frequency (fc) in Hz}}$$

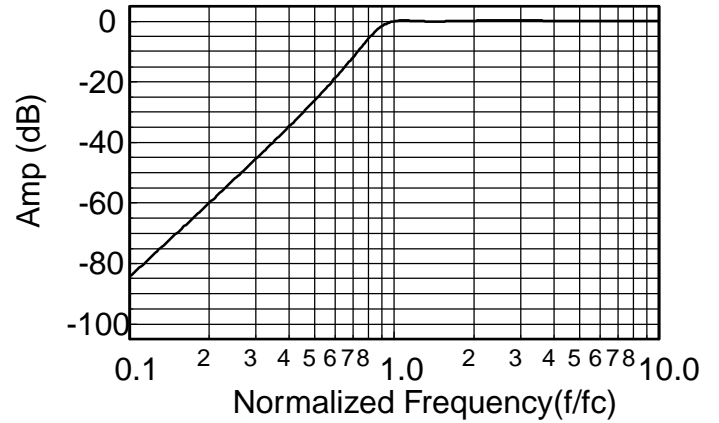


Appendix A

Theoretical Transfer Characteristics

| f/fc (Hz) | Amp (dB) | Phase (deg) | Delay ¹ (sec) |
|--------------|-------------|----------------|-----------------------------|
| 0.10 | -89.8 | 352 | .212 |
| 0.20 | -65.1 | 345 | .218 |
| 0.30 | -51.1 | 337 | .228 |
| 0.40 | -40.6 | 328 | .245 |
| 0.50 | -32.2 | 319 | .272 |
| 0.60 | -25.0 | 308 | .314 |
| 0.70 | -18.6 | 296 | .383 |
| 0.80 | -12.7 | 280 | .500 |
| 0.90 | -7.34 | 259 | .686 |
| 1.00 | -3.01 | 231 | .873 |
| 1.20 | .140 | 172 | .633 |
| 1.50 | .031 | 128 | .275 |
| 1.70 | .003 | 111 | .197 |
| 2.00 | .074 | 93.2 | .138 |
| 2.50 | .174 | 73.4 | .088 |
| 3.00 | .200 | 60.4 | .060 |
| 4.00 | .170 | 44.5 | .033 |
| 5.00 | .129 | 35.2 | .020 |
| 6.00 | .098 | 29.2 | .014 |
| 7.00 | .076 | 24.9 | .010 |
| 8.00 | .060 | 21.7 | .008 |
| 9.00 | .048 | 19.3 | .006 |
| 10.0 | .040 | 17.3 | .005 |

Frequency Response



1. Normalized Group Delay:

The above delay data is normalized to a corner frequency of 1.0Hz. The actual delay is the normalized delay divided by the actual corner frequency (fc).

$$\text{Actual Delay} = \frac{\text{Normalized Delay}}{\text{Actual Corner Frequency (fc) in Hz}}$$

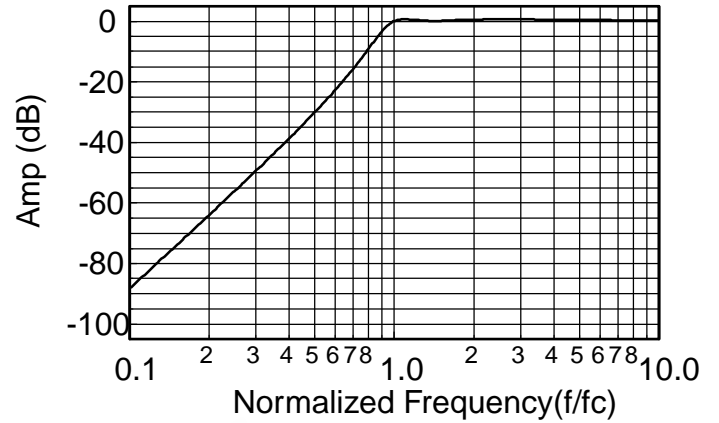


Appendix A

Theoretical Transfer Characteristics

| f/fc (Hz) | Amp (dB) | Phase (deg) | Delay ¹ (sec) |
|--------------|-------------|----------------|-----------------------------|
| 0.10 | -91.9 | 354 | .174 |
| 0.20 | -67.6 | 347 | .179 |
| 0.30 | -53.1 | 341 | .188 |
| 0.40 | -42.6 | 334 | .203 |
| 0.50 | -34.1 | 326 | .226 |
| 0.60 | -26.8 | 317 | .263 |
| 0.70 | -20.2 | 307 | .326 |
| 0.80 | -14.0 | 293 | .440 |
| 0.90 | -8.13 | 274 | .651 |
| 1.00 | -3.01 | 245 | .946 |
| 1.20 | .500 | 179 | .693 |
| 1.50 | .014 | 133 | .271 |
| 1.70 | .043 | 117 | .199 |
| 2.00 | .249 | 98.2 | .146 |
| 2.50 | .469 | 76.9 | .095 |
| 3.00 | .498 | 62.7 | .065 |
| 4.00 | .401 | 45.5 | .035 |
| 5.00 | .296 | 35.7 | .021 |
| 6.00 | .221 | 29.4 | .014 |
| 7.00 | .169 | 25.0 | .010 |
| 8.00 | .133 | 21.8 | .008 |
| 9.00 | .107 | 19.3 | .006 |
| 10.0 | .088 | 17.3 | .005 |

Frequency Response



1. Normalized Group Delay:

The above delay data is normalized to a corner frequency of 1.0Hz. The actual delay is the normalized delay divided by the actual corner frequency (fc).

$$\text{Actual Delay} = \frac{\text{Normalized Delay}}{\text{Actual Corner Frequency (fc) in Hz}}$$