# 824 Series

1 Hz to 102.4 kHz
8-Bit Programmable

2" x 2"
4-Pole Filters

### Description

The 824 Series are digitally programmable low pass and high pass active filters that are tunable over a 256:1 frequency range. 824 filters are available with any one of five standard factory-set tuning ranges up to 102.4 kHz. These units contain 8 CMOS logic inputs .

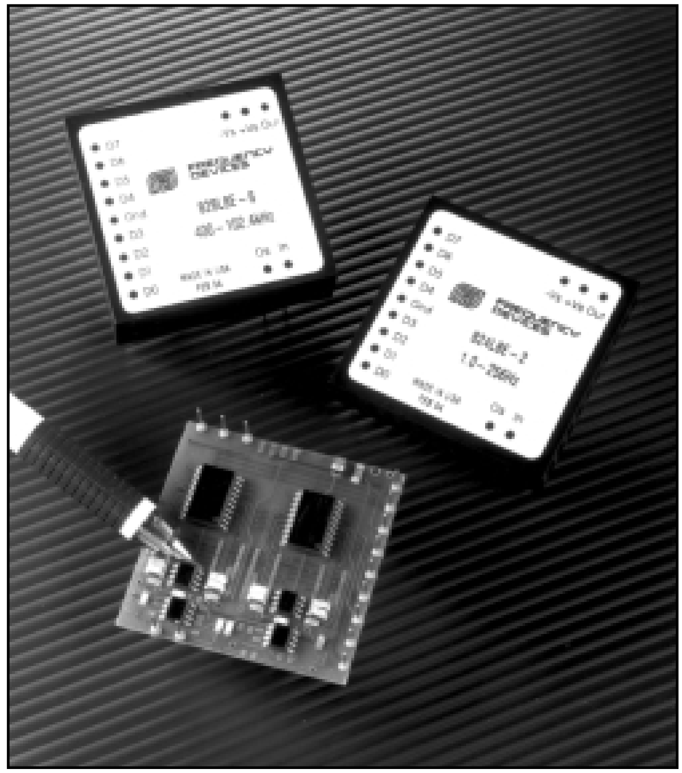
All 824 Series models are convenient, low profile, easy to use fully finished filters which require no external components or adjustments. They feature low harmonic distortion, and near theoretical phase and amplitude characteristics. 824 filters operate from non-critical ± 12 to ± 18 Vdc power supplies, have a 10 kΩ (min.) input impedance, a 10 Ω (max.) output.

### Features/Benefits:

- Compact 2" x 2" design 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-set tuning range, 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
- Sound and vibration testing
- Real and compressed time data analysis
- Noise elimination
- Signal reconstruction



## 8-Bit Programmable Filters

## Digital Tuning & Control Characteristics

### Digital Tuning Characteristics

The digital tuning interface circuits are a parallel set of eight (8) 4053 CMOS switches which accept CMOS compatible inputs for the eight tuning bits ($D_0$ - $D_7$).

Filter tuning follows the tuning equation given below:

$f_c = ( f_{max}/256 ) [ 1 + D_7 \times 2^7 + D_6 \times 2^6 + D_5 \times 2^5 + D_4 \times 2^4 + D_3 \times 2^3 + D_2 \times 2^2 + D_1 \times 2^1 + D_0 \times 2^0 ]$

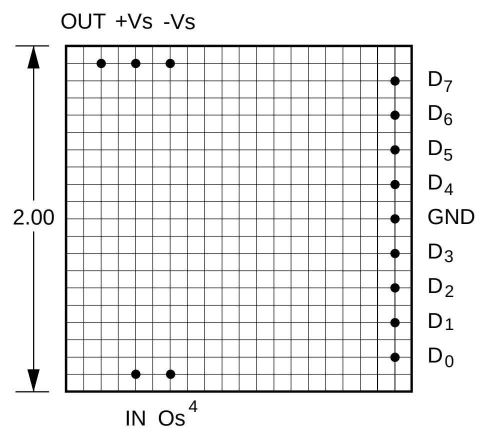
where $D_1$ - $D_7$ = "0" or "1", and
$f_{max}$ = Maximum tuning frequency;
$f_c$ = corner frequency;
Minimum tunable frequency = $f_{max}/256$ (D0 thru D7 = 0);
Minimum frequency step (Resolution) = $f_{max}/256$

### Data Input Specifications

| **Input Data Levels** | **(CMOS Logic)** | |
|---|---|---|
| Input Voltage (Vs = 15 Vdc) | | |
| Low Level In | 0 Vdc min. | 4 Vdc max. |
| High Level In | 11 Vdc min. | 15 Vdc max. |
| Input Current | | |
| High Level In | - $10^{-5}$ µA typ. | -1 µA max.. |
| Low Level In | +$10^{-5}$ µA typ. | +1 µA max. |
| Input Capacitance | 5 pF typ | 7.5 pF max. |
| **Input Data Format** | **Frequency Select Bits** | |
| Positive Logic | Logic "1" = +Vs | |
| | Logic "0" = Gnd | |
| Bit Weighting | (Binary-Coded) | |
| $D_0$ | LSB (least significant bit) | |
| $D_7$ | MSB (most significant bit) | |
| Frequency Range | 256 : 1, Binary Weighted | |

**Pin-Out Key**

| | | |
|---|---|---|
| IN | Analog Input Signal | $D_7$ Tuning Bit 7 (MSB) |
| OUT | Analog Output Signal | $D_6$ Tuning Bit 6 |
| GND | Power and Signal Return | $D_5$ Tuning Bit 5 |
| +Vs | Supply Voltage, Positive | $D_4$ Tuning Bit 4 |
| -Vs | Supply Voltage, Negative | $D_3$ Tuning Bit 3 |
| Os | Offset Adjustment | $D_2$ Tuning Bit 2 |
| | | $D_1$ Tuning Bit 1 |
| | | $D_0$ Tuning Bit 0 (LSB) |




Bottom View

| MSB | --- | --- | --- | --- | --- | --- | LSB | Bit Weight |
|---|---|---|---|---|---|---|---|---|
| $2^7$ $D_7$ | $2^6$ $D_6$ | $2^5$ $D_5$ | $2^4$ $D_4$ | $2^3$ $D_3$ | $2^2$ $D_2$ | $2^1$ $D_1$ | $2^0$ $D_0$ | fc Corner Frequency |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $f_{max}/256$ |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | $f_{max}/128$ |
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | $f_{max}/64$ |
| 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | $f_{max}/32$ |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | $f_{max}/16$ |
| 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | $f_{max}/8$ |
| 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | $f_{max}/4$ |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | $f_{max}/2$ |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | fmax |



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# 4-Pole Low-Pass Filters

## 8-Bit Programmable

| Model | 824L8B | 824L8L | 824L8Y2 | 824L8Y5 |
|---|---|---|---|---|
| **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, Model 2**<br>**Model 3 thru 6** | 2.0" x 2.0" x 0.5"<br>2.0" x 2.0" x 0.4" | 2.0" x 2.0" x 0.5"<br>2.0" x 2.0" x 0.4" | 2.0" x 2.0" x 0.5"<br>2.0" x 2.0" x 0.4" | 2.0" x 2.0" x 0.5"<br>2.0" x 2.0" x 0.4" |
| **Range $f_c$** | 1.0 Hz to 102.4 kHz | 1.0 Hz to 102.4 kHz | 1.0 Hz to 102.4 kHz | 1.0 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.<br>0 ± 0.05 dB typ. | 0 ± 0.1 dB max.<br>0 ± 0.05 dB typ. | 0 ± 0.1 dB max.<br>0 ± 0.05 dB typ. | 0 ± 0.1 dB max.<br>0 ± 0.05 dB typ. |
| **Stopband Attenuation Rate** | 24 dB/octave | 24 dB/octave | 24 dB/octave | 24 dB/octave |
| **Cutoff Frequency**<br>**Stability**<br>**Amplitude**<br>**Phase** | $f_c$ ± 2% max.<br>± 0.01% /°C<br>-3 dB<br>-180° | $f_c$ ± 2% max.<br>± 0.01% /°C<br>-3 dB<br>-121° | $f_c$ ± 2% max.<br>± 0.01% /°C<br>-3 dB<br>-231° | $f_c$ ± 2% max.<br>± 0.01% /°C<br>-3 dB<br>-245° |
| **Filter Attenuation** (theoretical) | 0.67 dB 0.80 $f_c$<br>3.01 dB 1.00 $f_c$<br>30.0 dB 2.37 $f_c$<br>40.0 dB 3.16 $f_c$ | 1.86 dB 0.80 $f_c$<br>3.01 dB 1.00 $f_c$<br>30.0 dB 3.50 $f_c$<br>40.0 dB 4.72 $f_c$ | -0.20 dB 0.80 $f_c$<br>3.01 dB 1.00 $f_c$<br>30.0 dB 1.89 $f_c$<br>40.0 dB 2.46 $f_c$ | -0.43 dB 0.80 $f_c$<br>3.01 dB 1.00 $f_c$<br>30.0 dB 1.80 $f_c$<br>40.0 dB 2.33 $f_c$ |
| **Phase Match**[1] | 0 - 0.8 $f_c$ ± 2° max.<br>± 1° typ.<br>0.8 $f_c$ - 1.0 $f_c$ ± 3° max.<br>± 1.5° typ. | 0 - $f_c$ ± 2° max.<br>± 1° typ. | 0 - 0.8 $f_c$ ± 2° max.<br>± 1° typ.<br>0.8 $f_c$ - 1.0 $f_c$ ± 3° max.<br>± 1.5° typ. | 0 - 0.8 $f_c$ ± 2° max.<br>± 1° typ.<br>0.8 $f_c$ - 1.0 $f_c$ ± 3° max.<br>± 1.5° typ. |
| **Amplitude Accuracy** (theoretical) | 0 - 0.8 $f_c$ ± 0.2 dB max.<br>± 0.1 dB typ.<br>0.8 $f_c$ - 1.0 $f_c$ ± 0.3 dB max.<br>± 0.15 dB typ. | 0 - $f_c$ ± 0.2 dB max.<br>± 0.1 dB typ. | 0 - 0.8 $f_c$ ± 0.2 dB max.<br>± 0.1 dB typ.<br>0.8 $f_c$ - 1.0 $f_c$ ± 0.3 dB max.<br>± 0.15 dB typ. | 0 - 0.8 $f_c$ ± 0.2 dB max.<br>± 0.1 dB typ.<br>0.8 $f_c$ - 1.0 $f_c$ ± 0.3 dB max.<br>± 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.



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# 8-Bit Programmable 4-Pole High-Pass Filters

| Model | 824H8B | 824H8Y2 | 824H8Y5 | |
|---|---|---|---|---|
| **Product Specifications** | | | | |
| **Transfer Function** | 4-Pole,<br>Butterworth | 4-Pole,Chebychev,<br>0.2 dB Ripple | 4-Pole, Chebychev,<br>0.5 dB Ripple | |
| **Size, Model 2**<br>**Model 3 thru 6** | 2.0” x 2.0” x 0.5”<br>2.0” x 2.0” x 0.4” | 2.0” x 2.0” x 0.5”<br>2.0” x 2.0” x 0.4” | 2.0” x 2.0” x 0.5”<br>2.0” x 2.0” x 0.4” | |
| **Range $f_c$** | 1.0 Hz to 102.4 kHz | 1.0 Hz to 102.4 kHz | 1.0 Hz to 102.4 kHz | |
| **Theoretical Transfer Characteristics** | Appendix A<br>Page 27 | Appendix A<br>Page 31 | Appendix A<br>Page 33 | |
| **Passband Ripple**<br>(theoretical) | 0.0 dB | 0.20 dB | 0.50 dB | |
| **Voltage Gain**<br>(non-inverting) | 0 ± 0.2 dB to 100 kHz<br>0 ± 0.5 dB to 120 kHz | 0 ± 0.2 dB to 100 kHz<br>0 ± 0.5 dB to 120 kHz | 0 ± 0.2 dB to 100 kHz<br>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**<br>**Stability**<br>**Amplitude**<br>**Phase** | $f_c$ ± 2% max.<br>± 0.01% /°C<br>-3 dB<br>180° | $f_c$ ± 2% max.<br>± 0.01% /°C<br>-3 dB<br>231° | $f_c$ ± 2% max.<br>± 0.01% /°C<br>-3 dB<br>245° | |
| **Filter Attenuation**<br>(theoretical) | 40 dB 0.31 $f_c$<br>30 dB 0.42 $f_c$<br>3.01 dB 1.00 $f_c$<br>0.02 dB 2.00 $f_c$ | 40.0 dB 0.41 $f_c$<br>30.0 dB 0.53 $f_c$<br>3.01 dB 1.00 $f_c$<br>-0.07 dB 2.00 $f_c$ | 40.0 dB 0.43 $f_c$<br>30.0 dB 0.56 $f_c$<br>3.01 dB 1.00 $f_c$<br>-0.25 dB 2.00 $f_c$ | |
| **Phase Match**[1] | $f_c$ - 100 kHz ± 3° max.<br>± 1.5° typ. | $f_c$ - 100 kHz ± 3° max.<br>± 1.5° typ. | $f_c$ - 100 kHz ± 3° max.<br>± 1.5° typ. | |
| **Amplitude Accuracy**<br>(theoretical) | 1.0 - 1.25 $f_c$ ± 0.3 dB max.<br>± 0.15 dB typ.<br>1.25 $f_c$-100 kHz ± 0.2 dB max.<br>± 0.1 dB typ. | 1.00 - 1.25 $f_c$ ± 0.3 dB max.<br>± 0.15 dB typ.<br>1.25 $f_c$-100 kHz ± 0.2 dB max.<br>± 0.1 dB typ. | 1.00 - 1.25 $f_c$ ± 0.3 dB max.<br>± 0.15 dB typ.<br>1.25 $f_c$-100 kHz ± 0.2 dB max.<br>± 0.1 dB typ. | |
| **Total Harmonic Distortion @ 1 kHz** | < - 100 dB typ. | < - 88 dB typ. | < - 88 dB typ. | |
| **Wide Band Noise** | 400 µVrms typ. | 400 µVrms typ. | 400 µVrms typ. | |
| **Narrow Band Noise**<br>(5 Hz - 100 kHz) | 100 µVrms typ. | 100 µVrms typ. | 100 µVrms 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.



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# FREQUENCY DEVICES™

# 824 Series

## Specification

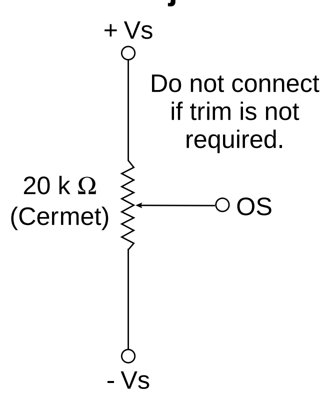
(25°C and Vs ± 15 Vdc)

## Pin-Out and Package Data
## Ordering Information

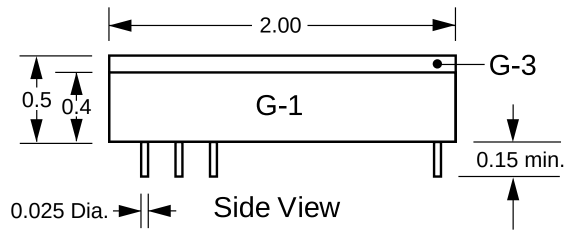
| | |
|---|---|
| **Analog Input Characteristics**[1] | |
| Impedance | 10 kΩ min. |
| Voltage Range | ± 10 Vpeak |
| Max. Safe Voltage | ±Vs |
| **Analog Output Characteristics** | |
| Impedance (Closed Loop) | 1 Ω typ. |
| | 10 Ω max. |
| Linear Operating Range | ± 10V |
| Maximum Current[2] | ± 2 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:
1. Input and output signal voltage referenced to supply common.
2. Output is short circuit protected to common.
   DO NOT CONNECT TO ±Vs.
3. Adjustable to zero.
4. Units operate with or without offset pin connected.

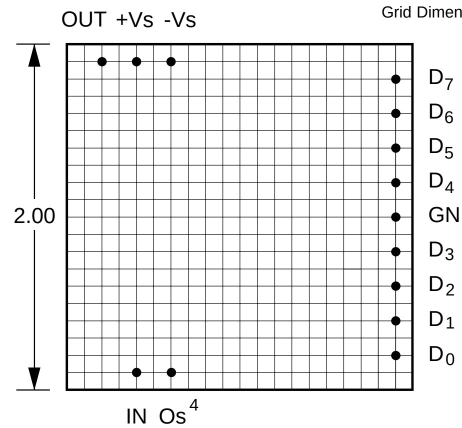
### DC Offset Adjustment




### Pin-Out & Package Data




All dimensions are in inches
All Case Dimensions ± 0.02"
Grid Dimensions 0.1" x 0.1"




Bottom View

**Filter Mounting Assembly-See FMA-02A**

## Ordering Information

**Filter Type**
- **L** - Low Pass
- **H** - High Pass

**Transfer Function**
- **B** - Butterworth
- **L** - Bessel
- **Y2** - Chebychev (0.2 dB Ripple)
- **Y5** - Chebychev (0.5 dB Ripple)

e.g., **824L8B-3**

**Model Number**

| e.g., Model Number | Tuning Range (Hz) | Minimum Step(Hz) | Case |
|---|---|---|---|
| **2** | 1.0 to 256 | 1.0 | G-3 |
| **3** | 10 to 2560 | 10 | G-1 |
| **4** | 100 to 25.6k | 100 | G-1 |
| **5** | 200 to 51.2k | 200 | G-1 |
| **6** | 400 to 102.4k | 400 | G-1 |





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# Appendix A

# Low-Pass 4-Pole Bessel

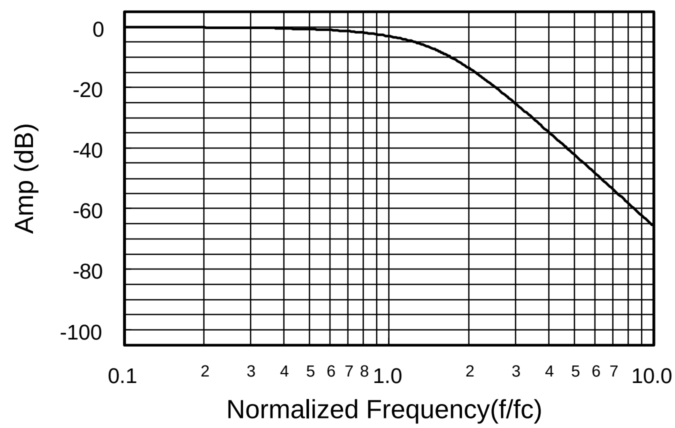
### Theoretical Transfer Characteristics

| 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 |

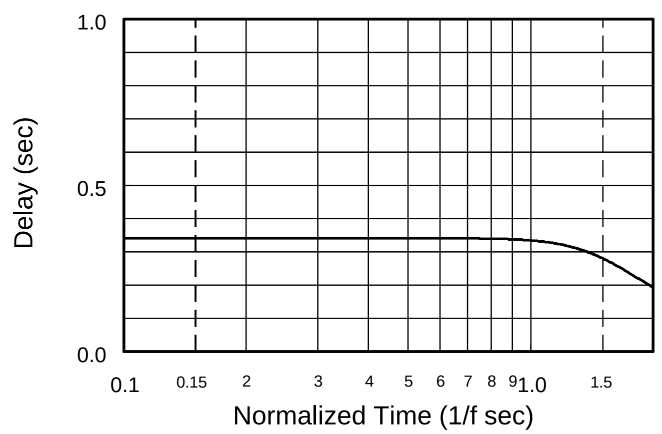
1. **Normalized Group Delay:**
The above delay data is normalized to a corner frequency of 1.0Hz.The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

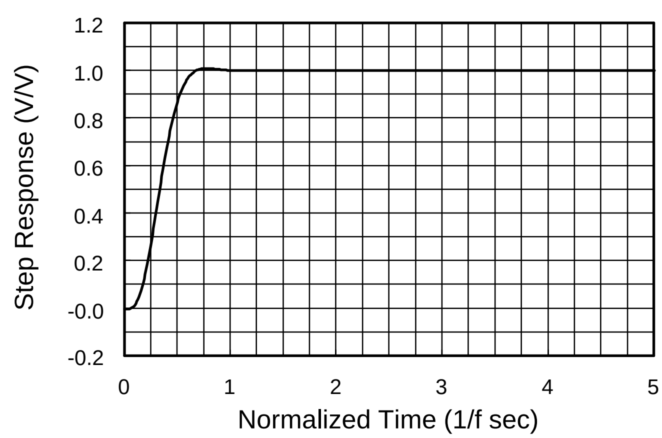
### Frequency Response




### Delay (Normalized)




### Step Response



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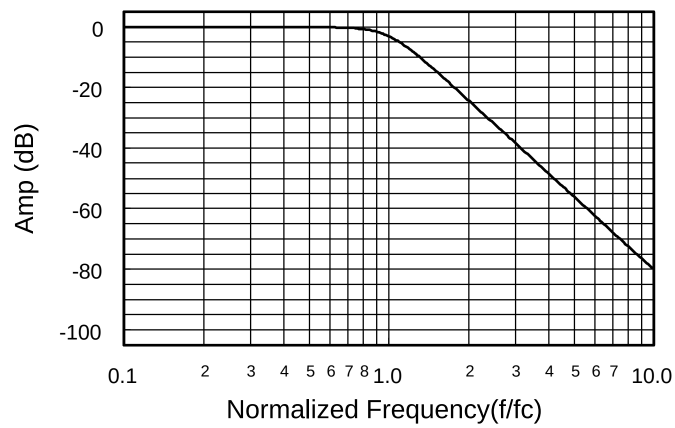
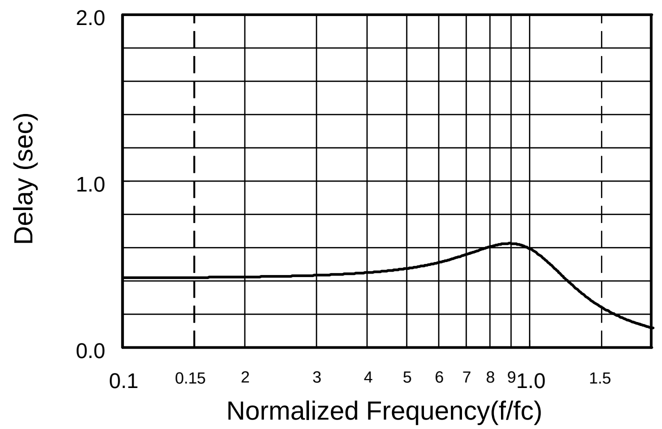
### Theoretical Transfer Characteristics

| 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 |

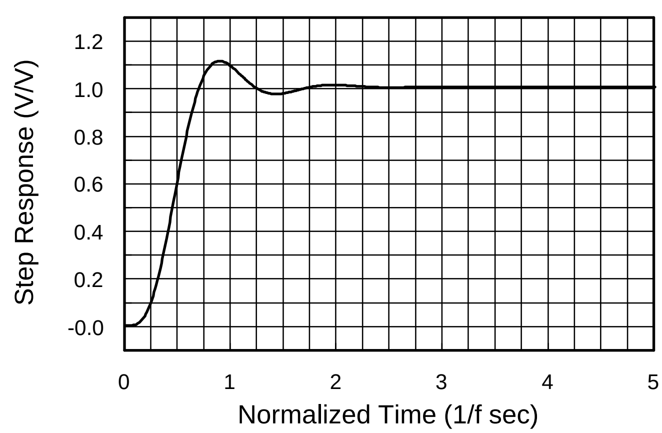
### Frequency Response




### 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).

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



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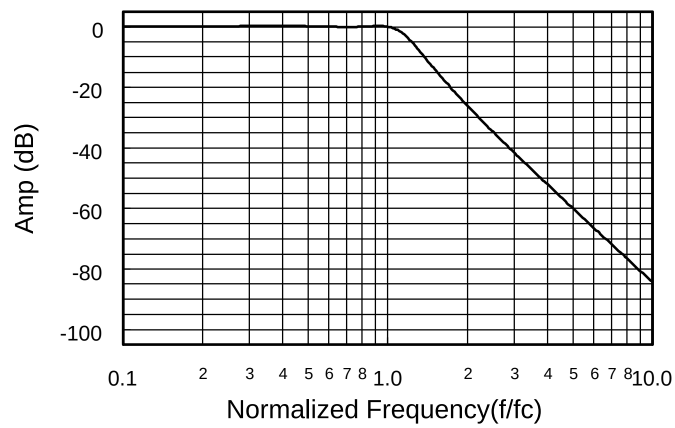
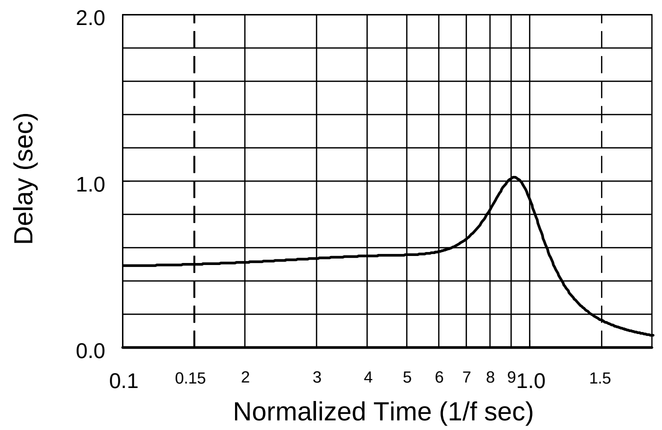
## Theoretical Transfer Characteristics

| 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 |

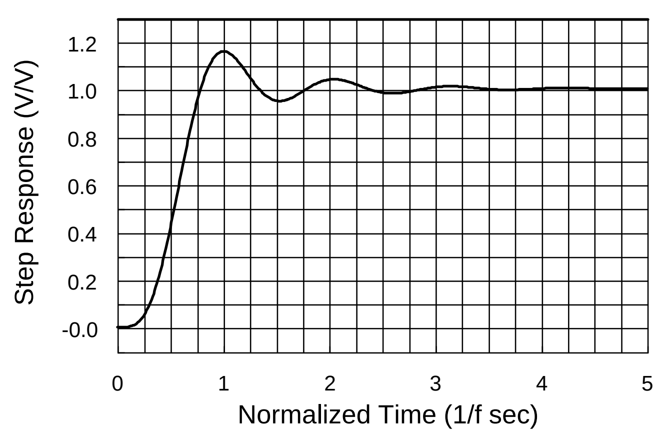
## Frequency Response




**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).

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



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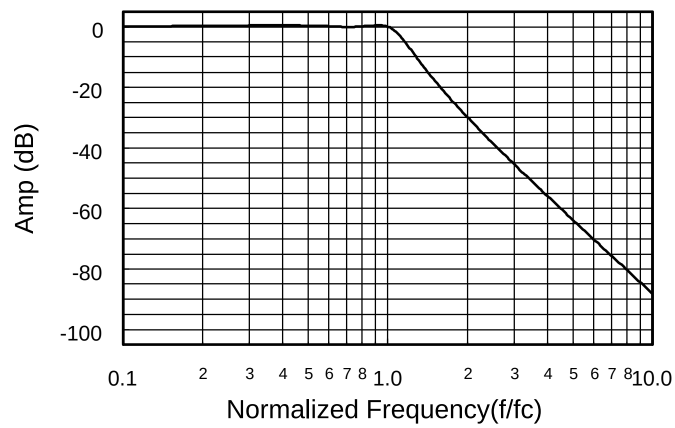
## Theoretical Transfer Characteristics

| 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 |

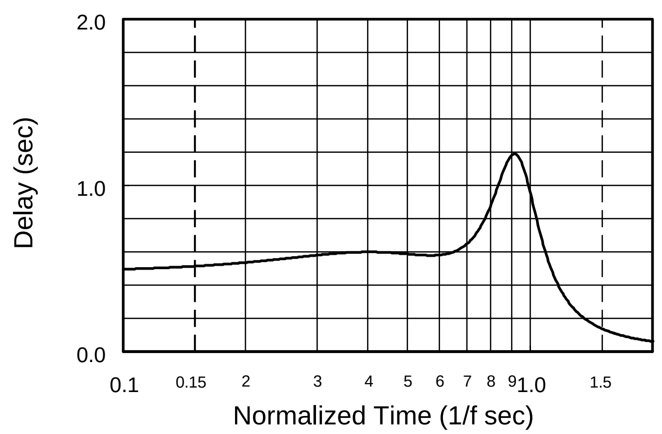
1. **Normalized Group Delay:**
The above delay data is normalized to a corner frequency of 1.0Hz.The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

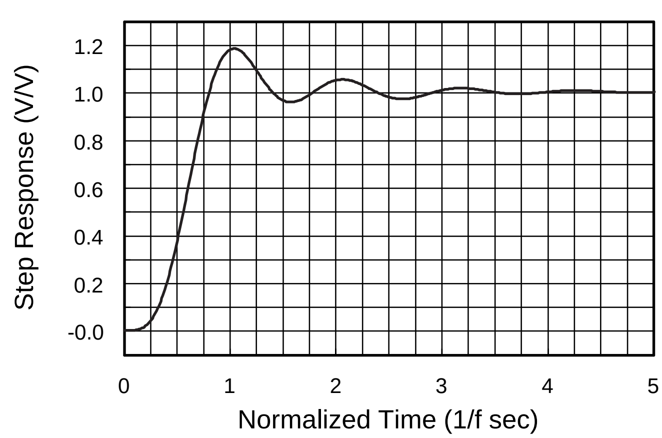
## Frequency Response




## Delay (Normalized)




## Step Response



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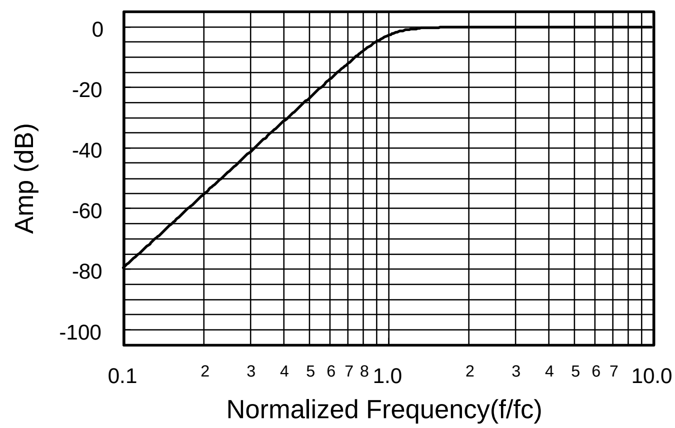
Appendix A

# High-Pass
# 4-Pole Butterworth

### 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




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).

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



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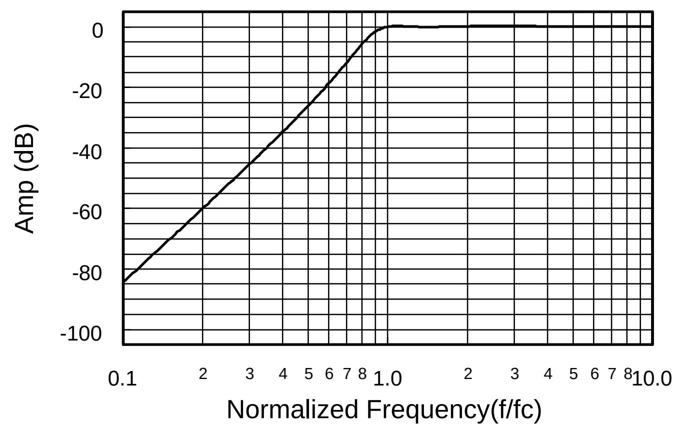
## Theoretical Transfer Characteristics

| 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).

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



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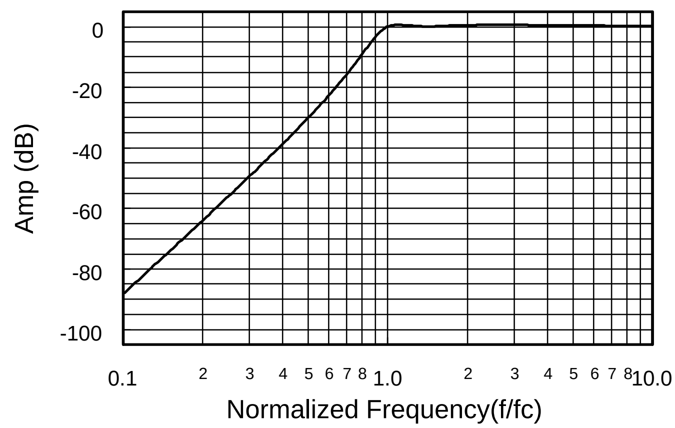
# High-Pass

# 4-Pole, 0.5 dB Ripple Chebychev

## 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).

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



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