



1.0 Hz to 102.4 kHz  
8-Bit Programmable

## Description

The D828 Series are digitally programmable low-pass and high-pass active filters with differential input that are tunable over a 256:1 frequency range. D828 filters are available with any one of five standard factory-set tuning ranges or 8-bit custom ranges from 1.0 Hz to 102.4 kHz. These units contain 8 CMOS logic inputs.

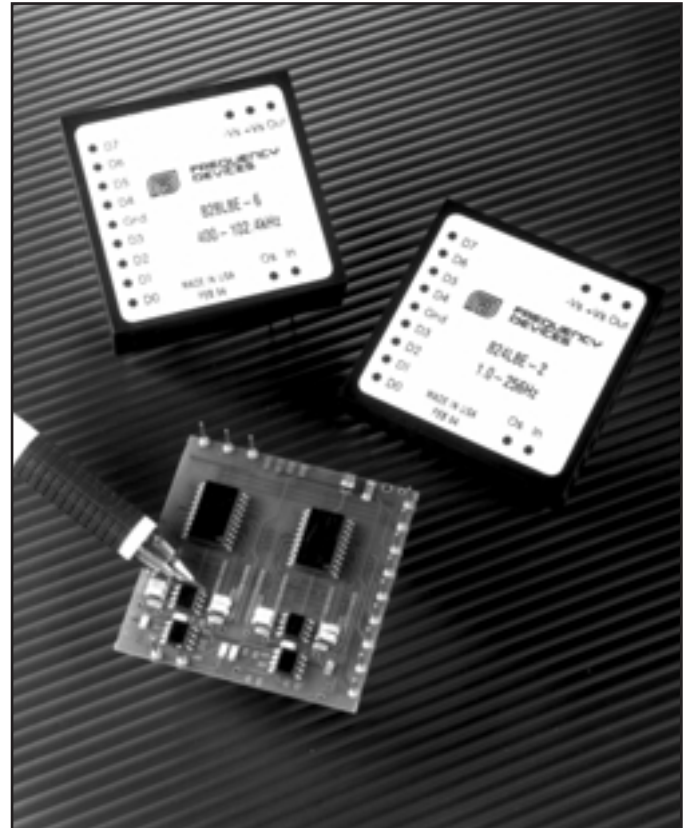
All D828 Series models are convenient, low profile, easy to use fully finished filters which require no external components or adjustments. They feature low harmonic distortion, and near theoretical phase and amplitude characteristics. D828 filters operate from non-critical  $\pm 12$  to  $\pm 18$  Vdc power supplies, have a 10 k $\Omega$  (min.) input and a 10  $\Omega$  (max.) output impedance.

## Features/Benefits:

- Compact 2" x 2" design minimizes board space requirements.
- Low harmonic distortion and wide signal-to-noise ratio to 16 bit resolution.
- 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



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## Digital Tuning & Control Characteristics

### 8-Bit Programmable Filters

#### 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<sub>0</sub> - D<sub>7</sub>).

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<sub>1</sub> - D<sub>7</sub> = "0" or "1", and

f<sub>max</sub> = Maximum tuning frequency;

f<sub>c</sub> = corner frequency;

Minimum tunable frequency = f<sub>max</sub>/256 (D<sub>0</sub> thru D<sub>7</sub> = 0);

Minimum frequency step (Resolution) = f<sub>max</sub>/256

#### Data Input Specifications

##### Input Data Levels (CMOS Logic)

Input Voltage (V<sub>s</sub> = 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 <sup>-5</sup> μA typ.	-1 μA max..
Low Level In	+10 <sup>-5</sup> μA typ.	+1 μA max.

Input Capacitance 5 pF typ 7.5 pF max.

##### Input Data Format Frequency Select Bits

Positive Logic Logic "1" = +V<sub>s</sub>  
Logic "0" = Gnd

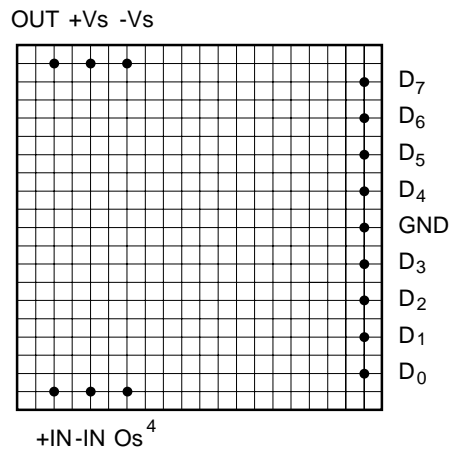
Bit Weighting (Binary-Coded)

D<sub>0</sub> LSB (least significant bit)  
D<sub>7</sub> MSB (most significant bit)

Frequency Range 256 : 1, Binary Weighted

#### Pin-Out Key

IN	Analog Input Signal	D <sub>7</sub> Tuning Bit 7 (MSB)
OUT	Analog Output Signal	D <sub>6</sub> Tuning Bit 6
GND	Power and Signal Return	D <sub>5</sub> Tuning Bit 5
+V <sub>s</sub>	Supply Voltage, Positive	D <sub>4</sub> Tuning Bit 4
-V <sub>s</sub>	Supply Voltage, Negative	D <sub>3</sub> Tuning Bit 3
Os	Offset Adjustment	D <sub>2</sub> Tuning Bit 2
		D <sub>1</sub> Tuning Bit 1
		D <sub>0</sub> Tuning Bit 0 (LSB)



MSB	---	---	---	---	---	---	LSB	Bit Weight
2 <sup>7</sup>	2 <sup>6</sup>	2 <sup>5</sup>	2 <sup>4</sup>	2 <sup>3</sup>	2 <sup>2</sup>	2 <sup>1</sup>	2 <sup>0</sup>	f <sub>c</sub> Corner Frequency
D <sub>7</sub>	D <sub>6</sub>	D <sub>5</sub>	D <sub>4</sub>	D <sub>3</sub>	D <sub>2</sub>	D <sub>1</sub>	D <sub>0</sub>	
0	0	0	0	0	0	0	0	f <sub>max</sub> /256
0	0	0	0	0	0	0	1	f <sub>max</sub> /128
0	0	0	0	0	0	1	1	f <sub>max</sub> /64
0	0	0	0	0	1	1	1	f <sub>max</sub> /32
0	0	0	0	1	1	1	1	f <sub>max</sub> /16
0	0	0	1	1	1	1	1	f <sub>max</sub> /8
0	0	1	1	1	1	1	1	f <sub>max</sub> /4
0	1	1	1	1	1	1	1	f <sub>max</sub> /2
1	1	1	1	1	1	1	1	f <sub>max</sub>



Model	D828L8B	D828L8E	D828L8EX	D828L8EY
<b>Product Specifications</b>				
<b>Transfer Function</b>	8-Pole Butterworth	8-Pole, 6 zero Elliptic	8-Pole, 6 zero Elliptic	8-Pole, 6 zero Elliptic
<b>Size, Model 2 Model 3 thru 6</b>	2.0" x 2.0" x 0.6" 2.0" x 2.0" x 0.5"	2.0" x 2.0" x 0.6" 2.0" x 2.0" x 0.5"	2.0" x 2.0" x 0.6" 2.0" x 2.0" x 0.5"	2.0" x 2.0" x 0.6" 2.0" x 2.0" x 0.5"
<b>Range fc, fr</b>	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
<b>Theoretical Transfer Characteristics</b>	Appendix A Page 9	Appendix A Page 24	Appendix A Page 23	Appendix A Page 25
<b>Passband Ripple</b> (theoretical)	0.0 dB	± 0.035 dB	- 0.05 dB	- 0.05 dB
<b>DC Voltage Gain</b> (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.
<b>Stopband Attenuation Rate</b>	48 dB/octave	80 dB min.	80 dB min.	100 dB min.
<b>Cutoff Frequency Stability Amplitude Phase</b>	fc ± 2% max. ± 0.01% /°c -3 dB -360°	fr ± 2% max. ± 0.01% /°c -0.035 dB -323.5°	fr ± 2% max. ± 0.01% /°c -0.05dB -414°	fr ± 2% max. ± 0.01% /°c -0.05 dB -419°
<b>Filter Attenuation</b> (theoretical)	0.12 dB      0.80 fc 3.01 dB      1.00 fc 60.0 dB      2.37 fc 80.0 dB      3.16 fc	0.035 dB      1.00 fr 3.01 dB      1.13 fr 60.0 dB      1.67 fr 80.0 dB      1.77 fr	0.05 dB      1.00 fr 3.01 dB      1.05 fr 60.0 dB      1.45 fr 80.0 dB      1.56 fr	0.05 dB      1.00 fr 3.01 dB      1.06 fr 80.0 dB      1.83 fr 100.0 dB      2.00 fr
<b>Phase Match<sup>1</sup></b>	0 - 0.8 fc ± 2° max. ± 1° typ. 0.8 fc - 1.0 fc ± 3° max. ± 1.5° typ.	0 - 0.8 fr ± 2° max. ± 1° typ. 0.8 fr - 1.0 fr ± 4° max. ± 2° typ.	0 - 0.8 fr ± 3° max. ± 1.5° typ. 0.8 fr - 1.0 fr ± 4° max. ± 2° typ.	0 - 0.8 fr ± 3° max. ± 1.5° typ. 0.8 fr - 1.0 fr ± 4° max. ± 2° typ.
<b>Amplitude Accuracy</b> (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 - 0.8 fr ± .2 dB max. ± .1 dB typ. 0.8 fr - 1.0 fr ± .3 dB max. ± .15 dB typ.	0 - 0.8 fr ± 0.2 dB max. ± 0.1 dB typ. 0.8 fr - 1.0 fr ± 0.5 dB max. ± 0.25 dB typ.	0 - 0.8 fr ± 0.2 dB max. ± 0.1 dB typ. 0.8 fr - 1.0 fr ± 0.5 dB max. ± 0.25 dB typ.
<b>Total Harmonic Distortion @ 1 kHz</b>	< - 100 dB typ.	< - 88 dB typ.	< - 88 dB typ.	< - 88 dB typ.
<b>Wide Band Noise</b> (5 Hz - 2 MHz)	200 µVrms typ.	200 µVrms typ.	250 µVrms typ.	250 µVrms typ.
<b>Narrow Band Noise</b> (5 Hz - 100 kHz)	50 µVrms typ.	50 µVrms typ.	75 µVrms typ.	75 µVrms typ.

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



## 8-Bit Programmable

## 8-Pole Low-Pass Filters

Model	D828L8L	D828L8D60	D828L8D80	D828L8D10
<b>Product Specifications</b>				
<b>Transfer Function</b>	8-Pole Bessel	8-Pole, 6 zero Constant Delay	8-Pole, 6 zero Constant Delay	8-Pole, 6 zero Constant Delay
<b>Size, Model 2 Model 3 thru 6</b>	2.0" x 2.0" x 0.6" 2.0" x 2.0" x 0.5"	2.0" x 2.0" x 0.6" 2.0" x 2.0" x 0.5"	2.0" x 2.0" x 0.6" 2.0" x 2.0" x 0.5"	2.0" x 2.0" x 0.6" 2.0" x 2.0" x 0.5"
<b>Range f<sub>c</sub></b>	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
<b>Theoretical Transfer Characteristics</b>	Appendix A Page 4	Appendix A Page 20	Appendix A Page 21	Appendix A Page 22
<b>Passband Ripple</b> (theoretical)	0.0 dB	0.15 dB	0.15 dB	0.15 dB
<b>DC Voltage Gain</b> (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.
<b>Stopband Attenuation Rate</b>	48 dB/octave	60 dB min.	80 dB min.	100 dB min.
<b>Cutoff Frequency Stability</b> <b>Amplitude</b> <b>Phase</b>	f <sub>c</sub> ± 2% max. ± 0.01% /°C -3 dB -182°	f <sub>c</sub> ± 2% max. ± 0.01% /°C -3 dB -306°	f <sub>c</sub> ± 2% max. ± 0.01% /°C -3 dB -306°	f <sub>c</sub> ± 2% max. ± 0.01% /°C -3 dB -311°
<b>Filter Attenuation</b> (theoretical)	1.91 dB      0.80 f <sub>c</sub> 3.01 dB      1.00 f <sub>c</sub> 60.0 dB      4.52 f <sub>c</sub> 80.0 dB      6.07 f <sub>c</sub>	3.01 dB      1.00 f <sub>c</sub> 40.0 dB      2.28 f <sub>c</sub> 60.0 dB      2.64 f <sub>c</sub>	3.01 dB      1.00 f <sub>c</sub> 60.0 dB      3.08 f <sub>c</sub> 80.0 dB      3.57 f <sub>c</sub>	3.01 dB      1.00 f <sub>c</sub> 80.0 dB      4.45 f <sub>c</sub> 100.0 dB      5.20 f <sub>c</sub>
<b>Phase Match<sup>1</sup></b>	0 - f <sub>c</sub> ± 2° max. ± 1° typ.	0 - f <sub>c</sub> ± 2° max. ± 1° typ.	0 - f <sub>c</sub> ± 2° max. ± 1° typ.	0 - f <sub>c</sub> ± 2° max. ± 1° typ.
<b>Amplitude Accuracy</b> (theoretical)	0 - f <sub>c</sub> ± 0.2 dB max. ± 0.1 dB typ.	0 - 0.8 f <sub>c</sub> ± 0.2 dB max. ± 0.1 dB typ. 0.8 f <sub>c</sub> - 1.0 f <sub>c</sub> ± 0.3 dB max. ± 0.15 dB typ.	0 - 0.8 f <sub>c</sub> ± 0.2 dB max. ± 0.1 dB typ. 0.8 f <sub>c</sub> - 1.0 f <sub>c</sub> ± 0.3 dB max. ± 0.15 dB typ.	0 - 0.8 f <sub>c</sub> ± 0.2 dB max. ± 0.1 dB typ. 0.8 f <sub>c</sub> - 1.0 f <sub>c</sub> ± 0.3 dB max. ± 0.15 dB typ.
<b>Total Harmonic Distortion @ 1 kHz</b>	< - 100 dB typ.	< - 100 dB typ.	< - 100 dB typ.	< - 100 dB typ.
<b>Wide Band Noise</b> (5 Hz - 2 MHz)	200 μVrms typ.	200 μVrms typ.	200 μVrms typ.	200 μVrms typ.
<b>Narrow Band Noise</b> (5 Hz - 100 kHz)	50 μVrms typ.	50 μVrms typ.	50 μVrms typ.	50 μVrms typ.

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



Model	D828H8B	D828H8E	D828H8EX	D828H8EY
<b>Product Specifications</b>				
<b>Transfer Function</b>	8-Pole Butterworth	8-Pole, 6 zero Elliptic	8-Pole, 6 zero Elliptic	8-Pole, 6 zero Elliptic
<b>Size, Model 2 Model 3 thru 6</b>	2.0" x 2.0" x 0.6" 2.0" x 2.0" x 0.5"	2.0" x 2.0" x 0.6" 2.0" x 2.0" x 0.5"	2.0" x 2.0" x 0.6" 2.0" x 2.0" x 0.5"	2.0" x 2.0" x 0.6" 2.0" x 2.0" x 0.5"
<b>Range <math>f_c, f_r</math></b>	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
<b>Theoretical Transfer Characteristics</b>	Appendix A Page 29	Appendix A Page 37	Appendix A Page 36	Appendix A Page 38
<b>Passband Ripple</b> (theoretical)	0.0 dB	$\pm 0.035$ dB	- 0.05 dB	- 0.05 dB
<b>Voltage Gain</b> (non-inverting)	$0 \pm 0.2$ dB to 100 kHz $0 \pm 0.5$ dB to 120 kHz	$0 \pm 0.2$ dB to 100 kHz $0 \pm 0.5$ dB to 120 kHz	$0 \pm 0.2$ dB to 100 kHz $0 \pm 0.5$ dB to 120 kHz	$0 \pm 0.2$ dB to 100 kHz $0 \pm 0.5$ dB to 120 kHz
<b>Power Bandwidth</b>	120 kHz	120 kHz	120 kHz	120 kHz
<b>Small Signal Bandwidth</b>	(-6 dB) 1 MHz	(-6 dB) 1 MHz	(-6 dB) 1 MHz	(-6 dB) 1 MHz
<b>Stopband Attenuation Rate</b>	48 dB/octave	80 dB	80 dB	100 dB
<b>Cutoff Frequency Stability</b>	$f_c \pm 2\%$ max. $\pm 0.01\%$ /°C	$f_r \pm 2\%$ max. $\pm 0.01\%$ /°C	$f_r \pm 2\%$ max. $\pm 0.01\%$ /°C	$f_r \pm 2\%$ max. $\pm 0.01\%$ /°C
<b>Amplitude Phase</b>	-3 dB -360°	-0.035 dB -323.5°	-0.05dB -414°	-0.05 dB -419°
<b>Filter Attenuation</b> (theoretical)	80 dB      0.31 $f_c$ 60.0 dB    0.42 $f_c$ 3.01 dB    1.00 $f_c$ 0.00 dB    2.00 $f_c$	80 dB      0.56 $f_r$ 60.0 dB    0.60 $f_r$ 3.01 dB    0.88 $f_r$ 0.03 dB    1.00 $f_r$ 0.00 dB    2.00 $f_r$	80 dB      0.64 $f_r$ 60.0 dB    0.69 $f_r$ 3.01 dB    0.95 $f_r$ 0.03 dB    1.00 $f_r$ 0.00 dB    2.00 $f_r$	100 dB      0.50 $f_r$ 80.0 dB    0.55 $f_r$ 3.01 dB    0.94 $f_r$ 0.03 dB    1.00 $f_r$ 0.00 dB    2.00 $f_r$
<b>Phase Match<sup>1</sup></b>	$f_c - 100$ kHz $\pm 3^\circ$ max. $\pm 1.5^\circ$ typ.	$f_r - 1.25 f_r \pm 4^\circ$ max. $\pm 2^\circ$ typ. $1.25 f_r - 100$ kHz $\pm 2^\circ$ max. $\pm 1^\circ$ typ.	$f_r - 1.25 f_r \pm 4^\circ$ max. $\pm 2^\circ$ typ. $1.25 f_r - 100$ kHz $\pm 2^\circ$ max. $\pm 1^\circ$ typ.	$f_r - 1.25 f_r \pm 4^\circ$ max. $\pm 2^\circ$ typ. $1.25 f_r - 100$ kHz $\pm 3^\circ$ max. $\pm 1.5^\circ$ typ.
<b>Amplitude Accuracy</b> (theoretical)	$f_c - 1.25 f_c \pm 0.3$ dB max. $\pm 0.15$ dB typ. $1.25 f_c - 100$ kHz $\pm 0.2$ dB max. $\pm 0.1$ dB typ.	$f_r - 1.25 f_r \pm 0.3$ dB max. $\pm 0.15$ dB typ. $1.25 f_r - 100$ kHz $\pm 0.2$ dB max. $\pm 0.1$ dB typ.	$f_r - 1.25 f_r \pm 0.5$ dB max. $\pm 0.25$ dB typ. $1.25 f_r - 100$ kHz $\pm 0.2$ dB max. $\pm 0.1$ dB typ.	$f_r - 1.25 f_r \pm 0.5$ dB max. $\pm 0.25$ dB typ. $1.25 f_r - 100$ kHz $\pm 0.2$ dB max. $\pm 0.1$ dB typ.
<b>Total Harmonic Distortion @ 1 kHz</b>	< - 100 dB typ.	< - 88 dB typ.	< - 88 dB typ.	< - 88 dB typ.
<b>Wide Band Noise</b> (5 Hz - 2 MHz)	400 $\mu$ Vrms typ.	400 $\mu$ Vrms typ.	500 $\mu$ Vrms typ.	500 $\mu$ Vrms typ.
<b>Narrow Band Noise</b> (5 Hz - 100 kHz)	100 $\mu$ Vrms typ.	100 $\mu$ Vrms typ.	150 $\mu$ Vrms typ.	150 $\mu$ Vrms typ.

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  $V_s \pm 15$  Vdc)

## Pin-Out and Package Data Ordering Information

### Analog Input Characteristics<sup>1</sup>

Impedance	10 k $\Omega$ min.
Voltage Range	$\pm 10$ Vpeak
Max. Safe Voltage	$\pm V_s$

### Analog Output Characteristics

Impedance (Closed Loop)	1 $\Omega$ typ. 10 $\Omega$ max.
Linear Operating Range	$\pm 10$ V
Maximum Current <sup>2</sup>	$\pm 2$ mA
Offset Voltage <sup>3</sup>	2 mV typ. 20 mV max.
Offset Temp. Coeff.	50 $\mu$ V/°C

### Power Supply ( $\pm V_s$ )

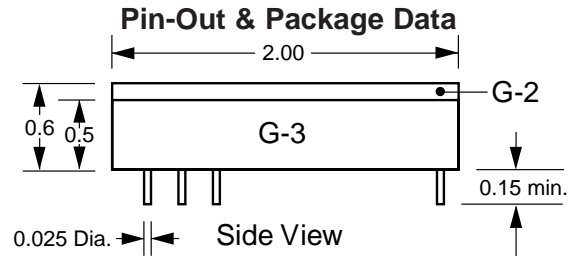
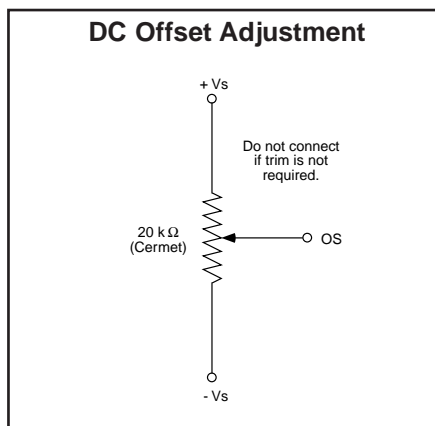
Rated Voltage	$\pm 15$ Vdc
Operating Range	$\pm 12$ to $\pm 18$ Vdc
Maximum Safe Voltage	$\pm 18$ Vdc
Quiescent Current	
8 Pole	$\pm 25$ mA typ. $\pm 40$ mA max.

### Temperature

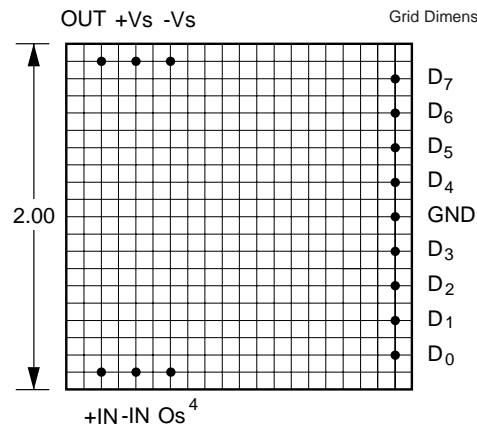
Operating	0 to +70°C
Storage	-25 to +85°C

### Notes:

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



All dimensions are in inches  
All Case Dimensions  $\pm 0.02$ "  
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  
D60 - constant delay (-60 dB)  
D80 - constant delay (-80 dB)  
D10 - constant delay (-100 dB)  
E - elliptic 1.77 (-80 dB)  
EX - elliptic 1.56 (-80dB)  
EY - elliptic 2.00 (-100 dB)

## D828L8E-3

### Model Number

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

We hope the information given here will be helpful. The information is based on data and our best knowledge, and we consider the information to be true and accurate. Please read all statements, recommendations or suggestions herein in conjunction with our conditions of sale which apply to all goods supplied by us. We assume no responsibility for the use of these statements, recommendations or suggestions, nor do we intend them as a recommendation for any use which would infringe any patent or copyright. **IN-00D828-00**

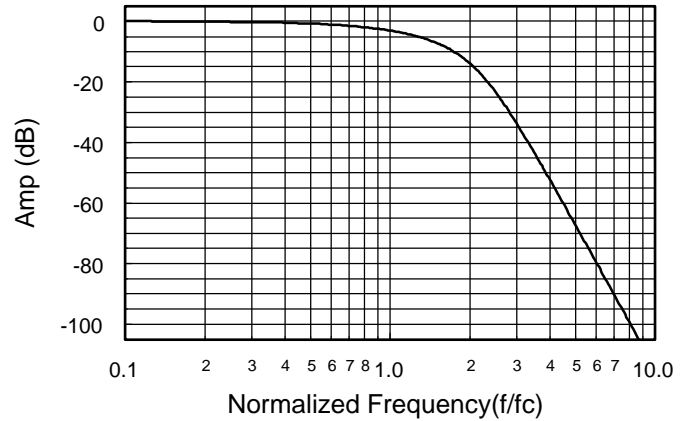


**Appendix A**

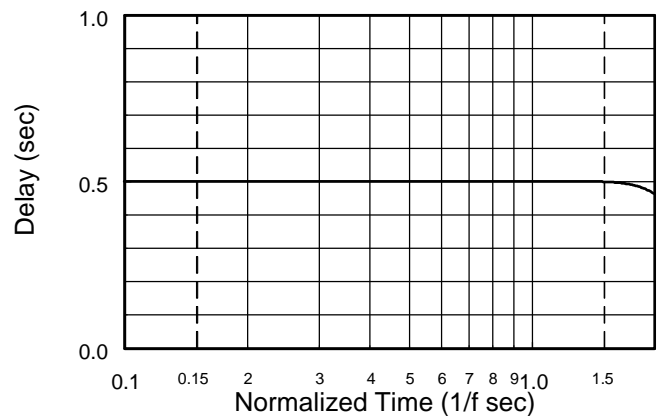
**Theoretical Transfer Characteristics**

f/fc (Hz)	Amp (dB)	Phase (deg)	Delay <sup>1</sup> (sec)
0.00	0.00	0.00	.506
0.10	-0.029	-18.2	.506
0.20	-0.117	-36.4	.506
0.30	-0.264	-54.7	.506
0.40	-0.470	-72.9	.506
0.50	-0.737	-91.1	.506
0.60	-1.06	-109	.506
0.70	-1.45	-128	.506
0.80	-1.91	-146	.506
0.85	-2.16	-155	.506
0.90	-2.42	-164	.506
0.95	-2.71	-173	.506
1.00	-3.01	-182	.506
1.10	-3.67	-200	.506
1.20	-4.40	-219	.506
1.30	-5.20	-237	.506
1.40	-6.10	-255	.505
1.50	-7.08	-273	.504
1.60	-8.16	-291	.502
1.70	-9.36	-309	.498
1.80	-10.7	-327	.492
1.90	-12.1	-345	.482
2.00	-13.7	-362	.468
2.25	-18.1	-402	.417
2.50	-23.1	-436	.352
2.75	-28.3	-465	.291
3.00	-33.4	-489	.241
3.25	-38.3	-509	.201
3.50	-43.1	-526	.170
4.00	-51.8	-552	.126
5.00	-66.8	-587	.077
6.00	-79.2	-610	.052
7.00	-89.8	-626	.038
8.00	-99.0	-638	.029
9.00	-107	-647	.023
10.0	-114	-655	.018

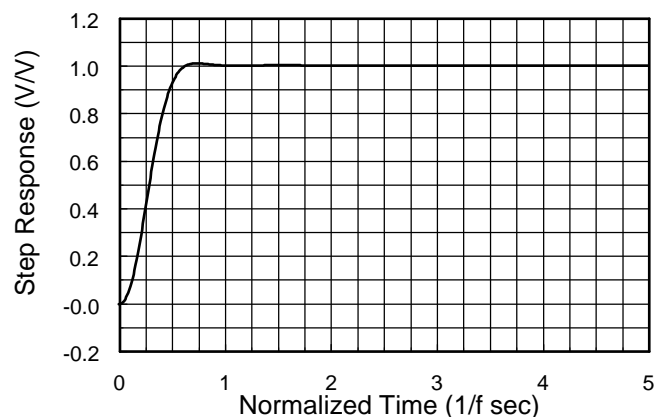
**Frequency Response**



**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**

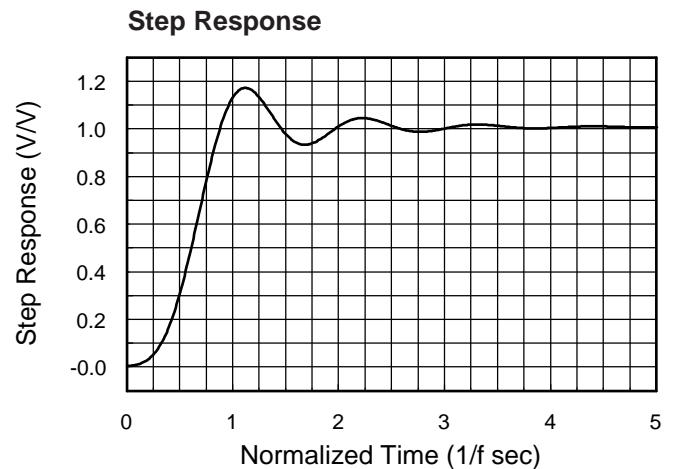
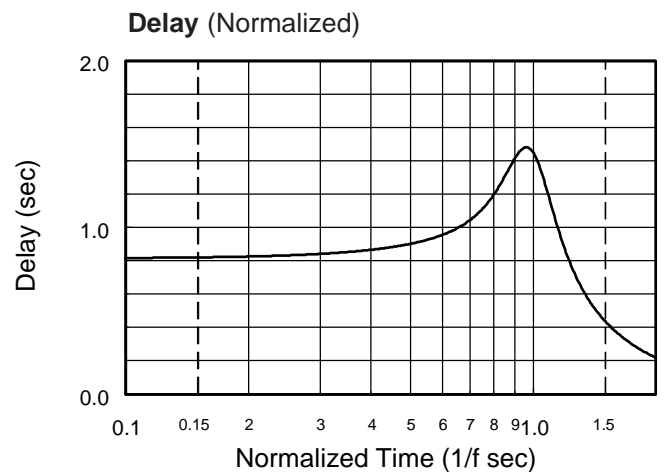
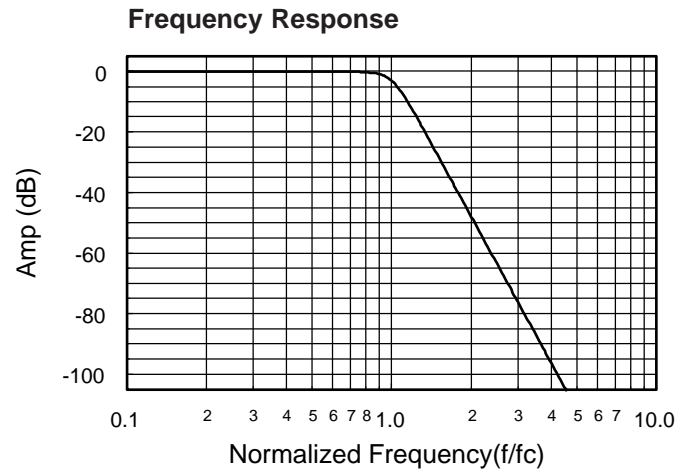
**Theoretical Transfer Characteristics**

f/fc (Hz)	Amp (dB)	Phase (deg)	Delay <sup>1</sup> (sec)
0.00	0.00	0.00	.816
0.10	0.00	-29.4	.819
0.20	0.00	-59.0	.828
0.30	0.00	-89.1	.843
0.40	0.00	-120	.867
0.50	0.00	-152	.903
0.60	-0.001	-185	.956
0.70	-0.014	-221	1.04
0.80	-0.121	-261	1.19
0.85	-0.311	-283	1.29
0.90	-0.738	-307	1.40
0.95	-1.58	-333	1.48
1.00	-3.01	-360	1.46
1.10	-7.48	-408	1.17
1.20	-12.9	-445	.873
1.30	-18.2	-472	.672
1.40	-23.4	-494	.540
1.50	-28.2	-511	.448
1.60	-32.7	-526	.380
1.70	-36.9	-539	.328
1.80	-40.8	-550	.287
1.90	-44.6	-560	.253
2.00	-48.2	-568	.226
2.25	-56.3	-586	.174
2.50	-63.7	-600	.139
2.75	-70.3	-611	.113
3.00	-76.3	-621	.094
3.25	-81.9	-629	.080
3.50	-87.1	-635	.069
4.00	-96.3	-646	.052
5.00	-112	-661	.033
6.00	-125	-671	.023
7.00	-135	-678	.017
8.00	-144	-683	.013
9.00	-153	-687	.010
10.0	-160	-691	.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).

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







**Appendix A**

**Theoretical Transfer Characteristics**

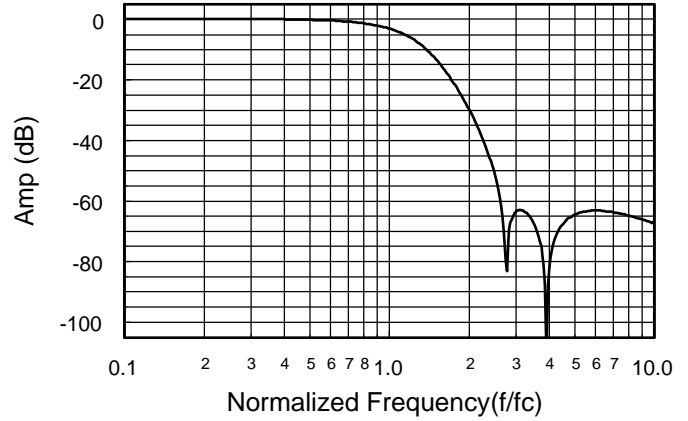
f/fc (Hz)	Amp (dB)	Phase (deg)	Delay <sup>1</sup> (sec)
0.00	0.00	0.00	.776
0.10	0.005	-28.0	.776
0.20	0.012	-55.9	.776
0.30	0.005	-83.9	.776
0.40	-0.042	-112	.776
0.50	-0.161	-140	.776
0.60	-0.384	-168	.776
0.70	-0.745	-196	.776
0.80	-1.28	-224	.776
0.85	-1.62	-238	.776
0.90	-2.02	-252	.776
0.95	-2.48	-265	.775
1.00	-3.01	-279	.773
1.10	-4.29	-307	.766
1.20	-5.91	-334	.749
1.40	-10.3	-386	.675
1.60	-15.9	-431	.558
1.80	-22.4	-467	.443
2.00	-29.4	-495	.351
2.25	-39.0	-523	.268
2.50	-50.5	-544	.212
2.75	-78.0	-561	.171
3.00	-63.7	-395	.142
3.25	-63.5	-407	.119
3.50	-66.9	-417	.102
3.75	-74.7	-425	.088
4.00	-85.0	-253	.077
4.25	-72.0	-259	.068
4.50	-67.9	-265	.060
4.75	-65.8	-270	.054
5.00	-64.6	-275	.048
5.25	-63.9	-279	.044
5.50	-63.5	-283	.040
5.75	-63.3	-286	.036
6.00	-63.2	-289	.033
6.50	-63.3	-295	.028
7.00	-63.7	-299	.024
8.00	-64.7	-307	.019
9.00	-66.0	-313	.015
10.0	-67.3	-318	.012

**1. Normalized Group Delay:**

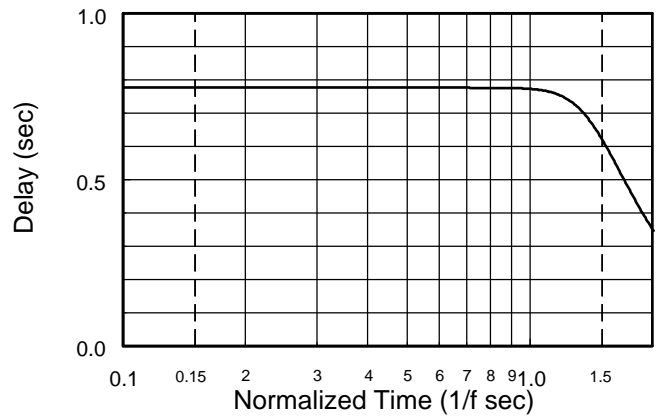
The above delay data is normalized to a corner frequency of 1.0Hz. The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

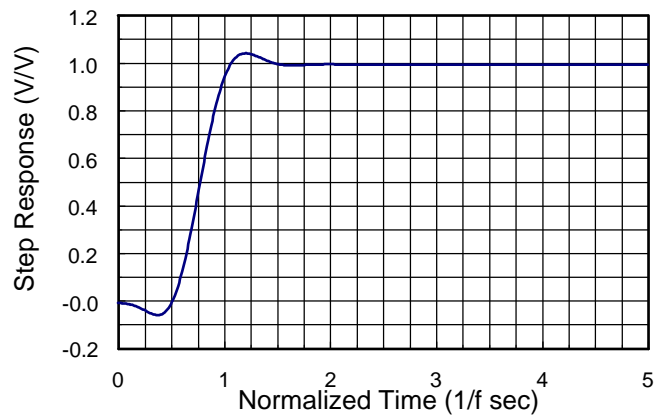
**Frequency Response**



**Delay (Normalized)**



**Step Response**





**Appendix A**

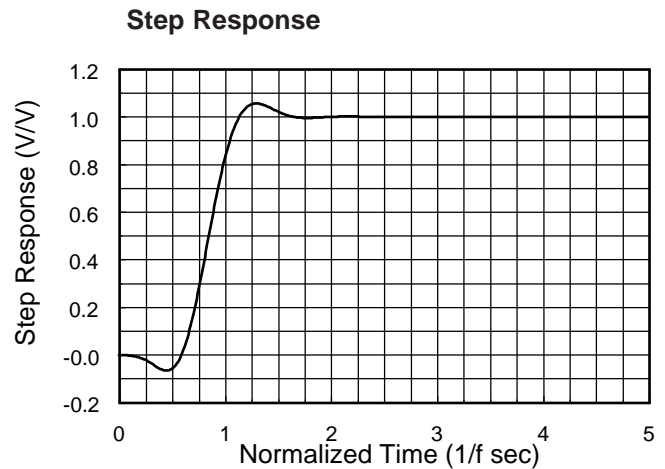
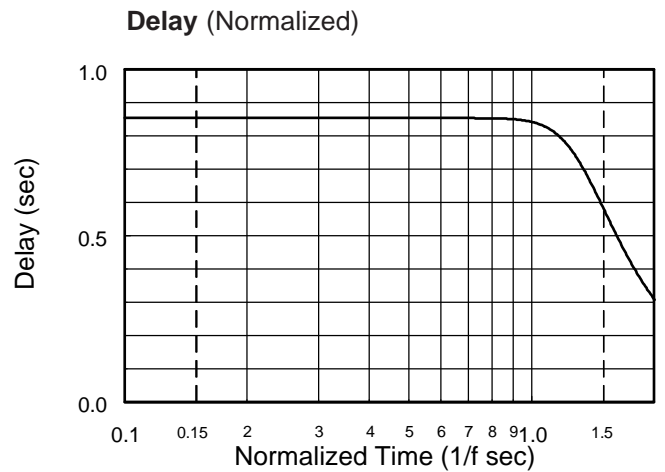
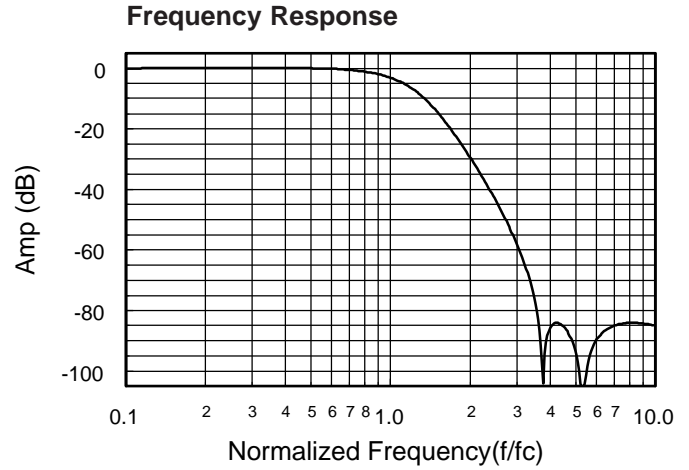
**Theoretical Transfer Characteristics**

f/fc (Hz)	Amp (dB)	Phase (deg)	Delay <sup>1</sup> (sec)
0.00	0.00	0.00	.852
0.10	0.017	-30.7	.852
0.20	0.058	-61.3	.852
0.30	0.099	-92.0	.852
0.40	0.105	-123	.852
0.50	0.034	-153	.852
0.60	-0.157	-184	.852
0.70	-0.510	-215	.852
0.80	-1.07	-245	.851
0.85	-1.44	-261	.850
0.90	-1.89	-276	.849
0.95	-2.41	-291	.846
1.00	-3.01	-306	.841
1.10	-4.50	-336	.821
1.20	-6.39	-365	.783
1.40	-11.3	-417	.656
1.60	-17.1	-459	.512
1.80	-23.2	-492	.396
2.00	-29.1	-517	.312
2.25	-36.3	-542	.239
2.50	-43.4	-561	.189
2.75	-50.3	-576	.153
3.00	-57.6	-589	.127
3.25	-62.5	-599	.107
3.50	-75.4	-608	.092
3.75	-98.3	-616	.079
4.00	-86.3	-442	.069
4.25	-84.1	-448	.061
4.50	-85.1	-454	.054
4.75	-87.9	-458	.049
5.00	-92.8	-462	.044
5.25	-104	-466	.040
5.50	-101	-289	.036
5.75	-93.3	-293	.033
6.00	-89.9	-295	.030
6.50	-86.6	-300	.026
7.00	-85.1	-305	.022
8.00	-84.1	-312	.017
9.00	-84.3	-317	.013
10.0	-84.9	-321	.011

**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**

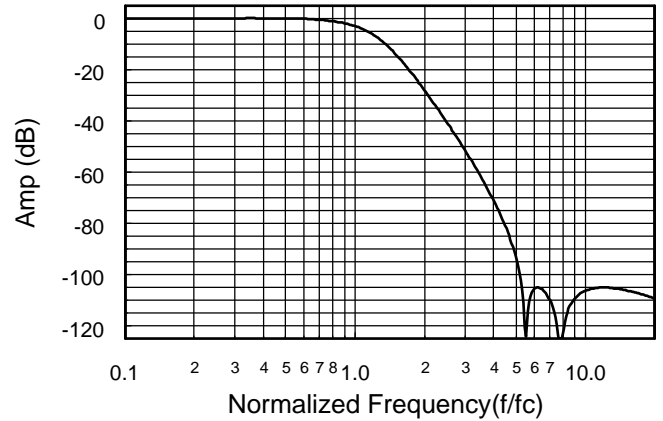
f/fc (Hz)	Amp (dB)	Phase (deg)	Delay <sup>1</sup> (sec)
0.00	0.00	0.00	.865
0.10	0.015	-31.1	.865
0.20	0.051	-62.3	.865
0.30	0.085	-93.4	.865
0.40	0.085	-125	.865
0.50	0.010	-156	.865
0.60	-0.182	-187	.865
0.70	-0.532	-218	.865
0.80	-1.09	-249	.864
0.85	-1.45	-265	.863
0.90	-1.89	-280	.861
0.95	-2.41	-296	.857
1.00	-3.01	-311	.851
1.10	-4.50	-341	.828
1.20	-6.38	-370	.785
1.40	-11.2	-422	.650
1.60	-16.8	-464	.504
1.80	-22.5	-496	.389
2.00	-28.0	-520	.306
2.25	-34.5	-544	.235
2.50	-40.5	-563	.186
2.75	-46.1	-578	.151
3.00	-51.4	-591	.125
3.50	-61.5	-610	.090
4.00	-71.2	-624	.068
4.50	-81.3	-635	.054
5.00	-93.4	-643	.043
5.50	-142	-651	.036
6.00	-105	-476	.030
6.20	-105	-478	.028
6.50	-106	-481	.025
7.00	-110	-486	.022
8.00	-122	-312	.017
9.00	-109	-318	.013
10.0	-106	-322	.011
12.0	-105	-328	.007
14.0	-106	-333	.005
16.0	-107	-336	.004
18.0	-108	-339	.003
20.0	-109	-341	.003

**1. Normalized Group Delay:**

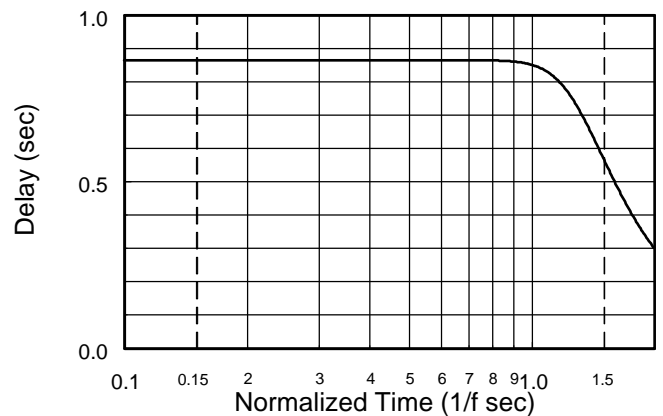
The above delay data is normalized to a corner frequency of 1.0Hz. The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

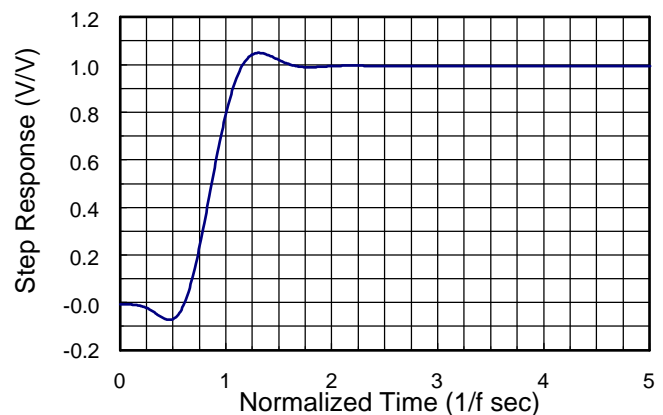
**Frequency Response**



**Delay (Normalized)**



**Step Response**





**Appendix A**

**Theoretical Transfer Characteristics**

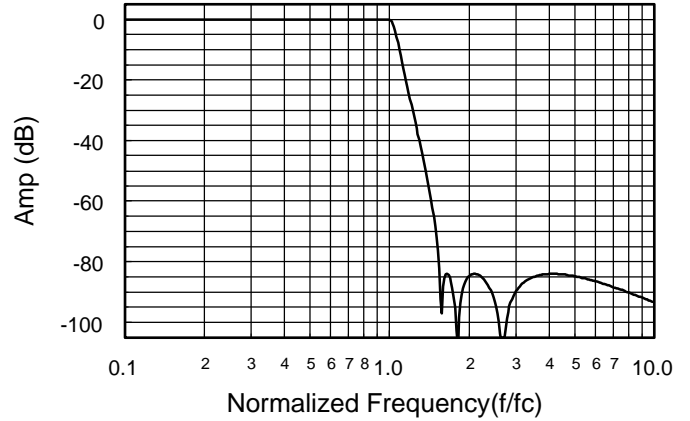
f/fc (Hz)	Amp (dB)	Phase (deg)	Delay <sup>1</sup> (sec)
0.00	0.00	0.00	0.823
0.10	-0.001	-29.7	0.829
0.20	-0.013	-59.8	0.844
0.30	-0.040	-90.5	0.865
0.40	-0.049	-122	0.904
0.50	-0.018	-156	0.972
0.55	-0.003	-174	1.016
0.60	-0.002	-192	1.064
0.65	-0.019	-212	1.116
0.70	-0.042	-233	1.178
0.75	-0.049	-255	1.264
0.80	-0.026	-279	1.388
0.85	-0.001	-305	1.557
0.90	-0.024	-335	1.767
0.95	-0.045	-369	2.111
1.00	-0.050	-414	3.062
1.10	-10.48	-531	2.043
1.20	-25.96	-576	0.814
1.30	-39.45	-598	0.493
1.40	-52.87	-614	0.348
1.50	-69.11	-624	0.265
1.60	-89.09	-453	0.211
1.70	-85.32	-459	0.174
1.75	-89.95	-463	0.156
1.80	-103.5	-465	0.147
1.85	-95.94	-288	0.158
1.90	-89.31	-290	0.126
1.95	-86.44	-292	0.117
2.00	-84.96	-295	0.110
2.20	-84.54	-302	0.087
2.40	-88.65	-307	0.069
2.60	-99.78	-311	0.057
2.80	-99.97	-135	0.048
3.00	-90.20	-139	0.041
3.50	-85.09	-145	0.029
4.00	-84.04	-150	0.022
5.00	-84.76	-156	0.014
6.00	-86.45	-160	0.009
7.00	-88.31	-163	0.007
8.00	-90.11	-165	0.005
9.00	-91.82	-167	0.004
10.0	-93.41	-168	0.003

**1. Normalized Group Delay:**

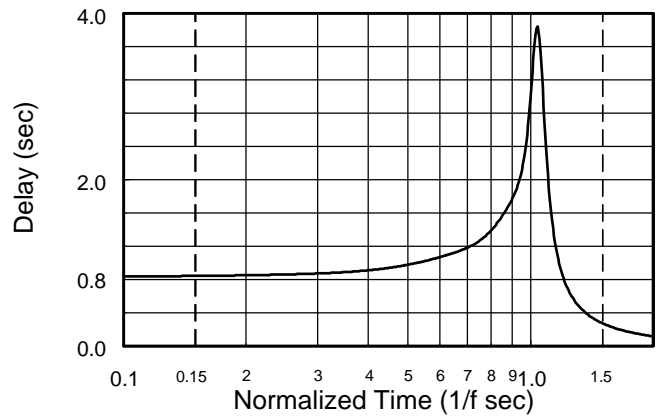
The above delay data is normalized to a corner frequency of 1.0Hz. The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

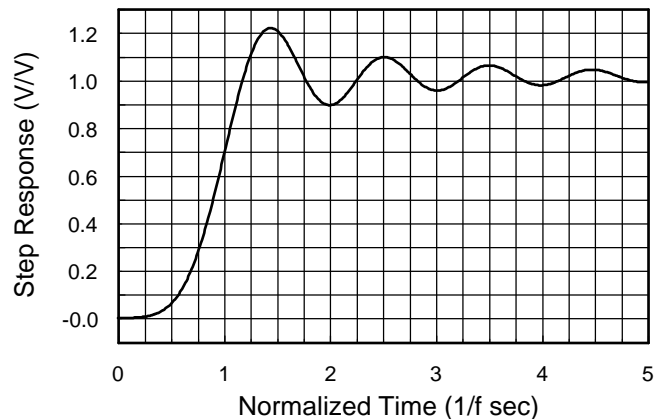
**Frequency Response**



**Delay (Normalized)**



**Step Response**





**Appendix A**

**Theoretical Transfer Characteristics**

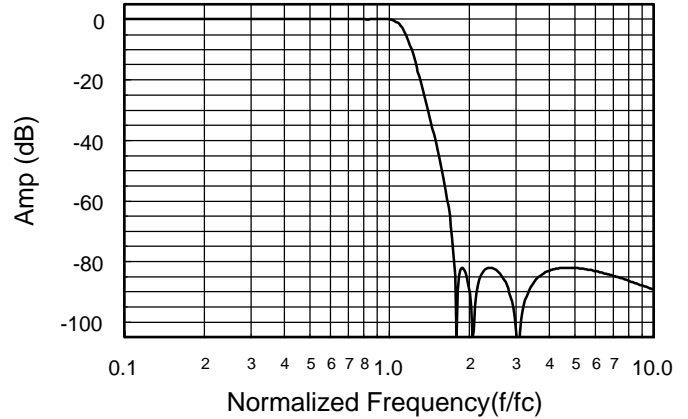
f/fc (Hz)	Amp (dB)	Phase (deg)	Delay <sup>1</sup> (sec)
0.00	0.00	0.00	0.713
0.10	-0.004	-25.7	0.716
0.20	-0.014	-51.6	0.724
0.30	-0.024	-77.9	0.740
0.40	-0.020	-105	0.767
0.50	0.007	-133	0.811
0.55	0.022	-148	0.840
0.60	0.033	-163	0.872
0.65	0.031	-179	0.908
0.70	0.014	-196	0.946
0.75	-0.015	-213	0.989
0.80	-0.041	-232	1.04
0.85	-0.046	-251	1.12
0.90	-0.016	-272	1.23
0.95	-0.025	-296	1.40
1.00	-0.035	-323	1.65
1.10	-1.76	-392	2.14
1.20	-8.28	-467	1.86
1.30	-18.4	-522	1.19
1.40	-29.3	-558	0.753
1.50	-40.1	-578	0.517
1.60	-51.5	-594	0.381
1.70	-65.2	-606	0.296
1.75	-75.0	-611	0.265
1.80	-113.0	-616	0.239
1.85	-83.6	-440	0.217
1.90	-82.0	-444	0.198
1.95	-83.7	-447	0.182
2.00	-87.8	-450	0.168
2.20	-85.8	-280	0.126
2.40	-82.0	-289	0.099
2.60	-83.5	-295	0.081
2.80	-88.2	-301	0.067
3.00	-99.9	-305	0.057
3.50	-87.2	-134	0.040
4.00	-83.1	-140	0.030
5.00	-82.1	-148	0.018
6.00	-83.1	-154	0.013
7.00	-84.6	-157	0.009
8.00	-86.2	-160	0.007
9.00	-87.8	-163	0.005
10.0	-89.3	-164	0.004

**1. Normalized Group Delay:**

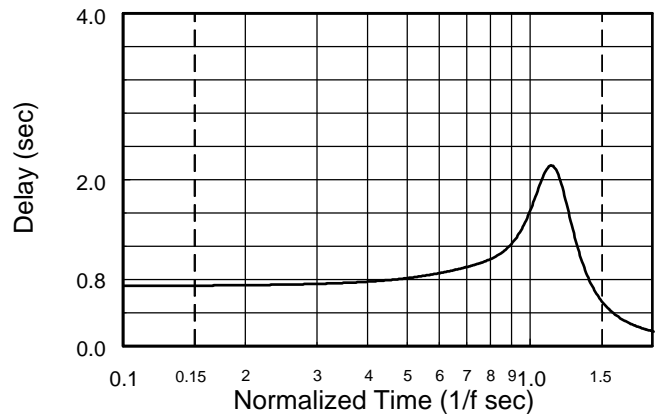
The above delay data is normalized to a corner frequency of 1.0Hz. The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

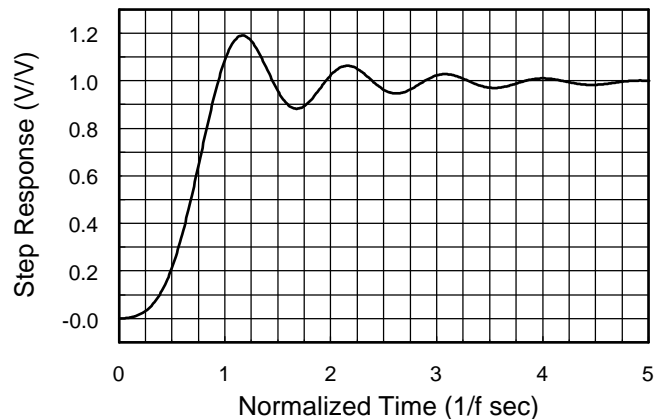
**Frequency Response**



**Delay (Normalized)**



**Step Response**





**Appendix A**

**Theoretical Transfer Characteristics**

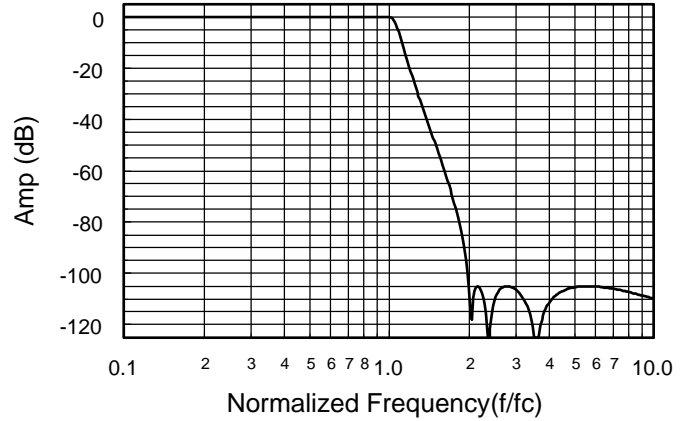
f/fc (Hz)	Amp (dB)	Phase (deg)	Delay <sup>1</sup> (sec)
0.00	0.00	0.00	0.885
0.10	-0.001	-31.9	0.891
0.20	-0.015	-64.2	0.903
0.30	-0.040	-97.0	0.922
0.40	-0.042	-131	0.958
0.50	-0.001	-166	1.020
0.55	0.000	-185	1.057
0.60	-0.007	-204	1.099
0.65	-0.027	-225	1.140
0.70	-0.045	-245	1.193
0.75	-0.040	-268	1.269
0.80	-0.014	-291	1.377
0.85	-0.001	-317	1.513
0.90	-0.031	-346	1.677
0.95	-0.036	-378	1.960
1.00	-0.046	-419	2.681
1.10	-7.910	-525	2.127
1.20	-21.06	-573	0.856
1.30	-31.96	-597	0.509
1.40	-41.51	-612	0.357
1.50	-50.35	-623	0.271
1.60	-58.90	-632	0.216
1.70	-67.54	-639	0.177
1.75	-72.04	-642	0.162
1.80	-76.79	-645	0.149
1.85	-81.93	-647	0.138
1.90	-87.78	-650	0.128
1.95	-95.04	-652	0.119
2.00	-106.6	-654	0.111
2.20	-106.0	-481	0.087
2.40	-121.3	-307	0.070
2.60	-106.5	-311	0.058
2.80	-105.0	-315	0.049
3.00	-106.4	-318	0.042
3.50	-123.6	-325	0.030
4.00	-111.5	-149	0.022
5.00	-105.4	-156	0.014
6.00	-105.1	-160	0.010
7.00	-106.0	-163	0.007
8.00	-107.3	-165	0.005
9.00	-108.6	-167	0.004
10.0	-110.0	-168	0.003

**1. Normalized Group Delay:**

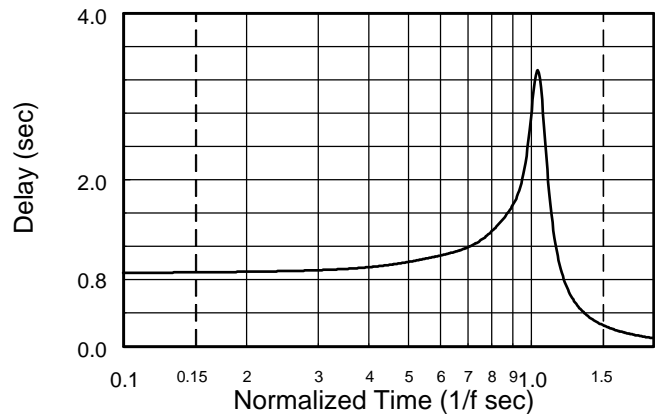
The above delay data is normalized to a corner frequency of 1.0Hz. The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

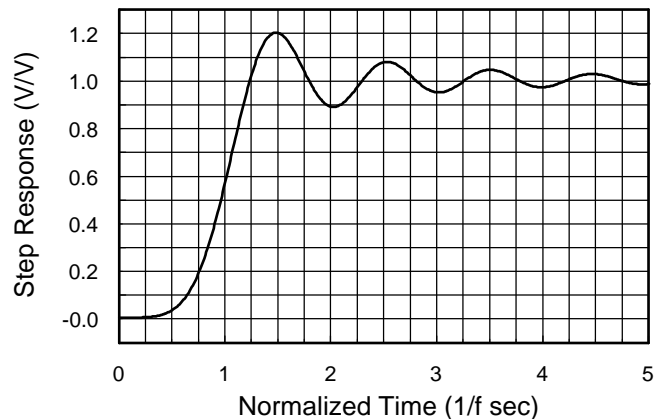
**Frequency Response**



**Delay (Normalized)**



**Step Response**



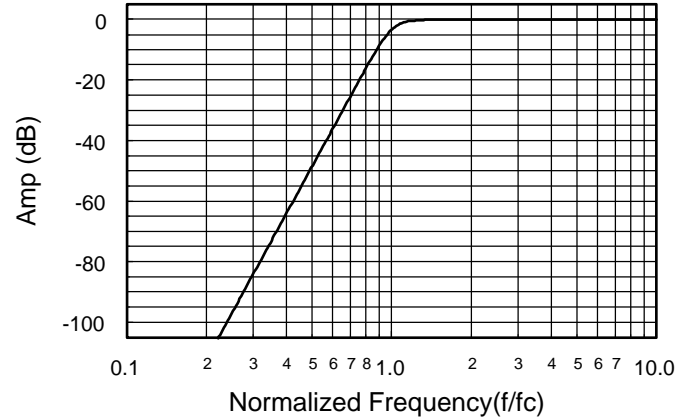


**Appendix A**

**Theoretical Transfer Characteristics**

<b>f/fc (Hz)</b>	<b>Amp (dB)</b>	<b>Phase (deg)</b>	<b>Delay<sup>1</sup> (sec)</b>
0.10	-160	691	0.819
0.20	-112	661	0.828
0.30	-83.7	631	0.843
0.40	-63.7	600	0.867
0.50	-48.2	568	0.903
0.60	-35.5	535	.956
0.70	-24.8	499	1.04
0.80	-15.6	459	1.19
0.85	-11.6	437	1.29
0.90	-8.06	413	1.40
0.95	-5.15	386	1.48
1.00	-3.01	360	1.46
1.20	-0.229	275	0.873
1.40	-0.020	226	0.540
1.60	-0.002	194	0.380
1.80	0.00	170	0.287
2.00	0.00	152	0.226
2.50	0.00	120	0.139
3.00	0.00	99.2	0.094
4.00	0.00	74.0	0.052
5.00	0.00	59.0	0.033
6.00	0.00	49.0	0.023
7.00	0.00	42.1	0.017
8.00	0.00	36.8	0.013
9.00	0.00	32.7	0.010
10.0	0.00	29.4	0.008

**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).

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



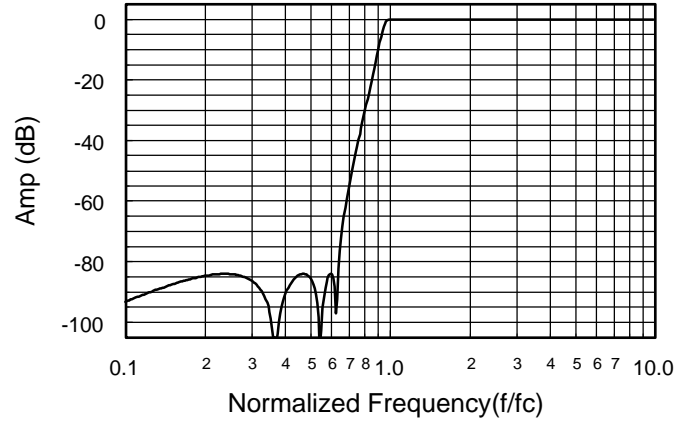


**Appendix A**

**Theoretical Transfer Characteristics**

<b>f/fc (Hz)</b>	<b>Amp (dB)</b>	<b>Phase (deg)</b>	<b>Delay<sup>1</sup> (sec)</b>
0.10	-93.4	168	0.334
0.20	-84.8	156	0.344
0.30	-86.0	143	0.363
0.40	-92.6	310	0.392
0.50	-85.0	295	0.439
0.55	-114	287	0.472
0.60	-84.1	458	0.515
0.70	-57.0	617	0.652
0.80	-32.8	589	0.962
0.85	-22.6	569	1.325
0.90	-12.3	538	2.198
0.95	-3.08	483	3.993
1.00	-0.05	414	3.062
1.10	-0.03	341	1.498
1.20	-0.01	296	1.039
1.30	-0.04	264	0.773
1.40	-0.05	239	0.612
1.50	-0.03	219	0.505
1.60	-0.01	202	0.426
1.70	0.00	188	0.364
1.80	0.00	176	0.315
1.90	-0.01	165	0.275
2.00	-0.02	156	0.243
2.50	-0.05	122	0.145
3.00	-0.05	101	0.097
4.00	-0.03	75.1	0.053
5.00	-0.01	59.8	0.034
6.00	-0.01	49.7	0.023
7.00	0.00	42.5	0.017
8.00	0.00	37.2	0.013
9.00	0.00	33.0	0.010
10.0	0.00	29.7	0.008

**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).

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

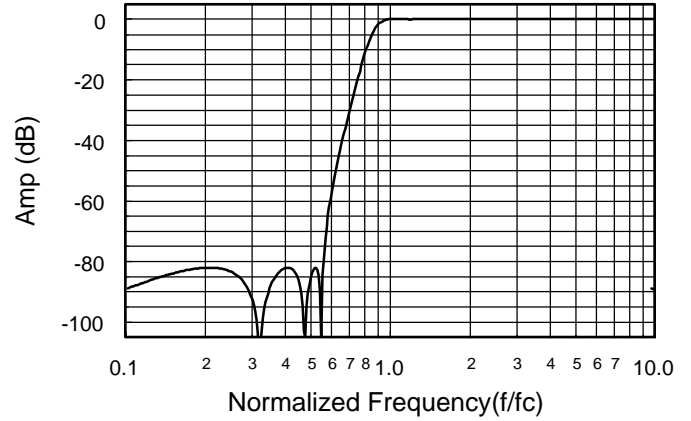


**Appendix A**

**Theoretical Transfer Characteristics**

f/fc (Hz)	Amp (dB)	Phase (deg)	Delay <sup>1</sup> (sec)
0.10	-89.3	164	0.440
0.20	-82.1	148	0.459
0.30	-90.6	131	0.495
0.40	-82.4	292	0.559
0.50	-87.8	450	0.671
0.55	-90.0	437	0.761
0.60	-60.2	603	0.890
0.70	-32.4	563	1.37
0.80	-13.1	498	2.35
0.85	-6.28	451	2.77
0.90	-2.21	401	2.66
0.95	-0.51	358	2.15
1.00	-0.03	324	1.64
1.10	-0.01	277	1.04
1.20	-0.05	225	0.757
1.30	-0.03	221	0.596
1.40	0.01	201	0.486
1.50	0.03	185	0.409
1.60	0.03	172	0.347
1.70	0.03	160	0.299
1.80	0.02	150	0.260
1.90	0.01	141	0.229
2.00	0.01	133	0.203
2.50	-0.02	105	0.123
3.00	-0.02	86.9	0.083
4.00	-0.02	64.7	0.046
5.00	-0.01	51.6	0.029
6.00	-0.01	42.9	0.020
7.00	-0.01	36.8	0.015
8.00	-0.01	32.1	0.011
9.00	-0.01	28.6	0.009
10.0	0.00	25.7	0.007

**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).

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

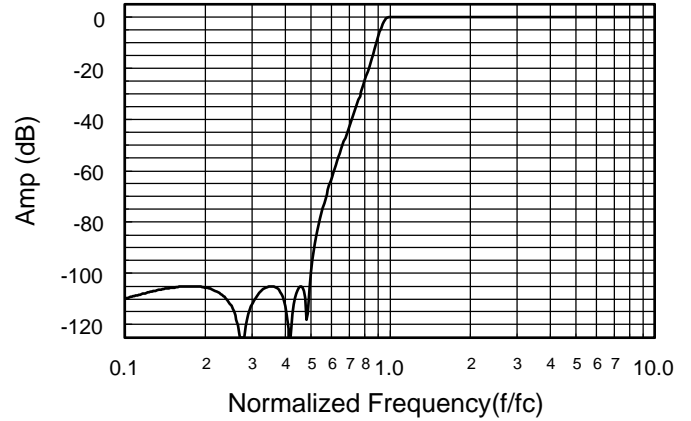


**Appendix A**

**Theoretical Transfer Characteristics**

<b>f/fc (Hz)</b>	<b>Amp (dB)</b>	<b>Phase (deg)</b>	<b>Delay<sup>1</sup> (sec)</b>
0.10	-110	168	0.338
0.20	-105	156	0.348
0.30	-114	323	0.367
0.40	-110	309	0.397
0.50	-107	654	0.445
0.55	-78.6	646	0.480
0.60	-64.6	637	0.524
0.70	-44.1	615	0.669
0.80	-26.7	586	1.001
0.85	-18.2	565	1.401
0.90	-9.46	533	2.315
0.95	-2.16	478	3.604
1.00	-0.046	419	2.681
1.10	-0.038	352	1.416
1.20	-0.001	308	1.018
1.30	-0.032	277	0.773
1.40	-0.046	252	0.618
1.50	-0.034	231	0.514
1.60	-0.016	214	0.436
1.70	-0.004	200	0.376
1.80	0.000	187	0.328
1.90	-0.003	176	0.288
2.00	-0.010	166	0.255
2.50	-0.042	131	0.153
3.00	-0.045	108	0.103
4.00	-0.028	80.6	0.057
5.00	-0.015	64.2	0.036
6.00	-0.008	53.4	0.025
7.00	-0.005	45.7	0.018
8.00	-0.003	40.0	0.014
9.00	-0.002	35.5	0.011
10.0	-0.001	31.9	0.009

**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).

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