



## 1 kHz to 1.28 MHz 8-Bit Programmable

## 2" x 4" 8-Pole Filters

### Description

The 818 Series are digitally programmable low-pass and high-pass active filters that are tunable over a 256:1 frequency range. 818 filters are available with any one of five standard factory-set tuning ranges or 8-bit custom ranges from 1 kHz to 1.28 MHz. These units contain 8 CMOS logic inputs.

818 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 amplitude characteristics. 818 filters operate from non-critical ±12 to ±18 Vdc power supplies, have a 5 kΩ (min.) input impedance, a 10Ω (max.) output impedance and low-pass models offer dc voltage offset adjustment.

### Features/Benefits:

- Low harmonic distortion and wide signal-to-noise ratio to 12-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 and band-pass filtering
- Data acquisition systems
- Satellite and telecommunications
- Acoustic and vibration analysis and control
- Aerospace, navigation and sonar
- Medical research and electronic equipment
- Engine test and simulation
- Noise elimination
- Video systems
- Signal reconstruction



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## Digital Tuning & Control Characteristics

### 8-Bit Programmable Filters

#### Digital Tuning Characteristics

The digital tuning interface circuits are two 4042 quad CMOS latches which accept the following CMOS-compatible inputs: eight tuning bits ( $D_0 - D_7$ ), a latch strobe bit (C), and a transition polarity bit (P).

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 =  $f_{max}/256$  ( $D_0$  thru  $D_7 = 0$ );

Minimum frequency step (Resolution) =  $f_{max}/256$

#### Data Control Specifications

##### Data Control Lines

Functions	Latch Strobe (C) Transition Polarity (P)
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##### Data Control Modes

Mode 1	$P = 0; C = 0$ frequency follows input codes $P = 0; C = 0 \uparrow$ frequency latched on rising edge
Mode 2	$P = 1; C = 1$ frequency follows input codes $P = 1; C = 1 \downarrow$ frequency latched on falling edge

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

Input Voltage ( $V_s = 15$  Vdc)

Low Level In	0 Vdc min.	4 Vdc max.
High Level In	11 Vdc min.	15 Vdc max.

Input Current

High Level In	$-10^{-5}$ $\mu$ A typ.	-1 mA max.
Low Level In	$+10^{-5}$ $\mu$ A typ.	+1 $\mu$ A max.

Input Capacitance

5 pF typ      7.5 pF max.

Latch Response

Data Set Up Time <sup>1</sup>	25 nS
Data Hold Time <sup>2</sup>	50 nS
Strobe Pulse Width	80 nS min.

##### Input Data Format Frequency Select Bits

Positive Logic Logic "1" = +Vs  
Logic "0" = Gnd  
(Binary-Coded)

Bit Weighting

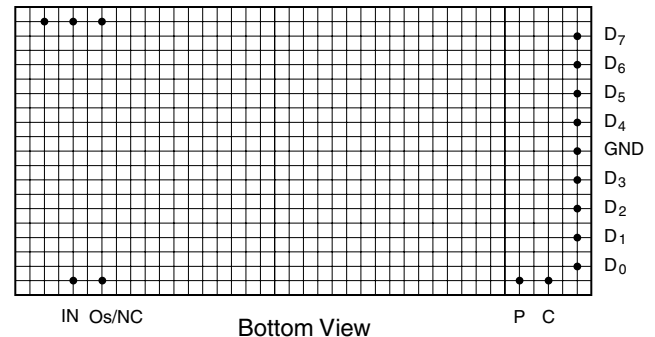
$D_0$	LSB (least significant bit)
$D_7$	MSB (most significant bit)

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
"P"	Transition Polarity Bit	$D_4$ Tuning Bit 4
"C"	Tuning Strobe Bit	$D_3$ Tuning Bit 3
+Vs	Supply Voltage, Positive	$D_2$ Tuning Bit 2
-Vs	Supply Voltage, Negative	$D_1$ Tuning Bit 1
Os	Optional Offset Adjustment	$D_0$ Tuning Bit 0 (LSB)
NC	No Connect (Highpass Models)	

OUT +Vs -Vs



MSB	---	---	---	---	---	---	LSB	Bit Weight
$D_7$	$D_6$	$D_5$	$D_4$	$D_3$	$D_2$	$D_1$	$D_0$	$f_c$ 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	$f_{max}$

Notes:

1.Frequency data must be present before occurrence of strobe edge.

2.Frequency data must be present after occurrence of strobe edge.



### 8-Bit Programmable

Model	818L8B	818L8L	818L8E	818L8D80
<b>Product Specifications</b>				
<b>Transfer Function</b>	8-Pole, Butterworth	8-Pole, Bessel	8-Pole, 6 zero, Elliptic	8-Pole, 6 zero, Constant Delay
<b>Size</b>	2.0" x 4.0" x 0.4"	2.0" x 4.0" x 0.4"	2.0" x 4.0" x 0.4"	2.0" x 4.0" x 0.4"
<b>Range <math>f_c</math></b>	1 kHz to 128 MHz	1 kHz to 1.28 MHz	1 kHz to 1.28 MHz	1 kHz to 1.28 MHz
<b>Theoretical Transfer Characteristics</b>	Appendix A Page 9	Appendix A Page 4	Appendix A Page 24	Appendix A Page 21
<b>Passband Ripple</b> (theoretical)	0.0 dB	0.0 dB	$\pm 0.035$ dB	0.15 dB
<b>DC Voltage Gain</b> (non-inverting)	0 $\pm$ 0.1 dB max. 0 $\pm$ 0.05 dB typ.	0 $\pm$ 0.1 dB max. 0 $\pm$ 0.05 dB typ.	0 $\pm$ 0.1 dB max. 0 $\pm$ 0.05 dB typ.	0 $\pm$ 0.1 dB max. 0 $\pm$ 0.05 dB typ.
<b>Stopband Attenuation Rate</b>	48 dB/octave	48 dB/octave	80 dB min.	80 dB min.
<b>Cutoff Frequency Stability</b> <b>Amplitude</b> <b>Phase</b>	$f_c$ $\pm 3\%$ max. $\pm 0.01\%$ /°C - 3 dB -360°	$f_c$ $\pm 3\%$ max. $\pm 0.01\%$ /°C - 3 dB -182°	$f_r$ $\pm 3\%$ max. $\pm 0.01\%$ /°C - 0.035 dB - 323.5°	$f_c$ $\pm 3\%$ max. $\pm 0.01\%$ /°C - 3 dB -306°
<b>Filter Attenuation</b> (theoretical)	0.12 dB      0.80 $f_c$ 3.01 dB      1.00 $f_c$ 60.0 dB      2.37 $f_c$ 80.0 dB      3.16 $f_c$	1.91 dB      0.80 $f_c$ 3.01 dB      1.00 $f_c$ 60.0 dB      4.52 $f_c$ 80.0 dB      6.07 $f_c$	0.035 dB      1.00 $f_r$ 3.01 dB      1.13 $f_r$ 60.0 dB      1.67 $f_r$ 80.0 dB      1.77 $f_r$	3.01 dB      1.00 $f_c$ 60.0 dB      3.08 $f_c$ 80.0 dB      3.57 $f_c$
<b>Phase Match<sup>1</sup></b>	See page 5 & 6	See page 5 & 6	See page 5 & 6	See page 5 & 6
<b>Amplitude Accuracy</b> (theoretical)	0 - 0.6 $f_c$ $\pm 0.5$ dB max. $\pm 0.25$ dB typ. 0.6 $f_c$ - 1.0 $f_c$ $\pm 1.0$ dB max. $\pm 0.6$ dB typ.	0 - $f_c$ $\pm 0.8$ dB max. $\pm 0.4$ dB typ.	0 - 0.8 $f_r$ $\pm 0.5$ dB max. $\pm 0.25$ dB typ. 0.8 $f_c$ - 1.0 $f_r$ $\pm 1.0$ dB max. $\pm 0.5$ dB typ.	0 - 0.8 $f_c$ $\pm 0.5$ dB max. $\pm 0.25$ dB typ. 0.8 $f_c$ - 1.0 $f_c$ $\pm 1.0$ dB max. $\pm 0.5$ dB typ.
<b>Total Harmonic Distortion @ 1 kHz</b>	< - 88 dB typ.	< - 88 dB typ.	< - 88 dB typ.	< - 88 dB typ.
<b>Wide Band Noise</b> (5 Hz - 2 MHz)	300 $\mu$ Vrms typ.	300 $\mu$ Vrms typ.	350 $\mu$ Vrms typ.	300 $\mu$ Vrms typ.
<b>Narrow Band Noise</b> (5 Hz - 100 kHz)	75 $\mu$ Vrms typ.	75 $\mu$ Vrms typ.	75 $\mu$ Vrms typ.	75 $\mu$ Vrms typ.
<b>Filter Mounting Assembly</b>	FMA-04A	FMA-04A	FMA-04A	FMA-04A

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-Pole High-Pass Filters

## 8-Bit Programmable

Model	818H8B	818H8E		
<b>Product Specifications</b>				
<b>Transfer Function</b>	8-Pole, Butterworth	8-Pole, 6-zero, Elliptic		
<b>Size</b>	2.0" x 4.0" x 0.4"	2.0" x 4.0" x 0.4"		
<b>Range <math>f_c</math></b>	1 kHz to 1.28 MHz	1 kHz to 1.28 MHz		
<b>Theoretical Transfer Characteristics</b>	Appendix A Page 29	Appendix A Page 37		
<b>Passband Ripple</b> (theoretical)	0.0 dB	$\pm 0.035$ dB		
<b>Voltage Gain</b> (non-inverting)	$0 \pm 0.5$ dB to 1.28 MHz	$0 \pm 0.5$ dB to 1.28 MHz		
<b>Power Bandwidth</b>	(-6 dB) 5 MHz	(-6 dB) 5 MHz		
<b>Stopband Attenuation Rate</b>	48 dB/octave	80 dB		
<b>Cutoff Frequency</b>	$f_c \pm 3\%$ max.	$f_r \pm 3\%$ max.		
<b>Stability</b>	$\pm 0.01\%$ /°C	$\pm 0.01\%$ /°C		
<b>Amplitude</b>	-3 dB	-0.035 dB		
<b>Phase</b>	-360°	-323.5°		
<b>Filter Attenuation</b> (theoretical)	80 dB            0.31 $f_c$ 60 dB            0.42 $f_c$ 3.01 dB        1.00 $f_c$ 0.00 dB        2.00 $f_c$	80.0 dB        0.56 $f_r$ 60.0 dB        0.60 $f_r$ 3.01 dB        0.88 $f_r$ 0.03 dB        1.00 $f_r$ 00.0 dB        2.00 $f_r$		
<b>Amplitude Accuracy</b> (theoretical)	1.0 - 1.25 $f_c \pm 0.5$ dB max. $\pm 0.3$ dB typ. 1.25 $f_c$ -1.28MHz $\pm 1.0$ dB max. $\pm 0.5$ dB typ.	1.00 - 1.25 $f_r \pm 0.5$ dB max. $\pm 0.3$ dB typ. 1.25 $f_r$ -1.28MHz $\pm 1.0$ dB max. $\pm 0.5$ dB typ.		
<b>Total Harmonic Distortion @ 1 kHz</b>	< - 88 dB typ.	< - 88 dB typ.		
<b>Wide Band Noise</b>	400 $\mu$ Vrms typ.	450 $\mu$ Vrms typ.		
<b>Narrow Band Noise</b>	100 $\mu$ Vrms typ.	100 $\mu$ Vrms typ.		
<b>Filter Mounting Assembly</b>	FMA-04A	FMA-04A		

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



## Phase and Phases Match Considerations

### 1 kHz to 1.28 MHz

#### Phase Deviation from Theoretical:

The phase response of the amplifiers and the capacitance of the frequency control switches of the 818 series contribute to the overall phase response and cause it to deviate from theoretical. For the higher frequency models ( -4 and -5 ), where the cutoff frequencies can be programmed up to 1.28MHz, the deviation from theoretical can be substantial.

Figure 1 is a normalized plot of the phase deviation from theoretical for an 818L8E-5 for programmed cutoff frequencies from 5kHz (  $f_{c \text{ min}}$  ) to 1.28MHz (  $f_{c \text{ max}}$  ). For  $f_c$  of 5kHz, the deviation from the 323° theoretical phase shift is 2° but for  $f_c$  of 1.28MHz the deviation is 78°. This set of curves can be used to estimate the deviation from theoretical phase for other models in the 818 series.

Figure 1 represents a "maximum deviation from theoretical phase" situation. Other models (i.e. -1 to -4) will exhibit a similar set of phase deviation curves with the phase scale being reduced by the ratio of the  $f$  max of the model to the  $f_{c \text{ max}}$  of the -5. For example, an L8E-1, whose programming frequency range is from 1kHz to 256kHz (1/5 of the range of the -5 model) will have a similar set of phase deviation curves but the maximum phase deviation, at the highest frequency setting (  $f_{c \text{ max}}$  ), will be approximately 1/5 that of the -5 model (78/5 = 15.6°). The other programmed settings of the -1 will also produce proportionally reduced phase deviations.

#### Unit to Unit Phase Match<sup>2</sup>

The actual phase shift through a filter at a frequency "  $f$  " is determined by its programmed frequency "  $f_c$  ", the theoretical phase response of the transfer function (B, L, E, or D80) and the phase deviation from theoretical which in turn depends upon component tolerances, the model # (i.e. -1 through -5) and frequency to which it is programmed. It is therefore not possible to have a meaningful unit to unit phase match that is specified by a single number.

For a group of the same model type and number, programmed to the same frequency, the unit to unit phase match can be approximated as a percentage of the theoretical phase shift with a correction term added to accommodate amplifier induced phase deviations.

#### EXAMPLE: Phase Match Calculation

$$\Delta\Phi(f)_{\text{max}} = 0.02^\circ \times \Phi_{\tau}(f) + \frac{4.0^\circ \times f/f_c \times f_{\text{max}}/1.28\text{MHz}}{\begin{matrix} 4.0^\circ - \text{L8L} \\ 3.0^\circ - \text{L8B \& L8D80} \\ 2.0^\circ - \text{L8L} \end{matrix}}$$

$$\Delta\Phi(f)_{\text{typ}} = 0.5 \times \Delta\Phi(f)_{\text{max}}$$

where:  $\Delta\Phi(f)$  = phase match at frequency  $f$   
 $\Phi_{\tau}(f)$  = theoretical phase shift at  $f$   
 $f$  = frequency of interest  
 $f_{\text{max}}$  = maximum  $f_c$  of the model  
 $f_c$  = frequency to which the filter is programmed

Eg. - for an 818L8E-3, the phase deviation from theoretical at a frequency of 192kHz, when the cutoff frequency  $f_c$  is programmed to 384kHz is:

$$f/f_c = 192\text{kHz}/384\text{kHz} = 0.5, f_{\text{max}} = 768\text{kHz}$$

$$\Phi_{\tau}(f) = 133^\circ \text{ (from data table at } f/f_c = 0.5)$$

#### Phase Match:

$$\Delta\Phi(f)_{\text{max}} = 0.02^\circ \times \Phi_{\tau}(f) + 4.0^\circ \times f/f_c \times f_{\text{max}}/1.28\text{MHz}$$

$$= 0.02 \times (-133^\circ) + 4.0^\circ \times 0.5 \times 768\text{kHz}/1.28\text{MHz}$$

$$= 2.66^\circ + 1.20^\circ = +3.86^\circ$$

$$\Delta\Phi(f)_{\text{typ}} = 0.5 \times \Delta\Phi(f)_{\text{max}} = 0.5^\circ \times 3.86^\circ = 1.93^\circ$$

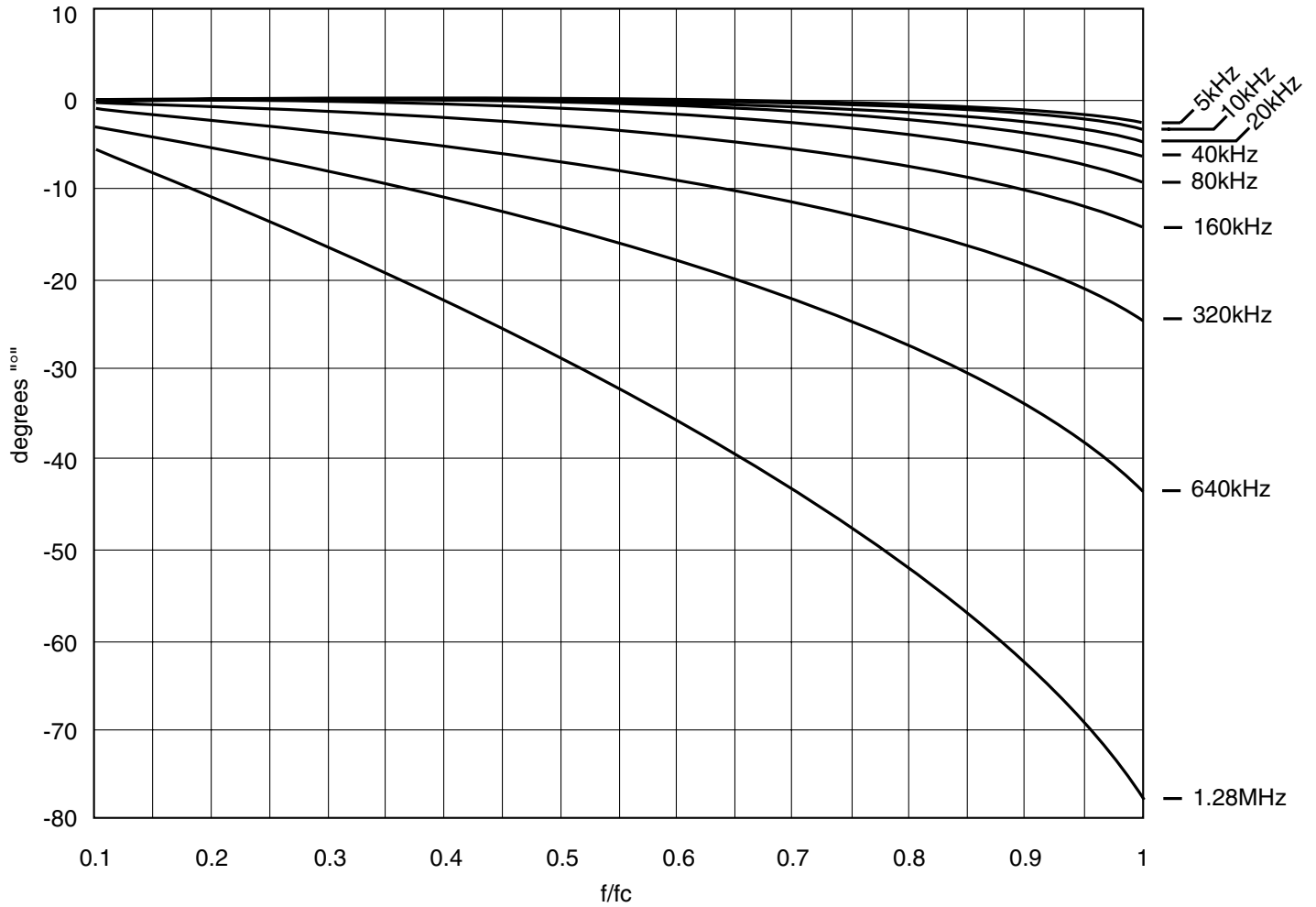
#### 818L8E Phase Deviation (in degrees "°") from Theoretical vs. Normalized Input Frequency

programmed setting of  $f_c$

$f/f_c$	5kHz	10kHz	20kHz	40kHz	80kHz	160kHz	320kHz	640kHz	1.28MHz
0.10	0.15	0.18	0.17	0.08	-0.12	-0.52	-1.18	-2.57	-5.32
0.20	0.30	0.32	0.30	0.17	-0.39	-1.03	-2.41	-5.17	-10.76
0.30	0.34	0.42	0.40	-0.18	-0.57	-1.59	-3.66	-7.89	-16.29
0.40	0.20	0.40	0.50	-0.20	-0.90	-2.30	-5.10	-10.80	-22.10
0.50	0.20	0.32	0.60	-0.40	-1.20	-3.00	-6.70	-14.00	-28.20
0.60	0.00	0.00	-0.10	-0.80	-1.90	-4.10	-8.70	-17.70	-35.10
0.70	-0.21	-0.30	-0.60	-1.30	-2.70	-5.40	-11.00	-21.80	-42.60
0.80	-0.50	-0.60	-1.30	-2.10	-3.80	-7.20	-13.90	-26.90	-51.30
0.85	-0.80	-1.00	-1.80	-2.80	-4.70	-8.40	-15.80	-30.10	-56.40
0.90	-1.20	-1.60	-2.50	-3.70	-5.80	-10.00	-18.40	-33.80	-62.30
0.95	-1.90	-2.40	-3.50	-4.80	-7.30	-12.00	-21.10	-38.30	-69.20
1.00	-2.50	-3.30	-4.60	-6.20	-8.90	-14.10	-24.30	-43.30	-77.50



## Phase Deviation from Theoretical





## Specification

(25°C and  $V_s \pm 15$  Vdc)

## Pin-Out and Package Data Ordering Information

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

Impedance	5 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>	$\pm 5$ mA
Offset Voltage <sup>3</sup>	2 mV typ. 10 mV max.

Offset Temp. Coeff. 50  $\mu$ V/°C

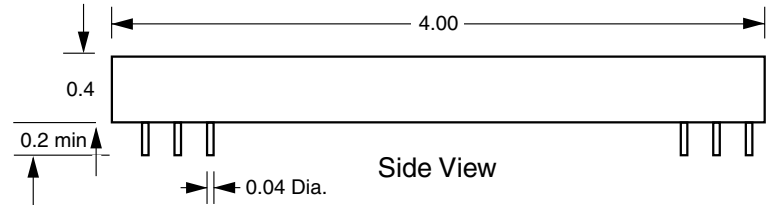
### Power Supply ( $\pm V_s$ )

Rated Voltage	$\pm 15$ Vdc
Operating Range	$\pm 12$ to $\pm 18$ Vdc
Maximum Safe Voltage	$\pm 18$ Vdc
Quiescent Current	100 mA typ. 120 mA max.

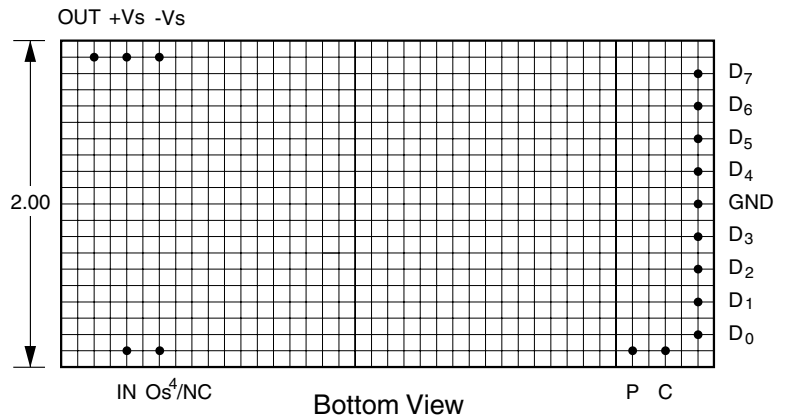
### Temperature

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

### Pin-Out & Package Data



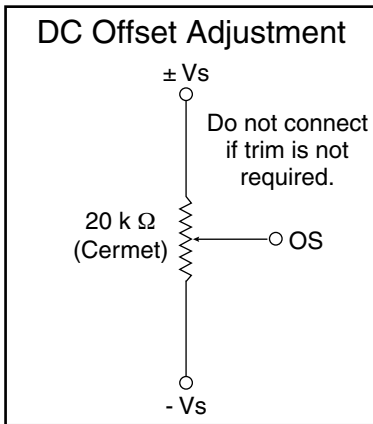
All dimensions are in inches  
All Case Dimensions  $\pm 0.02$ "  
Grid Dimensions 0.1" x 0.1"



Filter Mounting Assembly-See FMA-04A

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.



## Ordering Information

### Filter Type

- L - Low Pass
- H - High Pass

### Transfer Function

- B - Butterworth
- L - Bessel
- E - elliptic
- D80 - constant delay

# 818L8E-5

Model Number	Tuning Range (kHz)	Minimum Step (kHz)
1	1kHz to 256kHz	1kHz
2	2kHz to 512kHz	2kHz
3	3kHz to 768kHz	3kHz
4	4kHz to 1,024kHz	4kHz
5	5kHz to 1,280kHz	5kHz

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-00818-01**





## Programmable Filter Modules Power Sequence & ESD

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November 2000

### Programmable Filters Modules

**818, 824, 828, 828BP, 828BR, 854, 858, R854, R858**

#### I. Scope

The following precautions are necessary when handling and installing Frequency Devices programmable filter modules.

#### II. Digital Circuit Description

The digital input pins connect directly to 4000 series CMOS logic, such as the 4053 analog switch. The power supply (V<sub>ss</sub>) for the digital logic on the module comes directly from the +15 Volt pin on the module. This sets the threshold voltage at 11.0 V minimum to 15.0 V maximum for a "1" (High) level and 0.0 V minimum to 4.0 V maximum for a "0" (Low) level. Applying a voltage between 4.0 and 11.0 V will produce unpredictable operation. Connecting 5 Volt or 3.3 V logic devices directly to the filter module without using a voltage translator will result in erratic operation of the filter.

#### III. (VERY IMPORTANT) Power-Up and Power-Down Sequence

**Do not plug-in or un-plug module while power is applied.** It is imperative that power is supplied to the + 15 V pin on the filter module before or at the same instance that any digital pin is pulled High (> 0.0 V). Failure to do this will result in excessive current flowing through the digital input pin and through a protection diode internal to the 4000 logic, which will result in damage to the module. The proper power-up and power-down sequence is:

1. Connect filter module ground.
2. Connect filter module +15 V.
3. Connect filter module -15 V.
4. Connect the input signal.

All four of the above steps can also occur simultaneously. Power-down should occur in the reverse order.

#### IV. ESD Issues

Like most modern electronic equipment, the modules can be damaged by electrostatic discharge (ESD). The modules are shipped from the factory in sealed, anti-static packaging and should be kept in the sealed package prior to mounting on a circuit board. The following additional rules should also be observed when handling the modules after they are removed from the factory packaging:

1. Only a person wearing a properly grounded wrist strap should handle the modules.
2. Any work surface that the modules are placed on must be properly ESD grounded.
3. Any insulating materials capable of generating static charge (such as paper) should be kept away from the modules.

Static generating clothing should be covered with an ESD-protective smock.

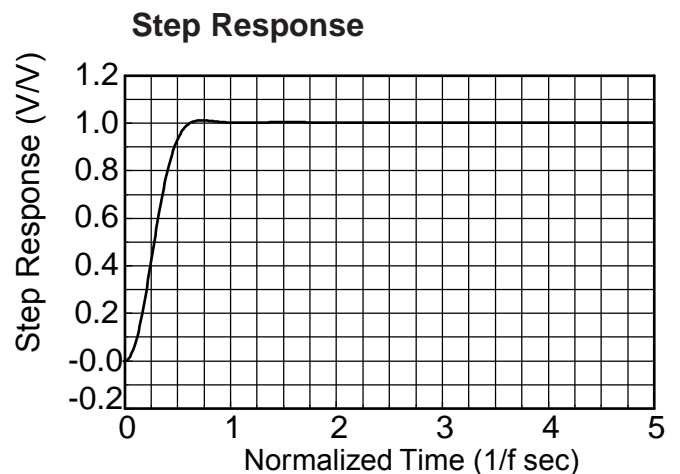
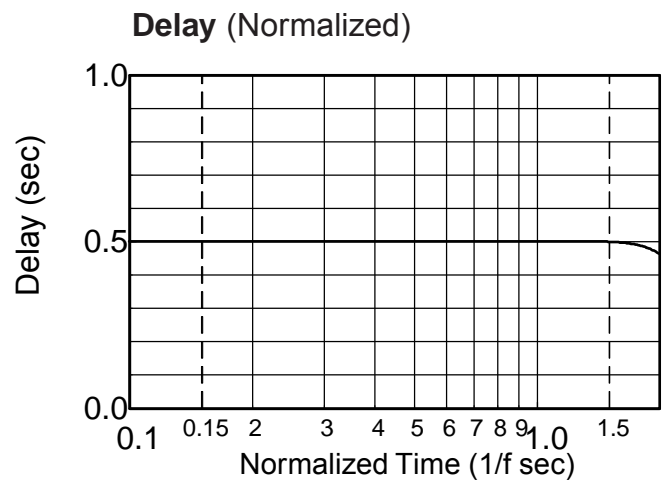
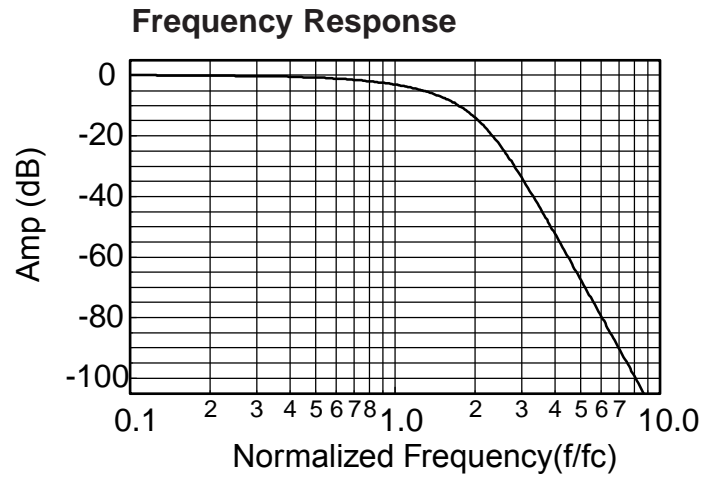




**Appendix A**

**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



<sup>1</sup> **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).

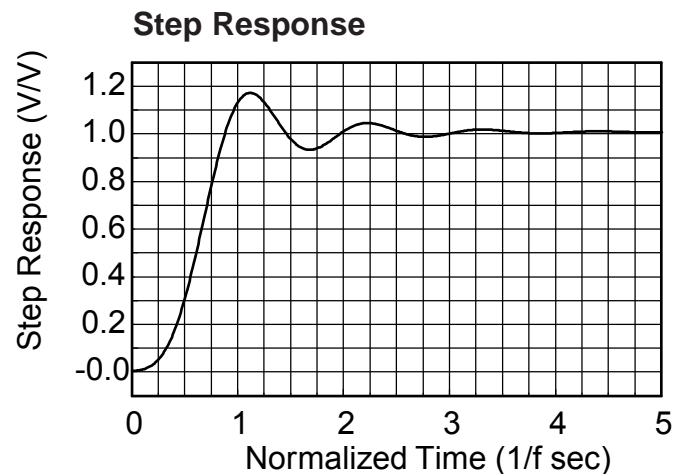
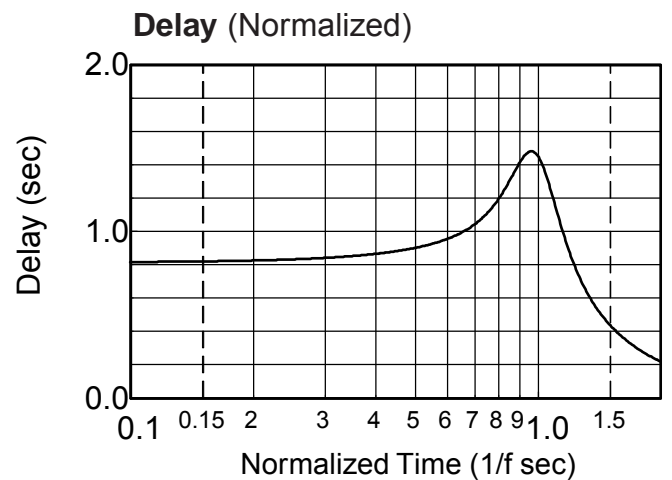
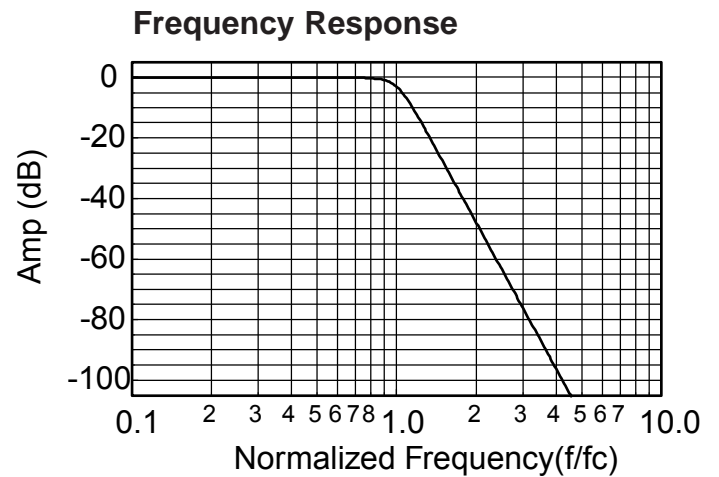
$$\text{Actual Delay} = \frac{\text{Normalized Delay}}{\text{Actual Corner Frequency (fc) in Hz}}$$



**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**

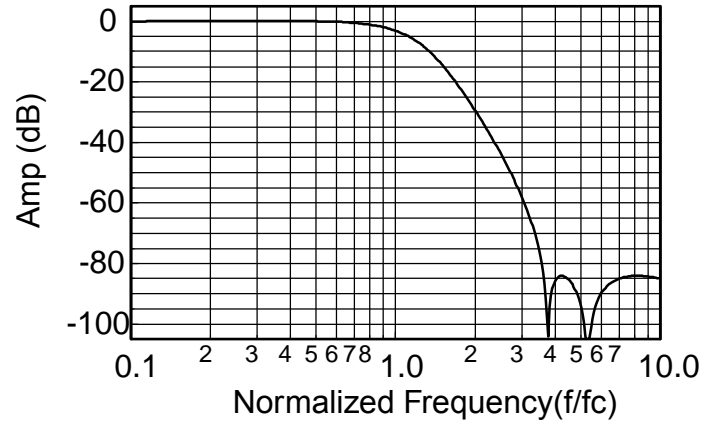
f/fc (Hz)	Amp (dB)	Phase (deg)	Delay <sup>1</sup> (sec)
0.00	0.00	0.00	.852
0.10	0.017	-30.7	.852
0.20	0.058	-61.3	.852
0.30	0.099	-92.0	.852
0.40	0.105	-123	.852
0.50	0.034	-153	.852
0.60	-0.157	-184	.852
0.70	-0.510	-215	.852
0.80	-1.07	-245	.851
0.85	-1.44	-261	.850
0.90	-1.89	-276	.849
0.95	-2.41	-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:**

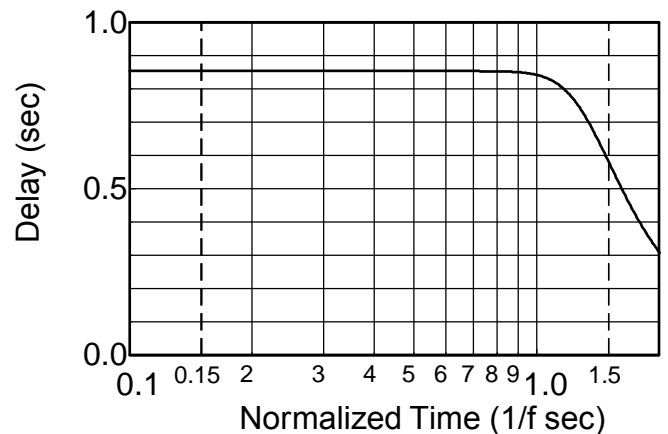
The above delay data is normalized to a corner frequency of 1.0Hz. The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

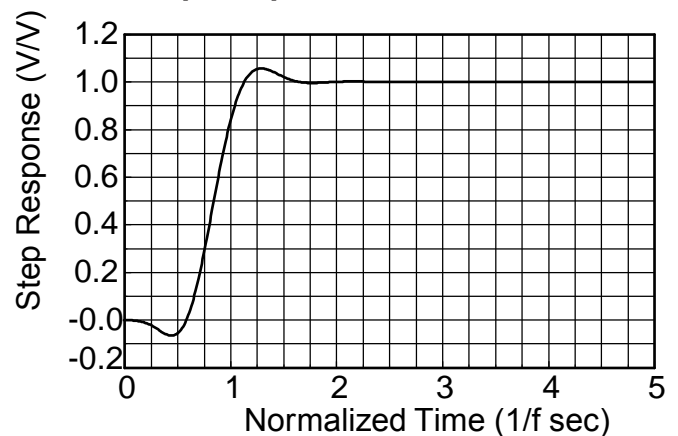
**Frequency Response**



**Delay (Normalized)**



**Step Response**





**Appendix A**

**Theoretical Transfer Characteristics**

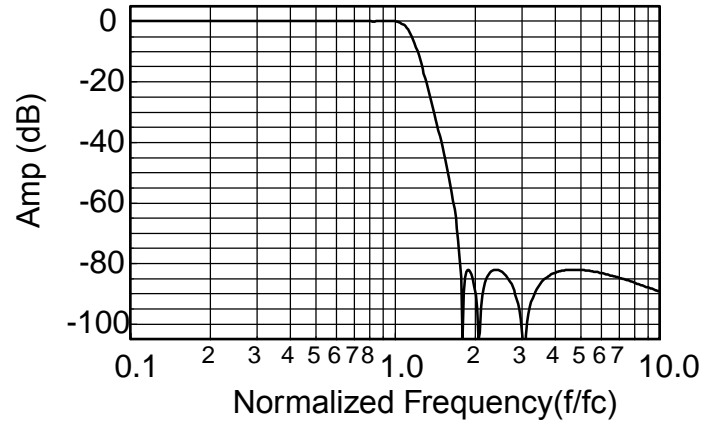
f/fc (Hz)	Amp (dB)	Phase (deg)	Delay <sup>1</sup> (sec)
0.00	0.00	0.00	0.713
0.10	-0.004	-25.7	0.716
0.20	-0.014	-51.6	0.724
0.30	-0.024	-77.9	0.740
0.40	-0.020	-105	0.767
0.50	0.007	-133	0.811
0.55	0.022	-148	0.840
0.60	0.033	-163	0.872
0.65	0.031	-179	0.908
0.70	0.014	-196	0.946
0.75	-0.015	-213	0.989
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:**

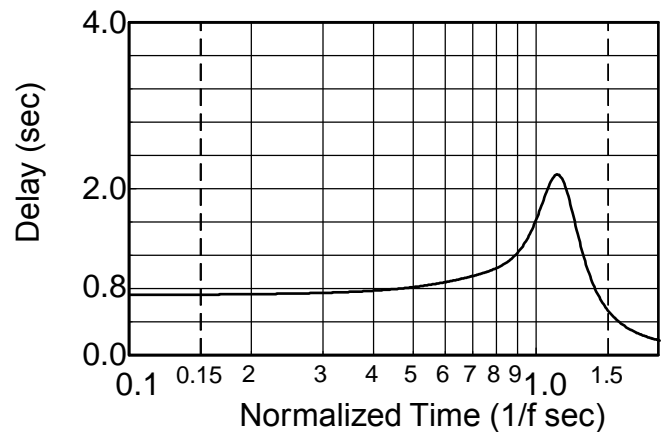
The above delay data is normalized to a corner frequency of 1.0Hz. The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

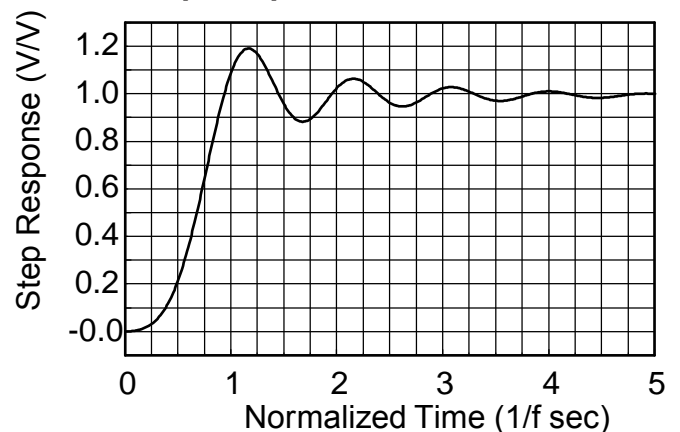
**Frequency Response**



**Delay (Normalized)**



**Step Response**

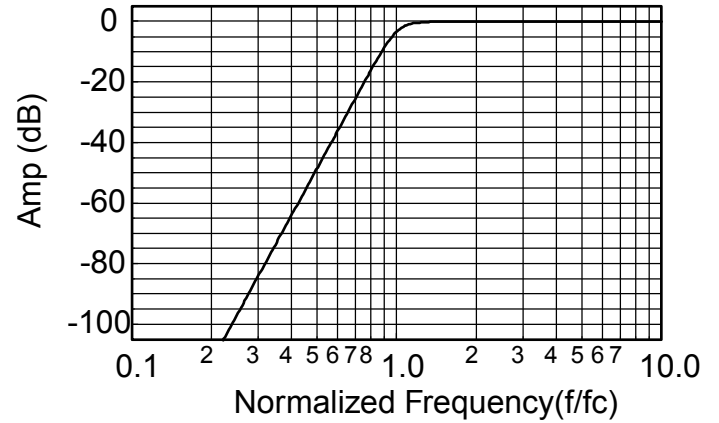




**Theoretical Transfer Characteristics**

<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).

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

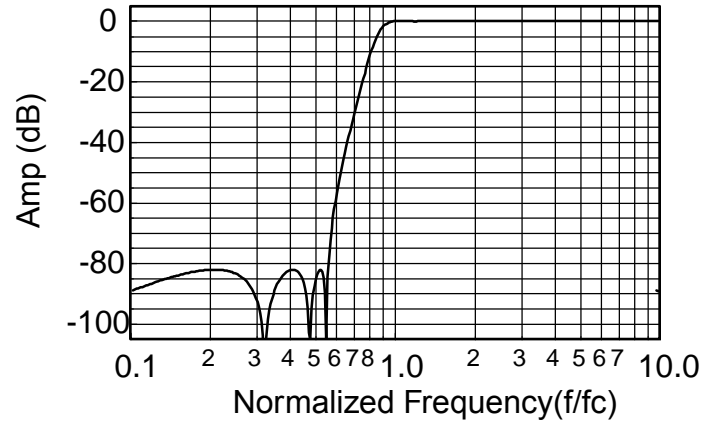


**Appendix A**

**Theoretical Transfer Characteristics**

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).

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