FREQUENCY DEVICES™, INC.

428 Series

10 Hz - 102.4 kHz 4-Bit Programmable

32-Pin DIP 8-Pole Filters

Description

The 428 Series are 8-pole digitally programmable low-pass and high-pass active filters. These new filters take advantage of the company's proprietary designs using surface-mount technology to provide a low profile, compact package in minimal board space. 428 filters are factory tuned to one of ten preset 4-bit binary ranges from 10 Hz to 102.4 kHz. Contact the factory for custom discrete tuning ranges, maximum span 1000:1.

All 428 Series models are easy to use fully finished filters which require no external components or adjustment. They feature low harmonic distortion, near theoretical phase and amplitude characteristics and operate over a dynamic input voltage range from non-critical ±12V to ±18V power supplies.

Features/Benefits:

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

Applications

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



U.S. Selling Price (1-9)	$320.00 ea.
Orders for Export	U.S. Selling Price + 20%
Minimum Order Value $150.00	F.O.B. Haverhill, MA
Lead-Time: 2-4 weeks A.R.O.	Accept Visa, Mcard, Amex

Programmable Specifications: Page

Digital Tuning & Control 2

Available Low-Pass Models:

428L4B 8-pole Butterworth 3
428L4E 8-pole, 6 zero elliptic, 1.77 (-80dB) 3
428L4EX 8-pole, 6 zero elliptic, 1.56 (-80dB) 3
428L4EY 8-pole, 6 zero elliptic, 2.00 (-100dB) 3
428L4L 8-pole Bessel 4
428L4D60 8-pole constant delay (-60dB) 4
428L4D80 8-pole constant delay (-80dB) 4
428L4D10 8-pole constant delay (-100dB) 4

Available High-Pass Models:

428H4B 8-pole Butterworth 5
428H4E 8-pole, 6 zero elliptic, 1.77 (-80dB) 5
428H4EX 8-pole, 6 zero elliptic, 1.56 (-80dB) 5
428H4EY 8-pole, 6 zero elliptic, 2.00 (-100dB) 5

General Specifications:

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Pin-out/package data 6

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4-Bit Programmable Filters

Digital Tuning & Control Characteristics

Digital Tuning Characteristics

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

Binary Tuning Range

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

Binary Tuning Equation:
$fc = (f_{max}/16)\ [1+ D_3 \times 2^3 + D_2 \times 2^2 + D_1 \times 2^1 + D_0 \times 2^0]$
where D_1 - D_3 = "0" or "1", and
f_{max} = Maximum tuning frequency
fc = Corner frequency;
Minimum tunable frequency = $f_{max}/16$ (D_0 thru D_3 = 0);
Minimum frequency step (Resolution) = $f_{max}/16$

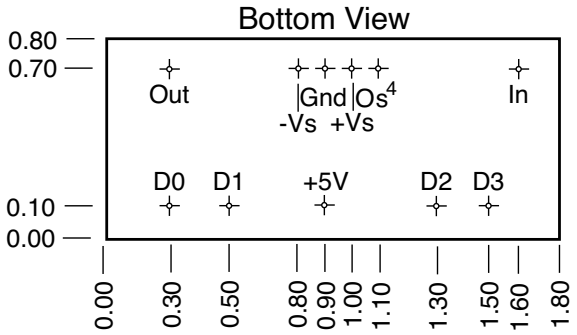
Discrete Frequencies

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

Discrete Tuning Equation:
$fc = F_B + D_0[\Delta f_0] + D_1[\Delta f_1] + D_2[\Delta f_2] + D_3[\Delta f_3]$
Δf_0, Δf_1, Δf_2, Δf_3 are the incremental frequency shifts for the data bits D_0, D_1, D_2 and D_3. They are selected to realize the five customer specified programming frequencies $F_B \Rightarrow F_4$. Other programming codes produce valid fc's between F_B and F_4.

Pin-Out Key

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



Data Input Specifications

Input Data Levels	**(+5Vdc CMOS Logic)**	
Input Voltage ($V_{s=15\ Vdc}$)		
Low Level In	0 Vdc min.	0.5 Vdc max.
High Level In	3.5 Vdc min.	5.0 Vdc max.
Input Current		
High Level In	-0.4μA typ.	-2.0μA max.
Low Level In	+0.4μA typ.	+2.0μA max.
Input Capacitance	20 pF typ.	30 pF max.

Input Data Format	**Frequency Select Bits**
Positive Logic	Logic "1" = (+5Vdc)
	Logic "0" = Gnd
Bit Weight	(Binary-Coded)
D_0	LSB (least significant bit)
D_3	MSB (most significant bit)

Frequency Range16:1 Binary Weighted

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Model	428L4B	428L4E	428L4EX	428L4EY
Product Specifications				
Transfer Function	8-Pole Butterworth	8-Pole, 6 zero Elliptic	8-Pole, 6 zero Elliptic	8-Pole, 6 zero Elliptic
Size	0.8" x 1.8" x 0.5"	0.8" x 1.8" x 0.5"	0.8" x 1.8" x 0.5"	0.8" x 1.8" x 0.5"
Range fc, fr	10.0 Hz to 102.4 kHz	10.0 Hz to 102.4 kHz	10.0 Hz to 102.4 kHz	10.0 Hz to 102.4 kHz
Theoretical Transfer Characteristics	Appendix A Page 9	Appendix A Page 24	Appendix A Page 23	Appendix A Page 25
Passband Ripple (theoretical)	0.0 dB	± 0.035 dB	-0.05 dB	-0.05 dB
DC Voltage Gain (non-inverting)	0 ± 0.1 dB max. 0 ± 0.05 dB typ.	0 ± 0.1 dB max. 0 ± 0.05 dB typ.	0 ± 0.1 dB max. 0 ± 0.05 dB typ.	0 ± 0.1 dB max. 0 ± 0.05 dB typ.
Stopband Attenuation Rate	48 dB/octave	80 dB min.	80 dB min.	100 dB min.
Cutoff Frequency	f_c ± 2% max.	f_r ± 2% max.	f_r ± 2% max.	f_r ± 2% max.
Stability	± 0.01% /°c	± 0.01% /°c	± 0.01% /°c	± 0.01% /°c
Amplitude	-3 dB	-0.035 dB	-0.05 dB	-0.05 dB
Phase	-360°	-323.5°	-414°	-419°
Filter Attenuation (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	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	0.05 dB 1.00 f_r 3.01 dB 1.05 f_r 60.0 dB 1.45 f_r 80.0 dB 1.56 f_r	0.05 dB 1.00 f_r 3.01 dB 1.06 f_r 80.0 dB 1.83 f_r 100.0 dB 2.00 f_r
Phase Match[1]	0 - 0.8 f_c ± 2° max. ± 1° typ. 0.8 fc - 1.0 f_c ± 3° max. ± 1.5° typ.	0 - 0.8 f_r ± 2° max. ± 1° typ. 0.8 f_r - 1.0 f_r ± 4° max. ± 2° typ.	0 - 0.8 f_r ± 3° max. ± 1.5° typ. 0.8 f_r - 1.0 f_r ± 4° max. ± 2° typ.	0 - 0.8 f_r ± 3° max. ± 1.5° typ. 0.8 f_r - 1.0 f_r ± 4° max. ± 2° typ.
Amplitude Accuracy (theoretical)	0 - 0.8 f_c ± 0.2 dB max. ± 0.1 dB typ. 0.8 fc - 1.0 f_c ± 0.3 dB max. ± 0.15 dB typ.	0 - 0.8 f_r ± .2 dB max. ± .1 dB typ. 0.8 f_r - 1.0 f_r ± .3 dB max. ± .15 dB typ.	0 - 0.8 f_r ± 0.2 dB max. ± 0.1 dB typ. 0.8 f_r - 1.0 f_r ± 0.5 dB max. ± 0.25 dB typ.	0 - 0.8 f_r ± 0.2 dB max. ± 0.1 dB typ. 0.8 f_r - 1.0 f_r ± 0.5 dB max. ± 0.25 dB typ.
Total Harmonic Distortion @ 1 kHz	< - 100 dB typ.	< - 88 dB typ.	< - 88 dB typ.	< - 88 dB typ.
Wide Band Noise (5 Hz - 2 MHz)	200 μVrms typ.	200 μVrms typ.	250 μVrms typ.	250 μVrms typ.
Narrow Band Noise (5 Hz - 100 kHz)	50 μVrms typ.	50 μVrms typ.	75 μVrms typ.	75 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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Model	428L4L	428L4D60	428L4D80	428L4D10
Product Specifications				
Transfer Function	8-Pole Bessel	8-Pole, 6 zero Constant Delay	8-Pole, 6 zero Constant Delay	8-Pole, 6 zero Constant Delay
Size	0.8" x 1.8" x 0.5"	0.8" x 1.8" x 0.5"	0.8" x 1.8" x 0.5"	0.8" x 1.8" x 0.5"
Range f_c	10.0 Hz to 102.4 kHz	10.0 Hz to 102.4 kHz	10.0 Hz to 102.4 kHz	10.0 Hz to 102.4 kHz
Theoretical Transfer Characteristics	Appendix A Page 4	Appendix A Page 20	Appendix A Page 21	Appendix A Page 22
Passband Ripple (theoretical)	0.0 dB	0.15 dB	0.15 dB	0.15 dB
DC Voltage Gain (non-inverting)	0 ± 0.1 dB max. 0 ± 0.05 dB typ.	0 ± 0.1 dB max. 0 ± 0.05 dB typ.	0 ± 0.1 dB max. 0 ± 0.05 dB typ.	0 ± 0.1 dB max. 0 ± 0.05 dB typ.
Stopband Attenuation Rate	48 dB/octave	60 dB min.	80 dB min.	100 dB min.
Cutoff Frequency **Stability** **Amplitude** **Phase**	f_c ± 2% max. ± 0.01% /°c -3 dB -182°	f_c ± 2% max. ± 0.01% /°c -3 dB -306°	f_c ± 2% max. ± 0.01% /°c -3 dB -306°	f_c ± 2% max. ± 0.01% /°c -3 dB -311°
Filter Attenuation (theoretical)	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	3.01 dB 1.00 f_c 40.0 dB 2.28 f_c 60.0 dB 2.64 f_c	3.01 dB 1.00 f_c 60.0 dB 3.08 f_c 80.0 dB 3.57 f_c	3.01 dB 1.00 f_c 80.0 dB 4.45 f_c 100.0 dB 5.20 f_c
Phase Match[1]	0 - f_c ± 2° max. ± 1° typ.	0 - f_c ± 2° max. ± 1° typ.	0 - fc ± 2° max. ± 1° typ.	0 - f_c ± 2° max. ± 1° typ.
Amplitude Accuracy (theoretical)	0 - f_c ± 0.2 dB max. ± 0.1 dB typ.	0 - 0.8 f_c ± 0.2 dB max. ± 0.1 dB typ. 0.8 f_c - 1.0 f_c ± 0.3 dB max. ± 0.15 dB typ.	0 - 0.8 f_c ± 0.2 dB max. ± 0.1 dB typ. 0.8 f_c - 1.0 f_c ± 0.3 dB max. ± 0.15 dB typ.	0 - 0.8 f_c ± 0.2 dB max. ± 0.1 dB typ. 0.8 f_c - 1.0 f_c ± 0.3 dB max. ± 0.15 dB typ.
Total Harmonic Distortion @ 1 kHz	< - 100 dB typ.	< - 100 dB typ.	< - 100 dB typ.	< - 100 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

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Model	428H4B	428H4E	428H4EX	428H4EY
Product Specifications				
Transfer Function	8-Pole Butterworth	8-Pole, 6 zero Elliptic	8-Pole, 6 zero Elliptic	8-Pole, 6 zero Elliptic
Size	0.8" x 1.8" x 0.5"	0.8" x 1.8" x 0.5"	0.8" x 1.8" x 0.5"	0.8" x 1.8" x 0.5"
Range fc, fr	10.0 Hz to 102.4 kHz	10.0 Hz to 102.4 kHz	10.0 Hz to 102.4 kHz	10.0 Hz to 102.4 kHz
Theoretical Transfer Characteristics	Appendix A Page 29	Appendix A Page 37	Appendix A Page 36	Appendix A Page 38
Passband Ripple (theoretical)	0.0 dB	± 0.035 dB	-0.05 dB	-0.05 dB
Voltage Gain (non-inverting)	0 ± 0.2 dB to 100 kHz 0 ± 0.5 dB to 120 kHz	0 ± 0.2 dB to 100 kHz 0 ± 0.5 dB to 120 kHz	0 ± 0.2 dB to 100 kHz 0 ± 0.5 dB to 120 kHz	0 ± 0.2 dB to 100 kHz 0 ± 0.5 dB to 120 kHz
Power Bandwidth	120 kHz	120 kHz	120 kHz	120 kHz
Small Signal Bandwidth	(-6 dB) 1 MHz	(-6 dB) 1 MHz	(-6 dB) 1 MHz	(-6 dB) 1 MHz
Stopband Attenuation Rate	48 dB/octave	80 dB	80 dB	100 dB
Cutoff Frequency	f_c ± 2% max.	f_r ± 2% max.	f_r ± 2% max.	f_r ± 2% max.
Stability	± 0.01% /°c	± 0.01% /°c	± 0.01% /°c	± 0.01% /°c
Amplitude	-3 dB	-0.035 dB	-0.05 dB	-0.05 dB
Phase	-360°	-323.5°	-414°	-419°
Filter Attenuation (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
Phase Match[1]	f_c - 100 kHz ± 3° max. ± 1.5° typ.	f_r - 1.25 f_r ± 4° max. ± 2° typ. 1.25 f_r-100 kHz ± 2° max. ± 1° typ.	f_r - 1.25 f_r ± 4° max. ± 2° typ. 1.25 f_r-100 kHz ± 2° max. ± 1° typ.	f_r - 1.25 f_r ± 4° max. ± 2° typ. 1.25 f_r-100 kHz ± 3° max. ± 1.5° typ.
Amplitude Accuracy (theoretical)	f_c-1.25 f_c ± 0.3 dB max. ± 0.15 dB typ. 1.25 f_c-100 kHz ± 0.2 dB max. ± 0.1 dB typ.	f_r-1.25 f_r ± 0.3 dB max. ± 0.15 dB typ. 1.25 f_r-100 kHz ± 0.2 dB max. ± 0.1 dB typ.	f_r-1.25 f_r ± 0.5 dB max. ± 0.25 dB typ. 1.25 f_r-100 kHz ± 0.2 dB max. ± 0.1 dB typ.	f_r-1.25 f_r ± 0.5 dB max. ± 0.25 dB typ. 1.25 f_r-100 kHz ± 0.2 dB max. ± 0.1 dB typ.
Total Harmonic Distortion @ 1 kHz	< - 100 dB typ.	< - 88 dB typ.	< - 88 dB typ.	< - 88 dB typ.
Wide Band Noise (5 Hz - 2 MHz)	400 µVrms typ.	400 µVrms typ.	500 µVrms typ.	500 µVrms typ.
Narrow Band Noise (5 Hz - 100 kHz)	100 µVrms typ.	100 µVrms typ.	150 µVrms typ.	150 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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Specification

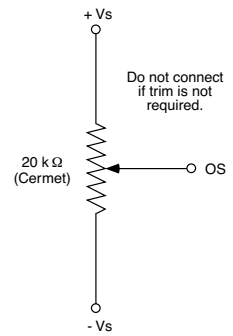
(25°C and Vs ± 15 Vdc)

Analog Input Characteristics[1]	
Impedance	10 k Ω min.
Voltage Range	± 10 Vpeak
Max. Safe Voltage	±Vs
Analog Output Characteristics	
Impedance (Closed Loop)	1 Ω typ.
	10 Ω max.
Linear Operating Range	±10V
Maximum Current[2]	±2 mA
Offset Voltage[3]	2 mV typ.
	20 mV max.
Offset Temp. Coeff.	50 µV/°C
Power Supply (±V)	
Rated Voltage	±15 Vdc
Operating Range	±12 to ±18 Vdc
Maximum Safe Voltage	±18 Vdc
Quiescent Current	±25 mA typ.
	±40 mA max.
Temperature	
Operating	0 to +70°C
Storage	-25 to +85°C

Notes:

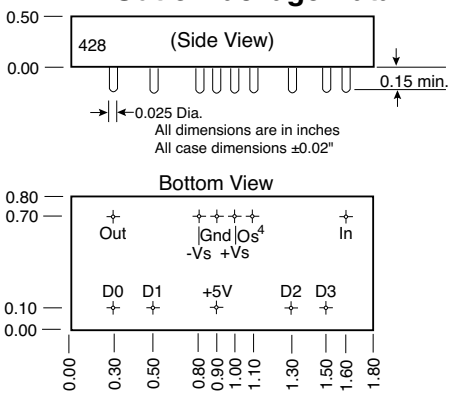
1. Input and output signal voltage referenced to supply common.
2. Output is short circuit protected to common.
   DO NOT CONNECT TO ±Vs.
3. Adjustable to zero.
4. Units operate with or without offset pin connected.

DC Offset Adjustment



Pin-Out and Package Data Ordering Information

Pin-Out & Package Data



Filter Mounting Assembly-See FMA-02A

Ordering Information

Filter Type

L - Low Pass
H - High Pass

428 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)

428 L4E-7

Model Number

Binary Tuning Ranges

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

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

Discrete Frequency's

Customer must specify f_1 ,f_2 ,f_3, f_4,f_5. Maximum span $f_1 \Rightarrow f_5$ 1,000:1.
Contact factory for custom frequency's

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.

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FREQUENCY DEVICES™, INC.

8-Pole

Bessel

Low-Pass

Appendix A

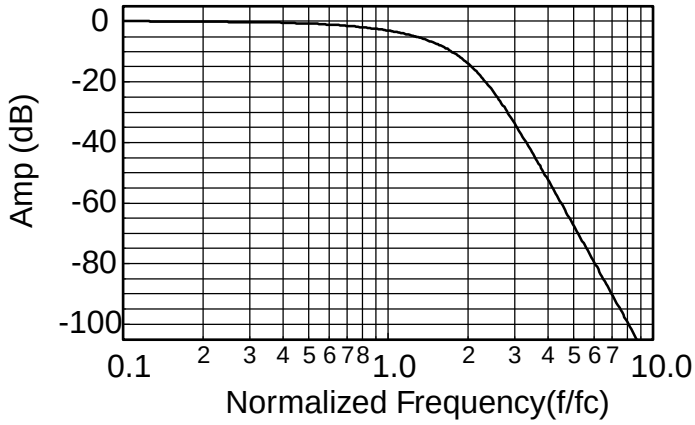
Theoretical Transfer Characteristics

f/fc (Hz)	Amp (dB)	Phase (deg)	Delay[1] (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

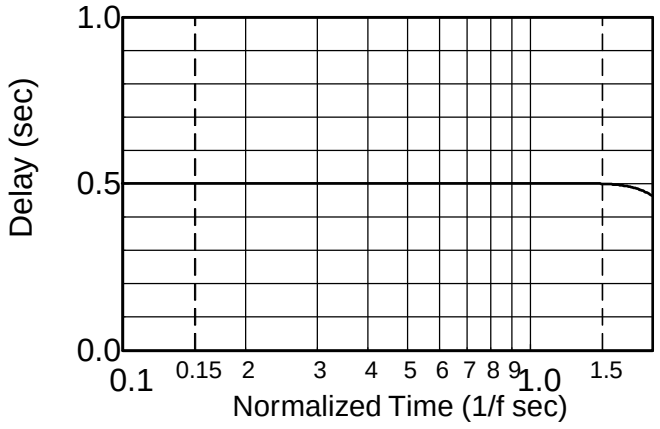
1.**Normalized Group Delay:**
The above delay data is normalized to a corner frequency of 1.0Hz.The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

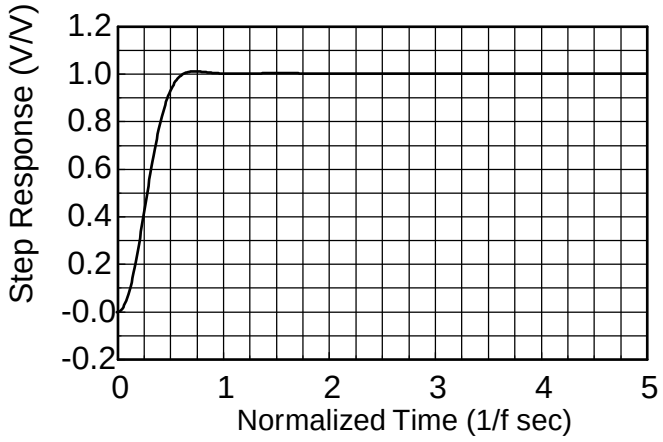
Frequency Response



Delay (Normalized)



Step Response



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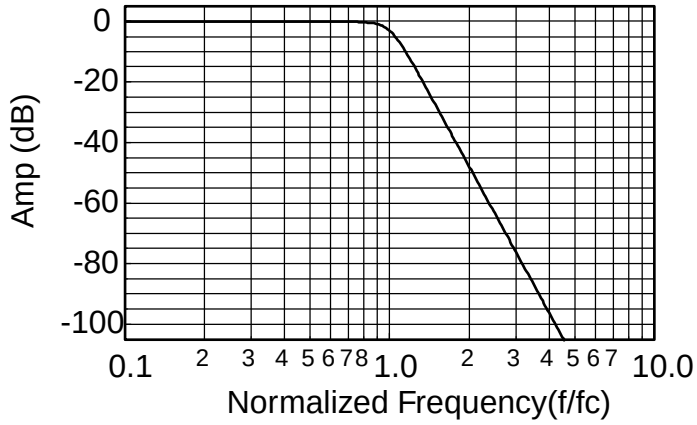
Theoretical Transfer Characteristics

f/fc (Hz)	Amp (dB)	Phase (deg)	Delay[1] (sec)
0.00	0.00	0.00	.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

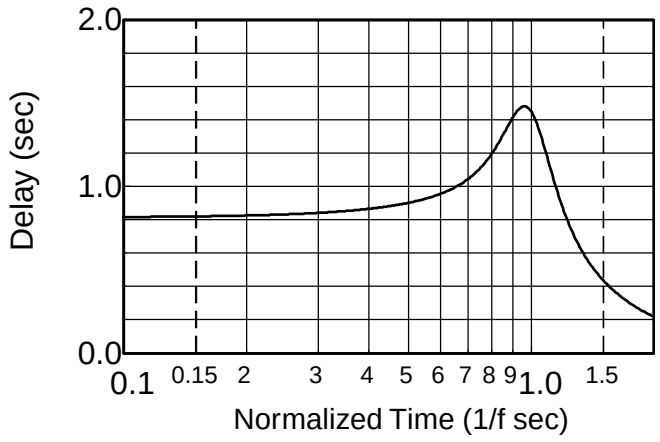
1.**Normalized Group Delay:**
The above delay data is normalized to a corner frequency of 1.0Hz.The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

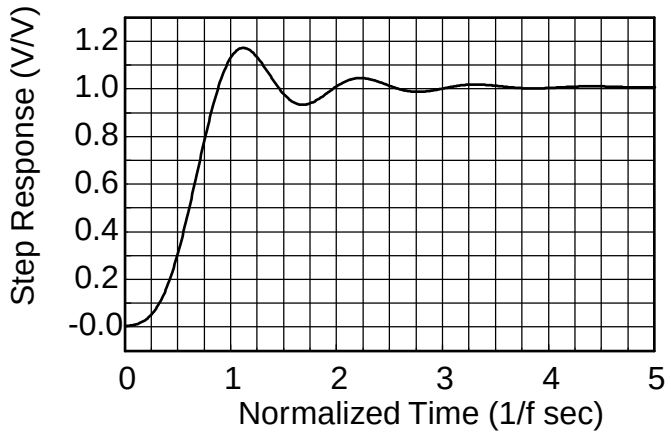
Frequency Response



Delay (Normalized)



Step Response



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FREQUENCY DEVICES™, INC.

8-Pole, 6-Zero

Constant Delay

Low-Pass (60 dB)

Appendix A

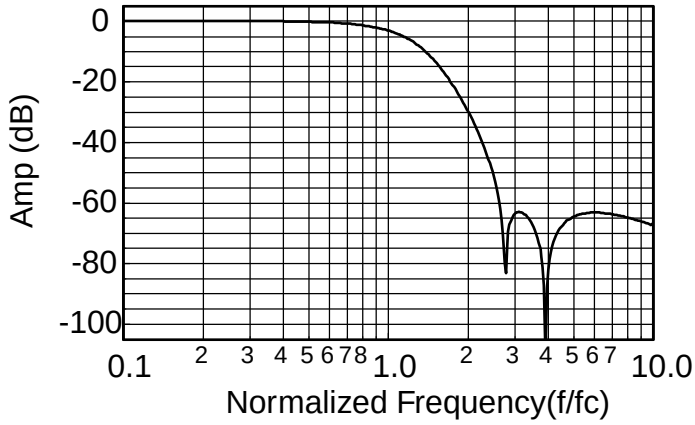
Theoretical Transfer Characteristics

f/fc (Hz)	Amp (dB)	Phase (deg)	Delay[1] (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

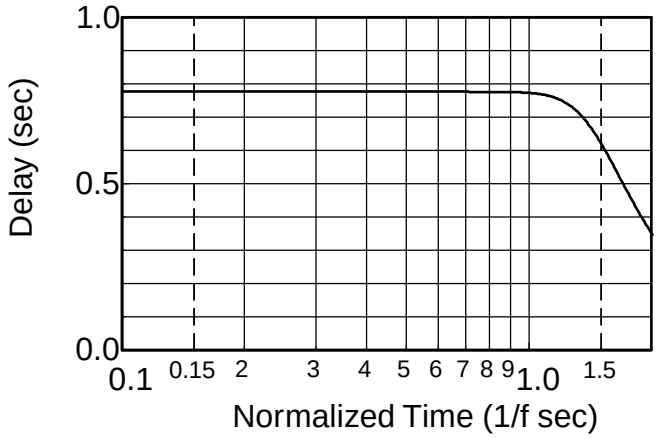
1. **Normalized Group Delay:**
The above delay data is normalized to a corner frequency of 1.0Hz.The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

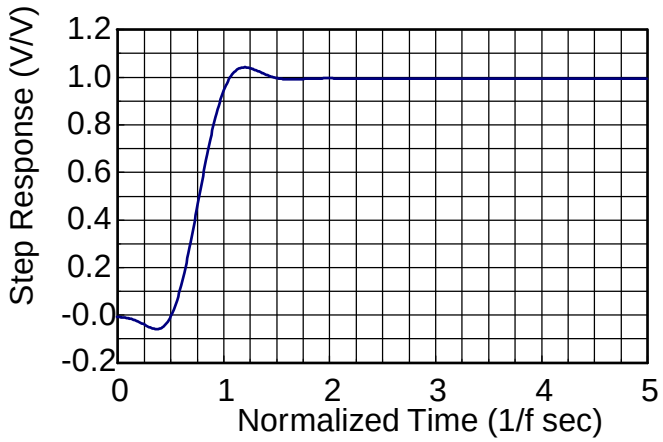
Frequency Response



Delay (Normalized)



Step Response



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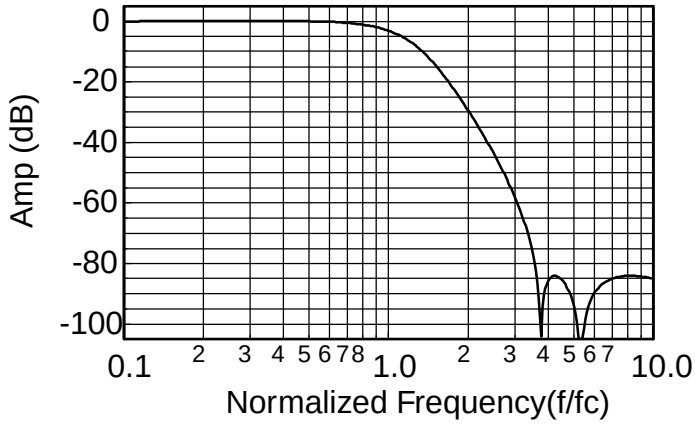
Theoretical Transfer Characteristics

f/fc (Hz)	Amp (dB)	Phase (deg)	Delay[1] (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

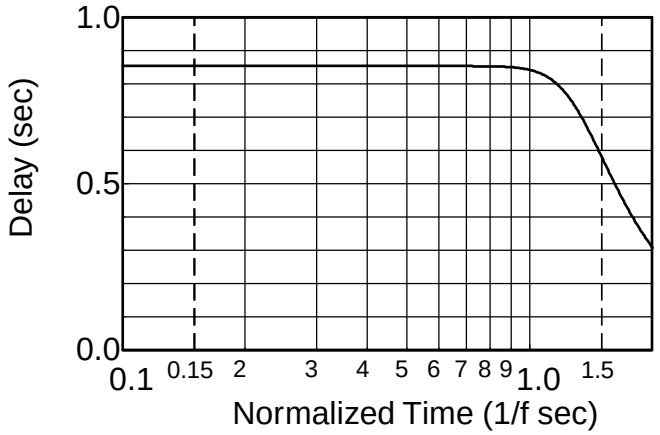
1. **Normalized Group Delay:**
The above delay data is normalized to a corner frequency of 1.0Hz.The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

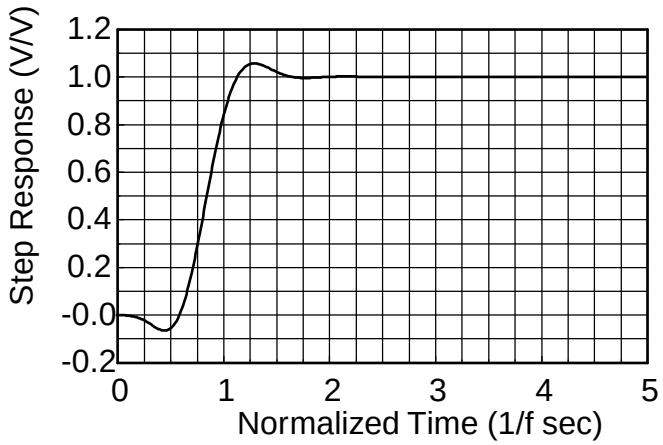
Frequency Response



Delay (Normalized)



Step Response



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FREQUENCY DEVICES™, INC.

8-Pole, 6-Zero

Constant Delay

Low-Pass (100 dB)

Appendix A

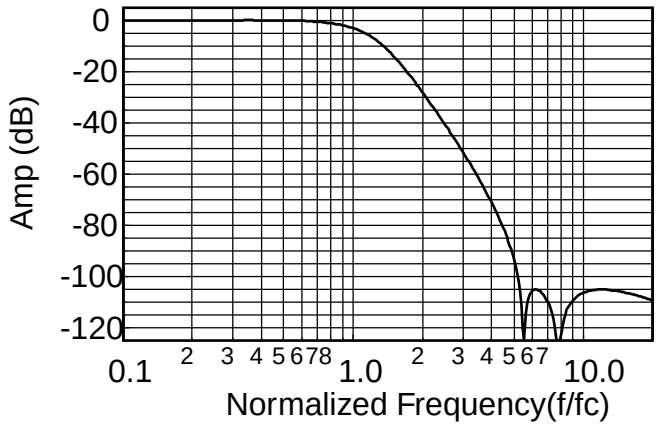
Theoretical Transfer Characteristics

f/fc (Hz)	Amp (dB)	Phase (deg)	Delay[1] (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

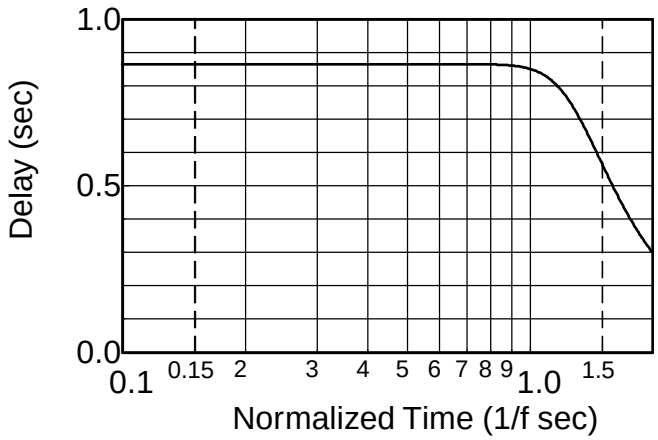
1. **Normalized Group Delay:**
The above delay data is normalized to a corner frequency of 1.0Hz.The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

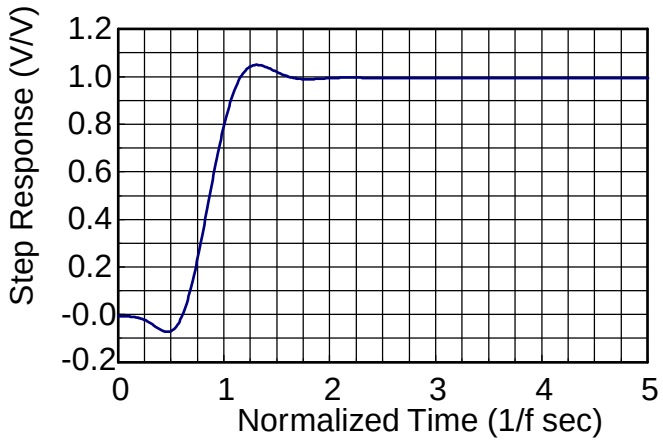
Frequency Response



Delay (Normalized)



Step Response



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FREQUENCY DEVICES™, INC.

8-Pole, 6-Zero

Elliptic, 1.56

Low-Pass

Appendix A

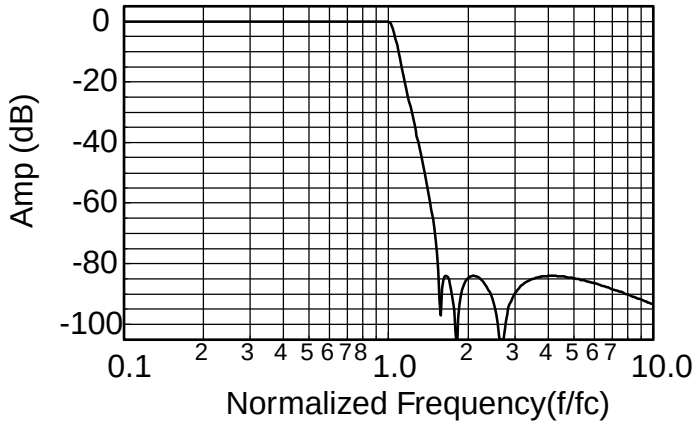
Theoretical Transfer Characteristics

f/fc (Hz)	Amp (dB)	Phase (deg)	Delay[1] (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

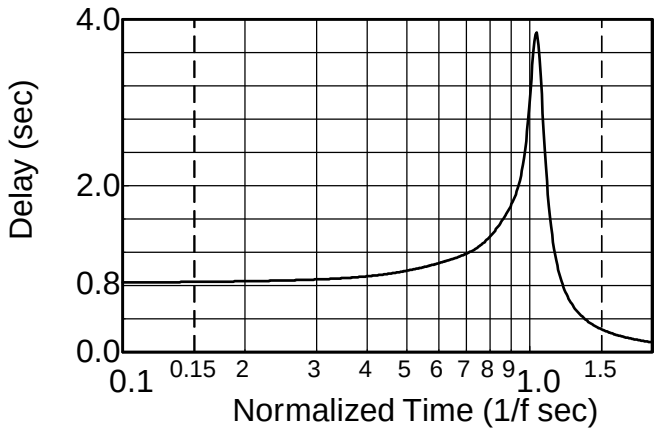
1. **Normalized Group Delay:**
The above delay data is normalized to a corner frequency of 1.0Hz.The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

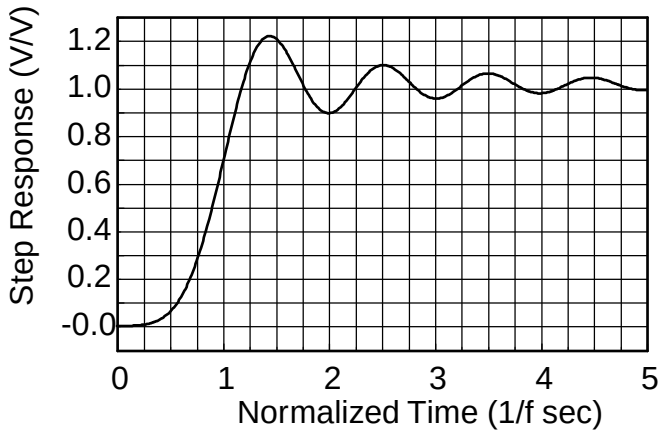
Frequency Response



Delay (Normalized)



Step Response



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FREQUENCY DEVICES™, INC.

8-Pole, 6-Zero

Elliptic, 1.77

Low-Pass

Appendix A

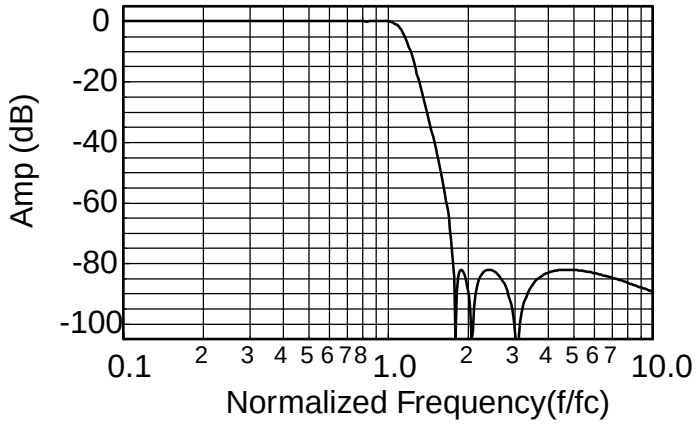
Theoretical Transfer Characteristics

f/fc (Hz)	Amp (dB)	Phase (deg)	Delay[1] (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

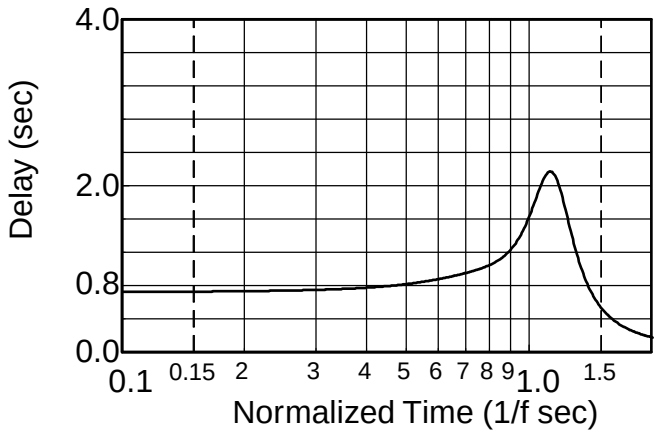
1. **Normalized Group Delay:**
The above delay data is normalized to a corner frequency of 1.0Hz.The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

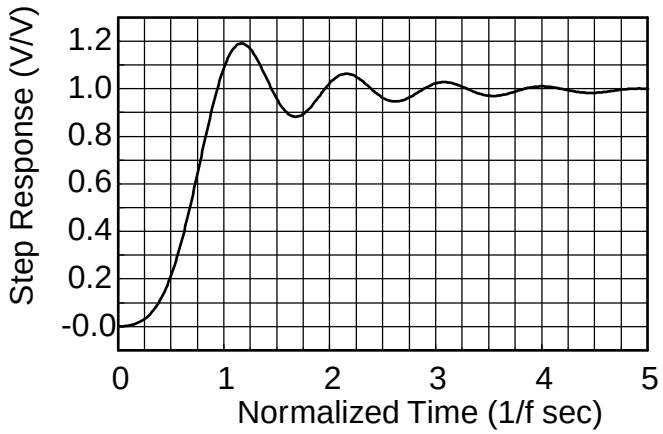
Frequency Response



Delay (Normalized)



Step Response



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FREQUENCY DEVICES™, INC.

8-Pole, 6-Zero

Elliptic, 2.00

Low-Pass

Appendix A

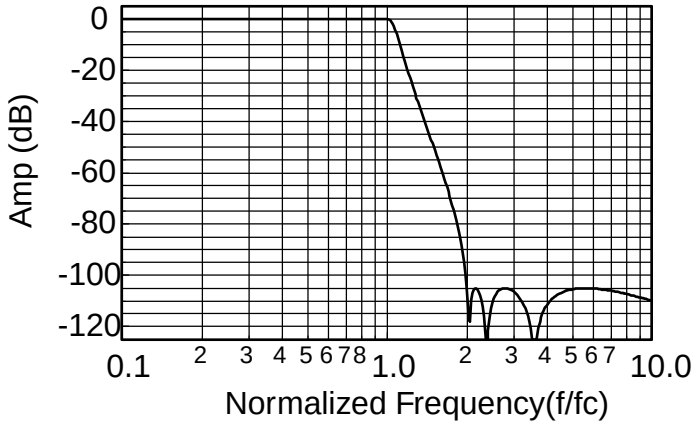
Theoretical Transfer Characteristics

f/fc (Hz)	Amp (dB)	Phase (deg)	Delay[1] (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

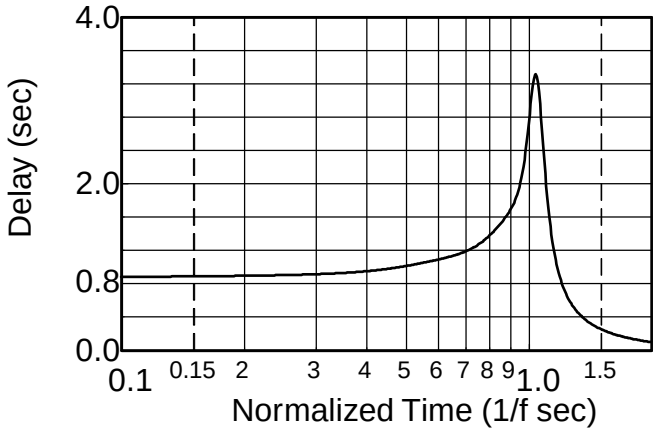
1. **Normalized Group Delay:**
The above delay data is normalized to a corner frequency of 1.0Hz.The actual delay is the normalized delay divided by the actual corner frequency (fc).

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

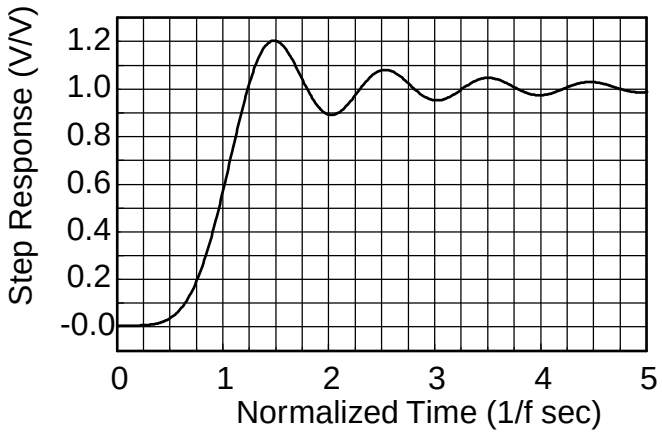
Frequency Response



Delay (Normalized)



Step Response

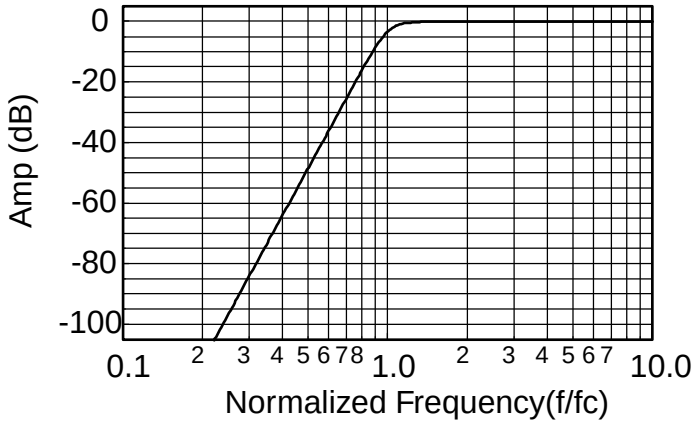


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e-mail: sales@freqdev.com • Web Address: http://www.freqdev.com • Fax on Demand: 978/521-5178

Theoretical Transfer Characteristics

f/fc (Hz)	Amp (dB)	Phase (deg)	Delay[1] (sec)
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).

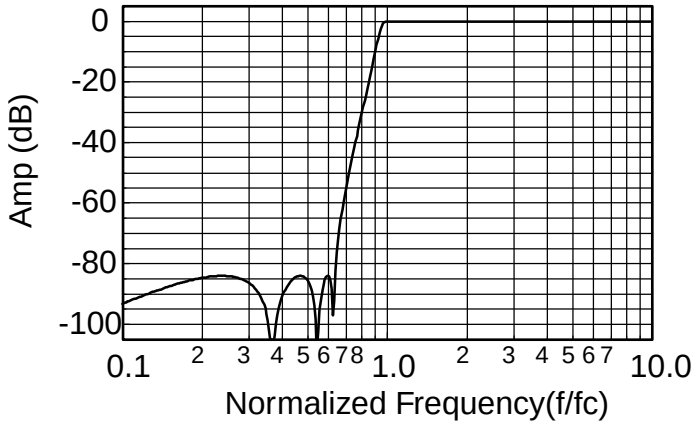
$$\text{Actual Delay} = \frac{\text{Normalized Delay}}{\text{Actual Corner Frequency (fc) in Hz}}$$

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Theoretical Transfer Characteristics

f/fc (Hz)	Amp (dB)	Phase (deg)	Delay[1] (sec)
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).

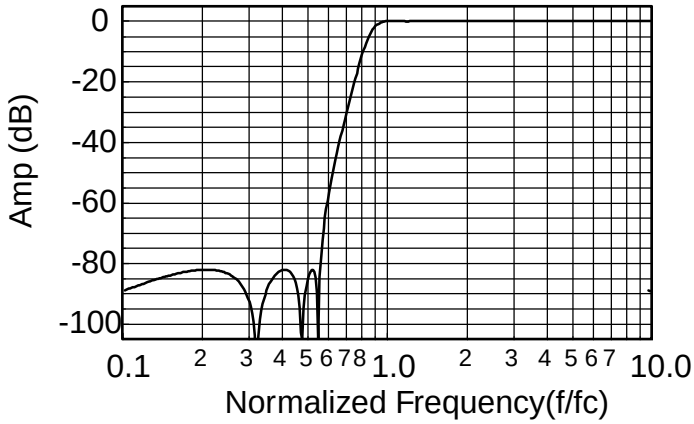
$$\text{Actual Delay} = \frac{\text{Normalized Delay}}{\text{Actual Corner Frequency (fc) in Hz}}$$

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Theoretical Transfer Characteristics

f/fc (Hz)	Amp (dB)	Phase (deg)	Delay[1] (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).

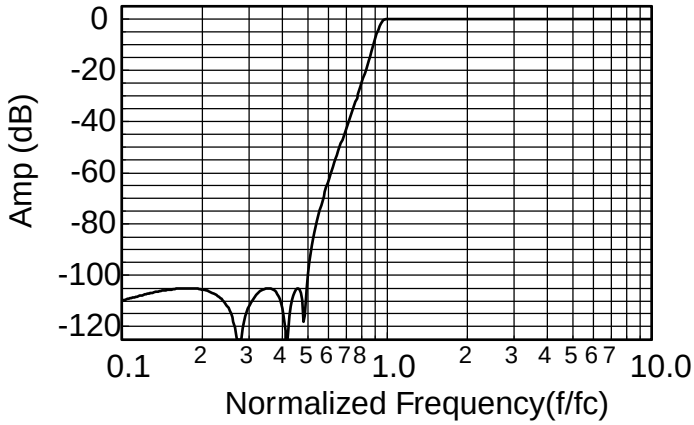
$$\text{Actual Delay} = \frac{\text{Normalized Delay}}{\text{Actual Corner Frequency (fc) in Hz}}$$

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Theoretical Transfer Characteristics

f/fc (Hz)	Amp (dB)	Phase (deg)	Delay[1] (sec)
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).

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

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