Filter Library

IIR Filter Design package user's Guide

C28x Foundation Software

TEXAS INSTRUMENTS

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Acronyms

xDAIS : eXpress DSP Algorithm Interface Standard
IALG : Algorithm interface defines a framework independent interface for the creation of algorithm instance objects
STB : Software Test Bench
QMATH: Fixed Point Mathematical computation
CcA : C-Callable Assembly
FIR : Finite Impulse Response Filter
IIR : Infinite Impulse Response Filter
FFT : Fast Fourier Transform

Contents

1. IIR filter specifications……. 1

2. ezIIR filter design script usage……..3

3. IIR filter design examples...6

   3.1. LPF Filter Design……. 6

   3.2. HPF Filter Design……. 9

   3.3. BPF Filter Design……..12

   3.4. BSF Filter Design……..15

4. Test Co-efficients……. 19

1. IIR Filter Specifications

Table 1. Description of Stop band and Pass band Filter Parameters

F_N	Nyquist frequency is ½ of the Sampling Frequency
F_P	Passband corner frequency is a scalar (F_P) or a two-element vector ([F_{P1}, F_{P2}]) with values between 0 and the Nyquist Frequency (F_N)
F_S	Stopband corner frequency is a scalar (F_S) or a two-element vector ([F_{S1}, F_{S2}]) with values between 0 and the Nyquist frequency (F_N).
R_P	Maximum permissible passband loss in decibels.
R_S	Minimum Stop-band attenuation, in decibels.

Table 2. Filter Type Stopband and Passband Specifications

Filter Type	Stopband and Passband Conditions	Stopband	Passband
LPF	$F_P < F_S$, Both Scalar	[F_S, F_N]	[0, F_P]
HPF	$F_P < F_S$, Both Scalar	[0, F_S]	[F_P, F_N]
BPF	$F_{S1} < F_{P1} < F_{P2} < F_{S2}$, F_P=[F_{P1}, F_{P2}] & F_S=[F_{S1}, F_{S2}] are Vector	[0, F_{S1}] & [F_{S2}, F_N]	[F_{P1}, F_{P2}]
BSF	$F_{P1} < F_{S1} < F_{S2} < F_{P2}$, F_P=[F_{P1}, F_{P2}] & F_S=[F_{S1}, F_{S2}] are Vector	[F_{S1}, F_{S2}]	[0, F_{P1}] & [F_{P2}, F_N]

The information's provided in the above tables are exemplified below, for all the four types of filter response.

Figure 1. LPF Filter Specification

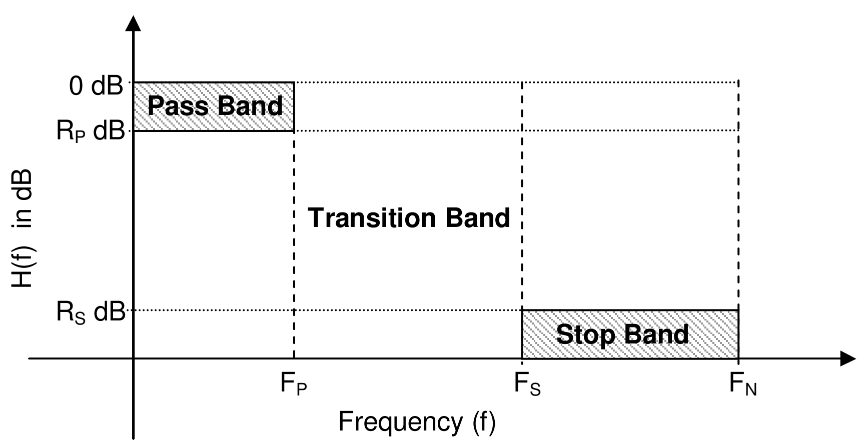


Figure 2. HPF Filter Specification

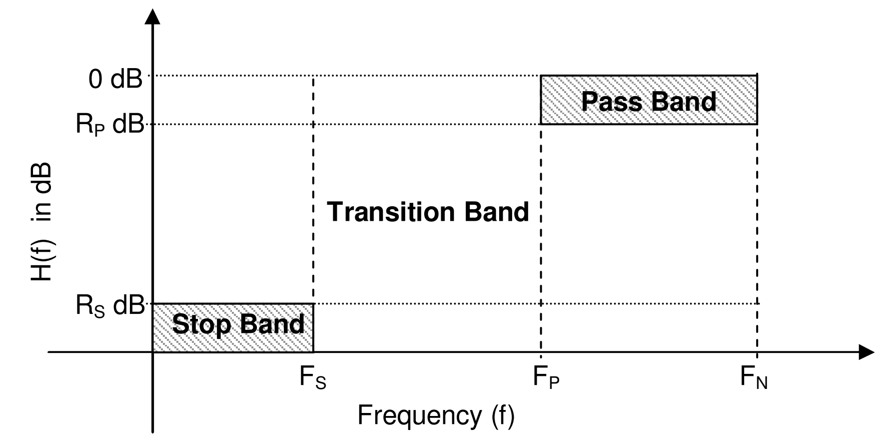


Figure 3. BPF Filter Specification

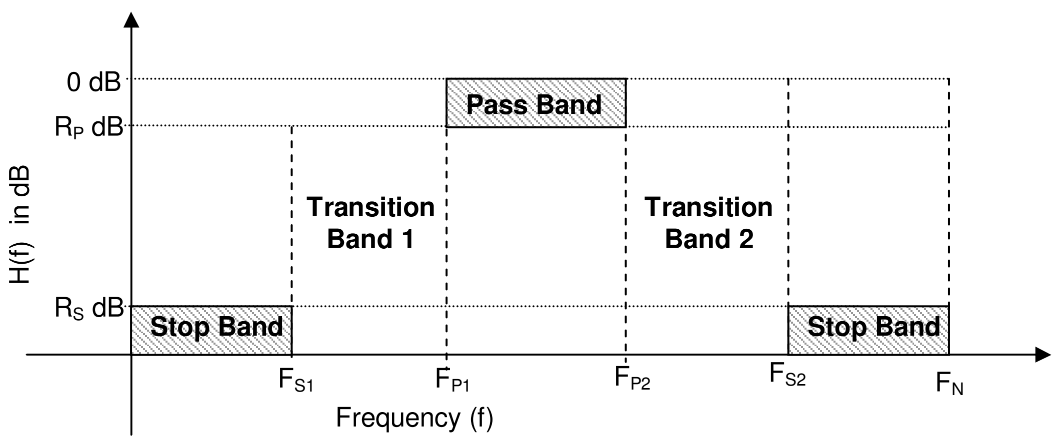
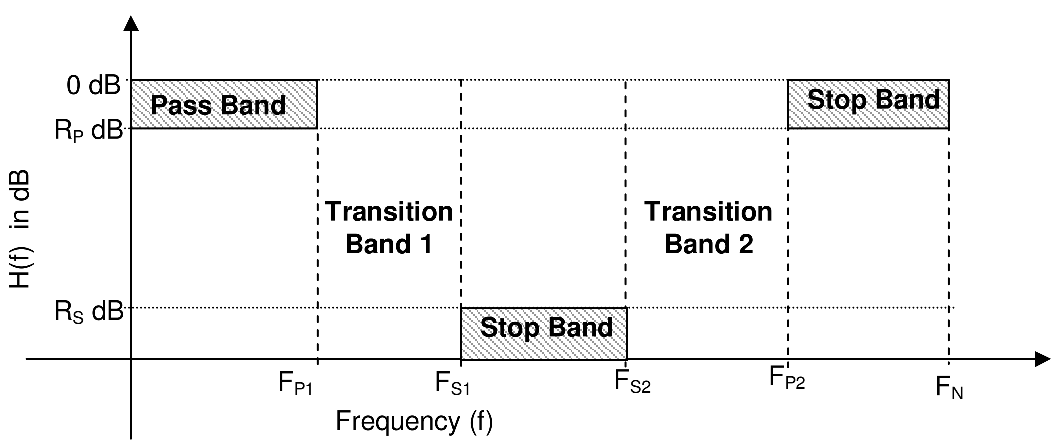


Figure 4. BSF Filter Specification



2. ezIIR Filter Design script usage

ezIIR filter design script facilitates the user to design cascade IIR filter using Second Order Section (SOS) without any overflow issues in the internal nodes of the filter.

Step 1:
Invoke the MATLAB software and modify the current working directory to
C:\TI\controlSUITE\libs\dsp\FixedPointLib\v100\examples_ccsv4\2833x_FixedPoint_IIR$\matlab (here $=16 or 32)

>>cd C:\TI\controlSUITE\libs\dsp\FixedPointLib\v100\examples_ccsv4 \2833x_FixedPoint_IIR$\matlab (here $=16 or 32)

Step 2:
Execute the **eziir16 or eziir32** script and input the required filter response parameters

Note:
eziir16 script generates filter co-efficients for IIR5BIQ16 module
eziir32 script generates filter co-efficients for IIR5BIQ32 module

>>eziir
The script requests the user to provide following information's for filter design viz.,

1. Type of Filter
2. Type of Response
3. Sampling frequency in Hz
4. Pass Band Ripples in Decibels
5. Stop Band Attenuation in Decibels
6. Pass Band Frequency in Hz
7. Stop Band Frequency in Hz
8. Name of the file to store the outputs

```
» cd C:\TI\controlSUITE\libs\dsp\FixedPointLib\v100\examples_ccsv4
\2833x_FixedPoint_IIR16\matlab

» eziir16
ezIIR FILTER DESIGN SCRIPT
Butterworth              : 1
Chebyshev(Type 1)        : 2
Chebyshev(Type 2)        : 3
Elliptic                 : 4
Select Any one of the above IIR Filter Type          : 1
Low pass                 : 1
High Pass                : 2
Band Pass                : 3
Band Stop                : 4
Select Any one of the above Response                 : 1
Enter the Sampling frequency                         : 20000
Enter the Pass band Ripples in dB(RP)                : 1
Enter the stop band Rippled in dB(RS)                : 20
Enter the pass band corner frequency(FP)             : 2000
Enter the stop band corner frequency(FS)             : 3000
Enter the name of the file for coeff storage         : filter.dat

Q format of the IIR filter coefficients:
   13
Input Scaling value:
   0.5369
Number of Biquads
    4
```

Step 3: ezIIR Filter design script outputs the following information viz.,

1. Set of SOS coefficients
2. Input Scaling Factor required to avoid the overflow in the first biquad
3. Number of Biquad required to obtain the specified filter characteristics
4. Q Format used to represent the scaled SOS filter coefficients
5. Displays the filter response in figure window 1 and window 2 (Fig 5 & 6)
   Figure window 1, displays the magnitude response in normal scale
   Figure window 2, displays the magnitude response in logarithmic scale

FILTER.DAT

```
#define IIR16_COEFF {\
                  0,3794,0,307,307,\
                  -2159,7894,668,1335,668,\
                  -3483,8904,541,1082,541,\
                  -6131,10923,13364,26729,13364}

#define IIR16_ISF 4398
#define IIR16_NBIQ      4
#define IIR16_QFMAT     13
```

Figure 5: Filter response using normal scale

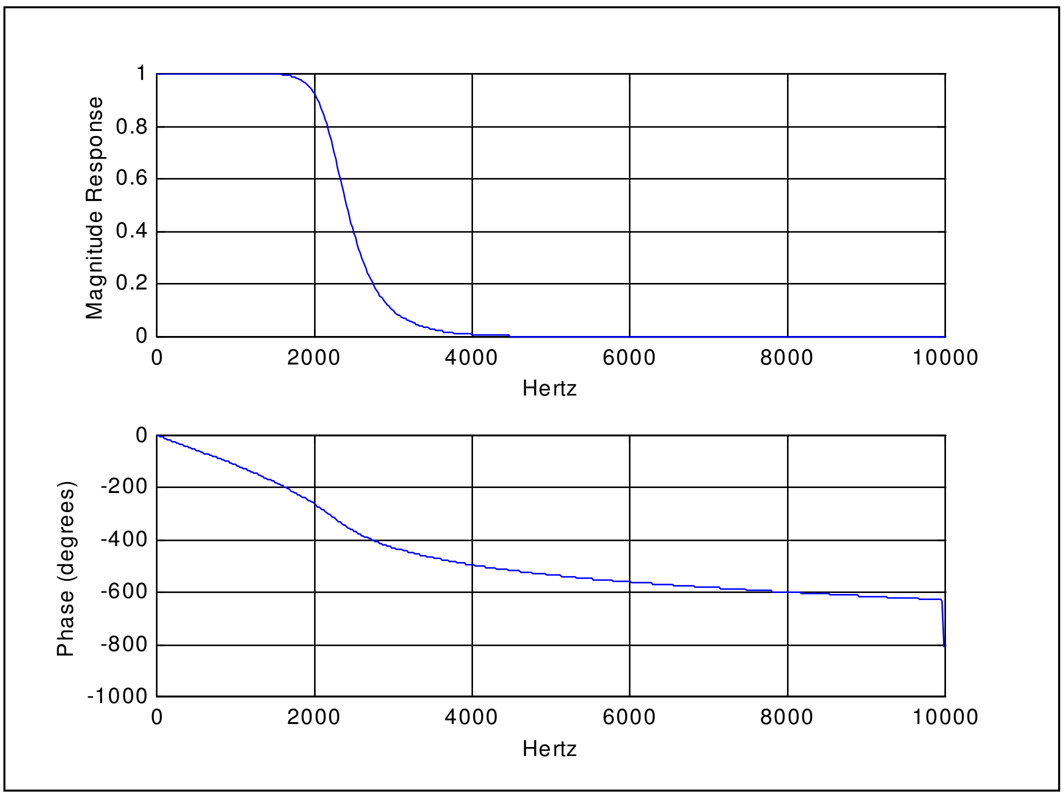
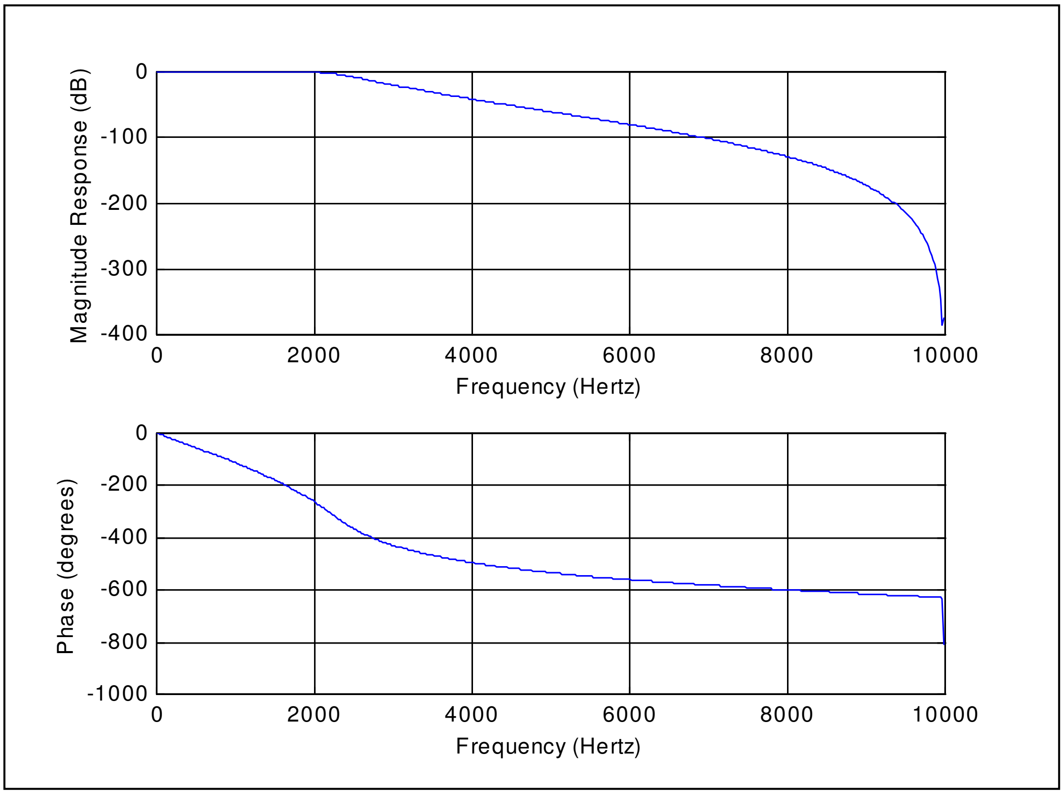


Figure 6: Filter response using logarithmic scale



Step 4: Rename the symbolic constants uniquely as required and copy it to the IIRCOEF file in order to initialize the filter object in the main system file.

3. IIR Filter Design Examples

3.1. LPF Design

LPF Specification:

Filter Type	: Butterworth
Pass Band cutoff frequency (F_P)	: 3000Hz
Stop Band cutoff frequency (F_S)	: 4000Hz
Sampling Frequency	: 20KHz
Pass Band Attenuation (R_P)	: 1 dB
Stop Band Attenuation (R_S)	: 30 dB

LPF Design using ezIIR script:

```
» ezIIR16
ezIIR FILTER DESIGN SCRIPT
Butterworth          : 1
Chebyshev(Type 1)    : 2
Chebyshev(Type 2)    : 3
Elliptic             : 4
Select Any one of the above IIR Filter Type      : 1
Low pass             : 1
High Pass            : 2
Band Pass            : 3
Band Stop            : 4
Select Any one of the above Response             : 1
Enter the Sampling frequency                     : 20000
Enter the Pass band Ripples in dB (RP)           : 1
Enter the stop band Rippled in dB (RS)           : 30
Enter the pass band corner frequency (FP)        : 3000
Enter the stop band corner frequency (FS)        : 4000
Enter the name of the file for coeff storage     : lpf.dat

Q format of the IIR filter coefficients:
   12

Input Scaling value:
   0.4995

Number of Biquads:
    6
```

LPF.DAT

```
#define IIR16_COEFF {\
                 -373,2423,132,264,132,\
                 -516,2500,561,1121,561,\
                 -819,2665,603,1207,603,\
                 -1324,2938,624,1248,624,\
                 -2103,3361,472,944,472,\
                 -3286,4003,8606,17212,8606}

#define IIR16_ISF 2046
#define IIR16_NBIQ      6
#define IIR16_QFMAT     12
```

Figure 7. Low Pass Filter Response using normal scale

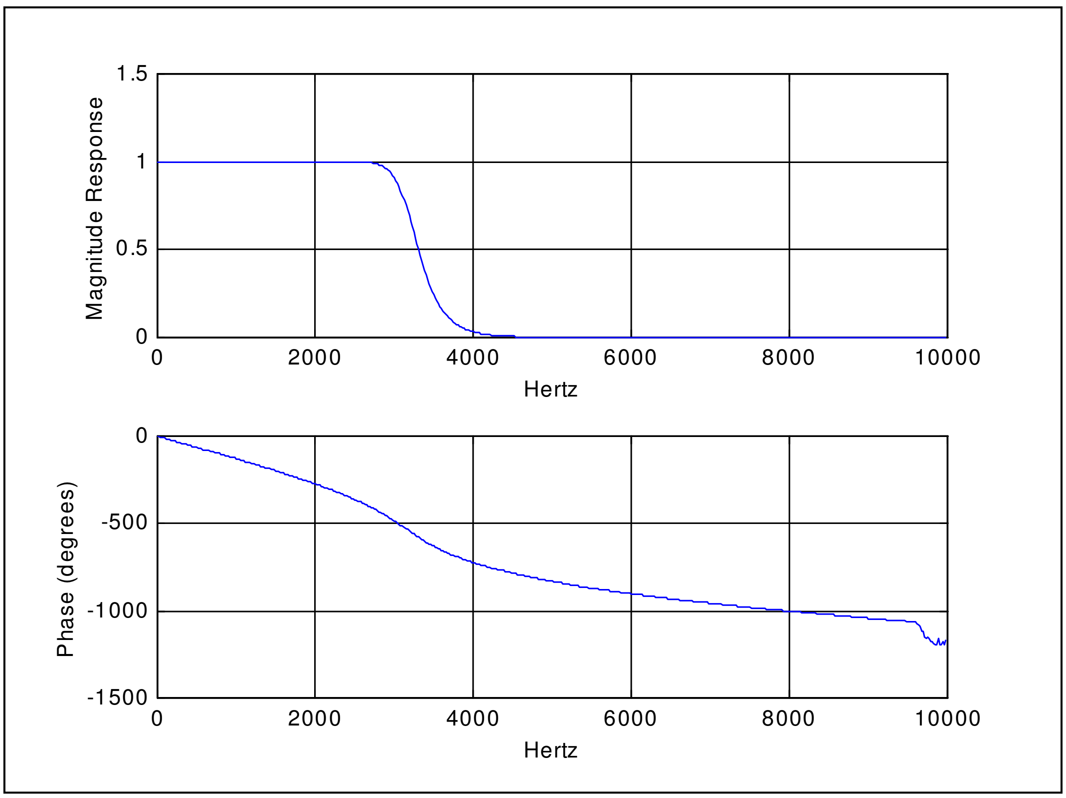
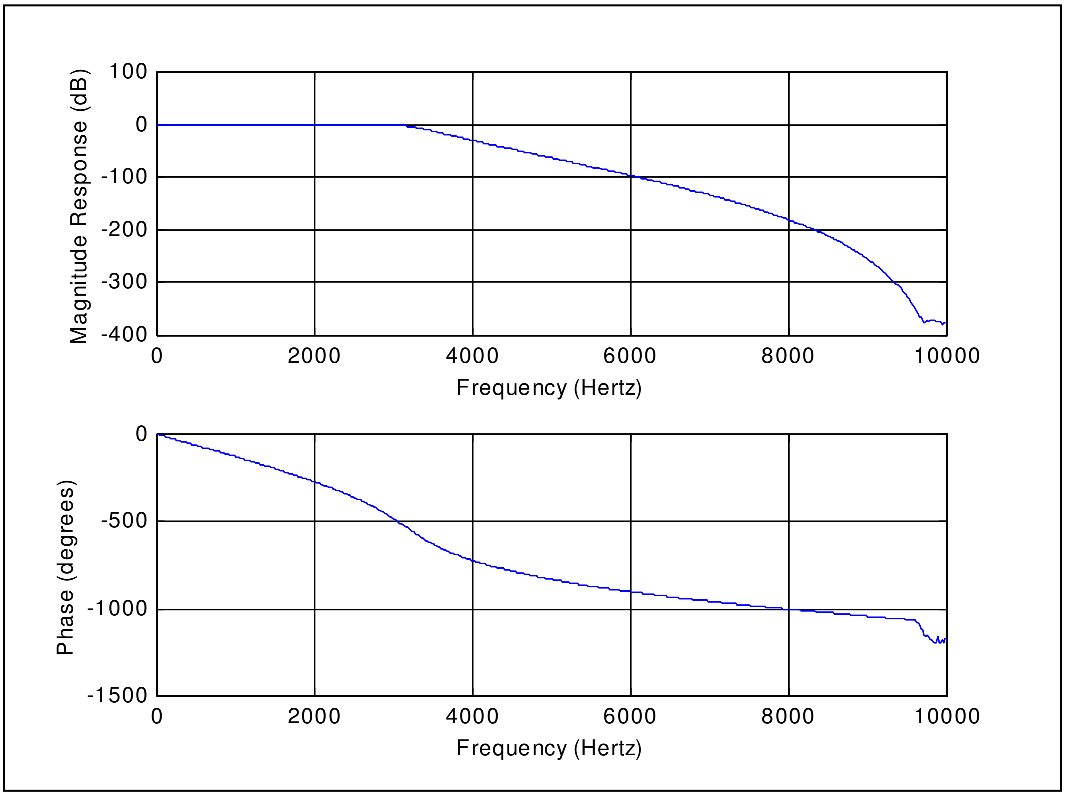


Figure 8. Low Pass Filter Response using logarithmic scale



3.2. HPF Design

HPF Specification:

Filter Type	: Chebyshev Type I
Pass Band cutoff frequency (F_P)	: 4000Hz
Stop Band cutoff frequency (F_S)	: 3000Hz
Sampling Frequency	: 20KHz
Pass Band Attenuation (R_P)	: 0.1 dB
Stop Band Attenuation (R_S)	: 30 dB

HPF Design using ezIIR script:

```
» ezIIR16
ezIIR FILTER DESIGN SCRIPT
Butterworth              : 1
Chebyshev(Type 1)        : 2
Chebyshev(Type 2)        : 3
Elliptic                 : 4
Select Any one of the above IIR Filter Type        : 2
Low pass                 : 1
High Pass                : 2
Band Pass                : 3
Band Stop                : 4
Select Any one of the above Response               : 2
Enter the Sampling frequency                       : 20000
Enter the Pass band Ripples in dB(RP)              : 0.1
Enter the stop band Rippled in dB(RS)              : 30
Enter the pass band corner frequency(FP)           : 4000
Enter the stop band corner frequency(FS)           : 3000
Enter the name of the file for coeff storage       : hpf.dat

Q format of the IIR filter coefficients:
   12

Input Scaling value:
   0.6830

Number of Biquads:
    4
```

HPF.DAT

```
#define IIR16_COEFF {\
                  0,-1298,0,-456,456,\
                  -1106,-1198,1486,-2971,1486,\
                  -2372,1138,1356,-2711,1356,\
                  -3523,2655,10912,-21824,10912}

#define IIR16_ISF 2798
#define IIR16_NBIQ      4
#define IIR16_QFMAT     12
```

Figure 9. High Pass Filter Response using normal scale

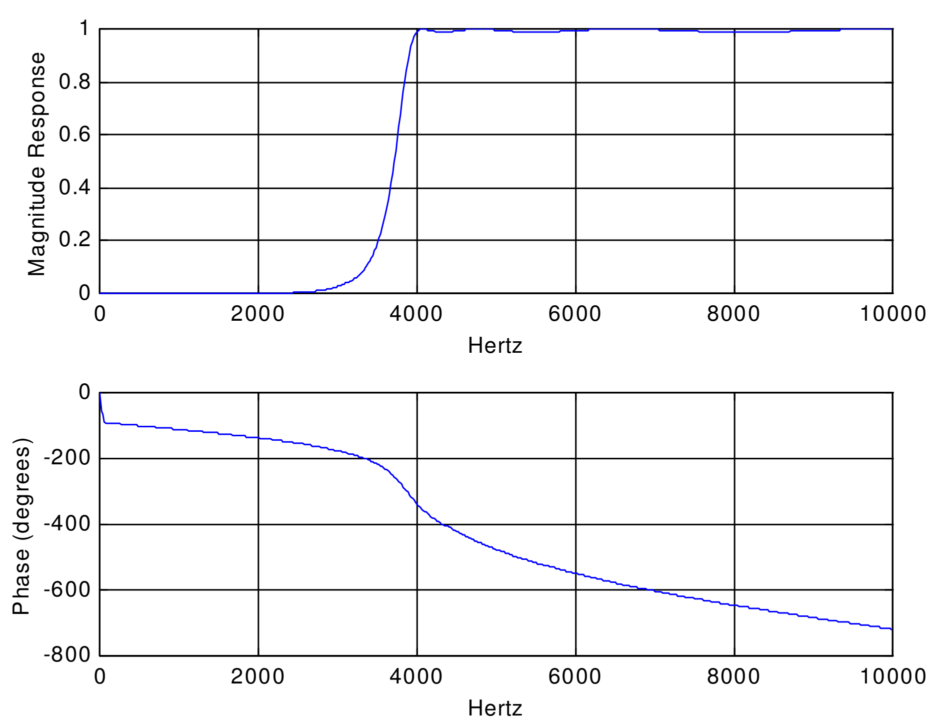
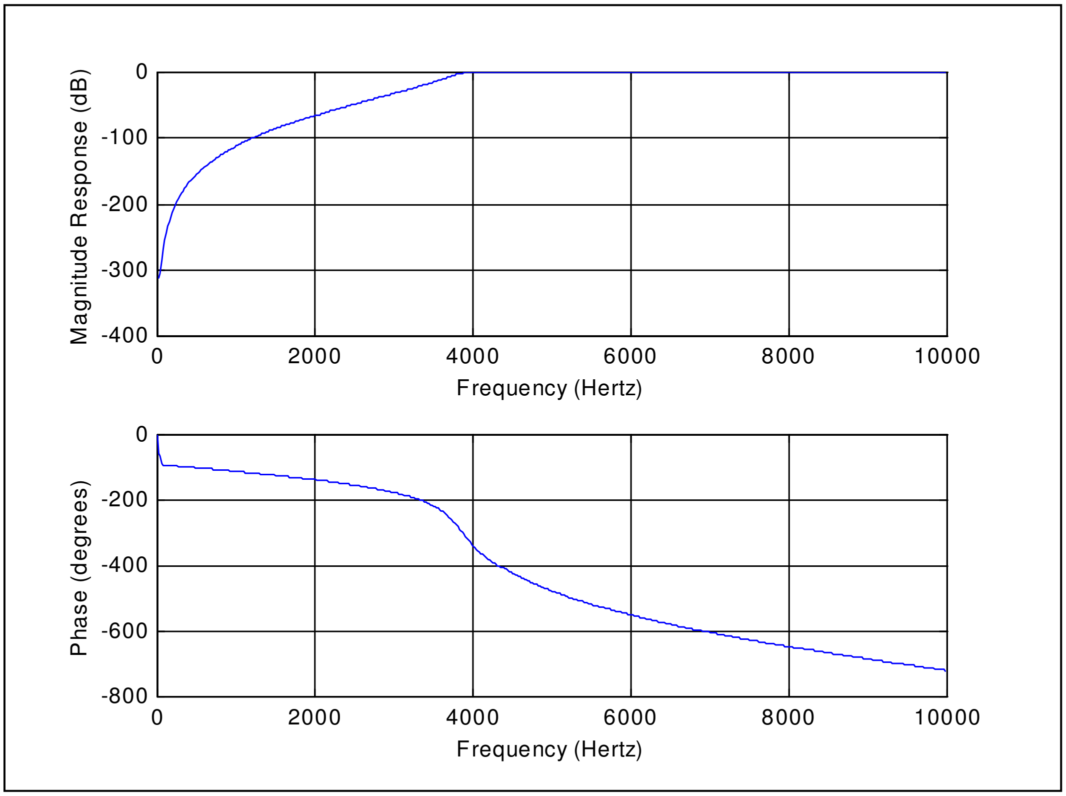


Figure 10. High Pass Filter Response using logarithmic scale



3.3. BPF Design

BPF Specification:

Filter Type	: Chebyshev Type II
Pass Band cutoff frequency (F_P)	: [3000, 4000]Hz
Stop Band cutoff frequency (F_S)	: [2500, 4500]Hz
Sampling Frequency	: 20KHz
Pass Band Attenuation (R_P)	: 0.1 dB
Stop Band Attenuation (R_S)	: 30 dB

BPF Design using ezIIR script:

```
» eziir16
ezIIR FILTER DESIGN SCRIPT
Butterworth                 : 1
Chebyshev(Type 1)           : 2
Chebyshev(Type 2)           : 3
Elliptic                    : 4
Select Any one of the above IIR Filter Type        : 3
Low pass                    : 1
High Pass                   : 2
Band Pass                   : 3
Band Stop                   : 4
Select Any one of the above Response               : 3
Enter the Sampling frequency                       : 20000
Enter the Pass band Ripples in dB(RP)              : 0.1
Enter the stop band Rippled in dB(RS)              : 30
Enter the pass band corner frequency(FP)           : [3000,4000]
Enter the stop band corner frequency(FS)           : [2500,4500]
Enter the name of the file for coeff storage       : bpf.dat

Q format of the IIR filter coefficients:
   11

Input Scaling value:
   0.3849

Number of Biquads:
    5
```

BPF.DAT

```
#define IIR16_COEFF {\
                  -986,1448,-408,0,408,\
                  -1323,889,648,96,648,\
                  -1452,2263,672,-1082,672,\
                  -1830,952,950,-264,950,\
                  -1877,2581,17695,-25335,17695}

#define IIR16_ISF 788
#define IIR16_NBIQ      5
#define IIR16_QFMAT     11
```

Figure 11. Band Pass Filter Response using normal scale

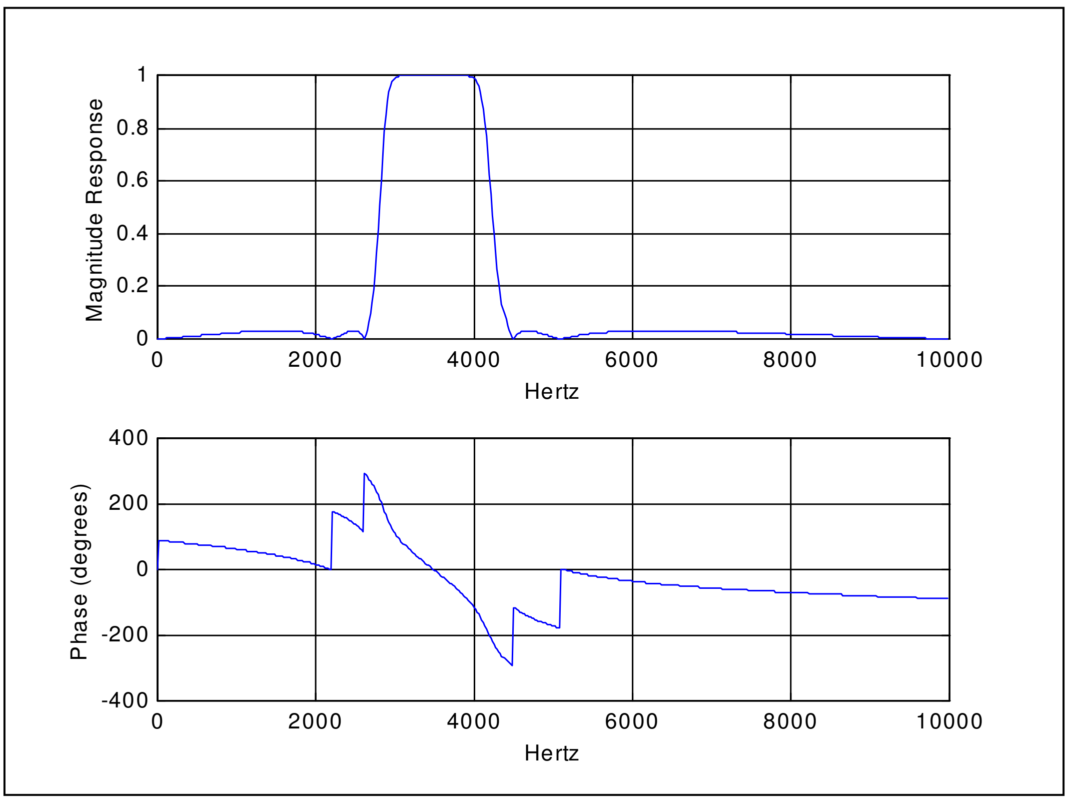
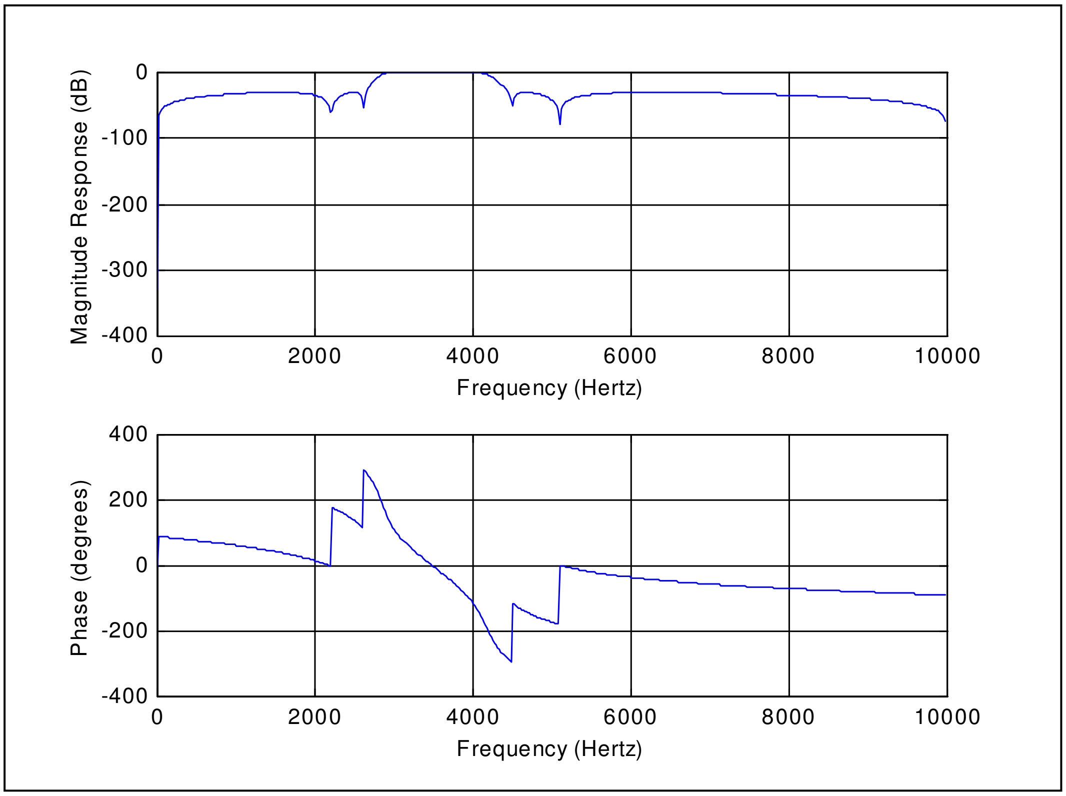


Figure 12. Band Pass Filter Response using logarithmic scale



3.4. BSF Design

BSF Specification:

Filter Type	: Elliptic
Pass Band cutoff frequency (F_P)	: [3000, 4000]Hz
Stop Band cutoff frequency (F_S)	: [3400, 3600]Hz
Sampling Frequency	: 20KHz
Pass Band Attenuation (R_P)	: 0.1 dB
Stop Band Attenuation (R_S)	: 30 dB

BSF Design using ezIIR script:

```
» ezIIR16
ezIIR FILTER DESIGN SCRIPT
Butterworth               : 1
Chebyshev(Type 1)         : 2
Chebyshev(Type 2)         : 3
Elliptic                  : 4
Select Any one of the above IIR Filter Type          : 4
Low pass                  : 1
High Pass                 : 2
Band Pass                 : 3
Band Stop                 : 4
Select Any one of the above Response                 : 4
Enter the Sampling frequency                         : 20000
Enter the Pass band Ripples in dB(RP)                : 0.1
Enter the stop band Rippled in dB(RS)                : 30
Enter the pass band corner frequency(FP)             : [3000,4000]
Enter the stop band corner frequency(FS)             : [3400,3600]
Enter the name of the file for coeff storage         : bsf.dat

Q format of the IIR filter coefficients:
   11

Input Scaling value:
   0.1848

Number of Biquads:
    3
```

BSF.DAT

```
#define IIR16_COEFF {\
                  -1515,1638,859,-790,859,\
                  -1883,1378,1998,-1631,1998,\
                  -1901,2198,21576,-21934,21576}

#define IIR16_ISF 379
#define IIR16_NBIQ      3
#define IIR16_QFMAT     11
```

Figure 13. Band Stop Filter Response using normal scale

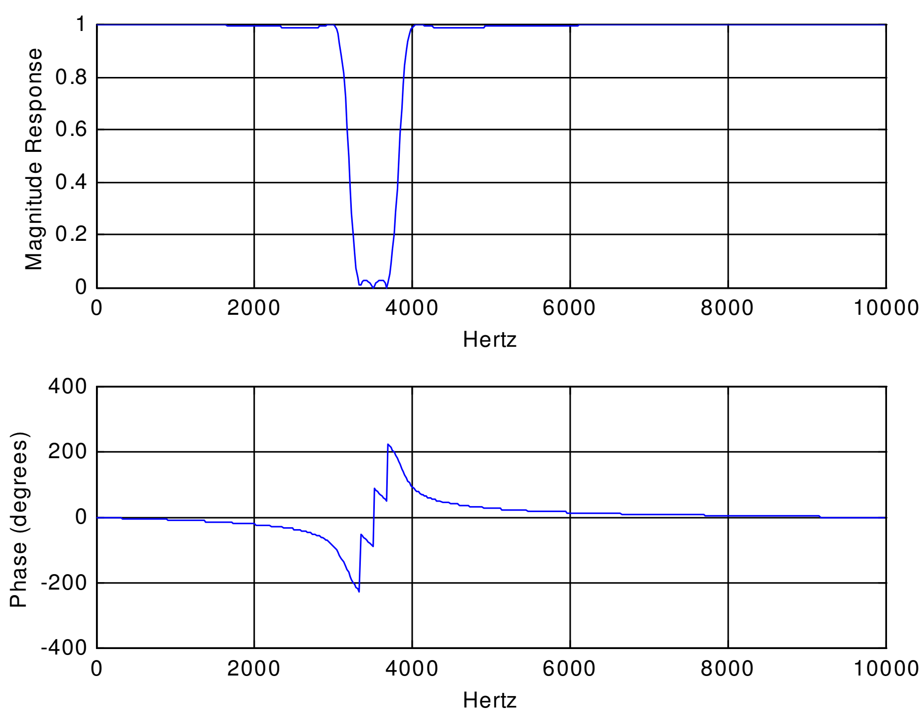
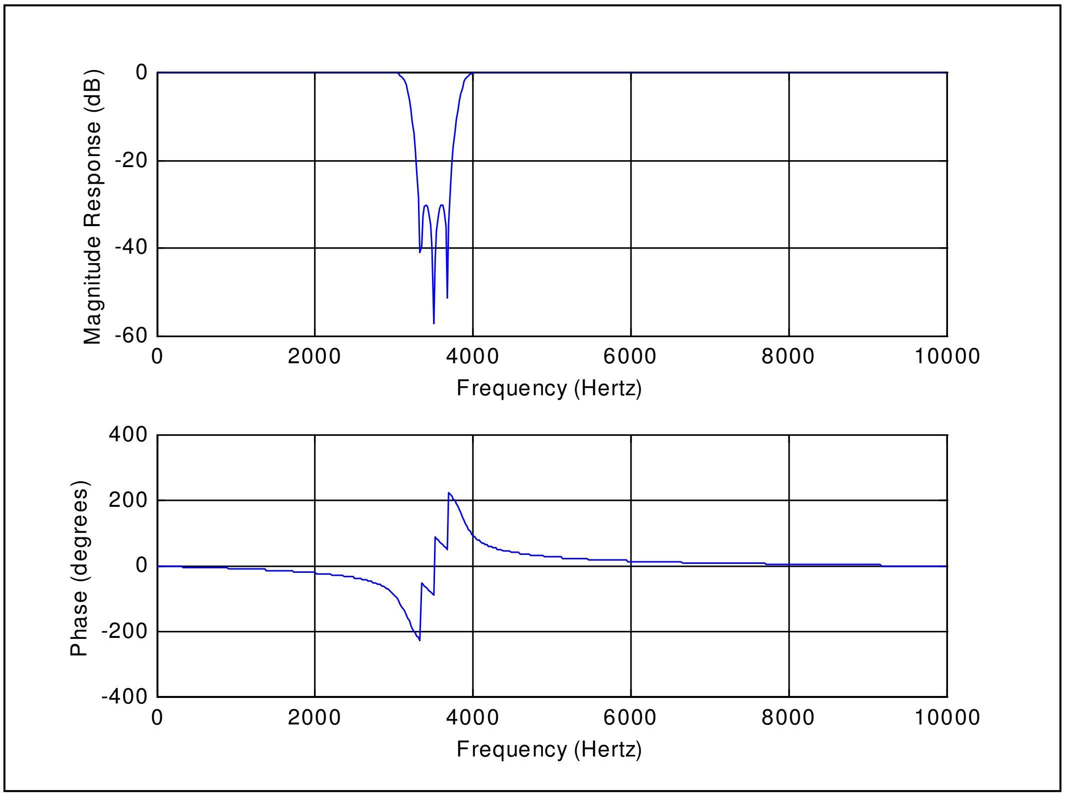


Figure 14. Band Stop Filter Response using logarithmic scale



4. Test coefficients for IIR filter

To demonstrate the **IIR5BIQ16 & IIR5BIQ16** filter modules, we have generated filter co-efficient for LPF, HPF, BPF and BSF responses using **eziir16 & eziir32** script and placed it in IIR.H header file.

These test co-efficients are generated using the same filter specification given in filter design examples in previous section.

IIR.H : Test Co-efficients for IIR5BIQ16 Module

```
/* LPF co-efficients for IIR16 module              */
#define IIR16_LPF_COEFF          {\
                                 -746,4846,1056,2111,1056,\
                                 -1032,5001,1120,2239,1120,\
                                 -1639,5330,1192,2385,1192,\
                                 -2647,5877,1211,2422,1211,\
                                 -4206,6722,872,1745,872,\
                                 -6573,8005,4861,9722,4861}
#define IIR16_LPF_ISF            4092
#define IIR16_LPF_NBIQ           6
#define IIR16_LPF_QFMAT          13
```

```
/* HPF co-efficients for IIR16 module              */
#define IIR16_HPF_COEFF          {\
                                 0,-2597,0,-3340,3340,\
                                 -2211,-2396,1746,-3492,1746,\
                                 -4745,2276,2007,-4014,2007,\
                                 -7046,5310,13685,-27370,13685}
#define IIR16_HPF_ISF            5595
#define IIR16_HPF_NBIQ           4
#define IIR16_HPF_QFMAT          13
```

```
/* BPF co-efficients for IIR16 module              */
#define IIR16_BPF_COEFF          {\
                                 -1078,1437,-367,0,367,\
                                 -1395,935,713,43,713,\
                                 -1496,2176,594,-917,594,\
                                 -1855,994,1022,-329,1022,\
                                 -1890,2462,18610,-25359,18610}
#define IIR16_BPF_ISF            721
#define IIR16_BPF_NBIQ           5
#define IIR16_BPF_QFMAT          11
```

```
/* BSF co-efficients for IIR16 module              */
#define IIR16_BSF_COEFF          {\
                                 -1532,1626,859,-781,859,\
                                 -1889,1374,2032,-1644,2032,\
                                 -1906,2168,22098,-22158,22098}
#define IIR16_BSF_ISF            366
#define IIR16_BSF_NBIQ           3
#define IIR16_BSF_QFMAT          11
```

IIR.H : Test Co-efficients for IIR5BIQ32 Module

```
/* LPF co-efficients for IIR32 module              */
#define IIR32_LPF_COEFF {\
        -24444800,158794151,8647611,17295223,8647611,\
        -33805581,163869390,36741777,73483554,36741777,\
        -53695266,174653202,39535955,79071910,39535955,\
        -86750921,192575355,40880726,81761451,40880726,\
        -137806611,220256787,30931379,61862757,30931379,\
        -215373186,262311922,564004144,1128008289,564004144}

#define IIR32_LPF_ISF           134086103
#define IIR32_LPF_NBIQ          6
#define IIR32_LPF_QFMAT         28
```

```
/* HPF co-efficients for IIR32 module              */
#define IIR32_HPF_COEFF {\
        0,-85096979,0,-29857202,29857202,\
        -72466417,-78522171,97363917,-194727833,97363917,\
        -155480100,74571693,88837952,-177675903,88837952,\
        -230891969,173985995,715131301,-1430262602,715131301}

#define IIR32_HPF_ISF           183338477
#define IIR32_HPF_NBIQ          4
#define IIR32_HPF_QFMAT         28
```

```
/* BPF co-efficients for IIR32 module              */
#define IIR32_BPF_COEFF {\
        -70620977,94154018,-24080177,0,24080177,\
        -91416523,61304763,46717868,2819319,46717868,\
        -98072227,142585344,38933432,-60070942,38933432,\
        -121545500,65135203,66986143,-21532217,66986143,\
        -123895267,161346553,1219596683,-1661914443,1219596683}

#define IIR32_BPF_ISF           47247113
#define IIR32_BPF_NBIQ          5
#define IIR32_BPF_QFMAT         27
```

```
/* BSF co-efficients for IIR32 module              */
#define IIR32_BSF_COEFF {\
        -100408845,106578277,56314524,-51161340,56314524,\
        -123814194,90035192,133182068,-107730821,133182068,\
        -124894576,142053666,1448196385,-1452129490,1448196385}

#define IIR32_BSF_ISF           23999390
#define IIR32_BSF_NBIQ          3
#define IIR32_BSF_QFMAT         27
```

Reference

1. SPRA509 TI Application Report: Overflow Avoidance Techniques in Cascaded IIR Filter Implementations on TMS320 DSP's
2. Scaling in Fixed Point Implementation of IIR systems (PP. 359 –370)
   Discrete Time Signal Processing Alan V. Oppenheim, Ronald W. Schafer
   Prentice Hall Signal Processing Series (1989)