ADS127L21 – Digital Filter Design

October 2023

Created by Keith Nicholas

ADS127L21 – Agenda

- ADS127L21 programmable coefficient filter options
  - Finite Input Response (FIR)
  - Infinite Input Response (IIR)
  - Convert decimal filter coefficients to fixed-point format
- ADS127L21EVM-PDK GUI Filter file format
  - MATLAB® *'fcf'* file format
- IIR filter design using Bilinear transform
  - Design 10kHz 2nd order filter starting with MFB topology
  - Create *'fcf'* file and evaluate using ADS127L21EVM-PDK hardware
- Filter design using MATLAB® Filter Designer
  - Design IIR 50Hz/60Hz power-line frequency notch filter for 1ksps data rate
  - Design FIR 20kHz Low pass filter for 256ksps data rate

ADS127L21

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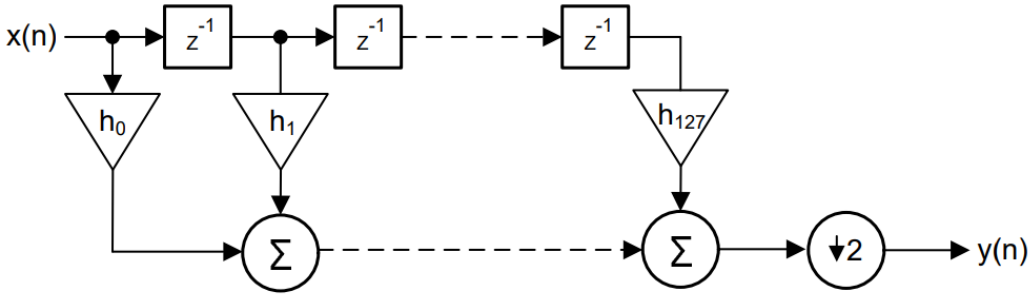
ADS127L21 Finite Input Response (FIR)

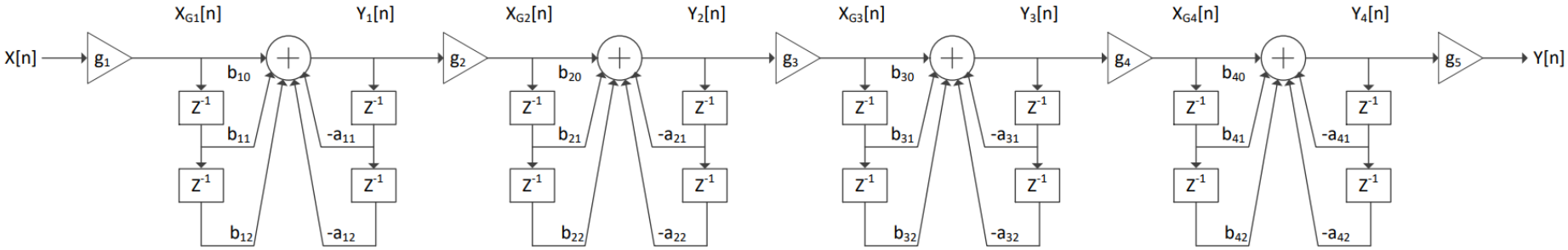
- FIR3 Filter Structure



- 128 coefficients h_0 through h_{127}
- Fixed-point 1.31 format represented as a 32b twos-complement integer
  - Represents decimal numbers in the range from -1 to +0.999999995343
- Note the decimation by 2 after the FIR3 stage; the input data rate will be 2x the final output data rate.

ADS127L21 Infinite Input Response (IIR)

- IIR Filter Structure



- Consists of 4 direct form I bi-quads, or Second order Sections (SOS)
  - Also includes five scaling factors, g_1 through g_5
- Each biquad uses 5 coefficients b_{k0}, b_{k1}, b_{k2}, a_{k1}, a_{k2} , k=1 to 4
- Fixed-point 2.30 format represented as a 32b twos-complement integer
  - Represents decimal numbers in the range from -2 to +1.999999999069

ADS127L21 – convert decimal to fixed-point

- Converting decimal to fixed-point 1.31 format.
  - 32b twos-complement 1.31 fixed-point equivalent of 0.25 decimal
    - $(+0.25)*2^{31}$ = 536,870,912d (0x20000000h)
  - 32b twos-complement 1.31 fixed-point equivalent of -0.25 decimal
    - $(-0.25)*2^{31}$ = -536,870,912d (0xE0000000h)
- Converting decimal to fixed-point 2.30 format.
  - 32b twos-complement 2.30 fixed-point equivalent of 1.25 decimal
    - $(+1.25)*2^{30}$ = 1,342,177,280d (0x50000000h)
  - 32b twos-complement 2.30 fixed-point equivalent of -1.25 decimal
    - $(-1.25)*2^{30}$ = -1,342,177,280d (0xB0000000h)

ADS127L21

- ADS127L21 programmable coefficient filter options
  - Finite Input Response (FIR)
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  - Convert decimal filter coefficients to fixed-point format
- ADS127L21EVM-PDK GUI Filter file format
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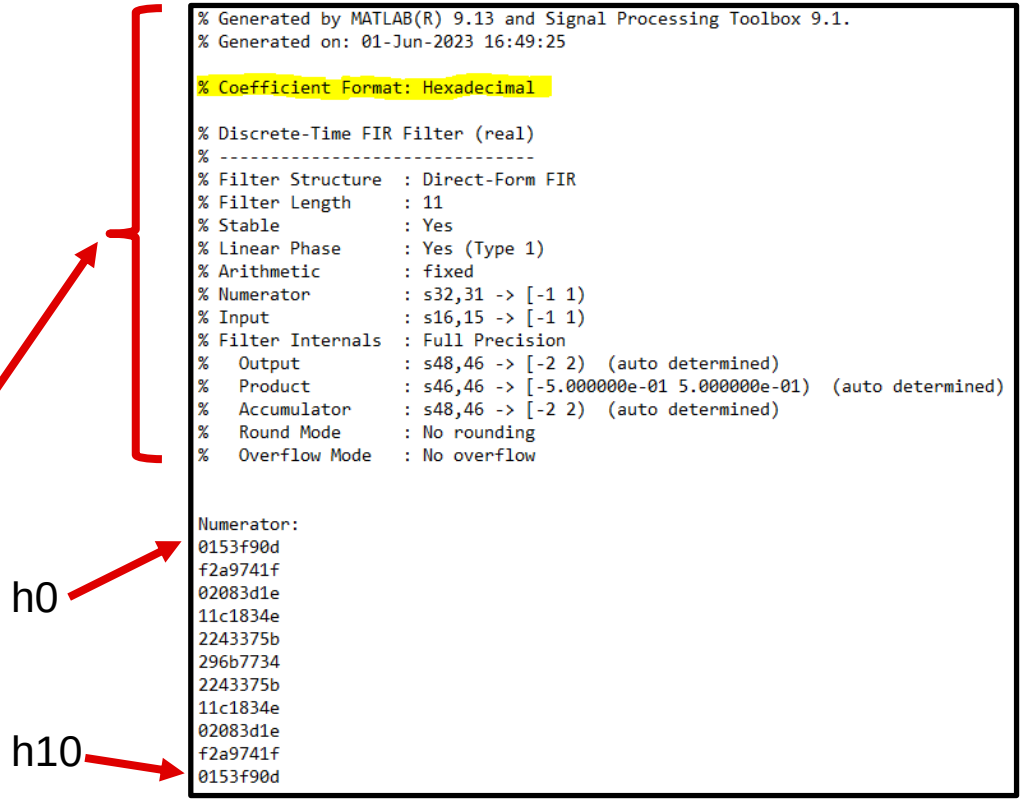
  - Design FIR 20kHz Low pass filter for 256ksps data rate

ADS127L21 – MATLAB® *fcf* file format for FIR

- The ADS127L21EVM-PDK-GUI supports the MATLAB® *fcf* file format
  - 32b coefficients in ASCII Hexadecimal format
  - First coefficient in file is h0, then h1, up to a maximum h127 (128 total)
  - The file does not need to include all coefficients
    - The GUI will autofill unused coefficients with default values (00000000h)
  - Lines beginning with '%' are comments and ignored by the GUI
    - Exception is *Coefficient Format* line



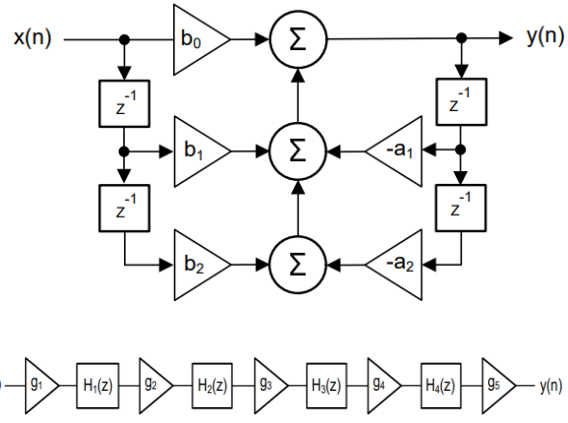
ADS127L21 – MATLAB® *fcf* file format for IIR

- The ADS127L21EVM-PDK-GUI supports the MATLAB® *fcf* file format
  - 32b coefficients in ASCII Hexadecimal format
  - Lines beginning with '%' are comments and ignored
    - Exceptions are *Coefficient Format* and *Number of Sections*
  - MATLAB® includes the a_{k0} coefficients (a_{10}, a_{20}, a_{30}, a_{40})
    - The GUI will ignore the a_{10}, a_{20}, a_{30} and a_{40} coefficients as these are always decimal value +1 (40000000h) and not implemented in the ADS127L21
  - GUI supports less than 4 bi-quads and less than 5 Scale Values
    - GUI will use default values (40000000h) for unused Scale Values
    - GUI will also use default values for unused bi-quads (SOS)

```
% Generated by MATLAB(R) 9.13 and Signal Processing Toolbox 9.1.
% Generated on: 13-Jun-2023 16:42:05

% Coefficient Format: Hexadecimal

% Discrete-Time IIR Filter (real)
% -------------------------------
% Filter Structure    : Direct-Form II, Second-Order Sections
% Number of Sections  : 4
% Stable              : Yes
% Linear Phase        : No
% Arithmetic          : fixed
% Numerator           : s32,30 -> [-2 2)
% Denominator         : s32,30 -> [-2 2)
% Scale Values        : s32,30 -> [-2 2)
% Input               : s16,15 -> [-1 1)
% Section Input       : s16,9 -> [-64 64)
% Section Output      : s16,11 -> [-16 16)
% Output              : s16,11 -> [-16 16)
% State               : s16,15 -> [-1 1)
% Numerator Prod      : s48,45 -> [-4 4)
% Denominator Prod    : s48,45 -> [-4 4)
% Numerator Accum     : s40,35 -> [-16 16)
% Denominator Accum   : s40,35 -> [-16 16)
% Round Mode          : convergent
% Overflow Mode       : wrap
% Cast Before Sum     : true


SOS Matrix:
40000000  85399fc0  40000000  40000000  b8d3e8e9  298b0977
40000000  8a3eef9e  40000000  40000000  85d2a71c  3b45fbdd
40000000  865e7ef2  40000000  40000000  914338f1  305d560b
40000000  886dd1e7  40000000  40000000  bd1a8876  14fc6f65

Scale Values:
35b10ebb
35b10ebb
2f63d50e
2f63d50e
```

ADS127L21 – MATLAB® *fcf* file format for IIR

- The ADS127L21EVM-PDK-GUI supports the MATLAB® *fcf* file format
  - Lines beginning with '%' are comments
  - Coefficients are defined as follows (a_{x0} ignored)



SOS Matrix:

b_{10} b_{11} b_{12} a_{10} a_{11} a_{12}
b_{20} b_{21} b_{22} a_{20} a_{21} a_{22}
b_{30} b_{31} b_{32} a_{30} a_{31} a_{32}
b_{40} b_{41} b_{42} a_{40} a_{41} a_{42}

Scale Values:

g_1
g_2
g_3
g_4
g_5

```
% Number of Sections  : 4
% Stable              : Yes
% Linear Phase        : No
% Arithmetic          : fixed
% Numerator           : s32,30 -> [-2 2)
% Denominator         : s32,30 -> [-2 2)
% Scale Values        : s32,30 -> [-2 2)
% Input               : s16,15 -> [-1 1)
% Section Input       : s16,9 -> [-64 64)
% Section Output      : s16,11 -> [-16 16)
% Output              : s16,11 -> [-16 16)
% State               : s16,15 -> [-1 1)
% Numerator Prod      : s48,45 -> [-4 4)
% Denominator Prod    : s48,45 -> [-4 4)
% Numerator Accum     : s40,35 -> [-16 16)
% Denominator Accum   : s40,35 -> [-16 16)
% Round Mode          : convergent
% Overflow Mode       : wrap
% Cast Before Sum     : true


SOS Matrix:
40000000  85399fc0  40000000  40000000  b8d3e8e9  298b0977
40000000  8a3eef9e  40000000  40000000  85d2a71c  3b45fbdd
40000000  865e7ef2  40000000  40000000  914338f1  305d560b
40000000  886dd1e7  40000000  40000000  bd1a8876  14fc6f65

Scale Values:
35b10ebb
35b10ebb
2f63d50e
2f63d50e
```

ADS127L21 – MATLAB® *fcf* file format

- FIR fcf file format
  - 32b 1.31 coefficients in ASCII Hexadecimal format
  - Unused coefficients should be set to 00000000h
- IIR fcf file format
  - 32b 2.30 coefficients in ASCII Hexadecimal format
  - Unused g_x, b_{10}, b_{20}, b_{30}, and b_{40} coefficients should be set to 40000000h
    - All other unused coefficients should be set to 00000000h.

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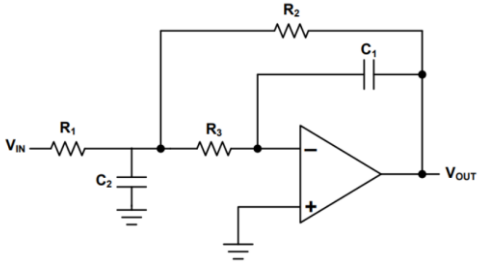
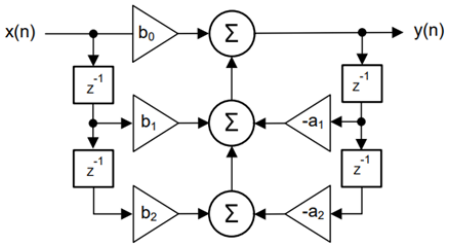
ADS127L21 – IIR filter Bilinear Transform design

- Start with continuous time design in s-domain
  - Can use filter design software, such as WEBENCH® analog filter designer
- Transform to z-domain using Bilinear Transform

$$s = K \cdot \frac{(z-1)}{(z+1)}$$

- Limited to 8th order filter designs
  - IIR filter limited to 4 Bi-quads
- Can transform multi-Feedback design directly to Bi-quad coefficients



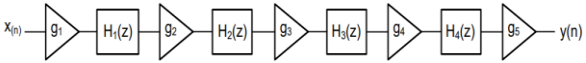


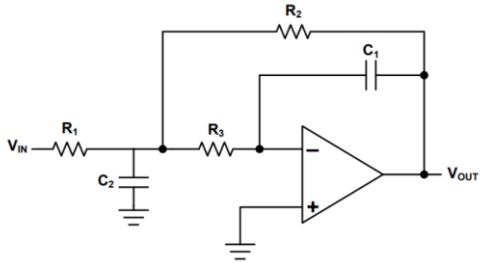
$$H(s) = \frac{B_0 + B_1 \cdot s^{-1} + B_2 \cdot s^{-2}}{A_0 + A_1 \cdot s^{-1} + A_2 \cdot s^{-2}}$$

$$H(z) = \frac{b_0 + b_1 \cdot z^{-1} + b_2 \cdot z^{-2}}{1 + a_1 \cdot z^{-1} + a_2 \cdot z^{-2}}$$

ADS127L21 – IIR filter Bilinear Transform design

- Use Multi-feedback (MFB) topology.
- Set Gain of MFB filter to 1; R1=R2
- Independent gain setting registers (g_X) in ADS127L21 can be used to adjust gain.





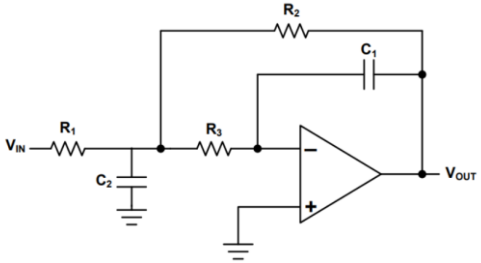
s-domain transfer function

$$H(s) = \frac{-\frac{R_2}{R_1}}{(R_2 \cdot R_3 \cdot C_1 \cdot C_2) \cdot s^2 + \left(R_3 \cdot C_1 + R_2 \cdot C_1 + \frac{R_2 \cdot R_3 \cdot C_1}{R_1}\right) \cdot s^1 + 1}$$

Gain=1
R1=R2

$$|H(s)| = \frac{1}{C_1 \cdot C_2 \cdot R_2 \cdot R_3 \cdot s^2 + (2 \cdot C_1 \cdot R_3 + C_1 \cdot R_2) \cdot s + 1}$$

ADS127L21 – IIR filter Bilinear Transform design



- Set Gain=1, R1=R2
  - Independent gain settings in ADS127L21 can be used if different gain is needed.

s-domain transfer function

$$H(s)=\frac{-\frac{R_2}{R_1}}{\left(R_2\cdot R_3\cdot C_1\cdot C_2\right)\cdot s^2+\left(R_3\cdot C_1+R_2\cdot C_1+\frac{R_2\cdot R_3\cdot C_1}{R_1}\right)\cdot s^1+1}$$

Gain=1
R1=R2

$$|H(s)|=\frac{1}{C_1\cdot C_2\cdot R_2\cdot R_3\cdot s^2+\left(2\cdot C_1\cdot R_3+C_1\cdot R_2\right)\cdot s+1}$$

Equation re-arranged to biquadratic form

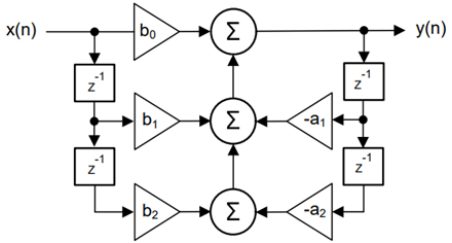
$$|H(s)|=\frac{0+0\cdot s^{-1}+1\cdot s^{-2}}{\left(C_1\cdot C_2\cdot R_2\cdot R_3\right)+\left(2\cdot C_1\cdot R_3+C_1\cdot R_2\right)\cdot s^{-1}+1\cdot s^{-2}}=\frac{B_0+B_1\cdot s^{-1}+B_2\cdot s^{-2}}{A_0+A_1\cdot s^{-1}+A_2\cdot s^{-2}}$$

Bilinear transform, s-domain to z-domain

$$H(s)=\frac{B_0+B_1\cdot s^{-1}+B_2\cdot s^{-2}}{A_0+A_1\cdot s^{-1}+A_2\cdot s^{-2}}\xrightarrow{substitute,\ s=K\cdot\frac{(z-1)}{(z+1)}}H\left(\frac{K\cdot(z-1)}{z+1}\right)=\frac{\left(B_0\cdot K^2+B_1\cdot K+B_2\right)\cdot z^2+\left(2\cdot B_2-2\cdot B_0\cdot K^2\right)\cdot z+B_0\cdot K^2-B_1\cdot K+B_2}{\left(A_0\cdot K^2+A_1\cdot K+A_2\right)\cdot z^2+\left(2\cdot A_2-2\cdot A_0\cdot K^2\right)\cdot z+A_0\cdot K^2-A_1\cdot K+A_2}$$

ADS127L21 – IIR filter Bilinear Transform design

Substitute R and C values, solve for z-domain coefficients



$$H(z)=\frac{b_0+b_1\cdot z^{-1}+b_2\cdot z^{-2}}{1+a_1\cdot z^{-1}+a_2\cdot z^{-2}}$$

$$b_0=\frac{1}{C_1\cdot C_2\cdot R_2\cdot R_3\cdot K^2+\left(2\cdot C_1\cdot R_3+C_1\cdot R_2\right)\cdot K+1}$$

$$b_1=\frac{2}{C_1\cdot C_2\cdot R_2\cdot R_3\cdot K^2+\left(2\cdot C_1\cdot R_3+C_1\cdot R_2\right)\cdot K+1}$$

$$b_2=\frac{1}{C_1\cdot C_2\cdot R_2\cdot R_3\cdot K^2+\left(2\cdot C_1\cdot R_3+C_1\cdot R_2\right)\cdot K+1}$$

$$a_1=\frac{-\left(2\cdot C_1\cdot C_2\cdot R_2\cdot R_3\cdot K^2\right)+2}{C_1\cdot C_2\cdot R_2\cdot R_3\cdot K^2+\left(2\cdot C_1\cdot R_3+C_1\cdot R_2\right)\cdot K+1}$$

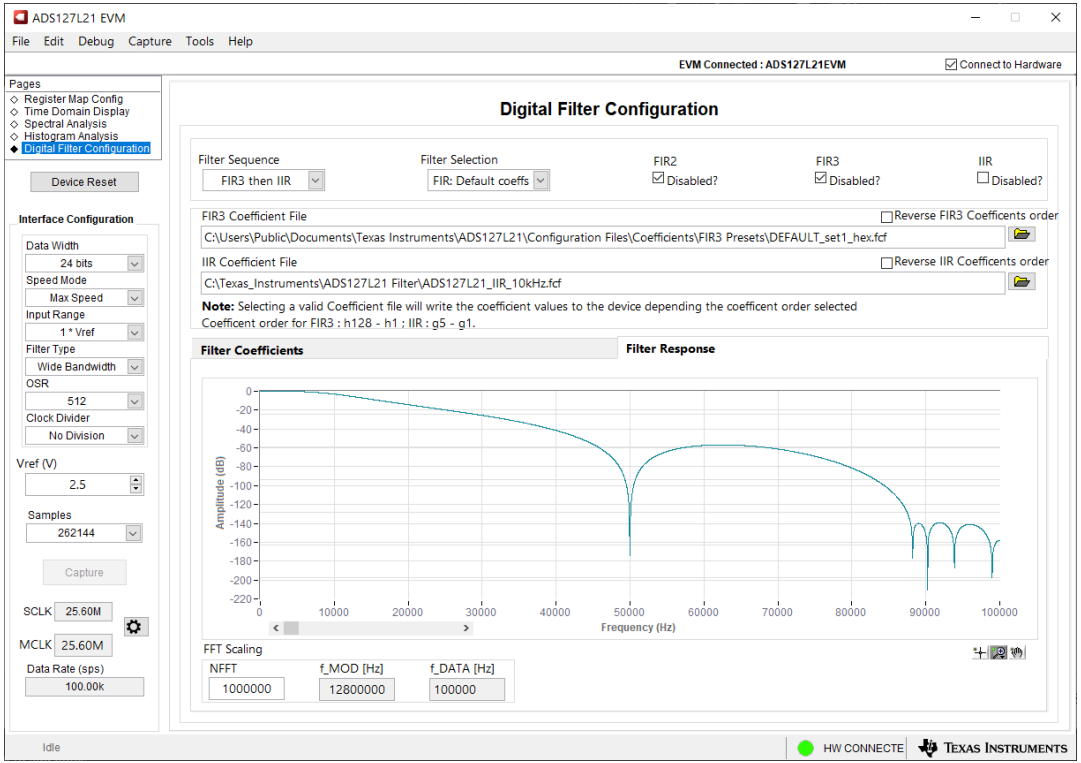
$$a_2=-\frac{2\cdot C_1\cdot K\cdot\left(2\cdot R_3+R_2\right)}{C_1\cdot C_2\cdot R_2\cdot R_3\cdot K^2+\left(2\cdot C_1\cdot R_3+C_1\cdot R_2\right)\cdot K+1}+1$$

Pre-warping filter response
ω_0 is the filter frequency (radians)
T is the sampling period (seconds)

$$K=\frac{\omega_0}{tan\left(\frac{\omega_0\cdot T}{2}\right)}$$

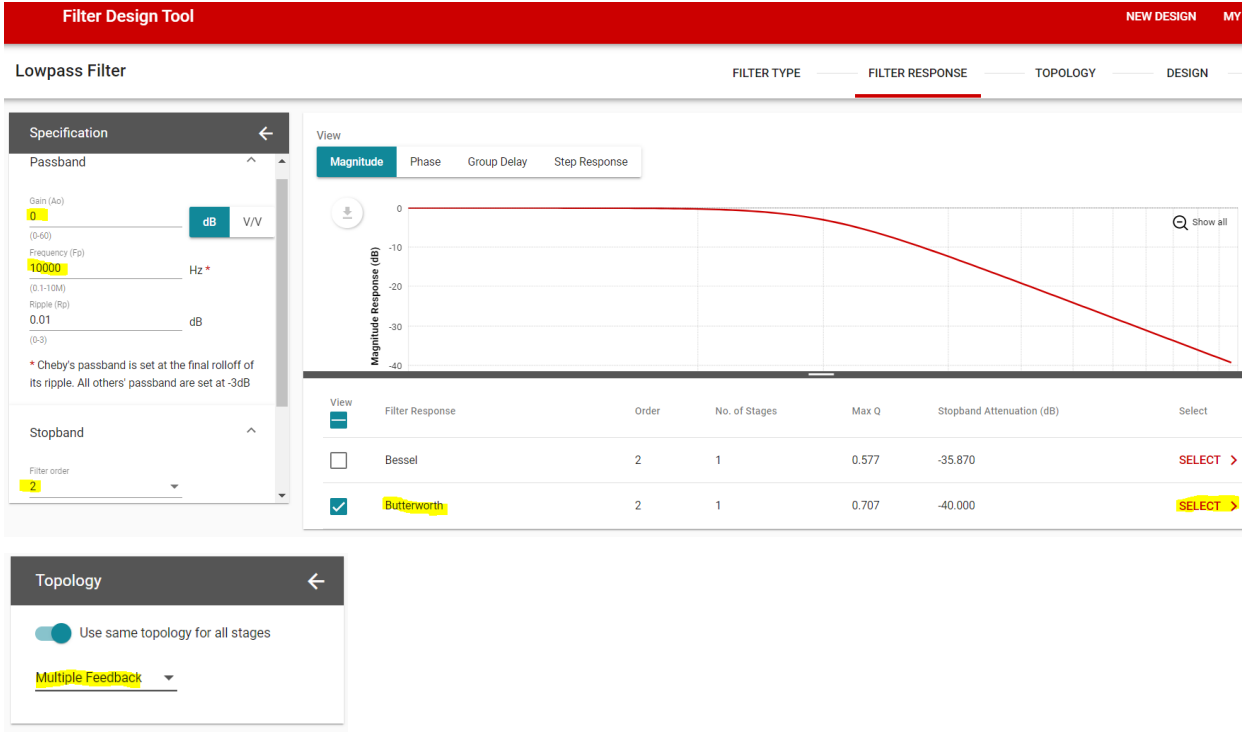
ADS127L21 – 10kHz IIR low-pass filter design

- Filter Design Criteria
  - 10kHz low-pass filter using IIR
  - Target sample rate of 100ksps
  - Example design is 2nd order Butterworth, using a single bi-quad
    - Can be extended to 8th order



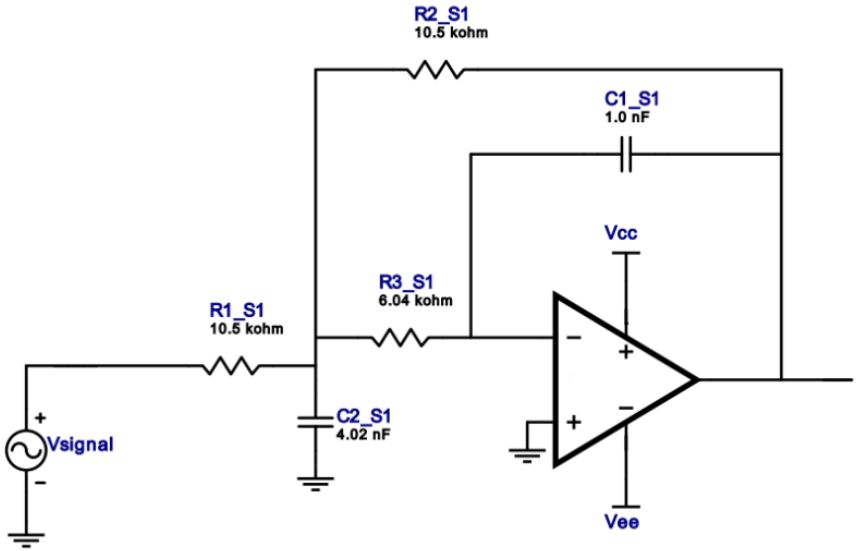
ADS127L21 – 10kHz IIR low-pass filter design

- Design low-pass filter using WEBENCH® analog filter designer
  - Enter 10kHz corner frequency
  - Choose Gain=1, or 0dB
  - Set filter order to 2.
  - Choose Butterworth
  - Select Multiple Feedback Topology



ADS127L21 – 10kHz IIR low-pass filter design

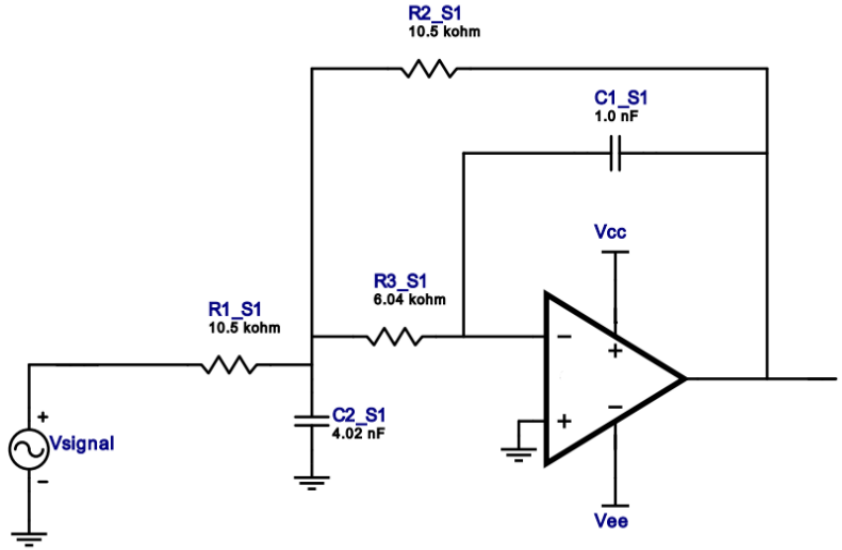
- Design low-pass filter using WEBENCH® analog filter designer
  - Enter 10kHz corner frequency
  - Choose Gain=1, or 0dB
  - Set filter order to 2.
  - Choose Butterworth for this example
  - Select Multiple Feedback Topology
- Software creates design with following values:
  - R1=R2=10.5kΩ
  - R3=6.04kΩ
  - C1=1.0nF
  - C2=4.02nF



ADS127L21 – 10kHz IIR low-pass filter design

- Sample rate 100ksps
  - T=10µs
- F_0=10kHz
  - $\omega_0=2\pi F_0$
- Use pre-warping to match gain and phase at F_0
  - T is the sampling period (seconds)
  - $\omega_0=2\pi F_0$ is the filter frequency (radians)

$$K=\frac{\omega_0}{tan\left(\frac{\omega_0 \cdot T}{2}\right)}$$



ADS127L21 – 10kHz IIR low-pass filter design

$$H(z)=\frac{b_0+b_1\cdot z^{-1}+b_2\cdot z^{-2}}{1+a_1\cdot z^{-1}+a_2\cdot z^{-2}} \qquad T:=10\ \mu s \qquad f:=10\ kHz \qquad \omega_0:=2\cdot\pi\cdot f=62831.8530717959\ \frac{1}{s} \qquad K:=\frac{\omega_0}{\tan\left(\frac{\omega_0\cdot T}{2}\right)}=193376.559809281\ \frac{1}{s}$$

$$b_0:=\frac{1}{C_1\cdot C_2\cdot R_2\cdot R_3\cdot K^2+\left(2\cdot C_1\cdot R_3+C_1\cdot R_2\right)\cdot K+1}=0.067113602521748 \qquad b_{0d}:=\text{round}\left(b_0\cdot 2^{30}\right)=72062682$$

$$b_1:=\frac{2}{C_1\cdot C_2\cdot R_2\cdot R_3\cdot K^2+\left(2\cdot C_1\cdot R_3+C_1\cdot R_2\right)\cdot K+1}=0.134227205043497 \qquad b_{1d}:=\text{round}\left(b_1\cdot 2^{30}\right)=144125364$$

$$b_2:=\frac{1}{C_1\cdot C_2\cdot R_2\cdot R_3\cdot K^2+\left(2\cdot C_1\cdot R_3+C_1\cdot R_2\right)\cdot K+1}=0.067113602521748 \qquad b_{2d}:=\text{round}\left(b_2\cdot 2^{30}\right)=72062682$$

$$a_0:=1 \qquad a_{0d}:=\text{round}\left(a_0\cdot 2^{30}\right)=1073741824$$

$$a_1:=\frac{-\left(2\cdot C_1\cdot C_2\cdot R_2\cdot R_3\cdot K^2\right)+2}{C_1\cdot C_2\cdot R_2\cdot R_3\cdot K^2+\left(2\cdot C_1\cdot R_3+C_1\cdot R_2\right)\cdot K+1}=-1.14545018755864 \qquad a_{1d}:=\text{round}\left(a_1\cdot 2^{30}\right)=-1229917774$$

$$a_2:=1-\frac{2\cdot C_1\cdot K\cdot\left(2\cdot R_3+R_2\right)}{C_1\cdot C_2\cdot R_2\cdot R_3\cdot K^2+\left(2\cdot C_1\cdot R_3+C_1\cdot R_2\right)\cdot K+1}=0.413904597645629 \qquad a_{2d}:=\text{round}\left(a_2\cdot 2^{30}\right)=444426678$$

Coeff	ASCII HEX
b0	044b96d9
b1	08972db3
b2	044b96d9
a0	40000000
a1	b6b0f1b3
a2	1a7d69b5

Calculate z-domain filter coefficients

Results are in floating point decimal

Convert to 2.30 fixed point decimal

Convert to 2.30 fixed point hexadecimal

ADS127L21 – 10kHz IIR low-pass filter design

- The ADS127L21EVM-PDK-GUI supports the MATLAB® *fcf* file format
  - 32b coefficients in fixed point 2.30 ASCII Hexadecimal format
  - The following lines need to be added in addition to the coefficients
    - % Coefficient Format: Hexadecimal
    - % Number of Sections : 4
  - Can use any text editor to create the file, such as Notepad.
  - Save text file with *.fcf extension, ADS127L21_IIR_10kHz.fcf

Coeff	ASCII HEX
b0	044b96d9
b1	08972db3
b2	044b96d9
a0	40000000
a1	b6b0f1b3
a2	1a7d69b5

SOS Matrix:

b_{10} b_{11} b_{12} a_{10} a_{11} a_{12}
b_{20} b_{21} b_{22} a_{20} a_{21} a_{22}
b_{30} b_{31} b_{32} a_{30} a_{31} a_{32}
b_{40} b_{41} b_{42} a_{40} a_{41} a_{42}

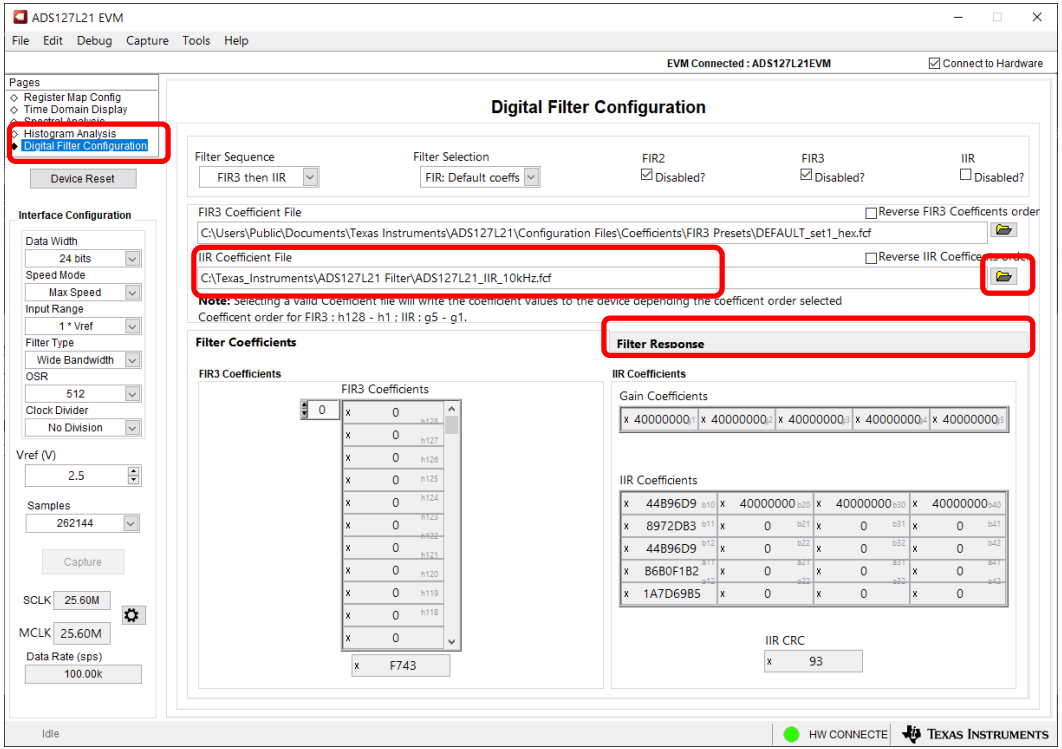
Scale Values:

g_1
g_2
g_3
g_4
g_5

```
% Coefficient Format: Hexadecimal
% Number of Sections  : 4

SOS Matrix:
044b96d9  08972db3  044b96d9  40000000  b6b0f1b2  1a7d69b5
40000000  00000000  00000000  40000000  00000000  00000000
40000000  00000000  00000000  40000000  00000000  00000000
40000000  00000000  00000000  40000000  00000000  00000000

Scale Values:
40000000
40000000
40000000
40000000
40000000
```

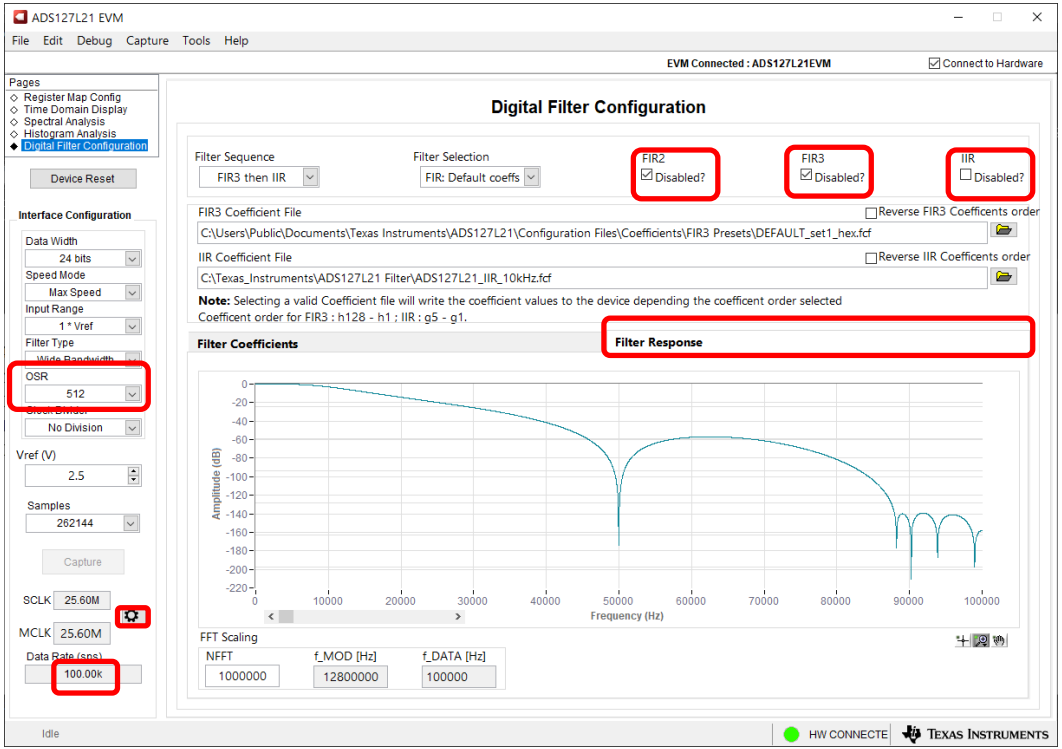
ADS127L21 – 10kHz IIR low-pass filter design

1. Start the ADS127L21EVM-PDK-GUI software and click on the Digital Filter Configuration page
2. Click the file button for the IIR coefficient File
3. Navigate to the *.fcf file just created in the text editor and select file
4. Click on the Filter Response tab



ADS127L21 – 10kHz IIR low-pass filter design

5. Set the sample rate to 100ksps
   - Set OSR to 512
6. Click, un-check, the IIR Disabled box
7. Click, check, the FIR2 and FIR3 boxes
8. Set the external MCLK to 25.6M (EVM requires external clock source set to 25.6MHz)
9. The combined IIR filter response, FIR1 and SINC5 response is now plotted and ready for use.

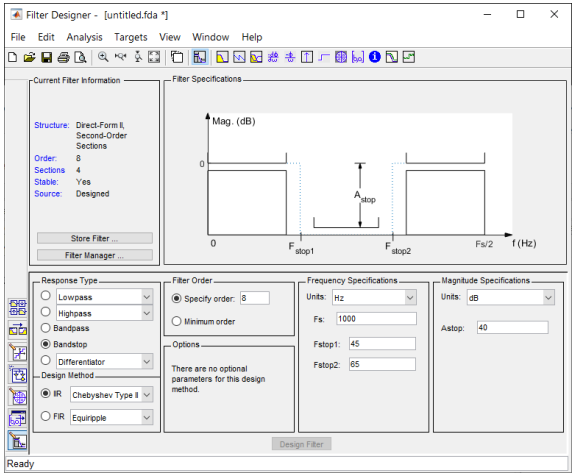


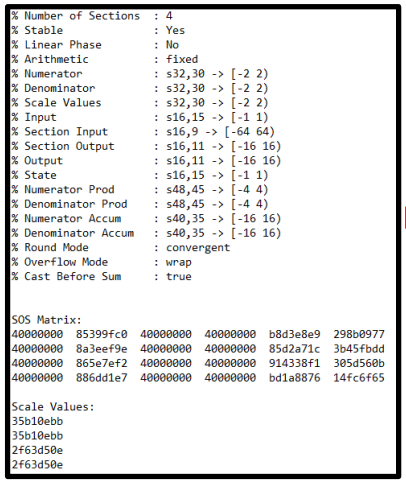
ADS127L21

- ADS127L21 programmable coefficient filter options
  - Finite Input Response (FIR)
  - Infinite Input Response (IIR)
  - Convert decimal filter coefficients to fixed-point format
- ADS127L21EVM-PDK GUI Filter file format
  - MATLAB® *'fcf'* file format
- IIR filter design using Bilinear transform
  - Design 10kHz 2nd order filter starting with MFB topology
  - Create *'fcf'* file and evaluate using ADS127L21EVM-PDK hardware
- Filter design using MATLAB® Filter Designer
  - MATLAB® Filter Design overview
  - Design IIR 50Hz/60Hz power-line frequency notch filter for 1ksps data rate
  - Design FIR 20kHz Low pass filter for 256ksps data rate

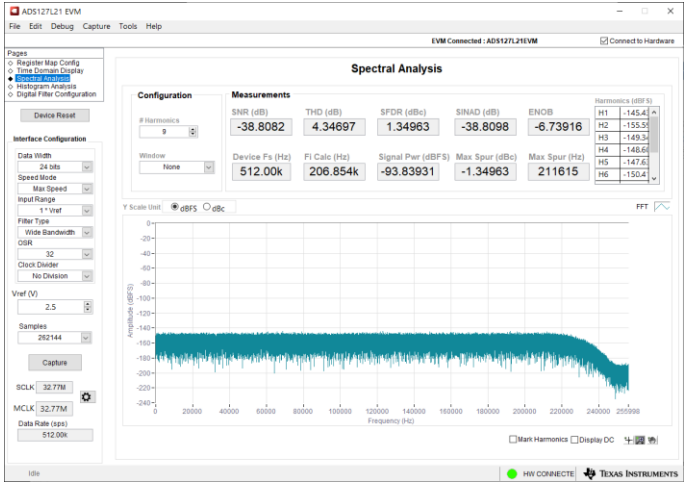
ADS127L21 – MATLAB® filter design overview

- MATLAB® is the preferred tool to directly design IIR and FIR filters
  - The following examples use MATLAB® version R2022b, but any version can be used
  - In addition to the MATLAB® software, you will need the following add-on packages
    - Signal Processing Toolbox, which includes the Filter Designer tool
    - Fixed-Point Designer, which converts to fixed point coefficients and ASCII HEX exports



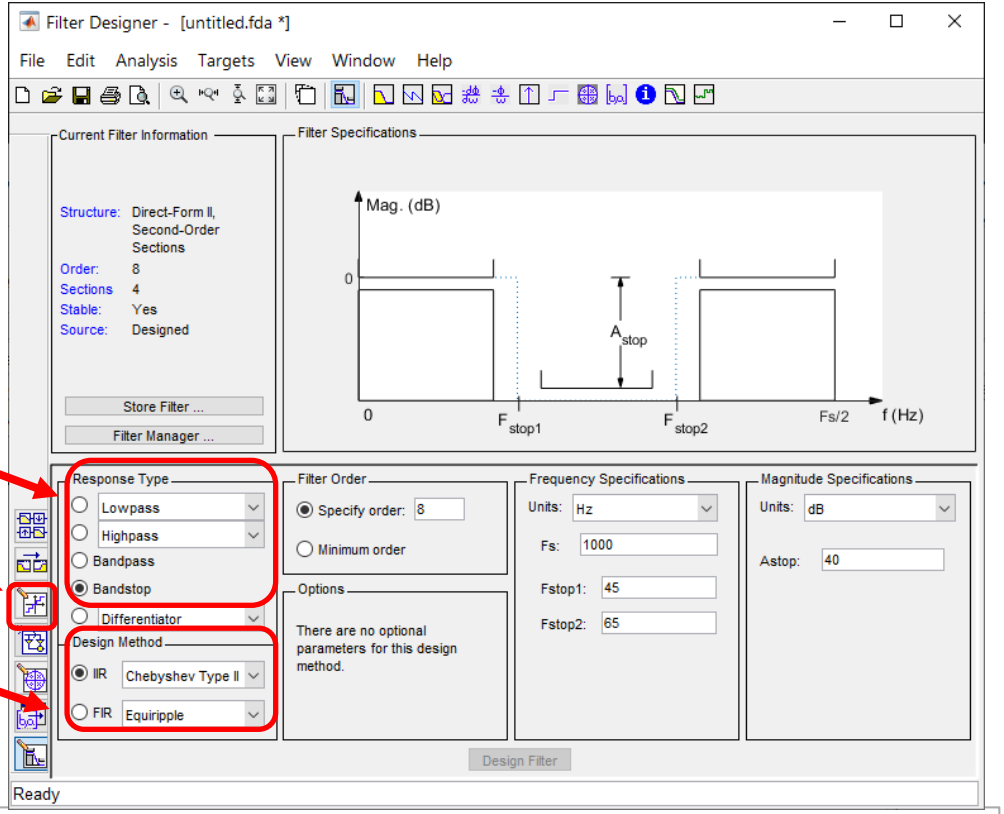


```
% Number of Sections     : 4
% Stable                 : Yes
% Linear Phase           : No
% Arithmetic             : fixed
% Numerator              : s32,30 -> [-2 2)
% Denominator            : s32,30 -> [-2 2)
% Scale Values           : s32,30 -> [-2 2)
% Input                  : s16,15 -> [-1 1)
% Section Input          : s16,9 -> [-64 64)
% Section Output         : s16,11 -> [-16 16)
% Output                 : s16,11 -> [-16 16)
% State                  : s16,15 -> [-1 1)
% Numerator Prod         : s48,45 -> [-4 4)
% Denominator Prod       : s48,45 -> [-4 4)
% Numerator Accum        : s40,35 -> [-16 16)
% Denominator Accum      : s40,35 -> [-16 16)
% Round Mode             : convergent
% Overflow Mode          : wrap
% Cast Before Sum        : true


SOS Matrix:
40000000  85399fc0  40000000  40000000  b8d3e8e9  298b0977
40000000  8a3eef9e  40000000  40000000  85d2a71c  3b45fbdd
40000000  865e7ef2  40000000  40000000  914338f1  305d560b
40000000  886dd1e7  40000000  40000000  bd1a8876  14fc6f65

Scale Values:
35b10ebb
35b10ebb
2f63d50e
2f63d50e
```



ADS127L21 – MATLAB® filter design overview

- Filter Designer is a graphical design tool that enables the creation of multiple filter types.
  - Supports creation of Lowpass, Highpass, Bandpass, and Bandstop profiles
  - Quantization of filter coefficients and export to ADS127L21EVM-PDK-GUI
  - The tool supports creation of both IIR and FIR filter types

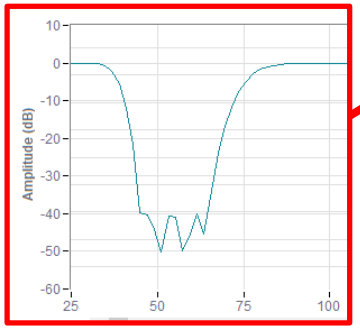


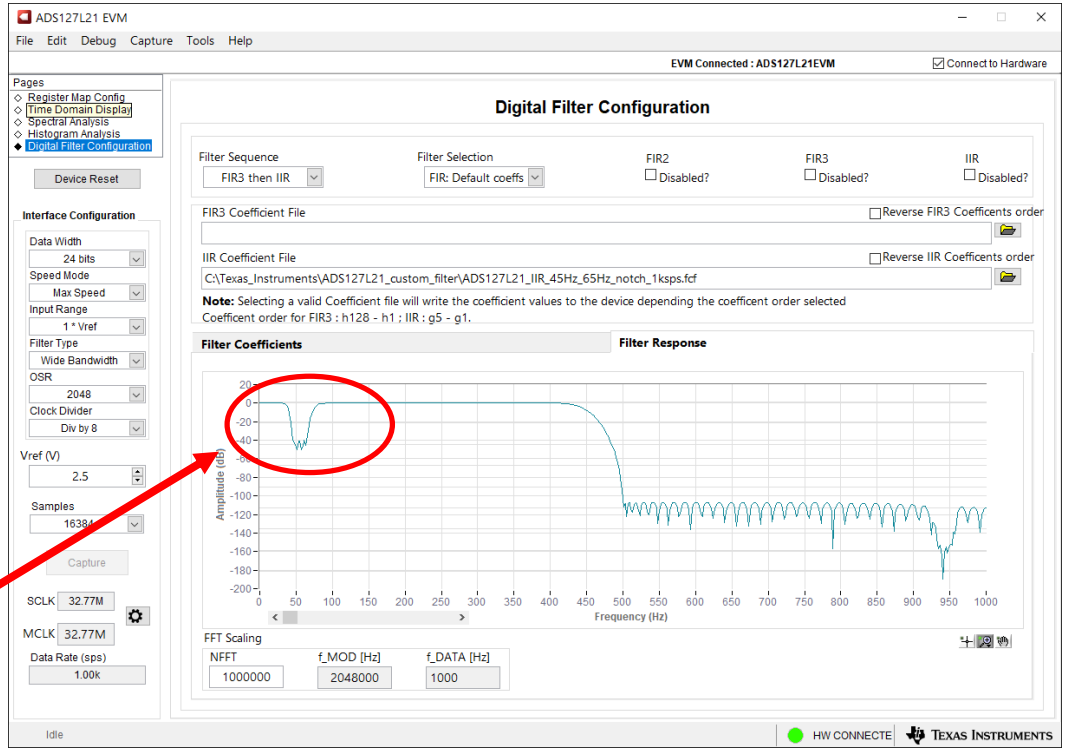
ADS127L21

- ADS127L21 programmable coefficient filter options
  - Finite Input Response (FIR)
  - Infinite Input Response (IIR)
  - Convert decimal filter coefficients to fixed-point format
- ADS127L21EVM-PDK GUI Filter file format
  - MATLAB® *'fcf'* file format
- IIR filter design using Bilinear transform
  - Design 10kHz 2nd order filter starting with MFB topology
  - Create *'fcf'* file and evaluate using ADS127L21EVM-PDK hardware
- Filter design using MATLAB® Filter Designer
  - MATLAB® Filter Design overview
  - Design IIR 50Hz/60Hz power-line frequency notch filter for 1ksps data rate
  - Design FIR 20kHz Low pass filter for 256ksps data rate

ADS127L21 – 50/60Hz IIR notch filter design

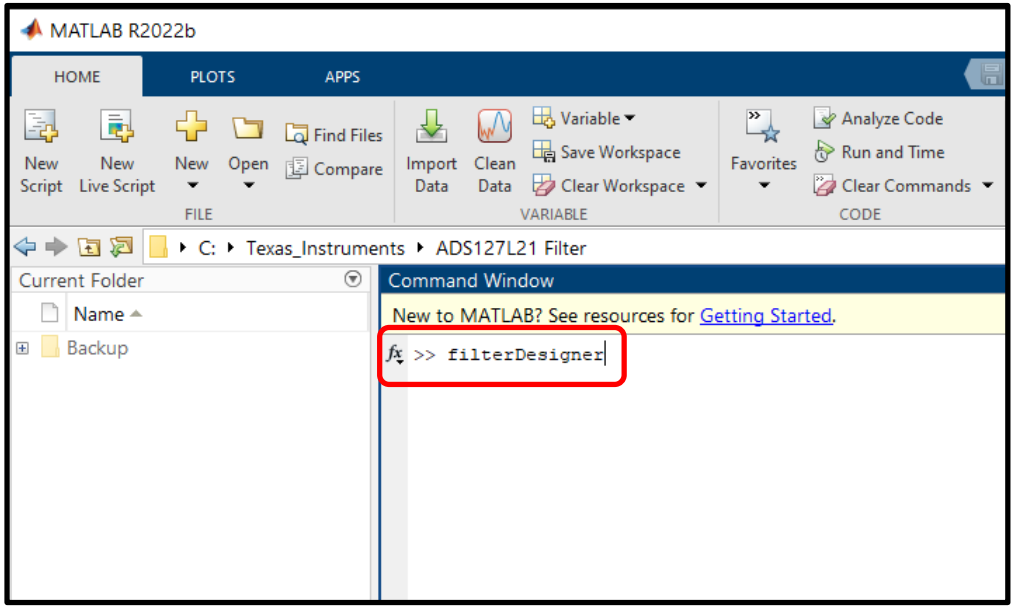
- Filter Design Criteria
  - 50/60Hz notch filter using IIR
  - Target sample rate of 1ksps
  - Limited to 8th order, or 4 Second-order-Sections
  - Filter Designer tool creates filter notch from 45Hz to 65Hz with 40dB of attenuation





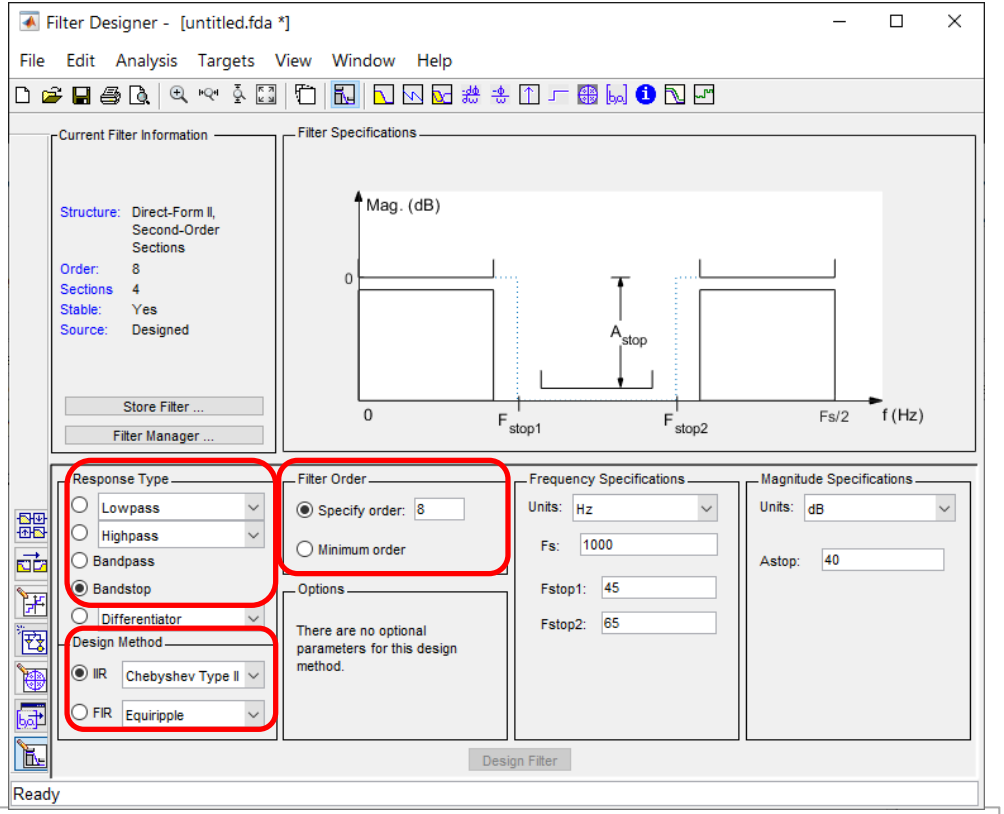
ADS127L21 – 50/60Hz IIR notch filter design

1. Open MATLAB®
2. In the Command Window, type filterDesigner and press Enter
   - This will launch the Filter Designer tool that is part of the Signal Processing Toolbox
3. Wait for Filter Designer to load



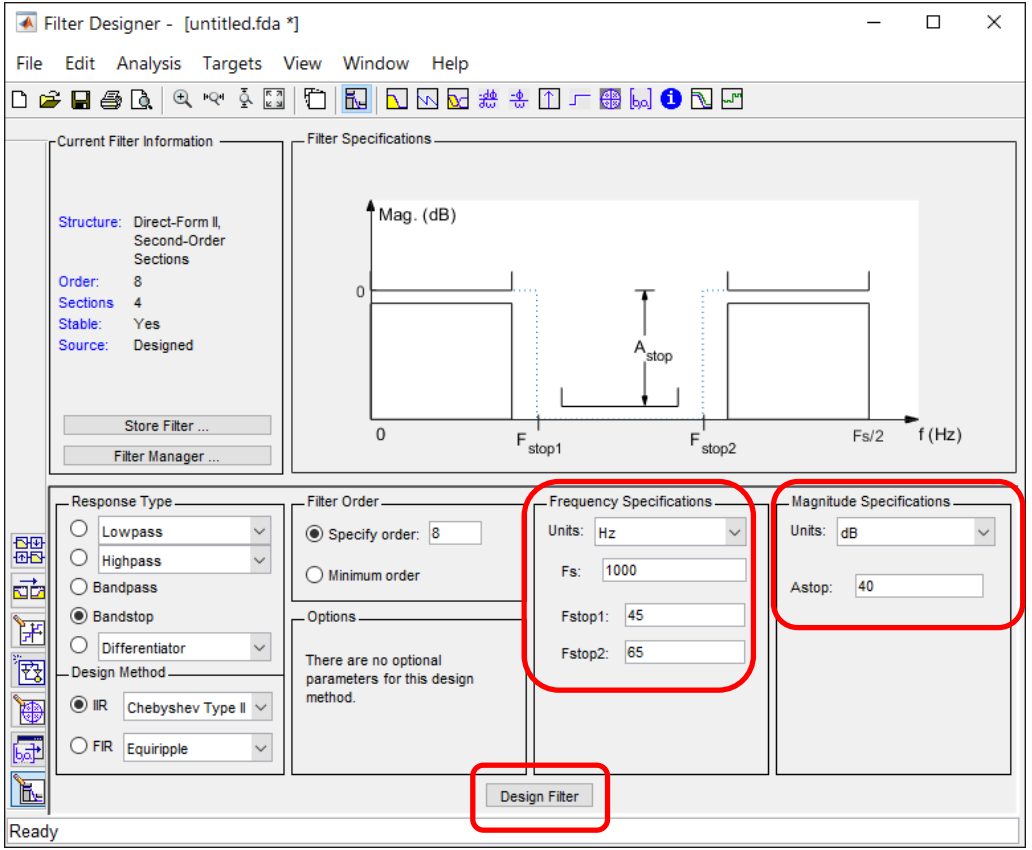
ADS127L21 – 50/60Hz IIR notch filter design

4. Select Bandstop under Response Type
5. Select IIR and Chebyshev Type II under Design Method
6. Select Specify order under Filter Order and enter 8
   - ADS127L21 IIR filter uses 4 bi-quad sections (or Second order Sections), for a total filter order of 8



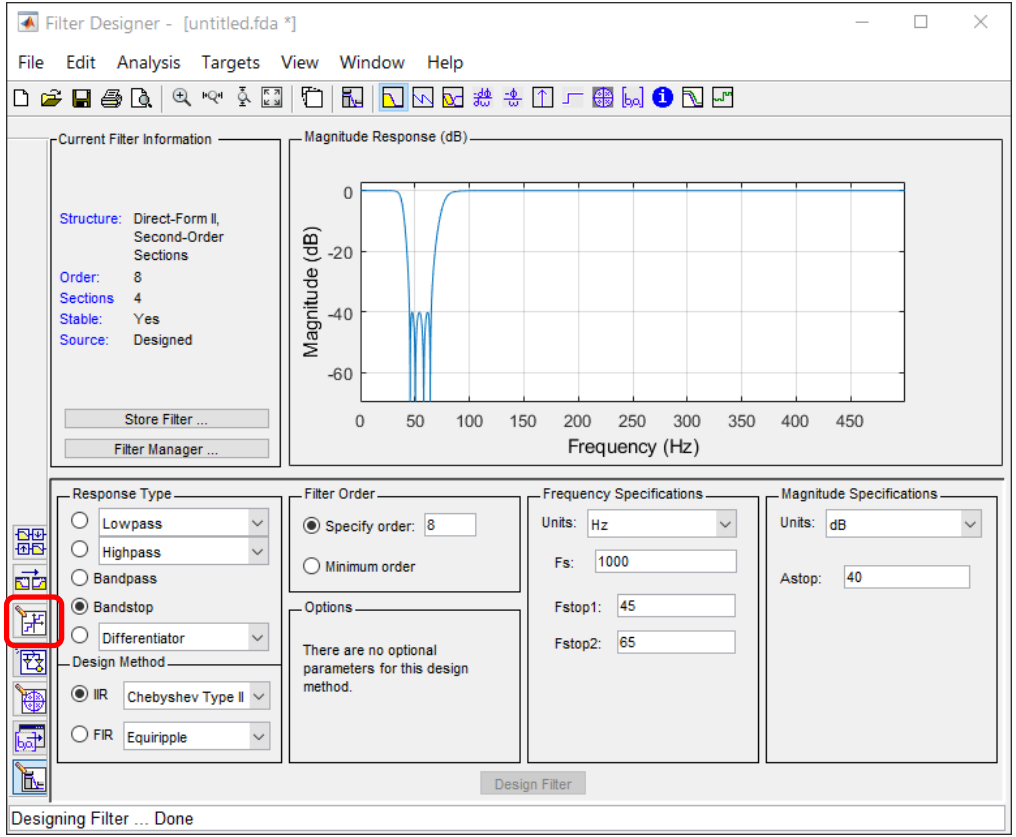
ADS127L21 – 50/60Hz IIR notch filter design

7. Enter Fs: 1000 (Hz) under Frequency Specifications
8. Enter Fstop1: 45 (Hz) and Fstop2: 65 (Hz) under Frequency Specifications
   - 45Hz to 65Hz covers variation in line frequency
9. Enter Astop: 40 (dB) under Magnitude Specifications
   - Higher attenuation results in wider transition bands
10. Click the ‘Design Filter’ button.



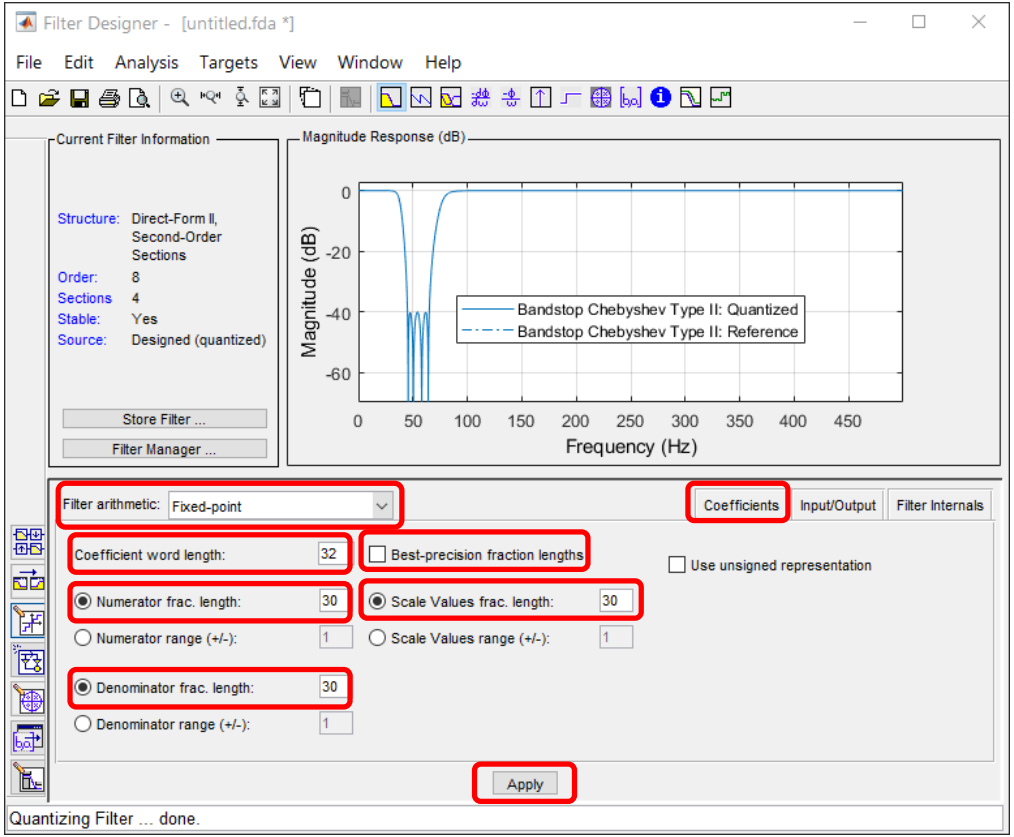
ADS127L21 – 50/60Hz IIR notch filter design

11. Filter Designer will now display the Magnitude response
    - You can now make adjustments and recalculate the response if needed
12. Click the ‘Set quantization parameters’ button 
    - The initial design uses floating point math. The quantization tool enables fixed point design



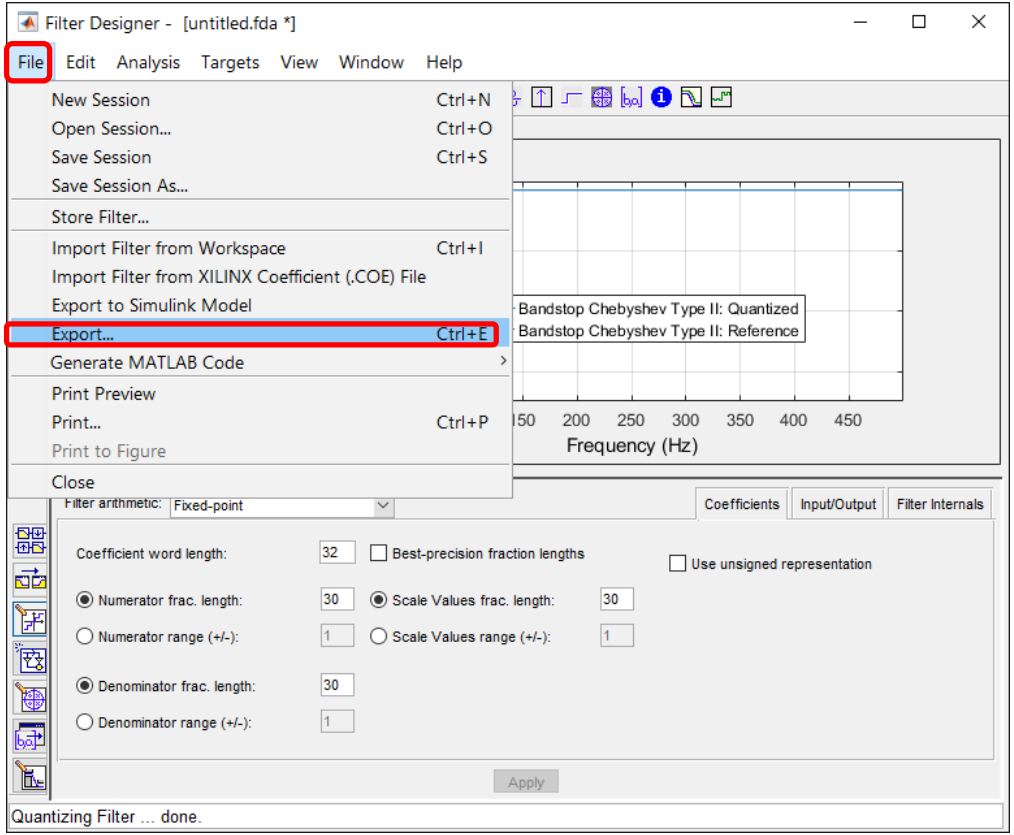
ADS127L21 – 50/60Hz IIR notch filter design

13. Select Fixed-point on the Filter arithmetic selection
14. Enter 32 for Coefficient word length in the Coefficients tab
15. Uncheck the Best-precision fraction lengths box
16. Enter 30 for:
    - Numerator fraction length
    - Denominator fraction length
    - Scale Values fraction length
17. Click the ‘Apply’ button



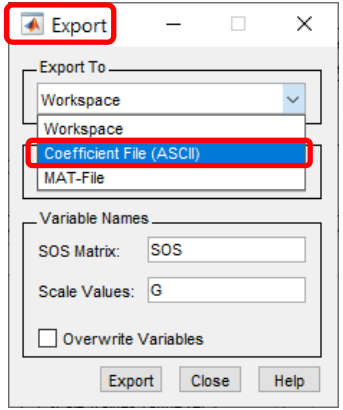
ADS127L21 – 50/60Hz IIR notch filter design

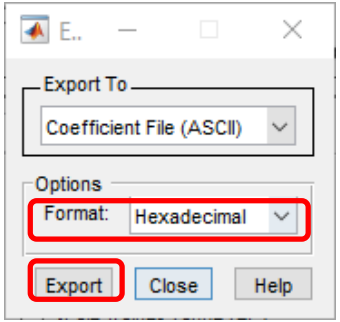
18. The Magnitude Response display now plots both the original floating point (Reference) and fixed-point (Quantized) results.
19. Select File->Export



ADS127L21 – 50/60Hz IIR notch filter design

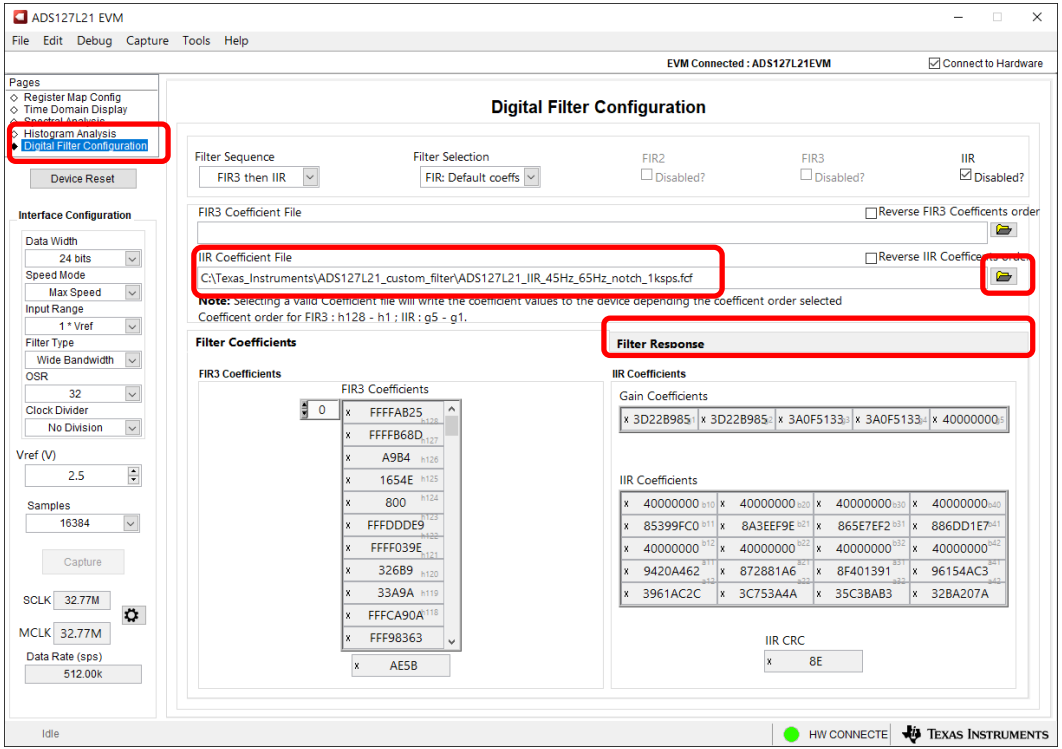
20. Under Export pop-up window, Export To, select Coefficient File (ASCII)
21. Under Options, Format, select Hexadecimal
22. Click the Export button
23. Choose directory and file name, save as default *.fcf file name
    - ADS127L21_IIR_45Hz_65Hz_notch_1ksps.fcf





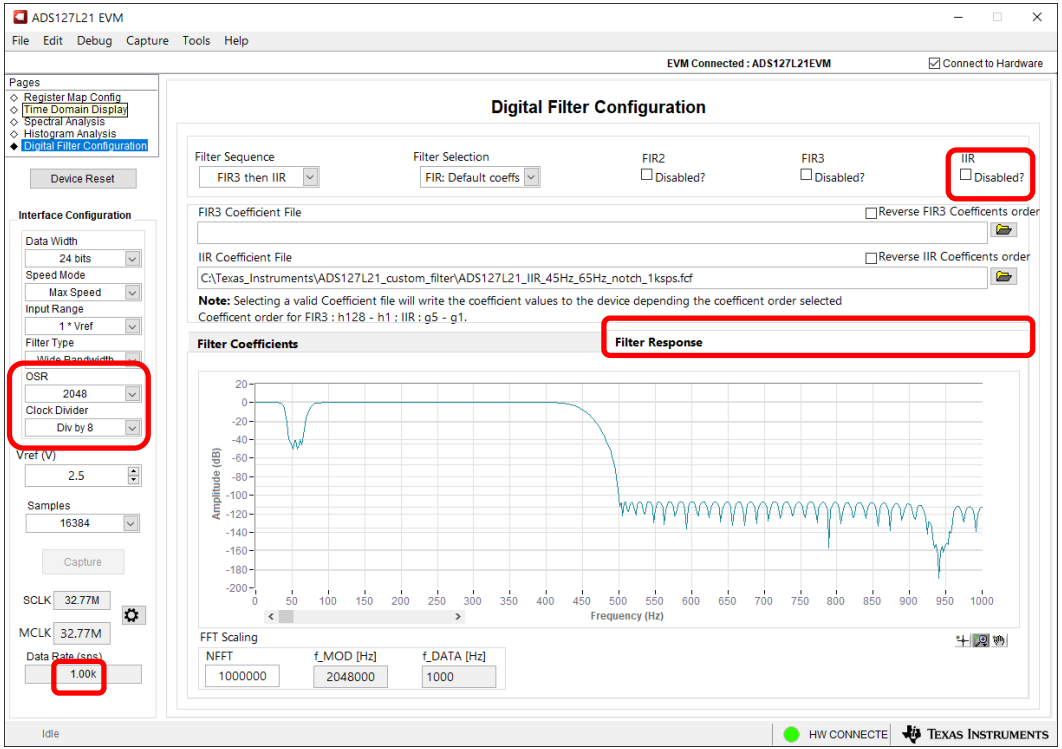
ADS127L21 – 50/60Hz IIR notch filter design

24. Start the ADS127L21EVM-PDK-GUI software and click on the Digital Filter Configuration page
25. Click the file button for the IIR coefficient File
26. Navigate to the *.fcf file just created in MATLAB® and select file
27. Click on the Filter Response tab



ADS127L21 – 50/60Hz IIR notch filter design

28. Set the sample rate to 1ksps
    - Set OSR to 2048
    - Set Clock Divider to Div by 8
29. Click, un-check, the IIR Disabled box
30. The combined FIR Wideband filter and IIR filter response are now plotted and ready for use.

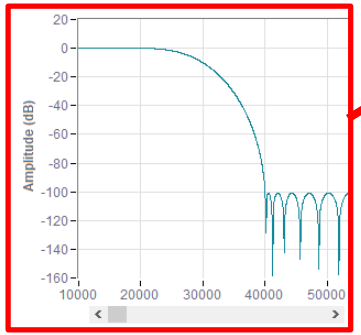


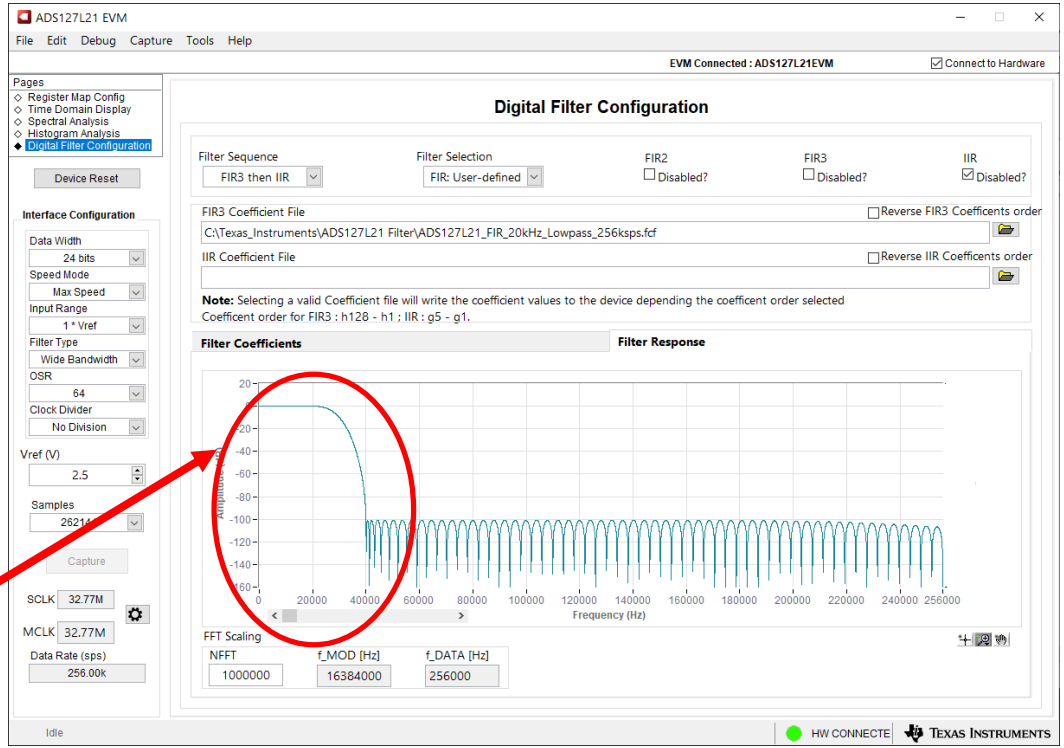
ADS127L21

- ADS127L21 programmable coefficient filter options
  - Finite Input Response (FIR)
  - Infinite Input Response (IIR)
  - Convert decimal filter coefficients to fixed-point format
- ADS127L21EVM-PDK GUI Filter file format
  - MATLAB® *'fcf'* file format
- IIR filter design using Bilinear transform
  - Design 10kHz 2nd order filter starting with MFB topology
  - Create *'fcf'* file and evaluate using ADS127L21EVM-PDK hardware
- Filter design using MATLAB® Filter Designer
  - MATLAB® Filter Design overview
  - Design IIR 50Hz/60Hz power-line frequency notch filter for 1ksps data rate
  - Design FIR 20kHz Low pass filter for 256ksps data rate

ADS127L21 – 20kHz FIR lowpass filter design

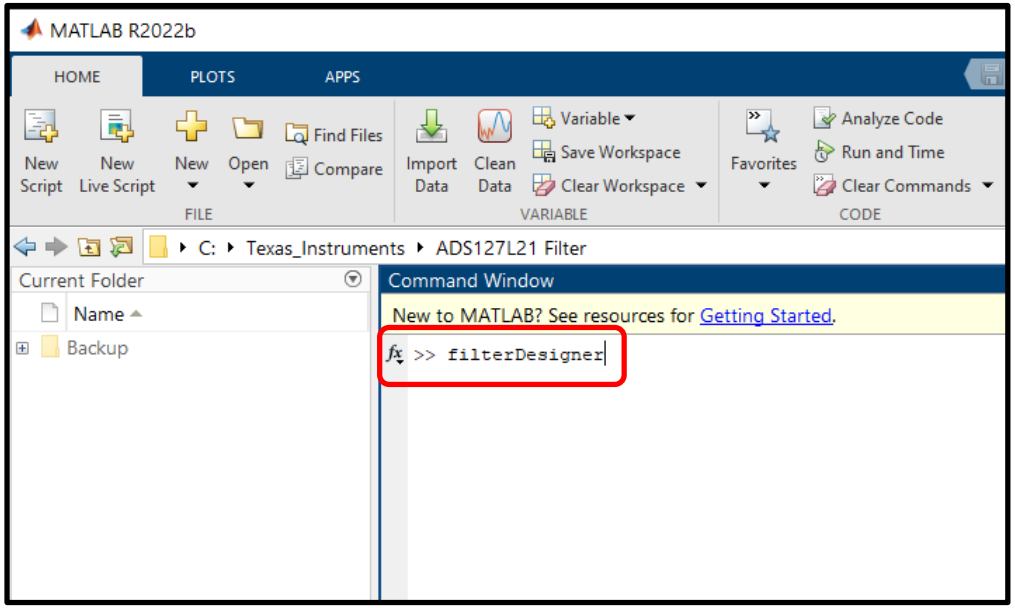
- Filter Design Criteria
  - 20kHz lowpass filter using FIR
  - Target sample rate of 256ksps
  - Limited to maximum of 128 coefficients
  - Filter Designer tool creates 20kHz lowpass with ≥100dB of attenuation





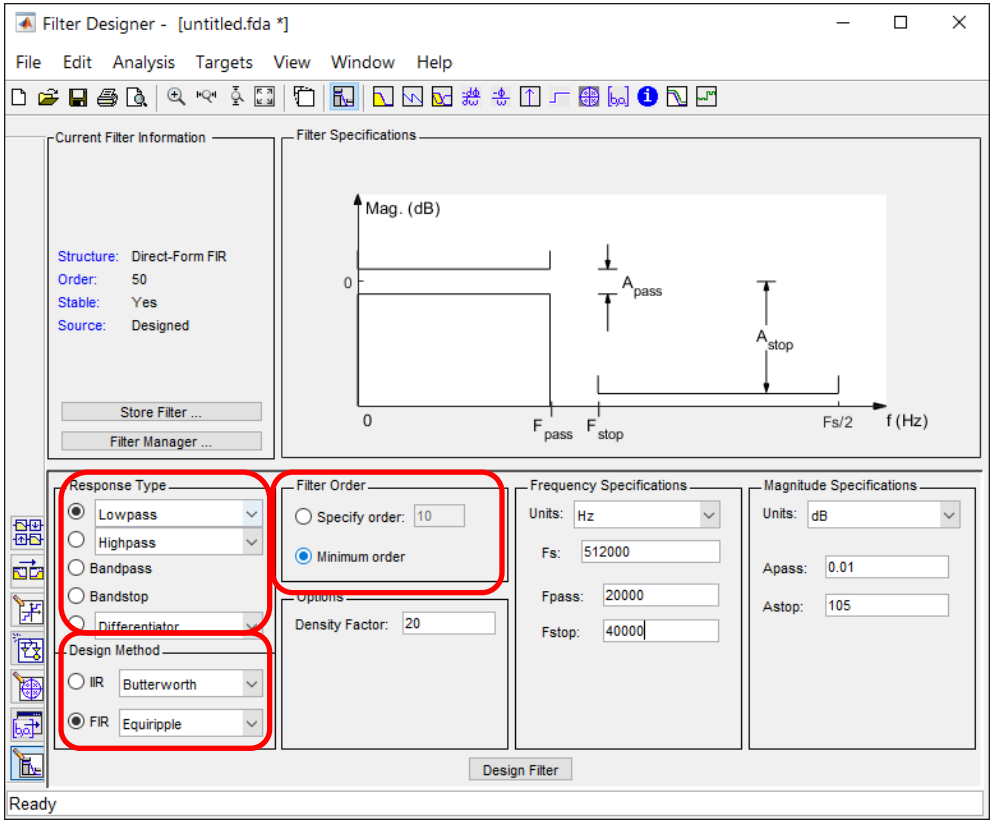
ADS127L21 – 20kHz FIR lowpass filter design

1. Open MATLAB®
2. In the Command Window, type filterDesigner and press Enter
   - This will launch the Filter Designer tool that is part of the Signal Processing Toolbox
3. Wait for Filter Designer to load



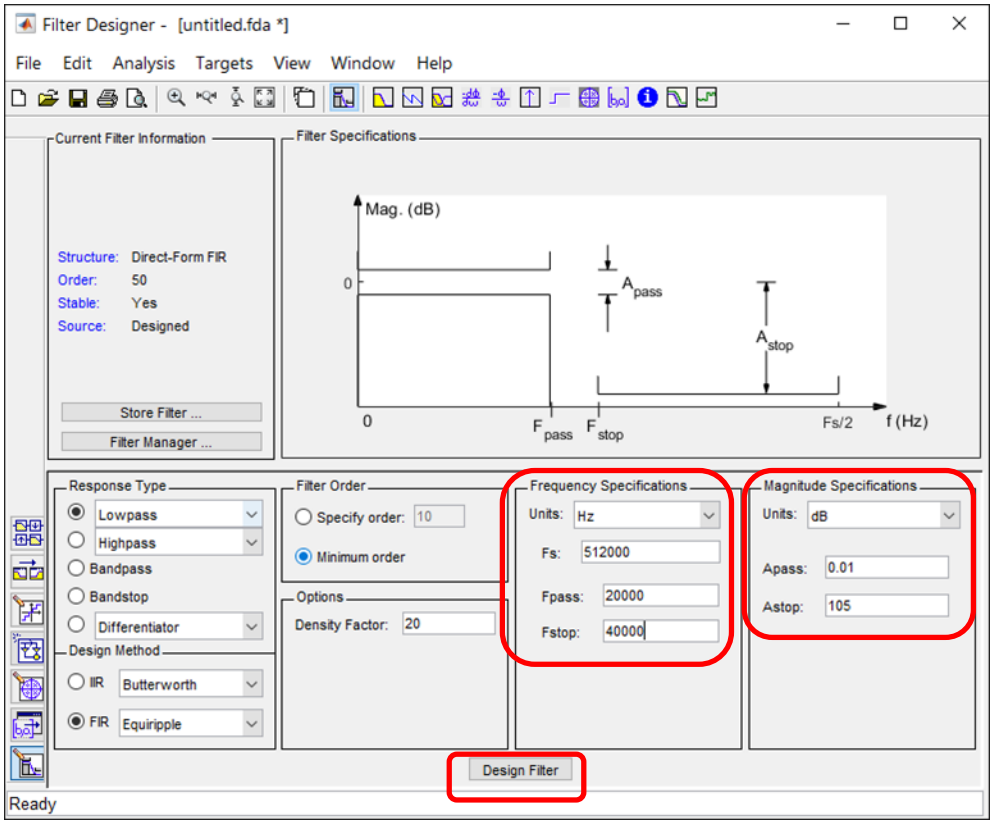
ADS127L21 – 20kHz FIR lowpass filter design

4. Select Lowpass under Response Type
5. Select FIR and Equiripple under Design Method
6. Select Minimum order under Filter Order
   - This option allows setting of desired passband ripple and stopband attenuation
   - Requires iterating transition bandwidth (Fpass-Fstop) until order is ≤127, or number of coefficients ≤128



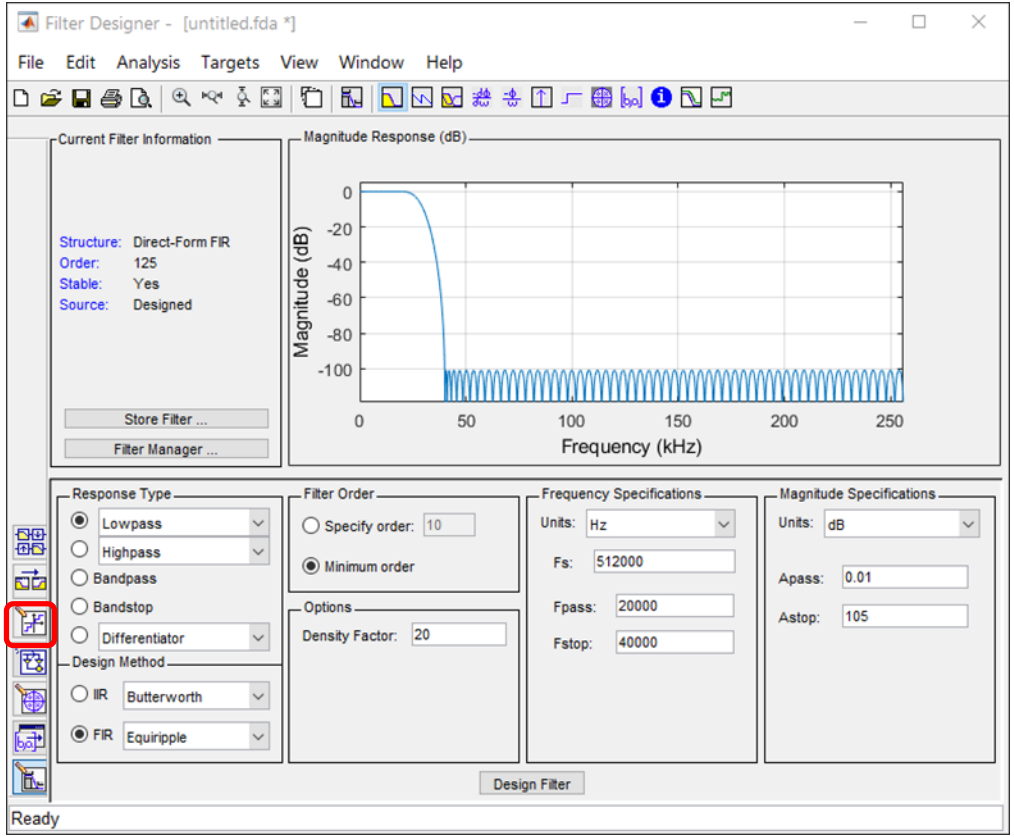
ADS127L21 – 20kHz FIR lowpass filter design

7. Enter Fs: 512000 (Hz) under Frequency Specifications
   - Final sample rate is 256kHz, Fs=2*256kHz to account for 2x decimation
8. Enter Fpass: 20000 (Hz) and Fstop: 40000 (Hz) under Frequency Specifications
9. Enter Apass: 0.01 and Astop: 105 (dB) under Magnitude Specifications
10. Click the ‘Design Filter’ button.



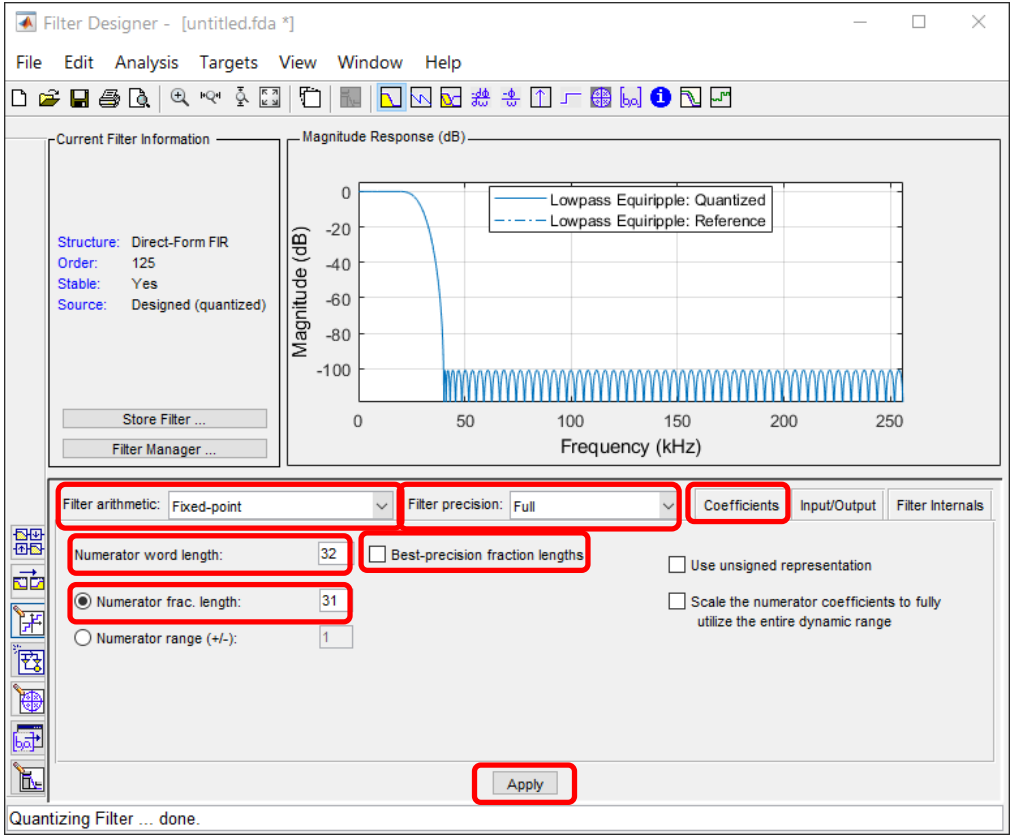
ADS127L21 – 20kHz FIR lowpass filter design

11. Filter Designer will now display the Magnitude response
    - You can now make adjustments and recalculate the response if needed
    - Filter Order = 125 (<128)
12. Click the ‘Set quantization parameters’ button 
    - The initial design uses floating point math. The quantization tool enables fixed point design



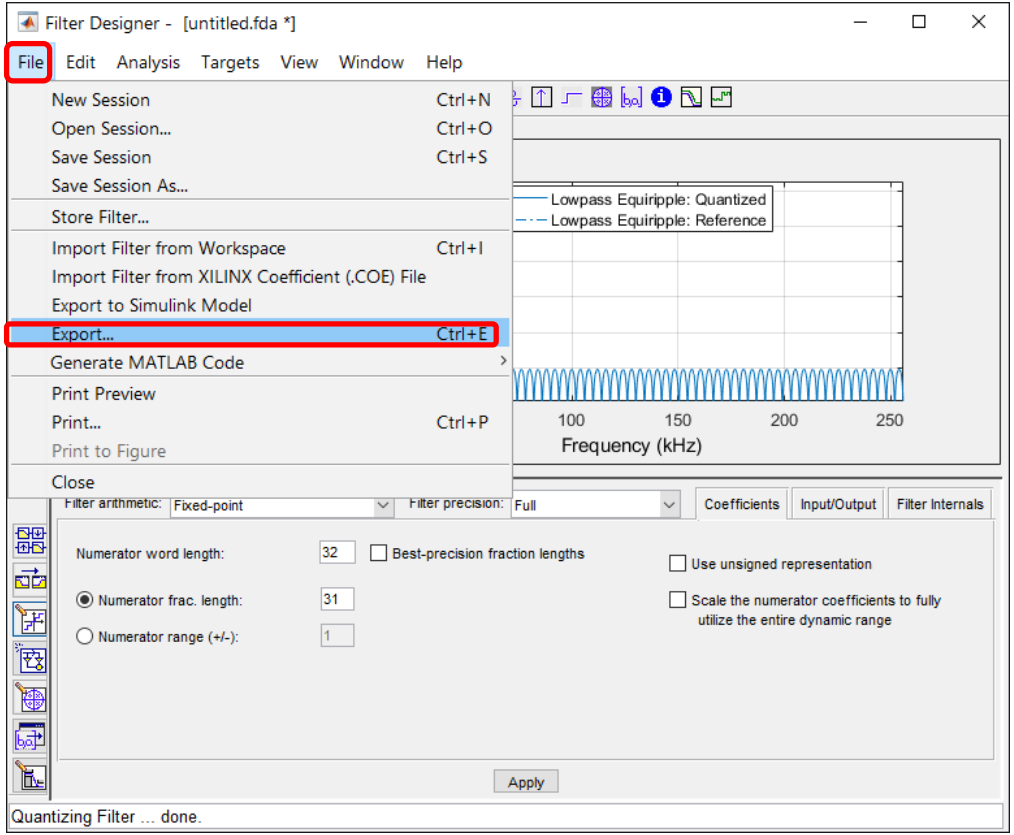
ADS127L21 – 20kHz FIR lowpass filter design

13. Select Fixed-point on the Filter arithmetic selection
14. Select Filter precision: Full
15. Enter 32 for Numerator word length in the Coefficients tab
16. Uncheck the Best-precision fraction lengths box
    - Leave other boxes unchecked
17. Enter 31 for Numerator fraction length
18. Click the ‘Apply’ button



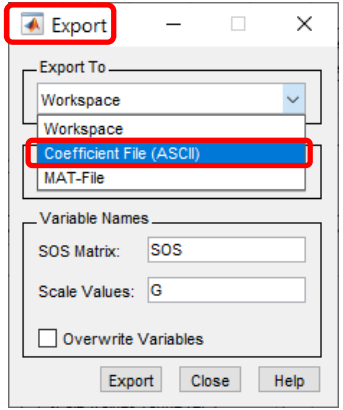
ADS127L21 – 20kHz FIR lowpass filter design

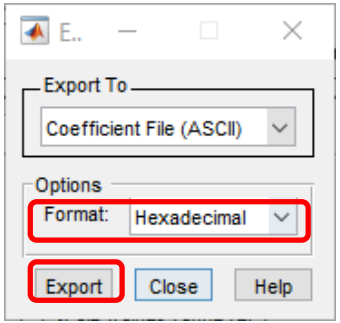
19. The Magnitude Response display now plots both the original floating point (Reference) and fixed-point (Quantized) results.
20. Select File->Export



ADS127L21 – 20kHz FIR lowpass filter design

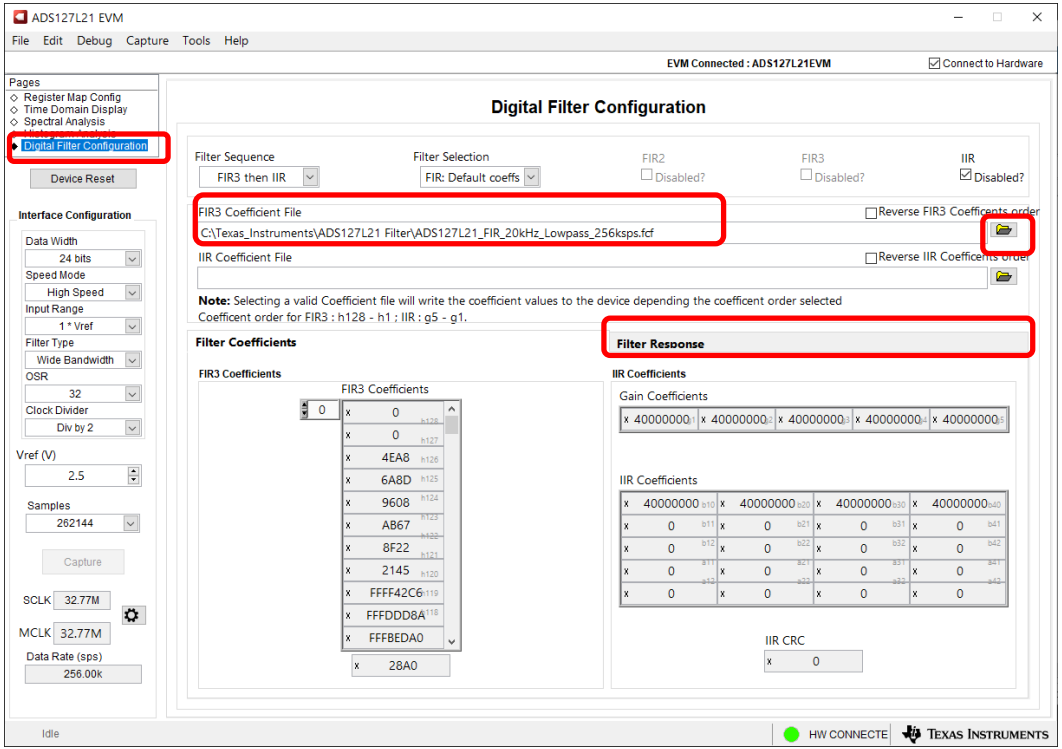
21. Under Export pop-up window, Export To, select Coefficient File (ASCII)
22. Under Options, Format, select Hexadecimal
23. Click the Export button
24. Choose directory and file name, save as default *.fcf file name
    - ADS127L21_FIR_20kHz_Lowpass_256ksps.fcf





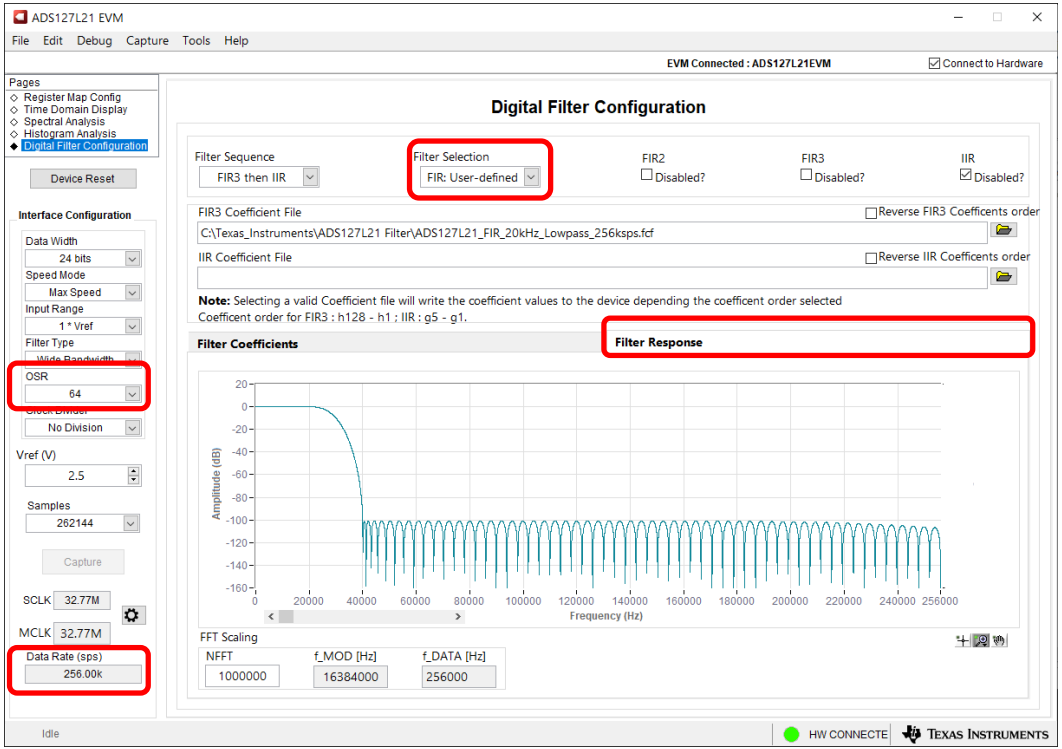
ADS127L21 – 20kHz FIR lowpass filter design

25. Start the ADS127L21EVM-PDK-GUI software and click on the Digital Filter Configuration page
26. Click the file button for the FIR coefficient File
27. Navigate to the *.fcf file just created in MATLAB® and select file
28. Click on the Filter Response tab



ADS127L21 – 20kHz FIR lowpass filter design

29. Set the sample rate to 256ksps
    - Set OSR to 64
30. Set Filter Selection to:
    - FIR: User-defined
31. The FIR Wideband filter response is now plotted and ready for use.



Thanks for your time!