Q330 Response Description

Guidelines for SEED Data

1. Overview

This document describes the instrument response of the Quanterra Q330 Data Engine in terms of an FIR filter and overall sensitivity. Additonal information is provided about data quality indicators embedded in the data. Because the Q330 allows four different filtering schemes, each producing seven output sample rates for every main (24bit) channel, there are 28 possibilities. We focus on identifying the configuration in use and simply match this to a concise single stage respresentation of the instrument response for any channel on hand.

A main channel is one of three differential analog inputs on the Sensor A or Sensor B connector that is converted to a 24bit digital sample. Usually only three or four of the available 7 rates for each channel are selected for output, for example 100, 20 and 1 sample per second (sps). During bootup, the Q330 will adopt one of four user-selected FIR filtering schemes for all data rates based on a frequency below which all rates use linear-phase FIR filters and above which the FIR filters are minimum phase. Selecting a different filtering scheme requires a system reboot. For example, the factory default settings choose "100Hz." as the rate below which linear phase filters as used. The default Data Recording selections output 100 sps data (with minimum phase filters) and 20 sps and 1 sps (with linear phase filters).

A Data Processor, the software application receiving data from a Q330, is provided the delay associated with each filter during registration and it applies this delay when constructing timeseries. Quanterra Data Processors, such as the local data storage device called a Packet Baler or the applications Socorro and MountainAir, write data in SEED format and report the Q330 configuration explicitily in a text message, including the delay that is applied to each SEED channel. These Data Processors obtain instructions about SEED writing preferences, such as SEED Channel codes, from a DP token that the Q330 sends during registration or on request.

The Q330 instrument response can be used to characterize the amplitude and phase information of the digitization process or to reconvolve the recorded data from, say linear phase to minimum phase in order to reduce acausal filter artifacts in sharp onset signals. This information is distinct from the additional step of describing the response in SEED form, which is dominated by user convention. Providing the Q330 instrument response in single stage FIR filter representation makes it easy to incorporate within the SEED description or to use independently of this data format.

2. Composite Description of the Q330 Filtering Scheme.

The "DP Writer's Guide" describes how to create accurate time labels for any timeseries format from Q330 packets. This is performed by Data Processing (DP) software such as Antelope, MountainAir, Socorro or a Baler. This section is focussed on

a simple description of the completed filtering process from the point of view of a data user, rather than data writing applications.

The entire process of filtering and decimating data to produce particular data rates is complex. In particular, accounting for the sample index of the input and output timeseries are important details in the actual processing, especially when the desired result is output samples on UTC time marks. Fortunately, it is possible to describe a single composite filter that incorporates all the time corrections and the frequency dependent phase corrections that are part of the Q330 processing, while at the same time being simple to use for the purpose of reconvolving the instrument response. This composite filter includes the effects of higher rate stages and the filtering and decimation chain to arrive at the output rate. As a result, the composite filters are nonsymetric-meaning the coefficients are not the same amplitude on either side of the midpoint. Applying these filters to a synthetic timeseries and subtracting the corresponding delay will produce an output timeseries identical to an analog signal presented at the Q330 input and recorded at the corresponding sample rate.

The filter name for every possible rate are shown in Table 1, the filter coefficients are available as text files collected into a single zip archive file. Two forms are available, one as simple text and a second form with the coefficients in reversed time order and formatted for reading by programs that seems more popular with SEED writing schemes.

We identify the delay reported by the Q330 and used by DP's to adjust time labels as the 330_delay. We identify the delay associated with a composite filter representation of the 330 response as the Composite_delay.

Composite_delay = (330_delay + (1/output_sample_rate))

For example, the factory default for BHZ data (linear below 100Hz) should have;

composite_delay= 1.580462 + (1/20) = 1.630462 seconds

This difference is simply an indexing issue, i.e. picking the relevant sample in the output vs input timeseries.

|	200 sps	100 sps	50 sps	40 sps	20 sps	10 sps	1 sps
Linear at All Freq.	0.090000 FLinear-200	0.330000 FLinear-100	0.820000 FLinear-50	0.500000 FLinear-40	1.700000 FLinear-20	4.100000 FLinear-10	16.000000 FLinear-1
Linear Below 100 sps	0.020462 FLbelow100-200	0.041607 FLbelow100-100	0.531607 FLbelow100-50	0.430462 FLbelow100-40	1.630462 FLbelow100-20	4.030462 FLbelow100-10	15.930462 FLbelow100-1
Linear Below 40 sps	0.020462 FLbelow40-200	0.041607 FLbelow40-100	0.084847 FLbelow40-50	0.082972 FLbelow40-40	1.282972 FLbelow40-20	3.682972 FLbelow40-10	15.582972 FLbelow40-1
Linear Below 20 sps	0.020462 FLbelow20-200	0.041607 FLbelow20-100	0.084847 FLbelow20-50	0.082972 FLbelow20-40	0.188697 FLbelow20-20	2.588697 FLbelow20-10	14.488697 FLbelow20-1

TABLE 1: COMPOSITE FILTER DELAY IN SECONDS.
Blue indicates the ouput sample rate was filtered with Linear Phase filter in the last stage (and possibly earlier stages).
Red indicates the output sample rate was filtered with Minimum Phase Filters.

An example of a Q330 Linear Phase Filter, (the coefficients are not symetric) :
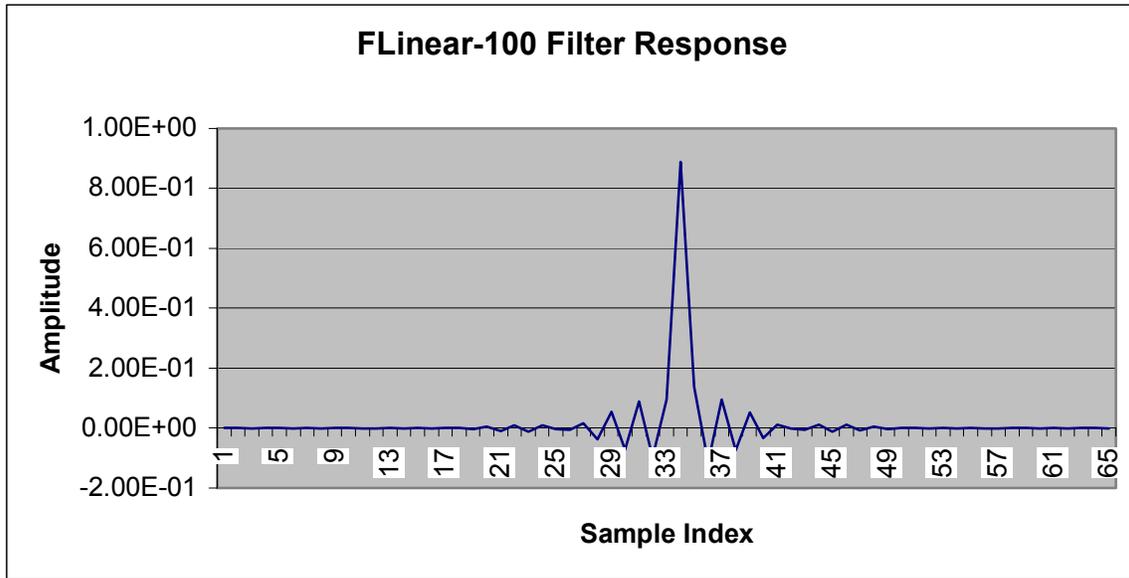
An example of a Q330 Minimum Phase Filter (coefficients in forward time order):

FLbelow100-100 Filter Response
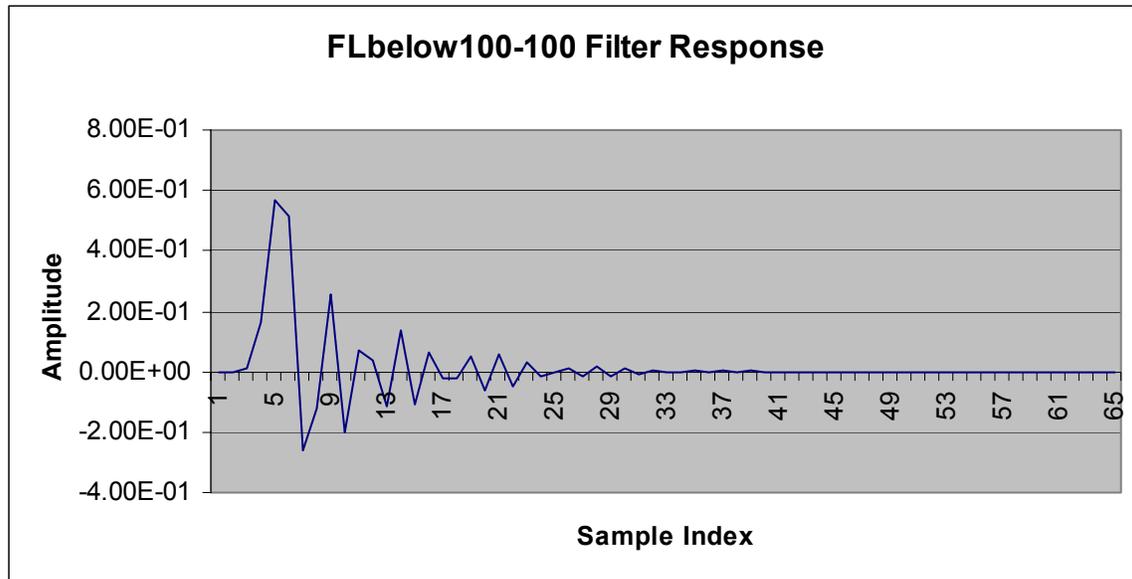
Amplitude Scaling

The composite filters are used to represent the frequency response of the Q330. The absolute sensitivity of a Q330 is set at each reboot (to within 0.1%) to 419430 counts / volt.   Any digital scaling the user selects should be accounted for as [scale x 419430 counts / volt], where the value of scale is set in C1_GLOB and may be frequency dependent. This is selected from Willard in the Global Settings configuration panel, by selecting the Scale button. Applying a digital scale factor is a special situation primarily used to optimize compression and is not recommended for typical applications. In SEED the amplitude sensitivity of the digitizer is normally entered Blockette 058 for Stage 2 (where Stage 1 is usuallythe Seismometer response).

3. SEED Response Description

An example of constructing a SEED response description can be found in appendix C of SEED Reference Manual V2.3. Examples of what a Q330 response looks like is shown in Appendix A for HHZ, 100sps data, Appendix B for BHZ, 20sps data and Appendix C for LHZ, 1sps of this document.

Response information usually is given as a station control blockette, indicating the time span and station details for which this response is valid. Then follows a series of stages representing the response for each instrument engaged in signal processing. The typical stages are;

Stage 1 Sensor
Stage 2 Digitizer amplitude sensitivity
Stage 3 Digital FIR Filter Stage(s)

Each stage in turn consists of blockettes, often two or three that form a set to describe this stage. In the Q330 case, Stage 3 is the composite response in one stage. It consists of three Blockettes;
Blockette 054--the number of coefficients and the coefficients in time-reverse order
Blockette 057--the sample rate, delay and decimation factor
Blockette 058--the gain of the filter, and frequency at which this gain applies.

For Q330, the composite filters all indicate the sample rate and have a decimation of 1-meaning the input and output rate are the same. The "estimated delay" and the "Correction applied" found in Blockette 058 should be entered as positive values, equal to that shown in Table 1 for the appropriate filter. Again, consult Appendix A, B and C for examples.

Alternative Description (Dictionary Records):
Blockette 060 identifies one or more blockettes to use for the station description. In particular, blockette 041 can be used to describe all the possible 330 FIR response descriptions and then particular SEED channel simply identifies the reference. This is an advanced technique, not discussed here.

4. SEED Data Quality Indicators

We detail some additional aspects of the SEED timeseries format since Quanterra Data Processors write data in this format. For the basics, please see the online documentation: http://www.iris.edu/manuals/SEED.pdf

SEED data records include fields to indicate the current state of certain data quality indicators. This allows time series analysis and display applications to take appropriate action based on the data records themselves without resorting to an associated database or text log. Calibration in progress, event detection, clipped data and "time tag is questionable" are some of the possibilities. See page 93 of the SEED manual for the flag definitions. Blockettes are also introduced in data records to describe such things as Clock quality and Event Detections.

Since the Q330 does not produce SEED itself, the Data Processor is responsible for creating the SEED data quality indications in SEED data record headers. The Q330 does provide corresponding indicators directly in each 330 data packet. Field 14 (Data Quality) bit 7 "Time tag is questionable" is set if the Q330 has not had a GPS lock since a reboot, this means the clock quality = 0% see below and derives from the Q330 packet C1_STAT, clock quality bit 0 or from a Q330 DT_DATA packet with channel id 10011000 the 8 bit parameter. Field 13 (IO and Clock flags) bit 5 "clock is locked" is set when 330 clock quality bit 1,2,or 3 is set. Field 12 (Activity flags) bit 0 is set when a calibration is present. and bits 2,3,6 indicate an event is declared. Consult the "DP writers Guide" for more detailed information as to mapping Q330 status into SEED indicators.

It is possible to view the SEED quality flags in action using the Comserv Client dataspy -v, which looks something like this;

```
[CRPA] < 2> Channel=HLN Received at=16:08:05.124055 Fri Jul 18 2003
       Time=16:08:01.968392 Fri Jul 18 2003   Blks=2   Samples=200
       Activity Flags=-------C   IO Flags=--L-----   Data Quality Flags=--------
       Encoding Format=Steim2   Frequency=100.00Hz  Clock Quality=90%
[CRPA] < 3> Channel=HHZ Received at=16:08:05.187805 Fri Jul 18 2003
       Time=16:08:01.968392 Fri Jul 18 2003   Blks=2   Samples=200
       Activity Flags=-------C   IO Flags=--L-----   Data Quality Flags=--------
       Encoding Format=Steim2   Frequency=100.00Hz  Clock Quality=90%
[CRPA] < 4> Channel=HHE Received at=16:08:05.189814 Fri Jul 18 2003
       Time=16:08:01.968392 Fri Jul 18 2003   Blks=2   Samples=200
       Activity Flags=-------C   IO Flags=--L-----   Data Quality Flags=--------
       Encoding Format=Steim2   Frequency=100.00Hz  Clock Quality=90%
```

Blockette 1001 inserted into each SEED Channel uses the same definition for Clock Quality as for generating the MSEED Channel LCQ, see below.

LCQ Clock channel, clock quality as a percentage. Calculation of the percentage uses three pieces of information:
1. The clock DP token, consisting of the fields (=default value):
   - zone : 32 bit signed offset in seconds =0
   - degrade_time : 16 bit loss of lock in minutes before degrading 1% =10min
   - q_locked : 8 bit PLL Locked quality =100
   - q_track : 8 bit PLL Tracking quality =90
   - q_hold : 8 bit PLL Holding quality =80
   - q_off : 8 bit Currently Locked, PLL Off =80
   - q_spare : 8 bit Spare
   - q_high : 8 bit has been locked highest quality =60
   - q_low : 8 bit has been locked lowest quality =10
   - q_never : 8 bit Never been locked quality =0
   - clock_filt : 16 bit minimum seconds between clock messages =60
2. The raw bitmap of clock status, either from a status poll or from a DT_DATA packet with channel id 10011000 the 8 bit parameter, let's call this "qual".
3. The minutes since the clock has been locked, either from a status poll or from a DT_DATA packet with channel id 10011000 the 16 bit parameter, let's call this "loss".

The calculation (of "val", the percentage) is as follows:

```
if (qual >= PLL_TRACK) or (qual and (CQ_3D or CQ_2D or CQ_1D) <> 0)
  then
    case qual and PLL_LOCK of
      PLL_LOCK : val := q_locked ;
      PLL_TRACK : val := q_track ;
      PLL_HOLD : val := q_hold ;
      PLL_OFF : val := q_off ;
    end
else if qual and CQ_LOCK <> 0
  then
    begin
      if degrade_time <> 0
        then
```

```
            i := q_high - loss div swap(degrade_time)
         else
            i := q_high ;
       if i < q_low
          then
             i := q_low ;
       val := i
     end
   else
     val := q_never ;
```

ACE channel is a text log produced by some Data Processors such as Socorro and the Baler to emulate a similar SEED channel produced by Quanterra MSHEAR systems. The chronological message text indicates significant changes in clock quality.

5. *Identifying the 330 configuration*

There are several ways to determine the configuration selection for data produced by the Q330.   In real-time you can request the structures directly from the Q330 or view these with the Willard application. In addition, the Q330 reports the configuration selections a programmed intervals, usually once a day. Most Data Processing applications such as a Baler or MountainAir write the configuration to a message log at each start of recording. Since the filter scheme cannot change without a 330 reboot, finding one configuration within a reboot interval is sufficient to determine the selection. Determining the configuration of a system after the fact is a matter of consulting either the DP logs or the archived configuration structures. Most network operators construct a database of Station operation information, in which annotation of the Q330 filter and sample rate configuration should be included.

The filter settings can be read with C1_RQGLOB see, filter settings
The Filter Bitmap has two bits per group of 3 channels. Channels 1-3 use bits 0 and 1, channels 4-6 use bits 2 and 3. The pattern for the two bits is :
    00 = Linear phase filters for all frequencies.
    01 = Linear phase filters below 100Hz.
    10 = Linear phase filters below 40Hz.
    11 = Linear phase filters below 20Hz.
The possible sample rates and the associated delay values are returned by C1_RQFIX.

If you are using Willard, you can view the filter scheme selection under the Configuration Menu, Global Settings panel. The radio button selection near the bottom determines the filter scheme. The selection of output rate(s) sent to the Data Port packet queue is determined by the logical port configuration. See the "Data Recording" panel of the Willard Configuration menu for the particular Data Port you are interested in. Note that different rates can be chosen for different Data Ports. This is also where the SEED channel name is assigned. Bear in mind, the Data Processor actually writing the SEED data may not use the SEED Channel name suggested the 330 supplies in the form of a DP token.

If you have a Baler as a Data Processor, at each power-cycle the Baler writes in the message log a message like;

```
2003/07/09 00:31:36.630 filters & delay HHZ:4@100,Linear below 100sps=0.031607
2003/07/09 00:31:36.630 filters & delay HHN:5@100,Linear below 100sps=0.031607
2003/07/09 00:31:36.630 filters & delay HHE:6@100,Linear below 100sps=0.031607
2003/07/09 00:31:36.630 filters & delay BHZ:4@20,Linear below 100sps=1.580462
2003/07/09 00:31:36.630 filters & delay BHN:5@20,Linear below 100sps=1.580462
2003/07/09 00:31:36.630 filters & delay BHE:6@20,Linear below 100sps=1.580462
2003/07/09 00:31:36.630 filters & delay LHZ:4@1,Linear below 100sps=14.930462
2003/07/09 00:31:36.630 filters & delay LHN:5@1,Linear below 100sps=14.930462
2003/07/09 00:31:36.630 filters & delay LHE:6@1,Linear below 100sps=14.930462
2003/07/09 00:31:36.630 filters & delay VHZ:LHZ@0.1000=214.430462
2003/07/09 00:31:36.630 filters & delay VHN:LHN@0.1000=214.430462
2003/07/09 00:31:36.630 filters & delay VHE:LHE@0.1000=214.430462
2003/07/09 00:31:36.630 filters & delay UHZ:VHZ@0.0100=2209.430462
2003/07/09 00:31:36.630 filters & delay UHN:VHN@0.0100=2209.430462
2003/07/09 00:31:36.630 filters & delay UHE:VHE@0.0100=2209.430462
2003/07/09 00:31:36.630 filters & delay HLZ:1@100,Linear below 100sps=0.031607
2003/07/09 00:31:36.630 filters & delay HLN:2@100,Linear below 100sps=0.031607
2003/07/09 00:31:36.630 filters & delay HLE:3@100,Linear below 100sps=0.031607
2003/07/09 00:31:36.630 filters & delay BLZ:1@20,Linear below 100sps=1.580462
2003/07/09 00:31:36.630 filters & delay BLN:2@20,Linear below 100sps=1.580462
2003/07/09 00:31:36.630 filters & delay BLE:3@20,Linear below 100sps=1.580462
2003/07/09 00:31:36.630 filters & delay LLZ:1@1,Linear below 100sps=14.930462
2003/07/09 00:31:36.630 filters & delay LLN:2@1,Linear below 100sps=14.930462
2003/07/09 00:31:36.630 filters & delay LLE:3@1,Linear below 100sps=14.930462
```

If a preamp is enabled on any channel, this selection is made in the "Global Setup …" panel of the Willard Configuration menu (see example below). The same panel also including a SCALE subpanel. This allows multipliers to be applied to the digital samples and this factor should be included in the overall gain value for Stage 2 or as a separate "preamp" Stage.

6. Testing time labelling accuracy

You can verify the time labelling of the recorded time series by applying a 1PPM pulse from a GPS receiver to the digitizer input. The resulting waveform will show the UTC transition time from the receiver to occur at exactly 1/2 the amplitude of the resulting step. The Q330 has the ability to internally generate a time reference pulse by selecting "Special Input: 0.05Hz" in Willard Configuration panel "Global Setup". When the GPS engine is Locked, this will produce a step transition at ten second intervals ocurring exactly on the UTC ten second boundaries, e.g. 00 10 20 30 … seconds after a UTC minute. This can be used to verify time label accuracy in data file formats far down the processing chain.

0252 Global Programming

Coldstart Timeout	Clock Timeout	DP Timeout	Initial VCO
100min	60sec	300sec	2048

Calibrator Offset	Phase Tolerance	Jump Filter	Jump Threshold
0	50000µs	5	250µs

☑ GPS Backup Power   Q330 Web Port: 80   User Tag Number: 0

Aux Rate
- ○ Off
- ○ 1.0Hz
- ○ 0.1Hz

Channel Enables
☑ Chan 1 ☑ Chan 2 ☑ Chan 3 ☑ Chan 4 ☑ Chan 5 ☑ Chan 6

Preamp Enables
☐ Chan 1 ☐ Chan 2 ☐ Chan 3 ☐ Chan 4 ☐ Chan 5 ☐ Chan 6

Status Rate
- ○ Off
- ○ 1.0Hz
- ◉ 0.1Hz

Special Input Select
☑ Chan 1 ☑ Chan 2 ☑ Chan 3 ☐ Chan 4 ☐ Chan 5 ☐ Chan 6

Channels 1-3 Special Input
- ○ Calibrator Output
- ○ Reference
- ○ Ground
- ◉ 0.05Hz

Channels 4-6 Special Input
- ○ Calibrator Output
- ○ Reference
- ◉ Ground
- ○ 0.05Hz

Channels 1-3 Linear Filters Below
- ○ All Frequencies
- ◉ 100Hz
- ○ 40Hz
- ○ 20Hz

Channels 4-6 Linear Filters Below
- ○ All Frequencies
- ◉ 100Hz
- ○ 40Hz
- ○ 20Hz

[✓ Apply]   [✗ Cancel]   [Messages]   [Scaling]

0252 - Data 3

4104601

IHLZ 100Hz 15 PTS/PIX OFFSET=1508514 MAX=4104601 MIN=-2534224

T1=2003-07-18 18:02:59.978391   dT=120.000   T2=2003-07-18 18:04:59.978391
Zoom=4, Ticks=10 SEC, dPixel=0.150, Filt=None Station=CRPA   Value=190.0 Rel=-1508324
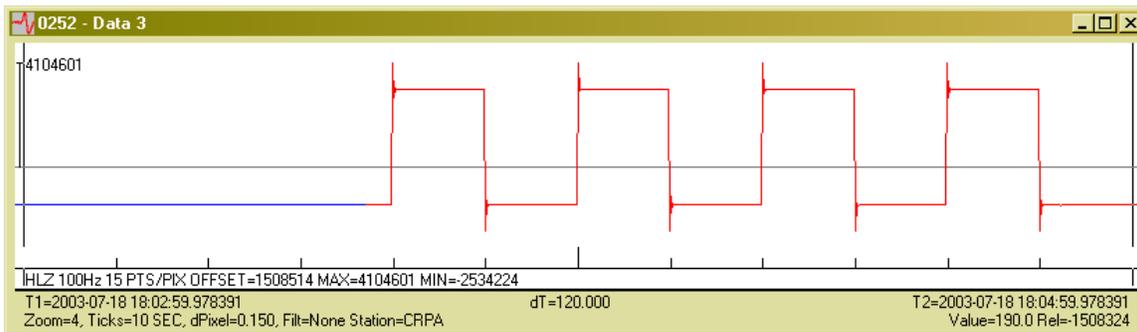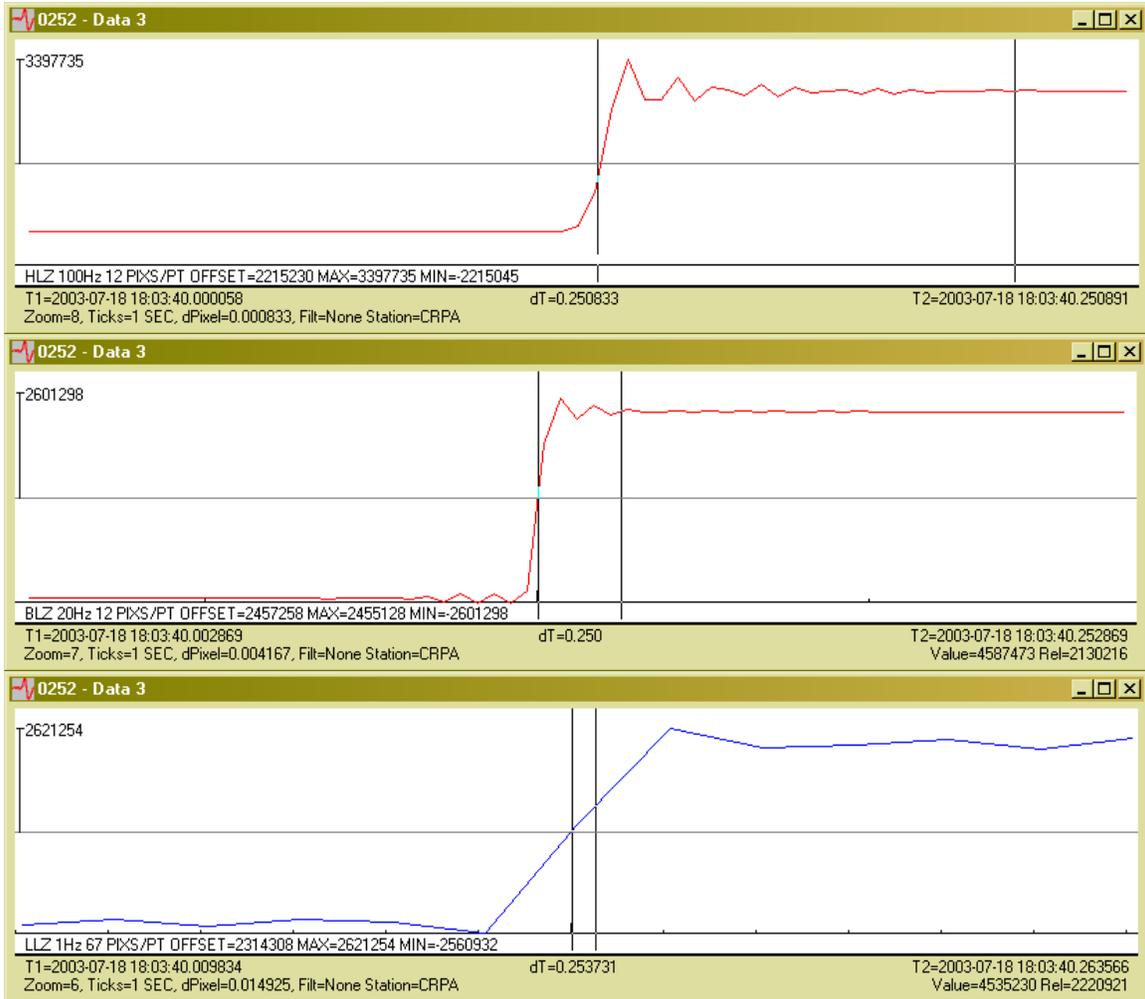
Appendix A:

A sample output of the program EVALRESP when reading a SEED response information for a Q330 channel HHZ (channel 4 at 100 sps) configured with the factory default selection of Filter Scheme as "Linear below 100Hz."

```
#                << IRIS SEED Reader, Release 4.18 >>
#
#                ======== CHANNEL RESPONSE DATA ========
B050F03    Station:     Q330
B050F16    Network:     QT
B052F03    Location:    ??
B052F04    Channel:     HHZ
B052F22    Start date:  2001,150,08:00
B052F23    End date:    No Ending Time
#                =======================================
#            +              +---------------------------------------------+
+
#            +              |   Response (Poles & Zeros),   Q330 ch HHZ   |
+
#            +              +---------------------------------------------+
+
#
```

```
B053F03    Transfer function type:              A [Laplace Transform (Rad/sec)]
B053F04    Stage sequence number:               1
B053F05    Response in units lookup:            M/S - Velocity in Meters Per Second
B053F06    Response out units lookup:           V - Volts
B053F07    A0 normalization factor:             5.96806E+07
B053F08    Normalization frequency:             0.02
B053F09    Number of zeroes:                    2
B053F14    Number of poles:                     5
#          Complex zeroes:
#              i  real          imag          real_error   imag_error
B053F10-13   0  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
B053F10-13   1  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
#          Complex poles:
#              i  real          imag          real_error   imag_error
B053F15-18   0 -3.564700E-02 -3.687900E-02  0.000000E+00  0.000000E+00
B053F15-18   1 -3.564700E-02  3.687900E-02  0.000000E+00  0.000000E+00
B053F15-18   2 -2.513300E+02  0.000000E+00  0.000000E+00  0.000000E+00
B053F15-18   3 -1.310400E+02 -4.672900E+02  0.000000E+00  0.000000E+00
B053F15-18   4 -1.310400E+02  4.672900E+02  0.000000E+00  0.000000E+00
#
#          +             +---------------------------------------+
+
#          +             |       Channel Gain,   Q330   ch HHZ       |
+
#          +             +---------------------------------------+
+
#
B058F03    Stage sequence number:               1
B058F04    Gain:                                1.500000E+03
B058F05    Frequency of gain:                   2.000000E-02 HZ
B058F06    Number of calibrations:              0
#
#
#          +             +-----------------------------------------+
+
#          +             |   Response (Coefficients),  Q330 ch HHZ   |
+
#          +             +-----------------------------------------+
+
#
B054F03    Transfer function type:              D
B054F04    Stage sequence number:               2
B054F05    Response in units lookup:            V - Volts
B054F06    Response out units lookup:           COUNTS - Digital Counts
B054F07    Number of numerators:                0
B054F10    Number of denominators:              0
#
#          +             +-----------------------------+
+
#          +             |   Decimation,  Q330 ch HHZ   |
+
#          +             +-----------------------------+
+
#
B057F03    Stage sequence number:               2
B057F04    Input sample rate:                   1.000000E+02
B057F05    Decimation factor:                   1
B057F06    Decimation offset:                   0
B057F07    Estimated delay (seconds):           0.0000000E+00
B057F08    Correction applied (seconds):        0.0000000E+00
#
#          +             +---------------------------------------+
+
#          +             |       Channel Gain,   Q330   ch HHZ       |
+
#          +             +---------------------------------------+
+
#
B058F03    Stage sequence number:               2
B058F04    Gain:                                4.194300E+05
B058F05    Frequency of gain:                   0.000000E+00 HZ
```

```
B058F06     Number of calibrations:               0
#
#             +             +------------------------------------------+
+
#             +             |   Response (Coefficients),  Q330 ch HHZ   |
+
#             +             +------------------------------------------+
+
#
B054F03     Transfer function type:               D
B054F04     Stage sequence number:                3
B054F05     Response in units lookup:             COUNTS - Digital Counts
B054F06     Response out units lookup:            COUNTS - Digital Counts
B054F07     Number of numerators:                 31
B054F10     Number of denominators:               0
#           Numerator coefficients:
#             i, coefficient,  error
B054F08-09    0     -7.0186227E-10 0.0000000E+00
B054F08-09    1      2.5779114E-09 0.0000000E+00
B054F08-09    2      1.0562748E-08 0.0000000E+00
B054F08-09    3      1.3885057E-08 0.0000000E+00
B054F08-09    4     -3.3252027E-08 0.0000000E+00
B054F08-09    5     -1.0990485E-07 0.0000000E+00
B054F08-09    6     -8.0741625E-08 0.0000000E+00
B054F08-09    7      3.2266382E-07 0.0000000E+00
B054F08-09    8      2.6428765E-07 0.0000000E+00
B054F08-09    9      1.0667707E-07 0.0000000E+00
B054F08-09   10     -1.2510258E-06 0.0000000E+00
B054F08-09   11      2.2418734E-07 0.0000000E+00
B054F08-09   12      7.0420640E-07 0.0000000E+00
B054F08-09   13      1.3762756E-06 0.0000000E+00
B054F08-09   14     -4.6481172E-06 0.0000000E+00
B054F08-09   15      8.7397951E-06 0.0000000E+00
B054F08-09   16     -1.5124650E-05 0.0000000E+00
B054F08-09   17      2.5302859E-05 0.0000000E+00
B054F08-09   18     -3.8564693E-05 0.0000000E+00
B054F08-09   19      5.1527710E-05 0.0000000E+00
B054F08-09   20     -5.6180479E-05 0.0000000E+00
B054F08-09   21      3.8075730E-05 0.0000000E+00
B054F08-09   22      2.4378010E-05 0.0000000E+00
B054F08-09   23     -1.5836647E-04 0.0000000E+00
B054F08-09   24      3.9217516E-04 0.0000000E+00
B054F08-09   25     -7.4604922E-04 0.0000000E+00
B054F08-09   26      1.2186428E-03 0.0000000E+00
B054F08-09   27     -1.7705155E-03 0.0000000E+00
B054F08-09   28      2.3074030E-03 0.0000000E+00
B054F08-09   29     -2.6661685E-03 0.0000000E+00
B054F08-09   30      2.5960431E-03 0.0000000E+00
B054F08-09   31     -1.7787575E-03 0.0000000E+00
B054F08-09   32     -8.9475628E-05 0.0000000E+00
B054F08-09   33      3.2551587E-03 0.0000000E+00
B054F08-09   34     -7.6757868E-03 0.0000000E+00
B054F08-09   35      1.2781987E-02 0.0000000E+00
B054F08-09   36     -1.7138655E-02 0.0000000E+00
B054F08-09   37      1.8797255E-02 0.0000000E+00
B054F08-09   38     -1.8469822E-02 0.0000000E+00
B054F08-09   39      1.2788211E-02 0.0000000E+00
B054F08-09   40     -2.3660751E-03 0.0000000E+00
B054F08-09   41     -1.2482940E-02 0.0000000E+00
B054F08-09   42      2.9777146E-02 0.0000000E+00
B054F08-09   43     -4.6233307E-02 0.0000000E+00
B054F08-09   44      5.7579308E-02 0.0000000E+00
B054F08-09   45     -5.9338288E-02 0.0000000E+00
B054F08-09   46      4.7680563E-02 0.0000000E+00
B054F08-09   47     -2.0931286E-02 0.0000000E+00
B054F08-09   48     -1.9271235E-02 0.0000000E+00
B054F08-09   49      6.7054813E-02 0.0000000E+00
B054F08-09   50     -1.1144746E-01 0.0000000E+00
B054F08-09   51      1.3547966E-01 0.0000000E+00
B054F08-09   52     -1.1431347E-01 0.0000000E+00
B054F08-09   53      3.8796662E-02 0.0000000E+00
```

```
B054F08-09     54     7.0758805E-02  0.0000000E+00
B054F08-09     55    -2.0290260E-01  0.0000000E+00
B054F08-09     56     2.5718129E-01  0.0000000E+00
B054F08-09     57    -1.2203293E-01  0.0000000E+00
B054F08-09     58    -2.6083604E-01  0.0000000E+00
B054F08-09     59     5.1738348E-01  0.0000000E+00
B054F08-09     60     5.6880941E-01  0.0000000E+00
B054F08-09     61     1.6442924E-01  0.0000000E+00
B054F08-09     62     1.3396814E-02  0.0000000E+00
B054F08-09     63     1.5010653E-04  0.0000000E+00
B054F08-09     64     1.3154932E-11  0.0000000E+00
#
#              +                    +----------------------------+
+
#              +                    |   Decimation,  Q330 ch HHZ  |
+
#              +                    +----------------------------+
+
#
B057F03     Stage sequence number:              3
B057F04     Input sample rate:                  1.000000E+02
B057F05     Decimation factor:                  1
B057F06     Decimation offset:                  0
B057F07     Estimated delay (seconds):          0.041607E+00
B057F08     Correction applied (seconds):       0.041607E+00
#
#              +                    +---------------------------------------+
+
#              +                    |      Channel Gain,  Q330 ch HHZ       |
+
#              +                    +---------------------------------------+
+
#
B058F03     Stage sequence number:              3
B058F04     Gain:                               1.000000E+00
B058F05     Frequency of gain:                  0.000000E+00 HZ
B058F06     Number of calibrations:             0
#
#
```

Appendix B:

A sample output of the program EVALRESP when reading a SEED response information for a Q330 channel BHZ (channel 4 at 20 sps) configured with the factory default selection of Filter Scheme as "Linear below 100Hz."

```
#              << IRIS SEED Reader, Release 4.18 >>
#
#              ======== CHANNEL RESPONSE DATA ========
B050F03    Station:     Q330
B050F16    Network:     QT
B052F03    Location:    ??
B052F04    Channel:     BHZ
B052F22    Start date:  2001,150,08:00
B052F23    End date:    No Ending Time
#              =======================================
#              +              +---------------------------------------------+
+
#              +              |   Response (Poles & Zeros),   Q330 ch BHZ   |
+
#              +              +---------------------------------------------+
+
#
B053F03    Transfer function type:            A [Laplace Transform (Rad/sec)]
B053F04    Stage sequence number:             1
B053F05    Response in units lookup:          M/S - Velocity in Meters Per Second
B053F06    Response out units lookup:         V - Volts
```

```
B053F07     A0 normalization factor:            5.96806E+07
B053F08     Normalization frequency:            0.02
B053F09     Number of zeroes:                   2
B053F14     Number of poles:                    5
#              Complex zeroes:
#               i  real        imag         real_error    imag_error
B053F10-13   0  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
B053F10-13   1  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
#              Complex poles:
#               i  real        imag         real_error    imag_error
B053F15-18   0 -3.564700E-02 -3.687900E-02  0.000000E+00  0.000000E+00
B053F15-18   1 -3.564700E-02  3.687900E-02  0.000000E+00  0.000000E+00
B053F15-18   2 -2.513300E+02  0.000000E+00  0.000000E+00  0.000000E+00
B053F15-18   3 -1.310400E+02 -4.672900E+02  0.000000E+00  0.000000E+00
B053F15-18   4 -1.310400E+02  4.672900E+02  0.000000E+00  0.000000E+00
#
#          +              +--------------------------------------+
+
#          +              |    Channel Gain,   Q330   ch BHZ     |
+
#          +              +--------------------------------------+
+
#
B058F03     Stage sequence number:              1
B058F04     Gain:                               1.500000E+03
B058F05     Frequency of gain:                  2.000000E-02 HZ
B058F06     Number of calibrations:             0
#
#
#          +              +-------------------------------------------+
+
#          +              |   Response (Coefficients),  Q330 ch BHZ   |
+
#          +              +-------------------------------------------+
+
#
B054F03     Transfer function type:             D
B054F04     Stage sequence number:              2
B054F05     Response in units lookup:           V - Volts
B054F06     Response out units lookup:          COUNTS - Digital Counts
B054F07     Number of numerators:               0
B054F10     Number of denominators:             0
#
#          +              +-----------------------------+
+
#          +              |   Decimation,  Q330 ch BHZ   |
+
#          +              +-----------------------------+
+
#
B057F03     Stage sequence number:              2
B057F04     Input sample rate:                  2.000000E+01
B057F05     Decimation factor:                  1
B057F06     Decimation offset:                  0
B057F07     Estimated delay (seconds):          0.0000000E+00
B057F08     Correction applied (seconds):       0.0000000E+00
#
#          +              +--------------------------------------+
+
#          +              |      Channel Gain,   Q330 ch BHZ     |
+
#          +              +--------------------------------------+
+
#
B058F03     Stage sequence number:              2
B058F04     Gain:                               4.194300E+05
B058F05     Frequency of gain:                  0.000000E+00 HZ
B058F06     Number of calibrations:             0
#
#          +              +-------------------------------------------+
+
```

```
#              +               |  Response (Coefficients),  Q330 ch BHZ   |
+
#              +               +------------------------------------------+
+
#
B054F03      Transfer function type:              D
B054F04      Stage sequence number:               3
B054F05      Response in units lookup:            COUNTS - Digital Counts
B054F06      Response out units lookup:           COUNTS - Digital Counts
B054F07      Number of numerators:                67
B054F10      Number of denominators:              0
#            Numerator coefficients:
#              i, coefficient,  error
B054F08-09    0       -5.4295424E-11 0.0000000E+00
B054F08-09    1        1.2571201E-09 0.0000000E+00
B054F08-09    2       -1.0638379E-08 0.0000000E+00
B054F08-09    3       -2.8333595E-07 0.0000000E+00
B054F08-09    4        1.5243504E-06 0.0000000E+00
B054F08-09    5       -1.2527285E-06 0.0000000E+00
B054F08-09    6        6.8079462E-07 0.0000000E+00
B054F08-09    7        8.1490938E-07 0.0000000E+00
B054F08-09    8       -1.4198475E-06 0.0000000E+00
B054F08-09    9        1.5773557E-05 0.0000000E+00
B054F08-09    10      -5.5680047E-05 0.0000000E+00
B054F08-09    11      -5.6503698E-04 0.0000000E+00
B054F08-09    12       5.0269974E-04 0.0000000E+00
B054F08-09    13      -4.5189730E-04 0.0000000E+00
B054F08-09    14       7.6771940E-05 0.0000000E+00
B054F08-09    15       7.1521751E-04 0.0000000E+00
B054F08-09    16      -1.9205198E-03 0.0000000E+00
B054F08-09    17       3.3821315E-03 0.0000000E+00
B054F08-09    18      -4.7611008E-03 0.0000000E+00
B054F08-09    19       5.5613106E-03 0.0000000E+00
B054F08-09    20      -5.1931990E-03 0.0000000E+00
B054F08-09    21       3.0979653E-03 0.0000000E+00
B054F08-09    22       1.0964539E-03 0.0000000E+00
B054F08-09    23      -7.4039828E-03 0.0000000E+00
B054F08-09    24       1.5321091E-02 0.0000000E+00
B054F08-09    25      -2.3525893E-02 0.0000000E+00
B054F08-09    26       3.1084166E-02 0.0000000E+00
B054F08-09    27      -3.8568668E-02 0.0000000E+00
B054F08-09    28       3.6153163E-02 0.0000000E+00
B054F08-09    29      -2.6671437E-02 0.0000000E+00
B054F08-09    30       3.1416839E-03 0.0000000E+00
B054F08-09    31       4.4257419E-02 0.0000000E+00
B054F08-09    32      -1.5690530E-01 0.0000000E+00
B054F08-09    33       7.2416703E-01 0.0000000E+00
B054F08-09    34       5.2765235E-01 0.0000000E+00
B054F08-09    35      -1.9175482E-01 0.0000000E+00
B054F08-09    36       9.6492313E-02 0.0000000E+00
B054F08-09    37      -4.4778678E-02 0.0000000E+00
B054F08-09    38       1.1752518E-02 0.0000000E+00
B054F08-09    39       8.6073391E-03 0.0000000E+00
B054F08-09    40      -2.2098646E-02 0.0000000E+00
B054F08-09    41       2.4039791E-02 0.0000000E+00
B054F08-09    42      -2.2970352E-02 0.0000000E+00
B054F08-09    43       1.9176457E-02 0.0000000E+00
B054F08-09    44      -1.3581463E-02 0.0000000E+00
B054F08-09    45       7.7780548E-03 0.0000000E+00
B054F08-09    46      -2.8051188E-03 0.0000000E+00
B054F08-09    47      -7.7197139E-04 0.0000000E+00
B054F08-09    48       2.8144109E-03 0.0000000E+00
B054F08-09    49      -3.5063897E-03 0.0000000E+00
B054F08-09    50       3.2253379E-03 0.0000000E+00
B054F08-09    51      -2.4062652E-03 0.0000000E+00
B054F08-09    52       1.4417474E-03 0.0000000E+00
B054F08-09    53      -6.0822221E-04 0.0000000E+00
B054F08-09    54       4.6325774E-05 0.0000000E+00
B054F08-09    55       2.1067676E-04 0.0000000E+00
B054F08-09    56      -5.1775947E-04 0.0000000E+00
B054F08-09    57       7.4733627E-06 0.0000000E+00
```

```
B054F08-09    58    5.4117187E-06  0.0000000E+00
B054F08-09    59    -3.7440260E-06 0.0000000E+00
B054F08-09    60    2.7874691E-06  0.0000000E+00
B054F08-09    61    -3.3727366E-07 0.0000000E+00
B054F08-09    62    -1.8759414E-07 0.0000000E+00
B054F08-09    63    1.1450196E-06  0.0000000E+00
B054F08-09    64    -4.2705963E-07 0.0000000E+00
B054F08-09    65    3.6748806E-08  0.0000000E+00
B054F08-09    66    -3.6534167E-17 0.0000000E+00
#
#            +                +----------------------------+
+
#            +                |  Decimation,  Q330 ch BHZ  |
+
#            +                +----------------------------+
+
#
B057F03    Stage sequence number:              3
B057F04    Input sample rate:                  2.000000E+01
B057F05    Decimation factor:                  1
B057F06    Decimation offset:                  0
B057F07    Estimated delay (seconds):          1.630462E+00
B057F08    Correction applied (seconds):       1.630462E+00
#
#            +                +-------------------------------------+
+
#            +                |      Channel Gain,  Q330 ch BHZ     |
+
#            +                +-------------------------------------+
+
#
B058F03    Stage sequence number:              3
B058F04    Gain:                               1.000000E+00
B058F05    Frequency of gain:                  0.000000E+00 HZ
B058F06    Number of calibrations:             0
#
#
```

Appendix C:

A sample output of the program EVALRESP when reading a SEED response information for a Q330 channel LHZ (channel 4 at 1 sps) configured with the factory default selection of Filter Scheme as "Linear below 100Hz."

```
#              << IRIS SEED Reader, Release 4.18 >>
#
#            ======== CHANNEL RESPONSE DATA ========
B050F03    Station:     Q330
B050F16    Network:     QT
B052F03    Location:    ??
B052F04    Channel:     LHZ
B052F22    Start date:  2001,150,08:00
B052F23    End date:    No Ending Time
#            =======================================
#            +                +--------------------------------------------+
+
#            +                |   Response (Poles & Zeros),   Q330 ch LHZ  |
+
#            +                +--------------------------------------------+
+
#
B053F03    Transfer function type:             A [Laplace Transform (Rad/sec)]
B053F04    Stage sequence number:              1
B053F05    Response in units lookup:           M/S - Velocity in Meters Per Second
B053F06    Response out units lookup:          V - Volts
B053F07    A0 normalization factor:            5.96806E+07
B053F08    Normalization frequency:            0.02
```

```
B053F09    Number of zeroes:                    2
B053F14    Number of poles:                     5
#          Complex zeroes:
#              i  real          imag           real_error    imag_error
B053F10-13  0  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
B053F10-13  1  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
#          Complex poles:
#              i  real          imag           real_error    imag_error
B053F15-18  0 -3.564700E-02 -3.687900E-02  0.000000E+00  0.000000E+00
B053F15-18  1 -3.564700E-02  3.687900E-02  0.000000E+00  0.000000E+00
B053F15-18  2 -2.513300E+02  0.000000E+00  0.000000E+00  0.000000E+00
B053F15-18  3 -1.310400E+02 -4.672900E+02  0.000000E+00  0.000000E+00
B053F15-18  4 -1.310400E+02  4.672900E+02  0.000000E+00  0.000000E+00
#
#          +              +-------------------------------------+
+
#          +              |    Channel Gain,   Q330   ch LHZ    |
+
#          +              +-------------------------------------+
+
#
B058F03    Stage sequence number:               1
B058F04    Gain:                                1.500000E+03
B058F05    Frequency of gain:                   2.000000E-02 HZ
B058F06    Number of calibrations:              0
#
#
#          +              +-----------------------------------------+
+
#          +              |   Response (Coefficients),  Q330 ch LHZ   |
+
#          +              +-----------------------------------------+
+
#
B054F03    Transfer function type:              D
B054F04    Stage sequence number:               2
B054F05    Response in units lookup:            V - Volts
B054F06    Response out units lookup:           COUNTS - Digital Counts
B054F07    Number of numerators:                0
B054F10    Number of denominators:              0
#
#          +              +------------------------------+
+
#          +              |   Decimation,  Q330 ch LHZ   |
+
#          +              +------------------------------+
+
#
B057F03    Stage sequence number:               2
B057F04    Input sample rate:                   1.000000E+00
B057F05    Decimation factor:                   1
B057F06    Decimation offset:                   0
B057F07    Estimated delay (seconds):           0.0000000E+00
B057F08    Correction applied (seconds):        0.0000000E+00
#
#          +              +-------------------------------------+
+
#          +              |    Channel Gain,  Q330 ch LHZ       |
+
#          +              +-------------------------------------+
+
#
B058F03    Stage sequence number:               2
B058F04    Gain:                                4.194300E+05
B058F05    Frequency of gain:                   0.000000E+00 HZ
B058F06    Number of calibrations:              0
#
#          +              +-----------------------------------------+
+
#          +              |   Response (Coefficients),  Q330 ch LHZ   |
+
```

```
#               +               +-------------------------------------------+
+
#
B054F03      Transfer function type:              D
B054F04      Stage sequence number:               3
B054F05      Response in units lookup:            COUNTS - Digital Counts
B054F06      Response out units lookup:           COUNTS - Digital Counts
B054F07      Number of numerators:                31
B054F10      Number of denominators:              0
#            Numerator coefficients:
#              i, coefficient,  error
B054F08-09   0 -2.5978267E-07  0.000000E+00
B054F08-09   1 -2.1529949E-06  0.000000E+00
B054F08-09   2  3.6562742E-05  0.000000E+00
B054F08-09   3  3.1420928E-03  0.000000E+00
B054F08-09   4  1.5220402E-03  0.000000E+00
B054F08-09   5 -6.5687263E-03  0.000000E+00
B054F08-09   6  1.2428614E-02  0.000000E+00
B054F08-09   7 -1.4443419E-02  0.000000E+00
B054F08-09   8  6.8963909E-03  0.000000E+00
B054F08-09   9  1.4259116E-02  0.000000E+00
B054F08-09  10 -4.8501567E-02  0.000000E+00
B054F08-09  11  8.8997526E-02  0.000000E+00
B054F08-09  12 -1.2304070E-01  0.000000E+00
B054F08-09  13  1.2459593E-01  0.000000E+00
B054F08-09  14  8.0991439E-01  0.000000E+00
B054F08-09  15  2.1776610E-01  0.000000E+00
B054F08-09  16 -1.4824265E-01  0.000000E+00
B054F08-09  17  8.8835267E-02  0.000000E+00
B054F08-09  18 -3.8596944E-02  0.000000E+00
B054F08-09  19  3.2269409E-03  0.000000E+00
B054F08-09  20  1.4731158E-02  0.000000E+00
B054F08-09  21 -1.8035660E-02  0.000000E+00
B054F08-09  22  1.2786087E-02  0.000000E+00
B054F08-09  23 -5.4045052E-03  0.000000E+00
B054F08-09  24  1.6753140E-04  0.000000E+00
B054F08-09  25  3.6581444E-03  0.000000E+00
B054F08-09  26 -1.2670077E-04  0.000000E+00
B054F08-09  27 -5.6355576E-07  0.000000E+00
B054F08-09  28 -4.3146524E-08  0.000000E+00
B054F08-09  29  3.1619205E-10  0.000000E+00
B054F08-09  30  1.2199295E-16  0.000000E+00
#
#               +               +------------------------------+
+
#               +               |   Decimation,  Q330 ch LHZ   |
+
#               +               +------------------------------+
+
#
B057F03      Stage sequence number:               3
B057F04      Input sample rate:                   1.000000E+00
B057F05      Decimation factor:                   1
B057F06      Decimation offset:                   0
B057F07      Estimated delay (seconds):            1.5930462E+01
B057F08      Correction applied (seconds):        1.5930462E+01
#
#               +               +----------------------------------+
+
#               +               |      Channel Gain,  Q330 ch LHZ      |
+
#               +               +----------------------------------+
+
#
B058F03      Stage sequence number:               3
B058F04      Gain:                                1.000000E+00
B058F05      Frequency of gain:                   0.000000E+00 HZ
B058F06      Number of calibrations:              0
#
#
```

MSHEAR FIR Filter F64CM
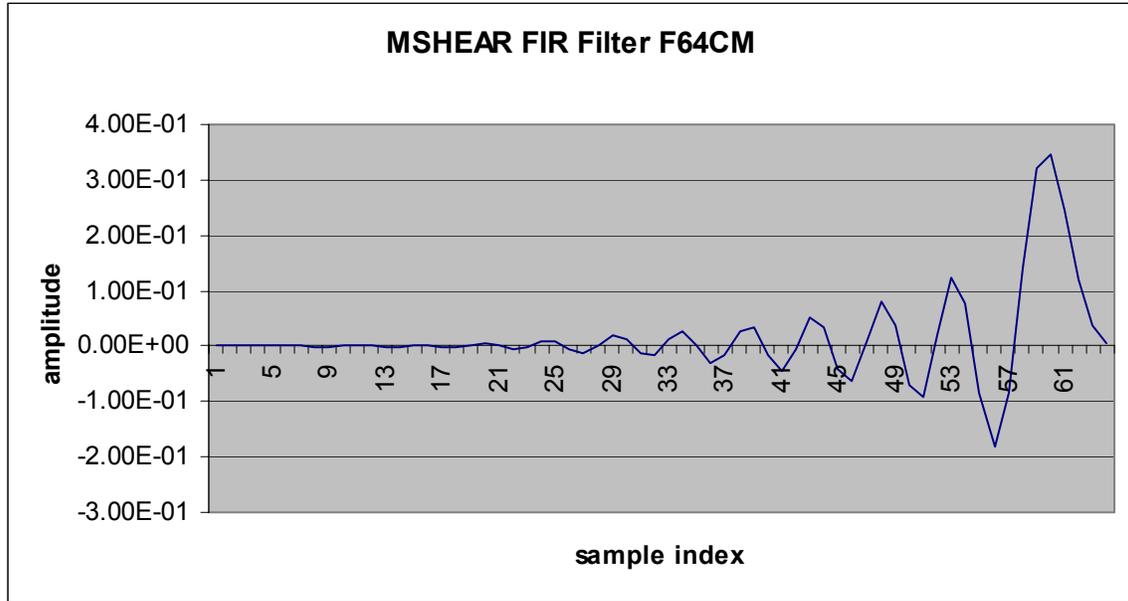
	200 sps	100 sps	50 sps	40 sps	20 sps	10 sps	1 sps
Linear at All Freq.	0.090000	0.330000	0.820000	0.500000	1.700000	4.100000	16.000000
Linear Below 100 sps	0.020462	0.041607	0.531607	0.430462	1.630462	4.030462	15.930462
Linear Below 40 sps	0.020462	0.041607	0.084847	0.082972	1.282972	3.682972	15.582972
Linear Below 20 sps	0.020462	0.041607	0.084847	0.082972	0.188697	2.588697	14.488697

TABLE 2: COMPOSITE FILTER DELAY IN SECONDS.
Blue indicates the ouput sample rate was filtered with Linear Phase filter in the last stage (and possibly earlier stages).
Red indicates the output sample rate was filtered with Minimum Phase Filters.