Title	Determination of seismograph response from poles and zeros
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1 Aim

The complex transfer function (or the related complex frequency response) of the analog part of a seismograph is a rational function of frequency. Such functions can be specified by corner frequencies and damping constants, by polynomial coefficients, or by their poles and zeros. The latter method is chosen in the IRIS SEED data volumes. For each data channel of each station, the data header contains a list of poles and zeros of the transfer function together with some auxiliary information. IRIS supplies a software library 'evalresp' for extracting and interpreting these parameters. The exercise aims at making you familiar with interpreting poles and zeros in terms of the amplitude response versus frequency.

2 Task

Interpret one or more of the annexed SEED headers with respect to the analog part of the seismograph. Sketch the amplitude response for one of the stations as a Bode-diagram on double logarithmic paper. (The digital part is usually of minor interest since it is supposed to have a flat amplitude response and zero phase delay.) Does the header describe a very broadband, broadband or narrowband system? Note that the answer does not only depend on the mathematical form of the response but also on the definition of the input signal - displacement, velocity or acceleration. A broadband seismograph is supposed to have a broadband response to velocity but a broadband accelerometer has a broadband response to acceleration. Be careful with the units - some headers refer to Hertz rather than radians/sec. Check also whether the poles and zeros refer to the Laplace transform or Fourier transform. Can you guess which type of sensor is used? Are the constants nominal or were they determined from an individual calibration?

A little computer program POL_ZERO in BASIC will be made available to you to do the numerical conversions and to plot the amplitude response (see PD_5.8). Use this program to analyze some more of the SEED headers. The stations are:

KIP (Kipapa, Hawaii)
KONO (Kongsberg, Norway)
KMI (Kunming, China)
PFO (Pinion Flat Observatory, California)
XAN (Xi'an, China)

3 Annex

SEED headers for stations KIP, KONO, KMI, PFO and XAN

KIP

```
:::::::::::::::
RESP.G.KIP..LHE
:::::::::::::::
#               << IRIS SEED Reader, Release 4.16 >>
#
#               ======== CHANNEL RESPONSE DATA ========
B050F03     Station:     KIP
B050F16     Network:     G
B052F03     Location:    ??
B052F04     Channel:     LHE
B052F22     Start date:  1988,147
B052F23     End date:    No Ending Time
#               ========================================
#               +               +-------------------------------------------+
#               +               |   Response (Poles & Zeros),   KIP ch LHE  |
#               +               +-------------------------------------------+
#
B053F03     Transfer function type:                 B [Analog (Hz)]
B053F04     Stage sequence number:                  1
B053F05     Response in units lookup:               M/S - Velocity
B053F06     Response out units lookup:              V - Volts
B053F07     A0 normalization factor:                25.0743
B053F08     Normalization frequency:                0.01
B053F09     Number of zeroes:                       2
B053F14     Number of poles:                        4
#               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 -1.964190E-03  1.964190E-03  0.000000E+00  0.000000E+00
B053F15-18    1 -1.964190E-03 -1.964190E-03  0.000000E+00  0.000000E+00
B053F15-18    2 -3.117500E+00  3.909120E+00  0.000000E+00  0.000000E+00
B053F15-18    3 -3.117500E+00 -3.909120E+00  0.000000E+00  0.000000E+00
#
#               +               +-------------------------------------+
#               +               |       Channel Gain,   KIP ch LHE    |
#               +               +-------------------------------------+
#
B058F03     Stage sequence number:                  1
B058F04     Gain:                                   2.398000E+03
B058F05     Frequency of gain:                      1.000000E-02 HZ
B058F06     Number of calibrations:                 0
#
#               +               +-------------------------------------------+
#               +               |   Response (Poles & Zeros),   KIP ch LHE  |
#               +               +-------------------------------------------+
#
B053F03     Transfer function type:                 B [Analog (Hz)]
B053F04     Stage sequence number:                  2
B053F05     Response in units lookup:               V - Volts
B053F06     Response out units lookup:              V - Volts
B053F07     A0 normalization factor:                15593.8
B053F08     Normalization frequency:                0.01
B053F09     Number of zeroes:                       0
B053F14     Number of poles:                        6
#               Complex zeroes:
#                 i  real          imag          real_error    imag_error
#               Complex poles:
#                 i  real          imag          real_error    imag_error
B053F15-18    0 -4.832580E+00  1.273240E+00  0.000000E+00  0.000000E+00
B053F15-18    1 -4.832580E+00 -1.273240E+00  0.000000E+00  0.000000E+00
B053F15-18    2 -3.538230E+00  3.529300E+00  0.000000E+00  0.000000E+00
B053F15-18    3 -3.538230E+00 -3.529300E+00  0.000000E+00  0.000000E+00
B053F15-18    4 -1.295000E+00  4.829390E+00  0.000000E+00  0.000000E+00
B053F15-18    5 -1.295000E+00 -4.829390E+00  0.000000E+00  0.000000E+00
#
```

KONO

```
::::::::::::::
RESP.IU.KONO.10.LHE
::::::::::::::
#               << IRIS SEED Reader, Release 4.16 >>
#
#               ======== CHANNEL RESPONSE DATA ========
B050F03     Station:     KONO
B050F16     Network:     IU
B052F03     Location:    10
B052F04     Channel:     LHE
B052F22     Start date:  1999,040,13
B052F23     End date:    No Ending Time
#               ========================================
#               +               +-------------------------------------------+
#               +               |   Response (Poles & Zeros),  KONO ch LHE  |
#               +               +-------------------------------------------+
#
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:               7.1367E+07
B053F08     Normalization frequency:               0.1
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 -3.701000E-02  3.701000E-02  0.000000E+00  0.000000E+00
B053F15-18    1 -3.701000E-02 -3.701000E-02  0.000000E+00  0.000000E+00
B053F15-18    2 -1.979000E+02  1.979000E+02  0.000000E+00  0.000000E+00
B053F15-18    3 -1.979000E+02 -1.979000E+02  0.000000E+00  0.000000E+00
B053F15-18    4 -9.111000E+02  0.000000E+00  0.000000E+00  0.000000E+00
#
#               +                 +-------------------------------------+
#               +                 |       Channel Gain,  KONO ch LHE    |
#               +                 +-------------------------------------+
#
B058F03     Stage sequence number:                 1
B058F04     Gain:                                  2.026400E+04
B058F05     Frequency of gain:                     2.000000E-02 HZ
B058F06     Number of calibrations:                0
#
#               +               +-------------------------------------------+
#               +               |   Response (Coefficients),  KONO ch LHE   |
#               +               +-------------------------------------------+
#
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,  KONO ch LHE    |
#               +                     +-------------------------------+
#
B057F03     Stage sequence number:                 2
B057F04     Input sample rate:                     5.120000E+03
B057F05     Decimation factor:                     1
B057F06     Decimation offset:                     0
B057F07     Estimated delay (seconds):             0.000000E+00
```

KMI

```
#
::::::::::::::
RESP.CD.KMI..LHZ
::::::::::::::
#               << IRIS SEED Reader, Release 4.16 >>
#
#               ======== CHANNEL RESPONSE DATA ========
B050F03     Station:     KMI
B050F16     Network:     CD
B052F03     Location:    ??
B052F04     Channel:     LHZ
B052F22     Start date:  1986,159
B052F23     End date:    1996,108
#               ======================================
#               +               +-------------------------------------------+
#               +               |   Response (Poles & Zeros),   KMI ch LHZ  |
#               +               +-------------------------------------------+
#
B053F03     Transfer function type:                A [Laplace Transform (Rad/sec)]
B053F04     Stage sequence number:                 1
B053F05     Response in units lookup:              M - Earth Displacement in Meters
B053F06     Response out units lookup:             COUNTS - Digital Counts
B053F07     A0 normalization factor:               0.000492889
B053F08     Normalization frequency:               0.04
B053F09     Number of zeroes:                      4
B053F14     Number of poles:                       10
#               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
B053F10-13    2  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
B053F10-13    3  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
#               Complex poles:
#                 i  real          imag          real_error    imag_error
B053F15-18    0 -2.221000E-01  2.221000E-01  0.000000E+00  0.000000E+00
B053F15-18    1 -2.221000E-01 -2.221000E-01  0.000000E+00  0.000000E+00
B053F15-18    2 -7.405000E-03  7.405000E-03  0.000000E+00  0.000000E+00
B053F15-18    3 -7.405000E-03 -7.405000E-03  0.000000E+00  0.000000E+00
B053F15-18    4 -2.023000E-01  5.420000E-02  0.000000E+00  0.000000E+00
B053F15-18    5 -2.023000E-01 -5.420000E-02  0.000000E+00  0.000000E+00
B053F15-18    6 -1.481000E-01  1.481000E-01  0.000000E+00  0.000000E+00
B053F15-18    7 -1.481000E-01 -1.481000E-01  0.000000E+00  0.000000E+00
B053F15-18    8 -5.420000E-02  2.023000E-01  0.000000E+00  0.000000E+00
B053F15-18    9 -5.420000E-02 -2.023000E-01  0.000000E+00  0.000000E+00
#
#               +               +-------------------------------------+
#               +               |   Channel Sensitivity,   KMI ch LHZ |
#               +               +-------------------------------------+
#
B058F03     Stage sequence number:                 0
B058F04     Sensitivity:                           1.800000E+09
B058F05     Frequency of sensitivity:              4.000000E-02 HZ
B058F06     Number of calibrations:                0
#
```

PFO

```
::::::::::::::
RESP.TS.PFO..LHZ
::::::::::::::
#               << IRIS SEED Reader, Release 4.16 >>
#
#               ======== CHANNEL RESPONSE DATA ========
B050F03     Station:     PFO
B050F16     Network:     TS
B052F03     Location:    ??
B052F04     Channel:     LHZ
B052F22     Start date:  1990,304
B052F23     End date:    No Ending Time
#               ========================================
#               +               +-------------------------------------------+
#               +               |   Response (Poles & Zeros),   PFO 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:               3948.58
B053F08     Normalization frequency:               0.02
B053F09     Number of zeroes:                      2
B053F14     Number of poles:                       4
#               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 -1.234000E-02  1.234000E-02  0.000000E+00  0.000000E+00
B053F15-18    1 -1.234000E-02 -1.234000E-02  0.000000E+00  0.000000E+00
B053F15-18    2 -3.918000E+01  4.912000E+01  0.000000E+00  0.000000E+00
B053F15-18    3 -3.918000E+01 -4.912000E+01  0.000000E+00  0.000000E+00
#
#               +               +---------------------------------------+
#               +               |       Channel Gain,   PFO ch LHZ      |
#               +               +---------------------------------------+
#
B058F03     Stage sequence number:                 1
B058F04     Gain:                                  2.122720E+03
B058F05     Frequency of gain:                     2.000000E-02 HZ
B058F06     Number of calibrations:                0
#
#               +               +-------------------------------------------+
#               +               |   Response (Coefficients),   PFO 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:                  43
B054F10     Number of denominators:                0
#               Numerator coefficients:
#                 i, coefficient,  error
B054F08-09    0 -3.557280E-09 -7.114550E-11
B054F08-09    1  3.273000E-06  6.546030E-08
B054F08-09    2 -3.791030E-04 -7.582060E-06
B054F08-09    3 -2.870530E-03 -5.741070E-05
B054F08-09    4 -2.949110E-03 -5.898210E-05
B054F08-09    5  3.191820E-03  6.383630E-05
B054F08-09    6 -2.121360E-03 -4.242730E-05
B054F08-09    7 -5.931070E-04 -1.186210E-05
B054F08-09    8  4.816940E-03  9.633870E-05
```

XAN

```
:::::::::::::::
RESP.IC.XAN..LHE
:::::::::::::::
#               << IRIS SEED Reader, Release 4.16 >>
#
#               ======== CHANNEL RESPONSE DATA ========
B050F03     Station:     XAN
B050F16     Network:     IC
B052F03     Location:    ??
B052F04     Channel:     LHE
B052F22     Start date:  1992,334
B052F23     End date:    1995,149
#               ======================================
#               +               +-----------------------------------------+
#               +               |   Response (Poles & Zeros),   XAN ch LHE  |
#               +               +-----------------------------------------+
#
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,   XAN ch LHE    |
#               +               +-------------------------------------+
#
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),   XAN ch LHE   |
#               +               +-----------------------------------------+
```

3 Solutions

KIP velocity very broadband, lower corner 360 s, upper corner 0.2 s
Obviously an older STS1-VBB seismometer. No extra filters.
Nominal parameters.

KONO velocity broadband, lower corner 120 s, upper corner 44.5 Hz
Must be an STS2 or a CMG3-T. Nominal parameters. Additional
low-pass Filter at 145 Hz.

KMI narrowband LP as a displacement sensor, but better characterized as
a long-period acceleration sensor. Response is flat to acceleration
from 30 s to 600 s. The sensor must be an old STS1 (20 s). A 6^{th}-order
Butterworth low-pass filter limits the bandwidth at 30 s; this would
today be done with digital filters in the recorder. Parameters are nominal.

PFO velocity very broadband, lower corner 360 s, upper corner 0.1 s.
A modern STS1-VBB. No extra filters. Nominal parameters.

XAN velocity broadband, lower corner 120 s, upper corner 44 Hz.
Probably an STS2 or a CMG3-T seismometer. Additional low-pass
filter at 77 Hz. Parameters were probably measured.