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

[Channel Response Data]

Station: KIP
Network: G
Location: ??
Channel: LHE
Start date: 1968,147
End date: No Ending Time

Transfer function type: B [Analog (Hz)]
Stage sequence number: 1
Response in units lookup: M/S - Velocity
Response out units lookup: V - Volts
AO normalization factor: 25.0743
Normalization frequency: 0.01
Number of zeros: 2
Number of poles: 4
Complex zeros:
- 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00
- 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00

Channel Gain:

Gain: 2.3980000E+03
Frequency of gain: 1.0000000E-02 Hz
Number of calibrations: 0

Transfer function type: B [Analog (Hz)]
Stage sequence number: 2
Response in units lookup: V - Volts
Response out units lookup: V - Volts
AO normalization factor: 15593.8
Normalization frequency: 0.01
Number of zeros: 0
Number of poles: 6
Complex zeros:
- 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00
- 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00
- 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00
- 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00
- 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00
- 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+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 |
+ + + + Channel Gain, KONO ch LHE |
+ + + + Response (Coefficients), KONO ch LHE |
+ + + + Decimation, KONO ch LHE |

B053F03 Transfer function type: A [Laplace Transform (Rad/sec)]
B053F04 Stage sequence number: 1
B053F05 Response 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 zeros: 2
B053F14 Number of poles: 5

# Complex zeroes:
# i real imag real_error imag_error
B053F10-13 0 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00
B053F10-13 1 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00

# Complex poles:
# i real imag real_error imag_error
B053F15-18 0 -3.701000E-02 3.701000E-02 0.0000000E+00 0.0000000E+00
B053F15-18 1 -3.701000E-02 -3.701000E-02 0.0000000E+00 0.0000000E+00
B053F15-18 2 -1.979000E+02 1.979000E+02 0.0000000E+00 0.0000000E+00
B053F15-18 3 -1.979000E+02 -1.979000E+02 0.0000000E+00 0.0000000E+00
B053F15-18 4 -9.111000E+02 0.0000000E+00 0.0000000E+00 0.0000000E+00

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 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

# :::::::::: :::::::: RRESP.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
#----------------------------------------#
# + + |
# + + |
# + + |
# + + |
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 -7.405000E-03 7.405000E-03 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 -5.420000E-02 5.420000E-02 0.000000E+00 0.000000E+00
B053F15-18 5 -5.420000E-02 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

::: IRIS SEED Reader, Release 4.16 :::

**--- CHANNEL RESPONSE DATA ---**

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<tr>
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<th>PFO</th>
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<td>Network</td>
<td>T6</td>
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<tr>
<td>Location</td>
<td>??</td>
</tr>
<tr>
<td>Channel</td>
<td>LHZ</td>
</tr>
<tr>
<td>Start date</td>
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<tr>
<td>End date</td>
<td>No Ending Time</td>
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**--- Complex zeroes ---**

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<td>imag</td>
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<td>B05F10-13</td>
<td>0.000000E+00</td>
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<tr>
<td>B05F10-13</td>
<td>1.000000E+00</td>
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**--- Complex poles ---**

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</tr>
<tr>
<td>B05F15-18</td>
<td>-1.234000E-02</td>
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<td>1.234000E-02</td>
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**--- Channel Gain ---**

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**--- Response (Coefficients) ---**

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<td>B05F10-09</td>
<td>-3.557280E-09</td>
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<tr>
<td>B05F10-09</td>
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<tr>
<td>B05F10-09</td>
<td>2.791030E-04</td>
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<td>B05F10-09</td>
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<td>B05F10-09</td>
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<td>B05F10-09</td>
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<td>B05F10-09</td>
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<td>B05F10-09</td>
<td>7.5391070E-04</td>
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<tr>
<td>B05F10-09</td>
<td>8.5168940E-03</td>
</tr>
</tbody>
</table>
XAN

::: RESPONSE IC.XAN..LHE :::
::: --- RESPONSE DATA --- :::

- **Station:** XAN
- **Network:** IC
- **Channel:** LHE
- **Start date:** 1992,334
- **End date:** 1995,149

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**Transfer function type:** A [Laplace Transform (Rad/sec)]
**Stage sequence number:** 1
**Response in units lookup:** M/S – Velocity in Meters Per Second
**Response out units lookup:** V – Volts
**A0 normalization factor:** 5.980000E+07
**Normalization frequency:** 0.02
**Number of zeroes:** 2
**Number of poles:** 5

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**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 -2.513500E-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

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**Stage sequence number:** 1
**Gain:** 1.500000E+03
**Frequency of gain:** 2.000000E+02 Hz
**Number of calibrations:** 0

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**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 6th-
     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.