Homework #1: Instrument responses and deconvolution **Due: 5:00 PM 01/30/17**

Please read the following questions carefully and make sure to answer the problems completely. In your MATLAB script(s), please include the problem numbers with your answers. Use the *Publish* function in MATLAB to publish your script to a *pdf* document; find something similar if not using MATLAB. LaTeXwith *mcode.sty* or some other language will work. For more on the *Publish* functionality within MATLAB see http://www.mathworks.com/help/matlab/matlab_prog/publishing-matlab-code.html. Upload your *pdf* file to Blackboard under Assignment #1. Your filename should be *GEOPH677_HW1_Lastname.pdf*. Hint: You can achieve this automatically by calling your MATLAB script *GEOPH677_HW1_Lastname.m*.

Intended Learning Outcomes

Students will be able to:

1. Derive the impulse response of an electromagnetic seismograph
2. Use poles/zeros and other instrument information to create and plot the phase and amplitude spectra of a seismograph
3. Relate the impulse response of an instrument to the data is measures and the actual ground displacement
4. Use MATLAB code from Matt Haney to create a stable and causal inverse filter for instrument deconvolution

Part 1: An electromagnetic velocity sensor *(35 pts.)*

Section 12.3.2 in Aki and Richards (2002) explains how an electromagnetic velocity sensor (Figure 1) works and derives the total damping given by this type of system (e.g. eqn 12.49). Starting from the beginning of this section complete or answer the following:

- Explain the Biot-Savart law. *(5 pts.)*
- Explain Onsager's reciprocal theorem. *(5 pts.)*
- How would you compute l given a coil with radius r and number of coils n. *(5 pts.)*
- Derive equation 12.49 (show all steps). *(15 pts.)*
- When was the electromagnetic sensor introduced in seismology and who introduced it? *(5 pts.)*

Note: If you need a copy of Aki and Richards come talk to me. Some of the answers to the above questions can be found with a search on Google.

Part 2: Creating the frequency response *(30 pts.)*

In the *Data/* folder on the GIT repository you will find the miniseed file *XX.BSM7.HHZ_MC-PH1_0426_20170112_180000.mini*
Load this into a computer however you like. You will need to access the header information to determine the sampling rate of the digital time series. Once you have that information, use the poles and zeros below to create your own frequency response for the Nanometrics Meridian sensors. *Keep in mind you will need to build a frequency vector and make sure to note the units of the poles and zeros below when are plugging them into functions. Some functions want Hz, some want rad*Hz (or rad/sec).*

```
zeros = [ % the zeros in 1/sec
     0.000000E+00;
     0.000000E+00;
    -3.920000E+02;
    -1.960000E+03;
    -1.490000E+03 + 1i*1.740000E+03;
    -1.490000E+03 + 1i*-1.740000E+03
    ];

poles = [ % the poles in 1/sec
    -3.691000E-02 + 1i* 3.702000E-02;
    -3.691000E-02 + 1i*-3.702000E-02;
    -3.430000E+02 + 1i* 0.000000E+00;
    -3.700000E+02 + 1i* 4.670000E+02;
    -3.700000E+02 + 1i*-4.670000E+02;
    -8.360000E+02 + 1i* 1.522000E+03;
    -8.360000E+02 + 1i*-1.522000E+03;
    -4.900000E+03 + 1i* 4.700000E+03;
    -4.900000E+03 + 1i*-4.700000E+03;
    -6.900000E+03 + 1i* 0.000000E+00;
    -1.500000E+04 + 1i* 0.000000E+00
    ];
```

If you are using MATLAB, you will want to use the functions **poly.m** and **freqs.m** to build the polynomials of the numerator and denominator and compute the frequency domain response. Multiply your response by the value A0=4.344928E+17; this is the conversion from counts to m/s for this particular instrument.

Note: There are two zeros equal to zero for this sensor. That means it is a velocity sensor. If there were three zeros equal to zero this would be a displacement sensors, and if there were one zero equal to zero this would be an acceleration sensor.

After you have build the frequency response, you should convert to the time domain and visualize the following:

- Amplitude spectral density *(5 pts.)*
- Phase spectra *(5 pts.)*
- The time-domain response *(5 pts.)*

You will likely note that the time-domain response is not causal. If that is the case, read through the Haney et al. (2012) paper to determine how they enforce causality with the Kramers-Kronig relationship. Plot your causal time-domain response after making this correction. *(5 pts.)*

When I do this, I get the plots shown in Figure 2.

Discuss what the amplitude, phase and time-domain plots tell you about this instrument and how it records different frequencies or resonates with time. *(10 pts.)*

Part 3: Instrument deconvolution *(35 pts.)*

Use the function *GEOPH677/Codes/Haney2012_CausalInstrumentCorrection/rm_instrum_resp.m* from the GIT repository to apply the instrument deconvolution given the poles and zeros from the last question. *(15 pts.)* In this case, set the sensitivity to 4.000000E+05. In this case setup the following inputs:

```
A0 = 4.344928E+17;
Sensitivity = 4.000000E+05;

% ordl          Butterworth order at flo, the low cutoff (between 2 and 4)
ordl = 2;
% ordh          Butterworth order at fhi, the high cutoff (between 3 and 7)
ordh = 3;
% digout:       inverse gain (m/s/count)
digout = Sensitivity/A0;
% digoutf:      frequency of normalization (Hz)
digoutf = 1;
% ovrsampl:     over-sampling factor for digital filter accuracy (e.g., 5)
ovrsampl = 10;
% idelay:       intrinsic delay in the acquisition system
idelay = 0;
```

After applying the instrument correction to the data, cut the data around your stomp. Compare the data before and after deconvolution. *Note: You will have to normalize the amplitudes to compare counts to m/s units. Concentrate on the phase and initial arrivals.* Comment on the differences and similarities. *(15 pts.)*

Make a plot of your deconvolved stomp. You can also make a plot of the normalized comparison. *(5 pts.)*

The stomps were made at the following times.

```
% Stomp test for meridians: 2017-01-12
%
% Alex: 18:41:10
% Tom: 18:41:30
% Diego: 18:41:40
% Zongbo: 18:41:54
% Matt: 18:42:07
% Rebekah: 18:42:21
```

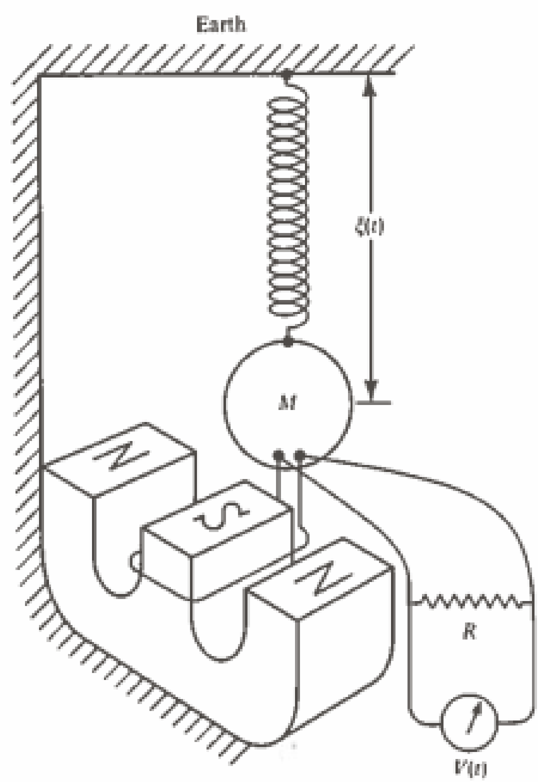

Figure 1: An electromagnetic seismometer – replace $\zeta(t)$ with $z(t)$ to follow our derivations in class.

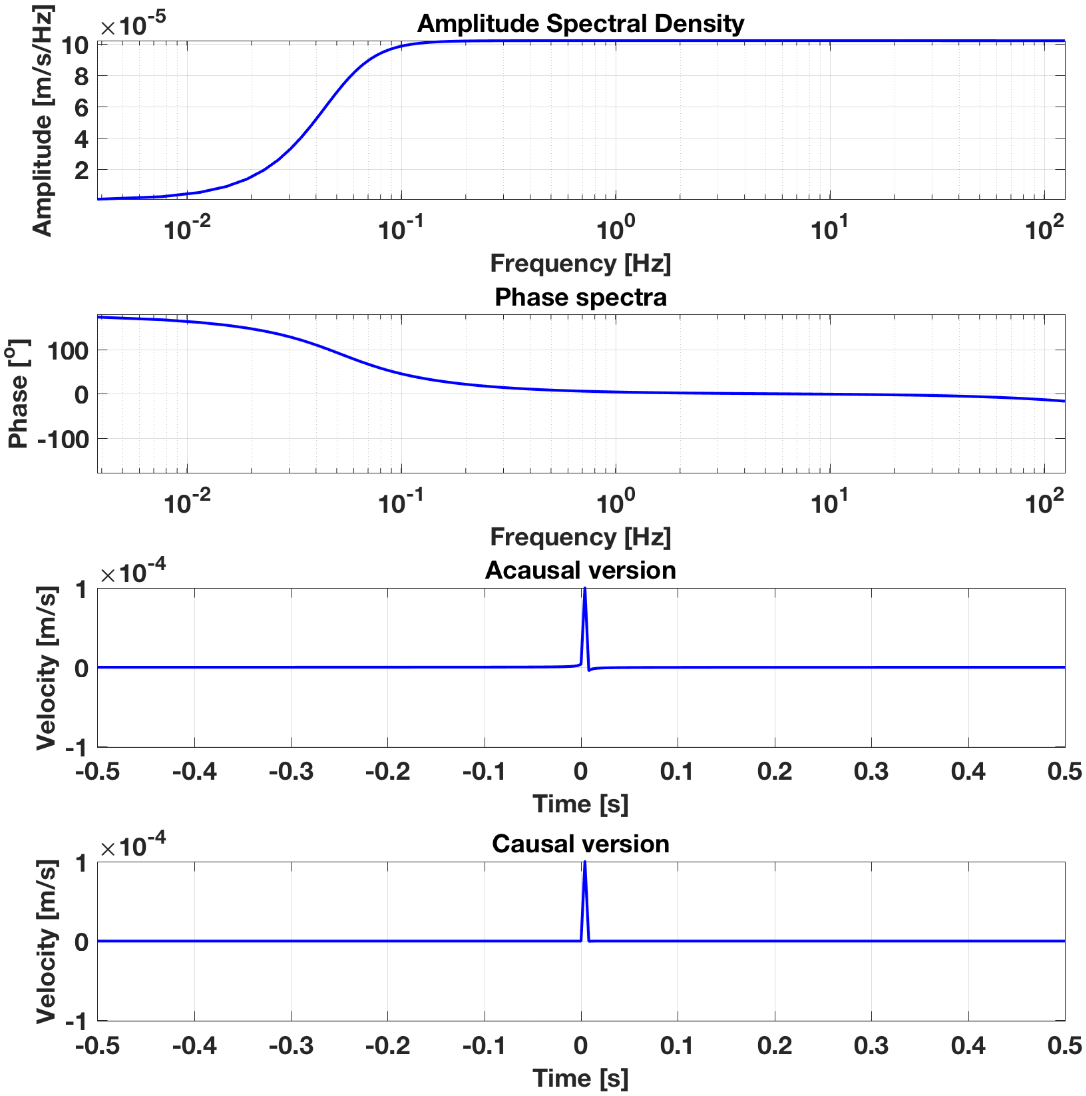

Figure 2: Frequency- and time-domain response of Meridian broadband seismometer.