
StationXML

1.1.0 (2020-09-02)

International FDSN

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OVERVIEW

1.1 Introducing StationXML

StationXML is an XML representation of metadata that describes the data collected by geophysical instrumentation. StationXML is defined by a schema that specifies the allowable format of StationXML documents.

1.1.1 StationXML Example

Example of StationXML [Show/Hide Code](#)

```
<?xml version='1.0' encoding='UTF-8'?>
  <FDSNStationXML xmlns="http://www.fdsn.org/xml/station/1" schemaVersion="1.1">
    <Source>IRIS-DMC</Source>
    <Sender>IRIS-DMC</Sender>
    <Module>IRIS WEB SERVICE: fdsnws-station | version: 1.1.35</Module>
    <ModuleURI>http://service.iris.edu/fdsnws/station/1/query?starttime=1990-01-
↪27T06&network=IU&level=response</ModuleURI>
    <Created>2018-11-08T14:57:56.000000Z</Created>
    <Network code="IU" restrictedStatus="open" startDate="1988-01-01T00:00:00.
↪000000Z">
      <Description>Global Seismograph Network (GSN - IRIS/USGS)</Description>
      <TotalNumberStations>269</TotalNumberStations>
      <SelectedNumberStations>6</SelectedNumberStations>
      <Station code="ANMO" endDate="1995-07-14T00:00:00.000000Z" restrictedStatus=
↪"open" startDate="1989-08-29T00:00:00.000000Z">
        <Channel>
          <Response>
            ...
          </Response>
        </Channel>
        <Channel>
          <Response>
            ...
          </Response>
        </Channel>
      </Station>
      <Station code="CCM" endDate="1998-05-26T00:00:00.000000Z" restrictedStatus=
↪"open" startDate="1989-08-29T00:00:00.000000Z">
        <Station>
          </Station>
        </Network>
      </FDSNStationXML>
```

Note that each XML element must have a start tag (e.g., <Station>) and an end tag (</Station>) and the element hierarchy must be maintained (e.g., a <Channel> may not exist outside of a <Station> and a <Station> may not exist outside of a <Network>, etc.).

1.1.2 The FDSN and StationXML schema

StationXML was developed through the International Federation of Digital Seismograph Networks (FDSN) to provide a standardized format for geophysical metadata.

Notice that the example StationXML excerpt above contains the following line:

```
<FDSNStationXML xmlns="http://www.fdsn.org/xml/station/1" schemaVersion="1.1">
```

This specifies the location and version of the schema to which the StationXML example must conform.

The FDSN maintains all versions of the StationXML schema at:

<https://www.fdsn.org/xml/station/>

For instance, at the time of this writing, the latest schema version is v1.1 and is located at:

<https://www.fdsn.org/xml/station/fdsn-station-1.1.xsd>

1.2 Documentation Organization

This documentation has 5 parts:

1. This introduction
2. StationXML Reference - Over time, once users have absorbed the other parts of the documentation, it is expected that this reference section will be the most frequently used. The reference section is auto-generated directly from the FDSN schema so that it should always be in sync with the schema. The reference itself is broken out by the 5 levels of response detail:
 - FDSNStationXML
 - Network
 - Station
 - Channel
 - Response
3. Specifying and using response information - In this section you will find theory and examples to help you create instrument responses for your own stations.
4. StationXML tools - contains examples of 3rd party tools available to help users create and edit StationXML files. This is expected to be a fluid page that changes as new tools become available and older tools are deprecated.
5. Appendices - In here you will find more technical details on specific parts of StationXML and metadata. For instance, the first section, Mapping SEED to StationXML, is meant to be used as a reference to help users migrate their SEED format metadata to StationXML

1.3 Some History - SEED

For three decades, the Standard for the Exchange of Earthquake Data (*SEED*) was the standard format for archiving and distributing metadata within the seismological community. Once representing file volumes binding metadata to data, a provision was later developed that allowed SEED metadata to stand on its own and was given the designation ‘dataless SEED’.

StationXML was developed through the FDSN (International Federation of Digital Seismograph Networks) as a replacement and extension of the SEED standard.

The purpose of the FDSN StationXML schema (*fdsn-station.xsd*) is to define an XML representation of the most important and commonly used structures of SEED 2.4 metadata with enhancements.

The goal of this document is to allow mapping between SEED 2.4 dataless SEED volumes and the StationXML schema with as little transformation or loss of information as possible, while at the same time simplifying station metadata representation when possible. Also, content and clarification has been added where lacking in the SEED standard.

1.4 StationXML Schema Changes

Changes from version 1.0 to 1.1 (2019-5-3) (Edited 2019-12-18 for small clarifications)

- Add (persistent) <Identifier> element to all base nodes (Network, Station, Channel)
- Unify response elements, allow “number” and disallow “unit” attribute to <Numerator> and <Denominator>
- Allow <CreationDate> to be optional
- Use xs:double for <ApproximationLowerBound>, <ApproximationUpperBound> and <MaximumError>
- Include data availability elements described in the *fdsn-station+availability-1.0.xsd* extension schema as optional elements of the main schema
- Remove <StorageFormat> from <Channel>
- Limit each <Operator> to a single <Agency>
- Allow more than a single <Equipment> occurrence in <Channel>, same as in <Station>
- Allow <Operator> at the <Network> level, same as in <Station>
- Add “sourceID” attribute, with URI value, to the base node type for <Network>,<Station>,<Channel>
- Do not require and disallow <StageGain> and <Decimation> for <Polynomial> response stages
- Add “measurementMethod” attribute to “uncertaintyDouble” attribute group used by azimuth, dip, distance, latitude, longitude, elevation, etc. types
- Add <WaterLevel> within <Station> and <Channel>
- Add “subject” attribute to <Comment> to allow relating comments, make “id” attribute optional.

1.5 Documentation Changes

Changes to this documentation.

Version 2020-09-02:

- Initial StationXML documentation.

The initial version of StationXML documentation was prepared by [ISTI](#) and sponsored by [IRIS Data Services](#) and [ORFEUS](#).

STATIONXML REFERENCE

2.1 <FDSNStationXML> required

Root-level for StationXML documents.

attribute	type	required	description	example
schemaVersion	<i>decimal</i>	yes	The StationXML schema version of this document.	schemaVersion='1.1'

2.1.1 <Source> required

FDSNStationXML → Source

type: *string*

Originator of the information contained in the document.

2.1.2 <Sender>

FDSNStationXML → Sender

type: *string*

Name of the institution sending this document.

2.1.3 <Module>

FDSNStationXML → Module

type: *string*

Name of the software module that generated this document.

Example: <Module>SeisComp3</Module>

2.1.4 <ModuleURI>

FDSNStationXML → ModuleURI

type: *anyURI*

Resource identifier of the query that generated the document, or, if applicable, the resource identifier of the software that generated this document.

2.1.5 <Created> required

FDSNStationXML → Created

type: *dateTime*

Date that this document was generated.

2.2 <Network> required

The Network container. All station metadata for this network is contained within this element. A Description element may be included with the official network name and other descriptive information. An Identifier element may be included to designate a persistent identifier (e.g. DOI) to use for citation. A Comment element may be included for additional comments.

Example: <Network code="IU" startDate=2016-01-27T13:00:00>

attribute	type	required	description	example
alternateCode	<i>string</i>	no	A code use for display or association	alternate-Code='GSN'
code	<i>string</i>	yes	Name of Network	code='IU'
endDate	<i>dateTime</i>	no	End date of network	endDate=2018-01-27T00:00:00
historicalCode	<i>string</i>	no	LevelDefault:A previously used code if different from the current code	historical-Code='II'
restrictedStatus	<i>RestrictedStatusType</i>	no	One of: 'open', 'closed', 'partial'	restrictedStatus='open'
sourceID	<i>anyURI</i>	no	A data source identifier in URI form	sourceID='http://some/path'
startDate	<i>dateTime</i>	no	Start date of network	startDate=2016-07-01T00:00:00

2.2.1 <Description>

Network → Description

type: *string*

Description of the Network.

Example: <Description>This is a description</Description>

2.2.2 <Identifier>

Network → Identifier

type: *string*

A type to document persistent identifiers. Identifier values should be specified without a URI scheme (prefix), instead the identifier type is documented as an attribute.

attribute	type	required	description	example
type	<i>string</i>	no	Identifier type	type='DOI'

2.2.3 <Comment>

Network → Comment

Container for a comment or log entry.

attribute	type	required	description	example
id	<i>CounterType</i>	no	An ID for this comment	id=12345
subject	<i>string</i>	no	A subject for this comment. Multiple comments with the same subject should be considered related.	subject='Scheduled maintenance'

<Value> required

Network → Comment → Value

type: *string*

Comment text.

Example: <Value>Temporary network deployment</Value>

<BeginEffectiveTime>

Network → Comment → BeginEffectiveTime

type: *dateTime*

Start time for when comment applies.

Example: <BeginEffectiveTime>2008-09-15T00:00:00</BeginEffectiveTime>

<EndEffectiveTime>

Network → Comment → EndEffectiveTime

type: *dateTime*

End time for when comment applies.

Example: <EndEffectiveTime>2008-09-16T12:00:00</EndEffectiveTime>

<Author>

Network → Comment → Author

Author of Comment.

<Name>

Network → Comment → Author → Name

type: *string*

Name of contact or author.

Example: <Name>Alfred E. Neuman</Name>

<Agency>

Network → Comment → Author → Agency

type: *string*

Agency of contact or author.

Example: <Agency>Mad Magazine, Inc.</Agency>

<Email>

Network → Comment → Author → Email

type: *string*

Email of contact or author.

Example: <Email>a.neuman@nosuchsite.com</Email>

<Phone>

Network → Comment → Author → Phone

Phone of contact or author.

attribute	type	required	description	example
description	<i>string</i>	no		

<CountryCode>

Network → Comment → Author → Phone → CountryCode

type: *integer*

Telephone country code.

Example: <CountryCode>64</CountryCode>

<AreaCode> required

Network → Comment → Author → Phone → AreaCode

type: *integer*

Telephone area code.

Example: <AreaCode>408</CountryCode>

<PhoneNumber> required

Network → Comment → Author → Phone → PhoneNumber

type: *string*

Telephone number.

Example: <PhoneNumber>5551212</PhoneNumber>

2.2.4 <DataAvailability>

Network → DataAvailability

A description of time series data availability. This information should be considered transient and is primarily useful as a guide for generating time series data requests. The information for a DataAvailability:Span may be specific to the time range used in a request that resulted in the document or limited to the availability of data within the request range. These details may or may not be retained when synchronizing metadata between data centers.

<Extent>

Network → DataAvailability → Extent

Data availability extents, the earliest and latest data available. No information about the continuity of the data is included or implied.

attribute	type	required	description	example
end	<i>dateTime</i>	yes	end date of extent	end=1988-12-31T00:00:00
start	<i>dateTime</i>	yes	start date of extent	start=1988-01-01T00:00:00

Network → DataAvailability → Span

A type for describing data availability spans, with variable continuity. The time range described may be based on the request parameters that generated the document and not necessarily relate to continuity outside of the range. It may also be a smaller time window than the request depending on the data characteristics.

attribute	type	required	description	example
end	<i>dateTime</i>	yes	end date of span	end=1988-12-31T00:00:00
maximumTime-Tear	<i>decimal</i>	no	The maximum time tear (gap or overlap) in seconds between time series segments in the specified range.	maximumTime-Tear=0.01
numberSegments	<i>integer</i>	yes	The number of continuous time series segments contained in the specified time range. A value of 1 indicates that the time series is continuous from start to end.	numberSegments=2
start	<i>dateTime</i>	yes	start date of span	start=1988-01-01T00:00:00

2.2.5 <Operator>

Network → Operator

Agency and contact persons who manage this network.

<Agency> required

Network → Operator → Agency

type: *string*

An operating agency and associated contact persons.

Example: <Agency>USGS</Agency>

<Contact>

Network → Operator → Contact

Person's contact information. A person can belong to multiple agencies and have multiple email addresses and phone numbers.

<Name>

Network → Operator → Contact → Name

type: *string*

Name of contact or author.

Example: <Name>Alfred E. Neuman</Name>

<Agency>

Network → Operator → Contact → Agency

type: *string*

Agency of contact or author.

Example: <Agency>Mad Magazine, Inc.</Agency>

<Email>

Network → Operator → Contact → Email

type: *string*

Email of contact or author.

Example: <Email>a.neuman@nosuchsite.com</Email>

<Phone>

Network → Operator → Contact → Phone

Phone of contact or author.

attribute	type	required	description	example
description	<i>string</i>	no		

<CountryCode>

Network → Operator → Contact → Phone → CountryCode

type: *integer*

Telephone country code.

Example: <CountryCode>64</CountryCode>

<AreaCode> required

Network → Operator → Contact → Phone → AreaCode

type: *integer*

Telephone area code.

Example: <AreaCode>408</CountryCode>

<PhoneNumber> required

Network → Operator → Contact → Phone → PhoneNumber

type: *string*

Telephone number.

Example: <PhoneNumber>5551212</PhoneNumber>

<WebSite>

Network → Operator → WebSite

type: *anyURI*

Website of operating agency.

Example: <WebSite>http://usgs.gov</WebSite>

2.2.6 <TotalNumberStations>

Network → TotalNumberStations

Warning

This field is likely to be deprecated in future versions of StationXML

type: *decimal* range: TotalNumberStations ≥ 0

The total number of stations in this network, including inactive or terminated stations.

Example: <TotalNumberStations>24</TotalNumberStations>

2.2.7 <SelectedNumberStations>

Network → SelectedNumberStations

Warning

This field is likely to be deprecated in future versions of StationXML

type: *decimal* range:SelectedNumberStations ≥ 0

The number of stations selected in the request that resulted in this document.

Example: <SelectedNumberStations>12</SelectedNumberStations>

2.3 <Station>

The Station container. All channel metadata for this station is contained within this element. A Description element may be included with the official station name and other descriptive information. An Identifier element may be included to designate a persistent identifier (e.g. DOI) to use for citation or reference. A Comment element may be included for additional comments.

attribute	type	required	description	example
alternateCode	<i>string</i>	no	A code use for display or association	
code	<i>string</i>	yes	Name of Station	code='ANMO'
endDate	<i>dateTime</i>	no	End date of station epoch	endDate=2018-01-27T00:00:00
historicalCode	<i>string</i>	no	LevelDefault:A previously used code if different from the current code	
restrictedStatus	<i>RestrictedStatusType</i>	no	One of: 'open', 'closed', 'partial'	restrictedStatus='open'
sourceID	<i>anyURI</i>	no	A data source identifier in URI form	sourceID='http://some/path'
startDate	<i>dateTime</i>	no	Start date of station epoch	startDate=2016-07-01T00:00:00

2.3.1 <Description>

Station → Description

type: *string*

Description of the Station.

Example: <Description>This is a description</Description>

2.3.2 <Identifier>

Station → Identifier

type: *string*

A type to document persistent identifiers. Identifier values should be specified without a URI scheme (prefix), instead the identifier type is documented as an attribute.

attribute	type	required	description	example
type	<i>string</i>	no	Identifier type	type='DOI'

2.3.3 <Comment>

Station → Comment

Container for a comment or log entry.

attribute	type	required	description	example
id	<i>CounterType</i>	no	An ID for this comment	id=12345
subject	<i>string</i>	no	A subject for this comment. Multiple comments with the same subject should be considered related.	subject='Scheduled maintenance'

<Value> required

Station → Comment → Value

type: *string*

Comment text.

Example: <Value>GPS CLock is unlocked</Value>

<BeginEffectiveTime>

Station → Comment → BeginEffectiveTime

type: *dateTime*

Start time for when comment applies.

Example: <BeginEffectiveTime>2008-09-15T00:00:00</BeginEffectiveTime>

<EndEffectiveTime>

Station → Comment → EndEffectiveTime

type: *dateTime*

End time for when comment applies.

Example: <EndEffectiveTime>2008-09-16T12:00:00</EndEffectiveTime>

<Author>

Station → Comment → Author

Author of Comment.

<Name>

Station → Comment → Author → Name

type: *string*

Name of contact or author.

Example: <Name>Alfred E. Neuman</Name>

<Agency>

Station → Comment → Author → Agency

type: *string*

Agency of contact or author.

Example: <Agency>Mad Magazine, Inc.</Agency>

<Email>

Station → Comment → Author → Email

type: *string*

Email of contact or author.

Example: <Email>a.neuman@nosuchsite.com</Email>

<Phone>

Station → Comment → Author → Phone

Phone of contact or author.

attribute	type	required	description	example
description	<i>string</i>	no		

<CountryCode>

Station → Comment → Author → Phone → CountryCode

type: *integer*

Telephone country code.

Example: <CountryCode>64</CountryCode>

<AreaCode> required

Station → Comment → Author → Phone → AreaCode

type: *integer*

Telephone area code.

Example: <AreaCode>408</CountryCode>

<PhoneNumber> required

Station → Comment → Author → Phone → PhoneNumber

type: *string*

Telephone number.

Example: <PhoneNumber>5551212</PhoneNumber>

2.3.4 <DataAvailability>

Station → DataAvailability

A description of time series data availability. This information should be considered transient and is primarily useful as a guide for generating time series data requests. The information for a DataAvailability:Span may be specific to the time range used in a request that resulted in the document or limited to the availability of data within the request range. These details may or may not be retained when synchronizing metadata between data centers.

<Extent>

Station → DataAvailability → Extent

Data availability extents, the earliest and latest data available. No information about the continuity of the data is included or implied.

attribute	type	required	description	example
end	<i>dateTime</i>	yes	end date of extent	end=1988-12-31T00:00:00
start	<i>dateTime</i>	yes	start date of extent	start=1988-01-01T00:00:00

Station → DataAvailability → Span

A type for describing data availability spans, with variable continuity. The time range described may be based on the request parameters that generated the document and not necessarily relate to continuity outside of the range. It may also be a smaller time window than the request depending on the data characteristics.

attribute	type	required	description	example
end	<i>dateTime</i>	yes	end date of span	end=1988-12-31T00:00:00
maximumTime-Tear	<i>decimal</i>	no	The maximum time tear (gap or overlap) in seconds between time series segments in the specified range.	maximumTime-Tear=0.01
numberSegments	<i>integer</i>	yes	The number of continuous time series segments contained in the specified time range. A value of 1 indicates that the time series is continuous from start to end.	numberSegments=2
start	<i>dateTime</i>	yes	start date of span	start=1988-01-01T00:00:00

2.3.5 <Latitude> required

Station → Latitude

type: *double* range: $-90.0 \leq \text{Latitude} < 90.0$

Station latitude, by default in degrees. Where the bulk of the equipment is located (or another appropriate site location).

Example: <Latitude unit="DEGREES" datum="WGS84">34.9459</Latitude>

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='DEGREES'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		
datum	<i>NMTOKEN</i>	no		

2.3.6 <Longitude> required

Station → Longitude

type: *double* range: $-180.0 \leq \text{Longitude} \leq 180.0$

Station longitude, by default in degrees. Where the bulk of the equipment is located (or another appropriate site location).

Example: <Longitude unit="DEGREES" datum="WGS84">-106.4572</Longitude>

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='DEGREES'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		
datum	<i>NMTOKEN</i>	no		

2.3.7 <Elevation> required

Station → Elevation

type: *double*

Elevation of local ground surface level at station, by default in meters.

Example: <Elevation unit="m">1850.0</Elevation>

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='m'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurementMethod	<i>string</i>	no		

2.3.8 <Site> required

Station → Site

Description of the location of the station using geopolitical entities (country, city, etc.).

<Name> required

Station → Site → Name

type: *string*

Name of the site.

Example: <Name>Albuquerque, New Mexico</Name>

<Description>

Station → Site → Description

type: *string*

A longer description of the location of this station.

Example: <Description>NW corner of Yellowstone National Park</Description>

<Town>

Station → Site → Town

type: *string*

The town or city closest to the station.

Example: <Town>Albuquerque</Town>

<County>

Station → Site → County

type: *string*

The county where the station is located.

Example: <County>Bernalillo</County>

<Region>

Station → Site → Region

type: *string*

The state, province, or region of this site.

Example: <Region>Southwest U.S.</Region>

<Country>

Station → Site → Country

type: *string*

The country of this site.

Example: <Country>U.S.A.</Country>

2.3.9 <WaterLevel>

Station → WaterLevel

type: *double*

Elevation of the water surface (in meters) for underwater sites, where 0 is mean sea level. If you put an ocean-bottom seismometer (OBS) on a lake bottom, where the lake surface is at elevation=0, then you should set WaterLevel=0.

Example: <WaterLevel>1200</WaterLevel>

attribute	type	required	description	example
unit	<i>string</i>	no	The unit of measurement. Use <i>SI</i> unit names and symbols whenever possible (e.g., 'm' instead of 'METERS').	unit='m'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		

2.3.10 <Vault>

Station → Vault

type: *string*

Type of vault, e.g. World-Wide Standardized Seismograph Network (WWSSN), tunnel, USArray Transportable Array Generation 2, etc.

2.3.11 <Geology>

Station → Geology

type: *string*

Type of rock and/or geologic formation at the station.

2.3.12 <Equipment>

Station → Equipment

Equipment used by all channels at a station.

attribute	type	required	description	example
resourceId	<i>string</i>	no	An identifier that serves to uniquely identify this resource. This identifier can be interpreted differently depending on the datacenter/software that generated the document. Also, we recommend using a prefix, e.g., GENERATOR:Meaningful ID. It should be expected that equipment with the same ID should indicate the same information/be derived from the same base instruments.	

<Type>

Station → Equipment → Type

type: *string*Type of equipment.

<Description>

Station → Equipment → Description

type: *string*Description of equipment.

<Manufacturer>

Station → Equipment → Manufacturer

type: *string*Manufacturer of equipment.

<Vendor>

Station → Equipment → Vendor

type: *string*Vendor of equipment.

<Model>

Station → Equipment → Model

type: *string*Model of equipment.

<SerialNumber>

Station → Equipment → SerialNumber

type: *string*

Serial number of equipment.

<InstallationDate>

Station → Equipment → InstallationDate

type: *dateTime*

Date this equipment was installed.

<RemovalDate>

Station → Equipment → RemovalDate

type: *dateTime*

Date this equipment was removed.

<CalibrationDate>

Station → Equipment → CalibrationDate

type: *dateTime*

Date this equipment was calibrated.

2.3.13 <Operator>

Station → Operator

Operator and associated contact persons.

<Agency> required

Station → Operator → Agency

type: *string*

An operating agency and associated contact persons.

Example: <Agency>USGS</Agency>

<Contact>

Station → Operator → Contact

Person's contact information. A person can belong to multiple agencies and have multiple email addresses and phone numbers.

<Name>

Station → Operator → Contact → Name

type: *string*

Name of contact or author.

Example: <Name>Alfred E. Neuman</Name>

<Agency>

Station → Operator → Contact → Agency

type: *string*

Agency of contact or author.

Example: <Agency>Mad Magazine, Inc.</Agency>

<Email>

Station → Operator → Contact → Email

type: *string*

Email of contact or author.

Example: <Email>a.neuman@nosuchsite.com</Email>

<Phone>

Station → Operator → Contact → Phone

Phone of contact or author.

attribute	type	required	description	example
description	<i>string</i>	no		

<CountryCode>

Station → Operator → Contact → Phone → CountryCode

type: *integer*

Telephone country code.

Example: <CountryCode>64</CountryCode>

<AreaCode> required

Station → Operator → Contact → Phone → AreaCode

type: *integer*

Telephone area code.

Example: <AreaCode>408</CountryCode>

<PhoneNumber> required

Station → Operator → Contact → Phone → PhoneNumber

type: *string*

Telephone number.

Example: <PhoneNumber>5551212</PhoneNumber>

<WebSite>

Station → Operator → WebSite

type: *anyURI*

Website of operating agency.

Example: <WebSite>http://usgs.gov</WebSite>

2.3.14 <CreationDate>

Station → CreationDate

Warning

This field is likely to be deprecated in future versions of StationXML

type: *dateTime*

Date and time (UTC) when the station was first installed.

2.3.15 <TerminationDate>

Station → TerminationDate

Warning

This field is likely to be deprecated in future versions of StationXML

type: *dateTime*

Date and time (UTC) when the station was terminated or will be terminated. Do not include this field if a termination date is not available or is not relevant.

2.3.16 <TotalNumberChannels>

Station → TotalNumberChannels

Warning

This field is likely to be deprecated in future versions of StationXML.

type: *decimal* range: TotalNumberChannels ≥ 0

Total number of channels recorded at this station.

2.3.17 <SelectedNumberChannels>

Station → SelectedNumberChannels

Warning

This field is likely to be deprecated in future versions of StationXML.

type: *decimal* range:SelectedNumberChannels ≥ 0

The number of channels selected in the request that resulted in this document.

2.3.18 <ExternalReference>

Station → ExternalReference

URI of any type of external report.

<URI> required

Station → ExternalReference → URI

type: *anyURI*

URI of the external reference.

<Description> required

Station → ExternalReference → Description

type: *string*

Description of the external reference.

2.4 <Channel>

The Channel container. A Description element may be included with other information. An Identifier element may be included to designate a persistent identifier (e.g. DOI) to use for citation or reference. A Comment element may be included for arbitrary comments.

attribute	type	required	description	example
alternateCode	<i>string</i>	no	A code use for display or association	
code	<i>string</i>	yes	Name of Channel	code='BHZ'
endDate	<i>dateTime</i>	no	End date of channel epoch	endDate=2018-01-27T00:00:00
historicalCode	<i>string</i>	no	LevelDefault:A previously used code if different from the current code	
locationCode	<i>string</i>	yes	The locationCode is typically used to group channels from a common sensor. For example, the channels of the primary sensor at global IDA-IRIS stations have locationCode = '00': 00_BHZ, 00_BHE, 00_BHN, 00_LHZ, ..., etc. Even though it is required, locationCode may be, and often is, an empty string, however, it is recommended that the locationCode not be empty.	location-Code='30'
restrictedStatus	<i>RestrictedStatusType</i>	no	One of:'open', 'closed', 'partial'	restrictedStatus='open'
sourceID	<i>anyURI</i>	no	A data source identifier in URI form	sourceID='http://some/path'
startDate	<i>dateTime</i>	no	Start date of channel epoch	startDate=2016-07-01T00:00:00

2.4.1 <Description>

Channel → Description

type: *string*

Description of the Channel.

Example: <Description>This is a description</Description>

2.4.2 <Identifier>

Channel → Identifier

type: *string*

A type to document persistent identifiers. Identifier values should be specified without a URI scheme (prefix), instead the identifier type is documented as an attribute.

attribute	type	required	description	example
type	<i>string</i>	no	Identifier type	type='DOI'

2.4.3 <Comment>

Channel → Comment

Container for a comment or log entry.

attribute	type	required	description	example
id	<i>CounterType</i>	no	An ID for this comment	id=12345
subject	<i>string</i>	no	A subject for this comment. Multiple comments with the same subject should be considered related.	sub- ject='Scheduled maintenance'

<Value> required

Channel → Comment → Value

type: *string*

Comment text.

Example: <Value>Large number of spikes</Value>

<BeginEffectiveTime>

Channel → Comment → BeginEffectiveTime

type: *dateTime*

Start time for when comment applies.

Example: <BeginEffectiveTime>2008-09-15T00:00:00</BeginEffectiveTime>

<EndEffectiveTime>

Channel → Comment → EndEffectiveTime

type: *dateTime*

End time for when comment applies.

Example: <EndEffectiveTime>2008-09-16T12:00:00</EndEffectiveTime>

<Author>

Channel → Comment → Author

Author of Comment.

<Name>

Channel → Comment → Author → Name

type: *string*

Name of contact or author.

Example: <Name>Alfred E. Neuman</Name>

<Agency>

Channel → Comment → Author → Agency

type: *string*

Agency of contact or author.

Example: <Agency>Mad Magazine, Inc.</Agency>

<Email>

Channel → Comment → Author → Email

type: *string*

Email of contact or author.

Example: <Email>a.neuman@nosuchsite.com</Email>

<Phone>

Channel → Comment → Author → Phone

Phone of contact or author.

attribute	type	required	description	example
description	<i>string</i>	no		

<CountryCode>

Channel → Comment → Author → Phone → CountryCode

type: *integer*

Telephone country code.

Example: <CountryCode>64</CountryCode>**<AreaCode> required**

Channel → Comment → Author → Phone → AreaCode

type: *integer*

Telephone area code.

Example: <AreaCode>408</CountryCode>**<PhoneNumber> required**

Channel → Comment → Author → Phone → PhoneNumber

type: *string*

Telephone number.

Example: <PhoneNumber>5551212</PhoneNumber>**2.4.4 <DataAvailability>**

Channel → DataAvailability

A description of time series data availability. This information should be considered transient and is primarily useful as a guide for generating time series data requests. The information for a DataAvailability:Span may be specific to the time range used in a request that resulted in the document or limited to the availability of data within the request range. These details may or may not be retained when synchronizing metadata between data centers.

<Extent>

Channel → DataAvailability → Extent

Data availability extents, the earliest and latest data available. No information about the continuity of the data is included or implied.

attribute	type	required	description	example
end	<i>dateTime</i>	yes	end date of extent	end=1988-12-31T00:00:00
start	<i>dateTime</i>	yes	start date of extent	start=1988-01-01T00:00:00

Channel → DataAvailability → Span

A type for describing data availability spans, with variable continuity. The time range described may be based on the request parameters that generated the document and not necessarily relate to continuity outside of the range. It may also be a smaller time window than the request depending on the data characteristics.

attribute	type	required	description	example
end	<i>dateTime</i>	yes	end date of span	end=1988-12-31T00:00:00
maximumTime-Tear	<i>decimal</i>	no	The maximum time tear (gap or overlap) in seconds between time series segments in the specified range.	maximumTime-Tear=0.01
numberSeg-ments	<i>integer</i>	yes	The number of continuous time series segments contained in the specified time range. A value of 1 indicates that the time series is continuous from start to end.	numberSeg-ments=2
start	<i>dateTime</i>	yes	start date of span	start=1988-01-01T00:00:00

2.4.5 <ExternalReference>

Channel → ExternalReference

URI of any type of external report, such as data quality reports.

<URI> required

Channel → ExternalReference → URI

type: *anyURI*

URI of the external reference.

<Description> required

Channel → ExternalReference → Description

type: *string*

Description of the external reference.

2.4.6 <Latitude> required

Channel → Latitude

type: *double* range: $-90.0 \leq \text{Latitude} < 90.0$

Latitude of this channel's sensor, by default in degrees. Often the same as the station latitude, but when different the channel latitude is the true location of the sensor.

Example: <Latitude unit="DEGREES" datum="WGS84">34.9459</Latitude>

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='DEGREES'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		
datum	<i>NMTOKEN</i>	no		

2.4.7 <Longitude> required

Channel → Longitude

type: *double* range: $-180.0 \leq \text{Longitude} \leq 180.0$

Longitude of this channel's sensor, by default in degrees. Often the same as the station longitude, but when different the channel longitude is the true location of the sensor.

Example: <Longitude unit="DEGREES" datum="WGS84">-106.4572</Longitude>

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='DEGREES'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		
datum	<i>NMTOKEN</i>	no		

2.4.8 <Elevation> required

Channel → Elevation

type: *double*

Elevation of the sensor, by default in meters. To find the local ground surface level, add the Depth value to this elevation.

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='m'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurementMethod	<i>string</i>	no		

2.4.9 <Depth> required

Channel → Depth

type: *double*

The depth of the sensor relative to the local ground surface level, in meters.

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='m'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurementMethod	<i>string</i>	no		

2.4.10 <Azimuth>

Channel → Azimuth

type: *double* range: $0.0 \leq \text{Azimuth} < 360.0$

Azimuth of the sensor in degrees clockwise from geographic (true) north.

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='DEGREES'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		

2.4.11 <Dip>

Channel → Dip

type: *double* range: $-90.0 \leq \text{Dip} \leq 90.0$

Dip of the instrument in degrees, positive down from horizontal.

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='DEGREES'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		

2.4.12 <WaterLevel>

Channel → WaterLevel

type: *double*

Elevation of the water surface in meters for underwater sites, where 0 is mean sea level. If you put an OBS on a lake bottom, where the lake surface is at elevation=0, then you should set WaterLevel=0.

attribute	type	required	description	example
unit	<i>string</i>	no	The unit of measurement. Use <i>SI</i> unit names and symbols whenever possible (e.g., 'm' instead of 'METERS').	unit='m'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		

2.4.13 <Type>

Channel → Type

type: *string*

Data type for this channel. One or more <Type> tags can be used to specify the nature of the data this channel collects. The value between the <Type> tags must be one of: TRIGGERED, CONTINUOUS, HEALTH, GEOPHYSICAL, WEATHER, FLAG or SYNTHESIZED.

Example: <Type>CONTINUOUS</Type>

2.4.14 <SampleRate>

Channel → SampleRate

type: *double*

Sample rate in samples per second. SampleRate is optional unless SampleRateRatio is present, in which case SampleRate is required.

Example: <SampleRate units='SAMPLES/S'>40.0</SampleRate>

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='SAMPLES/S'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		

2.4.15 <SampleRateRatio>

Channel → SampleRateRatio

Sample rate expressed as number of samples in a number of seconds. If present, then <SampleRate> must also be present. It can be useful for very slow data (e.g., greater than 10 days), since it allows for greater precision in the stored value.

Example: <SampleRate>3.859999367e-07</SampleRate> <SampleRateRatio><NumberSamples>1</NumberSamples> <NumberSeconds>2590674</NumberSeconds> </SampleRateRatio>

<NumberSamples> required

Channel → SampleRateRatio → NumberSamples

type: *integer*

Integer number of samples that span a number of seconds.

<NumberSeconds> required

Channel → SampleRateRatio → NumberSeconds

type: *integer*

Integer number of seconds that span a number of samples.

2.4.16 <ClockDrift>

Channel → ClockDrift

type: *double* range:ClockDrift ≥ 0.0

Tolerance value, measured in seconds per sample, used as a threshold for time error detection in data from the channel.

attribute	type	required	description	example
unit	<i>string</i>	no	The unit of drift value.	unit='SECONDS/SAMPLE'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		

2.4.17 <CalibrationUnits>

Channel → CalibrationUnits

Units of calibration (e.g., V (for Volts) or A (for amps)).

Example: <CalibrationUnits><Name>V</Name> <Description>Volts</Description> </CalibrationUnits>

<Name> required

Channel → CalibrationUnits → Name

type: *string*

Symbol or name of units, e.g. “m/s”, “V”, “Pa”, “C”. Use SI whenever possible.

<Description>

Channel → CalibrationUnits → Description

type: *string*

Description of units, e.g. “Velocity in meters per second”, “Volts”, “Pascals”, “Degrees Celsius”.

2.4.18 <Sensor>

Channel → Sensor

Details of the (typically analog) sensor attached to this channel. If this was entered at the Station level, it is not necessary to do it for each Channel, unless you have differences in equipment.

attribute	type	required	description	example
resourceId	<i>string</i>	no	An identifier that serves to uniquely identify this resource. This identifier can be interpreted differently depending on the datacenter/software that generated the document. Also, we recommend using a prefix, e.g., GENERATOR:Meaningful ID. It should be expected that equipment with the same ID should indicate the same information/be derived from the same base instruments.	

<Type>

Channel → Sensor → Type

type: *string*

Type of equipment.

<Description>

Channel → Sensor → Description

type: *string*

Description of equipment.

<Manufacturer>

Channel → Sensor → Manufacturer

type: *string*

Manufacturer of equipment.

<Vendor>

Channel → Sensor → Vendor

type: *string*

Vendor of equipment.

<Model>

Channel → Sensor → Model

type: *string*

Model of equipment.

<SerialNumber>

Channel → Sensor → SerialNumber

type: *string*

Serial number of equipment.

<InstallationDate>

Channel → Sensor → InstallationDate

type: *dateTime*

Date this equipment was installed.

<RemovalDate>

Channel → Sensor → RemovalDate

type: *dateTime*

Date this equipment was removed.

<CalibrationDate>

Channel → Sensor → CalibrationDate

type: *dateTime*

Date this equipment was calibrated.

2.4.19 <PreAmplifier>

Channel → PreAmplifier

Preamplifier (if any) used by this channel. If this was entered at the Station level, it is not necessary to do it for each Channel, unless you have differences in equipment.

attribute	type	required	description	example
resourceId	<i>string</i>	no	An identifier that serves to uniquely identify this resource. This identifier can be interpreted differently depending on the datacenter/software that generated the document. Also, we recommend using a prefix, e.g., GENERATOR:Meaningful ID. It should be expected that equipment with the same ID should indicate the same information/be derived from the same base instruments.	

<Type>

Channel → PreAmplifier → Type

type: *string*

Type of equipment.

<Description>

Channel → PreAmplifier → Description

type: *string*

Description of equipment.

<Manufacturer>

Channel → PreAmplifier → Manufacturer

type: *string*

Manufacturer of equipment.

<Vendor>

Channel → PreAmplifier → Vendor

type: *string*

Vendor of equipment.

<Model>

Channel → PreAmplifier → Model

type: *string*

Model of equipment.

<SerialNumber>

Channel → PreAmplifier → SerialNumber

type: *string*

Serial number of equipment.

<InstallationDate>

Channel → PreAmplifier → InstallationDate

type: *dateTime*

Date this equipment was installed.

<RemovalDate>

Channel → PreAmplifier → RemovalDate

type: *dateTime*

Date this equipment was removed.

<CalibrationDate>

Channel → PreAmplifier → CalibrationDate

type: *dateTime*

Date this equipment was calibrated.

2.4.20 <DataLogger>

Channel → DataLogger

Datalogger that recorded this channel. If this was entered at the Station level, it is not necessary to do it for each Channel, unless you have differences in equipment.

attribute	type	required	description	example
resourceId	<i>string</i>	no	An identifier that serves to uniquely identify this resource. This identifier can be interpreted differently depending on the datacenter/software that generated the document. Also, we recommend using a prefix, e.g., GENERATOR:Meaningful ID. It should be expected that equipment with the same ID should indicate the same information/be derived from the same base instruments.	

<Type>

Channel → DataLogger → Type

type: *string*

Type of equipment.

<Description>

Channel → DataLogger → Description

type: *string*

Description of equipment.

<Manufacturer>

Channel → DataLogger → Manufacturer

type: *string*

Manufacturer of equipment.

<Vendor>

Channel → DataLogger → Vendor

type: *string*

Vendor of equipment.

<Model>

Channel → DataLogger → Model

type: *string*

Model of equipment.

<SerialNumber>

Channel → DataLogger → SerialNumber

type: *string*

Serial number of equipment.

<InstallationDate>

Channel → DataLogger → InstallationDate

type: *dateTime*

Date this equipment was installed.

<RemovalDate>

Channel → DataLogger → RemovalDate

type: *dateTime*

Date this equipment was removed.

<CalibrationDate>

Channel → DataLogger → CalibrationDate

type: *dateTime*

Date this equipment was calibrated.

2.4.21 <Equipment>

Channel → Equipment

If the Equipment is entered at the Station level, it is not necessary to do it for each Channel, unless you have differences in equipment. If using a preamplifier, sensor, or datalogger, use their appropriate fields instead.

attribute	type	required	description	example
resourceId	<i>string</i>	no	An identifier that serves to uniquely identify this resource. This identifier can be interpreted differently depending on the datacenter/software that generated the document. Also, we recommend using a prefix, e.g., GENERATOR:Meaningful ID. It should be expected that equipment with the same ID should indicate the same information/be derived from the same base instruments.	

<Type>

Channel → Equipment → Type

type: *string*Type of equipment.

<Description>

Channel → Equipment → Description

type: *string*Description of equipment.

<Manufacturer>

Channel → Equipment → Manufacturer

type: *string*Manufacturer of equipment.

<Vendor>

Channel → Equipment → Vendor

type: *string*Vendor of equipment.

<Model>

Channel → Equipment → Model

type: *string*Model of equipment.

<SerialNumber>

Channel → Equipment → SerialNumber

type: *string*

Serial number of equipment.

<InstallationDate>

Channel → Equipment → InstallationDate

type: *dateTime*

Date this equipment was installed.

<RemovalDate>

Channel → Equipment → RemovalDate

type: *dateTime*

Date this equipment was removed.

<CalibrationDate>

Channel → Equipment → CalibrationDate

type: *dateTime*

Date this equipment was calibrated.

2.5 <Response>

The complete instrument response for this channel that expresses the effect of the geophysical instrumentation used to record the input ground motion. The information can be used to convert raw data to Earth unit measurement at a specified frequency or within a range of frequencies. It is strongly suggested that either InstrumentSensitivity or InstrumentPolynomial should be present.

attribute	type	required	description	example
resourceId	<i>string</i>	no	An identifier that serves to uniquely identify this resource. This identifier can be interpreted differently depending on the datacenter/software that generated the document. Also, we recommend using a prefix, e.g., GENERATOR:Meaningful ID. It should be expected that equipment with the same ID should indicate the same information/be derived from the same base instruments.	

2.5.1 <InstrumentSensitivity>

Response → InstrumentSensitivity

The total sensitivity for a channel, representing the complete acquisition system expressed as a scalar. All instrument responses except polynomial response should have an InstrumentSensitivity.

<Value> required

Response → InstrumentSensitivity → Value

type: *double*

A scalar value representing the amount of amplification or diminution, if any, the current stage applies to the input signal.

<Frequency> required

Response → InstrumentSensitivity → Frequency

type: *double*

The frequency (in Hertz) at which the Value is valid.

<InputUnits> required

Response → InstrumentSensitivity → InputUnits

The units of the data as input from the perspective of data acquisition. After correcting data for this response, these would be the resulting units.

<Name> required

Response → InstrumentSensitivity → InputUnits → Name

type: *string*

Symbol or name of units, e.g. “m/s”, “V”, “Pa”, “C”. Use SI whenever possible.

<Description>

Response → InstrumentSensitivity → InputUnits → Description

type: *string*

Description of units, e.g. “Velocity in meters per second”, “Volts”, “Pascals”, “Degrees Celsius”.

<OutputUnits> required

Response → InstrumentSensitivity → OutputUnits

The units of the data as output from the perspective of data acquisition. These would be the units of the data prior to correcting for this response.

<Name> required

Response → InstrumentSensitivity → OutputUnits → Name

type: *string*

Symbol or name of units, e.g. “m/s”, “V”, “Pa”, “C”. Use SI whenever possible.

<Description>

Response → InstrumentSensitivity → OutputUnits → Description

type: *string*

Description of units, e.g. “Velocity in meters per second”, “Volts”, “Pascals”, “Degrees Celsius”.

<FrequencyStart>

Response → InstrumentSensitivity → FrequencyStart

type: *double*

The lowest frequency for which the InstrumentSensitivity is valid. <FrequencyStart>, <FrequencyEnd> and <FrequencyDBVariation> are not required, however, if one of these is present, then all must be present.

<FrequencyEnd>

Response → InstrumentSensitivity → FrequencyEnd

type: *double*

The highest frequency for which the InstrumentSensitivity is valid. <FrequencyStart>, <FrequencyEnd> and <FrequencyDBVariation> are not required, however, if one of these is present, then all must be present.

<FrequencyDBVariation>

Response → InstrumentSensitivity → FrequencyDBVariation

type: *double*

Variation in decibels within the specified frequency range. <FrequencyStart>, <FrequencyEnd> and <FrequencyDBVariation> are not required, however, if one of these is present, then all must be present.

2.5.2 <InstrumentPolynomial>

Response → InstrumentPolynomial

For non-linear sensors (e.g., $N \geq 2$), such as some thermistors, pressure transducers, extensometers, etc.), it is required to express the sensor input (e.g., Temp) as a Maclaurin series expansion of powers of the *output* units (e.g., Volts):

$$Temp(V) = \sum_{k=0}^N a_k V^k \quad (2.1)$$

For such responses, two StationXML components are required to specify the response: 1. A Polynomial stage, which contains the values of the Maclaurin coefficients, a_k , and 2. An InstrumentPolynomial element that contains the same coefficients, but scaled by powers of the overall gain representing the combined effect of all the stages in the complete acquisition system.

attribute	type	required	description	example
name	<i>string</i>	no	A name given to this filter.	
resourceId	<i>string</i>	no	A resource identifier that serves to unique identify this filter or response. This identifier can be interpreted differently depending on the datacenter/software that generated the document. Also, we recommend using a prefix, e.g., GENERATOR:Meaningful ID. It should be expected that equipment with the same ID should indicate the same information/be derived from the same base instruments.	

<Description>

Response → InstrumentPolynomial → Description

type: *string*

The description of the filter/stage/response.

<InputUnits> required

Response → InstrumentPolynomial → InputUnits

The units of the data as input from the perspective of data acquisition. After correcting data for this response, these would be the resulting units.

<Name> required

Response → InstrumentPolynomial → InputUnits → Name

type: *string*

Symbol or name of units, e.g. “m/s”, “V”, “Pa”, “C”. Use SI whenever possible.

<Description>

Response → InstrumentPolynomial → InputUnits → Description

type: *string*

Description of units, e.g. “Velocity in meters per second”, “Volts”, “Pascals”, “Degrees Celsius”.

<OutputUnits> required

Response → InstrumentPolynomial → OutputUnits

The units of the data as output from the perspective of data acquisition. These would be the units of the data prior to correcting for this response.

<Name> required

Response → InstrumentPolynomial → OutputUnits → Name

type: *string*

Symbol or name of units, e.g. “m/s”, “V”, “Pa”, “C”. Use SI whenever possible.

<Description>

Response → InstrumentPolynomial → OutputUnits → Description

type: *string*

Description of units, e.g. “Velocity in meters per second”, “Volts”, “Pascals”, “Degrees Celsius”.

<ApproximationType> required

Response → InstrumentPolynomial → ApproximationType

type: *string*

The series type for the polynomial approximation.

<FrequencyLowerBound> required

Response → InstrumentPolynomial → FrequencyLowerBound

type: *double*

The lower bound of the frequency range.

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='HERTZ'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurementMethod	<i>string</i>	no		

<FrequencyUpperBound> required

Response → InstrumentPolynomial → FrequencyUpperBound

type: *double*

The upper bound of the frequency range.

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='HERTZ'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurementMethod	<i>string</i>	no		

<ApproximationLowerBound> required

Response → InstrumentPolynomial → ApproximationLowerBound

type: *double*

The lower bound of the approximation range.

<ApproximationUpperBound> required

Response → InstrumentPolynomial → ApproximationUpperBound

type: *double*

The upper bound of the approximation range.

<MaximumError> required

Response → InstrumentPolynomial → MaximumError

type: *double*

The maximum error of the approximation.

<Coefficient> required

Response → InstrumentPolynomial → Coefficient

type: *double*

attribute	type	required	description	example
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		
number	<i>CounterType</i>	no		

2.5.3 <Stage>

Response → Stage

Type for channel response entry or stage. A full response is represented as an ordered sequence of these stages.

attribute	type	required	description	example
number	<i>CounterType</i>	yes	Stage sequence number. This is used in all the response blockettes. Start from name='1' and iterate sequentially.	
resourceId	<i>string</i>	no	A resource identifier that serves to uniquely identify this response stage. This identifier can be interpreted differently depending on the datacenter/software that generated the document. Also, we recommend using a prefix, e.g., GENERATOR:Meaningful ID. It should be expected that equipment with the same ID should indicate the same information/be derived from the same base instruments.	

<PolesZeros>

Response → Stage → PolesZeros

Response stage described by the complex poles and zeros of the Laplace Transform (or z-transform) of the transfer function for this stage.

attribute	type	required	description	example
name	<i>string</i>	no	A name given to this filter.	
resourceId	<i>string</i>	no	A resource identifier that serves to unique identify this filter or response. This identifier can be interpreted differently depending on the datacenter/software that generated the document. Also, we recommend using a prefix, e.g., GENERATOR:Meaningful ID. It should be expected that equipment with the same ID should indicate the same information/be derived from the same base instruments.	

<Description>

Response → Stage → PolesZeros → Description

type: *string*

The description of the filter/stage/response.

<InputUnits> required

Response → Stage → PolesZeros → InputUnits

The units of the data as input from the perspective of data acquisition. After correcting data for this response, these would be the resulting units.

<Name> required

Response → Stage → PolesZeros → InputUnits → Name

type: *string*

Symbol or name of units, e.g. “m/s”, “V”, “Pa”, “C”. Use SI whenever possible.

<Description>

Response → Stage → PolesZeros → InputUnits → Description

type: *string*

Description of units, e.g. “Velocity in meters per second”, “Volts”, “Pascals”, “Degrees Celsius”.

<OutputUnits> required

Response → Stage → PolesZeros → OutputUnits

The units of the data as output from the perspective of data acquisition. These would be the units of the data prior to correcting for this response.

<Name> required

Response → Stage → PolesZeros → OutputUnits → Name

type: *string*

Symbol or name of units, e.g. “m/s”, “V”, “Pa”, “C”. Use SI whenever possible.

<Description>

Response → Stage → PolesZeros → OutputUnits → Description

type: *string*

Description of units, e.g. “Velocity in meters per second”, “Volts”, “Pascals”, “Degrees Celsius”.

<PzTransferFunctionType> required

Response → Stage → PolesZeros → PzTransferFunctionType

type: *string*

Allowable values are: “LAPLACE (RADIANS/SECOND)”, “LAPLACE (HERTZ)”, “DIGITAL (Z-TRANSFORM)”. For an analog stage this should be the units of the poles and zeros of the Laplace Transform, either: “LAPLACE (RADIANS/SECOND)” or “LAPLACE (HERTZ)”. For a digital z-transform (e.g., for an IIR filter), this should be “DIGITAL (Z-TRANSFORM)”.

Example: <PzTransferFunctionType>LAPLACE (RADIANS/SECOND)</PzTransferFunctionType>”.

<NormalizationFactor> required

Response → Stage → PolesZeros → NormalizationFactor

type: *double*

Normalization scale factor.

<NormalizationFrequency> required

Response → Stage → PolesZeros → NormalizationFrequency

type: *double*

Frequency at which the NormalizationFactor is valid. This should be the same for all stages and within the passband, if any.

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='HERTZ'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurementMethod	<i>string</i>	no		

<Zero>

Response → Stage → PolesZeros → Zero

Complex zero of the polezero stage.

attribute	type	required	description	example
number	<i>integer</i>	no	The position index of the pole (or zero) in the array of poles[] (or zeros[])	<Pole number='1'>

<Real> required

Response → Stage → PolesZeros → Zero → Real

type: *double*

Real part of the pole or zero.

attribute	type	required	description	example
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurementMethod	<i>string</i>	no		

<Imaginary> required

Response → Stage → PolesZeros → Zero → Imaginary

type: *double*

Imaginary part of the pole or zero.

attribute	type	required	description	example
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurementMethod	<i>string</i>	no		

<Pole>

Response → Stage → PolesZeros → Pole

Complex pole of the polezero stage.

attribute	type	required	description	example
number	<i>integer</i>	no	The position index of the pole (or zero) in the array of poles[] (or zeros[])	<Pole number='1'>

<Real> required

Response → Stage → PolesZeros → Pole → Real

type: *double*

Real part of the pole or zero.

attribute	type	required	description	example
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurementMethod	<i>string</i>	no		

<Imaginary> required

Response → Stage → PolesZeros → Pole → Imaginary

type: *double*

Imaginary part of the pole or zero.

attribute	type	required	description	example
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurementMethod	<i>string</i>	no		

<Coefficients>

Response → Stage → Coefficients

Response type for FIR coefficients. Laplace transforms or IIR filters can both be expressed using type as well but the PolesAndZerosType should be used instead.

attribute	type	required	description	example
name	<i>string</i>	no	A name given to this filter.	
resourceId	<i>string</i>	no	A resource identifier that serves to unique identify this filter or response. This identifier can be interpreted differently depending on the datacenter/software that generated the document. Also, we recommend using a prefix, e.g., GENERATOR:Meaningful ID. It should be expected that equipment with the same ID should indicate the same information/be derived from the same base instruments.	

<Description>

Response → Stage → Coefficients → Description

type: *string*

The description of the filter/stage/response.

<InputUnits> required

Response → Stage → Coefficients → InputUnits

The units of the data as input from the perspective of data acquisition. After correcting data for this response, these would be the resulting units.

<Name> required

Response → Stage → Coefficients → InputUnits → Name

type: *string*

Symbol or name of units, e.g. “m/s”, “V”, “Pa”, “C”. Use SI whenever possible.

<Description>

Response → Stage → Coefficients → InputUnits → Description

type: *string*

Description of units, e.g. “Velocity in meters per second”, “Volts”, “Pascals”, “Degrees Celsius”.

<OutputUnits> required

Response → Stage → Coefficients → OutputUnits

The units of the data as output from the perspective of data acquisition. These would be the units of the data prior to correcting for this response.

<Name> required

Response → Stage → Coefficients → OutputUnits → Name

type: *string*

Symbol or name of units, e.g. “m/s”, “V”, “Pa”, “C”. Use SI whenever possible.

<Description>

Response → Stage → Coefficients → OutputUnits → Description

type: *string*

Description of units, e.g. “Velocity in meters per second”, “Volts”, “Pascals”, “Degrees Celsius”.

<CfTransferFunctionType> required

Response → Stage → Coefficients → CfTransferFunctionType

type: *string*

Almost always a digital response, but can be an analog response in rad/sec or Hertz.

<Numerator>

Response → Stage → Coefficients → Numerator

type: *double*

Numerator for the coefficient.

attribute	type	required	description	example
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		
number	<i>CounterType</i>	no		

<Denominator>

Response → Stage → Coefficients → Denominator

type: *double*

Denominator for the coefficient.

attribute	type	required	description	example
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		
number	<i>CounterType</i>	no		

<ResponseList>

Response → Stage → ResponseList

Response type for a list of frequency, amplitude, and phase values.

attribute	type	required	description	example
name	<i>string</i>	no	A name given to this filter.	
resourceId	<i>string</i>	no	A resource identifier that serves to unique identify this filter or response. This identifier can be interpreted differently depending on the datacenter/software that generated the document. Also, we recommend using a prefix, e.g., GENERATOR:Meaningful ID. It should be expected that equipment with the same ID should indicate the same information/be derived from the same base instruments.	

<Description>

Response → Stage → ResponseList → Description

type: *string*

The description of the filter/stage/response.

<InputUnits> required

Response → Stage → ResponseList → InputUnits

The units of the data as input from the perspective of data acquisition. After correcting data for this response, these would be the resulting units.

<Name> required

Response → Stage → ResponseList → InputUnits → Name

type: *string*

Symbol or name of units, e.g. “m/s”, “V”, “Pa”, “C”. Use SI whenever possible.

<Description>

Response → Stage → ResponseList → InputUnits → Description

type: *string*

Description of units, e.g. “Velocity in meters per second”, “Volts”, “Pascals”, “Degrees Celsius”.

<OutputUnits> required

Response → Stage → ResponseList → OutputUnits

The units of the data as output from the perspective of data acquisition. These would be the units of the data prior to correcting for this response.

<Name> required

Response → Stage → ResponseList → OutputUnits → Name

type: *string*

Symbol or name of units, e.g. “m/s”, “V”, “Pa”, “C”. Use SI whenever possible.

<Description>

Response → Stage → ResponseList → OutputUnits → Description

type: *string*

Description of units, e.g. “Velocity in meters per second”, “Volts”, “Pascals”, “Degrees Celsius”.

<ResponseListElement>

Response → Stage → ResponseList → ResponseListElement

<Frequency> required

Response → Stage → ResponseList → ResponseListElement → Frequency

type: *double*

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='HERTZ'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurementMethod	<i>string</i>	no		

<Amplitude> required

Response → Stage → ResponseList → ResponseListElement → Amplitude

type: *double*

Representation of floating-point numbers used as measurements.

attribute	type	required	description	example
unit	<i>string</i>	no	The unit of measurement. Use <i>SI</i> unit names and symbols whenever possible (e.g., ‘m’ instead of ‘METERS’).	unit='m'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		

<Phase> required

Response → Stage → ResponseList → ResponseListElement → Phase

type: *double* range: $-360.0 \leq \text{Phase} \leq 360.0$

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='DEGREES'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		

<FIR>

Response → Stage → FIR

Response type for FIR filter. FIR filters are also commonly documented using the Coefficients element, with this newer type allowing representation of symmetric FIR coefficients without repeating them.

attribute	type	required	description	example
name	<i>string</i>	no	A name given to this filter.	
resourceId	<i>string</i>	no	A resource identifier that serves to unique identify this filter or response. This identifier can be interpreted differently depending on the datacenter/software that generated the document. Also, we recommend using a prefix, e.g., GENERATOR:Meaningful ID. It should be expected that equipment with the same ID should indicate the same information/be derived from the same base instruments.	

<Description>

Response → Stage → FIR → Description

type: *string*

The description of the filter/stage/response.

<InputUnits> required

Response → Stage → FIR → InputUnits

The units of the data as input from the perspective of data acquisition. After correcting data for this response, these would be the resulting units.

<Name> required

Response → Stage → FIR → InputUnits → Name

type: *string*

Symbol or name of units, e.g. “m/s”, “V”, “Pa”, “C”. Use SI whenever possible.

<Description>

Response → Stage → FIR → InputUnits → Description

type: *string*

Description of units, e.g. “Velocity in meters per second”, “Volts”, “Pascals”, “Degrees Celsius”.

<OutputUnits> required

Response → Stage → FIR → OutputUnits

The units of the data as output from the perspective of data acquisition. These would be the units of the data prior to correcting for this response.

<Name> required

Response → Stage → FIR → OutputUnits → Name

type: *string*

Symbol or name of units, e.g. “m/s”, “V”, “Pa”, “C”. Use SI whenever possible.

<Description>

Response → Stage → FIR → OutputUnits → Description

type: *string*

Description of units, e.g. “Velocity in meters per second”, “Volts”, “Pascals”, “Degrees Celsius”.

<Symmetry> required

Response → Stage → FIR → Symmetry

type: *string*

<NumeratorCoefficient>

Response → Stage → FIR → NumeratorCoefficient

type: *double*

attribute	type	required	description	example
i	<i>integer</i>	no		

<Decimation>

Response → Stage → Decimation

Representation of decimation stage.

<InputSampleRate> required

Response → Stage → Decimation → InputSampleRate

type: *double*

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='HERTZ'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurementMethod	<i>string</i>	no		

<Factor> required

Response → Stage → Decimation → Factor

type: *integer*

The factor of the input sample rate by which the rate is reduced.

<Offset> required

Response → Stage → Decimation → Offset

type: *integer*

Sample offset chosen for use. The value should be greater than or equal to zero, but less than the decimation factor. If the first sample is used, set this field to zero. If the second sample, set it to 1, and so forth.

<Delay> required

Response → Stage → Decimation → Delay

type: *double*

The estimated pure delay for the stage. This value will almost always be positive to indicate a delayed signal. Due to the difficulty in estimating the pure delay of a stage and because dispersion is neglected, this value should be considered nominal. Normally the delay would be corrected by the recording system and the correction applied would be specified in <Correction> below. See the Decimation Section in the StationXML documentation for a schematic description of delay sign convention.

attribute	type	required	description	example
unit	<i>string</i>	no	The unit of measurement. Use <i>SI</i> unit names and symbols whenever possible (e.g., 'm' instead of 'METERS').	unit='SECONDS'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		

<Correction> required

Response → Stage → Decimation → Correction

type: *double*

The time shift, if any, applied to correct for the delay at this stage. The sign convention used is opposite the <Delay> value; a positive sign here indicates that the trace was corrected to an earlier time to cancel the delay caused by the stage and indicated in the <Delay> element. Commonly, the estimated delay and the applied correction are both positive to cancel each other. A value of zero indicates no correction was applied. See the Decimation Section in the StationXML documentation for a schematic description of delay sign convention.

attribute	type	required	description	example
unit	<i>string</i>	no	The unit of measurement. Use <i>SI</i> unit names and symbols whenever possible (e.g., 'm' instead of 'METERS').	unit='SECONDS'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		

<StageGain> required

Response → Stage → StageGain

The gain at the stage of the encapsulating response element at a specific frequency. Total channel sensitivity should be specified in the InstrumentSensitivity element.

<Value> required

Response → Stage → StageGain → Value

type: *double*

A scalar value representing the amount of amplification or diminution, if any, the current stage applies to the input signal.

<Frequency> required

Response → Stage → StageGain → Frequency

type: *double*

The frequency (in Hertz) at which the Value is valid.

<Polynomial> required

Response → Stage → Polynomial

When a response is given in terms of a polynomial expansion of powers of the sensor output signal (e.g., Volts), a Polynomial Stage is required to specify the Maclaurin coefficients of the expansion. In addition, an InstrumentPolynomial element must be present at Response level to represent the whole acquisition process, which contains the same Maclaurin coefficients, but scaled by powers of the overall gain for all stages.

attribute	type	required	description	example
name	<i>string</i>	no	A name given to this filter.	
resourceId	<i>string</i>	no	A resource identifier that serves to unique identify this filter or response. This identifier can be interpreted differently depending on the datacenter/software that generated the document. Also, we recommend using a prefix, e.g., GENERATOR:Meaningful ID. It should be expected that equipment with the same ID should indicate the same information/be derived from the same base instruments.	

<Description>

Response → Stage → Polynomial → Description

type: *string*

The description of the filter/stage/response.

<InputUnits> required

Response → Stage → Polynomial → InputUnits

The units of the data as input from the perspective of data acquisition. After correcting data for this response, these would be the resulting units.

<Name> required

Response → Stage → Polynomial → InputUnits → Name

type: *string*

Symbol or name of units, e.g. “m/s”, “V”, “Pa”, “C”. Use SI whenever possible.

<Description>

Response → Stage → Polynomial → InputUnits → Description

type: *string*

Description of units, e.g. “Velocity in meters per second”, “Volts”, “Pascals”, “Degrees Celsius”.

<OutputUnits> required

Response → Stage → Polynomial → OutputUnits

The units of the data as output from the perspective of data acquisition. These would be the units of the data prior to correcting for this response.

<Name> required

Response → Stage → Polynomial → OutputUnits → Name

type: *string*

Symbol or name of units, e.g. “m/s”, “V”, “Pa”, “C”. Use SI whenever possible.

<Description>

Response → Stage → Polynomial → OutputUnits → Description

type: *string*

Description of units, e.g. “Velocity in meters per second”, “Volts”, “Pascals”, “Degrees Celsius”.

<ApproximationType> required

Response → Stage → Polynomial → ApproximationType

type: *string*

The series type for the polynomial approximation.

<FrequencyLowerBound> required

Response → Stage → Polynomial → FrequencyLowerBound

type: *double*

The lower bound of the frequency range.

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='HERTZ'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurementMethod	<i>string</i>	no		

<FrequencyUpperBound> required

Response → Stage → Polynomial → FrequencyUpperBound

type: *double*

The upper bound of the frequency range.

attribute	type	required	description	example
unit	<i>string</i>	no	The type of unit being used.	unit='HERTZ'
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurementMethod	<i>string</i>	no		

<ApproximationLowerBound> required

Response → Stage → Polynomial → ApproximationLowerBound

type: *double*

The lower bound of the approximation range.

<ApproximationUpperBound> required

Response → Stage → Polynomial → ApproximationUpperBound

type: *double*

The upper bound of the approximation range.

<MaximumError> required

Response → Stage → Polynomial → MaximumError

type: *double*

The maximum error of the approximation.

<Coefficient> required

Response → Stage → Polynomial → Coefficient

type: *double*

attribute	type	required	description	example
plusError	<i>double</i>	no	plus uncertainty or error in measured value.	plusError=0.1
minusError	<i>double</i>	no	minus uncertainty or error in measured value.	minusError=0.1
measurement-Method	<i>string</i>	no		
number	<i>CounterType</i>	no		

SPECIFYING AND USING RESPONSE INFORMATION

–By Mike Hagerty & Adam Ringler

3.1 Theory of Instrument Response

In geophysics, we often work with instrument responses in the frequency domain as they are simpler to combine and manipulate. For instrument responses specified in the time domain, we must first transform the response of the frequency domain using one or more transforms. Depending on the application, one or more of the following transforms may be used: The Fourier Transform, the Laplace Transform and the z-Transform.

3.1.1 The Fourier Transform

Introduction

The Fourier Transform ($t \rightarrow \omega$) is defined by

$$X(\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} x(t)e^{-j\omega t} dt$$

while the Inverse Fourier Transform ($\omega \rightarrow t$) is given by

$$x(t) = \int_{-\infty}^{\infty} X(\omega)e^{+j\omega t} d\omega$$

There are different conventions in use for the Fourier Transform. The conventions differ in which transform (forward vs. reverse) has the positive sign in the exponent, and which transform is scaled by $\frac{1}{2\pi}$. Some authors prefer to scale each transform by $\frac{1}{\sqrt{2\pi}}$ instead. What is important is that forward and reverse transforms must have exponents that are opposite in sign, and the product of the scalefactors must equal $\frac{1}{2\pi}$.

Discrete Time Fourier Transform (DTFT)

In the Fourier transform pair above, both time (t) and frequency (ω) are continuous parameters. In contrast, for signals sampled discretely in time, we may define the related Discrete Time Fourier Transform (DTFT) as

$$X(\omega) = \frac{1}{2\pi} \sum_{n=-\infty}^{\infty} x[n]e^{-j\omega n}$$
$$x[n] = \int_0^{2\pi} X(\omega)e^{+j\omega n} d\omega$$

where n is the discrete sample number, and ω is still continuous.

Discrete Fourier Transform (DFT)

And finally, when both time and frequency are discrete, we define the Discrete Fourier Transform (DFT) pair by

$$X[k] = \frac{1}{N} \sum_{n=0}^{N-1} x[n] e^{-j2\pi kn/N}$$

$$x[n] = \sum_{k=0}^{N-1} X[k] e^{+j2\pi kn/N}$$

Note that the popular Fast Fourier Transform (FFT) is a particular implementation of the DFT.

3.1.2 The Laplace Transform

Introduction

The Laplace Transform is defined by

$$X(\sigma, \omega) = \int_{-\infty}^{\infty} x(t) e^{-\sigma t} e^{-j\omega t} dt$$

If we make the substitution, $s = \sigma + j\omega$, this becomes

$$X(s) = \int_{-\infty}^{\infty} x(t) e^{-st} dt$$

Each point in the complex s-plane is associated with a frequency, ω and an exponent σ . Thus, each point in the s-plane describes a sinusoid of frequency ω that is either exponentially growing ($\sigma > 0$) or exponentially decaying ($\sigma < 0$) with time.

Note that the Laplace transform evaluated along the imaginary axis (where the attenuation parameter, $\sigma = 0$), reduces to the complex Fourier transform, $X(\omega)$.

The Laplace transform at point s is a measure of the similarity between the input signal, $x(t)$, and the corresponding exponentially growing/decaying sinusoid. A large value of $X(s)$ corresponds to a strong similarity between the input signal and the sinusoid $e^{-(\sigma+j\omega)t}$, indicating a strong presence of the sinusoid in the input signal.

In practice, we are often only interested in causal signals that begin at $t = 0$. Using the unit step function,

$$u(t) = \begin{cases} 1 & t \geq 0 \\ 0 & t < 0 \end{cases}$$

we may ensure causality by writing $x(t) = u(t)x(t)$, so that the Laplace Transform becomes

$$X(s) = \int_0^{\infty} x(t) e^{-st} dt$$

Poles and Zeros

Suppose we have a data processing system (e.g., analog sensor + datalogger) that can be characterized by the linear differential equation,

$$a_2 \ddot{y}(t) + a_1 \dot{y}(t) + a_0 y(t) = b_2 \ddot{x}(t) + b_1 \dot{x}(t) + b_0 x(t)$$

where $x(t)$ is the input signal (e.g., the ground motion), $y(t)$ is the output signal (the signal recorded) and a_k and b_k are constant (time-invariant) coefficients. If we assume the system is causal, so that the signals + derivatives are all 0 for $t < 0$, then the Laplace Transform of the equation gives

$$a_2s^2Y(s) + a_1sY(s) + a_0Y(s) = b_2s^2X(s) + b_1sX(s) + b_0X(s)$$

or

$$(a_2s^2 + a_1s + a_0)Y(s) = (b_2s^2 + b_1s + b_0)X(s)$$

From this we can write the system transfer function relating the output to the input as

$$H(s) = \frac{Y(s)}{X(s)} = \frac{b_2s^2 + b_1s + b_0}{a_2s^2 + a_1s + a_0}$$

or more generally,

$$H(s) = \frac{\sum_{k=0}^M b_k s^k}{\sum_{k=0}^N a_k s^k}$$

This is the coefficient representation of the transfer function. It represents the transfer function as the ratio of two polynomials. The roots of the numerator polynomial are called ‘zeros’, while the roots of the denominator polynomial are called ‘poles’.

Often, for analog stages, it is more convenient to factor the transfer function in terms of these poles and zeros:

$$H(s) = \frac{\prod_{k=1}^M (s - z_k)}{\prod_{k=1}^N (s - p_k)}$$

where z_k are the M zeros of the system, and p_k are the N poles.

Because the coefficients of the numerator and denominator polynomials are real, the corresponding roots (poles and zeros) must occur in complex conjugate pairs.

Thus, the poles and zeros are either real or form pairs that are symmetric with respect to the real axis in the complex s -plane. In addition, it can be shown that for systems that are stable and causal, the poles all have real parts ≤ 0 .

Recall that the Laplace transform variable is given by $s = \sigma + j\omega$. Along the imaginary axis, $\sigma = 0$ and hence $s = j\omega$. Thus, we may express the complex frequency response of the analog stage by calculating its polezero expansion

$$H(f) = A_0 \frac{\prod_{k=1}^M (s - z_k)}{\prod_{k=1}^N (s - p_k)}$$

where $s = j2\pi f$ [rad/s] or $s = jf$ [Hz].

Thus, given the poles and zeros of an analog stage, in order to properly calculate the stage frequency response, we must know the units of s used to calculate the poles and zeros.

In StationXML, these units are specified by the `PzTransferFunctionType` element within the `PolesZerosType` response stage:

```
<Stage number="1">
<PolesZeros>
  ...
  </OutputUnits>
  <PzTransferFunctionType>LAPLACE (RADIANS/SECOND) </
  <PzTransferFunctionType>
  <NormalizationFactor>1.0</NormalizationFactor>
  <NormalizationFrequency unit="HERTZ">1.0</NormalizationFrequency>
```

where the possible values for PzTransferfunctionType are:

1. “LAPLACE (RADIAN/SECOND)”
2. “LAPLACE (HERTZ)”
3. “DIGITAL (Z-TRANSFORM)” (Discussed in next section)

Note also the <NormalizationFactor> with unit “HERTZ”. These units are distinct from those used to identify s above. The <NormalizationFrequency> specifies the frequency (in Hz) at which the polezero transfer function is normalized. The recommended practice is to choose a value of normalization factor, A_0 , that normalizes the polezero expansion to unity at the specified normalization frequency, f_n :

$$|H(f_n)| = 1.0$$

3.1.3 The z-Transform

Introduction

The z-Transform is defined by

$$X(z) = \sum_{n=0}^{\infty} x[n]z^{-n}$$

where

$$\begin{aligned} z &= re^{j\omega} \\ z^{-n} &= r^{-n}e^{-j\omega n} \end{aligned}$$

Notice that on the unit circle, where $|z| \equiv |r| = 1$ and $z = e^{j\omega}$, the z-transform reduces to the discrete Fourier transform (DTFT):

$$X(e^{j\omega}) = \sum_{n=0}^{\infty} x[n]e^{-j\omega n}$$

The z-transform measures the similarity between the input signal $x[n]$ and the signal z^{-n} .

z^{-n} represents exponentially increasing (for $r < 0$) or decreasing ($r > 0$) sinusoids. e.g., $e^{-j\omega n}$ is a sinusoid with angular frequency ω [radians/sample] that expands with sample number n .

Thus, the location (value) of z in the complex plane controls what z^{-n} looks like.

The fractional or angular frequency, ω [radians/sample] is related to the linear frequency of the sinusoid through

$$2\pi[\text{radians/cycle}] = \omega[\text{radians/sample}] \cdot N[\text{samples/cycle}]$$

so the number of samples/cycle is given by

$$N = \frac{2\pi}{\omega} \text{samples/cycle}$$

and this corresponds to a period of $T = N\Delta t$ [seconds],

where Δt is the sampling interval (secs) and is related to the sampling rate by: $f_s = \frac{1}{\Delta t}$. Then the frequency of oscillation is given by $f = \frac{1}{T} = \frac{1}{N\Delta t} = \frac{f_s}{N}$ [Hz]

In other words, as the angle in the complex z-plane goes from $\omega = 0$ to $\omega = \pi$, the linear frequency goes from $f = 0$ to $f = f_{Nyq}$ [Hz], where the Nyquist frequency, $f_{Nyq} = \frac{f_s}{2}$ [Hz].

Thus, in implementing the frequency response of the z-transform (e.g., when calculating the response of a FIR filter), it is common to write it in a way that removes the dependency on the actual sample rate, or

$$X(e^{j\omega}) = \sum_{n=0}^{\infty} x[n]e^{-j2\pi n \frac{f}{f_s}} = \sum_{n=0}^{\infty} x[n]e^{-j2\pi n f \Delta t}$$

Difference Equations

z-transforms of linear time-invariant (LTI) systems described by difference equations play an important role in signal processing.

The general form of a difference equation is:

$$\sum_{k=0}^N a_k y[n-k] = \sum_{k=0}^M b_k x[n-k],$$

where $a_0 \neq 0$ (the coefficient of $y[n]$ can't be zero)

Taking the z-transform of both sides,

$$\sum_{k=0}^N a_k z^{-k} Y(z) = \sum_{k=0}^M b_k z^{-k} X(z)$$

or

$$Y(z) = \frac{\sum_{k=0}^M b_k z^{-k}}{\sum_{k=0}^N a_k z^{-k}} X(z)$$

From this we can write the system transfer function

$$H(z) = \frac{Y(z)}{X(z)} = \frac{\sum_{k=0}^M b_k z^{-k}}{\sum_{k=0}^N a_k z^{-k}}$$

The transfer function is the z-transform of the system impulse response, $h[n]$, or

$$H(z) = \sum_{n=0}^{\infty} h[n]z^{-n}$$

The transfer function can also be factored in terms of poles and zeros (for $b_0 \neq 0$)

$$H(z) = \frac{b_0 \prod_{k=1}^M (1 - c_k z^{-1})}{a_0 \prod_{k=1}^N (1 - d_k z^{-1})}$$

where c_k are the M zeros of the system, and d_k are the N poles.

For a system to be both stable and causal, its poles must lie inside the unit circle, or $|d_k| < 1$ for $k = 1, N$.

z-Transform Frequency Response

How does the location of the poles and zeros of the z-transform influence the complex frequency response, $H(f)$?

We start by only considering the magnitude response, $|H(f)|$.

The z-transform only exists within a region of the complex z-plane where the infinite sum [eqn X] converges. We call this region the Radius of Convergence (ROC) of the system.

If our system, described by difference equations, is stable, then the ROC must include the unit circle, $|z| = 1$ where

$$H(z) = \frac{Y(z)}{X(z)} = \frac{b_0 \prod_{k=1}^M (1 - c_k z^{-1})}{a_0 \prod_{k=1}^N (1 - d_k z^{-1})}$$

$$H(e^{-j\omega}) = \frac{b_0 \prod_{k=1}^M (1 - c_k e^{-j\omega})}{a_0 \prod_{k=1}^N (1 - d_k e^{-j\omega})}$$

The magnitude of the product is equal to the product of the magnitude, thus

$$|H(e^{-j\omega})| = \frac{|b_0| \prod_{k=1}^M |1 - c_k e^{-j\omega}|}{|a_0| \prod_{k=1}^N |1 - d_k e^{-j\omega}|} \quad (3.1)$$

$$= \frac{|b_0| \prod_{k=1}^M |e^{-j\omega}(e^{j\omega} - c_k)|}{|a_0| \prod_{k=1}^N |e^{-j\omega}(e^{j\omega} - d_k)|} \quad (3.2)$$

$$|H(e^{-j\omega})| = \frac{|b_0| \prod_{k=1}^M |e^{j\omega} - c_k|}{|a_0| \prod_{k=1}^N |e^{j\omega} - d_k|} \quad (3.3)$$

In other words, as we traverse the unit circle through circular ‘frequency’, ω , from $0 - 2\pi$, the magnitude of the response depends on the distance between the point on the unit circle, $e^{j\omega}$, and the zeros, $|e^{j\omega} - c_k|$, as well as the distance between the point and the poles, $|e^{j\omega} - d_k|$, or

$$|H(e^{-j\omega})| = \frac{|b_0| \prod_{k=1}^M |distance - to - zeros|}{|a_0| \prod_{k=1}^N |distance - to - poles|}$$

Thus, $|H(e^{j\omega})|$ is small when $e^{j\omega}$ is near the zeros and it is large when $e^{j\omega}$ is near the poles.

Examples

Example 1

Consider a system with zeros at $z = 1, -1$ and poles at $z = 0.95e^{\pm j\pi/4}$, with response function

$$|H(e^{-j\omega})| = \frac{|(e^{j\omega} - 1)|(e^{j\omega} + 1)|}{|(e^{j\omega} - 0.95e^{j\pi/4})|(e^{j\omega} - 0.95e^{-j\pi/4})|}$$

Poles near the unit circle push the magnitude response up at those frequencies, while zeros near the unit circle pull it down; if the zero is actually *on* the unit circle, then it forces the magnitude response to be exactly 0 at that frequency.

Example 2

Here’s an example pass-band filter comprised of 8 poles and 8 zeros. We can predict from the position of the poles and zeros that the frequency response will be 0 at $\omega = 0$ and will be maximum near $\omega = \frac{\pi}{2}$.

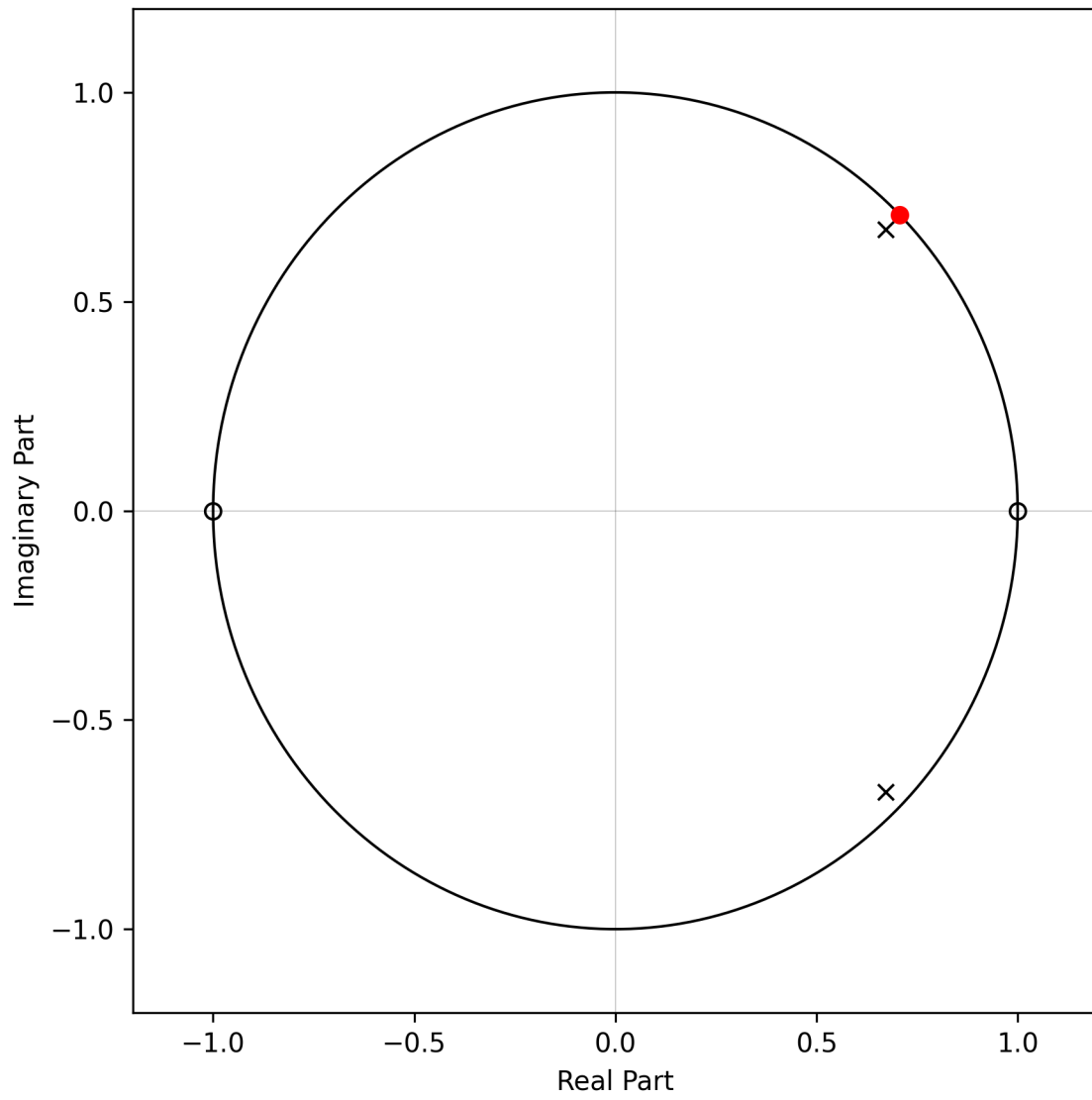
3.1.4 FIR-IIR Filters

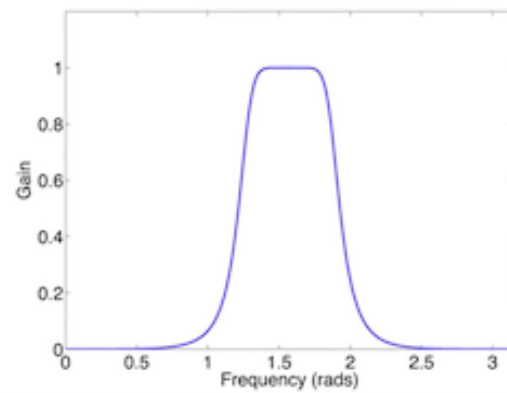
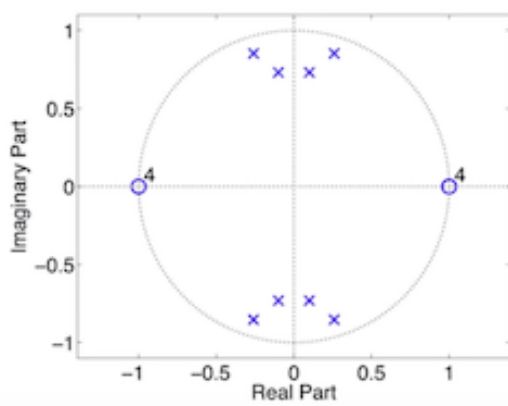
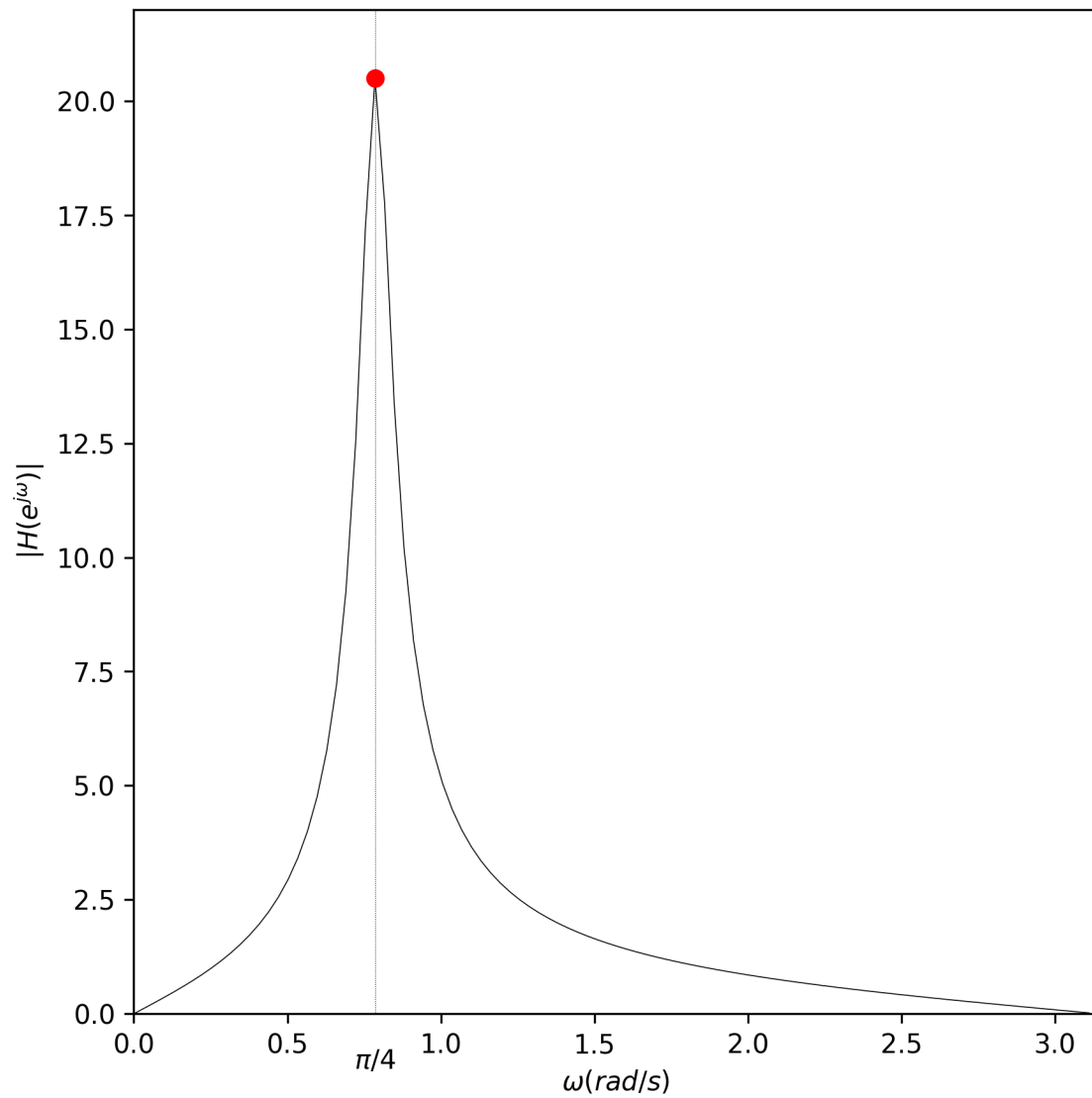
Introduction

As we’ll see in the next section, each of the multiple stages that comprise an instrument response can be thought of as a filter that modifies the amplitude and phase of the original signal (e.g., ground motion) in some way.

In fact, to truly understand instrument response and data processing in general, it is necessary to have some familiarity with digital signal processing.

There are two categories of discrete-time filters that we routinely encounter in seismology:





1. FIR filters (Finite Impulse Response)
2. IIR filters (Infinite Impulse Response)

Both filters can be constructed using difference equations, hence, they are often represented in terms of their z-transforms.

FIR filters can be written as:

$$y[n] = \sum_{k=0}^M b_k x[n-k]$$

while IIR filters can be written as:

$$y[n] = \sum_{k=0}^M b_k x[n-k] + \sum_{k=1}^N a_k y[n-k]$$

FIR filters can be thought of as a sum of weighted values of past inputs, $x[n-k]$ (the so called *moving average* filter). IIR filters have this same moving average component, but also offer the possibility of feedback, since the current output $y[n]$ can also depend on a weighted combination of past outputs, $y[n-k]$.

For a finite input impulse, the subsequent impulse response of a FIR filter is finite. However, because of the dependence on past outputs, the impulse response of the IIR filter is, at least in theory, infinite; it continues long after the input signal has finished.

In the FIR case, the system function, found by taking the z-transform of the difference equation, can be written

$$H(z) = \sum_{k=0}^M b_k z^{-k}$$

while for the IIR case, the system function is

$$H(z) = \frac{\sum_{k=0}^M b_k z^{-k}}{\sum_{k=0}^N a_k z^{-k}}$$

where $a_0 = 1$.

The system functions can be factored in terms of their poles and zeros as

$$H_{FIR}(z) = b_0 \prod_{k=1}^M (1 - c_k z^{-1}) \quad (3.4)$$

$$H_{IIR}(z) = \frac{b_0 \prod_{k=1}^M (1 - c_k z^{-1})}{\prod_{k=1}^N (1 - d_k z^{-1})} \quad (3.5)$$

Thus, the FIR filter has arbitrary zeros, but only has poles at the origin ($z = 0$). However, poles (or zeros for that matter) at the origin don't affect the frequency response since they are located a fixed distance ($|z| = 1$) from the unit circle.

In contrast, the IIR filter may have both zeros and poles at arbitrary locations, making them especially flexible.

The corresponding impulse responses are found by taking the inverse z-transform of the system functions,

$$h_{FIR}[n] = \begin{cases} b_n & 0 \leq n \leq M \\ 0 & \text{else} \end{cases} \quad (3.6)$$

Thus the FIR impulse response is given by the difference equation coefficients, b_k , themselves, and the impulse response dies after M terms.

The impulse response of the causal parts of the IIR filter can be written as

$$h_{IIR}[n] = \sum_{k=1}^N A_k (d_k)^n u[n] \quad (3.7)$$

where $u[n]$ is the unit step function ($u[n] = 1, n \geq 0$).

Because of the geometric series d_k^n , the IIR impulse response decays but never actually reaches zero.

FIR vs IIR

The primary distinguishing factor between FIR and IIR filters is this:

FIR filters are guaranteed to have a linear phase response, which is much easier to deal with, while IIR filters have non-linear phase response.

Some pros and cons of each filter type is summarized below.

FIR Filters:

- **Pros**
 - Can be designed using optimization techniques to match a desired magnitude/phase response
 - Allow for arbitrary magnitude/phase response
 - Allow for linear or zero phase response (no distortion)
 - Are always stable
- **Cons**
 - Can require a large number of coefficients (e.g., $M \approx 100$) to achieve desired accuracy, particularly for steep filters.

IIR Filters:

- **Pros**
 - Can be implemented very efficiently - fewer coefficients than FIR for comparable frequency selective filter accuracy (e.g., $M \approx N \approx 8$)
 - Filtering is fast
- **Cons**
 - Generally can't use optimization techniques to design
 - Better approach is to start from a well-known analog filter design and transform it to discrete-time filter.
 - Limited to frequency selective filters (e.g., bandpass, high-pass, etc)
 - Phase is nonlinear (will always cause phase distortion within the passband)
 - Zero phase filters are impossible to implement exactly (you can get this by filtering forward + backward, but this can't be implemented in real-time!)

In spite of the cons listed above, there are some instances where IIR filters are preferred. For instance, for implementing maximally flat selective filters (e.g., Butterworth bandpass filters) or for modeling the behavior of systems with feedback.

Nevertheless, the vast majority of filters encountered in seismic metadata are *anti-alias* filters used at each decimation stage of the digitizer, and the digital anti-alias filters most commonly used are linear phase FIR filters that produce a constant time shift.

Hence, in what follows we will concentrate on FIR filters.

Classification of FIR Filters

FIR filter frequency response can be written

$$H(e^{j\omega}) = \sum_{k=0}^M b_k z^{-k} = \sum_{k=0}^M b_k e^{-j\omega k} = \sum_{k=0}^M h[k] e^{-j\omega k}$$

where in the last expression, we identify the filter coefficients b_k as the impulse response values: $h[k] = b_k$ to show that the output of the FIR filter is the convolution of the input signal $x[n]$ with the filter impulse response.

It can be shown that the FIR filter response has generalized linear phase of the form,

$$H(e^{j\omega}) = A(e^{j\omega}) e^{-j(\omega\alpha + \beta)}$$

where $A(e^{j\omega})$ describes the real amplitude, β is a constant phase factor, and α is the constant group delay.

A consequence of this constant group delay (also called *phase* delay) is that the shape of the input waveform is not changed; all frequencies are delayed the right amount so that they add together in the same way to form the output signal. The resulting output signal has the same shape as the input signal but is delayed in time.

Some general observations about FIR filters are:

- FIR filters contain as many poles as they have zeros.
- The number of zeros (poles), M , is called the *order* of the FIR filter
- All the poles are located at the origin (inside the unit circle), hence FIR filters are said to be *stable*.
- These poles don't affect the magnitude of the frequency response, only the phase.

Note that a filter of order M has length $M+1$.

FIR filters with generalized linear phase are often divided into 4 types depending on whether the order M is even or odd, so that the number of points is either odd or even, and whether the impulse response (=FIR coefficients) exhibits even or odd symmetry about the middle point.

FIR filters with symmetrical impulse response are often called *two-sided* or *acausal*. As a consequence of the symmetry of the filter impulse response, the onsets of very impulsive signals (with energy at frequencies near the Nyquist cut-off for the FIR filter), may be contaminated by precursory (=acausal) oscillations.

Type I: M even

M even + even symmetry about the midpoint $M/2$

Note that in this case, there will be $M+1$ (odd) points in the filter and $M/2$ will fall on an index right in the middle:

$$h[k] = h[M - k], 0 \leq k \leq M$$

We can write out the frequency response and use symmetry to simplify,

$$H(e^{j\omega}) = \sum_{k=0}^M h[k]e^{-j\omega k} \quad (3.8)$$

$$= h[0] + h[1]e^{-j\omega \cdot 1} + h[2]e^{-j\omega \cdot 2} + \dots + h[M-1]e^{-j\omega \cdot (M-1)} + h[M]e^{-j\omega \cdot M} \quad (3.9)$$

$$= e^{-j\omega \frac{M}{2}} \left[h[0]e^{+j\omega \frac{M}{2}} + h[1]e^{-j\omega \cdot 1}e^{+j\omega \frac{M}{2}} + \dots + h[M-1]e^{-j\omega \cdot (\frac{M}{2}-1)} + h[M]e^{-j\omega \frac{M}{2}} \right] \quad (3.10)$$

$$= e^{-j\omega \frac{M}{2}} \left[h[0]e^{+j\omega \frac{M}{2}} + h[M]e^{-j\omega \frac{M}{2}} + h[1]e^{-j\omega \cdot 1}e^{+j\omega \frac{M}{2}} + \dots + h[M/2+1]e^{-j\omega \cdot 1} + h[M/2] \right] \quad (3.11)$$

$$= e^{-j\omega \frac{M}{2}} \left[h[0](e^{+j\omega \frac{M}{2}} + e^{-j\omega \frac{M}{2}}) + h[1](e^{+j\omega (\frac{M}{2}-1)} + e^{-j\omega (\frac{M}{2}-1)}) + \dots + h[M/2-1](e^{+j\omega} + e^{-j\omega}) + h[M/2] \right] \quad (3.12)$$

$$= e^{-j\omega \frac{M}{2}} \left[h[0]2\cos\left(\frac{M}{2}\omega\right) + h[1]2\cos\left(\left(\frac{M}{2}-1\right)\omega\right) + \dots + h[M/2-1]2\cos(\omega) + h[M/2] \right] \quad (3.13)$$

$$H(e^{j\omega}) = e^{-j\omega \frac{M}{2}} \sum_{k=0}^{M/2} a[k]\cos(\omega k) \quad (3.14)$$

where $a[0] = h[M/2]$, $a[1] = 2h[M/2 - 1]$, ..., $a[M/2] = 2h[0]$.

In general, $a[0] = h[\frac{M}{2}]$, and $a[k] = 2h[\frac{M}{2} - k]$, $k = 1, \dots, \frac{M}{2}$.

The $a[k]$ coefficients are real, hence the sum is real, and the response satisfies the generalized linear phase property:

$$H(e^{j\omega}) = A(e^{j\omega})e^{-j(\omega\alpha+\beta)}$$

Hence for Type I, the amp is: $A(e^{j\omega}) = \sum_{k=0}^{M/2} a[k]\cos(\omega k)$, while the phase term is: $e^{-j\omega \frac{M}{2}}$ and the corresponding group delay is: $\alpha = \frac{M}{2}$.

Type II: M odd

M odd + even symmetry about the midpoint M/2

Note that in this case, there will be M+1 (even) points in the filter, hence the symmetry mid-point falls between two sample points.

$$h[k] = h[M - k], 0 \leq k \leq M$$

By similar algebra as above, we can write the frequency response as

$$H(e^{j\omega}) = e^{-j\omega \frac{M}{2}} \sum_{k=1}^{\frac{(M+1)}{2}} b[k]\cos\left(\omega\left(k - \frac{1}{2}\right)\right)$$

where $b[k] = 2h\left[\left(\frac{M+1}{2} - k\right)\right]$, $k = 1, \dots, \frac{(M+1)}{2}$.

Thus, this system also has group delay $\alpha = \frac{M}{2}$.

Type III/IV anti-symmetric

Type III (M even) and Type IV (M odd) FIR filters exhibit anti-symmetry about the midpoint: $h[k] = -h[M - k]$.

As a result, their expansions reduce to summation of sine functions and can't be used to implement low-pass filters, hence they aren't used for anti-alias filtering.

Practical Concerns

Thus, we normally use FIR filters of type I or II for anti-alias filtering. Because of their symmetry, only half the coefficients need to be stored in the metadata.

In StationXML, a symmetric filter can be represented using a [FIR](#) response stage, with sub-element indicating the symmetry (odd/even).

In contrast, a non-symmetrical FIR can only be stored in a more general [Coefficients](#) response stage, which retains all of the coefficients.

In practice, even symmetric FIR filter coefficients are often stored in a [Coefficients](#) response stage.

This is how the FIR response is calculated in ObsPy, which uses the venerable `evalresp` C code underneath the hood. Note that in `evalresp`, this type of filter is termed `FIR_ASYM`, meaning it can handle both symmetric (about the midpoint) and non-symmetric FIR coefficients. All of the coefficients are used in the expansion to calculate the filter response.

In contrast, IIR filter coefficients can't be stored in a FIR response stage, since it only allows for numerator coefficients. IIR filter coefficients can be stored in a [Coefficients](#) response stage. However, IIR responses are very sensitive to round-off errors in the values of the stored coefficients and can become unstable. Therefore, many IIR filters are instead stored as a [PolesZeros](#) response stage of type 'D' (digital) and are expanded in terms of the poles and zeros of the z-transform as discussed above.

3.1.5 Convolution

Introduction

As we'll see in the next sections, a geophysical sensor (e.g., seismometer) connected to a datalogger that digitizes and records the input signal (e.g., ground motion), represents a linear time-invariant (LTI) system. We can thus model the overall effect of the instrumentation on the input signal as a linear combination of stages representing each component of the instrumentation. The stages are connected sequentially so that the output of stage 1, representing the sensor, forms the input of stage 2, which might represent either a pre-amplifier or a digitizer. As the input signal passes through each stage, we say that it is "convolved" with the impulse response of that stage, to form the output signal that then becomes the input signal for the subsequent stage.

Convolution is a mathematical operation between two functions. For instance, if function $f(t)$ represents the input signal to a stage, and function $g(t)$ represents the impulse response of the stage, then the output of the stage is the convolution between $f(t)$ and $g(t)$.

Given two functions $f(t)$ and $g(t)$ defined for all $t \geq 0$, their convolution at time t is defined by:

$$(f * g)(t) = \int_0^t f(t - \tau)g(\tau)d\tau$$

where $*$ represents the convolution operator.

Suppose that f and g are piecewise continuous and of exponential order. Then

$$L[f * g] = L[f]L[g]$$

Where L is the Laplace Transform operator.

Proof

If we extend the functions f and g to be 0 for $t < 0$, then the integral above is the same as

$$(f * g)(t) = \int_0^{\infty} f(t - \tau)g(\tau)d\tau$$

i.e., for $\tau > t$, $(t - \tau) < 0$ and $f(t - \tau) = 0$.

So we can write the Laplace Transform as

$$L[f * g](s) = \int_0^{\infty} \int_0^{\infty} f(t - \tau)g(\tau)d\tau e^{-st} dt$$

Interchanging the order of integration gives

$$L[f * g] = \int_0^{\infty} \int_0^{\infty} f(t - \tau)e^{-st} dt g(\tau)d\tau$$

Substitute $u = t - \tau$, $du = dt$,

$$L[f * g] = \int_0^{\infty} \int_0^{\infty} f(u)e^{-s(u+\tau)} du \cdot g(\tau)d\tau$$

or

$$L[f * g](s) = \int_0^{\infty} f(u)e^{-su} du \cdot \int_0^{\infty} g(\tau)e^{-s\tau} d\tau \quad (3.15)$$

$$= L[f]L[g] \quad (3.16)$$

In other words, the Laplace Transform of the convolution of f and g , is equal to the product of the Laplace Transform of f times the Laplace Transform of g . This holds true for all of the “frequency” transforms (Fourier, Laplace, z).

It is for this reason that most instrument response calculations are performed in the frequency domain, by multiplying the frequency response of subsequent stages (or filters) together.

3.1.6 References

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3.2 Practical Instrument Response

3.2.1 Introduction

Geophysical data are recorded by an instrument that imparts its own signature onto the data. When the data are later analyzed, one of the first steps is to remove the effect of the instrumentation used to record it, the so-called instrument response. This is typically done in the frequency domain, by dividing the complex Fourier Transform of the data by the complex Fourier Transform of the instrument response.

$$Z(f) = \frac{X(f)}{I(f)}$$

where $X(f)$ is the Fourier Transform of the recorded time series, $I(f)$ is the Fourier Transform of the instrument response, and $Z(f)$ is the Fourier Transform of the data with the instrument response removed.

So how does one obtain the Fourier Transform of the instrument response? Very often, this is calculated by combining the information describing each stage of the instrument response in specific formats.

3.2.2 Sensor Response as a Linear Sequence of Stages



A recording system (sensor + datalogger) represents a linear, time-invariant system. As such, the total response of the system (= the instrument response) can be calculated by linearly combining the response of each individual stage in the system. In the time domain, the operator that represents linear combination in this way is convolution, however, it's difficult to visualize the result of convolving several stages together. Fortunately, in the frequency domain, the operator that links the individual stage responses together is multiplication, and it's trivial to combine stage responses together.

The schematic shown in the figure above represents a generic ideal of the instrument response as a sequence of stages. Where each stage is implemented in the hardware, e.g., whether it physically resides in the sensor or the datalogger (or whether these are integrated into a single unit) is not specified.

A more specific description of instrument response particular to most seismic instrumentation is this: The ground motion (typically velocity or acceleration) is “input” to the seismic sensor which outputs continuous voltage (an analog signal) proportional to the input in some way. This continuous voltage could then be amplified, either by an external preamplifier (+ filter possibly) or, more commonly, by circuitry within the datalogger itself. Next, the continuous signal is sampled by the ADC (analog-to-digital conversion) circuit of the datalogger, resulting in discrete data samples.

Typically, the sampling is done over a sequence of stages where the first stage highly oversamples the input data. Each subsequent stage is a combination of low-pass filter, typically implemented using a FIR filter, followed by decimation of the data stream by some decimation factor. This anti-alias FIR filter is necessary at each decimation step to avoid aliasing of energy above the Nyquist frequency, which would contaminate the signal of interest. This cascade of filter/decimate stages begins at the high sample rate (e.g., 102400 samples per second for the Reftek RT130) and continues, with typical integer decimation factors (2,4,5,8,10,16 etc) at each step, until the final desired output sample rate is reached. Thus, the input units of the first sensor stage is the ground motion (e.g., m/s), while the input units of the first datalogger stage is Volts. After the ADC, the input/output units for each subsequent stage is Counts.

3.2.3 Stage 1: The Analog Sensor

The first stage of the response often represents the effect of an analog sensor (e.g., seismometer, microphone, etc), which takes as input a physical quantity (e.g., ground motion in $\mu m s^{-1}$, air pressure in Pa , temperature in $^{\circ}C$, etc.) and outputs Volts.

We need some way to represent how this sensor stage works and what distortion, if any, it applies to the underlying time series (the input physical quantity).

Commonly, the analog sensor stage is stored as a sequence of poles and zeros of the Laplace Transform (see Laplace Transform description above) along with associated scale factors.

Recall that the Laplace transform variable is given by $s = \sigma + j\omega$. Along the imaginary axis, $\sigma = 0$ and hence $s = j\omega$. Thus, we may express the complex frequency response of the analog stage by calculating its polezero expansion

$$H(f) = A_0 \frac{\prod_{k=1}^M (s - z_k)}{\prod_{k=1}^N (s - p_k)}$$

where $s = j2\pi f$ [rad/s] or $s = jf$ [Hz], z_k are the M zeros and p_k are the N poles. A_0 is the normalization factor, typically chosen so that $|H(f_n)| = 1.0$ where f_n is the normalization frequency.

Thus, given the poles and zeros of an analog stage, in order to properly calculate the stage frequency response, we must know the units of s (Hz or rad/s) used to calculate the poles and zeros using the expansion above.

With the normalization factor A_0 , the polezero expansion results in a complex frequency response with magnitude = 1.0 at the normalization frequency. For seismometers whose response is flat to ground velocity, the normalization frequency is typically chosen somewhere within the flat part of the response spectrum. For broadband sensors, it is also considered good practice to select a normalization frequency lower than two times the lowest sampling frequency. For example, if you are sampling VHZ data at 0.1 sps, then you want to describe A_0 at a frequency < 0.05 Hz.

Thus, the poles and zeros give the shape of the sensor response, but not the gain (see Fig. X below).

Analog polezero examples

Below are the poles and zeros for two broadband seismometers (STS-1 and STS-2) and a short-period sensor (L-22D). All have a response that is flat to velocity within some frequency band, which is controlled by the location of the poles and zeros in the s -plane.

Sensor: Streckeisen STS-2 (3rd Generation)			
Gain:	1500 [V/m/s]	Freq of gain:	1.0 [Hz]
A0 normalization:	3.4684E+17	Freq of normalization:	1.0 [Hz]
Poles:		Zeros:	
real (rad/s)	imag (rad/s)	real (rad/s)	imag (rad/s)
-0.037	-0.037	0.0	0.0
-0.037	+0.037	0.0	0.0
-15.54	0.0	15.15	0.0
-97.34	-400.7	-176.6	0.0
-374.8	0.0	-463.1	-430.5
-97.34	+400.7	-463.1	+430.5
-520.3	0.0		
-10530.0	-10050.0		
-10530.0	+10050.0		
-13300.0	0.0		
-255.097	0.0		

Sensor: Streckeisen STS-1			
Gain:	2400 [V/m/s]	Freq of gain:	0.02 [Hz]
A0 normalization:	3.94858E+03	Freq of normalization:	0.02 [Hz]
Poles:		Zeros:	
real (rad/s)	imag (rad/s)	real (rad/s)	imag (rad/s)
-0.01234	+0.01234	0.0	0.0
-0.01234	-0.01234	0.0	0.0
-39.18	+49.12		
-39.18	-49.12		

Sensor: Sercel L-22D			
Gain:	87.9 [V/m/s]	Freq of gain:	10.0 [Hz]
A0 normalization:	1.0	Freq of normalization:	10.0 [Hz]
Poles:		Zeros:	
real (rad/s)	imag (rad/s)	real (rad/s)	imag (rad/s)
-8.884	+8.887	0.0	0.0
-8.884	-8.887	0.0	0.0

Notice from the table above that the poles always appear in complex conjugate pairs (in the degenerate case this is represented by a single real pole). This will always be the case, since the poles and zeros ultimately relate to a polynomial expression with real coefficients that describes the seismometer response. In addition, notice that all of the poles have a negative real part. This is required for stability reasons as discussed in the theory section above.

The poles and zeros have units in the complex s-plane. For the examples given (and for most analog stages), <Pz-TransferFunctionType> is "LAPLACE (RADIANS/SECOND)", hence the poles and zeros have units of rad/s.

When viewing the total instrument response as a plot of amplitude and phase versus frequency, most of the shape is controlled by the polezero expansion of the analog sensor stage.

In the figure above we plot the analog stage polezero expansion for a broadband seismometer (STS-2) and a short-period seismometer (L-22D). In both cases, the A0 normalization frequency, f_n is located within the flat part of the spectrum, and each response has a corner frequency, f_c below which the magnitude response rolls off. The corner frequency is the frequency at which the response magnitude is -3dB below the flat part of the spectrum.

Given the poles and zeros, one can determine the low-frequency corner frequency, f_c , from the magnitude of the lowest frequency pole in the s-plane.

For instance, for the STS-2 example shown, the lowest frequency pole is at $-.037 \pm .037j$ in the complex s-plane, and the corresponding corner frequency is:

$$\omega = \sqrt{.037^2 + .037^2} = \sqrt{2} \times .037 = .052326 \text{ rad/s}$$

$$f_c = \frac{\omega}{2\pi} = 0.0083279 \text{ s}^{-1} \rightarrow T_c = 1/f_c = 120 \text{ sec}$$

As expected, the STS-2 sensor has a corner *period* of 120 s.

By similar reasoning, the corner frequency of the short-period L-22D sensor is

$$\omega = \sqrt{8.884^2 + 8.887^2} = 12.566 \text{ rad/s}$$

$$f_c = \frac{\omega}{2\pi} = 2.0 \text{ Hz}$$

For many applications the exact instrument response is not needed and it is sufficient to calculate a single scalefactor to convert from recorded COUNTS to ground motion (e.g, M/S). For instance, if the signal of interest only contains energy within the flat part of the spectrum (e.g., band-limited signal), then we might be able to ignore the polezero shape altogether and compute an overall scalefactor (to go from COUNTS to M/S) for the sensor + datalogger.

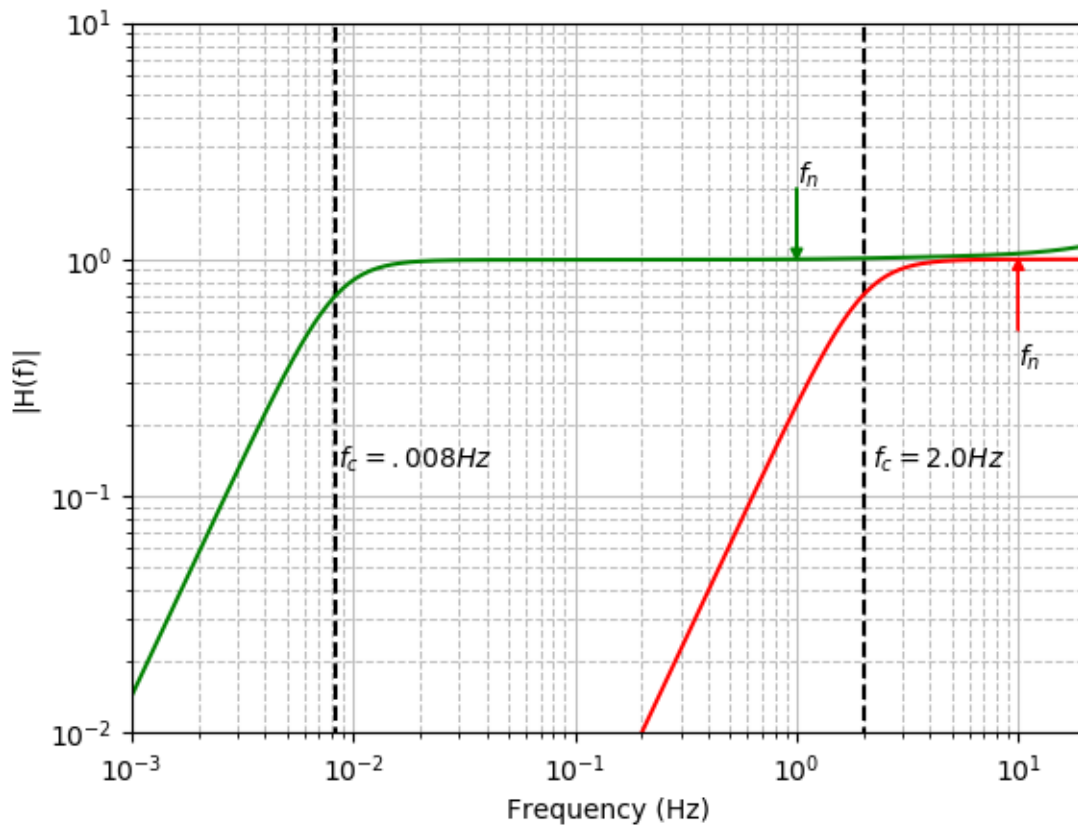


Fig. 1: Fig. X Plot of polezero expansion of analog sensor for Streckeisen STS-2 (green) and Sercel L-22D (red) [see table for polezero values used].

For instance, if the STS-2 sensor discussed above were connected to a generic Reftek RT-130 datalogger, we can calculate an approximate forward scalefactor:

$$1500[V/m/s] \times 6.291290 \times 10^5[Counts/V] = 9.4369 \times 10^8[Counts/m/s]$$

While this is often done to do a quick conversion to ground velocity, several caviats must be mentioned.

1. Very few signals are truly bandlimited this way and we're essentially applying the wrong correction factor to the signals outside the bandwidth
2. Often, the frequency at which the sensor response is normalized, is not the same as the frequency at which the datalogger response is normalized. For instance, the Reftek RT-130 is normalized at 0.05 Hz, while the STS-2 is normalized at 1.0 Hz. This matters because the amplitude response of the datalogger filters are not perfectly flat, hence to compute the overall instrument response (sensor + datalogger), the datalogger gain often has to be recalculated at the frequency of the sensor normalization.
3. It ignores the phase response, which can be very important for modelling waveforms, etc.

Alternatively, when simple scaling is insufficient, it is necessary to use all of the response stages to compute the exact instrument response. When the datalogger normalization frequency is different from the sensor normalization frequency, the datalogger response is *recalculated* at the sensor normalization frequency and the new *sensitivity*, equal to the product of each stage amplitude response at this normalization frequency, is stored in the StationXML <InstrumentSensitivity> element.

Converting s = rad/s to/from Hz

Recall the polezero expansion of the Laplace Transform of the transfer function,

$$H(s) = A_0 \frac{\prod_{k=1}^M (s - z_k)}{\prod_{k=1}^N (s - p_k)}$$

Consider a system with 1 zero and 2 poles (forming a complex conjugate pair) in the complex s -plane (rad/s). Say $z_1 = z_r + jz_i$, $p_1 = p_r + jp_i$ and $p_2 = \bar{p}_1$, where each term z_r, z_i, p_r, p_i has units of rad/s.

Then

$$H(s = j\omega) = A_0 \frac{j\omega - (z_r + jz_i)}{(j\omega - p_1)(j\omega - \bar{p}_1)} \quad (3.17)$$

$$= A_0 \frac{2\pi[jf - (z'_r + jz'_i)]}{(2\pi)^2[(jf - p'_1)(jf - \bar{p}'_1)]} \quad (3.18)$$

$$(3.19)$$

where the primed quantities equal the unprimed quantities divide by 2π , e.g., $z'_r = \frac{z_r}{2\pi}$

We can write this as

$$H(s = jf) = A'_0 \frac{[jf - (z'_r + jz'_i)]}{[(jf - p'_1)(jf - \bar{p}'_1)]}$$

where $A'_0 = \frac{2\pi}{(2\pi)^2} A_0$.

In general, we can write

$$H(s = jf) = A'_0 \frac{\prod_{k=1}^M (jf - z'_k)}{\prod_{k=1}^N (jf - p'_k)}$$

where $A'_0 = A_0 \cdot (2\pi)^{M-N}$ and where M is the number of zeros and N is the number of poles.

Thus, if we are given a polezero stage with units of rad/s (ω), we can convert this stage to units of Hz and maintain the proper normalization by first dividing each pole and zero by 2π , and then scaling the normalization factor A_0 by $(2\pi)^{M-N}$.

Conversely, if we are given a polezero stage with units of Hz (f), we can convert it to units of rad/s by first multiplying the each pole and zero by 2π , and then scaling the given normalization factor A_0' by $(2\pi)^{N-M}$.

For example, the poleszeros of the Streckeisen STS-I sensor are shown in the table below for units = Hz (<PzTransferFunctionType>LAPLACE (HERTZ)</PzTransferFunctionType>)

Sensor: Streckeisen STS-1 poleszeros given in Hz			
Gain:	2400 [V/m/s]	Freq of gain:	0.02 [Hz]
A0 normalization:	1.0001869E+02	Freq of normalization:	0.02 [Hz]
Poles:		Zeros:	
real (Hz)	imag (Hz)	real (Hz)	imag (Hz)
-0.0019639	+0.0019639	0.0	0.0
-0.0019639	-0.0019639	0.0	0.0
-6.2357	+7.8177		
-6.2357	-7.8177		

3.2.4 Stage 2: The Pre-Amplifier

Not all response sequences have a pre-amplifier. When present, it may be implemented using an analog circuit (V->V) or it may be a digital circuit integrated within the analog-to-digital (datalogger) recorder itself.

For example, an analog pre-amplifier stage with a gain of 8 would be represented as:

```
<Stage number="2">
  <StageGain>
    <Value>8</Value>
    <Frequency>1</Frequency>
  </StageGain>
</Stage>
```

where the <Frequency> is normally chosen to be the same as the normalization frequency, f_n in stage 1.

An external pre-amplifier stage could have an associated filter, either implemented using a polezero or coefficient representation.

Often, the preamplifier is integrated with the datalogger and merely adds a uniform scalefactor to the instrument response.

Warning

Using *place-holder* pre-amps at stage 2 may not be good practice.

Some entities (e.g., the Nominal Response Library or NRL) always include a pre-amp at stage 2 in order to standardize the numbering of response stages (e.g., so that the datalogger response always begins at stage 3). If no pre-amp was actually present, then a *place-holder* stage with gain=1 is used.

However, there is disagreement about whether *all* responses should have such a place-holder stage or whether it is better practice to have the response stages more faithfully correspond to the equipment that is actually used.

3.2.5 Stage 2+: The Datalogger

The datalogger, or analog-to-digital converter (ADC) has two main functions: 1. To digitize the analog signal (Volts) coming from the sensor and 2. To output the digitized signal (digital counts) at the desired sample rate(s).

These functions are typically achieved by first highly oversampling the analog signal, and then passing it through a sequence of filter/decimate steps to achieve the desired output sample rate(s).

Each filter/decimate step is represented by a stage in the StationXML response, representing the effects of low-pass filtering (typically implemented with an anti-alias FIR filter) and decimation to a lower sample rate.

FIR anti-alias filter

The recommended practice for storing FIR filters is to normalize the filter response at a specified frequency:

$$G(f) = S_d H_c(z) \Big|_{z=e^{j2\pi\Delta t f_s}} \quad (3.20)$$

$$= S_d \sum_{k=0}^M b_k z^{-k} \Big|_{z=e^{j2\pi\Delta t f_s}} \quad (3.21)$$

$$= S_d \sum_{n=0}^M b_k e^{-j2\pi f_s k \Delta t} \quad (3.22)$$

where b_k are the FIR coefficients, M is the filter order, Δt is the sample rate [seconds], and f_s is the frequency at which the filter is normalized to have a gain of S_d .

The Quanterra QDP380/QDP680 family of dataloggers employ the 64-element FIR filter described in Table X as a digital anti-alias filter in the stage 4 decimation from 40Hz down to 20 Hz.

The FIR coefficients, b_k are plotted in Fig. X

The FIR filter has 64 coefficients (order $M = 64 - 1 = 63$) and is symmetric about the midpoint (which lies in between samples 32 and 33). Hence it is a FIR Type II symmetric filter.

Decimation

In the normal process by which the datalogger holds and samples information, followed by decimation, a time delay is often introduced into the recorded trace (see Fig. X). This delay, if known, can be stored in the <Delay> element. For example, a delay of 1.0 seconds would be stored as:

```
<Response>
  <Stage>
    <Decimation>
      <Delay>1.0</Delay>
    </Decimation>
  </Stage>
</Response>
```

while any applied time correction, e.g., to cancel out the delay, can be stored in:

```
<Response>
  <Stage>
    <Decimation>
      <Correction>1.0</Correction>
    </Decimation>
  </Stage>
</Response>
```

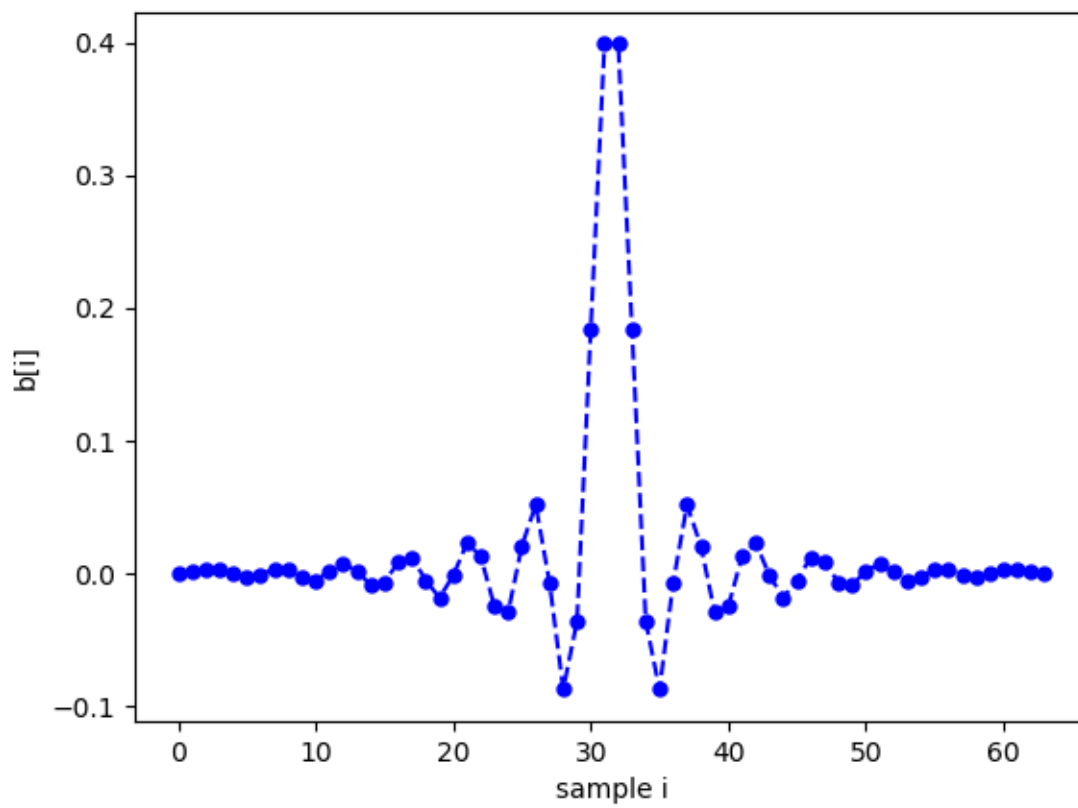
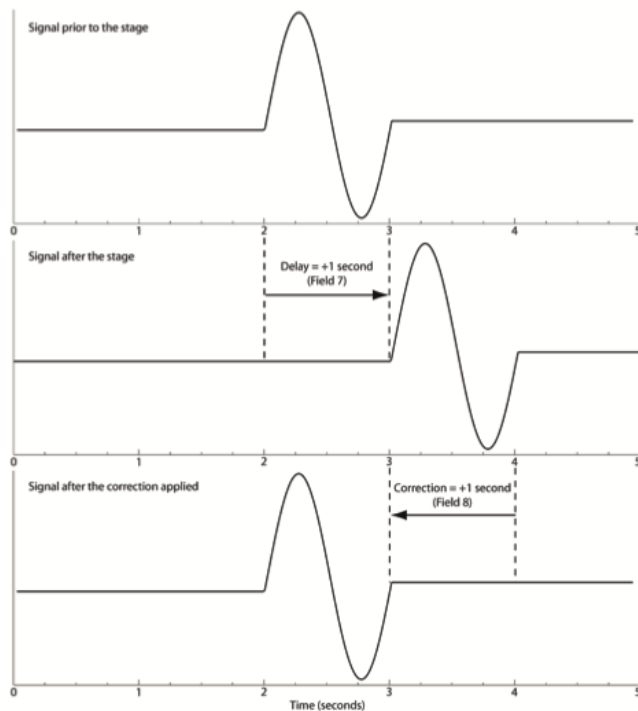



Fig. 2: Fig. X Plot of filter coefficients for Qx80 FIR filter

An anti-alias FIR filter normally introduces a positive delay into the recorded trace as indicated in the figure. If this delay is removed from the data, e.g., by introducing a negative offset -x prior to recording, then the positive value +x is stored in the <Correction> element.



3.3 StationXML Response Examples

3.3.1 Broadband sensor

3rd generation Streckeisen STS-2 sensor + Reftek RT130 datalogger

StationXML [Show/Hide](#)

```
<?xml version='1.0' encoding='UTF-8'?>
<FDSNStationXML xmlns="http://www.fdsn.org/xml/station/1" schemaVersion="1.1
↪">
  <Network code=..>
    <Station code=..>
      <Channel code=.. locationCode=..>
        ...
        <SampleRate>40.0</SampleRate>
        <Response>
          <InstrumentSensitivity>
            <Value>941864732.693</Value>
            <Frequency>1.0</Frequency>
            <InputUnits>
              <Name>M/S</Name>
              <Description>Velocity in Meters per Second</Description>
            </InputUnits>
            <OutputUnits>
              <Name>COUNTS</Name>
            </OutputUnits>
          </Response>
        </Channel>
      </Station>
    </Network>
  </FDSNStationXML>
```

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```

        <Description>Digital Counts</Description>
    </OutputUnits>
</InstrumentSensitivity>
<Stage number="1">
    <PolesZeros>
        <InputUnits>
            <Name>M/S</Name>
            <Description>Velocity in Meters per Second</Description>
        </InputUnits>
        <OutputUnits>
            <Name>V</Name>
            <Description>Volts</Description>
        </OutputUnits>
        <PzTransferFunctionType>LAPLACE (RADIANS/SECOND) </
↪PzTransferFunctionType>
            <NormalizationFactor>3.4684e+17</NormalizationFactor>
            <NormalizationFrequency unit="HERTZ">1.0</
↪NormalizationFrequency>
                <Zero number="0">
                    <Real>0.0</Real>
                    <Imaginary>0.0</Imaginary>
                </Zero>
                <Zero number="1">
                    <Real>0.0</Real>
                    <Imaginary>0.0</Imaginary>
                </Zero>
                <Zero number="2">
                    <Real>-15.15</Real>
                    <Imaginary>0.0</Imaginary>
                </Zero>
                <Zero number="3">
                    <Real>-176.6</Real>
                    <Imaginary>0.0</Imaginary>
                </Zero>
                <Zero number="4">
                    <Real>-463.1</Real>
                    <Imaginary>-430.5</Imaginary>
                </Zero>
                <Zero number="5">
                    <Real>-463.1</Real>
                    <Imaginary>430.5</Imaginary>
                </Zero>
                <Pole number="0">
                    <Real>-0.037</Real>
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                </Pole>
                <Pole number="1">
                    <Real>-0.037</Real>
                    <Imaginary>0.037</Imaginary>
                </Pole>
                <Pole number="2">
                    <Real>-15.64</Real>
                    <Imaginary>0.0</Imaginary>
                </Pole>
                <Pole number="3">
                    <Real>-97.34</Real>
                    <Imaginary>-400.7</Imaginary>

```

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```

</Pole>
<Pole number="4">
  <Real>-97.34</Real>
  <Imaginary>400.7</Imaginary>
</Pole>
<Pole number="5">
  <Real>-374.8</Real>
  <Imaginary>0.0</Imaginary>
</Pole>
<Pole number="6">
  <Real>-520.3</Real>
  <Imaginary>0.0</Imaginary>
</Pole>
<Pole number="7">
  <Real>-10530.0</Real>
  <Imaginary>-10050.0</Imaginary>
</Pole>
<Pole number="8">
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  <Imaginary>10050.0</Imaginary>
</Pole>
<Pole number="9">
  <Real>-13300.0</Real>
  <Imaginary>0.0</Imaginary>
</Pole>
<Pole number="10">
  <Real>-255.097</Real>
  <Imaginary>0.0</Imaginary>
</Pole>
</PolesZeros>
<StageGain>
  <Value>1500.0</Value>
  <Frequency>1.0</Frequency>
</StageGain>
</Stage>
<Stage number="2">
  <StageGain>
    <Value>1.0</Value>
    <Frequency>0.05</Frequency>
  </StageGain>
</Stage>
<Stage number="3">
  <Coefficients>
    <InputUnits>
      <Name>V</Name>
      <Description>Volts</Description>
    </InputUnits>
    <OutputUnits>
      <Name>COUNTS</Name>
      <Description>Digital Counts</Description>
    </OutputUnits>
    <CfTransferFunctionType>DIGITAL</CfTransferFunctionType>
    <Numerator>1.0</Numerator>
  </Coefficients>
  <Decimation>
    <InputSampleRate unit="HERTZ">102400.0</InputSampleRate>
    <Factor>1</Factor>

```

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```

    <Offset>0</Offset>
    <Delay>0.0</Delay>
    <Correction>0.0</Correction>
  </Decimation>
  <StageGain>
    <Value>629129.0</Value>
    <Frequency>0.05</Frequency>
  </StageGain>
</Stage>
<Stage number="4">
  <Coefficients>
    <InputUnits>
      <Name>COUNTS</Name>
      <Description>Digital Counts</Description>
    </InputUnits>
    <OutputUnits>
      <Name>COUNTS</Name>
      <Description>Digital Counts</Description>
    </OutputUnits>
    <CfTransferFunctionType>DIGITAL</CfTransferFunctionType>
    <Numerator>0.000244141</Numerator>
    <Numerator>0.000976562</Numerator>
    <Numerator>0.00244141</Numerator>
    <Numerator>0.00488281</Numerator>
    <Numerator>0.00854492</Numerator>
    <Numerator>0.0136719</Numerator>
    <Numerator>0.0205078</Numerator>
    <Numerator>0.0292969</Numerator>
    <Numerator>0.0393066</Numerator>
    <Numerator>0.0498047</Numerator>
    <Numerator>0.0600586</Numerator>
    <Numerator>0.0693359</Numerator>
    <Numerator>0.0769043</Numerator>
    <Numerator>0.0820312</Numerator>
    <Numerator>0.0839844</Numerator>
    <Numerator>0.0820312</Numerator>
    <Numerator>0.0769043</Numerator>
    <Numerator>0.0693359</Numerator>
    <Numerator>0.0600586</Numerator>
    <Numerator>0.0498047</Numerator>
    <Numerator>0.0393066</Numerator>
    <Numerator>0.0292969</Numerator>
    <Numerator>0.0205078</Numerator>
    <Numerator>0.0136719</Numerator>
    <Numerator>0.00854492</Numerator>
    <Numerator>0.00488281</Numerator>
    <Numerator>0.00244141</Numerator>
    <Numerator>0.000976562</Numerator>
    <Numerator>0.000244141</Numerator>
  </Coefficients>
  <Decimation>
    <InputSampleRate unit="HERTZ">102400.0</InputSampleRate>
    <Factor>8</Factor>
    <Offset>0</Offset>
    <Delay>0.00013672</Delay>
    <Correction>0.00013672</Correction>
  </Decimation>

```

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```

    <StageGain>
      <Value>1.0</Value>
      <Frequency>0.05</Frequency>
    </StageGain>
  </Stage>
  <Stage number="5">
    <Coefficients>
      <InputUnits>
        <Name>COUNTS</Name>
        <Description>Digital Counts</Description>
      </InputUnits>
      <OutputUnits>
        <Name>COUNTS</Name>
        <Description>Digital Counts</Description>
      </OutputUnits>
      <CfTransferFunctionType>DIGITAL</CfTransferFunctionType>
      <Numerator>0.000244141</Numerator>
      <Numerator>0.00292969</Numerator>
      <Numerator>0.0161133</Numerator>
      <Numerator>0.0537109</Numerator>
      <Numerator>0.12085</Numerator>
      <Numerator>0.193359</Numerator>
      <Numerator>0.225586</Numerator>
      <Numerator>0.193359</Numerator>
      <Numerator>0.12085</Numerator>
      <Numerator>0.0537109</Numerator>
      <Numerator>0.0161133</Numerator>
      <Numerator>0.00292969</Numerator>
      <Numerator>0.000244141</Numerator>
    </Coefficients>
    <Decimation>
      <InputSampleRate unit="HERTZ">12800.0</InputSampleRate>
      <Factor>2</Factor>
      <Offset>0</Offset>
      <Delay>0.00046875</Delay>
      <Correction>0.00046875</Correction>
    </Decimation>
    <StageGain>
      <Value>1.0</Value>
      <Frequency>0.05</Frequency>
    </StageGain>
  </Stage>
  <Stage number="6">
    <Coefficients>
      <InputUnits>
        <Name>COUNTS</Name>
        <Description>Digital Counts</Description>
      </InputUnits>
      <OutputUnits>
        <Name>COUNTS</Name>
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      </OutputUnits>
      <CfTransferFunctionType>DIGITAL</CfTransferFunctionType>
      <Numerator>0.000244141</Numerator>
      <Numerator>0.00292969</Numerator>
      <Numerator>0.0161133</Numerator>
      <Numerator>0.0537109</Numerator>

```

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```

    <Numerator>0.12085</Numerator>
    <Numerator>0.193359</Numerator>
    <Numerator>0.225586</Numerator>
    <Numerator>0.193359</Numerator>
    <Numerator>0.12085</Numerator>
    <Numerator>0.0537109</Numerator>
    <Numerator>0.0161133</Numerator>
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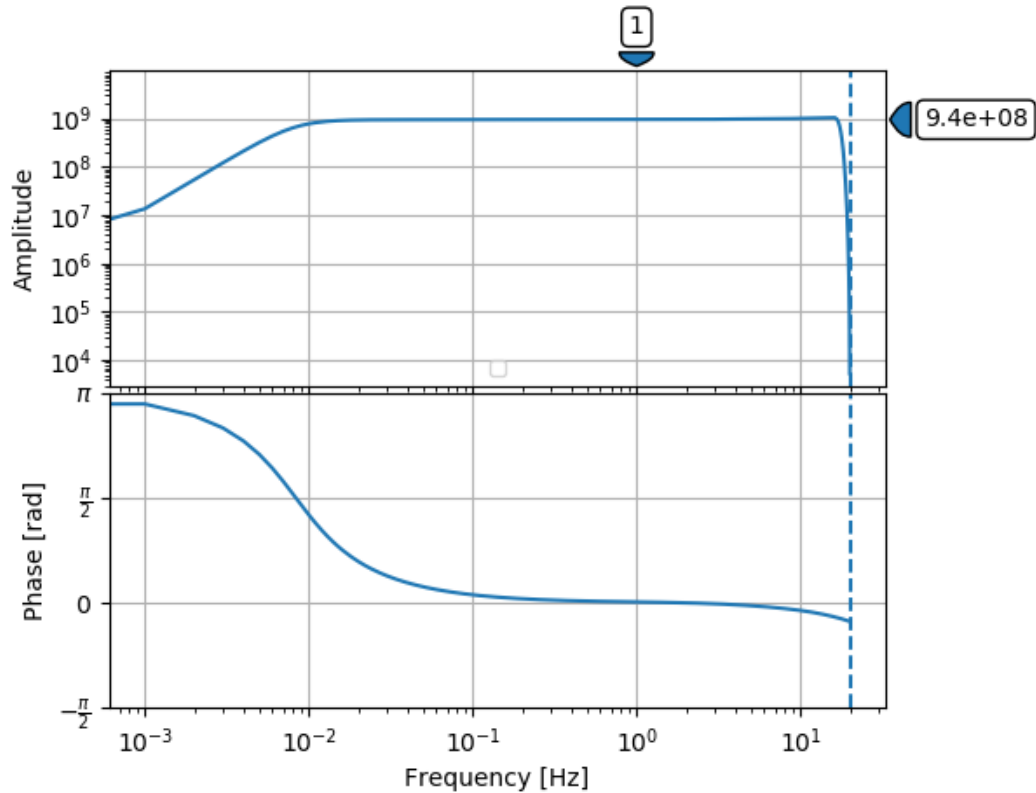
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3.3.2 Broadband sensor

Streckeisen STS-1 sensor (360 s) + Quanterra Qx80 datalogger (80)

StationXML [Show/Hide](#)

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          <Description>Velocity in Meters per Second</Description>
        </InputUnits>
        <OutputUnits>
          <Name>V</Name>
          <Description>Volts</Description>
        </OutputUnits>
        <PzTransferFunctionType>LAPLACE (RADIANS/SECOND) </
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        <OutputUnits>
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    </Coefficients>
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            <Description>Digital Counts</Description>
        </InputUnits>
        <OutputUnits>
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            <Description>Digital Counts</Description>
        </OutputUnits>
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        <Numerator>-0.001008</Numerator>
    </Coefficients>

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  </Coefficients>
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    <Delay>0.006152344</Delay>
    <Correction>0.006</Correction>
  </Decimation>
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    <Frequency>0.05</Frequency>
  </StageGain>
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<Stage number="5">
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      <Description>Digital Counts</Description>
    </InputUnits>
    <OutputUnits>
      <Name>COUNTS</Name>
      <Description>Digital Counts</Description>
    </OutputUnits>
    <CfTransferFunctionType>DIGITAL</CfTransferFunctionType>
    <Numerator>0.000150487</Numerator>
    <Numerator>0.000305924</Numerator>
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    <Numerator>-0.000970772</Numerator>
    <Numerator>-0.00230317</Numerator>
    <Numerator>-0.00370638</Numerator>
    <Numerator>-0.00462505</Numerator>
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    <Numerator>-0.0109214</Numerator>
    <Numerator>-0.0116364</Numerator>
    <Numerator>-0.00726515</Numerator>
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    <Numerator>-0.00464369</Numerator>
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<Numerator>0.000442949</Numerator>
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</Stage>

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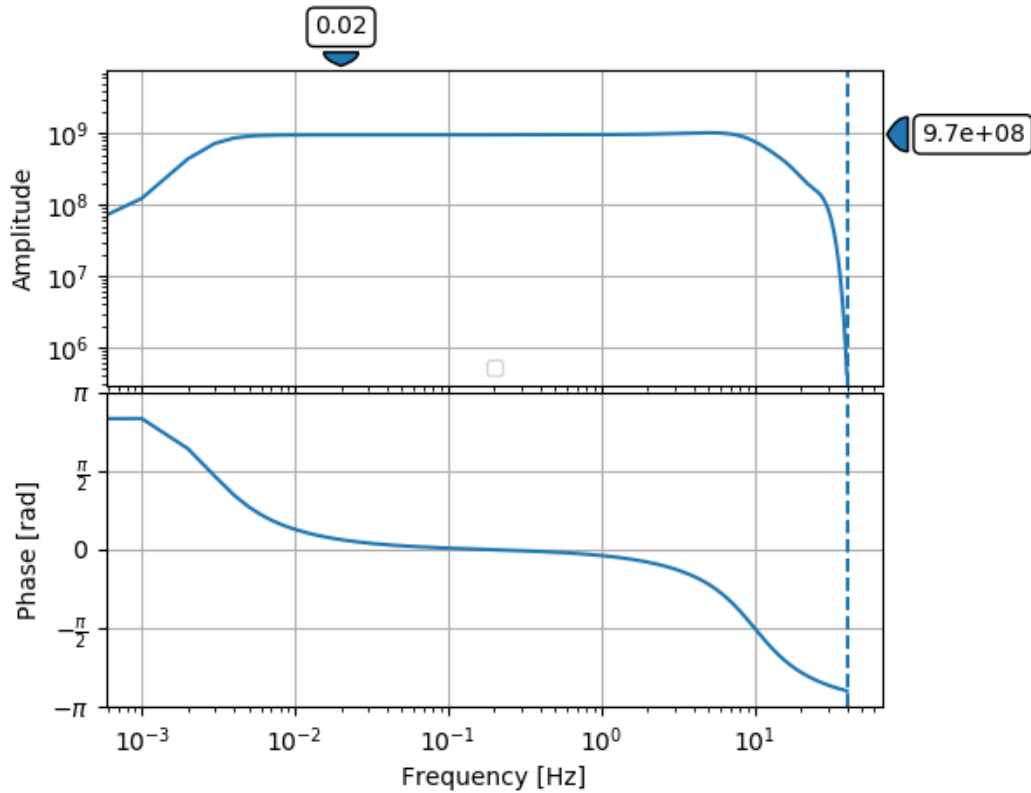
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```

</Response>
</Channel>
</Station>
</Network>
</FDSNStationXML>

```



3.3.3 Short-period sensor

Geotech GS-13 short-period sensor + Quanterra Quanterra Qx80 datalogger

StationXML [Show/Hide](#)

```

<?xml version='1.0' encoding='UTF-8'?>
<FDSNStationXML xmlns="http://www.fdsn.org/xml/station/1" schemaVersion="1.1
↪">
  <Network code=..>
    <Station code=..>
      <Channel code=.. locationCode=..>
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        <Response>
          <InstrumentSensitivity>
            <Value>264268099.805</Value>
            <Frequency>5.0</Frequency>
            <InputUnits>
              <Name>M/S</Name>
              <Description>Velocity in Meters per Second</Description>

```

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```

    </InputUnits>
    <OutputUnits>
      <Name>COUNTS</Name>
      <Description>Digital Counts</Description>
    </OutputUnits>
  </InstrumentSensitivity>
  <Stage number="1">
    <PolesZeros>
      <InputUnits>
        <Name>M/S</Name>
        <Description>Velocity in Meters per Second</Description>
      </InputUnits>
      <OutputUnits>
        <Name>V</Name>
        <Description>Volts</Description>
      </OutputUnits>
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↪PzTransferFunctionType>
      <NormalizationFactor>1.0</NormalizationFactor>
      <NormalizationFrequency unit="HERTZ">5.0</
↪NormalizationFrequency>
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        <Imaginary>0.0</Imaginary>
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      </Pole>
    </PolesZeros>
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  </Stage>
  <Stage number="2">
    <StageGain>
      <Value>1.0</Value>
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    </StageGain>
  </Stage>
  <Stage number="3">
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      <InputUnits>
        <Name>V</Name>
        <Description>Volts</Description>
      </InputUnits>
      <OutputUnits>
        <Name>COUNTS</Name>

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    <Description>Digital Counts</Description>
  </OutputUnits>
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</Decimation>
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</Stage>
<Stage number="4">
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      <Description>Digital Counts</Description>
    </InputUnits>
    <OutputUnits>
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      <Description>Digital Counts</Description>
    </OutputUnits>
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    <Numerator>-0.00208418</Numerator>
    <Numerator>-0.00238538</Numerator>
    <Numerator>-0.00260956</Numerator>
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    <Numerator>-0.00273316</Numerator>
    <Numerator>-0.00258472</Numerator>
    <Numerator>-0.00226412</Numerator>
    <Numerator>-0.00174847</Numerator>
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</Stage>
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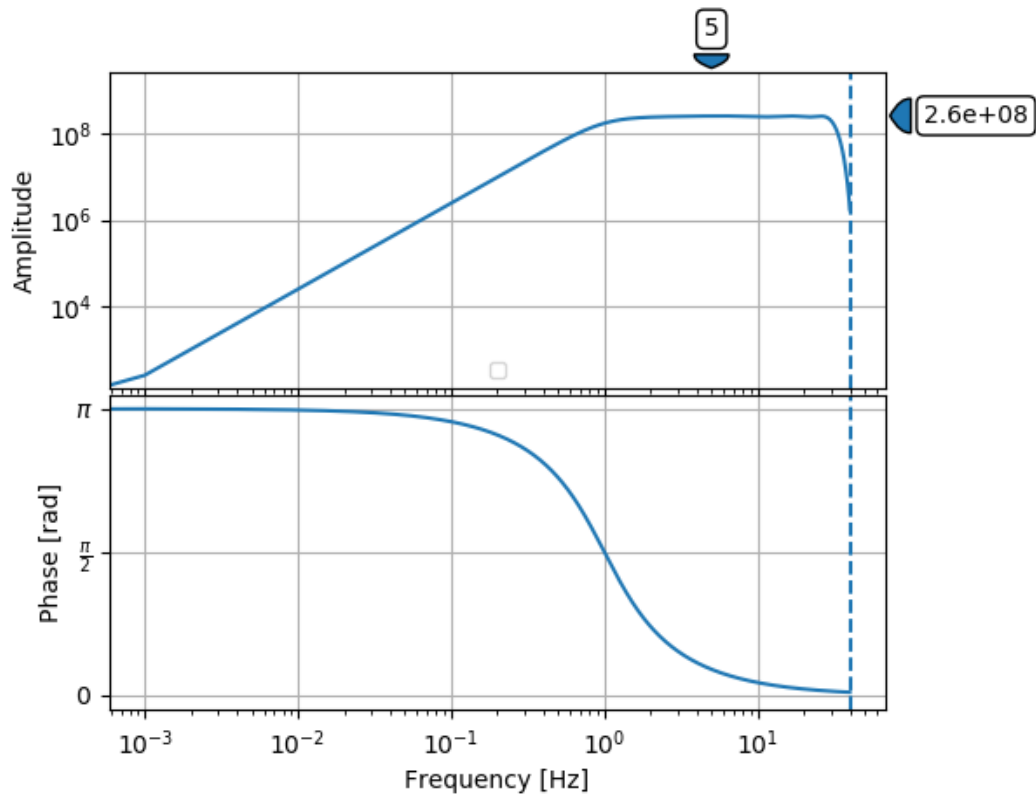
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<Numerator>0.000442949</Numerator>
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  <Frequency>0.05</Frequency>
</StageGain>
</Stage>
</Response>
</Channel>
</Station>
</Network>
</FDSNStationXML>
```



3.3.4 Short-period sensor

Sercel L-22D short-period sensor ($R_c=5470$ Ohms, $R_s=20000$ Ohms) + Reftek RT72A-08 24-bit datalogger, 1 stream, 100 Hz, gain 32

StationXML Show/Hide

```
<?xml version='1.0' encoding='UTF-8'?>
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  >
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        <Response>
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              <Description>Velocity in Meters per Second</Description>
            </InputUnits>
            <OutputUnits>
              <Name>COUNTS</Name>
              <Description>Digital Counts</Description>
            </OutputUnits>
          </Response>
        </Channel>
      </Station>
    </Network>
  </FDSNStationXML>
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```

</InstrumentSensitivity>
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      <Name>M/S</Name>
      <Description>Velocity in Meters per Second</Description>
    </InputUnits>
    <OutputUnits>
      <Name>V</Name>
      <Description>Volts</Description>
    </OutputUnits>
    <PzTransferFunctionType>LAPLACE (RADIANS/SECOND) </
↪PzTransferFunctionType>
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      <NormalizationFrequency unit="HERTZ">10.0</
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        </Zero>
        <Zero number="1">
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          <Imaginary>0.0</Imaginary>
        </Zero>
        <Pole number="0">
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          <Imaginary>8.887</Imaginary>
        </Pole>
        <Pole number="1">
          <Real>-8.884</Real>
          <Imaginary>-8.887</Imaginary>
        </Pole>
      </PolesZeros>
      <StageGain>
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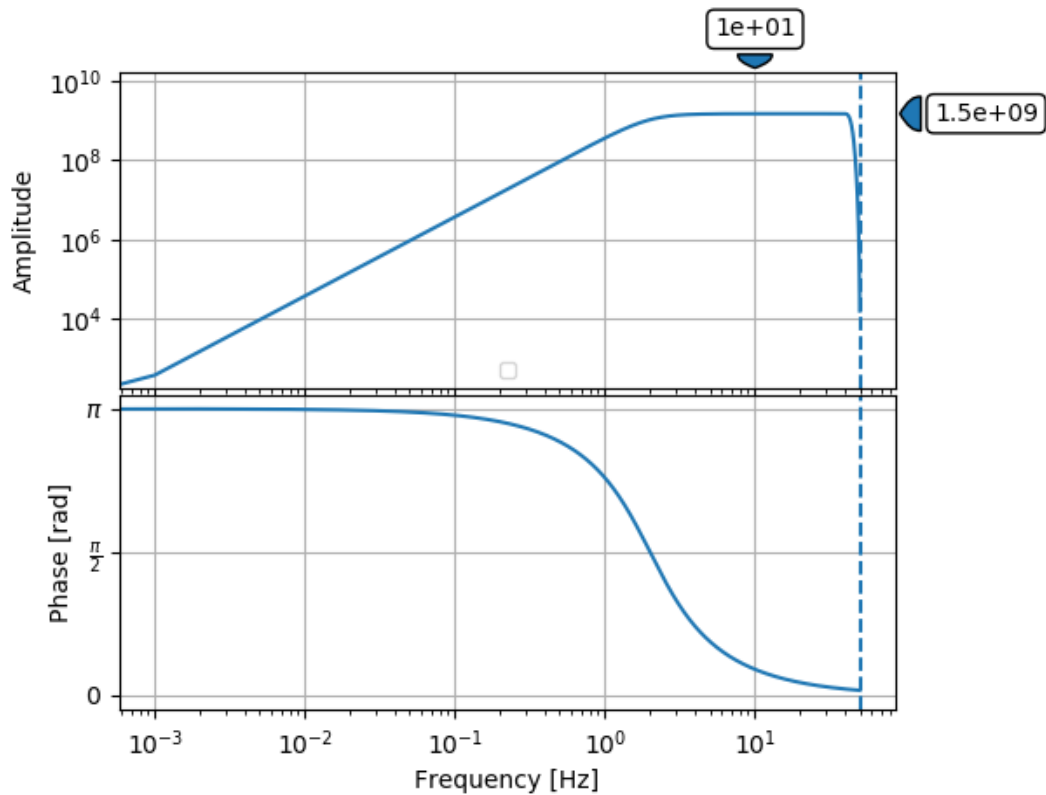
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</Station>
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</FDSNStationXML>
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3.3.5 Accelerometer

Kinometrics FBA-3 + Kinometrics Etna

StationXML **Show/Hide**

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            <OutputUnits>
              <Name>COUNTS</Name>
              <Description>Digital Counts</Description>
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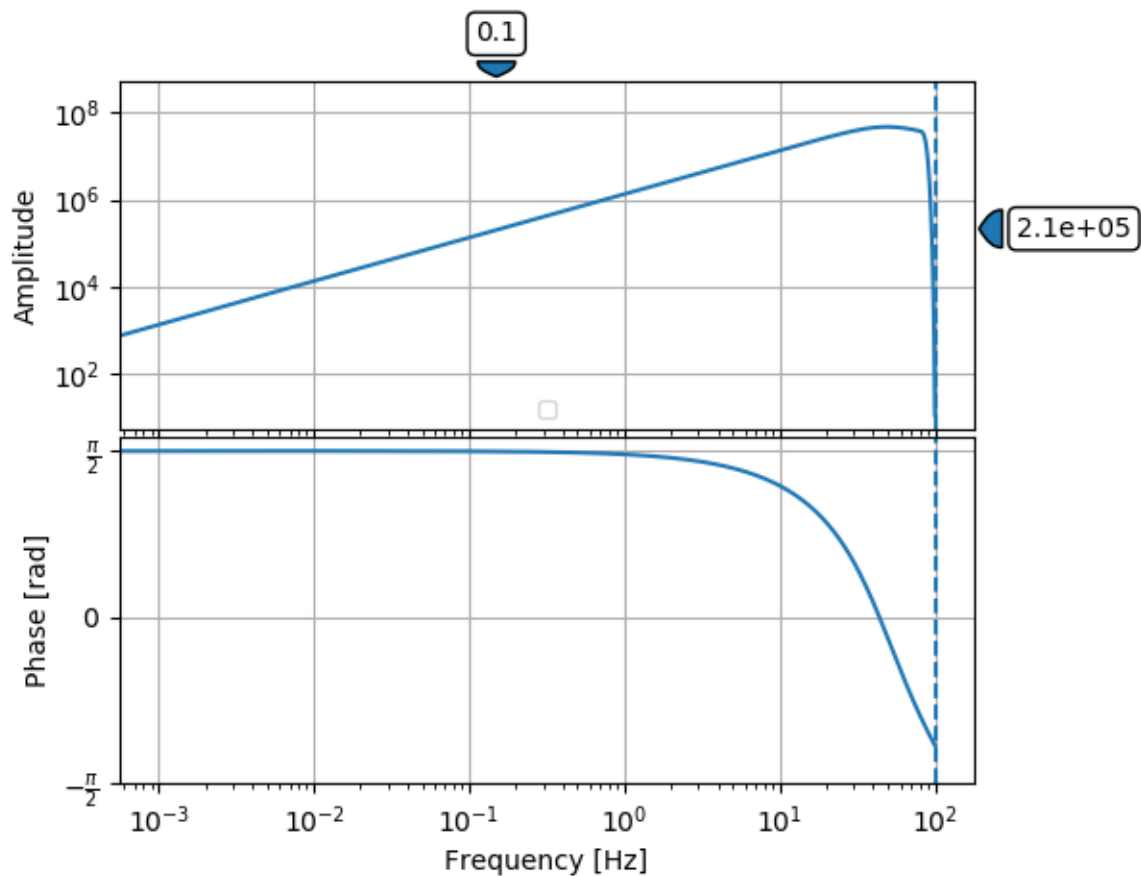
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    <Frequency>1.0</Frequency>
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</Stage>
</Response>
</Channel>
</Station>
</Network>
</FDSNStationXML>

```



3.3.6 YSI 44031 thermistor

The Berkeley Digital Seismic Network (BDSN) seismometers, use a Yellow Springs Instrument Co. (YSI) 44031 thermistor to monitor the temperature of the seismometer. The thermistor response has been determined by measuring its voltage output as a function of input temperature. It has been calibrated within a range of temperatures from -5C to 68.59C.

The resistance of the thermistor is a non-linear function of the temperature and its response can be described by a polynomial.

In order to model the response within 0.2 degrees C accuracy, a MacLaurin polynomial with 11 coefficients:

$$Temp(V) = \sum_{n=0}^{10} a_n V^n$$

The coefficients are given in Table 1.

a_n	value
a_0	0.12505E+02
a_1	0.13824E+02
a_2	0.41039E+01
a_3	0.12932E+01
a_4	0.18741E+01
a_5	0.17250E+01
a_6	-0.61021E+00
a_7	-0.10540E+01
a_8	0.13974E+00
a_9	0.39061E+00
a_{10}	0.95345E-01

Because this is a *polynomial* response, the corresponding StationXML looks a little different than the usual responses (e.g., for seismometers). Instead of a InstrumentSensitivity element, there is an InstrumentPolynomial element. In addition the analog stage is represented by a Polynomial stage. The Polynomial stage and the InstrumentPolynomial stage both contain all of the MacLaurin coefficients, however, in the InstrumentPolynomial stage, those coefficients have been scaled by the datalogger sensitivity to give units of Counts instead of Volts.

How the InstrumentPolynomial was calculated

The InstrumentPolynomial stage looks a lot like the Polynomial stage except that the overall system gain has been incorporated into the polynomial coefficients.

The overall system gain is just the product of the individual stage gains:

$$g0 = \prod_{n=0}^N gain_n$$

where $g0$ is the system gain.

Then the n^{th} coefficient of the MacLaurin series is scaled by the inverse n^{th} power of the system gain:

$$a'_n = \frac{a_n}{(g0)^n}$$

For the example shown, the system gain is $g0 = 838860.80$ so that the scaled coefficients are:

coefficient	value
a'_0	0.12505E+02
a'_1	1.64795e-05
a'_2	5.83199e-12
a'_3	2.19077e-18
a'_4	3.78471e-24
a'_5	4.15279e-30
a'_6	-1.75122e-36
a'_7	-3.60588e-42
a'_8	5.69904e-49
a'_9	1.89904e-54
a'_{10}	5.52585e-61

A complete StationXML Response element is shown below for the YSI-44301 thermistor attached to a Reftek RT130 datalogger sampling at 40Hz.

StationXML Show/Hide

```
<?xml version='1.0' encoding='UTF-8'?>
<FDSNStationXML xmlns="http://www.fdsn.org/xml/station/1" schemaVersion="1.1">
  <Network code=..>
    <Station code=..>
      <Channel code=.. locationCode=..>
        ...
        <SampleRate>40.0</SampleRate>

      <Response>
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          <InputUnits>
            <Name>degC</Name>
            <Description>TEMPERATURE in Celsius</Description>
          </InputUnits>
          <OutputUnits>
            <Name>COUNTS</Name>
            <Description>Digital Counts</Description>
          </OutputUnits>
          <ApproximationType>MACLAURIN</ApproximationType>
          <FrequencyLowerBound unit="HERTZ">0.0</FrequencyLowerBound>
          <FrequencyUpperBound unit="HERTZ">0.01</FrequencyUpperBound>
          <ApproximationLowerBound>-5.02</ApproximationLowerBound>
          <ApproximationUpperBound>68.59</ApproximationUpperBound>
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          <Coefficient>5.525847819332687e-61</Coefficient>
        </InstrumentPolynomial>
        <Stage number="1">
```

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<Polynomial name=" SENSOR RESPONSE  ">
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    <Description>TEMPERATURE in Celsius</Description>
  </InputUnits>
  <OutputUnits>
    <Name>V</Name>
    <Description>Volts</Description>
  </OutputUnits>
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    <Correction>0.0</Correction>
  </Decimation>
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        <Description>Volts</Description>
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      <Frequency>0.0</Frequency>
    </StageGain>
  </Stage>
  <Stage number="5">
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  <Description>Volts</Description>
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    </OutputUnits>
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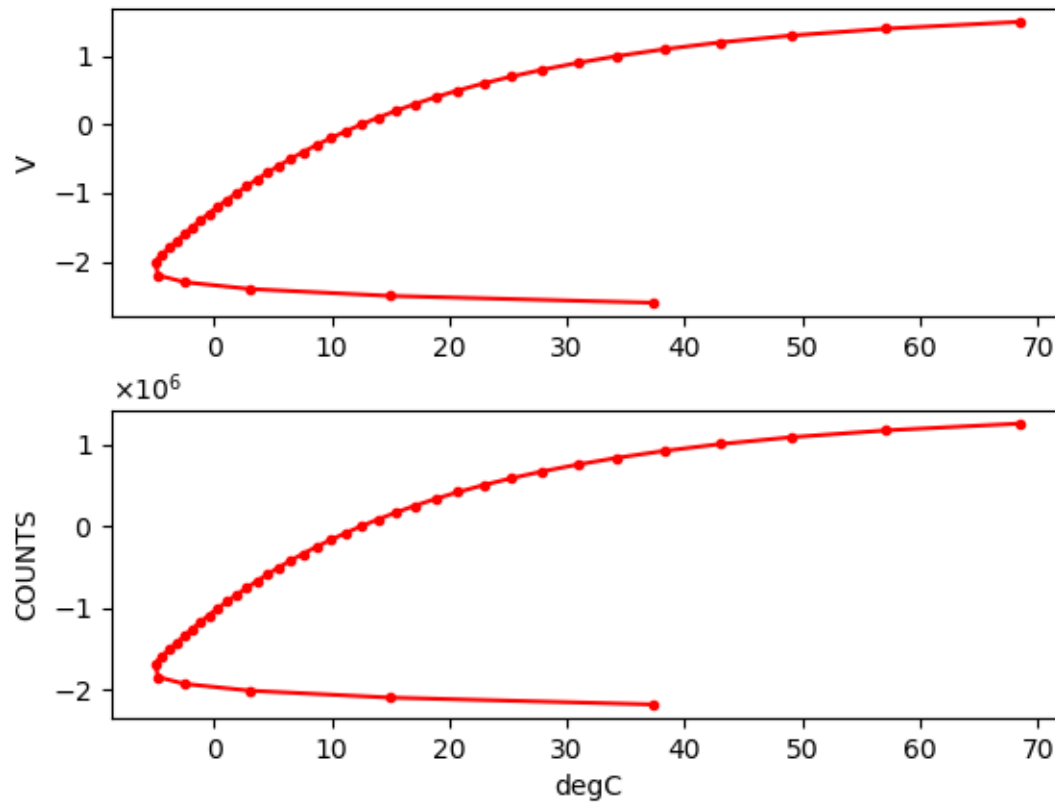
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</Network>
</FDSNStationXML>
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3.3.7 Setra 270

Setra 270 Pressure Transducer

This example was lifted from [62] Response [Polynomial] Blockette section (p.85) of the SEED manual (v.2.4).

The Setra Model 270 Pressure Transducer response is given as a polynomial response with 2 coefficients, valid for input pressure between 600-1100 mbar.

$$Pressure(V) = \sum_{n=0}^1 a_n V^n$$

where $a_0 = 600$ and $a_1 = 100$

Volts	mbar
0.0	600
1.0	700
2.0	800
3.0	900
4.0	1000
5.0	1100

e.g., over this voltage range (0-5V), the input (mbar of pressure) is a linear function of the output (Volts).

The Response element for the Setra sensor alone consists of a Polynomial stage and an InstrumentPolynomial Stage

Warning

This part is not finished!

StationXML Show/Hide

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        <Channel code=.. locationCode=..>
          ...
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  </FDSNStationXML>
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      <Description>TEMPERATURE in Celsius</Description>
    </InputUnits>
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      <Description>Volts</Description>
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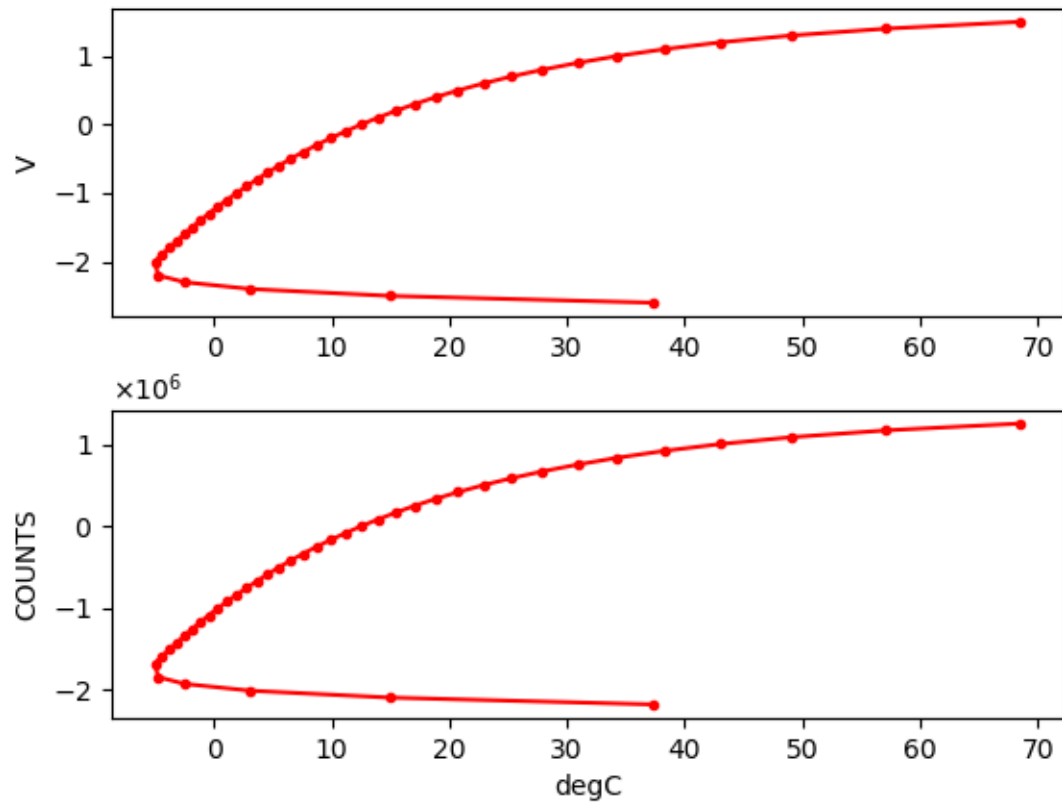
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STATIONXML TOOLS

As StationXML files are ordinary text files, they may be edited with any text editor (e.g., vi/VIM, TextWrangler, Notepad/Wordpad, etc)

However, StationXML files can become very large and unwieldy as more stations and channels are added. For instance a regional seismic network can generate a StationXML file of size > 30Mb on disk (>400,000 lines).

Fortunately, several tools exist that allow creation and editing of StationXML files.

4.1 obspy + NRL

ObsPy contains a number of very useful modules for working with StationXML. In particular, ObsPy contain a module able to connect to the IRIS Nominal Resource Library (NRL) and download full responses (sensor + datalogger) for various combinations of sensor + datalogger contained within the NRL.

The excerpts below provide examples of how to work with ObsPy and the NRL.

```
from obspy.clients.nrl import NRL

from lib.valid import stationxml_validator

def main():

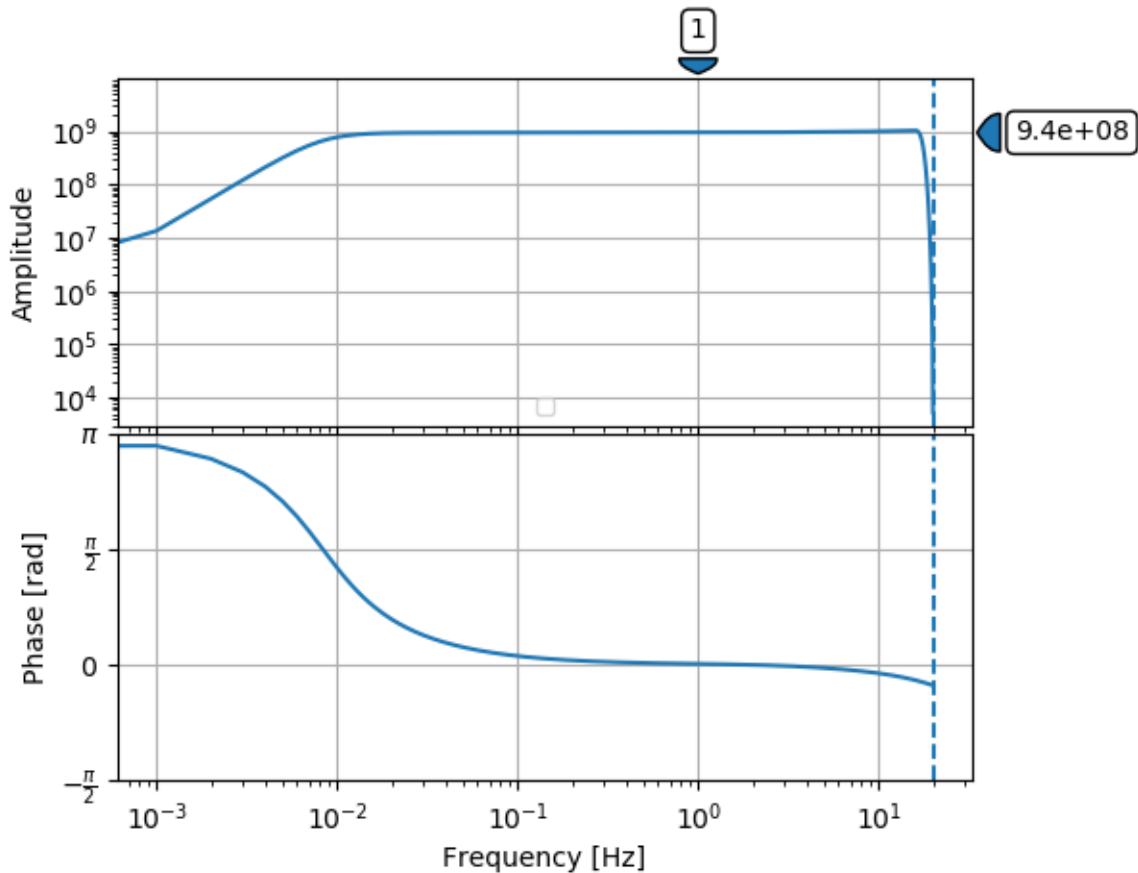
    nrl = NRL('http://ds.iris.edu/NRL/')
    datalogger_keys = ['REF TEK', 'RT 130 & 130-SMA', '1', '40']
    sensor_keys = ['Streckeisen', 'STS-2', '1500', '3 - installed 04/97 to_
↳present']

    response = nrl.get_response(sensor_keys=sensor_keys, datalogger_
↳keys=datalogger_keys)

    response.plot(min_freq=.001)

    for stage in response.response_stages:
        print(stage)
```

The resulting response plot looks like



Output for the response stages **Show/Hide Stages**

```
<?xml version='1.0' encoding='UTF-8'?>
Response type: PolesZerosResponseStage, Stage Sequence Number: 1
  From M/S (Velocity in Meters per Second) to V (Volts)
  Stage gain: 1500.0, defined at 1.00 Hz
  Transfer function type: LAPLACE (RADIANS/SECOND)
  Normalization factor: 3.4684e+17, Normalization frequency: 1.00 Hz
  Poles: (-0.037-0.037j), (-0.037+0.037j), (-15.64+0j), (-97.34-400.7j), (-97.
↪ 34+400.7j), (-374.8+0j), (-520.3+0j), (-10530-10050j), (-10530+10050j), (-13300+0j),
↪ (-255.097+0j)
  Zeros: 0j, 0j, (-15.15+0j), (-176.6+0j), (-463.1-430.5j), (-463.1+430.5j)
Response type: ResponseStage, Stage Sequence Number: 2
  From V to V
  Stage gain: 1.0, defined at 0.05 Hz
Response type: CoefficientsTypeResponseStage, Stage Sequence Number: 3
  From V (Volts) to COUNTS (Digital Counts)
  Stage gain: 629129.0, defined at 0.05 Hz
  Decimation:
    Input Sample Rate: 102400.00 Hz
    Decimation Factor: 1
    Decimation Offset: 0
    Decimation Delay: 0.00
    Decimation Correction: 0.00
  Transfer function type: DIGITAL
```

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```
Contains 1 numerators and 0 denominators
Response type: CoefficientsTypeResponseStage, Stage Sequence Number: 4
From COUNTS (Digital Counts) to COUNTS (Digital Counts)
Stage gain: 1.0, defined at 0.05 Hz
Decimation:
    Input Sample Rate: 102400.00 Hz
    Decimation Factor: 8
    Decimation Offset: 0
    Decimation Delay: 0.00
    Decimation Correction: 0.00
Transfer function type: DIGITAL
Contains 29 numerators and 0 denominators
Response type: CoefficientsTypeResponseStage, Stage Sequence Number: 5
From COUNTS (Digital Counts) to COUNTS (Digital Counts)
Stage gain: 1.0, defined at 0.05 Hz
Decimation:
    Input Sample Rate: 12800.00 Hz
    Decimation Factor: 2
    Decimation Offset: 0
    Decimation Delay: 0.00
    Decimation Correction: 0.00
Transfer function type: DIGITAL
Contains 13 numerators and 0 denominators
Response type: CoefficientsTypeResponseStage, Stage Sequence Number: 6
From COUNTS (Digital Counts) to COUNTS (Digital Counts)
Stage gain: 1.0, defined at 0.05 Hz
Decimation:
    Input Sample Rate: 6400.00 Hz
    Decimation Factor: 2
    Decimation Offset: 0
    Decimation Delay: 0.00
    Decimation Correction: 0.00
Transfer function type: DIGITAL
Contains 13 numerators and 0 denominators
Response type: CoefficientsTypeResponseStage, Stage Sequence Number: 7
From COUNTS (Digital Counts) to COUNTS (Digital Counts)
Stage gain: 1.0, defined at 0.05 Hz
Decimation:
    Input Sample Rate: 3200.00 Hz
    Decimation Factor: 2
    Decimation Offset: 0
    Decimation Delay: 0.00
    Decimation Correction: 0.00
Transfer function type: DIGITAL
Contains 13 numerators and 0 denominators
Response type: CoefficientsTypeResponseStage, Stage Sequence Number: 8
From COUNTS (Digital Counts) to COUNTS (Digital Counts)
Stage gain: 1.0, defined at 0.05 Hz
Decimation:
    Input Sample Rate: 1600.00 Hz
    Decimation Factor: 2
    Decimation Offset: 0
    Decimation Delay: 0.00
    Decimation Correction: 0.00
Transfer function type: DIGITAL
Contains 13 numerators and 0 denominators
Response type: CoefficientsTypeResponseStage, Stage Sequence Number: 9
```

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```

From COUNTS (Digital Counts) to COUNTS (Digital Counts)
Stage gain: 1.0, defined at 0.05 Hz
Decimation:
    Input Sample Rate: 800.00 Hz
    Decimation Factor: 2
    Decimation Offset: 0
    Decimation Delay: 0.01
    Decimation Correction: 0.01
Transfer function type: DIGITAL
Contains 13 numerators and 0 denominators
Response type: CoefficientsTypeResponseStage, Stage Sequence Number: 10
From COUNTS (Digital Counts) to COUNTS (Digital Counts)
Stage gain: 1.0, defined at 0.05 Hz
Decimation:
    Input Sample Rate: 400.00 Hz
    Decimation Factor: 2
    Decimation Offset: 0
    Decimation Delay: 0.12
    Decimation Correction: 0.12
Transfer function type: DIGITAL
Contains 101 numerators and 0 denominators
Response type: CoefficientsTypeResponseStage, Stage Sequence Number: 11
From COUNTS (Digital Counts) to COUNTS (Digital Counts)
Stage gain: 1.0, defined at 0.05 Hz
Decimation:
    Input Sample Rate: 200.00 Hz
    Decimation Factor: 5
    Decimation Offset: 0
    Decimation Delay: 0.58
    Decimation Correction: 0.58
Transfer function type: DIGITAL
Contains 235 numerators and 0 denominators

```

Up until now we've been examining the response in ObsPy format, that is, as an instance of type `obspy.core.inventory.response.Response`.

We can also examine this as part of a StationXML file, however, StationXML does not allow children to exist without parents. Thus, a response must be contained within a `<Channel>` element, which itself must be contained within a `<Station>` element, which must be contained within a `<Network>` element, etc.

The excerpt below creates a generic structure to contain our Response object, exports this to StationXML, and validates it against the StationXML schema.

```

from obspy.clients.nrl import NRL

...

inventory = Inventory(networks=[], source="demo")
network = Network(code='US')
station = Station(code='ANMO',
                  latitude=34.945911,
                  longitude=-106.457199,
                  elevation=1820.0,
                  creation_date=UTCDateTime(1970, 1, 1), #_
↳required                  site=Site(name='Albuquerque, New Mexico, USA') #_
↳required

```

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```

    )

    channel = Channel(code='BHZ',
                      location_code='10',      # required
                      latitude=34.945911,     # required
                      longitude=-106.457199,   # required
                      elevation=1820.0,        # required
                      depth=0.,                # required
    )

    channel.response = response

    inventory.write("Test.xml", format="stationxml", validate=False)

```

The output StationXML file looks like:

```

<?xml version='1.0' encoding='UTF-8'?>

Response type: PolesZerosResponseStage, Stage Sequence Number: 1

<?xml version='1.0' encoding='UTF-8'?>
<FDSNStationXML xmlns="http://www.fdsn.org/xml/station/1" schemaVersion="1.0">
<Source>demo</Source>
<Module>ObsPy 1.1.0</Module>
<ModuleURI>https://www.obspy.org</ModuleURI>
<Created>2020-02-07T22:26:54.123236</Created>
<Network code="US">
  <Station code="ANMO">
    <Latitude unit="DEGREES">34.945911</Latitude>
    <Longitude unit="DEGREES">-106.457199</Longitude>
    <Elevation unit="METERS">1820.0</Elevation>
    <Site>
      <Name>Albuquerque, New Mexico, USA</Name>
    </Site>
    <CreationDate>1970-01-01T00:00:00</CreationDate>
    <Channel code="BHZ" locationCode="10">
      <Latitude unit="DEGREES">34.945911</Latitude>
      <Longitude unit="DEGREES">-106.457199</Longitude>
      <Elevation unit="METERS">1820.0</Elevation>
      <Depth unit="METERS">0.0</Depth>
      <Response>
        <InstrumentSensitivity>
          <Value>941864732.6931986</Value>
          <Frequency>1.0</Frequency>
          <InputUnits>
            <Name>M/S</Name>
            <Description>Velocity in Meters per Second</Description>
          </InputUnits>
          <OutputUnits>
            <Name>COUNTS</Name>
            <Description>Digital Counts</Description>
          </OutputUnits>
        </InstrumentSensitivity>
        <Stage number="1">
          <PolesZeros>
            <InputUnits>

```

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```

    <Name>M/S</Name>
    <Description>Velocity in Meters per Second</Description>
  </InputUnits>
  <OutputUnits>
    <Name>V</Name>
    <Description>Volts</Description>
  </OutputUnits>
  <PzTransferFunctionType>LAPLACE (RADIANS/SECOND)</PzTransferFunctionType>
  <NormalizationFactor>3.4684e+17</NormalizationFactor>
  <NormalizationFrequency unit="HERTZ">1.0</NormalizationFrequency>
  <Zero number="0">
    <Real minusError="0.0" plusError="0.0">0.0</Real>
    <Imaginary minusError="0.0" plusError="0.0">0.0</Imaginary>
  </Zero>
  <Zero number="1">
    <Real minusError="0.0" plusError="0.0">0.0</Real>
    <Imaginary minusError="0.0" plusError="0.0">0.0</Imaginary>
  </Zero>
  <Zero number="2">
    <Real minusError="-15.15" plusError="-15.15">-15.15</Real>
    <Imaginary minusError="0.0" plusError="0.0">0.0</Imaginary>
  </Zero>
  <Zero number="3">
    <Real minusError="-176.6" plusError="-176.6">-176.6</Real>
    <Imaginary minusError="0.0" plusError="0.0">0.0</Imaginary>
  </Zero>
  <Zero number="4">
    <Real minusError="-463.1" plusError="-463.1">-463.1</Real>
    <Imaginary minusError="-430.5" plusError="-430.5">-430.5</Imaginary>
  </Zero>
  <Zero number="5">
    <Real minusError="-463.1" plusError="-463.1">-463.1</Real>
    <Imaginary minusError="430.5" plusError="430.5">430.5</Imaginary>
  </Zero>
  <Pole number="0">
    <Real minusError="-0.037" plusError="-0.037">-0.037</Real>
    <Imaginary minusError="-0.037" plusError="-0.037">-0.037</Imaginary>
  </Pole>
  <Pole number="1">
    <Real minusError="-0.037" plusError="-0.037">-0.037</Real>
    <Imaginary minusError="0.037" plusError="0.037">0.037</Imaginary>
  </Pole>
  <Pole number="2">
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    <Imaginary minusError="0.0" plusError="0.0">0.0</Imaginary>
  </Pole>
  <Pole number="3">
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    <Imaginary minusError="-400.7" plusError="-400.7">-400.7</Imaginary>
  </Pole>
  <Pole number="4">
    <Real minusError="-97.34" plusError="-97.34">-97.34</Real>
    <Imaginary minusError="400.7" plusError="400.7">400.7</Imaginary>
  </Pole>
  <Pole number="5">
    <Real minusError="-374.8" plusError="-374.8">-374.8</Real>
    <Imaginary minusError="0.0" plusError="0.0">0.0</Imaginary>

```

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```

    </Pole>
    <Pole number="6">
      <Real minusError="-520.3" plusError="-520.3">-520.3</Real>
      <Imaginary minusError="0.0" plusError="0.0">0.0</Imaginary>
    </Pole>
    <Pole number="7">
      <Real minusError="-10530.0" plusError="-10530.0">-10530.0</Real>
      <Imaginary minusError="-10050.0" plusError="-10050.0">-10050.0</
↪Imaginary>
    </Pole>
    <Pole number="8">
      <Real minusError="-10530.0" plusError="-10530.0">-10530.0</Real>
      <Imaginary minusError="10050.0" plusError="10050.0">10050.0</Imaginary>
    </Pole>
    <Pole number="9">
      <Real minusError="-13300.0" plusError="-13300.0">-13300.0</Real>
      <Imaginary minusError="0.0" plusError="0.0">0.0</Imaginary>
    </Pole>
    <Pole number="10">
      <Real minusError="-255.097" plusError="-255.097">-255.097</Real>
      <Imaginary minusError="0.0" plusError="0.0">0.0</Imaginary>
    </Pole>
  </PolesZeros>
  <StageGain>
    <Value>1500.0</Value>
    <Frequency>1.0</Frequency>
  </StageGain>
</Stage>
<Stage number="2">
  <StageGain>
    <Value>1.0</Value>
    <Frequency>0.05</Frequency>
  </StageGain>
</Stage>
<Stage number="3">
  <Coefficients>
    <InputUnits>
      <Name>V</Name>
      <Description>Volts</Description>
    </InputUnits>
    <OutputUnits>
      <Name>COUNTS</Name>
      <Description>Digital Counts</Description>
    </OutputUnits>
    <CfTransferFunctionType>DIGITAL</CfTransferFunctionType>
    <Numerator>1.0</Numerator>
  </Coefficients>
  <Decimation>
    <InputSampleRate unit="HERTZ">102400.0</InputSampleRate>
    <Factor>1</Factor>
    <Offset>0</Offset>
    <Delay>0.0</Delay>
    <Correction>0.0</Correction>
  </Decimation>
  <StageGain>
    <Value>629129.0</Value>
    <Frequency>0.05</Frequency>

```

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```

    </StageGain>
  </Stage>
  <Stage number="4">
    <Coefficients>
      <InputUnits>
        <Name>COUNTS</Name>
        <Description>Digital Counts</Description>
      </InputUnits>
      <OutputUnits>
        <Name>COUNTS</Name>
        <Description>Digital Counts</Description>
      </OutputUnits>
      <CfTransferFunctionType>DIGITAL</CfTransferFunctionType>
      <Numerator>0.000244141</Numerator>
      <Numerator>0.000976562</Numerator>
      <Numerator>0.00244141</Numerator>
      <Numerator>0.00488281</Numerator>
      <Numerator>0.00854492</Numerator>
      <Numerator>0.0136719</Numerator>
      <Numerator>0.0205078</Numerator>
      <Numerator>0.0292969</Numerator>
      <Numerator>0.0393066</Numerator>
      <Numerator>0.0498047</Numerator>
      <Numerator>0.0600586</Numerator>
      <Numerator>0.0693359</Numerator>
      <Numerator>0.0769043</Numerator>
      <Numerator>0.0820312</Numerator>
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      <Numerator>0.0205078</Numerator>
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      <Numerator>0.00244141</Numerator>
      <Numerator>0.000976562</Numerator>
      <Numerator>0.000244141</Numerator>
    </Coefficients>
    <Decimation>
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      <Factor>8</Factor>
      <Offset>0</Offset>
      <Delay>0.00013672</Delay>
      <Correction>0.00013672</Correction>
    </Decimation>
    <StageGain>
      <Value>1.0</Value>
      <Frequency>0.05</Frequency>
    </StageGain>
  </Stage>
  <Stage number="5">
    <Coefficients>

```

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```

<InputUnits>
  <Name>COUNTS</Name>
  <Description>Digital Counts</Description>
</InputUnits>
<OutputUnits>
  <Name>COUNTS</Name>
  <Description>Digital Counts</Description>
</OutputUnits>
<CfTransferFunctionType>DIGITAL</CfTransferFunctionType>
<Numerator>0.000244141</Numerator>
<Numerator>0.00292969</Numerator>
<Numerator>0.0161133</Numerator>
<Numerator>0.0537109</Numerator>
<Numerator>0.12085</Numerator>
<Numerator>0.193359</Numerator>
<Numerator>0.225586</Numerator>
<Numerator>0.193359</Numerator>
<Numerator>0.12085</Numerator>
<Numerator>0.0537109</Numerator>
<Numerator>0.0161133</Numerator>
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<Numerator>0.000244141</Numerator>
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<Correction>0.00046875</Correction>
</Decimation>
<StageGain>
<Value>1.0</Value>
<Frequency>0.05</Frequency>
</StageGain>
</Stage>
<Stage number="6">
  <Coefficients>
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    <Description>Digital Counts</Description>
  </InputUnits>
  <OutputUnits>
    <Name>COUNTS</Name>
    <Description>Digital Counts</Description>
  </OutputUnits>
  <CfTransferFunctionType>DIGITAL</CfTransferFunctionType>
  <Numerator>0.000244141</Numerator>
  <Numerator>0.00292969</Numerator>
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  <Numerator>0.0537109</Numerator>
  <Numerator>0.12085</Numerator>
  <Numerator>0.193359</Numerator>
  <Numerator>0.225586</Numerator>
  <Numerator>0.193359</Numerator>
  <Numerator>0.12085</Numerator>
  <Numerator>0.0537109</Numerator>
  <Numerator>0.0161133</Numerator>

```

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```

<Numerator>0.00292969</Numerator>
<Numerator>0.000244141</Numerator>
</Coefficients>
<Decimation>
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</StageGain>
</Stage>
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    <Description>Digital Counts</Description>
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  <OutputUnits>
    <Name>COUNTS</Name>
    <Description>Digital Counts</Description>
  </OutputUnits>
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  <Numerator>0.0537109</Numerator>
  <Numerator>0.12085</Numerator>
  <Numerator>0.193359</Numerator>
  <Numerator>0.225586</Numerator>
  <Numerator>0.193359</Numerator>
  <Numerator>0.12085</Numerator>
  <Numerator>0.0537109</Numerator>
  <Numerator>0.0161133</Numerator>
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  </Coefficients>
  <Decimation>
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  <Offset>0</Offset>
  <Delay>0.001875</Delay>
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  </Decimation>
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  <Value>1.0</Value>
  <Frequency>0.05</Frequency>
  </StageGain>
</Stage>
<Stage number="8">
  <Coefficients>
  <InputUnits>
    <Name>COUNTS</Name>
    <Description>Digital Counts</Description>

```

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```

</InputUnits>
<OutputUnits>
  <Name>COUNTS</Name>
  <Description>Digital Counts</Description>
</OutputUnits>
<CfTransferFunctionType>DIGITAL</CfTransferFunctionType>
<Numerator>0.000244141</Numerator>
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</Stage>
<Stage number="9">
  <Coefficients>
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    <Name>COUNTS</Name>
    <Description>Digital Counts</Description>
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  <OutputUnits>
    <Name>COUNTS</Name>
    <Description>Digital Counts</Description>
  </OutputUnits>
  <CfTransferFunctionType>DIGITAL</CfTransferFunctionType>
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  <Numerator>0.0161133</Numerator>
  <Numerator>0.0537109</Numerator>
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  </Coefficients>

```

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```

    <Decimation>
    <InputSampleRate unit="HERTZ">800.0</InputSampleRate>
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    <Offset>0</Offset>
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    <StageGain>
    <Value>1.0</Value>
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  </Stage>
  <Stage number="10">
    <Coefficients>
    <InputUnits>
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      <Description>Digital Counts</Description>
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    <OutputUnits>
      <Name>COUNTS</Name>
      <Description>Digital Counts</Description>
    </OutputUnits>
    <CfTransferFunctionType>DIGITAL</CfTransferFunctionType>
    <Numerator>-7.15032e-07</Numerator>
    <Numerator>-5.60109e-06</Numerator>
    <Numerator>-2.62179e-06</Numerator>
    <Numerator>-4.31403e-05</Numerator>
    <Numerator>-4.64771e-06</Numerator>
    <Numerator>1.43006e-06</Numerator>
    <Numerator>2.34769e-05</Numerator>
    <Numerator>1.43006e-06</Numerator>
    <Numerator>-5.27932e-05</Numerator>
    <Numerator>-0.000366692</Numerator>
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    <Numerator>-0.0209407</Numerator>
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  </Stage number="10">

```

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```
<Numerator>0.0166669</Numerator>
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```

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<Numerator>0.000261821</Numerator>
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<Numerator>-9.99854e-05</Numerator>
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<Numerator>-2.94355e-05</Numerator>
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<Stage number="11">
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</OutputUnits>
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<Numerator>-3.29668e-05</Numerator>
<Numerator>-4.39561e-05</Numerator>
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4.2 IRIS SEED-StationXML Converter

IRIS maintains a Java-based tool that can convert between dataless SEED and StationXML formats at:

<https://github.com/iris-edu/stationxml-seed-converter>

4.3 IRIS StationXML Validator

IRIS maintains a Java-based validator for StationXML documents.

Note: this tool validates documents against the official schema in addition to a set of rules that are not possible to represent in the XML Schema language.

<https://github.com/iris-edu/stationxml-validator>

APPENDICES

5.1 Mapping SEED blockettes to StationXML

5.1.1 B34 Units Abbreviations

Field	Field Name	StationXML Element	Attribute	Dictionary Field(s)
B034F03	Unit Lookup Code	Multiple Mappings		
B034F04	Unit Name	Multiple Mappings		<ul style="list-style-type: none"> • B053F05, • B053F06, • B055F04, • B055F05, • B061F06, • B055F07, • B062F05, • B062F06
B034F05	Unit Description	Multiple Mappings		

5.1.2 B50 Station Identifier

Field	Field Name	StationXML Element	Attribute	Dictionary Field(s)
B050F03	Station Call Letters	<i>Station</i>	code	
B050F04	Station Latitude	<i>Station/Latitude</i>		
B050F05	Station Longitude	<i>Station/Longitude</i>		
B050F06	Station Elevation	<i>Station/Elevation</i>		
B050F07	Number Of Channels	<i>Station/TotalNumberChannels</i>		
B050F08	Number Of Station Comments	<i>Station/Comments</i>		
B050F09	Site Name	<i>Station/Site/Name</i>		
B050F10	Network Identifier Code	No Mapping		
B050F11	32-bit Word Order	No Mapping		
B050F12	16-bit Word Order	No Mapping		
B050F13	Start Effective Date	<i>Station</i>	startDate	
B050F14	End Effective Date	<i>Station</i>	endDate	
B050F15	Update Flag	No Mapping		
B050F16	Network Code	<i>Network</i>	code	

5.1.3 B52 Channel Identifier

Field	Field Name	StationXML Element	Attribute	Dictionary Field(s)
B052F03	Location Identifier	<i>Channel</i>	locationCode	
B052F04	Channel Identifier	<i>Channel</i>	code	
B052F05	Subchannel Identifier	No Mapping		
B052F06	Instrument Identifier	No Mapping		
B052F07	Optional Comment	<i>Channel/Comment</i>		
B052F08	Units Of Signal Response	No Mapping		
B052F09	Units Of Calibration Input	<i>Channel/CalibrationUnits/Name</i>		
B052F10	Latitude	<i>Channel/Latitude</i>		
B052F11	Longitude	<i>Channel/Longitude</i>		
B052F12	Elevation	<i>Channel/Elevation</i>		
B052F13	Local Depth	<i>Channel/Depth</i>		
B052F14	Azimuth	<i>Channel/Azimuth</i>		
B052F15	Dip	<i>Channel/Dip</i>		
B052F16	Data Format Identifier Code	No Mapping		
B052F17	Data Record Length	No Mapping		
B052F18	Sample Rate	<i>Channel/SampleRate</i>		
B052F19	Max Clock Drift	<i>Channel/ClockDrift</i>		
B052F20	Number Of Comments	No Mapping		
B052F21	Channel Flags	No Mapping		
B052F22	Start Date	<i>Channel</i>	startDate	
B052F23	End Date	<i>Channel</i>	endDate	
B052F24	Update Flags	No Mapping		

5.1.4 B53 Response Poles & Zeros

Field	Field Name	StationXML Element	Attribute	Dictionary Field(s)
B053F03	Transfer Function Type	<i>Response/Stage/PolesZeros/PzTransferFunctionType</i>		
B053F04	Stage Sequence Number	<i>Response/Stage/PolesZeros</i>	number	
B053F05	Stage Signal Input Units	<i>Response/Stage/PolesZeros/InputUnits/Name</i>		B034F04, B043F06
B053F06	Stage Signal Output Units	<i>Response/Stage/PolesZeros/OutputUnits/Name</i>		B034F04, B043F07
B053F07	A0 Normalization Factor	<i>Response/Stage/PolesZeros/NormalizationFactor</i>		
B053F08	Normalization Frequency	<i>Response/Stage/PolesZeros/NormalizationFrequency</i>		
B053F09	Number Of Complex Zeros	No Mapping		
B053F10	Real Zero	<i>Response/Stage/PolesZeros/Zero/Real</i>		
B053F11	Imaginary Zero	<i>Response/Stage/PolesZeros/Zero/Imaginary</i>		
B053F12	Real Zero Error	<i>Response/Stage/PolesZeros/Zero/Real</i>	minusError plusError	
B053F13	Imaginary Zero Error	<i>Response/Stage/PolesZeros/Zero/Imaginary</i>	minusError plusError	
B053F14	Number Of Complex Poles	No Mapping		
B053F15	Real Pole	<i>Response/Stage/PolesZeros/Pole/Real</i>		
B053F16	Imaginary Pole	<i>Response/Stage/PolesZeros/Pole/Imaginary</i>		
B053F17	Real Pole Error	<i>Response/Stage/PolesZeros/Pole/Real</i>	minusError plusError	
B053F18	Imaginary Pole Error	<i>Response/Stage/PolesZeros/Pole/Imaginary</i>	minusError plusError	

5.1.5 B55 Response List

Field	Field Name	StationXML Element	Attribute	Dictionary Field(s)
B055F03	Stage Sequence Number	<i>Response/Stage/ResponseList</i>	name	
B055F04	Signal Input Units	<i>Response/Stage/ResponseList/InputUnits/Name</i>		B034F04, B045F05
B055F05	Signal Output Units	<i>Response/Stage/ResponseList/OutputUnits/Name</i>		B034F04, B045F06
B055F06	Number Of Responses Listed	No Mapping		
B055F07	Frequency	<i>Response/Stage/ResponseList/ResponseListElement/Frequency</i>		
B055F08	Amplitude	<i>Response/Stage/ResponseList/ResponseListElement/Amplitude</i>		
B055F09	Amplitude Error	<i>Response/Stage/ResponseList/ResponseListElement/Amplitude</i>	minusError plusError	
B055F10	Phase Angle	<i>Response/Stage/ResponseList/ResponseListElement/Phase</i>		
B055F11	Phase Angle Error	<i>Response/Stage/ResponseList/ResponseListElement/Phase</i>	minusError plusError	

5.1.6 B57 Decimation

Field	Field Name	StationXML Element	Attribute	Dictionary Field(s)
B057F03	Stage Sequence Number	<i>Response/Stage/Decimation</i>	number	
B057F04	Input Sample Rate	<i>Response/Stage/Decimation/InputSampleRate</i>		
B057F05	Decimation Factor	<i>Response/Stage/Decimation/Factor</i>		
B057F06	Decimation Offset	<i>Response/Stage/Decimation/Offset</i>		
B057F07	Estimated Delay	<i>Response/Stage/Decimation/Delay</i>		
B057F08	Correction Applied	<i>Response/Stage/Decimation/Correction</i>		

5.1.7 B58 Channel Sensitivity/Gain

Field	Field Name	StationXML Element	Attribute	Dictionary Field(s)
B058F03	Stage Sequence Number	No Mapping		
B058F04	Sensitivity/Gain	<i>Response/InstrumentSensitivity/Value</i>		
B058F05	Frequency	<i>Response/InstrumentSensitivity/Frequency</i>		
B058F06	Number Of History Values	No Mapping		
B058F07	Sensitivity For Calibration	No Mapping		
B058F08	Frequency Of Calibration	No Mapping		
B058F09	Time Of Calibration	No Mapping		

5.1.8 B61 FIR Response

Field	Field Name	StationXML Element	Attribute	Dictionary Field(s)
B061F03	Stage Sequence Number	<i>Response/Stage/FIR</i>	number	
B061F04	Response Name	<i>Response/Stage/FIR</i>	name	
B061F05	Symmetry	<i>Response/Stage/FIR/Symmetry</i>		
B061F06	Signal In Units	<i>Response/Stage/FIR/InputUnits/Name</i>		B034F04, B041F06
B061F07	Signal Out Units	<i>Response/Stage/FIR/OutputUnits/Name</i>		B034F04, B041F07
B061F08	Number of Coefficients	No Mapping		
B061F09	FIR Coefficient	<i>Response/Stage/FIR/NumeratorCoefficient</i>		

5.1.9 B62 Response Polynomial

Field	Field Name	StationXML Element	Attribute	Dictionary Field(s)
B062F03	Transfer Function Type	No Mapping		
B062F04	Stage Sequence Number	<i>Response/Stage/Polynomial</i>	number	
B062F05	Stage Signal Input Units	<i>Response/Stage/Polynomial/InputUnits/Name</i>		B034F04, B042F06
B062F06	Stage Signal Output Units	<i>Response/Stage/Polynomial/OutputUnits/Name</i>		B034F04, B042F07
B062F07	Polynomial Approximation Type	<i>Response/Stage/Polynomial/ApproximationType</i>		
B062F08	Valid Frequency Units	No Mapping		
B062F09	Lower Valid Frequency Bound	<i>Response/Stage/Polynomial/FrequencyLowerBound</i>		
B062F10	Upper Valid Frequency Bound	<i>Response/Stage/Polynomial/FrequencyUpperBound</i>		
B062F11	Lower Bound Of Approximation	<i>Response/Stage/Polynomial/ApproximationLowerBound</i>		
B062F12	Upper Bound Of Approximation	<i>Response/Stage/Polynomial/ApproximationUpperBound</i>		
B062F13	Maximum Absolute Error	<i>Response/Stage/Polynomial/MaximumError</i>		
B062F14	Number Of Polynomial Coefficients	No Mapping		
B062F15	Polynomial Coefficient Error	<i>Response/Stage/Polynomial/Coefficient</i>	minusError plusError	

5.2 Embedded Schema Keywords

The *StationXML Reference* of this documentation is auto-generated from documentation tags in the StationXML schema document. In this way a single source of documentation is maintained for the purposes of this generated documentation and those reading the XSD schema specification directly.

To allow additional granularity and clarity in the generated documentation, special embedded keywords are parsed from the content of standard documentation tags of [XML Schema](#).

The following keywords are recognized in the standard `<documentation>` tags:

1. “Example:”
2. “Warning:”
3. “LevelChoice:”
4. “ElementChoice:”

These serve the following roles:

- “Example:” - Text that follows appears after Example: in the documentation.

For instance, NetworkType element contains 2 *documentation* tags:

```

<xs:complexType name="NetworkType">
  <xs:annotation>
    <xs:documentation>The Network container. All station metadata for
↪this network is contained within this element.
    Description element may be included with the official network
↪name and other descriptive information.
    An Identifier element may be included to designate a persistent
↪identifier (e.g. DOI) to use for citation.
    A Comment element may be included for arbitrary comments.
  </xs:documentation>
  <xs:documentation>Example:&lt;Network code="IU" startDate=2016-01-
↪27T13:00:00&gt;</xs:documentation>
  </xs:annotation>
</xs:complexType>
```

The first documentation text appears directly beneath the Network element in the StationXML documentation (it is the Network description), while the second is used to create the example beneath the description:

Example: `<Network code="IU" startDate=2016-01-27T13:00:00>`

- “Warning:” - This is used to wrap the text that follows it in an ReStructuredText admonition wrapper.

It is used, for example, to present a caution that a particular element may be deprecated in future versions of the StationXML documentation.

- “LevelChoice:X” - where X is in {N, S, C}.

When a particular XML element is used more than once in the documentation, this allows us to specify different documentation for different BaseNodeElements. For example, Network, Station and Channel types all inherit code from the BaseNodeElement. By using the LevelChoice flag, we can specify a unique Description and Example for the Network.code, Station.code and Channel.code.

For example,

```

<xs:attribute name="code" type="xs:string" use="required">
  <xs:annotation>
    <xs:documentation>LevelChoice:N Name of Network Example:code='IU'</
↪xs:documentation>
    <xs:documentation>LevelChoice:S Name of Station Example:code='ANMO'
↪</xs:documentation>
    <xs:documentation>LevelChoice:C Name of Channel Example:code='BHZ'</
↪xs:documentation>
  </xs:annotation>
</xs:attribute>

```

If LevelChoice is not used (or if no choice is present that matches the Network, Station or Channel element, then the default value is used.

- “ElementChoice:” - Serves a similar function to LevelChoice except that it helps disambiguate StationXML elements that share a common parent type. For example:

```

<xs:complexType name="FloatType">
  <xs:attribute name="unit" type="xs:string" use="optional">
    <xs:annotation>
      <xs:documentation>The unit of measurement. Use SI unit names and symbols,
↪whenever possible.
    </xs:documentation>
    <xs:documentation>Example:unit='SECONDS'</xs:documentation>
    <xs:documentation>ElementChoice:WATERLEVEL Example:unit='&apos;METERS&
↪&apos;.</xs:documentation>.
    <xs:documentation>ElementChoice:AMPLITUDE Example:unit='&apos;METERS&apos;
↪.</xs:documentation>
  </xs:annotation>
</xs:complexType>

```

Because several elements are of FloatType but may have different units (METERS, SECONDS, etc), we use this to give more specific examples based on the element itself (Waterlevel, Amplitude). Note the default Example has unit='SECONDS'.

5.3 Identifiers and codes

For information on Network, Station, Location, and Channel codes, in addition to their combination into Source Identifiers, used in StationXML see:

(as of this writing, this documentation is in progress) <http://docs.fdsn.org/projects/source-identifiers>

5.4 Unit Naming Rules

The FDSN strongly recommends the use of SI unit names whenever possible, which are defined case sensitively.

In the SEED format all unit names are recommended to be uppercase and SI when possible. For this reason, some unit documentation and required declarations in StationXML are in “uppercase SI” and these remain in order to maintain backward compatibility with the initial schema version. With the next major change to the specification the FDSN will very likely remove these “uppercase SI” unit names in favor of proper SI unit names.

5.5 Type Glossary

Type	Type Details	Examples
anyURI	Represents a Uniform Resource Identifier Reference, which often describes URLs and file paths.	<ul style="list-style-type: none"> • http://some/path • http://usgs.gov
CounterType	Integers greater than or equal to 0.	<ul style="list-style-type: none"> • 0 • 12345
dateTime	Integer values used to represent the year, day, hours, minutes. Decimals represent seconds, a boolean represents the timezone.	
decimal	The subset of real numbers	<ul style="list-style-type: none"> • -123.45 • 53.7
double	A number between 2.23×10^{-308} and 8.98×10^{307} (rounded), along with positive and negative infinity and NaN.	<ul style="list-style-type: none"> • 12.78e-2 • -32
integer	A decimal number without the period and numbers following it.	...-2,-1,0,1, 2, ...
RestrictedStatusType	an NMTOKEN that is either “open”, “closed,” or “partial.”	<ul style="list-style-type: none"> • open • closed
string	A finite sequence of characters.	foo bar
NMTOKEN	a combination of name characters, which include letters, digits, periods, hyphens, underscores, colons.	<ul style="list-style-type: none"> • ANMO • a1.-_:

INDICES AND TABLES

- *Overview*
- *StationXML Reference*
- response-theory
- *StationXML Tools*
- *Appendices*