Dynamic Range and the Seismic System

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Graduated from UBC in 1977

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Amoco Canada 1977 to 1981

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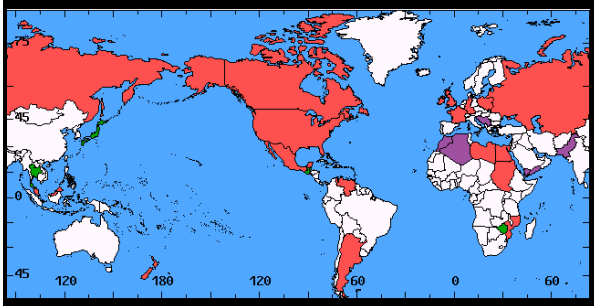
1981 to 1983

Mustagh Resources Ltd.
Founded in 1983

23 Countries Spanning 6 Continents



Dynamic Range and The Seismic System

- What Has Been Accomplished and Where Must We Go

NORM COOPER
MUSTAGH RESOURCES LTD.

Dynamic Range and the Seismic System

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Please do not alter this tutorial !

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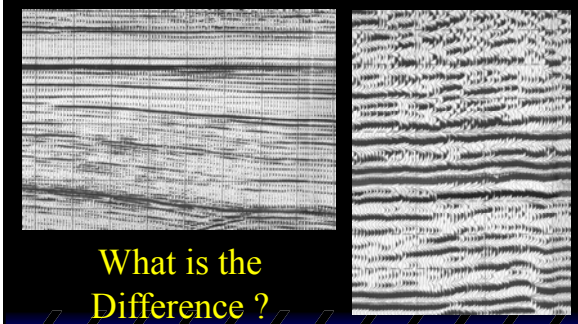
We also provide training programs in 3D design, Vibroseis Theory, Land Seismic Acquisition and Instrumentation.

Moving Through This Tutorial

- Pressing the **PGDN** key or the **ENTER** key will advance to the next slide
- Pressing the **PGUP** key or the **BKSP** key will reverse to the previous slide
- If you wish to jump to a specific **Slide Number** (located in lower right corner of each slide) type the number and press **ENTER**

Good Data / Poor Data



What is the Difference ?

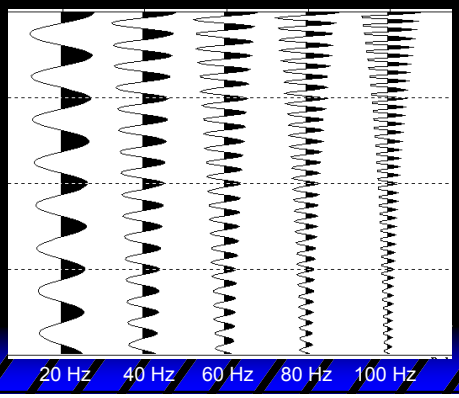
Seismic Objectives

- **Broad Bandwidth**
- **Strong Signal to Noise Ratio**
- **Stable, Recoverable Phase**

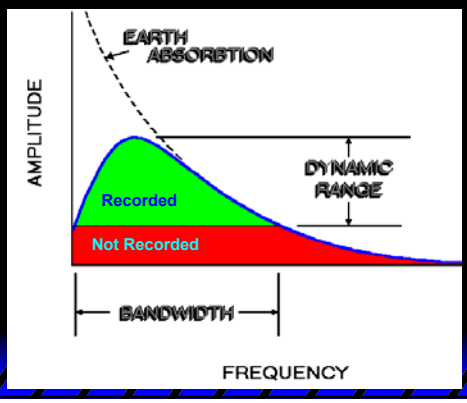
Energy Loss Mechanisms

- **Reflection and Transmission Losses**
- **Mode Conversion**
- **Spherical Divergence**
- **Absorption**

Absorption is Frequency Dependent



The Need for Greater Dynamic Range



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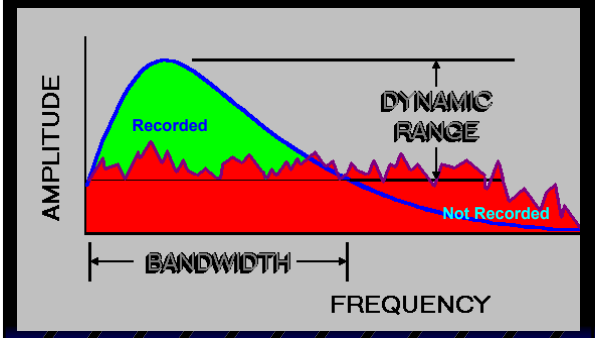
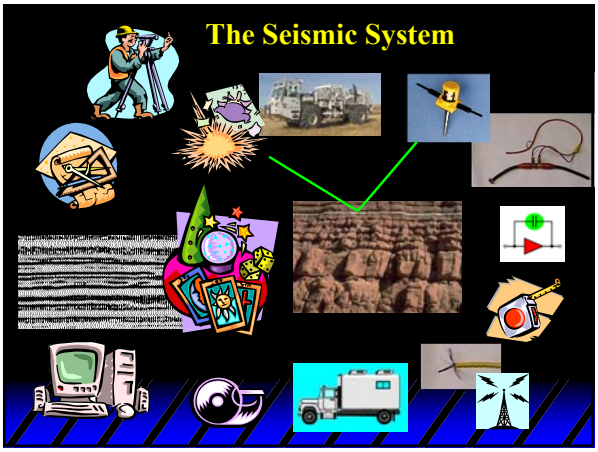


Illustration of Dynamic Range

The Seismic System



The Seismic System

- Parameter Design
- Survey
- Energy Source
- The Earth
- Geophones
- Analogue Cable
- Pre Amp
- A-D Converter
- Telemetry Cable
- Tape and format
- Deconvolution and filtering
- Display
- Geologic Model
- Interpretation

Parameter Design

Science …

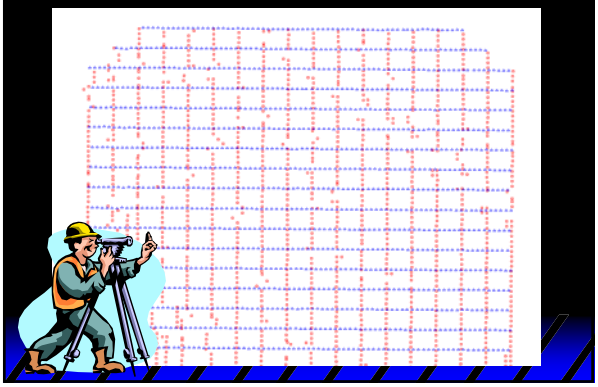
… or Otherwise ?

… or Worse ?

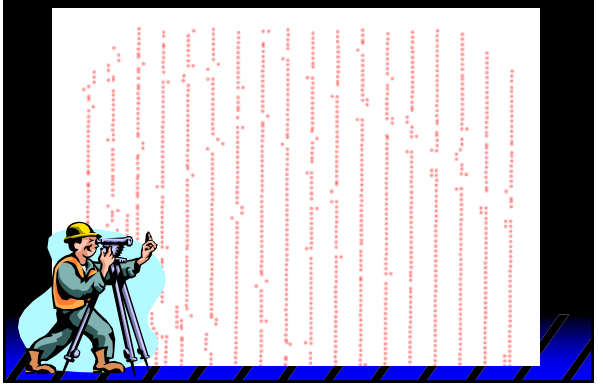
Parameter Design

- Proactive, target driven
  - Requires good geologic model
  - Spatial Sampling of wavefield
  - Statistical diversity, homogeneity
  - Accommodates available instruments
  - Optimizes cost / benefit for user budget
- Modeling alone is NOT Design

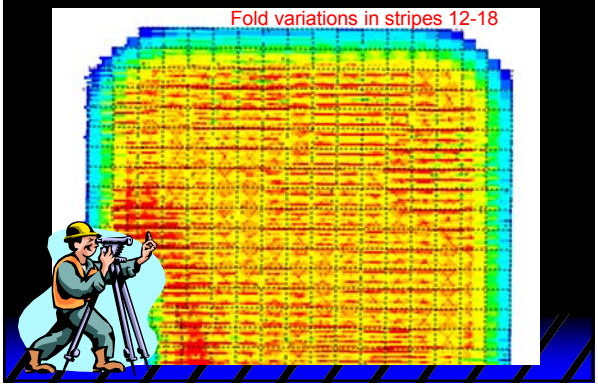
An Area Requiring Skidding and Offsetting



Source Moves Made by Surveyor



Resulting Fold Patterns – Bad Skids



Sources

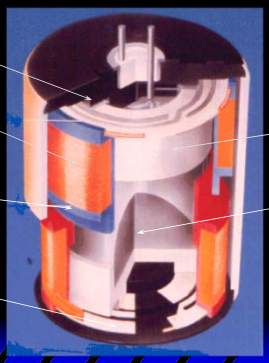
- Explosive Type
- Charge size
- Hole Depth
- Coupling
- Patterns

- Bandwidth, linearity
- Sweep Length
- Tapers
- Sweep Rate
- Effort
- Distortion
- Quality Control
- Array Effect

The Earth

- Coupling (S & R)
- Attenuation
- Dispersion
- Trapped Mode
- Ray Path Distortion
(long offsets for steep dips)
- Diffractions

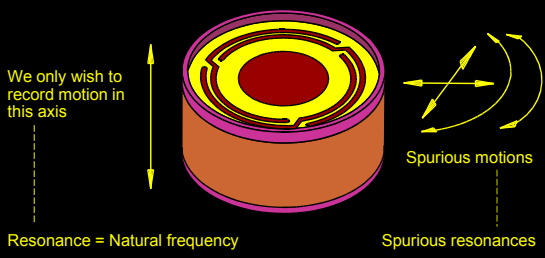
The Geophone



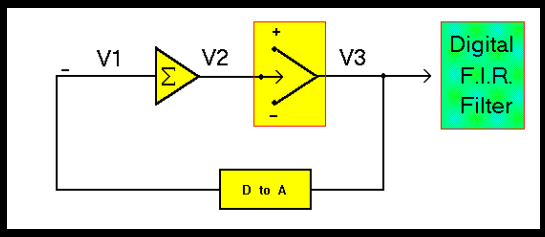
Close Tolerance Geophones

High speed CNC lathes	-	Reduced tolerances in mechanical parts
Rigorous QC	-	Less variation in parts
	-	matched spring sets and coil forms
	-	more uniform wire and coating
Revised coil winding technique	-	Reduced variances in coils
Modified pole pieces	-	More linear magnetic field
Coil rest position more precisely set	-	Improved symmetry & tilt
	-	better springs, reduced spurious
Statistical Process Control	-	Improved yield

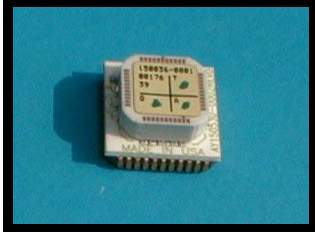
Spurious Frequency



The Delta-Sigma Receiver Sensor



I/O Digital Sensor (VectorSeis)



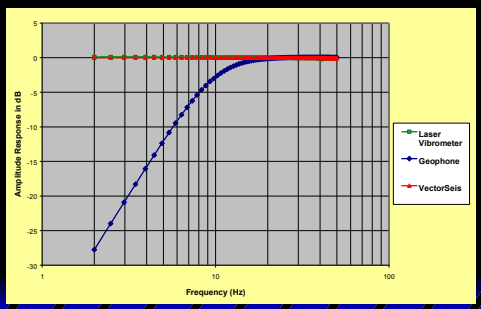
I/O Digital Sensor (VectorSeis)

I/O Digital Sensor (VectorSeis)

- Based on Micro Machined Accelerometer
- Low Frequency Response to 0 Hz (dc)
- DC component is gravity
- 3 Component sensors
- Possibly can "auto detect" orientation from DC component

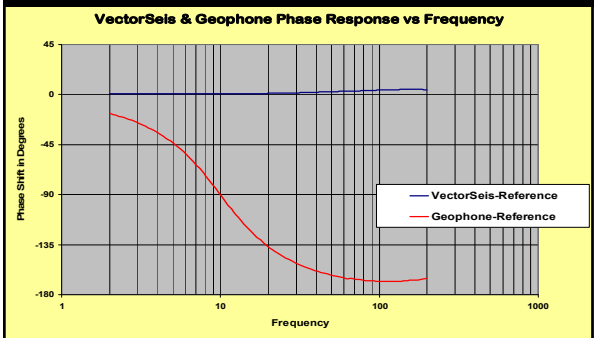
Low Frequency Response

Geophone & VectorSeis™ simultaneously shaken, table motion measured by Laser Vibrometer, Geophone and VectorSeis outputs normalized to Vibrometer



VectorSeis™ Digital Sensor

(without further effect of instrument filters)

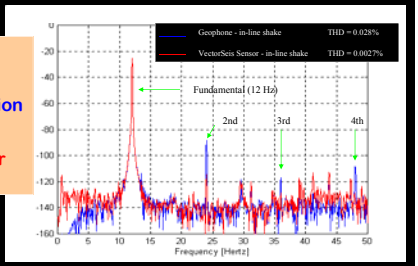


VectorSeis™ Digital Sensor

Low distortion shaker table data

Geophone distortion -71dB

VectorSeis Sensor distortion < -91dB



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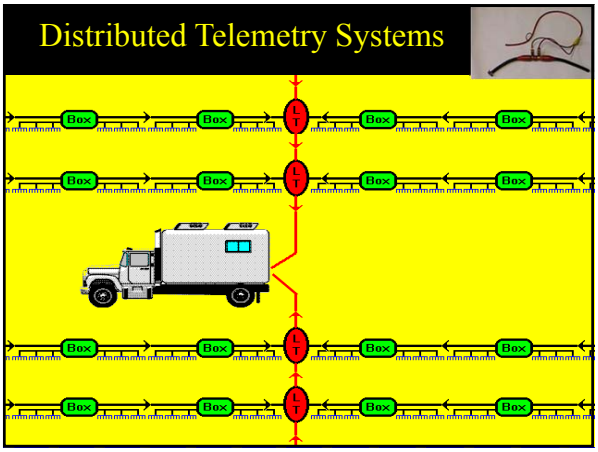
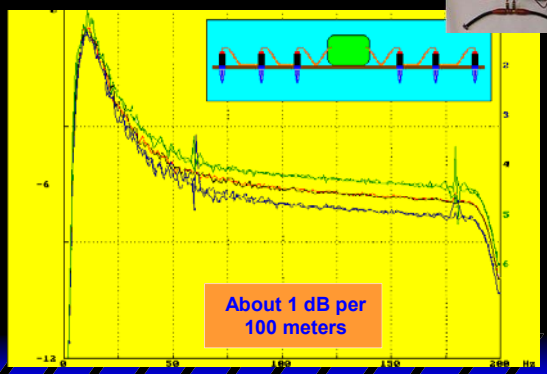
Distributed Telemetry Systems

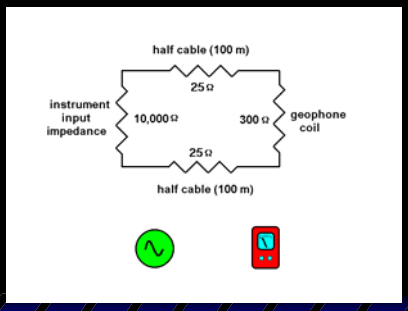


Analogue Cables

Signal Attenuation Due to Cable Losses



Explanation of Cable Losses



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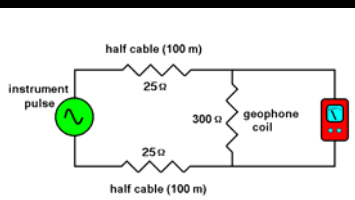
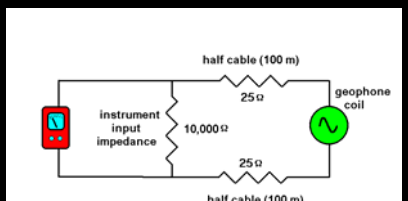


$$\text{Voltage divider} = 20 \log\left(\frac{300}{25 + 300 + 25}\right) = -1.339 \text{ dB}$$

Explanation of Cable Losses

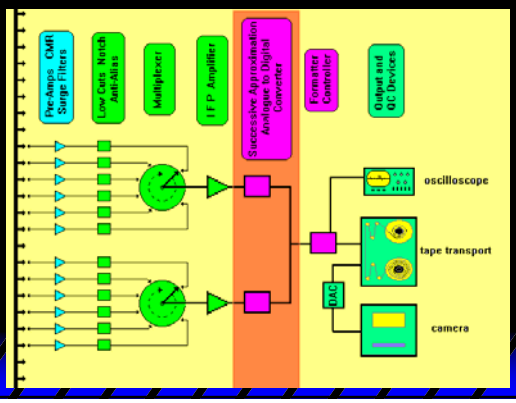


$$\text{Voltage divider} = 20 \log\left(\frac{10{,}000}{25 + 10{,}000 + 25}\right) = -0.043 \text{ dB}$$

Sercel 408UL

Practical implementation of a single channel per “box”

IFP Instruments and Analogue to Digital Converter

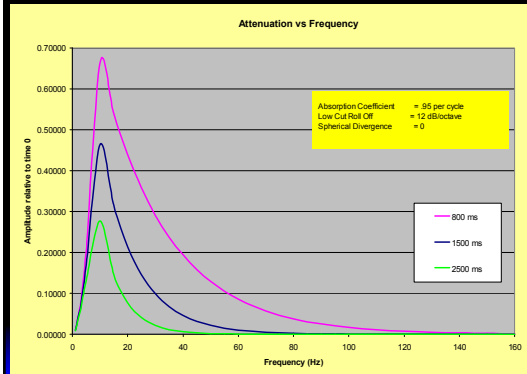


Successive Approximation A-D Converter

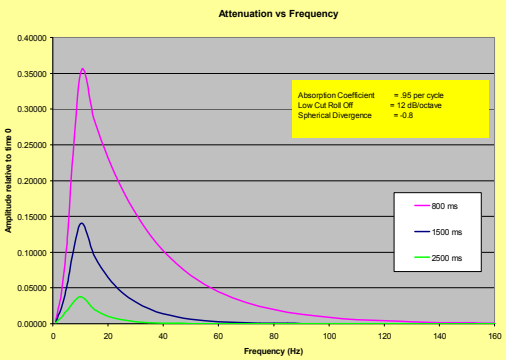
	Sample	Reference	Bit	D-A	
MSB	6.50844	4.0960	1	4.0960	IFP STEPS
	2.41244	2.0480	1	2.0480	
	0.36444	1.0240	0	0.0000	
	0.36444	0.5120	0	0.0000	useful
	0.36444	0.2560	1	0.2560	
	0.10844	0.1280	0	0.0000	
84 dB	0.10844	0.0640	1	0.0640	dynamic 60 dB
	0.04444	0.0320	1	0.0320	
	0.01244	0.0160	0	0.0000	
	0.01244	0.0080	1	0.0080	range
	0.00444	0.0040	1	0.0040	
	0.00044	0.0020	0	0.0000	
	0.00044	0.0010	0	0.0000	Instrument Noise
LSB	0.00044	0.0005	0	0.0000	
	0.00044				

Input Voltage	6.50844
D-A value	6.50800
Quantization Error	0.00044

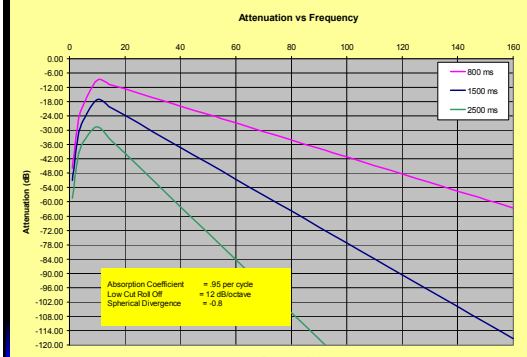
Absorption Only



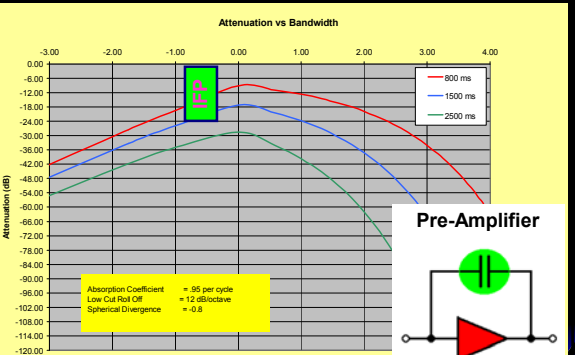
Absorption and Spherical Divergence



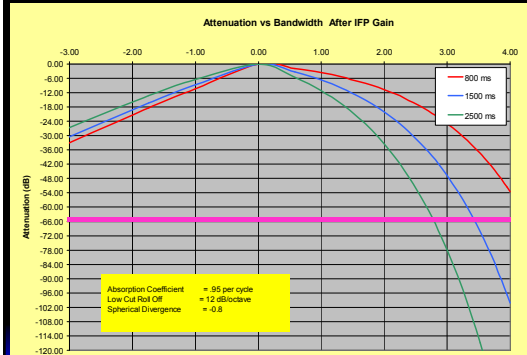
Absorption and Spherical Divergence



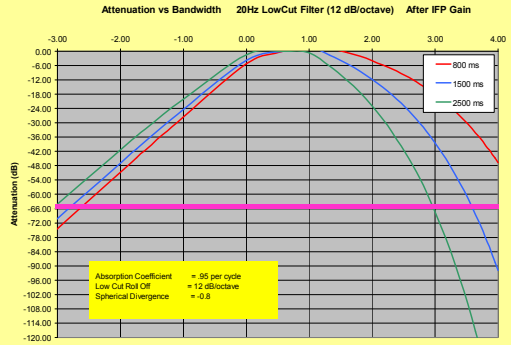
Absorption and Spherical Divergence



Absorption and Spherical Divergence

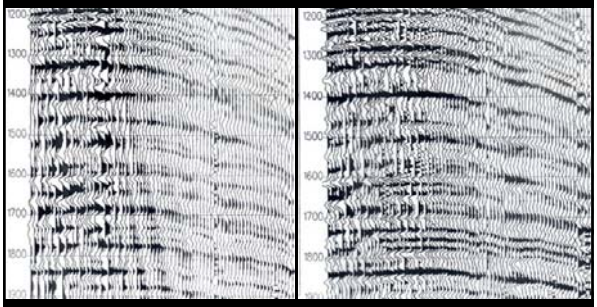


Absorption and Spherical Divergence



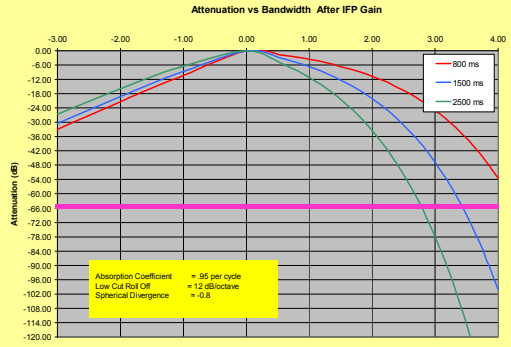
Conditioning of Data with Instrument Filters

Filters Out **18 Hz 18 db/oct Low Cut**

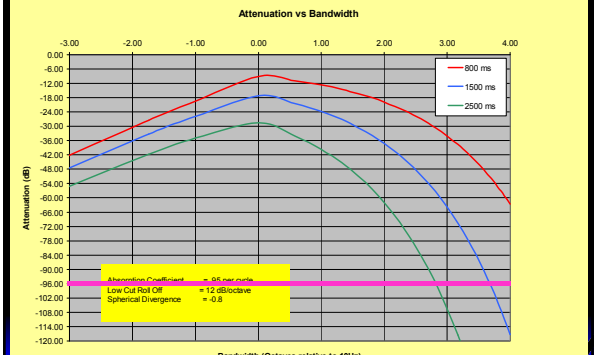


Gain and Trace Spiking Deconvolution Applied

Absorption and Spherical Divergence



Absorption and Spherical Divergence



0.40 can be the average of 10 binary bits

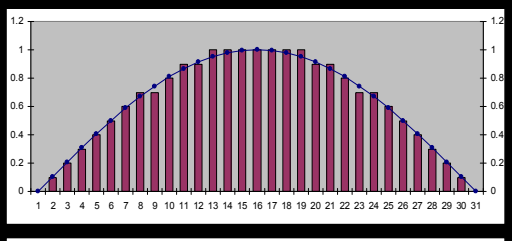
0 1 0 1 0

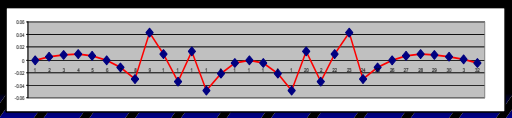
1 0 0 0 1

0.43 requires more precision and must be estimated by the average of 100 binary bits

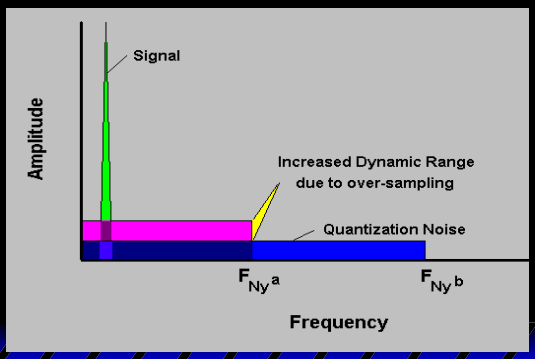
0 1 0 1 0 0 1 0 0 1 0 1 1 0 1 0 0 1 0 1
1 0 0 1 0 0 1 0 1 0 0 1 0 1 0 0 1 0 0 1
1 0 0 1 0 1 0 1 0 1 1 0 0 1 1 0 0 1 0 1
0 1 0 0 0 0 1 0 0 1 0 1 0 0 1 0 0 1 0 1
1 0 0 1 0 1 0 0 0 1 1 0 1 0 1 0 0 1 0 1

Quantization Noise

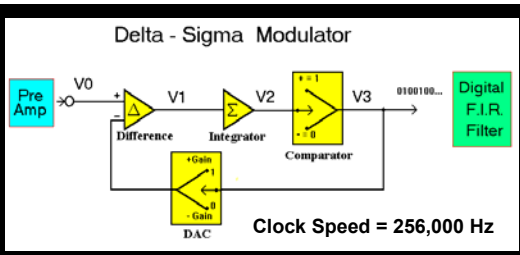




Quantization Noise and OverSampling



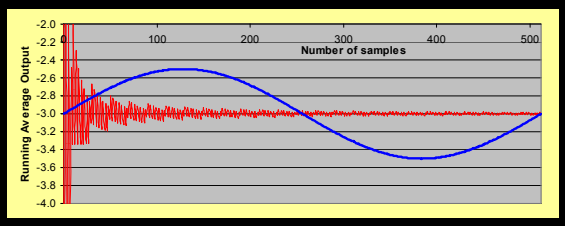
Delta - Sigma Modulator



Clock Speed = 256,000 Hz

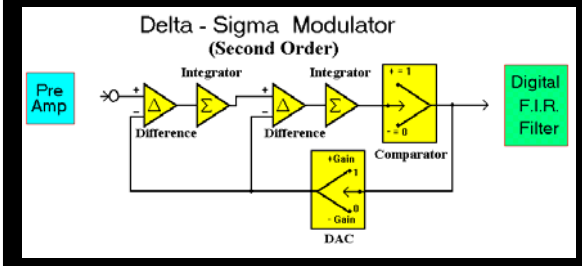
Cycle Number	Input Voltage	Difference Voltage	Integrated Voltage	1-Bit A/D	Running Average
0	0.00000	0.00000	0.00000	0	0.00000
1	-3.00000	-3.00000	-3.00000	-10	-10.00000
2	-3.00000	7.00000	4.00000	10	0.00000
3	-3.00000	-13.00000	-9.00000	-10	-3.33333
4	-3.00000	7.00000	-2.00000	-10	-5.00000
5	-3.00000	7.00000	5.00000	10	-2.00000
6	-3.00000	-13.00000	-8.00000	-10	-3.33333
7	-3.00000	7.00000	-1.00000	-10	-4.28571

The Averaged Output for 512 clock cycles

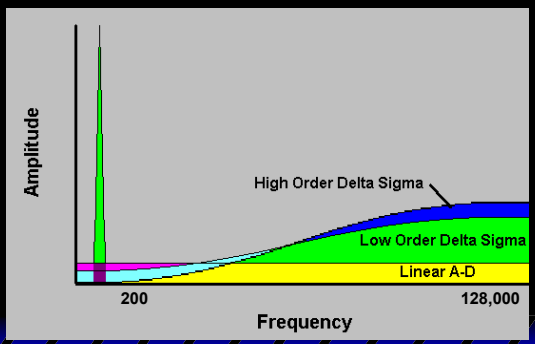


Quantization Noise is about 128 KHz

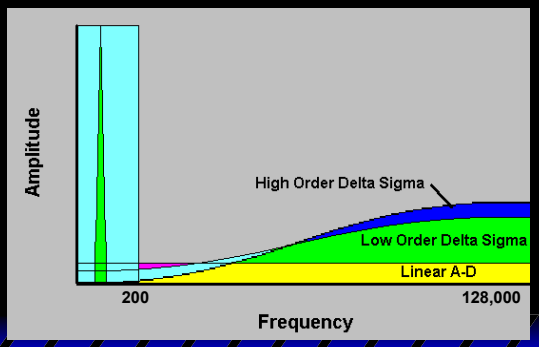
A Second Order Modulator



Noise Shaping

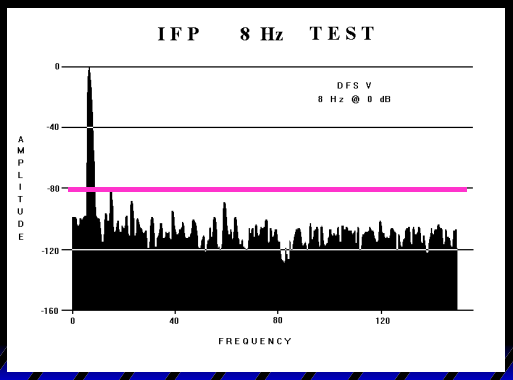


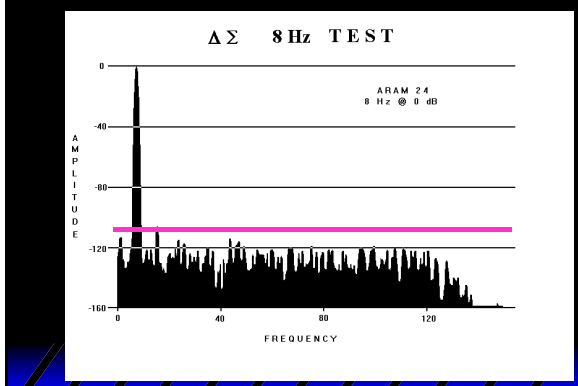
Noise Shaping and Filtering

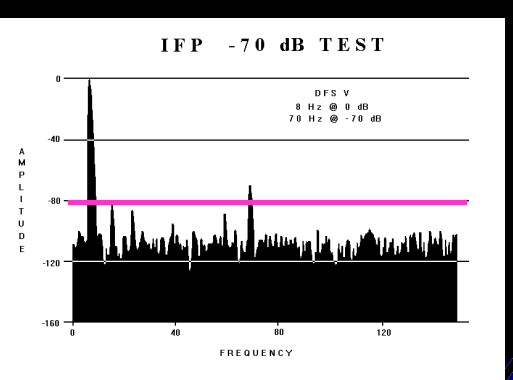


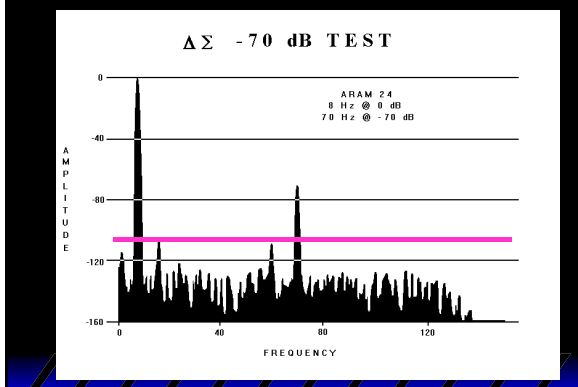
Delta Sigma High Cut Filter

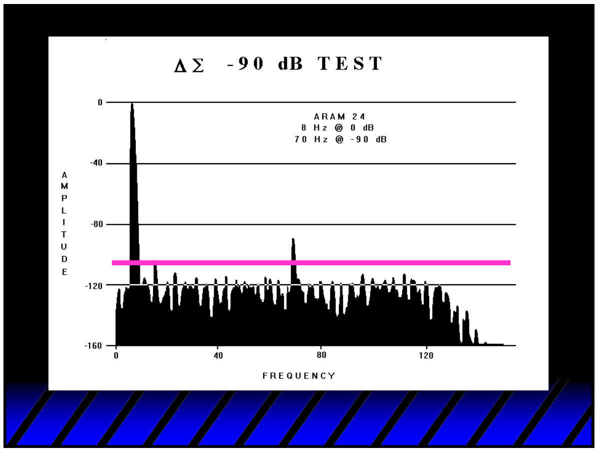
- Digitial "Brick Wall" filter
- Usually two choices per sample rate near ½ and ¾ output Nyquist
- Should only be high enough to pass expected signal
- Higher filters (or finer sample rates) allow more high frequency noise to occupy the dynamic range

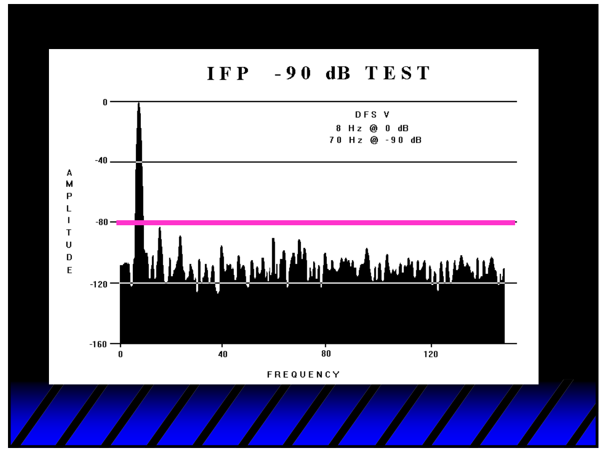


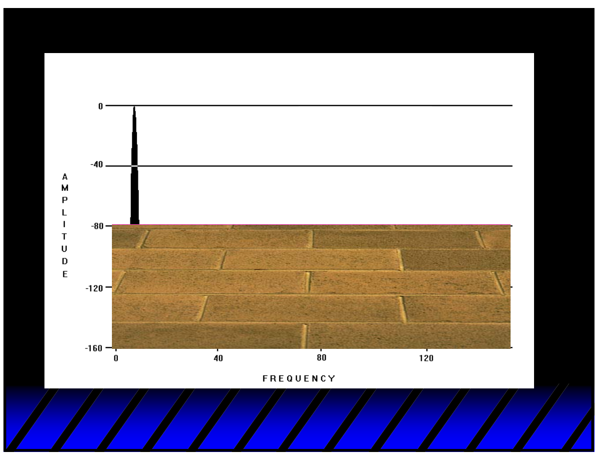


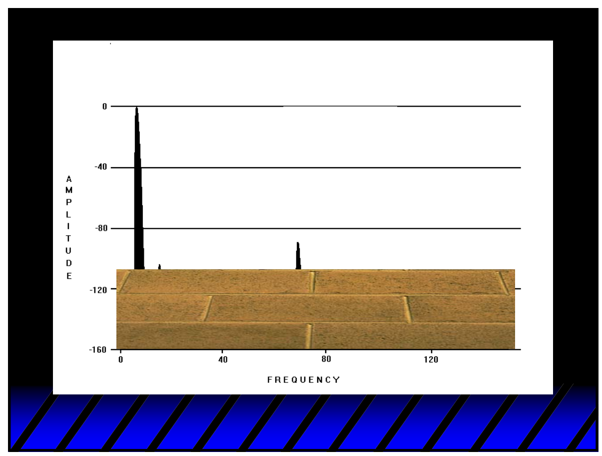


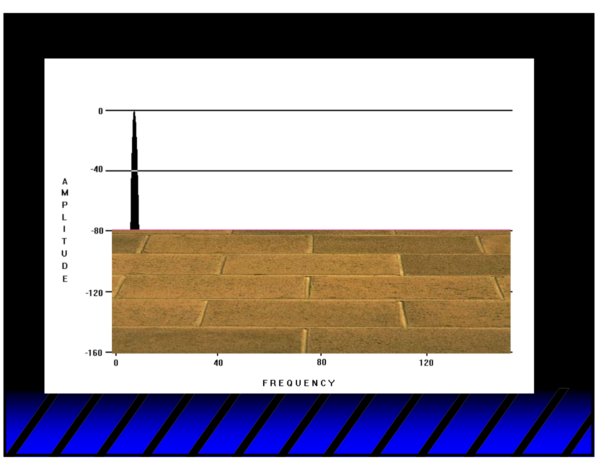


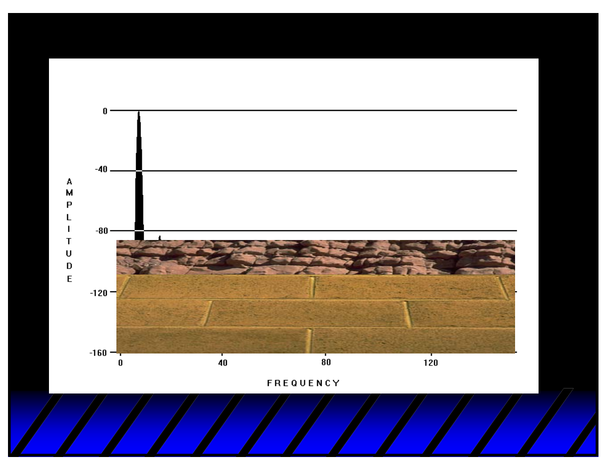

ΔΣ -90 dB TEST
ARAM 24
8 Hz @ 0 dB
70 Hz @ -90 dB
AMPLITUDE
0
-40
-80
-120
-160
0
40
80
120
FREQUENCY


IFP -90 dB TEST
DFS V
8 Hz @ 0 dB
70 Hz @ -90 dB
AMPLITUDE
0
-40
-80
-120
-160
0
40
80
120
FREQUENCY


AMPLITUDE
0
-40
-80
-120
-160
0
40
80
120
FREQUENCY


AMPLITUDE
0
-40
-80
-120
-160
0
40
80
120
FREQUENCY

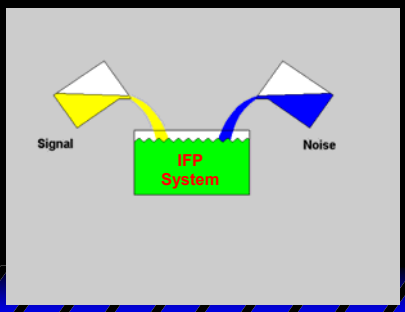

AMPLITUDE
0
-40
-80
-120
-160
0
40
80
120
FREQUENCY


AMPLITUDE
0
-40
-80
-120
-160
0
40
80
120
FREQUENCY

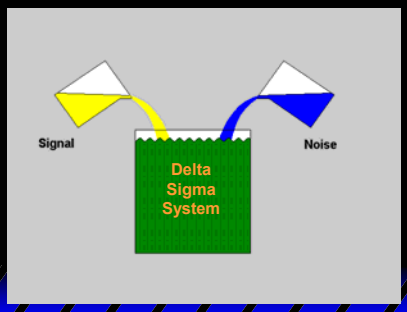
Delta Sigma Practical Advantages

- Greatly enhanced channel capacity
- Reduced electronics per channel
- Reduced weight per channel
- Lower power consumption
- Reduced cost per channel
- Better crossfeed isolation
- Less harmonic distortion

Delta Sigma and Dynamic Range



Delta Sigma and Dynamic Range



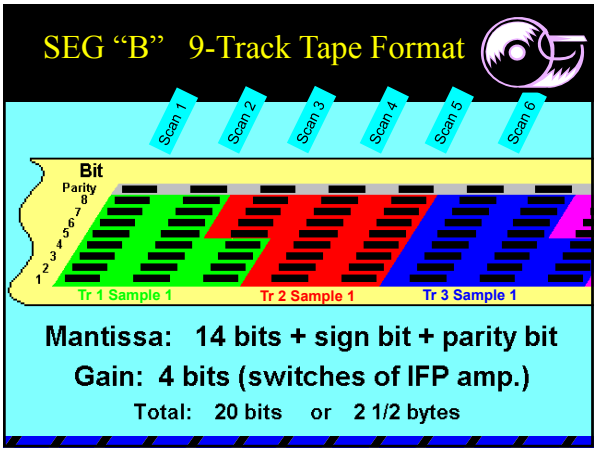
Digital Data Transmission

- About 600 m between repeaters
  - Weak cables limit bit load
- Small sample intervals increase bit load
  - Failures result in "Drop Outs"
- Network based system desirable to re-route data around bad cables

Unnecessary 1 ms Sampling

- Reduces ΔΣ oversampling and reduces Dynamic Range
- Increases FIR high cut filters and allows more high frequency noise
- Generates more bit load and results in more crew down time due to cable failures → increased cost

SEG "B" 9-Track Tape Format

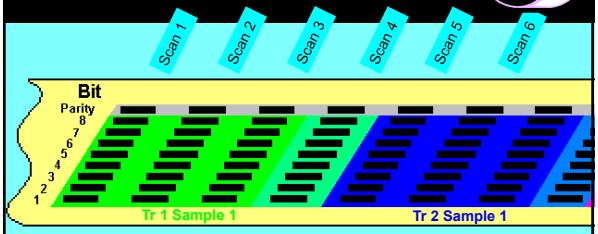


Mantissa: 14 bits + sign bit + parity bit

Gain: 4 bits (switches of IFP amp.)

Total: 20 bits or 2 1/2 bytes

SEG "D" 9-Track Tape Format



Mantissa: 23 bits + sign bit + hidden bit

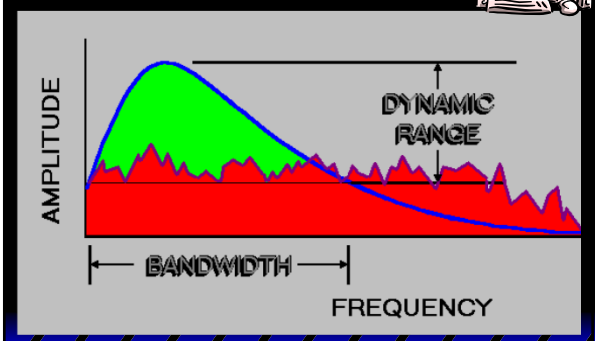
Gain: 8 bits 2's compliment

total 32 bits, 4 bytes

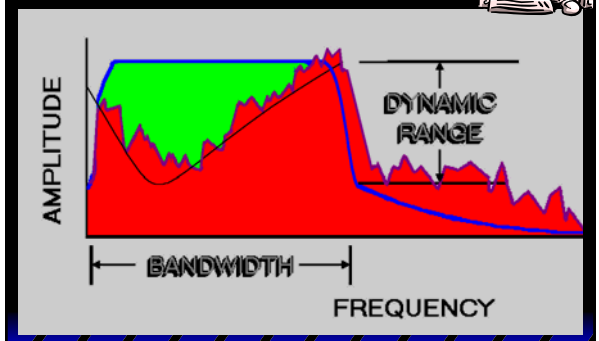
IEEE floating point format

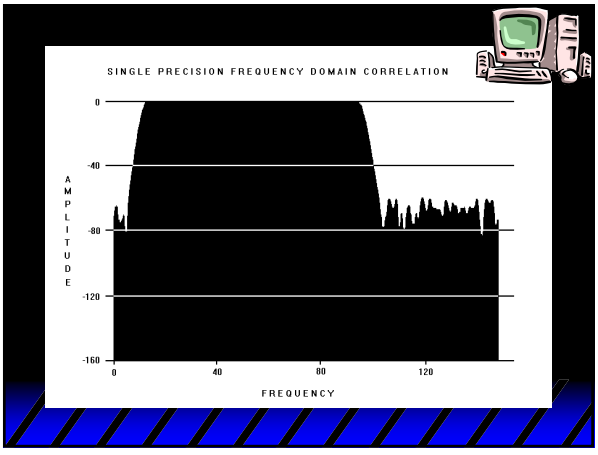
- Express normal binary number
- Bit shift until first bit of mantissa is 1
- Bit shift accumulates to exponent
- All mantissas now start with 1
- No need to record first bit and can use extra bit for 24 bit precision (sign bit + 23 mantissa + "hidden bit")

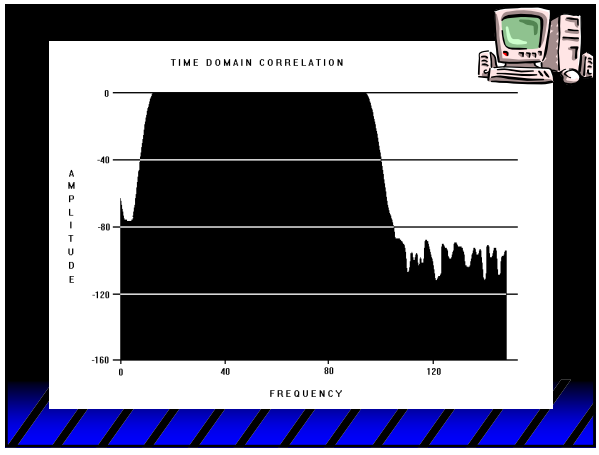
Spectral Model of Signal with Noise



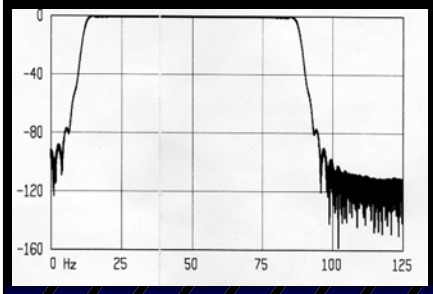
Signal and Noise after Decon





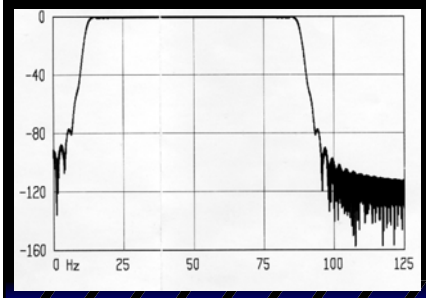


Time Domain Correlation Single Precision



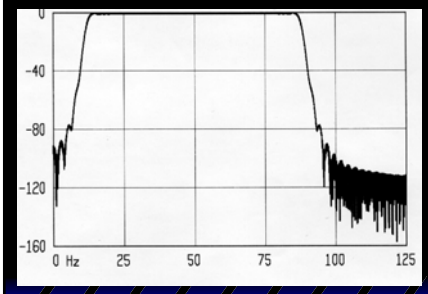
Sweep:
10-90 Hz
10 seconds
0.400 start taper
0.400 end taper
2 ms sample int.

Time Domain Correlation Double Precision Accumulation



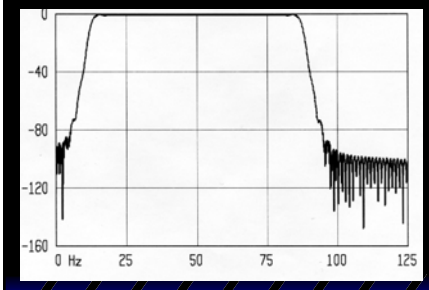
Sweep:
10-90 Hz
10 seconds
0.400 start taper
0.400 end taper
2 ms sample int.

Frequency Domain Correlation Single Precision



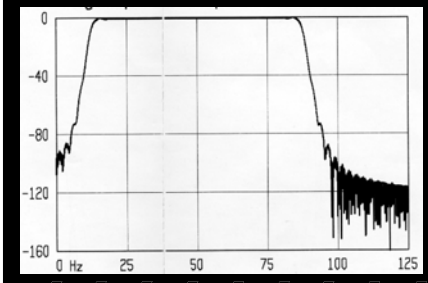
Sweep:
10-90 Hz
10 seconds
0.400 start taper
0.400 end taper
2 ms sample int.

Frequency Domain Correlation Padded to 8192 for FFT



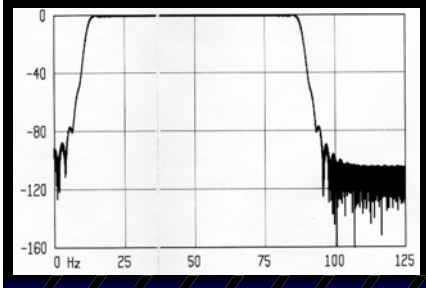
Sweep:
10-90 Hz
8 seconds
0.320 start taper?
0.320 end taper?
2 ms sample int.

Frequency Domain Correlation Padded to 16384 for FFT



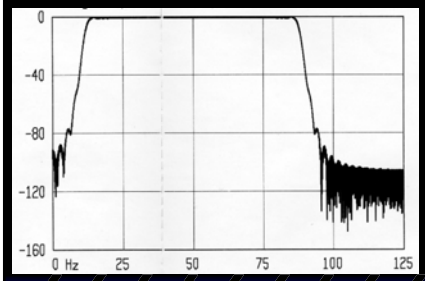
Sweep:
10-90 Hz
8 seconds
0.320 start taper?
0.320 end taper?
2 ms sample int.

Time Domain Correlation Single Precision



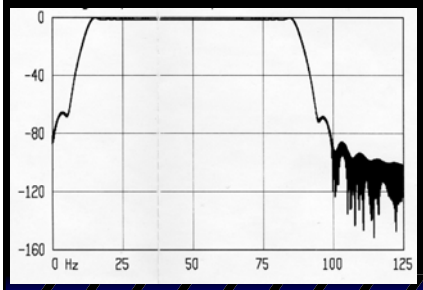
Sweep:
10-90 Hz
10 seconds
0.400 start taper
0.400 end taper
4 ms sample int.

Frequency Domain Correlation Single Precision



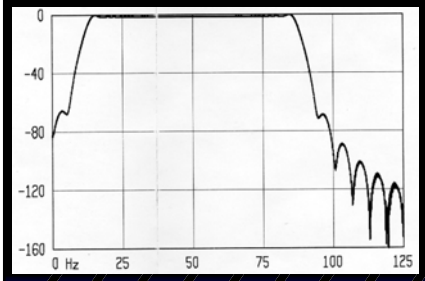
Sweep:
10-90 Hz
10 seconds
0.400 start taper
0.400 end taper
4 ms sample int.

Time Domain Correlation Single Precision



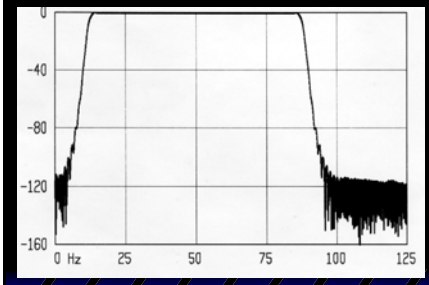
Sweep:
10-90 Hz
4 seconds
0.160 start taper
0.160 end taper
2 ms sample int.

Frequency Domain Correlation Single Precision



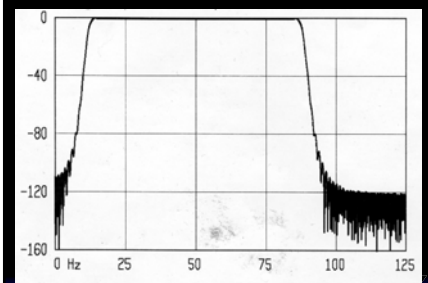
Sweep:
10-90 Hz
4 seconds
0.160 start taper
0.160 end taper
2 ms sample int.

Time Domain Correlation Single Precision



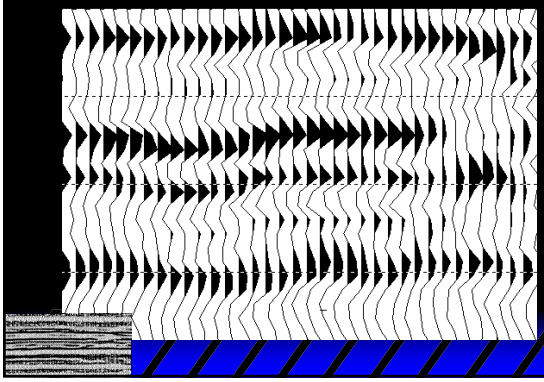
Sweep:
10-90 Hz
20 seconds
0.800 start taper
0.800 end taper
2 ms sample int.

Frequency Domain Correlation Single Precision

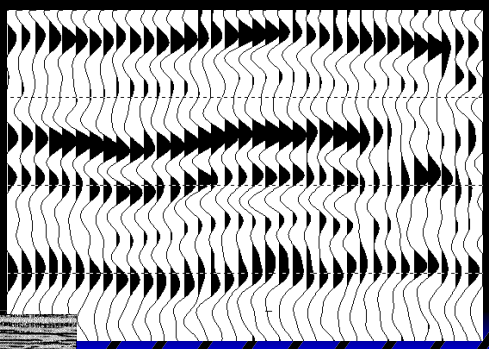


Sweep:
10-90 Hz
20 seconds
0.800 start taper
0.800 end taper
2 ms sample int.

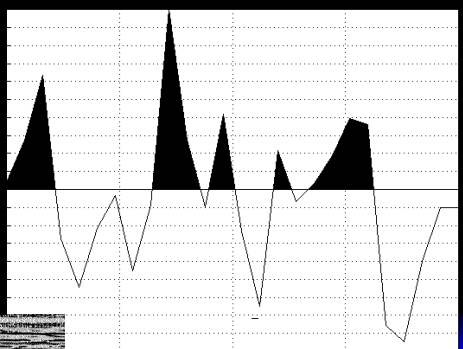
Cretaceous Channel at 4 ms



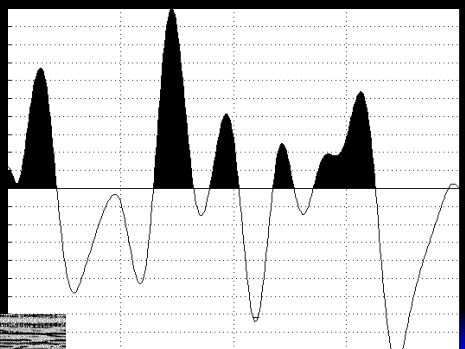
Cretaceous Channel at 1/4 ms



Cretaceous Channel at 4 ms



Cretaceous Channel at 1/4 ms



Plotting Filters

Why to 90 % of final stacked plots reflect a bandpass filter that starts

10 - 15 -? - ?

Can we work harder to stabilize phase and S/N in lower frequencies?

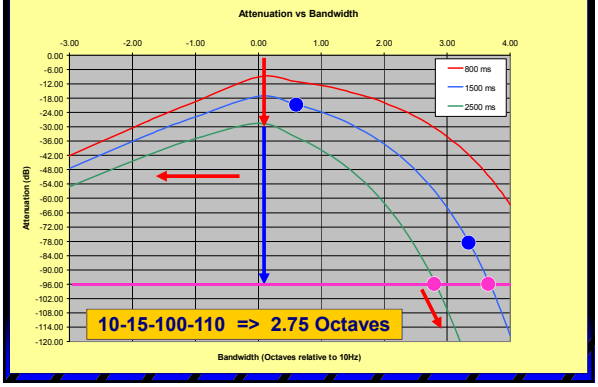
Raster Filters

Many raster plotting programs still retain a 125 Hz high cut filter from the days of 2 ms recording with IFP instruments

A Few Causes of Poor Data

- Bad Geological Model, Statistical distributions, sampling
- Poor Skidding, Offsetting
- Distortion, Trapped Mode
- Distortion, Spurious
- Induction, Back EMF,Crossfeed
- Distortion
- Quantization Noise, Distortion
- Bit drop out, lost channels
- Stiction
- FFT padding, wrap around, round off
- Digital vs Rastered
- Feasible interpretation
- Geological ties, recognizing artifacts (geometric imprinting, migration, multiple)

Where Must We Go ??



I am grateful for the input of:

Geo-X Systems Ltd.

Input-Output

Kelman Seismic Processing

Mitcham Canada (Sercel)

Oyo Geospace

MUSTAGH RESOURCES LTD.

If you desire more information or would like a copy of this tutorial, please contact Norm Cooper or Yajaira Herrera

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