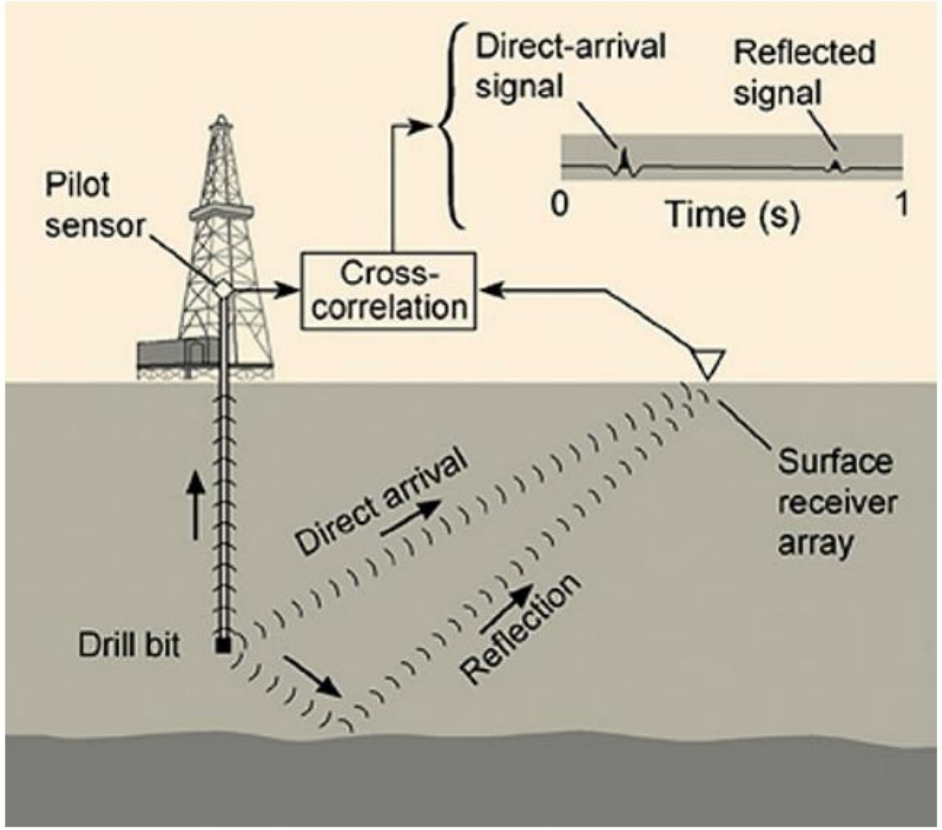
Physical Modeling of Seismic Illumination and Seismic While Drilling (SWD)

Hongliang Zhang, Joe Wong, Nasser Kazemi,*
*Kevin Bertram, Kris Innanen, Roman Shor**

** Department of Chemical and Petroleum Engineering*

Surface-only sources and receivers do not effectively illuminate sub-vertical interfaces

- ***Increase*** … ***surface sources*** …
- ***Use the*** … ***a sub-surface*** …

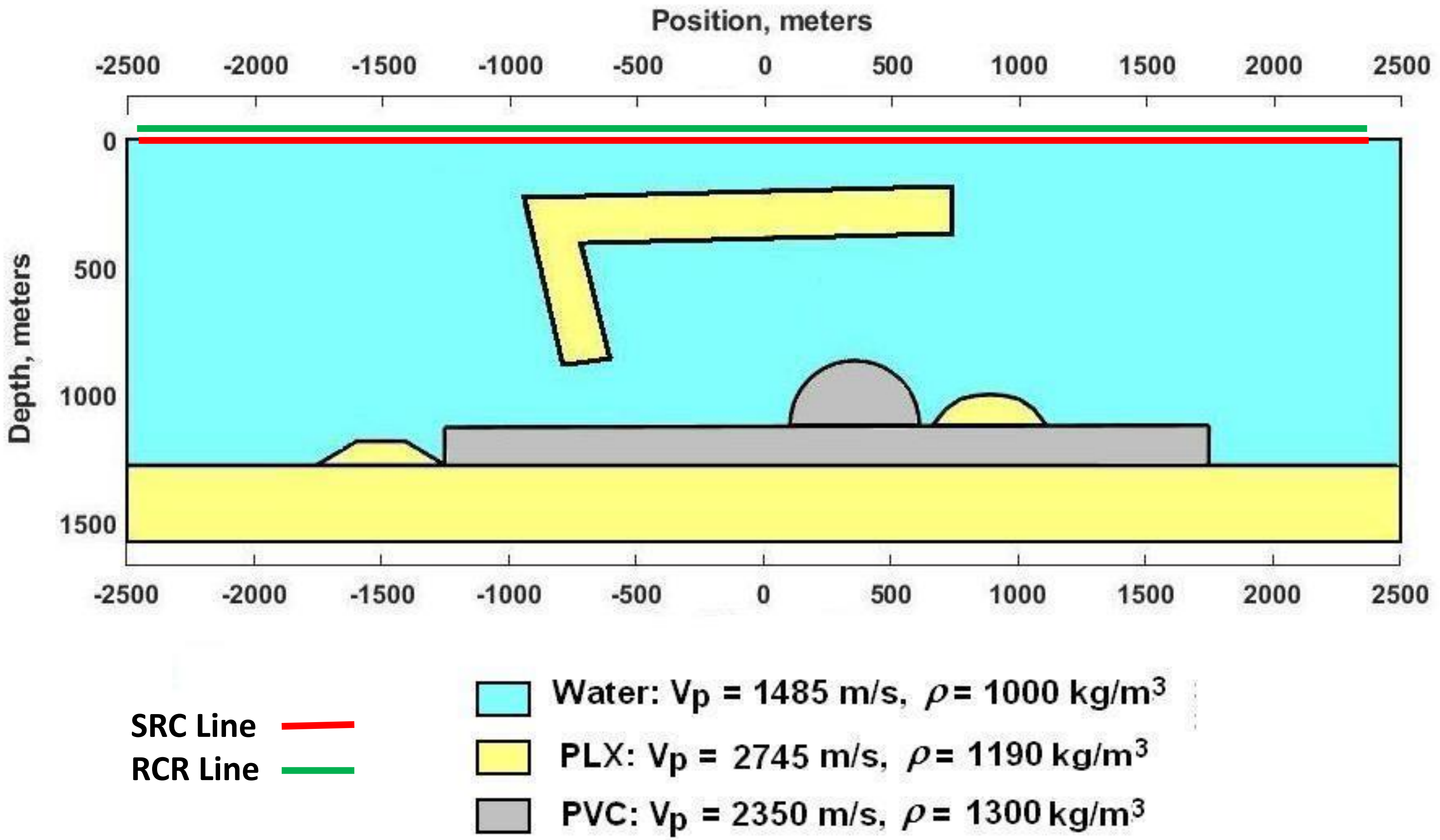


(Hardage, 2009)

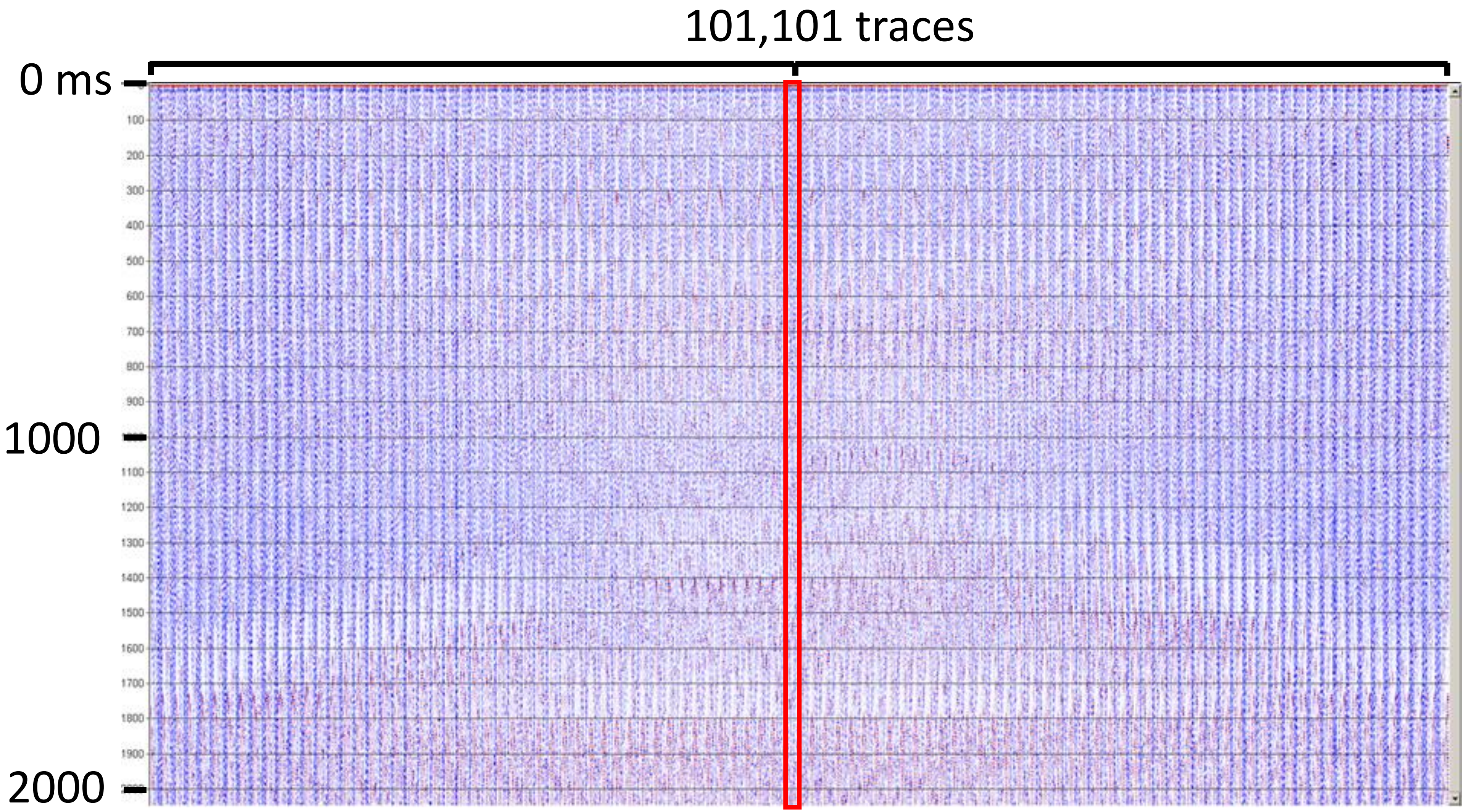
Part 1

Physical Modeling of Seismic Illumination.

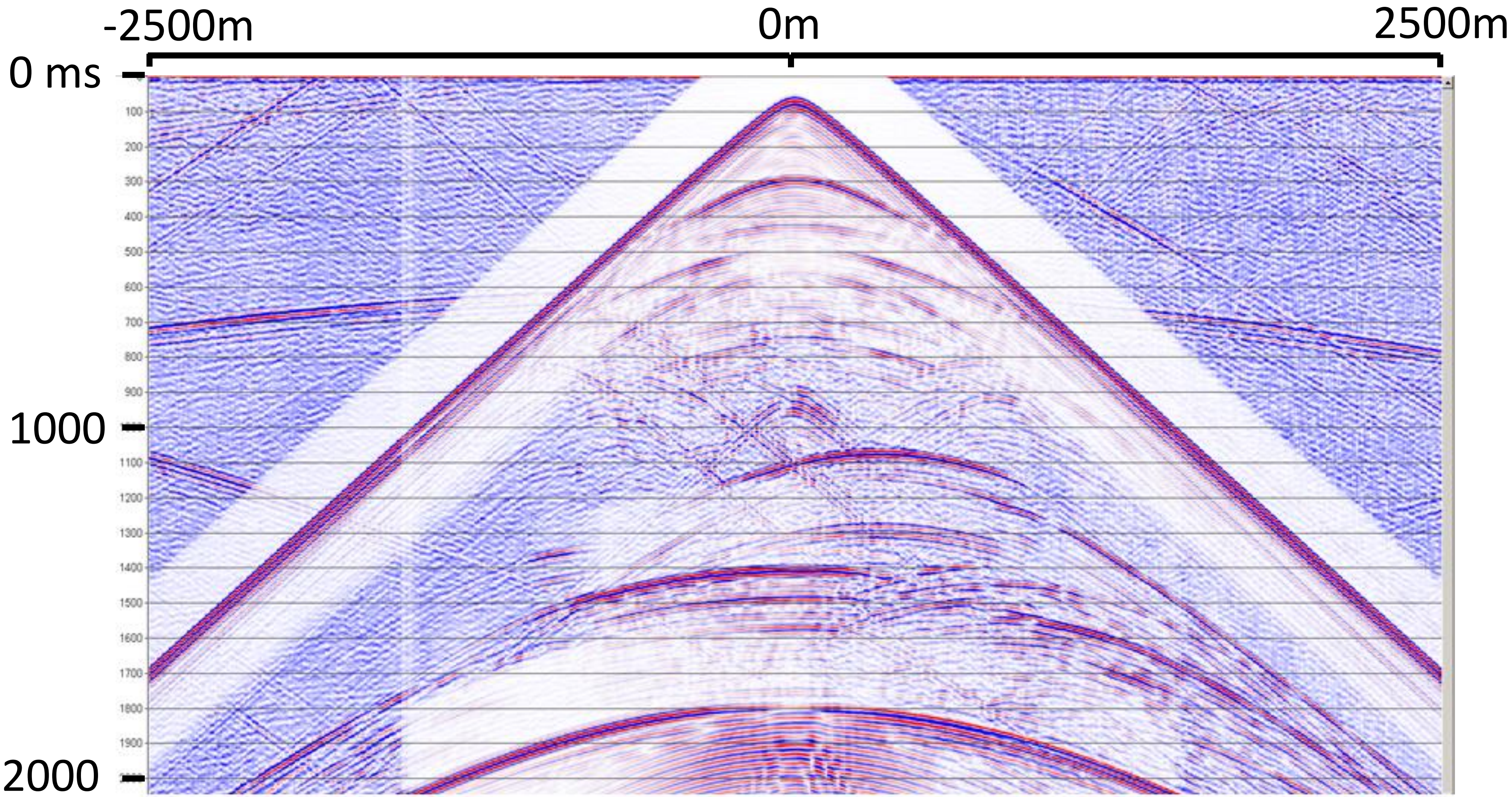
Model Setup



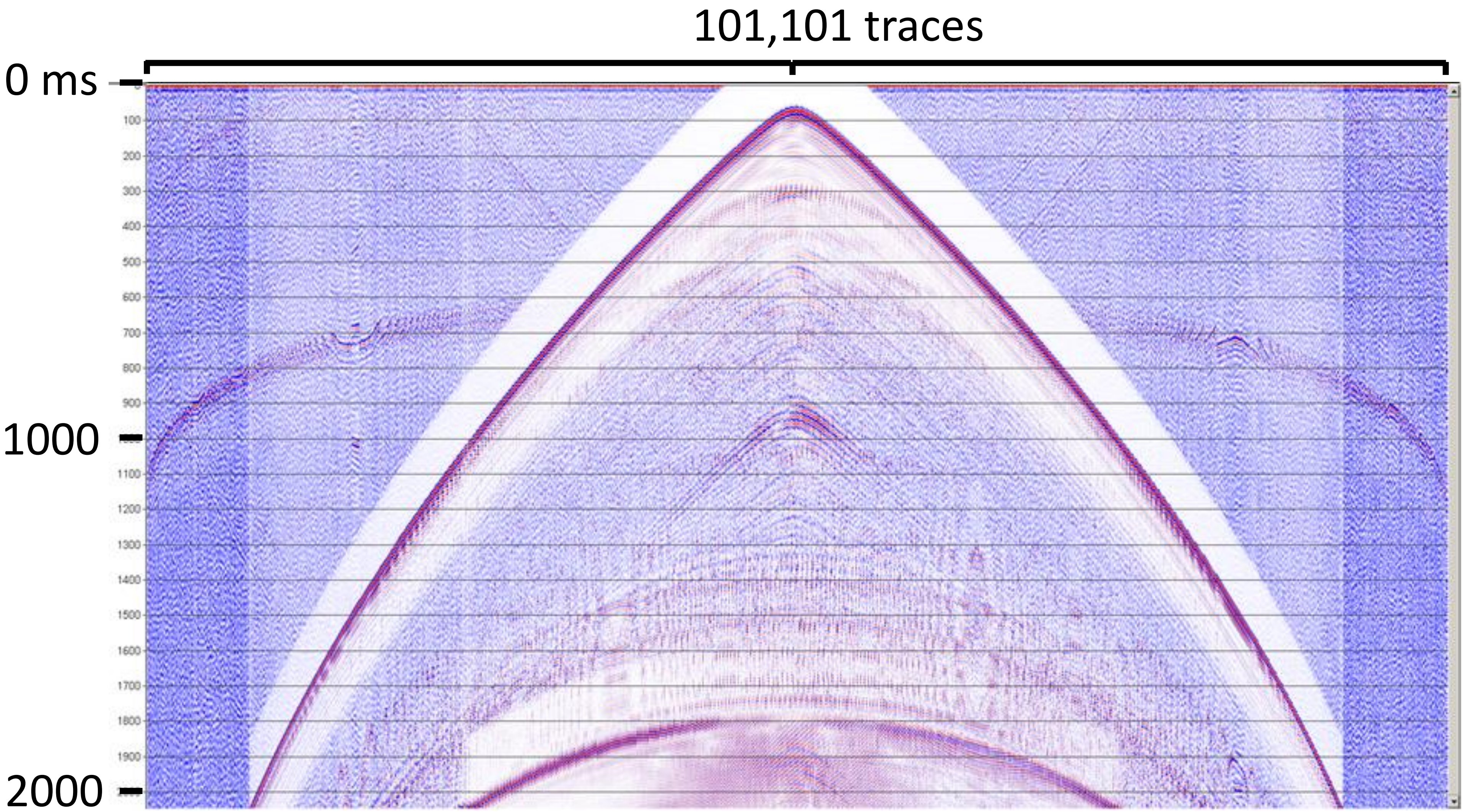
Position, meters
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500
Depth, meters
0
500
1000
1500
SRC Line
RCR Line
Water: Vp = 1485 m/s, ρ= 1000 kg/m3
PLX: Vp = 2745 m/s, ρ= 1190 kg/m3
PVC: Vp = 2350 m/s, ρ= 1300 kg/m3


101,101 traces
0 ms
1000
2000
100
200
300
400
500
600
700
800
900
1100
1200
1300
1400
1500
1600
1700
1800
1900

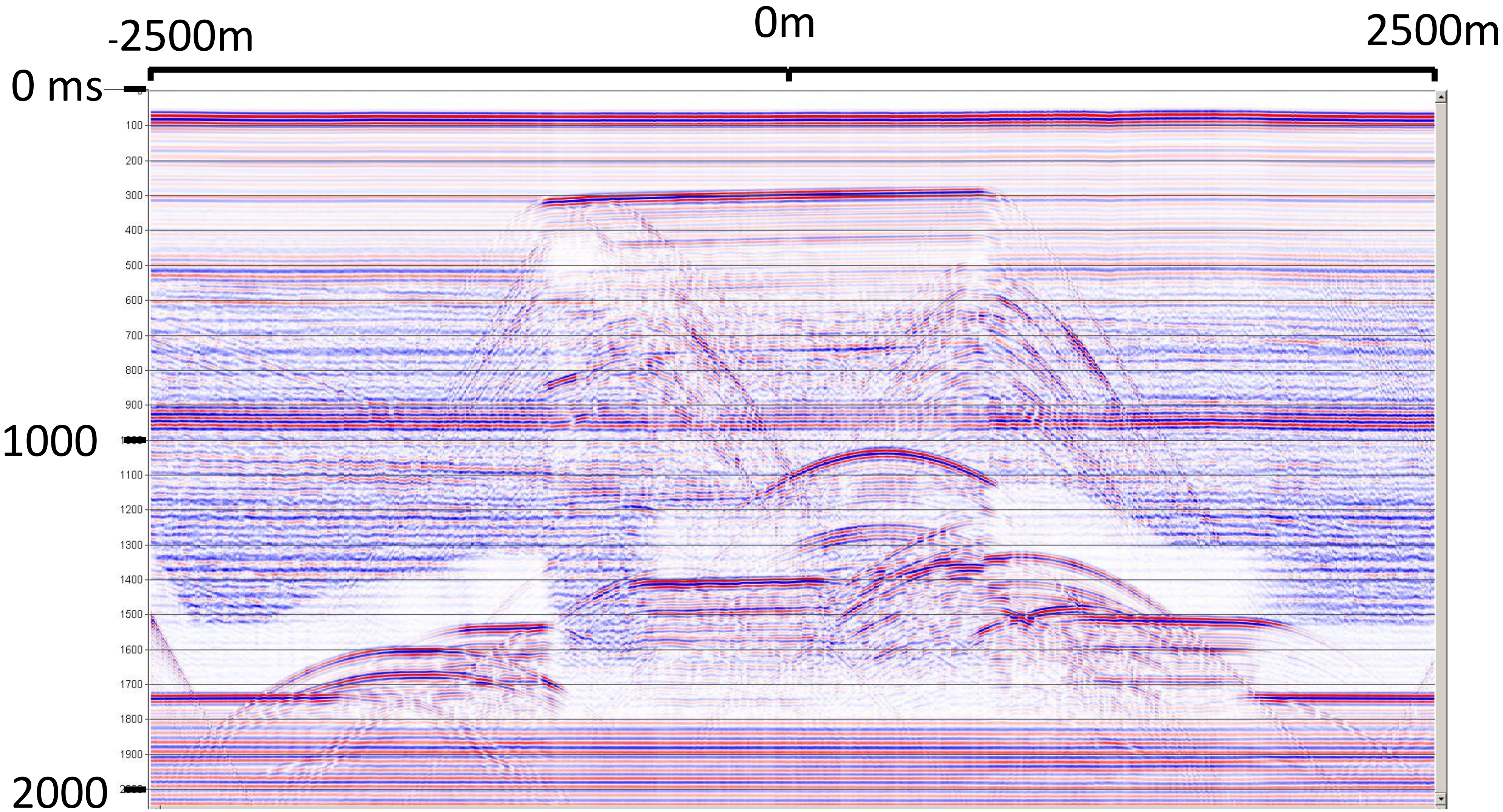
Common-Source Gather

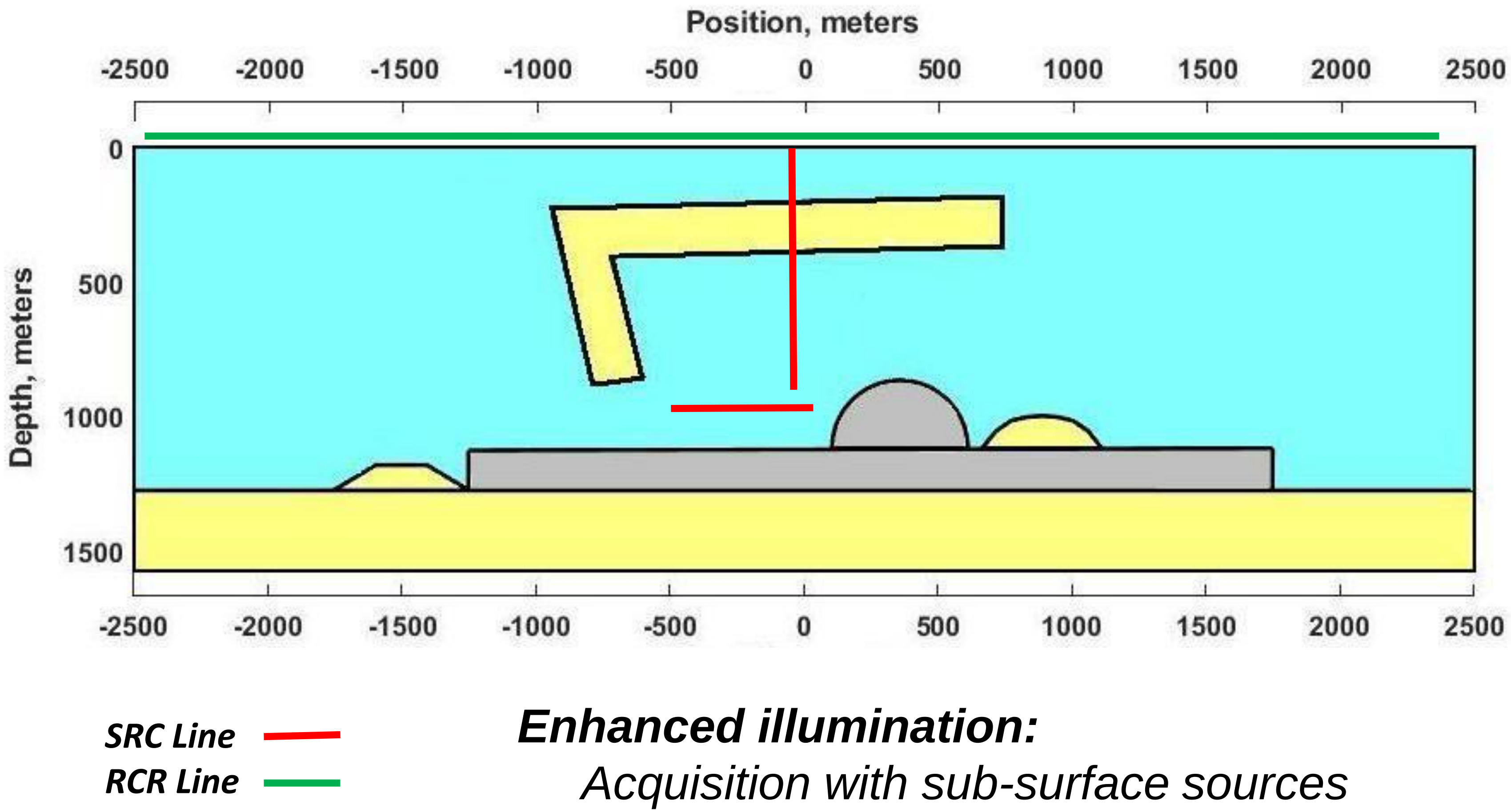


Common-Offset Gathers



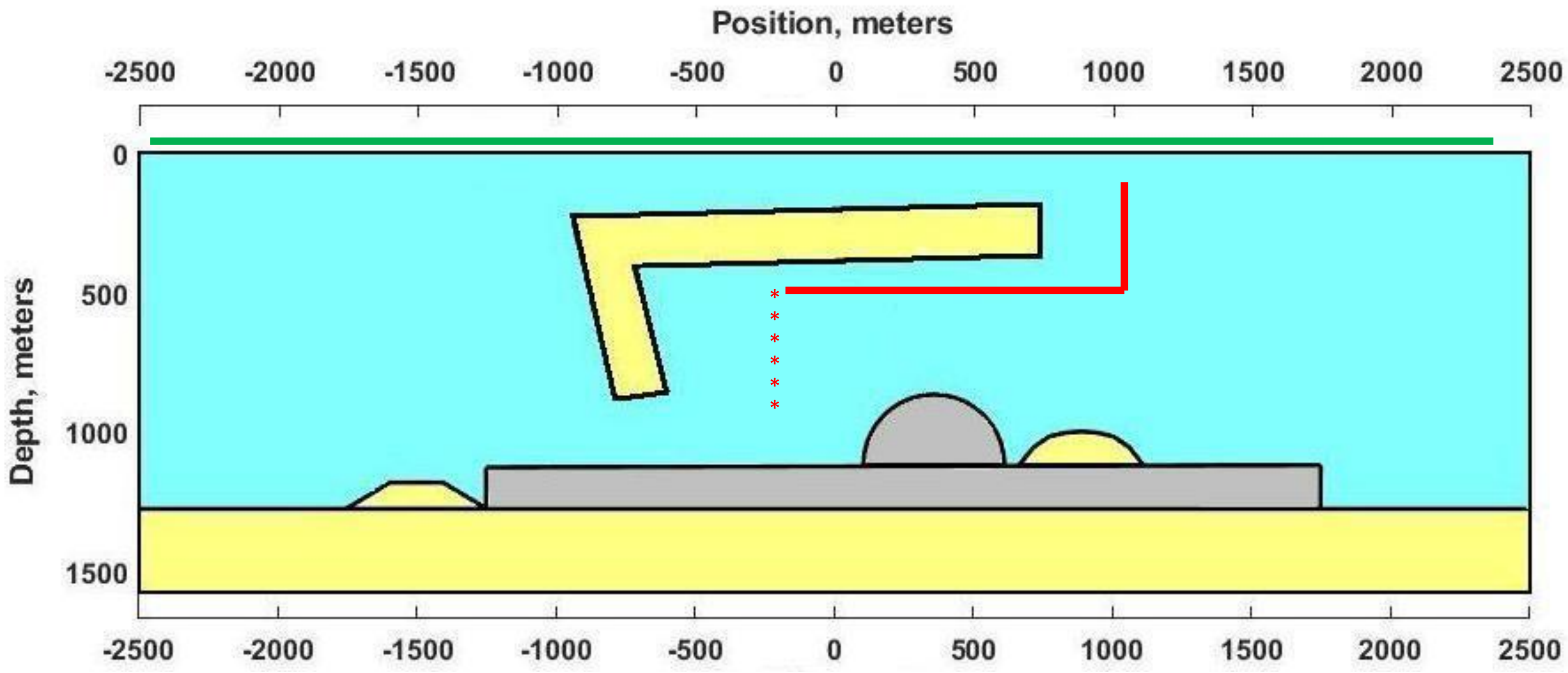
Vertically Incident Data





Enhanced illumination:

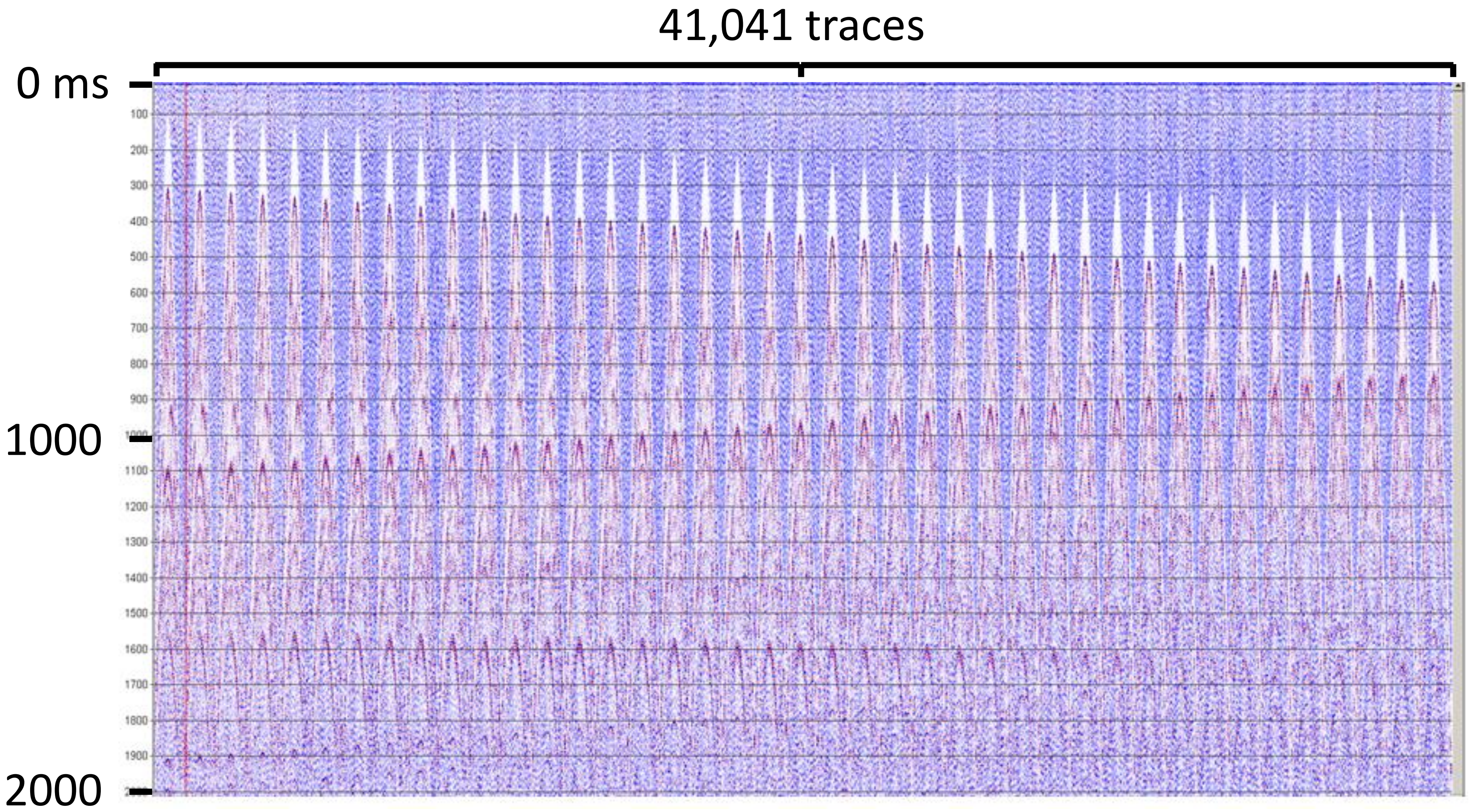
Acquisition with sub-surface sources and surface receivers.



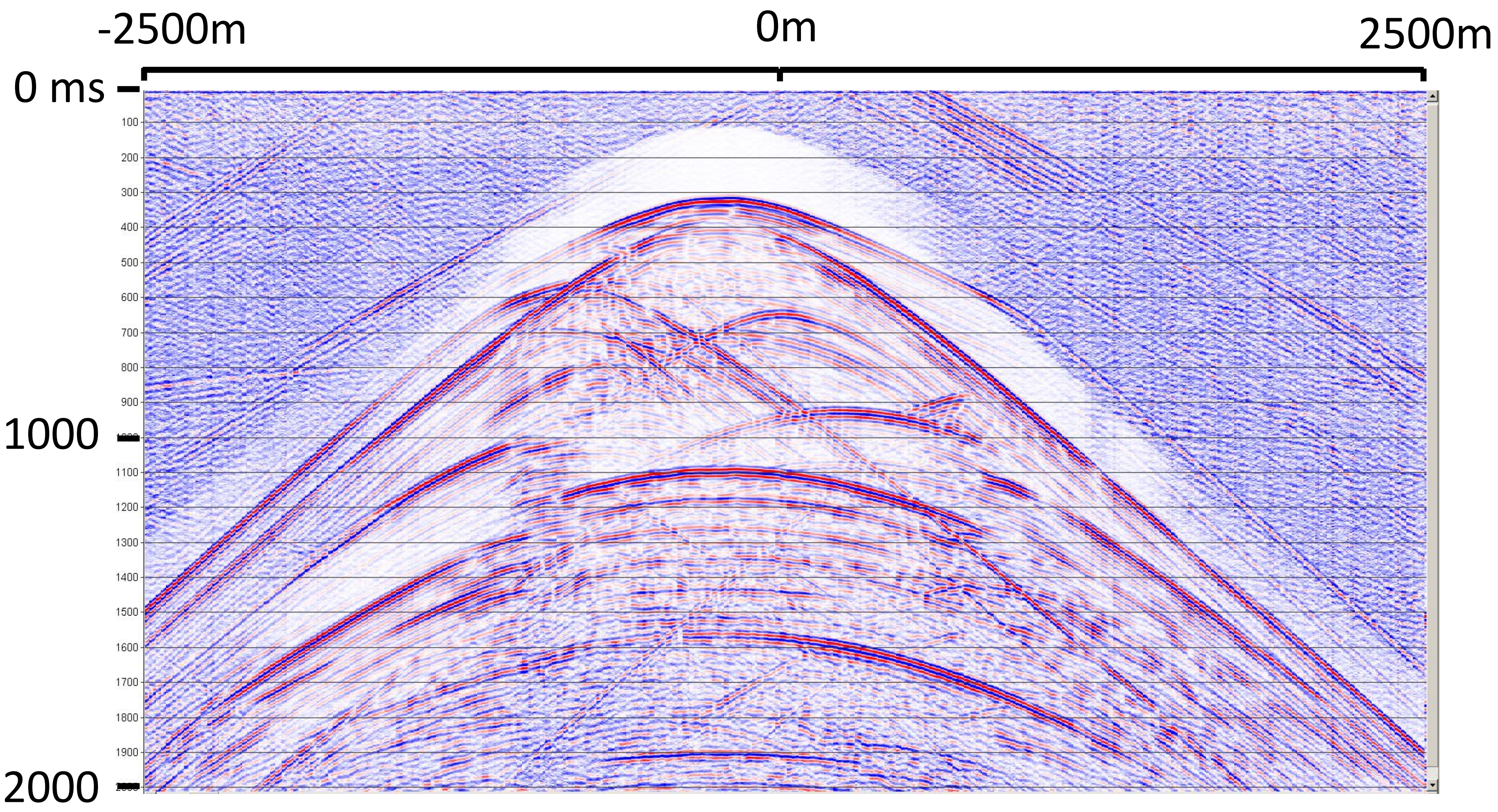
RCR Line

Enhanced illumination:

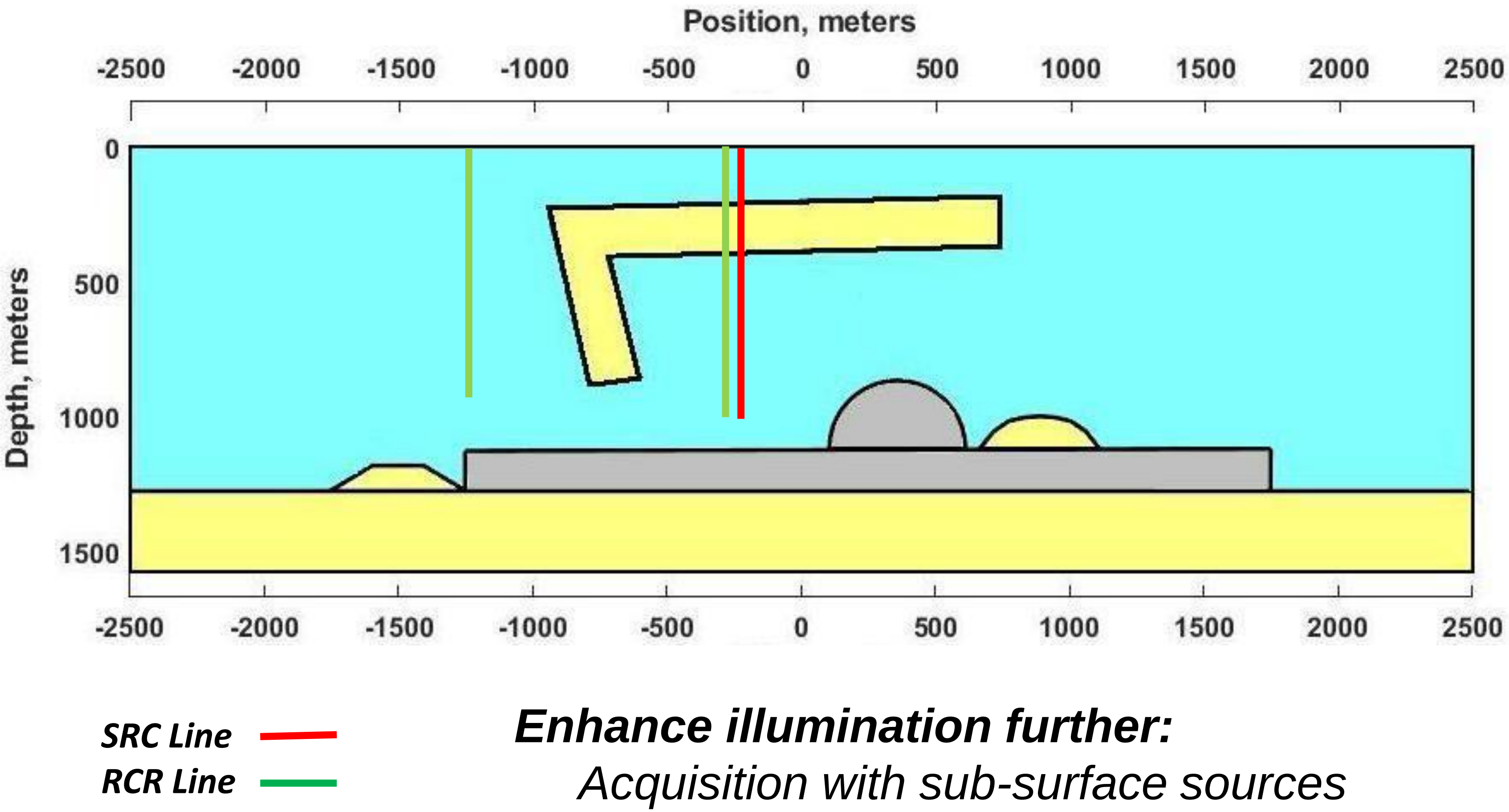
Acquisition with sub-surface sources and surface receivers.



41,041 traces
0 ms
1000
2000



-2500m
0m
2500m
0 ms
1000
2000



Enhance illumination further:

Acquisition with sub-surface sources and sub-surface receivers.

ANALYSIS

Imaging the velocity structure.

Processing challenges:

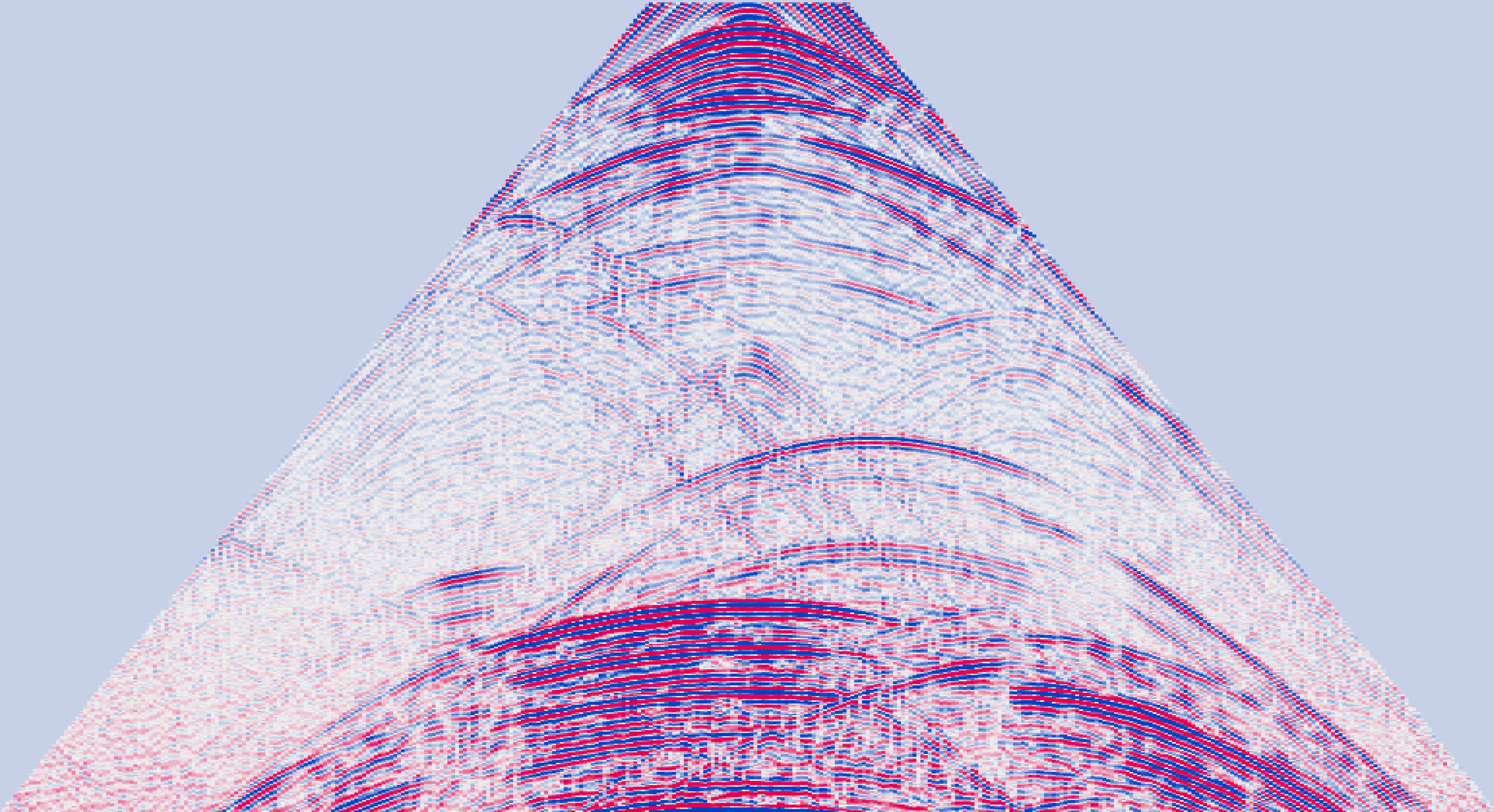
- ***Systematic noise.***
- ***Non-stationary waveforms.***
- ***PSP converted arrivals.***
- ***Internal multiples.***

ANALYSIS

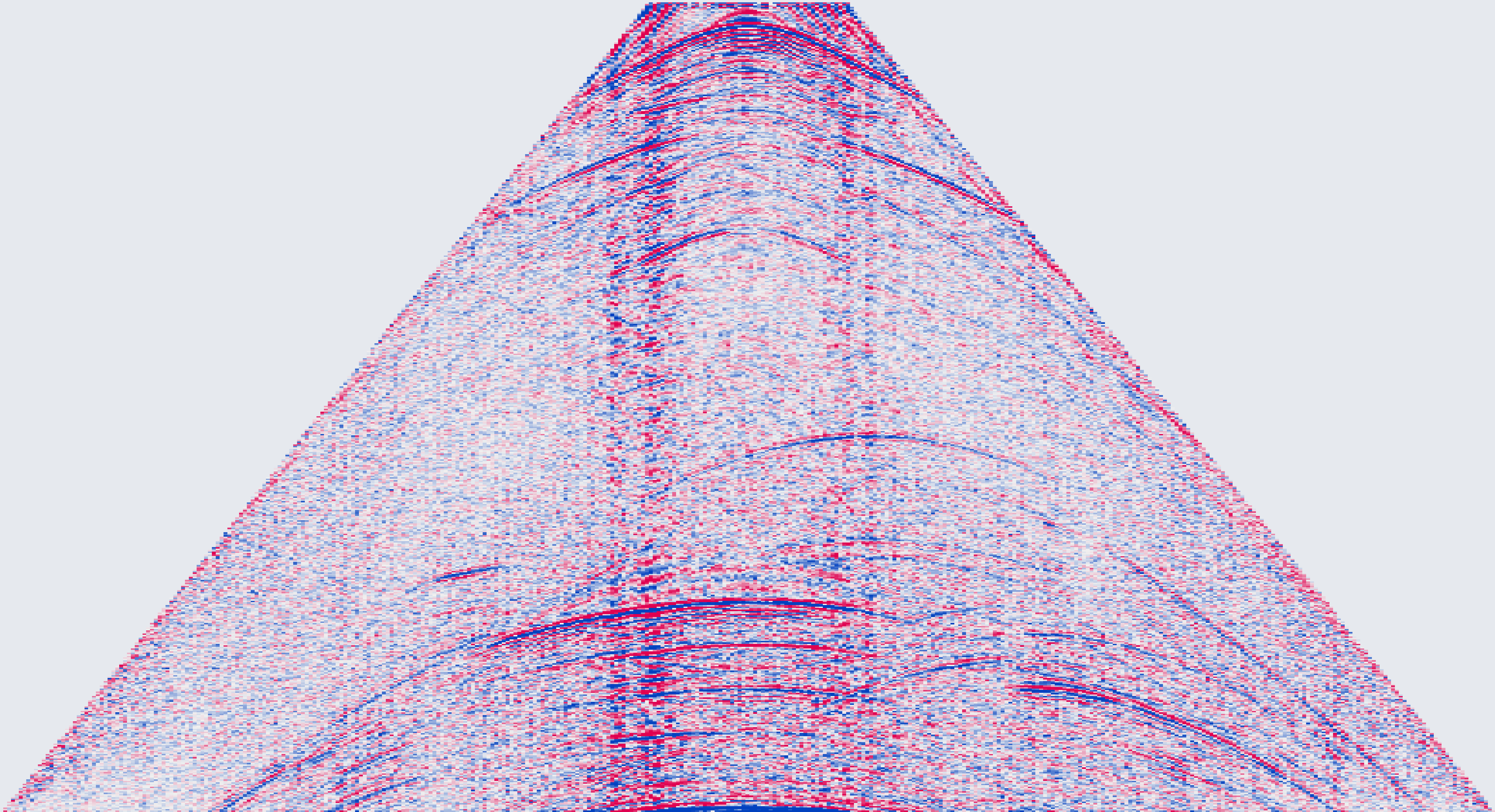
Conditioning data for imaging

- *First arrival removal*
- *Compensating for attenuation*
- *Suppression of water column reverberations and internal multiples*

Shot gather: AGC + first arrival mute



Shot gather: AGC+ first arrival mute + multiple suppression



1. ***Travel Time Tomography (TTT)***

   – fit transmission and reflection times using ray-tracing.

2. ***Depth Migration (post and pre-stack)***

   – Kirchhoff
   – RTM.

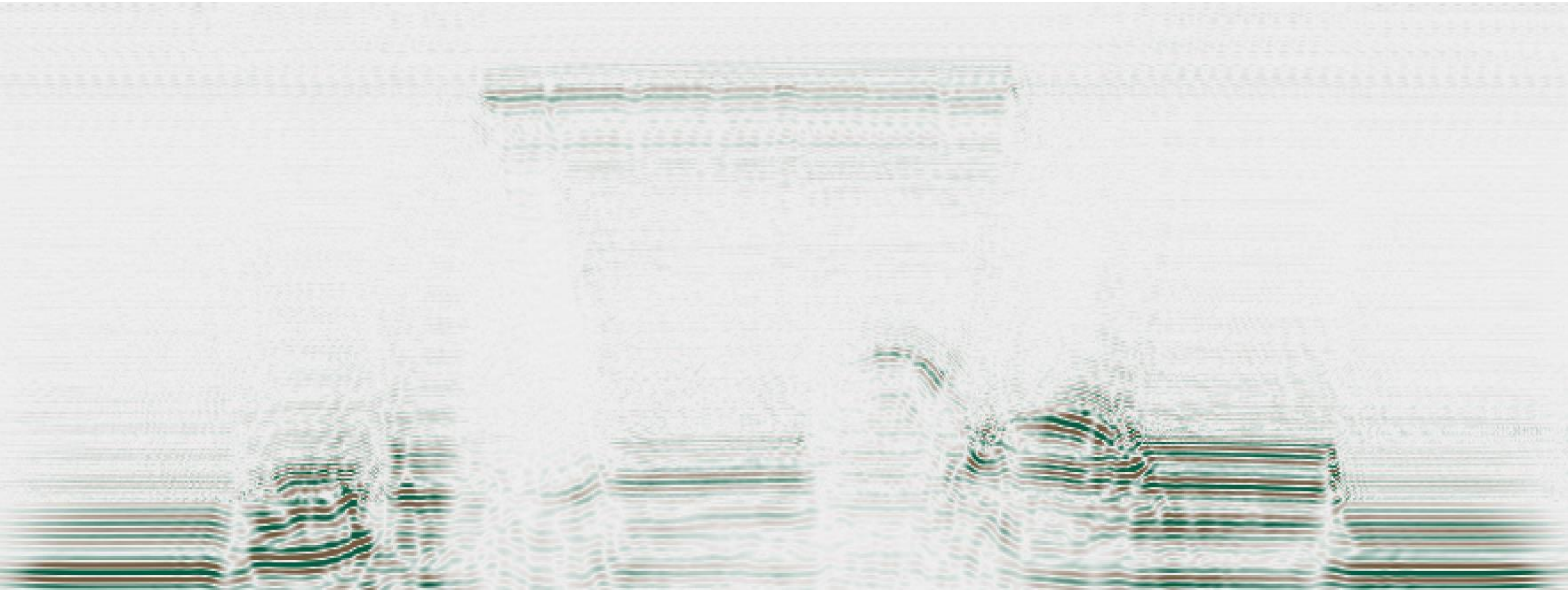
3. ***FWI in frequency or time domain.***

Prestack Depth Migration

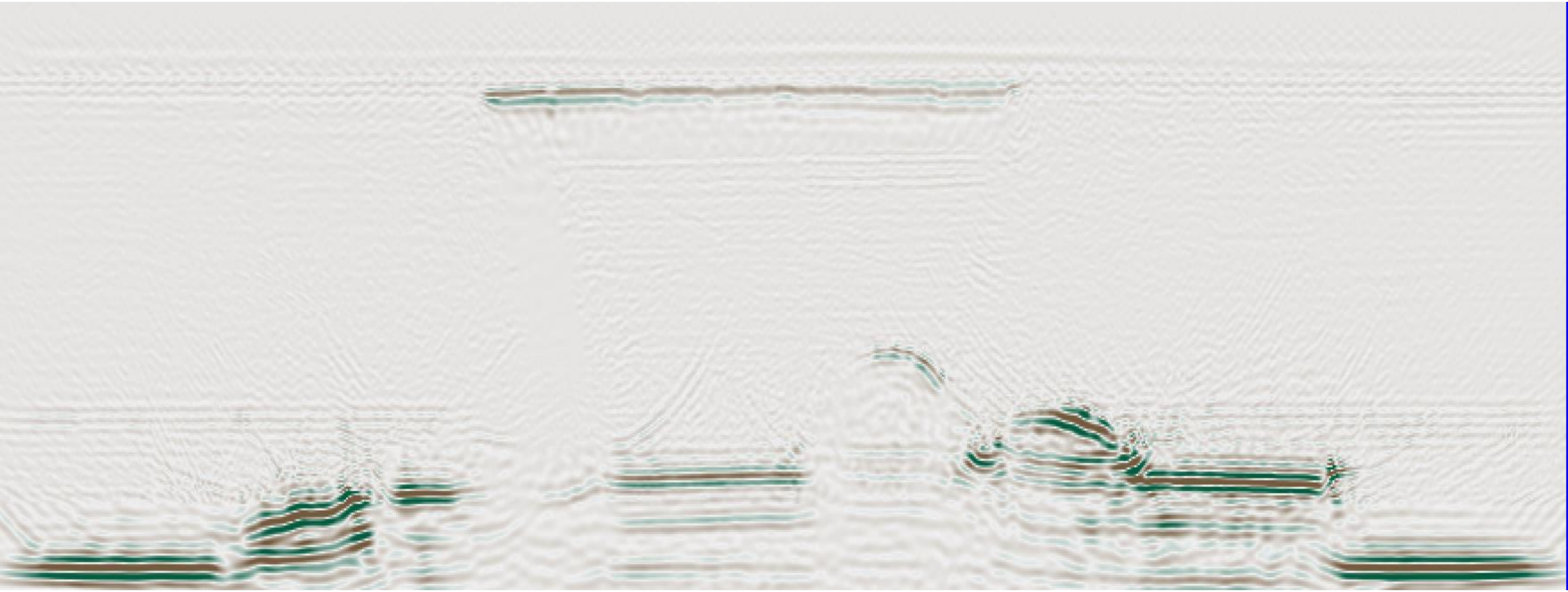
Fourier finite difference method

Dietrich Ristow and Thomas Rühl, Fourier finite-difference migration, Geophysics, 1994.

Prestack Depth Migration without multiple suppression



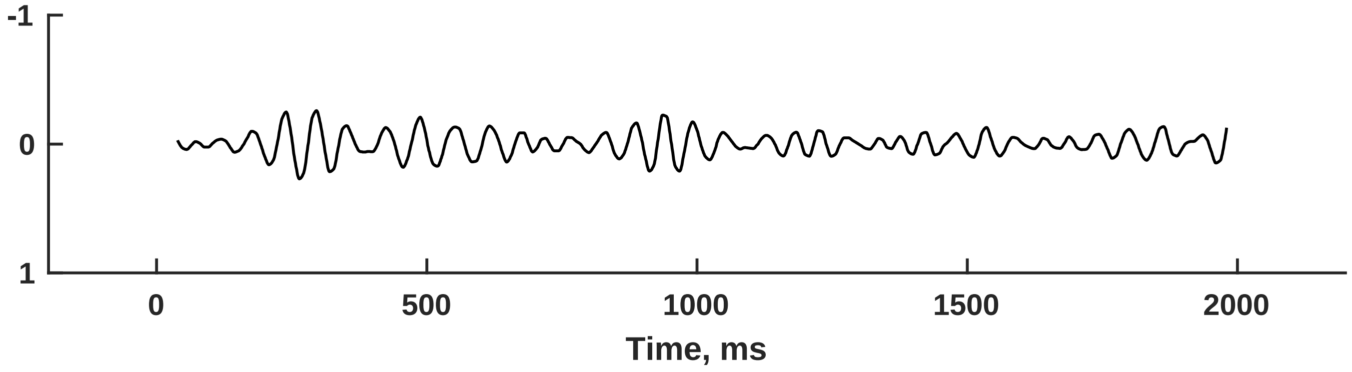
Prestack Depth Migration with multiple suppression



Part 2

Designing Electronic Circuits for Generating the Drill-bit Source Waveform.

W_{SWD} = drill-bit waveform



Mathematical model of SWD

d_{imp} = *impulsive-source seismic data;*
W_{SWD} = *drill-bit waveform;*
d_{SWD} = *seismic field data acquired with drill-bit source;*
d_{est} = *estimated impulsive-source seismic data.*

Convolution:

$$d_{imp} \otimes W_{SWD} = d_{SWD}$$

Deconvolution:

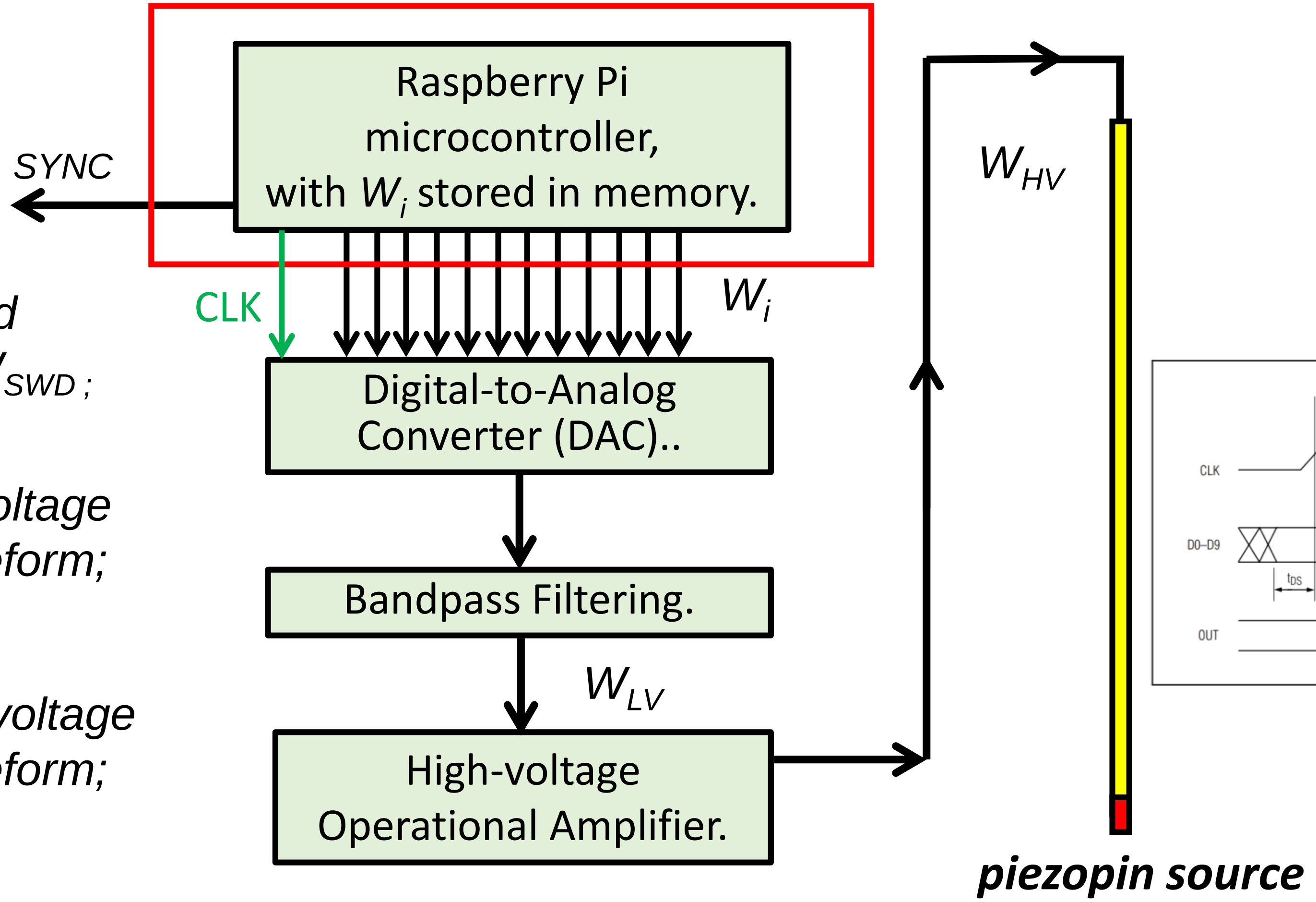
$$d_{est} = d_{SWD} \oplus W_{SWD}$$

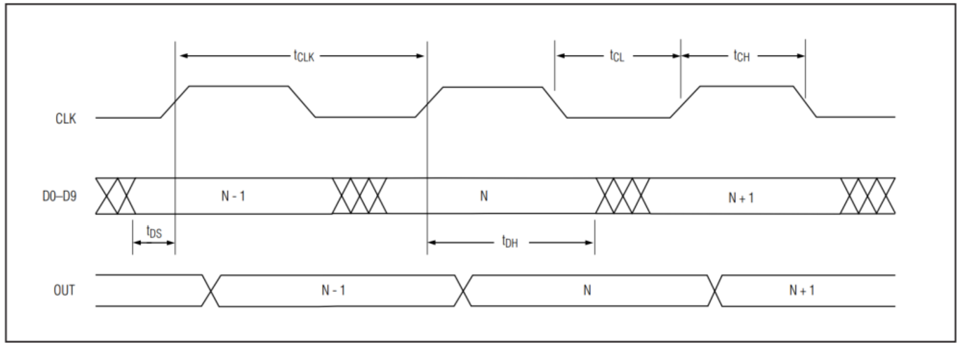
Block Diagram of Electronics to Generate Drill Bit Waveform

W_i = digitized version of W_{SWD};

W_{LV} = low-voltage drill-bit waveform;

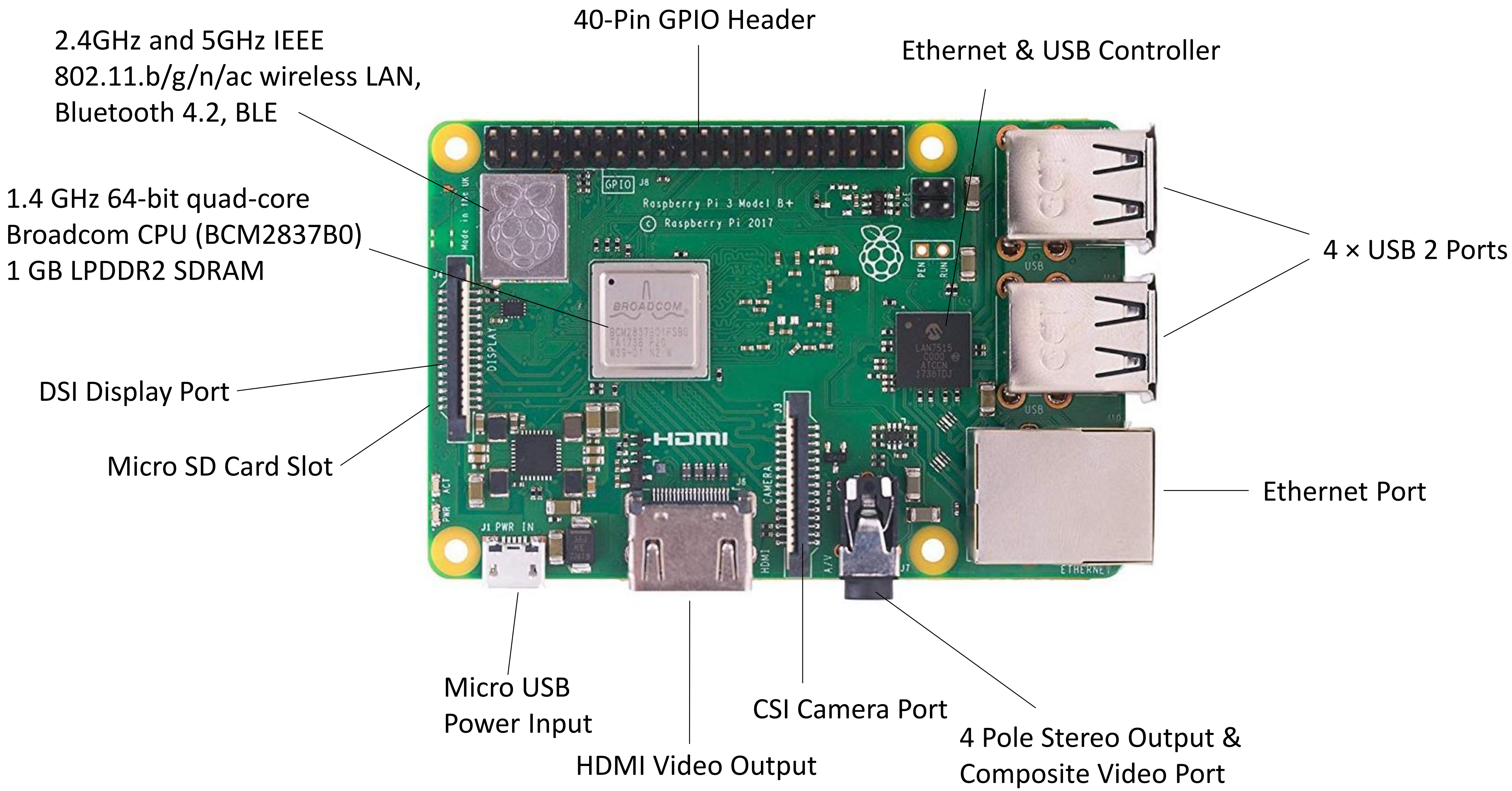
W_{HV} = high-voltage drill-bit waveform;





Timing Diagram

Raspberry Pi 3 B+

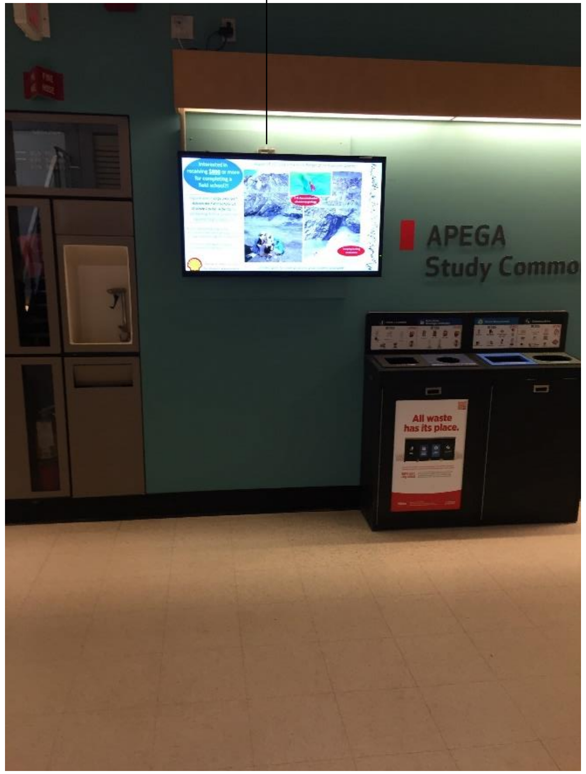


Raspberry Pi

Main Floor @ ES

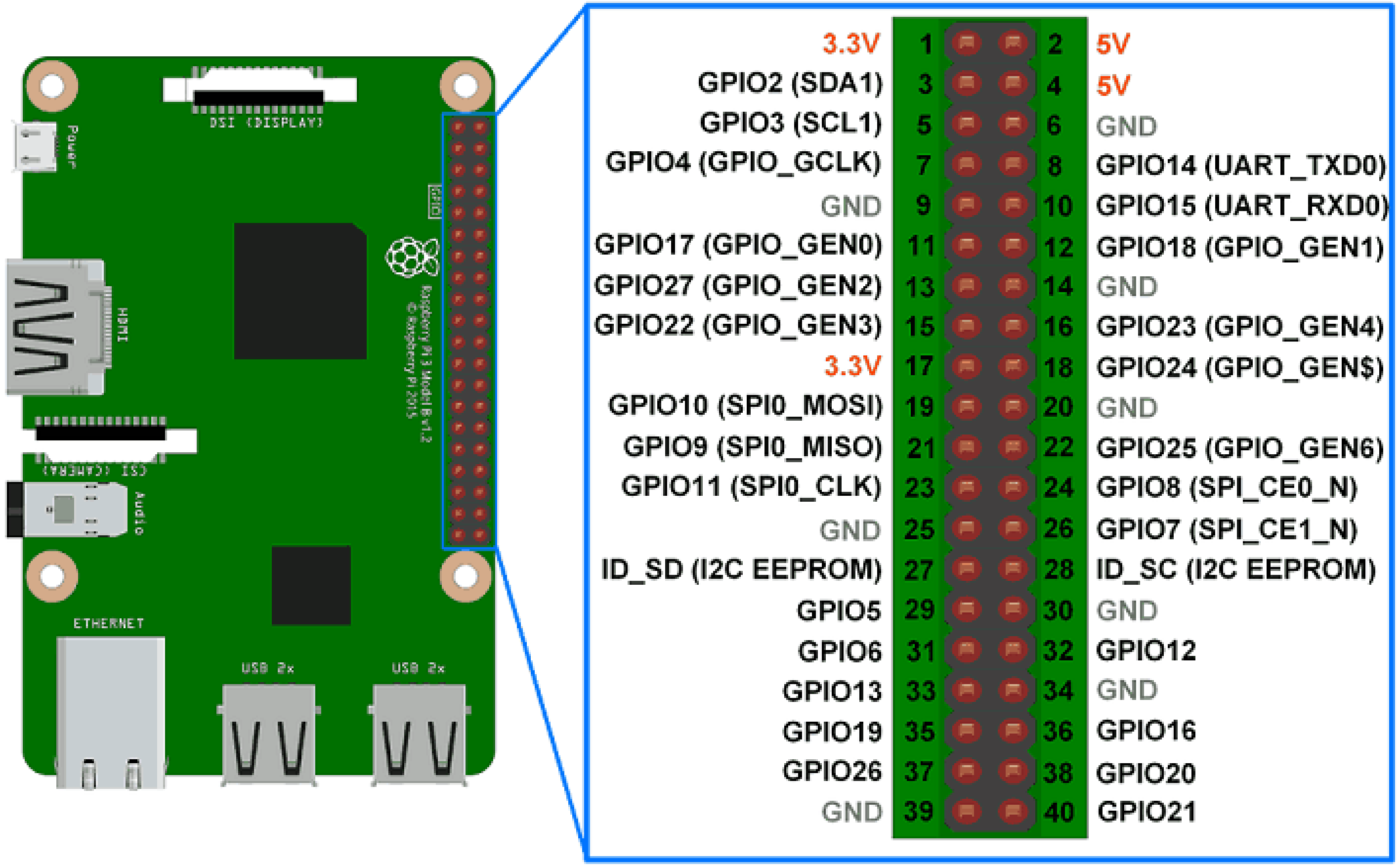
Raspberry Pi

Raspberry Pi

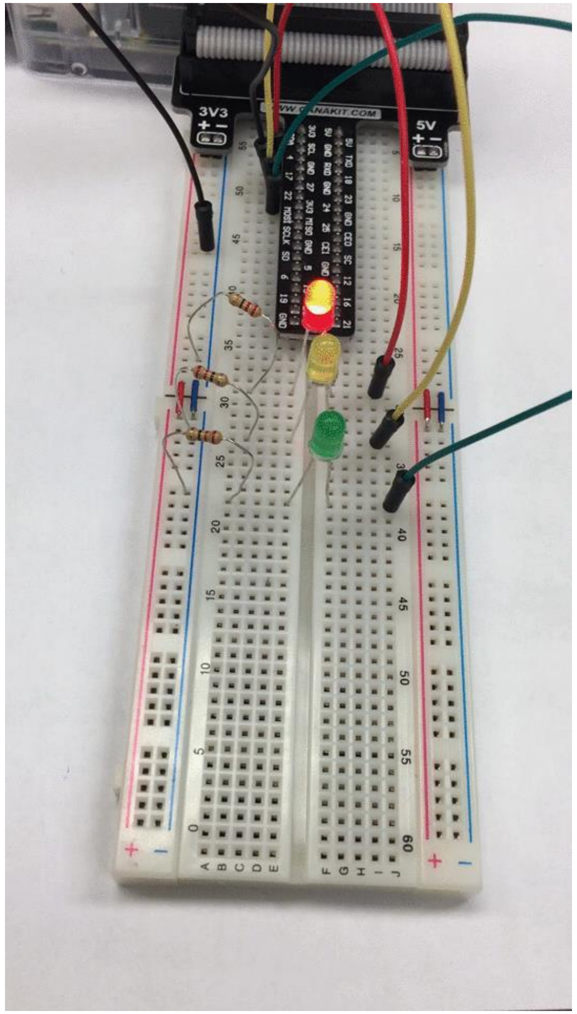


2nd Floor @ ES

General Purpose Input / Output (GPIO)



Source: https://www.electronicwings.com/raspberry-pi/raspberry-pi-gpio-access



General Purpose Input / Output (GPIO)

GPIO Interface library/Module

C Library:

wiringPi
pigpio

……

Python Module:

RPi.GPIO
RPIO
wiringPi2-Python

……

Direct GPIO Register Manipulation in C-code

Address	Field Name	Description	Size	Read/ Write
0x 7E20 0000	GPFSEL0	GPIO Function Select 0	32	R/W
0x 7E20 0000	GPFSEL0	GPIO Function Select 0	32	R/W
0x 7E20 0004	GPFSEL1	GPIO Function Select 1	32	R/W
0x 7E20 0008	GPFSEL2	GPIO Function Select 2	32	R/W
0x 7E20 000C	GPFSEL3	GPIO Function Select 3	32	R/W
0x 7E20 0010	GPFSEL4	GPIO Function Select 4	32	R/W
0x 7E20 0014	GPFSEL5	GPIO Function Select 5	32	R/W
0x 7E20 0018	-	Reserved	-	-
0x 7E20 001C	GPSET0	GPIO Pin Output Set 0	32	W
0x 7E20 0020	GPSET1	GPIO Pin Output Set 1	32	W
0x 7E20 0024	-	Reserved	-	-
0x 7E20 0028	GPCLR0	GPIO Pin Output Clear 0	32	W
0x 7E20 002C	GPCLR1	GPIO Pin Output Clear 1	32	W
0x 7E20 0030	-	Reserved	-	-
0x 7E20 0034	GPLEV0	GPIO Pin Level 0	32	R
0x 7E20 0038	GPLEV1	GPIO Pin Level 1	32	R
0x 7E20 003C	-	Reserved	-	-
0x 7E20 0040	GPEDS0	GPIO Pin Event Detect Status 0	32	R/W

41 GPIO Registers (BCM 2837)

Source: https://cs140e.sergio.bz/docs/BCM2837-ARM-Peripherals.pdf

General Purpose Input / Output (GPIO)

Direct GPIO Register Manipulation

Address	Field Name	Description	Size	Read/ Write
0x 7E20 0000	GPFSEL0	GPIO Function Select 0	32	R/W
0x 7E20 0000	GPFSEL0	GPIO Function Select 0	32	R/W
0x 7E20 0004	GPFSEL1	GPIO Function Select 1	32	R/W
0x 7E20 0008	GPFSEL2	GPIO Function Select 2	32	R/W
0x 7E20 000C	GPFSEL3	GPIO Function Select 3	32	R/W
0x 7E20 0010	GPFSEL4	GPIO Function Select 4	32	R/W
0x 7E20 0014	GPFSEL5	GPIO Function Select 5	32	R/W
0x 7E20 0018	-	Reserved	-	-
0x 7E20 001C	GPSET0	GPIO Pin Output Set 0	32	W
0x 7E20 0020	GPSET1	GPIO Pin Output Set 1	32	W
0x 7E20 0024	-	Reserved	-	-
0x 7E20 0028	GPCLR0	GPIO Pin Output Clear 0	32	W
0x 7E20 002C	GPCLR1	GPIO Pin Output Clear 1	32	W
0x 7E20 0030	-	Reserved	-	-
0x 7E20 0034	GPLEV0	GPIO Pin Level 0	32	R
0x 7E20 0038	GPLEV1	GPIO Pin Level 1	32	R
0x 7E20 003C	-	Reserved	-	-
0x 7E20 0040	GPEDS0	GPIO Pin Event Detect Status 0	32	R/W

41 GPIO Registers (BCM 2837)

Bit(s)	Field Name	Description	Type	Reset
31-30	---	Reserved	R	0
29-27	FSEL19	FSEL19 - Function Select 19 000 = GPIO Pin 19 is an input 001 = GPIO Pin 19 is an output 100 = GPIO Pin 19 takes alternate function 0 101 = GPIO Pin 19 takes alternate function 1 110 = GPIO Pin 19 takes alternate function 2 111 = GPIO Pin 19 takes alternate function 3 011 = GPIO Pin 19 takes alternate function 4 010 = GPIO Pin 19 takes alternate function 5	R/W	0
26-24	FSEL18	FSEL18 - Function Select 18	R/W	0
23-21	FSEL17	FSEL17 - Function Select 17	R/W	0
20-18	FSEL16	FSEL16 - Function Select 16	R/W	0
17-15	FSEL15	FSEL15 - Function Select 15	R/W	0
14-12	FSEL14	FSEL14 - Function Select 14	R/W	0
11-9	FSEL13	FSEL13 - Function Select 13	R/W	0
8-6	FSEL12	FSEL12 - Function Select 12	R/W	0
5-3	FSEL11	FSEL11 - Function Select 11	R/W	0
2-0	FSEL10	FSEL10 - Function Select 10	R/W	0

GPIO Pins

GPIO Alternate function select register 1

Source: https://cs140e.sergio.bz/docs/BCM2837-ARM-Peripherals.pdf

General Purpose Input / Output (GPIO)

Direct GPIO Register Manipulation

Address	Field Name	Description	Size	Read/ Write
0x 7E20 0000	GPFSEL0	GPIO Function Select 0	32	R/W
0x 7E20 0000	GPFSEL0	GPIO Function Select 0	32	R/W
0x 7E20 0004	GPFSEL1	GPIO Function Select 1	32	R/W
0x 7E20 0008	GPFSEL2	GPIO Function Select 2	32	R/W
0x 7E20 000C	GPFSEL3	GPIO Function Select 3	32	R/W
0x 7E20 0010	GPFSEL4	GPIO Function Select 4	32	R/W
0x 7E20 0014	GPFSEL5	GPIO Function Select 5	32	R/W
0x 7E20 0018	-	Reserved	-	-
0x 7E20 001C	GPSET0	GPIO Pin Output Set 0	32	W
0x 7E20 0020	GPSET1	GPIO Pin Output Set 1	32	W
0x 7E20 0024	-	Reserved	-	-
0x 7E20 0028	GPCLR0	GPIO Pin Output Clear 0	32	W
0x 7E20 002C	GPCLR1	GPIO Pin Output Clear 1	32	W
0x 7E20 0030	-	Reserved	-	-
0x 7E20 0034	GPLEV0	GPIO Pin Level 0	32	R
0x 7E20 0038	GPLEV1	GPIO Pin Level 1	32	R
0x 7E20 003C	-	Reserved	-	-
0x 7E20 0040	GPEDS0	GPIO Pin Event Detect Status 0	32	R/W

41 GPIO Registers (BCM 2837)

Bit(s)	Field Name	Description	Type	Reset
31-0	SETn (n=0..31)	0 = No effect 1 = Set GPIO pin *n*	R/W	0

GPIO Output Set Register 0

Bit(s)	Field Name	Description	Type	Reset
31-22	-	Reserved	R	0
21-0	SETn (n=32..53)	0 = No effect 1 = Set GPIO pin *n*.	R/W	0

GPIO Output Set Register 1

Bit(s)	Field Name	Description	Type	Reset
31-0	CLRn (n=0..31)	0 = No effect 1 = Clear GPIO pin *n*	R/W	0

GPIO Output Clear Register 0

Bit(s)	Field Name	Description	Type	Reset
31-22	-	Reserved	R	0
21-0	CLRn (n=32..53)	0 = No effect 1 = Clear GPIO pin *n*	R/W	0

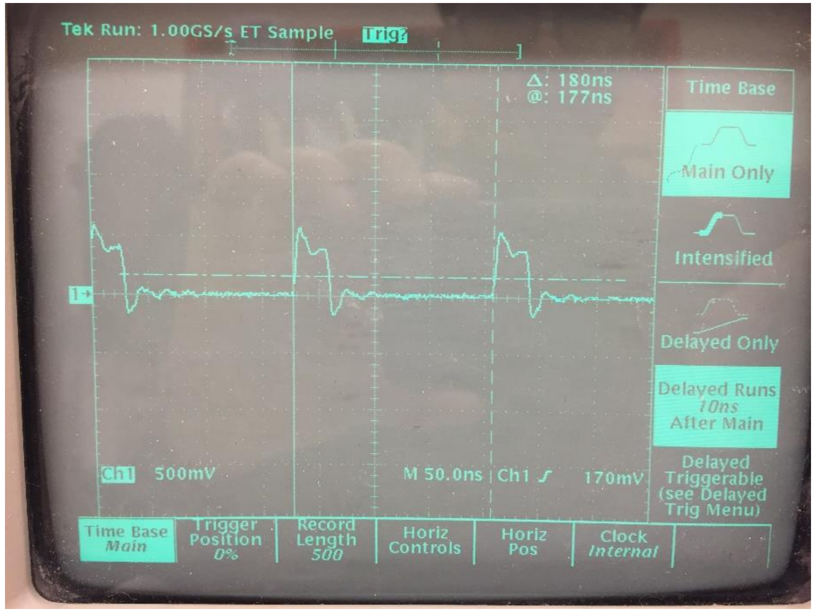
GPIO Output Clear Register 1

Source: https://cs140e.sergio.bz/docs/BCM2837-ARM-Peripherals.pdf

General Purpose Input / Output (GPIO)

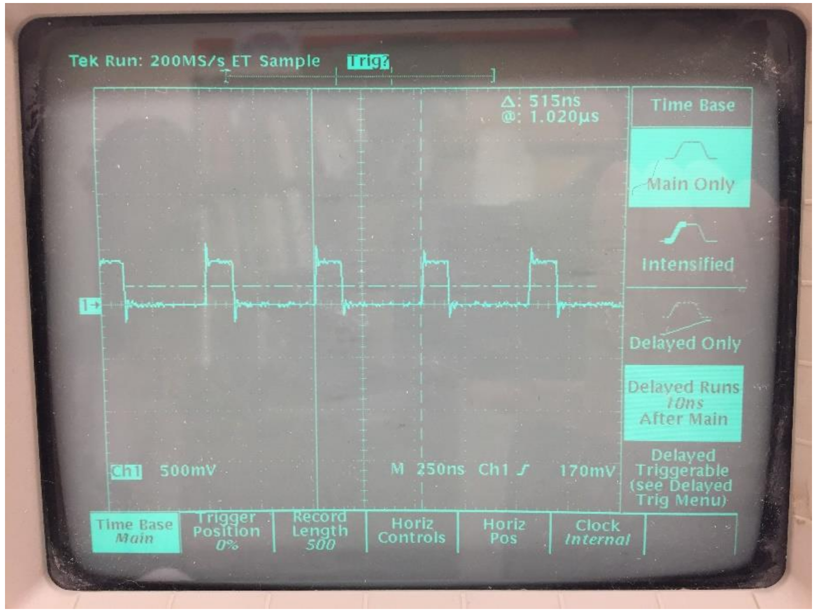
CLK Signal for 8-Bit Numbers

180 ns



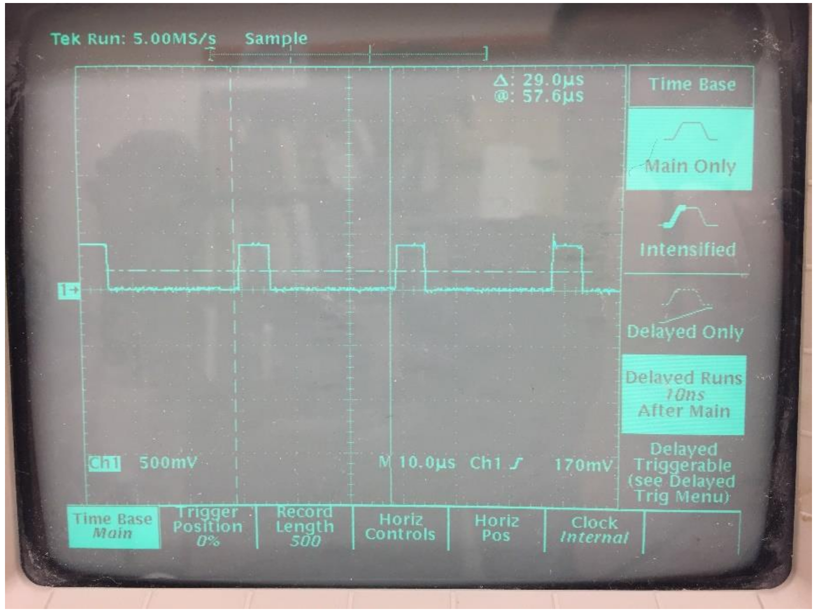
GPIO Register Manipulation

515 ns



WiringPi (C)

29,000 ns

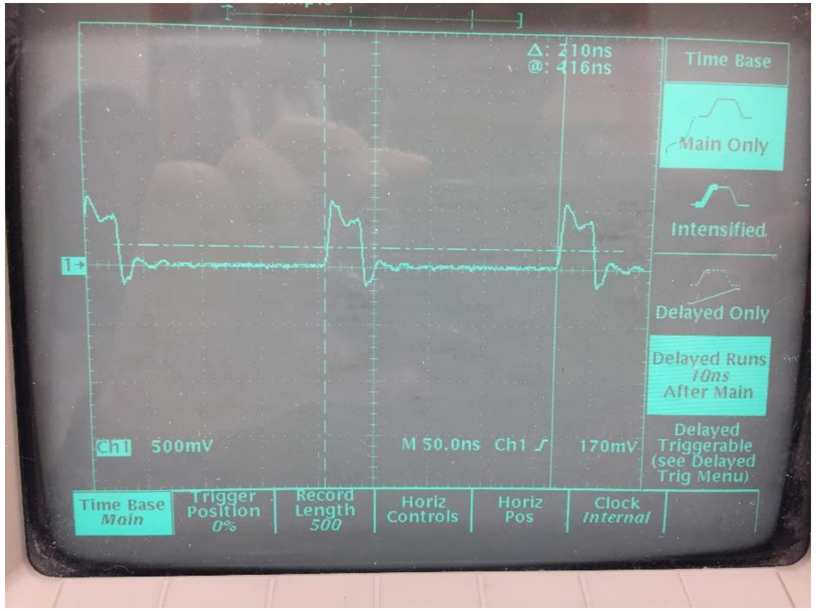


RPI.GPIO (Python)

General Purpose Input / Output (GPIO)

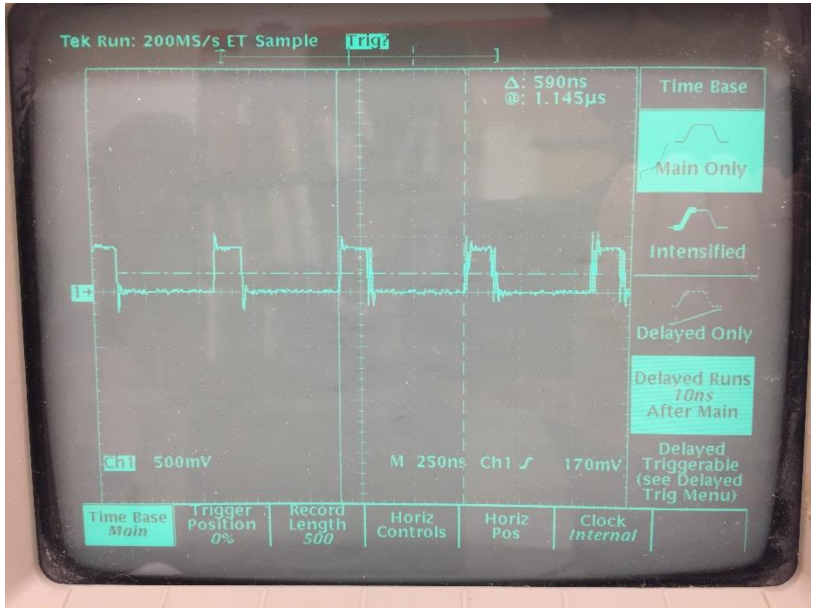
CLK Signal for 10-Bit Numbers

210 ns



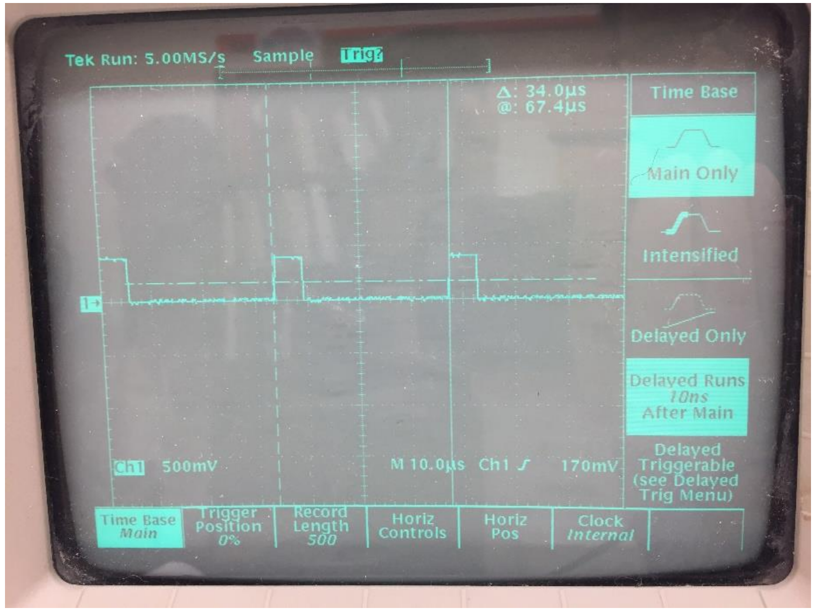
GPIO Register Manipulation

590 ns



WiringPi (C)

34,000 ns



RPI.GPIO (Python)

Conclusions

- **We have collected physically-modeled impulsive-source seismic data to address the problem of illuminating sub-vertical velocity interfaces. The data was collected with surface and sub-surface sources shooting into a surface receiver line.**

- **Subsurface piezopin sources driven by complicated waveforms (mimicking signals produced by drill bits cutting into rock) simulate seismic while drilling (SWD) acquisition.**

- **The complicated drill-bit waveform required for physical-modeling of SWD is produced by a Raspberry Pi microcontroller linked to a DAC and a high-voltage amplifier.**

Acknowledgements

- **Sponsors of CREWES**
- **Canada First Research Excellent Fund (CFREF)**
- **Natural Sciences and Engineering Research Council of Canada (NSERC)**