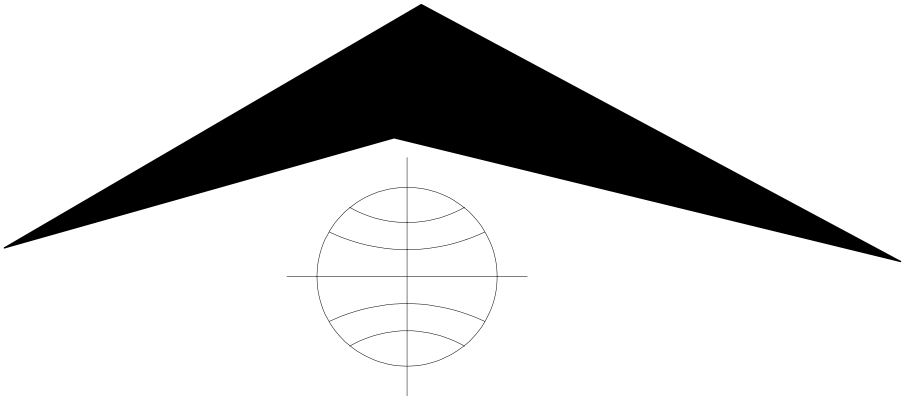
2SAA-1000
Sonic Probe



Mount Sopris Instrument Co., Inc.
Golden, CO U. S. A.
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General Information

Overview

The 2SAA-1000 sonic probe is a versatile tool that can be used in a wide variety of logging applications. Compressional wave velocity, shear wave velocity, Stoneley wave velocity, and Stoneley wave amplitude can be easily measured in real time in almost any situation.

An updated version of the probe is available designated the 2SAA-1000/F. The 2SAA-1000/F allows the addition of the 2SNA-1000, section to provide a natural gamma radiation measurement or a second 2STA-1000 transmitter. The updated version has new firmware in the 2STA-1000, transmitter and can be identified by a F stamped at the end of the transmitters serial number. The 2SAA-1000, 2STA-1000, transmitter can be updated with this firmware at the factory.

Several features of the 2SAA-1000 sonic probe set it apart from conventional probes. The tool is modular, which allows the user to connect various sections together to form the specific tool needed. It is a variable frequency tool that can be used for surveys in many different environments and can be configured in the monopole or dipole mode of operation. The receivers can also stack and average multiple waveforms to cancel noise when the received signal amplitude is low.

Layout and Operating Parameters

The 2SAA-1000 sonic probe is a modular system which can be configured for specific types of surveys. The probe can be disassembled into individual receiver sections, transmitter section(s), isolator section(s), and a modem section. The user can assemble a tool with the desired number of receivers, transmitters, and appropriate isolator lengths. A maximum of two transmitters and eight receivers can be assembled in one tool. Additionally, a 2SNA-1000 natural gamma section can be added.

The proper sequence of connecting sections for a single transmitter probe is (from top to bottom): the modem section, all receivers, an isolator section, and finally, the transmitter section (see Figure 1). Make sure that the transmitter sections is installed so that the transmitter elements are close to the isolator section. The standard spacing between the transmitter and the first receiver is 3 feet. An optional isolator (2SIC-1000) is available to provide a 6 foot transmitter to receiver spacing for low frequency surveys. The spacing between adjacent receivers is 1 foot. For receiver spacings other than 1 foot, additional spacers (2SSA-1000) are also available. Note the alignment markings on each transmitter and receiver. A 2SNA-1000 natural gamma section can be added between the modem and the receiver sections if desired. Centralizers are installed on the modem and transmitter sections. Do not cover up the transmitter elements with the centralizer. To install the centralizer, slide it over the tool to the desired position and tighten the aluminum locking collar.

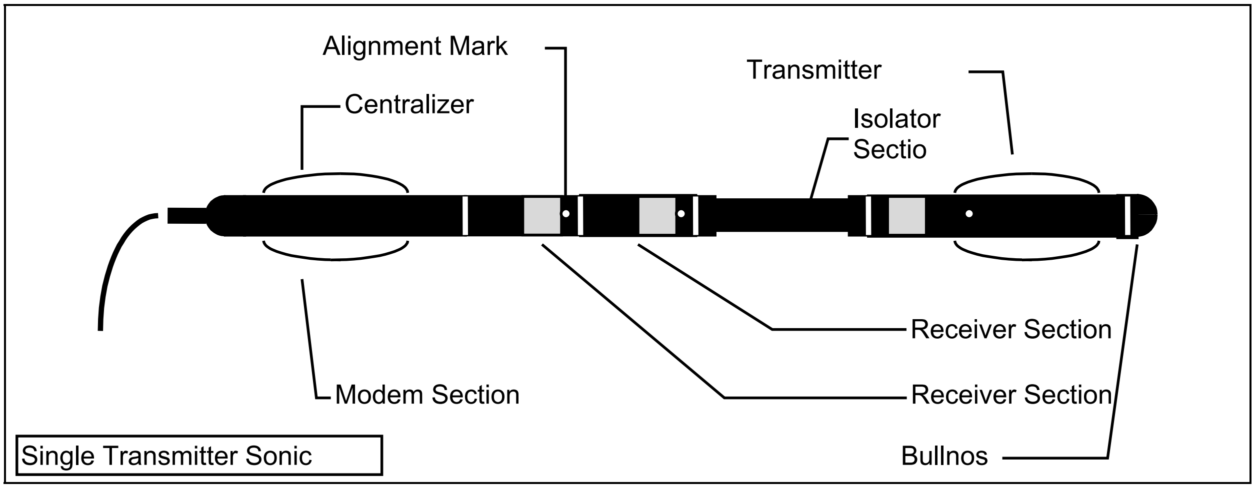


Figure 1: Single Transmitter Probe

The proper sequence of connecting the sections for a dual transmitter probe is (from top to bottom): the modem section, a transmitter section, an isolator section, all receivers, an isolator section, and finally, the other transmitter section (see Figure 2). Make sure that the transmitter sections is installed so that the transmitter elements are close to the isolator section. An optional isolator (2SIC-1000) is available to provide a 6 foot transmitter to receiver spacing for low frequency surveys. The spacing between adjacent receivers is 1 foot. For receiver spacings other than 1 foot, additional spacers (2SSA-1000) are also available. Note the alignment markings on each transmitter and receiver section. A 2SNA-1000 natural gamma section can be added between the modem and the receiver sections if desired. Centralizers are installed on the modem and lower transmitter sections. Do not cover up the transmitter elements with the centralizer. To install the centralizer, slide it over the tool to the desired position and tighten the aluminum locking collar.

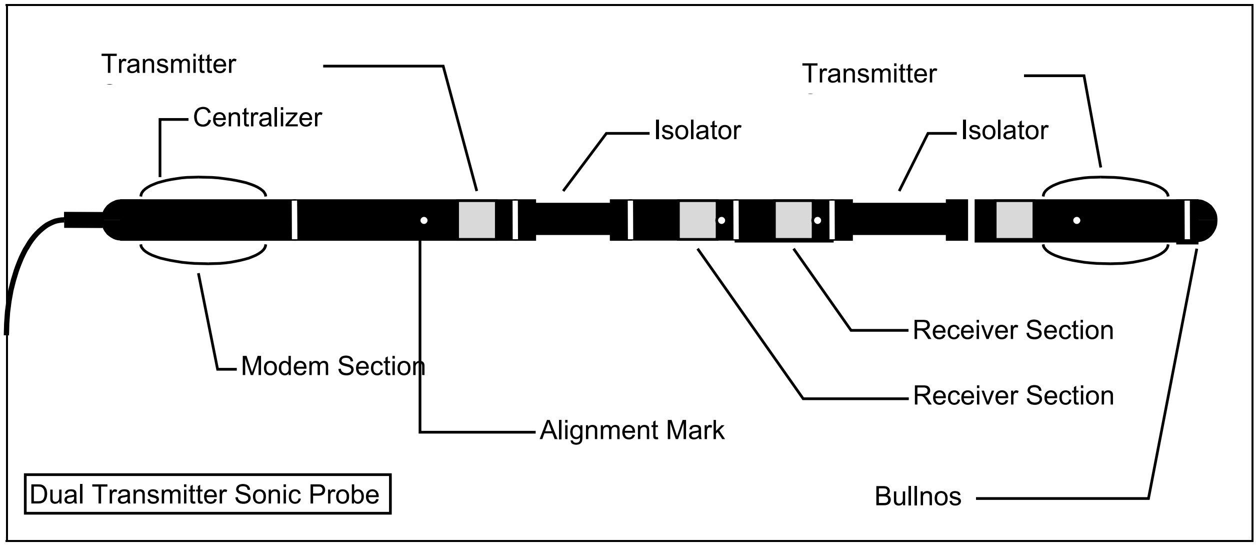


Figure 2: Dual Transmitter Probe

To assemble the various probe sections: 1) remove three radial screws near the 10 pin connectors of the sections to be joined, 2) line up the connector alignment pin between sections to be joined and push the two sections together, and 3) replace the three radial screws so that the sections are fastened together. Do not over tighten the radial screws because they become more difficult to remove after the probe has been logged and the screws subjected to corrosive fluids.

To disconnect the various sections, 1) remove the three radial screws between the sections to be disconnected, 2) pull the sections apart, 3) push the protective caps onto the section ends, and 4) replace the three radial screws so that the protective caps are retained.

The 2SAA-1000 probe was designed for use with the MGX-II and MGX-III series loggers. Supported logging cables are Rochester (or equivalent) steel armored cables: 3/16 inch single conductor to 1800 meters, ¼ inch coaxial cable to 1800 meters, 1/8 inch single conductor cable to 1000 meters, 1/10 inch single conductor cable to 800 meters, and 3/16 inch 4 conductor cable to 1000 meters.

The 2SAA-1000 sonic probe is comprised of an acoustic transmitter and a number of receivers. The transmitter transmits an acoustic signal that propagates through the borehole fluid to the rock interface where some of the energy is critically refracted along the borehole wall (Figure 3). As a result of wavefront spreading (Huygens' principal), some of the refracted energy is transmitted back into the borehole. At some point, energy will be transmitted back into the borehole adjacent to a receiver. Each receiver picks up the signal, amplifies it, digitizes it, and then sends the digitized signal to the surface. The recorded waveforms are then examined, and wave arrival times are selected. The arrival times are the transit times of the acoustic energy. By measuring the acoustic transit time, and knowing the distance between source and receiver, the fluid velocity, and borehole diameter, the sonic velocity of the rock can be calculated.

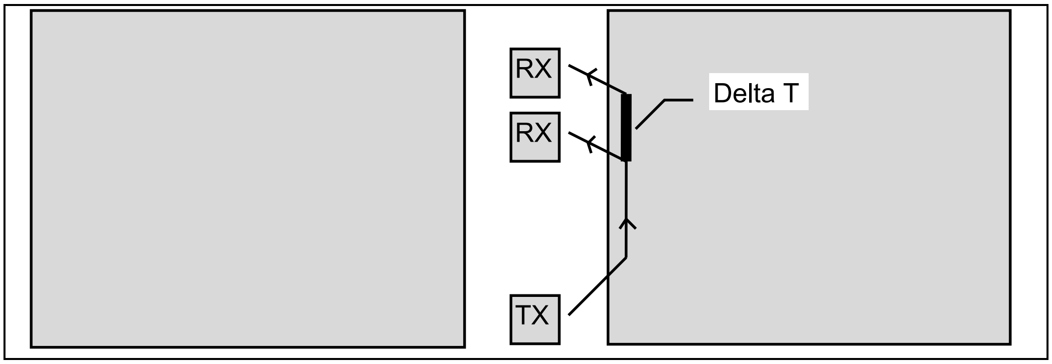


Figure 3: Single Transmitter Array

Note that part of the travel path shown is through the borehole fluid. Since the diameter of the borehole frequently changes, and the fluid velocity is usually much slower than the rock velocity, significant errors can result using the above method. A better method is to measure the transit time between multiple receivers. For the two receiver case, both travel paths are identical except that path through the rock is longer for one receiver. If the travel times measured with each receiver are subtracted, then the resultant time (termed delta T) is the travel time through the rock between the receivers (see Figure 3). Knowing the distance between the receivers allows one to calculate the acoustic velocity of the rock without having to know the fluid velocity or the borehole diameter.

The single transmitter two receiver approach works well when the probe is centralized in the borehole. By using two transmitters, effective delta T measurements can be made even when the probe is tilted in the borehole. When the probe is tilted, the travel time to each receiver may be different. As shown in Figure 4, the delta T measurements from the upper and lower transmitter are averaged. The improvement is minimal and not usually worth the additional cost in instrumentation. The two transmitter configuration can be used to conduct two different types of sonic surveys in the same logging run. This is described later in this manual.

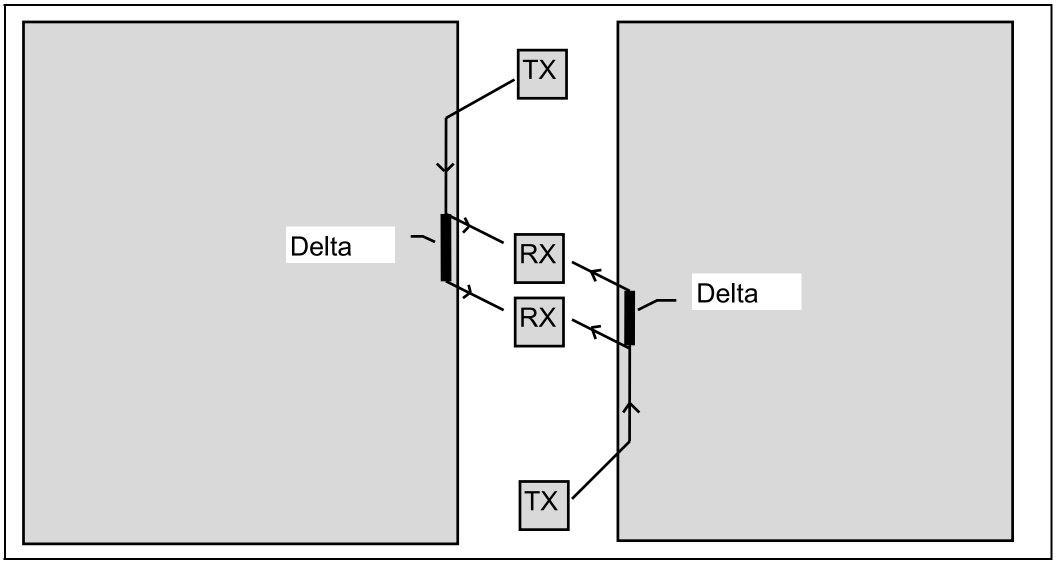


Figure 4: Dual Transmitter Array

The acoustic energy incident on the receivers is converted to an electrical signal, amplified, filtered, digitized and finally sent to the surface. The timing is shown in Figure 5. The **Transmitter Frequency**, **Holdoff Time**, **Sample Rate**, **Number of Samples**, **Stack Interval**, **Number Stacked**, **Monopole/Dipole**, and **Reverse Dipole Stacking** are all parameters that can all be controlled and changed at any time with the acquisition software. The purpose of each parameter is described below.

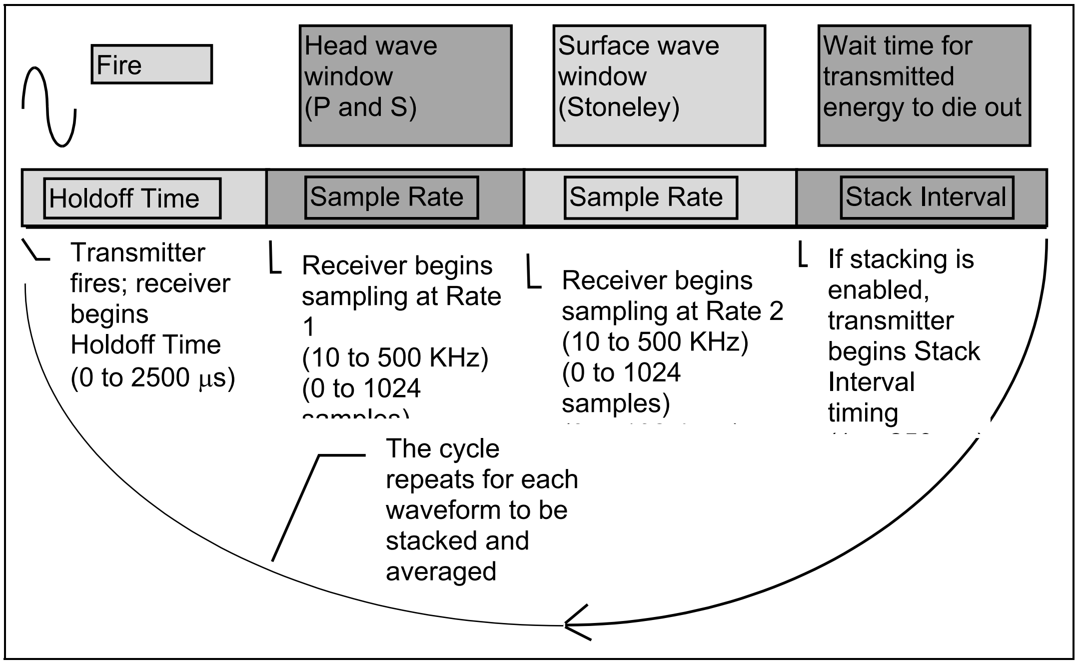


Figure 5: Receiver Timing

The transmitter is driven with a single cycle sinusoid at a frequency between 1 and 30 KHz and is specified by the **Transmitter Frequency** parameter. The spectrum contained by this waveform has a bandwidth of approximately the transmitted frequency. This source band is also centered on the transmitted frequency. For example, a single cycle sinusoid at 5 KHz will contain all frequencies between about 2.5 and 7.5 KHz. The transmitted frequency band described here is an approximation. For precise frequency control, the data are frequency filtered in post processing. The Transmitter Frequency for each transmitter is independent of the settings of the other transmitter.

Holdoff Time is the period between when the transmitter fires, and the beginning of data sampling. There is no need to record data before the energy from the transmitter has time to reach the receiver. The Holdoff Time for each receiver is independent of the settings of other receivers.

Sample Rate is the frequency at which the receiver samples the impinging wave and converts the current wave amplitude to a digital number. The higher the Transmitter Frequency, the higher sample rate needed. Also, a higher sample rate more accurately records an impinging wave so that it's exact arrival time can be more accurately determined. A sample rate of at least 10 times the frequency of the received waveform is recommended. Generally speaking, the first part of the waveform will contain higher frequencies than the latter part of the waveform. Additionally, logging speed is optimized when the number of samples sent back is minimized. Therefore, two Sample Rates are provided so that fast sampling is not inefficiently spent on a part of the received waveform containing low frequencies. The Sample Rate for each receiver is independent of the settings of other receivers.

The **Number of Samples** the receiver records, together with the Sample Rate specifies the length of time over which the receiver will record. For instance, if the Number of Samples is 500, and the Sample Interval is 4 μs, then the receiver will record 2 ms of data. Two Sample Rates are provided so that fast sampling is not inefficiently spent on a part of the received waveform containing low frequencies. The Number of Samples for each receiver is independent of the settings of other receivers.

Stacking may be necessary when conducting a survey in poorly consolidated or soft formations. The receiver sections stack and average all of the waveforms received in a given stacking sequence. This technique cancels the noise and makes it easier to process low amplitude data. **Stack Interval** is the time the transmitter waits between successive firings in a given sample cycle. After the transmitter fires, and the receiver has finished digitizing the received signal, the transmitter must wait for the energy currently propagating to dissipate before transmitting another energy burst. All subsequent received waveforms are averaged with the previously received waveforms until the sample cycle completes. If the Stack Interval is too short, then there will be energy in the received waveform before the expected first arrival. Longer Stack Intervals are necessary for lower transmitter frequencies. The sample cycle completes after all the waveforms to be stacked have been received and averaged. The number of waveforms stacked and averaged is referred to as the **Number Stacked**. This number can be between 1 and 16. It is best to keep the number of stacks and the Stack Interval as small as possible because these parameters significantly affect logging speed. The Stack Interval and Number Stacked for each transmitter is independent of the settings of other transmitter.

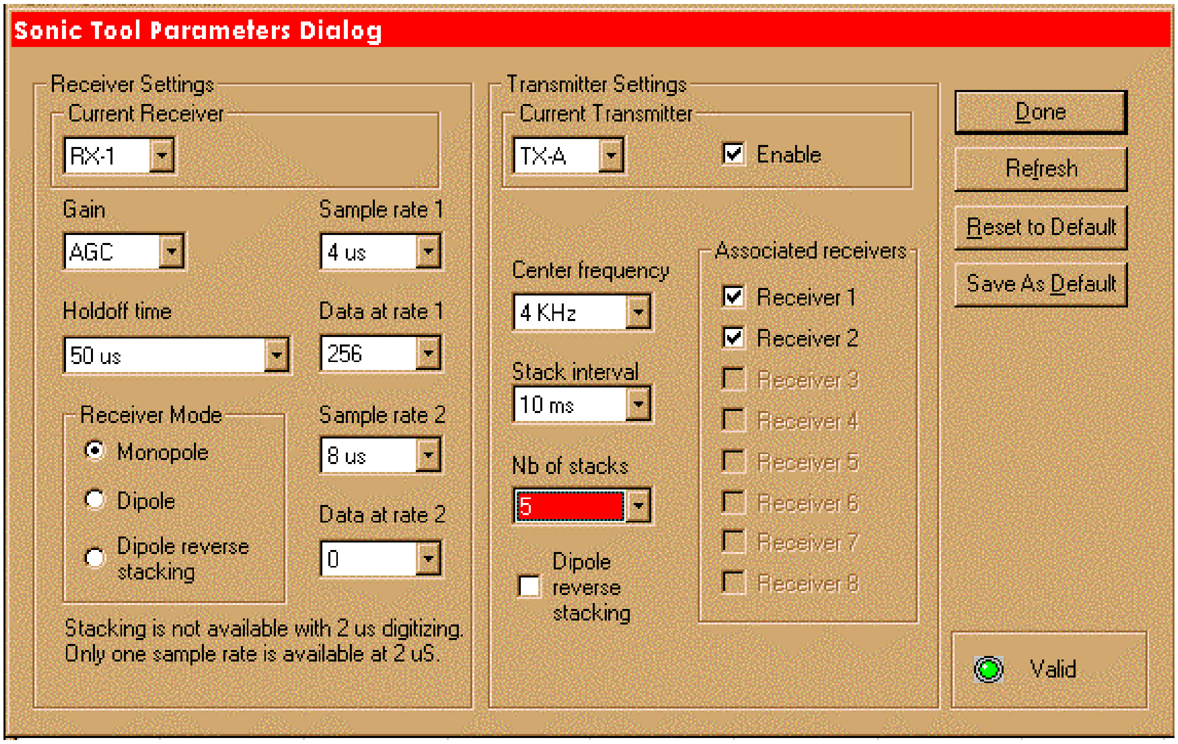
Receiver Gain is applied to the received signal before it is digitized. The gain is selectable between 1, 2, 4, 8, 16, and AGC (automatic gain control). The AGC setting chooses a gain of 1, 2, 4, 8, or 16 depending on the maximum amplitude of the previously received waveform. When operating in AGC mode, if the maximum amplitude in a received waveform is less than half of the digitizer's range than the gain is increased one step for the next waveform. If the digitizer saturates, then the gain is decreased by one step for the next waveform. The Receiver Gain for each receiver is independent of the settings of other receivers.

The probe can be configured for monopole or dipole operation. For the receivers, this is done by setting the **Monopole/Dipole** parameter using the acquisition software. See the Operation Procedure section for details on how to configure the transmitter staves for monopole or dipole operation. If the transmitter is set up for monopole operation, then the receiver must be set for monopole operation and visa versa. Monopole operation is almost always used except when conducting a low frequency shear wave survey in slow rocks. Each transmitter or receiver section can be operated in Monopole or Dipole mode independent of the settings for other receivers or transmitters.

Each transmitter can have any number of **Associated Receivers**. Generally, the operator will set receiver parameters for each receiver based on the transmitter settings. When the tool sends data from a given transmitter, receiver data is sent for each receiver associated with the transmitter. For instance, a two transmitter four receiver tool could have the upper transmitter and upper two receivers set for low frequency dipole logging; and the lower transmitter and lower two receivers could be set for high frequency compressional wave logging.

Reverse Dipole Stacking mode can be used to cancel unwanted modes such as the Stoneley mode during dipole shear wave logging. When using this feature, make sure that both the transmitter and associated receivers are set for Reverse Dipole Stacking. Also, make sure that the transmitter staves are set in dipole mode as described in the Operation Procedure section.

The parameters described above are set with the sonic tool parameters dialog shown below. To access this dialog from the MSLog software, use the 'Tool Settings / Commands' button on the dashboard. The Receiver Settings shown are for the receiver that is currently selected. To display/set settings for another receiver, change the current receiver selection. The transmitter settings are displayed/set in a similar fashion. See the MSLog user manual for more information.



Sonic Tool Parameters Dialog

Receiver Settings

Current Receiver: RX-1

Gain: AGC

Sample rate 1: 4 us

Holdoff time: 50 us

Data at rate 1: 256

Receiver Mode:
● Monopole
○ Dipole
○ Dipole reverse stacking

Sample rate 2: 8 us

Data at rate 2: 0

Stacking is not available with 2 us digitizing.
Only one sample rate is available at 2 uS.

Transmitter Settings

Current Transmitter: TX-A

☑ Enable

Center frequency: 4 KHz

Stack interval: 10 ms

Nb of stacks: 5

☐ Dipole reverse stacking

Associated receivers:
☑ Receiver 1
☑ Receiver 2
☐ Receiver 3
☐ Receiver 4
☐ Receiver 5
☐ Receiver 6
☐ Receiver 7
☐ Receiver 8

Figure 6: Sonic Tool Parameters Dialog

The logging system digitizes against depth or time. When logging against depth at a certain speed, the logging system will be acquiring data at a certain number of records per second; just as the system does when logging against time. Maximum logging speed is:

$$\text{maximim speed [ft. per min.]} = \frac{60 \cdot \text{depth digitize interval [ft. per record]}}{\text{packet time [seconds per record]}}$$

A data cycle is shown in Figure 6. The time required to collect a data packet is:

$$\text{packet time [seconds]} = ((\text{Number Stacked} - 1) \cdot \text{Stack Interval [ms]} \cdot 10^{-3}) + (\text{number of receivers} \cdot \text{Number of Samples} \cdot 528 \cdot 10^{-6}) + 0.005$$

For example, if the **Stack Interval** is 50 ms, the **Number Stacked** is 4, the number of receivers is 2, and the number of samples is 256, then the time required to collect a data packet is about 0.434 seconds. Recording data every 0.1 foot, this translates into a maximum logging speed of about 13.8 feet per minute.

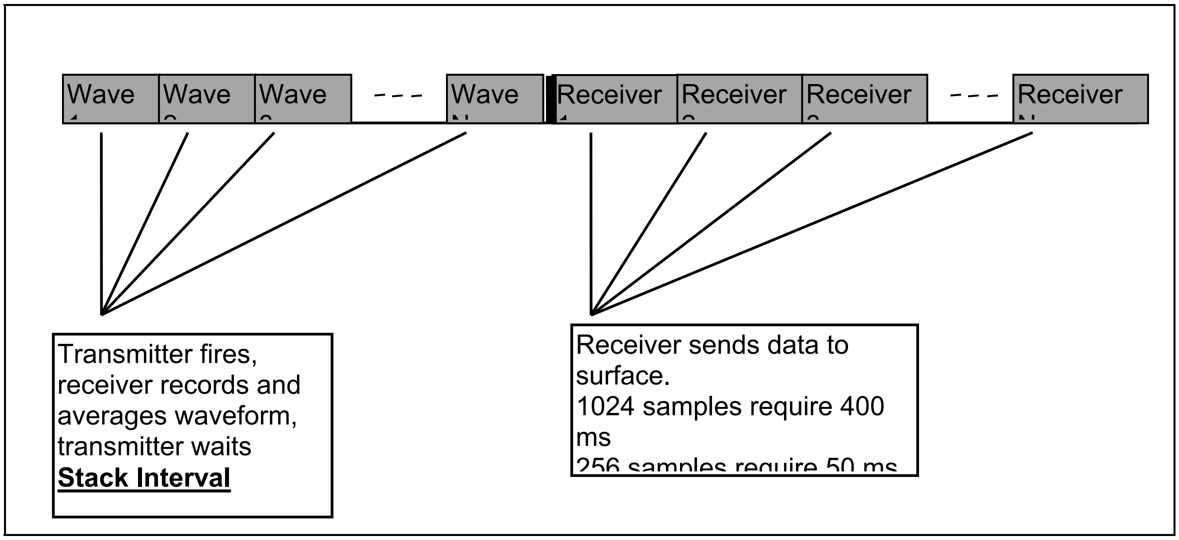


Figure 6: Data Cycle

Theory of Operation

Generally speaking, the borehole is a waveguide. It can propagate energy in many different modes. These modes include the compressional and shear head waves, an infinite series of normal compressional and normal shear modes, as well as the Stoneley wave modes. The energy from the infinite series of normal compressional and normal shear modes, as well as the Stoneley wave modes are fully trapped in the borehole. Subsequently, the received waveforms for these modes have high amplitudes.

The normal compressional and normal shear modes are an infinite series of modes with successively higher frequencies. These modes are excited when the source spectrum contains sufficiently high frequencies (as is often the case). If a wideband source is used, then the received waveform can be very complicated and cause shear wave first arrival picking to be very difficult. The complicated waveform is the result of the interference between the multiple modes received. By controlling the transmitted frequency band, the complexity of the received wavefrom can be dramatically reduced.

Normal modes are a result of constructive interference in the waveguide (borehole). For each normal mode, there exists a frequency below which the mode cannot be excited. This is called the cutoff frequency for the given mode. The normal modes are highly dispersive, with their phase velocities approaching head wave velocities as frequency approaches the mode cutoff frequency. A related resonance phenomenon produces high amplitude head waves at frequencies near mode cutoff frequencies. The optimal frequency band for producing head waves narrowly includes the cutoff frequencies for the first order compressional and shear normal modes. In this manner, unwanted modes are not excited, received head wave amplitudes are high, and the complexity of the received waveform is reduced.

Shear wave velocities less than borehole fluid velocities cannot be measured by a conventional monopole logging sonde. A dipole system can excite a flexural wave in the borehole. Flexural waves have a velocity less than or equal to the shear velocity. Flexural waves are dispersive, but at low frequencies (1 to 3 KHz), the flexural mode velocity is very near the shear velocity. Flexural waves can be used to measure both fast and slow shear velocities.

Stoneley wave amplitudes are affected by permeability to a much larger degree than the standard compressional and shear head waves. The Stoneley wave can be exited at all frequencies, but has a higher amplitude at low frequencies. At frequencies below the lowest normal mode cutoff, the Stoneley wave dominates. If we log at a frequency below the compressional and shear wave cutoff frequencies, then the Stoneley wave is easily delineated because the amplitude of the head waves will be low. With this method, Stoneley wave amplitude and velocity can be accurately measured without interference from other modes. Stoneley velocity is always slightly less than fluid velocity. This makes it easy to set a window for determining Stoneley wave amplitude.

Most users want to conduct a compressional and shear wave velocity survey. The objective in conducting this survey is to select a transmitter source spectrum that narrowly includes the compressional and shear wave cutoff frequencies, but few frequencies higher. This setup gives a high amplitude compressional and shear wave arrival that is not complicated by unwanted modes. Subsequently, shear wave arrivals are easily picked in post processing. The cutoff frequencies for the 2SAA-1000 are given by:

$$f_{pco} = \frac{\nu_p}{2.5 \cdot D} \qquad \text{and} \qquad f_{sco} = \frac{\nu_s}{1.2 \cdot D}$$

where f_{pco} and f_{sco} are the compressional and shear cutoff frequencies, v_p and v_s are the expected compressional and shear rock velocities, and D is the borehole diameter.

The following tables show the cutoff frequencies for the compressional and shear waves at various borehole diameters and rock velocities for the 2SAA-1000 probe. For most rocks, the shear velocity is 0.59 to 0.72 times the compressional velocity.

Rock Type	Compressional Velocity Km/s	Density g/cm^3
Slates and shale	2.4 – 5	2.65
Limestones and dolomites	3.4 – 6	2.71 – 2.87
Sandstone	2 – 4.5	2.65
Pure water	1.4 – 1.5	1
Water 10,000 mg/l NaCl	1.58	1.01
Ice	3 – 4	
Alluvium	0.3 – 1.7	
Glacial moraine	1.5 – 2.6	
Anhydrite	3.5 – 5.5	2.95
Rock salt	4 – 5.5	2.16
Granites and gneisses	5 – 6.2	2.67
Basalt	5.5 – 6.3	

Gabbro	6.4 – 6.8	2.98
Dunite	7.5 – 8.1	
Peridotite	7.8 – 8.4	
Drilling Mud	1.83	
Air	0.330	
Calcite	6.1	2.71
Concrete	3.7	1.9 – 2.35

Table 1: Velocities of Various Rocks

For example, consider a 10 cm borehole through limestone and dolomite. We can estimate the compressional velocity at 4 Km/s and the shear velocity at 2.6 Km/s. With these numbers, the compressional and shear cutoff frequencies work out to 16 KHz and 21.6 KHz respectively. The source spectrum should contain at least the compressional cutoff frequency. Since the shear velocity is greater than the expected fluid velocity, shear waves can be generated with a monopole source and the source spectrum should also contain the shear cutoff frequency. For this example, select a source Transmitter Frequency of 15 KHz or 20 KHz.

For another example, consider a 20 cm borehole through sandstone. We can estimate the compressional velocity at 3 Km/s and the shear velocity at 2 Km/s. With these numbers, the compressional and shear cutoff frequencies work out to 6 KHz and 8.3 KHz respectively. The source spectrum should contain at least the compressional cutoff frequency. Since the shear velocity is greater than the expected fluid velocity, shear waves can be generated with a monopole source and the source spectrum should also contain the shear cutoff frequency. For this example, select a source Transmitter Frequency of 7 KHz.

To measure compressional velocity, use a monopole configuration and a transmitter frequency that contains the compressional cutoff frequency. Once compressional velocity is known, porosity can be obtained from the Wylie equation.

Shear velocity can be measured with a variety of techniques. First, if the shear velocity is greater than the fluid velocity, select a transmitter frequency that narrowly contains the compressional and shear cutoff frequencies, then find shear velocity from a semblance algorithm. Second, a dipole survey can be used to measure shear velocities even if the shear velocity is less than the fluid velocity. Another approach is to measure calculate velocity from a Stoneley wave survey. Shear velocity is then calculated using the Stoneley wave dispersion relationship.

To measure permeability, measure the Stoneley wave amplitude and the shear velocity. The Stoneley wave amplitude varies mostly due to shear velocity and permeability. Once the measured amplitudes are corrected for variations in shear velocity, permeability can be calculated.

Other properties can also be measured. Bulk modulus is a function of compressional velocity and bulk density. Shear modulus is a function of shear velocity and bulk density. Poisson's ratio is a function of the compressional and shear velocities.

Survey Type	**Conditions**	**Transmitter Frequency Band**
Monopole compressional and shear wave survey	v_p and v_s are greater than v_f	Narrowly contains f_{pco} and f_{sco}
Monopole Stoneley wave survey	All	Below all cutoff frequencies, usually 1-3 KHz

Cement bond log	All	15-20 KHz
Dipole shear wave survey	All	1-3 KHz

Table 2: Survey Types

Specifications

Maximum pressure	3000 PSI
Operation temperature range	-20 to 70 degrees C
Storage temperature	-40 to 100 degrees C

Sample resolution:	12 bit
Receiver frequency response	1 - 40 KHz
Receiver gain:	1, 2, 4, 8, 16, AGC
Sampling	2uS (no stacking) 4 uS - 100 in 4 uS increments
Number of samples per receiver:	0 to 1024
Sample holdoff time	10 to 2500 uS in 10 uS increments
Number of waveforms stacked and averaged	1 to 16
Stack interval	1-250 ms
Receiver modes	software configurable Monopole, dipole, reverse dipole stacking
Number of receivers	1-8

Transmitter frequency bands	0.5 to 1.5 KHz, 1 to 3 KHz, 1.5 to 4.5 KHz, 2 to 6 KHz, 2.5 to 7.5 KHz, 3.6 to 10.5 KHz, 5 to 15 KHz, 7.5 to 22.5 KHz, 10 to 30 KHz, 12.5 to 37.5 KHz, and 15 to 45 KHz.
Transmitter modes	user configurable Monopole, dipole, reverse dipole stacking
Number of transmitters	1-2

2SMA-1000 Modem Section

Length (assembled)	24.625 inches (62.55 cm)
Diameter	1.5 inches (3.81 cm)

2SRA-1000 Receiver Section

Length (assembled)	1 ft (30.48 cm)
Diameter	1.5 inches (3.81 cm)

2SIA-1000 and 2SIB-1000 (2SIC-1000 and 2SID-1000) Isolator Sections

Length (assembled)	29 (65) inches (73.66 (165.1) cm)
Diameter	1.75 inches (4.445 cm)

2STA-1000 Transmitter Section

Length (assembled)	25.25 inches (64.135 cm)
Diameter	1.5 inches (3.81 cm)

Centralizers

Diameter	1.75 inches (4.445 cm)

Two receiver single transmitter probe

Length (assembled)	80.875 inches (205.42 cm)
Diameter	1.75 inches (4.445 cm)
Weight	26 lbs (9.7 Kg)

Installation

Installing the 2SAA-1000

A software driver for the probe must be installed on the PC for the acquisition software to operate with the 2SAA-1000 sonic probe. Consult the software instruction manual for specific instructions.

The most common reason for failure of a logging probe is mechanical damage. Often this occurs in transportation. Provide a safe place for the probe during transportation and storage. Despite efforts to make logging probes as rugged as possible, they are still fragile instruments; they need to be protected.

The individual sections of the 2SAA-1000 probe may need to be assembled before logging. This process is easy and straightforward. Simply remove the protective caps from the ends of the sections and connect the sections. When assembling each section, insert the male end of one section into the female part of the next section. Rotate the sections until they mate properly. Install the three retaining screws.

The probe is assembled from the top to the bottom (see Figures 1 and 2). Start by connecting a modem section to the cable head. If using two transmitters, then add a transmitter section followed by an isolator section. Then add all of the receiver sections. Next add the isolator section followed by a transmitter section. If a second transmitter section is used, add another isolator section followed by the second transmitter section. Last, add the modem section.

Remember to always use the protective caps for each section and the probe top when disassembling the tool. This will keep the connectors free of corrosion, protect from mechanical damage, and keep the ‘O’ rings clean so that they will seat properly under pressure.

Operating Procedure

Operation

Assemble the desired transmitter and receiver array. When conducting a low frequency survey, longer isolators may be necessary. Generally, a 6 foot isolator is used for transmitter frequencies lower than 5 KHz; otherwise a 3 foot isolator is used. Adjust the centralizers for the nominal borehole diameter.

Before connecting the 2SAA-1000 sonic probe to the cable head, remove the probe top and cable head protectors and inspect the 'O' rings to make sure they have lubricant and are in good condition. When connecting the cable head, push the cable head into the probe top and rotate the probe (not the cable head) until the cable head is fully seated. Place a couple of wraps of vinyl electrical tape around the cable head - probe top connection to insure that the connection does not loosen in the borehole. Place the logging cable in the over the sheave wheel so that the probe hangs in the borehole. Use the winch to locate the probe at the beginning logging depth.

Select the proper probe driver in the acquisition software and power up the probe. Set up the probe parameters as described below. Note that the user may set up probe drivers with all of the probe parameters automatically setup for a particular type of survey. The maximum logging speed will depend on the number of receivers, **Number Stacked**, and the total **Number of Samples**. This is described in the Layout and Operating Parameter section. After setting the operating parameters for the probe, the probe can be logged as usual. Some examples for setting the operating parameters are provided below.

When operating the tool with two transmitters, it is possible dedicate receivers to a given transmitter. One transmitter and associated receivers could be operating in low frequency dipole mode (for a shear velocity survey), while the other transmitter and it's associated receivers could be operating in high frequency monopole mode (for a compressional velocity survey).

When finished logging the probe, make sure to thoroughly wash the transmitter staves and the space between them. Disassemble the probe as necessary and replace the protective caps.

After data collection, process the data with the SonProc and WellCAD programs. Since the transmitter frequency band cannot be precisely controlled, survey data are filtered using the SonProc program before conventional analysis begins. Use a band pass filter with the same corner frequencies as the approximated transmitter frequency band. For example if the transmitter center frequency was 5 KHz, set the SonProc band pass filter to 2.5 – 7.5 KHz. Pick first arrivals and amplitudes as usual with WellCAD.

In order to properly set the operating parameters for the probe, the user needs to know what parameters they are trying to measure. A thorough knowledge of this section will greatly assist the user in collecting quality data that can be processed with ease. Make sure you have read the Theory of Operation section before proceeding. Refer Figures 5 and 6 throughout the discussion in this section. Guidelines for setting each parameter follow.

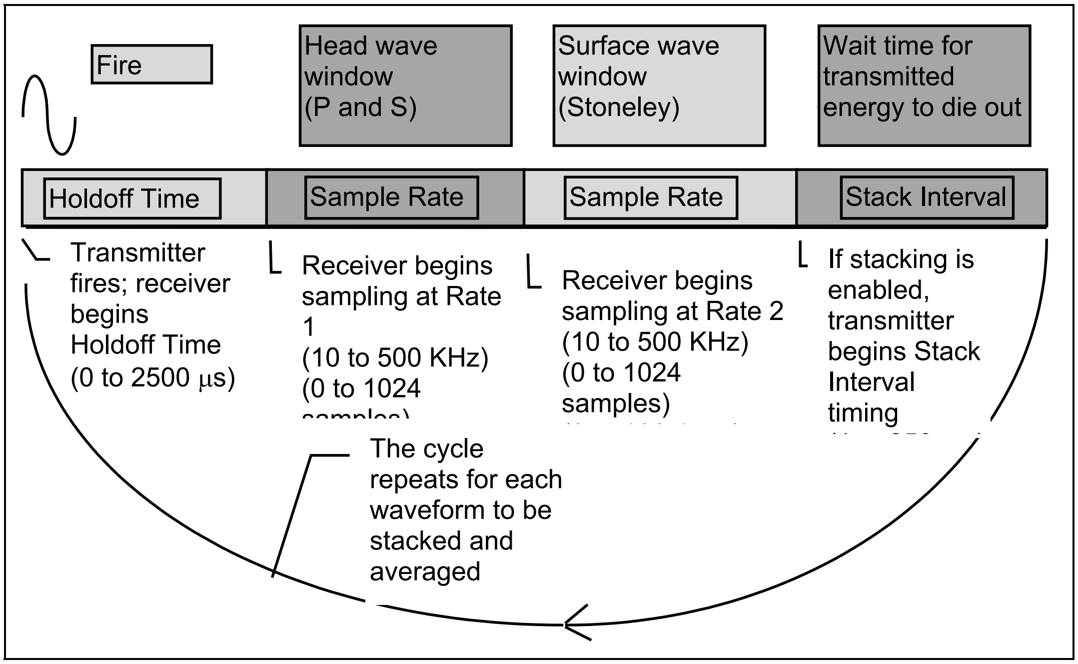
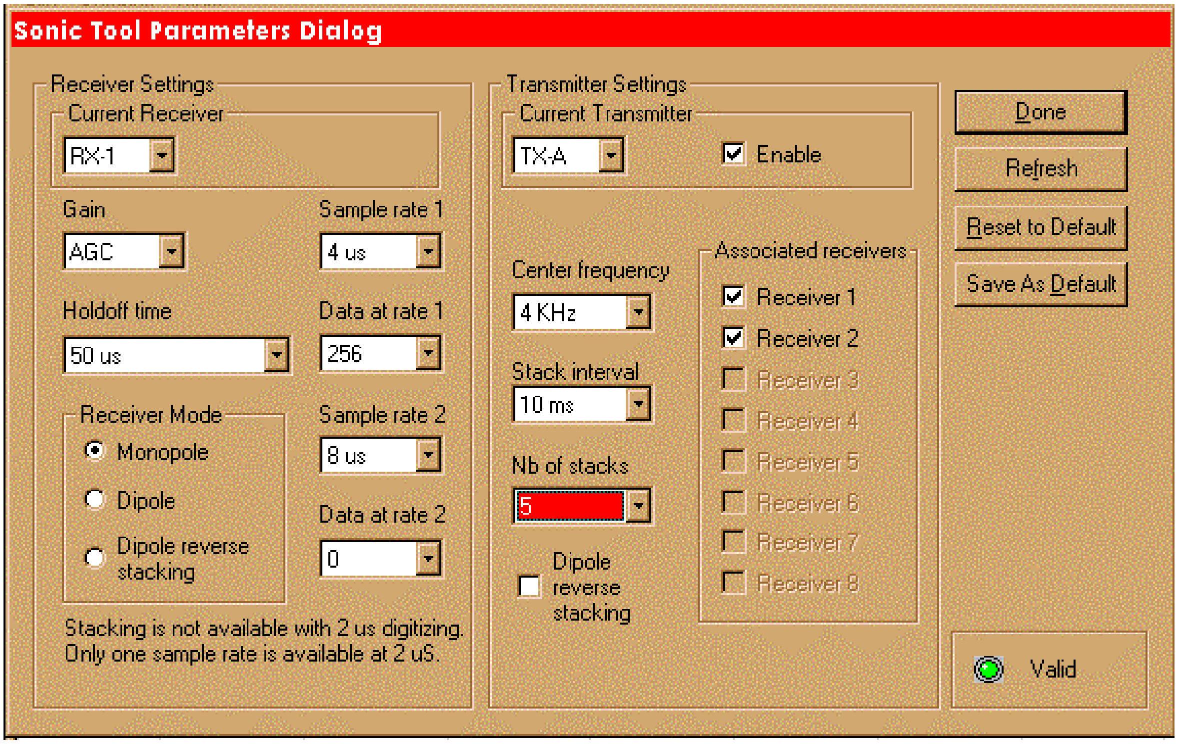


Figure 5: Receiver Timing (repeated for convenience)


Sonic Tool Parameters Dialog

Receiver Settings
Current Receiver: RX-1
Gain: AGC
Sample rate 1: 4 us
Holdoff time: 50 us
Data at rate 1: 256
Receiver Mode: ● Monopole ○ Dipole ○ Dipole reverse stacking
Sample rate 2: 8 us
Data at rate 2: 0
Stacking is not available with 2 us digitizing.
Only one sample rate is available at 2 uS.

Transmitter Settings
Current Transmitter: TX-A ☑ Enable
Center frequency: 4 KHz
Stack interval: 10 ms
Nb of stacks: 5
☐ Dipole reverse stacking
Associated receivers: ☑ Receiver 1 ☑ Receiver 2 ☐ Receiver 3 ☐ Receiver 4 ☐ Receiver 5 ☐ Receiver 6 ☐ Receiver 7 ☐ Receiver 8

Figure 6: Sonic Tool Parameters Dialog (repeated for convenience)

Sampling Rate 1 is usually set so that the first wavefront arrival can be accurately picked. The smaller the sample rate, the more accurate the first arrival pick. The tradeoff is that recording a large amount of data requires slower logging speeds and creates large data files. A good rule of thumb is to select a sample rate that is at least 10 times faster than the maximum frequency contained in the received waveform. For instance, if the transmitter frequency is 10 KHz, then the sample rate should be at least 100 KHz or 10 µs.

Sample Rate 2 is usually slower than **Sample Rate 1** because later in the received wave train (after the compressional and shear wave arrivals) are lower frequency surface waves (Stoneley). Geophysicists are usually interested only in the amplitude of these waves. Therefore, Sample Rate 2 is usually less than Sample Rate 1, sometimes by as much as factor of 5 or 10.

The **Number of Samples**, that is **Sample Rate 1** plus **Sample Rate 2**, can add to a maximum of 1024. The **Holdoff Time**, **Sample Rates**, and **Number of Samples** are sometimes chosen so that compressional and shear wave arrivals fall into the head wave window, and the Stoneley wave falls into the surface waves window. For example, given a source to receiver spacing of 3 feet, expected compressional wave rock velocities between 10 K ft/s and 13 K ft/s (75 to 100 μs/ft), expected Stoneley wave velocities slightly less than the fluid velocity (approximately 5 K ft/s or 200 μs/ft), and a nominal borehole diameter of 4 inches, the following parameters are selected. The **Transmitter Frequency** is chosen to be 15 KHz from the cutoff frequency calculations. The head wave window is selected as 100 to 600 μs, and the surface wave window is selected as 600 to 1200 μs. Since the transmitted frequency is 10 KHz, the head wave window **Sample Rate** is selected as 4 μs, and the surface wave window **Sample Rate** selected as 8 μs . The **Holdoff Time** is set to 100 μs , the **Number of Samples 1** to 200, and **Number of Samples 2** to 100. These parameters can be changed to account for a more wide variety of conditions, but the more samples that are recorded, the slower the logging speed. Sometimes, a single sample rate is used for the entire waveform. This simplifies the probe setup procedure. Some general guidelines follow.

The **Receiver Gain** is usually set to the AGC (automatic gain control). Sometimes the user is interested in the amplitude of the received waveform (i. e. cement bond or Stoneley wave logging). In this instance, the **Receiver Gain** may be set to 1,2,4,8, or 16. If the AGC setting is used, the receiver automatically chooses the best gain.

The transmitters and receivers can independently be configured for **Monopole**, **Dipole**, or **Reverse Dipole** operation. The receiver configuration is done with software settings. The transmitter configuration is a combination of software settings and transmitter stave positions. To configure the transmitter staves, refer to Figure 7 and proceed as follows. When operating the transmitter in Monopole mode, the six transmitter staves should be convex out. When operating the transmitter in Dipole or Reverse Dipole mode, the three transmitter staves nearest the machined flat on the tool should be concave out. To invert a transmitter stave, remove the stave, flip it, and re-attach it. Use a 3mm hex wrench to remove and install the staves. Before inverting the staves, make sure that the transmitter stave array has been carefully cleaned. Be careful not to damage the screw heads. If this operation is performed often, the screws should be replaced periodically. Be careful not to bend the staves.

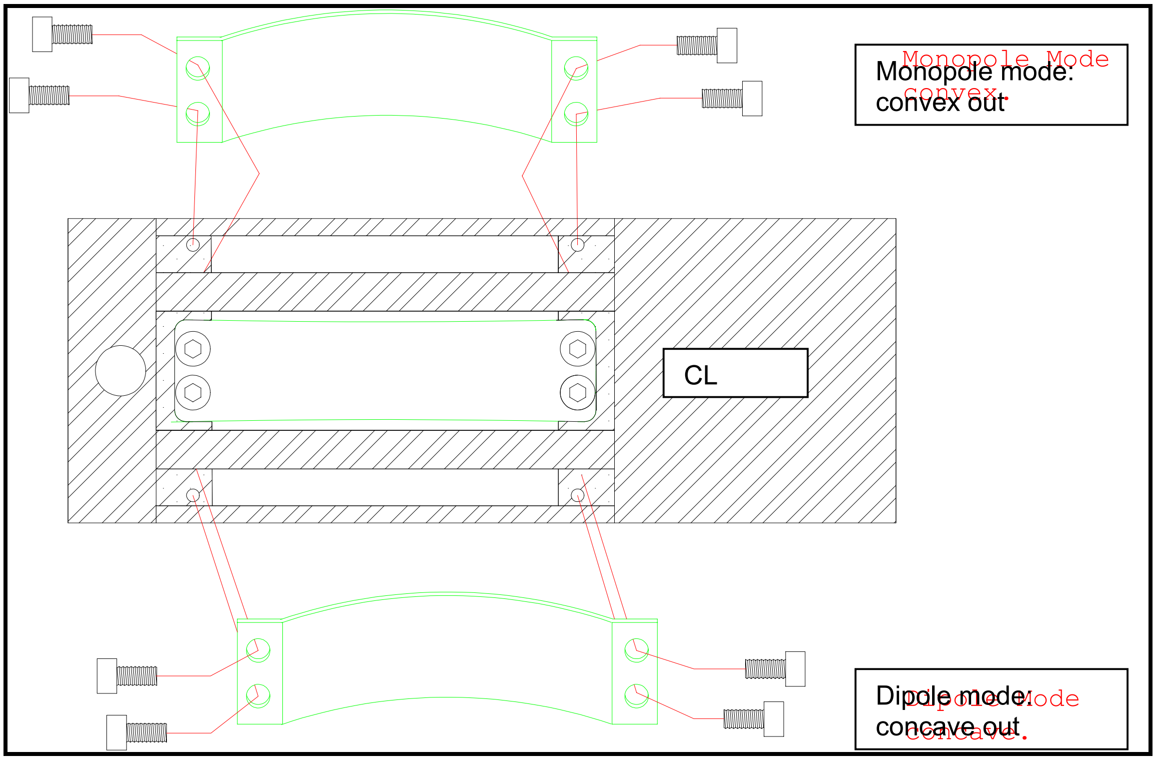

Monopole mode:
convex out
Monopole Mode
convex.
CL
Dipole mode:
concave out
Dipole Mode
concave.

Figure 7

Most users want to conduct a compressional and shear wave velocity survey. The objective in conducting this survey is to select a transmitter source spectrum that narrowly includes the compressional and shear wave cutoff frequencies, but few frequencies higher. This setup gives high amplitude compressional and shear wave arrivals that are not complicated by unwanted high frequency modes. Subsequently, shear wave arrivals can be picked in post processing using a semblance algorithm. Set the survey frequency band as described in the Theory of Operation section. Since the defining parameters for cutoff frequency may change as the probe is logged in different types of rocks, the user may need to change the survey frequency during logging. After collecting the data, perform processing as usual with SonProc and WellCAD.

Compressional and shear monopole logging without Stoneley window	
Number of Associated Receivers	2 or more (3 or more for semblence processing)
Receiver Gain	AGC
Receiver Holdoff Time	100 µs
Receiver Mode	Monopole
Sample Rate 1	4 µs
Number of Samples 1	256
Sample Rate 2	4 µs
Number of Samples 2	0
Transmitter Center Frequency	15 KHz depending on expected rock types
Stack Interval	50 ms
Number of Stacks	1
Transmitter to first receiver spacing	3 feet
Transmitter Mode	Monopole (all staves convex out)

Table 3: General guidelines for conducting a compressional and shear monopole survey without Stoneley window

A compressional and shear wave velocity survey can be conducted with the addition of a Stoneley wave window. This is not the optimal methods for conducting a Stoneley wave survey, but does have the advantage of collecting all data in a single logging pass. After collecting the data, perform processing as usual with SonProc and WellCAD.

Compressional and shear monopole logging with Stoneley window	
Number of Associated Receivers	2 or more (3 or more for semblence processing)
Receiver Gain	AGC, may choose fixed gain if measuring Stoneley wave amplitude
Receiver Holdoff Time	100 µs
Receiver Mode	Monopole
Sample Rate 1	4 µs
Number of Samples 1	200
Sample Rate 2	8 µs
Number of Samples 2	200
Transmitter Center Frequency	15 KHz depending on expected rock types
Stack Interval	50 ms
Number of Stacks	1
Transmitter to first receiver spacing	3 feet
Transmitter Mode	Monopole (all staves convex out)

Table 4: General guidelines for conducting a compressional and shear monopole survey with Stoneley window

A low frequency dipole survey can be used to measure shear velocity. This method is especially useful when the shear velocity is less than that of formation fluid. This is usually the case for soft formations such as shale, or poorly consolidated sediments. To configure the tool for this type of survey, refer to Figure 7 and proceed as follows. Invert the three transmitter staves on the same side of the tool as the reference dots on the receiver sections. After collecting the data, perform processing as usual with SonProc and WellCAD.

Shear dipole logging	
Number of Associated Receivers	2 or more
Receiver Gain	AGC
Receiver Holdoff Time	150 μs
Receiver Mode	Dipole Reverse Stacking
Sample Rate 1	16 μs
Number of Samples 1	256
Sample Rate 2	16 μs
Number of Samples 2	0
Transmitter Center Frequency	1-5 KHz depending on signal strength, lower frequencies give more accurate the shear velocity measurement
Stack Interval	50 ms
Number of Stacks	4
Transmitter to first receiver spacing	6 feet
Transmitter Mode	Dipole Reverse Stacking (3 staves convex out, 3 staves by center line flat concave out)

Table 5: General guidelines for conducting a shear dipole survey

Stoneley waves are best recorded using a survey frequency less than the cutoff frequency of both the compressional and shear waves. Refer to the table in the compressional and shear wave section. Generally, a survey frequency of a 1-3 KHz works well. Stoneley wave are slower than fluid waves, therefore the optimal window for determining Stoneley wave amplitude would begin at 600 μs for a three foot transmitter to receiver spacing (the slowness of water is about 200 μs per foot). After collecting the data, perform processing as usual with SonProc and WellCAD.

Stoneley wave monopole logging	
Number of Associated Receivers	2 or more
Receiver Gain	Fixed (1-16)
Receiver Holdoff Time	150 μs
Receiver Mode	Monopole
Sample Rate 1	16 μs
Number of Samples 1	256
Sample Rate 2	16 μs
Number of Samples 2	0
Transmitter Center Frequency	1-5 KHz depending on signal strength, higher frequencies have less interference from tool body waves
Stack Interval	50 ms
Number of Stacks	1
Transmitter to first receiver spacing	6 feet
Transmitter Mode	Monopole (all staves convex out)

Table 6: General guidelines for conducting a Stoneley wave survey

Cement bond logs are usually conducted in the 15 to 20 KHz frequency range. The cement bond log requires amplitude calibration. Waveforms in free pipe (casing) and fully cemented pipe are needed for post processing. After collecting the data, perform processing as usual with SonProc and WellCAD.

Cement bond logging	
Number of Associated Receivers	2 or more
Receiver Gain	Fixed (1-16)
Receiver Holdoff Time	100 µs
Receiver Mode	Monopole
Sample Rate 1	4 µs
Number of Samples 1	256
Sample Rate 2	4 µs
Number of Samples 2	0
Transmitter Center Frequency	15 – 20 KHz
Stack Interval	50 ms
Number of Stacks	1
Transmitter to first receiver spacing	3 feet
Transmitter Mode	Monopole (all staves convex out)

Table 7: General guidelines for conducting a cement bond log survey

Performance Checks and Calibrations

The best running test of the probe is whether or not it will produce a clean relatively noise free signal in most environments. A standard test jig can easily be constructed out of a 3" Aluminum or steel pipe that is sealed at one end. Fill the tube full of water and then centralize the probe in it. A good clean received waveform should be observed when the probe is operated. When using a steel pipe, a consistent acoustic travel time (58 μs/ft) should be observed. Using a 1 foot receiver spacing, the reported Delta T should be 58 μs.

Verify that each of the following parameters has a corresponding effect on the received waveform when changed: **Transmitter Frequency**, **Holdoff Time**, **Sample Rate**, **Number of Samples**, and **Monopole/Dipole.** Listen to the clicking sound the transmitter makes when firing. By varying the **Stack Interval**, and **Number Stacked** parameters, the number of clicks and the time between them should change.

Calibration is usually not required unless a cement bond log is being run. A cement bond log calibration is simply recording the amplitude of the received waveform in free ringing steel pipe and fully cemented pipe. Consult a standard geophysical logging text for more information on cement bond logs.

Preventative Maintenance

The best advice for preventative maintenance is to keep the probe clean. This is especially true for the transmitter stave array. Also, the probe should be stored in a cool dry place. If the probe is stored on a logging truck, protect it from shock and vibration.

If the transmitter will be repeatedly changed back and forth from monopole to dipole mode, then the stave mounting screws should be replace periodically. It is recommended that these screws be replaced after every 5 to 10 time the staves are removed. There are 4 screws for each stave. These are special screws (P/N 2STA-0013) and are available from Mt. Sopris Instruments.

Troubleshooting

Problems with the Probe

If the probe does not perform properly using the aluminum or steel test tank described in the performance checks and calibrations section, then proceed as follows. Make sure that the logger is powered up and that the serial cable between the PC and the logger is not faulty. Try a different serial cable. Is the software probe driver the correct one for this probe? Do other probes work with the system?

The cable head and wireline are the most frequent cause of problems with any logging system. To test the wireline, remove the probe from the wireline. Remove power from the system. Using a digital multimeter, measure the resistance between the top of each wireline conductor (at the slip rings) and the bottom (at the cable head). For 24 gauge wireline, the resistance should be about 24 ohms for each 1000 feet (300 meters) of logging cable. If the resistance is less, or if it is very high, then there is likely a problem with the logging cable. Also check the resistance between each conductor in the logging cable and the cable armor. The resistance should be infinite. If not, then there is a problem with the wireline. Most problems with the wireline occur in the cable head or near the cable head. With a good preventative maintenance schedule, the cable head will be cut off and re-installed about every few hundred logging runs or every few months.

If other probes operate properly, then the problem is most likely the probe. When operating, are the ‘To Probe’ and ‘From Probe’ lights flashing on the MGX II logger? Both lights should flash periodically at about 1 second intervals (depending on the current time digitize interval). If the lights are flashing, but the transmitter is not making a clicking sound, then the transmitter is probably defective. Try reducing the number of sections in the probe to a minimum of a modem section, a receiver section, and a transmitter section. If you have more than one transmitter or receiver section, try swapping out different sections to isolate a defective section. **Do not connect or disconnect probe sections when power is applied**.

Disassembly Instructions

There are no user serviceable parts inside the probe. Since the probe sections are sealed, accessing the internal parts is not necessary. The disassembly instructions are provided to keep those who feel that they must open the probe from causing damage during disassembly. If a seal is broken on the probe in an extremely humid environment, the internal parts may begin to corrode. After the probe has been disassembled into it’s composite sections, the housings may be remove from each section.

To disassemble the modem section, remove the three radial screws near the probe top. Pull the probe top connector assembly out of the housing and unplug the cable from the circuit board. Unscrew the housing containing the circuit board. Strap wrenches may be necessary to remove the housing.

To disassemble a receiver section, remove the single set screw and unscrew the receiver housing. Strap wrenches may be necessary to remove the housing. Do not apply torque across the black portion of the receivers! Do not exchange housings between receiver sections. The receiver housings are not interchangeable.

The isolator section should not be disassembled.

To disassemble a transmitter section, remove the three radial screws near the end of the probe section away from the staved transmitter elements. Remove the Bullnose or attached probe section. Unscrew the housing containing the circuit board. Strap wrenches may be necessary to remove the housing. Do not apply torque across the staved transmitter elements! Do not attempt to disassemble the transmitter section any further.

To re-assemble each section, perform the disassembly process in reverse. While re-assembling the tool, inspect each ‘O’ Ring for damage and dirt. Clean or replace if needed. Coat the ‘O’ Rings with Parker ‘O’ ring compound.

Schematics

2SAA-1000

Drawing Number	Title

Appendix

Suggested QA Procedures

General notes for Quality Assurance (QA) are presented here for users who need to utilize these techniques when collecting data. These users will need to periodically calibrate their equipment using equipment whose calibration is traceable to an approved standard. Details of these calibrations must be recorded.

When an instrument is calibrated, records need to be kept regarding the calibration standard(s) used and what was changed on the instrument to calibrate it. Typically, the corrections made to the instrument involve changing constants that are used to scale the raw instrument reading so that the proper value is reported. The constants must be recorded during a calibration procedure. Mt. Sopris acquisition programs record the calibration constants that were used to acquire the data. This aids the QA process, but does not replace the need for recording these constants at the time of calibration. The reason for this is that the length of time since the last calibration is unknown with only this information.

The device providing the standard must be traceable to an accepted standard. Examples of organizations providing standards for measuring instrumentation are: The U. S. National Bureau of Standards; The American Petroleum Institute; and the American Society for Testing Materials. For example, if the voltmeter or the density standard used for calibration is not traceable to an approved organization, such as those listed above, the calibration should not be considered valid. Records should be kept indicating the last time that standard being used for calibration was calibrated or checked against an approved standard. The QA procedure necessary for some programs mandate that the calibration standards be periodically checked against a standard approved by a proper agency.

A QA procedure may dictate that data taken from a given locale be associated with records indicating the exact time and location that the data was collected. The data itself may have to be collected in a certain format to meet requirements. Often, QA procedures specify that surveys must be repeated and the data from the successive surveys compared. This technique is used to eliminate poor or invalid data.