RBT003 (1 11/16”)
RBT004 (3 1/8”)

ULTRAWIRE™ RADIAL BOND TOOL

User Guide

V1.0 November 2005

This User Guide is intended as a general reference source for the UltraWire™ Radial Bond Tool and principles of cement bond logging relating to it. The information and data provided has been checked for accuracy where possible. However Sondex and its employees do not accept responsibility for any decisions made by the reader or data results obtained from the use of this document and its associated materials.

For more information please refer to our manuals or contact sales@sondex.com.

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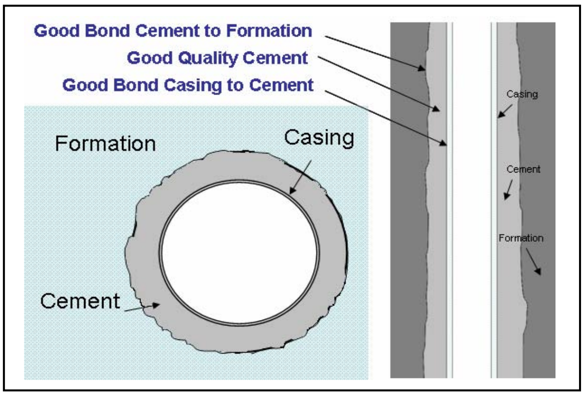
Functional Description

The prime use for the Radial Cement Bond Tool is to assure the asset owner of hydraulic isolation between producing and non-producing zones, and the integrity of the well, by the effective placement of the cement between the well tubulars (typically casing) and the formation. Poor cement can result in unwanted water or gas production, fluid migration in the annulus and inadequate support of the casing. In some instances the safety and integrity of the entire well can be threatened.

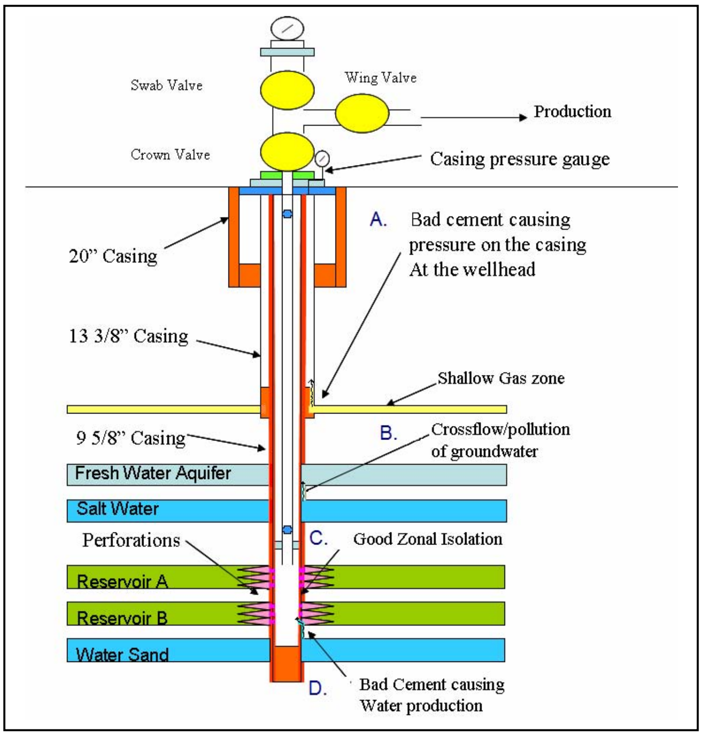
The ideal situation:



In an ideal situation the cement is of good quality (i.e. high compressive strength), has high bond strength between formation-cement and casing-cement and the cement column will have sufficient length for hydraulic isolation.

Possible Problems:

If the casing is not cemented into the well properly this can be detrimental to the integrity of the well and lead to fluid migration and communication between zones. Correct diagnosis is the key to remediation of the problem. Cement bond logging tools such as the RBT provide an answer as to how good or bad the cement is however sometimes the data from additional logging tools may be required. Below is an illustration of potential problems that can occur when the cement quality and bond are poor.



A: Pressure on Casing	A poor cement bond to the formation has allowed gas from a gas zone to percolate into the casing annulus causing high casing pressure which can endanger the well.
B: Pollution of Groundwater	Poor cement is allowing cross flow behind casing of saline formation water into a freshwater aquifer. This would also corrode the casing.
C: Good Zonal Isolation	A zone is isolated and has good cement bond when fluids from the zone cannot flow behind the casing. An approximation of how much cement would be needed for good isolation, **[2 x casing size" - 5] = cement column in feet***, e.g. for 7" casing this would be 9ft of good cement.
D: Water flow behind pipe	Poor cement is allowing unwanted water flow from a lower formation to enter the well bore and be produced to surface. Production logging could be used to identify the water entry point and bond logs used confirm cement quality at that point.

* This formula is used only as a guide. Cement reference manuals should be used to accurately determine the cement column. Sondex accepts no responsibility for any results obtain or decisions made by using this formula.

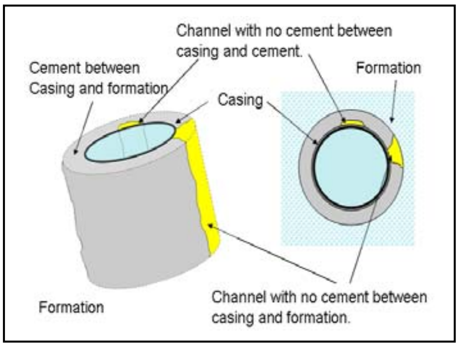
Oilwell cementing is a technologically advanced science. Despite this problems can occur, especially in deviated wells and those where the formation pressure is depleted.

It is not unusual for channels to occur where there is no cement, they provide a path for fluid migration; thus it is important that logging tools are run that can reliably identify these channels. Though conventional cement bond tools can indicate the quality of the formation-cement and casing-cement bonds, they cannot identify channelling in the cement conclusively. Radial bond tools allow the client to obtain a circumferential 'cement map' of the casing-cement bond enabling better identification channels.

In addition to channelling there are documented cases where helical buckling of casing has occurred due to a combination of sand production and inadequate support of the casing with cement. Various placement methods have been developed to deal with these problems. However, there is no substitute in the construction of critical wells for checking the condition of the cement by running a cement bond log. In the past some wells were completed without running a cement bond log, there may now be a need to bond log these wells.

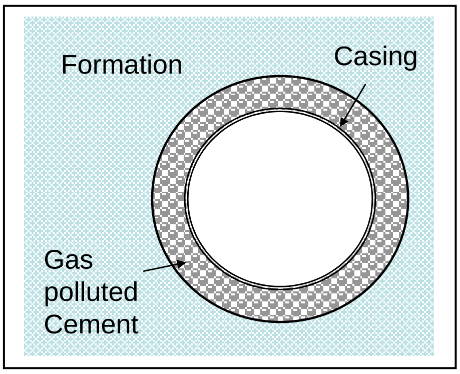
Cement Channelling

Cement channels are longitudinal pockets with no cement. This can happen when the mud is not adequately flushed from the wellbore during the cementing process (this is accentuated when the casing is not centralised). It can also be caused by gas or water migration during the time that the cement is curing and in high angle wells where heavy cement sinks to the low side of the wellbore leaving little or no cement on the high side. Standard CBL tools, average cement bond quality around the whole pipe and cannot indicate, relative to high or low side of the pipe, where the changes occur. On a traditional CBL map, channels show up as low compressive strength cement/intermediate bond.



Low compressive strength cement

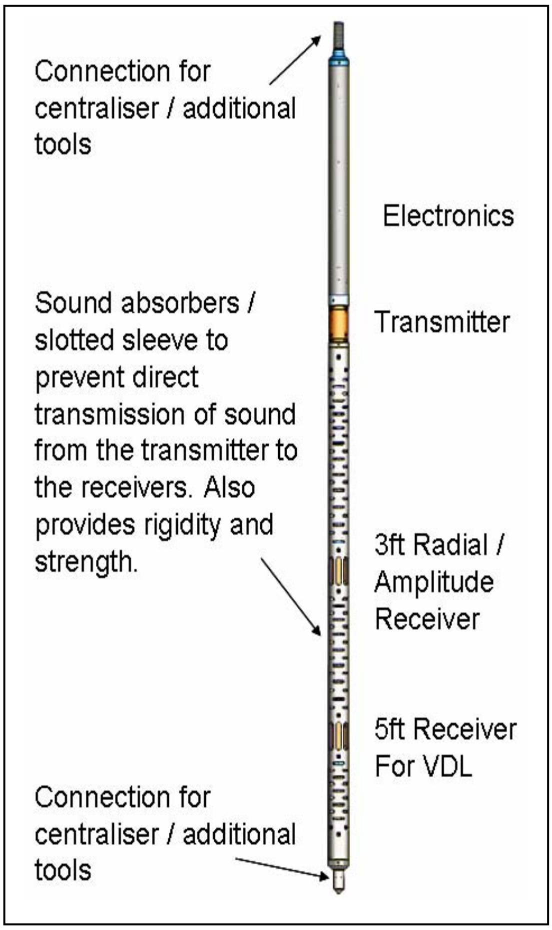
If the cement is poor quality or the wrong type for the well the compressive strength of the cement may be reduced. Also the situation may occur where cement further up the hole sets prematurely which isolates the hydrostatic pressure and allows the pressure of the uncured cement to drop to formation pressure. When this happens the cement can be polluted by formation fluids and thus become porous and permeable. For example tests have shown gas polluted cement to have a permeability as high as 5 md. The RBT produces a cement map which allows the oil



company to differentiate chanelling from low compressive strength cement and identify where it occurs in relation to pipe high or low side.

In both the above situations the cement is not fulfilling it's prime function which is to hydraulically isolate the formations.

Construction of the UltraWire™ Radial Bond Tool

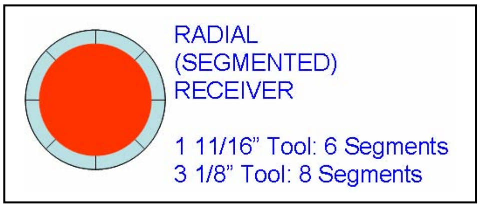


- An omni-directional piezoelectric transmitter crystal generates acoustic energy in response to an electrical signal sent from the tool electronics. The pulsed sonic signals are at 18 Khz ($3^{1}/_{8}$" tool) or 22 kHz ($1^{11}/_{16}$" tool).

- This acoustic energy travels at different speeds as a wavefront through the mud, casing cement and formation. During this time the signal is also attenuated.

- Sonic dampers within the tool prevent the transmitted signals travelling down through the tool to the receivers below.

- At 3ft (1m) from the transmitter is a segmented piezoelectric radial receiver. Each segment captures the returning acoustic energy and converts it into an electrical signal. As each segment detects the acoustic energy of a portion of the casing it allows the creation of a cement map.



- Internally the individual signals from the segments are electrically combined to obtain the omni directional amplitude which is equivalent to the standard 3ft signal from non segmented CBL tools.

- At 5ft from the transmitter is an omni directional piezoelectric receiver. This position has a greater depth of investigation and is used to record the waveform trace from which the Variable Density Log (VDL) is produced. In general the VDL is used to assess the cement-formation bond and CBL for the casing-cement bond.

- The sonic signals are received by the main analogue circuit board, conditioned and then portions of the waveform are digitized. From the 3ft segmented receivers the portion of the signal between 170-370 µs is digitized and from the 5ft receiver the full waveform 200-1200 µs is digitized.

- The digitized waveform data is stored in temporary memory and on command from the UltraWire™ controller or UMT memory recorder the digitized waveform data is transmitted to surface via the XTU or recorded into the UMT memory recorder.

- Additional UltraWire™ Gamma Ray and CCL tools are run in the string for depth correlation. The RBT can also be run with an UltraWire™ temperature logging tool.

- The RBT is run between strong centralisers; if the tool is not properly centralized data integrity is compromised. As little as 1/4” off centre can reduce the casing arrival amplitude by up to 2/3 of the signal.
- Additional Sondex UltraWire™ tools can be run in series with the RBT if required.
- The top and bottom tool connections are Sondex-GO.

RBT tools for high temperature environments

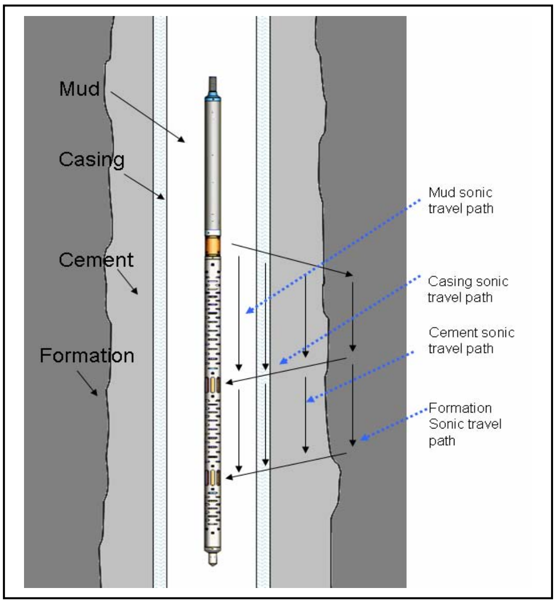
For operation in very high temperature wells, 3 $^1/_8$” UltraWire™ RBT can be encased in a flask; this option will be available from 2006. The temperature rating of the tool increases to 400°F (204°C) and pressure rating to 30,000 psi (207 MPa). The string is made up of 2 modules - UltraLink™ telemetry/gamma ray/CCL in one flasked sub and the RBT tool in another. As with all UltraWire™ the RBT is fully compatible with other tools using this telemetry.

For more information on flasked RBT tools please contact Sondex.

Theory of Measurement of the Radial Bond Tool

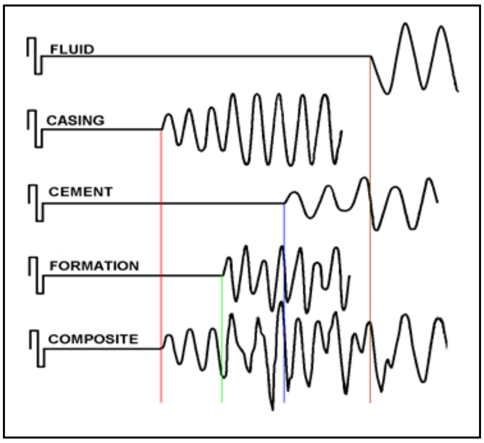
Cement bond tools use acoustic signals to evaluate the condition of the cement.

- A piezoelectric crystal is used to convert pulsed electrical energy to sonic energy for transmission. Reciever piezoelectric crystals are used to convert the arriving acoustic energy into electrical energy for recording.
- A high frequency acoustic pulse is transmitted out to the casing at regular intervals.
- Sound travels through the borehole fluid, contacts the casing and travels along it before returning through the borehole fluid back to the receiver.
- Some of the signal will pass through the casing into the cement, and into the formation before it is returned.
- The segmented receiver 3ft from the transmitter detects the early part of the returning signal to determine the casing-cement bond.



- The single crystal receiver 5ft from the transmitter detects the later part of the signal that comes from the cement and formation and is used to generate a VDL which is used to evaluate the cement-formation bond.
- The return signals contain components from several sources - compressional waves returning from the casing and fluid, and also compressional/shear waves from the cement and formation.
- The waveform is used to interpret the cement bond.

The diagram on the left illustrates the different components of the received signal. The recievers record the composite signal comprised of casing, formation, cement and fluid arrivals. In general the casing has the highest sonic velocity so this signal arrives first followed by the formation signals. In very hard formations with high sonic velocity (called 'fast' formations) the formation signals can arrive first and interfere with the casing returns.

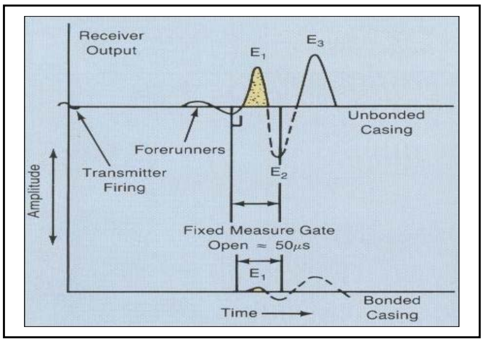


- Sonic energy reverberates within the casing.
- If the casing is unbonded the amplitude of the casing arrival will be high.
- If the casing is bonded the amplitude of the casing arrival will be low.

Curves on the log.

Amplitude

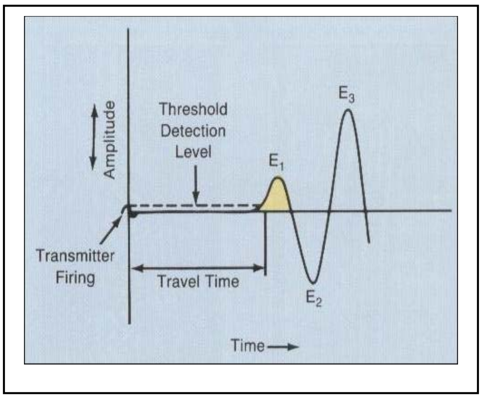
By measuring the amplitude of the casing arrival we have a way of evaluating the casing-cement bond. An analogy is to imagine the casing as if it were a bell being struck by a hammer. If the bell was clamped when it was struck the ringing would be low and dull – it is said to be attenuated; this would equate to there being cement behind the casing. If the bell is free it rings loud and strong; the signal is not attenuated and there is no cement behind the casing.



- For the casing-cement bond the 3ft signal is used. Typically, at this spacing the casing signal is usually separated from the formation signals.
- The amplitude measurement is made within a specific window in time known as a "Gate". This corresponds to the casing arrival or 'E1'.
- The highest point within the "Gate" is the amplitude measurement.
- This amplitude is plotted on the log and scaled in millivolts.

Travel Time curve (also known as Arrival or Transit Time)

The time taken between transmitter firing and the recievers detecting a signal above a set amplitude is also measured.



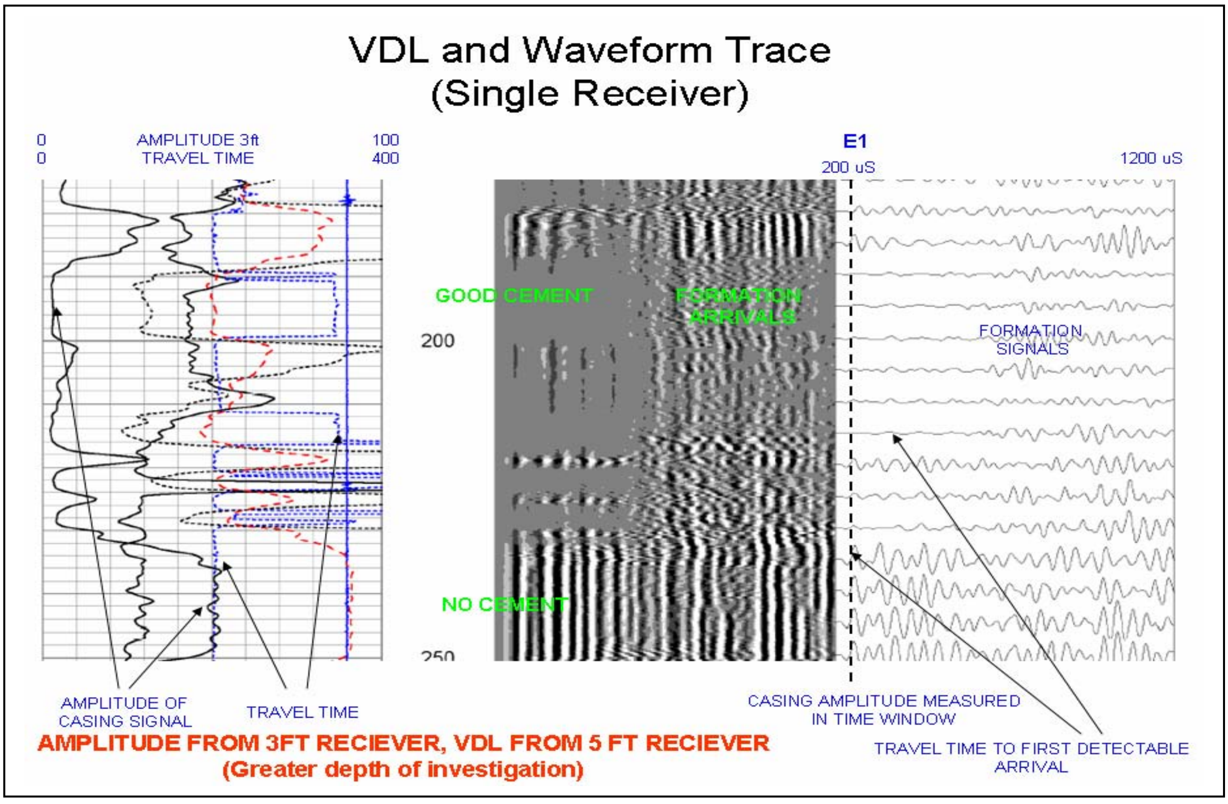
- Travel time is the time between the firing of the transmitter and the first point that the signal meets a fixed detection level.
- The travel time measurement will increase or "Stretch" as the amplitude of the E1 decreases.
- If the amplitude of E1 decreases below the threshold level, the reading will "Cycle Skip" and trigger on the E3 or later.

Using travel time to cross check the signal response:

i) Observe variation in transit time in areas of the well that indicate a good bond.
ii) Check for good centralisation of the tool in areas where E1 can be detected.
iii) Identify any fast formations where the first arrival will come from the formation and thus mask the casing arrivals. In fast formations formation arrivals in the casing 'gate' will falsely show the casing as non bonded. In this situation the travel time is less than the expected casing arrival time. A further check to verify a fast formation is if the difference in travel time between the 3ft and 5ft recievers is less than 114 µs.
iv) Check recorded transit time with transit time reference charts for known formations.

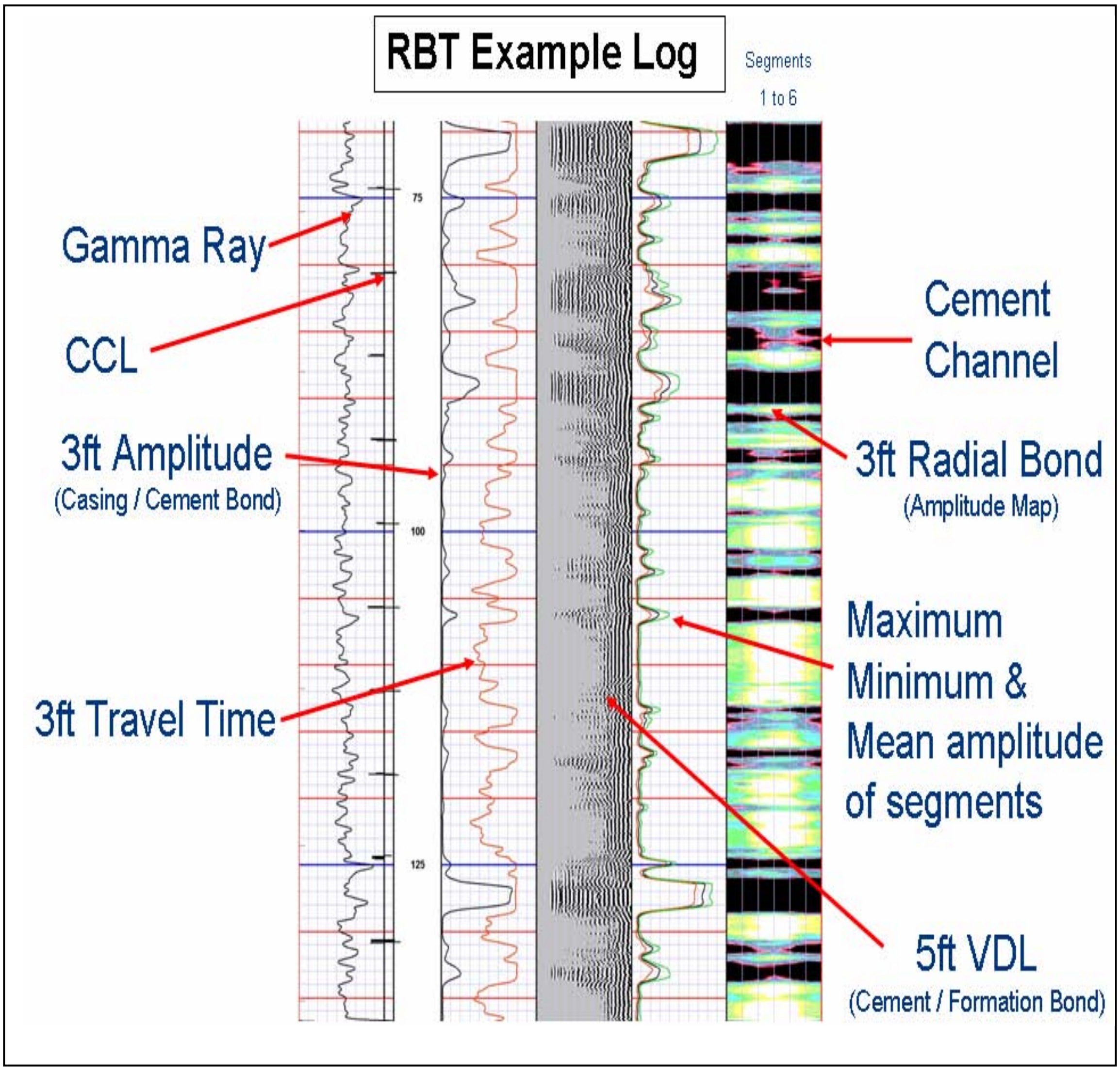
The Variable Density Log (VDL)

The VDL is used to illustrate the composite wave. This allows qualitative evaluation of the casing-cement and cement-formation bonds. The VDL is a 'top down' (Z-axis) plot of the amplitude of the composite sonic wave in grey scale. The diagram below shows the sonic waveform in track 3 and it's equivalent VDL in track 2.



Additional curves and displays from the RBT tool

Basic CBL tools have only 3ft and 5ft recievers, this is not usually enough to identify and locate channelling. The RBT produces additional data from each of the segmented crystals at 3ft which can be plotted on the log as 3 curves showing maximum, minimum and average amplitude and also as a 'cement map' where the amplitude of each segment is converted into a colour or gray scale. An illustration is overleaf.



Specifications

The UltraWire™ Radial Bond tools are available in $1^{11}/_{16}$" and $3^{1}/_{8}$" diameter versions. The $1^{11}/_{16}$" tool has 6 segments at the 3ft receiver and the $3^{1}/_{8}$" tool has 8 segments at the 3ft receiver. The choice of tool is dictated by the casing size the $3^{1}/_{8}$" tool will work better in larger casing but when re-entering production wells with small restrictions a $1^{11}/_{16}$" tool can be passed through 2 7/8" tubing to log in casing sizes up to 7".

The standard UltraWire™ RBT is temperature and pressure rated to 350°F (177°C) and 20,000 psi (138 MPa) respectively. Non UltraWire™ versions of the tools using analogue telemetry are available with temperature and pressure ratings of 400°F (204°C) /20,000 psi (138 MPa) for the $1^{11}/_{16}$" tool and 375°F (191°C) / 20,000 psi (138 MPa) for the $3^{1}/_{8}$" tool.

Primary calibration is within a 5.5" pressurized calibration tank. Calibration verification at the wellsite is done in area of known free pipe (assuming there is truly free pipe).

The prime quantifiable measurements are the 3ft omni and radial amplitudes which correspond to casing-cement bond and the 5ft measurement which is generally used for the cement-formation bond; this is considered to be qualitative.

Tool power requirements are 16-18VDC (the same as any other UltraWire™ tool) and 50-60 mA. The tools can be run in combination with all other Sondex UltraWire™ tools. They can be operated in surface read-out mode or in memory mode.

Suitable borehole fluids: Oil, Fresh Water, Brine. The fluid should be static; the tool will not work well in gas cut or moving fluids because the signal is rapidly dispersed before it is detected by the receivers.

Specification	$1^{11}/_{16}$" UltraWire™ Radial Bond	$3^{1}/_{8}$" UltraWire™ Radial Bond
Casing/Tubing Range	2.0 to 7.5" (50.8 to 191 mm)	3.75" to 13 3/8" (95 to 340 mm)
Length	9.9ft (3.03m)	9.5ft (2.89m)
Primary curves	Amplitude (3ft, Radial 1-6), Amplitude Map, Travel Time (3ft), VDL (5ft), Rotation	Amplitude (3ft, Radial 1-8), Amplitude Map, Travel Time (3ft), VDL (5ft), Rotation
Optional additional curves (plus any UltraWire™ tool) typically:	Scintillation Gamma Ray, CCL, Borehole Temperature	Scintillation Gamma Ray, CCL, Borehole Temperature
Transmitter Freq / interval	≈18 kHz	≈22 kHz
Number of radial receivers	6 at 3ft	8 at 3ft
3 ft Receiver (piezoelectric)	Yes (combined radials)	Yes (combined radials)
5ft Omni Receiver (piezoelectric)	Yes	Yes
High side indicator/rotation sensor	Yes	Yes
Precision	<1 mV	<1 mV
Weight	40 lbs (18.1 Kg)	140 lbs (63.5 Kg)
Position	Centralised	Centralised
Logging speed (SRO), 4 rdgs/ft	70 ft/min at 50 kbps telemetry	70 ft/min at 50 kbps telemetry
Logging speed (SRO), 4 rdgs/ft	100 ft/min at 100 kbps telemetry	100 ft/min at 100 kbps telemetry
Logging speed (memory)	30 ft/min (0.5s sampling. 4 rdgs/ ft)	30 ft/min (0.5s sampling. 4 rdgs/ ft)
Logging speed (memory)	75 ft/min (0.2s sampling. 4 rdgs/ ft)	75 ft/min (0.2s sampling. 4 rdgs/ ft)

Notes:

- The UltraWire™ Radial Bond Tool is combinable with all other UltraWire™ tools, e.g. Multi-finger Imaging Tool (MIT) or Metal Thickness Tool (MTT).
- The tools may be run in surface readout mode or memory mode.
- The UltraWire™ RBT has special high rigidity transmitter/receiver sections with a patented slot design.
- The RBT must be centralised during logging. High centralization force centralisers are recommended.
- In high angle wells knuckle joints may be used to de-couple other tools in the string above the centralisers e.g. XTU, gamma ray and CCL. This will help to maintain centralization of the RBT. In this situation only the RBT is run between centralisers.
- The high speed digital telemetry enables a faster logging speed and the setup of the tools is easier as line attenuation effects (seen with analog tools) are removed.
- High data sampling rates during memory logging operations reduce memory capacity. Sampling rates should be optimised to ensure the memory is not filled up before the log is completed. If there is insufficient memory a warning will be seen on programming.

Tool Calibration

There are 2 basic calibrations of the tool, for both the Sondex RCT001 pressurized calibration tank is used.

Shop Calibration of the Receiver crystals

The RBT is checked and calibrated during manufacture; however it is recommended that calibrations should be performed as part of the annual maintenance schedule or after a major service or repair. To do this a calibration test harness (part of p/n 4000006 Kit-HST) is fitted to the tool such that the transmitter/receiver sonde is inside the calibration tank and the electronic section is outside of it; the sonde should be centralised and the tank filled with water. Pressure of 500-700 psi is applied and the RBT transmitters turned on.

The signal gain of each individual receiver are set in the lab by fitting different resistors on the amplifier board and comparing the signal to an on-screen ‘oscilloscope’ which is included in the Warrior acquisition software. In the calibration tank under pressure, the received casing signal amplitude (E1) from each of the radials, the sum of the radials (near receiver) and the far receiver should be 1.0V +/- 0.02v.

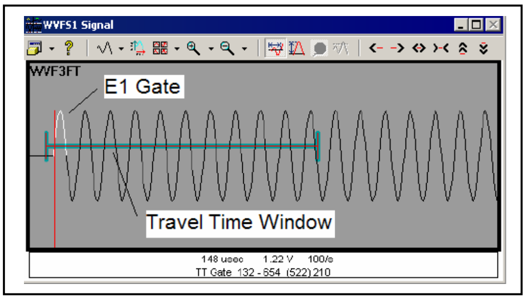
This master calibration is performed by Sondex Canada Inc on manufacture and can be repeated at client’s locations when required.

Pre-job Calibrations

It can be difficult to find truly free pipe in a well. Therefore before a job the free pipe calibration is performed using the calibration tank. To simulate downhole conditions and to compress any air voids the tank is filled with water and pressurized to 500 psi using a hand pump.

Setting the casing signal gates and travel time windows

- The Sondex UltraLink™ RBT service is selected and the tool is started up.
- The waveform window is loaded automatically by the acquisition software. This shows the waveforms of the 3ft, 5ft and individual receiver segments.
- Using Edit Variables the operator sets the casing OD (for calibration use 5.5”).



- From the onscreen viewer select the waveform to work with.
- Select the gate position button and using this button and gate width buttons set the timing gate at the correct position and width on the waveform, this should correspond to E1 peak.

- The width of the gate is typically 20-30 µS. The gate for the 5ft receiver should be approximately 114 µS later than the 3ft gate.

- Select the travel time button and using this button and gate width buttons position the travel time window to cover at least the first 3 peaks of the waveform. The amplitude threshold should be set high enough to avoid any baseline noise.

- Perform the same operation for each waveform. Care should be taken with the travel time window for the Near and Far waveforms.

- Save the free-point gate position file for further use.

Setting the Free-point Calibration

Before starting, check the amplitude gates have been positioned correctly.

- Select Action – Calibrate - SCBL Master Free Pipe Calibration. The SCBL amplitude calibration window is displayed.

- Edit the Target Pipe Amplitude to show 100 mV (the standard value for 5.5" casing is 71.9 mV however this is to compensate for the fact that the calibration tank is surrounded by air rather than fluid as you would get in a well).

- Edit the Target Sector E1 amplitude as 100.

- Select Sample-Begin to determine the calibration gains and offsets and save the calibrations.

- Select Action – Calibrate - SCBL Master Zero. Save the calibrations.

Setting the Zero Calibration

Before starting the amplitude gates should have been correctly positioned to measure the baseline before the casing waveforms arrive. Initially the gate positions will have to be set up and saved. For subsequent runs the saved gate position file can be loaded. As the tool is digital the baseline should be very close to zero.

- Perform the same steps as those for setting the free-point but set the Target Pipe Amplitude to zero and save.

Calibrating in memory mode.

In memory mode the calibrations are performed by running the tool in monitor mode via the UMT and MIP and viewing the waveforms with Warrior as you would with surface readout.

Surface Readout or Memory Mode?

The UltraWire™ digital system allows jobs to be performed in surface read-out (SRO) or memory mode. This is usually decided by the client though the service company can make recommendations. With surface readout RBT logging, the tool data and depth data are merged on acquisition. With memory RBT logging, the two tool data sets are stored in memory and merged after the job.

Advantages of SRO RBT operations. It is a big advantage to see real time tool responses and log curves because this allows the logging engineer and wellsite witness to make decisions on what is happening downhole before the tool is pulled out of the well. For example, a repeat section can be logged over zones of particular interest where there may be channels or very poor cement bond. If a section of free pipe is identified in the well the tool setup can be cross checked. When the logging operation is taking place in a very hot well or where rig costs are high (and non-production time must be minimised) it is always best to perform real time logging.

Advantages of Memory RBT operations. The advantage of memory operations is that minimal equipment and personnel are needed and thus the service is very cost effective. The tools are easily transported and can be deployed on using slickline or coiled tubing. Tool data is recorded directly into the memory section of the tool without being transmitted up-hole via the cable, which is a particular advantage in sour wells (with hydrogen-sulphide) and where rig power is poor.

Memory logging also provides an easy start up for new or small service companies and may fit in well with existing coiled tubing and slickline services.

Make up of Radial Bond Tool Logging Strings

The make up of the toolstring is dependent upon the size of tool used and whether the tool is run in SRO or memory mode.

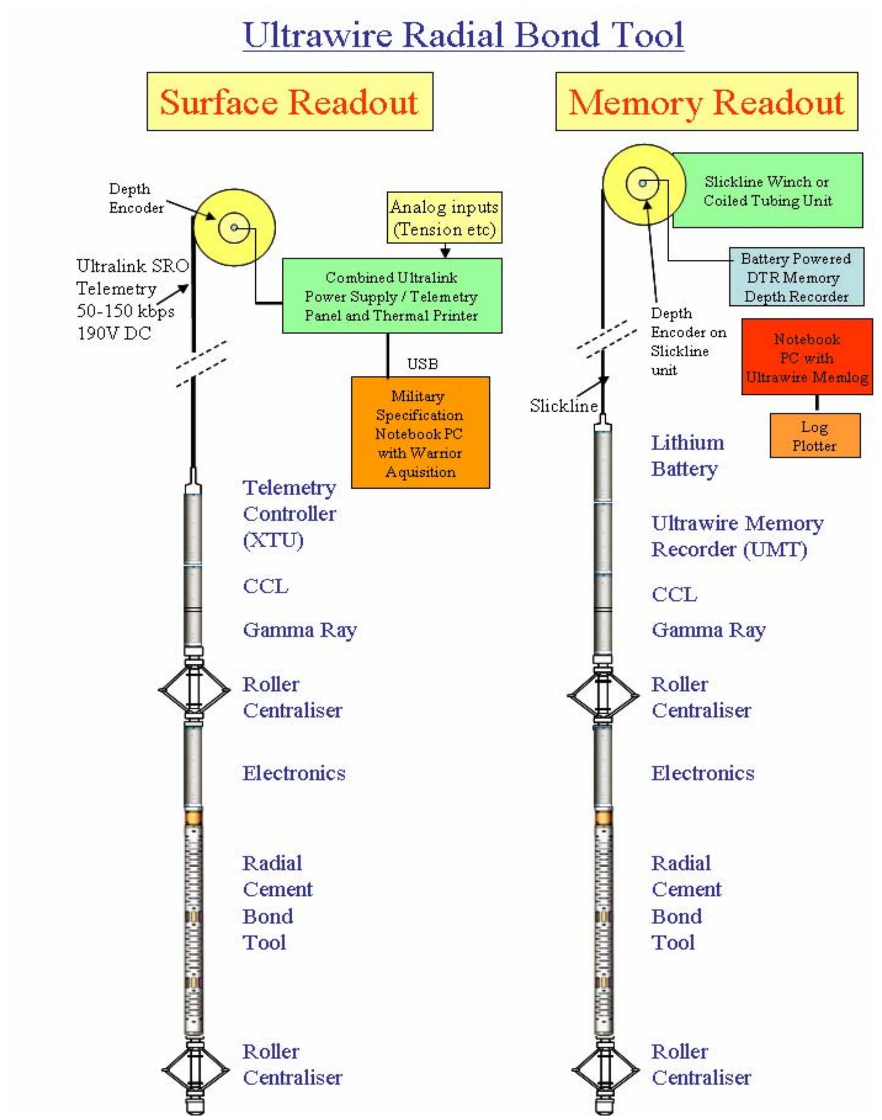


Illustration of SRO and Memory RBT systems

Typical toolstring components

XTU (SRO)	For **surface readout** an XTU telemetry controller is used at the top of the string. This interrogates the UltraWire™ tools and transmits the data to surface via UltraLink™. Tool power is sent via the cable from control panels in the logging unit.
UMT (MRO)	For **memory readout** a programmable UMT memory recorder is used at the top of the string. This interrogates the UltraWire™ tools and records the data into EEPROM memory. The UMT and logging string is powered by a high temperature lithium battery.
Roller Centralisers and knuckle joints	The RBT tool must be run centralized. For the $1^{11}/_{16}$” RBT, 4 arm roller centralisers PRC034 are used. These have a high centralisation force and can be used in casing sizes up to $9^{5}/_{8}$. The $3^{1}/_{8}$” RBT is heavy; use either the $2^{1}/_{8}$” PRC041 or 2¾” PRC057 centralisers. The design of the centraliser wheel assembly (with tandem rollers) minimizes ‘road noise’ from vibrations – noise can mask the sonic signal detected by the tool receivers. If using $1^{11}/_{16}$” centralisers with the heavy $3^{1}/_{8}$” RBT then the toolstring must be made up vertically which may require a special clamp. An additional centraliser can be placed above the XTU or UMT if required. In highly deviated wells knuckle joints can also be de-couple the RBT and associated centralisers from the rest of the string to assist with centralization.
Gamma Ray	An UltraWire™ scintillation gamma ray tool is used for depth correlation.
CCL	An UltraWire™ casing collar locator is used to produce a GR/CCL (completion) log and for depth correlation. For the $3^{1}/_{8}$” RBT a $3^{1}/_{8}$” CCL is used.
Radial Bond Tool	A $1^{11}/_{16}$” Radial Bond tool is used for tubing or casing sizes from 2.00” to 7.50”. The 3ft receiver has 6 segments. The 5 ft receiver is omni-directional. A $3^{1}/_{8}$” Radial Bond tool is used for tubing or casing sizes 3.75” to 13.38”. The 3ft receiver has 8 segments. The 5 ft receiver is omni-directional.
Temperature (Optional)	A temperature tool can be included in the string to locate the top of the cement and identify fluid movement behind the casing. Cement curing is exothermic thus a rise in temperature may be detected where the cement is placed.
Bull Nose	If no additional UltraWire™ tools are run a bull nose is required for the bottom of the string. The bull nose contains an UltraWire™ terminator.

Typical RBT String Lengths

A full RBT string with tandem knuckle joints, centralisers, gamma ray and CCL has the following dimensions:

Tool Type	MRO string length	MRO string wt.	SRO string length	SRO string wt.
$1^{11}/_{16}$” RBT	23.0 ft	107 lbs	21.3 ft	96 lb
$3^{1}/_{8}$” RBT	22.6 ft	207 lbs	20.9 ft	196 lb

Acquisition Software

SRO RBT logging is performed using a Sondex modified version of the Windows® based Warrior software. The software includes calibration routines and a variety of RBT data presentation formats. The UltraLink™ RBT data is routed to the PC via an UltraLink™ panel or via an UltraLink™ module fitted within a Warrior STIP panel.

Memory RBT logging is performed using Sondex Ultrawire Memlog™ for the UMT memory recorder. The software programs the tools, merges the data and outputs the merged logging passes as raw data into the Warrior database for post acquisition re-calculation and production of the logs.

Performing the logging job

- The tools are pre-job calibrated at surface using the 5.5” pressurized calibration tank. This sets the gains and offsets for the correct amplitude in 5.5” free pipe. The free pipe amplitude in the well will vary depending on the casing size.

- Connected RBT to centralisers and other UltraWire™ tools in the string, rigged up and run in the well. Running in hole/pulling out of hole speed should not exceed 50 m/min.

- For amplitude corrections the Warrior well variables are set for the casing size to be logged.

- If a section of casing with free pipe is observed the amplitude gates are re-set to correspond for the arrival time of E1 peak for that casing size. If no free pipe is seen use a saved gate position file for that casing size. In memory mode the gate setting is made after the job but a pre-established gate position file can be used as a starting point. It is also possible to specify an auto gate look up file which is referred to by cross reference with the casing size in the zoned variables.

- For SRO operations the tools should be depth correlated downhole to a reference log, before the cement log is run. Position the RBT below the logging interval, where there is enough rat-hole this should be a distance equivalent to the overall tool length below the interval; this will ensure that no data is missed once the log is started. In memory mode data should be recorded from below the logging interval and the log is depth matched after the job.

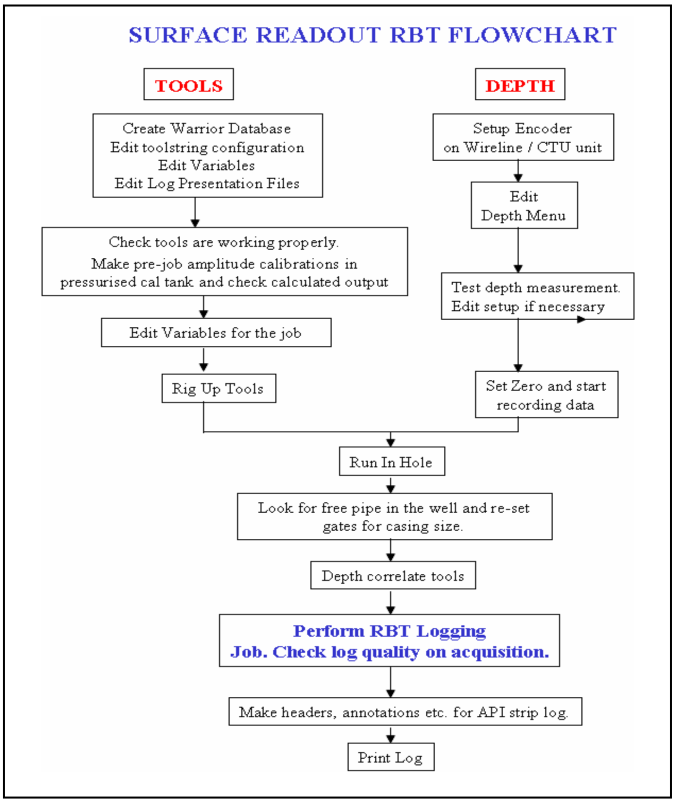
- The toolstring is logged up the hole at a recommended 30 to 45 ft/min (10-15 m/min). However, the high bandwidth of UltraWire™ allows logging speeds up to 100 ft/min (30 m/min) when rig time is paramount.

- In SRO mode the engineer should check that the gate settings remain correct, these can be adjust if E1 drifts outside the gate or a new casing size is seen. A new casing size can be handled automatically if the auto gate function is used.

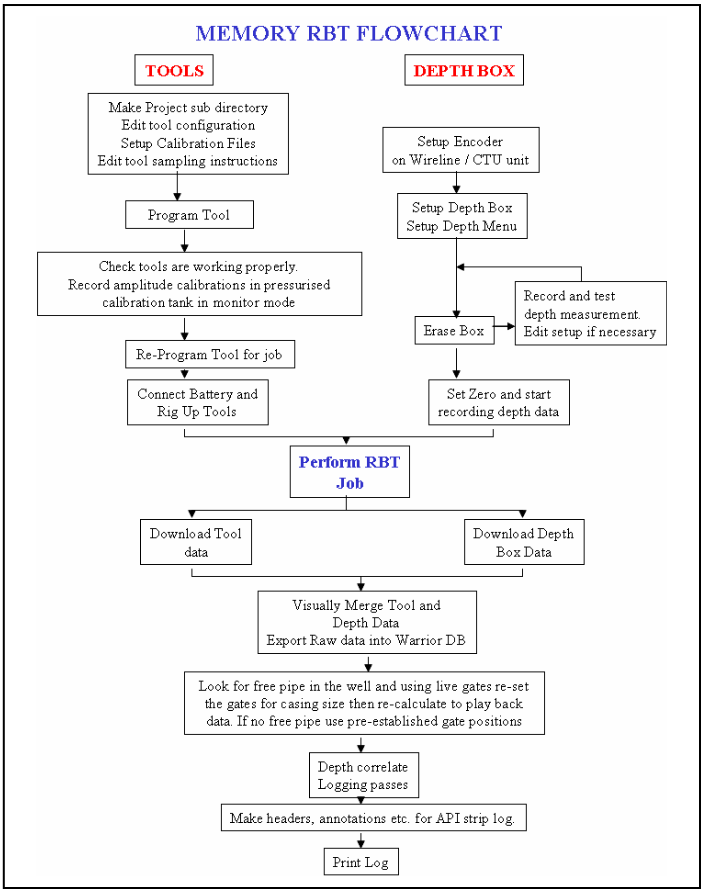
- Perform a repeat log over sections where there may be channels, changes in cement quality, fast formation, etc. For memory logging it is recommended that a repeat section over the whole interval be done if there is enough memory capacity. If not the zone of main interest should be repeated.

- When logging is complete the tool string is pulled out of hole and rigged down.

Job Flowchart Surface Readout

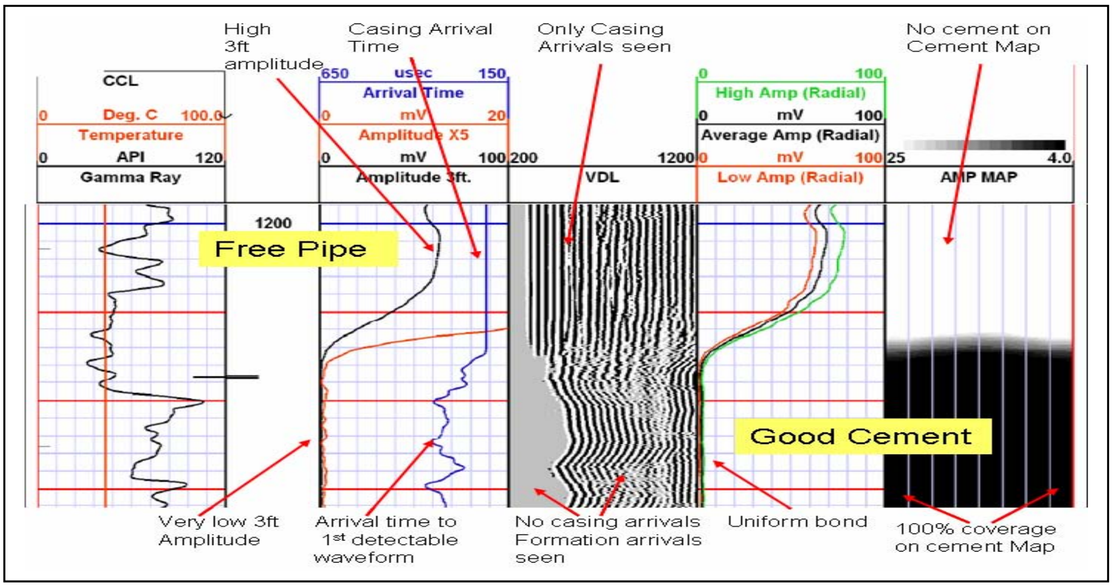


Job Flowchart Memory Readout



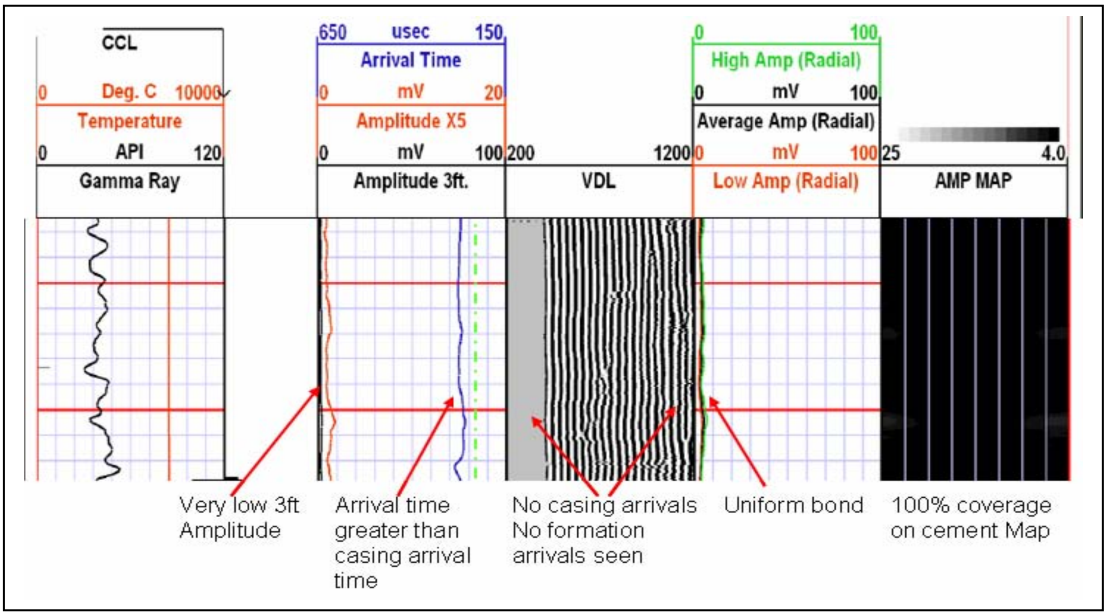
EXAMPLE LOGS

Good cement with free pipe on top



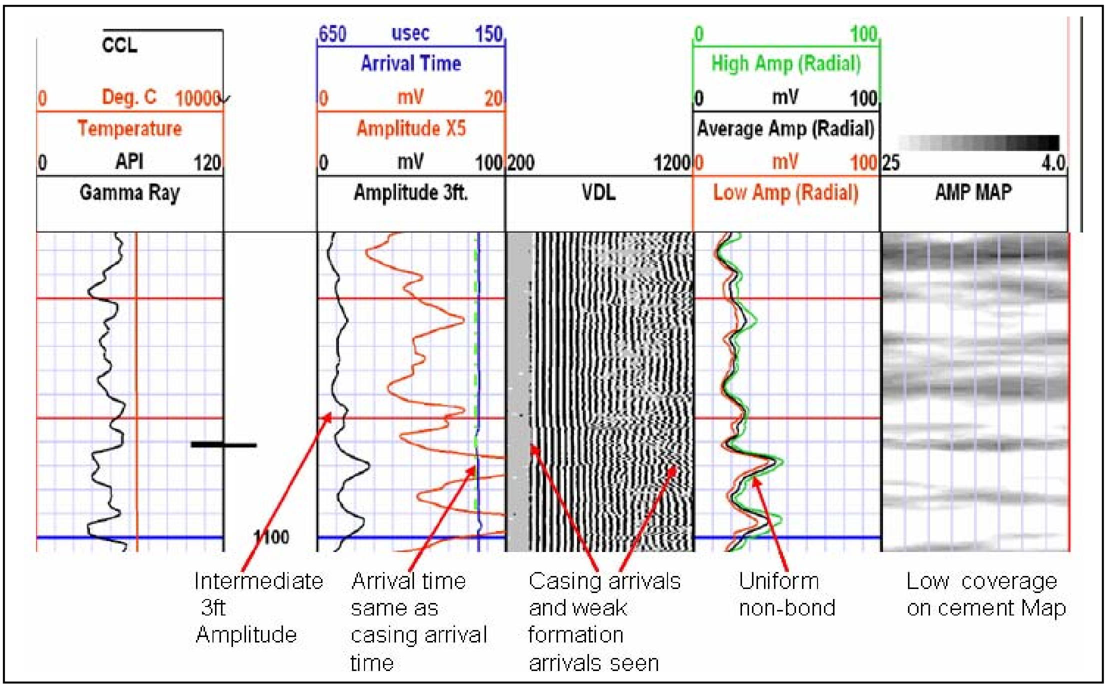
In this example there is free pipe at the top of the log. There is high casing amplitude, the arrival time corresponds to the casing arrival time, reverberation can be seen on the VDL and the cement map shows 0% cement bond. At the bottom the pipe is well bonded, signal amplitude is very low, arrival time increases and there is 100% cement bond. Formation arrivals can be seen on the VDL indicating a good cement-formation bond; where present formation arrivals can be loosely correlated to the gamma ray as formation type changes.

Good casing-cement bond, poor cement-formation bond



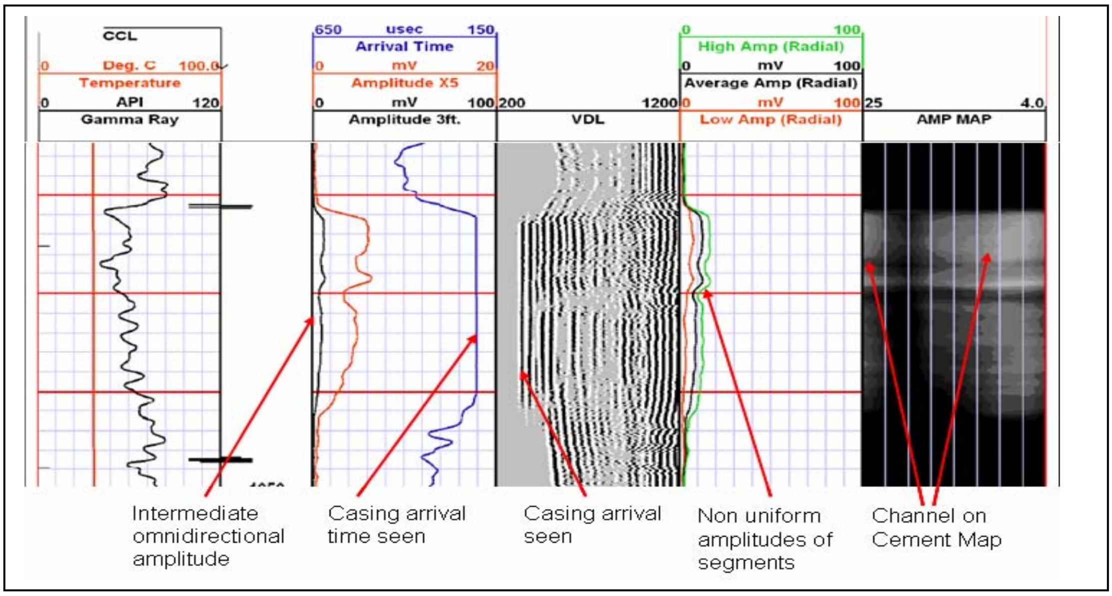
In this example the pipe is bonded to the cement, but the cement is not bonded to the formation. The signal amplitude is low, arrival time increases and the cement map shows 100% cement. However qualitatively we can say that the cement-formation bond is poor because we cannot see the formation arrivals. The casing may have a thin cement sheath. Note though that unconsolidated formations can look a little like this.

Poor bond casing cement, good bond to formation (possible micro annulus)



In this example there is high casing amplitude, the arrival time matches the casing arrival time and the cement bond shows relatively low bond quality. The VDL shows weak formation arrivals. It is also possible that this could be a micro annulus. The log should be repeated with the well fluids under low pressure. If a micro annulus exists the casing amplitude under pressure will be lower than that with no pressure.

Channelling



In this example there is channelling. The bond is shown as intermediate on the CBL but the radial segments show that there is approximately 30% cement bonded to the casing and the rest is poorly bonded or not present. Above and below the channel is good cement.

GUIDELINES FOR DATA/INTERPRETATION

Interpretation of a radial cement bond log is often qualitative from a visual appraisal. At the wellsite the engineer and the client witness will look at the log together in order to agree on the cement condition and any remedial action. If an immediate decision is not needed the data can reviewed in town.

Travel Time (also known as Arrival/Transit Time)

- For bonded pipe the travel time should increase as it triggers on the E3 peak or later arrivals.
- For free-pipe, the travel time should match the expected time for that casing size.
- If the travel time decreases below casing arrival time and the amplitude drops then suspect eccentralisation and cross check against the cement map.
- If the travel time decreases below casing arrival time and the amplitude increases suspect fast formations.
- The travel time difference between the 3ft and 5ft receivers should be 114 µs. If it less than this suspect fast formations.

Amplitude

- For bonded pipe the amplitude should be low.
- For free-pipe the amplitude will be high.
- If the amplitude is intermediate cross check with the cement map to see if the problem is cement channelling or low compressive strength cement.

Cement Map

- In bonded pipe the cement map should show uniform low amplitude.
- In non bonded pipe the cement map should show uniform high amplitude.
- In cases with channelling the signal amplitude at some of the receiver segments will be high.
- In cases of low compressive strength all the segments will show intermediate amplitude.
- If the tool is eccentralised the cement map will be non uniform.
- If the pipe is lying against the formation the cement map may be non uniform.

Bond Index

Bond Index is essentially the ratio of measured signal attenuation (taken from the log) to maximum attenuation. Readings of un-bonded pipe (free pipe amplitude = zero attenuation), bonded pipe (close to zero amplitude = maximum attenuation) and log value are used. A bond index of 0.8 or higher is accepted as indicating good cement. For cement showing a bond index of 0.8 a rule of thumb for the required interval of good cement for hydraulic isolation in ft is 2 x Casing OD – 5. For example in 9 5/8" casing the minimum interval of good cement for hydraulic isolation would be 13.25ft.

Compressive Strength.

Compressive strength is a measure of the strength of the cement to support the casing and its resistance to crushing. The units of measurement are psi. It is a non linear calculation from amplitude, casing size and casing thickness. For a manual interpretation nomograms may be found in industry text books. Higher amplitude equates to low compressive strength, low amplitude equates to high compressive strength. With standard CBL tools it is almost impossible to differentiate between low compressive strength cement and a cement channel. To use the nomograms correctly the tool should be properly calibrated.

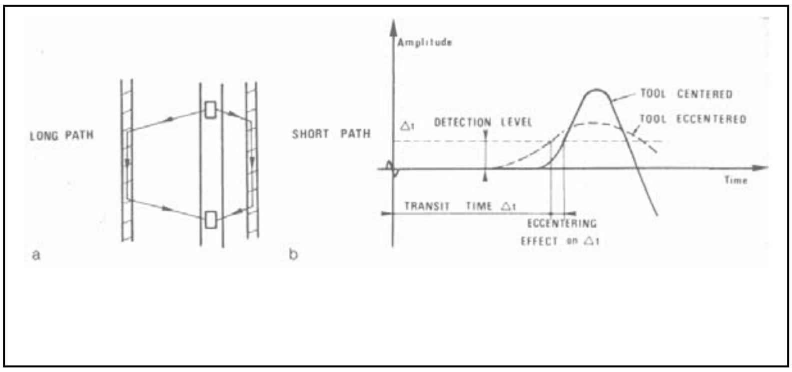
Variable Density Logs

This is a qualitative interpretation of the complete waveform. In an ideal situation the amplitude of the casing arrival is low (or not existent) and the formation arrivals can be seen.

POSSIBLE PROBLEMS

Eccentralised Tool

Centring of the RBT is critical for valid measurements. If the tool is eccentralised there are 2 paths for the sonic signal to take and the waveform at the receiver becomes smeared. The travel time will be reduced to be less than the expected travel time and the amplitude will be too low which will falsely indicate good bonding. The tool must be well centralized. Indications on the log will be the amplitude decreasing at the same time as the travel time decreases. If the tool is eccentralised the cement map will not be uniform.

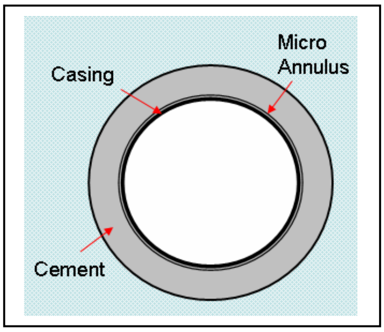


Fast formations

Fast formations are often very hard rock such as chert where the sonic velocity is unusually high (faster than the sonic velocity in casing), because of this the formation signals can arrive at the 3ft receiver before the casing signal. When this happens there will be a high signal within the amplitude gate which will be interpreted as a poor bond giving a false result. As a check the travel time to the first arrival should be examined, if it is less than the expected first arrival travel time for that casing size, suspect a fast formation. Indications on the log are increasing amplitude at the same time as the travel time decreases. The good news in this situation is that casing-cement-formation bonds must be good to detect fast formation i.e. if fast formations are seen then the cement is good.

Micro annulus

A micro annulus is a microscopic gap between the cement and the casing which has poor acoustic coupling. This can be due to a lowering of pressure in the casing after the cement job or thermal contraction. The gap has been estimated in the range of 0.005-0.01" (0.12 to 0.25 mm). It is assumed that a micro annulus does not compromise hydraulic isolation but the result on a bond log is to show a medium casing signal amplitude and moderate casing and formation arrivals. This can result in misinterpretation of the log which shows a poor bond when actually cement is present. If a micro annulus is suspected the usual course of action is to re-run the log with the casing under pressure (500 to 1000 psi). If the casing amplitude decreases and the formation signals get stronger then a micro annulus is suspected and the cement bond is considered to be OK.



Low compressive strength cement

Low compressive strength cement will show as intermediate amplitude. By reference to the cement map it is possible to determine if the apparent intermediate amplitude is due to a channel, if it is not then nomograms may be used to calculate the apparent compressive strength. Low compressive strength can occur when insufficient time has been given for the cement to cure. In this instance a second bond log may be run after the cement has fully cured.

Foamed or Lite Cement

When formation pressures are low in depleted fields it is not always possible to run standard cement due to lost circulation or formation fracturing problems. In this event the cement is lightened by foaming with nitrogen or by running special particulates in the cement. This type of cement provides isolation but has an extremely low compressive strength, and correspondingly reduced attenuation of the sonic signal. This means that even in well bonded pipe, the amplitude may not approach zero.

One method for running a CBL in this environment is to find the best bond in the well, cross check against the cement map for uniformity and assume that the amplitude of the sonic signal at that point corresponds to 100% bonding. The free pipe signal will be the same as in any other case. Thus, you may end up with an amplitude scale of perhaps 10 to 100, rather than 0 to 100. This approach can be a tough sell against ultrasonic tools so it may be necessary to discuss this with the client prior to the job. The ability to produce a cement map will help as it should show even distribution of the cement with no channels even when the amplitude is not zero.

"Road Noise"

When the tools are moving the centralisers can generate noise which is picked up by the RBT. This is minimized by using roller centralisers which have 2 wheels on each arm and thus ride over collars. The standard Sondex roller centralisers are PRC034, PRC041 and PRC057 which have 2 wheels on each arm. The signal amplitude will decrease as the logging speed is reduced and stop when the tools are stationary. In this case road noise should be suspected.

Oil Based Mud

Oil based mud has different sonic properties to water based mud. The travel time will be longer and the free pipe amplitude will be lower. The tool should be re-calibrated in zones with oil based mud. Problems can occur at pressures above 10,000 psi. Ideally cement bond logs should be run in water based mud with a low particulate volume.

Eccentralised free pipe

In deviated wells free pipe may rest against the formation and the classic free pipe VDL may not be seen. The CBL will show high amplitude and medium to strong formation arrivals will be seen on the VDL. Reference to the cement map may show lower amplitudes where the pipe rests against the formation. The signal response in this situation could be mistaken for a channel except that they occur over tens of feet (or more) in length which is not likely to be the case with a channel.

TOOL MAINTENANCE

Tool	Routine Maintenance
Roller Centralisers	Change rollers as required. Inject grease through grease ports. Change 'O' rings. Check continuity and insulation.
Knuckle Joints	Inject grease through grease ports. Check continuity and insulation.
Swivel Joint (if used)	Change 'O' rings. Refill with silicon oil as required.
RBT tool	Clean the tool thoroughly after a job (do not use a pressure hose). Inspect and change seals and 'O' rings as required. Before the job perform a calibration.
Gamma Ray and CCL	Change housing 'O' rings as required. Check for loose screws.

STORAGE / TRANSPORT

The tools should be oiled externally with a film of WD40 to prevent possible corrosion and transported within foam lined protective boxes. The watertight end caps should be fitted and the tools should be protected against shock. The 'cans' around the crystals are thin and can be easily dented do not push screw drivers, sticks or similar items through the slots on the sonde. **NB:** The CCL should be stored away from the Gamma Ray tool; the magnetic field can magnetise the housing which prevents the photomultiplier tube in the gamma ray from working properly.

REFERENCES

Sondex UltraWire™ RBT Manual
Sondex Warrior Software Manual
Cased Hole Log Analysis and Reservoir Performance Monitoring. R.M. Bateman 1985