# DETECTING AND LOCATING TUBING-CASING LEAKS FROM ANALYSIS OF ADVANCED ACOUSTIC FLUID LEVEL RECORDS

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The efficiency of most artificial lift systems is reduced significantly whenever the tubing and the casing annulus are in communication due to the presence of unwanted holes or leaks developed in some of the hardware used in the completion. Detection of the problem from analysis production records must be followed with field tests that verify the diagnostic before proceeding with repair operations.

Conventional single-shot acoustic fluid level measurements have been used in the past, using special procedures, to generate acoustic records that, in the presence of tubing-casing holes, may exhibit anomalies that point to the location of the hole or leak.

This paper describes a new, advanced user-friendly system that allows simultaneous acquisition of dual acoustic records, one via the tubing and one via the annulus, using wireless sensors for easy and efficient installation. The procedures for acquiring the data and the latest software tools used for the analysis to verify the presence of the hole and locate its position within the wellbore are discussed in detail. Several field examples of measurements performed in Gas Lift and Plunger Lift wells are presented to illustrate the new application.

## INTRODUCTION

The objective of acoustic fluid level measurements is primarily to determine the depth of the gas/liquid interface in all types of wells. However, a byproduct of the analysis of the acoustic record is the possibility of observing echo signals that correspond to unwanted holes in the tubing or casing 1, as seen in Figure 1, where repeated measurements in a gas well indicate that the echo observed consistently at the midpoint between the surface and the liquid level is generated by the presence of a hole. The hole acts as an enlargement of the pipe cross-section generating a signal of inverted polarity (up-kick indicated by the arrows) that can be easily identified in these records that do not show any other interfering signals. The actual hole is shown in the pictures of Figure 2.

The clarity of the records is enhanced by the fact they were acquired in a gas well with uniform casing and tubing diameters and with significant pressure which facilitated the propagation and persistence of the echoes.

Unfortunately, when applying this technology to other types of wells such as gas lift or gas lift-assisted plunger wells, where the completion includes installation of downhole valves and mandrels, the acoustic records become more complicated and often it is not possible to determine the presence of anomalies such as valves stuck open or pipe holes that allow unwanted communication between the casing and the annulus.

## DUAL SHOT METHOD

To facilitate the detection of echoes caused by holes in the tubing, one solution is to use two acoustic pulse generators with microphones to alternately generate the pulse in the tubing while listening in the casing and vice versa. Figure 3 shows schematically this dual shot arrangement using a gas gun attached to the tubing that is used to fire the pressure pulse and a second gas-gun attached to the casing that is used to listen to the acoustic noise in the annulus.

The pressure in this example well is less that the closing pressure of all the gas lift valves and therefore the pulse that is generated in the tubing should not be detected when listening in the casing annulus. In this example, the shot pulse is an increase in pressure that travels down the tubing and is transmitted to the casing through the eight-gas-lift valve that is stuck open.

The left side of the figure shows the acoustic record that is recorded in the annulus by the listening microphone. The amplitude of the acoustic record from time zero to about 10 seconds is fairly random and corresponds to the background noise present in the annulus. Just past 10 seconds a signal is clearly displayed as a down-kick. This signal is generated by the pulse that is coming through the open valve from the tubing into the annulus and propagates to the surface and detected by the listening microphone. The pressure pulse generated in the tubing has traveled down to the communication point (open valve) entered the annulus and then traveled back to the surface. Measuring the travel time of the signal and knowing the acoustic velocity of the gas in the well the distance to the communication point is computed.

## FIELD EXAMPLES AND ANALYSIS

Figure 4 displays a typical installation of the dual shot equipment on a gas lift well using two manually operated wireless gas guns, one connected to the tubing head and one connected to the casing gas injection line.

The acoustic record, in this figure, shows two traces: the upper trace is the signal generated by the tubing gun and recorded by its microphone. The shot is fired at time zero and signals are received with decreasing amplitude until the end of the record at 8.5 seconds.

The lower trace is the signal received at the listening microphone located at the casing. Most of the signal corresponds to the background noise except for the down-kick at about 4.508 seconds that is indicated by the vertical marker. This corresponds to the pulse that has crossed from the tubing to the casing through a communication point (hole). The software has computed the distance to that point, from the acoustic velocity that has been entered by the user, and displays its value of 2680 ft at the top of the vertical marker.

To verify that the signal observed at 4.5 seconds is consistent and is not caused by a random event it is recommended to acquire additional records, reversing the process: fire the shot with the gun attached to the casing and listen to the record with the gun connected to the tubing. The signal received at the tubing microphone should show a down kick at about the same time as the signal previously recorded by the casing microphone.

This recommended procedure is illustrated in the following detailed field examples.

**Field Example 1 – Gas Lift Well**

Before acquiring dual shots it is convenient to have a good understanding of the current distribution of fluids and pressures in the well. This well is a gas lift completion in a horizontal well. The annulus is packed at the bottom. Casing and tubing pressures are in the range of 1100 to 1200 psi.

Figure 5 shows the acoustic record for a single shot acquired in the casing. Liquid level is deep but it is above the bottommost valve. Currently the casing pressure is 1093 psi and is used to generate an implosion shot with the manually fired gas gun. The echoes from the mandrels are fairly visible, when the low pass filter is applied, and the deepest echo is used to compute an average acoustic velocity of 1197-99 ft/sec as shown in Figure 6. This yields an estimated depth to the liquid level of 8069 ft.

A similar single shot record was acquired in the tubing and shown in Figure 7. The focus of this figure is on the latter part of the record from 11 to 32 seconds, showing the echoes from the bottom of the tubing (end of tubing and liquid level) and their repeats in the upper trace. The reason for focusing on this latter part of the record is to get away from the high frequency shot noise that is present in the early part of the record between zero and five seconds.

The lower trace (blue) is an overlay of the single shot acquired in the casing and shown in Figure 5.

Note that the liquid level in the casing is indicated at 7572 feet while the liquid level from the tubing shot is below the end of the tubing at 8854 feet. The echo from the end of the tubing is used to compute the average acoustic velocity of 1222 ft/sec for the gas in the tubing. The pressure in the tubing is 1232 psi while the pressure in the casing was recorded at 1093 psi and an acoustic velocity of 1125 ft/sec. The difference in pressures explains the difference in acoustic velocity. Five internal reflections between the liquid level that is below the EOT and the packer can be seen clearly spaced at about 0.406 seconds RTTT. For these repeats the EOT is an area restriction so the repeat echoes are all down-kicks.

The fact that the pressures in casing and tubing are different would indicate that currently there is no communication between the annulus and the tubing. Also there does not seem to be any unexpected echoes that would indicate a point of communication.

Following the acquisition and analysis of these single records, a dual shot was acquired by firing the tubing gun and listening to the casing microphone, as shown in Figure 8 that focuses and zooms-in at the time that corresponds to the end of the tubing. The firing trace is plotted centered at about zero mV and shows the echo from the end of the tubing that is used to compute the average acoustic velocity of 1220 ft/sec. The listening trace from the casing annulus (lower trace, red) instead of being quiet, shows several signals beginning at 13.385 seconds before the echo from the end of the tubing is detected at 14.101 seconds in the tubing trace (black). The presence of these signals is a clear indication that the pulse from the tubing has entered the annulus and is propagating both upwards to the microphone attached to the casing and downwards towards the packer. The polarity of the signal, in the listening trace at 13.385, is a down-kick which corresponds to the polarity of the shot and the liquid level echo below the tubing, received by the tubing microphone at 14.495 seconds.

A detailed analysis of the various echoes from the tubing and the casing is performed by noting the arrival times of each echo and constructing a time-distance diagram that shows the wave paths and the corresponding arrival times of the wave fronts, as shown in Figure 9. The blue arrows represent the waves traveling in the tubing and the red arrows those traveling in the casing. Dashed lines represent inversion of polarity (up-kicks).

The pulse starts at the tubing and then splits at the point of communication. One wave travels through the hole and up to the microphone in the casing arriving at 13.385 seconds (Hole echo). The second wave continues to the bottom of the tubing and is reflected as an up-kick at the end of the tubing (EOT), arriving at 14.101 seconds. The tubing pulse continues past the end of the tubing and is reflected by the gas/liquid interface in the wellbore below the packer and reaches the tubing microphone at 14.495 seconds (TLL). Multiple internal reflections between the liquid level and the bottom of the packer are generated and are received with constant spacing after the TLL echo at TLL2, TLL3 and TLL4.

The pulse that entered the casing annulus via the tubing hole also travels down and reaches the liquid level in the annulus is reflected and reaches the casing microphone at 14.224 seconds (CLL). When this pulse passes by the hole (which corresponds to an enlargement of the annulus) it creates an echo of inverted polarity (dashed arrow) that travels back down to the liquid level, it is reflected and is received at the casing microphone at 14.622 seconds (CLL2).

The purpose of doing this detailed analysis is to explain the provenance of all the signals that are recorded in the listening trace and eliminate the possibility that there may be additional holes and communication points. The conclusion of this analysis is that there is only one point of communication indicated by the down-kick at 13.385 seconds and estimated at a depth of 8165 feet in the tubing.

As mentioned earlier, verification of this conclusion should be obtained by repeating the dual shot test but inverting the procedure: firing the shot with the casing gun and listening with the tubing microphone.

The repeat dual shot records are displayed in Figure 10. The trace centered at zero mV (black) is the record from the firing gun attached to the casing. The upper trace (red) is the trace from the listening microphone in the tubing. The figure zooms-in to the lower section of the tubing.

The tubing listening trace shows a signal at 13.28 seconds that corresponds to the pulse that has traveled in the casing to the point of communication and into the tubing. Its depth is estimated at 8034 feet. Following this signal there is the echo from the end of the tubing (EOT) and the echo from the liquid level in the wellbore below the tubing. Also in this record can be seen the internal reflections of the pulse between the liquid level and the bottom of the casing packer.

The echo from liquid level in the casing annulus is received at 13.469 seconds and is estimated at a depth of 8230 ft based on an acoustic velocity of 1222 ft/sec entered manually by the user. Note that the liquid level in the annulus is now below the depth of the point of communication. If the liquid level in the annulus had been above this point there would be no pulse transmission from the casing to the tubing. This is one reason for acquiring several records especially when the casing and tubing pressures are different and are not constant.

Figure 11 presents the wave path analysis for the dual shot presented in Figure 10. The shot is fired in the casing (blue arrows) is transmitted to the tubing at the communication point and reaches the tubing listening microphone at 13.28 seconds. The casing pulse continues to the bottom of the annulus, is reflected by the liquid level and reaches the casing microphone at 13.469 seconds.

The pulse transmitted into the tubing also travels to the bottom creating an up-kick echo from the end of the tubing (EOT) at 14.082 seconds, then continues below the tubing and is reflected by the liquid level in the wellbore at 14.477 seconds and is followed by the echoes from internal reflections between the liquid level and the bottom of the packer at 14.913 and 15.305 seconds.

The signal from the hole at 13.28 seconds is estimated to be generated at a depth of 8034 feet as shown in the note by the black reference line.

The difference in the estimated depth of the communication point (8034 ft from casing firing and 8164 ft from casing firing) is due to the difference in casing and tubing pressures at the times when the records were acquired and the values used in the depth calculation. The difference in the recorded travel times: 13.385 seconds for casing listening and 13.28 seconds for tubing listening are close enough to conclude that the signals are generated at the same communication point.

To get a more precise distance to the communication point, it would be recommended to wait until the casing and tubing pressures would equalize and then repeat the acquisition of dual shots.

**Field Example 2 – Plunger Lift Well**

Figure 12 shows a dual shot record acquired in a relatively deep well with a plunger lift installation.

The records were acquired by firing the shot in the casing and listening in the tubing. The tubing record (in red, centered at about 20 mV) shows significant background noise but it is possible to see a clear down kick at around 4.6 seconds that exceeds the average noise amplitude, followed by echoes from the check valve at the bottom of the tubing. This signal near the top of the record indicates that there is a communication point between the casing and the tubing. The casing trace shows an echo from the top of the casing liner followed by echoes from the liquid level very near the bottom of the tubing.

Details of the two records are shown in Figure 13 with labels (A, B, C, D) attached to the various signals. The liner depth at 9000 feet is used to compute the acoustic velocity of the gas in the casing of 1182 ft/sec. This value agrees with the measured casing pressure of 237 psi.

Figure 14 shows the details of the wave paths for the records in Figure 13. Black arrows represent waves in the casing and red arrows waves in the tubing. The shot is fired in the casing and a portion of the pulse travels through the communication point into the tubing and is received at 4.602 seconds (A) at the listening microphone. The remaining casing pulse travels down to the top of the liner where a down-kick echo is created that travels back to the casing microphone and is received at 15.178 seconds (B). This casing pulse continues until it reaches the annular liquid level and is reflected back to the casing microphone and received at 16.697 seconds (D).

The pulse that was transmitted to the tubing travels to the bottom and is reflected by the combination of the bumper spring and check valve at 9679 feet. This echo is received at 16.498 seconds (C).

The acoustic velocity in the tubing was obtained by a single shot record in the tubing and estimated at 1215 ft/sec compared to 1188 ft/sec from the casing shot. The average of these velocities was used to estimate the depth of the communication point as 2714 feet.

SUMMARY

The special dual acoustic record method, described in this paper, is a reliable tool to determine the presence of holes or other points of communication between the tubing and casing in all types of well completions. It is most beneficial when the single shot records are too noisy to detect the presence of echoes from the holes. To verify the accuracy of the analysis is beneficial to have a correct detailed description of the mechanical wellbore with all accessories that may generate acoustic echoes.

Conventional single shot records should also be acquired to determine accurately the acoustic velocity in the casing and the tubing.

## REFERENCES


1) A. Podio and J.N. McCoy: “Acoustic Fluid Level Measurements in Oil and Gas Wells Handbook,” Chapter 10, Petroleum Extension (PETEX) University of Texas, 2017. https://petex.utexas.edu/publications/479-acoustic-fluid-level-measurement

FIGURES

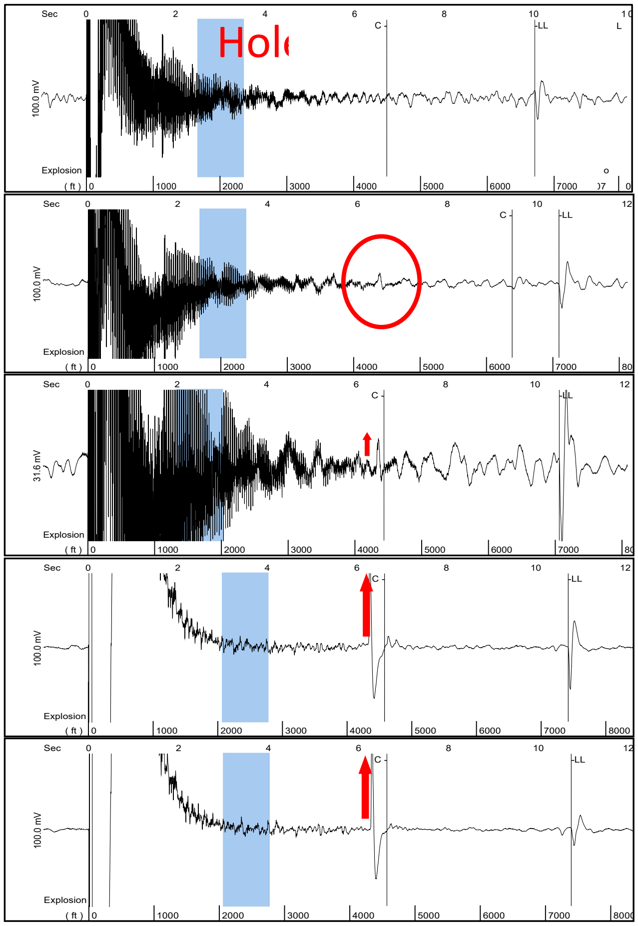
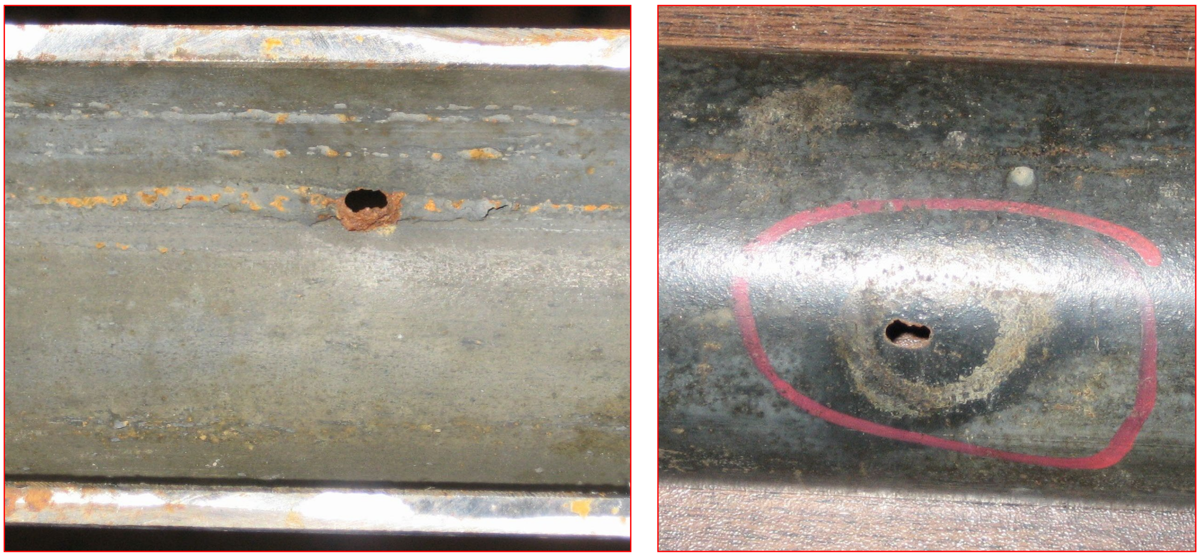



Figure 1 – Series of acoustic measurements in a gas well casing and tubing showing the presence of an echo(up-kick) generated by a hole at 4325 ft. (From Reference 1)

## Can’t be a Hole ~ Tubing is New

### Hole @ Depth 4325 Ft from Surface



**Inside Pipe** **Outside Pipe**

Figure 2 – Pictures of the hole in the tubing that generated the echoes in the records of Figure 1

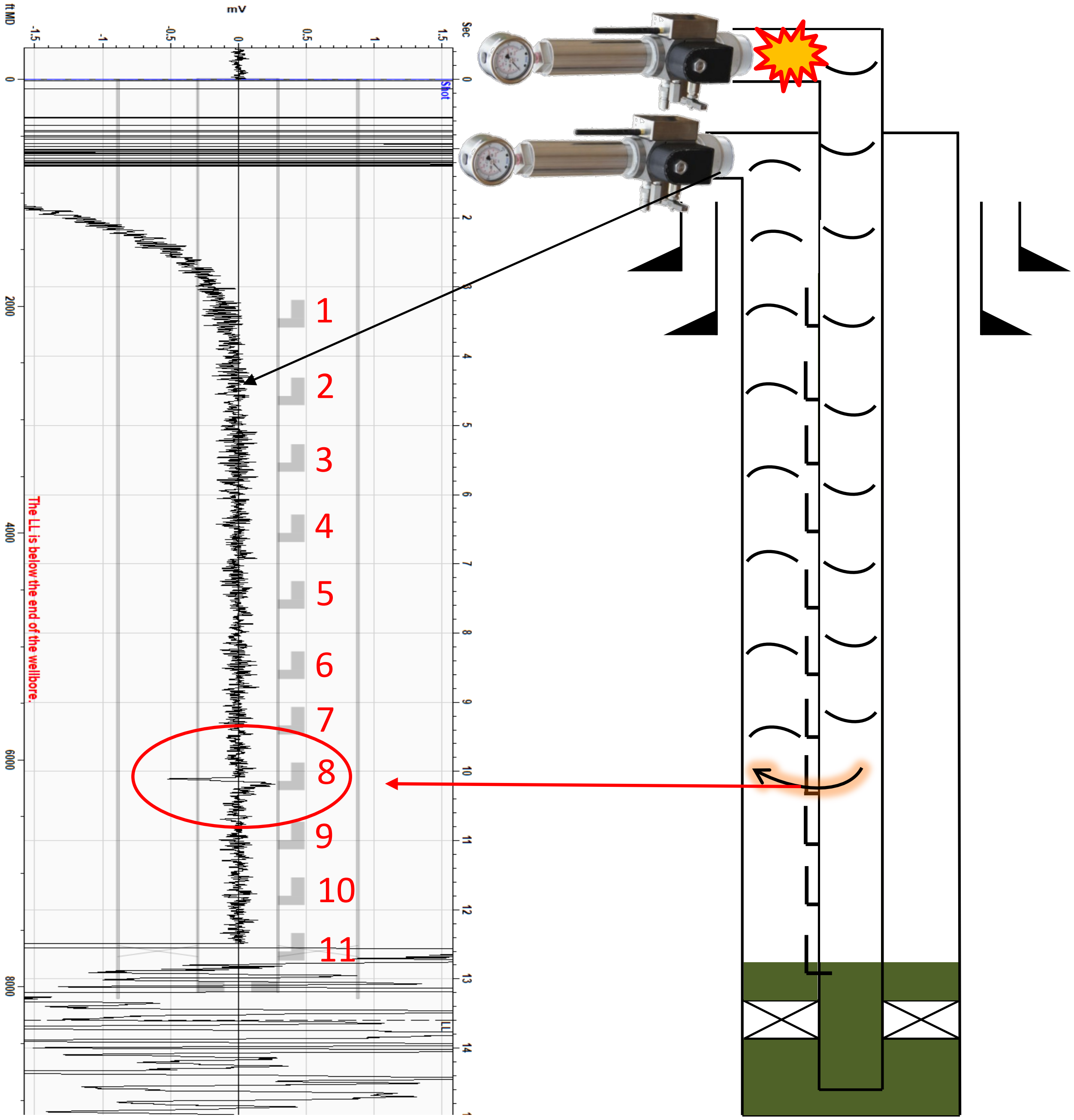



Figure 3- Listening Record on the left and gas lift well schematic on the right illustrating dual shot recording. Firing shot in tubing and listening for echoes in the casing annulus.

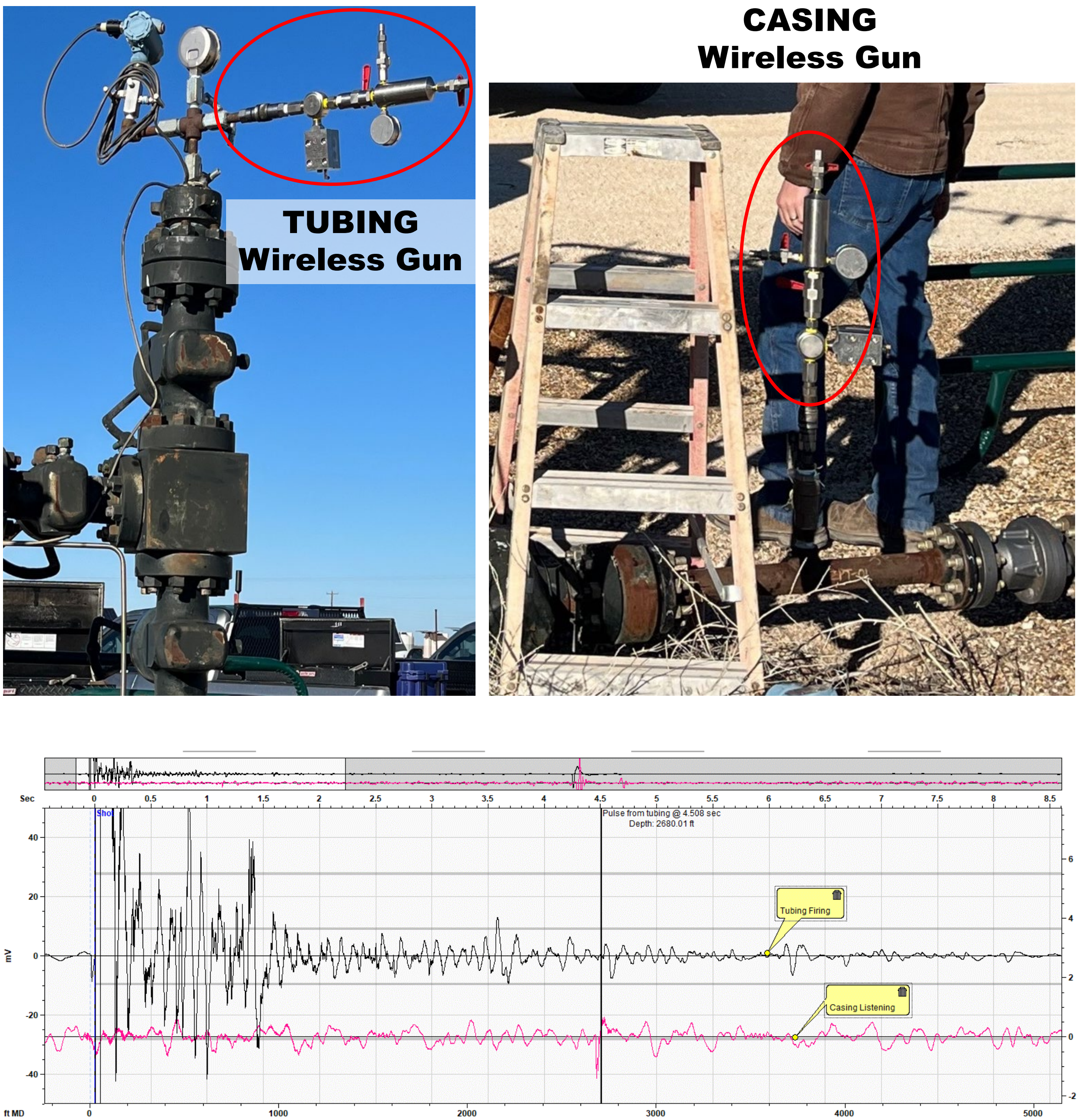



Figure 4 – Field Setup for dual shot using wireless guns and TAM dual shot screen record.

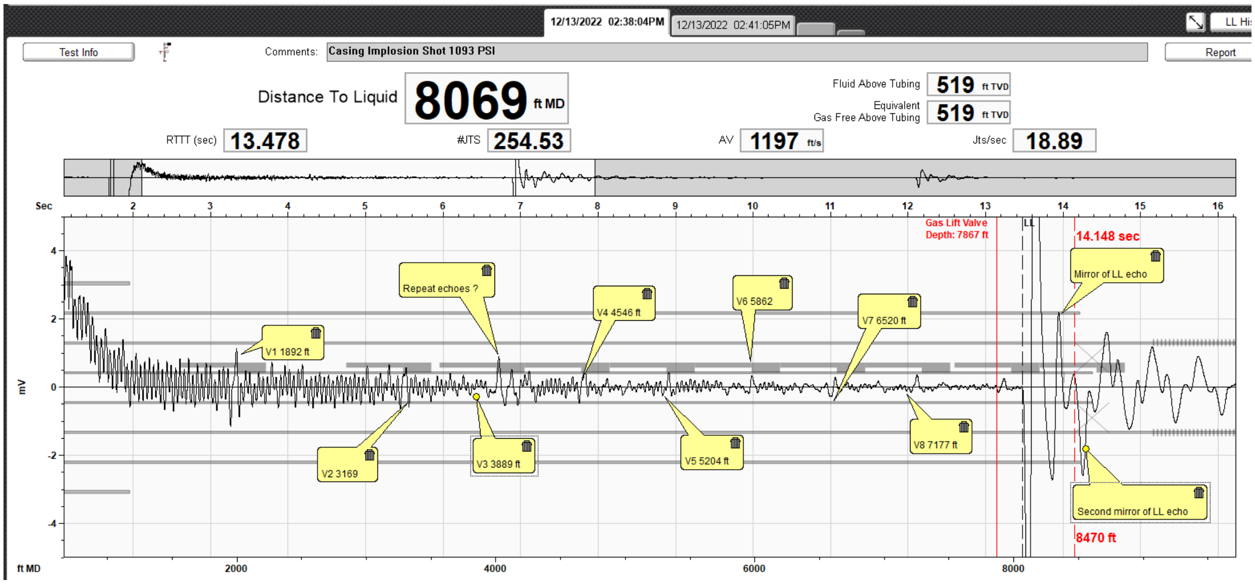



Figure 5 – Gas Lift Well - Casing implosion single shot.

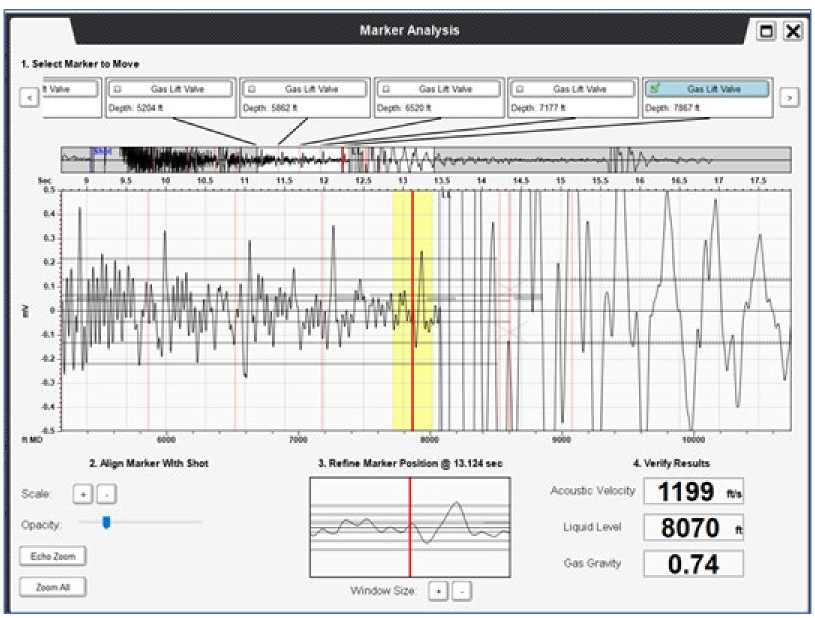



Figure 6 – Detail of downhole Marker Analysis to estimate acoustic velocity in casing for record shown in Figure 5.

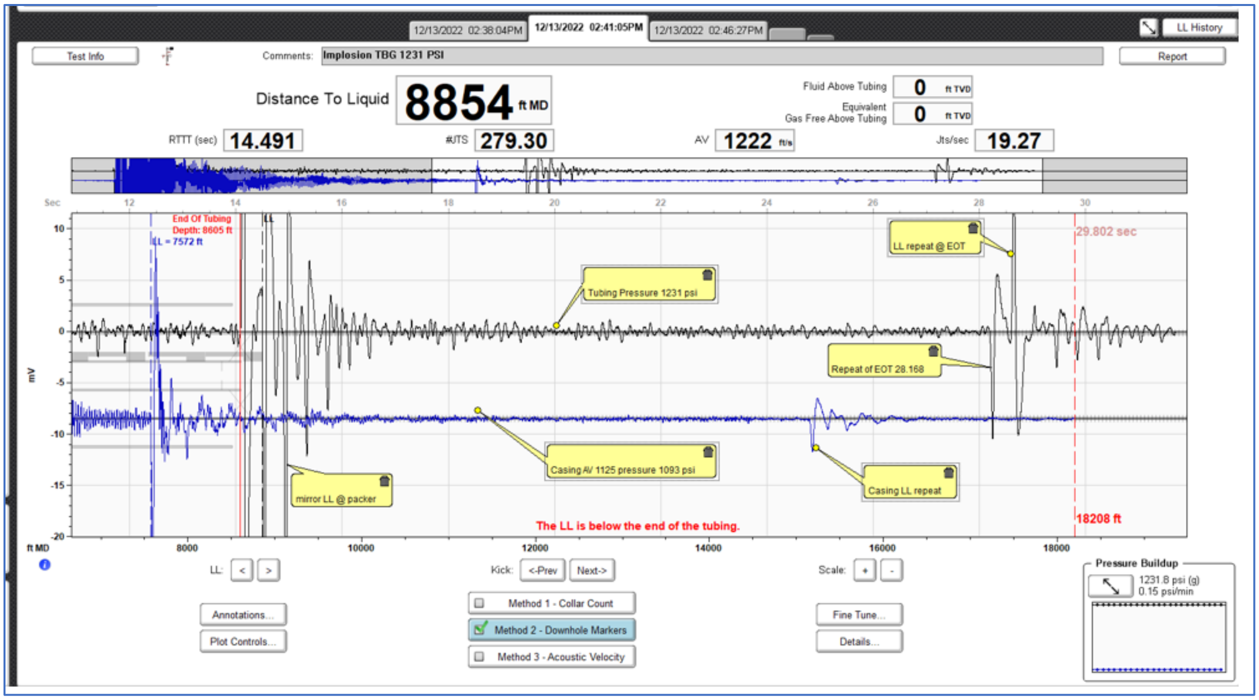



Figure 7 – Overlay of Tubing single shot record (upper trace) with casing single shot (lower trace) acquired separately and combined in the figure.


Figure 8 – Dual shot Tubing Firing and Casing listening acquired simultaneously. Communication point is indicated at 8164 feet.

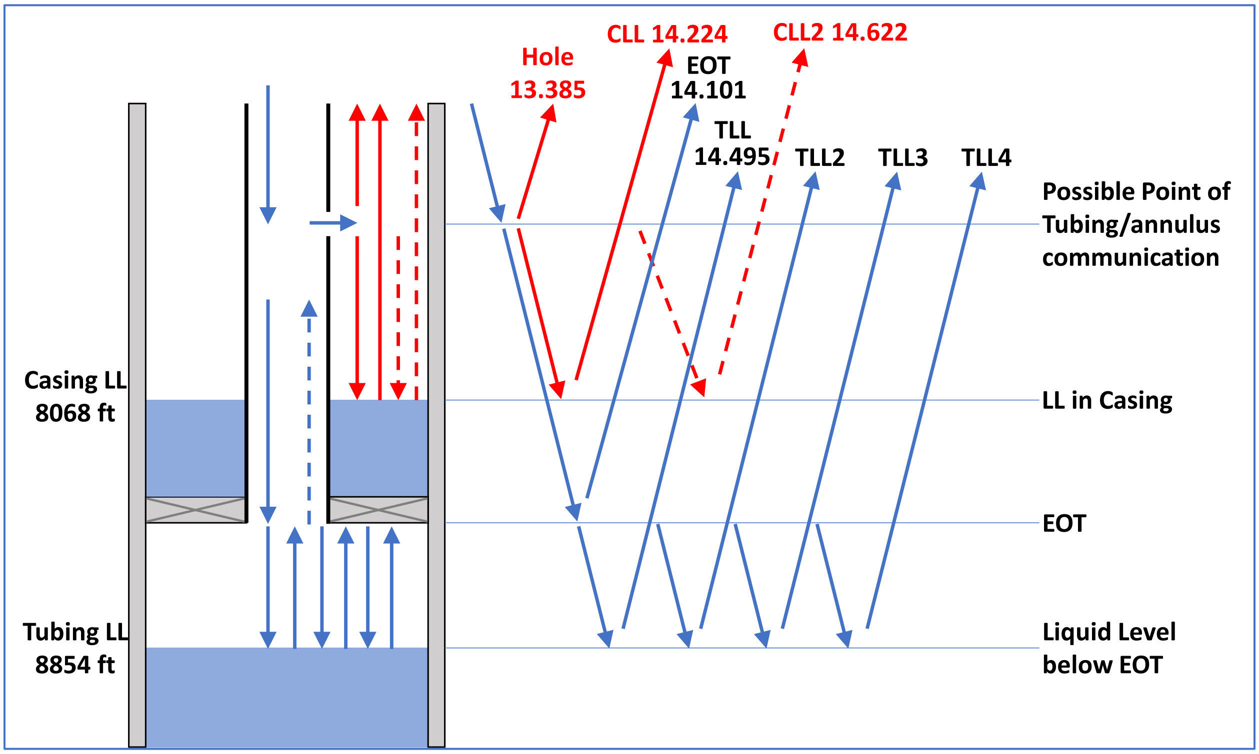



Figure 9 -Wave path analysis for Gas Lift well dual shot records in Figure 7, Tubing firing and Casing listening.


Figure 10 – Dual shot Casing Firing and Tubing Listening. Communication point at 8034 feet.

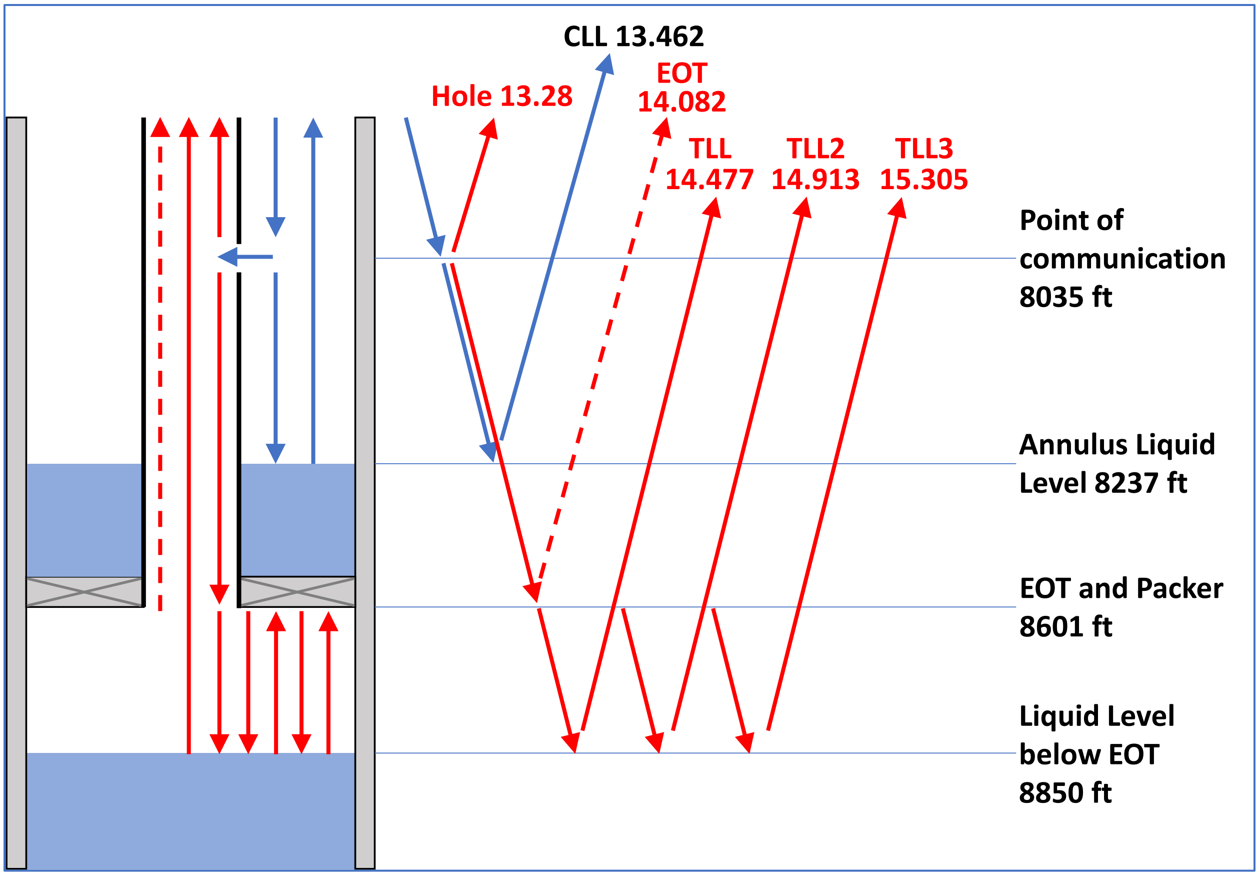



Figure 11 – Wave path analysis for records in Figure 9. Casing Firing and Tubing Listening.

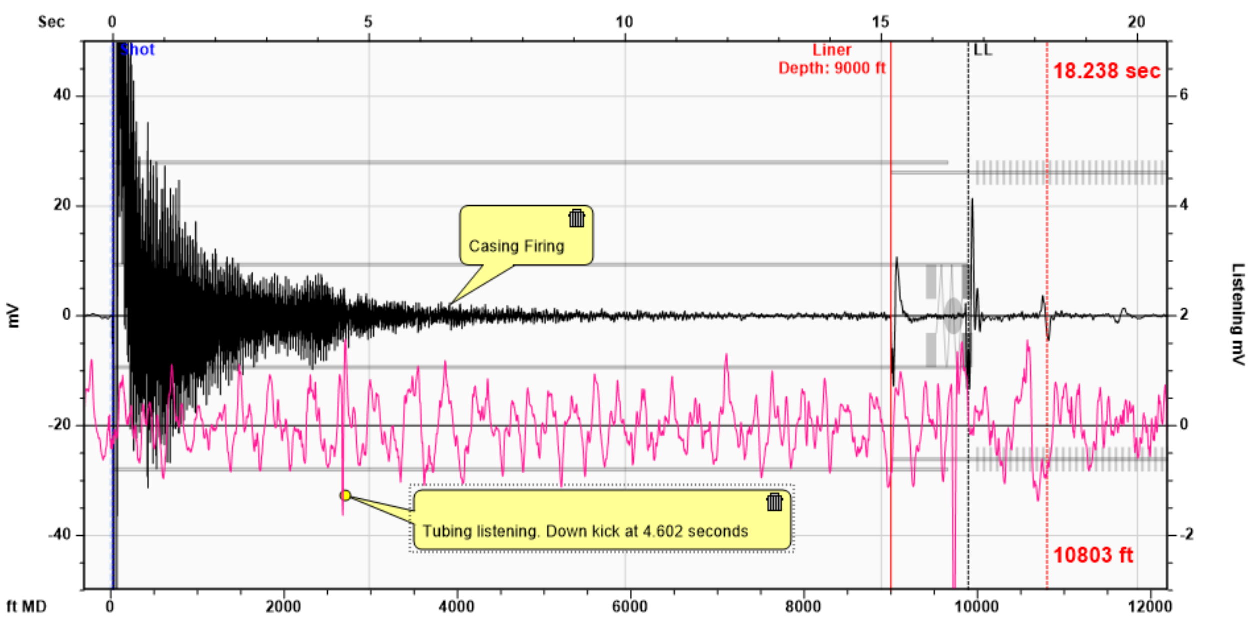



Figure 12- Dual shot records in Plunger Lift Well

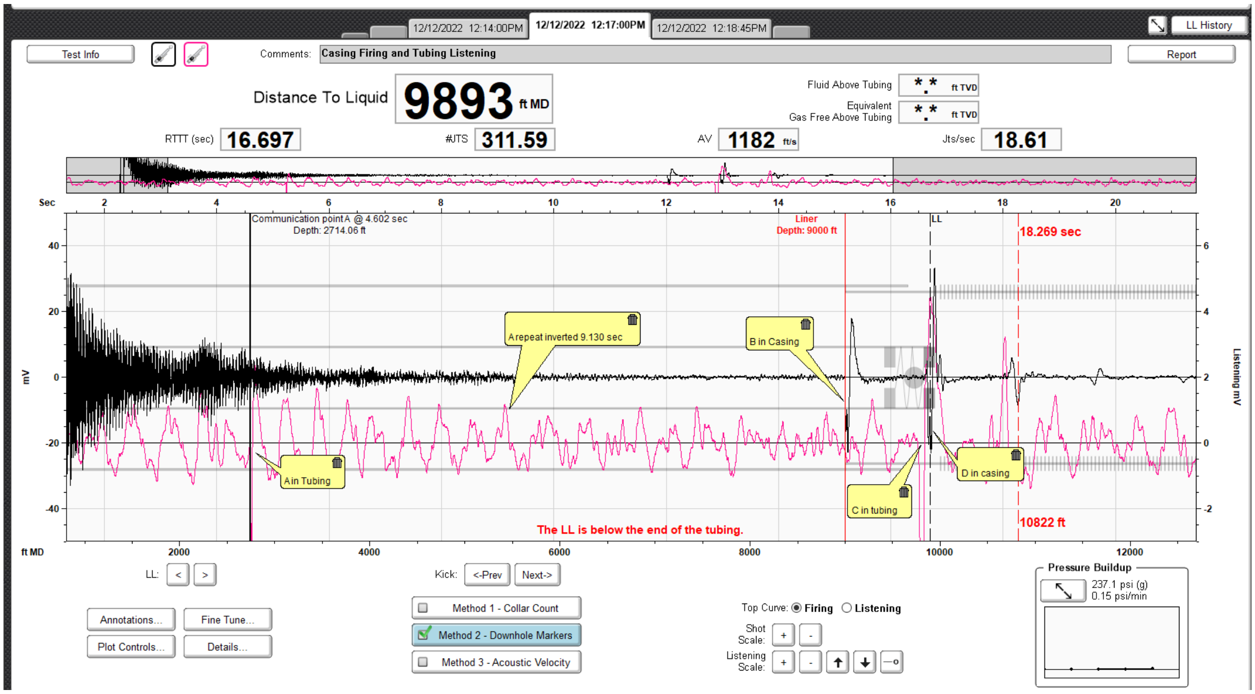



Figure 13 – Plunger lift well. Dual shot Casing gun firing and Tubing gun listening.

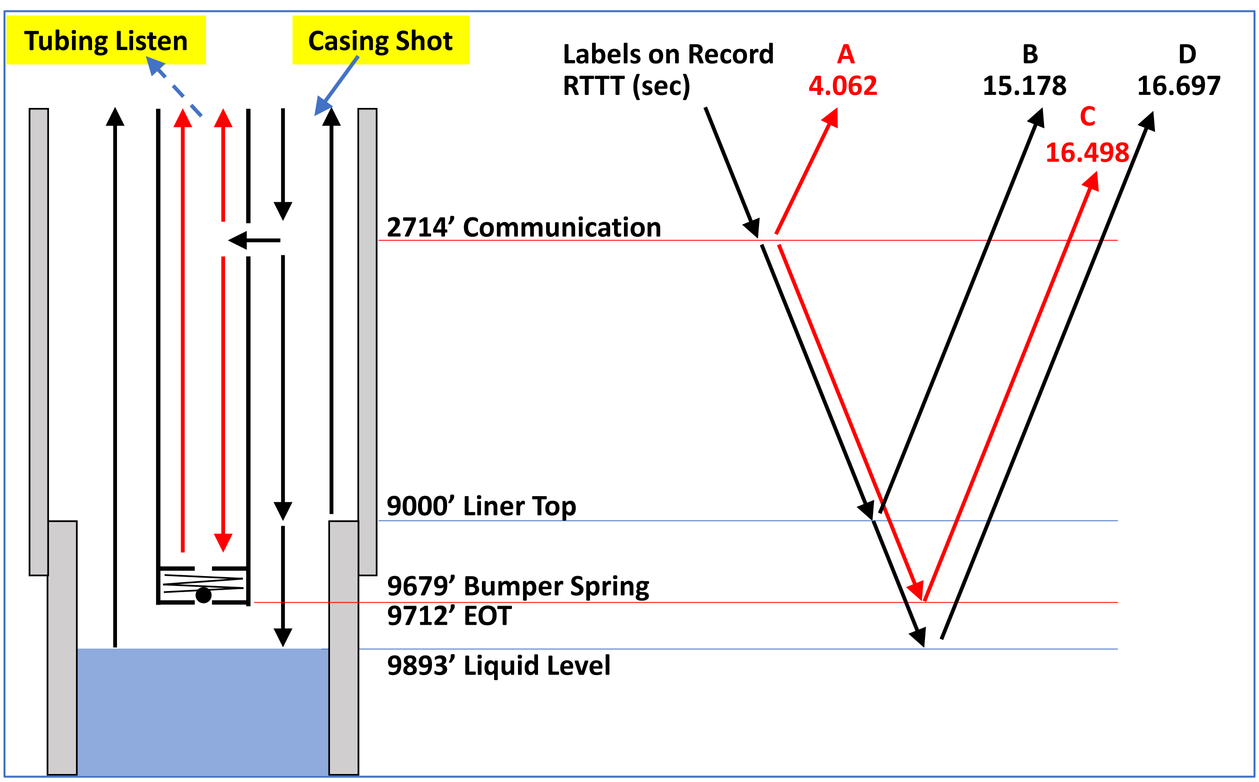



Figure 14 – Wave path analysis for plunger well records in Figure 11