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Optimization of a New Array Noise Tool; Analysis & Interpretation of Case Studies of Down- Hole Leak Detection

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OPTIMIZATION OF A NEW ARRAY NOISE TOOL; ANALYSIS & INTERPRETATION OF CASE STUDIES OF DOWN- HOLE LEAK DETECTION

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This thesis is submitted in partial fulfillment of the requirements for the degree of Master of Science in Petroleum Engineering

Under the Supervision of Professor Abdulrazag Y. Zekri

March 2018

Declaration of Original Work

I, Moustafa Mahmoud Hassan Ismail the undersigned, a graduate student at the United Arab Emirates University (UAEU), and the author of this thesis entitled "*Optimization of a New Array Noise Tool; Analysis & Interpretation of Cases Studies of Down- Hole Leak Detection*", hereby, solemnly declare that this thesis is my own original research work that has been done and prepared by me under the supervision of Professor Abdulrazag Y. Zekri, in the College of Engineering at UAEU. This work has not previously been presented or published, or formed the basis for the award of any academic degree, diploma or a similar title at this or any other university. Any materials borrowed from other sources (whether published or unpublished) and relied upon or included in my thesis have been properly cited and acknowledged in accordance with appropriate academic conventions. I further declare that there is no potential conflict of interest with respect to the research, data collection, authorship, presentation and/or publication of this thesis.

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Abstract

This thesis is concerned with optimization and analysis of new array noise tool. Various lab and field case studies are analyzed to test the capabilities and determine the optimum operation conditions of the new tool for leak detection purposes. The purpose of this study is to optimize the logging procedure of real time array noise tool, selecting adequate gain parameters and frequency band in processing phase, and to analyze the data acquired through multiple lab and field tests. The study methodology involved the following steps:

1. Performing lab and field tests for the tool in a range of different scenarios.
2. Carrying out multiple real-life case studies and provide interpretation using commercial software.

Gain setting was optimized to obtain best results through logging and adding additional auxiliary logging accessories was proven to enhance the acquisition process. Moreover, implementing proper logging procedure that suits the tool capabilities aid the analysis process and the objective was met successfully. The tool was tested and proved consistent results which can be commercialized and used as real time noise tool. The new array noise tool overcomes the limitations of the memory noise tool in which it will save both time and money on the oil companies and will be able to provide in situ answer for leak detection purposes.

Keywords: Array noise tool, analysis, leak detection, optimization, down hole logging.

Title and Abstract (in Arabic)

تعظيم الاستفادة من أداة الكشف عن الضوضاء الجديدة ك تحليل امثله عمليه من الكشف عن التسريب في الآبار

الملخص

تعنى هذه الأطروحة بدراسة الاستفادة القصوى من معدات تسجيل الضوضاء المصفوفة الجديدة وتحليلها. وقد جرى تحليل دراسات حالة مختلفة من المختبر ومن الحقل لتحديد أوضاع التشغيل المثلى للمعدات الجديدة واختبار قدراتها وذلك بهدف كشف التسرب. إن الهدف من هذه الدراسة هو تحسين إجراءات القياس للزمن الفعلي لمعدات تسجيل الضوضاء المصفوفة التي تظهر نتائج لحظية، عبر تحديد مؤشرات التضخم الكافية والنطاق الترددي في مرحلة المعالجة، وتحليل البيانات الناتجة من خلال عدة اختبارات في المختبر والحقل. تضمنت منهجية هذه الدراسة الخطوات التالية:

1 .أداء تجارب في المختبر والحقل للمعدات بسيناريوهات متعددة.

2 .القيام بعدة دراسات حالة واقعية وتقديم تحليل للبيانات باستخدام برامج تجارية.

جرى تحسين إعدادات المضخم على النحو الأمثل للحصول على أفضل النتائج من خلال القياس وإضافة أدوات قياس تكميلية مساعدة وقد أثبت ذلك تحسين عملية القياس. وإضافة إلى ذلك فإن تطبيق إجراءات قياس ملائمة تناسب إمكانات المعدات يساعد في عملية التحليل وقد تم تحقيق الهدف بنجاح. تم تجربة المعدات وأظهرت نتائج موثوقة يمكن استخدامها تجاريا واستخدامها كمعدات تسجيل ضوضاء تظهر نتائج لحظية.

تتجاوز المعدات المصفوفة لتسجيل الضوضاء الجديدة القيود الموجودة في معدات تسجيل الضوضاء المعتمدة على الذاكرة وسيوفر ذلك الوقت والمال لشركات النفط والغاز وستتمكن الشركات من تقديم رد فوري لأغراض كشف التسرب.

مفاهيم البحث الرئيسية: معدات تسجيل الضوضاء المصفوفة، التحليل، كشف التسرب، الاستفادة القصوى، قياس الضغط والحرارة الجوفية.

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I would like to thank my committee for their guidance, support, and assistance throughout my preparation of this thesis, especially my advisor Professor Abdulrazag Y. Zekri. I would like to thank the chair and all members of the Department of Chemical and Petroleum Engineering at the United Arab Emirates University for assisting me all over my studies and research. My special thanks are extended to the Library Research Desk for providing me with the relevant reference material.

Special thanks go to my mother, brothers, and sisters who helped me along the way. I am sure they suspected it was endless.

Dedication

To my beloved mother and family

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List of Abbreviations

ADP	Advanced Data Processing
BAP	Basic Array Processing
F153	Energy in 15-30 kHz Frequency Band
F345	Energy in 30-45 kHz Frequency Band
F515	Energy in 5-15 kHz Frequency Band

Chapter 1: Introduction

1.1 Overview

Noise leak detection tools have been in high demand in the past few decades. The recent failures in wells have led oil service companies to constantly design and enhance new technologies for leak detection, as monitoring the well by various logging tools proved to be the best way to plan a work-over and help to maintain the asset and cost management. Microphone was first used in wells to identify casing leaks (Enright, 1955). Later on, McKinley introduced a multi sensor noise tool, in which the basic principle is to record noise in different frequency bands (McKinley et al., 1973) and used also for locating cross flow behind casing (McKinley, 1994) Recent advancements in the noise-logging technique have made it a valuable tool for dealing with problem wells (Robinson, 1976). New technologies of spectral noise tools were used in wider applications such as generating high sensitivity boards which can be used to monitor and improve reservoir characterization (Suarez et al., 2013). Noise logging is applicable whenever fluid flow, either in the borehole or in the casing formation annulus, produces a detectable noise (Bateman & Richard, 2015).

1.2 Statement of the Problem

One of the main limitations of Stationary noise tools is the lengthy operation time to identify the leak source throughout the well. In such cases, the memory noise tool will have to stop for stations down hole, and without prior estimation where the leak source, this process might take hours or even days before the whole well would be logged. Another limitation is that all noise tools work at memory mode, which means that you have to finish logging, retrieve the memory from the tool to view the data, while if it was accessible to view the data on surface while logging would have gave the engineer the chance to focus more on a suspected interval. This workflow could be inefficient in terms of urgent well interventions and immediate action is required. Moreover, when the leak source noise signal is not strong enough (less than 30 dB), the process of stationary measurements might miss the leak source as the activation of the leak source wouldn’t last long enough to be recorded by the tool. All of these limitations lead the Oil industry to find another innovative, more practical and efficient methods to overcome such challenges. One of them is to design a real time noise tool in which measurements would be continuous and the data can be analyzed on spot for a faster remedial action if needed. Recently, a well-known manufacturer has released an array spectral high frequency noise tool which can record continuously and provide real time data while logging (Zhao. J & Yang. Q, 2017).

The new technology of noise tools comes with challenges and for that it requires a lot of lab and field testing to optimize the logging procedure, mode and gain settings, proper logging speed for the best data quality, how to overcome the background road noise generated by continuous logging, and related interpretation and analysis workflow in order to be implemented in oil industry.

1.3 Tool Physics and Relevant Literature

1.3.1 Tool Design

A well manufacturer designed and produced the Array noise tool (Zhao.J & Yang.Q, 2017). The array noise tool consists of 38 hydrophones, 3 set of monopole and 6 sets of dipole sensors and azimuthal sensors to record acoustic measurements in four different directions (Figure 1). Sensors are defined as monopoles, dipoles or quadruples based on the number of sensor surfaces (Figure 2) to be able to measure detailed acoustic noise and further away from the sensor, they must achieve large aperture, it can be achieved using more sensor surface and/ or combining sensor surface to produce a larger aperture.

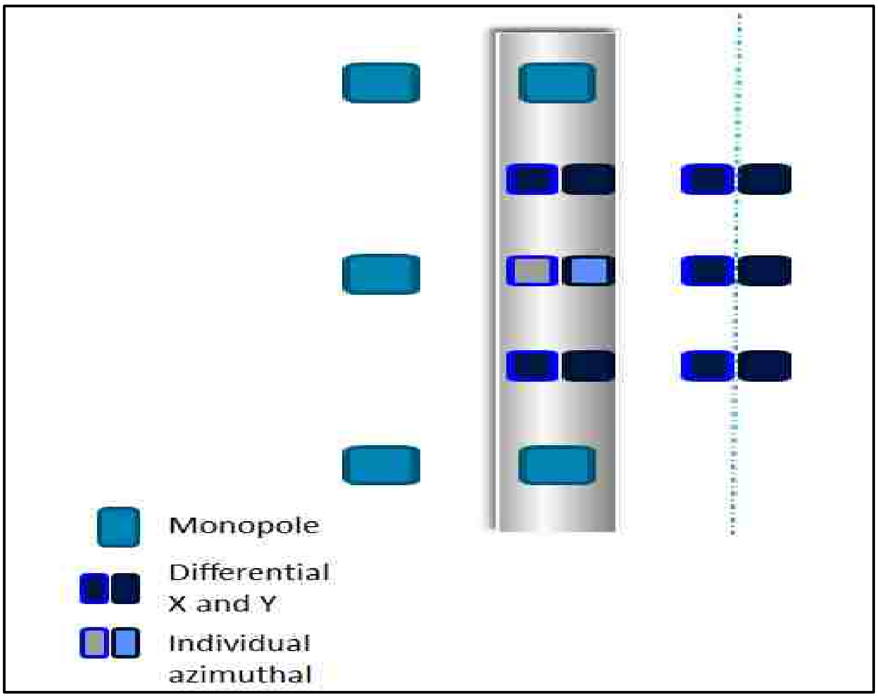

Figure 1: Sensor onfiguration of array noise tool

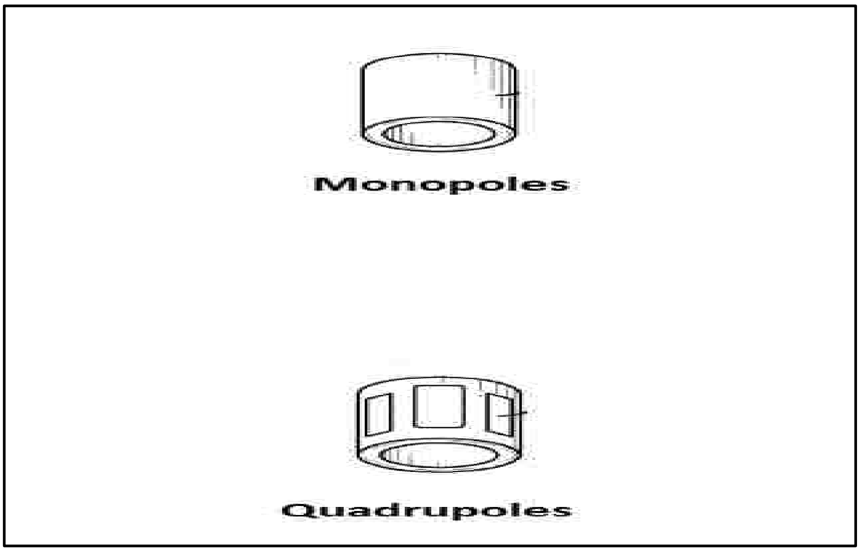

Figure 2: Monopole and quadrupole sensors

Moreover, a phased control method can be used to generate a larger aperture as shown below:

$$P_a(\emptyset) = \sum_{i=1}^{n} W_i e^{j(K_0 (i-1) d\sin(\emptyset) + \theta_i)}$$

W_i and θ_i are the weighted factors for the i-th component, d is the distance between sensors, N is number of sensors and K is wave number.

d can be optimized using the following equation;

$$d < \lambda/2$$

where λ is the wavelength of the signal.

Sensor surfaces are made of pizoceramic materials which can record noise generated within a wellbore.

Differential sensor principle of work is that, each sensor (sensor x and sensor y) has two sensor faces, in which acoustic noise is recorded in different directions and then compared to each other (Figure 3).

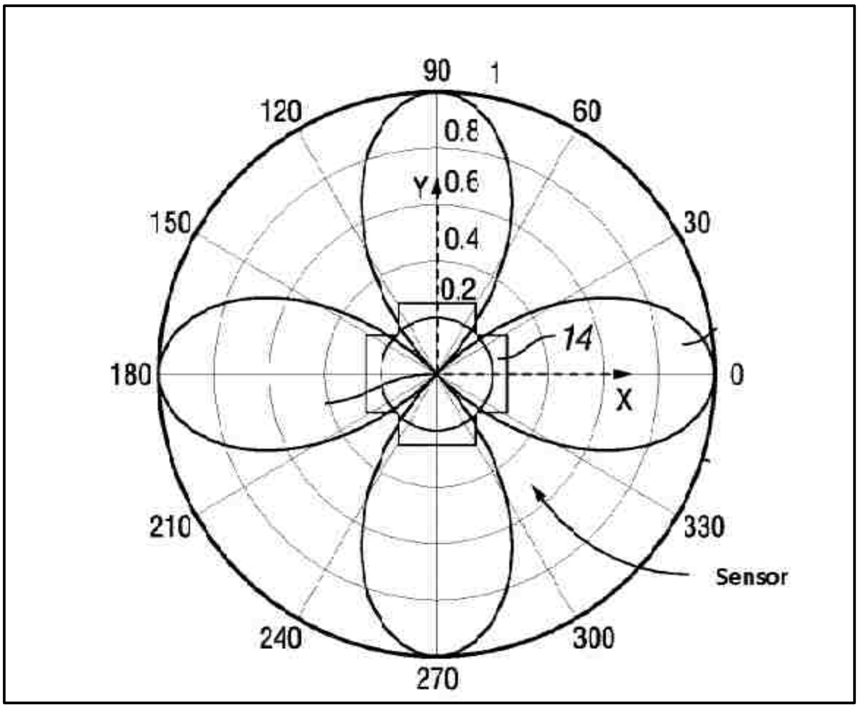

Figure 3: Dipole measurements

1.3.2 Tool Recording Principle

The array noise tool works in integration of data acquisition and data processing. As the tool goes down hole, it records different noise in well bore, along with acoustic noise properties which could be frequency, amplitude, acoustic mode, propagation direction, azimuthal location and distribution from a noise source where data is stored in memory mode and is transferred to the surface for real time analysis (Zhao. J & Yang. Q, 2017). Moving down-hole, a road noise is picked up by the tool; this noise is generated due to centralizers or due to the tool movement in wellbore. Road noise will generate a signal and picked up by the tool, as the signal recorded by the differential sensors one in the y direction and another in x direction. These signals are identical in shape and by comparing signal from opposite sensors, the tool may cancel out as shown in Figure 4.

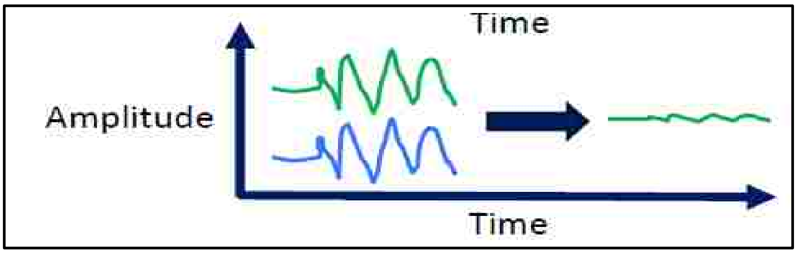

Figure 4: Road noise propagating in the tool arrives with the same phase and amplitude which will cancel out

As for the defect signal (Figure 5), it will not be affected by the interference and thus cancels out, as that signal will not have the same amplitude and wavelength.

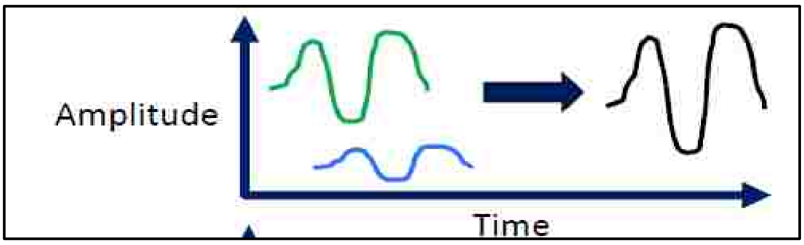

Figure 5: Defect source will have large differential signal

Another major important factor to differentiate between road noise and the leak noise is that the road noise will be generated and recorded as the tool moves while the leak source is stationary; therefore, it will have an angle from the sensor as illustrated in Figure 6. As the tool moves closer to the leak, this angle will start to decrease till it reaches zero and will start to increase again as the tool moves beyond it.

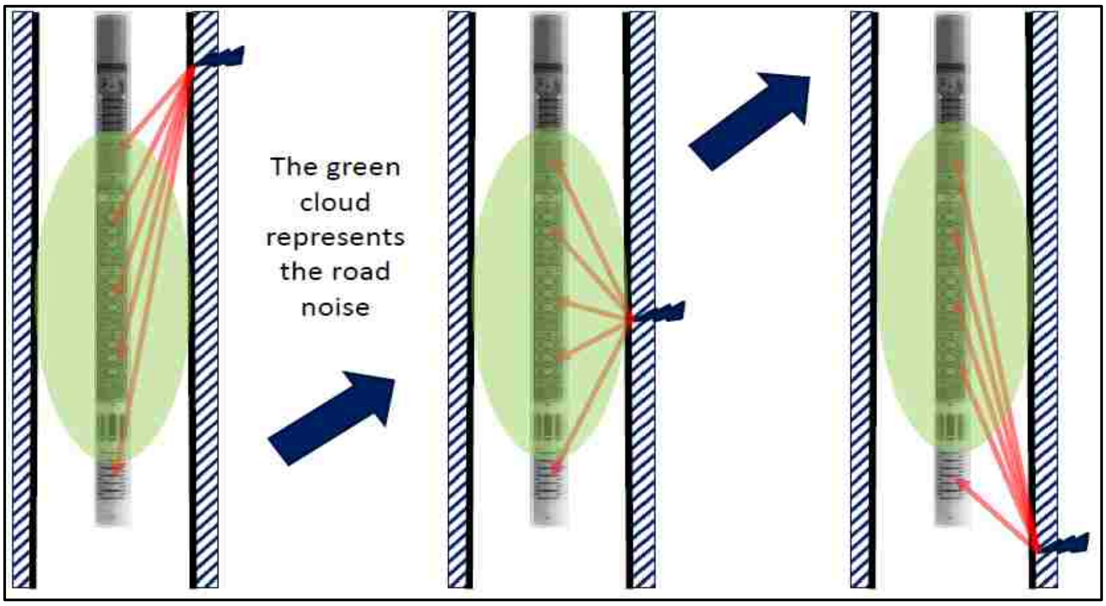

Figure 6: Represents the stationary leak source vs. the moving road noise

Chapter 2: Data Analysis and Processing

2.1 Advanced Processing Technique

When the tool is recording, it captures three types of data; Road noise, background noise along with leakage noise if found. The three types of signals illustrated in Figure 7, are mixed and interfered with each other over the range from 5-40 kHz as follows:

- Road noise – 5k-40 kHz
- Background noise 1k-40 kHz
- Leakage noise 25 k-40 kHz

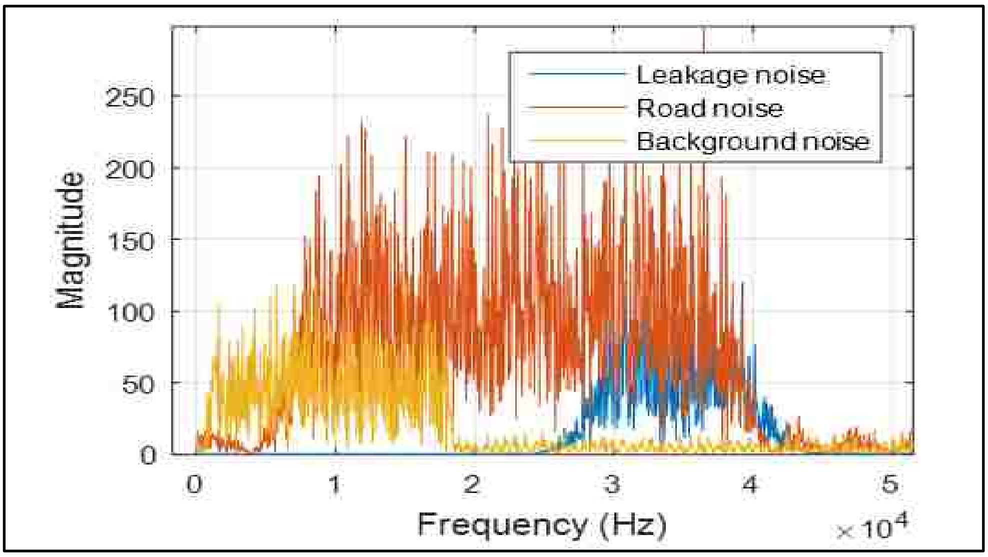

Figure 7: Different type of noise signals

One of the main issues is that the leak noise is mixed with the unsymmetrical road noise. In the interval where is no leak, the tool is recording only road noise until it reaches the leak source, there will be interference between the signals where the leak noise will suppress the road noise and will have a different signal phase and amplitude that differentiate it from the other unwanted noise. The following procedure will present how the tool, through Advanced processing, will capture the leak source and remove the unwanted other noises (Figure 8). Hence, dispersion analysis is needed. Dispersion analysis is technique consists of acquiring waveforms from an array of receivers distributed along the tool. The method depends on processing in the frequency domain and exploiting phase information to measure the travel time for each frequency component.

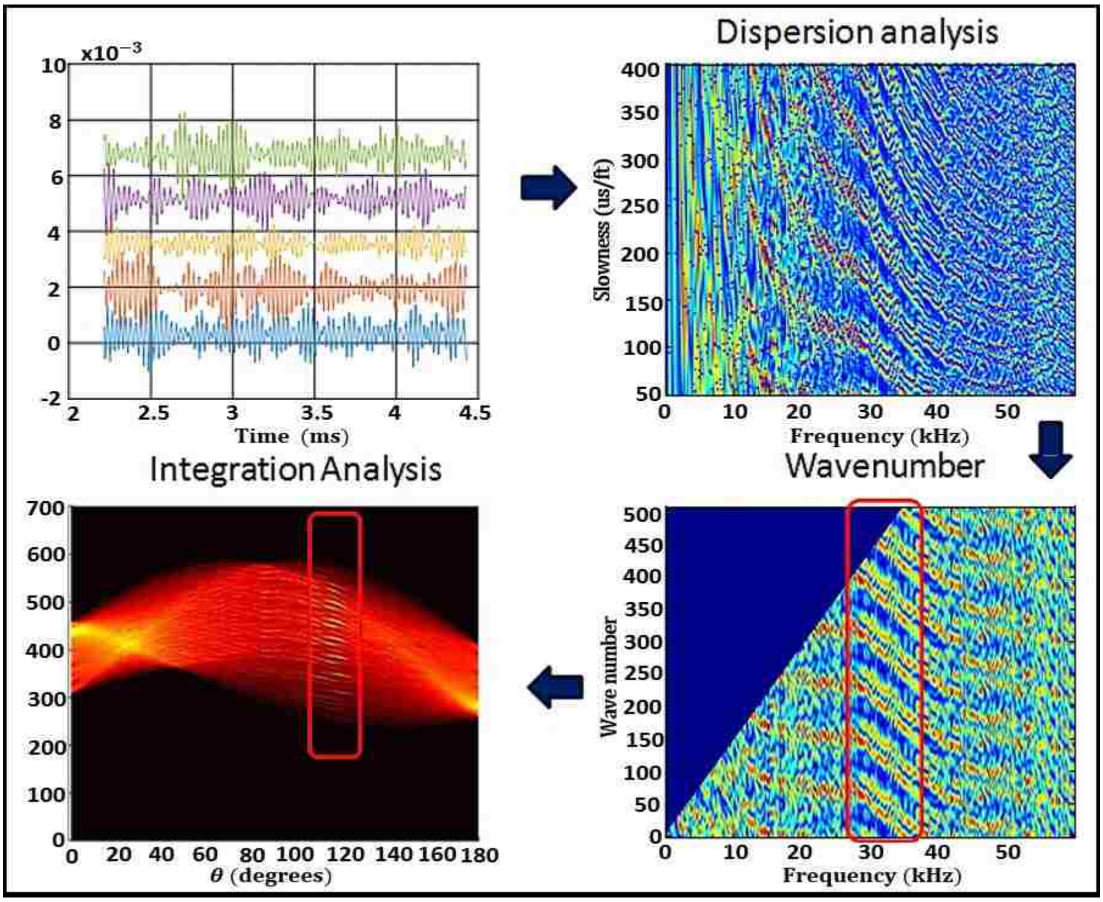

Figure 8: Steps for advanced processing workflow

The main idea of dispersion is to differentiate between different signals based on the arrival time, however we still in need to find out which is a real response of the leak and which is still a road or background noise. In this matter, the concept that leak source is stationary unlike the other road noise will be a decisive step in which the data will on go integration analysis (Figure 9).

Integration analysis or propagation analysis concept is based on that the leak source is stationary and when the tool propagates downwards and comes near the leak source, angle θ, which is the angle of leak source to the sensor, will starts to decreases until it reaches zero, and after the tool passes it the angle θ will start to increase again as the tool propagates upwards (Figure 10).

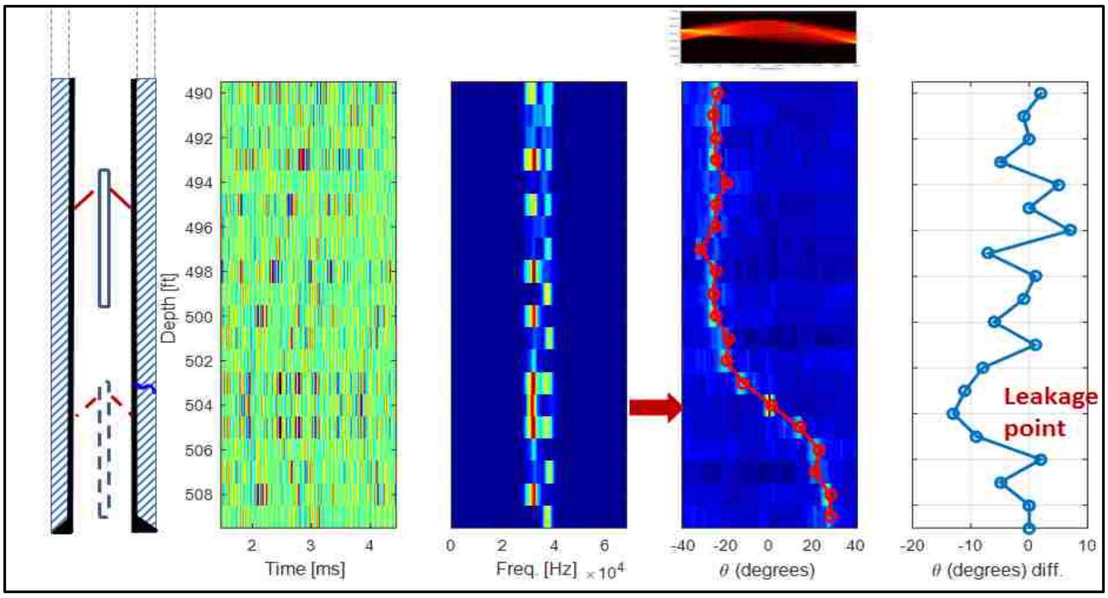

Figure 9: Identifying leak point

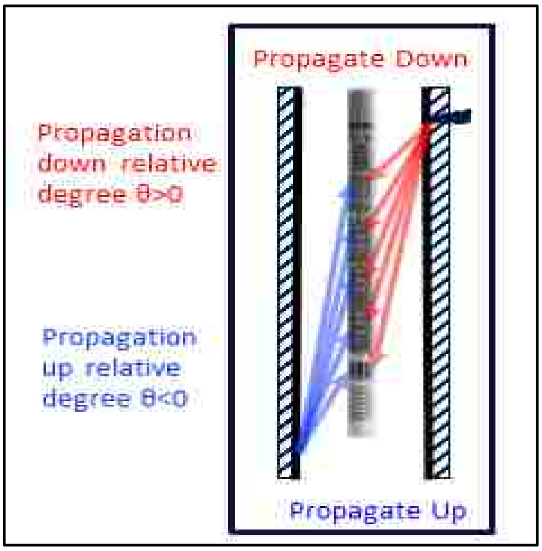

Figure 10 : Wave propagation analysis

2.2 Software Processing Workflow

Using commercial software designed for the array noise tool, data will be processed and displayed. The data is loaded to software in the form of PLF file. Next step is to go to data editor tab and implement different types of processing mainly are basic processing and advanced processing (Figure 11).

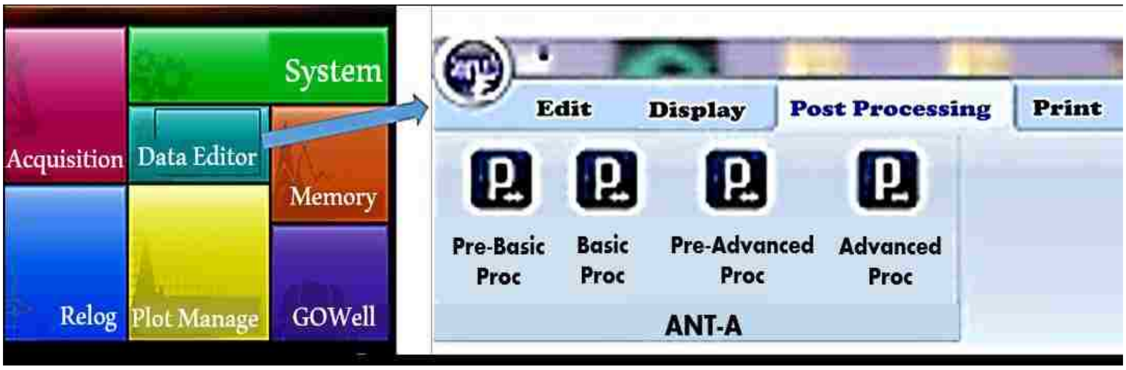

Figure 11 : Commercial software interface with the processing tab

Figure 12 shows the end results of basic and advanced processing. Basic processing will produce spectrum, which is raw frequency spectrum from all the differential sensors and BAP spectrum which is the advanced spectrum to enhance leak point detection. Advanced processing is where the propagation analysis occurs and it produces ADP spectrum along with the frequency curves as follows:

- F515 is 5-15 kHz frequency band
- F153 is energy in 15-30 kHz frequency band
- F345 is energy in 30-45 kHz frequency band
- Energy curve
- Baseline curve

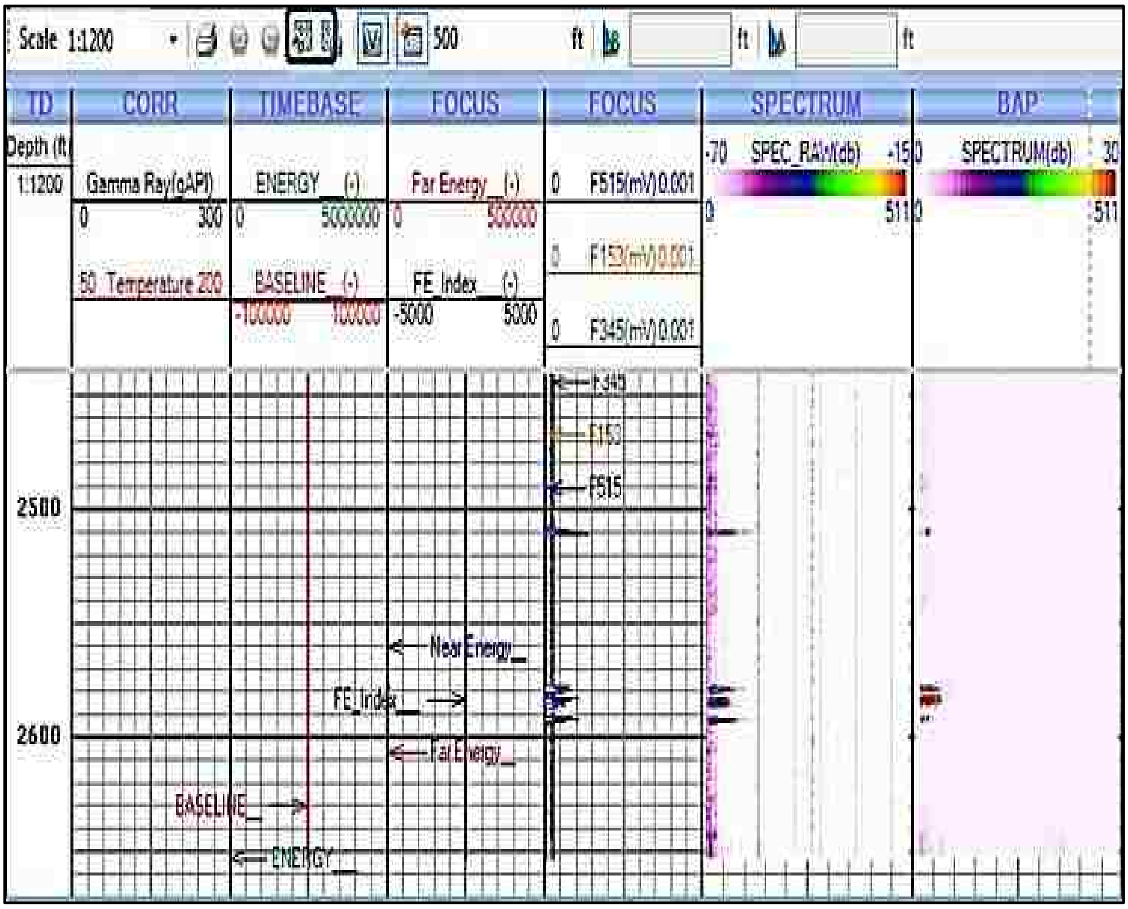

Figure 12: End result of basic and advanced processing

Chapter 3: Optimization of Array Noise Tool

It is crucial to validate data recorded and optimize related operational procedures such as gain settings, adequate logging speed and related accessories attached to tool string (centralizers). These steps are important to maintain and enhance the data quality and to understand more about the tool limitations and where it could have more improvements. The process was done in three stages as it is shown in Figure 13.

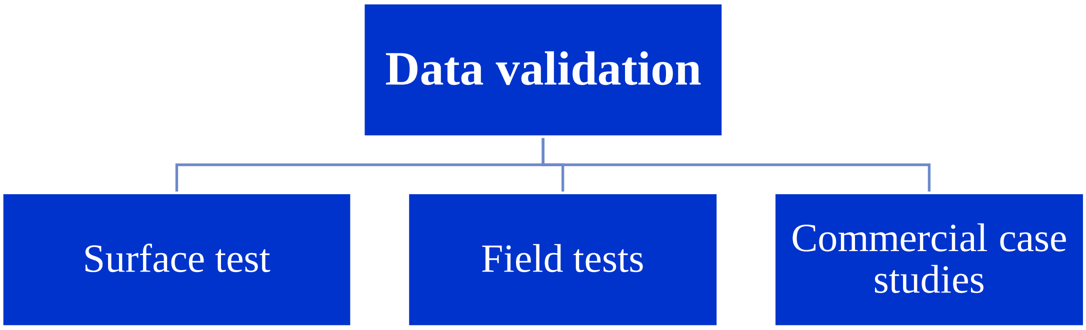

Figure 13: Steps to optimize and validate array noise tool

3.1 Surface Test

In order to obtain the highest signal to noise ratio and maximize the amount of data recorded during logging, some tests were applied on the sensors readings to find out the optimum values in which adequate data is recorded. Gain is a logarithmic mode which is used to amplify the data and enhance signal to noise ratio.

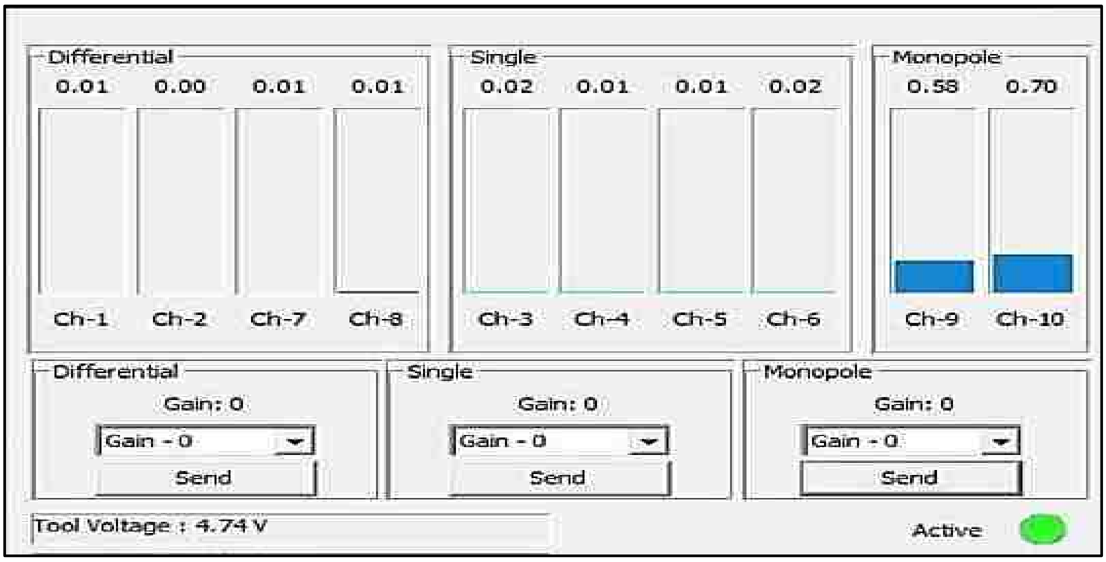

Figure 14: Test for channels reading in sensors at 0-0-0 gain setup

Figure 14 shows the sensors reading at the 0-0-0 gain setup. It shows that the reading is too low for differential and single sensors, however the monopoles are reading good. Monopole gain setting should be kept zero.

Figure 15 shows channels reading in sensors at 1-1-1. It shows that the monopole reading is saturated, single reading is good and the differential reading should increase.

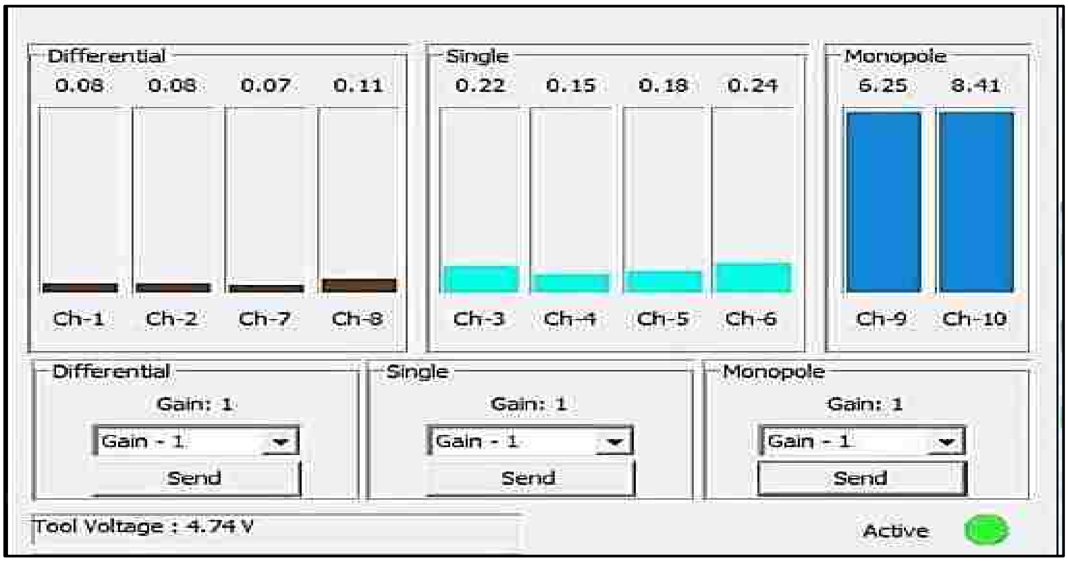

Figure 15: Test for channels reading in sensors at 1-1-1 gain setup

That means we need to reduce the monopole reading as it got saturated and increase single to have better response and differential sensors as well. In Figure 16, it shows that we applied gain setting in the form of 2-2-0. The monopoles reading are showing high values even if it was at the lowest gain possible, suggesting that the reading are affected with gain from another sensors. Single channels are quite saturated however differential sensors are reading normal values which can be increased. It is also recommended to plan the surface test each time prior to logging to quick QC tool response on surface before commencing to log down hole.

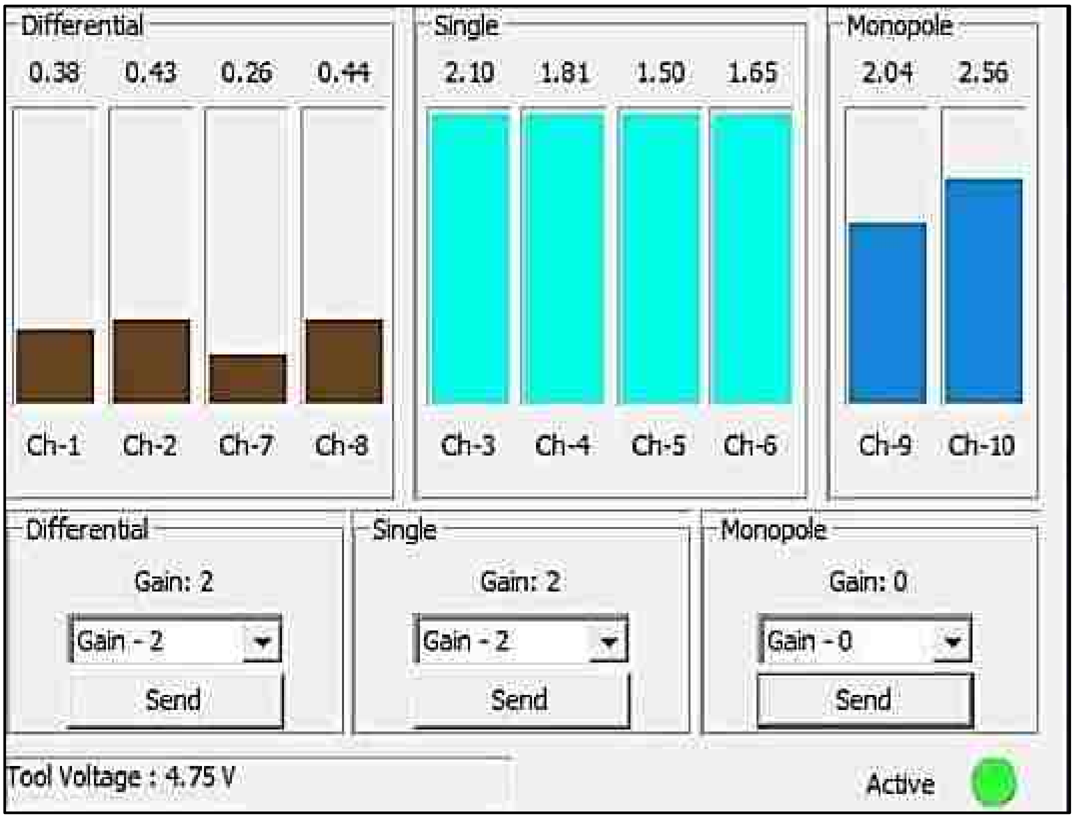

Figure 16: Test for channels reading in sensors at 2-2-0 gain setup

Applying different gain settings, we can conclude that around 1/3 of the height of the bar for each channel reading is adequate for the best response, and the recommended gain setting would be 2-1-0 or 2-2-0 depending on how the tool will respond down hole.

One of the surface tests was conducted to show the implications of using inadequate gain setting on the data. Figure 17 illustrate a noise log from a surface test pipe, with the top section using gain setting of 2-2-0 and the bottom section using gain setting of 3-1-1. The gain setting of the top interval shows good quality data and the noise signal are in range, while the bottom section shows that the data was excessively "boosted" which result in masking the actual noise signal and hence decreasing the signal to noise ratio instead of increasing it.

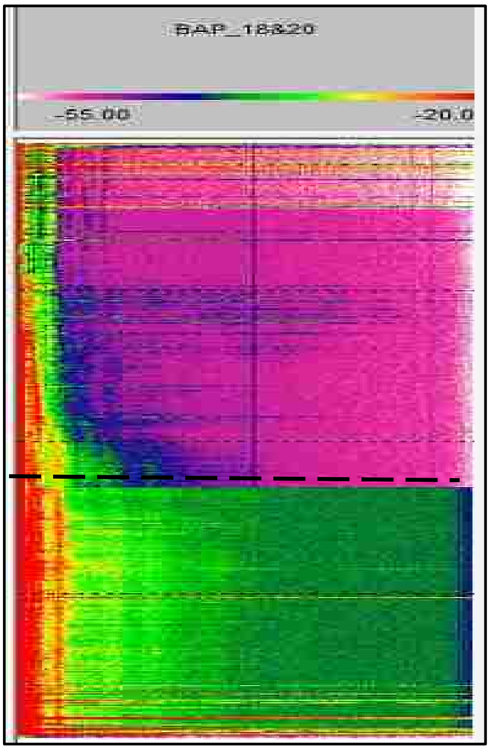

Figure 17: Effect of different gain setting on the data

In order to make sure the gain settings that were tested are working properly, a test was conducted on a test well, with water injection line that will simulate a casing leak (Figure 18). Two runs were done; one was done when the well was in shut in condition and the other run, where the other run water was injected in one of the water lines while the other is closed. The tool was recorded in both runs using gain setting of 2-2-0 as mentioned above.

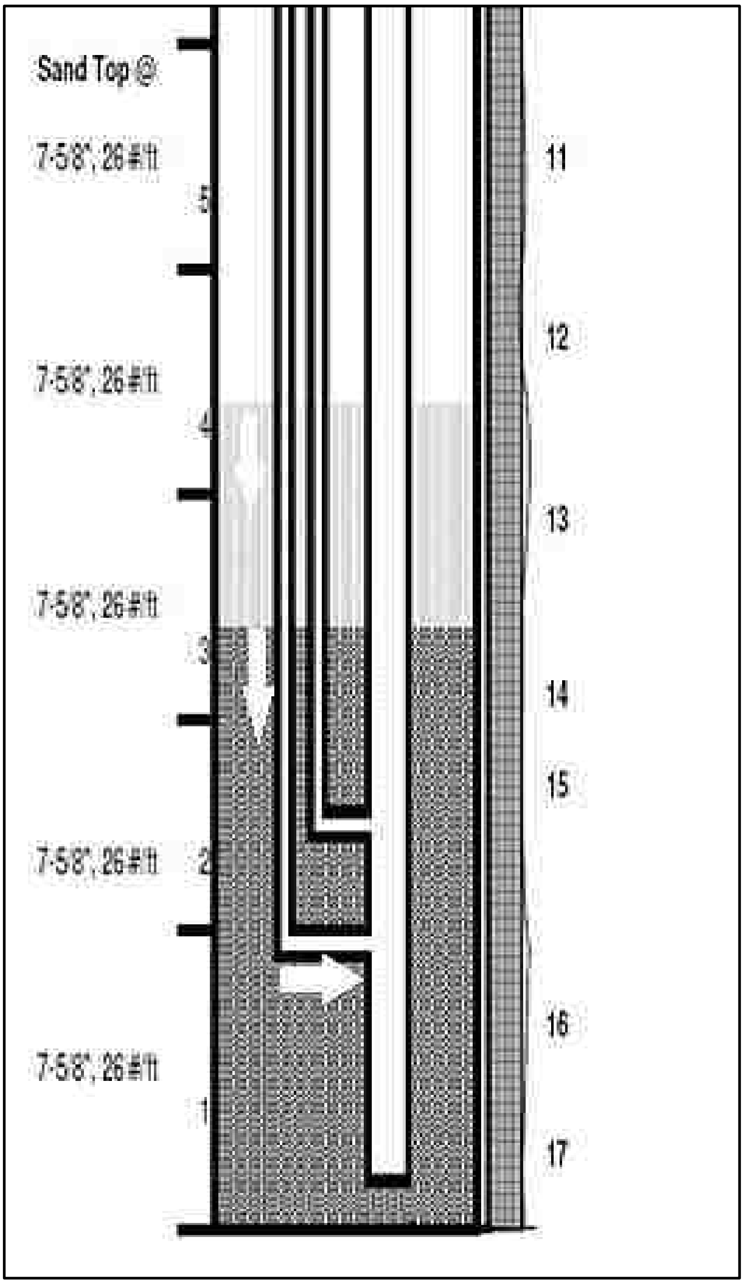

Figure 18: Test well and the injection line to simulate a leak

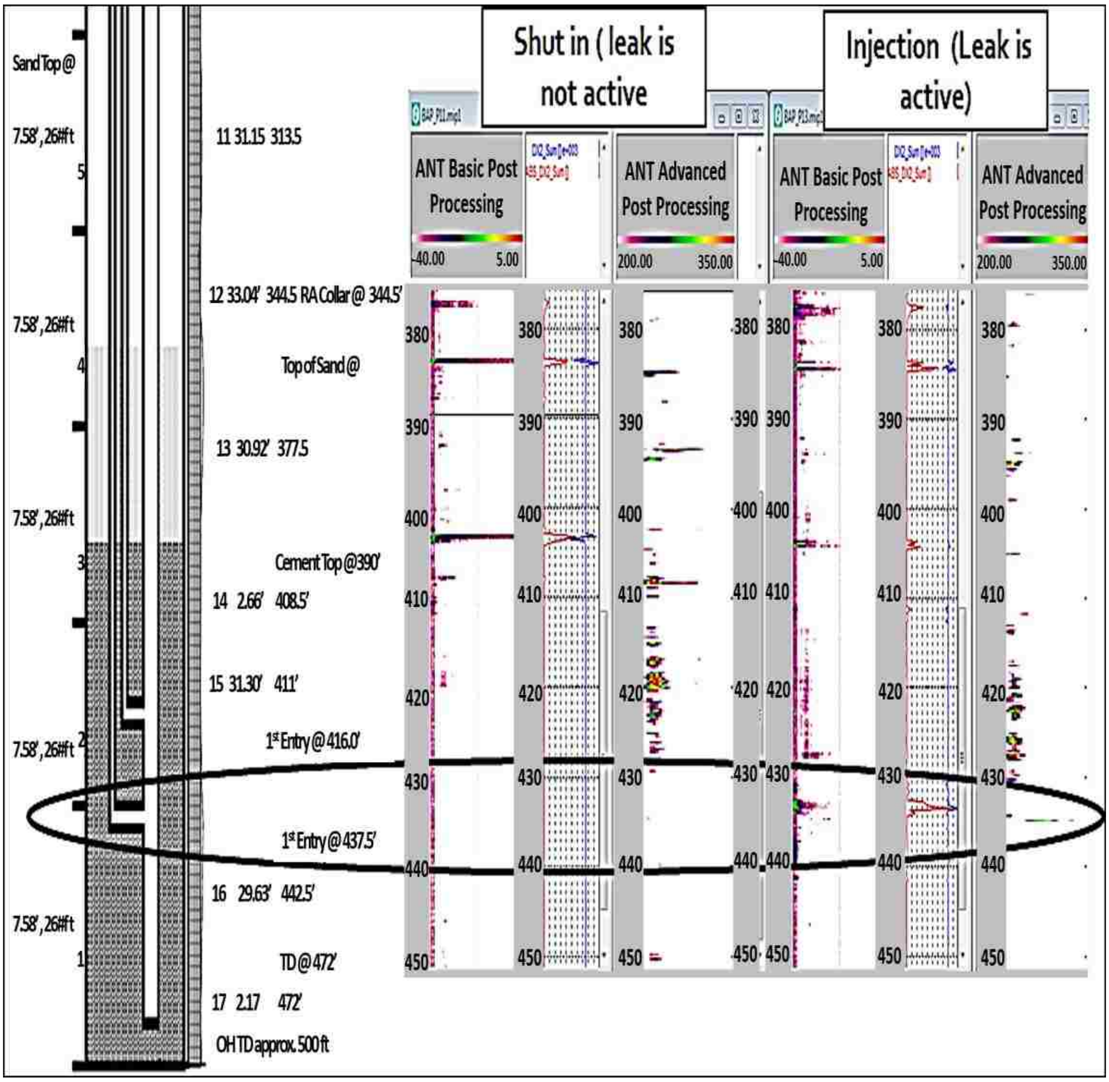

Figure 19: Simulated active leak recorded by array noise tool

As shown in Figure 19, the array noise tool was able to record fluid movement through the water entry point, which confirms the gain setting of 2-2-0 is working properly.

3.2 Field Tests

Running the array noise tool in actual wells may face some challenges in terms of assessing the optimum logging speed that the tool should be logging with down hole, also to assess the effect of having centralizers along with the tool down hole. Figure 20 shows centralizers used in down-hole logging tool. Moreover, the idea is also to decide the adequate logging procedure for implementing, as the array noise tool measurements is quite different than the ordinary and stationary logging tools. Some field tests were implemented in order to investigate the above points and for the analyst to get more hands on experience and anticipate how the tool response with the environments around.

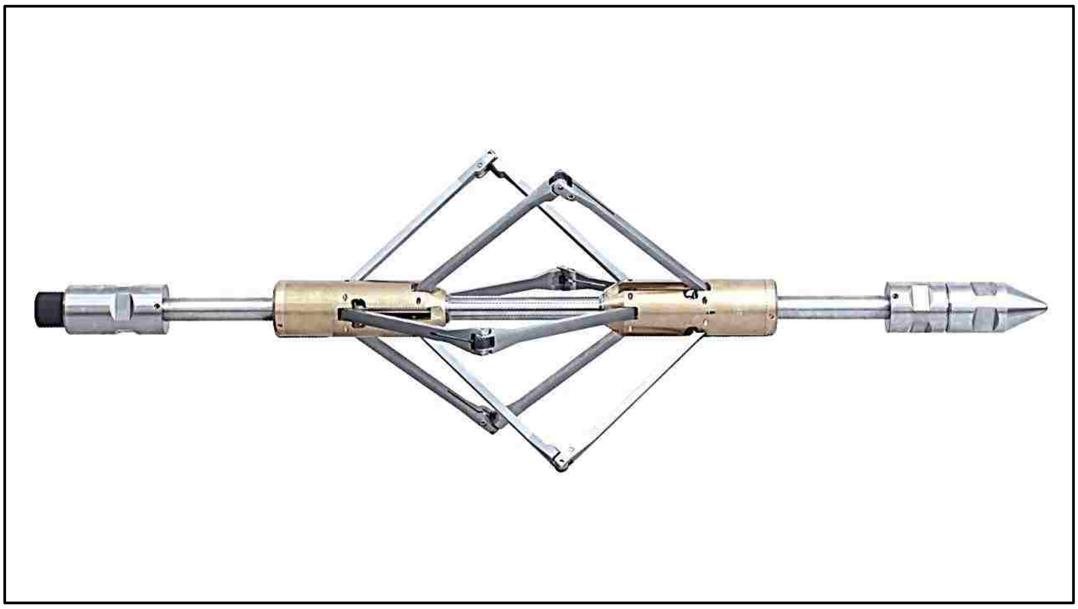

Figure 20: Centralizers used in down-hole logging

Array noise log was recorded in well under A-Annulus injection (Figure 21) and another run under B-Annulus injection (Figure 22). The tool string had centralizers in order to maintain the tool movement in the well to be properly centralized. The proposed logging speed was 16 ft/min.

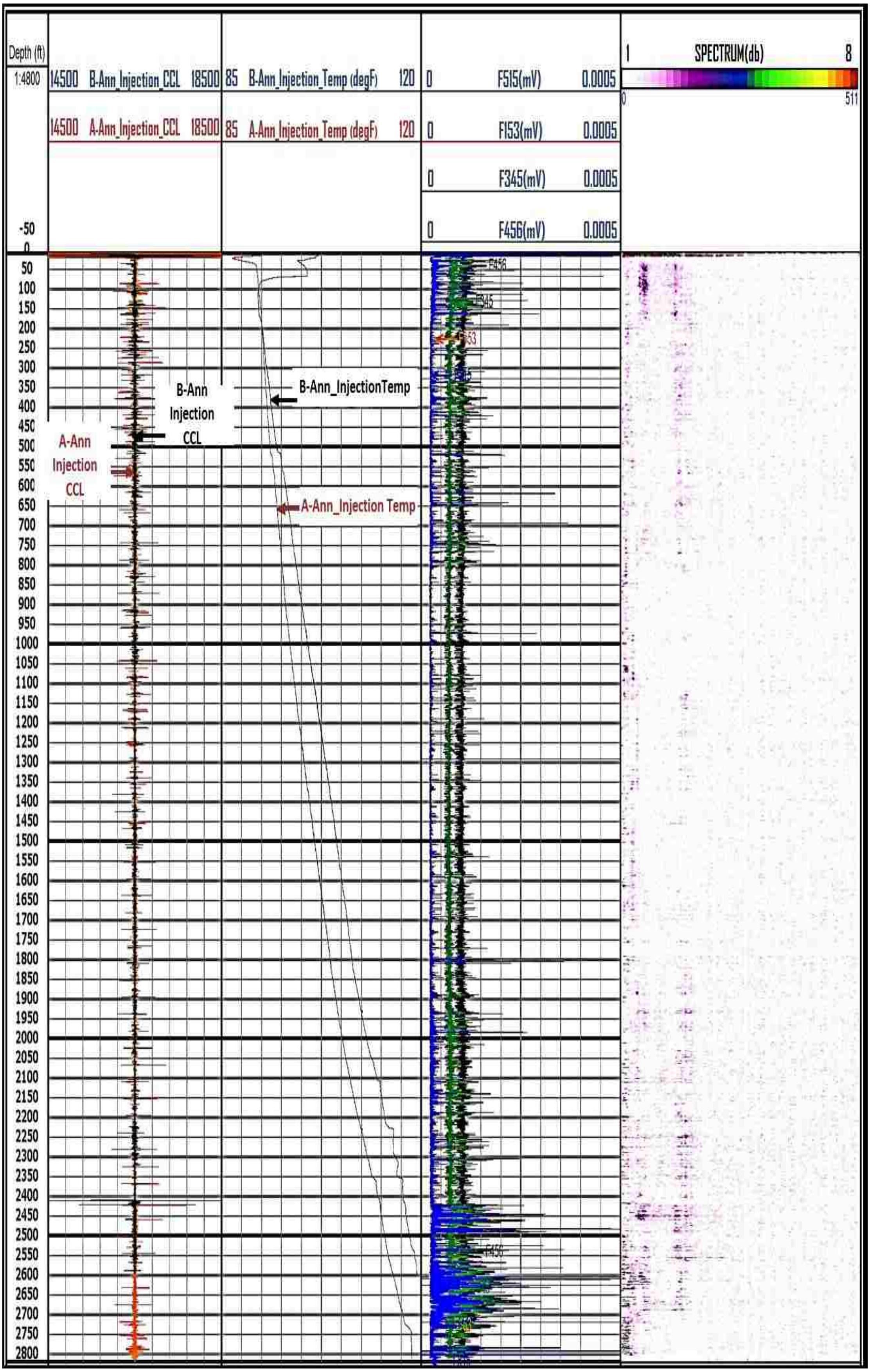

Figure 21: Array noise tool survey under A-Annulus injection

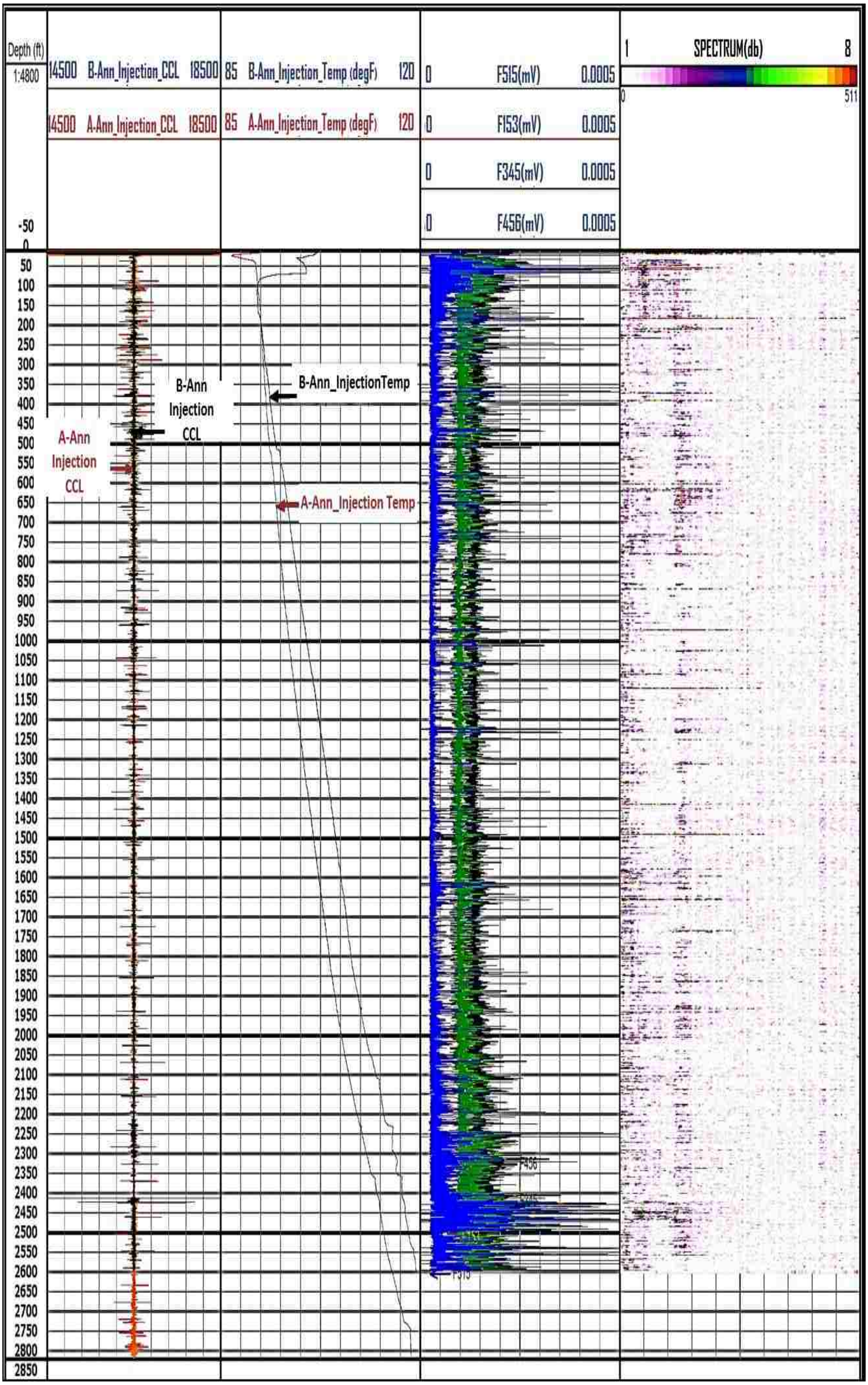

Figure 22: Array noise tool survey under B-Annulus injection

It is noticed that throughout the entire log up normal spikes where popping up at repeated intervals. These spikes are not due to Background or road noise, as in the basic processing step, these are already eliminated. Therefore, the noise is coming from a stationary source inside the well. Having them repeatedly all over the entire logging intervals could not be interpreted as noise coming from either casing leak. Analysis is that one of the tool string accessories are causing noise with the well equipment and therefore generating the same noise source that the tool captures and masks the actual noise coming due to leak source. Having that the tool was logging inside the tubing (less than 4 ½”), it is possible that the centralizer arms are colliding with the tubing collars and creating such a noise.

To overcome this issue, a centralizer will be replaced by rubber peak standoff. The standoff will still help in centralizing the tool down hole and will have less friction with the tubing collars.

Figure 23 : Design of wire line peak standoff (G.Weather, Lee Paterson, Ben Kidd et al. 2015).

Another field test was done to check the effect of stand offs to reduce collision with tubing collars.

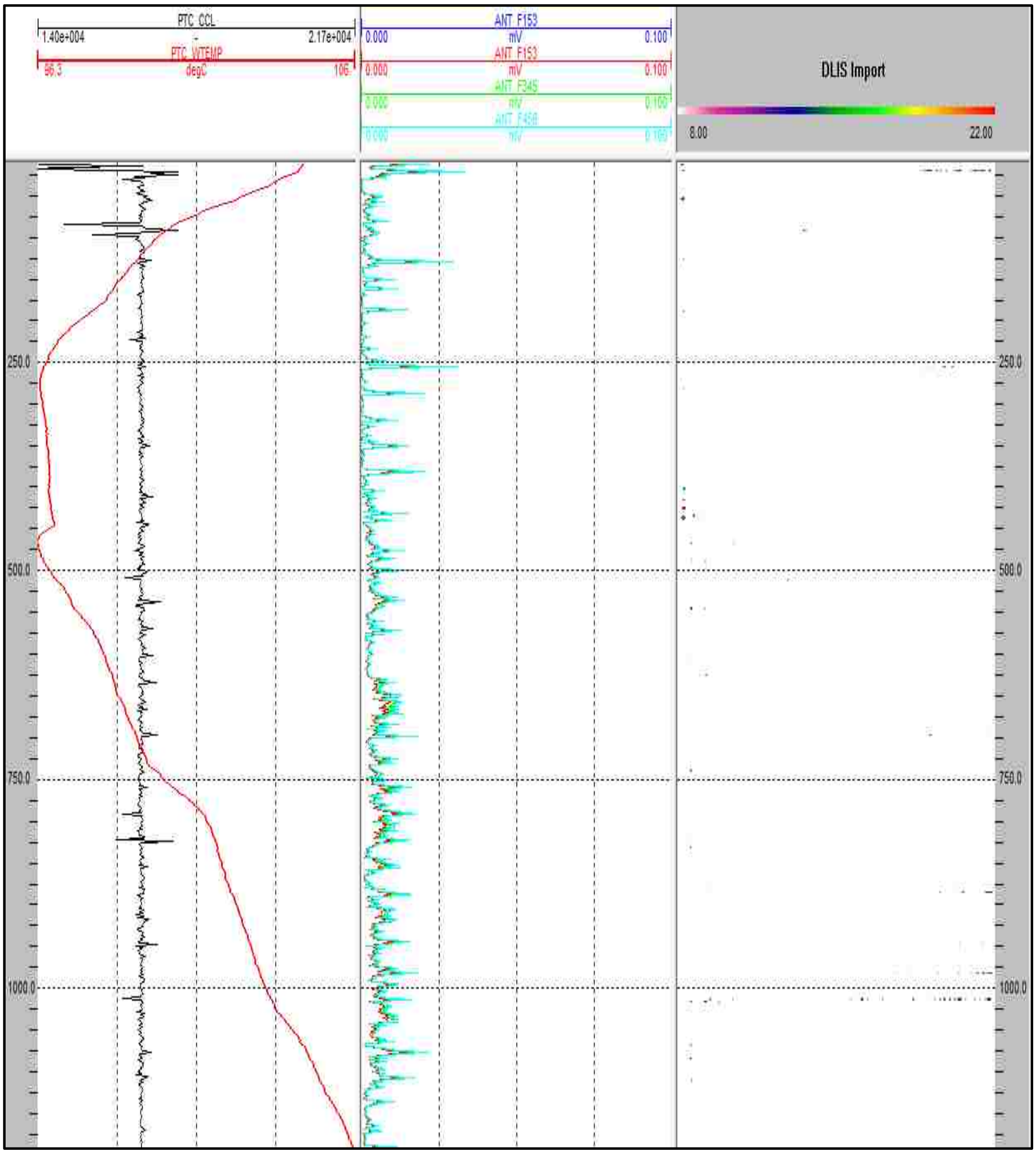

Figure 24: Array noise tool survey under shut in condition

The effect of using standoff was clearly shown in Figure 23, as throughout the entire logging survey, the tool response showed no up normal spikes which confirms that it was a centralizer issue and the rubber standoff was effective to reduce the unwanted noise and enhance the tool response quality.

The conclusion from the above cases is that whenever we log in tubing (4 ½” or less), centralizers should be replaced by a peak standoff, as the centralizers are making unwanted noise with the tubing collars. However, if the tool is running in the inner pipe and it is greater than 4 ½” OD, then it is preferred to use centralizers. The use of centralizers in this case will not have much impact with the collars as the centralizer arms will be having less friction with the pipe collars (larger pipe would make the centralizer arm opens more and hence its tension and impact will be lower which will generate a lower sound print and will be easily eliminated by the processing software as road or background noise.

Figure 24 highlights the effect of speed. The higher noisy unwanted data was at speed of 16-20 ft/min however the speed in the below interval was reduced to 10-12 ft/min.

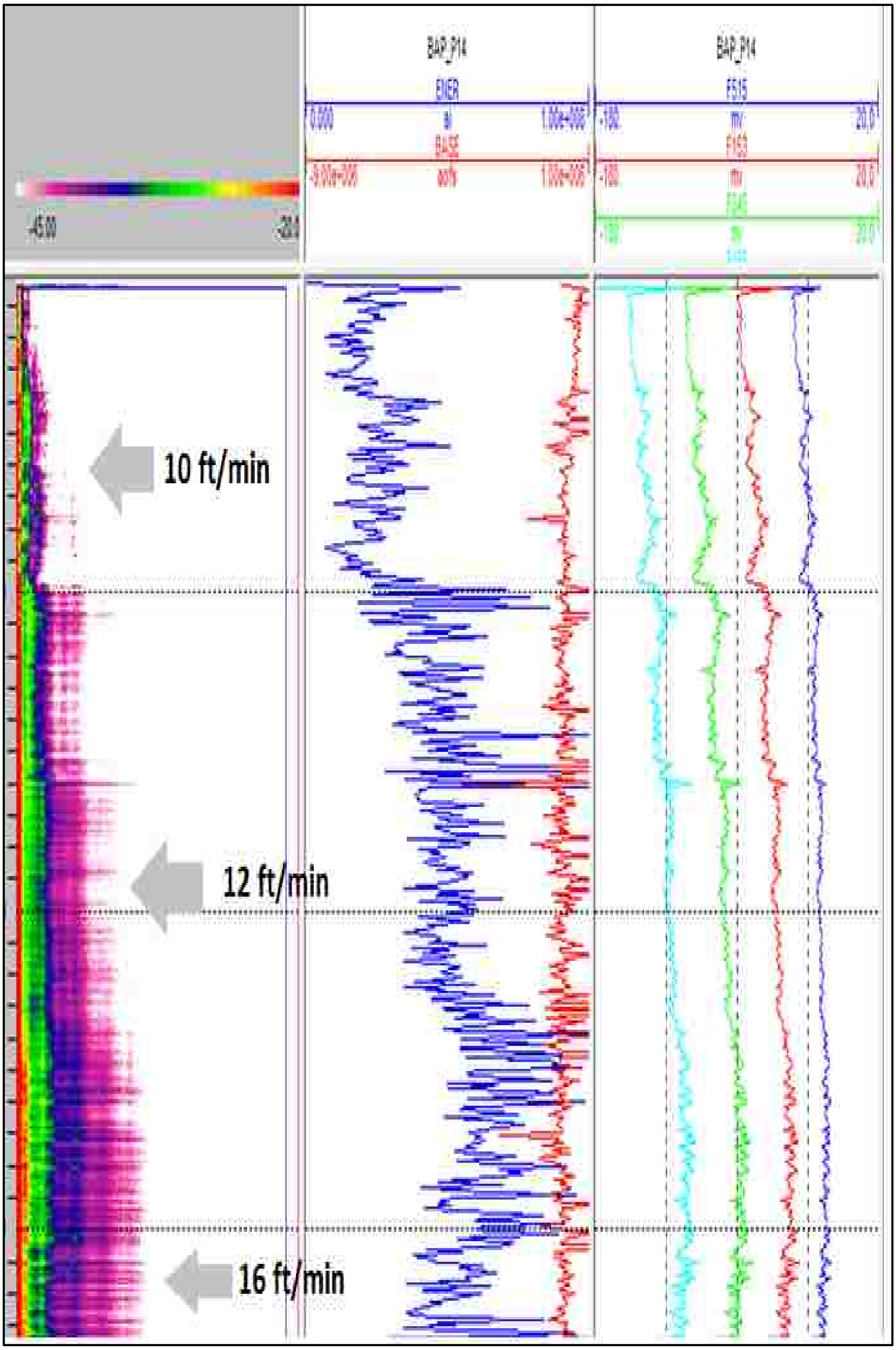

Figure 25: Effect of speed on array noise tool

From Figure 25, it is observed that the resolution of the noise spectrum was not as high as it should be; suggesting either the gain settings or the speed was not adequate. Therefore, the recommended speed should be as follows:

- In case of the down pass, go 10-12 ft/min and observe on surface if there are any indications on a leak down –hole.
- In case of the up pass, either if the depth was suspected before or found by during the down pass, go with the speed of 6 ft/min.

3.3 Case Studies

The Array noise tool was subjected to field and surface tests in order to optimize main parameters such as speed, mode and gain settings and tool accessories within the string. Array noise tool was nominated to investigate various leak detection candidate wells in order to point out where the leak source is coming from.

3.3.1 Case Study No.1

Array noise log was recorded in XX well under A Annulus injection survey. The objective is to locate the source of A-Annulus pressure buildup. The objective was to check for possible leak source coming from the packer at interval B and the Packer at interval A is holding.

Logging procedure was proposed as follows:

- Log at speed of 10-12 ft/min with gain setting 2-0-0.
- Interval A and Interval B, log at speed of 6 ft/min.

As shown in Figure 26, the ANT recorded noise throughout the whole frequency domain spectrum (0-30 kHz) across the packer setting in interval A. It is also shown in the temperature curve where we can observe a break, suggesting a fluid entry through that interval. Figure 27 shows the noise log at packer depth in interval B. As observed from the data, there is no noise recorded or any temperature perturbation at the packer depth, which concludes that the leak source is not from that interval.

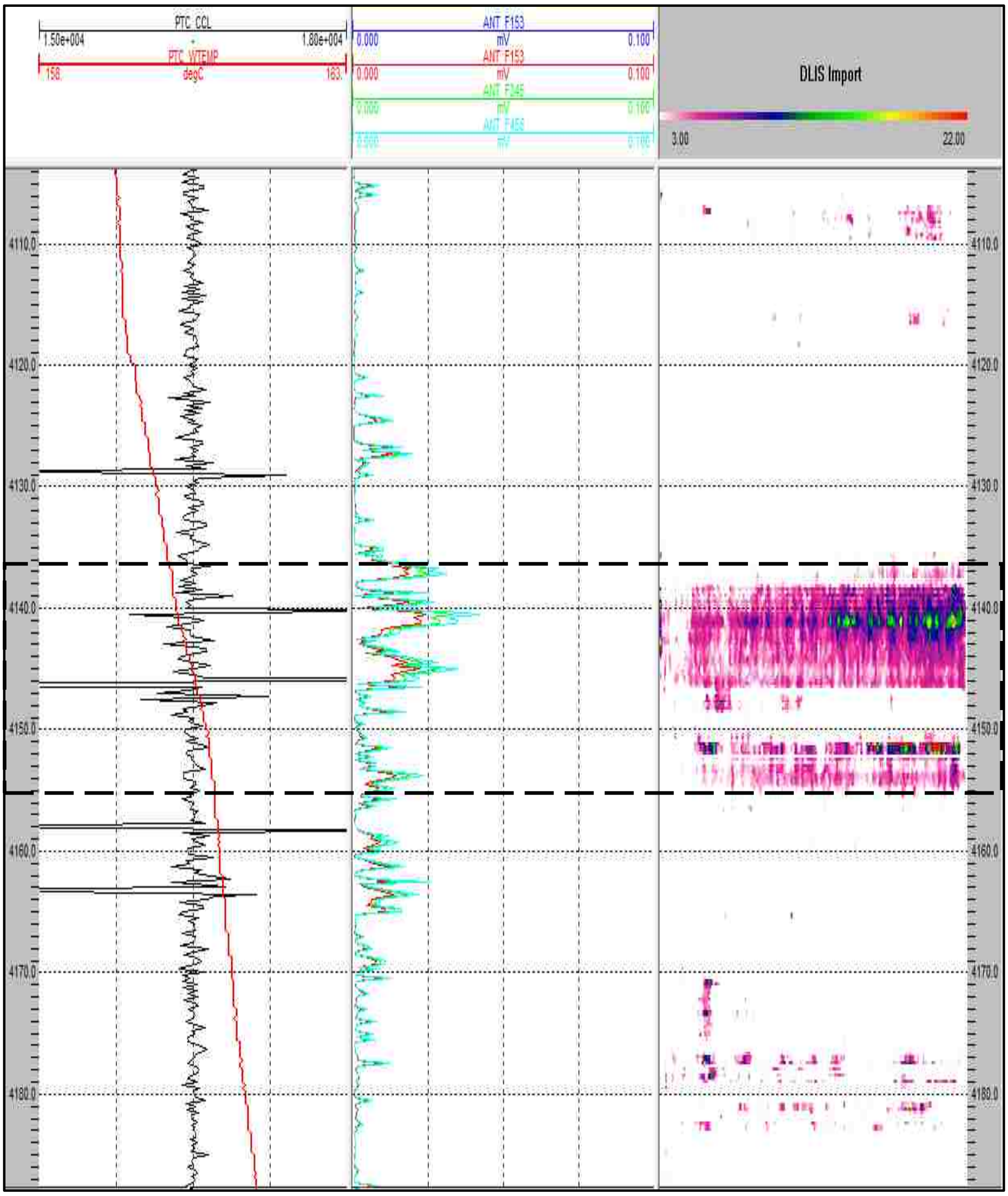

Figure 26: Array noise tool recorded noise at packer setting depth in interval A

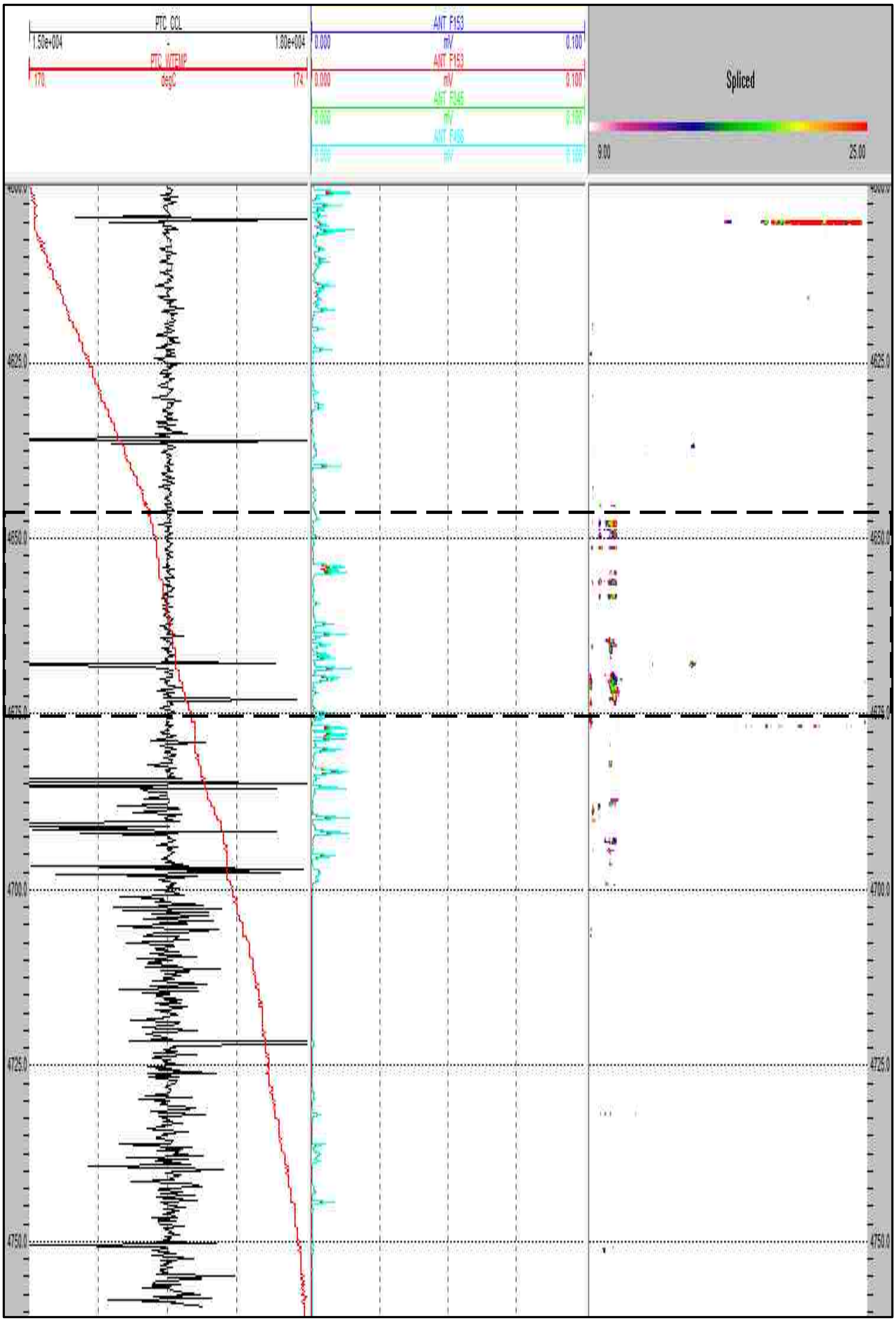

Figure 27 : Array noise tool data at packer in Interval B

3.3.2 Case Study No.2

The objective of the array noise tool is to identify any tubing leak and to check the integrity of Gas lift mandrels. There will be another run using a well-known stationary noise tool to compare and validate results of the new technology. Logging was done under A –Annulus bleed off and logging plan was as follows:

- Log at speed of 16 ft/min.
- Gain setting should be 2-0-0.

In Figure 28, it shows the full interval log and at the GLM intervals, there is noise recorded over gas lift mandrel 1 and 2.Tool recorded noise at the depth range of the first gas lift mandrel which suggests that the lift is leaking and it is not fully closed (Figure 29) Noise was recorded In all frequency range up to 30 kHz and it is showing at energy curves as well. Although it was not the optimum speed to log using the noise tool, it showed very precise results and was able to capture the leak despite some high background noise due to the speed. Figure 30 shows that tool recorded noise at the GLM-2 interval. Comparing both array noise tool and the stationary noise tool, it shows good match, as the stationary tool detected noise coming from the leak source in GLM-1 and GLM-2 (Figure 31 and 32).

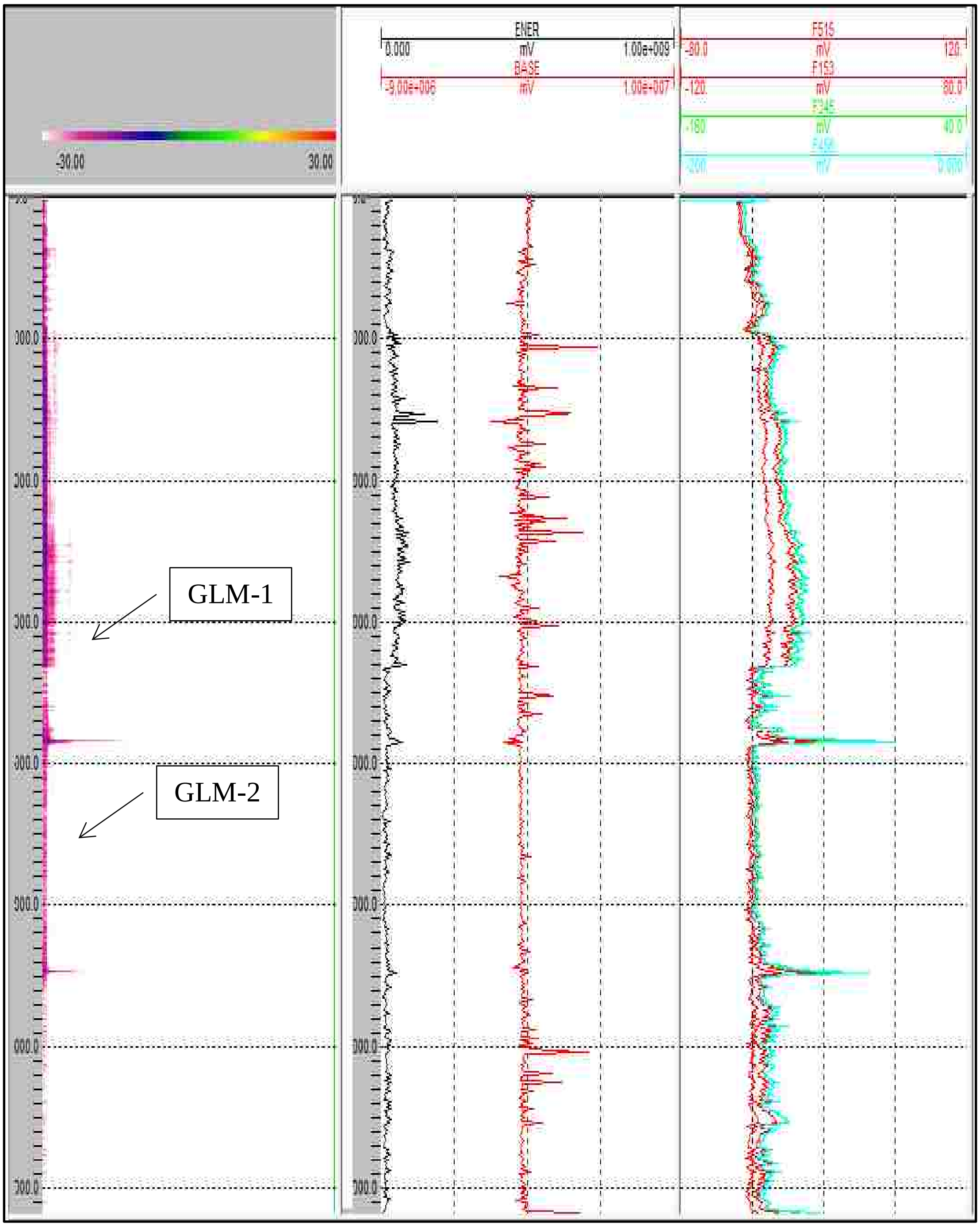

Figure 28: Noise tool data over the whole interval

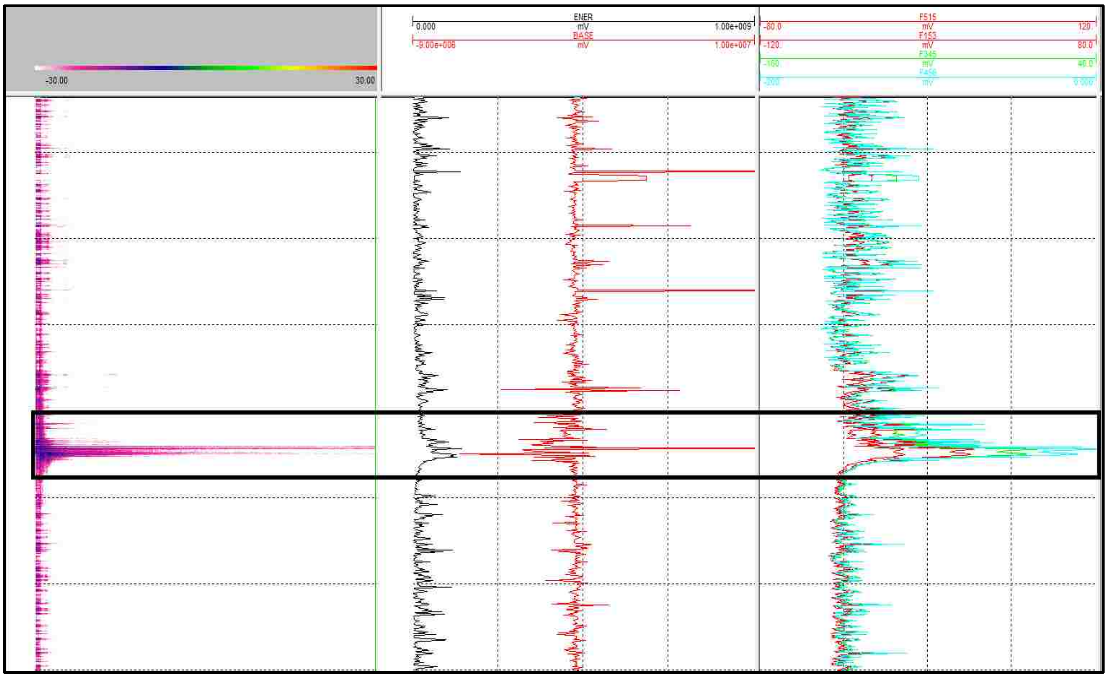

Figure 29: Noise tool recorded data over GLM-1 interval

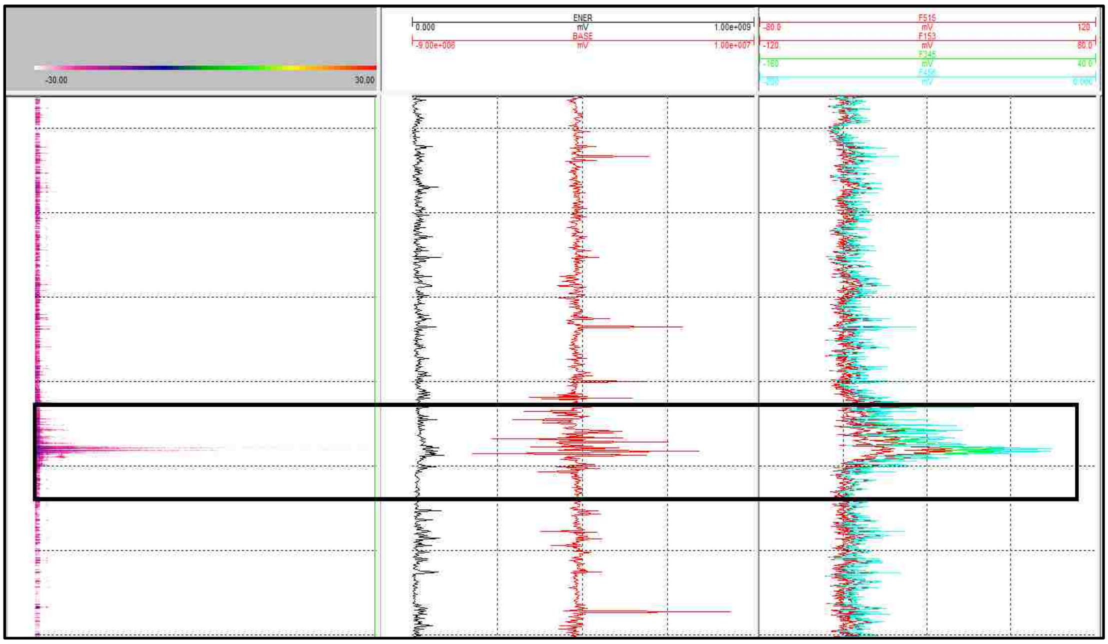

Figure 30: Noise tool recorded data over GLM-2 interval

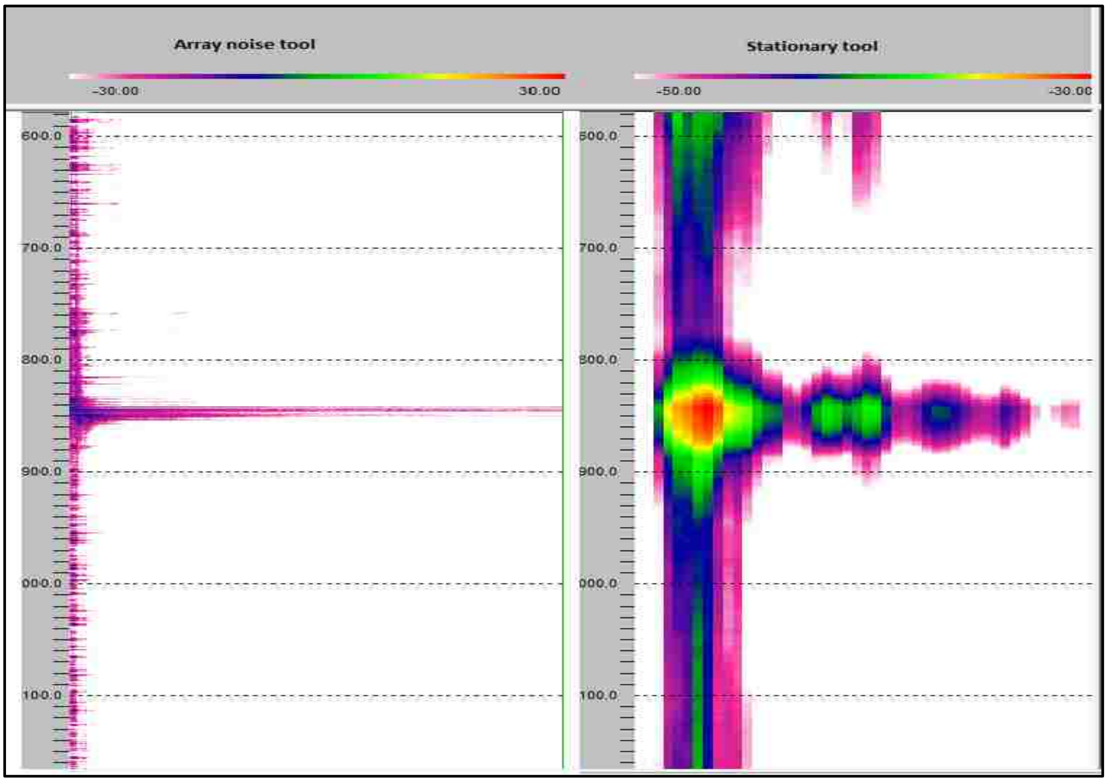

Figure 31: Array noise tool and stationary tool data comparison at GLM-1

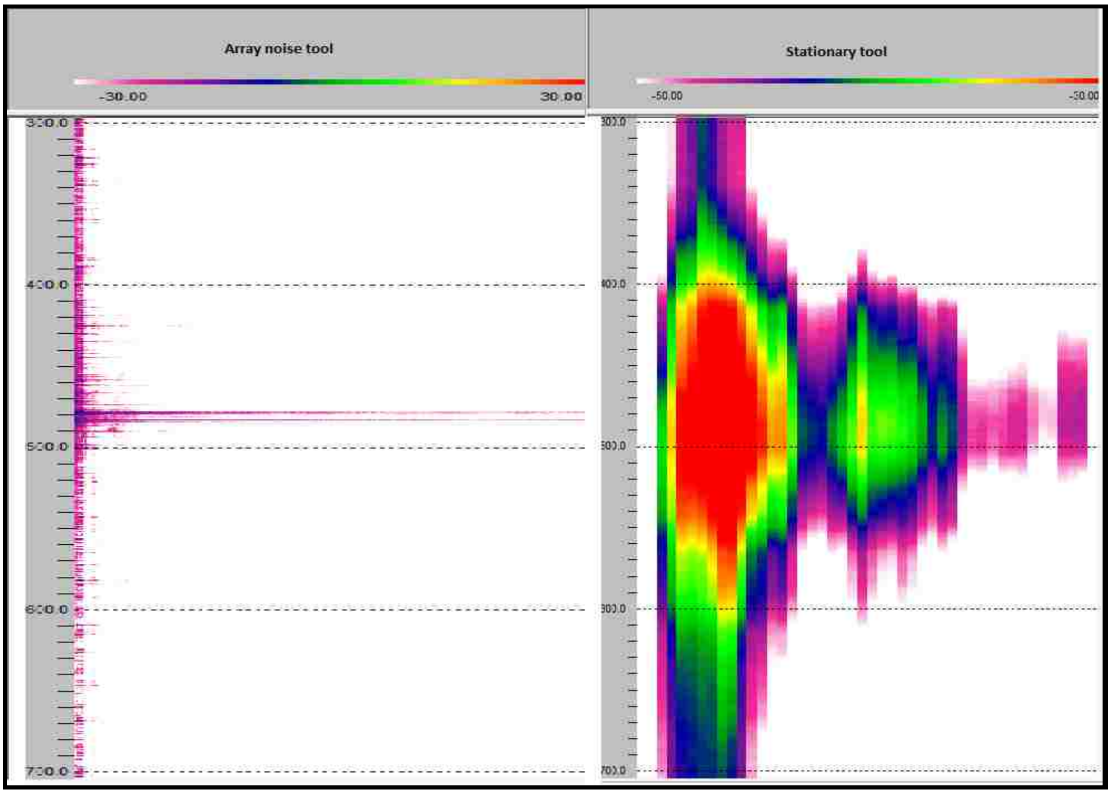

Figure 32: Array noise tool and stationary tool data comparison at GLM-2

3.3.3 Case Study No.3

Objective of the job was to find out communication between A- Annulus and tubing, therefore the Array noise log was recorded under three different conditions; A-Annulus bleed off, injection with opening A-Annulus and Injection with closing A-Annulus. The other secondary objective for this well is to optimize which of the following 3 conditions could be classified as the best logging procedure for the Array noise tool and which will yield the best results in terms of leak detection.

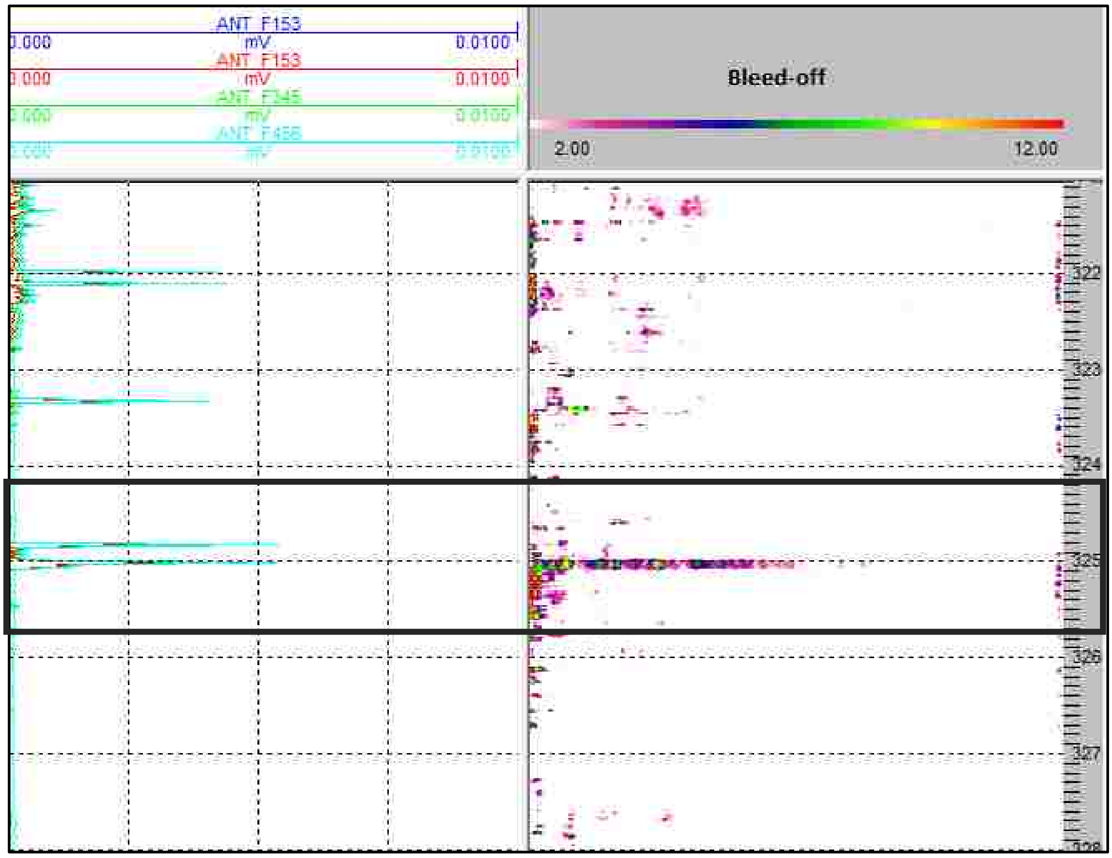

Figure 33: Array noise log under bleed off condition at the packer interval

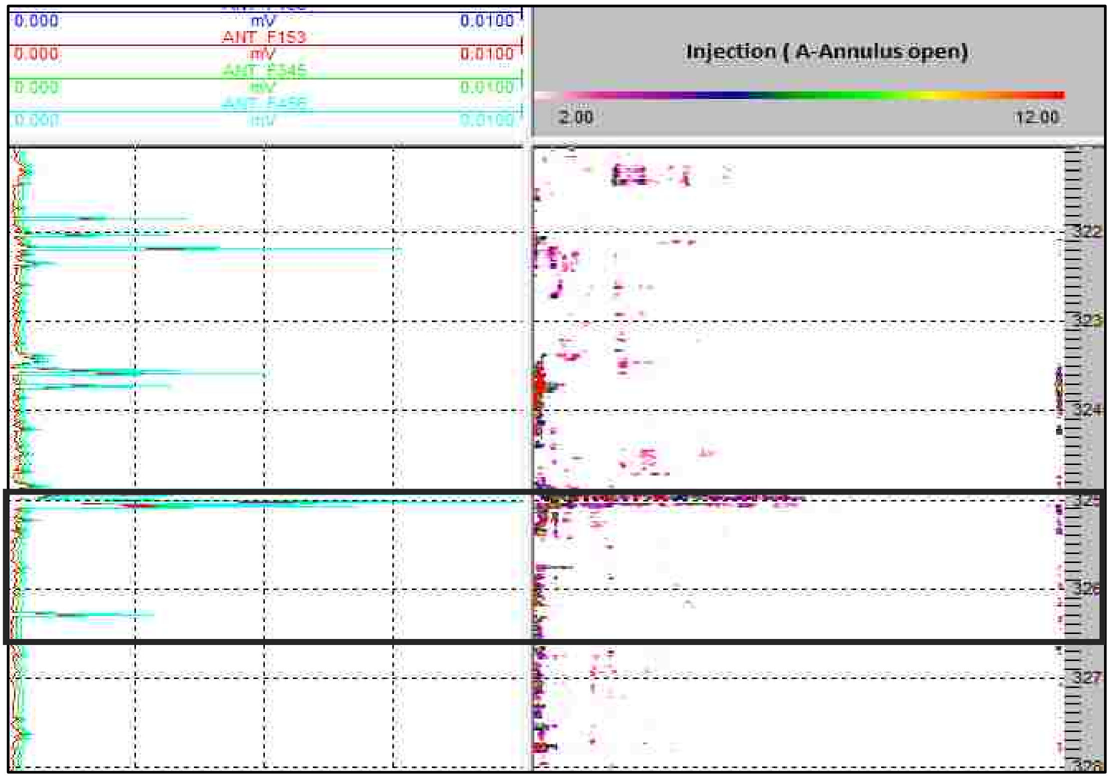

Figure 34: Array noise log under injection with open A-Annulus condition at the packer interval

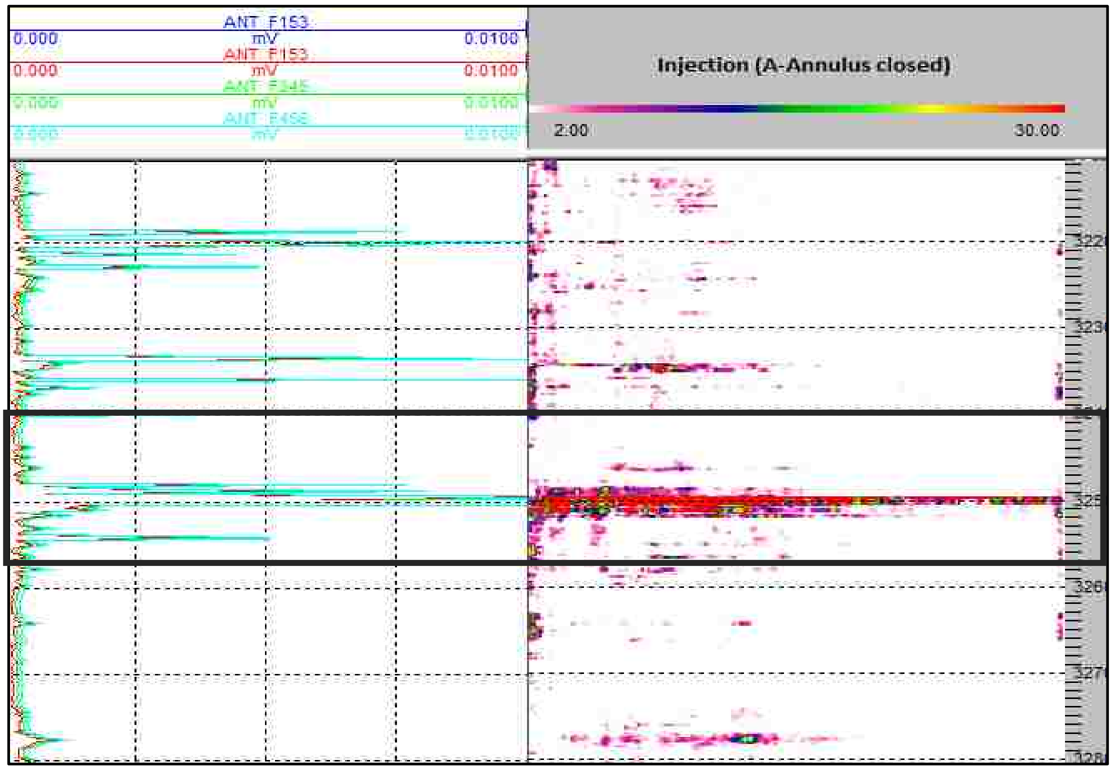

Figure 35 : Array noise log under injection with closed A-Annulus condition at the packer interval

Under the three different conditions, Array noise tool was able to record noise across the packer setting depth interval (Figures 33, 34 and 35). By comparing the three logs together, the tool seems to record a better noise signal with higher amplitude under the injection with A-Annulus is closed than the other two passes. The injection pass will create a better environment for the tool to record noise as there will be continuous flow from inside the tubing across the leak source, unlike the bleed off where venting gas from annulus will not create a high signal print that can be recorded on the tool. Injecting with closing the A-Annulus was better, as injecting from tubing side and closing the annulus side created a high pressure on the leak source which reflected on the noise log, on the other hand opening the A-Annulus while injecting will create at some point equilibrium in between the tubing and annulus, hence the delta pressure will go to minimum and the leak signal response will be weak.

Chapter 4: Conclusion

Optimizing the new array noise tool was done through several steps from lab and surface test to actual field implementations and meeting the objective. The Array noise tool was successfully able to analyze data and detect leak source precisely. By the aid of the advanced software processing, the interference of road / background noise with the actual leak source noise signal was minimized.

Throughout this process, few findings and observations were made to further enhance and elaborate the applications of the tool.

- Adding extra differential sensors will boost the signal to noise ratio and therefore focus more on the leak noise signal.
- Implement a beam forming analysis; a technique which will aid to identify the distance of the leak from the vicinity of the well bore. The beam forming technique depends on the wavelength propagation.
- Enhance the tool hardware material to accommodate harsh environments (H_2S compatible material).
- Further enhance the noise rejection from tool movement and tool accessories.

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