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Intelligent Running Tools for Subsea Drilling and Completion Equipment Using Acoustical Two-Way Communication Between the Subsea Wellhead and the Surface

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ABSTRACT

The development of intelligent running tools (smart tools) for subsea drilling and completion equipment is presented. The system provides intelligent feed-back of critical parameters while landing and operating subsea marine wellhead equipment. Two way communication is provided between the rig floor and the subsea wellhead and real time data is provided to the operator to allow informed decisions to be quickly made. Many other subsea applications are envisioned for this simple and rugged communication system.

INTRODUCTION

With the recent upturn in subsea drilling and production activities, safety and reliability have continued to grow in importance. To maintain the level of safety required, subsea operators must be able to reliably verify that all operations are performed accurately.

In 1987, a cause-of-malfunction survey conducted for marine wellhead equipment showed that a significant number of field problems were not caused by equipment failure, but rather by various types of mislocation errors associated with improper component positioning within the wellhead. Such errors were especially noted during installation of casing hangers and seal assemblies and retrieval of wear bushings. In any case, the misinstallation of a hanger or seal assembly or the failure to properly retrieve a wear bushing could have expensive and potentially dangerous consequences to the drilling program.

In the past, subsea operators have had to perform vital operations with minimal feedback to the surface. Standard rig floor indications (which can be vague or misleading, especially in deep water) have been the basic means to tell the rig operator if procedures have been successfully completed.

DEVELOPMENT GOAL

The development goal was to produce a system which could provide real time data to the rig operator while operating in a background mode without interfering with normal rig operations. Further, the goal was to prove the feasibility of using acoustical means of transmitting data from the subsea wellhead to the surface rig floor.

THE SMART TOOL SYSTEM

The smart tool system is shown schematically in figure 1. System components are shown in figure 2. The system consists of three main assemblies: A) a remote communications and control box, B) a surface sub, and C) a subsea smart sub.

A) The remote communications and control box allows the operator to collect data via FM radio while located in a position remote from the drill floor to eliminate interference with normal rig operations. The control box contains a computer which is preprogrammed with all the

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References and illustrations at end of paper.

pertinent operating parameters for a number of predetermined equipment systems (For example, different wellhead systems, different functions within the wellhead system, etc.). The operator enters the data to tell the computer which specific type of equipment is being used and which operation is being performed. Then, upon request from the operator, the computer initiates two way communications with the surface sub via FM radio and requests the desired information.

B) The surface sub in turn requests the required information from the subsea smart sub. Two way communication between the surface sub and the smart sub is provided by sending binary data via acoustical pulses through the drill pipe running string using an FSK (frequency shift keying) communication scheme. Specialized electronic circuits filter the signal from the background noise. This, along with a sophisticated software error detection/ correction code, allows high reliability transmission of data. The surface sub is self-contained and includes batteries, electronics for communications and driving the acoustic transducers, and a two way radio to communicate with the remote control box.

C) The subsea smart sub contains the same components as the surface sub (less radio) plus additional devices to monitor pertinent conditions at the wellhead such as relative location of equipment being installed. The ability to monitor positioning during landing is provided by proximity sensors which read the profile of the wellhead housing and indicate the relative location of the smart sub in the housing. This data is transmitted acoustically to the surface sub which relays it to the control box. With this, the computer is able to calculate the position of the equipment being installed and verify to the operator that the equipment has been installed in the proper position.

Some of the many applications foreseen as readily suitable for intelligent running tools include:

Casing hanger landing--- Verify that the casing hanger is located properly in the housing.

Cementing--- Monitor cement returns at the hanger and signal successful completion of cementing.

Seal assembly landing--- Verify that the casing hanger is properly landed (or the separate seal assembly is landed with two trip systems) prior to attempting to set the seal.

Seal assembly setting--- verify that the seal assembly has been properly energized.
Wear bushing retrieval--- Verify that the wear bushing has been captured and retained during retrieval.

Additional applications for future development of intelligent tools may include monitoring BOP ram position, collet connector position, flex joint position, tool joint location and condition, and detecting casing annulus seal leaks. In addition, production applications involving subsea Christmas trees, and TLP's are foreseen.

Figures 3 and 4 show the locating capability built into the prototype. Figure 3 shows the smart sub located in the top of a casing hanger housing with the proximity sensor array detecting the groove profile in the inside of the housing. Figure 4 shows the smart sub being used to verify the correct location of a 9-5/8 casing hanger being landed into the housing. Since the casing hanger landing shoulder is a known distance from the groove profile at the top of the housing, the computer can calculate the location of the casing hanger based on the location of the smart tool with respect to the grooves.

DEVELOPMENT PLAN

The key to developing a successful smart tool system was developing a reliable communication system. Once this was available any number of sensors could be added to the subsea smart sub to accomplish the desired tasks as outlined above.

An acoustical communication method was chosen due to knowledge of it's successful application in the MWD (monitoring while drilling) field. However, unlike the MWD systems we chose to utilize the drill pipe running string as the transmission medium. This was only marginally successful in MWD work due to their greater depth. With our relatively shallower depth goal of 3000 ft without repeaters, it appeared feasible. If it proved out, this would be the simplest system to implement and use.

The plan, therefore, was to develop the acoustical data transmission system first, then add a minimal number of sensors to the smart sub. This minimal system would then be used for field testing to prove the feasibility and practicality of the smart tool concept.

ACOUSTICAL TRANSMISSION

Background Search

A research paper by Barnes and Kirkwood (ref. 1) describes the phenomenon of frequency passbands at which very low attenuation is encounter in transmission of compressional acoustical waves through pipe. These passbands are interspersed between reject bandwidths which exhibit very high attenuation (Figure 5). The next question was which passband was best suited for our application. U.S. Patent No. 4,314,365 (Ref. 2) describes some field testing done using a test drill string of 1243 ft of 4 1/2" pipe. Figure 6 shows the results of the testing. From this it can be seen that lower frequencies exhibit less signal loss (attenuation) than higher frequencies, and definite passbands as predicted by Barnes and Kirkwood are evident.

Acoustical Field Test

To verify the research findings and help in selecting a suitable transmission frequency a field test was devised. A recorder sub was built to house an accelerometer, an analog recorder, and associated electronics. This sub was run in the drill string of a floating drilling operation while retrieving a wear bushing. These tests resulted in improved understanding of background noise and attenuation characteristics of a drill string during offshore operations.

An axial impact load of 5 ft-lb (6.7788 watt-sec) energy was applied to 5"-19.5# drill pipe at the drill floor. Figures 7 and 8 show the time domain and frequency domain plots of these noise bursts recorded through 93 ft of pipe. Figures 9 and 10 are the same plots after the signal has traveled 372 ft. The scale on the two plots are the same (approximately 207 mv peak on maximum peak signal). The attenuation/gain of the signals was highly frequency dependent. It is apparent from these two plots that the 650 hz signal has no attenuation and the 300 to 400 hz signal has very little attenuation. It is also apparent that there is little energy above 2 khz.

The frequency domain analysis of the average noise during normal operation indicated a flat frequency spectrum up to 1 khz, much like "white noise". The average RMS amplitude of the noise over the operation was 35 mv rms which should be referenced to the figures 7/8 and 9/10. The characteristic of the noise is difficult to define in the frequency domain as it consisted of large bursts of noise for very short periods (Figure 12).

By comparing the frequency amplitude at different depths we were able to calculate the attenuation versus depth for various frequencies. Selected frequencies were plotted onto the plot in Fig. 6 as triangles. It can be seen that these points correlate well with this earlier work. It also showed that with the proper selection of frequency, attenuations as low as 10db to 15db per 1000 ft of depth were possible.

Laboratory Testing

To investigate the transmission of compressional waves in drill pipe under more controlled conditions a laboratory test was set up. A string of 247 ft of 5"-19.5 #/ft drill pipe was laid horizontally supported on the tool joints and filled with water to increase the attenuation. An acoustical transducer was mounted to one end, and accelerometers mounted at both ends. The transducer was driven by a frequency generator and swept through the frequency range of 100hz to 2000hz. The amplitude of the signals received by the accelerometers at both ends were recorded simultaneously. From this data it was possible to determine the best operating frequency and also the attenuation at that frequency. Figure 11 is a plot of the receiving end amplitude versus frequency. The peak signal occurred at 335hz, which represents the lowest attenuation over that frequency range. From the relative amplitude of the signal at both ends of the pipe an attenuation of 16.56db/1000ft was calculated. This matches well with the previous research data.

One of the main objectives set for the smart tool electronics was to be able to transmit and receive data through large bursts of mechanical noise. The present electronics package has been shown in the laboratory to be able to work in spite of a 2 lb sledge hammer being used to generate acoustical noise bursts on the 90 foot test pipe. The signal being received by the acoustical pickup had an amplitude of approximately 1 volt peak, and the noise being generated by the sledge hammer generated 5 volt peak signals. This signal was comparable to the magnitude of the largest noise bursts encountered during the drilling operation.

The key to successful communications in a noisy environment is to concentrate all of the energy transmitted in one narrow band frequency range and then to filter all other frequencies out on the receiver end. This same approach is widely used in radio/TV and is called narrow band FM. The noise is primarily wide band noise and has comparably little energy in the signal band.

While the attenuation figures were encouraging, it still would require a high energy input into the pipe in order to transmit over the design goal 3000 ft depth. To satisfy this requirement a special magnetostrictive type acoustic transducer was built. This type of transducer produces a high power output per unit volume. The transducer is driven with 40 watts power input. Subsequent testing of the transducer resulted in an acoustic wave in the pipe which generated a 1 volt signal at the output of the acoustical pickup (mounted near the transducer end of the pipe). By combining three transducers in the field test tool a total of 120 watts will be available. This should provide a 3 volt signal at the source.

CONCLUSIONS

With the projected 3 volt signal level at the transmitter, and assuming the 16.56 db/1000 ft attenuation, and the receiver can detect 20 microvolts on the far side, the theoretical working depth should be 6000 ft. This provides a comfortable margin over our design goal of 3000 ft. We therefore predict a high probability of successful operation at 3000 ft using acoustic communication.

All smart tool system components have been thoroughly lab tested. The prototype system is being readied for field testing. Testing should begin in about six weeks, subject to rig availability.

REFERENCES

1. T. C. Barnes and Bill R. Kirkwood, "Passbands for Acoustic Transmission in an Idealized Drill String," Journal of the Acoustic Society of America, pp. 1606-1608, Vol. 51, No. 5 (Part 2), 1972.

2. "Acoustic Transmitter and Method to Produce Essentially Longitudinal, Acoustic Waves", U.S. Patent No. 4,314,365, Feb. 2, 1982.

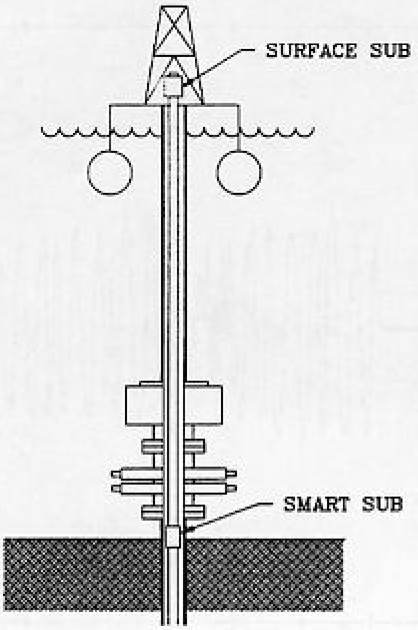

FIG. 1 SMART TOOL MONITORING SYSTEM

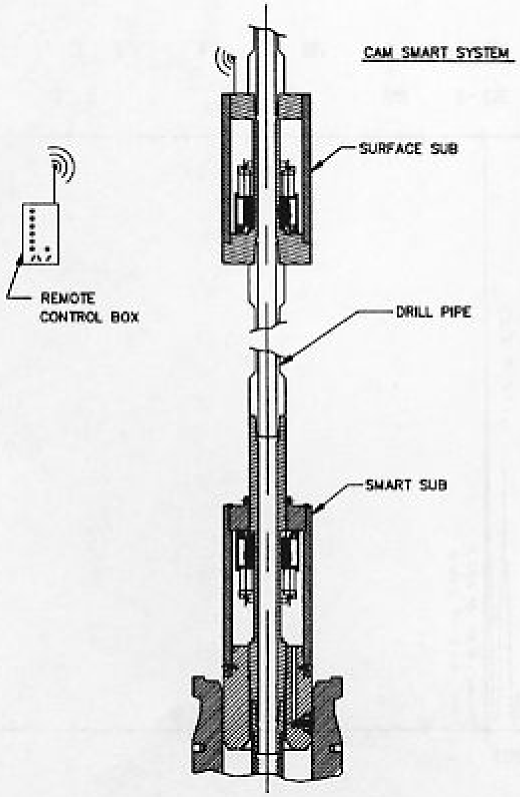

FIG. 2 SYSTEM COMPONENTS

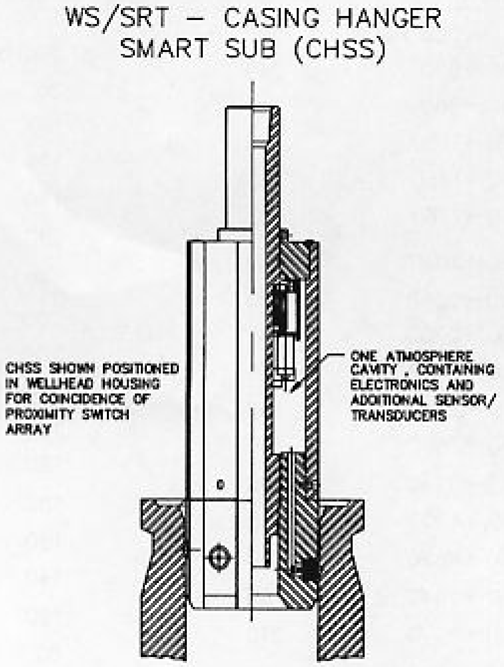

FIG. 3 SMART SUB

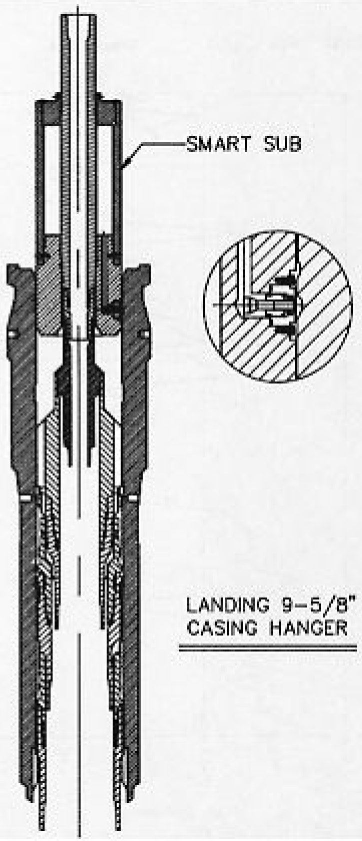

FIG. 4 SMART SUB MONITORING LANDING OF 9-5/8" CASING HANGER

PASSBAND	PASS BANDWIDTH	REJECT BANDWIDTH
C→280 Hz	280 Hz	50 Hz
330→570	240	80
650→860	210	110
970→1150	180	140
1290→1450	160	170
1620→1760	140	180
1940→2070	130	190
2260→2380	120	200
2580→2700	120	200
2900→3020	120	190
3210→3340	130	190
3530→3660	130	180
3840→3980	140	180
4160→4300	140	160
4460→4620	160	140
4760→4940	180	120
5060→5270	210	80
5350→5590	240	40
5630→6180	550	

FIG. 5 BARNES & KIRKWOOD THEORETICAL FREQUENCIES FOR WHICH COMPRESSIONAL WAVES PROPAGATE WITHOUT LOSS

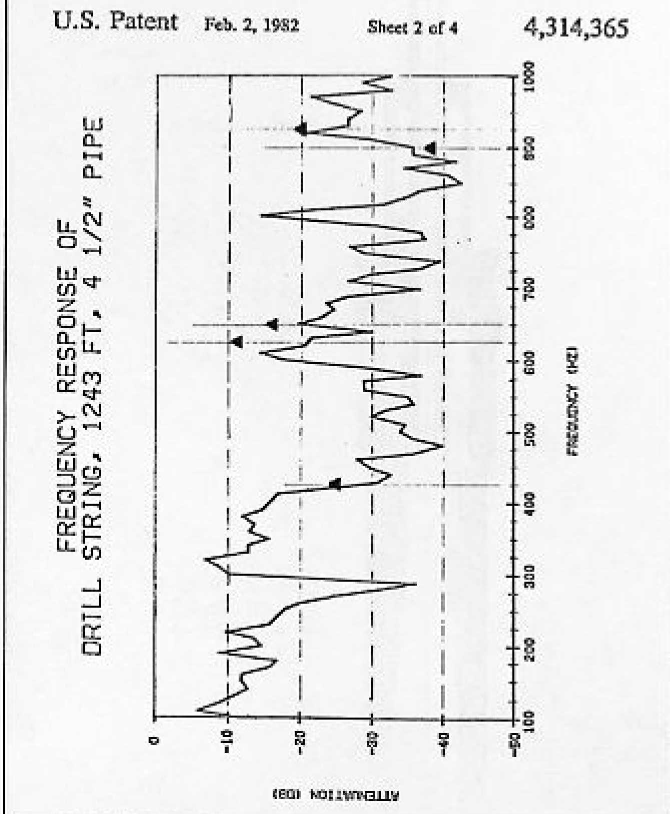

FIG. 6 FREQUENCY RESPONSE OF DRILL STRING, 1243 FT, 4-1/2" PIPE, U.S. PATENT 4, 314, 365.

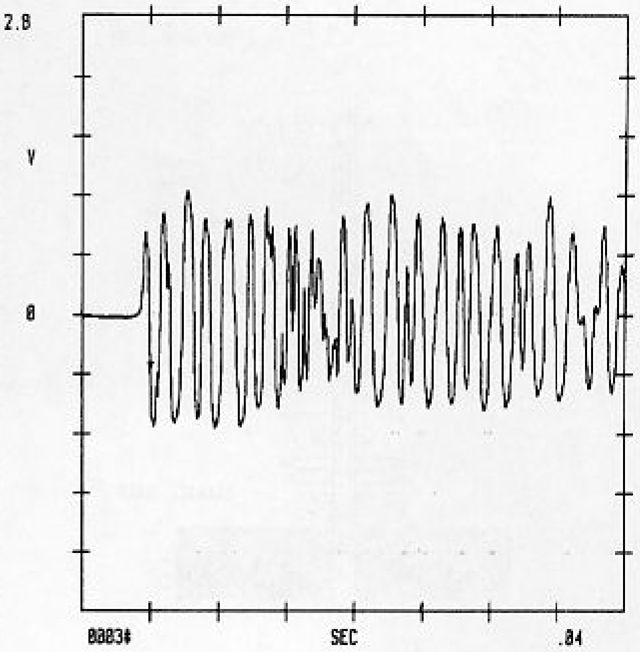

FIG. 7 TIME DOMAIN PLOT OF NOISE BURST THROUGH 93 FT OF 5"-19.5# DRILL PIPE

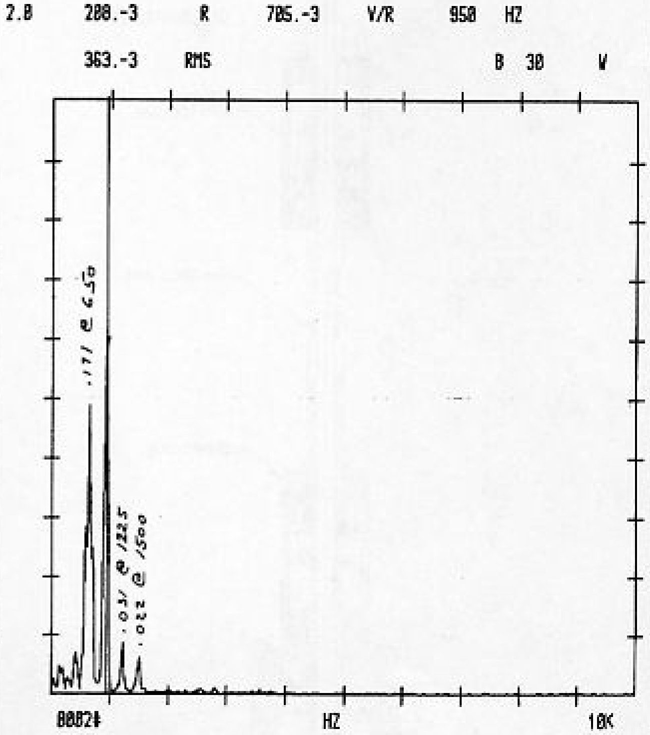

FIG. 8 FREQUENCY DOMAIN PLOT OF NOISE BURST THROUGH 93 FT OF 5"-19.5# DRILL PIPE

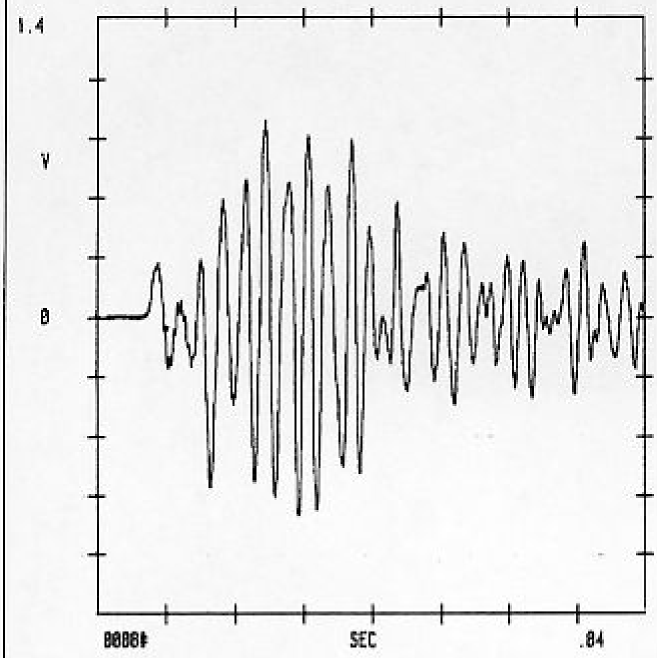

FIG. 9 TIME DOMAIN PLOT OF NOISE BURST THROUGH 372 FT OF 5"-19.5# DRILL PIPE

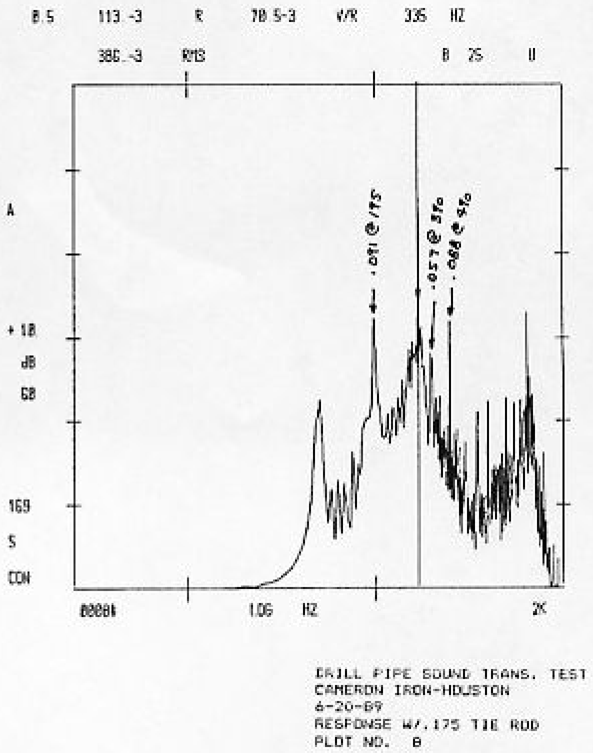

FIG. 11 FREQUENCY VS RECEIVED SIGNAL AMPLITUDE, 0 TO 2000 HZ

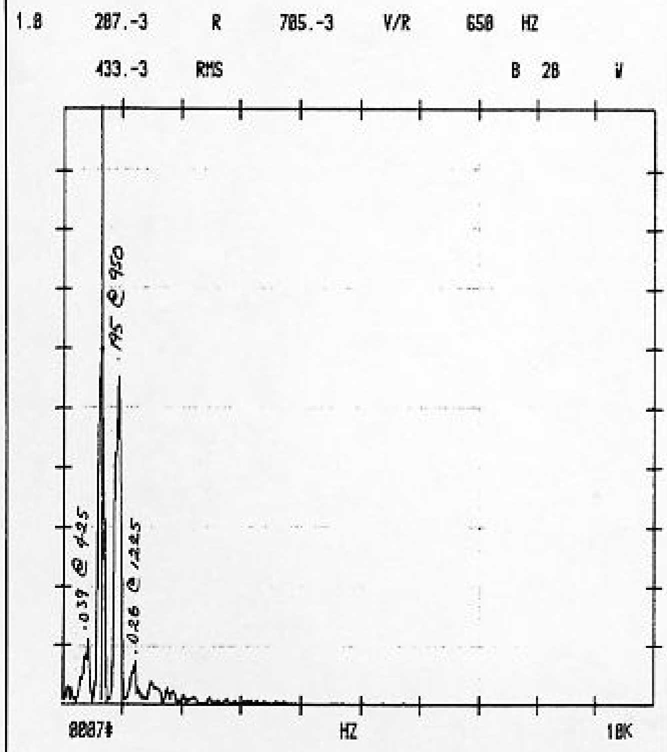

FIG. 10 FREQUENCY DOMAIN PLOT OF NOISE BURST THROUGH 372 FT OF 5"-19.5# DRILL PIPE

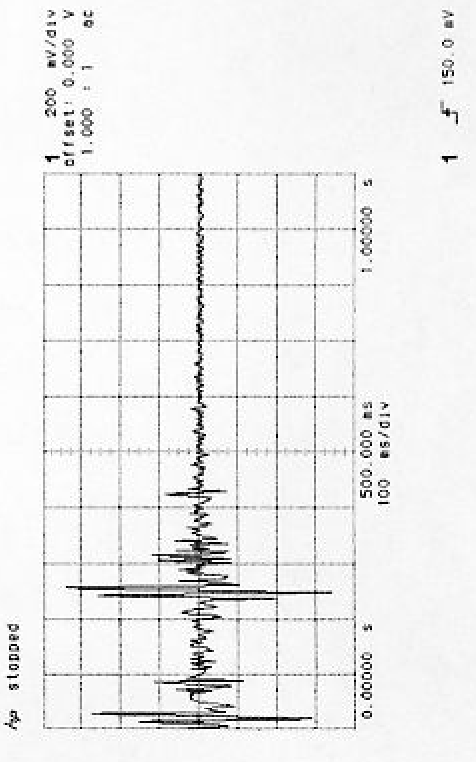

FIG. 12 FREQUENCY DOMAIN OF BACKGROUND NOISE BURST, 1 SECOND TIME SPAN