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Leading Academic Lab Experimental Trial Demonstrating the Intelligent Drill Pipe Technology Functionality

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ABSTRACT

Nowadays, it is common for oil and gas boreholes to be drilled with many sensors located at the bottom-hole assembly to continuously measure directional and geological information while drilling. The measured information must be transmitted to the surface in real-time, so that engineers on the surface can monitor and navigate the well bores to targeted reservoirs in real-time and make educated decisions about the boreholes during drilling operations. Many telemetry methods have been developed in the past five decades to uplink the information in the boreholes in real-time during drilling operations, such as electromagnetic, mud pulse telemetry, acoustic telemetry, and intelligent drill pipes (also known as wired pipes). However, among all these methods, intelligent drill pipes have the highest data transmission rates and unlimited transmitting range. Despite their potential, there is a lack of research studies in the literature, particularly at the university level, investigating the process of data transmission in boreholes using wired pipes. The main objective of this study is to fill this gap by designing and developing a laboratory prototype and testing the functionality of the intelligent drill pipes for data transmission in boreholes in the lab. The prototype has been developed and tested successfully at Tishk International University as a first step. This small-scale prototype has great potential to simulate the process of data transmission in boreholes using intelligent drill pipes and offers good opportunities for further investigations and collaboration with universities and companies. These include, but not limited to, testing different codes, signal analysis approaches, the signal reflection and attenuation value, developing models, etc., in order to improve the process of data transmission in boreholes with intelligent pipes in a cost-effective and low power-consumption manner.

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1. INTRODUCTION

These days it is difficult to imagine drilling operations for oil and gas wells without real-time transmission of information from downhole sensors to the surface, such as directional information, geological information and drilling mechanics. The placement of sensors at the bottom-hole assembly has now become an essential part of, almost, all drilling operations. Displaying real-time downhole measurements, both at the rig site and in remote operations centers, is crucial as it contains valuable information that can be used to monitor drilling operations, prevent various problems, and make informed decisions during drilling. In the past five decades, several telemetry methods have been developed to transmit the measured downhole data to the surface, such as through the drilling fluid (mud pulse or continuous wave process), the earth (electromagnetic process), the drill pipes (acoustic signals), or an electrical conductor inside the drill pipes. Among all these methods, the intelligent drill pipe telemetry method has an unlimited transmission distance and high data rates. The wired dill pipe (WDP) telemetry enabled bi-directional high-speed data transmission to and from downhole tools at speeds up to 57600 bps [1]. The intelligent drill pipe telemetry has been under experimental trials in oil and gas companies for different applications, such as drilling optimization, hole cleaning, reduction of drilling risks and reduction of non-productive time (NPT), but has not yet been the focus of research studies in universities based on the available literature.

In 1997, Novatek, Inc. began developing a high-speed data system for use with segmented drill pipe, now known as IntelliPipe®. A few years later, Novatek entered into a Cooperative Agreement with the U.S. Department of Energy to develop a robust high-data rate communications system (WDP) for the downhole drilling environment [2]. Meanwhile, sensor technology advanced to the point where nearly all traditional wireline sensors could be replaced by logging-while-drilling (LWD) sensors that could provide data equal to or even better than wireline sensors. However, a limiting factor for measurement-while-drilling (MWD) and LWD data has been their reliance on mud-pulse telemetry and the restrictions it places on transmission speed [3]. [4] claimed that utilizing wired pipe to its full potential resulted in an average time savings of 10% in drilling. The ability of wired drill pipe telemetry to transmit data from distributed pressure sensors along the drill string in real-time and the real-time analysis at the rig, is used for kick evaluation and handling during managed pressure drilling (MPD) [5]. [6] presented results showing the benefits of using wired drill pipe to transmit pressure measurements when drilling with back-pressure managed pressure drilling (MPD) in an extended-reach drilling (ERD) operation. [7] claimed that wired drill pipes can reduce the number of days per well through the instantaneous transmission of data up and down the drill string, compared to wells drilled with conventional mud pulse telemetry. [8] summarized the efficiency gains and quantified time savings achieved by combining innovative under reaming and wired drill pipes (WDP) technologies, claiming that the combination allows wells to be drilled without the typical limitations imposed by conventional reaming and telemetry methods. [9] introduced a case history of the deployment of a drilling automation system pilot, including wired drill pipe, in an Arctic drilling operation. [10] presented the smart wired pipe concept with field trials in Oklahoma and claimed that it enables drilling system automation and logging-while-drilling applications, such as seismic-while-drilling with a long-string sensors, by providing a fully open acquisition and control platform for the industry. [11] highlighted a new drill pipe design that can supply downhole tools with power in addition to bi-directional high-speed data communication telemetry. Through trials on a land rig, [12] demonstrated the deployment of a wired drill pipe system downhole to power multiple tools from the surface without the need for batteries or power-generating turbines downhole and to provide bi-directional telemetry between downhole tools and the surface. [13] presented the application of the battery-operated Remotely Operated Completion System

(ROCS) on a wired drill pipe (WDP) used in the offshore North Sea.

Hardly any laboratory test rigs, specifically in universities, can be found in available literature for studying and investigating the process of data transmission in boreholes using wired or intelligent pipe telemetry. The main objective of this study is to develop a laboratory test rig and conduct preliminary tests. Over the past ten years, significant experience has been gained in deep borehole data transmission, including the development of new tools and software for improved signal detection at the surface by [14- 19], [20]. This experience has been utilized to develop a small-scale intelligent drill pipe test rig at Tishk International University to simulate data transmission process in boreholes by intelligent drill pipe telemetry. The test rig has been used to study and conduct basic research on the subject, and preliminary laboratory experiments have been successfully carried out with promising results. The functionality of intelligent drill pipes for data transmission in boreholes in the lab has been positively tested and demonstrated in the first phase. The test rig offers great opportunities for further research and collaboration with companies and researchers, both locally and internationally.

2. Fundamentals Of Intelligent Pipe Telemetry

Compared to conventional drill pipes, wired drill pipes include a section of coaxial cable in each joint. The cable passes through a small, drilled hole in the connection on each end of the pipe joint. The cable is encased in a strong stainless-steel sheath between connections, which is held under tension within the inner diameter of the pipe off center adjacent to the inner wall [21]. All cables and wires are sealed and electrically insulated from the pipe work and surroundings. Figure 1 shows the drill pipe tool joint connection, highlighting the location of the inductive coils.

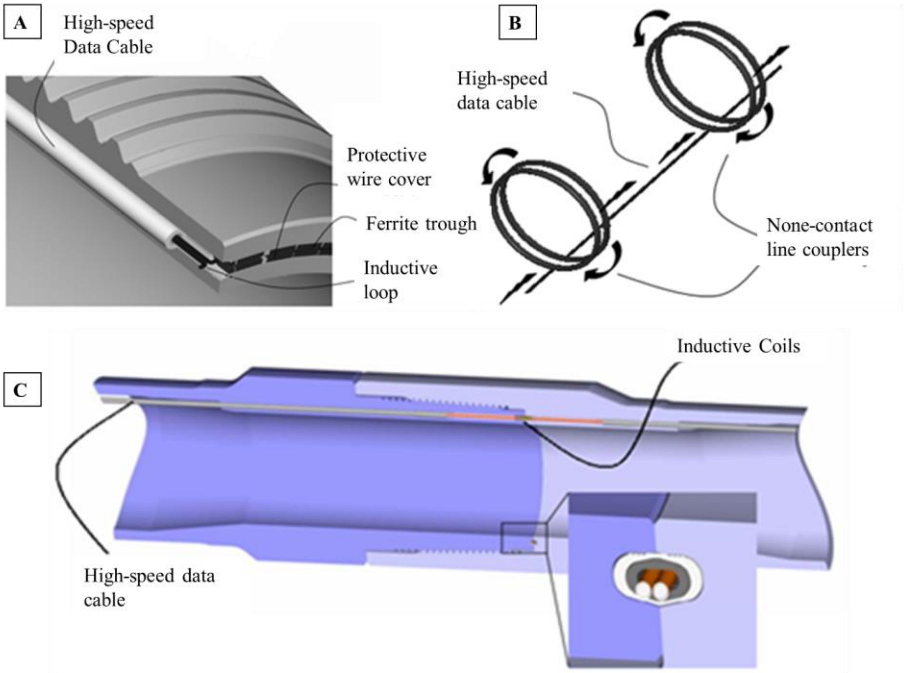


Figure 1 (A) Cutaway view of the telemetry drill pipe system in a drill pipe connection. The inductive coil fits in a shallow groove inside the secondary torque shoulder of the tool joint. (B) The non-contact line coupler uses induction to transmit data from one connection to another [22]. (C) Cutaway of a made-up drill pipe tool joint connection showing the location of the inductive coils and data conduit [23].

The inductive coupling coils, embedded in a protective groove machined in the steel of the tool joint, enable the passive transmission of signals across a small gap from one joint to the next through ferrous coils that are embedded in the pin end of one joint of pipe and the opposing box end of the subsequent joint of pipe. Figure 2 shows a drill pipe at rest with a data conduit.

Figure 2 One drill pipe at rest with data conduit [23]

When the drill pipes are connected to form the drillstring during drilling operations, the coils in the pipe joints come very close to each other, but they do not need to touch directly (inductive coupling). Thus, insulating materials, such as pipe dope, do not block the signal [21]. However, as the drillstring is made up of many joints of pipe, there is a loss of signal strength. To counteract this, a battery-powered booster sub is deployed approximately every 1500 ft. On the bottom-hole-assembly (BHA) end of the drillstring, the wired pipe connects to the measurement providers and steering assembly through an interface subsystem, enabling two-way communication with the network. At the top of the drillstring, the network is connected to surface servers by a data swivel housed in the top drive [21]. During drilling operations, information is constantly measured by sensors at the bottom hole assembly above the drill bit and transmitted to the surface through the intelligent drill pipes cascaded from one pipe joint to the next via the coils in the joints until the signal reaches the surface, where it is sensed, processed, displayed and interpreted in a meaningful form on a computer screen to enable dedicated engineers to make real-time decisions and optimize the drilling activities. Figure 3 below shows the components of the intelligent drilling system.

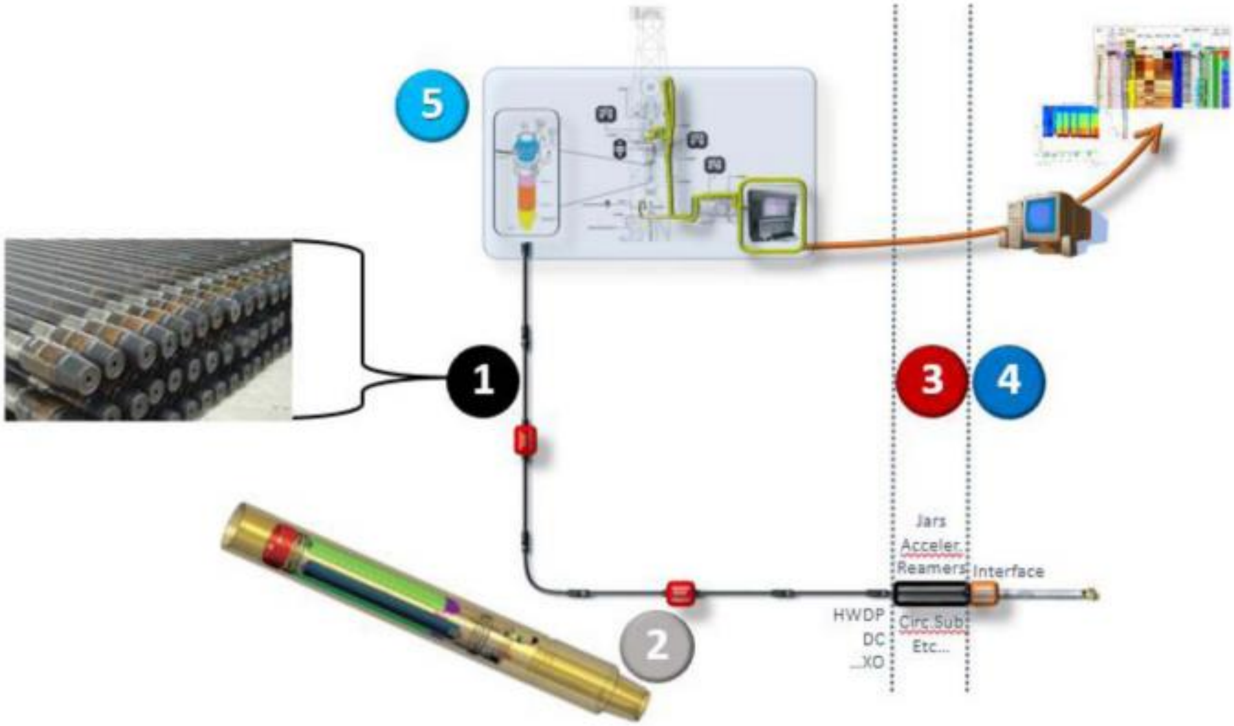


Figure 3 Intelligent Drilling System Components. #1 is the Wired Drill Pipe, #2 are the Datalinks, #3 are the Bottom Hole Assembly Components (Jars, Drill Collars, etc.), #4 is the Interface Sub, and #5 is the

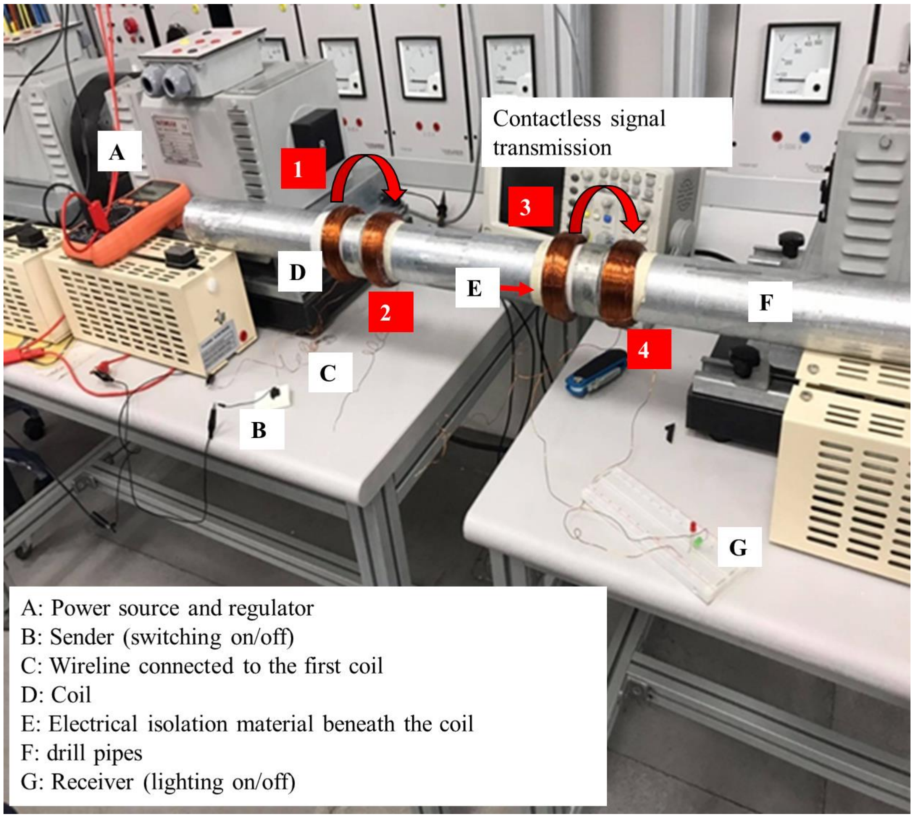
Surface System [24].

3. Experimental Investigation

3.1 Intelligent Drill Pipe Test Rig

A small-scale intelligent drill pipe telemetry test rig has been designed and built by a collaboration between two departments at the Tishk International University in Erbil, Kurdistan Region of Iraq. The Petroleum and Mining Engineering department and the Mechatronics Engineering department worked together to simulate the process of data transmission in boreholes using intelligent pipes in the laboratory. The test rig, shown in Figure 4, consists of several components, which will be explained in the following sections.

Figure 4 shows the test rig, which consists of a power source and regulator (A) connected to a sender (B) via a wire line (C). The first coil (D) which is connected via wire line to the sender is wrapped in an electrically insulating material (E) between the drill pipe (F) and the coils on the drill pipe. The last coil (4) is connected to the receiver, LED, (G) via a wire line. The signal is transmitted contactless (by induction) from the first coil (1) on the lefthand side to the second coil (2). Then, the signal is transmitted through a line from the second coil (2) to the third coil (3). Finally, the signal is transmitted contactless by induction from the third coil (3) to the fourth coil (4), which is connected to the receiver via a wire line again.



A: Power source and regulator
B: Sender (switching on/off)
C: Wireline connected to the first coil
D: Coil
E: Electrical isolation material beneath the coil
F: drill pipes
G: Receiver (lighting on/off)

Figure 4 A small-scale test rig for performing tests on data transmission in boreholes by intelligent drill pipe telemetry.

3.2 Type of Drill Pipes and Threading Process

In the intelligent drill pipe test rig, instead of traditional drill pipes, three tubings with a total length of 90 cm are used for conducting tests. The tubings have similar appearances and behavior to drill pipes, but with smaller dimensions. The material used for the tubings is steel, alloy of iron with a small amount of carbon.

The outside diameter of the tubings is 6.35 cm with a thickness of 1 cm.

Figure 5 Drill pipe used for the intelligent drill pipe test rig.

Three drill pipe sections had to be prepared prior to performing the tests. The length of each pipe section was set to be 30 cm, adding up to 90 cm total length of the string. The ends of the pipe sections are threaded, male/female to be able to join them together as shown in Figure 6. Therefore, one pipe section was threaded on both sides that would be attached in the middle and the other two were threaded only on one end which is shown in Figure 6. The length of each threading is 2 cm to provide good rigidity.

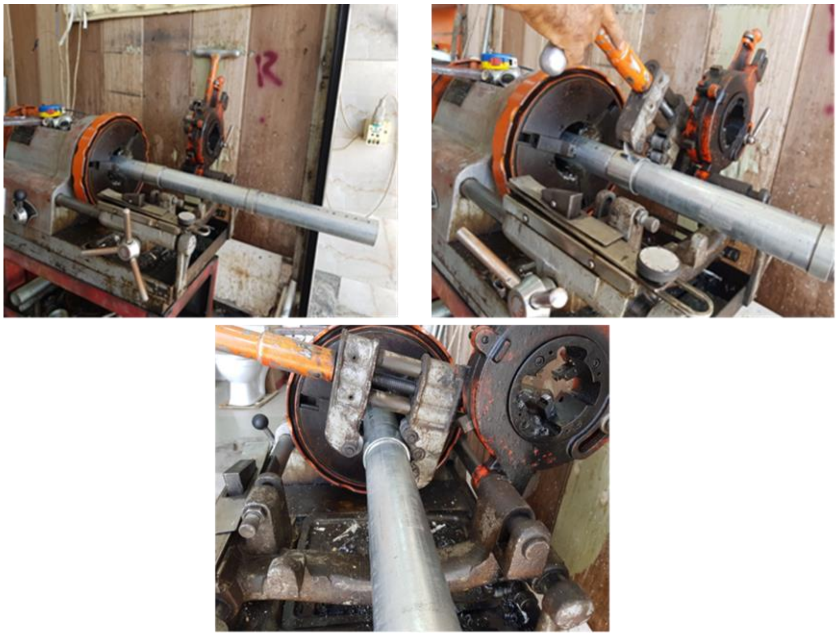


Figure 6 The process of preparing and threading the drill pipes (manufacturing process)

3.3 Coils

Varnished Copper (Cu) wires are used for preparing coils around the drill pipes. The thickness of the copper line used for forming the coils is 0.55 mm, and it is isolated from the drill pipe with a very thin layer of varnish. To enable contactless induction signal transfer from one coil to another, a total of 2000 wraps of copper line were used to prepare four coils, each coil having 500 wraps of line as shown in Figure 7-A. The coils are located in four positions along the drill pipes as shown in Figure 7-B on both sides of the pipe joints. The first coil, with 500 wraps of line, was placed just before the first joint of drill pipe, and approximately 2 to 3 cm away from the adjacent coil, the second coil (also with 500 wraps of line) was placed after the first joint without a direct electrical connection to the first coil. The third coil (500 wraps of line) is then located before the second joint at a distance of approximately 30 cm from the second coil, with a direct connection to it. This means that the coils of each pipe sections are electrically connected with same wrapping orientation, either clockwise or counter clockwise to avoid magnetic field weakening. Finally, the fourth coil (500 wraps of line) was placed after the second joint, approximately 2 to 3 cm away from the adjacent coil, without a direct connection to the third coil.

A line extends from the first coil to a power supply in order to provide power (electricity) to create magnetic fields for contactless signal transfer from the first coil to the second coil. Then, a line extends from the second coil to the third coil, and lastly contactless signal transfer from the third coil to the fourth coil would be achieved, via magnetic field, as shown in Figure 7-B. Although the coil lines are insulated with a thin layer of varnish around them, an electrical isolation material is wrapped around the drill pipe between the coils and the drill pipes to ensure that there would be no direct connection between the coils via the drill pipes or between the coils and the drill pipes. The last coil (coil number four) is connected directly with wires to the receiver to check signal reception. When a sinusoidal carrier frequency is applied to coil (1) this instantaneously generates a localized magnetic field which in turn induces an electric current in the coil (2). The same electric current that flows in the coil (2) is flowing in the coil (3) which will produce another localized magnetic field that will induce electric current in the coil (4) which is then collected by the final receiver. In this research work, the receiver is either a LED light or an Oscilloscope.

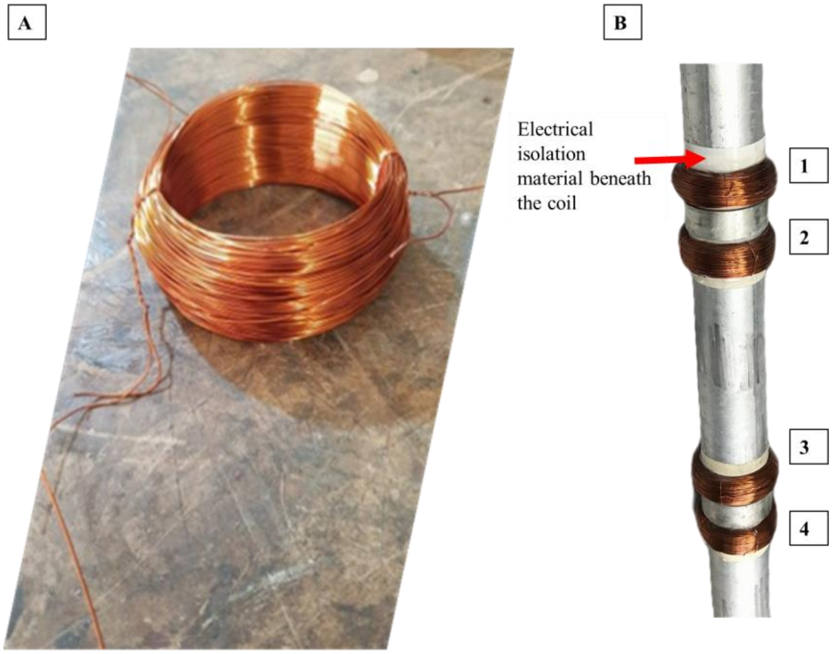


Figure 7 (A) wrapped coils, (B) four wrapped coils around the drill pipes.

In this test rig, the coils are not engraved into the thickness of the pipes, but rather wrapped around the pipe to facilitate easy necessary modifications for the first trial study of intelligent pipes in the academic sector, such as increasing or decreasing the number of wraps in the coils, changing the distance between the coils, etc. The coils were wrapped in the same direction to ensure signal transfer consistency. Figure 7 shows the coils on the pipes simulating wired drill pipe (WDP) or intelligent pipe.

3.4 Experimental Procedure, Results and Discussions

3.4.1 First Test

A preliminary test is conducted to demonstrate the contactless signal transmission through the intelligent drill pipes. The test is performed using a standard Alternating Current (AC) power supply and a LED as the sender and receiver respectively. An auto transformer and a resistor were used to decrease the voltage from the standard 220 V to 35-50 V. This was necessary because voltage below 35 V would not emit LED light, while voltage above 50 V could damage the LED. Schematic diagram of the experimental setup is shown below.

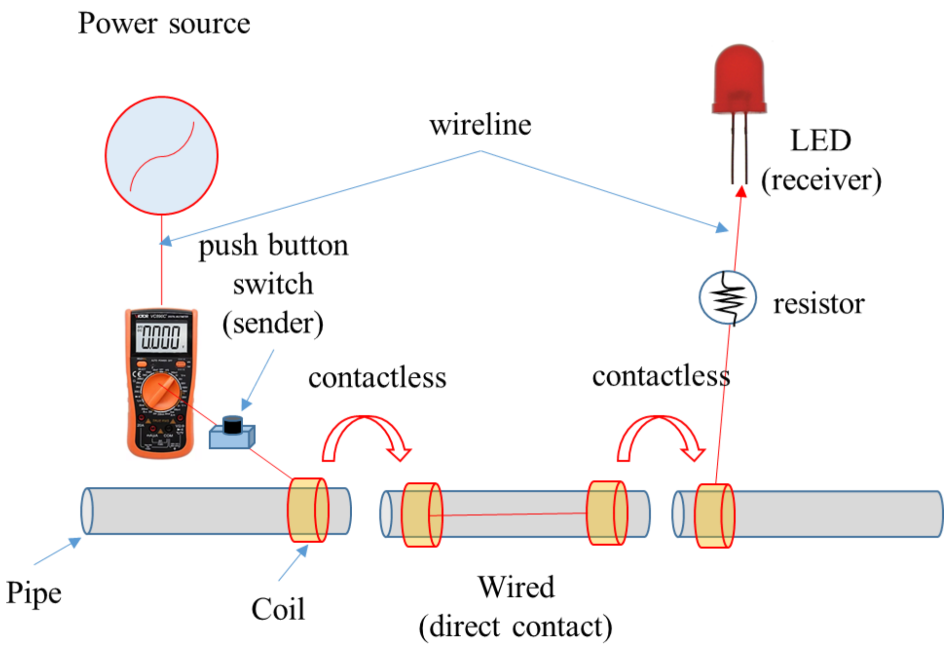


Figure 8 Schematic diagram of the experimental setup for the first test

A line from the power supply was connected to a sender/controller that switches the power on/off. The sender/controller was hardwired to the first coil, which transmitted signals contactless to the second coil. The second coil was hardwired to the third coil, which transmitted the signal contactless to the fourth coil. The last coil was hardwired to the resistor and LED, as shown in Figure 8 and 9. The receiver in this experiment is, merely, a LED that emits light when receives signal and it is connected in series to a current limiting resistor to protect the LED from overcurrent. This setup allowed the signal to be transmitted through the test rig, simulating intelligent drill pipe telemetry. The test was now ready to be performed.

A push button switch represents the sender or controller, and the LED represents the receiver. To transmit data, first, the information is transformed into binary values, and then the data is transmitted. For example, when the LED is on, it represents binary value 1, and when the LED is off, it represents binary value 0, and vice versa is also possible. There are various models and codes that can be used for transmitting information. In this way, information can be transmitted from one side to the other side.

Once the switch button is pressed, the first coil is supplied with power, creating a magnetic field between the contactless coils (1 and 2) and (3 and 4) through the test rig. The second and third coils are directly connected with a line to conduct electricity. The line, which is extended from the fourth coil, powers the LED that emits light. It is shown in Figure 9, that the LED is on when the button is pressed (Figure 9, C and D) and off when no signal is transmitted through the coils and the test rig, as shown in (Figure 9, A and B). The preliminary results are positive, and the signal could be transmitted contactless through the test rig.

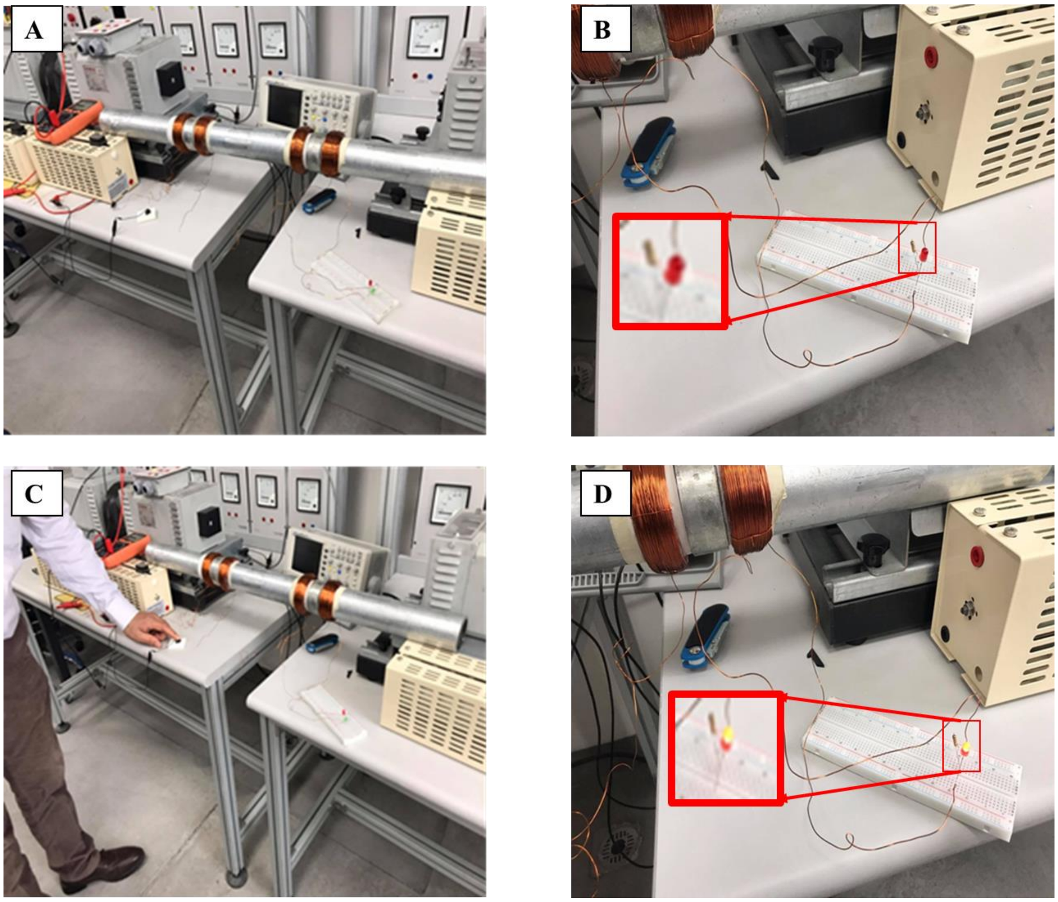


Figure 9 Intelligent drill pipe test experiment with all components, (A-B) no signal; the LED is off, and (C-D) there is signal; the LED is on.

Based on the available results, it has been clearly demonstrated that the signal can be transmitted through the intelligent test rig, which is an encouraging outcome. This research work has the potential to open up new avenues for further studies and collaborations with researchers and industries.

3.4.2 Second test

Another test was conducted to showcase the successful transmission of signals through intelligent drill pipes via a contactless method, and to measure quantitatively the output signal. The experiment involved utilizing a standard power supply from an electric bench as the sender and an Oscilloscope as the receiver. The current was monitored through the bench and digital ammeters. The schematic diagram for the experiment setup is shown in Figure 10.

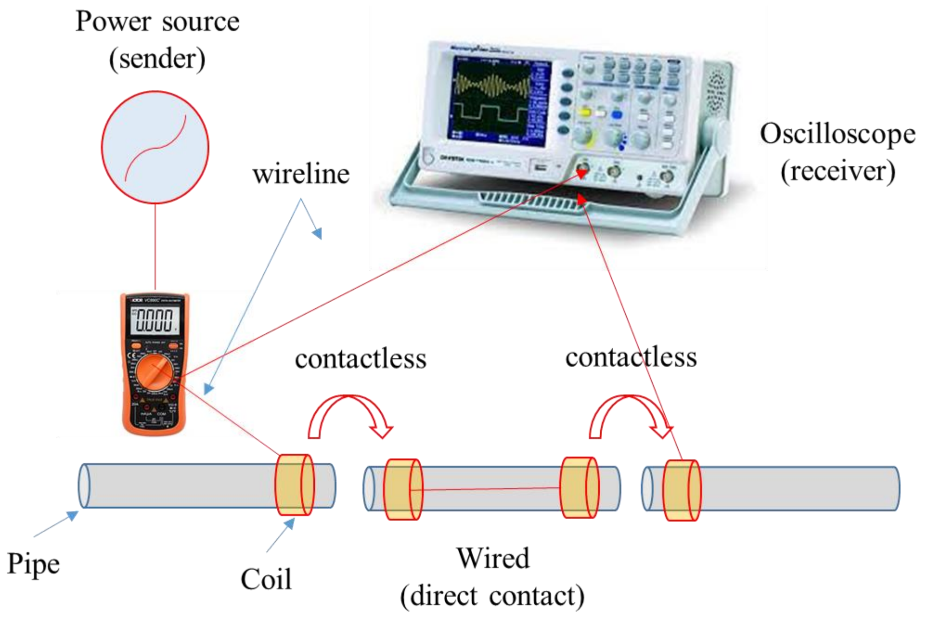


Figure 10 Schematic diagram of the experimental setup for the second test, only the oscilloscope image [25].

As shown in Figure 10 and 11, a sinusoidal AC supply of 50 Hz is connected to the first coil, an Avometer is used to monitor the input voltage. A two channel Oscilloscope is also used to display the input and output waveforms. The electric current is then transmitted to the other three coils by induction once and via electric cables another, alternatively, till it reaches the end coil and hence the receiver.

This arrangement, effectively, allowed the signal to be transmitted through the test rig, simulating the telemetry system of intelligent drill pipes. With this setup, the test proven the readiness of the system of Figure 1 to conduct the intended task, as shown in Figure 11.

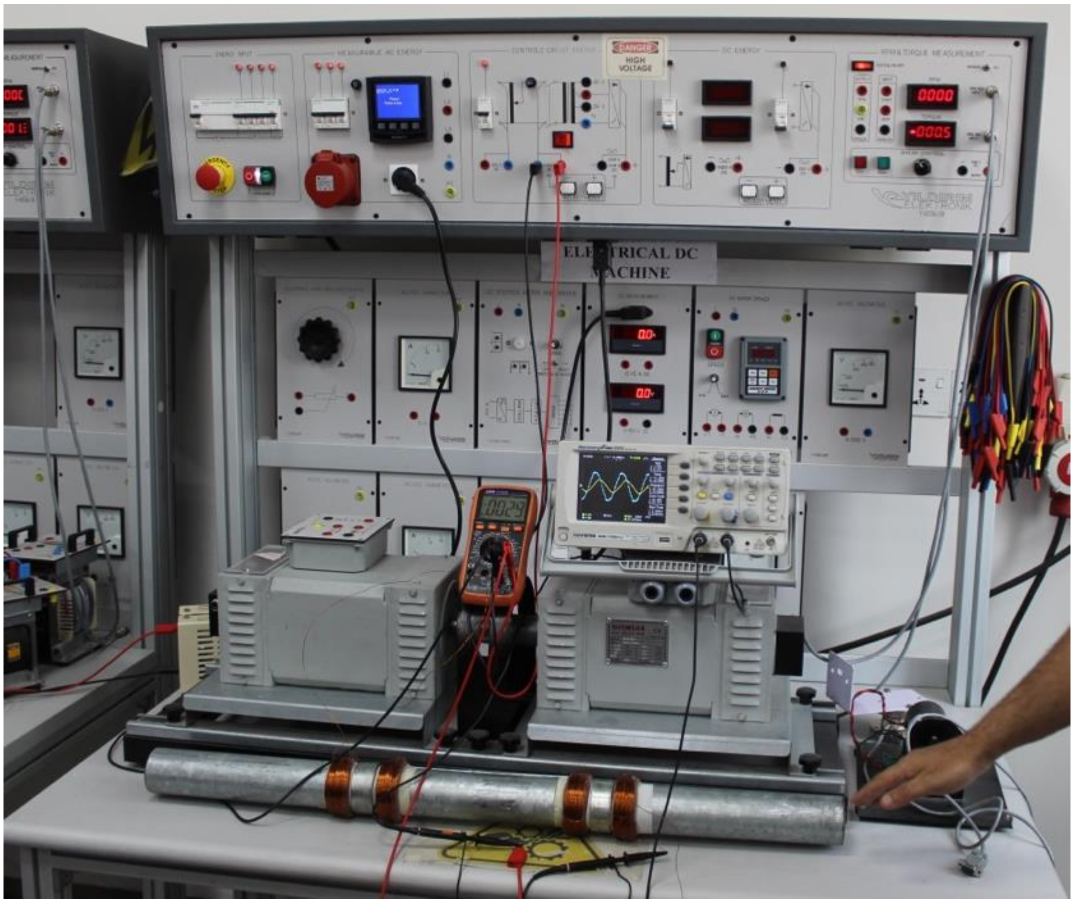


Figure 11 Complete test rig setup for performing the second test

Upon pressing the switch button, power was supplied to the first coil, generating a magnetic field between the contactless coils (1 and 2) and (3 and 4) within the test rig. The second and third coils were directly linked by a wire line to facilitate the flow of electricity. The line extended from the fourth coil to the Oscilloscope, which shows the measured signal on the screen. The input and output signals were simultaneously measured and displayed on the Oscilloscope's screen as shown in the figure 12.

As Figure 12 demonstrates, when the signal is sent by the sender, it could successfully be picked up by the last coil and recorded with some amount of noise, and a little phase shifting. The blue line on the Oscilloscope's screen is the input signal and the yellow line is the output signal as shown the figure 12.

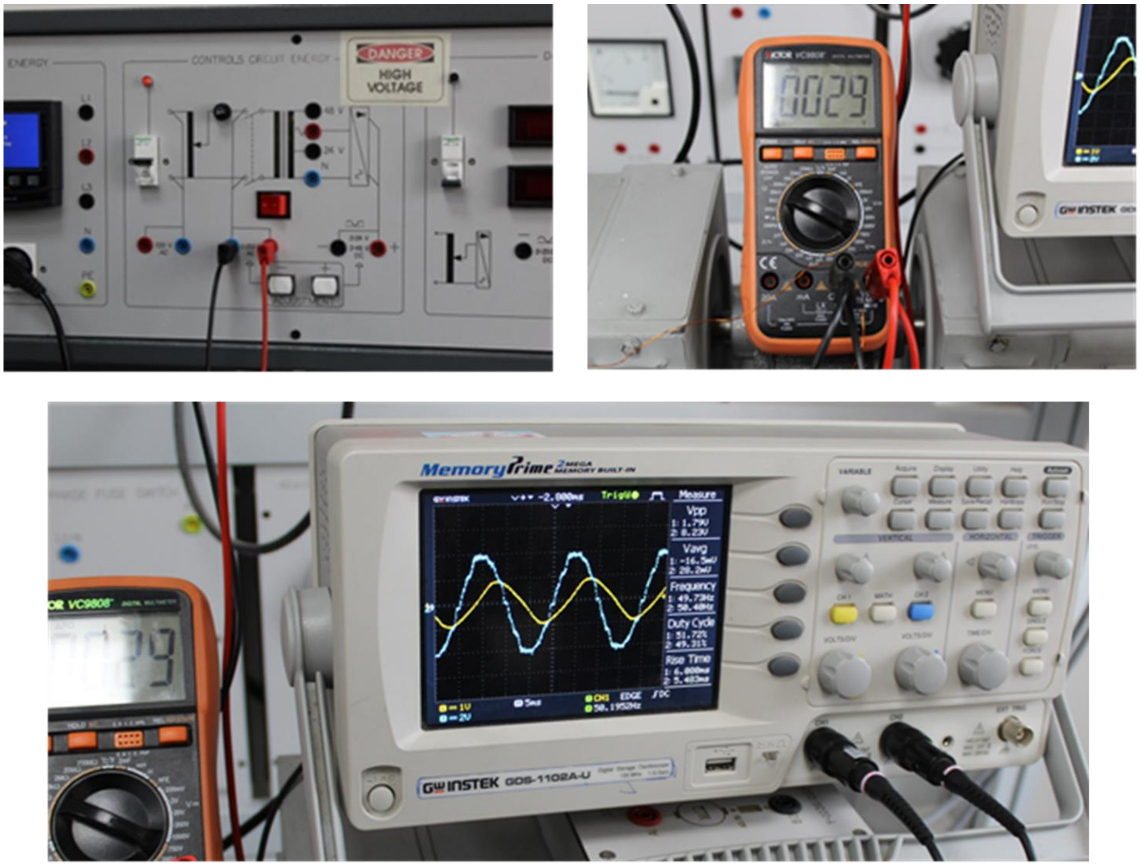


Figure 12 (bottom) the measured signal by Oscilloscope, (top left) the electric bench and (top right) the digital ammeters

It is clear from Figure 12 (bottom) that the Oscilloscope waveform of the input signal suffers a small distortion expressed in a node-like dotes along the sinusoid waveform. The reason for this, due fact that the first and last coils are, actually, entirely isolated earth-wise and the Oscilloscope earth, in this particular experiment, is connected to the receiver side leaving the input earth, completely, floating, i.e. unleashed. This has no effect on the system performance as the transmitted data are not affected by this whatsoever and it is restrained to measuring equipment that needs earthing; such as the Oscilloscope in this case. Notice that if the Oscilloscope earth is connected to the input supply earth, the problem disappears from the input signal waveform and will appear on the output waveform, as the output this time will be unhinged from the Oscilloscope earth and will be relatively floating compared to the measuring equipment.

It is crucial to re-stress on the fact that noise explained above, does not hamper the communication process and the relayed data quality and is not a deficiency at all. It can be overcome by having two separate Oscilloscopes, one for the input and one for the output; each locally earthed in isolation of the other.

Encouragingly, the preliminary results confirmed the successful contactless transmission of the signal through the test rig. Based on these initial findings, it has become evident that signal transmission through intelligent test rigs is achievable, serving as a promising outcome. This research work has the potential to pave the way for further investigations and collaborations with researchers and industries, opening up new avenues for exploration.

4. Conclusions and recommendations

Based on the available preliminary results, the following conclusions and recommendations can be made:

- A small-scale intelligent drill pipe test rig was successfully developed and built up at the university laboratories to study the process of data transmission in boreholes in a laboratory setting. According to the available literature, this test rig is the first of its kind at a university/academic level.
- Two tests were performed on the developed test rig, one qualitative using a LED and one quantitative using an Oscilloscope as a receiver, to simulate real-time data transmission in boreholes using intelligent drill pipe telemetry.
- Despite its complexity, the intelligent drill pipe technology function was clearly demonstrated in the first research phase. It has been successfully shown that the signal could be transmitted contactless between two coils at pipe joints through the test rig and all the way to the other side.
- This test rig provides a foundational platform for further collaboration with researchers and industries, both nationally and internationally. The next research phase is anticipated to study different codes, signal analysis approaches, signal reflection and attenuation value, developing a model, and to conduct tests on longer strings of pipes, among other potential areas of investigations.

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