



Université Mohamed Khider de Biskra
Faculté des Sciences et de la Technologie
Département de génie électrique

MÉMOIRE DE

Sciences et Technologies
Électrotechnique
Energies Renouvelables dans L' Électrotechnique

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Présenté et soutenu par :

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Le :

Conceptual Design and testing of a Wirless Data Transmission System for Real – time Downhole to Surface Communication

Jury :

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Présenté par :
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Dedication

We dedicate this work :

To our parents may allah protect them all hoping that we may have been succeeded in being worthy of thier trust and hopes.

To everyone who taught us a letter or contributed directly or inderctly to our formation.

Acknowledgements

First of all we want to thank and praise Allah Almighty for aiding us and giving us the courage, willpower and the patience to complete this work.

We would like to thank Ms. **Hadri Amal Hamida**, Professor at the University of Biskra, who supervised us throughout this thesis and shared her utmost knowledge and expertise with us.

We also extend our gratitude and thanks to the members of the jury :

Abstract:

In the oil and gas industry, getting real-time data from deep underground is essential for making fast, informed decisions during drilling. Traditional wired systems are often expensive, hard to install, and not ideal for harsh downhole conditions. This thesis explores the design of a wireless communication system that enables real-time data transmission from downhole tools to the surface during drilling operations. Traditional methods like mud pulse telemetry are often slow, limited in bandwidth, and unreliable under harsh downhole conditions. The proposed system uses wireless technology to improve data speed, reliability, and overall efficiency.

Résumé:

Dans l'industrie pétrolière et gazière, l'obtention de données en temps réel en profondeur est essentielle pour prendre des décisions rapides et éclairées pendant le forage. Les systèmes câblés traditionnels sont souvent coûteux, difficiles à installer et peu adaptés aux conditions difficiles du forage. Cette thèse explore la conception d'un système de communication sans fil permettant la transmission de données en temps réel des outils de forage vers la surface pendant les opérations de forage. Les méthodes traditionnelles, comme la télémétrie par impulsions de boue, sont souvent lentes, limitées en bande passante et peu fiables dans des conditions difficiles du forage. Le système proposé utilise la technologie sans fil pour améliorer la vitesse, la fiabilité et l'efficacité globale des données.

المخلص :

في قطاع النفط والغاز، يُعدّ الحصول على بيانات آنية من أعماق الأرض أمرًا بالغ الأهمية لاتخاذ قرارات سريعة ومدروسة أثناء الحفر. غالبًا ما تكون الأنظمة السلكية التقليدية باهظة الثمن، ويصعب تركيبها، وليست مثالية لظروف الحفر القاسية. تستكشف هذه الأطروحة تصميم نظام اتصالات لاسلكي يُمكن من نقل البيانات آنيًا من أدوات الحفر إلى السطح أثناء عمليات الحفر. غالبًا ما تكون الطرق التقليدية، مثل القياس عن بُعد بنبضات الطين، بطيئة، ومحدودة النطاق الترددي، وغير موثوقة في ظروف الحفر القاسية. يستخدم النظام المقترح تقنية لاسلكية لتحسين سرعة البيانات وموثوقيتها وكفاءتها الإجمالية.

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General Introduction

Oil and gas constitute the backbone of the Algerian economy, accounting for over 90% of the country's export revenues and a significant portion of its GDP. At the heart of this sector stands **Sonatrach**, Algeria's national oil company and the largest in Africa, playing a strategic role in the exploration, production, and export of hydrocarbons. The complexity of oil well operations, particularly in deep and high-temperature reservoirs such as those found in Hassi Messaoud and the southern basins, necessitates the use of increasingly sophisticated monitoring technologies to ensure safety, optimize production, and extend the lifespan of wells. Among the most critical parameters to monitor are **pressure and temperature**, which provide essential insights into reservoir behavior, well integrity, and flow assurance.

Currently, high-precision tools such as **Sonic gauge** and **WiMo gauges** are widely used to measure these parameters. These devices rely on durable sensors capable of withstanding extreme downhole conditions. However, a persistent limitation of many traditional systems is their **inability to transmit data in real-time**. Instead, data is often recorded internally and retrieved only after the tool is brought back to the surface, which can delay critical decisions and risk missing dynamic well events.

With the global shift toward **smart oilfield technologies** and **digital transformation** in hydrocarbon operations, there is an increasing demand for **real-time monitoring systems**. One promising solution is the integration of **Sonic Telemetry**, which allows for the wireless transmission of data using acoustic waves through drilling mud or production tubing. This method eliminates the need for physical cabling and reduces data latency, offering a more efficient and safer alternative for downhole communication.

This research project aims to **enhance an existing pressure and temperature measurement system** by developing a communication module capable of real-time data transmission using **Sonic Telemetry**, supported by a simulation model implemented in **MATLAB**. The work is structured into five chapters:

- **Chapter 1** : provides a general overview of the oil and gas industry in Algeria, highlighting the role of Sonatrach and the importance of real-time downhole monitoring.
- **Chapter 2** : investigates different methods of real-time data transmission in oil wells, with an emphasis on the theoretical background and challenges of **Sonic Telemetry** in high-pressure/high-temperature environments and presents a technical review of pressure and temperature measurement tools, focusing on Sonic and WiMo systems, and outlines their operational principles and limitations.
- **Chapter 3** : In this chapter we have discussed the results of a matlab simulation of a sonic telemetry gauge, we have outlined the main advantages and disadvantages of this technique and we have underlined the promising new techniques such as Internet of things and Edge Computing and their advantages in upgrading the telemetry field.

By aligning with the strategic technological ambitions of Sonatrach and the broader oil and gas sector, this study contributes to the development of **smart well instrumentation** and more autonomous monitoring systems that can respond in real-time to operational dynamics in Algeria's energy sector.

Chapitre 1 :

The oil sector in Algeria and the importance of wells monitoring

INTRODUCTION :

The oil sector in Algeria is one of the key pillars of the national economy, serving as the main source of revenue and profit. In this chapter, we will focus on the importance of the oil sector in Algeria, highlighting the significant impact the oil industry has on various aspects of the economy and development. We will also examine the operations that take place in oil wells, the operational environment that varies across different fields, and the critical importance of precise measurements of temperature and pressure in improving well productivity and ensuring operational safety. Additionally, we will explore modern trends in real-time data measurement using smart technologies, which contribute to enhancing the effectiveness and reliability of these measurements.

1.1 Overview of the oil and gaz sector in algeria :

The oil and gas sector is the backbone of Algeria's economy, contributing over 90% of the country's total export revenues and nearly 60% of the national budget (*OPEC, 2023*). As one of Africa's top hydrocarbon producers, Algeria has long relied on its vast oil and natural gas reserves, mainly located in the Sahara Desert, to fuel both its domestic development and international trade. The national oil company, **Sonatrach**, plays a dominant role in exploration, production, and export activities and is considered the largest oil and gas company in Africa (*Sonatrach Annual Report, 2022*).

Key oil and gas fields such as **Hassi Messaoud** (oil) and **Hassi R'Mel** (gas) are at the heart of Algeria's energy infrastructure. These fields demand high-performance drilling technologies and real-time monitoring systems to ensure optimal performance and safety under extreme conditions (*BP Statistical Review, 2023*).

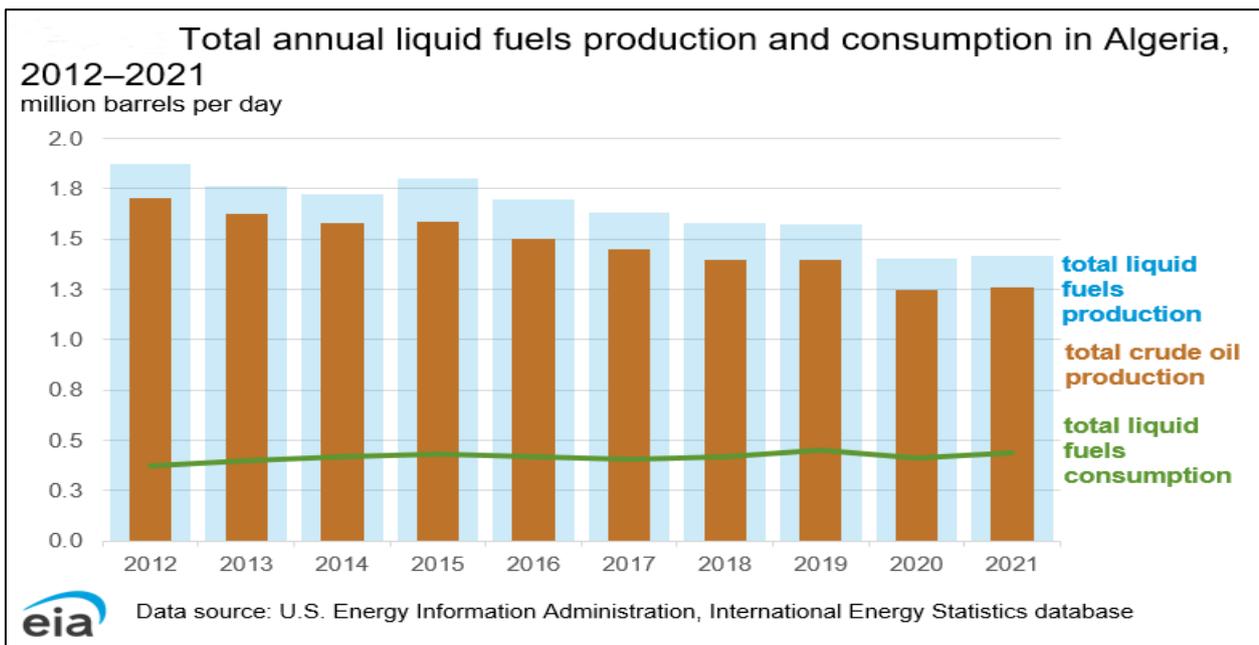


Figure 01 : Total annual liquid fuels production and consumption in Algeria between 2012-2021

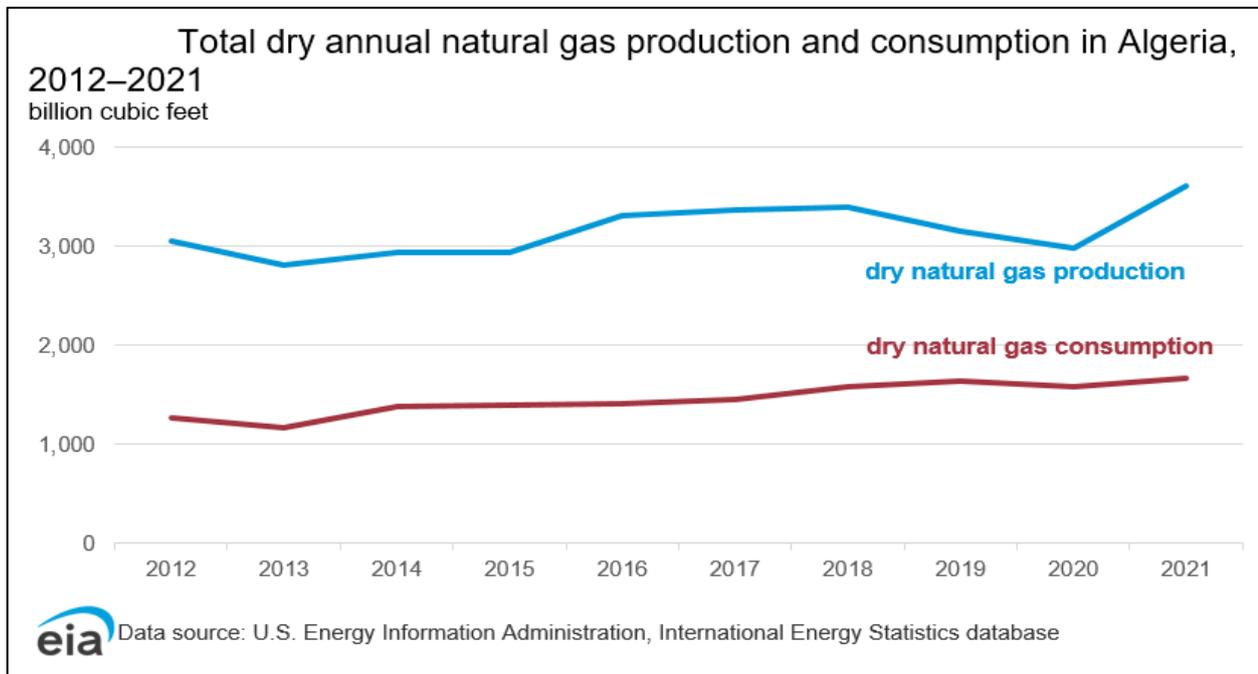


Figure 02 : Total annual natural gas production and consumption in Algeria between 2012-2021

Figure 01 and 02 shows the vast difference between the algerian liquid fuels and gas production and consumption, and that indicates that algeria has a strong and reliable production infrastructure that provides the consumption needs and supports the country’s economy.

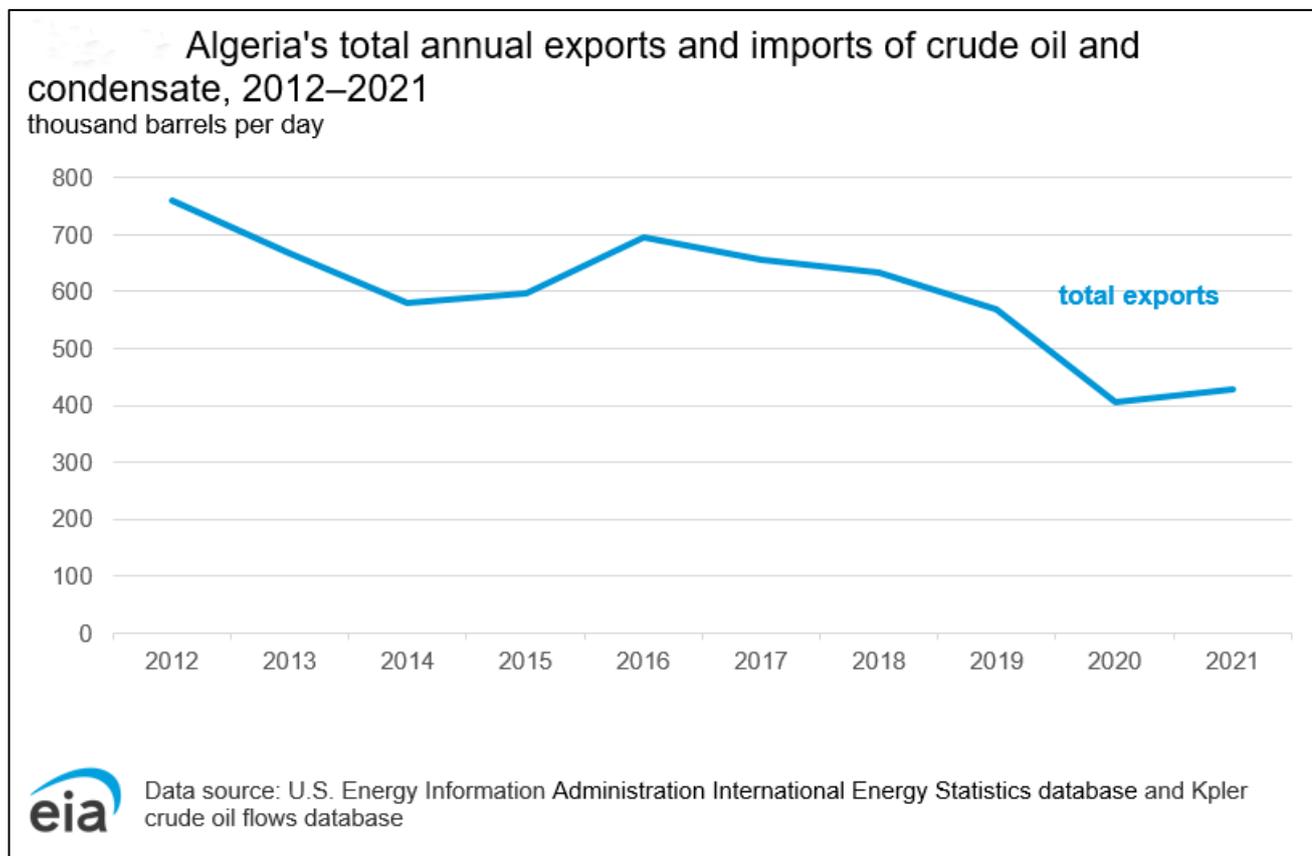


Figure 03 : Algeria’s total annual exports and imports of crude oil and condensate between 2012-2021

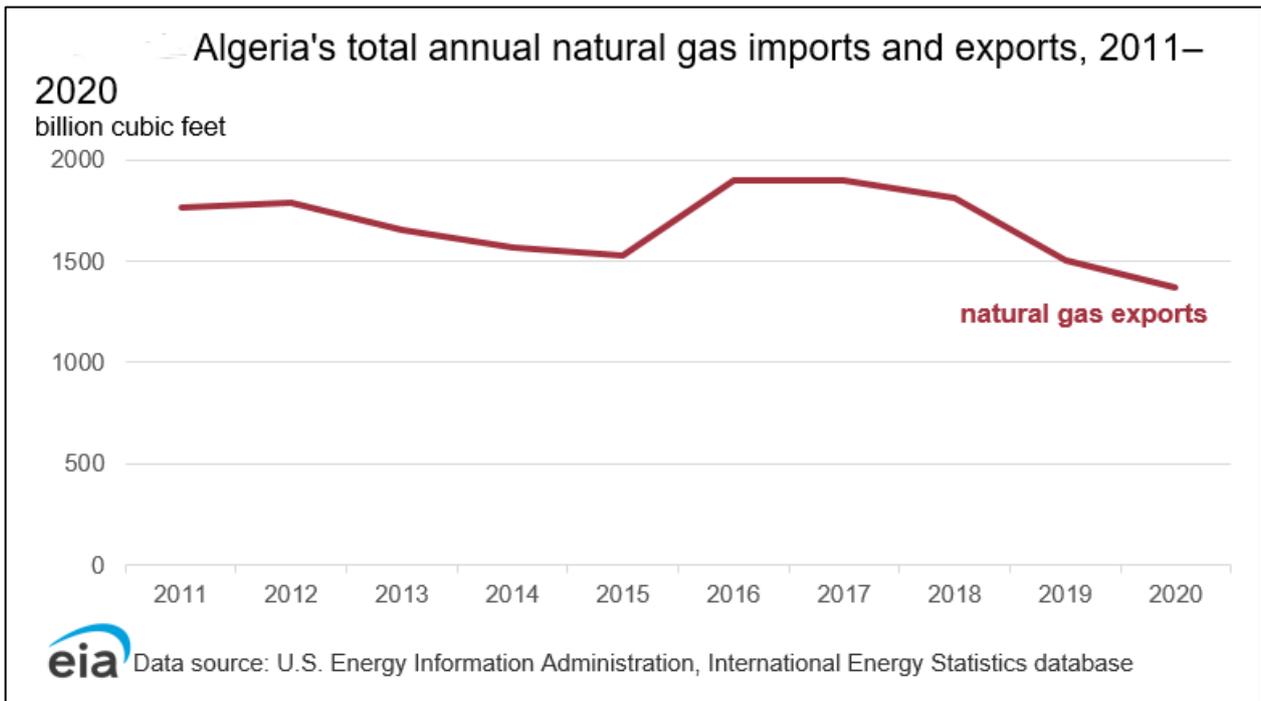


Figure 04 : Algeria’s total annual exports and imports of natural gas between 2011-2020

Between 2012 and 2021, Algeria's oil and gas exports were significant, with oil exports averaging around 599,000 barrels per day. Natural gas production averaged about 3.2 trillion cubic feet, while consumption averaged 1.5 trillion cubic feet over the same period. The country's natural gas exports were particularly prominent, with volumes fluctuating between 1.5 and 1.9 trillion cubic feet.

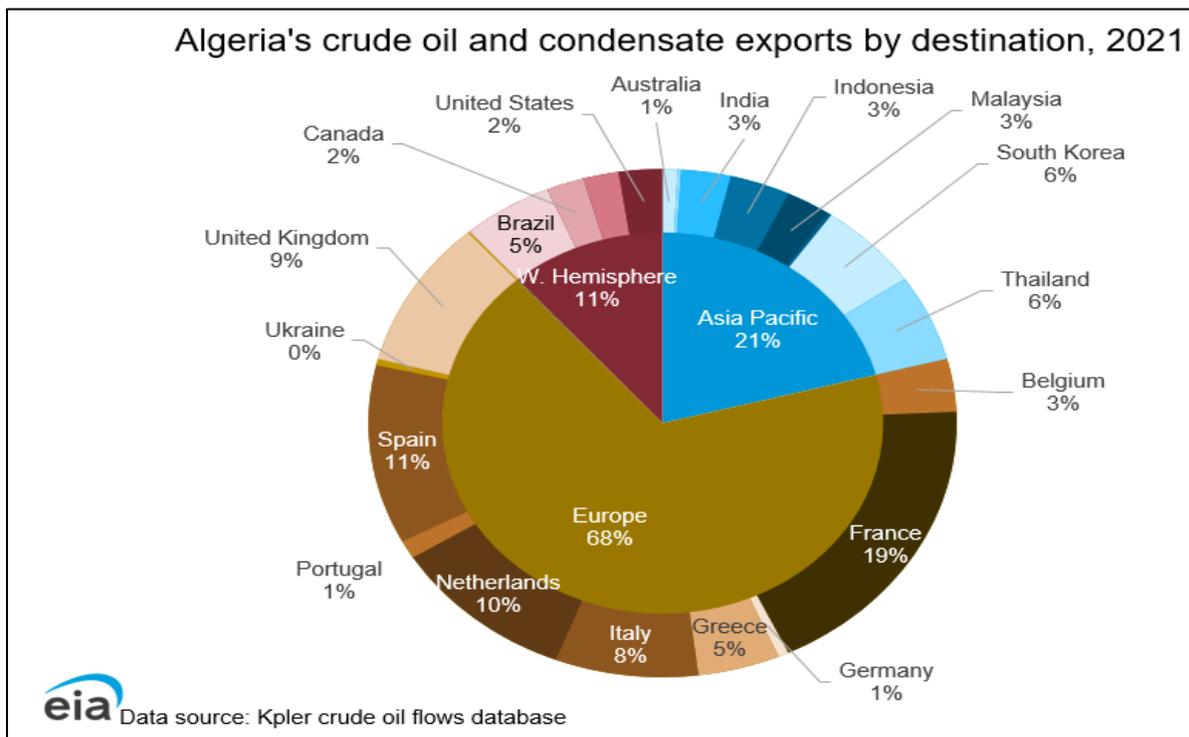


Figure 05 : Algeria’s crude oil and condensate exports by destination in 2021

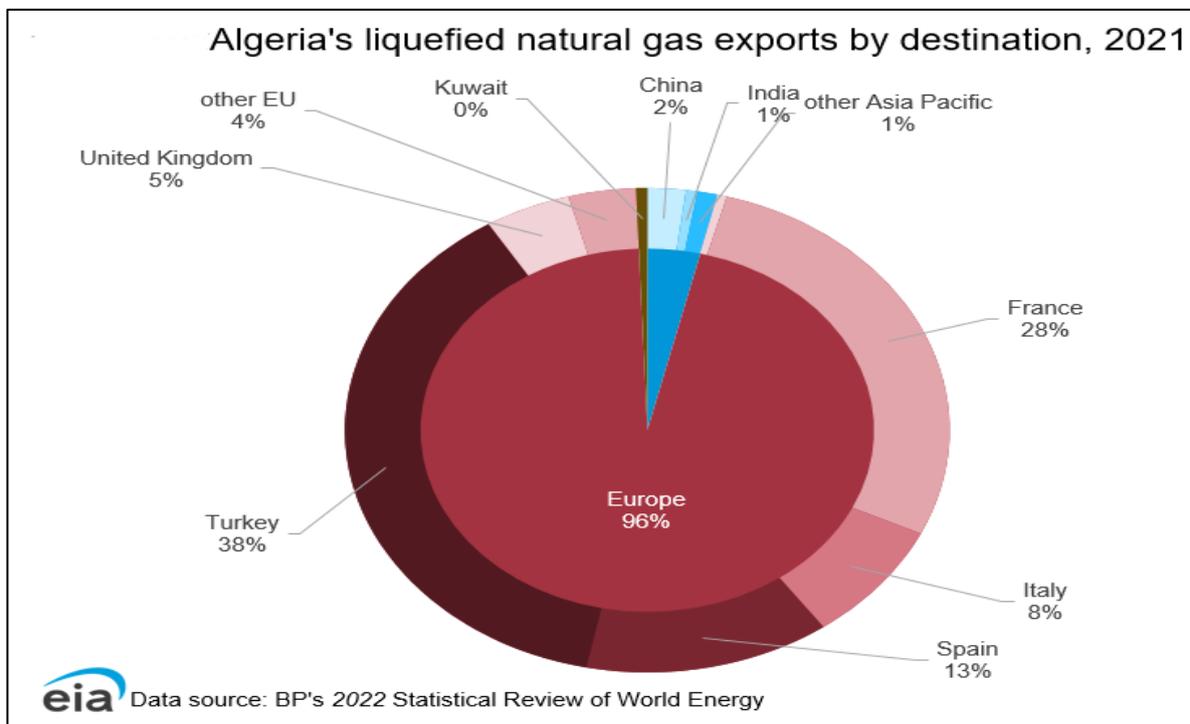


Figure 06 : Algeria’s liquefied natural gas exports by destination in 2021

Figures 05 and 06 showcases the worldwide shares from the algerian crude oil and liquefied natural gas in 2021, if we examine the data from the figures we will notice that the algerian market focuses in dealing with the european union more than other regions of the world, and that is due to the close distance between algeria and europe, the scarcity of these materials in the european market and the geopolitical, historical and economical factors that necessitates the trade with the algerian market.

1.2 The Operating environment in Oil wells :

Oil wells, especially in Algeria, are characterized by harsh and extreme operational conditions that demand high-precision technologies. The country’s oil production is concentrated in the central and southern regions, particularly within the Sahara Desert, where vast sedimentary basins hold significant hydrocarbon reserves.

The key basins include:

- **Berkine Basin**
- **Illizi Basin**
- **Oued Mya Basin**
- **Ahnet-Timimoun Basin**
- **Reggane Basin**
- **Hassi Messaoud Field** (largest oil field in Algeria)
- **Hassi R'Mel Field** (largest gas field)

These basins are located in remote desert environments, which present numerous logistical, technical, and environmental challenges for oil exploration and production.

1.2.1 Geographical and Climatic Conditions

- **Location:** Most wells are in the Sahara Desert.
- **Temperature:** Surface temperatures can exceed 50°C in summer. Downhole temperatures range from 80°C to over 150°C, depending on depth and geothermal gradient.
- **Accessibility:** Many sites are located in remote regions with minimal infrastructure, requiring air transport or long-distance ground logistics.
- **Sandstorms:** Frequent in desert areas, affecting both surface equipment and personnel safety.

1.2.2 Downhole Environment

The downhole conditions in Algerian oil wells are characterized by:

- **High Pressure:** Reservoir pressures can range from 3,000 to over 10,000 psi.
- **High Temperature:** Many wells are classified as High Temperature, High Pressure (HTHP) environments, especially at depths >3,000 meters.
- **Corrosive Fluids:** Presence of H₂S (hydrogen sulfide) and CO₂, which can lead to corrosion of downhole equipment.
- **Abrasive Formation:** Some reservoirs contain sand or hard rock formations, requiring high-performance drilling tools and liners.

1.2.3 Characteristics of Algerian Oil Wells

1.2.3.1 Drilling Depth and Well Types :

- **Depth:** Most wells are between 2,000 and 4,500 meters deep (*Sonatrach, 2022; Zhou et al., 2021*).
- **Well Configurations:**

Vertical wells are common in mature fields (*BP, 2023*).

Directional and horizontal wells are increasingly used for efficiency and reach (*Zhou et al., 2021*).

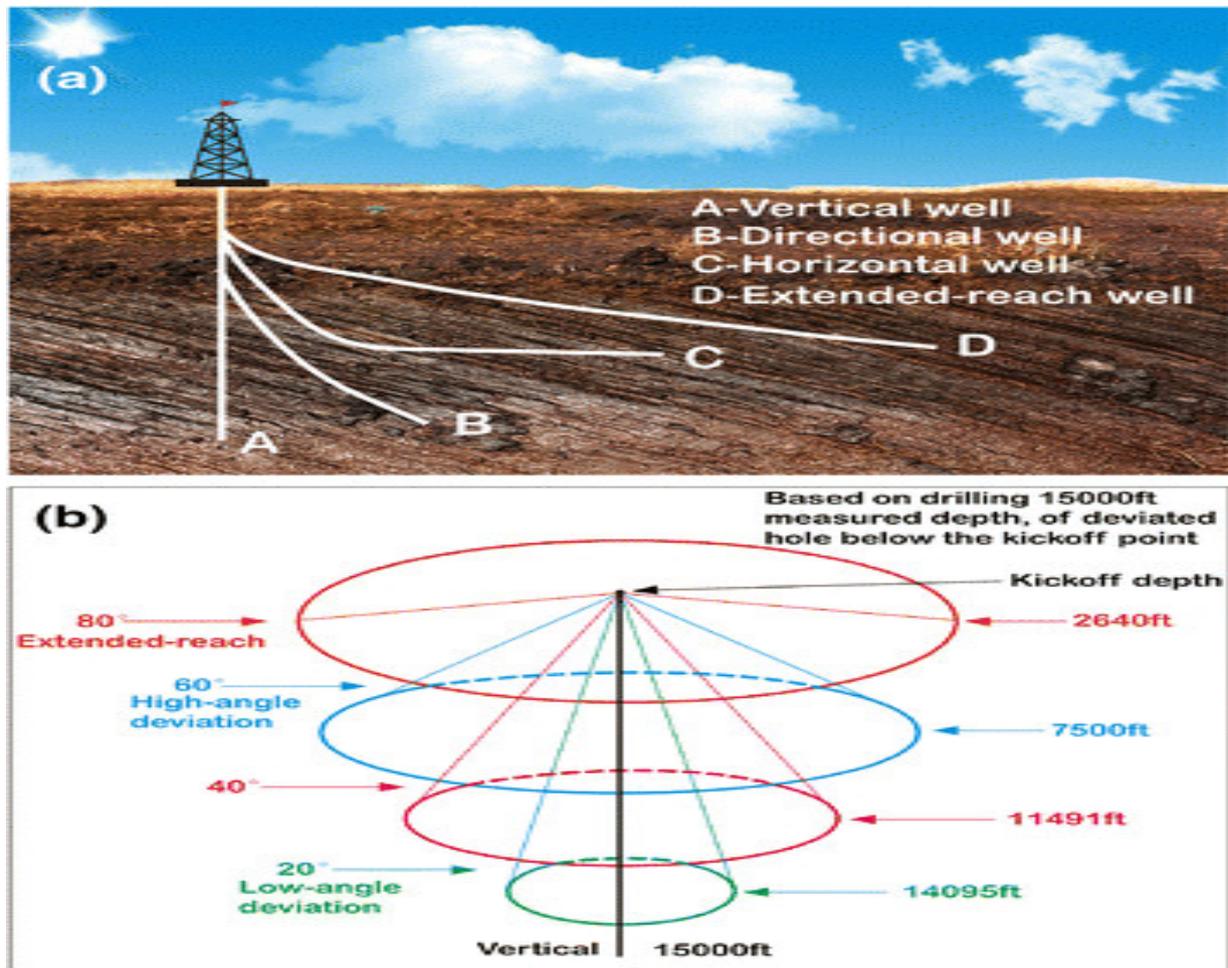


Figure 07 : The schematic plot of different kinds of wells. (a) Four typical kinds of wells and (b) the classification of well types based on deviated angle.

1.2.3.2 Reservoir and Fluid Properties

- **Reservoir Rock:** Mostly sandstone and carbonates (*Boudia & Ouadfeul, 2021*).
- **Porosity:** Typically ranges from 15% to 25% (*Boudia & Ouadfeul, 2021*).
- **Permeability:** Varies from 100 millidarcies to over 1 Darcy (*Boudia & Ouadfeul, 2021*).
- **Fluids:**

Light crude oil with API gravity >32 (e.g., Hassi Messaoud) (*OPEC, 2023*).

Associated gas and presence of sour gases (H₂S, CO₂) (*Zhou et al., 2021*).

1.2.4 Operational and Technical Challenges

1.2.4.1 Harsh Environmental Conditions:

- High-temperature and pressure require HTHP-rated equipment (*Abdel-Rahman et al., 2020*).
- Downhole sensors must resist corrosion and thermal degradation (*Zhou et al., 2021*).

1.2.4.2 Communication & Monitoring:

- **Mud Pulse Telemetry (MPT)** is the dominant method but suffers from low data rates (<20 bps) and signal loss in deep or complex wells (*Abdel-Rahman et al., 2020*).
 - Real-time data transmission is limited in remote locations due to weak digital infrastructure (*Zhou et al., 2021*).

1.2.4.3 Infrastructure & Logistics:

- Most wells operate off-grid, using diesel-powered rigs and generators. (*Sonatrach, 2022*)
- Water scarcity in desert regions limits water-based mud use. (*BP, 2023*)

Table 1 : a summary of the key parameters

Parameter	Typical Range in Algerian Oil Wells
Well Depth	2,000 – 4,500 meters
Reservoir Pressure	3,000 – 10,000+ psi
Downhole Temperature	80°C – 150°C+
API Gravity	32 – 45 (light crude)
Rock Type	Sandstone, Carbonate
Porosity	15% – 25%
Permeability	100 mD – 1+ Darcy
Fluid Types	Oil, Gas, Condensates, H ₂ S, CO ₂
Common Telemetry System	Mud Pulse Telemetry (MPT), Electromagnetic (EM)
Surface Conditions	Extreme heat, dust, remote desert

1.3 The Importance of measuring temperature and pressure in oil wells :

Accurate measurement of pressure and temperature (P/T) in oil wells is essential for effective reservoir management, drilling optimization, and ensuring operational safety. These parameters serve as key indicators of the reservoir's state and dynamic behavior throughout the life cycle of a well, from exploration and drilling to production and enhanced recovery.

1.3.1 Reservoir Characterization and Evaluation

Downhole pressure and temperature data provide critical insight into the reservoir properties such as fluid composition, saturation, and phase behavior. For instance, pressure measurements allow engineers to determine formation pressure and assess reservoir drive mechanisms (natural water drive, gas expansion, etc.) which directly affect recovery strategies (Ahmed, 2010). Temperature profiles also help identify geothermal gradients and fluid movement, influencing completion design and artificial lift methods (Economides et al., 2012).

1.3.2 Drilling Operations and Safety

In drilling operations, real-time pressure monitoring is crucial for well control and preventing blowouts, particularly in high-pressure/high-temperature (HPHT) environments. Deviations in expected pressure values can indicate formation kicks or lost circulation zones, requiring immediate intervention. Similarly, temperature affects drilling fluid viscosity, tool integrity, and the performance of measurement-while-drilling (MWD) and logging tools (Bourgoyne et al., 1986).

1.3.3 Production Optimization

Monitoring bottomhole pressure and temperature enables engineers to optimize production rates and improve artificial lift performance. For example, pressure drawdown analysis helps evaluate reservoir permeability and skin factor, while temperature anomalies can indicate water or gas breakthrough, or leaks in casing and tubing (Craft et al., 1991). These measurements are also used in nodal analysis and inflow performance relationship (IPR) modeling.

1.3.4 Well Integrity and Surveillance

Sustained casing pressure, temperature fluctuations, or unexpected thermal behavior are often indicators of well integrity issues, such as leaks or gas migration behind casing. Downhole sensors installed in smart wells or fiber-optic distributed temperature sensing (DTS) systems can provide continuous surveillance, improving preventive maintenance and reducing intervention costs (Hou & Alfi, 2014).

1.3.5 Enhanced Oil Recovery (EOR) and Reservoir Simulation

In EOR operations, pressure and temperature measurements are used to monitor the injection process and model fluid front movement, especially in thermal recovery or gas injection projects. Accurate P/T data improve history matching and numerical reservoir simulation, resulting in better decision-making and recovery forecasting (Lake, 2014).



Figure 08 : Common threats to Onshore well performance (www.link-labs.com/blog/iot-oil-gas-use-cases)

1.4 Towards Smart measurement and Real-Time monitoring in oil wells

As the oil and gas industry continues to evolve, there's a growing shift toward smarter, more connected technologies especially when it comes to monitoring what's happening deep underground. Pressure and temperature are among the most critical parameters in oil wells, and being able to track them in real time is changing the way fields are managed.

Today, many wells are equipped with smart sensors that can continuously measure and transmit data from downhole to the surface. This means engineers can monitor pressure and temperature changes as they happen and respond quickly to anything unusual, like gas or water breakthrough, or unexpected pressure drops (Hou & Alfi, 2014). Compared to older methods that relied on occasional readings, this kind of real-time insight is a big step forward.

In Algeria, companies like Sonatrach and its international partners have started integrating these systems into new projects, especially in major fields such as Hassi Messaoud and Berkine, where Permanent Downhole Gauges (PDG) linked to SCADA systems are being deployed.

The benefits of real-time monitoring include:

- Reduced downtime and faster reaction to operational issues
- Equipment protection from unexpected stress or failure
- Support for predictive rather than routine maintenance
- Enhanced safety at production sites (Aouadj, M., Naceri)

New technologies like wireless telemetry and fiber-optic cables are playing a big role in this change. Fiber-optic systems, for example, can provide a detailed temperature profile along the entire wellbore, helping to identify leaks, track fluid movement, and spot thermal changes that might signal a problem (Zhou et al., 2021). Wireless systems are also gaining popularity because they reduce the need for complex wiring and are more flexible, especially in remote or hard-to-reach locations.

What makes these tools even more powerful is how they work alongside artificial intelligence. By feeding real-time data into machine learning systems, companies can detect early warning signs of equipment failure, fine-tune production settings, and even automate certain decisions (Abdel-Rahman et al., 2020). This kind of smart automation not only improves efficiency but also helps reduce costs and safety risks.

In Algeria, where many oil wells are deep and operate under high pressure and temperature, these smart monitoring solutions are becoming increasingly valuable. They offer a practical way to improve safety, optimize production, and extend the life of wells key goals for both operators and the national energy strategy (Sonatrach, 2022).

CONCLUSION

In conclusion, this chapter has provided a comprehensive overview of the oil sector in Algeria and its significant impact on the national economy. It has emphasized the importance of accurate measurements in oil wells, particularly in terms of pressure and temperature, and how these measurements play a crucial role in ensuring operational safety and improving production efficiency. As oilfields become deeper, hotter, and more technically demanding, the need for precise and real-time information becomes even more critical.

Through this chapter, it has become clear that the shift towards smart measurement and real-time monitoring is the way forward to achieving maximum efficiency in well operations. This will form the foundation upon which the next section of the thesis will build, which will focus on the devices used for measurement and how they can be improved to meet the challenges of modern times

Chapitre 2 :
The wireless technologies
and devices commonly
implemented in oil wells
monitoring

INTRODUCTION

This chapter presents a general overview of the main wireless technologies implemented in the oil well exploiting and monitoring industry, also we will be discussing about the leading devices used to measure pressure and temperature in downhole oil wells, with a particular focus on the SonicGauges and WiMo devices. These tools are essential for monitoring well performance and ensuring safe production, especially in harsh environments like the Algerian desert. We will also be addressing the technical and environmental challenges that may affect the operating of these devices, which justifies the need for technical improvements, especially in terms of communication and data transmission to the surface.

1. The main wireless telemetry technologies in the oil monitoring industry

Wireless telemetry technologies have become essential in modern oil well monitoring, offering real-time data transmission without the complexity of physical wiring. Traditional wired systems face limitations in remote and harsh environments, such as high installation costs and vulnerability to damage. Wireless systems provide a more flexible and cost-effective alternative, enabling continuous monitoring of well conditions [1].

Wireless telemetry enables the transmission of data from sensors deployed in downhole and surface equipment to central processing units without the need for physical cables. This approach not only reduces infrastructure complexity but also enhances flexibility and scalability in monitoring systems. [2].

Here are the main wireless telemetry methods used in the oil industry :

1.1. Mud Pulse Telemetry

Mud pulse telemetry (MPT) was introduced commercially in the 1970s. Mud pulse telemetry (MPT) is the oldest telemetry technique to transmit borehole data. This discovery was a milestone in the industry, especially in directional drilling. It gave the directional driller real-time details on the steering system's output and the wellbore's geometric location. In addition, this caused significant improvement in directional drilling's performance and accuracy while minimizing risk [10], [25].

Like any communication system, a telemetry system needs a transmitter and a receiver to transfer information or data effectively. The two primary processes of a telemetry system are the uplink and downlink. The drill string achieves downlink communication by changing the rotation rate, usually used for trajectory regulation or steering. It can also be achieved by intermittent mud flow rate changes. Here, the flow rate variance or rotational motion identifies and reacts to the sensors in the downhole measurement while drilling. For up-link communication, data is transmitted via the MWD instrument in the bottom-hole assembly (BHA) by producing pressure pulses in the mud stream, including the support of a mud pulser, a pressure-inducing pressure system. Here, the sensors in the receiving system determine pressure fluctuations at the surface, and signal processing units analyze the readings. This technique is known as decoding [25].

The mud pulse telemetry system consists of multiple parts: the downhole transmitter, the surface receiving system, the transmission channel, and associated downhole surface processing units [25]. The downhole and surface modules are engineered to achieve the highest data rate and reliability level. Several additional components are interfaced with the surface system to account for signal alterations during transmission [25]. It should be noted that the frequency of the pressure wave (to be propagated) and the properties of the drilling mud and the drill string determine how much the pressure wave propagates [27]. In order to express mathematically, the wave equation suitable for pressure wave propagation considering a continuous flow of pressure is given by equation (1) [27]:

$$\nabla^2 p = \frac{\rho_0}{B} \frac{\partial^2 p}{\partial t^2} \quad (1)$$

where:

ρ_0 = the drilling mud's density

B = the drilling mud's bulk modulus

p = wave pressure

The pressure's wave time and spatial relationship to the drilling mud density are related by equation (1). Pressure, depth, and temperature often affect density fluctuations in drilling mud. An analytical model relating temperature, pressure, and density has been established and is given by equation (2) [27]:

$$\rho = \rho_{sf} e^{\Gamma \rho_0 T} \quad (2)$$

where:

ρ_{sf} = drilling mud static density (at the surface)

$\Gamma \rho_0 T$ = temperature and pressure differentials define the analytical function

T = mud temperature

With an increase in depth, temperature and pressure also rise, causing a decrease in density because of thermal expansion and increased density due to the drilling mud's compressibility. While the drilling mud's density changes influence the pressure wave's attenuation, the wave will be further attenuated by the radiative losses, the stiffness of the tool joints, and the moment of inertia [27]. Another characteristic of the mud channel is its signal attenuation. The distance determines the signal's attenuation as it passes across the mud channel, the mud signals travel, and the mud properties used, are defined by [28] using lamb's law. Equations (3) - (6) give a mathematical expression to prove that with increasing distance, the mud pulse's attenuation also increases exponentially [25].

$$P(x) = P_0 e^{-x/L} \quad (3)$$

With :

$$L = \frac{d_i c}{2} \sqrt{\frac{2}{vw}} \quad (4)$$

where:

$P(x)$ = pressure wave's amplitude at a distance x from the source, measured in Pascal (Pa) or psi

P_0 = pressure wave's amplitude at the source, measured in Pascal (Pa) or psi

d_i = pipe's internal diameter measured in feet or meters

v = kinematic viscosity, measured in ft^2/s or m^2/s

c = velocity of the wave in ft/s or m/s

w = angular velocity in radians per second

By ignoring the pipe modulus effects, wave velocity (c) can be mathematically expressed as [25]:

$$c = \sqrt{\frac{B}{\rho}} \quad (5)$$

Where :

ρ = drilling mud or fluid density, measured in kg/m^3

B = mud bulk modulus, measured in Pascal (Pa)

Substituting :

(5) into (4), we have the mathematical expression as [25]:

$$L = \frac{d_i c}{2} \sqrt{\frac{2B}{\eta w}} \quad (6)$$

Where:

$\eta = \rho v$ = plastic viscosity.

Notable, equation (3) holds only for high-frequency telemetry systems more significant than 10 Hertz. For a low-frequency system, equation (7) is more suitable to be used or applied, and R is defined in equation (8) and C in (9) [25]:

$$P(x) = P_0(1 - e^{-R/C}) \quad (7)$$

$$R = P/Q \quad (8)$$

$$C = V/B \quad (9)$$

where:

R = mechanical resistance, measured in Pascal

Q = volumetric flow rate in m^3/s

C = mechanical compliance in m^3/Pa

V = mud's volume above MWD instrument (m^3)

The MPT is only usable during the drilling process [27]. It is a highly dependable and stable method with a regulated medium for transmission, low signal attenuation, and the capacity to transmit data over a long distance. However, it achieves low data rates. The low data rate is due to signal interference and signal attenuation, as an increase in length causes an increase in pulse length, which is necessary to acquire the signals reliably. So, the data rate reduces [25]- [26]. The reduction in data rates is affected by the properties of the drilling mud (which affects the signal attenuation), which is not approvable for underbalanced drilling. Because of the hardware's long-term stability, MPT has been restricted to MWD systems [27]. In addition, the signal in the fluid can only propagate at the speed of sound, which in turn causes latency [26].

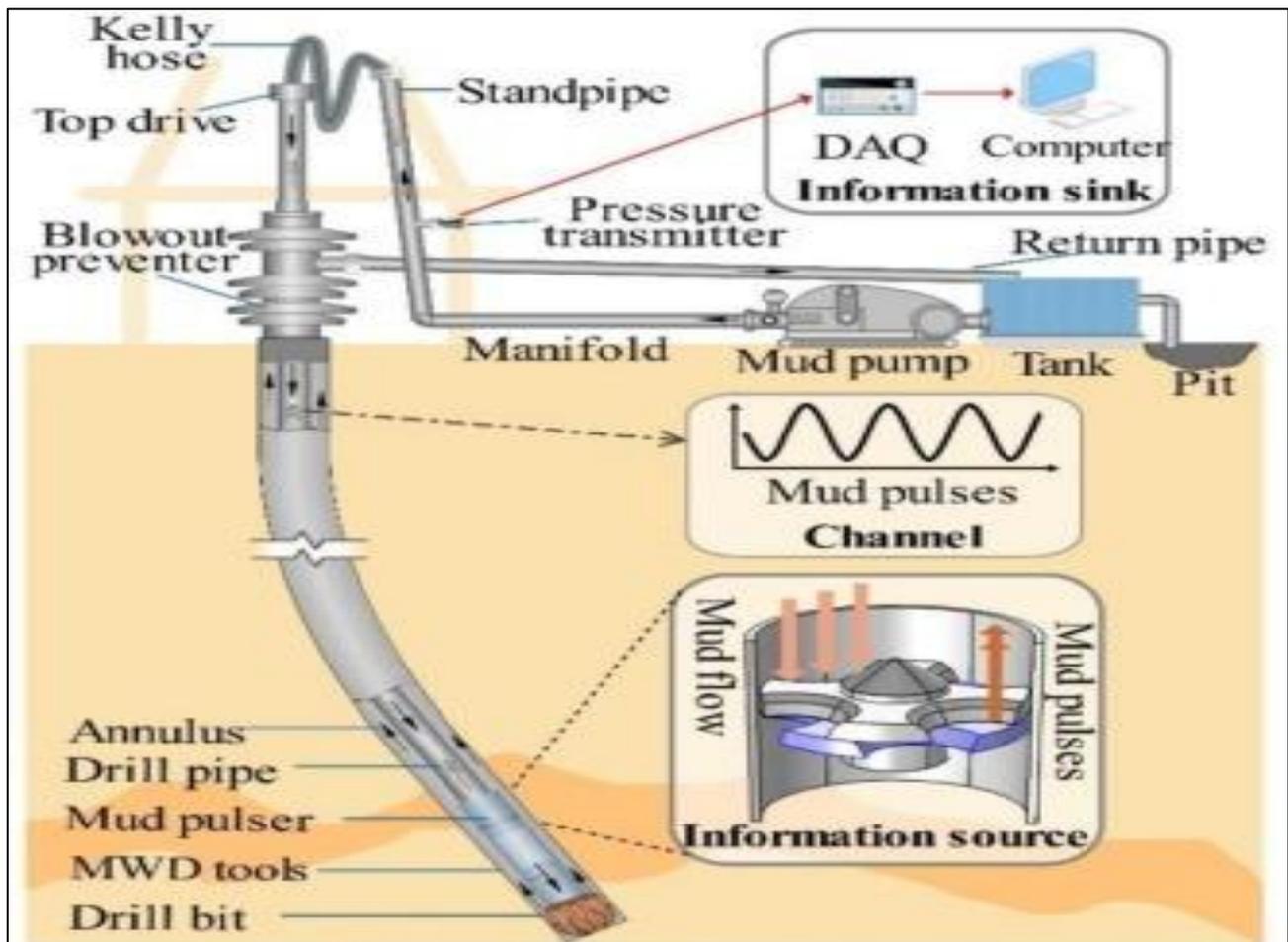


Figure 09 : a schematic diagram of a mud pulse telemetry system

There are three mud pulse telemetry techniques :

a) Positive pulse:

In this method a poppet valve or a similar restrictor is used to momentarily reduce the flow area in the mud column. This causes an increase in downhole pressure (discrete high pressure pulses), which travels up the wellbore column and is detected by surface pressure transducers, this system usually uses a binary encoding (1 = pulse, 0 = no pulse). This technique is mechanically simple and reliable and it has a good performance in moderate-depth and high-flow conditions. [6]

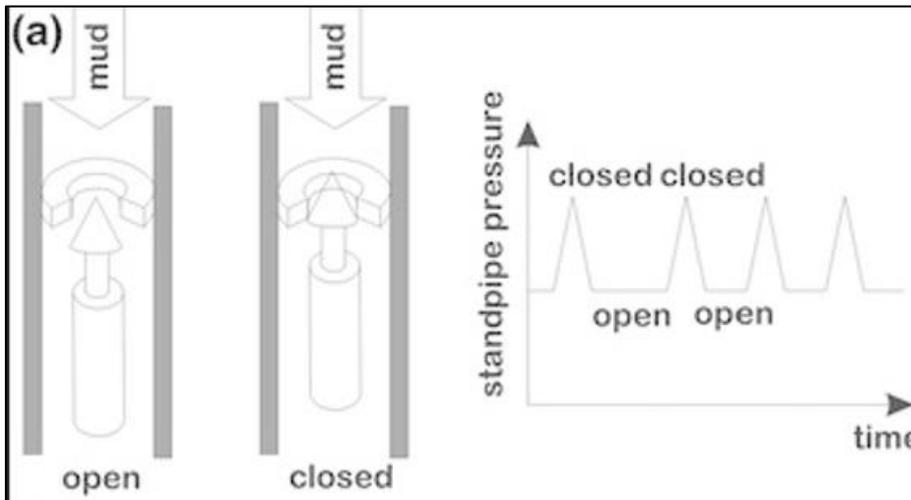


Figure 10 : positive pulse

b) Negative pulse:

This technique uses a bypass valve that opens briefly to vent drilling mud into an annular cavity or bypass line, causing a momentary drop in pressure. These drops are detected and interpreted as data, similar binary methods are used, or in some cases time-domain encoding like pulse duration modulation. This technique is cleaner, has more distinct signals especially in high-density muds and it has less impact on the flow of the fluid. [7]

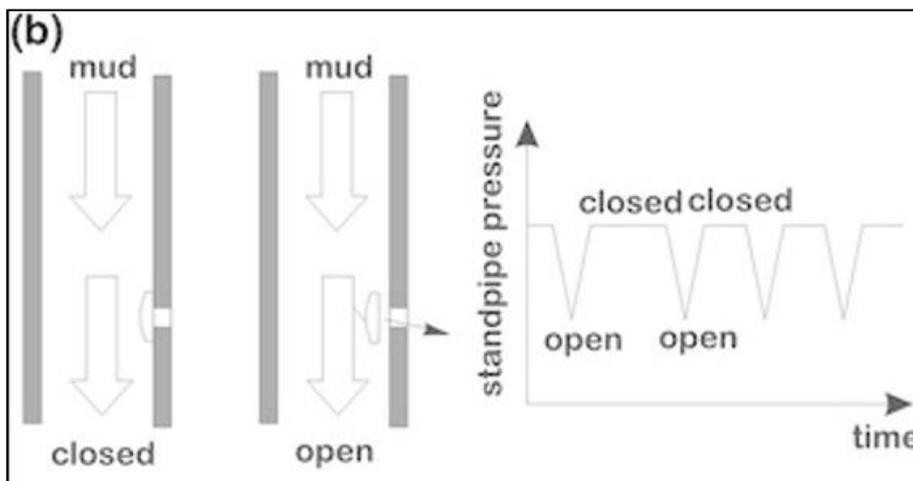


Figure 11 : negative pulse

c) Continuous pulse:

In this method a slotted rotating disk is positioned over a matching fixed disk. As the slots align and misalign, the flow area oscillates producing a sinusoidal pressure wave whose frequency, amplitude, or phase is varied to encode data (different frequencies represent binary values.). This method has a much higher data transmission rate, a stronger signal-to-noise ratio and it is more resistant to attenuation. [7]

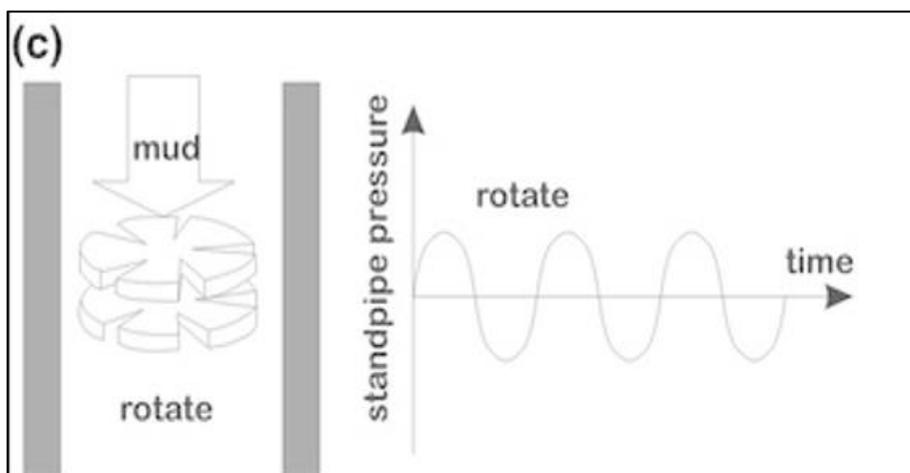


Figure 12 : continuous pulse

Table 2 : a comparison between all three MPT methods

Feature	Positive Pulse	Negative Pulse	Continuous Wave
Pulse Type	Pressure Increase	Pressure Decrease	Sinusoidal Wave
Mechanism	Flow restriction	Flow bypass	Rotary flow modulation
Data Rate	Low–Moderate (1–3 bps)	Moderate (2–4 bps)	High (4–10+ bps)
Complexity	Low	Medium	High
Signal Clarity	Good	Very Good	Excellent
Depth Limitation	Moderate	Moderate	Best for deep wells
Application	Standard MWD	Mud-sensitive drilling	High-speed operations

The table highlights key differences among the three MPT methods, each mud pulse telemetry method has its own strengths, and the best choice really depends on the drilling conditions. **Positive pulse** systems are the simplest and most commonly used—they're reliable and easy to maintain, but they don't transmit data very quickly, which can be a drawback in deeper or more complex wells. **Negative pulse** systems create cleaner signals by briefly dropping pressure, which helps in muddy or noisy environments, though they're a bit more complicated and can be prone to clogging. Then there's **continuous wave** telemetry, which is more

advanced and offers faster, clearer data great for deep wells or when real-time info is critical but it's also more complex and expensive. In the end, it's about choosing the right balance between simplicity, speed, and reliability for the specific job.

1.2. Electromagnetic Telemetry

The electromagnetic telemetry (EMT) system was introduced in the 1980s it is a pivotal technology used in Measurement While Drilling (MWD) and Logging While Drilling (LWD) systems. It enables the real-time transmission of downhole data to the surface, significantly improving operational efficiency and allowing for more informed decision-making during drilling operations. [4] It consists of a transmitter that transmits data via coded EM waves, using an installed electrical insulating sub (the transmitter) [10]. This installation is possible as the drill string is made used as a dipole electrode which produces a voltage difference that is altered [10]. The rest of its communication parts are the channel / propagating medium that uses the formation (which is) adjacent to the wellbore. The receiver receives the data transmitted as a measured voltage difference between the wellhead and an antenna anchored on the earth's surface. In addition to the system, a casing antenna can also be included for operation[10]. A typical EM wireless telemetry system is illustrated in the figure below.

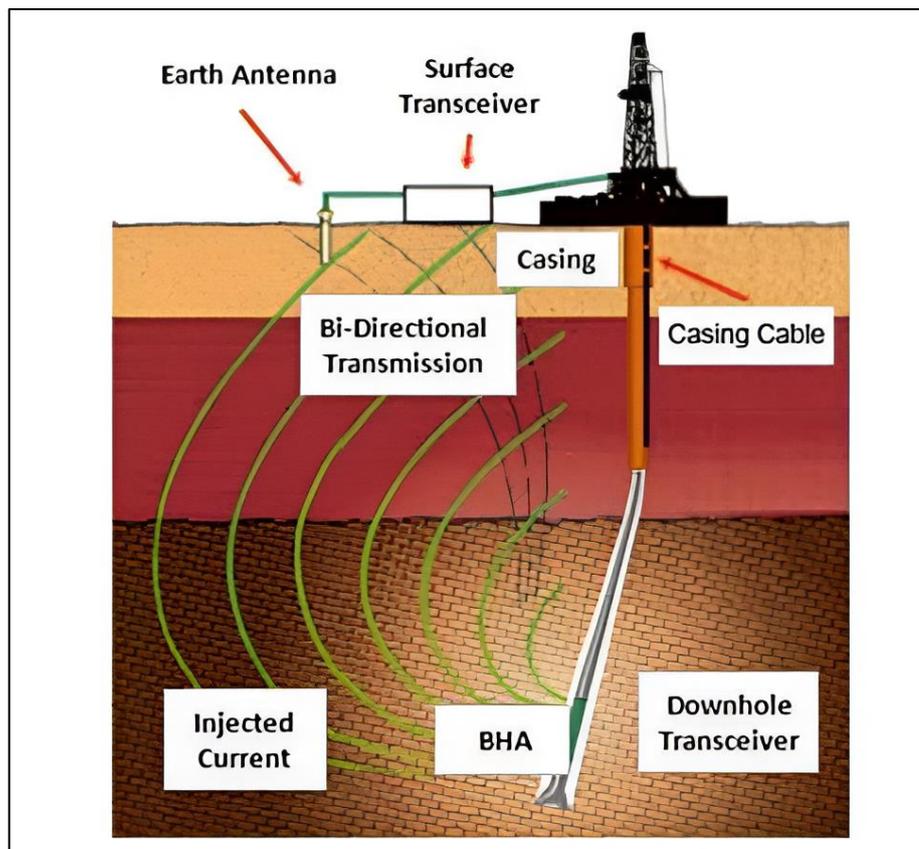


Figure 13 : example of a wireless electromagnetic telemetry in a well (Zeng 2017)

EM waves can be divided into many useful categories based on frequency. See Table 1 below for a more complete description of the electromagnetic spectrum.

Band Name	Frequency	Wavelength	Application
Extremely Low Frequency (ELF)	3 Hz to 30 Hz	100 to 10 Mm	Power Line Frequencies
Voice Frequency (VF)	300 Hz to 3 KHz	1,000 to 100 km	Telephone Communications
Very Low Frequency (VLF)	3 KHz to 30 KHz	100 to 10 km	Marine Communications
Low Frequency (LF)	30 KHz to 300 KHz	10 to 1 km	Marine Communications
Medium Frequency (MF)	300 KHz to 3 MHz	1000 to 100 m	AM Broadcasting
High Frequency (HF)	3 MHz to 30 MHz	100 to 10 m	Long Distance Aircraft, Ship Communications
Very High Frequency (VHF)	30 MHz to 300 MHz	10 to 1 m	FM Broadcasting
Ultra High Frequency (UHF)	300 MHz to 3 GHz	1 to 0.1 m	Cellular Telephone
Super High Frequency (SHF)	3 GHz to 30 GHz	100 to 10 mm	Satellite Comms, Microwave Links, WiFi
Extremely High Frequency (EHF)	30 GHz to 300 GHz	10 to 1 mm	Wireless Local Loop
Infrared (IR)	300 GHz to 300 THz	1 mm to 1 μ m	Consumer Electronics
Visible Light (VL)	400 THz to 800 THz	740 to 380 nm	Optical Comms, Blu-Ray
Ultraviolet (UV)	3 PHz to 30 PHz (10^{15})	100 to 10 nm	Sterilization, Photocuring
X-Rays	30 PHz to 300 PHz (10^{15})	10 to 1 nm	Medicine, Security, Industrial
Gamma Rays	30 EHz to 300 ZHz (10^{18} to 10^{21})	10 pm to 1 am	NDT Inspection, Medical, Density Measurement
Cosmic Rays	300 ZHz – 300 YHz (10^{21} to 10^{24})	1 am to 1 zm	Space travel exposure limits

Table 3 : List of electromagnetic frequencies, wavelengths, and their applications [14]

Electromagnetic telemetry for downhole applications uses Extremely Low Frequency waves or ELF for several reasons: unguided wave, long transmission distance, and conductive and heterogeneous media. All these factors contribute to the total attenuation; therefore the frequency is reduced as low as possible, typically 0.1 to 20 Hz, and distance limited to 500 to 3000 meters. When greater distances must be covered, multiple EM devices can be used at regular intervals to receive and retransmit the signals. These additional devices are called repeaters and increase cost and complexity and reduce reliability of the system [14].

Maxwell's equations relate to the electric and magnetic fields and can calculate how the EM waves propagate across conductive media. The EMT system works in the near field because the electric field's wavelength has higher magnitude orders greater than the good casting's measurement. Relatively, an estimation of the circuit can be obtained during transmission [27].

$$\nabla \times E = -j\omega\mu H$$

$$\nabla \times H = (\sigma + j\omega\varepsilon)E$$

Where:

E: Electric field (V/m)

H: Magnetic field (A/m)

$\omega = 2\pi f$: Angular frequency (rad/s)

σ : Electrical conductivity (S/m)

ε : Permittivity (F/m)

μ : Permeability (H/m)

Reference : Stratton, J. A. *Electromagnetic Theory*. McGraw-Hill, 1941.

In a lossy medium, the propagation constant is:

$$\gamma = \alpha + j\beta = \sqrt{j\omega\mu(\sigma + j\omega\varepsilon)}$$

While :

α : Attenuation constant (Np/m)

β : Phase constant (rad/m)

For conductive media ($\sigma \gg \omega\varepsilon$), simplify to:

$$\alpha \approx \beta \approx \sqrt{2\pi f\mu\sigma}$$

Reference: Cheng, D. K. *Field and Wave Electromagnetics*, Addison-Wesley, 1989.

Skin depth or penetration depth (δ) indicates how far EM waves can travel in the formation, this parameter is critical in determining effective telemetry range.

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} = \frac{1}{\alpha}$$

Reference: Kaufman, A. A., & Keller, G. V. *Frequency and Transient Soundings*. Elsevier, 1983.

EM telemetry between downhole tool and surface can be modeled as a lossy transmission line.

$$\frac{dV(z)}{dz} = -(R + j\omega L)I(z)$$

$$\frac{dI(z)}{dz} = -(G + j\omega C)V(z)$$

Where :

R: Resistance per unit length (Ω/m)

L: Inductance per unit length (H/m)

G: Conductance of the medium (S/m)

C: Capacitance per unit length (F/m)

In oil well EM telemetry, signals are transmitted from downhole tools to the surface through conductive rock formations, which heavily attenuate the signal. For telemetry reliability, Signal to Noise Ratio is key :

- Low SNR: The surface equipment might struggle to decode the signal.
- High SNR: The signal is much stronger than the noise so that results in an accurate, real-time data

$$SNR (dB) = 20 \log_{10}\left(\frac{V_{signal}}{V_{noise}}\right)$$

Reference: T.W. Parks and C.S. Burrus, *Digital Filter Design*, Wiley, 1987.

Electromagnetic signal power decreases exponentially with distance :

$$P(z) = P_0 e^{-2\alpha z}$$

Where:

P_0 : Initial transmitted power

Z : Distance traveled

Efficiency :

$$\eta = \frac{P_{received}}{P_{transmitted}} = e^{-2\alpha L}$$

Reference: Telford, W. M., Geldart, L. P., & Sheriff, R. E. *Applied Geophysics*. Cambridge University Press, 1990.

To minimize reflection and maximize transmission proper impedance matching between the downhole tool and formation improves signal propagation :

$$Z = \sqrt{\frac{R+j\omega L}{G+j\omega C}}$$

Some advantages of the EMT are its low failure rate, not including rotating pieces in the downhole, is also a two-way communication technology and can be used in underbalanced drilling (far more suitable and dependable than MPT) [10]. However, the EMT has high signal attenuation and interference. One of the reasons is the elevation of the water in the formation, which causes the reduction of signal intensity (strength) [20], [26]. For the EMT, as stated above, the signal must pass through the ground, making multiple formations at each drill site. The signal transmitted to the surface from the downhole is (generally) affected by conductivity and permittivity. Based on the formation's material properties, there can be hardly any usable signal at the surface because of extremely high signal attenuation [26]. It is also relatively costly, achieves low data rates and can only be applied in wells with shallow depths. Although when applied in deeper wells, its performance is dependent on a fairly low formation resistivity [10], [20] and [26].

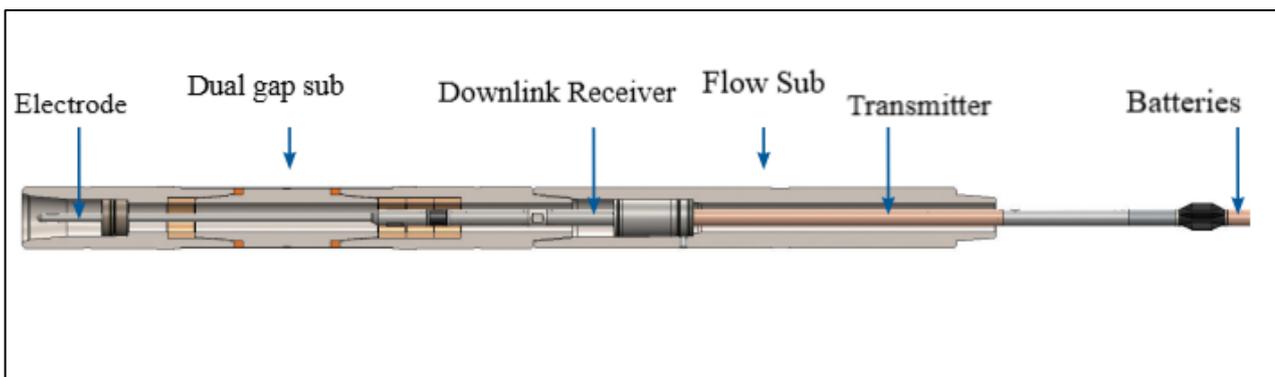


Figure 14 : an electromagnetic telemetry tool trceiver (SureShot™ EM Telemetry system) and its components [30]

Component breakdown :

- **Electrode :** Injects the EM signal into the surrounding formation and acts as the electrical contact point for transmitting or receiving EM fields.

- **Dual gap sub** : Electrically isolates different sections of the drill string and ensures effective signal transmission by controlling current paths in the collar.
- **Downlink Receiver** : Receives signals from the surface and allows operators to send commands downhole (like tool settings or configuration changes).
- **Flow Sub** : Maintains mud flow through the tool and ensures continued drilling fluid circulation while housing internal components.
- **Transmitter** : Converts sensor data (like pressure, temperature, inclination) into an EM signal and sends data upward through the formation to be captured at the surface receiver.
- **Batteries** : Power source for the entire EM telemetry system and enables autonomous operation without external power cables.

1.3. Acoustic Telemetry

Acoustic telemetry stands out as a promising technique due to its potential for higher data transmission rates, especially in environments where conventional methods such as mud pulse telemetry (MPT) and electromagnetic telemetry (EMT) face limitations. Acoustic telemetry involves the transmission of information via acoustic waves (typically within the ultrasonic frequency range) through solid conductors, such as the drill string, or through fluid mediums, such as drilling mud. In drill-string acoustic telemetry, vibrational waves are generated at a source—usually within the bottom hole assembly (BHA)—and propagate along the metal drill pipe to the surface, where they are captured by highly sensitive accelerometers or transducers. This method exploits the mechanical properties of steel drill pipes to act as a waveguide for signal propagation.

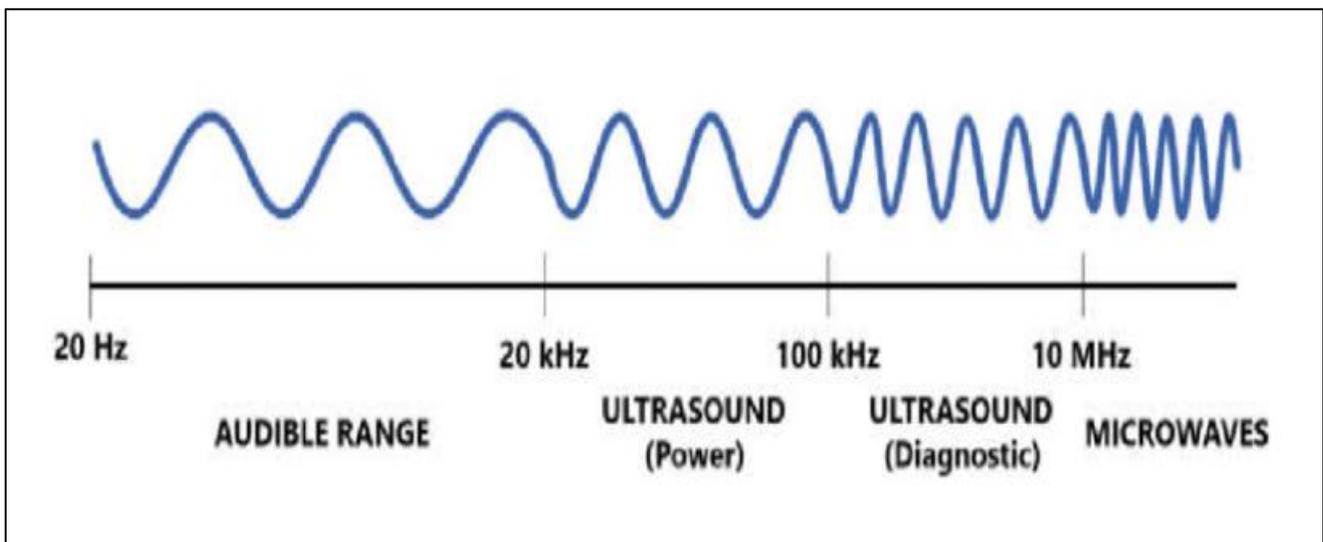


Figure 15 : The sound spectrum: audible range (20 Hz–20 kHz), ultrasound range (20 kHz–10 MHz) and microwave range (>10 MHz).[32]

Frequency Range	Frequency (Hz)	Wavelength in Air (m)	Category	Typical Applications
Infrasound	< 20 Hz	> 17.2 m	Sub-audible	Seismic exploration, structural monitoring, detecting volcanic or tectonic activity
Low Frequency	20 Hz – 1 kHz	17.2 m – 0.34 m	Audible (lower end)	Sonic logging, wellbore fracture detection, geophysical surveying
Mid Frequency	1 kHz – 20 kHz	0.34 m – 0.017 m	Audible range	Acoustic telemetry in mud, borehole imaging, formation evaluation
Ultrasound	20 kHz – 1 MHz	17 mm – 0.34 mm	Ultrasonic	Ultrasonic telemetry, non-destructive testing, casing inspection, fluid flow monitoring
High Ultrasound	1 MHz – 10 MHz	0.34 mm – 34 μ m	High-frequency ultrasonic	High-resolution imaging (e.g., cement bond logs), detailed pipe and casing inspection
Hypersound	>10 MHz	< 34 μ m	Hypersonic	Lab-based nano-imaging, specialized instrumentation (rare in downhole use)

Table 4 : List of electromagnetic frequencies, wavelengths, and their applications [33]

Formulas Used in Acoustic Telemetry :

Used to calculate wavelengths of acoustic telemetry signals for given frequencies, critical for signal design and sensor placement [33].

$$\lambda = \frac{f}{v}$$

Where:

λ : Wavelength (meters)

v : Speed of sound in the medium (m/s)

f : Frequency (Hz)

The propagation of acoustic waves along a drill string is modeled by the one-dimensional wave equation [33] :

$$\frac{\partial^2 u(x, t)}{\partial t^2} = c^2 \frac{\partial^2 u(x, t)}{\partial x^2}$$

Where :

$u(x, t)$: Displacement or pressure wave at position x and time t

c : Speed of sound in the medium (e.g., steel pipe, ~5000 m/s)

This equation determines the wave velocity in solids and is essential for estimating wavelengths and travel time in telemetry systems [34] :

$$c = \sqrt{\frac{E}{\rho}}$$

Where :

c : Speed of longitudinal waves in steel (m/s)

E : Young's modulus of the drill pipe material (Pa)

ρ : Density of the material (kg/m^3)

Attenuation of acoustic signal describes signal loss with distance, vital for telemetry system design [33].

$$A(x) = A_0 e^{-\alpha x}$$

Where :

$A(x)$: Amplitude at distance x

A_0 : Initial amplitude

α : Attenuation coefficient (depends on frequency, joint friction, mud type, etc.)

Signal to Noise Ratio (SNR) used to assess quality and reliability of acoustic telemetry data and influences selection of carrier frequency and modulation schemes [33] :

$$SNR_{dB} = 10 \log_{10} \left(\frac{P_{signal}}{P_{noise}} \right)$$

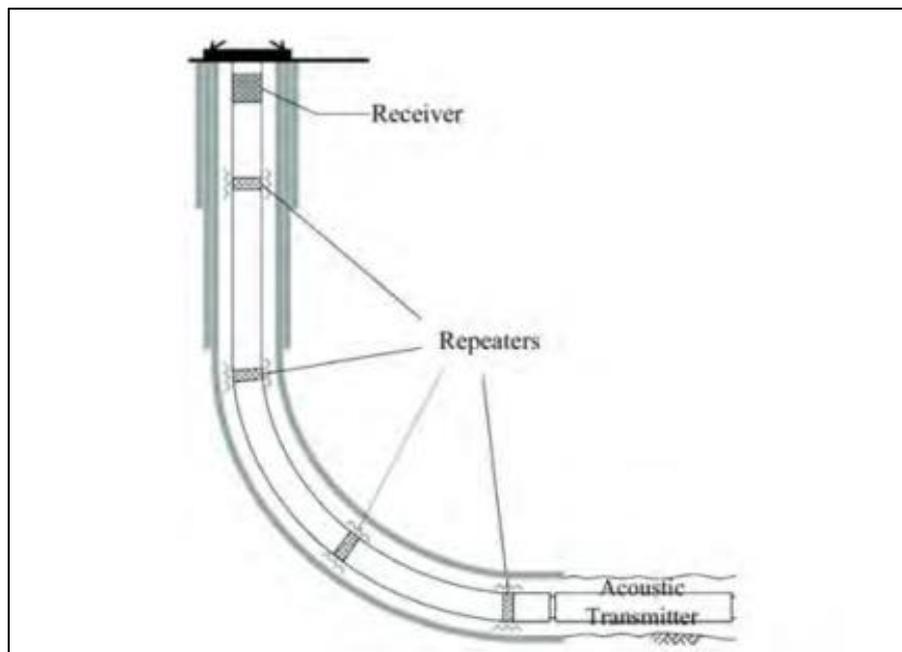


Figure 16 : Acoustic telemetry in wellbore tubulars with repeaters [35]

Component	Function / Role	Details
Downhole Acoustic Transmitter	Converts digital or analog sensor data into acoustic pressure waves in the drill string or mud column	Typically a piezoelectric or magnetostrictive transducer. Encodes data via modulation (e.g., FSK, PSK).
Drill String (Waveguide)	Acts as the medium through which acoustic waves travel from the downhole tool to the surface	Steel drill pipes conduct acoustic signals; propagation influenced by length, joints, damping, and geometry
Sensors (MWD/LWD tools)	Measure downhole parameters (e.g., pressure, temperature, gamma ray, resistivity)	Mounted in the bottom-hole assembly (BHA); send data to telemetry unit
Coupling Unit	Ensures efficient transfer of acoustic energy between transducer and drill pipe	Mechanical interface designed to minimize energy loss
Surface Receiver / Transducer	Detects acoustic waves arriving from the downhole tool and converts them back into electrical signals	Typically mounted on the top drive or drill pipe at surface; high sensitivity is required
Signal Processing Unit	Amplifies, filters, and demodulates the received signal; extracts the original data	Employs digital signal processing (DSP); removes noise and distortion
Power Supply	Provides energy for the downhole telemetry tool and transducer	Battery or turbine-generator-based in downhole environments
Control and Communication Unit	Manages data encoding, telemetry timing, signal triggering, and system health	Coordinates between sensors and transmitter; applies error-checking algorithms

Table 5 : Components of an Acoustic Telemetry System (used in Oil Wells) [33]

Feature	Mud Pulse Telemetry (MPT)	Electromagnetic Telemetry (EMT)	Acoustic Telemetry (AT)
Transmission Medium	Drilling mud (fluid column in the drill string)	Formation and surface through electromagnetic waves	Drill string (solid steel pipes as waveguides)
Signal Type	Pressure pulses (positive, negative, or continuous waves)	Low-frequency EM waves	Mechanical/acoustic waves (vibrations)
Typical Data Rate	1–12 bits per second	0.5–3 bits per second	10–100 bits per second (can reach 1000+ bps in ideal conditions)
Depth Limitations	Up to 35,000 ft (~10,500 m)	Generally < 10,000 ft (3,000 m), signal weakens with depth and resistive formations	Can exceed 20,000 ft (6,000 m), depends on attenuation and signal processing
Suitability in HPHT Wells	Very good	Limited, EM signals attenuate significantly in conductive formations	Good (quartz and robust sensors can withstand HPHT)
Power Consumption	Moderate	Low to moderate	Moderate to high
Latency	Moderate	Low (good for real-time alerts)	Low (due to high-speed data transmission)
Interference Sensitivity	Affected by mud properties and pump noise	Affected by formation resistivity, steel casing	Affected by pipe geometry, tool joints, mud motor noise
Surface Detection Equipment	Pressure transducers and signal decoders	Surface EM antenna and receiver	Vibration or strain sensors, acoustic pickups on the top drive
Environmental Limitations	Requires circulating mud	Poor performance in saline water and highly resistive formations	Performance can degrade in complex geometries and noisy environments
Tool Complexity and Cost	Mature and cost-effective	Moderate cost	High cost, complex signal processing
Advantages	- Reliable and mature- Deep well capability- Well-supported by industry	- Fast surface response- Good for underbalanced drilling (UBD) and low-flow	- High data rates- Real-time transmission potential- Works without mud flow
Disadvantages	- Lower data rate- Requires mud flow- Susceptible to pump noise	- Limited depth- Signal attenuation- Formation-dependent	- Complex design- Sensitive to drilling noise- Signal loss at tool joints

Table 6 : Comparison of Mud Pulse, Electromagnetic, and Acoustic Telemetry Systems [33] [36] [37] [38].

Use Case	Best Telemetry Type	Reason
Deep wells (>10,000 ft)	Mud Pulse or Acoustic	MPT is mature; AT has better data rate at depth
Underbalanced or air drilling	Electromagnetic	Does not require mud column
High-speed data needs (e.g., imaging)	Acoustic Telemetry	Can support higher bit rates
High noise environments (e.g., motors)	Mud Pulse or EM (with filtering)	AT may suffer from signal interference
High pressure/high temperature (HPHT)	Quartz-based Acoustic or Mud Pulse	Ruggedness and thermal tolerance needed

Table 7 : Use case suitability for each telemetry type [33] [36] [37] [38].

2. The main devices used in oil well monitoring

Oil well monitoring is essential for ensuring efficient production, reservoir management, safety, and equipment integrity. To achieve these goals, a wide range of sophisticated downhole and surface devices are deployed to collect, transmit, and analyze real-time data from within the wellbore and surrounding formation. These devices provide critical insights into pressure, temperature, flow rate, fluid composition, and mechanical integrity, enabling informed decision-making throughout the well’s lifecycle—from drilling and completion to production and abandonment. We will be taking a deeper look on two of the major leading gauges in the industry, **WiMo™** and **SonicGauge™**.

2.1. WiMo™ Gauges :

The WiMo™ (Wireless Monitoring) gauge is an advanced downhole monitoring system designed for real-time measurement of pressure and temperature in oil and gas wells. Unlike traditional gauges that rely on physical wiring, the WiMo gauge employs electromagnetic (EM) telemetry to transmit data wirelessly to the surface. This makes it especially useful in environments where conventional cable deployment is impractical or cost-prohibitive. The EM telemetry system allows the gauge to send data through the formation or along the casing to a surface receiver, even in challenging well conditions. This capability significantly enhances well diagnostics, artificial lift optimization, and reservoir management by providing continuous, real-time data without the need for intervention. The WiMo system also supports long-term deployments due to its energy-efficient design and robust construction, making it suitable for both new wells and brownfield retrofits. WiMo™ is optimized for simple, low-intervention installations, particularly where cabling is impractical. It’s best suited for shallow to mid-depth wells with good EM propagation conditions.

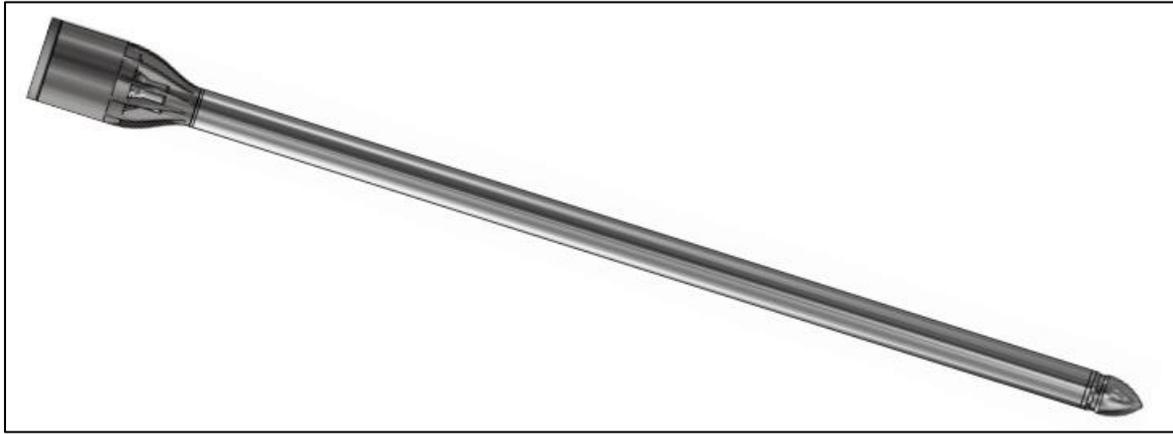


Figure 17 : WiMo™ Wireless Monitoring System attached to Halliburton Otis X® Lock Mandrelrepeaters [39].

WiMo™ for production or injection monitoring enables rig-less and retrofit installation of single or multiple downhole gauges, seamlessly connecting the reservoir with the operator’s downhole dashboard. WiMo™ for well testing enables real-time pressure, temperature, and flow rate data to be reviewed and monitored during the well test program maximizing the results and reducing the operations time [39].

Gauge Specs :

Pressure Sensor	Range Choices :	5,000, 10,000, or 15,000 psi
	Accuracy :	±0.01% FS
	Resolution :	0.00005% FS
Temperature Sensor	Range Choices :	125°C ²
	Resolution :	0.001°C FS
Flow Sensor	Range Choices :	800–4,000, 1500–7,000, or 2,500–12,500 bpd
	Accuracy :	±2% Full Scale
Telemetry Distance		25,000+ ft
Tool Length and Weight		41.5” / 40 lbs
Tool Upper Thread Interface		TR60x2 (adapters available)
Materials		Inconel 718 / MP35N – NACE MR0175 / ISO 15156 Compliant
Pressure and Temperature sensor from Quartzdyne® 150°C version will be available soon		

Table 7 : Specifications table of the WiMo™ gauge [39]

Applications:

- Addition of real time measurements to any standard well.

- Repair of failed permanent downhole gauges.
- Drill stem testing supplement.
- Draw Down and Pressure Build Up (PBU) testing in production wells.
- Constant Injection and Pressure Fall Off (PFO) testing in injection wells.
- Productivity Index (PI) or Inflow Performance Relationship (IPR) curve generation.
- Interference testing between wells.
- Use of Deconvolution yields better reservoir insight, avoids long PBU tests.

References : <https://www.wins.no/cms/wp-content/uploads/2022/10/Wimo2-Datasheet-29SEP22.pdf>

Features and Benefits:

- World's first practical, wireless production monitoring system.
- Turbine-Generator ensures unlimited power.
- Wireless telemetry uses pressure perturbations created with the generator, therefore no repeaters (relay stations) are required.
- Pressure, temperature, and flow rate are measured
- When no flow available, onboard batteries record data for up to 3 months. Data is transmitted once flow resumes.
- Solar powered surface system relays data gathered from wimo wellhead sensors anywhere, instantly.
- Configured for fast supply and deployment. In most cases, only a wireline adapter is needed.
- Inconel 718 construction is suitable for a wide range of well environments.

References : <https://www.wins.no/cms/wp-content/uploads/2022/10/Wimo2-Datasheet-29SEP22.pdf>

WiMo™ gauge represents a significant advancement in downhole monitoring technology, particularly for oil and gas well applications requiring reliable, real-time data transmission. Its use of electromagnetic telemetry eliminates the need for traditional cabling, reducing installation complexity and improving deployment flexibility in both new and mature wells. Key features such as real-time pressure and temperature monitoring, long battery life, and robust performance in high-pressure/high-temperature (HPHT) environments make it a powerful tool for optimizing production, enhancing reservoir management, and enabling predictive maintenance strategies. The wireless nature of the WiMo™ system not only

simplifies well interventions but also reduces operational risks and long-term costs. As digital oilfield initiatives continue to evolve, technologies like the WiMo™ gauge are essential in supporting data-driven decision-making and improving overall field efficiency [40] [41] [42].

2.2. SonicGauge™

The SonicGauge™ Wireless Monitoring System is a state-of-the-art, real-time downhole data acquisition technology designed for seamless, plug-and-play deployment. It provides operators with real-time downhole pressure and temperature data for well-testing campaigns and long-term monitoring across the entire well lifecycle. The system delivers continuous data streaming during the production, injection, and observation (no-flow) phases [44].

The SonicGauge™ system uses an acoustic telemetry protocol based on low-frequency pressure pulses transmitted through the tubing or annulus, enabling high-speed communication without the need for wired infrastructure. This makes it particularly valuable for complex well configurations, including multi-zone completions, deepwater wells, and unconventional reservoirs where cable deployment is impractical or impossible. The system integrates high-accuracy quartz pressure and temperature gauges, capable of operating in extreme HPHT conditions—up to 25,000 psi and 260°C—while offering data rates that significantly exceed those of traditional electromagnetic or mud-pulse systems [43] [44].

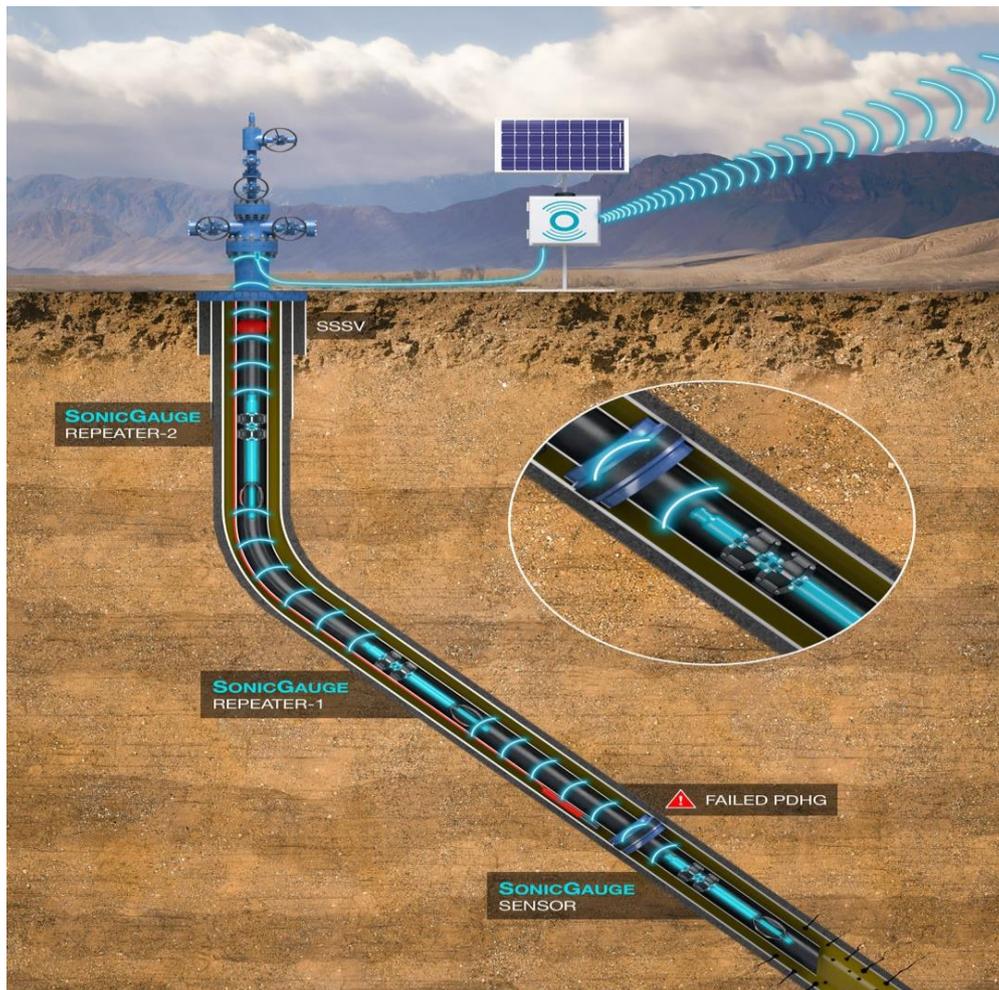


Figure 18 : SonicGauge™ system with repeaters and surface detection system [45].



Figure 19 : SonicGauge™ as seen in the wellbore [45].

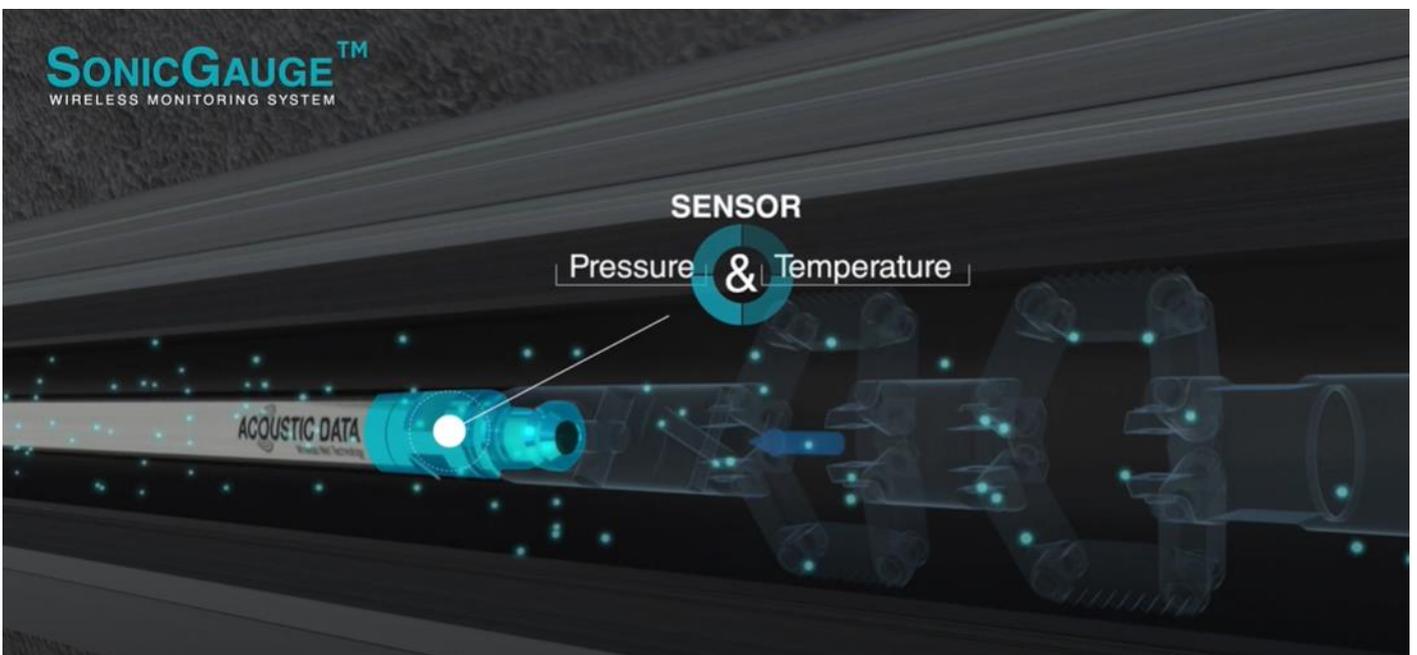


Figure 20 : SonicGauge™ Pressure and Temperature sensor placement [45].

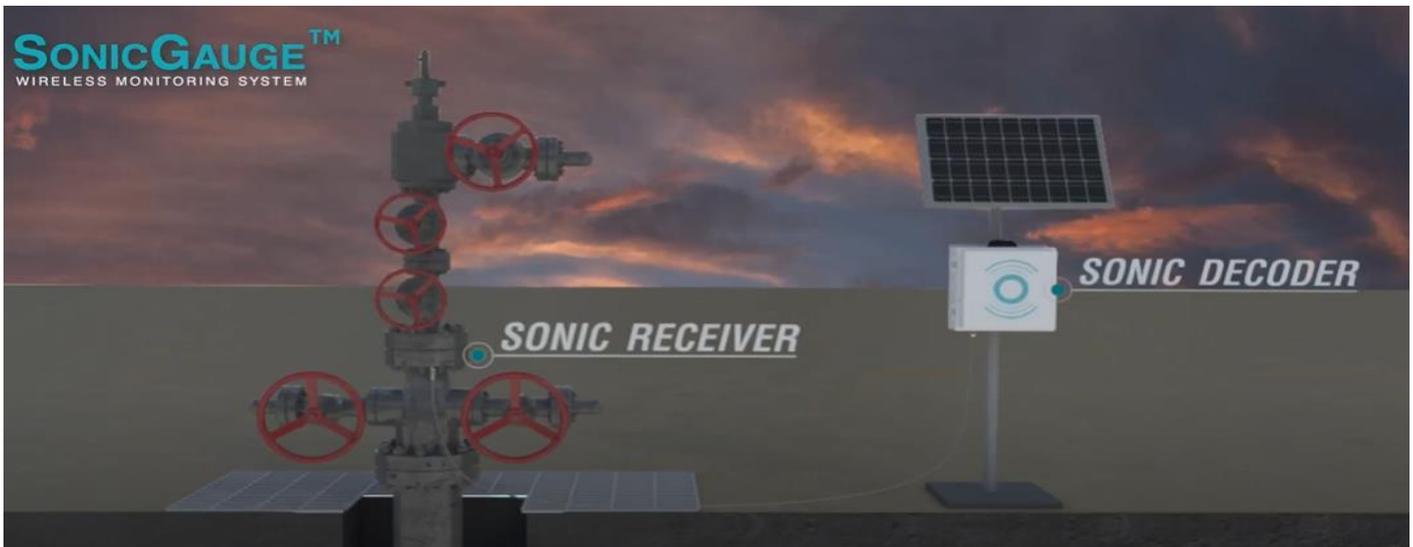


Figure 21 : Sonic Surface detection system (Sonic Receiver and Sonic Decoder) [45].

SonicGauge™ sensors and SonicRepeater stations can be easily attached to the outside of the well tubing or installed inside the tubing using tools like slickline or e-line, even in pipe sizes ranging from 2-3/8 inches to 9-5/8 inches. They use a special tool called the Barracuda™ HEX-Hanger™ to hold them in place. This tool is small (only 1.31 inches wide) and doesn't block the flow of fluids much it causes less than 3 psi of pressure drop and it doesn't need any special fittings in the pipe to work. The SonicGauge™ Data Logger is the device that collects and stores data from the sensors. It picks up acoustic (sound-based) signals that are sent wirelessly from down in the well. It uses a special vibration sensor (accelerometer) that sticks to the outside of the wellhead using magnets so there's no need to drill or modify the wellhead. This data logger can be placed in various spots, like control rooms or automated monitoring units, and it can even run on solar power. From anywhere, field operators can view live data from the well using communication systems like Modbus, Ethernet, 3G/4G, LoRaWAN, or Satellite. This setup provides a complete remote monitoring solution, allowing better decisions without needing to be physically at the wellsite [45].

Specification	Details
Sampling Rate	From 1 Second to Hourly Data
Battery Life	Up to 8 Years (Incl. 20% Safety Factor)
Communication Type	Two-Way Mesh Network (Controlled by SonicSync™)
Transmission Distance	Unlimited with SonicRepeaters (Providing Gradient Data)
Downhole Sensor	Piezo Quartz (Incl. Multi-Sensor Configuration)
Temperature Rating (Max.)	150°C (302°F)

Pressure Rating Options (Max.)	10,000 15,000 25,000 psi
SonicGauge™ Dimensions	L: 1300–1800 mm (51.2–70.9") OD: 33.4 mm (1.31")

Table 8 : Specifications table of the SonicGauge™ [45].

Comparative Analysis between WiMo™ gauge and SonicGauge™

Feature/Aspect	SonicGauge	WiMo Gauge
Technology Used	Ultrasonic measurement	Capacitive or resistive measurement
Measurement Accuracy	High ($\pm 1\%$ of full scale)	Medium to High ($\pm 2-3\%$ depending on model)
Response Time	Fast (real-time or near real-time updates)	Moderate (some delay in updates)
Power Consumption	Low	Moderate to high depending on configuration
Connectivity	Bluetooth, Wi-Fi, sometimes LoRa	Wi-Fi, NB-IoT, and GSM options
Data Logging	Yes (cloud-based or local depending on setup)	Yes (often includes SIM/cloud service)
Installation	Easy (non-invasive, external mounting)	Moderate (may require tank modifications)
Durability	High (IP67 rated, no contact with fluid)	Varies (depends on model; some are submersible)
Maintenance	Minimal (no contact with fluid means less wear)	Periodic checks needed (especially submerged)
Price Range	Medium to High	Low to Medium
Use Case Suitability	Ideal for industrial tanks, fuel, water systems	Suitable for home tanks, agriculture, smart homes
Battery Life	Long (months to years)	Shorter, often depends on update frequency

Table 9 : Comparaison between the two gauges in specs.

The SonicGauge stands out in applications where high accuracy, minimal maintenance, and remote monitoring are essential. Its ultrasonic technology allows for non-invasive measurements, making it ideal for industries handling hazardous or sensitive fluids. Additionally, the low power consumption and wireless connectivity make it a strong candidate for IoT-enabled monitoring systems. On the other hand, the WiMo Gauge is a more cost-effective option, better suited for less demanding environments such as home water tanks, agriculture, or simple smart home integrations. While it may not match the SonicGauge in terms of precision or ease of installation, it compensates with its flexibility in connectivity and lower initial cost. In summary, the SonicGauge is ideal for high-performance and professional use, whereas the WiMo Gauge is better for budget-conscious users in less critical applications.

CONCLUSION

In this chapter, we took a closer look at how wireless telemetry systems are used to monitor fluid levels, focusing on two specific devices: the WiMo Gauge and the SonicGauge. Although both tools aim to solve the same problem measuring and transmitting tank levels remotely they approach it in different ways. The SonicGauge relies on ultrasonic technology, while the WiMo uses capacitive or resistive methods.

Our comparison showed that the SonicGauge performs better in terms of accuracy, durability, and low maintenance, which makes it a great fit for industrial or more critical environments. On the other hand, the WiMo stands out for its affordability and simpler setup, making it a smart choice for everyday applications like home tanks or small farms.

What this really shows is that there's no one-size-fits-all solution. Choosing the right telemetry system depends on what you need it to do, how often you want to maintain it, and how much you're willing to invest. Both devices represent the growing move toward smarter, more connected monitoring systems and each has its place, depending on the situation.

This comparison helps paint a clearer picture of how wireless telemetry is evolving and where it's heading in the future.

Chapitre 3

System Simulation using Matlab

INTRODUCTION

This chapter presents a simulation of the Sonic Telemetry technique using MATLAB. It begins with an overview of the simulation process, including how the data is generated, processed, and transmitted. The results obtained from the simulation are then analyzed to assess the performance and effectiveness of the technique. Additionally, the limitations encountered during the simulation are discussed, and several suggestions for future improvements and enhancements are proposed.

1. Explanation of the proposed Model

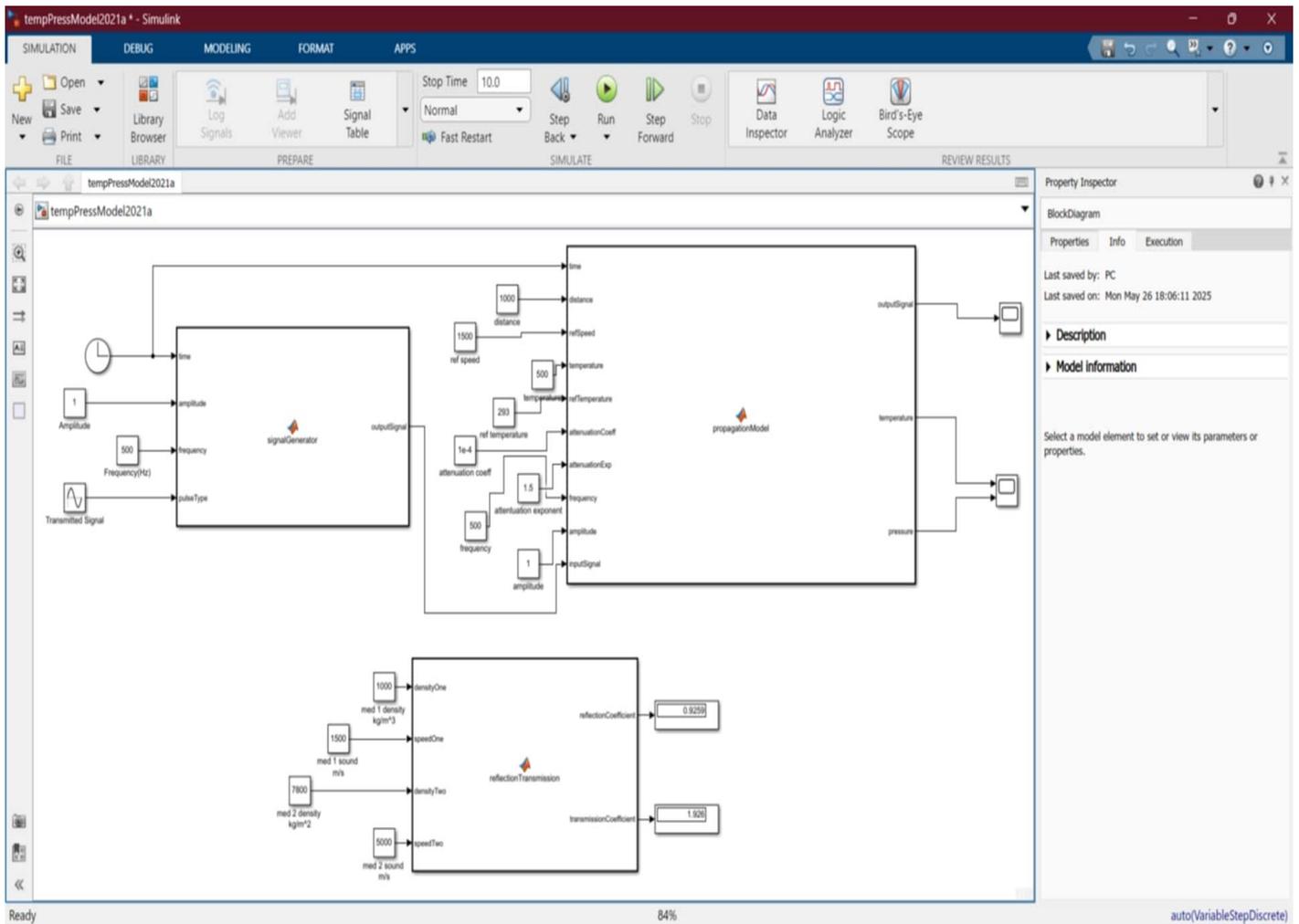


Figure 22 : System Simulink Model

```
Block: tempPressModel2021a/MATLAB Function1

EDITOR VIEW
New Open Save Find Files Compare Print FILE
Go To Find NAVIGATE
Insert Comment Indent EDIT
Breakpoints Run Model Stop Model Build Model SIMULINK
BREAKPOINTS RUN

1 function [outputSignal, temperature, pressure] = propagationModel(time, distance, refSpeed, temper
2
3     speed = refSpeed * sqrt(temperature / refTemperature);
4     timeDelay = distance / speed;
5     attenuation = attenuationCoeff * frequency^attenuationExp;
6     amplitudeDecay = exp(-attenuation * distance);
7
8
9     delayedTime = time - timeDelay;
10    timeStep = 1 / (frequency * 10); % 10 times of it
11    delayedIndex = round(delayedTime / timeStep);
12
13
14    outputSignal = zeros(size(inputSignal));
15    validIndices = delayedIndex > 0 & delayedIndex <= length(inputSignal);
16    outputSignal(validIndices) = amplitude*amplitudeDecay * inputSignal(delayedIndex(validIndices));
17
18    temperature = 300 + 5 * sin(2 * pi * time / 86400);
19    pressure = 101325 - 500 * sin(2 * pi * time / 43200);
20
21 end
22
23

Ready Ln 1 Col 1
```

Figure 23 : Propagation and attenuation Formulas.

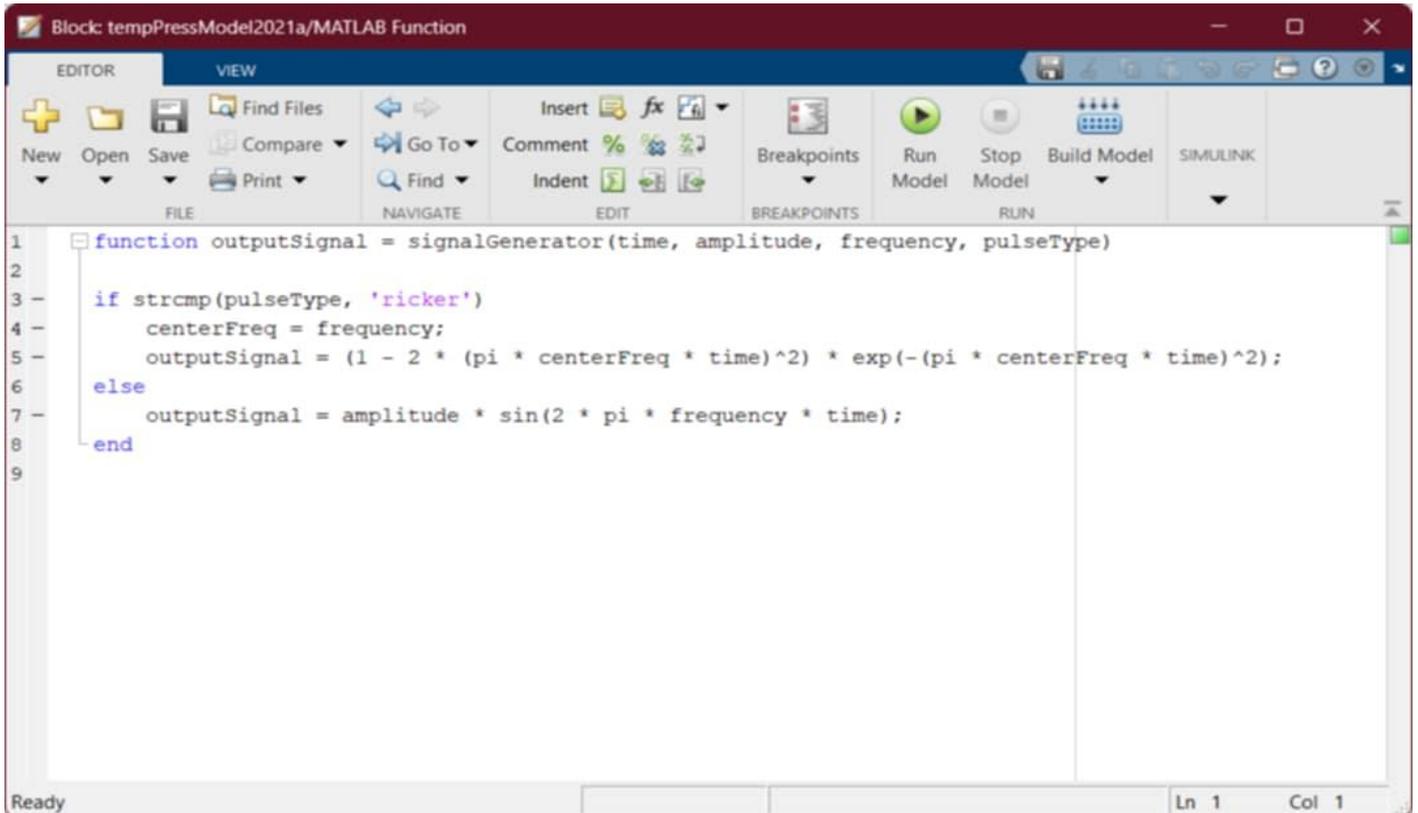
```
Block: tempPressModel2021a/MATLAB Function2

EDITOR VIEW
New Open Save Find Files Compare Print FILE
Go To Find NAVIGATE
Insert Comment Indent EDIT
Breakpoints Run Model Stop Model Build Model SIMULINK
BREAKPOINTS RUN

1 function [reflectionCoefficient, transmissionCoefficient] = reflectionTransmission(densityOne, speed
2
3     impedanceOne = densityOne * speedOne;
4     impedanceTwo = densityTwo * speedTwo;
5     transmissionCoefficient = (2 * impedanceTwo) / (impedanceOne + impedanceTwo);
6     reflectionCoefficient = (impedanceTwo - impedanceOne) / (impedanceOne + impedanceTwo);
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

Ready Ln 1 Col 1
```

Figure 24 : Reflection,Transmission coefficient Formulas.

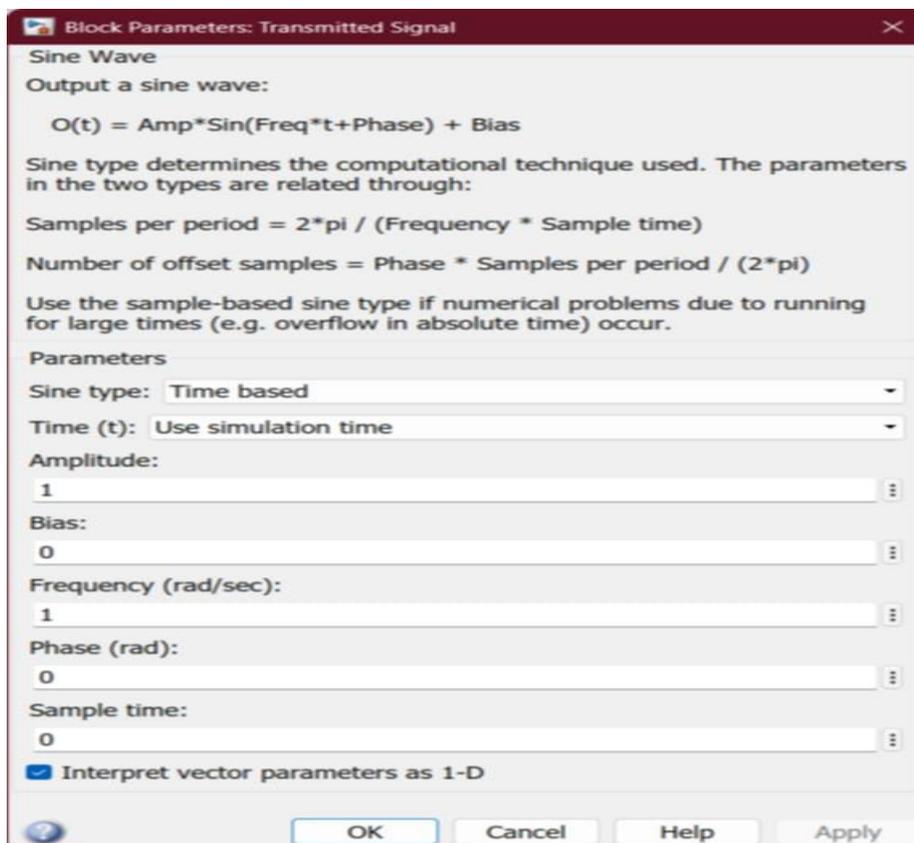


The image shows a MATLAB Function Editor window titled "Block: tempPressModel2021a/MATLAB Function". The editor contains the following MATLAB code:

```
1 function outputSignal = signalGenerator(time, amplitude, frequency, pulseType)
2
3 if strcmp(pulseType, 'ricker')
4     centerFreq = frequency;
5     outputSignal = (1 - 2 * (pi * centerFreq * time)^2) * exp(-(pi * centerFreq * time)^2);
6 else
7     outputSignal = amplitude * sin(2 * pi * frequency * time);
8 end
9
```

The status bar at the bottom indicates "Ready" and "Ln 1 Col 1".

Figure 25 : Sending and receiving signal amplitude.



The image shows the "Block Parameters: Transmitted Signal" dialog box. It contains the following information:

Sine Wave
Output a sine wave:
$$O(t) = \text{Amp} * \text{Sin}(\text{Freq} * t + \text{Phase}) + \text{Bias}$$

Sine type determines the computational technique used. The parameters in the two types are related through:
Samples per period = $2 * \pi / (\text{Frequency} * \text{Sample time})$
Number of offset samples = $\text{Phase} * \text{Samples per period} / (2 * \pi)$

Use the sample-based sine type if numerical problems due to running for large times (e.g. overflow in absolute time) occur.

Parameters

Sine type: Time based
Time (t): Use simulation time
Amplitude: 1
Bias: 0
Frequency (rad/sec): 1
Phase (rad): 0
Sample time: 0

Interpret vector parameters as 1-D

Buttons: OK, Cancel, Help, Apply

Figure 26 : Transmitted Signal Parameters.

2. Results Discussion

3. Improved Model Suggestions

CONCLUSION

This chapter presented the simulation results of the SonicGauge system, focusing on its performance under various operational conditions. Through simulated scenarios, we were able to assess its accuracy, response time, signal stability, and sensitivity to environmental factors such as temperature, humidity, and tank geometry.

The results confirmed that the SonicGauge performs reliably in most standard use cases, particularly in environments where non-contact measurement is essential. Its ultrasonic sensing technology proved to be both precise and consistent, with minimal deviation across different test conditions. The simulations also highlighted its strength in low-maintenance, long-range applications, especially where safety or contamination concerns limit direct contact with the fluid.

However, certain limitations were observed. For instance, the performance slightly declined in tanks with irregular internal structures, which can cause signal reflections or distortions. Similarly, very high humidity or temperature extremes introduced small, yet measurable, delays in response time.

Overall, the simulation validated the SonicGauge's core advantages—accuracy, robustness, and remote operability—while also pointing out key areas for optimization. These insights not only support its suitability for industrial and environmental monitoring applications but also provide a foundation for future design improvements and more targeted field testing.

GENERAL CONCLUSION

This thesis has examined the current state and future potential of telemetry systems in the Algerian oil industry, highlighting how both traditional and modern technologies can be leveraged to improve operational efficiency, safety, and decision-making.

Chapter 1 provided an overview of the oil sector in Algeria, emphasizing its central role in the national economy and the operational challenges it faces—many of which can be addressed through better monitoring and data management systems. This context highlighted the urgent need for adopting smarter, more efficient technologies in the field.

In Chapter 2, we explored key telemetry systems used in downhole operations: EM telemetry, acoustic telemetry, and mud pulse telemetry. Each method was analyzed in terms of technical performance, limitations, and suitability for different field conditions. Additionally, we evaluated two surface-level monitoring devices—SonicGauge and WiMo. Through comparative analysis, we identified the SonicGauge as more suitable for industrial use due to its higher accuracy and low-maintenance design, while the WiMo gauge offers a more affordable solution for less demanding applications. These comparisons underscored the importance of selecting technologies that align with operational and environmental needs.

Chapter 3 presented a simulation of the SonicGauge using MATLAB. This model tested the system's behavior under varying conditions, such as tank geometry, fluid levels, and signal interference. The results validated the SonicGauge's robustness and reliability but also revealed areas where performance may be affected by physical design constraints or environmental noise. The simulation confirmed that such tools are valuable for pre-deployment evaluation and design optimization.

Moreover, this thesis emphasized the growing importance of **emerging digital technologies** such as the **Internet of Things (IoT)** and **edge computing**. These innovations are transforming the oil industry by enabling real-time data collection, on-site analytics, and autonomous system responses. When integrated with telemetry systems like SonicGauge or WiMo, IoT and edge computing can drastically reduce latency, improve decision-making, and minimize operational disruptions—even in remote or high-risk environments.

In summary, this work demonstrates that the integration of advanced telemetry systems—combined with IoT and edge computing—can significantly enhance the oil industry's ability to monitor, analyze, and respond to field data in real time. For Algeria, adopting these solutions represents a strategic move toward smarter resource management and greater technological independence. Future research could expand on this foundation by incorporating field testing, multi-sensor integration, and AI-based data analysis for predictive maintenance and optimization.

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