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Comprehensive Redesign of the Low-Cost DR-74 Instrument for Soil Evaluation Through the Measurement of Electrical Parameters

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***Abstract*– This research addresses the diagnosis and redesign of the resistivity system in DR-74 well logging equipment, an analog instrument designed to record shallow vertical wells through spontaneous potential, normal, and lateral curves. This instrument has presented failures that prevent its correct operation. A redesign was proposed to increase its precision without altering the measurement principle, based on a digital data acquisition system using Arduino and signal conditioning through an instrumentation amplifier. From the theoretical analysis of the four-electrode resistivity system and the review of field records, it was determined that the failures are mainly due to the degradation of the power supply, the contacts, and the variation of the reference resistances due to aging. Due to this redesign, the stability of the current is improved, preserving the original architecture, which will allow extending the useful life of the DR-74.**

***Keywords*– Equipment diagnostics, DR-74 device, electrical measurement, well logging, soil resistivity.**

I. Introduction

The measurement of soil electrical resistivity is a fundamental procedure in hydrogeological and electrical studies, as it allows the estimation of subsurface properties related to its conductivity, groundwater quality, and the feasibility of grounding systems. Among the equipment developed for this purpose is the Geotech Borehole Resistivity System (DR-74), a device designed to record shallow vertical wells through spontaneous potential, normal, and lateral curves. This system has been used for decades in the characterization of geological formations; however, its analog design and prolonged exposure to adverse environmental conditions have caused degradation in its electronic and mechanical components. The present work aims to analyze the current condition of the DR-74 meter, identify the factors that affect its performance, and develop a proposal for electronic and structural redesign that allows extending its useful life and maintaining the required accuracy in resistivity measurements. In this way, it seeks to contribute to the modernization of geotechnical logging instruments, promoting technical solutions that optimize their operation without altering their physics and operation.

II. Methodology

The methodology of this research was designed to diagnose failures and improve the operation of the DR-74 borehole resistivity meter, through the technical analysis of the internal components of the equipment and the proposal of an electronic redesign.

The adopted approach was mainly quantitative, using experimental measurements and field diagnostic tests to identify failures in components such as the power supply, standard resistances, and mechanical contacts. In addition, it was complemented with a qualitative analysis, evaluating the feasibility of the redesign through simulations and analysis of results. Advanced measurement tools such as the multimeter and the ohmmeter were used, as well as an Arduino system for data acquisition. [1].

A. Equipment Description

For field data collection, a set of equipment specialized in soil resistivity measurement was used. The system included:

TABLE I
TECHNICAL EQUIPMENT

Equipment	Model	Operating Range	Function	Connection
Resistivity Meter	DR-74	0 – 10000 Ω·m	Measures soil resistivity in boreholes	Probe connector
Current Generator	Integrated (DR-74)	0–1 mA	Injects current into the soil	Internal connector
Reference Resistance	Integrated (DR-74)	According to specs.	Compares the voltage drop to calculate resistivity	Internal connector
Voltage Amplifier	Integrated (DR-74)	–	Amplifies the voltage signal	Internal connector
Voltage Meter	Integrated (DR-74)	9V	Measures the reference voltage	Input connector
Power Supply	Integrated (DR-74)	45V DC	Supplies power to the system	Power connector
Measurement Probes	Integrated	–	Capture voltage and allow calculation of soil resistivity	Probe connector

The DR-74 is an analog meter used to evaluate soil resistivity in boreholes, which allows observing the variation of the electrical behavior of the subsurface. To perform these measurements, the equipment uses a probe with electrodes placed vertically. The operation of the DR-74 is based on a resistivity bridge; an internal generator injects current into the ground, while a set of reference resistances allows comparing the voltage drop captured by the probe. With this comparison, the apparent resistivity of the subsurface formations can be estimated.

Fig. 1 DR-74 Meter.

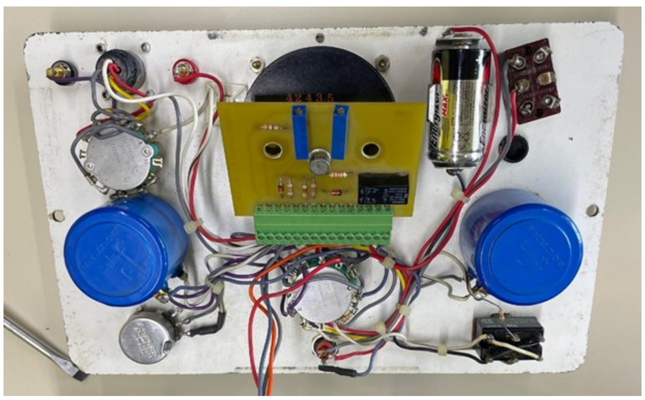

Fig. 2. Meter Internal Circuit.

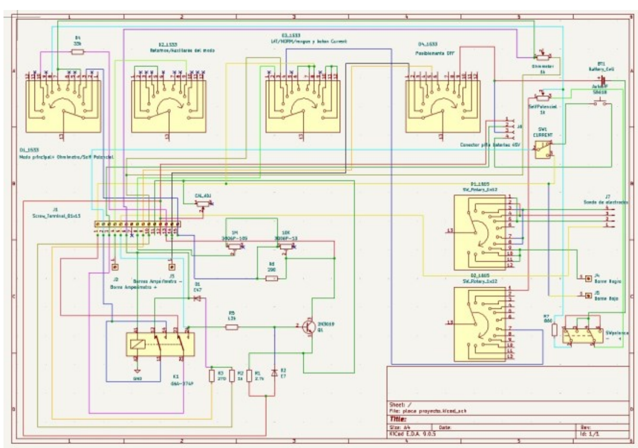

Fig. 3. Original Circuit of the DR-74 Meter in KiCad. This diagram is the result of an inspection of the device verifying its current state.

B. Study Area and Measurement Procedure

The study was carried out both in the laboratory of the Universidad Nacional Autónoma de Honduras (UNAH) and in field tests in Santa Ana, Francisco Morazán, Honduras. This area was selected due to its importance in geotechnical studies and the complexity of its structure, factors that directly influence the behavior of soil resistivity.

To obtain reliable results, a measurement scheme was applied based on the insertion of probes at different points within the borehole, following the established procedure for field tests. The study area was organized into segments, where each point represents a specific measurement, which allowed observing the variations in resistivity in an orderly and comparative manner.

During the tests, multiple measurements were taken at different depths, using the standard ranges of the DR-74 meter. This allowed a more precise evaluation of the electrical properties of the subsurface and its conduction capacity.

TABLE II
LABORATORY MEASUREMENTS

Ohmmeter Position	Multiplier	Voltage Measurement (4-digit meter)	Conventional Multimeter
0	0	2.3121	2.52
50	0	2.4656	2.44
0	1	2.5869	2.45
50	1	1.6636	2.42
0	2	1.9691	2.40
50	2	0.8166	2.44
0	3	1.5652	2.62
50	3	1.4803	1.54
0	4	1.5877	2.68
50	4	2.0033	2.49
0	5	2.1620	2.55
50	5	2.0574	2.46
0	6	2.1264	2.61
50	6	2.1882	2.49
0	7	2.1350	2.56
50	7	2.2202	2.57
0	8	2.5835	2.61
50	8	2.8379	2.63
0	9	2.6132	2.69
50	9	2.3335	2.87
0	10	3.2251	2.91
50	10	3.2714	2.92

In electrical engineering, soil resistivity is fundamental for the design of grounding systems and for electrical safety studies, since it determines the capacity of the ground to dissipate fault currents. [2].

A low resistivity indicates good conductivity, while high values represent dry, rocky, or compact soils where current disperses with greater difficulty [3].

TABLE III

SOIL CLASSIFICATION AND RESISTIVITY ANALYSIS

Soil Type	Typical Resistivity (Ω·m)	Characteristics	Reference
Very wet / saturated clay soil	10 – 50	High conductivity	IEEE Std 80-2013 [4]
Normal clay soil	20 – 100	Good conductivity	Martínez, Puestas a Tierra [5]
Moist sandy soil	30 – 150	Medium conductivity	IEC 60479 [6]
Dry sandy soil	200 – 3000	Low conductivity	IEEE Std 81 [7]
Gravel / fractured rock	1000 – 10000	Very low conductivity	McPartland, Grounding [8]

C. Interpretation

The obtained measurements correspond to low voltages between the probes, which according to technical references (IEEE Std 80 and 81) are associated with soils with resistivity below 100 Ω·m. This indicates a high conductivity soil, ideal for grounding wells.

D. Spontaneous Potential (SP)

The spontaneous potential log measures the natural voltage that is generated between the geological formation and a reference electrode, without the need to apply current. [9]. This phenomenon originates mainly due to differences in salinity and permeability between clayey and sandy formations. SP is useful for identifying lithological contacts, permeable zones, and changes in the fluid properties within the borehole [10].

E. Borehole Resistivity Measurement Equipment

Borehole resistivity systems, such as the DR-74, use a current generator and a set of standard resistances to create a measurement bridge that allows comparing the voltage detected by the electrodes with a reference value. The correct operation of the equipment depends on the stability of the current source, the sensitivity of the potential detector, and the accuracy of the internal resistances. Over time, factors such as temperature, humidity, contact corrosion, and component aging can significantly alter the accuracy of the measurements [11].

Modern equipment integrates analog-to-digital conversion, differential amplifiers, and automatic compensation to minimize reading error. However, analog instruments such as the DR-74 require proper maintenance to preserve their original accuracy. The degradation of standard resistances, the variation of the probe conductors, or the loss of sensitivity of the galvanometer can cause errors in the estimation of resistivity [12].

F. Importance of Resistivity for Geological and Electrical Applications

Soil resistivity analysis is widely used in hydrogeology, geotechnics, civil engineering, and mining exploration. It allows identifying aquifer zones, determining water quality, locating fractures in rocks, evaluating ground stability, and supporting structural design decisions. In the electrical field, the precise measurement of soil resistivity is essential for the design of grounding systems, potential rise studies, and safety analysis for power installations [13].

G. Need for the Update of the DR-74

Since the DR-74 is an analog instrument that is several decades old, a process of diagnosis and updating is necessary to guarantee its operability under current conditions. The reliability of the obtained data strictly depends on the stability of the power supply system, the integrity of the mechanical contacts, the nominal value of the internal resistances, and the continuity of the probe wiring. The modernization of critical components allows improving the reproducibility of the measurements and extending the useful life of the instrument without altering its physical principle of operation [14].

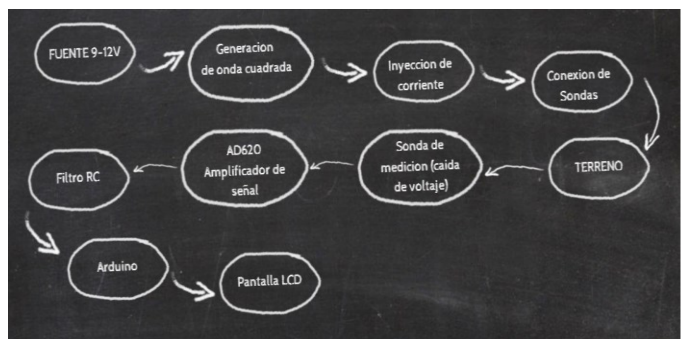

Fig. 4. Implementation Diagram of the Updated Meter

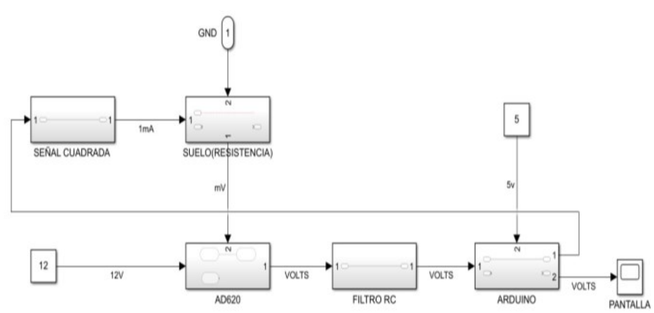

Fig. 5. DR-74 Redesign Flowchart

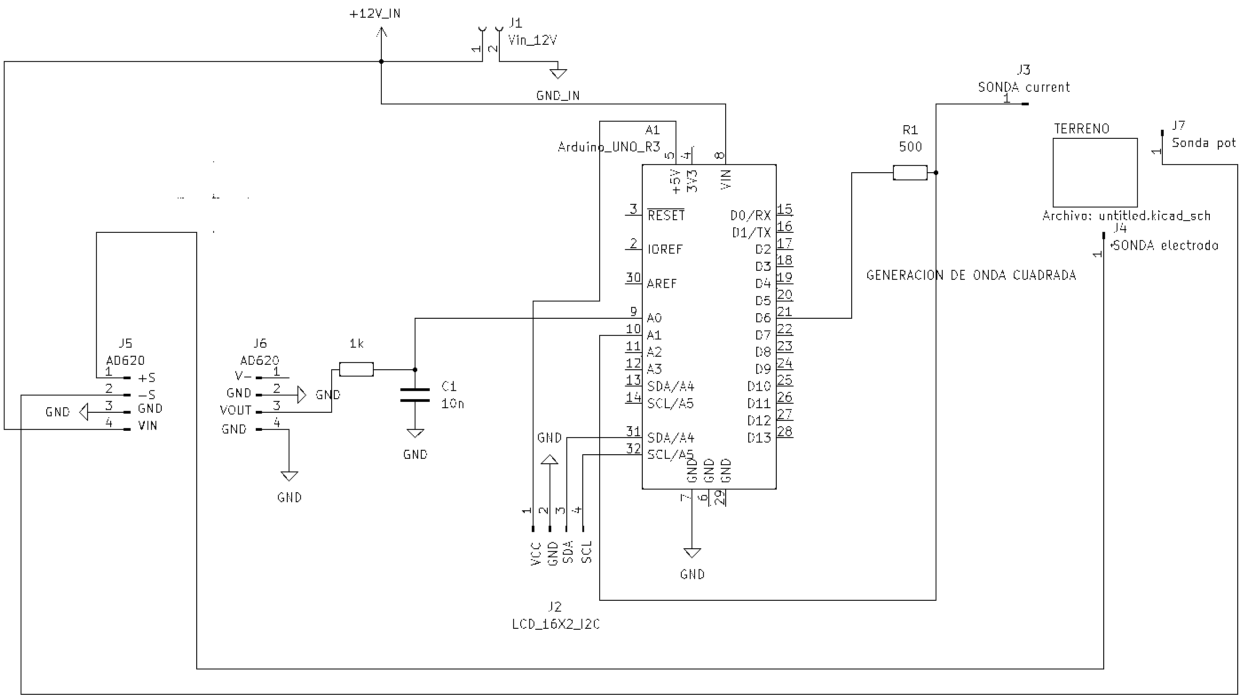

Fig. 6. Proposed Updated DR-74 Circuit

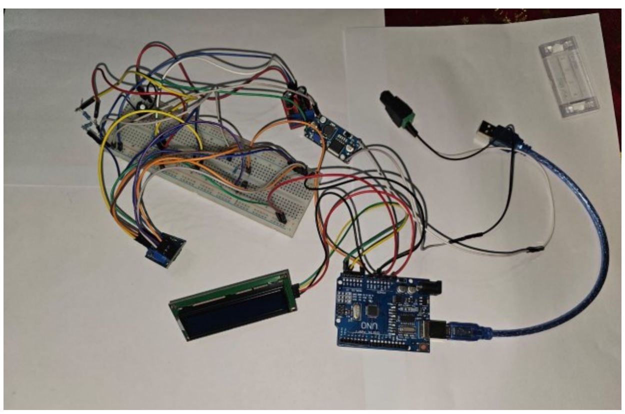

Fig. 7. Prototype Board of the New DR-74 Design

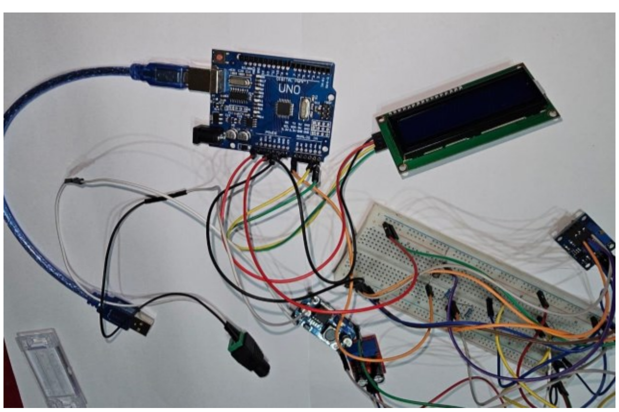

Fig. 8. Breadboard Connected with LCD Display, Arduino UNO, and Modules

III. Analysis of Resistivity Measurements

The data collected during the study were consolidated into a single structured database that includes technical parameters such as borehole depth, measured resistance (Ω), soil type, and geographic location (latitude and longitude). This integration allowed performing a statistical analysis by depth.

TABLE IV
MEASUREMENTS PERFORMED IN A WATER WELL

Ohmmeter Position	Multiplier	Voltage Measurement (Conventional Multimeter)
0	0	1.51
50	0	1.45
0	1	1.36
50	1	1.64
0	2	1.66
50	2	1.73
0	3	1.49
50	3	1.78
0	4	1.86
50	4	2.16
0	5	2.27
50	5	2.02
0	6	1.95
50	6	2.24
0	7	2.25
50	7	2.38
0	8	2.57
50	8	2.81
0	9	3.18
50	9	3.01
0	10	3.17
50	10	3.19

TABLE V
MEASUREMENTS PERFORMED IN A GROUNDING WELL

Ohmmeter Position	Multiplier	Conventional Multimeter
0	0	0.35
50	0	0.33
0	1	0.61
50	1	0.53
0	2	0.71
50	2	0.84
0	3	1.09
50	3	1.14
0	4	1.30
50	4	1.43
0	5	1.61
50	5	1.71
0	6	1.88
50	6	2.00
0	7	2.17
50	7	2.30
0	8	2.40
50	8	2.47
0	9	2.78
50	9	3.15
0	10	3.11
50	10	3.17

A. *Evaluation of mathematical model formulas.*

Injected Current I into the Ground (Shunt) based on the Voltage Across the Shunt V_{sh} and Shunt Resistance R_{sh}.

$$I = \frac{V_{sh}}{R_{sh}} \tag{1}$$

Signal V_m between Potential Electrodes V_{P1} and V_{P2}

$$V_m = V_{P1} - V_{P2} \tag{2}$$

Output V_{amp} of the Instrumentation Amplifier with gain G

$$V_{amp} = G \cdot V_m \tag{3}$$

AD620 configurated gain G based on resistance R_G

$$G = 1 + 49.4\,k\Omega / R_G \tag{4}$$

Voltage V_{adc} in V Read by the ADC in ADC_{lect} (bits)

$$V_{adc} = ADC_{lect} \cdot V_{ref} / 1023 \tag{5}$$

Actual Voltage Before the Amplifier

$$V_m = V_{adc} / G \tag{6}$$

Voltage Across the Shunt

$$V_{sh} = ADC_{sh} \cdot V_{ref} / 1023 \tag{7}$$

Measured Resistance

$$R = V_m / I \tag{8}$$

Resistivity (Wenner)

$$\rho = (2\pi a) \cdot (V_m / I) = K_W (V_m / I) \tag{9}$$

Resistivity (Schlumberger)

$$\rho = K_S \cdot V_m / I \tag{10}$$

Geometric Factor K (Schlumberger)

$$K_S = \pi \cdot \left(L^2 - I^2\right) / I \tag{11}$$

Generator Power

$$P = V_{gen} \cdot I \tag{12}$$

The equations presented above describe the relationship between the current injected into the ground, the voltage measured at the probes, and the apparent resistivity of the soil. From these relationships, it is possible to transform the obtained electrical signals into physical parameters that allow characterizing the behavior of the ground.

The injected current establishes the excitation of the system, while the measured voltage represents the response of the soil, which depends on its conductivity. This relationship allows determining the resistance of the medium and, through the geometric factor, it is possible to calculate the apparent resistivity.

The equations associated with amplification allow correcting the measured voltage, taking into account the gain of the AD620, which ensures that the calculations are performed with the real value present at the probes.

The mathematical model allows interpreting the experimental measurements in a coherent way, directly relating the electrical variables with the physical properties of the soil.

B. *Calculation of the apparent resistivity of the soil.*

Taking into account the mathematical expressions presented above, apparent resistivity calculations were performed using the experimental data obtained.

Previously, the classical electrical resistivity measurement arrangements were considered, particularly the Wenner and Schlumberger methods. However, since the DR-74 system operates through a borehole measurement configuration, the electrode geometry does not correspond directly to a conventional surface arrangement. Therefore, the Wenner model was chosen, with an apparent approximation of the soil, due to its simplicity and mathematical stability. The Schlumberger model is included as a theoretical reference due to the application of additional geometric parameters that could not be clearly determined in the research.

Therefore, the apparent resistivity of the soil was calculated using the expression in equation (10), where ρ is the soil resistivity in $\Omega \cdot$m, V is the voltage measured between the potential electrodes, I is the injected current, and K is the geometric factor of the arrangement, defined in equation (9).

For the separation between electrodes, it was considered $a = 1.5$ m, Therefore $K_W = 9.425$.

The current injected into the ground was constant and equal to $I = 1$ mA = 0.001 A.

Since the signal was amplified using the AD620 instrumentation amplifier, the voltage for the calculation does not correspond directly to the output voltage of the amplifier, but to the actual voltage that was present at the potential probes. Therefore, the following correction was applied:

$$V = V_{out}/G \quad (13)$$

Where, for the measured voltage of V_{out} = 2.85V and an approximate gain of G = 200 V/V, we obtained V_{real} = 0.01425 V which was substituted into the resistivity equation (10):

$$\rho = K \cdot V_m / I = 9.425\left(\frac{0.01425V}{0.001A}\right) = 134.31\Omega \cdot m$$

Which corresponds to the typical range of moist or moist sandy soils according to the classification shown in Table III, which is consistent with the conditions of the evaluated ground.

The calculated resistivity corresponds to the apparent resistivity, which depends directly on the geometric factor of the system. In the Wenner model, the factor is proportional to the distance between the electrodes, so variations in this separation generate linear changes in the obtained resistivity values.

TABLE VI

CALCULATED APPARENT RESISTIVITY

Measurement	Voltage (V)	Resistivity (Ω·m)
1	1.51	14.236
2	1.45	13.666
3	1.36	12.818
4	1.64	15.457
5	1.66	15.645
6	1.73	16.311
7	1.49	14.043
8	1.78	16.777
9	1.86	17.531
10	2.16	20.358

The resistivity values in Table VI correspond to calculations using the measured voltage without gain correction, therefore they represent comparative reference values.

C. Experimental validation and error analysis.

To evaluate the accuracy of the proposed system, an experimental validation analysis was carried out in which the measurements obtained with the redesigned system are compared with the values measured using conventional instruments used as reference.

In Table II, different measurements performed with the conventional multimeter and the higher-resolution four-digit meter are presented, in which we observed errors associated with the measurement system.

To quantify these differences, the relative error was used, which is defined as:

$$Error = \left|\frac{V_{measured} - V_{conventional}}{V_{conventional}}\right| \times 100\% \quad (14)$$

Where:

$V_{measured}$ is the value obtained by the digital system.

$V_{conventional}$ is the value measured with the conventional instrument.

Therefore, by performing the corresponding calculations, the data for the relative measurement error will be obtained.

TABLE VII

RELATIVE MEASUREMENT ERROR

Measurement	Measured V (V)	Reference V (V)	Error (%)
1	2.3121	2.52	8.25
2	2.4656	2.44	1.05
3	2.5869	2.45	5.59
4	1.6636	2.42	31.28
5	1.9691	2.40	17.95
6	0.8166	2.44	66.54
7	1.5652	2.62	40.27
8	1.4803	1.54	3.88
9	1.5877	2.68	40.78
10	2.0033	2.49	19.54

The relative error shown above presents significant variations, where the values range from 1% to more than 60%. These high errors can be mainly associated with low signal conditions, where there is influence of noise and inherent limitations of the proposed system.

The variations can be attributed to various factors, among which the following can be mentioned:

- Limited resolution of the analog-to-digital converter of the Arduino UNO.
- Tolerance of electronic components.
- Variability in the contact between the probes and the ground.

Considering the use of the AD620 instrumentation amplifier, which allows improving the detection of low-level signals, it also introduces amplification of noise, which could affect the final measurement.

Additionally, from the point of view of the proposed system, the Arduino Uno uses a 10-bit analog-to-digital converter. This allows discretizing the analog signal into 2^{10} = 1024 levels.

Considering a reference voltage of 5 V, the resolution of the system is estimated based on the sensibility *Sens*:

$$Sens = \frac{V_{ref}}{2^n - 1} \quad (15)$$

As a result, an approximate value of 4.88 mV is obtained according to the technical specifications of the device.

Unlike the original system, the proposed design allows identifying, quantifying, and analyzing these deviations through digital tools; although the proposed system still requires additional calibration, it represents an important improvement in data traceability and analysis capability compared to the original analog instrument. In general, the redesign does not modify the physical principle of measurement of the DR-74, but rather improves the way in which the signal is captured, adapted, and conditioned. This makes it possible to extend the useful life of the instrument and increase the reliability of its use in applications where it is necessary to know the electrical conditions of the soil.

D. *Excitation signal and frequency effects.*

In the proposed system, the current injected into the ground is generated by a square signal produced by the Arduino Uno, applied through a 5 kΩ resistor, which allows establishing an approximate current of 1 mA.

The use of a square signal is justified by its easy generation in digital systems and its amplitude stability, which can be represented as a sum of sinusoidal components through the Fourier series, allowing it to be interpreted as an alternating excitation with a defined fundamental frequency [15].

The use of alternating signals in resistivity measurements is important, since it reduces polarization effects at the electrodes, which can introduce significant errors when direct current signals are used [2], [3]. These phenomena are associated with electrochemical interactions between the soil and the electrode.

Likewise, the electrical response of the soil may depend on the excitation frequency, especially in media with variations in moisture and composition [3]. In this research, a frequency analysis was not performed, so the square signal is considered a practical and functional approximation for evaluating the resistive behavior of the ground.

IV. Results Analysis

The proposed system uses the Arduino UNO both for generating the excitation signal and for data acquisition. The square signal generated with levels between 0 V and 5 V is applied to the ground through a 5 kΩ resistor, in which an approximate current of 1 mA is established. The soil response is captured through probes, which is amplified by the AD620 and subsequently filtered before the signal is digitized. It is important to highlight that the measured voltage does not directly represent the soil resistivity, but rather the electrical response of the medium to the injected current. The resistivity is obtained from the corresponding mathematical transformation, considering the injected current and the geometric factor of the measurement system.

The experimental results show an improvement in signal stability and processing capability compared to the proposed system. The amplification stage allows increasing low-level signals to values measurable by the redesigned system, as observed in the tests carried out on moist soil, where an input voltage of 0.42 V was amplified to approximately 2.85 V.

To validate the behavior of the system, a controlled test was carried out through the simulation of a 1 kΩ resistance, which represents a low-conductivity medium. Therefore, the results show that the system maintains a stable response to variations in resistance, demonstrating its ability to detect changes in soil conductivity.

It was observed that higher amplified voltage values are associated with conditions of higher soil conductivity, which is characteristic of moist soils. In contrast, lower voltage values are related to soils with lower conductivity, such as dry soils. This relationship confirms the experimental results and the theory of soil electrical resistivity.

Likewise, the average value of the voltage measurements obtained in Table IV was determined, where an approximate value of 2.17 V was obtained. This value represents the general behavior of the system during data acquisition and confirms the stability of the measurements under operating conditions. The variation observed around this average value is consistent with the previously calculated relative errors, which indicates the presence of dispersion in the data due to factors such as soil conditions, electrical noise, and limitations of the redesigned system.

Therefore, the redesigned system not only preserves the operating principle of the DR-74, but also significantly improves stability, sensitivity, and analysis capability, allowing a more precise reading of the electrical behavior of the soil.

V. Conclusions

The main hypothesis of the research is confirmed, since it was verified that the failures present in the DR-74 borehole resistivity meter are directly related to the deterioration of the internal power supply, the variation of the nominal value of the standard resistances, the oxidation of mechanical contacts, and the loss of continuity in the conductors associated with the probe. These factors affect the stability of the injected current and generate errors in the measurement of the potential voltage, compromising the balance of the resistivity bridge and reducing the accuracy of the equipment.

The obtained results also demonstrated that the original measurement principle of the equipment, based on the relationship between injected current and measured voltage at depth, remains valid and functional, as long as its internal elements operate within their nominal parameters. This confirms that the proposed update does not alter the measurement method of the device, but rather contributes to optimizing it through the incorporation of modern components with better tolerance, thermal stability, and reliability.

According to the data obtained during the diagnostic process and experimental tests, it can be concluded that the DR-74 meter, once updated and properly calibrated, is capable of providing sufficiently accurate resistivity measurements for geological, hydrogeological studies, and applications in electrical engineering. Therefore, the device can continue to be used as a valid tool for the characterization of formations in shallow boreholes, as long as an adequate preventive maintenance program and periodic verification of its critical parameters are maintained.

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