SNR on the Four Probe Measurement System at Earth Surface

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Abstract. In the real world, the presence of noise is undeniable. Electric fields, magnetic fields, temperature changes, atomic structures, and so forth are contributing to the reality and the magnitude of noise. Data acquisition of physical quantities in nature is always needed, which subsequently is required for the interpretation in the laboratory. For this reason, the presence of noise needs to be eliminated or known. In the four-probe measurement system, the two electrodes are injecting current, while the other two electrodes are used for acquisition of the arising voltage. The voltage that arises is greatly influenced by the natural environment and the conductor cables, which are usually in long spans and unprotected. For this reason, noise minimization is very needed. This study aims to compare several types of conductors in reducing noise and reducing attenuation. The study was conducted in an open field with a 20-meter cable, and the front-end amplifier was varied to get the highest SNR.

1. Introduction

In the real world, the presence of noise is undeniable. Electric fields, magnetic fields, temperature changes, atomic structures, and so forth are contributing to the reality and the magnitude of noise. Noise can be separated into two distinct categories, extrinsic (interference) and intrinsic (inherent) [1].

On a conductor who was used to transmit an electrical signal, noise can arise on the conductor. The causative factors are external induction and or random electron movement due to ambient temperature. The three main types of noise are necessary noise, thermal noise, shot noise and low-frequency noise (1/f). Random thermal excited vibrations cause thermal noise from a charge carrier in a conductor [2].

In electronic devices, graphical analysis often shows the presence of small voltage fluctuations at the output of the electronic amplifier. In sound amplifiers, a hissing sound is ubiquitous on the loudspeaker. Shot noise in electronic devices results from the inevitable random statistical fluctuation of electric current when a charge carrier (such as an electron) crosses the gap. If electrons flow across the barrier, they have a different arrival time. The separate arrival shows shot noise. In noisy areas, noise can cause loss of information. In the real world, all signs are almost entirely analogous. The magnitude of the signal is always proportional to the changing phenomena. But sometimes noise is present in importance that is not much different from the sign. Noise needs to be avoided in data acquisition. If noise is included in the geophysical measurement data, the interpretation can be blurred or wrong. If noise is involved in the shooting, the image can be blurred. If noise is involved in the gyro sensor, the drone can shake. For that, the presence of noise needs to be eliminated or reduced. Several
ways to reduce the noise figure can be done by selecting transistors, performance stability, text stabilization, and adjusting the input-output reflection coefficient. [3].

In communication or information transmission, noise from the transmitter circuit, medium interference, or noise on the receiver is sent to affect the received information. As a result, the ratio of signal to noise, or signal to noise ratio is often used. One of the noises is the Gaussian noise. Gaussian noise is evenly distributed over all frequencies. Flicker noise tends to get bigger as the frequency decreases [4].

For geophysics, shallow exploration geoelectric methods are often used. Current is injected at two electrodes, and voltage is measured at the other two electrodes. Current and voltage electrode position configurations vary widely. One of difficult factor is the presence of noise in all configurations. Four-electrode systems are often used in Earth resistivity measurements. Two electrodes are embedded in the earth to transmit current, and two other electrodes are used to measure voltage. The cables used to measure the relative length, often reaching 100 meters, or even more. An increase in temperature can increase electron mobility. Rotating magnets activity, generator sets, or large current electronic devices also increases electron mobility. A wire that conducts an electric current will produce a magnetic field proportional to the magnitude of the current delivered, and inversely proportional to the square of the distance. The electric field will also affect the movement of electrons. The ultra-high voltage channel needs to be considered in its presence in contributing to the noise.

Besides, the measurement of four probes often involves an AC 50 / 60Hz mains power source, or the location of the data collection is in the environment of this grid electricity user. As a result, noise due to nets needs to be taken into account. In the traps themselves, some events can cause noise, namely when the load is turned on and off. This noise is known to interfere with the network communication system [5]. Ultra high power channel, has a definite frequency, that is 50-60Hz. If this creates noise, it will be easier to address. Mains line noise (50 or 60 Hz interference from the power supply) can be eliminated by using a notch filter with a cut-off frequency of 50 or 60 Hz [6]. In addition to the 50-60Hz frequency, the presence of noise at specific frequencies due to certain system resonances can be removed with a notch filter as well. Notch filter design methodology is used so that the resonant behaviour of the motor and the transmission model in the positional loop can also be suppressed [7]. If a conductor is straight along l, moves perpendicular to the magnetic flux B with constant speed v, the charge along the conductor will be subjected to a force so that one end of the conductor becomes more positive than the other. Charge q inside the conductor is influenced by B, which changes in proportion to the speed of movement v. As a result, an electric field occurs in the conductor of E.

\[ qE = qvB \]
\[ E = vB \]
\[ El = vBl \]

Or

\[ \Delta V = vBl \]

At the ends of the conveyor, the wire will arise a voltage of \( \Delta V \).

2. Background
In the four-probe measurement system, it always includes an electrode that plays a role in injecting current. The current injection, which is often done is constant current injection. The current that flows causes a magnetic field that is proportional to the strength of the current. If the current that flows changes, then there will be changes in the magnetic flux as well. If electrons are affected by a magnetic field, electrons will be mobilized too. If a cylinder has volume \( \Delta V \), with a total charge \( \Delta Q \), flows synchronously along the axis of the cylinder \( z \), with velocity \( v_z \), then

\[ \frac{\Delta Q_e}{\Delta t} = q_v \frac{\Delta V}{\Delta t} = q_v \frac{\Delta s \Delta z}{\Delta t} = q_v \Delta s \frac{\Delta z}{\Delta t} \]
If $\Delta s$ is a cross-section area of a cylinder, then the amount of electric current that flows is equal to:

$$\Delta I = \lim_{\Delta t \to 0} \left[ \frac{\Delta Q_e}{\Delta t} \right] = \lim_{\Delta t \to 0} \left[ q_0 \Delta s \frac{\Delta z}{\Delta t} \right] = q_0 v_2 \Delta s$$  \[8\]

If an electric field $E$ exposes a coaxial cable, the value of $E$ can be written in terms of its vector and frequency as follows.

$$E_{inc}(x, y, z, \omega) = E_0 (e_x \hat{a}_x + e_y \hat{a}_y + e_z \hat{a}_z) e^{-j \beta_x x} e^{-j \beta_y y} e^{-j \beta_z z}$$

with the $a_x$, $a_y$, and $a_z$ is the electric field vector in the direction $x$, $y$, and $z$ [9]. This electric field can be an unwanted addition or reduction in the measured electric signal. Shielded cables are generally more immune to outside interference. The signals transmitted in it are less distracted because they are protected. Then the shield is connected to ground to neutralize the electromagnetic induction hitting the casing. The sheath is usually made of copper, silver, copper plated with silver, or aluminium. Some materials exhibit different shielding capabilities against electromagnetic interference (EMI) depending on their frequency and the position of shielding against components that tend to noise. [10]. Some equipment that has the potential to emit fluctuating magnetic fields is usually equipped with a metal casing or packaging that is used to minimize the emission of magnetic and electric fields. The metal motor case usually provides sufficient protective capability to reduce over-the-air RF interference, but the extra metal enclosure should give much better RF interference reduction capability [11].

3. Experiment Design

The experiment is carried out by injecting an electric current into the earth with two electrodes. A 16 mm metal electrode is immersed about 30cm into the earth. Two electrodes act as electrodes that inject current and are often called current electrodes. The current is carried using a cable of 0.1mmx6 dimension of 20 meters. Two other electrodes are used to take a signal of the voltage that arises or often called the voltage electrode. A 15 meters long NYAF cable 1.5mm is used to conduct this voltage signal. Inevitably, noise from the earth and wires will be brought into the voltage measurement. The following figure shows an overview of the experimental design carried out in this study.

![Figure 1. Block Diagram of Experiment Design](image-url)
In the Figure 1, it appears that the power supply is separated between the measuring instrument and the current source. H-Bridge MOSFET driver supplied by a 48V x 2 inverter. This inverter is powered by a 12V / 10A power supply with 220V 50/60Hz power line. A microcontroller controls current injection with the h-bridge Mosfet circuit as the output end. At the same time, the voltage is taken by the front end amplifier in the form of an instrumentation amplifier with the main component INA121. The INA121 IC was chosen because it has an impedance front end amplifier $10^{12}$ Ohm with FET front end, which is expected to have high impedance while the noise is not as good as CMOS. CMOS and JFET front end amplifiers have a different character. CMOS has a flicker noise in the range of 3.5dB-5dB per octave, while the JFET provides flicker noise of up to 5dB per octave. The reason is the fabrication process of the IC component layout factors [4]. At the current electrode, the current is injected with a non-continuous current. Electric current flows for a moment then cut off and flowed again for a moment in the opposite direction. And so on for the current electrode.

Noise is measured before the current injection. The goal is to determine the noise figure system with its environment. Furthermore, the current infusion is carried out, and the voltage arising at the voltage electrode is measured. Moreover, the noise is measured from the signal captured on the DSO. Then the voltage electrode conduit cable is replaced with another type of cable, and measurements are made with DSO. This step is repeated for different cable types.

4. Results and Discussions

In the resistivity survey, electric current (I) is passed into the ground through the current electrodes (A and B). The resulting potential difference ($\Delta V$) is measured between the potential electrodes M and N. Then, the apparent resistivity of the soil is calculated. The resistivity of the subsurface medium is reduced by dividing the value $\Delta V$ by I multiplied by the geometry factor of the electrode configuration used [12]. In this experiment, the current injected is the current whose frequency is 438Hz. This frequency is chosen on the basis that at this frequency, enough current can enter the earth and the voltage that appears at the voltage electrode can still be measured by existing measuring instruments.

Furthermore, the relationship between the current frequency and value of the voltage electrode is expected to reveal more soil characteristics. Specific soil structures, which store a lot of water or vertical layer structures due to landslide or accumulation phenomena, are possible to give a more visible phenomenon because between layers is possible to have similarities with the capacitor structure. At the same time, parallel channels can be assumed to be resistors. Physical conditions are similar to porous channels, which can be modelled as a mathematical model. The model is derived with the assumption that the porous medium is represented by a bundle of tortuous capillary tubes with a fractal pore size distribution [13].

In this research, the research is focussed on the amount of noise that appears on several cables used for the voltage electrode. Figure 1 shows the amount of noise due to the environment before the current injected, which has 82mV and 50Hz frequency. This noise always appears and is predicted to be due to the noise of the electric grids.

The current injected with 438Hz frequency, the 50Hz noise is invisible. It causes observation in 438Hz frequency, and not on 50Hz frequency. This data adds to the validity of the measurement system that the measurement system does not have disconnected cables. Because there is a bad connection, it will cause noise. Bad connections and noise picked up through uncovered cables and circuits that are not correctly grounded will result in inaccurate data [14].

By considering the data from Figure 1, it is predicted that all cables are connected correctly and adequately. The measured voltage from the voltage electrode appears in phase with the injection current, which is 30 meters away. The signal magnitude is in the range of 4.40V. Meanwhile, the noise is in the range of 0.40V. The highest noise when using NYAF cable 1.5mm and lowest when using a shielded cable (microphone cable). Surge noise during current injection transition is still present for all cable types. From this symptom, it is predicted that the occurrence of this jolt noise signal is due to a jolt in the power supply area, not due to the magnetic field or electric field generated from the conducting wire to the current electrode. If the current-conducting wires cause the jolting noise to the
electrodes, one can predict that the sheathed cables will not be affected. However, the current source system is separated from the voltage electrode signal amplifier. The power source is only connected to the grid system, but it turns out to be sufficient to influence the transition in the direction of the electrode current. In this circuit, the voltage electrode is connected to a differential amplifier. Likewise, the current electrode is connected to the Mosfet H-Bridge system, but the ground line is not joined. This is done so that the ground loop can be minimized. When the ground loop is formed, the current flowing in the ground system is very unpredictable [15].

In this circuit, the power supply for the current electrode amplifier is separate from the voltage electrode power supply. The voltage electrode amplifier is built from IC INA121 with the power supply made from a 1A 50 / 60Hz transformer, with a symmetrical rectifier and a 7812 and 7912 regulator. Meanwhile, the current electrode is built from the H MOSFET bridge circuit. The ATMega8 microcontroller controls the timing of the four gates. A toroid-based switching power supply supplies the H bridge circuit with a voltage of 48V x 2 which is obtained from a 12V / 10A 50 / 60Hz power supply. The two systems are grounded together. The connection between direct current (DC) earthing of your local electronic circuit and the reference potential earthing from the mains is usually provided by a local power supply converting the line voltage to the required DC output [16].

The voltage meter circuit is built on a separate PCB board from the current source and current controller. Circuits s is intended to minimize the influence of various noise caused by switching of large currents and large voltages on the current source. Taking into account that, the design of electronic devices is subject to multiple limitations at an early stage, which increases the difficulties arising from achieving a balance between signal quality and electromagnetic interference [17]. The noise that appears before the injection is shown in Figure 2 below.

![Figure 2. Noise at the Voltage Electrode](image)

Current is injected at two electrodes which are 30 meters away. This current is measured with a clamp meter. The injection current was varied, forward for 570μS, off for 570μS and backward for 570ms, and so on for a long time until a measurement was obtained with a storage oscilloscope. The current injection results are shown in Figure 2 channel 2 in blue below.
Figure 3. Current injection, Forward-Off-Reverse.

At the same time, the voltage that occurs at the voltage electrode is also measured. With a 1.5mm NYAF cable, voltage electrode signals are supplied to the INA121 based instrumentation amplifier. The amount of voltage at the voltage electrode is shown in Figure 4 channel 1 in yellow below.

Figure 4. Signals on Voltage Electrodes
The value of the signal voltage from the figure is 4.4 volts. At the same time, the amount of noise is shown in Figure 5 below.

![Figure 5. Noise on the Voltage Electrode Line](image)

Noise is displayed on channel 2, in yellow. The amount of noise on these signals is 0.64V. In this measurement, the signal size compared to the noise level is $\frac{4.4}{0.64}$ or 6.87. In the same way, 0.1x6 cables and sheathed cables (small microphone cables) are listed in the following table.

| Type            | $V_{\text{signal}}$ | $V_{\text{noise}}$ | $\frac{V_{\text{signal}}}{V_{\text{noise}}}$ |
|-----------------|---------------------|---------------------|---------------------------------------------|
| NYAF 1.5        | 4.40                | 0.64                | 6.87                                        |
| 6x0.1           | 4.56                | 0.60                | 7.60                                        |
| Small Microphone| 4.36                | 0.40 – 0.76         | 10.9 – 5.77                                 |

### 5. Conclusion

Current injection at 438Hz frequency can travel to earth with ATMega8 microcontroller control with H-Bridge Mosfet as current exciter, and the voltage that arises at the voltage electrode can also be measured at the 438Hz frequency. In the 438Hz frequency controlled current electrode signal application, the largest SNR is obtained when using a shielded cable. At the same time, the smallest SNR is obtained on NYAF 1.5 cable. However, the difference is relatively small. Noise still occurs quite a lot during the transition of the current direction, even though the current source system and the small-signal amplifier are separated.
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