MODELING AND ANALYSIS OF ELECTROMAGNETIC INTERFERENCE IN GROUNDING CIRCUITS OF CONTROL SYSTEMS

Shermuradova M.F.

Navoi state university of mining technologies

Abstract: This paper analyzes the impact of electromagnetic interference caused by improperly designed grounding systems. A simplified model is proposed that includes receivers and equipment as sources of interference, allowing assessment of its effects on overall system performance. The presence of special circuit filters defines the boundary frequency bands for interference evaluation. It is shown that reducing the length of grounding conductors minimizes voltage drops caused by inductive reactance. In high-inductance conductors, interference increases proportionally with frequency and conductor length. The study also explores the effects of mutual electromagnetic induction between closely spaced conductors and quantifies the induced EMF.

Keywords:grounding system, electromagnetic interference, mutual induction, inductive impedance, differential signal, common-mode signal, signal errors, analog amplifier, induced EMF, circuit filters

Introduction: In modern automated industrial systems, ensuring the accuracy and reliability of signal transmission is critical for effective monitoring and control. One of the most common sources of signal degradation is electromagnetic interference (EMI), which often arises from poorly designed or improperly implemented grounding systems. Grounding not only serves as a safety mechanism but also plays a vital role in minimizing electrical noise and stabilizing circuit behavior.

This paper investigates the mechanisms by which EMI propagates through grounding systems, with a focus on induced voltages, impedance mismatches, and the influence of conductor geometry. A simplified model is developed to estimate interference effects, and practical calculations are provided to assess the voltage drops and error levels resulting from common grounding configurations. Furthermore, the paper emphasizes the importance of differential signal processing and highlights design strategies—such as the use of differential amplifiers and proper cable layout—for minimizing the impact of common-mode signals and ensuring robust system performance.

Main part: An analysis of the influence of interference, which is associated with the creation of an incorrect grounding system, will force a plausible simplified model of it, which will include such elements as receivers and equipment as a source. The study of such circuits makes it possible to assess the influence of interference on the parameters of the entire system as a whole [20; pp. 1-10, 21; S. 1-10;].

If there are special circuitry filters used in the active circuits, then the frequency level of the filters within the boundary frequency bands should be taken as the maximum frequency level of the interference having an effect. To reduce the load voltage on the ground electrodes, it is necessary to reduce the length of the lines. In conductors with high grounding inductance, the limiting noise levels f equals XL =2Ll, where L usually has a value of 0.80 microns. Mr. /m, l - the value of the length of the contour. [22; pp. 1-14; 23; S. 1475-1485; 24; pp. 62-66;]πf

According to the block diagram, it can be seen that in cases where the ground loop or conductors are located at small distances from each other, then among them will appear with a certain way the electromagnetic effects of mutual induction (Fig. 1.1.). On each section of the wires in the grounding system, a certain level of inductance emf appears, as well as disturbing pickup. interference Epij appearing according to the intensity of the induction of the electromagnetic action. Typically, the resistance level of copper conductors with a length of 100 cm and a working diameter of 1.0 mm has a value of 0.0220 ohms. In modern automated industrial networks, when the control system is serviced with a large number of measuring elements over large areas, the length of the ground wires increases accordingly and can be more than 100 meters. Hence, a wire with a length of about 0.1 km will have a resistance value of about 2.2 ohms. If the system is powered by 20 automation modules, consuming 0.1 A each, which are powered from one source, the total voltage drop across the existing grounding bus resistance will be about 4.40 V. [25; pp. 12-17;]

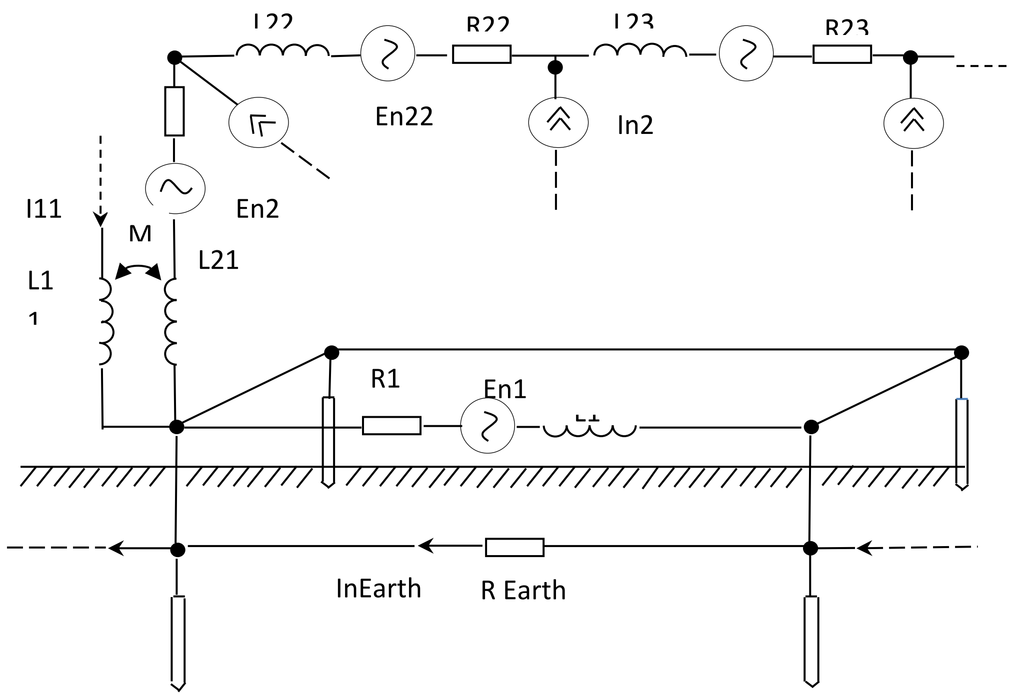

Fig. 1.1. Structural diagram of the ground loop

When the interference frequency is determined above 1.0 MHz, the dependence of the inductive resistance in the ground circuits increases, and in addition, the interdependence of the capacitive and inductive connections between the elements in the ground circuits increases. Grounding conductors, in fact, become emitters of electromagnetic waves and introduce interference into the system.

To determine the total impedance of the complex resistance between the points of connection of wires to grounded devices and the nearest point of a metal structure, it can be approximately expressed using the formula for 2-wire overhead transmission lines:

$$Z_{inp} = R_{inp} tg(2\pi L / \lambda) \qquad (1.3)$$

where R_{in} is the level of wave resistance, L - the length of the ground wire;

λ - interference wavelength $\lambda \approx c / f$;

c -is the speed of the light flux in a vacuum environment (300,000.0 km/s);

f -interference frequency.

A graphical visualization built according to the indicated formula for typical ground wires (screens) with a diameter of 0.3 cm at a distance of 0.5 meters from the nearest reinforced concrete structure of the house (the level of impedance will be 630.0 Ohm) is shown in Figure 1.2.

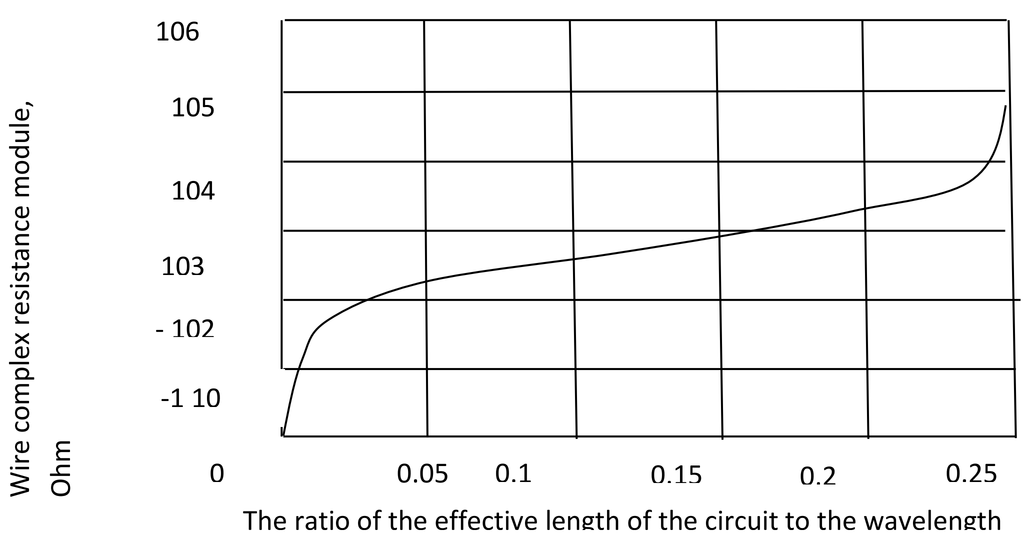

Fig. 1.2. Graph of the change in the total impedance of the resistance.

Passing through the amplifier (analog input systems), the voltage V1 will appear at its output as V = (1-1)K0V1, where 1 is the multiplicative errors on the 1st channel, K0 are the gain factors in the input device. [31; pp. 46-49; 32; pp. 28-33; 33; pp. 85-102; 34; pp. 37-43; 35; pp. 49-56; 36; pp. 169-190; 37; pp. 687-690; 38; S. 2635-2640;].$'\gamma\ \gamma$

By analogy, for the 2nd channel it will be V2=(1-)K0V2 . Builds to assume that it is necessary to select a differential signal as a voltage difference V0 = V1-V2. Under optimal conditions, when 1 = 2 = 0, it will be obtained, as it should,$'\gamma_2\ \gamma\gamma$

$$V_0 = K_0(V_1 - V_2) \qquad (1.4)$$

In reality, multiplicative errors do not equal zero, and include errors in the gain factor, zero offset voltage, ADC errors, noise from electronic equipment, electromagnetic and conductive type interference, errors in methods for debugging information in a PC, that is, all errors from sources signals to the subtractor. Therefore, in the worst conditions, when the error of the values that are entered through the 2 channels are equal to each other in absolute value ($|\gamma_1| = |\gamma_2| = \gamma$)and have the opposite sign, then

$$V^{'} = (1+\gamma_1)K_0V_1 \qquad \text{or} \qquad V^{'} = (1+\gamma_2)K_0V_2$$

$$V_0 = V_1 - V_2 = (1+\gamma)V_1 - (1-\gamma)K_0V_2$$

Using the term differential $V_0 = V_1 - V_2$ and common mode

signals, formula (1.3) can be expressed as follows: $V_a = \frac{V_1 + V_2}{2}$

$$V_0 = K_0V_d + 2\gamma K_0V_a \qquad (1.5)$$

Since the 1st term in (1.3) is the equation for ideal subtractors, the 2nd term of the equation is the absolute additive error for real subtractors. Therefore, the relative error that occurs due to the previously described effect can be calculated using the formula:

$$\gamma_c = \frac{2\gamma K_0 V_d}{K_0 V_a} = 2\gamma {V_d}/{V_a} \qquad (1.6)$$

It should be said that in the previously studied situation, it was assumed that the coefficient for the attenuation of common-mode signals is equal to the value of infinity, and because of this it was not introduced in formula (1.3).

To determine the measured signals in the form of small emf, or with large common-mode signal differences in analog circuits, the ${V_d}/{V_a}$ ratio can reach several orders of magnitude, and for a similar increase in the error level C.γ

For its successful resolution, it is necessary to lower the level of the value, which is possible by using differential amplifiers that subtract signals as close as possible to their original source.γ[26; pp. 94-99; 39; pp. 44-49; 40; pp. 207-211; 41; S. 56-62;].

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