A novel method of applying external hardware to instruments in order to achieve guarding

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***Abstract* — This paper explains the basis of grounding, guarding, floating measurements, their importance and basic problems, at the end new hardware solution used to make an instrument be guarded witch is the main goal of this paper. In addition to the explanation, emphasis is also given on the floating voltmeter as well as the guard voltmeter in the connection configuration of the system on which the measurements are performed. The best way to connect the guard in the electrical circuit is also mentioned, as well as the basic rules that must be followed when connecting the guard in the electrical circuit. At the very end electrical circuit model that can be used is defined.**

***Index terms* — Guard, floating measurements, floating voltmeter, guard voltmeter, guard connection, guarding, grounding.**

I. INTRODUCTION

At the very beginning, it is important to point out how different positions of the probe affect different voltage readings on the oscilloscope. This is important so readers can understand what is the main difference between ground, guard and shielding and this introduction is going to explain to them. This technique, in which the position of the cold end plays an important role, defines our indication as well as the sign of the voltage being measured. Grounding, guarding and shielding are three different terms in metrology that are defined and presented in this document. More about this topic you can find in book from author Predrag Popović which is shown in literature, in a head "Problems with earthing". [3]

In the following examples we see the importance of the problem that arises with grounding. Let the values of the resistors be R1 = R2 = R3 = 2 kΩ while the voltage applied to the input is V = 6 V. What will be the voltage and power values in the following cases? In the following examples, connect the oscilloscope probes between the hot end (voltage one) and ground.

In all the following examples, different situations will be shown, how the oscilloscope reacts to changes in the position of the probes in the electrical circuit, in order to finally reach the last situation, which represents the generator in a short circuit and its display in that situation.

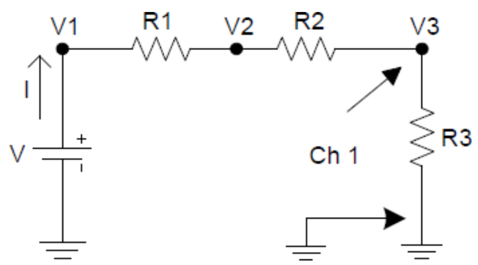

Figure 1. first circuit

The connection in the first case shows a voltage of 2 V on the oscilloscope screen, the current will be 1 mA, and the power developed on the resistors will be 2 mW, which means that there will be no damage.

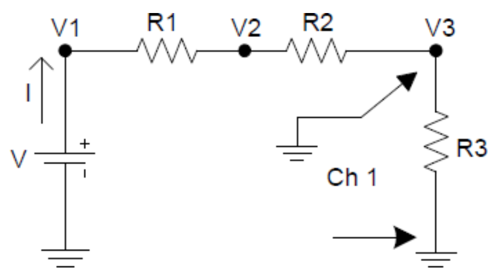

Figure 2. secound circuit

By connecting the probe in this way, it leads to a short circuit of the cold end and the hot end, and we have a voltage value of 0 V. Since the resistor R3 is short-circuited, the current generated by the voltage source will be 1.5 mA, which creates a power on the resistors of 4.5 mW. Due to the low power dissipated, no damage will occur.

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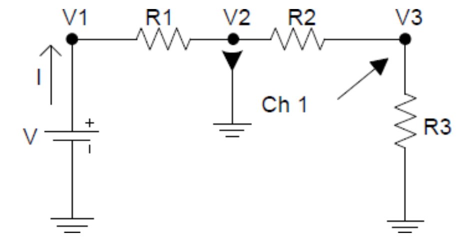

Figure 3. third circuit

With configuration in figure 3, we get that the last two resistors are short-circuited, which indicates that the voltage read on the oscilloscope will be equal to 0. The problem is the current that is sent from the voltage source, because the dissipation on the resistor R1 will increase. The current developed on the resistor R1 will be 3 mA, while the power developed on it will be equal to 18 mW, which is far more than the designed value.

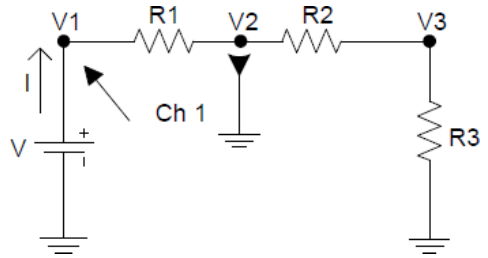

Figure 4. fourth circuit

With connection in figure 4, the voltage on the oscilloscope will read a voltage value of 6 V, while the rest of the circuit analysis will be identical to the previous example.

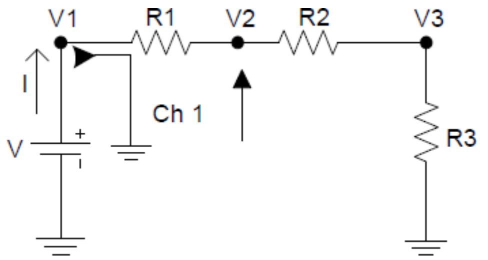

Figure 5. fifth circuit

This indication in figure 5 indicates that the voltage source is short- circuited. This further results in a 0 V indication on the oscilloscope, however such an indication will last a short time and depends on the power of the source which will burn the first element in the system.

II. GROUNDED MEASUREMENTS

This paragraph will show what is the solution and discuss all about grounding. More information about this topic you can found in HP Aplication Note 123 [2], guarding and floating measurements, which has a large explanation. The creation of a new voltage source between grounds that are at a different reference potential is a huge problem in floating measurements, so the solution of which we are looking for is in the guarding. By using a guard in an electric circuit, we eliminate a new unwanted voltage that occurs in the circuit, but by doing so we form a new line (terminal) called a guard terminal.

The biggest problem that occurs is that the undesired offset voltage can cause a certain current in the circuit which will create a voltage drop on the resistors and this cause a systematic error. Additional voltage applied to the instrument will cause an error in the voltage reading on the voltmeter and this show an inaccurate measurement.

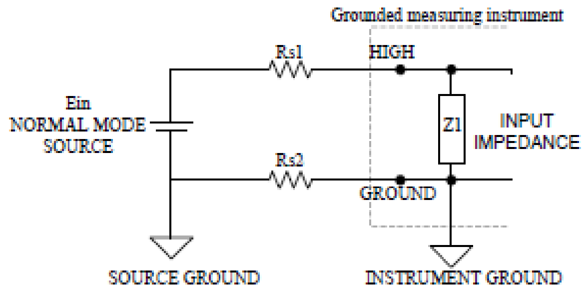

Figure 6. Simple grounded measurement

The circuit shown at a Figure 6 represents a simple measurement of DC voltage. Based on the electrical diagram, we see that there is a voltage source Ein (NORMAL MODE SOURCE) which is measured together with all the noise that can occur due to the imperfection of the environment and construction. Resistor Rs1 ("HIGH" SOURCE RESISTANCE) represents the sum of the internal resistance of the voltage source as well as the resistance of the high line, i.e. the wire connected to the HIGH line. Rs2 (GROUND LEAD RESISTANCE)
represents the resistance of the ground wire, the conductor that connects the opposite end. Impedance Z1 in the circuit configures the internal resistance of the instrument, whose ground line is connected to INSTRUMENT GROUND. Current from the voltage source flows through Rs1 and Z1 and the instrument itself responds to the voltage drop across Z1. As long as both potential points on the ground line are connected to the same potential value, together on the equipotential surface, no current will flow through Rs2, since the potential difference will be equal to 0, that is, there will be no voltage on the ground line.

In the electric circuit which is on the Figure 7, a slightly different situation is shown. Now we have an example where the ground line of the instrument and the ground line of the source being measured are at different reference potentials. The reason for this may be a voltage drop on the ground line, whereby we have current flowing through Rs2. The measurement is represented in the following electrical diagram with the given contours.

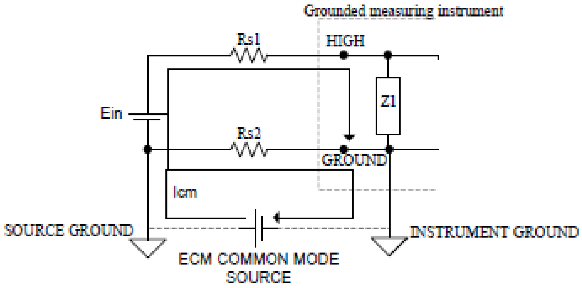

Figure 7. Grounded measurement with ECM

Due to the potential difference that is connected at the two ends of the ground wire, a new voltage source ECM (COMMON MODE SOURCE) appears. The given voltage source represents the common voltage caused by the high and ground lines. The current originating from this source can flow either through Rs2 or through the serial connection of Rs1 and Z1. We can safely assume that the internal resistance of the instrument Z1 is much higher than the resistance of Rs1, while it is clearly observed from the diagram that Z1+Rs1 are in parallel connection with Rs2, we conclude that the voltage appearing on Z1 is equal to the voltage on Rs2. The ECM will sense the ground wire and sense the resistor Rs2, which will cause an error reading on the instrument panel.

III. FLOATING MEASUREMENTS

We use the term floating measurements when we want to show the measurements that take place between two different grounds, the consequence of which is the occurrence of the ECM voltage. The name floating indicates that the voltage floats due to the occurrence of unwanted ECM voltage.

Ideally, floating measurements would be immune to the appearance of ECM voltages, and would only measure the voltage applied to the circuit input regardless of how much ECM there is in the circuit.

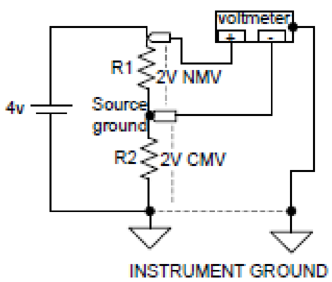

Figure 8. ECM caused by measuring the voltage referenced above the ground line

The wiring diagram above shows the simplest example of a floating measurement. The voltmeter is connected in the circuit so that it is on the same ground wire with the source, but in this configuration it measures a voltage that is not directly referenced to the same ground. The instrument measures the voltage across the top resistor R1, and is referenced to the top of the second resistor R2. It further follows that the top of resistor R2 is the ground for the voltage source, while the voltage drop across resistor R2 is the ECM voltage in the circuit, which occurs due to various grounds. If the voltmeter can eliminate the ECM voltage, in that case it can measure the 2 V appearing on R1 accurately, but if the one shown in the previous circuit diagram, in that case it will short circuit R2, a large current will pass through the ground wire, and in which case all 4 volts from the power supply will appear on R1. The voltmeter will now read twice the value it should.

IV. FLOATING VOLTMETER

Ground voltmeter shown on Figure 7 can be upgraded to obtain a floating voltmeter. This is achieved by adding a special shield between electrical circuit (inside) and the outer case (on the chassis). The newly obtained measuring instrument has three input lines HIGH, LOW; GROUND. The HIGH line has the same role as on the electrical. scheme shown at figure 7, GROUND as well, while the new LOW terminal that connects the elements of el. circuits inside the instrument with an internal chassis. Z1, Z2, Z3 show the internal impedances, of which Z1 is the internal impedance of the instrument, Z2 is the isolation impedance between the low terminal and the ground terminal, and Z3 is the isolation impedance between the high terminal and the ground terminal. Let's pay attention to the following shematic shown at figure 9.

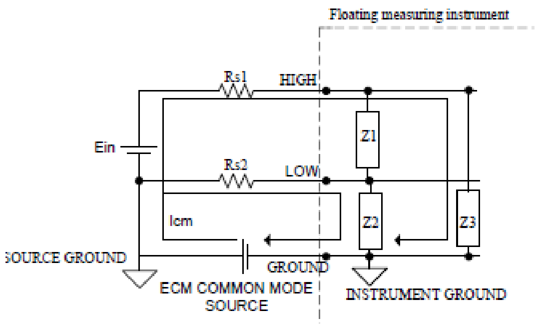

Figure 9. The interior of an ideal floating voltmeter

Let's say that Z3 and Z2 are equal and much larger in value than Rs1 and Rs2. In that case, the current originating from the ECM would be divided into two contours that would have approximately equal values. If Rs1 and Rs2 were also equal then the voltage drop across Z3 connected to the top of Z1 would be equal to the voltage drop across Z2 connected to the end of Z1. In that case there is no potential difference between the top and end of Z1, so ECM will not occur and offset. A floating voltmeter like this is called a balanced floating voltmeter. If Rs1 and Rs2 are not equal, a potential difference will appear at the top and end of Z1, and a voltage proportional to the difference between Rs1 and Rs2 will appear, and introduce an offset.

In the majority of floating instruments, Z2 and Z3 are not equal, usually Z3 is far greater than Z2, so ECM occurrences are inevitable. In practice, the following situation shown in the electrical diagram which is represent on Figure 10.

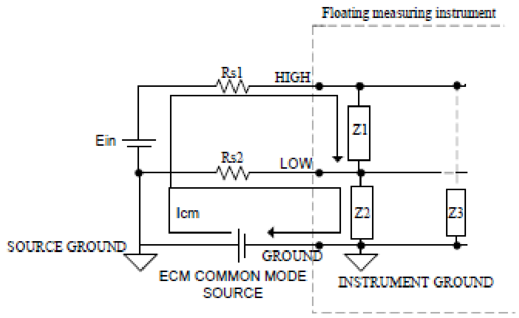

Figure 10. A more realistic representation of a floating voltmeter

Current from the ECM flows through two parallel paths (loops) and creates a voltage drop across Rs2. The same voltage will also develop across Rs1 + Z1, with more of it across Z1 (due to the higher resistance) and the instrument will see a voltage drop across Z1. The voltage on Rs2 coming from the ECM will offset the input voltage, so the resulting error depends on the connection between Rs2 and Z2. If Rs2 is much less than Z2 the error will be small. Since Rs2 is only the resistance of the lines, and Z2 is the insulation impedance, which is of the order of 10^8-10^{10} Ω and the capacitance is several hundred pF to tens of ųF. In DC mode, Z2 >> R2, but gradually decreases with increasing frequency, since at high frequencies it becomes less resistant to ECM signals. Also, unwanted physical quantities such as moisture, rust, can affect Z2 so that the ECM effect increases and an error follows.

Such a voltmeter can reject the effects of ECM voltages in the range of 80 dB to 120 dB of gain in DC mode as well as the range of 60 dB to 100 dB of line frequency, if Z2 is maintained adequately and resistance Rs2 is the resistance of the wire. If the ECM is 120 V and the CMR is 100 dB factor of 10^5 the resulting Normal mode offset will be 1.2 mV. With these parameters, we will not be able to perform measurements on all ranges. High resolution and high sensitivity measurements require a voltmeter with a higher CMR factor than a floating voltmeter. The only instrument that could meet these needs is a guarded instrument.

V. GUARD VOLTMETER

An instrument that has a guard on it, in this case a voltmeter, has an additional shield that is formed between the low terminal and the ground terminal. This achieves an effective increase in impedance from the low line to the ground line. The additional shield that is formed is called a guard and is connected to the electrical circuit that is measured through the guard terminal. A special guard terminal line is formed. The electrical diagram shows an additional shield, a guard formed to divide the low and ground impedance into two series impedances Z2 and Z3, which increases the resistance (series connection of the resistor) and reduces the total capacitance (series connection of the capacitor, capacitive part of the impedance). The result of this will be seen in connecting the guard in a proper way and a direct impact on the measurement.

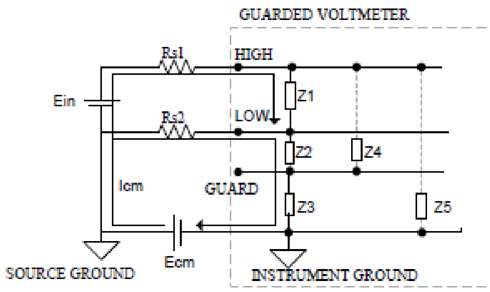

Figure 11. Display of the flow of currents from the ECM

The electrical diagram at Figure 11, shows the working principle of the guard. The working principle is based on the story of the floating voltmeter, which is the difference in the insulation impedance between the low and ground terminals. Current from the ECM can flow through a parallel path and will create a voltage drop across Rs2 resulting in a potential difference across Z1 creating a fault. As already explained in the example of the floating voltmeter, the same situation will be repeated that the error is very small if the isolation impedances Z2 + Z3 are of large values and Rs2 of small values. In DC mode, adding a guard will significantly increase the impedance of leakage currents, especially in a dry, constant temperature environment. In the AC mode at the line frequency the impedance will increase by just some value, which will result in significant improvements in the CMR factor in the DC mode and small improvements in the AC mode.

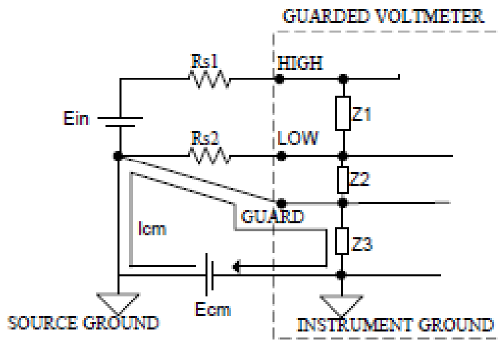

Figure 12. current flow from ECM

If the guard is connected in a proper way like in figure 12, all current flowing from the ECM will close its circuit as shown in el. scheme which will eliminate Rs1 and Rs2 from the influence of that current that will pass through the guard terminal. Due to this, no error can occur because current does not pass through Rs2. Also, as long as the low terminal and ground terminal are at approximately equal potential, the potentials at the top and end of impedance Z2 are approximately equal, causing very little voltage drop across Z2 and very little current to flow through impedance Z2. Guard has the ability to improve the CMR factor for a certain range of frequencies, so a good guarded voltmeter will reject signals up to about 160 dB in DC and 140 dB in AC mode at line frequency. The rules that must be followed in order to properly connect the guard:

-Connect the guard terminal and the low terminal to the same voltage or make the difference between these two terminals as small as possible.

- Connect the guard so that the current from the ECM, or the current of the guard does not flow along any resistance that can create a negative effect on the input voltage.

Applying these two rules, the connected guard will look like the following electrical diagram shown in figure 13.

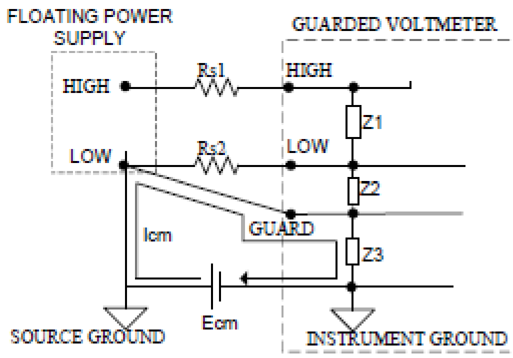

Figure 13. The best way to connect the guard

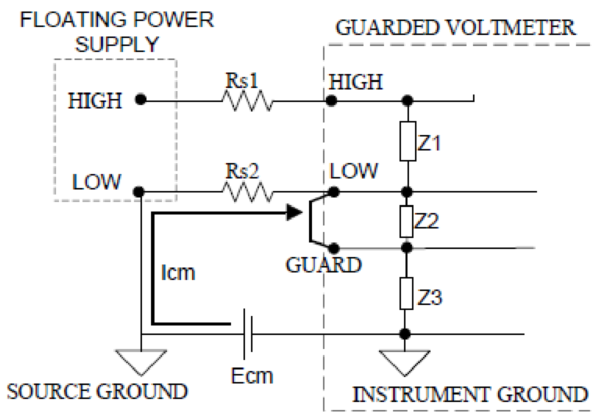

Figure 14. The alternative way to connect the guard

By connecting the guard in this way, we short-circuit the low and guard terminals, whereby the current from the Ecm passes through the impedance of Z3 and does not reach the instrument and does not cause an error. This is easier way to connect the guard and instrument without opening the power supply source. We use all those informations so we can create something new which is shown in the next head number VI.

VI. ELECTRICAL CIRCUIT

In this example, we will use an electric circuit that can be used as an input stage of the measuring system. Additional hardware is designed so that a PCB can be made from this block. The main features are based on the application of the electrical schemes from figure 13 and figure 14. So our goal is to connect the hardware so that there are 3 separate lines. GND, GUARD, LOW terminal line. Such a board with the existing three lines is placed so that the signal source comes to those three lines, while the board is connected to the instrument. It was noticed on the electrical sheme that there is a switch that performs the function that is designed in figure 14.

The principle of connection is as follows:

The H1 hdr block is connected to the low terminal line on the instrument, that is, the COM port on most devices, while the positive end is connected directly to the signal being measured.

With this way of connection, we created a low terminal so that there is a guard terminal while we connected the gnd wire to the gnd input of the instrument. When we connect the system in this way, all the current that is induced from the ECM voltage, which is caused by different masses, will be closed via the guard terminal, and thus there will be no voltage drop on the resistor, which can create a further systematic error.

The electrical circuit for multimeter which we make represents the basic form of a measuring instrument that has the ability to measure voltage, current and resistance.

We will use the common jack end as the low terminal on which we define the guard terminal as well as the ground. Also, such measurements can only be applied to an instrument that has a separate output for the GND terminal.

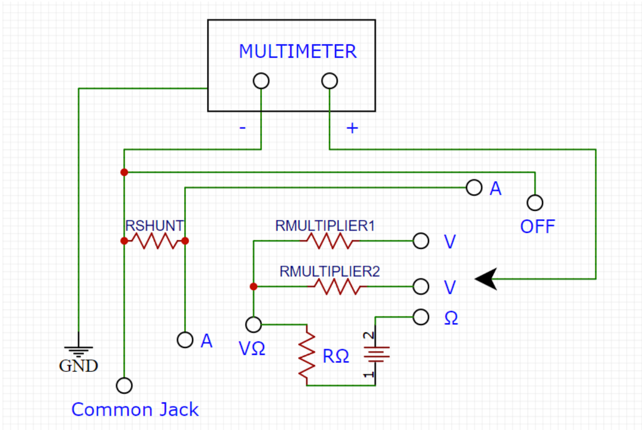

Figure 15. multimeter scheme [1]

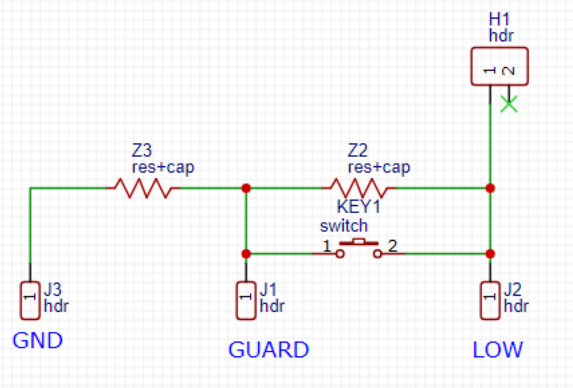

Figure 16. small hardwer adapter for multimeter

Hardwer made for multimeter in electrical circuit has 3 male hdr pins, and 1 female hdr port. We use external hardwer to connect it to measuring instrument and made new guard terminal. Also GND net label is used for ground terminal witch instrument has to have so this circuit would work on. Impedance are made like in electrical sheme used for description while switch is used to turn on the alternative way of connecting the guard.

VII. CONCLUSION

The final result is achieved by creating a printed circuit board and testing it. The part of the voltage Ecm is constant and can make an error in the measurement, so this new way of creating additional hardware for the measuring instrument is one of the possible solutions for this problem if we do not have a physical guard. For this reason, our goal would be to create a board that would perform the function of a guard instead of itself, since all the components that the guard itself contains are passive.

Such measurements are used in very precise metrology for measuring high resistances and small currents. There is the possibility of adding voltage to the reference point, which can physically create a model that shows the difference between using the guard terminal and only the low terminal, as well as the systematic error that occurs in that case. For such a configuration, it is necessary to set up a resistor network and connect the capacitors in order to act the impedance in the right way. Such systems are not applied to devices that do not have a GND terminal, because there is no possibility of creating an Ecm voltage. This work is an introduction to this topic and based on knowing the basics of guarding, we can do further analysis and better research on this topic.

This block can later be used to make a precise printed circuit board that will have a large number of resistors and capacitors, which will play the role of acting as impedance in the circuit and thus collect all the excess current that is there.

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