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PHILIPS

Guarding techniques

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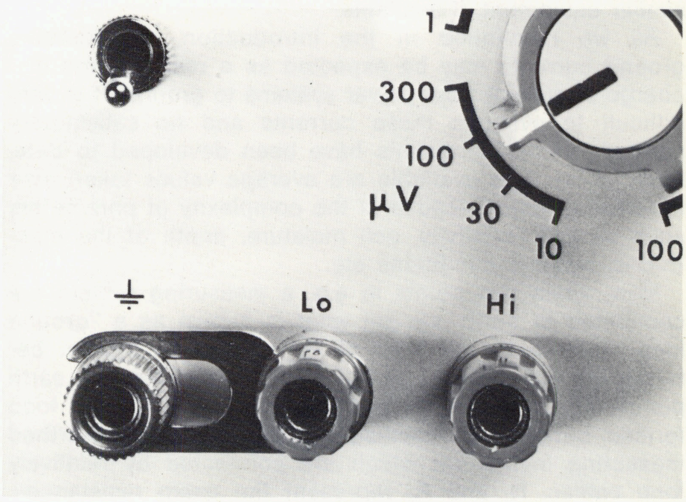

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Introduction

Measuring systems involving instruments such as digital voltmeters and recorders with accuracies of around 0.1% or even better must be designed with great care to keep parasitic voltages and other electrical noise out of the system. For example, the recorder PM 8245 has a guaranteed accuracy of 0.25%. When this instrument is used with a full-scale deflection of 1 mV, a parasitic voltage of 10 μV (which can easily arise in the measuring system unless special precautions are taken) represents an error of 1%, thus completely annulling the high accuracy which is one of the main features of this instrument.

One of the main sources of parasitic voltages in measuring systems is the mains voltage, and in this supplement we shall discuss mainly means of reducing errors due directly or indirectly to the mains voltage. There are two main methods of eliminating these errors: the use of isolating transformers and the shielding of leads. The shielding of leads helps to keep out induced parasitic voltages. This form of "electrical environmental pollution" has assumed considerable proportions now that so much electrical power equipment discharges its operating current to earth.

However, the use of shielding techniques and isolating transformers can itself lead to errors in the measuring system. The main purpose of this supplement is to explain how this can come about, and how guarding systems can be intelligently designed on this basis to keep out parasitic voltages.

1. Distinction between safety guard and signal ground

Many instruments have three input terminals, marked "High" "Low" and "Earth" or "+", "—" and "⊥". The "Low" or "—" terminal is the signal ground. Both the biassing voltages and the voltages to be measured in the instrument are related to this. The terminal marked "⊥" is the safety earth; all external metal parts of the instrument are connected to this point, which is in its turn connected to the earth lead of the AC mains cable flex.

In a proper installation this earth connection ensures that none of the conducting parts of the instrument which personnel or oher people could touch can rise in potential above the safety margin (42 V) with respect to earth. A metal link is often provided between the "—" (or "Low") and "⊥" terminals (fig. 1). The signal "common" point is then earthed. If the instrument in question has the only connection to earth in the measuring system, measurements can be performed in a straightforward way. However, measuring errors may occur in cases where the device under test has also a connection to earth. (See the section "Ground loops and ground currents" below). The terminals "—" and "⊥" must now be disconnected. The instruments cabinet is of course still connected to earth, so that the system is still electrically safe, but the above-mentioned errors are eliminated because the "common" is floating with respect to earth. The reason for this will be considered in the next section.

2. Ground loops and ground currents

We all know that the metallic cabinet of electrical equipment should be earthed as mentioned above, to ensure electrical safety. In power installations, the earth connection may be obtained by driving a copper or iron rod into the ground to a depth of 10-100 feet beneath the surface. The depth will depend on the local conductivity of the soil, which is subject to seasonal variation.

If one rod does not give a sufficiently low earth spread resistance, a system of rods connected by a copper ground bus can be used. The required value of the earth spread resistance depends on the maximum current which may be obtained from the power system in use. In any case, possible defects in the equipment should not lead to a voltage exceeding 42 V between the metallic housing of an instrument and earth.

Sometimes the iron rods of a reinforced concrete structure are welded together and connected to special conducting rods to gove the required low earth spread resistance. A metallic underground water piping system also provides good contact with earth and is probably the best solution for the earthing of measuring instruments and similar equipment, if available.

As we mentioned in the introduction, considerable ground currents may be expected as a result of the discharge of current from power systems to ground. It is very difficult to evaluate these currents and no satisfactory methods of measurements have been developed to date. Most of the data available are average values taken over a period of time because of the complexity of parameters such as soil resistivity, soil moisture, depth of the electrodes, weather conditions etc.

Now, when two points in e.g. a measuring system are connected to earth, we get what is known as a "ground loop" formed by the part of the measuring system between the two points and the soil between the two earth points. Fig. 2 shows an example of such a ground loop formed between an earthed transducer and an earthed measuring instrument which are connected by relatively long cables. R_1 and R_2 represent the cable resistances. The transducer might be a thermocouple or a strain gauge connected to an earthed object, while the instrument can be a strip chart recorder, an impedance bridge, an oscilloscope or a data acquisition system.

The earth currents and the soil resistivity create a virtual voltage source E_{cm}, causing a current to flow through the measuring set-up. The preventions to be taken in order to avoid or to reduce the effect of this current will be discussed below.

An analogous situation arises in a measuring installation consisting of different instruments mounted in a 19" rack. A current flow through the rack via the signal ground terminals of the instruments, no matter whether the latter are connected to earth or not. If such a current does exist it is very likely to be coupled back into the circuit by means of resistive or capacitive coupling or electromagnetic induction. The current loop formed in this way is commonly called a "ground loop" too. The precautions which may be taken to reduce errors due to this type of ground loop will also be discussed below.

Summarizing, we may state that accurate measuring systems must be designed to reduce or eliminate errors due to:

— 1. ground currents flowing below the surface of the earth and

— 2. ground currents associated with the measuring set-up itself.

3. Common-mode and series-mode voltages

Common-mode voltages are those voltages which appear on both sides of a signal line to a common reference point, normally the common point or earth. As already mentioned above, they can be coupled to the measuring set-up in a resistive, capacitive or electromagnetic way. Such common-mode voltages can give rise to "series-mode" (normal-mode) voltages in a measuring system. It is the series-mode voltages that really concern us, because they can lead to measuring errors.

The conversion of a common-mode voltage into a series-mode voltage is illustrated in fig. 3. In this measuring set-up a ground current flows in the low-ohmic circuit ABCD due to the common-mode generator E_{cm}. However, a small current also flows through the transducer impedances Zt and Zin of the measuring instrument. (AEFCD). Because Zin is generally very high ($> 10^6\ \Omega$), the current through AEFCD will be much smaller than that through ABCD ($Z_t \leqslant 1\ k\Omega$). A voltage will thus exist between the points E and B due to the difference in loop currents originating from E_{cm}. This voltage can be considered as being in series with the voltage which we intended to develop in the transducer, and has thus received the name "series-mode voltage" (also called "normal-mode voltage").

It is this series-mode voltage which causes us most concern, since it directly influences the accuracy of the measuring system. We will see that there are means available (filtering, integrating) for solving this problem to a great extent.

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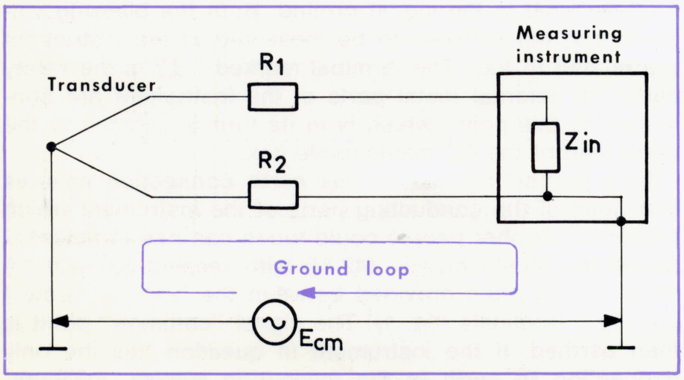

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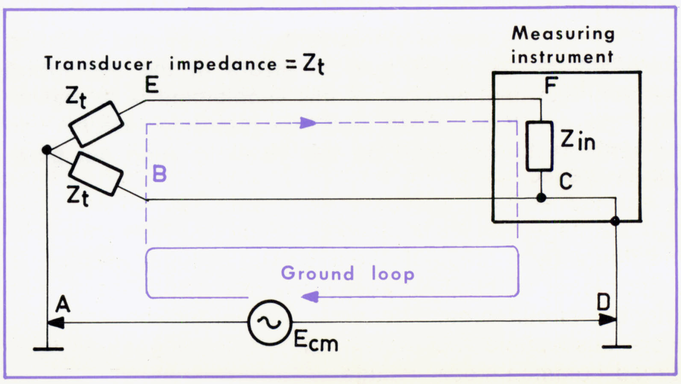

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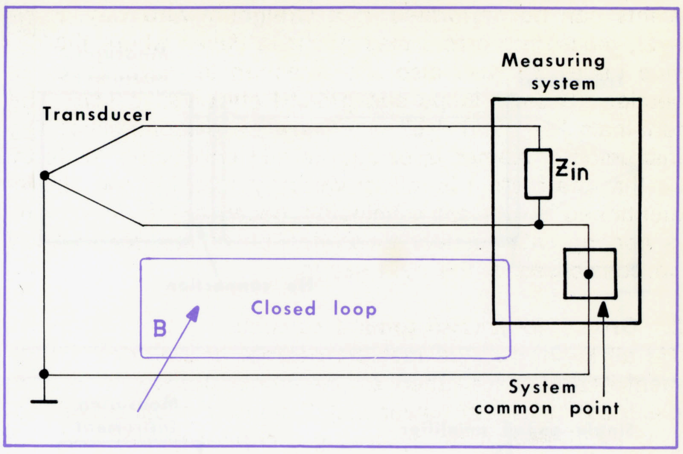

Both in fig. 2 and fig. 3, the source of E_{cm} is a difference in potential between the two earth points; this kind of common-mode voltage is therefore referred to as an *earth common-mode voltage.* It is generally related in frequency to the mains power supply.

Fig. 4 illustrates another kind of common-mode voltage source. Here the resistance bridge is fed by a voltage source E one terminal of which is earthed. The bridge could be of a normal resistance type but could also be a configuration of transducers. With one terminal of the supply voltage earthed, the bridge points A and B are at a potential of E/2 above ground. Thus the common-mode voltage at the input terminals of the amplifier is E/2. The power supply for the bridge is generally DC, but AC bridge supplies do exist too. This type of common-mode voltage is referred to as a *transducer common-mode voltage.* At the present state of the art, amplifiers and similar circuits will reject DC common-mode voltages up to 100-120 dB, but the possibility of error from this source should be borne in mind when extremely accurate measurements are to be made.

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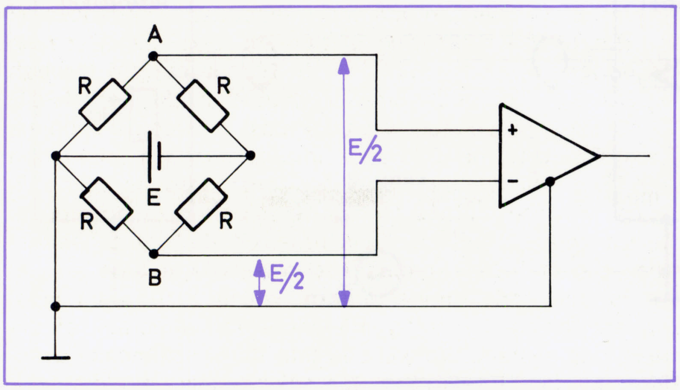


The last type of common-mode voltage to be mentioned here is the *system common-mode voltage,* which is magnetically induced in a closed loop in the measuring system by an alternating (stray) magnetic field. Fig. 5 gives an example of a measuring set-up in which a system common-mode voltage may arise. The set-up is basically the same as in fig. 2, but in order to avoid earth common-mode voltages in the measuring system, the signal common points are combined in the system common point which is earthed at the transducer earth point. It will be clear that a voltage may be induced in the closed loop shown in the figure by a magnetic field B. The induced voltage is proportional to the flux density, the rate of change of flux and the circuit area. Therefore, the larger the area the more susceptible the system will be to magnetically induced common-mode voltage.

4. Rejecting common-mode and series-mode voltages

Once we know the origin and kind of parasitic voltages likely to influence a measuring system, it will not be too difficult to understand the steps to be taken to reduce their effect. The two main methods used are *shielding* the signal path against intrusion of a parasitic voltage, and *isolating* this voltage from the signal path.

We shall first discuss some consequences of shielding a cable, and then the use of transformers to avoid hum in the measuring circuitry.

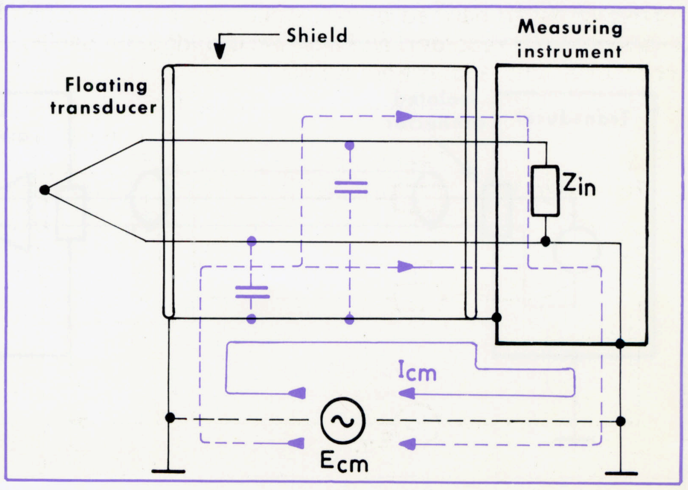
4.1 Shielding techniques

Shielding may be necessary to keep parasitic signals out of certain areas in low-level instrumentation. Before we can shield effectively against these signals, we have to know whether they are induced by electrostatic or electromagnetic fields. Electrostatic fields form a more common threat to electronic instrumentation, but are simpler to shield against: a metal housing will shield an instrument efectively against electrostatically induced currents because they flow through the surface. A braided copper sheet is most commonly applied for shielding cables, although aluminium foil is becoming increasingly important.

High-permeability ferromagnetic materials are the best magnetic shield against magnetic flux. These shields are for instance used round CRT's in oscilloscopes. The higher the permeability of a magnetic shield the better. Nickel-iron alloys have permeabilities in the range from 10000 to 100000.

Regardless of the type of shield used, it is possible to cause more noise in the signal lines by improper grounding of the shields than the extraneous noise against which is shielded. Some examples will be given here. In fig. 6 a common-mode current I_{cm} is introduced in the signal path

6



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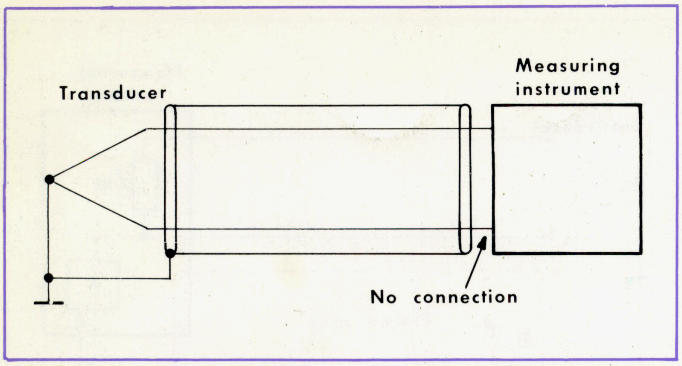

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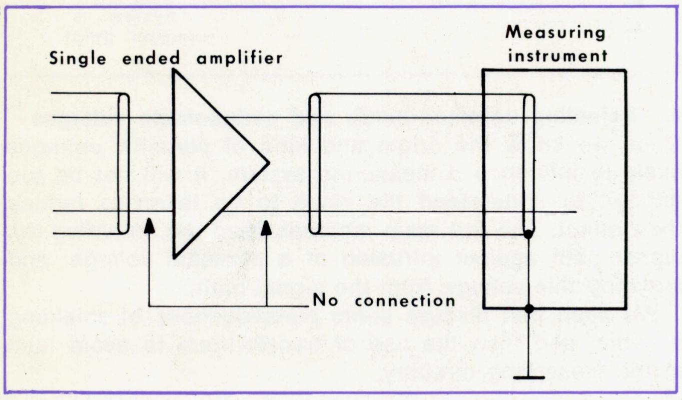

by capacitive coupling to the shield which is connected to earth both at the transducer side and at the instruments housing. The transducer is floating here.

Figure 7 gives a better solution in this case, with an eathed transducer and a floating instrument. When the transducer consists of an ungrounded bridge configuration the whole bridge may be shielded and earthed.

In many signal transport configurations, line amplifiers have to be used to keep the signal at a proper level. In case of a single-ended amplifier, the system should be shielded as shown in fig. 8.

It will be seen that the amplifier is not connected to the shield. However, there are right and wrong ways of applying this shielding technique. Fig. 9 shows one of the wrong ways. Obviously, the two ground-loop currents can introduce series-mode voltages in the measuring chain by capacitive coupling.

A correct way of connecting the shield for this set-up is given in fig. 10. Although all instrument housings are earthed for safety reasons, no ground current can flow because the only point where the shielding has been earthed is at the instrument side.

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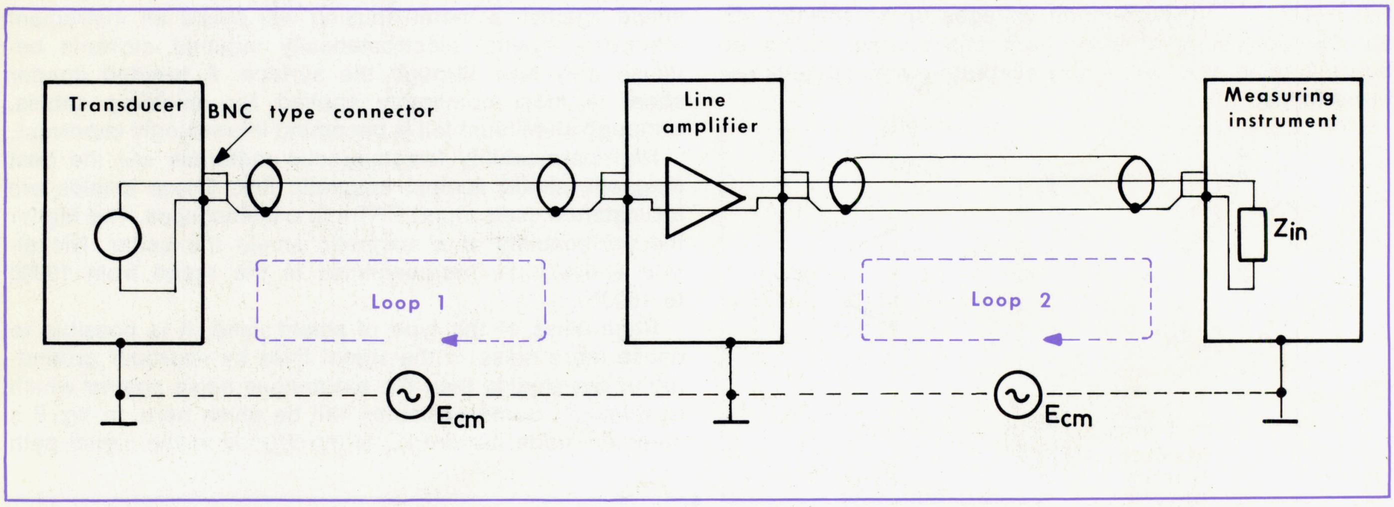

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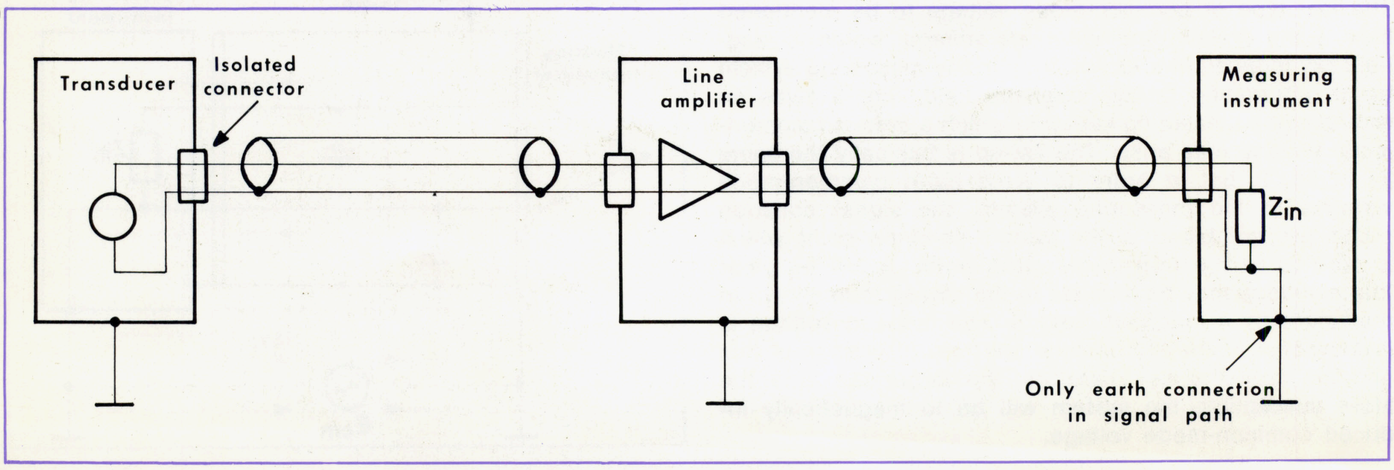

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