X-Y RECORDER NOTES

NUMBER 3

X-Y RECORDER INPUT CONNECTION CONFIGURATION AND INPUT NOISE

An X-Y recorder's ability to accurately reproduce data can be seriously degraded by input noise. Hewlett-Packard's X-Y Recorder Note #1 discussed normal-mode input noise and explained why null-balance servo systems, as used in conventional X-Y recorders, can be extremely sensitive to this form of input noise. Several other forms of input noise, such as common-mode, can also affect the recorder's response.

This note describes several traditional and "not-so-traditional" methods of minimizing the effects of common-mode noise and, more importantly, discusses an often overlooked but potentially serious noise "source" – the recorder's input terminal connection configuration.

SOURCES OF NOISE AND CONNECTION PROBLEMS

The type and severity of input noise is largely dependent on the input connection configuration used. For instance, if the low side of the input is connected to ground, very few problems will occur. This type of connection (Figure 1) is by far the easiest to work with. However, for practical reasons it is often not totally attainable. A more severe problem occurs when the high terminal is grounded. This type of input connection (Figure 2) is the most difficult to work with. This configuration may appear one that is infrequently encountered, but surprisingly, that is not the case. In applications where the input is connected across a grounded bridge signal source, or when the input wires are reversed to reverse the pen's direction, the high terminal is grounded. Generally, if the characteristics of this configuration are understood along with the resulting problems, most potential connection pitfalls can be anticipated or avoided.

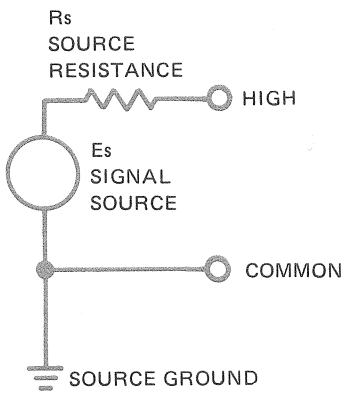

Figure 1.

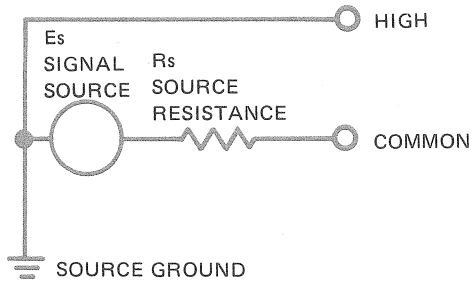

Figure 2.

First, to illustrate how this "worst case" input configuration can aggravate common-mode input noise, consider the circuit shown in Figure 3a. The input signal is connected between the high and common terminals and the common-mode signal is in series with the input signal and the common terminal. The common-mode voltage is applied to both the common and high input terminals. This is the same basic circuit as shown in Figure 2. In this case, the common-mode voltage causes a current to flow through the source resistance into the common input terminal, then through the leakage impedance to ground within the instrument, and back to the common-mode voltage source. This causes a voltage to develop across the source resistance which appears as a normal-mode noise input.

Second, to illustrate how this "worst case" input configuration can by itself cause input noise, let Ecm equal zero as shown in Figure 3b, and consider what is happening to circuit common. Note that X-Y recorders usually attain input isolation by isolating the entire amplifier and power supply from ground (Figure 4). Circuit common is therefore connected to the power supply whose components cause a noise voltage (via transformer winding capacitance unbalance to ground, etc.). This noise voltage creates a current flow out the common input terminal, through the source resistance and then to ground. This current is commonly called "pump-out" current. The resulting voltage developed across the source resistance appears as a normal-mode input signal.

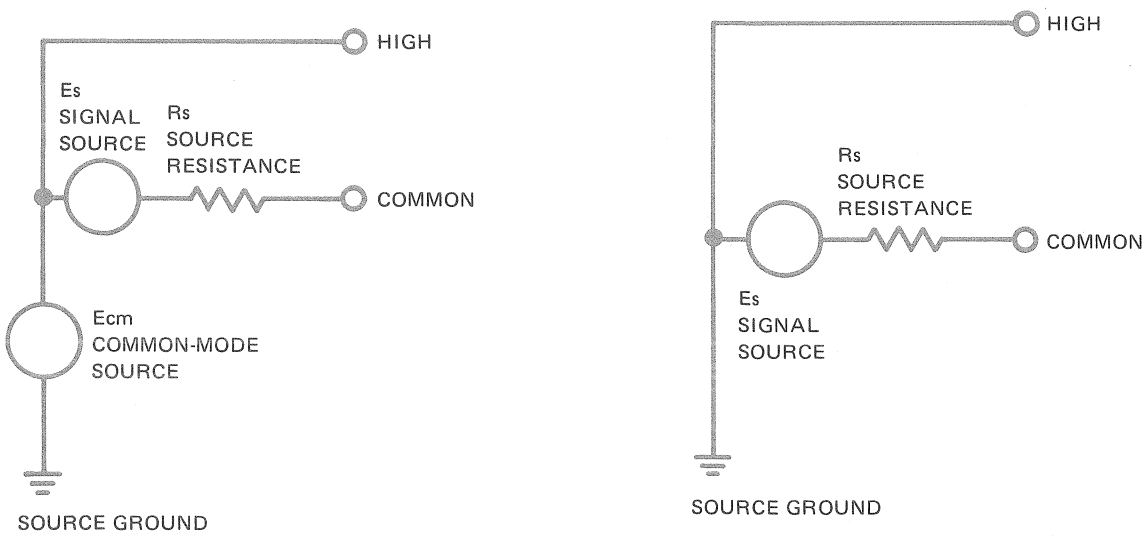

Figure 3.

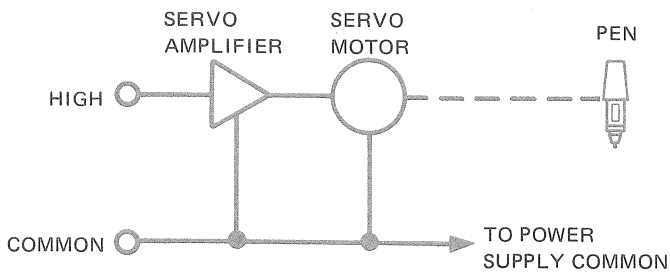

Figure 4.

In both cases, this noise in an X-Y recorder can potentially be severe. X-Y Recorder Note #1 indicated that normal-mode input noise exceeding 0.1% of full scale can be sufficient to start degrading servo performance; 1% sufficient to virtually destroy performance. Consider, then, a typical X-Y recorder with a "pump-out" current of 0.1 microamps. With the input connection of Figure 2, when Rs is 1000 ohms, the recorder experiences 0.1% input noise on the 5 mV/cm range. Considering that typical X-Y recorders have sensitivities exceeding 0.5 mV/cm, many high sensitivity ranges can be unusable when the inputs are connected in this manner.

As you can see, the typical X-Y recorder input circuit connected with the high input "grounded" can be very sensitive to both the application of a common-mode voltage and the noise generated by current flowing through circuit common.

TRADITIONAL SOLUTIONS

Several methods have traditionally been used by X-Y recorder manufacturers to alleviate the noise superimposed on the input signal, whether resulting from a common-mode voltage or "pump-out" current. One complex method used is to apply "box shielding" techniques to internal transformers and minimize problems such as the unbalance capacitance to ground in the power transformer. This method can reduce the stray unbalance capacitance by a factor of perhaps ten, and therefore, the magnitude of the noise problem by ten, but it is very expensive.

A second method, often referred to as "true differential inputs" utilizes separate but identical input amplifiers for each input terminal. The high impedance characteristic of the input amplifiers is utilized to prevent any currents from flowing out the input terminals. The problem with this configuration is that the voltage drift of both input amplifiers has an additive effect and common-mode rejection is well below the industry standard where 140 dB is common. Improving performance in these areas is usually not economically feasible.

A third scheme and perhaps the most common, guarding, places an electrical shield around the input circuit and signal source to isolate them from ground, thereby eliminating any paths for the noise currents to flow out. However, guarding has some drawbacks such as additional cost, the possible need for guard amplifiers, the burden of driving a guard terminal, and the expertise required on the part of the user to properly interconnect guard circuitry.

A fourth scheme, less complex and often encountered, is to provide a polarity switch in the amplifier of the recorder which can reverse the polarity of the output for a given input signal. This effectively turns the common input terminal into the high input terminal and vice versa. This solution, however, is inadequate in measurement applications where an impedance must exist in series with both terminals such as when connecting across a grounded bridge.

"NOT-SO-TRADITIONAL" SOLUTIONS

A "not-so-traditional" solution, in the sense that it is often overlooked when dealing with this type of noise problem, is to use an input filter. An input filter is also one of the simplest and most effective solutions in applications not requiring high dynamic performance. Basically, whether the input noise comes from common-mode voltage or "pump-out" current sources, the problem exists when this source noise is converted

to normal-mode noise. Therefore, adding a filter as indicated in Figure 5 can attenuate the developed normal-mode noise to an acceptable level. Several appropriate filters are described in Note #1. Interestingly, this is the reason why most low dynamic performance recorders usually have input filters and therefore, tend to exhibit noise immunity.

A second "not-so-traditional" solution is a simple input circuit design now available. This basic circuit (Figure 6) can be referred to as a Circuit Common Driver. This circuit, patented and presently used on the high sensitivity (20 uV/cm) HP 7047A, eliminates all restrictions on the input connection's configuration by virtually eliminating "pump-out" current. Additionally, it eliminates the need for an external guard connection while maintaining maximum CMR (typically 150 dB).

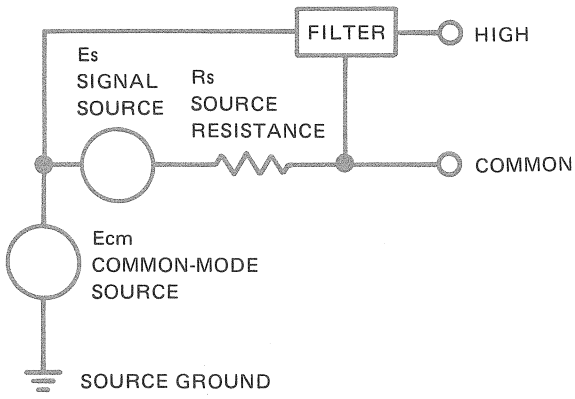

Figure 5.

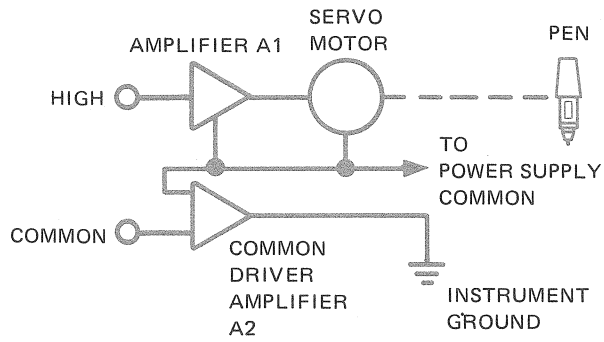

Figure 6.

The characteristics and applications of the Circuit Common Driver are covered in X-Y Recorder Note #4. However, the following explanation describes its operation in the most basic sense. The circuit's goal is to keep "pump-out" current zero, thus the common input terminal is an input to amplifier A2; its other input is circuit common. A current in either of these two inputs is amplified by A2. The active output of amplifier A2 is not the grounded output but actually is its power supply common. Note that circuit common and power supply common are one and the same. The amplifier can therefore drive its power supply common (also circuit common and the second input to the amplifier) in such a direction that zero current flow is maintained through the common input terminal.

IN SUMMARY

It is important to be aware that performance degrading input noise in X-Y recorders can come from many sources. Normal-mode noise on the input signal is perhaps the most common. Techniques available to eliminate this problem are treated in X-Y Recorder Note #1. Common-mode noise, often ignored or misunderstood, is well covered in the literature (i.e., HP Application Note 123) and to a much lesser extent in this note. Input connections, however, can be configured to cause serious input noise problems when using many X-Y recorders. The least desirable configuration, when the high input is grounded, not only makes common-mode rejection a significant problem but can itself actually generate noise. Understanding these potential problems and the available solutions can serve as a guide, both in selecting equipment and in avoiding potential application problems.