Active balanced inputs & outputs

By Richard Cabot, P.E.

Using balanced inputs and outputs can provide a clean connection while overcoming many of the problems early system engineers encountered.

Since the first audio engineer tried to wire two pieces of equipment together, system interfacing problems have existed. Equipment that works flawlessly alone can wreak havoc when wired together. Early audio workers used transformers to solve differences in ground potentials between equipment or signals picked up in cabling. These transformers helped to usher in the age of balanced and floating interfacing. However, they also added significant cost, weight and distortion to the equipment. As the performance of the electronic equipment improved, these shortcomings became more noticeable. The large size of the transformers also made them inconvenient for use in the ever-shrinking chassis of transistorized equipment. Designers sought ways around the use of transformers and discovered electronically balanced inputs and outputs (I/O).

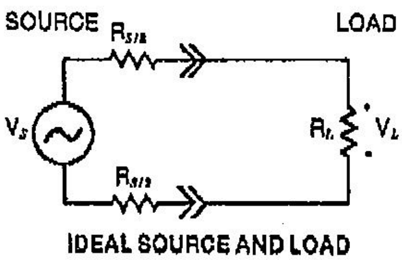
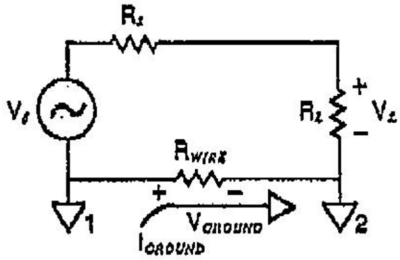


Figure 1A. A basic source—load connection. No grounds are indicated, both source and load float.

Let's first examine what a balanced line is and what problems it solves. Figure 1A shows a basic source and load connection. No grounds are indicated, both source and load float. This is nirvana for equipment interconnection.

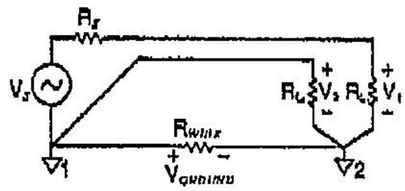
Either the source or the load may be tied to ground with no problems, but



$V_L = V_S + V_{GROUND}$

Figure 1B. An unbalanced system where each piece of equipment has one of its connections tied to the ground.

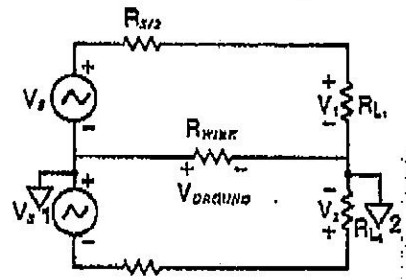
there can be only one ground connection. *Unbalanced systems* are when each piece of equipment has one of its connections tied to ground, as shown in Figure 1B. This occurs, for example, because the source is an amplifier output whose power supply is tied to chassis. The difference in ground potential causes current to flow in the ground wire and develops a voltage across the wire resistance. The ground noise voltage directly adds to the signal itself. Because this ground current is usually from leakage in power transformers and line filters, the current is 60Hz ac and gives rise to hum. If the wire resistance is reduced by using heavier ground wire, the hum will be reduced but it is difficult to get an adequately low resistance.



$V_1 = V_S + V_{GROUND}$
$V_2 = V_{GROUND}$
$V_1 - V_2 = V_S$

Figure 1C. The cancellation of ground loop noise by amplifying both the high side and ground side of the source and subtracting the two.

By amplifying both the high side and ground side of the source and subtracting the two, it is possible to cancel the ground loop noise, as shown in Figure 1C. This is the basis of a *differential input* circuit. The cancellation runs into trouble when the source impedance of the unbalanced source is taken into account. One side of the line will have a slightly lower amplitude because of the attenuation of the source impedance. By creating a signal that is out of phase with the original, we make the source balanced and eliminate this error, as shown in Figure 1D. An added benefit is that for a given maximum output voltage from the source, the signal voltage is doubled over the unbalanced case.



$V_1 - V_2 = 2V_S$

Figure 1D. A balanced source where the amplitude error is eliminated.

CMRR

The measure of how well an input rejects ground noise is called *common-mode rejection ratio* (CMRR). (See Figure 2.) If a differential input is used to reject noise, the desired signal is applied between the plus and minus inputs of the amplifier. The amplifier will have a certain gain for this signal condition called the *differential gain.* ground noise voltage appears on both plus and minus inputs simultaneously, or *common* to the two inputs. Because the amplifier subtracts the

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floating output of their products. The basis of these designs is shown in Figure 8. The circuit consists of two operational amplifiers, which are cross-coupled with positive and negative feedback. The output of each amplifier is dependent on the input signal and the signal present at the output of the other amplifier. These designs may have gain or loss depending on the selection of resistor values. Also, the output impedance may be set via appropriate selection of values. Some resistance is needed from the output to ground to keep the output voltage from floating to one of the power supply rails.

Because of the added resistors to ground and any output ac coupling, the impedance from the output to ground is not infinite. This reduces the coupling of ground noise experienced with the previous circuit but does not eliminate it. If care is not taken with compensation, stability problems may result. Designing the output stage with a gain of two allows the signal to drive balanced loads to approximately 20V from standard op-amp supplies, as with the previous circuit. However, when unbalanced loads are used, the swing is limited to one half this value before clipping occurs. If the circuit is designed with unity gain it will not clip until the circuits driving it clip, but the output voltage is halved. Aside from these minor problems the circuit works well and can exhibit superior bandwidth to a transformer output stage at significantly lower cost.

Interfacing problems

Susceptibility to radio frequency interference (RFI) is a common problem with active balanced inputs. Strong radio signals can often be rectified by nonlinearities in the input operational amplifiers or transistors. Although wideband, low-distortion circuits will be less prone to this problem they are not immune. Therefore any signals that are outside the range of the active circuits must be filtered out before they are inadvertantly demodulated. Most manufacturers add small series resistors and capacitors to ground at the input terminals.

Inductors may also be added. Inductors are coils of wire just waiting for a passing magnetic field to sneak in. However, if package shielding is inadequate, they may pick up as much garbage as they are supposed to filter out. The use of torroidal inductors will usually reduce pickup of external signals substantially. A schematic of a typical input RFI-rejection filter is shown in Figure 9. For the reasons cited above and because of cost, the inductors are often omitted.

The clipping point of actively balanced inputs and outputs is often not what you might expect. The active balanced output stages discussed earlier can deliver as much as 20V into a high-impedance balanced load. However, when they are unbalanced the maximum output is cut in half. The maximum output specifications of any product you intend to use should include the conditions over which the level must be reduced and the amount of reduction.

Output floatability is often unspecified in the actively balanced and floating outputs. When driving a remote power amplifier in a large sound reinforcement system from the main equipment cluster, there is often a large potential difference between chassis. This may be a result of the equipment being on different phases of the power line. A transformer floating output will have a small capacitance from the center tap of the balanced line to ground and will induce very little 60Hz common mode onto the line. An active balanced and floating output has an impedance from each output to ground, typically several tens of thousands of ohms. This induces a common mode potential between the chassis which must then be rejected by the CMRR of the balanced differential input.

Mixing balanced and unbalanced outputs and inputs can be done if care is taken in planning where signals go and how wiring is to be performed. Simply remember that the ground of one device is not quite the same as the ground of another. The biggest problems will arise with patchbays because all outputs and inputs are thrown together in potentially random order. In these circumstances it is best if all inputs are of one type and all outputs are of one type. Otherwise, one repatching of an effects device can destroy the S/N ratio of the entire system.

Although active balanced I/O circuits are not as good as transformers for rejecting ground noise and RFI, they are usually adequate if well designed. Their advantages in cost, weight and low distortion generally make them the solution of choice in all but the most difficult situations. S&VC

RFI PROTECTION

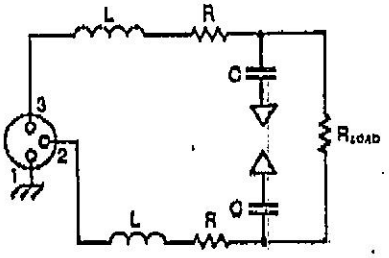


Figure 9. A typical input RFI rejection filter.

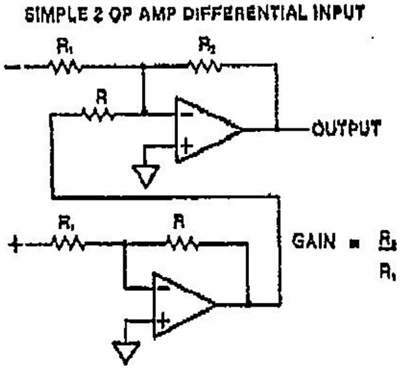


Figure 3. One approach to active balanced inputs.

inverted and will cancel when it is added to the negative input signal. Both inputs are the same impedance and can be easily protected from overloads because of the large input resistor. The matching of resistors limits the CMRR to about 50dB without adding adjustments. With the addition of an adjustment it is possible to achieve 80dB CMRR, but component aging will degrade this substantially over time.

The simplest and least expensive active balanced input is the single op-amp circuit shown in Figure 4. For a unity gain stage, all of the resistors are made the same value. This circuit presents an input impedance to the line, which is different for the two sides. The positive input impedance will be twice that of the negative input. This does not cause a problem except in applications where many of these inputs are paralleled. This input has a common-mode rejection ratio dependent on the matching of the four resistors and the balance of the source impedance. The noise performance of this circuit is usually limited by the resistors and is a trade-off between low loading of the line and low noise.

Adding a pair of buffer amplifiers before this circuit results in an instrumentation grade input. (See Figure 5.) The input impedance is greatly in-

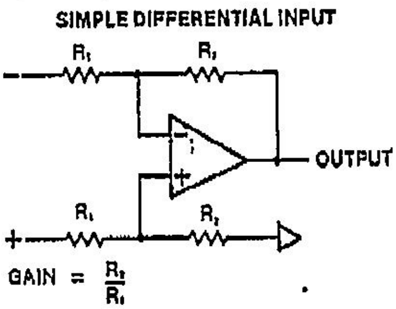


Figure 4. The simplest and cheapest active balanced single op-amp circuit.

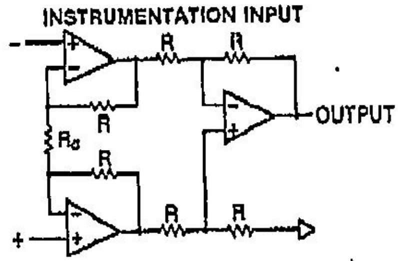


Figure 5. An instrumentation grade input.

creased and source impedance effects are eliminated. Additional noise is introduced by the two added op-amps but the resistor noise can usually be reduced by dropping impedances, giving a net improvement in noise. By adding resistors to the input stage it is possible to add gain while maintaining the low noise. This gain also increases the CMRR by the amount of the gain in decibels. However, the amount of gain that can be used is limited by the line level and the clipping point of the op-amps.

Active balanced outputs

Early equipment with active balanced output stages used the approach in Figure 6. The signal was buffered to provide one phase of the balanced output signal. This signal was then inverted with an op-amp inverter to provide the other phase of the output. The outputs are taken through two resistors, which are each one half of the desired source impedance. Because the load is driven between the outputs of two op-amps, the maximum output voltage is about 20V, double that of an unbalanced output. This circuit works reasonably well if the load is always balanced, but it suffers from two problems.

The first problem arises when driving unbalanced loads or when one side of the signal is inadvertently shorted to ground. If the negative output is shorted to ground by an unbalanced load connection, the first op-amp is likely to distort. This produces a distorted signal at the other side of

SIMPLE BALANCED OUTPUT

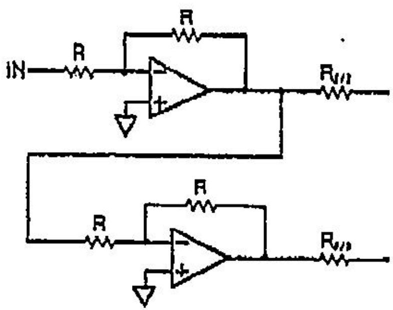


Figure 6. A simple balanced output.

REMOTE GROUND SENSING OUTPUT

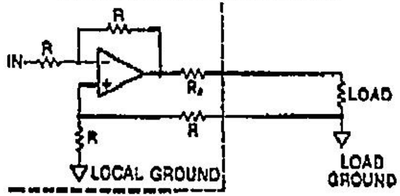


Figure 7. A remote ground sensing output.

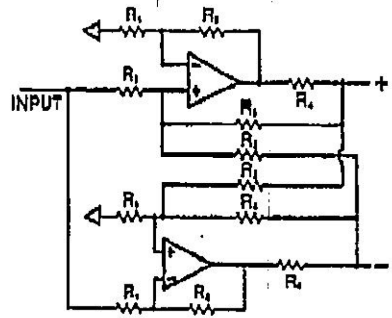
the output. Even if the output is arranged to have the signal from the second op-amp be the one which is shorted by unbalanced loads, the distorted output current is likely to show up in the output from coupling through grounds or circuit board traces. Equipment that uses this type of balanced output often provides a second set of output jacks, which are wired to only one amplifier for unbalanced applications.

The second problem is that the output does not *float*. If there is any voltage difference (power line hum) between the local ground and the ground of the device receiving the signal it will appear added to the signal. The only rejection of the ground noise will be from the CMRR of the input stage at the receive end.

A few companies offer unbalanced outputs that sense ground at the load and attempt to reject hum voltage. A schematic of such an arrangement is shown in Figure 7. They are notorious for problems driving long lines. However, in short interconnect situations they can work well. They do not lend themselves to driving several loads in parallel because there is no longer a single remote ground to sense. They also have a problem patching into other devices because they require that the load be unbalanced and that the ground be isolated from the patchbay or system.

Several manufacturers are now offering an electronically balanced and

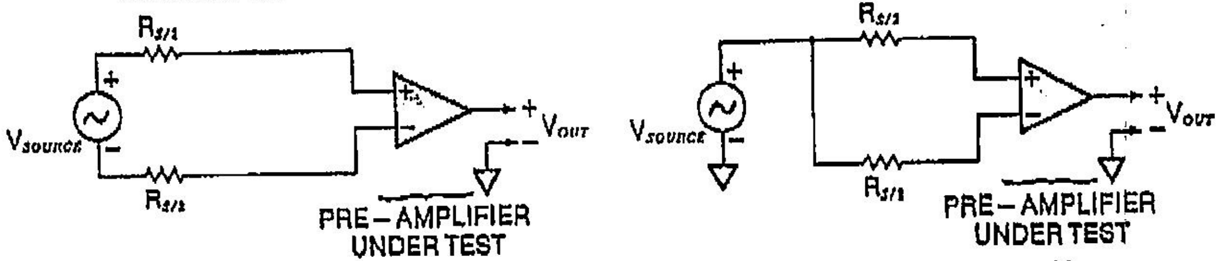
FLOATING AND BALANCED OUTPUT



R_1 MAY BE OMITTED

Figure 8. An electronically balanced and floating output.

COMMON MODE REJECTION



COMMON MODE GAIN = $\frac{V_{OUT}}{V_{SOURCE}}$

DIFFERENTIAL GAIN = $\frac{V_{OUT}}{V_{SOURCE}}$

CMRR (DB)=20 LOG$_{10}$ $\left(\frac{\text{DIFFERENTIAL GAIN}}{\text{COMMON MODE GAIN}}\right)$

Figure 2. An illustration of common-mode rejection ratio (CMRR).

two inputs, giving only the difference between the voltage at the two terminals, the output voltage, and therefore the gain under this condition should be zero. However, in practice it is not. CMRR is the ratio of these two gains in decibels. The larger the number the better. For example, a 60dB CMRR means that a ground signal common to the two inputs will have 60dB less gain than the differential signal. If the ground noise is 40dB below the desired signal level, the differential input will make it 100dB below. However, if the noise is already part of the differential signal the CMRR will do nothing to improve that signal.

Common-mode range is a specification of the largest common-mode signal that can be handled at the input without clipping or other malfunction. Virtually all active input stages are adequate in this parameter, being able to handle several volts of common-mode signal. If there is more than this in the system, the grounding is grossly inadequate. However, with 1V of common-mode signal the CMRR of a typical active input (about 60dB) will not provide adequate S/N ratio; time for a transformer.

Active balanced input circuits

One approach to active balanced inputs is shown in Figure 3. The positive input is buffered and inverted by an inverting op-amp stage. This signal is now added to the signal from the negative input in a second inverting amplifier stage. Any common-mode signal on the positive input has been