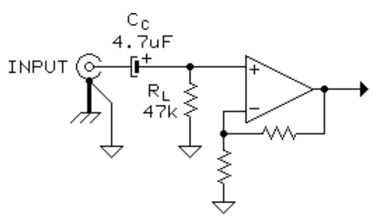
Jensen AN-003
INTERCONNECTION OF BALANCED AND UNBALANCED EQUIPMENT
by Bill Whitlock

Techniques for interconnecting balanced and unbalanced equipment in audio systems seems to be a murky topic for many users, technicians, and system designers. It is the subject of numerous calls to our applications engineers. Confusion, and even controversy, is further fueled by some published "guides" whose engineering basis is dubious, at best. This paper briefly explains the hardware, some underlying engineering theory, and includes wiring diagrams for interfaces that solve many typical system problems.

1 - "UNBALANCED" and "BALANCED"

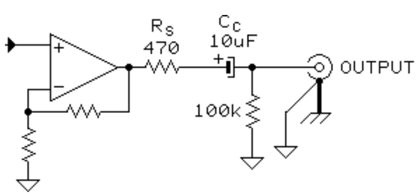
What do these terms really mean? Since I have previously written about the subject of balanced lines in some detail, I will just summarize the most important points here. ***Balance is defined in terms of the impedances of the two signal conductors with respect to a reference, which is usually "ground"***.

An UNBALANCED input or output connects one of its signal conductors to ground and has a non-zero impedance at the other signal conductor. Unbalanced inputs and outputs are very popular in consumer electronics, electronic musical instruments, and low cost (often called "semi-pro") audio equipment. Examples of typical circuits are shown below.



Typical Unbalanced Input

Usual values for R_L are 10 kΩ to 100 kΩ, regardless of the equipment type. It is R_L that effectively determines the input impedance of the circuit.

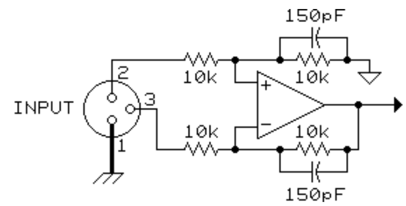


Typical Unbalanced Output

Usual values for R_S are 330 Ω to 1 kΩ and for C_C are 4.7 μF to 47 μF in consumer and musical instrument equipment, often specified to drive a 10 kΩ minimum load. In Semi-pro audio equipment, often specified to drive a 600 Ω minimum load, R_S is usually 47 Ω to 220 Ω and C_C is 47 μF to 220 μF.

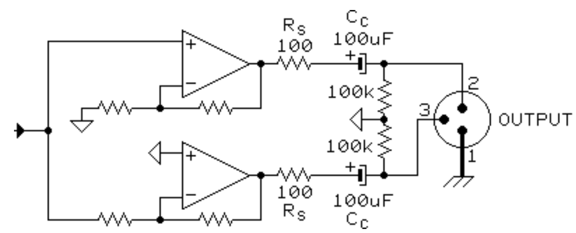
The inherent weakness of unbalanced interconnections is that the shield, which is also a signal conductor, is a path for power line related currents that always flow between equipment grounds. The voltage drop across the resistance of the shield and connectors adds directly to the signal, producing the familiar hum and buzz.

A BALANCED input or output uses two signal conductors which have equal impedances to ground. Balanced inputs and outputs are widely used in professional equipment because the input differential amplifier can, in theory at least, totally null its response to ground noise which exists equally on both signal lines. Examples of typical circuits are shown below.



Typical Balanced Input

Because of its low cost and small size, this "active balanced" differential input circuit (or some variation of it) is very widely used. The pairs of 10 kΩ resistors are trimmed to match within 0.01% in order to null response to ground noise. When used in real-world systems, however, a major drawback of this circuit is its exquisite sensitivity to unbalances in the output (source) impedances of the line driver. This seriously compromises ground noise rejection or CMRR (Common-Mode Rejection Ratio) of the system.



Typical Balanced Output

This output circuit provides two equal amplitude but opposite polarity (symmetrical) signals and equal output (source) impedances to the lines. Values for R_S and C_C are generally in the same range as those for semi-pro equipment and tolerances are typically ±5% for R_S and ±20% for C_C. Although the balance of these (source) impedances strongly control system CMRR performance, especially when used with active balanced inputs, few equipment makers seem to recognize its importance. *The signal symmetry of this, or any other, balanced line driver has nothing to do with ground noise rejection.*

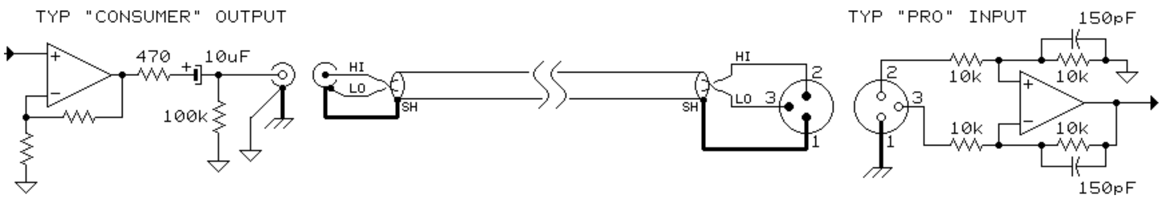
2 - UNBALANCED to BALANCED INTERFACES

The interfaces on the following page do NOT provide the 12 dB gain necessary to raise the nominal −10 dBV (316 mV RMS) "consumer" reference level to the nominal +4 dBu (1.23 V RMS) "pro" reference level. If the pro equipment doesn't have enough gain "reach", an active interface may be necessary. A step-up transformer, even an ideal lossless one, is not a viable source of gain in this application. Reflected impedances cause excess level losses and compromise both low frequency response and distortion.

2 - UNBALANCED to BALANCED INTERFACES (cont'd)

For the applications below, cables should be high quality shielded twisted pair and, to prevent high frequency losses, no more than 1000 pF total capacitance. This is about 20 feet for standard types.

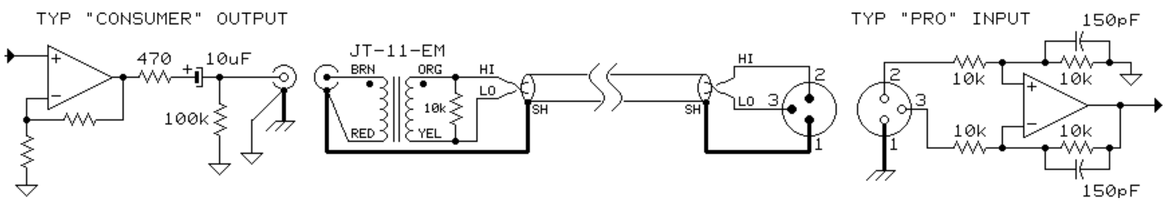
In all cases, unbalanced semi-pro outputs, which generally have lower R_S and higher C_C values, will typically improve ground noise rejection (CMRR) by several dB.



2.1 - "MINIMAL" is an Adapter Cable

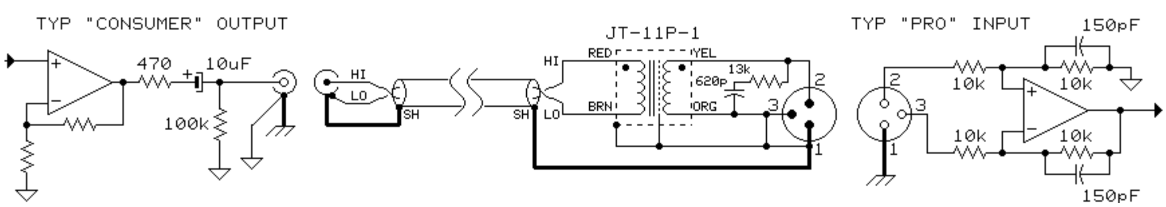
This interface is sometimes called a "pseudo-balanced" direct connection. Chassis ground currents flow in the shield of the cable and the balanced input senses the signal at the unbalanced output connector. This *theoretically* allows the differential input stage to reject the common-mode ground noise.

However, the 470 Ω source impedance unbalance will seriously degrade the CMRR of any simple active balanced input stage. **In the example above, CMRR will be only 30 dB at 60 Hz.** *If the "pro" input already uses a Jensen line input transformer, CMRR will be about 100 dB at 60 Hz, with only this cable needed.*



2.2 - "BETTER" uses an Output Transformer to Improve Balance

This interface uses a bifilar type output transformer to improve the impedance balance. This will reduce the degradation of CMRR at low frequencies for the active balanced type input stage. **In the example above, CMRR will be about 55 dB at 60 Hz**, but because of the interwinding capacitance in an output transformer, CMRR will gradually fall to about 30 dB for frequencies over 1 kHz. Compared to the simple adapter cable, it does not improve buzz, which contains many high frequency components, but it further reduces 60 Hz hum by about 25 dB. This method can also reduce hum by over 70 dB when used with an *unbalanced* input.

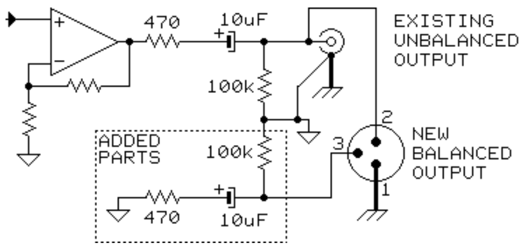


2.3 - "BEST" uses an Input Transformer to "Fix" the Input Stage

This interface uses an input transformer to effectively replace the "active balanced" input stage. The input transformer, unlike the input stage, can tolerate source impedance unbalances with very little CMRR degradation. **In the example above, CMRR will be about 100 dB at 60 Hz** and near 70 dB at 3 kHz, making it very effective at eliminating both the hum and buzz components.

The input stage is operated unbalanced by grounding its – input and driving its + input with the transformer's output. ***If the transformer can be installed inside the "pro" equipment, the resulting balanced input will give outstanding CMRR performance from either balanced or unbalanced (using the adapter cable) sources.***

2.4 - A Simple Alternative



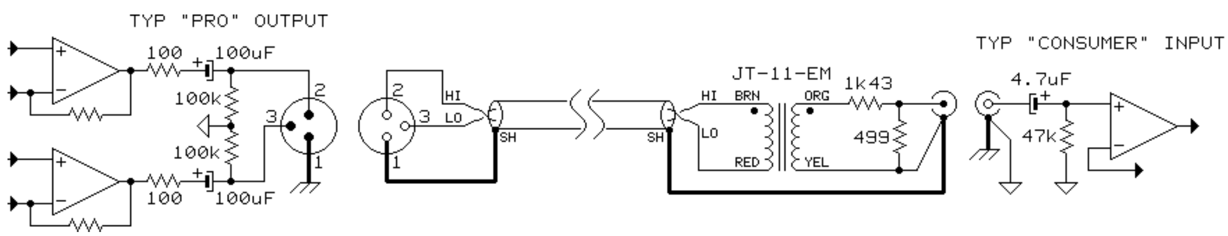
Adding a Balanced Output

A simple modification to equipment with unbalanced outputs can convert it to have true balanced outputs. Get (or trace the circuit to make) a schematic of the equipment's output circuitry. Depending on available panel space, the new 3-conductor output connector can be added or used to replace the existing connector. This modification uses the existing unbalanced output as the + output and adds an impedance matched passive network to ground for the – output. In most cases, it is as simple as shown above.

The output impedance of the existing output is defined by the network between the op-amp output (whose closed loop output impedance is negligible) and the output connector. An identical network to ground is then added as shown.

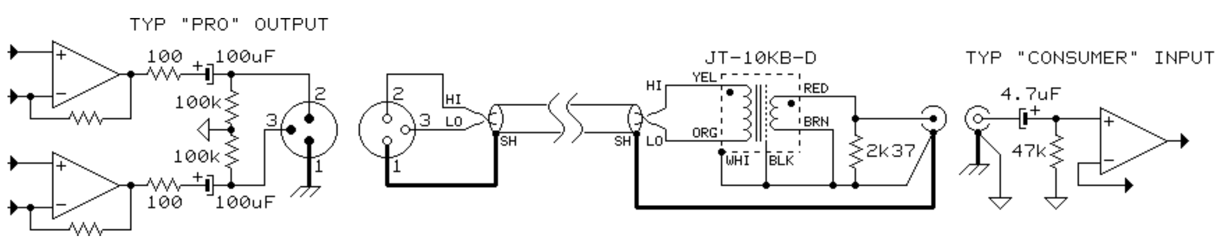
This is also a good opportunity to "hot-rod" the output stage, by lowering and tightly matching its output impedances. Lowering R_S to 100 Ω, ±1% and increasing C_C to 220 μF, ±20%, works well with any popular op-amp known to the author, except for the TL06x, TL07x, or TL08x series (their high open loop output impedance makes them unstable with capacitive loads such as cables). For op-amps operating from symmetrical supplies up to ±18 volts, we recommend Panasonic 16 volt bi-polar electrolytics, part number ECE-A1CN221S, available from Digi-Key or other Panasonic distributors. These parts have the lowest distortion characteristic of any we've tested. The modified output will have balance as good or better than most current pro gear and, with the exception of the possible "gain reach" problem mentioned earlier, will produce excellent results in a professional environment. If the unbalanced output is retained, do not use (or connect cables to) both outputs at the same time.

3 - BALANCED to UNBALANCED INTERFACES



3.1 - "BETTER" uses an Output Transformer and a "Pad"

If the balanced output uses a transformer, omit the one shown and connect HI and LO directly to ORG and YEL respectively. **In the example above, CMRR will be about 60 dB at 60 Hz**, but decrease at 6 dB per octave, making it effective for hum but not for buzz. The same transformer capacitance will unbalance the balanced line at high frequencies, which won't affect the interface itself, but may affect the CMRR of other inputs "bridging" the line. The 12 dB signal attenuation is provided by the two resistor "pad".



3.2 - "BEST" uses a 4:1 Input Transformer to "Do It All"

This interface uses a 4:1 step-down input transformer to provide 12 dB of signal attenuation, excellent ground noise rejection, very little line loading, and full preservation of the line's balance. **In the example above, CMRR will be about 120 dB at 60 Hz** and 85 dB at 3 kHz, effectively eliminating hum *and* buzz. The transformer must be located as shown to reduce capacitive loading.

4 - ABOUT UNBALANCED CONNECTIONS

Please note that, in all the schematic diagrams, connections to the unbalanced IHF plug (formerly the "RCA plug" or "phono plug") are shown as the single point to join SH (shield) and LO (signal low or –). This is very important to absolutely ***minimize the resistance of any remaining path used by both signal and ground currents***. If connections are made as shown, the only remaining common path is the contact resistance of the shield connection between IHF plug and IHF socket. Use a good quality IHF plug with high spring force contacts and make sure the contact points are clean and free of oxides.

With a little extra effort, this small remaining shared path can be bypassed altogether. Leave signal LO connected to the IHF plug shield, but connect the cable shield directly to the equipment chassis. If the equipment manufacturer has thoughtfully provided a binding post or banana jack marked GND, this will be easy. If not, there is almost always room to mount one and then use a mating spade lug or banana plug on the cable's shield.

5 - ABOUT BALANCED SHIELD CONNECTIONS

In the schematic diagram for the typical "pro" balanced input stage, pin 1 of the input socket is shown connected directly to the equipment chassis, based on widely used conventional practice. However, in previous writings, I have proposed that in large, very high performance audio systems using balanced interconnections, this practice can degrade CMRR and introduce system crosstalk or oscillation. I have also proposed that "ground lift" switches be included in all balanced line input circuits, but never on microphone inputs *(a microphone "floats" with no ground path of its own)* or line outputs.

Probably to avoid adding a new dimension of frustration to unbalanced consumer audio systems, this equipment rarely has a power connector that includes a safety ground. Its chassis floats above the environmental ground, sometimes over 50 volts above it. If connected to ground, or other equipment that is grounded, a small current (generally under 1 mA) will flow through the connection. If this floating equipment were connected to a balanced input with pin 1 lifted, the common-mode voltage presented to the input could be over 50 volts. This would tax the common-mode rejection capabilities of any input stage. Obviously, allowing the equipment to float is not a good idea. Unless it is grounded elsewhere, it must be grounded through the cable shield at the balanced input. If you should have some well-designed equipment that actually has a ground lift switch, set it to GND.

REFERENCES

[1] B. Whitlock, "Balanced Lines in Audio - Fact, Fiction, and Transformers", Journal of the AES, Vol 43, No 6, June, 1995.

[2] B. Whitlock, "Answers to Common Questions about Audio Transformers", Jensen Application Note AN002

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