Balanced and Unbalanced Connections

Mike Rivers

The meaning and significance of balanced and unbalanced connections is one of the most misunderstood concepts in audio. It's also somewhat difficult to explain because there are many variations of the balanced topology as well as several possible ways to a balanced and an unbalanced device. Balanced connections have a long history, dating back to telephony. The phone company runs miles and miles of unshielded cable, not even twisted in pairs with very little hum or noise, tet sometimes we can't seem to connect two devices in our studio with ten feet of boutique cable without hum. Some things are just better balanced than others, and there are right and wrong ways of making connections.

A Few Myths, Half Truths, and Misconceptions

Old stories die hard. To begin, let's clear up a few misconceptions that at one time had some basis in fact.

- Unbalanced inputs and outputs are high impedance. Nope. Some unbalanced inputs and outputs are high impedance, but today these are nearly exclusively limited to musical instrument pickups. Why? Because they've always been that way, based on how instrument amplifiers and pickups were built back in the dark ages.

- Balanced inputs and outputs are low impedance, and therefore hum less. Partially true. Most balanced outputs are low impedance. Most balanced inputs are medium impedance. They can hum just as badly as anything else when improperly connected.

- Balanced connections are "professional." Unbalanced connections are stricly for consumer or "prosumer" gear. This was close to true in the early days of project studio gear but it's no longer so. The lines between "pro" and "consumer" are too blurry to try to make this generalization.

- If you connect a balanced output to an unbalanced input you'll lose half the level. Sometimes, sometimes not. It depends on the output topology.

Now, on with the show.

Topology?

That's a ten dollar word but it's becoming pretty common when talking about networking, and that's something we talk about quite a bit these days. In the context of audio interfacing, topology refers to the way that input and output circuits are built. Regardless of what's inside the box, whether a connection between an output and an input is balanced or unbalanced is determined solely by the source – its output must appear between two terminals, each of which has the same source impedance when measured with respect to ground. That's the classic definition, but it takes two to tango. In order to have a balanced connection, the input must be designed to accommodate the balanced two-wire source. Although the term "balanced input" is in common usage, it's really a misnomer. To make a proper balanced connection, a balanced output must be connected to a *differential* input. This is can be either a differential amplifier ("electronically balanced") or a transformer ("transformer balanced").

Balanced vs. Unbalanced Circuits

The signal voltage from a device with an unbalanced output appears between a single "hot" output connection and the signal common point, which is usually electrically bonded to the equipment's chassis. Similarly, a device with an unbalanced input receives its input voltage between a single "hot" input connection and ground. All "mono" (Tip-Sleeve or TS) 1/4" phone and RCA connectors are unbalanced regardless of whether they're used for inputs or outputs. The "ground" connection serves double duty, first by completing the electrical circuit and second, providing a convenient way to connect the cable shield to the chassis. A good shield can be pretty effective, but with an unbalanced connection, any noise that gets through and is induced in the cable will be amplified and passed on through the chain just like the desired signal

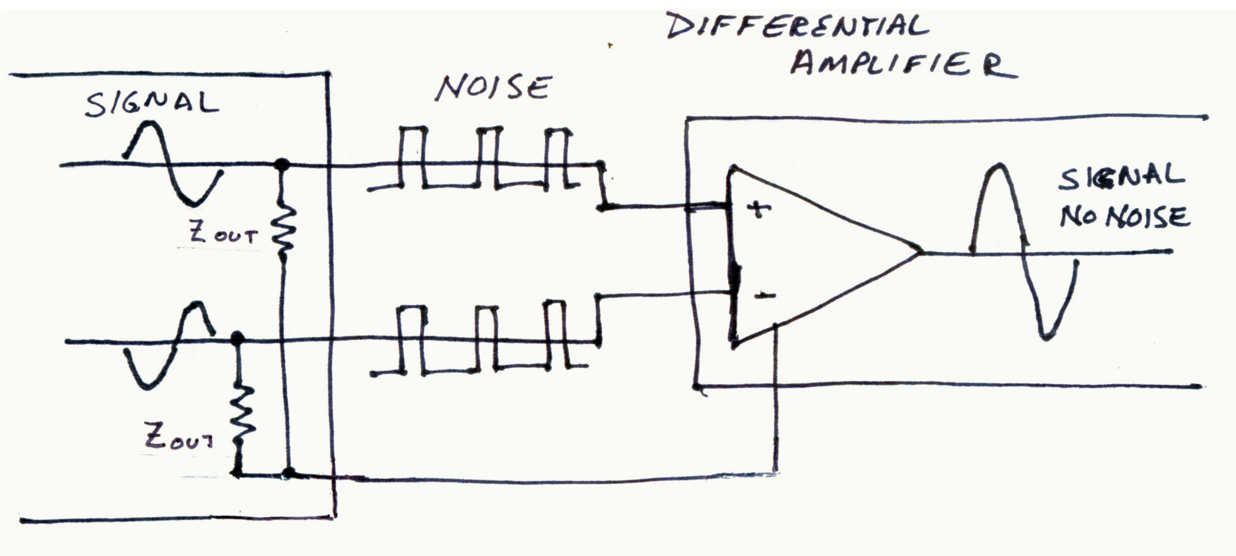
A Balanced output always consists of two signal leads. The ground carries no signal current (at least it's not supposed to) but in addition to being the place where the cable shield is connected, it's the reference point for any noise voltage picked up by the cable on its way to the next input in the signal chain. You may encounter terms such as transformer balanced, electronically balanced, floating, servo balanced, and differential. These are different circuit topologies for creating a two-wire output with the desired signal voltage appearing between the two balanced output leads rather than either lead and ground. Note that for certain topologies, the voltage on least one (sometimes both) of the two signal leads is *also* referenced to ground, but that's incidental, not a requirement for a balanced output.

With a balanced connection, the signal is applied between the two inputs of a differential amplifier or a transformer rather than between a single input and ground. The output of the differential amplifier, as its name suggests, is the *difference* between the two signal inputs. What gives a differential input its advantage is its ability to cancel out *common mode* noise, that is, noise that's the same on both signal leads. Since the difference between two identical numbers is zero, any noise common to both signal leads will be cancelled. This not only includes noise picked up by the wires, but also noise on the ground, since the ground may be common to both inputs.

Since we're only concerned with amplifying the difference between two signals, one of them can be zero (at ground potential) all the time and you'll still have a difference at the output of the differential amplifier. More about this shortly. What's important, and what defines a balanced connection, is that the source impedance, referenced to ground, of each of the two signal leads, must be identical. Here's why:

Forget about the desired signal for a moment and just consider the electrical circuit of the connection between two devices. In addition to the wire between the two boxes, the circuit consists of the source impedance of the output device, the input impedance of the differential amplifier, and it's completed by the common (ground) connection between the two devices. Each of the two signal paths is an independent circuit which, when excited, can produce a voltage at the input of the differential amplifier. When that two-conductor wire connecting the two devices gets too close to a noise source, noise is induced (presumably equally) into both wires, causing a noise current to flow. In accordance with Ohm's Law, this results in a voltage appearing across the output impedance of the source device. To the differential amplifier, volts are volts, and the noise is indistinguishable from the desired signal.

If the impedance at the source end of both wires is identical, assuming that the same current is induced in both wires (a reasonable assumption the way shielded-pair cable is constructed) the same voltage will appear at each terminal of the balanced output. When the two equal voltages get subtracted by the differential amplifier at the other end of the cable, the noise is canceled.



Typically, XLR and TRS (tip-ring-sleve or "stereo") 1/4" phone plugs are used for balanced connections, but be aware that while something might look like a balanced connector, the manufacturer doesn't necessarily wire it that way. Some XLRs are wired unbalanced, sometimes with a balancing option available at extra cost. TRS jacks are commonly used for headphones and channel inserts, but these are actually two unbalanced circuits. Don't get fooled by connector types. RTFM!

Interconnecting Balanced and Unbalanced Devices

These days, most equipment is designed in a manner that allows balanced and unbalanced connections to mixed successfully in a system, but different topologies (there's that $10 word again) require different ways of making two wires out of three. Connecting an unbalanced output to a "balanced" input is straightforward. Simply connect the low (inverting) side of the input to ground. This makes one input to the differential amplifier always zero. Subtract zero from the input signal and it comes ou unchanged. If the balanced input is on a TRS jack, simply using an unbalanced (TS) plug, also known as a common "guitar" cable, will do the trick. The tip of the plug makes contact with the tip terminal of jack as usual, while the ring terminal of the jack connects to the sleeve of the plug, grounding the low side of the input.

Connecting a balanced output to an unbalanced input is a little trickier. You need to know the output topology in order to do it properly. Although the output connector can come in various forms, for consistency, let's use the standard XLR for talking purposes. Conventional wiring, pretty much standard at least since around 1980 when the Europeans and Americans settled on which pin was hot, (but there's always someone who does it backwards) is: Pin 1 – Shield/ground, Pin 2 – Signal High, Pin 3 – Signal Low. TRS jack equivalents are nearly always Pin 1 = sleeve, Pin 2 = tip, Pin 3 = ring.

Output Topologies

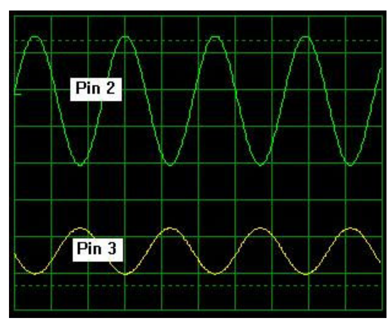
Throughout the tube era, and for several years following with semiconductor designs, nearly every output was balanced by using a transformer. Not only does it provide a near perfect balanced output, it also isolates the signal leads from ground, and converts the high output impedance and voltage of a tube circuit to a more useful lower impedance and voltage. While a decent transformer is the most expensive way to balanced an output, transformers are still found today in many boutique products, primarily for their sometimes desirable sound coloration, ground isolation, and high noise immunity. To unbalance a transformer output, it's necessary to connect pins 1 and 3 together (plugging a TS plug into a TRS jack will do this automatically). This does no harm to either the hardware, the signal quality, or the output level, and even when connected to an unbalanced input, it'll still sound like a transformer. The only compromise is to common mode noise rejection (there isn't any). Incidentally, if you don't ground the low side of the transformer, but rather leave it floating, you'll get a very low level signal between pin 2 and ground, and it will have no bass. This is because the only connection to ground to complete the circuit is through capacitive leakage.

Electronically balanced outputs come in a several flavors. Each of the two signal pins carries the identical audio signal, but opposite in polarity. When the voltage on pin 2 goes to +1 volt with respect to ground, the voltage on pin 3 will be -1 volt. If you were to measure the voltage between pins 2 and 3, you'd see 2 volts, and that's the voltage that a differential input would see.

The simplest method of creating the inverted output is to add a unity gain inverting operational amplifier (op amp) after the non-inverted output. Op amps, however, become unhappy when their outputs are shorted, so simply tying pin 3 to ground, while electrically valid, isn't a good way to connect this type of balanced output to an unbalanced input. It might work OK, but in the worst case, the shorted-out op amp could be damaged, or the short could be reflected back to the non-inverted output, causing the desired signal to distort. The best way to connect this type of output is to simply leave pin 3 unconnected. There's still signal between pin 2 and pin 1, which is just what we want. If the output is on a TRS jack, use a TRS (not TS) plug and connect to the tip only.

It's with this type of output where the story about "you lose half your level" originates. Since you're using only one half of the bipolar output, you're working with only half of the designed signal voltage. If the spec sheet says that the maximum output before clipping is +24 dBu, you'll only be able to get +18 dBu out of it. Using half of an output can also throw off your metering. Since it's fairly common for 0 on a meter to represent the nominal output level, typically +4 dBu for a professional balanced output, instead of +4 dBu, you'll only see 6 dB (half) less, -2 dBu, for a 0 reading on the meter.

Another electronically balanced configuration uses what's often called a "cross-coupled" or "servo" balanced circuit. This generally uses three op amps and delivers the full voltage between pins 2 and 3 even if one of those pins is connected to ground as it must be when unbalancing the output. This output circuit is designed to emulate a transformer, and, while it's far less expensive than a good transformer, requires more parts than a simple op amp inverter. With this output circuit, pin 3 can (and should) be grounded with no detrimental effects when connecting to an unbalanced input. In essence, this puts the inverted and non-inverted outputs in series, which retains the full voltage. In a well-trimmed circuit, the outputs will be truly symmetrical – both will be the same voltage, but this isn't an essential requirement. Although the two outputs will always sum correctly, one voltage may be higher than the other. Taking the output between pins 1-2 without grounding pin 3 can give you unpredictable results. The scope trace at the right shows the relative output levels at pins 3 and 3 from the main output of a popular (and very good) mixer that employs a cross-coupled output stage.



One method of creating a balanced output is so simple it seems almost like cheating, and indeed, some people condemn it as such, but really it works quite well. The signal is connected between pins 1 and 2 only. A resistor equal to the output impedance of the op amp driving pin 2 is connected between pins 1 and 3. This satisfies the requirement for a balanced output that the source impedance for pins 2 and 3 must be identical. How well it works is a function of how closely the "dummy" source impedance matches the active source impedance.

Since, with this configuration, the signal voltage on pin 3 is always zero, there's always a difference between pins 2 and 3, which is just what the differential amplifier at the input of the next device in the chain wants to see. While you'll occasionally find a balanced XLR output configured this way (it works so well that it's even used in a couple of pricey microphones), it's more commonly found on balanced ¼" TRS output jacks. When connecting it to an unbalanced input, grounding pin 3 by inserting an "unbalanced" plug into the balanced jack works just fine. Manufacturers like this arrangement because they don't have to tell novices everything that you're reading here, they can say "just use an unbalanced cable."

This configuration is often called "impedance balanced" or "single ended balanced." If you see the term "balanced/unbalanced" on a spec or feature sheet, it nearly always means the output has this arrangement. Needless to say, it's the simplest and least expensive approach of the bunch, which makes it popular with manufacturers.

Identifying Your Output Configuration

So, how do you know what type of balanced output you have? The easiest way is to look at the schematic diagram, but schematics are scarce these days (most gear isn't built for serviceability any more), but you might get a clue from the product specs or literature. If it's transformer balanced, the manufacturer will probably brag about it. If it's a ¼" jack and the manual or spec sheet says "balanced/unbalanced" it's probably single-ended, balanced with a resistor. You can confirm this (easiest if it's a ¼" jack) by sending a signal to the output in question and gently plugging in a set of headphones. Stop at the first "click" of the plug. If it's a single ended balanced output you'll hear no sound because you've connected one of the earphones to ring (the low side) terminal of the jack. Plug the phones in the rest of the way and you'll hear the signal, but in one ear only since you will have only connected one of the earphones.

If you try that headphone trick with an output that uses an inverting op amp or cross-coupled output, you'll hear a signal (in one ear) at the first click. With the plug fully inserted, you'll hear the signal in both ears, but they'll be out of phase. You can tell because it will sound like it's trying to split your head down the middle. It's a little more complicated to determine if it's a cross-coupled or inverting configuration. To do that, you'll need to look at the level on pin 2 while temporarily shorting pin 3 to pin 1 or ground. If the level increases, you have a cross-coupled output stage. If it doesn't, or decreases slightly or distorts, you have an inverter output stage.

What's Best?

Using balanced connections throughout your system, of course. This will assure that you're not sacrificing operating level or headroom, it offers the best immunity from outside noise sources like interference from your computer monitor or the neon BEER sign in the window right behind the stage, and it will provide you with the best way to deal with grounding and shielding. In practice, however, particularly when a studio grows over a period of time using mixed generations of equipment, you'll be mixing balanced and unbalanced gozoutas and gozintas. You can survive.