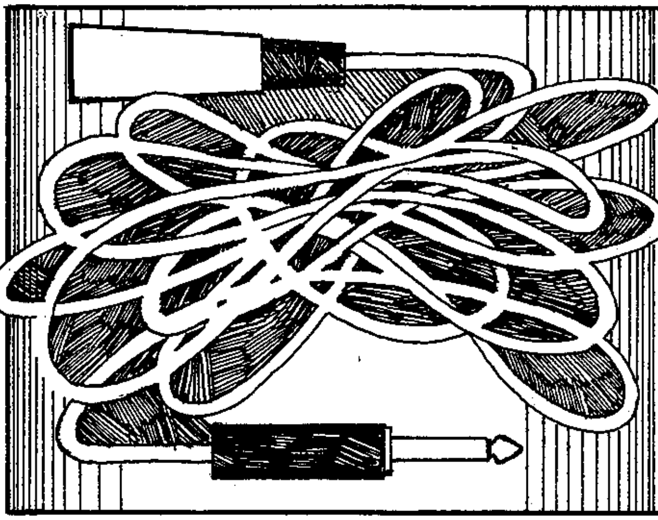
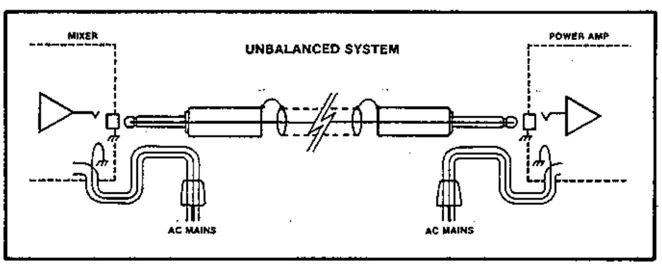


talk about BALANCED vs UNBALANCED systems

By Jack Sondermeyer

The idea of a balanced system is one that has confused even the most experienced audiophile. The actual application of balanced systems are further confused by relating them to the characteristics of low vs. high impedance. A balanced system is unique in that it possesses an electrical characteristic called common mode rejection. If one can grasp the idea of common mode rejection, then a balanced system can be easily understood. The fact that a system is balanced or unbalanced has nothing whatever to do with its impedance level, although usually balanced systems are low impedance, but do not necessarily have to be. To begin with however, let's start with an unbalanced system, which is so called because it is simply not balanced. Whenever separate chassis are used for different parts of an audio chain, such as a separate mixer and power amplifier, the signal must be patched through some connector and cable system. The most common connector used is the telephone plug and jack developed by Ma Bell many years ago. These are simply called a "phone" plug and jack, but other type connectors will work equally well. The cable used must be some sort of shielded type, required to reduce stray pickup of extraneous hum and noise and R.F. signal always present around us. An unshielded cable should never be used in this application. Such a system is shown in figure 1.

FIGURE 1



Notice the ends of the shield are grounded at each chassis and the signal is present on the single conductor with reference to the chassis grounds. Usually the mixer output will have a low impedance source which will help to minimize external interference and fairly short cable runs using this configuration are generally satisfactory. Where the problems usually begin is when the cable length gets excessive (20 Ft. or more), and the separate chassis are connected to different AC mains sources. Such is the condition in a typical sound system with the mixer in the audience and the power amplifiers on stage near the speaker system.

The first problem encountered is an increase in hum and noise due to the failure of the shielded cable to provide adequate shielding in the longer cable run. Any such interference that gets into the shielded conductor simply adds to the signal and cannot be eliminated. If a powerful radio station or a boosted CB radio is located nearby, it too can play havoc with this system.

A similar problem exists whenever unbalanced microphones and other sources are used with a mixer over long cable runs and usually is worse because of the lower signal levels involved and the fact that often those microphones are high impedance.

The second and more critical problem, however, is the different AC mains sources which cause a completely different set of problems. Now mixers and power amplifiers employ a three wire line cord with the usual grounding type plug with the large pin that is supposed to be left alone (not broken off as is normally done). This, of course, is provided to minimize the risk of shock hazard dictated by our various testing agencies. The ground pin is supposed to be grounded through a separate third wire in the typical AC mains recepticle. This ground pin is always connected internally to chassis ground of the associated equipment. Thus the individual chassis are supposed to be grounded to good old Mother Earth. Unfortunately, what is said to ground, really is not. Often ground systems are inadvertently miswired. Other equipment tied to the same ground introduces voltage transients and spikes which cannot be eliminated. Three phase AC voltage systems introduce additional hum voltages into the grounds. If the AC distribution system transformers are located significant distances from the equipment, the long ground wires can actually pick up local radio and TV stations' signals. Lighting dimmers also introduce spikes into the grounds. So, our separate chassis are actually connected to different interference sources rather than common ground as we thought.

The obvious question is, why is this difference in chassis voltage so bad?

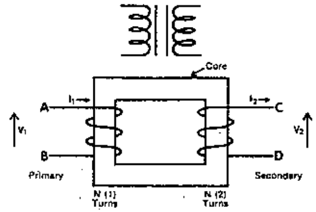
Reviewing figure 1, we see the shielded cable connects the two chassis together via the shield itself. Now, that shield might seem an effective connection between those chassis, but it actually isn't....not even close. The different ground signals that appear at each AC mains recepticle will drive the individual chassis much more so than that small gauge shield wire can short out. In reality, the shield does little for the grounds except shield the signal wire itself. The power amplifier is "looking" for a signal from the mixer to amplify and actually "sees" the mixer signal plus the difference in ground signals that appears between chassis. So, that different signal, which is interference, is actually amplified along with the desired audio signal....The results which are less than desirable.

It might seem that an obvious solution might be to break the ground pin on the units....Heaven forbid....And interestingly enough, sometimes that really works. Another solution is to connect the mixer through a long extension cord to the same AC mains as the power amplifiers, thereby assuring that the grounds are the same. A third alternative is to tie the two chassis together with a very heavy gauge external grounding wire.

All these "fixes" are not totally effective, however, and the only real solution lies in the use of a balanced system, to be discussed next.

Consider the transformer diagram shown in figure 2.

FIGURE 2



Transformers are relatively simple devices consisting of separate turns of wire on a magnetic core. In this case we have constructed a transformer using a certain number of turns on the primary (terminals A & B), and a certain number of turns on the secondary (terms C & D), again both wound on the same magnetic core. These turns are specified as N (1) & N (2) respectively. The actual number of turns and wire size is of no particular importance at this point.

If a signal voltage is applied across terminals A & B, a signal current will flow in the primary windings proportional to that signal voltage. This current will in turn cause a magnetic field to circulate in the core which will be proportional to the signal current and the number of turns used in the primary winding. Continuing, this circulating magnetic field will induce a current into the secondary windings proportional to the magnetic field and the number of secondary turns. This, in turn, will produce a voltage across the secondary terminals C & D which is proportional to that secondary current.

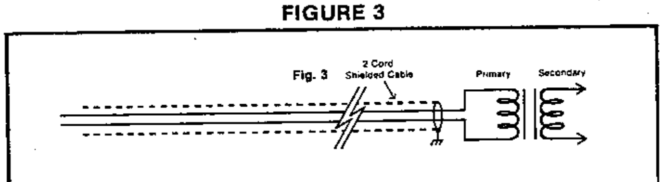
We have just described typical transformer action. Notice there is an energy transformation from electrical to magnetic and back to electrical. Also notice that if both primary and secondary turns are the same, then the output voltage is the same as the input voltage. The actual voltage transformation is determined by the turns ratio as indicated in the following formula:

$$V(2) = V(1)\frac{N(2)}{N(1)}$$

Thus a transformer can "transform" voltages up or down depending upon the turns ratio involved. The actual number of turns are not important....just the ratio....in this formula. There are other considerations such as voltage and power levels which determine the actual turns required in a typical transformer but these will not be treated here.

The important thing to notice about the transformer is that signal will only get through it if a signal current is established in the primary. This current is only possible if a signal voltage is impressed across it. In other words, there must be a difference in potential between terminals A & B in order for current flow. Such a condition would occur if, for example, a microphone were connected across the primary terminals. The microphone signal itself would be this difference in potential. If both primary terminals were connected together and a signal connected to that common point with reference to ground, then both primary terminals would have signal on them but both would be at the same potential and thus no primary current could be established and consequently this signal would not get through the transformer. This is referred to as common mode signal...the same signal on both terminals...and the transformer is said to have "common mode rejection." In other words, common signals don't get through the transformer...and uncommon or difference signals do get through it.

FIGURE 3

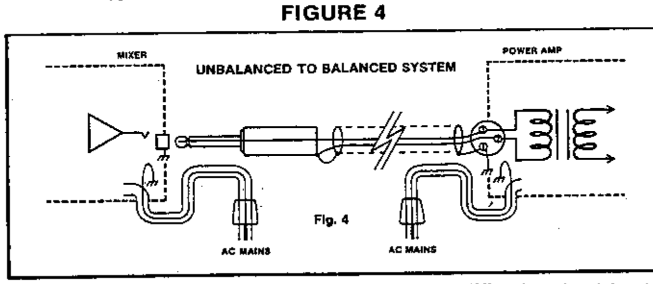


Referring to figure 3, we have connected a two conductor shielded cable to a typical input transformer. Notice the two conductors are wired to the transformer primary and the shield is grounded to the chassis. In our previous unbalanced situation, we mentioned the failure of the shield itself to adequately prevent outside interference from getting into the single conductor and thus this interference would add to the audio signal. In this case, we have two conductors, both being the same length and both reasonably close to one another. Therefore, it's safe to assume that any outside interference that does get through the shield will be picked up by both conductors equally. Thus this "common mode" signal will be rejected by the input transformer and will not be a problem. Any signal that is applied across these two wires, such as a balanced microphone or mixer output will not be a "common mode signal", but rather a difference signal and this will cause transformer action to take place and this signal will get through and be amplified by the system free of outside interference. This then is why balanced systems should always be used for long cable runs....Because they have the inherent capability to reject interference.

We will also show that a balanced system will effectively solve the differences in chassis potentials that exist in separately grounded systems. First, notice that a balanced system always needs two conductors plus ground to work. A single conductor shielded cable can never be balanced. This is why all balanced system connectors have at least three pins. The most common connector used is the three pin XLR type which has become a standard on most contemporary mixing consoles and equipment. Most balanced microphones are also fitted with it. The three pins are always conveniently numbered: 1, 2, and 3, with pin 1 always the ground pin. Pins 2 and 3 are the respective conductors in the cable, and become the differential input for the system. A polarity standard exists for most audio equipment using this connector. Simply described...."A positive voltage potential applied to pin 3 of an input connector will produce an associated positive output voltage potential of the equipment." In other words, pin 3 is defined as the positive input to the mixer or power amplifier. Unfortunately, many times this standard is ignored. A similar standard exists for balanced microphones in that a positive or inward audio pressure wave will produce a positive output on pin 3 of the associated XLR connector. Notice that for transformer balanced systems, this standard is adhered to by simply connecting the primary winding up the correct way depending on how the transformer is constructed. A phase reversal can be accomplished by simply flipping it over. This feature is often included in many mixing consoles....especially studio equipment. A mis-wired XLR connector can do the same thing. In any sound system it is important to maintain the same phase relationship in all the microphones. An out-of-phase microphone will cause endless problems for an unknowing audio technician. A point to remember...the fact that a system uses the XLR connector does not necessarily make it a balanced system. Many times, especially on inexpensive equipment, the XLR connector is wired with pin 3 as the input to an unbalanced system. Pin 2 simply goes to ground and, of course, so does pin 1. Occasionally pin 2 might be the input instead. Now two conductor shielded systems such as microphones and mixer outputs will effectively drive such an arrangement, but obviously it is not balanced, and naturally will be susceptible to interference such as light dimmers and radio station pickup.

In order for the connector to be a balanced input, both pins 2 and 3 must connect to some "common mode rejection system" such as a transformer primary. Consider the wiring arrangement shown in figure 4.

FIGURE 4



Notice that the input to the power amplifier is wired in the conventional balanced configuration with the two-conductor cable wired through an XLR connector to the transformer primary and the shield tied to chassis ground. At the mixer end, however, we are driving the cable from an unbalanced output (referred to as single ended...one conductor output plus chassis ground). Such an output, which is usually a simple phone jack, is only available on many high quality mixers.

Again notice the wiring arrangement. One of the two wires in the two-conductor shielded cable (usually the wire associated with pin 3 on the XLR connector to maintain a proper phase relationship discussed) connects to the actual mixer output signal (the tip of the phone jack). The remaining wire, together with the cable shield, connects to the chassis ground of the mixer (the sleeve of the phone jack). This system is usually referred to as an "unbalanced to balanced" configuration.

Now, referring back to our previous discussion of differences in chassis potentials, notice that one of our differential inputs is connected (by a separate wire) to the mixer chassis. The other input is connected to the actual mixer output. In other words, our input transformer in the power amplifier "thinks" (of course, it's wired to it) it's actually at the mixer chassis and thus it simply "ignores" any differences in chassis potential interferences that exist. Put another way, because the power amplifier input has "common mode rejection" and the differences in chassis potential are common mode signal, they don't get through the transformer. The mixer output is applied to the transformer as a differential signal. Thus it gets through and gets amplified.

Various adaptors are available to convert a standard three-wire XLR connector to a two-wire phone plug to make a convenient conversion. Of course, for permanent installations, the XLR connector can be removed and a simple phone plug substituted and correctly wired. Remember, the two-conductor shielded cable must be maintained the entire cable length to preserve the balanced system.

This unbalanced to balanced configuration performance is usually quite acceptable for most applications. Occasionally, however, levels in interference or professional requirements simply demand a completely balanced distribution system, but first we must discuss typical applications and types of audio transformers.

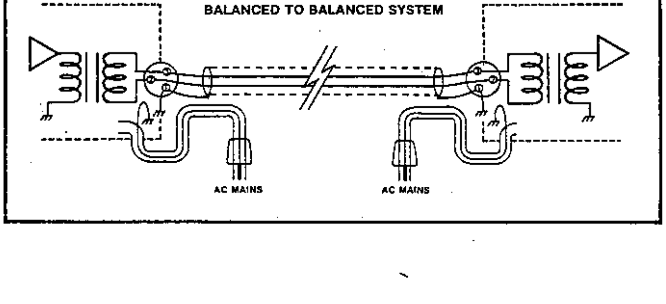
Audio transformers are generally designed for two basic levels of application, line levels and microphone levels. Line level types are designed to work at relatively high voltage levels of 1V RMS or more and are usually found in balanced outputs of mixers and balanced inputs of power amplifiers. These are almost always one to one turns ratio types, providing no voltage gain (or impedance transformation), but rather are employed to provide the balanced condition. Occasionally the 1:1 ratio might be adjusted slightly to provide additional output voltage capability.

Microphone level types are usually designed to work at lower primary levels and the turns ratio is adjusted to provide a voltage step-up to raise the microphone signal to so called line levels. Typically a 1 to 10 turns ratio might be used to raise the microphone signal by a factor of 10. This then would effectively convert the typical low impedance microphone to high impedance and raise the signal level to adequately drive standard high impedance inputs on sound equipment which does not have low Z inputs. The cable/transformer combination supplied with Peavey's PBH™ microphone has such an arrangement. The cable used is the two-conductor shielded type previously described and fitted with a standard male XLR connector wired as outlined. It is designed to work with a standard low impedance microphone and as such, the system is balanced due to the transformer. Cable lengths are of no important consequence due to the characteristics of low impedance systems, and impedance conversion occurs at the mixer end of the cable. Again, this transformer is referred to as a mic to line level type. Notice that this plug-in transformer itself effectively converts high impedance unbalanced inputs to low impedance balanced types providing a way to use low Z balanced microphones with all the obvious advantages of such. Separate transformer packages are available from many manufacturers for this purpose with a wide variety of connector options. Both mic-to-line and line-to-line types are available, the latter being used to balance graphic equalizer and power amplifier inputs. In this case, an impedance conversion is not required and signal conditions are usually at line levels. These types can also be used to provide a balanced output for mixers and equipment which only have unbalanced outputs. These applications will be discussed later. Obviously, if the equipment has low Z transformer balanced in's and out's with the proper XLR connectors, the transformers are provided internally.

Many microphones are available with the conversion transformer in the mic itself. Unfortunately, the space available will only allow a very small transformer to be used and often both the low and high end response is degraded. These microphones are usually fitted with a standard phone plug for use with conventional high impedance inputs. Remember, in this case the microphone is no longer balanced (and cannot be used in balanced inputs) and since it is now a high impedance device, excessive cable lengths cannot be used.

The truly optimum distribution system is the so called "balanced to balanced" configuration. Such a system is shown in figure 5.

FIGURE 5



In this case, the mixer output uses a line-to-line transformer and is connected through an XLR connector to the two-conductor shielded cable. The power amplifier arrangement is similar to that of figure 4, again using a line-to-line transformer connected through an XLR connector. The output connector on the mixer is usually a male type and the power amp input is usually a female type, as are most microphone inputs. This, too, is sort of a standard, compatible with most "snakes" on the market.

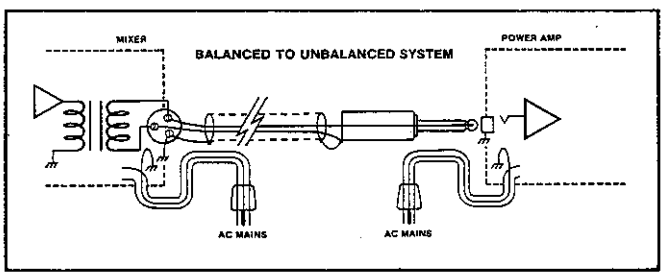
The system is completely balanced since the mixer signal comes from a transformer winding and the power amplifier input is supplied through a transformer winding. Again, of course, our two-conductor shielded cable is used.

Our input has a "common mode rejection" due to the "true differential input"....These points have been discussed. Our output is a "true differential output"....That is, the output is completely floating....there is no ground reference. This output provides a perfect differential signal which will drive the input transformer and be amplified. Notice the current induced in the secondary of the mixer output transformer is the same current which will cause transformer action in the amplifier input transformer. Outside interference is minimized by the common mode rejection of the input arrangement and differences in chassis potential are not part of the circuit because of the differential output. This is truly the perfect, professional system....one that should always be used if possible.

If a mixer does not have a balanced output, it can be done easily with a plug-in transformer package. Similar possibilities exist for unbalanced power amp inputs. (Be sure to use a line-to-line type.) This distribution system is so effective in eliminating outside interference that it is generally used by radio and TV stations to set up a simple remote broadcast using a telephone distribution line for the audio feed. In this case, the balanced-to-balanced system effectively eliminates crosstalk commonly encountered with the telephone company, and minimizes hum and noise pickup, even though telephone lines are usually not shielded.

One more distribution combination exists. This is the balanced-to-unbalanced system as shown in figure 6.

FIGURE 6



In this case, the mixer has a transformer balanced output with the usual XLR connector, but the power amplifier is unbalanced, using a standard phone plug. Often, for economic or simplistic reasons, this is all you have to work with.. Also, as previously mentioned, the power amplifier or in-line effects device might have an XLR input connector, but it is not balanced. A typical example of this is on the Peavey CS-400™ and CS-800™ power amplifiers, where the balanced transformer module, PL-2™, is not used. Instead, a PL-1™ blank plug is used, rendering the XLR connector unbalanced.

In the diagram of figure 6, our two-conductor shielded cable is converted to a single-ended configuration at the power amplifier by wiring a phone plug in the same manner as our example of figure 4. As before, adaptors are also available for this. Obviously, with the input unbalanced, it no longer has common mode rejection capability, and any interference that gets through the shielding of the cable will not be rejected. The signal from the mixer, however, is transformer balanced, with the secondary winding connected to the two available conductors. This true differential output will effectively isolate the chassis differences in potential problems caused by the different grounding locations of the equipment. This condition is usually more troublesome than cable pickup so this arrangement, although not as good as the previous two examples, will at least solve the worst problem. Again, it is a compromise....The best situation is still balanced-to-balanced.

It should now be obvious that whenever parts of the audio chain are separated by any distance and powered from different AC mains, the distribution cable or cables must be balanced. In a typical sound system there might be one main output and two monitor outputs and in this case, all three signal cables must be balanced for optimum performance. However, once these signals reach their destination, any further distribution of them does not necessarily have to be balanced, provided that portion of the distribution system is accomplished on equipment all powered from the same AC mains source. Such a system might be several on-stage power amps connected to a loudspeaker array to produce the desired sound pressure levels with the same signal driving all amplifier channels. In this case, one of these amplifier channels would require a balanced input transformer to maintain a balanced condition in the distribution line from the mixer. The remaining power amplifier inputs can be connected together using single-conductor shielded cables plugged into the unbalanced phone jack inputs, provided there is access to the audio signal after the balanced input transformer. This access point exists on the Peavey CS-400™/CS-800™ power amps and the dual (bridging) phone jack inputs will allow "daisy-chaining" between various channels.

Always remember the concept of "balancing a line", not "balancing a channel" of a power amplifier, if the same signal is to drive each of those channels. Obviously a "stereo" system requires two "lines."

A new technique is beginning to become more popular on contemporary equipment. This is the so called "electronic balanced" inputs and outputs. Here the input transformer is replaced by an electronic device called an operational amplifier. This integrated circuit has two input ports, as does the transformer, and electronically duplicates the common mode rejection characteristic required to create a balanced input. The balanced outputs are usually arranged using two "op amps" to generate two out-of-phase signals necessary to create a true differential output.

Now, it is desirable to design mixers, and especially powered mixers (mixers with internal power amplifiers), with the power transformer as an integral part of the chassis. The power transformer is the device that converts normal 120 VAC line voltage to levels which can be used by the various electronic circuits. As such, it generates high levels of external magnetic fields (@ 60 Hz, the power line frequency....Hum), which are extremely difficult to eliminate. This external hum field will interact with the audio transformer and cause an interference signal to be generated within the transformer itself due to the external magnetic coupling. Although costly shielding techniques, including MU metal cans and covers, are usually provided on most high quality audio transformers, this injected hum can not be completely eliminated. Consequently, some manufacturers remove the power transformer from the mixer itself and offer it as an add-on in a separate box using cables between the box and the mixer. This, of course, is extremely undesirable...especially in portable equipment. For powered mixers, it's impossible.

The alternatives are to either use electronically balanced inputs and outputs, which then eliminate the audio transformers themselves, or use special power transformers which have very low external hum fields. The latter is usually possible in non-powered mixers (Peavey does this in their Mark III™ mixers), but is totally impractical in powered mixers due to the size and physical location requirements. (Again Peavey uses electronically balanced microphone inputs on all their powered mixers.) Given a choice, the use of a transformer is always the better approach due to the superior common mode rejection ratio performance. Also, because of the "gain function" characteristics of transformers, input noise levels are usually lower with input transformers. In the electronically balanced case, all the mic gain will have to come from the "op amp" stage itself. However, with the new operational amplifiers available in today's marketplace, good levels of performance can be achieved economically in both these critical areas.

Unless very carefully designed, the electronic approach will be somewhat more susceptible to radio frequency and light dimmer interference, but in this case, it's a matter of severity.

Often, electronically balanced outputs are simply two out-of-phase line signals which are not "floating" and thus will not isolate differences in chassis grounding problems. However, more elaborate designs will electronically create this important feature. The best, but unfortunately the most expensive approach, is still the transformer....which will always be available.