BALANCED LINES

a paper by:

Mark Levinson
President, Cello, Ltd.

&

Thomas P. Colangelo *V.P.*
Engineering, Cello, Ltd.

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Acknowledgement

Richard S. Burwen/ my original electronics mentor, proposed the use of balanced lines for residential equipment back in 1971 when I first met him. Dick gave me the idea of making no-compromise audio products, providing technology, concepts, and encouragement which serve me today. His own legendary (and now unavailable) Noise Filters and Noise Eliminators used active balanced inputs with staggering CMRR figures, flawless grounding networks, and unheard-of performance long before "high-end" audio existed. Much of the material in this paper came to me from Dick Burwen.

• Mark Levinson

(Note: this paper is intended for readers with limited technical background and is not a definitive engineering text on this subject)

Introduction

Manufacturers of consumer audio products are now becoming more interested in balanced line systems as a means of obtaining a better sound quality.

Cello developed high performance, fully discrete. Class A balanced line audio equipment to interface with professional +32dBm studio environments. Cello was the first company to introduce fully balanced line systems to residential audio. Being active in both the professional (balanced) world and the consumer (unbalanced) world has provided Cello with opportunities to identify, understand and solve certain problems which face the manufacturers and users of high quality audio products with balanced line circuitry.

Audio is an industry which loves buzzwords. Real progress in sonic performance can be obtained, but no single design parameter is all-important. A product with balanced line inputs and outputs is not necessarily better sounding than one with unbalanced circuitry.

Although this paper was written to explain balanced lines to readers with little or no technical training, a certain amount of engineering vocabulary is required. Please consult an engineering dictionary for precise definitions of unfamiliar words contained in this paper.

Advantages of Balanced Lines

Balanced Lines are employed to minimize hum and noise voltages that may be introduced when transmitting an audio signal by cables connecting one chassis to another. Two audio chassis may have different ground potentials due to internal capacitance to the power line which are shorted together by the shield of the cable. The ground current flowing through this shield causes a hum or buzz to be added to the audio signal. The use of balanced inputs in conjunction with balanced lines typically reduces this noise by 30 to 80dB and avoids system degradation.

Theory of Operation

Unbalanced lines (cables) use two points of contact and are the standard system in residential audio. (FIG. 1A)

Balanced lines (cables) use three points of contact and a shield. Balanced lines are the standard system in professional audio. (FIG. 1B)

AUDIO GROUND	PINttI
AUDIO + AUDIO-	PINttZ
SHIELD	PIN*3
	CASE

FRONT VIEW

CENTER (AUDIO+)•

SHIELD (AUDIO GROUND)

SIDE VIEW

L

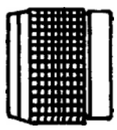
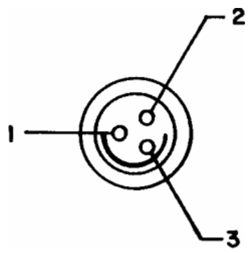
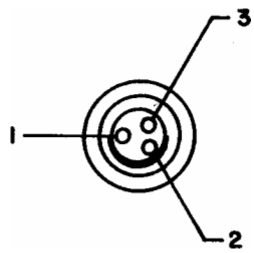


FIG.1A

FISCHER MALE

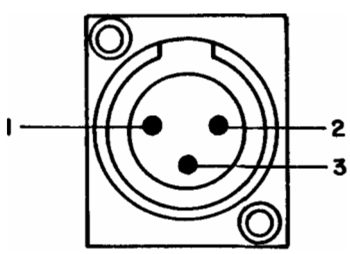


FISCHER FEMALE



PINOUTS FOR
(OUTSIDE VIEW)

XLR MALE



XLR FEMALE

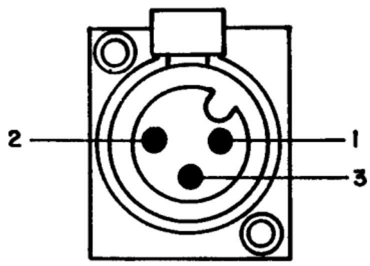


FIG.1B

Balanced line systems are sensitive to the potential difference or voltage between the two balanced conductors (normally referred to as signal+ or non-inverted, and signal-or inverted). The signal common or ground lies at the mid-voltage of these two balanced conductors. These systems use bi-phase transmission of the audio signal referenced to a center tap, ground, or signal common.

In normal practice, two types of balanced line cable construction may be used: 1. the conductors carrying the signal+, signal-, and signal common are twisted together and then covered with an overall shie ld which ties the two chassis together, or 2. the audio+ and audio- conductors are twisted together, covered with a shield for signal ground, a layer of insulation is added, and a final shield connects the two chassis together. The second type can offer better shielding.

Due to the electrical arrangement of this system, undesired electro-magnetic fields intercepting the balanced line are first attenuated by the overall shield. Those fields that do penetrate the shield(s) induce a voltage into the balanced conductors of the same polarity. Since the balanced line system is not sensitive to voltages of the same potential and phase, these electro-magnetic disturbances are rejected.

The degree of rejection offered by any balanced line system is dependent upon how well the system is balanced. This parameter is expressed as the system's "common mode rejection ratio" (CMRR) and will vary with the design of the system.

As with all system parameters, trade-offs are normally made to achieve the best overall system performance concurrent with the particular application. For example, CMKR's in excess of 140dB have been achieved but some of the tactics used to do this could result in sonic degrading effects. Better overall sonic quality usually can be achieved by trying for 40-80dB CMRR.

Factors such as input impedance and cable construction are also important design considerations.

hi unbalanced systems, the shield acts as a conductor for the signal ground and usually the chassis ground. In balanced systems, signal ground and chassis ground are carried by separate conductors. This allows the audio signals (audio+ and audio-) to reference to a signal ground which is independent from the chassis ground or shielding of the system. The quality of the grounding has a major effect on the performance of an audio system, and balanced lines allow superior grounding to be achieved.

Origins

In the early days of recording, overcoming hum was a serious problem due to limitations in technology available at that time. Balanced line cables were designed so that audio signals could be transmitted, and hum (picked up by the cables) could be rejected. These first balanced lines were obtained by using input and output transformers. Input and output transformers are still used in studio equipment throughout the world.

Now, active balanced line amplifiers are being built without transformers. Audio circuits with dual outputs generate two identical but out-of-phase signals. Balanced inputs, with two identical but out-of-phase input connections, accept these signals in place of transformers.

Balanced Line Connection Standards

Just because you see a three-pin connector does not mean that the circuitry is balanced or that the wiring conforms to industry standards.

Some companies are using pin 3 for audio+ and pin 2 for audio-. This practice comes from misunderstandings in the professional audio world which were resolved finally in favor of the pin 2+ system. If pin 3+ equipment is connected to pin 2+ equipment, the wires to pin 2 and 3 must be reserved on one end or the absolute phase of the audio signals will be reversed.

Symmetry

Unbalanced lines are relatively simple to understand as there are only two points of contact.

Balanced lines are based on two symmetrical but out-of-phase signals which operate in push-pull with respect to ground. A balanced line input has two input impedances (FIG. 2): across pin 1 and 2, and across pin 1 and 3. The resistance, capacitance, bandwidth, gain, and other parameters should be the same for each "side" of the balanced line input.

C1

C2

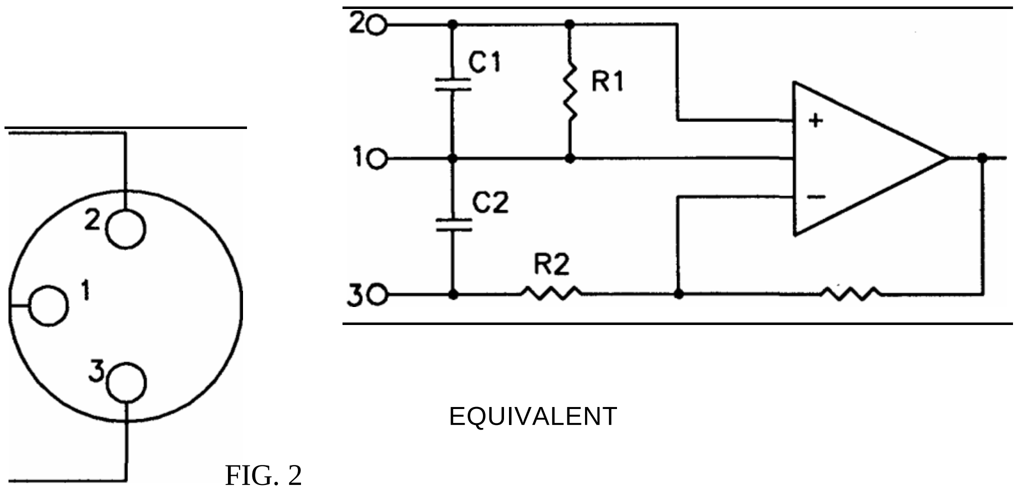


FIG. 2

R1 SHOULD BE EQUAL TO R2 C1 SHOULD BE EQUAL TO C2

Balanced line outputs also must be symmetrical. Both sides of the balanced line output must have identical output impedance across the frequency band, identical gain, and output current capability.

Extremely stable circuitry and parts must be used, or drifts may cause asymmetry to arise which can compromise performance. Providing long-term stability and symmetry is essential for high quality balanced line systems.

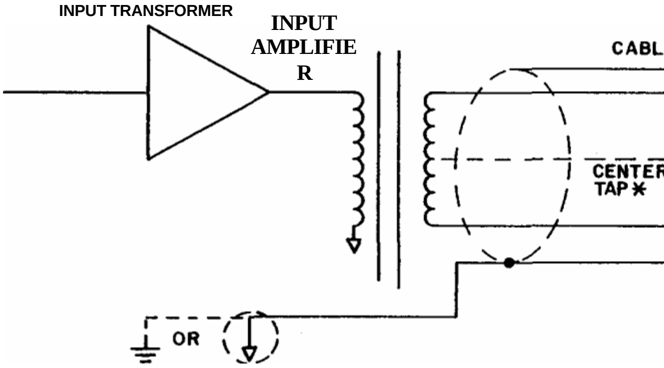
Vacuum tube equipment of the past used input and output transformers to create balanced line terminations (FIG. 3). Drifts in the vacuum tube circuits was not critical because the symmetry was established largely by the transformers which are generally stable.

OUTPUT AMPLIFIER

OUTPUT TRANSFORMER

INPUT TRANSFORMER

INPUT AMPLIFIER

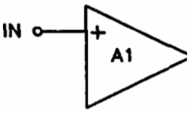


***SOME SYSTEMS DO NOT USE CENTER TAPS.**

Active balanced circuitry is more critical since deviations in circuit performance are more easily created causing sonic degradation. 1% tolerance parts, low impedance signal paths, and thoroughly engineered circuitry must be used in order to guarantee correctly operating balanced lines.

Balanced Outputs

Most active balanced output circuitry is obtained by taking the signal of an amplifier and flipping the phase 180 degrees with another amplifier operating in the inverting mode (FIG. 4).

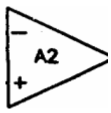


OUTSIDE LOAD

FIG. 4

R1

-0



This is often done using integrated circuits with very low output current capability. The resistor R1 must be approximately lOkOhms. If it is significantly higher, too much noise will be generated. If it is significantly lower, distortion will be too high since R1 is functioning as a load on Al (- input is at ground potential). The load presented to Al by outside equipment will be in parallel with R1. If R1 is 10k and the outside load is 10k, then the total load on Al is 5k. Most integrated circuits sound better loaded with lOOkOhms or more. This is a real problem which can sometimes cause equipment with unbalanced outputs to sound better since the output circuitry is not as heavily loaded.

Also, any distortion caused by loading Al will also appear in A2, which will then add distortion products of its own.

It is therefore important that balanced output circuitry be designed for adequate output current as well as symmetrical gain and frequency response.

Balanced Inputs

Balanced inputs make possible the major advantages of balanced lines. Although balanced outputs provide 6dB more level and other potential advantages, balanced inputs alone allow common mode rejection. Even with unbalanced drive they can offer good rejection if used correctly.

Just as a balanced output must generate symmetrical but out-of-phase signals, a balanced input should terminate each side of the signal with equal resistive and capaci-tive loading such that frequency response and gain are the same. Resistive loading may differ across 1 and 2 compared with 1 and 3 provided that the output circuitry driving the balanced input has sufficiently low source impedance and high output current.

Most balanced inputs use the non-inverting input and inverting input of an operational-type amplifier (FIG. 5). Operational amplifiers (op-amps) are built in discrete, 1C, and vacuum tube formats, but function much the same in terms of balanced input parameters.

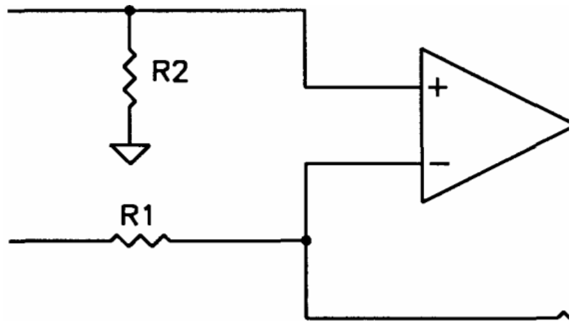


FIG. 5

If Rl is greater than lOkOhms, excessive noise may be generated. If Rl is less than lOkOhms, too much loading will be presented to the incoming signal. An option is to provide a buffer amplifier in front of Rl, but this is complex and poses other problems.

R2 should be equal to Rl for balanced line operation. R2 can be higher if the output signal driving each side of the input has low source impedance.

Terminating Balanced Line Outputs

Balanced line outputs offer no advantages unless terminated with a balanced line input.

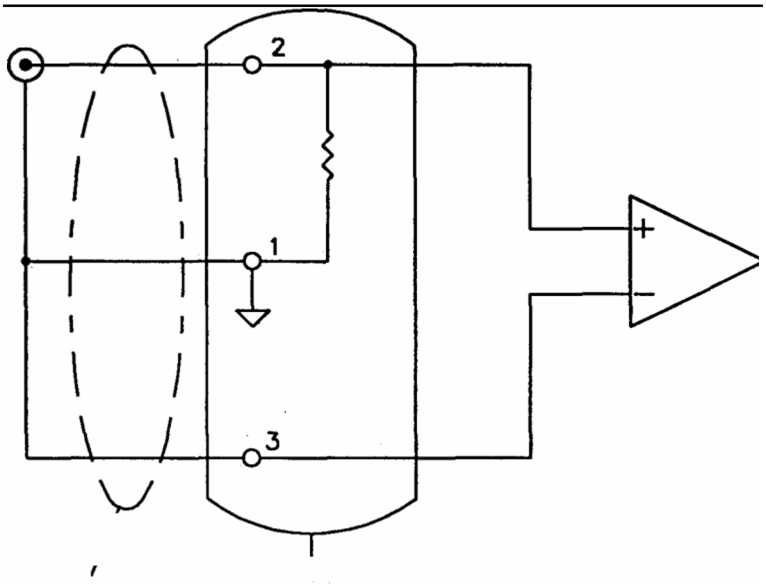
If balanced outputs are connected to unbalanced inputs, care must be taken to terminate the outputs correctly. A balanced output should be connected so that the unused half is not shorted to ground. If an output transformer is used, consult the manufacturer for loading instructions.

Terminating Balanced Inputs

Balanced inputs offer advantages whether driven from unbalanced or balanced outputs/ as long as proper cables and terminations are used.

If a balanced input is driven from an unbalanced output/ then pin 3 must be connected to pin 1 (ground) at the source unit. The shield is generally connected only to the "earth" or chassis ground of the balanced input (FIG. 6).

FIG. 6



Balanced line inputs provide advantages as long as the 3 wires and shield are used between input and output.

Whether driven from unbalanced or balanced output/ the inverting input is returned to ground at the source (output impedance of an amplifier is/ or should be/ essentially at ground potential). Remote ground sensing/ common mode rejection/ and proper shielding are thus obtained. If driven from a balanced line output/ a balanced input system will produce 6dB higher gain than if driven from an unbalanced output because each half of the line is being driven (twice the voltage = 6dB gain).

Noise measurements of a balanced input amplifier must be made with each half of the line correctly terminated. With no termination/ a balanced input will not reflect true noise since gain of the amplifier depends on proper termination of the (-) input (to ground or to an amplifier output at ground potential).

Capacitance, CMRR, and Output Current

Capacitance/ CMRR/ and Output Current are three important and related parameters in balanced line systems.

CMRR is highest when source impedance of audio+ and audio- are equal. Many consumer audio products have output amplifier circuitry with between 100 and 2000 Ohms in series with the output to buffer the circuitry from cable capacitance. If the resistor is left out/ the circuitry does not have enough output current to drive capacitance loads and may distort or go into slew rate limiting. Cables have a certain number of picofarads per meter, and input stages of equipment have capacitive loading for RF filtering and/or circuit compensation to prevent oscillation. Optimum balanced line performance cannot be achieved with such circuits in either unbalanced or balanced output configuration.

Frequency response and distortion are also affected by capacitive loading. An amplifier with IkOhms in series driving a cable with a capacitive reactance of 2500 Ohms at 16kHz will produce a loss of -IdB at 16kHz, a clearly audible effect. Most consumer audio products with unbalanced or balanced line outputs distort audibly when loaded with 2500 Ohms.

Balanced lines can have more capacitive loading than unbalanced lines since the two audio conductors are capacitively coupled to each other as well as to the shield. For example, a 13 meter cable with 230pf per meter (3000pf) plus another possible lOOOpf from an amplifier input stage totals 4000pf. This is a capacitive reactance of about 2500 Ohms at 15kHz. The kind of output stages necessary to drive such loads are not to be found in most consumer audio products today, especially those using integrated circuits with very limited output drive.

Obtaining the best CMRR figures plus low distortion and flat frequency response requires carefully-designed output stages with 100 Ohms or less output impedance and adequate output current capability to drive real-world loading caused by cables and other equipment.

Connectors

In recent years, a number of companies have designed high quality RCA connectors using good materials and improved mechanical designs. Most expensive (unbalanced) consumer audio products use these improved RCA's which are generally superior to the old cadmium-plated steel RCA's of the past. Unfortunately, no such improvements have been developed for XLR-type connectors. This is a major obstacle to be overcome for high quality balanced lines to be more fully utilized in residential and professional audio.

XLR-type connectors, the industry standard for balanced lines, are made by a number of companies including Cannon, Switchcraft, and Neutrik. XLR-type connectors are available with silver or gold-plated contacts.

At the founding of the company in 1984, and after careful consideration. Cello, Ltd. adopted a 3-pin connector series made by W.W. Fischer of Switzerland as their standard balanced line system. This connector is made of the finest materials and offers superior contact pins, sockets, grounding and locking mechanisms.

W.W. Fischer also is making available a small rectangular plate which has the same dimensions as an XLR-type chassis connector, with a 3-pin Fischer connector mounted in the center. Metal chassis punched or milled for XLR connectors can be fitted with this part if conversion to Fischer connectors is desired.

W.W. Fischer makes precision connectors for medical instruments, nuclear research, and other demanding applications. The camac connector used by some companies is made by Fischer (among others). However, this is an unbalanced connector system and cannot be used for balanced line interconnections.

Cable and Terminations

Balanced line cable must include three conductors (audio+, audio-, audio ground) and a shield.

One danger is that people will try to use unbalanced cable and adapt to balanced line use by eliminating some points of contact or jumping some pins together. It is important to make a clear distinction between balanced and unbalanced cable and not mix them.

Balanced line cable can also present higher capacitance per meter than unbalanced cable because the construction usually has conductors in close proximity with only small amounts of dielectric between them. Carefully designed balanced line cable must offer reasonably low capacitance specifications by using sufficient amounts of high quality dielectric such as teflon while preserving conductor thickness.

One reason why capacitance is an issue is that many audio components have limited output current capability and will have increased distortion when driving a more capacitive load.

Shield quality should not be overlooked. The mechanical construction must also be rugged enough to withstand flexing without degradation of cable integrity and provide good strain relief gripping.

If cables are too small or too large for the connector/ the wires may be pulled or twisted which can cause short circuits or broken wires. Only wire specified for the connector size should be used.

It is difficult to bridge the gap between an RCA center pin and the shield with solder. In balanced line connectors, it is possible to short pins together if too much solder is used. Shields can fray and stray wires can short out signal-carrying pins. Greater care and skill is required to make balanced line cables. Either pre-made cables should be sold by stores, or the required skill and care must be possessed by a store's technician. Instead of the simplicity of reaching for RCA cables, store personnel will have to ask what connector goes on each end, length required, pin system (2 hot, 3 hot, or one end unbalanced), and so forth.

Litz-type cables feature conductors comprised of a large number of very fine wires, each separately insulated by a coating of enamel. This construction offers very low inductance properties which can preserve high frequency information. To terminate Litz cable, a solder pot is required. The cable must be stripped and then dipped into the solder pot where the insulating material is burned off and the metal wires tinned. The wire ends (now a group of fine wires soldered together) can be soldered to a connector contact pin. This type of termination requires a solder pot, clean solder and appropriate ventilation. Care must be taken to prepare and tin each end without melting the cable's dielectric or outer jacket while making sure that all wires in each group are totally stripped of enamel and properly tinned. Litz braid shields are particularly difficult to prepare. Litz cables especially should be made under controlled circumstances by trained personnel with adequate equipment.

The basic unbalanced audio cable predictably has an RCA connector on each end. Balanced line cables will have an XLR male or female or Fischer male or female connector on one end. The other end will have an XLR or Fischer of the opposite sex, if it has a balanced cable. If the cable is unbalanced (unbalanced output to balanced input or balanced output to unbalanced input), the cable will have an RCA or camac on one end.

It will be necessary to check whether the balanced equipment is industry standard (pin 2 plus) or non-standard (pin 3 plus). The cable should be marked so that it will not be used with equipment of the other type.

The shield (case) is sometimes tied to audio ground in the connector. This is not correct. Shields should always be separate audio grounds, except at tie points provided in the equipment chassis to prevent ground loops. For example, when a 3-pin connector is on one end of the cable and an RCA is on the other end, the shield should be connected to the case of the 3-pin connector only, provided that a wire in the cable connects pin 1 of the balanced connector to the case of the RCA connector.

When using XLR connectors, efforts should be made to use the same brand of line and chassis connector, i.e. Switchcraft to Switchcraft, Cannon to Cannon, Neutrik to Neutrik. XLR connectors of different brands may not lock and may not establish case-to-case contact (shielding). If the shielding is not connected, hum and noise are likely to be picked up.

Failure Modes

Unbalanced cable is relatively simple to terminate. As there are only two points of contact, cables usually work if they pass signal. Balanced line cables are far more complex to assemble and test.

If connections to pin 2 and 3 are reversed, absolute phase will be flipped. If this is done in both left and right channel cables, the sonic effect may be negligible. If only one channel is phase-reversed, drastic losses will probably occur due to cancellations.

If any pins are shorted or not connected, a number of problems can occur. For this reason it is important to test with a voltohmeter for continuity on all pins of every cable.

With XLR connectors, it is a good idea to check for continuity between the case of line connector and case of the chassis connector, even if connectors are of the same brand. Studies have shown that case-to-case contacts between XLR connectors are not to be counted on.

Fischer connectors virtually never go bad and require no maintenance. XLR connectors without gold-plated pins should be periodically checked for oxidation and corrosion as these will impair performance. XLR connectors can be disassembled and cleaned manually with solvents and steel wool or fine sandpaper.

Gold-plated XLR connectors should still be checked for worn plating. Actual contact area of XLR pins and sockets is erratic since the socket is bent metal formed to no precise dimension. This creates a high wear factor on plating. Even if line and chassis connector contacts are both gold-plated, case (shield) contacts are not possible to gold-plate.

Summary

Balanced lines offer theoretical advantages which are only gained by thorough implementation of correctly-designed circuits, connectors, and cables. Unbalanced lines are still a practical and sensible solution for most home audio applications. Sonic improvements with balanced lines can be obtained only when all components are optimized for quality and compatibility.