DIFFERENTIAL TECHNOLOGY IN RECORDING CONSOLES AND THE IMPACT OF TRANSFORMERLESS CIRCUITRY ON GROUNDING TECHNIQUE

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"DIFFERENTIAL TECHNOLOGY IN RECORDING CONSOLES AND THE IMPACT

OF TRANSFORMERLESS CIRCUITRY ON GROUNDING TECHNIQUE"

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Possibly, the least understood problem encountered during the construction of a recording studio is the powering and grounding of the equipment. While the arts of acoustics, monitoring, and equipment design have been studied extensively it seems that the art of studio powering and grounding has been left to the "Black Art" category.

As an appendix, I have included a short comparative analysis of performance of Differential Technology to Transformer Technology. While many readers will sigh relief that their opinions concerning transformers have been proven true, the remainder of the readers will have their eyes opened.

The Transformerless Technology is here now!

Technological advances in equipment interconnect design during the past two years dictate we remove the science of grounding from the archives of mystical magic and bring it into the daylight. To this end I have written the following paper covering basic powering and grounding practices which I have learned over the years and have applied with complete success in every instance. I have attempted to write in layman's terms such that no degree in mathematics or electrical engineering will be required to follow the guidelines and procedures outlined.

THE A.C. LINE

All hum, buzz, and many of the R.F. problems in a studio installation start with the A.C. mains and their relation to ground. The A.C. power wiring, light fixtures, power cords, and virtually every piece of equipment connected to the A.C. Line projects an electrostatic and an electromagnetic field which may be picked up by every audio wire and circuit in the studio. Additionally, the A.C. mains are a carrier of many forms of Radio Frequency Interference (R.F.I.) generated by electric motors, S.C.R. Dinmers, medical equipment, computers, and a host of other appliances in day to day use. To minimize the effect of these fields on the audio installation, careful, thoughtful design implemented with extensive quality control of the actual electrical work is essential.

The first step to proper A.C. Power is:

Isolate the studio from the power company and all general purpose electrical wiring in the building.

The simplest way to accomplish the isolation is to request the power company to provide a separate power transformer and electrical service from their service pole. Most smaller studios in their own building will have no problem with this, however, in some areas and large buildings it may not be possible. If the power company can not provide a separate power entry, then you must obtain an isolation transformer. The isolation transformer should be equipped with a Faraday Shield which connects to the secondary ground side.

Power Lines are available in many formats. The three most prevalent are Single Phase, 2 Phase and 3 Phase. (See Figure 1.) The most common entrance format is the 240 VAC-2 phase. Three phase entries are found in larger buildings. Direct connection to three phase systems should be avoided as they are usually used for air conditioning and other heavy power equipment.

Use Single Phase Power for the Control Room

A piece of electronic equipment with a power transformer will still have a small capacitive coupling between the case and the A.C. Line. If connected to another piece of equipment running on a different phase or the power line an electric current will flow in the ground between the two pieces of equipment. (See Figure 2.)

An example of this type of leakage is the requirement to reverse the plug on your turntable to minimize hum in a stereo system.

When wiring the control room be sure that all outlets are wired to the same phase of the A.C. Line - the best way to be sure of this is to order a single phase output winding on the isolation transformer. By having all equipment connected to the same phase of the A.C. Line, you will minimize the amount of 60Hz leakage current flowing between pieces of equipment.

Keep the "Clean" Circuits Clean

Do not use the studio mains power for any purpose other than power audio equipment. Never - power flourescent lights, fans, S.C.R. dimmers, or coke machines on the studio power.

If requirements to run refreshment equipment or game room equipment exist, run a separate circuit on a different service entrance, or at the minimum a different phase of the mains than the control room is powered from.

Shield all A.C. power wires in conduit and isolate from the audio.

Locate your master power panel and the entrance power conduit at least 30 feet from the console and other electronics, particularly tape machines. Avoid running conduit or A.C. power in troughs with audio wiring, under the console, etc. Remember that the A.C. wires radiate magnetic fields which decrease in intensity proportional to the square of the distance from your equipment.

Always use a separate ground wire for 3rd pin ground.

Many studio installations have the 3rd pin of all the power cords cut off. <u>This is unsafe and unnecessary</u>. ALWAYS run a separate insulated #14 or #16 ground wire to each outlet's 3rd pin. Use receptacles having an isolated 3rd pin such as: <u>Hubble - IG5362</u>

nuppre	-	100002
G.E.	-	GE8300-IG

and if you use Waverly strips, clip the case grounding prong off the back of each socket, then run the 3rd wire (GRN) of the strip to your system ground plate and tie the outer metal case to the conduit.

Each 3rd pin ground should return directly back to the "Ground Plate", discussed later in this article. Always use "Star" wiring, wherein each outlet has its own wire back to the "Ground Plate" rather than daisy chain wiring. The ideal ground will not require that any piece of equipment share a reference wire with any other piece of equipment. (See Figure 3.) Never let the 3rd pin ground short to the conduit as this will always produce ground loops. Electricans allow conduits to touch each other, touch water pipes, and interconnect. Conduit is not a useable ground for audio work.

water pipes, and interconnect. Conduit is not a useable ground for audio work. When the studio wiring is being installed, the studio technician will do well to have all 3rd pin grounds left unconnected at the ground plate. Then, after the wiring is run, each receptacle can have the 3rd pin ohm'ed to conduit to verify isolation - connected to ground - then ohm'ed to verify ground.

GROUNDING

Having gotten into the subject of grounds, several key points must be understood.

What is Earth?

Earth is correctly used to describe the power company ground. The heavy ground wire brought into the breaker box and grounded to the ground plate in the breaker box is "earth". This should be the only interconnect to the world outside of the studio. Frequently a ground rod and/or water pipe ground is tied at this same point. In most communities, the water pipe ground connection is a legal requirement.

What is Ground?

Ground is a relative term. Ground is the name we give to the point we want to call the zero signal reference. It is the zero signal reference only if every piece of equipment ties to this exact spot. There must be one and only one Ground Point in the entire studio complex. It is to this point that all 3rd pin grounds, case grounds, etc. should tie, like the spokes of a bicycle wheel.

Ground should tie to "earth" by one interconnect from the zero signal reference node to the power company ground.

The best point in the control room to make the zero signal reference is a ground lug on the mixing console. M.C.I. recording consoles as well as many others currently produced have such a ground plate. If such a ground plate is not available or inadequate use a conventional buss strip available at an electrical supply. (See Figure 4.)

Alternatively, (See Figure 4.) Alternatively, the ground plate in the fuse box can be used and a single heavy wire run to the mixing console ground. While this is a much easier system to implement it will not be as good as having all grounds at the console where signal amplification occurs, and the closer these amplifiers reference to "Ground", the less they will amplify ground noise. (See Figure 5.) For example, a wire having of lo microvolts or a signal that is -100dB below line level. If this signal is applied to 8 microphone preamps with 40dB of gain it will be -42dBv, or 23dB above tape noise.

Grounding the Equipment Rack

Acceptable performance can usually be achieved from the typical equipment rack if a single heavy ground is brought back from each power receptacle in the rack to the ground point. When doing this the following three precautions should be observed:

- 1. Be sure that the power line input of each piece of equipment mounted in the rack is transformer isolated. If not, connect to power through an isolation transformer.
- 2. Any piece of equipment which is not balanced in and out should be

isolated from the rack and a separate ground wire taken back to the ground point. (Note: if done correctly the 3rd pin will usually be adequate.)

3. Each piece of equipment installed in the rack should follow correct grounding and shielding design:

To properly ground and shield a piece of electronic equipment, tie the case, the 3rd pin earth (or ground reference), and the electronics ground together at only one point. The point on the electronics ground should be the zero potential point which is that point from which all current flows to the circuits. (See Figure 6.)

If you find a piece of rack equipment which does not follow this grounding format, be cautious when wiring it into the system. You may find that electrical isolation from the rack or modification of the unit is necessary.

A violation of rule 1 can cause a power/ground loop if the low side of the A.C. Line is tied to chassis. (See Figure 7.) If the equipment is also unbalanced in/out as most any low cost unit not having a power transformer will be, then the low side of the line is linked back thru the entire audio signal system and A.C. power can actually be fed thru the console circuits to ground causing 50/60Hz modulation of the console ground. Always remember that the low side of the A.C. Line has current from each device flowing thru it. Thus, there is usually a voltage drop of a volt or more between Ground and the low side of the A.C. Line.

A violation of rule 2 can cause A.C. leakage current from every piece of equipment in the rack to be superimposed on the audio low side as an A.C. voltage or hum.

What about the "Carry In" Equipment?

Frequently mixers or groups will bring their own electronic device and want to connect it into the system. Since much of this carry in equipment will be unbalanced and may not have a power transformer, the console patch bay should have several 1:1 line transformers available on patch. Usually isolating the inputs and outputs of the piece of equipment will solve most hum and R.F. problems if the control room power circuits are properly done.

SHIELDING AND THE AUDIO INTERCONNECTS

Once we have all the equipment connected to power and to the ground reference, we must interconnect the signal lines.

The best installation procedure to follow when interconnecting the studio equipment is:

- Step 1. Connect Control Monitor System and Console. Apply power and with all faders closed, monitoring the 2 mix bus with the mix master fader and monitors at full level - listen for hum, buzz, and R.F.. Only when you are satisfied with the system noise character go to Step 2.
- Step 2. Connect noise reduction units and multitracks to the console one at a time. Apply power and with appropriate channel faders at nominal level and machines in Input, check for hum, buzz, and R.F.. Only when you are satisfied with the noise character, go to Step 3.

Step 3. Connect one piece of peripheral equipment at a time to the console. Monitor the equipment at signal levels and verify operation and acceptable hum, buzz, and R.F.

By following the above three steps you will be able to pin point problem connections as they are made, saving much work and time.

Careful adherence to the following shielding and signal interconnect rules will provide a sound basis to prevent most of the hum, buzz, R.F., and cross-talk problems usually encountered when wiring a new studio.

Shields should connect to signal ground at the earth tie point on the signal source end.

This statement is important because of three critical current paths which need to be optimized. (See Figure 8.) Three sources of signal being impressed on the shield of a cable are; the capacitive coupling between the signal wires inside the shield and the shield itself, the extraneous electrostatic fields cutting the shield, and the point to which the shield is tied.

Any signal within the shield is capacitively coupled to the shield and causes a current to flow in the shield. This current must ultimately return to the source of the signal, either thru a direct connection to that source's ground or via the entire ground system, if tied to the receiving end. Since the capacitive coupling impedance goes down as frequency goes up, an incorrectly grounded shield will cause excessive high frequency crosstalk in the system by generating a voltage drop in the ground system.

The shield is also carrying a current radiated into the shield from A.C. and R.F. fields near the shield. These currents need to be returned to earth by the shortest route and thru the fewest signal grounds as they will cause a voltage drop on a signal ground. This voltage drop will appear on the signal output of the electronics referenced to the signal ground.

Lastly, the shield must be at the zero potential of the signal within the shield or the shield will itself become a source of radiation onto the signal lines within.

Every signal line should have its own shield

If signal lines are put within a common shield they will capacitively couple to each other. If shields are shorted together other than at the signal reference point, then they will share coupled signal currents and will not be a true shield to the signal line within since the finite resistance of the shield will cause a voltage drop lifting the shield above the signal reference. (See Figure 9.)

In high R.F. areas, the "receiving end" of a shielded wire (that end not tied directly to signal ground) should be tied thru a 0.01 uf capacitor to Signal/Earth Ground.

At R.F. frequencies, this 0.01 uf capacitor will appear as a short lowering the effective shield impedance to ground. A 24 track tape recorder connected thusly will have 0.5 uf of the capacitance between the two systems which is about 530 ohms at 60Hz - not a significant ground loop problem. In summary, when interconnecting individual pieces of studio equipment, there are three possible input/output circuit configurations; unbalanced, balanced, and differential. These can be connected nine different ways.

balanced, and differential. These can be connected nine different ways. Figures 10 thru 18 diagram each of the nine possible interconnect schemes. I have noted particular considerations of each interconnect with the applicable drawing.

Care should be taken when reviewing each type of interconnect. The ground points indicated need to be connected as shown in the drawings. When interconnecting several inputs or outputs from the same unit, only one ground reference wire should be needed to that unit.

APPENDIX A

A discussion of current "Differential Technology" being used in professional recording equipment. Currently, "Differential Technology" is being used to replace virtually

every audio transformer in M.C.I. equipment. Many other manufacturers are following similar trends. While the most remarkable improvements in signal processing have been a result of replacing microphone and tape head transformers with low noise instrumentation amps, the use of differential inputs and active differential line drivers also warrants review. The following is only a brief discussion touching on basic design philosophies and significant factors of improved performance demonstrated with comparative data samples.

THE LINE INPUT

Most manufacturers are using a differential line input amplifier consisting of a classic single op-amp design. (See Figure 19.) This circuit can provide improved performance in every parameter including C.M.R.R. (Common Mode Rejection Ratio) which is typically 70dB or more at all frequencies from 10Hz to 1 megahertz.

> The common mode signal is that signal common to both inputs of an amplifier. The rejection ratio is a number comparing the audio signal gain to the common mode signal gain - a larger number is better.

Comments on the Circuit (Figure 19.)

A few comments on the configuration are in order. At M.C.I., we chose to use a Non-Polar capacitor on the output of the circuit for interstage coupling and D.C. couple all input/feedback circuits. This D.C. coupling produces the best pulse/transient characteristics. A constraint placed on the use of this circuit is that any D.C. difference on the input will reduce headroom. In this circuit, ½ volt of D.C. on the input will reduce the headroom by LdB since the circuit has 23dB of headroom this is not a problem.

The input circuit comprised of the 1K and 1000pf capacitors forms an R.F. trap to stop R.F. entering the module.

The circuit shown in Figure 19. has a maximum input level of +27dBv when powered on + 18V and a dynamic range of over 128dB with unmeasurable distortion.

THE MICROPHONE PREAMPS

Several manufacturers are now offering transformerless microphone preamps. Most are balanced input instrumentation amplifiers with specially designed low noise transistor pairs used for the high gain front stage. It is the differential preamps, I am comparing to transformers. Several articles written in the past year have expounded on the virtues of the transformerless preamp so I will only briefly recap and detail the

factors I believe are worth noting.

Distortion

Typical microphone transformer low frequency distortion is 0.1% rising rapidly above -10dBv input level. The overall usable dynamic range of a typical microphone transformer is approximately 75dB. The usable dynamic range of the M.C.I. preamp is 150 to 155dB since distortion is less than 0.03% at any input level up to +16dBv and any audio frequency (at +16dBv in the output is at clipping).

Transient Capability

The ability to pass low frequency transients without excessive base line shift is an important virtue of the tranformerless preamps, however, caution when selecting a manufacturer is necessary. Some preamps contain internal coupling capacitors which degrade this performance. Figure 21 shows transient signals thru two preamps; a Jensen Transformer Circuit and an M.C.I. Transformerless Preamp. The Harrison Preamp, being D.C. coupled is similar in performance to M.C.I., while the Allison unit is internally A.C. coupled in its feedback loop.

Constant Load Impedance

I believe one of the most important characteristics of the transformerless preamp is its constant and non-reactive input impedance. The input of an M.C.I. Preamp, for example, is 2K ohms resistive and does not change from 20 -20KHz. As the input of a transformered preamp as shown in Figure 22 is shown to vary from 800 to 1450 ohms over the audio band and is not purely resistive. Since the typical microphone output is 150 ohms (Dynamic) to 250 ohms (transistor) and is flat with frequency it can be seen that transformer loading and line resonance alone can "equalize" the microphone signal.

Hum and Microphonics

A transformer, because it is a coil of wire, picks up any hum field cutting its windings. The well designed transistor preamp will not be subject to any hum pickup. Also due to the wound coil, high impedance nature of the microphone transformer it is subject to mechanical shock produced noise. This is a result of motion of the coils relative to the surrounding metal case and laminations resulting in small capacitive/impedance changes which are amplified by the high gain amplifier following the transformer. Transformerless designs are only subject to this if mechanically defective designs or parts are used.

Common Mode Rejection Ratio

The C.M.R.R. of the microphone transformer is about 65 to 70dB over the audio band and becomes less as the frequency goes up. The transformerless units being produced are 75dB or better at all audio frequencies. Unlike transformers, the transformerless designs maintain their rejection past 1Mhz.

What about the Thorns?

Yes, there are a few thorns in the rose garden. Because of the wider bandwidth and higher input impedance, the microphone cables need to be more carefully produced. I have found hum and R.F. reduced measurably by trimming the balanced microphone wires to be more closely the same length to insure matched pickup on each wire.

Shielding the microphone lines must be handled very carefully. Microphone shields must not interconnect and must be well decoupled for R.F..

Also, due to the ground referenced nature of a differential input, connecting an unbalanced source to a transformerless preamp will usually cause enough ground current (hum) to flow thru the cable to produce unacceptable results. One microamp of 60Hz noise current across 2K ohms to ground when amplified 60dB will produce 2 volts of signal at the output.

THE LINE OUTPUT

Differential Line Outputs have been used for several years. Their two obvious advantages are the balanced differential signal line and the ability to get 6dB more output level from the same power supply rails. Until recently, the problem has been that few if any have provided the ability to operate balanced or unbalanced without a change in output level or distortion.

The classic differential driver wherein one side is driven with an inverted signal is shown in Figure 23. Shorting either side results in a 6dB reduction of output level and usually distortion, oscillation, and eventual op-amp failure. Thus, this circuit is limited to balanced line use only not very realistic in the real world of recording studios. The circuit used by M.C.I. is examined in Figure 24. The unique portion

The circuit used by M.C.I. is examined in Figure 24. The unique portion of this circuit is the cross coupled output sensing feedback. In an effort to make the operation understandable, I have provided a node voltage chart for the 3 modes of output operation.

Comparison

In comparing the differential output amplifier I have provided two sets of square wave photos. (See Figure 25.) These photos exhibit the output characteristics of M.C.I.'s Active Differential Output Amplifier, M.C.I.'s 1:1 output transformer used in the 500 A and B Series (the 500 C now use active differential amp outputs), and the 6dB step up transformer used by some manufacturers to achieve headroom on + 18V rails.

While the transmission of 15KHz Is good for all choices, note the degradation of the low frequency square wave.

Cautions when using the Active Differential Output

The active differential outputs use either a shut off circuit

or use the current limit of the Op-Amp output when working into an unbalanced load with one side to ground. If this short to ground is at the load, then the turn off or current limit circuits must work thru the cable capacitance and inductance. The phase shifts (delays) caused by the lumped inductance/capacitance can cause rise time anomalies. (See Figure 26.)

Whenever running the active differential output into an unbalanced load short the low side to signal ground at the output (drive) end of the cable, this will provide the path of least impedance to ground and will prevent driving the output current thru the ground reference system. POWER LINE PHASES



A.C. LEAKAGE





STAR VS. SERIES GROUNDING



GOOD-STAR GROUND



BAD-SERIES GROUND

SYSTEM GROUND





PROPER EQUIPMENT GROUNDING



UNBALANCED A.C. INPUT



THE SECONDARY RETURN CURRENT PATH CAUSES VOLTAGE DROPS IN THE GROUND REFERENCE WIRES SUCH THAT THE EQUIPMENT RACK DOES NOT "SEE" GROUND REFERENCE BUT RATHER SOME A.C. VOLTAGE.

SHIELD CURRENT PATHS



IF THE SHIELD IS TIED AT THE RECEIVING END THEN CAPACITIVE COUPLING TO THE SIGNAL LINES CAUSE CURRENT THRU SYSTEM REFERENCE GROUND RESULTING IN A VOLTAGE DROP.



IF THE SHIELD IS TIED TO THE RECEIVING END, NOISE OR REFERENCE ERROR IS CAPACITIVELY COUPLED TO THE SIGNAL LINES.

FIGURE 8





UNBALANCED OUTPUT TO UNBALANCED INPUT



THIS IS A VERY POOR INTERCONNECT METHOD. EXPECT GROUND LOOP PROBLEMS, BEST WAY TO AVOID - BE SURE A.C. IS THRU TRANSFORMER AND GROUND REFERENCE CONNECTION IS EXCELLENT. AVOID SHARING GROUND REF. WIRE WITH OTHER EQUIPMENT.

UNBALANCED OUTPUT TO BALANCED INPUT



FARADAY SHIELD ON THE TRANSFORMER IS IMPORTANT AS THE PRIMARY WINDING HAS ONE END AT GROUND AND WILL COUPLE TO THE SECONDARY AND INJECT HUM AND NOISE IF NOT ISOLATED.

UNBALANCED OUTPUT TO DIFFERENTIAL INPUT



BALANCED OUTPUT TO UNBALANCED INPUT



NOTE THAT THE SHIELD IS TIED TO THE GROUND REFERENCE AT THE UNBALANCED INPUT - THIS IS AN EXCEPTION TO NORMAL PRACTICE SINCE THE LINE BEING SHIELDED IS REFERENCED TO THE INPUT, NOT THE OUTPUT.

BALANCED OUTPUT TO BALANCED INPUT



BE SURE SHIELD IS TIED AT SOURCE.

FIGURE 14

BALANCED OUTPUT TO DIFFERENTIAL INPUT





NOTE: OUTPUT TRANSFORMER A IS FLOATING SO LINES ARE REFERENCED TO DIFFERENTIAL INPUT – TIE SHIELD TO DIFFERENTIAL INPUT GROUND.

DIFFERENTIAL OUTPUT TO UNBALANCED INPUT



- 1 NOTE * GROUND-THIS IS IMPORTANT TO ACTIVE DIFFERENTIAL OUTPUTS. WHEN ONE OUTPUT SIDE IS SHORTED THE OUTPUT CURRENT NEEDS TO RETURN TO GROUND VIA THE SHORTEST, LEAST INDUCTIVE/CAPACITIVE ROUTE.
- 2. THIS IS NOT A DESIRABLE INTERCONNECT-WATCH FOR GROUND LOOPS AND OSCILLATIONS OF DIFFERENTIAL OUTPUT.

DIFFERENTIAL OUTPUT TO BALANCED INPUT



FOR BEST PERFORMANCE CHECK 20KHz IMPEDANCE FROM EACH TRANSFORMER INPUT LEAD TO CHASSIS. POOR TRANSFORMER DESIGN RESULTING IN UNEQUAL IMPEDANCES TO GROUND WILL UNBALANCE THE DIFFERENTIAL OUTPUT AT HIGH FREQUENCIES WHICH MAY DETERIORATE PERFORMANCE BY REDUCING EFFECTIVE HEADROOM.

DIFFERENTIAL OUTPUT TO DIFFERENTIAL INPUT



THIS IS THE BEST METHOD OF INTERCONNECT USING TODAYS TECHNOLOGY.

STANDARD DIFFERENTIAL INPUT CIRCUIT

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MCI TRANSFORMERLESS PREAMP OUTPUT

TRANSFORMER PREAMP OUTPUT

2V P.P. @ 50 ms/dv - 20 Hz SINE WAVE BURST





NOTE: THE BASELINE SHIFT CAUSED BY LACK OF D.C. RESPONSE.

2V P.P. @ 50 ms/div 20 Hz PULSE BURST





MIC TRANSFORMER INPUT Z



FIGURE 22



FIGURE 23

MCI DIFFERENTIAL OUTPUT CIRCUIT



NODES	BALANCED	SHORT INV OUT	SHORT NON INV OUT
Α	+1/3V	2/3V	ov
в	+1/3V	2/3V	ov
с	+1/3V	2/3V	ov
D	+1/3V	2/3V	ov
INV OUT	-v	0	-2V
NON INV OUT	+V	+2V	0



INPUT

OUTPUT



20 Hz, 2V P.P.



ACTIVE DIFFERENTIAL OUTPUT, 5K LOAD











15kHz, 2V P.P.



ACTIVE DIFFERENTIAL OUTPUT, 5K LOAD

1:1 TRANSFORMER, 5K LOAD

1:2 STEP UP TRANSFORMER, 5K LOAD



ONE SIDE SHORTED AT THE END OF 50' OF SHIELDED CABLE 5K OHM LOAD



ONE SIDE SHORTED AT THE SOURCE DRIVING 50' OF CABLE WITH AN UNBALANCED LOAD OF 5K OHMS

UNBALANCED ACTIVE DIFFERENTIAL OUTPUT