[Reprinted with permission, with minor revisions, from **Recording ■ Engineering ■ Production**, November 1990]

THE NEED FOR STAND-ALONE MICROPHONE PRE-AMPLIFICATION

OUTBOARD MIC PRE-AMPS:

WHAT'S THE DEAL?

By John Hardy

You would think that spending half a million dollars on an audio console would guarantee that you are getting the best mic pre-amps that money can buy. You might also think that the newest DAT recorders would have a pair of equally incredible mic pre-amps built in. Not necessarily.

True, not everyone is looking for the most accurate reproduction. Many pros deliberately want a not-so-perfect sound quality that happens to be perfect for the occasion. Like a "warm" sound for a vocalist, or just a touch of distortion for an instrumental overdub. A blues harp player might go to the extreme of using a tube-type guitar amp for his mic pre-amp. Lots of distortion. Perfect! Yet the engineer recording it might use the most accurate microphone he can get, to capture the sound coming from the guitar amp as clearly as possible.

John Hardy is president of the John Hardy Company, Evanston, IL. www.johnhardyco.com

And there at the end of the studio's mic cable is a console pre-amp that may not be doing its job accurately. Certainly some console pre-amps are better than others, but generally speaking, there is room for improvement at most price levels.

Engineers often begin their careers with the misconception that all mic pre-amps are pretty much equal, and pretty much perfect. If you don't like the sound quality, blame it on the microphone (or the source), but never on the mic pre-amp.

Some magazines perpetuate this misconception by asking famous engineers which microphones they used for a particular hit record, but neglecting to ask which mic pre-amps they used. Most know, but few remember it's a package deal. The total sound is the result of both devices.

You can listen to a Neumann U87 through ten different brands of mic pre-amps and get ten different sound qualities. Just as engineers choose different microphones for different situations, they should also be aware of the fidelity options available from different pre-amps.

THE LOST ART?

There is so much emphasis on digital circuitry these days that analog design is getting lost in the shuffle. An analog circuit that looks great on paper can be seriously compromised by improper grounding techniques, whether it is part of the PCB design, or part of discrete hand-wiring design. All parts to be grounded must have their own independent path to a central grounding point, logically called star grounding.

Even with massive copper ground areas on the PCB, or heavy bus bars within a console (or within a module of a console), there will still be a small, but measurable, resistance from one point to another in a grounding system. If two or more parts share a common ground return path, they can interact, as the current from one part of the circuit flows through the resistance of the ground bus to the other.

Yet for ideal performance, each part of the grounded circuit needs to see absolutely 0V. If an audio signal is nominally 1V, and there is 1mV of error being induced due to shared grounds, there will be some kind of distortion or noise a mere 60dB below the signal.

I recall a digital voltmeter circuit I prototyped long ago using one of those plug-in proto-board things, complete with two long ground buses with many parts grounded randomly along the buses. When I shorted the input to ground, the display should have read 0.0000. Instead, it read anywhere from 0.0000 to 0.0014, depending on which point along the ground buses I chose to ground the input.

The 0.0014 represented 1.4mV of error caused by shared grounds. The digital circuitry was working flawlessly because it is generally immune to such errors. It was no longer my digital voltmeter experiment; it became my grounding technique demonstrator.

CHOICES AND OPTIONS

Because stand-alone outboard pre-amps can be ideally designed, they seldom suffer from the design compromises and limitations found in many console pre-amps. Additionally, outboard pre-amps come in many technologies, shapes and sizes: with and without input transformers, and having monolithic op-amps, discrete op-amps or vacuum tubes for amplification. They may be rack-mounted, or a direct plug-in replacement into existing console slots. There are those designed to be extremely accurate, while others are designed to add a certain desirable inaccuracy. They can cost hundreds of dollars or thousands of dollars for a pair of channels.

Some outboard pre-amps offer continuously variable gain controls, others offer stepped-gain switches with values of 6dB per step or so. A variable pot allows gain-riding at the pre-amp, while a switch-selectable gain control allows exact resetability, so alternate channels can be closely matched. Everyone has their preferences, and with outboard pre-amps you have choices.

Listing other attributes, some outboard pre-amps can handle higher input levels and provide higher output levels without distortion than stock pre-amps. Many have a higher slew rate and track high frequencies and transients better. Power-wise, there are many condenser microphones that require relatively high current from the phantom supply, and not all stock supplies can provide enough power. Outboard pre-amps with phantom power capabilities usually satisfy this requirement.

PERFORMANCE CONSIDERATIONS

Stepping back a moment, it's fair to ask why outboard mic pre-amps differ so much from stock units and each other, performance-wise. Electrically, there are many ways that a pre-amp can alter the signal coming from a microphone. One basic issue is improper matching of the microphone's output impedance to the mic pre-amp's input impedance. If all microphones had an output impedance of exactly 150Ω at all frequencies, and all mic pre-amps had an input impedance of 1,500Ω at all frequencies (including frequencies far above and below the basic 20Hz-20kHz range), this critical interface between microphone and mic pre-amp would not cause any error in frequency response.

The problem is that many microphones have an output impedance that varies with frequencies, and many mic pre-amps have an input impedance equally variable. This affects performance in any of several ways, including a possible rise in high frequency response, a roll-off of high frequencies, or a roll-off of low frequencies. There could be a resonant peak in the high frequencies, higher distortion, reduced maximum output level, or even some microphone instability in extreme cases. Sometimes the effect is helpful, but more often it is not.

These impedance variations can be caused by a poorly designed output transformer in a microphone, or a poorly designed input transformer in a mic pre-amp. Perhaps each of those transformers is superb, but not the appropriate impedance for each other. The same thing can happen with transformerless microphones and transformerless pre-amps.

Regardless of whether a microphone or mic pre-amp is transformer-coupled or transformerless, there will unavoidably be residual capacitances, inductances and resistances present that create these impedance variations. Recall that these are the basic components used in equalizers and crossovers to deliberately create variations in frequency response. The best mics and pre-amps will be designed so that these variations occur well beyond the audio bandwidth, but the errors can start to creep in before you know it. When you add the capacitance of a long mic cable to the equation, the errors are even more pronounced.

TRANSFORMER INSIGHT

Which begs the question: which is better: a mic pre-amp with a transformer-coupled input, or one that is transformerless? Much of that depends on the characteristics of the transformer.

All transformers have a maximum signal level they can handle before the core material begins to saturate and distortion becomes excessive. All else being equal, a small transformer will saturate before a big one will, and the lowest frequencies will be affected first. Sometimes the distortion caused by core saturation can be used to creative advantage, depending on the type of sound one is looking for.

All things considered, a transformer with a low impedance ratio will be more linear in total performance than one with a high ratio. A transformer with a low impedance ratio (typically 150Ω:600Ω) will have flatter frequency response, flatter input impedance, more linear phase response and wider bandwidth than one with a high impedance ratio (typically 150Ω:15kΩ or higher). The impedance ratio is generally dictated by the requirements of the amplifier that follows the transformer.

Steel-core transformers are less expensive than nickel-core transformers, but the best nickel-core transformers will clearly outperform the best steel-core ones, assuming you are looking for the highest accuracy.

There are even differences between the nickel-core materials. The two most common nickel materials are the "50% nickel" material, and the "80% nickel" material (often called "Mu Metal", which is actually a trade name used by one core supplier). The 80% nickel material is best for audio, but there are many sources for the material, and substantial variations exist in performance, depending on the source.

To get further insight into transformers, let's look at three popular Jensen models, the JT-115K-E, the JT-13K7-A and the JT-16-B. The JT-115K-E has a high impedance ratio (150Ω:15kΩ), the JT-13K7-A has a medium impedance ratio (150Ω:3,750Ω) and the JT-16-B has a low impedance ratio (150Ω:600Ω). All three use a proprietary 80% nickel-core material. The one that is commonly used in high-end recording consoles is the JT-115K-E.

An interesting point is that the JT-13K7-A is an even better transformer than the JT-115K-E because of its lower impedance ratio, yet it is generally not used in consoles due to numerous circuit design and cost considerations. Even more interesting (or disappointing) is that the JT-16-B is superior to both the JT-115K-E and the JT-13K7-A because it has the lowest impedance ratio of them all, yet the JT-16-B is not used in consoles either! The JT-16-B is available in a variety of outboard pre-amps and retrofit cards, however.

ELECTRONIC ANSWERS

Transformerless mic pre-amps are popular at least in part because they are much cheaper to make than a mic pre-amp with a transformer-coupled input. They are also smaller and lighter. Instead of costing anywhere from $35 to more than $100 for a premium input transformer, a few inexpensive transistors can provide the balanced input capability, while a pair of 10-cent capacitors can be used as input coupling capacitors to keep the 48V phantom voltage from damaging the transistors. You can see the temptation of some designers (or accountants) to go for the transformerless design, since it can offer performance that in many ways rivals that of the better transformer-coupled designs, at a fraction of the expense.

As with most things, there are excellent transformerless pre-amps and there are marginal ones. One limiting factor will be the type of capacitor that is used for the input coupling capacitors. An input transformer will naturally block the phantom supply voltage and keep it from reaching and damaging the amplifier circuit, but the capacitors must do that job in a transformerless circuit.

Unfortunately, the entire audio signal must pass through the capacitors in

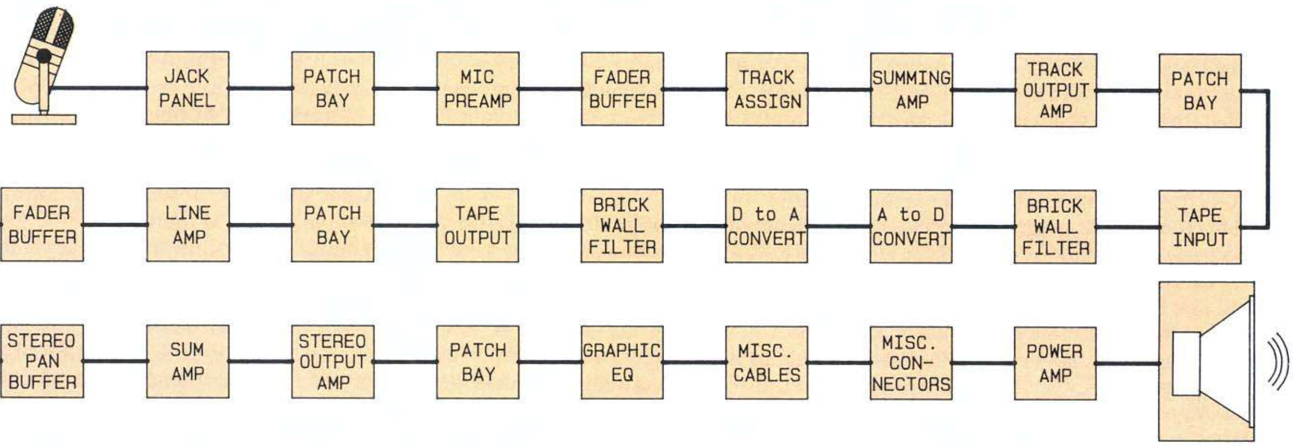

Figure 1. A tortuous path: by the time audio passes through a typical signal chain, the result may not be pleasing to your ears.

transformerless designs, and the problem of dielectric absorption in the capacitors will tend to smear the sound. Capacitors with a Teflon, polypropylene, polystyrene or polycarbonate dielectric are preferred since they have much lower dielectric absorption properties than others.

A clear disadvantage of transformerless inputs is that although good low voltage common-mode rejection ratios can be achieved, common-mode voltage range is extremely limited. A transformer might have a common-mode voltage range of typically several hundred volts, which is the basic breakdown voltage of the windings. But transformerless inputs are limited by the voltage rating of the input coupling capacitors, as well as the voltage limits of the op-amp that they are protecting.

If the electrical noise or interference that is picked up by the mic cable exceeds the power supply voltages of the op-amp (typically ±18V), you no longer have your rejection of common-mode voltages. Radio frequency interference and interference from solid state light dimmers can create induced noise voltages that approach or exceed the supply rails of the amplifier.

GAIN STAGES

In the early days, vacuum tubes provided amplification. Thereafter came the solid state transistor. Discrete op-amps were constructed using individual, or “discrete”, transistors and other parts. Then came the “miracle in a can”: the monolithic op-amp, where a complete op-amp circuit could be fabricated on a single 1/16-inch square “monolithic” chip of silicon.

Occasionally, discrete transistors are added in front of the inputs of a monolithic op-amp to provide lower noise than the op-amp is capable of on its own. Discrete transistors are sometimes added after the output of a monolithic op-amp to increase the output power of the op-amp. These are called semi-discrete circuits (or sometimes semi-monolithic or hybrid circuits).

Some people prefer the sound quality of a tube pre-amp, claiming it has a warmer and smoother character than solid-state pre-amps. Tubes have the advantage of going into distortion gradually at higher signal levels, and this distortion can be pleasing in controlled amounts. On the other hand, solid state pre-amps have very little distortion until they reach their maximum output level, where distortion rises rapidly. This is not as pleasing.

Solid state pre-amps are sometimes thought to be cold and harsh-sounding, but it is important to realize that only some solid state pre-amps are cold and harsh. Don't condemn them all; it depends on the individual design of the solid state circuit. It's the same story for op-amps, although many feel the discrete op-amp has the highest potential among the solid states for the best possible sound quality compared to monolithic op-amps. This is true specifically because each transistor, diode, resistor and capacitor in a discrete design can be carefully and individually chosen and optimized for its specific function within the circuit.

In a monolithic op-amp, substantial compromises must be made because there are process limitations inherent in monolithic construction. For example, it is difficult if not impossible to fabricate the best possible input transistors with their unique requirements, and the best possible output transistors with their radically different requirements, on the same tiny silicon chip.

Another disadvantage of monolithic op-amps is their size. In the case of our Hardy 990 discrete op-amp, each output transistor is fabricated with a silicon chip that is larger than an entire monolithic op-amp. This allows the 990 to have higher output power, which makes it possible to use lower impedance parts in the feedback loop, all providing lower noise. The higher power also makes the 990 a better line driver than typical common monolithic op-amps.

Additionally, there are voltage limitations in monolithic op-amps, putting a ceiling on total dynamic range. Most operate on ±18V power supplies, while a discrete design can operate with ±24V supplies or higher, providing greater headroom.

DIRECT TO STORAGE

Many engineers use outboard mic pre-amps so they can completely avoid the recording console and the potential degradation of sound quality it may cause from the sheer quantity of amplification stages: fader buffer amps, EQ amps, summing amps, channel output amps, switches, connectors and more cable.

Whenever possible, most users of outboard pre-amps go straight to the tape deck or disc drive. If needed, a limiter can be patched between the pre-amp and the storage medium. The rule is: Keep It Simple.

Additional improvement to the sound quality can be had by putting the pre-amps as close as possible to the microphone, allowing the use of a very short mic cable. Low microphone voltages are very sensitive to the effects of cable capacitance. The longer the cable, the higher the capacitance, and the greater the deterioration of sound quality.

In a typical studio the mic cable length could easily reach 100 feet by the time it gets to the console's mic pre-amps. In a remote recording situation or PA system, a mic cable could reach at least several hundred feet in length. Instead of traveling hundreds of feet at mic level, it is better to use a ten-foot low capacitance mic cable to an outboard mic pre-amp, with the signal then traveling the remaining distance at line level. The higher-voltage, lower-impedance line output of a pre-amp is usually much better equipped to drive long cables than a microphone is.

Another advantage to traveling long distances at line-level rather than at mic level is that you can achieve a much better signal-to-noise ratio. If your microphone signal travels a long distance at -50dBv, and there is noise being picked up by the long cable at a -80dBv level, you have an S/N of only 30dB If you first amplify the signal with a local outboard pre-amp, you can send the signal the entire distance at line level, typically 50dB or so higher. This increases your S/N in the above case to 80dB. Not bad!

PERSONAL RACK

Many engineers are assembling their own personal rack of mic pre-amps and other goodies such as limiters, digital delays, etc. That way they can offer not just their superior talent, but also a superior rack of specialized equipment. They realize that no single mic pre-amp is right for all occasions, so they bring a variety of pre-amps with them. I know of several people who bring a rack of twelve or more channels of pre-amps with them wherever they work.

Bottom line: Understand the benefits and limitations of your console pre-amps. Then try every outboard pre-amp you can get your hands on. Get to know each one intimately. Try every microphone in every pre-amp, under as many diverse situations as possible. But be certain that your evaluations are done under the best possible conditions, and make sure you know what the rest of the audio chain sounds like. Please refer to the article "Proper Mic Pre-amp Evaluation Methodology" [R•E•P, November 1988, page 30] for more information.

I promise you, if the only pre-amps you have ever used are stock console pre-amps, you may be surprised, even shocked, at how different a particular microphone will sound through some of the various outboard pre-amps. Whether it's an abused SM-57, or a brand new large diaphragm ultra condenser microphone, you will be surprised. Find new combinations and special applications. Learn. You won't know until you try.■