Why the Fuss about Plus or When You're Hot, You're Pin 2
An Essay on Pin 2 Hotness and Absolute Polarity

A frequent question on the Usenet rec.audio.pro newsgroup (which is where I often get inspirations for these articles, in case you wondered) is: "Is (insert equipment name here) Pin 2 Hot?". Sometimes it matters, sometimes it doesn't. This month we'll explore the meaning of what's hot and what's not and why you should care.

What's Hot?

In order to measure any voltage, we need a reference point which is considered to be at zero potential. An audio signal constantly alternates from positive to negative and back again with respect to that reference point. We call the reference the "low" or "cold" terminal, and we call the one that changes relative to it "hot". Since we're only looking for a difference in voltage between two terminals, it's arbitrary which one we designate as "hot".

So, why the fuss? Two reasons. One reason is that, in certain configurations, one terminal is always be at zero potential - it can never be "hot". Another is that we want to be able to maintain (or at least be cognizant of) the actual polarity of the signal throughout our chain so that what moves the air that eventually hits our ears (the loudspeaker) accurately reflects the motion of the air that originally hit the diaphragm of the microphone that recorded it.

Pin 2?

The Pin 2 we're talking about is Pin 2 of the three pin XLR-type connector commonly used on audio equipment. Back when every connection was transformer balanced to an XLR, life was simple. Pin 1 was where you connected the cable shield. The signal was connected between pins 2 and 3.

Everything was cool as long as inputs and outputs were truly balanced, differential, and floating. The signal voltage always appeared between pins 2 and 3, with Pin 1 keeping the cable shield intact and at ground potential. Attention to design and wiring could assure that when Pin 2 was positive with respect to Pin 3 at the input, the same would be true at the output. Any voltage measured between Pin 1 and either Pins 2 or 3 was purely incidental, due to electrical leakage or capacitive coupling. A low signal level with practically no mass meant that there was a broken connection to one of the two signal pins.

But then a devilish deception came along - an XLR connector that was actually wired to an unbalanced input or output. With an unbalanced connection, the voltage reference point is always the equipment ground. To this end, one of the two signal pins was connected, along with the cable shield, to Pin 1. This makes the signal voltage appear between pins 2 and 3 like on a balanced XLR, however there is also signal voltage between one of those two pins and Pin 1.

Which signal pin? The one not tied to Pin 1, of course. Now, there's a significance to one particular signal pin being "hot".   Ampex usually gets the blame (or the credit) for initially setting an industry standard of Pin 3 hot. Many of their units were supplied unbalanced, but could be made balanced by installation of an optional plug-in transformer. (cost saving in a basic model is not a new concept). A jumper plug installed in lieu of the transformer tied pins 1 and 2 together assuring that signal voltage would appear between pins 2 and 3 as expected.

But you know what they say about standards - gotta love 'em because we have so many. Since this wasn't really a published standard, other companies, most notably those in Europe, wired their unbalanced products with Pin 2 hot with respect to ground rather than Pin 3.

Enter Mr. Mike

The most common point where signals enter the recording chain is the microphone. Fairly early on, the American microphone manufacturers adopted a wiring convention such that positive pressure on the mic diaphragm caused the voltage on the mic's Pin 2 to go positive with respect to Pin 3.

Unfortunately, things weren't quite so organized in Europe, where some makers wired their mics like the Americans (purely by chance) and some wired them the opposite way - positive air pressure made Pin 3 go positive with respect to Pin 2. It wasn't even consistent within a company. I've found AKG mics wired each way.

Along came a real standard, IEC Standard 268 "Sound System Equipment", which states in the section about microphones: "The polarity shall be indicated by a mark, preferably a colored dot, at that output terminal at which a positive instantaneous voltage is produced by an inward movement of the diaphragm, i.e., and increase in sound pressure.". There's a similar paragraph in the standard which addresses the issue of polarity of loudspeakers, stipulating that the terminal at which a positive voltage causes an outward movement of the speaker cone be marked as positive.

The standard required identification of the positive terminal, but didn't define it relative to a standard connector (many European mics used a DIN or Tuchel connector rather than an XLR). Eventually, mic manufacturers settled on the XLR Pin 2 positive convention world wide, and this probably led to the decision to adopt a similar convention for electronics. Balanced or unbalanced, if a system is wired correctly, sound which pushes air against a mic diaphragm will cause the speakers to push air against the listener.

The Balanced and Unbalanced Mix

Where the Pin 2 Hot issue becomes significant today is when interconnecting balanced and unbalanced equipment. While we usually recognize an XLR connector as being balanced, much of today's equipment employs 1/4" phone jacks. This is both a cost saving and a convenience for many users (and an inconvenience for others, but the dollar usually wins). The 1/4" jack is available with either one or two signal conductors, so the same format can accommodate balanced or unbalanced connections.

In an unbalanced configuration, the tip contact is hot, the sleeve serving as both the low signal terminal and shield connection. For a balanced configuration, the tip and ring of the jack carry the signal, with the sleeve again being the shield. If an unbalanced plug is inserted into a balanced jack, the jack's ring contact gets automatically connected to the sleeve. This is the equivalent of tying Pin 1 of the XLR connector to one of the signal pins. Which signal pin? Another standard to the rescue!

With AES14-1992 "AES standard for professional audio equipment - Application of connectors, part 1, XLR-type polarity and gender", the Audio Engineering Society established the wiring convention of Pin 2 Hot. Since the tip of a 1/4" jack is always hot, it becomes the equivalent to Pin 2 of the XLR, with the ring (if it's a TRS) being the equivalent of Pin 3. Most modern equipment adheres to this convention, making it straightforward to interconnect balanced and unbalanced equipment without losing the signal or inverting polarity. (I say most because there was a popular 16 channel mixer just a few years ago which was inadvertently wired with tip and ring reversed at the output)

Unconventional Inversions

One the reasons for this article was prompted by one of those innocent questions about whether a certain vintage multitrack tape recorder was Pin 2 or Pin 3 hot. My initial answer was "Who cares? It's balanced, and as long as they didn't foul up the design, a positive-going input when recording should play back positive-going at the output.". But there's a piece of tape between the input and output. Suppose that tape is played on a different recorder? Will it still play back with the correct polarity?

A tape recording can be conceptualized as being a string of little bar magnets laid end to end along the length of the tape. The record head is an electromagnet which magnetizes the tape in proportion to the current flowing through its coil. Current flowing in one direction creates a little magnet on tape with its north pole pointing toward one end of the tape, while current in the other direction orients the magnet with the north pole pointing in the opposite direction.

The playback head is a coil of wire mounted so those little magnets pass near it when the tape is moving. The changing magnetic field as the tape moves induces an electrical current in the coil. This small current is amplified and that's what we hear. The current will flow in one direction when the north pole reaches the head first, and in the opposite direction when the south pole gets there first. The two different directions of current flow represent positive or negative signal polarity.

It's easy enough to design a recorder so that it plays its own tapes back with the correct polarity, but in order to assure interchangeability, we need a standard to define which direction of magnetic orientation represents plus. Jay McKnight of Magnetic Reference Laboratory, storehouse of knowledge of all good things about magnetic recording steered me to a reference.

The Society of Motion Picture and Television Engineers (SMPTE) Recommended Practice RP 134-1986 "Polarity for Audio Analog Magnetic Recording and Reproduction" tells us that the direction of magnetization of the tape corresponding to a positive-going audio signal should be in the same direction as the motion of the tape. It's difficult to apply this standard directly since we can't readily examine the orientation of the magnetic domains, but we can stimulate the playback head in a known manner in order to determine if the output polarity is correct.

The simplest way to do this is to play an MRL polarity test tape, a recording of a truncated sawtooth wave of the correct polarity orientation according to the standard. When the playback waveform is viewed on an oscilloscope, a recorder with proper polarity will have the points of the sawtooth going upward. Once proper playback polarity is verified, a similar test signal connected to the recorder's input, recorded, and played back will verify recorded polarity.

I don't have any information on recently manufactured analog recorders, but in an article in the December 1979 issue of R-e/p Magazine, Peter Butt, a studio maintenance technician operating in the Los Angeles area reported testing a variety of recorders in his area and discovered that Ampex and 3M recorders were of opposite in polarity at the heads. The Ampex machines were "correct" when Pin 3 was considered hot while 3M recorders were inverted (These were American recorders, which used the Pin 3 Hot convention at the time).

This means that using the modern Pin 2 Hot convention, playback of an MRL polarity test tape on an Ampex would show inverted polarity. (Oops! I own a couple of these!) A European Lyrec recorder indicated correct polarity relative to the (then current European) Pin 2 Hot convention - meaning that tapes were polarity-accurate between Lyrec and 3M recorders, but inverted when playing a Lyric tape back on an Ampex. Confusing?

Digital recorders aren't immune to this polarity pitfall either. In the original Alesis ADAT design, the audio polarity was inverted before it hit the analog-to-digital converter, and inverted once again at the output of the digital-to-analog converter, before reaching the analog output connectors (there was actually a good technical reason for that). Absolute polarity was maintained through the recorder, and all was well, almost. Since this polarity inversion scheme was unique to Alesis, digitally transferring a pair of ADAT tracks to another medium (a DAT recorder or workstation, for instance) resulted in the polarity being inverted on the digital copy, which made it not quite a clone.

While the polarity inversion issue went unnoticed to most users, a bit of a fuss was raised shortly after the introduction of the next generation ADAT XT. Alesis recognized polarity inversion issue, and to avoid perpetuating it (a good move, in my opinion), changed their recording scheme so that polarity was not inverted on tape. Now, however, a tape recorded on an original ADAT will play back with opposite polarity on an XT (and vice versa). Users with a mix of original and XT ADATs need to keep straight which tape was recorded on which recorder in order to preserve polarity through the recording chain.

A more significant problem could occur if a recording of several tracks with common material was spread between two ADATs of the same flavor and then played back on a different system with one original ADAT and one XT. (the same would be true if recorded on a mixed pair and played back on an identical pair)

Suppose you had carefully positioned your drum mics so that the sound of the snare drum in the overheads solidly reinforced the sound of the close snare mic. If those three mics were recorded on three tracks of a single recorder, all would be fine. But, if due to other track commitments, you had to record the snare mic on the second recorder, you could have a problem on mixdown if you mixed in a studio with a different mix of ADATs and XTs. You could have the snare track that’s 180 degrees out of phase with the overheads, substantially changing your carefully engineered drum sound. Avoid the problem by being aware of the difference between generations of ADATs, or prepared to invert the polarity when mixing.

Why the Fuss About Plus?

Most engineers, having given little thought to the issue of absolute audio polarity, don’t expect that it makes any difference to the listener. Most of us know about the hollow sound which results when the leads on one loudspeaker are swapped, but few people worry about which wire on the speaker goes to which terminal on the amplifier. We even got an irate letter when I mentioned this in a previous article (Oops Wrong Button, June 1997) from a reader who claimed that this was nonsense (curious that the reader worked for Alesis). Well, folks, it really does matter.

Consider the sound of a kick drum as heard by the player and by the audience. They’re on opposite sides of the head producing the sound. The audience hears the beater attack as air that is initially compressed, while the drummer hears the attack as air that is initially rarefied. Our ears perceive these two different changes in air pressure differently. The same effect is true for anything that makes a sound, but the reason (and the effect) is most apparent for a simple vibrating membrane.

Blame it on non-linear components if you must, but we can't easily replace the suspension of our eardrums or swap out op-amps in our brain. If we want our recording to sound to the listener the same as it sounded in the studio, we must preserve polarity, at least as far as we can.

Since you can't check and rewire every home playback system, someone will always hear polarity incorrectly, but as a responsible recording engineer, it doesn't hurt to get it right when you record it. And it's not difficult to do, either. Check your mics and cables and fix any that are miswired. Check for polarity inversions in your equipment and for correct wiring when going between balanced and unbalanced connectors. Awareness is the biggest step.

Try This At Home, Kids

One of the things that fell into the hopper which resulted in this article was the Neutrik Minirator reviewed in this issue. One of the first things I did with it was to select the polarity test waveform, plug it into a mic input on my console, listen to it, and then flip the polarity ("phase") switch. The audible difference when reversing polarity was immediately apparent, much more so than when listening to music or even a solo kick drum.

The Minirator polarity test waveform is a 20 Hz sawtooth. The voltage rises slowly up the ramp, then drops down very quickly. When translated to loudspeaker cone motion, the cone moves toward the listener slowly (this is the defined polarity for loudspeakers) then snaps back rapidly. When the polarity is inverted, the cone moves toward the listener very quickly and pulls back slowly. Not surprising that there's a difference in sound. Most people perceive this as one polarity sounding more "bassy" than the other. Note that you're not hearing absolute frequency here - few speakers can reproduce 20 Hz, and few listeners can hear it accurately - You're hearing harmonics due to the non-symmetrical complex waveform.

For those of you with World Wide Web access and the means to play a WAV file, here's a demonstration. I've created a short WAV file of a 20 Hz sawtooth that changes polarity halfway through. Download it, play it, and you'll be convinced that you can indeed hear the difference in polarity. No need to try to rationalize it, saying you have inferior equipment or non-linear speakers (or ears), it's a fact of life. With this demonstration, I can hear an obvious difference listening on the dinky speakers attached to my computer as well as on my control room monitors and living room listening speakers. While this isn't intended to be a test to determine if your system maintains correct polarity, I'll give you a hint. The second half of the waveform should sound more bassy than the first.

You can find the demonstration waveform at http://www.d-and-d.com/mrivers/poltest.html. Or if you don't want to bother with an 800 MB download and have the tools, you can construct the same demo yourself. Using the waveform generator function that's available on many of the audio editing programs (I used Cool Edit), create a 20 Hz sawtooth, highlight half its length, and apply the polarity inversion to the highlighted half.

Now that you have a tool, start checking out your system, fixing polarity inversions as you discover them. While having a "polarity pure" system may not change your life, at least you can be proud that you're not contributing to someone else's problem down the road. It never hurts to do things right. Even if you can't hear a difference, perhaps someone else can.