An LP Primer

HOW THE LP WORKS

Robert Harley

It's as improbable as the bumblebee. A piece of polished diamond is dragged through a series of wiggles in a groove just three-thousandths of an inch wide pressed into a piece of mass-produced plastic and at the other end of the system Bach emerges.

One hundred and thirty years ago this year, Thomas Edison demonstrated that vibrating air—sound—could be converted into a mechanical form and back into sound. Ten years later, Emile Berliner made sound recording more practical by inventing the flat disc that evolved into the modern LP.

These early devices were strictly mechanical. Sound was acoustically amplified by a large horn, the throat of which held a diaphragm connected to a sharp point that inscribed those air-pressure variations as modulations in a groove. On playback, the point followed the groove modulations, moving the diaphragm back and forth to produce sound that was acoustically amplified by the horn.

The electronic era of disc recording and playback began in 1925 with the invention of the vacuum tube. Amplified electrical signals could now drive disc-cutting heads, and groove modulations could be converted into an electrical signal for amplification. Music was now freed from the acoustical horn.

Despite 130 years of development, today's LP relies on the fundamental principles of recording and playback invented by Edison—namely that vibrating air can be converted into a physical representation, and that physical representation can be converted back into vibrating air.

The Modern LP

Today's long-playing discs are the culmination of decades of innovation and refinement. One of the most significant of these innovations is the so-called "45/45" cutting system that makes it possible to record two different signals—stereo—in a single groove. The name describes the "V" groove in the LP in which each groove wall is angled 45° relative to the disc surface and 90° to the other wall. Left-channel information is recorded on the LP's inner wall (closest to the record center), and right channel information in the outer wall of the V groove as seen in Fig.1.

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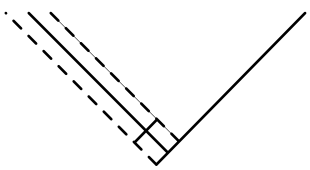
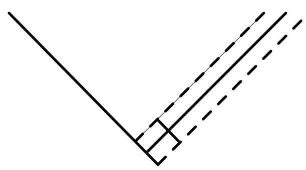
(This is a simplified explanation. Lateral information is the sum of the left and right channels, and there's a vertical component to groove modulation that is the difference between the left and right channels. This combination of signals is automatically decoded in the cartridge by the coils' orientation.)

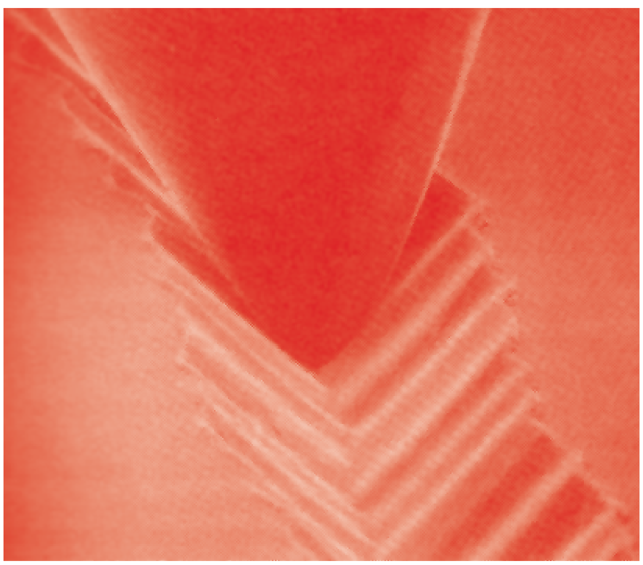
The 45/45 cutting system gave us stereo, but the long-play (LP) record was made possible by the microgroove along with variable pitch (the spacing between grooves). High-level signals create wide groove modulations, which require wider pitch than low-level signals. With variable pitch, a second playback head on the analog tape machine (called the "preview head") positioned before the signal-playback head cues the cutting lathe to widen the spacing between grooves to accommodate the high-level signal. The result is the ability to record up to 22 minutes of stereo per LP side, a significant improvement over the five monophonic minutes per side of the 78 rpm record. Incidentally, each side of a modern LP contains about 1400 feet of groove.



Stereo groove with left-channel signal

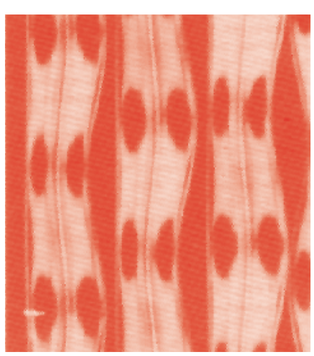


Stereo groove with right-channel signal



A stylus in a groove produces a force of nearly four tons per square inch. (Photo courtesy Stanton Magnetics, Inc.)

Stereo LP groove with predominantly left-channel signal (Photo courtesy Stanton Magnetics, Inc.)



Stereo LP groove with predominantly right-channel signal (Photo courtesy Stanton Magnetics, Inc.)

In The Groove

The forces involved in playing a record boggle the mind. A playback stylus with one gram of vertical tracking force produces a pressure of nearly four tons per square inch. That's because the contact area between stylus and groove is just 0.2 millionths of a square inch. The friction between stylus and groove creates enough heat (500° F) to melt the groove wall for a brief instant.

Ideally, the playback stylus would follow the groove modulation exactly as it was inscribed by the mastering lathe's cutting head. In practice, a number of factors introduce differences between the motions of the cutting and playback styli. First, *tracing distortion* is introduced because the shapes of the cutting and playback styli are different; cutting styli have sharp edges and playback styli are polished smooth, making it impossible for the two styli to follow exactly the same path. Second, *mistracking* occurs when the stylus momentarily breaks contact with the groove walls, usually because the stylus encounters a complex, high-level groove modulation. The stylus simply can't follow the cutting-head's path; instead, it is sent skittering through the groove, which we hear as severe distortion. Mistracking not only adds distortion, it also damages the record as the stylus is slammed back and forth between the facing groove walls.

Another problem is *tangent error*, which describes a difference in the geometric relationship between the groove and the cutting and playback styli. Master lacquers are inscribed by a cutting head moving in a straight line across the disc; pivoted tonearms play back the disc in an arc. Adding an offset to the tonearm (the bend at the cartridge end) greatly reduces tangent error (the tangent error is reduced to less than 3° worst case, and is zero at two points along the record). But this tonearm offset introduces a force that pulls the tonearm toward the spindle—the familiar *skating* force that we compensate for with the tonearm's anti-skate adjustment. Skating is caused by friction between the stylus and the groove wall, pulling the stylus away from the tonearm pivot point and toward the record center. An equal but opposite force is applied to the tonearm to counteract skating force. Note that tangential-tracking tonearms move in the same path as the cutting head and thus allow the playback stylus to maintain the same geometric relationship to the groove as the cutting stylus. Consequently, no skating force is developed with tangential-tracking tonearms. In practice, however, tangential-tracking arms are quite fussy. Specifically, it is impossible to achieve equal force applied to both groove walls; the cartridge is "pushed" by friction against the outer groove wall to follow the spiral track.

A stylus sails through the LP's outer grooves with ease; the linear speed as seen by the stylus is quite high—20" per second. This means that high frequencies are inscribed with long wavelengths, making it relatively easy for the stylus to correctly track complex passages cut at a high modulation level. But as the stylus moves toward the inner grooves, the linear speed gradually decreases. The record spins at a constant angular velocity (360° in 1/33.3 minutes), but the distance the stylus travels in each revolution is much shorter on the inner grooves than the outer grooves. Specifically, at the innermost groove the linear velocity is just 8" per second—less than half the speed as at the outermost groove. This means that a 10kHz signal at the outermost groove is inscribed with a wavelength of 0.002", but with a wavelength of just 0.0008" at the innermost groove. The same information is crammed into smaller space. Because of this inherent characteristic of the LP, inner grooves are more difficult to track and are prone to higher distortion.

It's astonishing that infinitesimally small physical features can be inscribed in a piece of mass-manufactured plastic and then recovered as richly filigreed musical detail. On an LP with a signal-to-noise ratio of 50dB, the stylus can respond to, and recover the information encoded in, a physical feature in the groove of less than 0.1 microns in size. To put this feat into perspective, a human hair has a diameter of about 75 microns. That the LP works is amazing; that it works so well is nothing short of miraculous.

One would intuitively think that the Compact Disc with its laser-based optical system is vastly more precise, refined, and resolving than the crude technology of dragging a piece of diamond through a modulating groove in a plastic disc. For example, about 50 CD tracks would fit inside the middle portion of a typical LP groove. But consider this: That piece of polished diamond can resolve physical features in the groove of 0.1 microns; the smallest pit or land length on a CD is 0.8 microns.

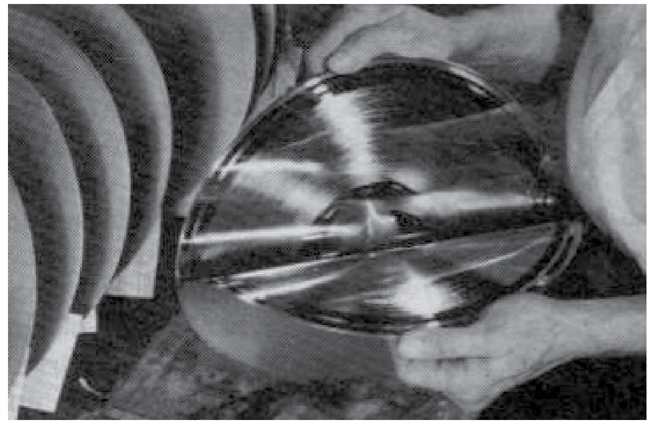
LP Cutting and Pressing

The classic view of disc mastering (as Bob Ludwig mentions in this issue's Back Page) is that it's the last creative step in making records and the first manufacturing step. The disc-mastering engineer transfers tape to disc, making any final tweaks to the sound, processing the signal so it best fits the LP medium, and making the physical disc from which LPs will be eventually pressed. A great mastering engineer is worth his weight in gold; he brings a fresh perspective and pair of ears to the project, and can give a record the final polish that makes it shine.

An important part of disc mastering is conditioning the signal so that it makes the highest-quality LP. For example, the mastering engineer selects the cutting level (amount of groove modulation for a given signal level on tape) by weighing the program length, the amount of low-bass content in the music (low bass takes up more space), and program dynamics. The higher the signal level cut into the groove, the better (up to a cartridge's tracking ability). The engineer makes trade-offs such as compressing peaks to increase the average signal level, or rolling off the extreme bottom end to allow for wider dynamics or a hotter overall signal level. The engineer also takes into account the limitations of the LP medium by equalizing the signal in a way that compensates for losses in the mastering and manufacturing process.

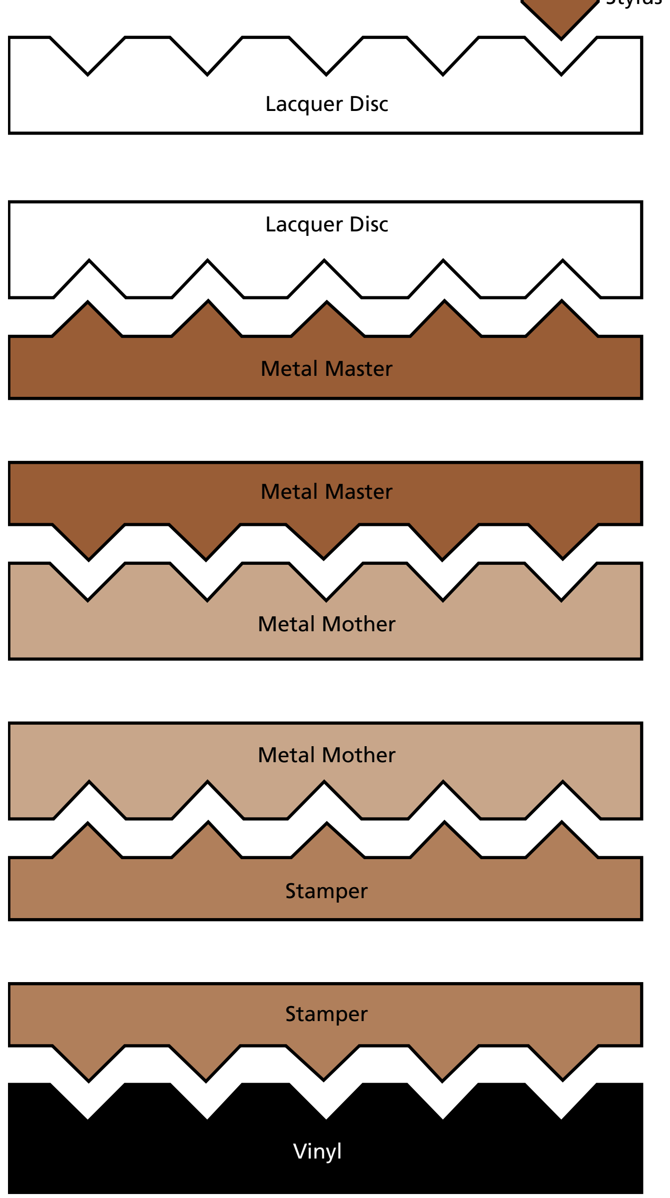
Mastering is also where the signal is equalized according to the RIAA curve. Specifically, bass is cut and treble boosted (–19.3dB at 20Hz, +19.6dB at 20kHz) before the signal is cut into the lacquer; an inverse equalization curve is applied on playback in our phono preamplifiers to restore flat response. RIAA equalization improves the signal-to-noise ratio (surface noise is attenuated on playback) and more signal can be cut into the groove because the bass (which takes up more space) has been attenuated.

The cut master lacquer is sent to the plating house, which



The stamper is peeled from the metal mother (above). (Photo courtesy Stanton Magnetics, Inc.)

The master-mother-stamper process allows many stampers to be made from a single metal mother (below).



makes metal parts from which discs can be pressed. First, the lacquer is sprayed with silver nitrate so that it can be electrically charged. The silvered lacquer is immersed in a chemical bath; an electrical charge is applied between the silvered lacquer and bags of nickel pellets that are also immersed in the bath. The electrical charge causes nickel atoms to migrate through the chemical solution and be deposited on the silvered lacquer. After many hours, the nickel-coated lacquer is removed from the bath and the nickel layer peeled off. The lacquer's groove modulations are impressed in the nickel, but as a negative impression (the grooves stick up from the surface). This part, called the metal master, is then put back into the chemical bath and electroplated with nickel. The nickel layer that is peeled off is called the metal mother. The metal mother is then electroplated. The nickel layer peeled off the metal mother is the stamper that is put into the record press. (Although a metal master can be used as a stamper, it would wear out after about one thousand LPs. The master-mother-stamper process is more cumbersome, but allows many stampers to be produced from a single metal mother.)

The stampers (one for each LP side) are loaded into a record press and a puck of vinyl (called a "biscuit"), heated to 300° and extruded from pellets, is placed into the press center. The labels are inserted now so that the LP emerges from the press as a finished product. The press closes and the vinyl, under heat and pressure, oozes to fill the void between the two stampers. Injected steam heats the press during this cycle, and then cold water cools the press so that the record solidifies and can be removed. If you've noticed that most noise in noisy pressings occurs at the outer diameter, it's because of incomplete vinyl flow to the stampers' outer edges. The longer the biscuit stays in the press, and the more precise the control of the heating/cooling cycle, the quieter the pressing (all other factors being equal).

Final Thought

Despite all the theoretical technical limitations of the LP format, there's an ineffable magic in the sound of a good LP played back on a high-quality front-end that even high-resolution digital audio doesn't capture. Some have even suggested that the LP in many ways sounds better than the mastertape from which it was cut.

Doug Sax, the great mastering engineer, speculated on this subject in our TAS Roundtable in Issue 149. He said "The disc has a certain magic. Everything you measure about the disc is worse, except that it has very good phase relationships. I'll tell you what it is. The disc forces the sound into mechanical motion. The speaker is being fed something that's been 'predigested' and put into the laws of mechanical motion, which is what musical instruments obey, to start with."

I don't know whether Sax is right about this, but I do know that this 130-year-old technology still provides the ultimate listening experience. This bumblebee can, indeed, fly. ***TAS***