Cartridge 101

What is a phono cartridge?

Think of it as a mechanical microphone. As a microphone converts air pressure changes into a corresponding voltage, a phono cartridge converts the mechanical topography of a record groove into a corresponding voltage. How does it do it? To begin, let's look at the anatomy of a phono cartridge from the vinyl up. Given the general simplicity and relatively few parts that comprise a phono cartridge (and the precision with which it must execute its job), each component plays a significant role in the success of a design. No single component is fully isolated from the others, and any deficiency in one will adversely affect the task of the others.

Stylus – The material that contacts the record surface. Its mass and shape are instrumental in its ability to accurately trace the specific type of groove cut into the record surface. The goal is for the stylus to hold the groove despite mechanical conflict between it and the record surface.

Cantilever – A rod or tube that connects the stylus to the generator of the cartridge.

Suspension – An elastic device (typically a variety of rubber) that secures the cantilever firmly in position yet allows it to remain compliant enough to allow it to move as the stylus does.

Suspension Wire (MC cartridges only) – On the generator end, a wire is attached to the cantilever that can be pulled to create a tension of the coil assembly against the suspension elastomer. This tension defines the behavior of the suspension in relation to the mass and tracking force of the cartridge. It is a critical adjustment when building the cartridge.

Generator – The part of the cartridge that converts stylus movement into voltage. There are many different types of generators. We will focus on what Sumiko offers, which are moving magnet and moving coil designs. The amount of movement in either the coils or the magnets is miniscule. To achieve uniform voltage output from all angles of movement as directed by the stylus, the tolerance and positioning of the various components that make up the generator must be very precise.

Cartridge Body (mounting structure) – The assembly that houses the generator and provides the attachment method of the generator to the tonearm.

Details on the Cartridge Component Parts

Stylus Material & Shape

The stylus' job is to maintain contact with the vinyl. As it turns out, doing so is no simple task. The stylus must be small enough to fit down inside the tiny record groove. It must be strong enough to withstand the punishment of tracking the record groove at a very high relative velocity. It must be made of a material that will yield very low friction against the record material while not wearing it down excessively, and it must be low in mass. This is a rigorous set of design goals to achieve, and diamond fits the bill perfectly. Diamond withstands heat extremely well, can be cut and polished into many different shapes, and given these attributes, is sufficiently low in mass. The grooves cut into the various record types are broadly similar, but they vary significantly in shape and size. A mono record, be it 78 or 33, has grooves that follow a side-to-side pattern, however, the dimensional groove size between the two record types is quite different. The stereo record groove, or "Microgroove," has grooves that follow both side-to-side and vertical patterns. The stylus' shape is one of the major determining factors in how well the stylus can accurately follow, or "trace," the record groove.

Mono Groove Dimensions and Stylus Sizes

The 78rpm disc revolutionized how people listened to music at home and were consequently very popular. However, there were practically no standards established when 78s were being made so there are just about as many different groove dimensions as there were manufacturers. That said, all 78 grooves are much wider than those found on an LP. The stylus shape and size best for playing all these groove types varies with groove size and record material. The primary stylus shape recommendation for 78s is spherical (or conical). When first introduced, the stylus shape was basically that of a round ball attached to the end of the cantilever. Later, a rounded tip at the end of a square shank was used. The recommended spherical stylus tip radius for 78s is somewhere between 1.8 to 4 mil, depending on who made the record.

Stereo 45 & LP Groove Dimensions and Stylus Shapes

In 1948, Columbia introduced the stereo Microgroove LP. With its much smaller and tighter grooves pressed into a plastic material, the modern record was born. A new groove shape was introduced as well. The sides of the groove now have a 45 degree angle that allows the stylus to follow the groove both horizontally and vertically. This provides frequency, amplitude, and phase relationships between the two channels as the stylus traces the groove, hence stereo sound and imaging. Columbia also introduced variable pitch to the manufacturing process, which allows for variable spacing between the grooves during the cutting process. This further allows for groove spacing to increase when high amplitude grooves are cut, then to be brought closer together for quieter passages. This dramatically increases the length of musical material that can fit on each side of a record, but it also makes the stylus' job more difficult.

Some numbers to think about before we continue…

Narrowest Groove Dimension: <4 microns
Widest Groove Dimension: >50 microns
Linear Travel Velocity of Stylus (Outer Grooves): 20" per second
Linear Travel Velocity of Stylus (Inner Grooves): 8" per second
Stylus Force on Record Surface: 4 tons per square foot
Stylus Tip Temperature: 320 degrees
Vinyl Melting Point: 500 degrees
Smallest Groove Deviation: 0.075 micron
Linear Travel for 10,000Hz Tone (Outer Grooves): 0.002" – 50.8 microns
Linear Travel for 10,000Hz Tone (Inner Grooves): 0.0008" – 20.32 microns

From the numbers, you can see that the groove on an LP are tiny, and as the stylus gets closer to the center of the record, the diameter of the record effectively decreases. It also means the distance the stylus travels to trace high frequency grooves is reduced and the grooves get tighter. A normally sized spherical stylus is too large to fit high frequency grooves as they get closer to the center. A small radius spherical stylus fits this space, but does not track optimally because the extreme topography within the groove prevents it from remaining seated during playback. Additionally, the entirety of the downforce is applied to very small contact points, resulting in very high PSI on the vinyl. Here, distortion and record wear become a problem.

Enter the elliptical stylus. The shape provides a broader contact point that is slightly elongated and fairly narrow, shaped like an ellipse to yield greater contact area and wider weight distribution to lower the PSI. Tip mass is reduced by about 50% and higher depending on the diamond profile, and most of this mass is removed from the leading and tailing ends so that the diamond can fit the tighter modulations at the end of a record. The industry's standard elliptical sizes are as follows:

10 x 18 micron – budget
8 x 18 micron – quality
5 x 18 micron – premium

Typically these sizes are not referred to as any special name or configuration. They are designated by size and cost at the manufacturing level and are very standard go-to styli for many manufacturers. Elliptical styli work quite well for stereo LP playback of the day, but the introduction of the CD-4 Quad (four channel) LP brought forth new challenges for the diamond stylus as it were. The requirements of the stylus became quite a bit more stringent as CD-4 required playback up to 45kHz (twice the high frequency goal for which the elliptical stylus was developed). The grooves at such high a frequency are very delicate and susceptible to mistracking, damage and friction wear. In 1972, Norio Shibata developed the now famous Shibata stylus for JVC. This then-new shape was meant to handle playback frequencies up to the requirements of CD-4 by decreasing the stylus' contact width and increasing its contact length. This stylus shape is also much lower in mass, a requirement for tracing the 45 kHz grooves, but also to decrease friction. The contact area of Shibata is much greater than that of a spherical and elliptical stylus, but because it further distributes the tracking force over a greater area, the PSI is significantly reduced which lowers friction and heat.

As a reference for comparison to elliptical dimensions listed above, Shibata styli sizes are as follows:

6 x 75 micron – large
6 x 50 micron – small

For the companies who did not want to promote nor market the Shibata name, the stylus was also termed "Line Contact" and marketed under many other names. A significant side benefit of Shibata's narrower and longer contact patch is greatly improved tracking ability, high frequency playback, and better record wear characteristics for standard LPs. A new level of standard LP performance was achieved. Where the spherical and larger elliptical stylus shapes may have damaged records due to mistracking and frictional wear, the Shibata stylus could reach deeper into the groove, bypassing some or all of that damage and LPs thought to be worn out sounded like new. It was quite a revelation.

The next phase of stylus development was brought about by industry experts looking more closely at (and striving to replicate) the cutter head. They knew that the rubies on the cutterhead used to cut the lacquers when making an LP were cutting grooves smaller and more precise than what even the Shibata stylus could accurately trace. The goal was to further reduce side radius distortion (the width of the contact patch) to further increase tracking ability for high frequencies and to reduce friction even further. The benefits here present a wider, cleaner and more dynamic frequency spectrum as well as longer stylus and record life. Using computer controlled devices, these diamonds are cut and polished to have extremely small and uniquely shaped contact patches. This continually developing wave of stylus shapes are capable of tracing the LP groove in very little conflict with the vinyl. Set up and optimized properly, they can provide astonishing levels of clarity, dynamics, naturalness, and yes, longevity. However, set-up can be their downfall as well. Because the contact patch is very narrow, the reduced mass of the stylus is more susceptible to damage if the alignment, tracking force, azimuth, and anti-skating are not properly optimized. Even poor bearings in the tonearm can contribute to the problem. Additionally, a misbehaving stylus of any of these shapes can also do a good job of carving up your vinyl.

To sum up stylus shapes, the many exotic styli available strive to closely replicate the cutterhead. Over the years, line contact styli have become increasingly refined and will provide the greatest possible performance with LPs old and new.

Conditions for the Modern Stylus to Negotiate

We will stick to pivoted tonearms for this discussion. Some are narrower and longer than others, but the principles remain constant. As mentioned earlier, the stylus will traverse the record in an arc. With the geometry used to align a stylus in the LP groove, there are only two points on an LP where the two faces of the stylus are exactly tangential to the way the cutter stylus cut the lacquer. In every other place on the record, the two faces follow a continuing rotation of the stylus in the groove and one channel is never exactly equal to the other channel in how it “sees” the record groove. There are strategies in stylus design that allow the stylus to better negotiate a difficult circumstance. Generally speaking, with exotic shapes come exotic set-up requirements. The narrower the contact face on the stylus, the more precise the alignment requirements become. A misaligned stylus with a very small contact face can quickly become a blade, carving up records very easily, while at the same time being damaged by the friction and increased heat levels. On the other hand, a well aligned small faced stylus yields very low friction, minimal tracking problems, and a very long useable lifespan (in addition to sounding better).

Cantilever

The cantilever is the component that connects the movement of the stylus to the generator at the end opposite the stylus. Given the amount of energy you are now familiar with at the stylus level, you can begin to understand how much energy is being transferred through the cantilever as well. The perfect cantilever will be low in mass so as not to interfere with the groove tracing of the stylus, perfectly stiff so it transfers the movements perfectly, and will not resonate such to add its own energy to the stylus nor generator. Cantilevers can be made from aluminum, boron, sapphire, ruby, and a number of other materials.

Suspension

A phono cartridge suspension is like the gatekeeper to success in a phono cartridge. The suspension is typically made with a compliant elastomer material that allows the cantilever to move freely in the dimensions the stylus requires, but also acts to damp resonance coming from the cantilever. It also to stave off micro jitters of stylus in the record groove, and holds the cantilever in its proper place relative to the generator. How much it moves is measure in ‘cu’ (compliance units). It is expressed as a number that looks like this: 10-6cm/dyne@100Hz, or in everyday speak, 10cu. The higher the first number, the more compliant the suspension. The lower the number, the stiffer the suspension (less compliant). The suspension is typically positioned along the cantilever so that it defines the pivot point of the cantilever assembly, and is located much closer to the generator than to the stylus. If designed incorrectly (too stiff, not stiff enough, too much rebound, too long a

memory, or treated incorrectly), sound quality as well as stylus/record life will be negatively impacted. Tracking force and even room temperature are further considerations for a properly performing suspension. A correctly designed and applied suspension system perpetuates a stylus that can smoothly and effortlessly follow the record groove, allowing the moving structure at the opposite end of the stylus to interact with the generator in a uniform way. As the suspension is typically made from a variety of rubber, it is susceptible to degradation over time due to shear use, but also due to environmental conditions. A suspension system in a hot and humid environment will not last as long as one in a mild climate, just as a cartridge in a very hot and dry climate will also be adversely affected. If the turntable is in direct sunlight, it will shorten the life. Advances in materials over the years have provided more robust rubber compounds that hold up better, but the very small amount of material relative to the amount of vibrational energy it deals in makes for a very difficult design brief for engineers. In terms of performance, a consistent ambient temperature is the single greatest key to getting a consistently great result from a properly set up phono cartridge. Some audiophiles even place a lamp near the turntable to control the ambient temperature for the
cartridge, and many even keep a temperature gauge nearby. For practical purposes, a suspension too cold is not sufficiently compliant, a suspension too warm is excessively compliant.

Moving Magnet (MM) Generators

At the top end of the cantilever is affixed a magnet that has a positive and negative aspect to it, just as any magnet does. The magnet emanates energy called a flux field, which is measured in units of density called gauss. Being part of the same assembly, the motion of the stylus moves the magnet correspondingly. Positioned near the magnet are a fixed pair of wire coils (two wires, four ends, positive and negative for each channel) that wrapped in a very specific configuration around a core material. Based on the Law of Induction, when the field of the magnet changes position relative to the fixed coils, the result is electromotive force (voltage). Here, the use of the word ‘force’ is not a physical description, rather it refers to electrical pressure or intensity, and it plays a role in the nature of how the voltage is developed. This is an important concept to understand. As a direct response to the stylus in the record groove, electromotive force (voltage) is actively produced. It is not a mathematical representation like that of digital material. When we speak or when a musical instrument is played, air pressure changes are physically set into motion as a direct result of that activity, hence our common use of the word analog; the basic action of LP playback mimics what happens in the real world. A microphone is very similar in concept. The diaphragm in a microphone reacts to pressure changes caused by a source, e.g. a voice, which causes magnets and coils to interact and produce electromotive force that can be amplified for listening and/or recording. In a phono cartridge, the direction the stylus moves (left, right, up, down) determines what combination of coil windings are energized by the changing position of the magnet. This is how the signal becomes left or right channel information (or both). The strength of the magnet and the number of windings on the coils determine how much output voltage the system will generate. A point of commercial interest here: the line level input stage of a preamplifier requires 1.0 – 1.5V of signal level at the input to further amplify the music signal and pass it on to the amplifier. Considering a phono cartridge develops only up to its rated output voltage, the remaining voltage must be developed through some sort of electronic gain method (amplification). Developing the amount of gain (45dB) for a higher output device such as a MM cartridge is much easier and cheaper to accomplish that what is required for a low output MC (60dB – 65dB). The primary cost associated with high gain is developing the needed amount while minimizing noise. A very strong commercial case can be made that unless one is willing to spend more on a properly designed and executed low noise, high gain phono section, a higher output MM cartridge could, on the whole, very well outperform a lower output MC design. Additionally, the nature of voltage generation varies between MM and MC. With a higher voltage-output cartridge, more of the electromotive force is generated physically rather than electronically, which is an area where a MM design may actually have a distinct performance advantage over a lower output MC. The primary disadvantage of the MM design is that the mass of the magnet is higher than that of the stylus. Due to the mass at the top end of the cantilever, the reaction time of stylus is slower because it must also put into motion (while maintaining control) the more massive magnet. To help the stylus accommodate the mass of the magnet, the suspension system for an MM cartridge is typically tuned to be fairly compliant, meaning the rubber suspension applies very mild mechanical resistance to the movement dictated by the stylus. Because of the higher compliance in this type of design, the mass of the cartridge is usually quite low (with a higher cu value) and is partnered with a lower mass tonearm. Due to the higher internal impedance of an MM cartridge, resistive loading is not an issue and the standard 47kHz load value is appropriate. However, due to the coil inductance of an MM generator, it can be heavily influenced by capacitance. A long-time industry recommendation of using 400pF of capacitance with MM cartridges is a bit odd. A capacitance value of 150pF generally results in a high frequency rise beginning at about 3kHz and is up +2dB at 10kHz. A 256pf value begins rising even lower and has a +5dB peak at 9kHz. Keeping the capacitance choice below 200pF or the lowest value on the phono section is a good rule of thumb, though if the information is available, go with what the manufacturer recommends!

Moving Coil (MC) Generators

An MC generator uses the same basic principal as an MM, but at the top end of the cantilever are a pair of coils wrapped around a former and the heavier magnetic system is fixed in place. The advantage of this design is that much less mass is attached to the cantilever; the stylus has less mass to put into motion and is thusly much less influenced by that corresponding movement. There are many strategies to reducing the mass of the structure around which the coils are wrapped, as well as to the wires themselves. As in a MM cartridge, the strength of the magnetic field and the amount of wire wrapped around the former determine the output voltage. One problem to solve with this design is attaining a uniform flux field around the coils and many different solutions have been used over the years. In some MC designs, the magnet is positioned above and to the back of the coils. Attached to the magnet are two magnetized components called pole pieces, and as their name suggests, they extend the positive or negative fields down to the front or back of the coil assembly. As the pair of coils changes position relative to the pole pieces, voltage is generated that corresponds to what the stylus dictates. Because the goal is to generate voltage that evenly represents the modulations in the grooves, creating a uniform flux field is hugely important.

Other MC designs use ring magnets on either side of the coils to achieve a more balanced flux field. Bear in mind that the movement of the stylus is miniscule, and since it is at the opposite end of the cantilever, it is far away from the pivot point near the coils, so the stylus is moving with far greater displacement than the coils do in the flux field. Think about that for a moment and consider that the smallest deviation in the groove is 0.01 microns. To create a precise electrical model that represents the minute movement of the stylus, uniformity of magnet strength, resistance of the wire, precision of coil windings, and probably the phase of the moon will determine how well the system generates voltage that resembles the movement of the stylus. Output voltage from an MC design can range from as low as 0.15mV to 3mV at the top of the range. When the output voltage is much below 0.2mV, phono gain needs to be at least 62dB if not more, and noise can begin to present a problem. Most high output MCs 2.0mV and higher can run through an MM phono stage with no noise issues.

Cartridge Mounting Structure (Housing or Body)

This is a very important part of the equation. The cartridge body (housing) must hold the generator assembly firmly in place. Any movement of the generator assembly compromises the precision of the whole system. Much energy is transferred to the body from the generator because they are so firmly connected, thus the body should be as free from resonance as possible. Any energy that is generated as resonance in the body may also transfer back to the generator, compromising its function. One goal of the body is to create a clean and direct energy path with low mechanical impedance between the generator and headshell. Energy will pass from the cartridge into the tonearm. The more direct and low-resistance that mechanical pathway is, the less mechanical energy stored in the generator, which allows it to function ideally. As with all things in audio, there is a multitude of strategies involved in accomplishing this goal, some more effective than others. As they are responsible for securing the cartridge to the tonearm, mounting screws are also a factor. When choosing what material to use for the screw, it is always best to use something non-magnetic material so as not to have affect the magnetic system in the generator. Non-magnetic stainless steel, aluminum, and brass are the most popular, and yes, because the screws become part of the mechanical system, the material from which they are made can influence the resonant characteristics of the cartridge & headshell relationship. Although they add a bit of mass, and some would say they compromise the energy transfer from cartridge to tonearm, it is a good idea to use washers between the screws and the headshell. The twisting force of the screw head against the headshell can compromise the headshell’s surface. Using a washer will require less twisting and yield more uniform downforce with little or no damage to the headshell.

Cartridge Loading

‘Resistive loading’ refers to the practice of applying load resistors across the + and – leads on a MC cartridge. There are two aspects of this fairly misunderstood topic: what resistance does to the cartridge and what does to the system. First let’s look at loading resistance and the system. The wires in the cartridge have inductance. The cabling that goes from the tonearm to the phono section has capacitance. The inductance of the cartridge interacts with the capacitance of the cable, which forms a resonant energy spike at very high frequencies (MHz). This is not the same reaction as capacitance in a MM design where the capacitance value can cause an audible high frequency rise beginning in the 3kHz region. The inductance in a MC cartridge is too low to react in the same fashion. How much energy is in this spike and exactly how high a frequency it occurs depends on the output impedance of the cartridge and the capacitance of the tonearm wire. Although the frequency of the resonant energy is far too high to hear, it is also most likely far outside the functional bandwidth of the phono section which causes it to react in some way. This energy spike will probably decrease signal stability, increase noise, and produce intermodulation distortion in the phono electronics. Resistive loading of the phono cartridge can have the effect of damping that resonant energy to almost zero, taking a potentially huge burden away from the phono section. The rule for this aspect of resistive loading is as follows: a high capacitance phono cable (>150pF) requires a lower value load resistor to damp the spike, a low or ultra-low capacitance phono cable (<50pF) requires less resistive loading to achieve the same goal. Note: With a 47kHz load and even while using an ultra-low capacitance phono cable, a low internal impedance cartridge will cause a very significant resonant energy peak to occur.

The second aspect of cartridge loading involves how it affects the cartridge itself. When a load resistor is inserted across the + and – pins of the cartridge (typically using a set of switches on the phono section) the voltage that is generated by the cartridge flows through the resistor as current. The effect on the cartridge is an electromechanical stiffening of the suspension system and decreased output from the generator. The closer the load resistor value to the internal impedance of the cartridge, the greater the effect on the compliance and the lower the output voltage becomes. Hindering the compliance of the cartridge with too low a resistor value will stifle dynamics and high frequency response, and lowering the output voltage will force you to recruit more gain from the phono section or volume knob. As it turns out, determining the correct load resistor value can be very complicated if you want to abide by the theoretical solutions. The good news is that most listeners use the load resistor values that are predetermined in the phono section, and loading can be set by recommended values and/or by ear. We find that most low output MC cartridges end up with a loading value of 100 – 1000 ohms, with most tending more toward the lower resistor values of that range. If you choose a piece of music with good clarity to the recording, nice dynamics, and extended bass, you will easily determine which value best suits your system regardless of what components or cabling you are using.

Phono Preamp Active Gain

Variable gain settings determine the gain the phono section will use to increase the output voltage of the cartridge going to the line stage. The goal for the cartridge to have similar voltage output to a line level device (roughly 1V). Matching of phono section gain to the output voltage of the cartridge should be carefully considered. Too much voltage going to a high-gain circuit will result in overload distortion. Conversely, low output voltage going to a circuit with too little gain will be noisy with poor dynamics. Here are typical output voltages and corresponding gain settings:

3 – 6mV: 36dB
1 – 3mV: 43 dB
0.3 – 1.0mV: 53dB
0.25 – 0.3mV: 62dB
0.15 – 0.3mV: 65 db

Cartridge Alignment

At this point, it should be clear that the alignment of the stylus in the groove is critical. The relationship between the stylus and groove cannot be seen with the naked eye, so we need to rely on tools to get the job done. There is a variety of ways to accomplish this. The most accurate way is to use a triangulation tool. As the cartridge moves across the LP, there are only two null points on the entire record where the two stylus faces are tangential to what the cutting head etched into the lacquer. For the rest of the record, it is a compromise. The goal is to place the cartridge in the headshell so that is has the least about of mistracking or distortion as possible. In 1938, Erik Lofgren created a calculation based on Thales Circle Theorem that provides location coordinates for a cartridge to obtain low tracking error and distortion figures. By providing the distance from the turntable spindle to the pivot point of the tonearm and the effective length of the tonearm, the calculation will produce values for overhang and offset angle. In other words, these values provide guidance for where in the headhsell at what angle to secure the cartridge. Any deviation from the exact numbers for spindle-to-pivot and effective tonearm length and there is a multiplying effect on how far off the stylus tip will be from proper alignment. The beauty of a triangulation alignment tool is that it bolts in place where the tonearm is actually located, even if in the wrong place! There are other alignment tools that take into account where the arm is actually located, one being a dual-point alignment gauge. This tool will allow you to find the correct position and angle to mount the cartridge by placing the stylus tip on one of two grids, then the other, and moving the cartridge until the stylus tip and cantilever line up evenly on both grids. It can be time consuming, but the tool is inexpensive and accurate. There are also alignment geometries from names like Baerwald, Stevenson, Seagrave, Kessler and Pisha. All of which use exactly the same math as what Lofgren provided, but have been altered alignment goal to provide different null points on the record.

Cartridge Set-Up Optimization

If we think of cartridge alignment as a fixed value, there are four variables to address in helping a cartridge perform optimally on the vinyl. From the get-go, understand that nothing can be ‘perfected’ when it comes to cartridge alignment and optimization. The best we can provide is a balanced system where all aspects of the mechanism are fighting each other the least.

Tracking Force (Stylus Pressure or Tracking Weight)

There are two primary goals for finding the correct tracking force value: 1. To achieve sufficient downforce to the stylus tip on the vinyl so it maintains contact with the record groove, and 2. To position the coils in a neutral spot within the flux field. In general, the tracking force within the range provided by the manufacturer will result in enough downforce to keep the tip firmly planted in groove. This leaves the coil orientation as the remaining value to determine. When the coils are in a magnetically equal position between the two charged poles, the coils will have uniform movement and will develop voltage equally. Depending on the design and implementation of how the flux field is defined relative to the coils, there may not be linear behavior from the cartridge one way or the other in terms of how the cartridge responds to a change in tracking force. The correct tracking force value for two cartridges of the same design will most likely be different from one another. Both will be within the specified range, but do not be surprised if there is a difference of as much as 0.75g between samples.

VTA & SRA

Vertical tracking angle (VTA) and stylus rake angle (SRA) refer to different aspects of cartridge alignment. VTA is the angle of the cantilever relative to the surface of the record, SRA is the angle of the stylus in the groove relative to that surface. There is a lot of discussion on the correct SRA for a stylus. In practice, the record groove is not cut into a lacquer at a specific angle. Conditions of the lacquer, cutter head, and even music content will influence how the recording engineer will cut that particular record, using a cutting angle that allows for a clean and consistent groove over the entire record. Additionally, record thickness will change the required arm height to maintain the correct SRA.

Azimuth

Azimuth is the relationship of one side of the cartridge relative to the other side as the stylus is in the groove. The goal is that the left and right sides are equidistant from the record groove. Azimuth is affected by the headshell position, anti-skating force, and stylus velocity. One can rotate the headshell (or entire tonearm) to affect the azimuth attitude, but forces such as anti-skate should also be considered. The azimuth on a uni-pivot tonearm is readily affected by improper anti-skate force, for example. Even with fixed-bearing tonearms, azimuth can be disturbed by the compliant nature of the cartridge suspension system reacting to skating forces. The concept of adjusting azimuth by using a test tone and a measurement device may get the azimuth close, but if one were to take the same measurement farther into the record, the skating force would provide enough influence to show an incorrect azimuth setting. Azimuth therefore is best adjusted by ear, using a wide variety of music at various points in the tonearm’s arc. Finding the best overall azimuth position will be an average of how the cartridge performs with many different factors taken into account.

Anti-Skate Force

Anti-skate force counteracts sideways-directed force applied by groove drag and friction to the stylus changing direction in record groove. As the record circumference decreases with the stylus moving toward the center, stylus velocity, narrowing grooves, alignment parameters, compliance, arm stability and center of arm mass all affect how the skating is impacting stylus friction. Anti-skate is another adjustment that is best made with a wide variety of music and at various points on the record.

When optimizing the various parameters in cartridge set-up, remember that changing one variable has an impact on the others. For example, once the cartridge is aligned, changing either the tracking force or SRA will affect that alignment. Varying with the arm design, changing SRA will affect tracking force, anti-skate will impact azimuth, cartridge loading will affect tracking force and anti-skate. The best one can do is come to a balance of consistent performance across all parameters. The final ‘dialing in’ of a cartridge is best done by listening closely to your favorite recordings. You know best how they should sound in your system. Happy listening!