Disc Recording Equalization Demystified

By Gary A. Galo

The subject of disc-recording equalization has generated much confusion over the years. Many knowledgeable collectors and audio professionals have been content with conventional explanations. Transfer engineers and collectors are well aware that electrically recorded discs require a bass boost, and sometimes a treble cut, in playback.

They often assume that the playback correction, or equalization, compensates only for the method by which the actual recording was made. If the bass is attenuated during the recording process, it must be boosted in playback; similarly, if the treble is boosted when the record is cut, it must be attenuated in playback. Close examination shows that the recording and playback process is more complex.

Selecting playback equalization must take account not only of the recording characteristics, but also those of the playback cartridge. This tutorial will explain the methods of cutting disc records, the characteristics of magnetic phono cartridges, and how their combined response determines the required playback equalization.

This article is based on a paper I presented at the May 1996 conference of the Association for Recorded Sound Collections (ARSC) in Kansas City, and was first published in the Fall 1996 issue of the ARSC Journal. *The Association is a nonprofit organization serving librarians, scholars, sound archivists, dealers, private collectors, discographers, and reviewers. The biannual* ARSC Journal *is devoted to research on sound-recording history, preservation and restoration of sound recordings, record and book reviews, and much more. You can obtain membership information from Peter Shambarger, Executive Director, ARSC, PO Box 543, Annapolis, MD 21404-0543.*

In this article, italicized terms are defined in the Glossary on p. 52.

INTRODUCTION

Disc-recording *equalization* is often misunderstood by audio professionals and hobbyists alike. Even the most casual collector of 33-1/3-rpm long-playing (LP) records has probably encountered the term RIAA equalization. Most serious collectors involved with the playback of 78 rpm recordings are familiar with terms such as *bass turnover* and *treble turnover*, since any audio system suitable for the playback of "historic" recordings must have provisions for adjusting these parameters.

Currently available preamplifiers with suitable adjustment capabilities include the veteran Owl 1, distributed by Audio 78, the Resolution Series high-end preamps from the Swiss firm FM Acoustics, and the Esoteric Sound Re-Equalizer, which is intended to correct a modern preamp's RIAA response to match older recording characteristics.

Some collectors use vintage tube units from the 1950s, either in stock or modified form, since many preamplifiers from that period offer flexible equalization settings that reflect the lack of standards at the time they were manufactured. The best of these audio "classics" include the McIntosh C-8 and the Marantz Audio Consolette.

As most of you are probably aware, disc records are not cut with a *flat frequency response*. The method of cutting a record is known as the *recording characteristic*, and a typical explanation for the 33-1/3-rpm LP record is illustrated in *Fig. 1*. The recording curve shows the bass rolled off (attenuated) and the treble boosted, with a flatter region in the middle of the curve. In order to obtain a flat frequency response in playback, a complementary equalization is necessary. The playback curve shows the bass boosted and the treble attenuated.

This equalization is normally accomplished in the preamplifier, which also provides sufficient amplification of the relatively weak signal from the phono cartridge (which was known in the early days of *electrical playback* as the *pickup*, a term still used by the British). If the playback equalization curve is an exact mirror of the recording curve, a potentially flat response will result.

Closer investigation shows that this explanation is an over-simplification, at best. The "record" curve of *Fig. 1* is, in fact, not the recording curve at all, at least not in terms of recorded amplitude. Rather, it is the frequency response of the record when played back with a *magnetic phono cartridge*.

To add to the confusion, some sources label the rising curve *constant amplitude*, and the flatter region in the middle *constant velocity*, which, on the face of it, makes little sense.[1] These terms describe the two basic cutting methods, but the recording curve is a result of the disc cutting and the response of the magnetic cartridge used in playback. The principles of disc recording and playback equalization are the same whether the record is lateral, vertical, or 45/45 stereo.

TWO CUTTING METHODS

Constant-amplitude (*Fig. 2*) is the cut-

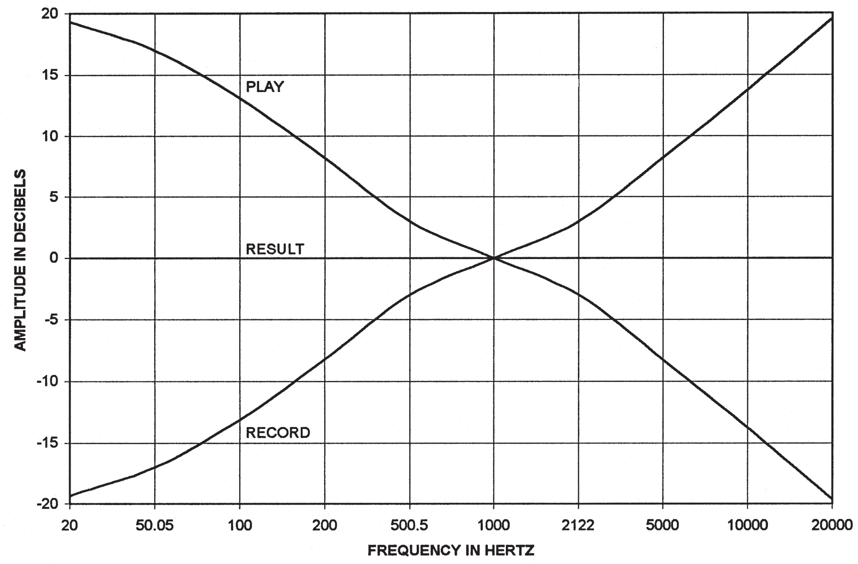

FIGURE 1: Typical graph illustrating the RIAA recording characteristic for 33⅓-rpm long-playing records. The record curve shows the bass rolled off and the treble boosted. A complementary equalization during playback restores a flat response.

ting method easiest to understand. If the signal being recorded is at the same level for all frequencies, the recorded amplitude will also be the same. *Constant velocity* is somewhat more difficult to grasp. The *velocity* of the playback stylus is the speed with which it moves while tracing the record groove, and is directly related to the physical distance the stylus travels during a given time period.

Referring to *Fig. 2*, if the stylus is tracing at a very low frequency, say 20Hz, it must move back and forth 20 times each second. As the frequency rises, the number of times the stylus must move back and forth in one second also increases. At 10kHz, for example, the stylus must move back and forth 10,000 times each second. If the amplitude of the signal remains constant, it stands to reason that the stylus velocity must increase as the frequency rises.

In order to keep the stylus velocity constant at all frequencies, it is necessary to reduce the amplitude of the recorded signal as the frequency increases. *Figure 3* illustrates this concept. The large waveform is one cycle at an arbitrary frequency—the exact frequency does not matter for the purposes of illustration. Each time the frequency doubles, the amplitude must be cut in half to keep the velocity constant.

If each of the three waveforms in *Fig. 3* were made with a piece of string, the lengths of all three pieces would be identical. The stylus travels the same physical distance during the time period, and thus moves at the same rate of speed in tracing each of the waveforms. *Figure 4* shows a constant-velocity recording characteristic, with the amplitude progressively decreasing as the frequency rises.

MAGNETIC TRANSDUCERS

Disc playback normally involves the use of magnetic phonograph cartridges, whether the playback system is modest or "state of the art." A phonograph cartridge is a *transducer*, since it converts mechanical energy into electricity (a transducer is a device that converts one form of energy into another). There are several variations on the magnetic-cartridge theme, including moving-magnet, moving-iron, and moving-coil. In principle, all function the same way—a magnetic field is in motion relative to a coil of wire.

Magnetic transducers are *velocity-sensitive* devices—they produce a flat frequency response only when the recorded velocity remains constant as the frequency rises. Understanding the behavior of magnetic phono cartridges is the key to the mystery of disc recording and playback equalization.

The horizontal line at the bottom of *Fig. 4* shows the output of a magnetic cartridge playing a constant-velocity recording. The cartridge output is flat across the entire recorded spectrum. The slanting line in *Fig. 2* shows the cartridge's output playing a constant-amplitude recording. Here, the cartridge's output increases as the frequency rises, at a rate of *6dB/octave*. In these illustrations, the straight lines not only illustrate the playback cartridge's relative output, but also show relative recorded velocity.

BASIC REQUIREMENTS

The cutting of a phonograph record involves two seemingly contradictory requirements. First, the record must be cut at a level higher than its own residual surface noise, particularly in the high frequencies. This at first appears easy—simply cut the record at a very high level, and any surface noise will be virtually inaudible. Unfortunately, doing so would violate the second requirement—playback tracking and tracing ability.

If a record is cut at too high a level, the playback cartridge and stylus will be unable to track the record. At both low and high frequencies, the cartridge will be unable to cope with excessively wide groove *excursions*. The excursion is the physical distance the stylus must travel from the center of the *groove modulation* (called the *zero crossing*) to either peak.

At high frequencies, there is an addi-

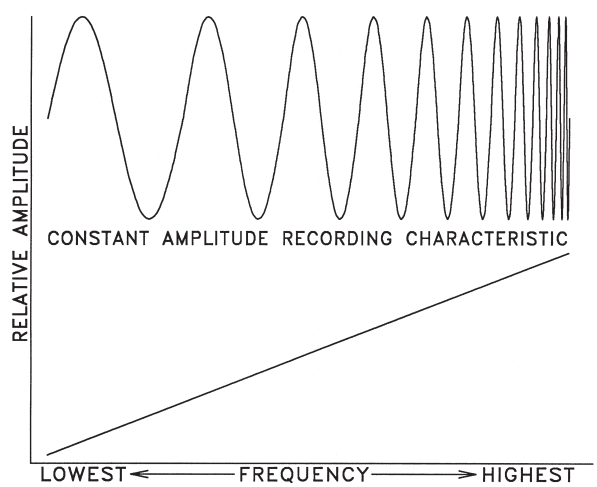

FIGURE 2: Constant-amplitude recording characteristic. The recording amplitude is held constant as the frequency increases. The diagonal line shows the relative output of a magnetic cartridge, and also illustrates the increase in velocity as the frequency rises.

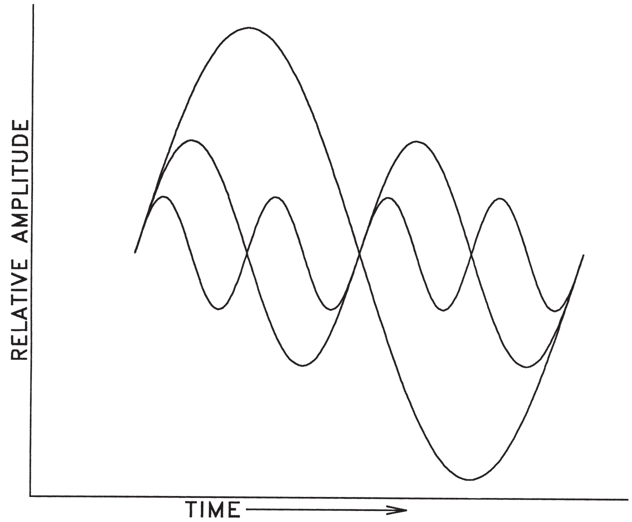

FIGURE 3: Conceptual illustration of constant-velocity recording. In order for the playback stylus to travel the same physical distance in a given time period, the amplitude must be cut in half each time the frequency is doubled.

tional problem, technically called the *radius of curvature*, that is directly related to the physical size of the playback stylus. As you can see in *Fig. 2*, the playback stylus must change direction as it passes through each peak of the groove modulation. At low frequencies, the turn is far less sharp than it is at high frequencies; i.e., the radius of the curve is longer.

As the frequency increases, however, the radius becomes shorter and shorter, and a point is reached where the radius of the playback stylus is actually greater than that of the curve. This results in tracing distortion. If the tracking force is heavy enough, the playback stylus will cut its own path through the vinyl or shellac, destroying the original recorded vibrations. These problems were fully understood by Maxfield and Harrison,[2] the inventors of electrical disc recording.

UNIQUE ADVANTAGES

Neither a constant-amplitude nor a constant-velocity recording characteristic can meet all of the requirements, yet both have unique advantages. If a record is cut with a constant-velocity characteristic, playback equalization is unnecessary, since the magnetic cartridge has a flat frequency response playing this type of recording. However, constant-velocity recording has two inherent problems.

First, since the recorded amplitude rises as the frequency decreases, groove excursions at low frequencies become too large. This not only makes the record difficult or impossible for the playback stylus to track, but it also limits the playing time on the record.

Playing time is directly related to the *groove pitch*, which, in this context, does not refer to high or low pitch (i.e., frequency), but instead to the spacing of the record grooves. Normally, groove pitch is defined as the number of lines per inch across the radius of the record surface. (Adjacent grooves are called lines, since a record technically has only one groove—a continuous spiral from the beginning to the end of the side.) If the excursions are extremely wide, the spacing must be increased to prevent bridging of adjacent grooves, which would decrease the number of lines and thus reduce the playing time.

The second problem with constant-velocity recording is that relative to the low frequencies, the highs are recorded at an extremely low level, potentially lower than the surface noise of the record. If a wide frequency response is possible, constant-velocity cutting is not desirable at extremely high frequencies, since the surface noise will mask the treble region. This was not a concern during the early years of *electrical recording*, since it was not possible to achieve a wide frequency response at that time.

The particular advantage of constant-amplitude cutting is that it works well at low frequencies. It holds groove excursions to a reasonable level, since the recorded amplitude does not increase as the frequency drops. It also minimizes the high-frequency noise problem, because the recorded amplitude will always be higher than the surface noise of the record.

However, there is no free lunch here, either. Recording high frequencies at these levels will also cause stylus-tracing distortion, in part due to the radius-of-curvature problem described above. Wide excursions at high frequencies also cause cartridge/stylus tracking problems. The physical mass of the stylus assembly limits the velocity at which the stylus can travel.

HYBRID APPROACH

Maxfield and Harrison opted for a hybrid recording characteristic that used both constant-amplitude and constant-velocity cutting to best advantage. *Figure 5* shows the electrical-recording characteristic used during the early years of the 78-rpm era. The lower frequencies used a constant-amplitude characteristic, while that of the treble region was a constant-velocity type. The point where the transition from a constant-amplitude to a constant-velocity characteristic occurs is known as the bass turnover frequency, or simply the turnover frequency.

The constant-amplitude characteristic limits the groove excursions in the bass region, thus minimizing stylus-tracking problems and maximizing playing time. The constant-velocity characteristic minimizes high-frequency tracking and tracing problems by limiting groove excursion and preventing an excessively narrow radius of curvature. A comparison of *Figs. 2* and *4* shows that reducing the amplitude at a given frequency increases the radius of curvature.

At high recorded amplitudes, the lines connecting the peaks of the waveform are steeper; consequently, the radius at the peaks is smaller. Maxfield and Harrison were not concerned about high-frequency surface noise, since the high-frequency response of the first electrical recordings was extremely limited.

Maxfield and Harrison initially set the bass turnover frequency at 200Hz. From 200 to 4kHz, they employed a constant-velocity characteristic. In their 1926 paper, they describe using an approximate *constant-acceleration* characteristic between 4k and 6kHz.[2] For the purpose of this discussion, all that need be said about constant acceleration is that, as the frequency rises, the amplitude decays even more rapidly than with constant velocity—6dB/octave faster, to be specific.[1] They used constant acceleration to further minimize tracing problems in the treble region due to an excessively short radius of curvature.

EARLY PHONOGRAPH DESIGN

Maxfield and Harrison initially designed an acoustic phonograph for the playback of electrical recordings. They sold the exclusive rights to this design to the Victor Talking Machine Company, which then marketed it as the *Orthophonic Victrola*.

Like previous acoustic phonographs,

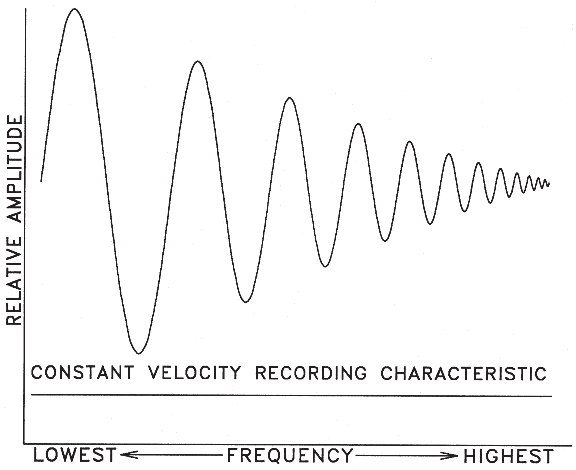

FIGURE 4: Constant-velocity recording characteristic. The recorded amplitude must decrease as the frequency increases. The straight line shows the relative output of a magnetic cartridge, and also shows the velocity being held constant as the frequency rises.

this machine used large steel needles and a heavy, metal sound box. The only way to prevent destruction of the high-frequency information during playback was to attenuate the response above 4kHz—hence the need to reduce the amplitude even more rapidly above this frequency.

Bell Laboratories subsequently modified the cutting apparatus to allow a constant-velocity characteristic up to 5.5kHz. Recordings made with the modified characteristic were best suited for electrical playback.[3]

With the introduction of electrical phonographs having magnetic cartridges, it was possible to equalize the signal below the turnover frequency to restore a flat response in the bass region. The ability to do so was an advantage of electrical playback that Maxfield and Harrison recognized.

The solid line in *Fig. 5* shows the output of a magnetic cartridge playing a 78-rpm electrical recording. In the constant-amplitude region, beginning at the lowest recorded frequency, the cartridge response rises up to the turnover frequency. Above the turnover frequency, in the constant-velocity region, the response is flat up to the highest recorded frequency. (The graphs in *Figs. 5*, *6*, and *7* are asymptotic curves. The transition points from constant amplitude to constant-velocity are gradual, as you can see in *Fig. 1*. An asymptotic curve simply removes the bends in the graph for the purposes of illustration.)

Relative to the constant-velocity region, the bass frequencies are attenuated. The dashed line in *Fig. 5* shows the playback equalization necessary to achieve a flat response; the bass is boosted below the turnover frequency. The desired flat response is shown by the dotted line. The term flat response is a theoretical ideal. Due to variety of mechanical and electrical limitations, this ideal was never realized during the 78-rpm or LP era. Even with modern, sophisticated disc-recording and playback equipment, a perfectly flat response is rarely achieved.

NONSTANDARD TURNOVER FREQUENCIES

One problem faced by those who play 78-rpm records is the lack of a standard turnover frequency. During the course of the 78-rpm era, turnover frequencies varied widely, anywhere from 250Hz to as high as 1kHz. Even a given record label may be inconsistent from year to year, or from one recording session to the next.

In order to achieve a flat response in the bass region, an electrical 78 must be equalized with the same turnover frequency with which it was recorded. If the playback turnover frequency is set too high, excessive, "boomy" bass will result; if it is too low, the bass region will sound "thin." In order to properly reproduce 78-rpm recordings, a preamplifier with adjustable bass turnover is absolutely necessary (see "Demos" sidebar).

TREBLE TRANSITION TO CONSTANT AMPLITUDE

As electrical recording advanced, it became possible to extend the high-frequency response of the recording well beyond Maxfield and Harrison's 6kHz limit. In order to prevent surface noise from burying the extended high frequencies, later electrical 78s were cut with the characteristic shown in *Fig. 6*. Here, the constant-velocity characteristic was not used up to the highest recorded frequency. At a predetermined transition point, the *treble transition* (or *treble turnover*) *frequency*, the cutting characteristic became, once again, constant amplitude.

This switch back to a constant-amplitude characteristic is often referred to as treble *preemphasis*, but this term is misleading. The treble region is boosted only in terms of recorded velocity—the amplitude is still lower than it is below the treble transition frequency.

Since the amplitude in the treble region is substantially lower than in the bass, high-frequency tracking and tracing problems are minimal. By the late 1930s, phono cartridges possessed improved high-frequency tracking abilities that made possible a constant-amplitude characteristic, provided the amplitude was held at a reasonable level.

The constant-velocity characteristic between the bass and treble turnover points then functioned as a transitional region between the higher amplitude in the bass and the lower amplitude of the treble. The solid line in *Fig. 6* shows the response of a magnetic cartridge, differing from *Fig. 5* in that the cartridge output rises above the treble transition frequency.

The dashed line shows the required playback equalization—the treble is now attenuated above the treble transition frequency. The dotted line shows the resulting flat response.

TREBLE TRANSITION FREQUENCY ADJUSTMENT

Playback of these recordings is problematic, since the treble transition frequency was not standardized, but was typically somewhere between 2k and 3kHz. A preamplifier suitable for playback of these old recordings must allow the insertion of a treble transition frequency, if needed, and must also provide for the variation of that frequency to match the characteristics of each recording. If the playback transition frequency is set too high, the playback will be excessively bright in the treble region; if it is set too low, the high frequencies will be dull.

Every preamplifier with adjustable high-frequency equalization is calibrated in decibels of attenuation at 10kHz, with the 0dB reference set at 1kHz. In fact, what you are adjusting is the treble turnover frequency. Each setting on the preamplifier produces a 6dB/octave rolloff, beginning at a specific turnover frequency.

It is only the turnover frequency, not the rate of rolloff, that you are adjusting. The lower the turnover frequency, the greater the 10kHz attenuation (*Table 1*).

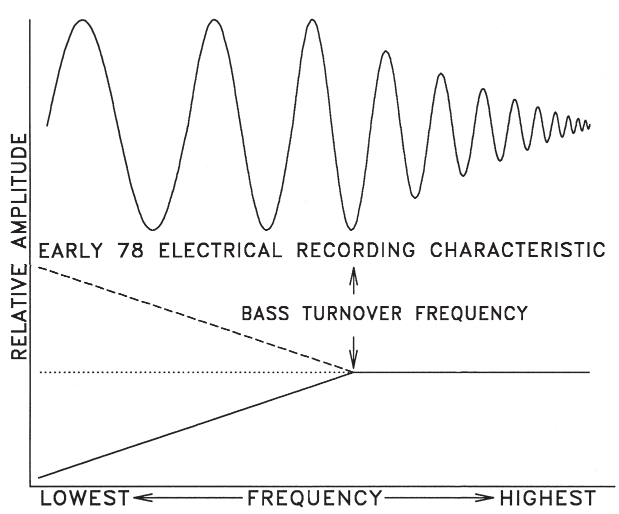

FIGURE 5: Recording characteristic for early 78-rpm electrical recordings. At the bass turnover frequency, the characteristic changes from constant amplitude to constant velocity. The solid line shows the relative velocity and a magnetic cartridge's output. The dashed line shows the playback equalization required to produce the flat response shown by the dotted line.

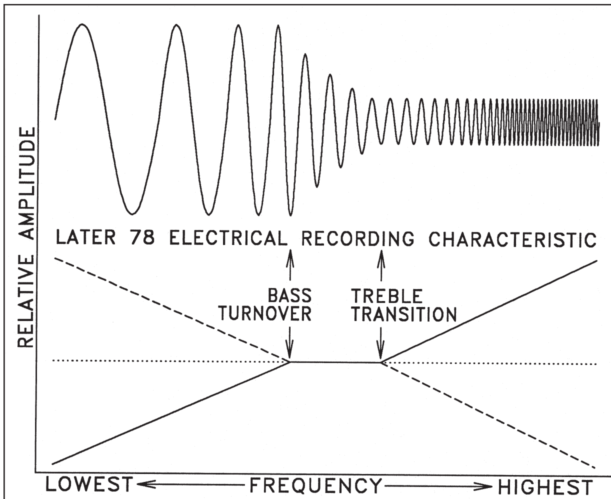

FIGURE 6: Later 78-rpm electrical recording characteristic. A constant-amplitude characteristic is used above the treble transition frequency. The solid line shows the relative velocity and a magnetic cartridge's output. The dashed line shows the playback equalization required to produce the flat response shown by the dotted line.

(This turnover frequency is really the 3dB point for the equalization circuit. At the turnover frequency, the response will be either 3dB down or 3dB up, depending on whether a cut or a boost is involved. This is why the transitions are gradual, as mentioned previously.)

Determining the exact dates when various record companies began using treble preemphasis is difficult, and beyond the scope of this work. R. C. Moyer's article[3] sheds considerable light on the evolution of Victor's recording curves.

Many Victor electrical 78s recorded from the mid-'20s through the late '30s sound bright in the treble region, even though Victor was using a constant-velocity characteristic up to the highest recorded frequency. The brightness more likely has its source in the microphones or microphone preamps. Early Victor electrics used Western Electric condenser microphones, which had an elevated response in the higher frequencies. Frayne, in his interview with Sutheim, notes that "The condenser had a peak about 5 or 6dB at 3.5kHz."[4]

In 1932, Victor began using ribbon microphones. The conversion to these was gradual, though, and some recordings made through the mid '30s still used the older condenser *mikes*. Ribbon microphones had a much flatter high-frequency response, and consequently few people liked them as well as the condensers—many missed the presence and brilliance of the condenser mikes. In order to achieve the same recorded brightness levels, Victor engineers added equalization to the ribbon-mike preamplifiers.[3] This electronic high-frequency boost was called *voice effort equalization*.[4]

TABLE 1
TURNOVER FREQUENCIES FOR COMMON ATTENUATION LEVELS

10kHZ ATTENUATION	TURNOVER FREQUENCY
–5dB	6.8kHz
–8.5dB	4.0kHz
–10dB	3.3kHz
–12dB (AES)	2.5kHz
–13.75dB (RIAA)	2.122kHz
–14dB	2.05kHz
–15dB	1.8kHz
–16dB (NAB and Columbia LP)	1.6kHz
–20dB	1kHz

A NEW RECORDING-CHAIN DESIGN

In 1938, RCA Victor redesigned the entire recording chain. They removed the high-frequency equalization from the microphone preamplifiers and added it to the disc-cutting equipment after the recording bus.[3] At this point, the high-frequency boost, or preemphasis, became part of the actual disc-recording characteristic.

Some authors and engineers consider the recording characteristic to be the combined response of the actual disc-cutting equipment, the microphones, and any equalization applied in the recording bus, which includes the mike preamps. But this does not appear to have been the official position at RCA Victor.

On Oct. 30, 1935, in response to an inquiry from J.M. Kaar of Menlo Park, CA, E.C. Forman, of Victor's Recording and Record Sales Division, described the Victor recording characteristic as follows:

"From 300 cycles down to 30 cycles, the recording is made at constant amplitude and can be represented on the curve as a straight line down 20dB at 30 cycles. From 300 cycles to 5,000 cycles, the curve is flat at zero level within ½dB. At 6,000 cycles, the curve is up 1½dB, with zero level again reached at approximately 6,500 cycles. The curve then trails down to –30dB at approximately 7,500 cycles.

"The above should enable you to apply the recording curve, and we believe that if you compensate your equipment in line with the above curve, you will have the counterpart of our recorder. However, you should bear in mind that instrument placement during recording plays almost as important a part as the actual recorder characteristic, and that even with proper compensation, certain records may have too many or too few lows or highs. This particular situation can be corrected only by the use of adjustable low and high-frequency tone controls to give the desired balance."

VICTOR'S OFFICIAL POSITION

The above letter is extremely significant in that it clearly states RCA Victor's official position on what constituted the recording

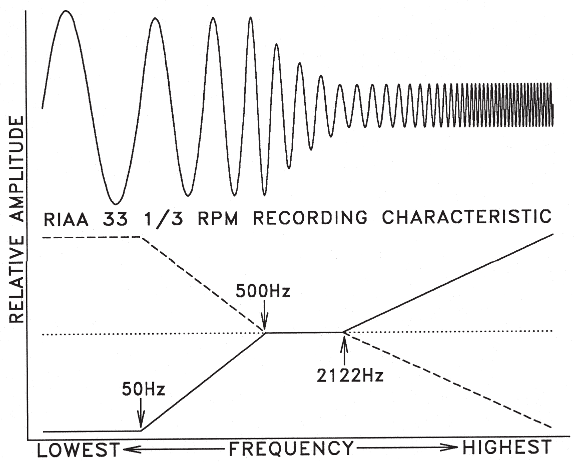

FIGURE 7: Modern RIAA recording characteristic for 33⅓-rpm long-playing records. Bass turnover and treble transition frequencies are standardized at 500Hz and 2.122kHz. A constant-velocity characteristic is used below 50Hz. The solid line shows the relative velocity and a magnetic cartridge's output. The dashed line shows the playback equalization required to produce the flat response shown by the dotted line.

characteristic—it is the characteristic of the disc-cutter head and its associated electronics. The 1½dB peak at 6kHz is a cutter-head resonance, but the frequency-response characteristics of microphones and mike preamplifiers are not described as part of the actual recording characteristic. Interestingly, Mr. Forman does not discuss microphones and mike preamps at all, but he clearly recognizes that factors other than the recording characteristic can affect the tonal balance of a recording, which may make additional compensation desirable.

It is also possible that some record manufacturers introduced a moderate high-frequency boost into the recording process in order to compensate for the high-frequency rolloff that can occur at the inner grooves of a disc record. This was called *diameter equalization*.

Moyer also notes that additional pre-emphasis was applied when lacquer replaced wax as the disc-mastering medium. This was necessary to compensate for high-frequency losses that occurred when lacquer was cut with a cold stylus (a heated stylus was not used until 1950).[3] Moyer does not give a specific date for the introduction of lacquer, but Powell implies that it was around 1937.[5]

On modern wideband playback equipment, a variety of factors can make a record sound too bright. There is nothing fundamentally incorrect about using a preamp's treble rolloff switches to correct these problems. However, it is important to understand what is being corrected. The actual disc-recording characteristic should not be confused with other factors that can cause brightness in playback.

During the late '40s and early '50s there were several attempts to arrive at a standardized recording characteristic. In 1950, the Audio Engineering Society (AES) endorsed a recording characteristic specifying a 400Hz bass turnover and a 2.5kHz treble transition frequency. The AES standard was originally proposed as a compromise playback curve that would yield satisfactory results with a variety of recording characteristics. Some very late 78s as well as many early LPs were recorded using the AES bass and treble turnover frequencies.[6]

THE MODERN LONG-PLAYING RECORD

Columbia's introduction in 1948 of the *modern long-playing record* (33-1/3 rpm) brought another turnover frequency into the equation. Now there were three such frequencies, and no industry standards to govern them. In 1953, RCA Victor introduced the recording characteristic shown in *Fig. 7* as the *New Orthophonic* curve. This characteristic is similar to that shown in *Fig. 6*, with the

DEMOS

When I presented my paper on this subject to the ARSC conference, I played a recording to demonstrate the effects of different bass turnover frequencies in playback (a cassette tape of the recorded examples is available; see ordering information at the end of the article). The recording was an excerpt from the 4th movement of Beethoven's Seventh Symphony, performed by the Philadelphia Orchestra conducted by Leopold Stokowski and recorded on April 24, 1927 (Victor 6674-A in Album M-17).

The source was an original "scroll label" Orthophonic pressing, transferred using a Technics SP-15 turntable, SME 3012R tonearm, and a Stanton 500AL cartridge with a 2.5 mil truncated elliptical stylus. My modified McIntosh C-8 preamplifier provided the equalization, and I used a modified Phoenix Systems P-94SR parametric equalizer for additional rumble filtering. I made the transfers directly to DAT, using a Panasonic SV-3700 DAT recorder, with no high-frequency filtering in order to avoid adding another variable to the equation.

I first played the recording with a 300Hz bass turnover, which resulted in a realistic balance between bass and treble, and I then repeated it with a 500Hz bass turnover, which produced a slightly heavy, "tubby" bass reproduction. I then played the excerpt with no bass equalization, i.e., a completely flat playback. The bass disappeared and the resulting playback was thin and lacking in warmth. Finally, I played the Stokowski recording with RIAA equalization. The resulting playback was bass-heavy with a dull, muffled treble.

I also demonstrated varied approaches to *acoustical playback* at the ARSC conference, using an excerpt from George M. Cohan's "Over There," recorded by Enrico Caruso on July 11, 1918 (Victor 87294). I used an original, single-faced, ten-inch "wing label" pressing for the transfer. First, I played the recording completely flat, with no phono equalization. Caruso's voice was rather thin, lacking in warmth on this transfer.

The second transfer used a flat phono equalization, with the addition of the parametric equalizer set for a 4dB boost, 0.7 octave wide, centered around 180Hz. The vocal warmth was considerably improved, yet there was no increase in low-frequency rumble. The third transfer used a 300Hz bass turnover, with the parametric equalizer removed. The vocal warmth remained, but low-frequency rumble was clearly audible.

Finally, I played the recording with a 1kHz bass turnover, which made Caruso's voice assume an unnatural heaviness, and the level of low-frequency rumble was extremely distracting. At higher playback levels, the excessive rumble could cause loudspeaker damage.

addition of the third turnover frequency in the low bass region.

Below 50Hz (actually 50.05), the characteristic is constant velocity. The bass and treble turnover frequencies have been set at 500Hz (actually 500.5) and 2.122kHz. By 1956, the Recording Industry Association of America (RIAA) had adopted the RCA Victor standard, and the entire industry followed suit.

The reason for the switch to constant velocity below 50Hz is related to low-frequency noise in the playback process. As the turntable speed progressively decreases, from 78 to 33-1/3 rpm, turntable rumble and record-warp noise also become lower in frequency.

The late-78 recording characteristic, with its playback bass equalization extending down to the lowest recorded frequency, also boosts turntable rumble and record-warp noise. If the low-frequency noise is severe enough, the excessive boost can cause amplifiers and loudspeakers to operate in a nonlinear manner, producing an unacceptable amount of distortion. In the worst case, damage to these components, especially loudspeakers, is possible.

If a constant-velocity characteristic is used below 50Hz, the output of a magnetic cartridge is flat up to this frequency, as shown by the solid line in *Fig. 7*. Consequently, no bass boost below this frequency is needed in playback, as shown by the dashed line. This minimizes low-frequency noise problems, including turntable rumble, record-warp noise and AC power-line hum.

The flat response resulting from the playback equalization is shown by the dotted line. Columbia had set the low bass turnover at 100Hz for the first long-playing records, which was even more effective at minimizing low-frequency noise problems in playback. RCA Victor decided that this frequency was too high, since it could result in excessively wide groove excursions at the lowest recorded frequencies. Hence, a frequency of 50Hz was accepted as a sensible compromise between reasonable groove excursions and noise levels.

MODIFIED NAB CURVE

The original Columbia LP record also used a bass turnover frequency of 500Hz, but its treble transition frequency was 1.6kHz. The Columbia recording characteristic was a modification of the National Association of Broadcasters (NAB) standard, a curve in use for 33-1/3 rpm broadcast transcriptions since 1942.

The NAB curve used the same bass and treble turnover frequencies as the Columbia LP curve, but the NAB characteristic did not have the low bass transition to constant velocity described above. The 100Hz low bass turnover was added by Columbia.[5,7]

Both Victor and AES found the high-frequency amplitude to be too high with a 1.6kHz treble turnover, since it might cause *mistracking* and tracing distortion on wideband high-fidelity recordings. By 1950 improved microphones, electronics, and disc-cutting equipment made it possible to record frequencies up to an unprecedented 15kHz.[6]

The Columbia/NAB curve had originally been optimized for 16″ discs. The radius-of-curvature problem is not nearly as severe on a 16″ record, since most of the playing surface has a high linear recording speed—and consequently longer physical wavelengths—than a 12″ record. At any given frequency, the physical wavelengths will be shortest near the center of the record, where the linear recording speed is slowest.

The *RIAA*, *AES*, *NAB* and *Columbia LP playback characteristics* are unacceptable for nearly all 78-rpm recordings. Playback of most electrically recorded 78s with any of these curves invariably results in dull, muffled sound in the upper midrange and treble region. Early electric discs also sound bass-heavy, since the turnover frequency is too high for many of these recordings.

At least one source, Tremaine, has erroneously listed the RIAA bass turnover frequency as 1kHz. The front panel of one of FM Acoustics' Resolution Series preamps is also labeled this way in an ad in *Stereophile* (May 1996, p. 80). This is incorrect—1kHz is simply a 0dB reference point to which the record and *playback equalization* levels at all other frequencies are compared; it is not the turnover frequency.

ACOUSTICAL RECORDINGS

The first commercial electrical recordings appeared in 1925. Before then, all disc records and cylinders were made with the *acoustical recording* process. Although there was no electrical means by which record companies could adjust the recording characteristic, the acoustical process did possess an inherent mechanical equalization. Even the best acoustic records were limited to a frequency range of 150–4kHz, and most were even narrower.

Within their limited frequency range, acoustical recordings exhibited a constant-velocity characteristic. This characteristic yields a flat frequency response from a magnetic cartridge, but that response is flat over a very narrow range. Only those who adhere to a strictly scientific approach to restoration of historic recordings use a completely flat playback.

(Due to horn resonances and other mechanical limitations, acoustical recordings have many irregularities. These prevent them from having a perfect constant-velocity characteristic—and hence a true flat response—when played with a magnetic cartridge.)

Most listeners, including myself, find that acoustical recordings sound extremely thin in the bass when played back without any bass equalization. One solution is to set the phono *preamplifier* for an unequalized, flat response, and then apply a discreet amount of boost in the 100–200Hz region with an external equalizer, preferably parametric rather than graphic. This can "warm up" the upper bass/lower midrange region, resulting in a more realistic sonic presentation, assuming there is any information on the record at these frequencies.

Another approach is to set the preamplifier to a low turnover frequency, 250–300Hz; the bass boost will add some warmth to the recording.[8] This approach can be problematic, however, since the preamplifier's bass equalization will also boost low-frequency noise and rumble well below the usable range of the recording. It makes little sense to boost the low frequencies down to 20Hz if the record contains virtually no musical information below 150Hz. One restoration equipment dealer actually recommends using a turnover frequency of 1kHz for acoustic records.

SUMMARY

Electrical recordings are not cut with a flat frequency response, but conventional descriptions of the recording characteristics used for 78-rpm and long-playing records are often misleading. Disc records are not cut with the bass attenuated and the treble boosted, at least not in terms of recorded amplitude. Electrical recordings are made using a combination of constant-amplitude and constant-velocity cutting.

Early electrical 78s were cut with a constant-amplitude characteristic in the bass region, and a constant-velocity characteristic in the treble. Later electrical 78s and all modern 33-1/3-rpm LPs were cut with a constant-amplitude characteristic in the treble region, as well.

Since a magnetic cartridge is a velocity-sensitive device, its response rises with frequency when playing a constant-amplitude characteristic, and is flat when playing a constant-velocity characteristic. In order to achieve a flat playback response, a phono preamplifier must apply equalization that is the complement of the cartridge's output. For optimum playback of historic recordings, with their myriad of nonstandard recording characteristics, adjustable preamplifier equalization is a necessity.

MORE ABOUT CARTRIDGES

AMPLITUDE-SENSITIVE CARTRIDGES

At the conclusion of the conference presentation, a number of interesting questions and points were raised. Joe Salerno, president of the Texas chapter of ARSC, asked if there were phono cartridges which were *amplitude-sensitive*. Crystal phono cartridges (sometimes called "ceramic" cartridges, if they are made with ceramic crystals) are amplitude-sensitive, and were usually found on inexpensive portable equipment during the LP era. They were often supplied with a "flip-over" stylus assembly, with one side labeled "33/45" and the other "78." Due to heavy tracking forces and poor high-frequency tracking ability, they are equally adept at destroying both types of records.

Crystal cartridges have two advantages, however. First, they have very high output (0.5-1V) and do not require a phono preamplifier. Second, they produce a flat frequency response when playing a constant-amplitude recording characteristic, and exhibit a high-frequency rolloff when playing a constant-velocity characteristic.

When they are playing records with high-frequency preemphasis, equalization circuits are not absolutely necessary. The results are less than optimum, though, since there is no compensation for the rolloff in the constant-velocity region. On the other hand, the reduced high-frequency output tends to mask the high-frequency distortion caused by poor tracking. In any case, crystal cartridges are not suitable for high-fidelity applications.

One high-end audio manufacturer, Win Research, makes an amplitude-sensitive cartridge with outstanding performance characteristics. Its model FET-10 retails for $3,500, and does not use piezoelectric crystals for operation. Instead, the stylus assembly is connected to the gate of a field-effect transistor (FET), controlling the current flow between the source and the drain. The current through the transistor is an electrical representation of the recorded amplitude rather than the recorded velocity.

The cartridge is supplied with a power supply and preamplifier, the latter containing equalization circuits that provide correct response in the constant-velocity regions of the RIAA curve. The replacement stylus, which costs $450, is not user-replaceable, and is available only in one size, for stereo LP records. Therefore, it is not suitable for archival work. The Win Labs cartridge is actually an FET version of the strain-gauge cartridge, which is also amplitude-sensitive.

RELEVANT QUESTIONS

Dennis Rooney, producer of Sony Classical's Columbia Masterworks Heritage reissue series, asked when Victor and other record labels began using treble preemphasis, suggesting that it was earlier than I had originally stated. Related to this issue, Michael Biel pointed out the switch to ribbon microphones by Victor in the early 1930s, and mentioned the use of microphone preamp equalization to achieve the same tonal balance as condenser mikes. For readers interested in further information on the specific recording characteristics used by various record companies, I highly recommend the books by James R. Powell (see References and Bibliography).

These questions also raised the issue of what constitutes the actual recording characteristic—is it the combined response of the microphones and the disc-cutting equipment, or is it strictly the characteristic of the disc cutter and its associated electronics? I have always taken the latter view, and I am grateful to Doug Pomery, an independent audio engineer and the proprietor of Pomeroy Audio, for sharing the letter from E. C. Forman with me. Forman's letter shows RCA Victor's official position on this issue to be in line with my own.

CRYSTAL CARTRIDGES

Dennis Rooney also pointed out that I give the impression that 78-rpm recording characteristics were developed with magnetic cartridges in mind, noting that crystal cartridges were widely used from the mid-1930s through the 1950s. It is true that Maxfield and Harrison, and their successors, did not develop their recording characteristics specifically for magnetic cartridges.

However, in every source I have encountered, graphs illustrating recording characteristics show recorded velocity, like the record curve in *Fig. 1* and the solid lines in my other illustrations. Since the record curves illustrate velocity, they also show the response of a magnetic cartridge. I have never seen a graph of a recording curve that showed recorded amplitude.

When an electrical recording is played, the bass frequencies are boosted and the treble region is sometimes attenuated because magnetic cartridges are used in playback. If an amplitude-sensitive crystal cartridge is used to play an electrically recorded 78, the bass must be played without equalization, i.e., completely flat, below the bass turnover frequency.

Above the bass turnover, the cartridge's output should actually be boosted in order to compensate for the decreasing amplitude as the frequency rises. If a recording contains high-frequency preemphasis, the high-frequency boost must stop at the treble transition frequency. Above that frequency, the playback response must again be flat, without any equalization.

Crystal cartridges were a cost-effective choice for 78s with treble brightness, whether due to microphone/preamp characteristics or preemphasis in the disc cutter, since the cartridge's output was much flatter, and considerably higher, than that of a magnetic transducer. For this reason, phonograph manufacturers could dispense with both playback equalization and the preamplifier required for magnetic cartridges.

To achieve a truly flat response, it would be necessary to equalize the constant-velocity region as described above. I have not researched electric phonographs from the 1930s and '40s in any detail, so I am not sure whether any manufacturers actually went to the trouble of providing proper equalization for crystal cartridges.

The point, however, is that all phono preamplifiers for high-fidelity use, whether straight RIAA or with adjustable equalization, are designed for use with magnetic cartridges. The playback-equalization curves provided by these preamps—as shown in *Fig. 1* and the other illustrations—are incorrect for amplitude-sensitive transducers. The velocity-sensitive nature of the magnetic cartridge is the reason we apply bass boost and treble rolloff to electrically recorded discs.

I am grateful to Dennis Rooney, Michael Biel, and Doug Pomeroy for the points they raised and the information that they subsequently provided. I believe this is a stronger article thanks to their input. I would also like to thank C. Victor Campos for his help in proofreading the manuscript and for his input on several technical matters.

GLOSSARY

Terms italicized in the definitions below are also listed as independent Glossary entries.

Acoustical Playback: A purely mechanical playback process whereby a playback stylus connected to a diaphragm traces the mechanical undulations in the record groove. The diaphragm is attached to a horn that provides mechanical amplification of the sound vibrations, like a megaphone. Acoustical phonographs were manufactured well into the era of *electrical recording*.

Acoustical Recording: A purely mechanical recording process whereby sound vibrations are collected by a recording horn, and funneled to a diaphragm that is, in turn, connected to a cutting stylus. The cutting stylus is moved by sound power alone. The acoustical method of recording was used until 1925, when it was replaced with *electrical recording*. Acoustical recordings have very limited *frequency* response, 150Hz to 4kHz at best, and are plagued with resonance problems. Within their limited frequency range, acoustical recordings approximate a *constant-velocity recording characteristic*.

AES Recording Characteristic: Characteristic proposed by the Audio Engineering Society in 1950. *Bass* and *treble turnover frequencies* were set at 400Hz and 2.5kHz, respectively. It was originally proposed as a compromise playback curve that would yield satisfactory results with a variety of *recording characteristics*. Some very late 78s and many early LPs were recorded with this characteristic.

Amplitude: The level, or volume of a sound vibration or recorded signal. On a disc recording, the higher the amplitude, the wider the *groove modulation* or *excursion*.

Amplitude-Sensitive: If a *phono cartridge* is amplitude-sensitive, its output is proportional to the recorded amplitude at all frequencies. *Crystal cartridges* are amplitude-sensitive. A crystal cartridge will produce a *flat frequency response* when playing a *constant-amplitude* recording characteristic. When playing a *constant-velocity* recording, its output decreases as the *frequency* rises.

Bass Turnover Frequency: The *frequency* where the transition from a *constant-amplitude* to a *constant-velocity* characteristic occurs, usually between 300–500Hz. The *recording characteristic* is constant amplitude below this frequency, and constant velocity above. The bass turnover frequencies of some electrical 78s fall outside the 300–500Hz range.

Columbia LP Recording Characteristic: *Recording characteristic* used by Columbia for the *modern long-playing record* introduced in 1948. *Bass* and *treble turnover frequencies* are set at 500Hz and 1.6kHz, respectively. A *low bass turnover frequency* of 100Hz is also specified. The record is cut with a *constant-velocity* characteristic below this *frequency*. The Columbia LP characteristic is a modification of the *NAB recording characteristic*. The 100Hz low bass turnover was added by Columbia to reduce low-frequency noise in playback.

Constant Acceleration: A *recording characteristic* in which the *amplitude* of the recorded signal decreases at a rate of *12dB/octave* as the *frequency* rises, or 6dB/octave faster than a *constant-velocity* characteristic. This characteristic was used above 4kHz on early electrical 78s to prevent destruction of the high-frequency information by heavy acoustical reproducers.

Constant Amplitude: A *recording characteristic* in which all frequencies are recorded at the same level. Recorded *velocity* increases as the *frequency* rises, at the rate of *6dB/octave*.

Constant Velocity: A *recording characteristic* in which the stylus speed is held constant at all recorded frequencies. Recorded *amplitude* decreases as the *frequency* rises, at the rate of *6dB/octave*.

Crystal Phono Cartridge: A crystal *phono cartridge* has a stylus attached to a thin slab of piezoelectric crystal. As the stylus traces the record groove, the crystal slab is twisted back and forth, generating electricity. Crystal cartridges have very high output, and do not normally require a *preamplifier*. They are also *amplitude-sensitive*, and were often used without any *playback equalization*, though the results were usually less than optimum. They require heavy tracking forces and are not suitable for high-fidelity applications.

dB/Octave (decibels per octave**):** The standard method of specifying the rate of rolloff or boost relative to a specific *frequency*, usually the turnover frequency. For example, if the recorded *amplitude* decreases at the rate of *6dB/octave* above 500Hz, the level of a 1kHz signal will be 6dB lower than a 500Hz signal. A 2kHz signal will be 6dB lower than the 1kHz signal, and so on.

Diameter Equalization: A high-frequency boost applied during the disc recording process. The purpose is to compensate for inner groove high-frequency losses caused by tracing errors (see *tracing distortion*).

Electrical Playback: Playback involving a *phono cartridge*, amplifier, and loudspeaker. The phono cartridge is a *transducer* that converts the mechanical vibrations in the record groove into electricity. The electrical signal is then amplified and fed to a loudspeaker. The loudspeaker is also a transducer, converting the amplified electrical signal into sound vibrations.

Electrical Recording: Recording involving the use of a microphone, an amplifier, and an electrical disc-cutting head. The microphone is a *transducer* that converts sound vibrations into electricity. The electrical signal is then amplified and fed to the disc-cutting head. The cutting head, also a transducer, converts the amplified electrical signal into mechanical vibrations that cut the record groove. Electrical disc recording was invented by Maxfield and Harrison of Western Electric (Bell Laboratories) and introduced commercially in 1925.

Equalization: The deliberate alteration of the *frequency* response of a recording or playback system. Disc records are not recorded with a *flat frequency response*. In order to achieve a flat response, equalization that is the complement of the *recording characteristic* and *phono-cartridge* response must be applied in playback.

Excursion: The physical distance between the *zero crossing* and the peak of the *groove modulation* on a disc record.

Flat Frequency Response: A recording or playback system is said to have a *flat frequency* response if all frequencies across the entire audible spectrum can be recorded and reproduced at the same *amplitude*. Disc records are not cut with a flat frequency response, but by applying correct *equalization* in playback, a flat response can be achieved.

Frequency: The number of times per second that a sound vibration repeats itself. It is measured in *hertz*, abbreviated Hz. One Hz equals one vibration, or cycle, per second. The human ear, in good condition, can perceive sound vibrations between 20Hz and 20kHz. Higher frequencies are often specified in kilohertz, abbreviated kHz. 1kHz equals 1000Hz, 20kHz equals 20,000Hz, and so on. Frequency is directly related to pitch. The lower the frequency, the lower the pitch; conversely, the higher the frequency, the higher the pitch. The note A above middle C on the piano, used as a tuning reference by musicians, is normally 440Hz, or 440 vibrations per second. The piano has a range of 27.5Hz (the lowest A) to 4186Hz (the top C). Harmonics produced by the piano and other musical instruments extend well beyond the range of human hearing.

Groove Modulation: The side-to-side movement of the record groove, as formed by the cutting stylus, on either side of the *zero crossing*. An unmodulated groove remains at the zero crossing at all times. Modulating the groove with sound vibrations causes the recording stylus to move back and forth on either side of the zero crossing, cutting a physical picture of the original musical waveform. A vertically cut recording causes the stylus to move up and down, rather than side-to-side. A 45/45 stereo recording produces diagonal stylus motion.

Groove Pitch or Pitch of Grooves: The physical spacing of the record grooves across the surface of the disc. Groove pitch is usually specified in "lines per inch" rather than "grooves per inch," since a record has only one groove which spirals continuously from the beginning to the end. 78-rpm records have a coarse groove pitch, typically about 75 lines per inch. Modern long-playing records average about 225 lines per inch, but can be as high as 300.

Hertz (Hz): See *frequency*

Low Bass Turnover Frequency: The low-frequency turnover used on modern long-playing records, set at 50.05Hz by RIAA. The *recording characteristic* is *constant velocity* below this *frequency*. This minimizes turntable rumble and hum in playback, since there is no bass boost in playback below this frequency. On the first Columbia LP records, the low bass turnover frequency was set at 100Hz.

Magnetic Phono Cartridge: In a magnetic *phono cartridge*, the playback stylus is attached to a magnet placed in close proximity to a coil of wire. The movement of the magnet generates electricity in the coil. Moving-magnet cartridges are the most popular, since they can be manufactured relatively inexpensively and have user-replaceable stylii (essential for playback of historic recordings). Variations on the same principle include moving-coil and moving-iron cartridges. Magnetic cartridges are *velocity-sensitive transducers*. They normally have very low output, which must be boosted by the *preamplifier*.

Mike: Short for microphone (see *transducer*).

Mistracking: A situation that occurs when the stylus loses contact with the record groove. Causes include recorded *velocities* and/or groove *excursions* that exceed the physical and/or mechanical capabilities of the stylus assembly.

Modern Long-Playing (LP) Record: The 33-1/3-rpm record invented by Goldmark, Bachman, and Snepvangers, and introduced by Columbia in 1948. The Columbia LP used microgroove cutting, requiring a playback stylus with a much smaller tip radius than those used for 78-rpm records. Victor introduced a 33-1/3 rpm record in 1931, but the groove width of the Victor LP was similar to that of the 78-rpm record. The early Victor LP was not a success, technically or commercially, and should not be confused with the modern LP record. (See *Columbia LP recording characteristic*.)

NAB Recording Characteristic: Established by the National Association of Broadcasters for 33⅓ rpm transcription discs in 1942. *Bass* and *treble turnover frequencies* were set at 500Hz and 1.6kHz, respectively.

New Orthophonic Recording Characteristic: Proposed by RCA Victor in 1953 and subsequently adopted by RIAA. *(See RIAA recording characteristic.)*

Orthophonic Victrola: An acoustical phonograph designed by Western Electric for playback of the first electrically recorded discs. The exclusive rights to the design were sold to the Victor Talking Machine Company, which marketed it as the Orthophonic Victrola.

Phono Cartridge or Pickup: The *transducer* that converts the mechanical vibrations in the record groove into an electrical signal. The term "pickup" has fallen out of favor in the United States, but it is still used by the British.

Playback Equalization: The electronic compensation provided by the *preamplifier* that is the reverse of the *recording characteristic* and the *phono cartridge's* output. Correct playback *equalization* will result in a *flat frequency response*.

Preamplifier: The control center of an audio playback system. A preamplifier with a phono input contains circuitry to boost the very low output of a *magnetic phono cartridge*, as well as to apply correct *playback equalization*. Modern preamplifiers are normally designed to provide only *RIAA playback equalization*. Preamplifiers suitable for the playback of 78s and early LPs must have variable equalization to accommodate the variety of *recording characteristics* encountered on old records. The equalization circuits in phono preamplifiers are designed for use with magnetic phono cartridges, which are *velocity-sensitive*. These playback equalization curves are not suitable for *amplitude-sensitive transducers*, such as *crystal phono cartridges*. Preamplifiers are also used in the *electrical recording* chain to amplify the relatively weak signal from the microphone. A mike preamplifier will not have disc playback equalization, but it can be designed to alter the *frequency response* of the microphone.

Preemphasis: The high-frequency *velocity* boost above the *treble turnover frequency* in later 78-rpm records, and all *modern long-playing records*. Records cut with preemphasis are *constant amplitude* above the treble turnover frequency. The term "preemphasis" is misleading since it implies a boost in recorded *amplitude*. In reality, only the recorded velocity is boosted. The amplitude above the treble transition frequency appears boosted only when the record is played with a *magnetic phono cartridge*.

Radius of Curvature: The radius of the curve at the peak of the *groove modulation*, where the stylus reverses direction. The higher the *frequency*, the shorter the radius. If the radius of the playback stylus is larger than the radius of this curve, high-frequency *tracing distortion* and record groove damage may result.

Recording Characteristic: The method used for cutting a phonograph record, defined by the relationship of recorded *amplitude*, recorded *velocity,* and *frequency*. The two most common recording characteristics are *constant amplitude* and *constant velocity*. Practical disc records are made using a hybrid of these two characteristics.

RIAA Recording Characteristic: Endorsed by the Recording Industry Association of America in 1956. It was originally proposed by RCA Victor as the *New Orthophonic recording characteristic* in 1953. *Bass* and *treble turnover frequencies* are set at 500.5Hz and 2.122kHz, respectively. A *low bass turnover frequency* of 50.05Hz is also specified. The record is cut with a *constant-velocity* characteristic below this *frequency*, which reduces low-frequency noise in playback. Since 1956, all LP records have been made with the RIAA Characteristic.

Tracing Distortion: Distortion produced when the playback stylus cannot follow the exact path cut by the recording stylus. In extreme cases, record groove damage can result from this mismatch. (See *radius of curvature*.)

Transducer: A device that converts one form of energy into another. In disc recording and playback, a transducer such as a microphone or phono cartridge may convert mechanical energy into electricity, or vice versa in the case of a disc-cutter head or a loudspeaker. These are called electromechanical transducers. There are also electromagnetic transducers, such as the magnetic tape head, that convert magnetic information into electricity, or vice versa.

Treble Turnover or Treble Transition Frequency: The *frequency* at which the transition from a *constant-velocity* to a *constant-amplitude* characteristic takes place, usually between 2k and 3kHz. The *recording characteristic* is constant-velocity between the *bass-turnover* and treble-turnover frequencies, and constant-amplitude above the treble turnover. The switch to a constant-amplitude characteristic in the high frequencies is sometimes called treble *preemphasis*.

Velocity: The speed at which the stylus moves while tracing the record groove. It is directly related to the physical distance the stylus must travel in a given time period.

Velocity-Sensitive: If a *phono cartridge* is velocity-sensitive, its output is proportional to the recorded *velocity* at all frequencies. *Magnetic phono cartridges* are velocity-sensitive. A magnetic cartridge will produce a *flat frequency response* playing a *constant-velocity recording characteristic*. When playing a *constant-amplitude recording*, its output increases as the *frequency* rises.

Voice Effort Equalization: A high-frequency boost added in the microphone *preamplifiers* used with ribbon mikes. This was done to give the ribbon mikes the same level of brightness as the condenser mikes they had replaced.

Zero Crossing: The position of the recording or playback stylus at rest. When a record is cut, the recording stylus moves back and forth on either side of the zero crossing, cutting a physical picture of the original musical waveform. The playback stylus traces the path cut by the recording stylus. The zero crossing is at the center of the *groove modulation*.

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A CD-R of the eight recorded examples is available for $10 in the US, $12 in Canada, $15 for all other countries. Prices include postage (air mail outside the USA). Total time on the CD-R is 6:45. Send payment in US funds to: Gary Galo, 72 Waverly St., Potsdam, NY 13676 USA.

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