The Columbia Lp Equalization Curve

During the development of a design for an archival phono preamplifier, the author found a number of conflicting opinions on the nature of the recording curve used for the long-playing microgroove record introduced by American Columbia in 1948. This paper will discuss the various popular views on the Columbia curve, and the method the author used to verify its actual characteristics. This paper is based on a presentation given on 29 March 2008 at the ARSC Conference held at Stanford University in Palo Alto, CA.

The RIAA recording characteristic, which has been in widespread use since it became an industry standard in 1956, uses a hybrid of constant-amplitude and constant-velocity cutting (Figure 1). Three turnover, or transition, frequencies are involved in this curve, which we'll call F1, F2 and F3.[1] The low-bass turnover, F1, is set at 50.05Hz (this is sometimes call the low-bass shelf, since it flattens the response at the lowest frequencies). The bass turnover, F2, is at 500.5Hz, and the treble transition is 2122Hz. These three frequencies correspond to time constants of 3180µS (T1), 318µS (T2), and 75µS (T3). The RIAA curve is actually defined by the three time constants; those numbers are essential for the design of accurate playback equalization circuits.

Below F1 the record is cut with a constant-velocity characteristic. Between F1 and F2 the characteristic is constant-amplitude. Between F2 and F3, the characteristic reverts to constant-velocity. Above F3 the characteristic is constant amplitude and remains so up to the top of the audible spectrum. Phonograph records are generally played back with magnetic cartridges (pickups), which are velocity-sensitive devices. When playing a constant-velocity recording, magnetic cartridges produce a flat frequency response; a constant-amplitude characteristic produces an output that rises with frequency at the rate of 6dB/octave. Hence, the hybrid recording characteristic shown in the upper portion of Figure 1, played with a magnetic cartridge, produces the frequency response shown by the solid line at the bottom of Figure 1. The curve shown by the solid line is often referred to as the recording characteristic, but it really represents two different pieces of information. As a graph of the recording characteristic, it is a graph of recorded velocity, *not* recorded amplitude. It becomes a graph of recorded amplitude when the record is played with a velocity-sensitive magnetic pickup. The complementary playback response, provided by the phono preamplifier, is shown by the dashed line; the resulting flat playback response is shown by the dotted line across the center.

The treble portion of the curve is frequently specified in terms of the number of decibels of velocity boost at 10kHz in recording process – which becomes an amplitude boost when the record is played with a magnetic pickup – and the corresponding cut required at that frequency during playback. The RIAA curve is ±13.73dB at 10kHz: 13.73dB of boost in the recording process, and a complementary 13.73dB of roll-off in playback. Note that the treble portion of the curve can be specified three different ways:

1. +dB (record) or –dB (playback) at 10kHz

2. The actual transition frequency (±3dB frequency)

3. The time constant associated with the transition frequency

The formula for converting the playback attenuation (–dB) at 10kHz to the actual transition (±3dB) frequency is given in the sidebar accompanying this article. Table 1 gives the transition frequencies for common 10kHz playback attenuation levels. For a detailed discussion of disc recording equalization, readers are referred to the paper cited in Reference 1 (a .PDF version is available for download).

Conflicting Opinions

Table 1. Treble Transition Frequencies for Common 10kHz Playback Attenuation Levels

10kHz Attenuation	Transition Frequency (& Time Constant)
– 5dB	6800Hz (23.41µS)
– 8.5dB	4056Hz (39.24µS)
– 10dB	3333Hz (47.75µS)
– 10.5	3128Hz (50.88µS)
– 12dB (AES)	2595Hz (61.33µS)
– 13.73dB (RIAA)	2122Hz (75µS)
– 14dB	2036Hz (78.17µS)
– 15dB	1807Hz (88.08µS)
– 16dB (NAB and Columbia Lp)	1591.55Hz (100.0µS)
– 20dB	1005Hz (158.36µS)

Prior to the standardization of the RIAA curve, each record label had its own, and preamplifiers for disc playback manufactured in the 1940s and 1950s often had adjustable equalization to accommodate the myriad curves in use at the time. The Columbia Lp[2] equalization curve pre-dated industry-wide adoption of RIAA by eight years. The year after Columbia introduced the long-playing record, its inventors Peter C. Goldmark, René Snepvangers and William S. Bachman published a technical article on the new recording system, and included the graph shown in Figure 2 (Reference 2). Since René Snepvangers did most of the work on the Columbia Lp record, and has traditionally received the least amount of credit, I will refer to Figure 2 as the "Snepvangers Graph" throughout the remainder of this paper.

In the paper cited in Reference 1, I stated that F1, F2 and F3 were 100Hz, 500Hz and 1590Hz, respectively, yet in the thirteen years that have elapsed since that paper was writ-

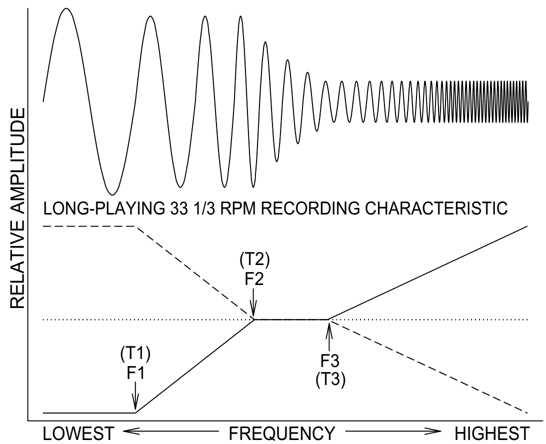
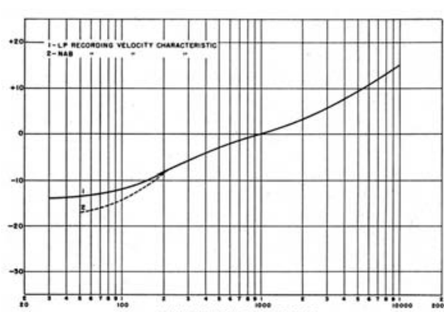


Figure 1. *Recording characteristic for long-playing records. Three turnover frequencies, and their corresponding time constants, are involved. Below F1 the record is cut with a constant-velocity characteristic. Between F1 and F2 the characteristic is constant amplitude. Between F2 and F3 the characteristic is constant velocity, reverting to constant amplitude above F3. The solid line in the lower portion of the illustration is a plot of recorded velocity; it becomes a plot of recorded amplitude when the record is played back with a magnetic pickup, which is velocity sensitive. The complementary playback equalization is shown by the dashed line, which produces the flat response shown by the dotted line.*



BELOW 200Hz: CURVE #1 IS COLUMBIA; CURVE #2 (DASHED) IS NAB

30Hz	–14.00dB
50Hz	–13.55dB
100Hz	–11.87dB
200Hz	–8.38dB
500Hz	–2.86dB

Figure 2. *The Columbia Lp recording characteristic published by Goldmark, Snepvangers and Bachman. Below 200Hz, curve #1 is the Columbia curve. The NAB curve, from which the Columbia curve was derived, is #2. The authors failed to provide any data on the time constants or turnover frequencies used to produce the curves. The data shown for the low-frequency portion of the curve was derived by carefully measuring curve #1 using a set of precision dial calipers.*

ten, I have continued to encounter widely-varying opinions on the turnover frequencies. This paper will demonstrate that my definition of the Columbia curve, back in 1996, was correct, and will illustrate the steps I took to verify its characteristics. Table 2 gives seven common views on the Columbia Lp curve. Note that some of the sources used for Table 2 specify the turnover frequencies, while others give time constants. Still others specify the dB of record boost and playback roll-off at 10kHz. In each case, the information that appears first in Table 2 is as specified by the source, followed by my own conversions in parentheses.

Table 2. The Columbia Lp Equalization Curve: Conflicting Opinions

Note: F = Turnover Frequency and T = Time Constant
T = 1 / 2πF and F = 1 / 2πT

1 KAB Souvenir EQS MK12 Manual:
F1 = 50Hz (T1 = 3180µS)
F2 = 500Hz (T2 = 318µS)
F3 = 1590Hz (T3 = 100 µS or ±16dB at 10kHz)

2. Tremaine
F1 not specified
F2 = 300Hz
F3 not specified

3. Copeland:
T1 = 1590µS (F1 = 100Hz)
T2 = 400µS (F2 = 398Hz)
T3 = 100µS (F3 = 1590 Hz or ±16dB at 10kHz)

4. Copeland's interpretation of Langford-Smith's Figure 17.15:
T1 = 1590µS (F1 = 100Hz)
T2 = 350µS (F2 = 455Hz)
T3 = 100µS (F3 = 1590 Hz or ±16dB at 10kHz)

5. McIntosh C-8 Equalization Chart (12/20/1956, S.N. 10600 and up):
F1 not specified
F2 = 750 Hz (with Bass control set at –2)
F3 = ±16dB at 10kHz (1590Hz; T3 = 100µS)

6. Powell, *High Fidelity* Magazine (Sept. 1955), Rek-O-Kut (Esoteric) Re-Equalizer II Operating Manual, and others:
F1 not specified
F2 = 500Hz (modified NAB) (T2 = 318µS)
F3 = ±16dB at 10kHz (NAB) (1590Hz; T3 = 100µS)

7. Eargle and others:
F1 = 100Hz (T1 = 1590µS)
F2 = 500Hz (T2 = 318µS)
F3 = 1590Hs (T3 = 100µS or ±16dB at 10kHz)

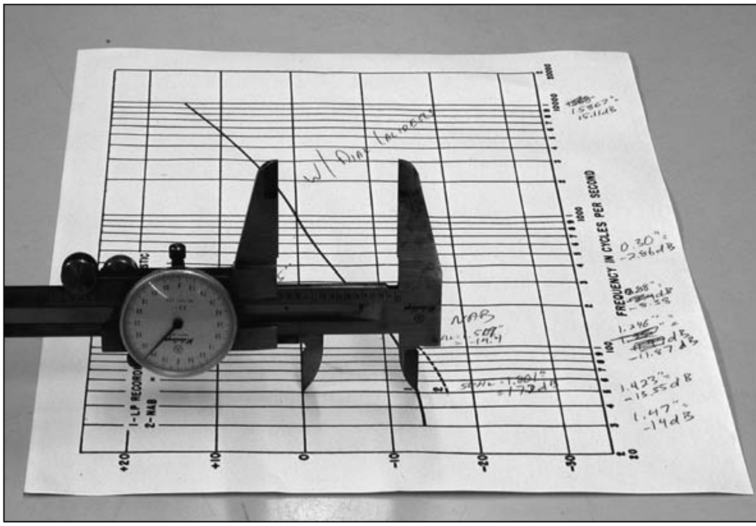
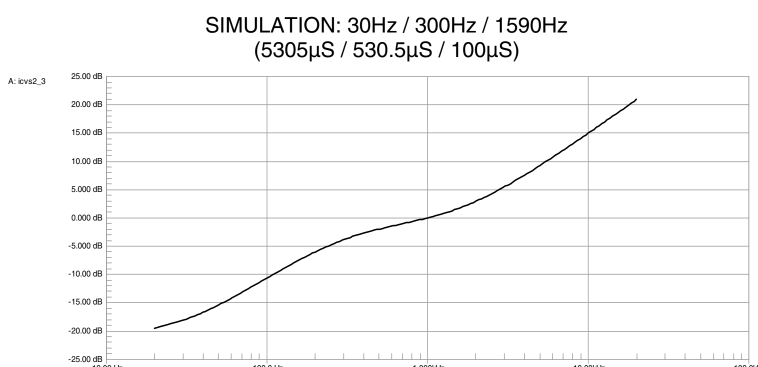


Figure 3. *Measuring the Snepvangers graph using precision dial calipers.*



	SNEPVANGERS et al.	THIS SIMULATION	ERROR
30Hz	–14.00dB	–18.1dB	4.10dB
50Hz	–13.55dB	–15.4dB	1.85dB
100Hz	–11.87dB	–10.7dB	1.17dB
200Hz	–8.38dB	–6.0dB	2.38dB
500Hz	–2.86dB	–2.0dB	0.86dB

Figure 4*. This curve was generated by a computerized circuit simulation model using turnover frequencies of 30Hz, 300Hz and 1590Hz, corresponding to time constants of 5305µS, 530.5µS and 100µS. The table compares the results with the data derived from the Snepvangers graph. This combination deviates significantly from Snepvangers' graph.*

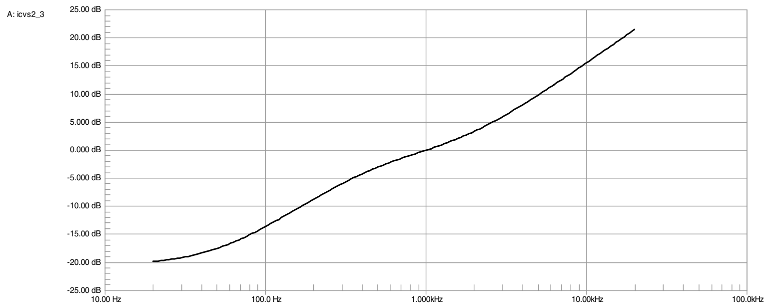
The owner's manual for the fine KAB Souvenir EQS MK12 Disc Remastering Preamplifier defines F1, F2 and F3 as 50Hz, 500Hz, and 1590Hz; an F3 of 1590Hz corresponds to ±16dB at 10kHz (Reference 3). However, my own measurements on that preamplifier showed that the low-frequency gain stop built into the Columbia playback curve produced the correct result (Reference 4). Tremaine specifies F2 as 300Hz, but fails to give any other information (Reference 5). In an unpublished manuscript generously supplied to me by ARSC member and audio restoration engineer Doug Pomeroy, the late Peter Copeland noted that he had not seen any official statement on the Columbia Lp curve, but he offered two interpretations (Reference 6). The first is based on his own understanding and research, and the second is his interpretation of a graph published by Fritz Langford Smith (Reference 7). The equalization chart supplied with a McIntosh C-8 preamplifier manufactured in 1956 does not specify F1, and gives F2 as 750Hz. This specification for F2 can't be taken literally, however, since the chart also recommends that the bass control be set to –2 (Reference 8). Powell and several others omit mention of F1, but give F2 as 500Hz, noting that this is a modification of the NAB curve used throughout the 1940s for 16-inch broadcast transcription discs (References 9, 10 and 11). Finally, Eargle offers 100Hz, 500Hz and 1590Hz for F1, F2 and F3 (Reference 12, which I cited in Reference 1). Note that there is no dispute regarding the treble portion of the curve – all sources give the treble transition frequency F3 as 1590Hz, corresponding to T3 of 100µS, or ±16dB at 10kHz. The disagreements are over F1 and F2, and the corresponding T1 and T2.

The Snepvangers Graph

As already mentioned, Snepvangers, Bachmann and Goldmark failed to accompany the graph in Figure 2 with any data on the time constants or turnover frequencies used to produce it. I decided to carefully measure the Snepvangers graph using a pair of precision dial calibers, with resolution of 0.001 inch, as shown in Figure 3. First, I scanned the graph and enlarged it to fill an 8-1/2 x 11 sheet. I then measure the distance occupied by the 10dB increments on the graph and divided that number by 10 to determine the distance for 1dB. Of primary concern was the portion of the curve from 500Hz down to 30Hz, the latter being the lowest frequency plotted by Snepvangers. The Snepvangers graph actually has two curves in the low-frequency portion of the spectrum. The top curve, labeled "1", is the Columbia Lp; the lower, dashed curve, labeled "2", is the NAB curve, from which the Columbia Lp curve was derived. Note that the "0dB" reference is placed at 1kHz, which it typical of frequency response graphs. This is done as a matter of convenience, since 1kHz falls roughly in the middle of the ten-octave audible spectrum. Measurement of curve #1 on the graph yielded the following data (the negative dB measurements are relative to the 1kHz reference):

30Hz = –14.00dB
50Hz = –13.55dB
100Hz = –11.87dB
200Hz = –8.38dB
500Hz = –2.86dB

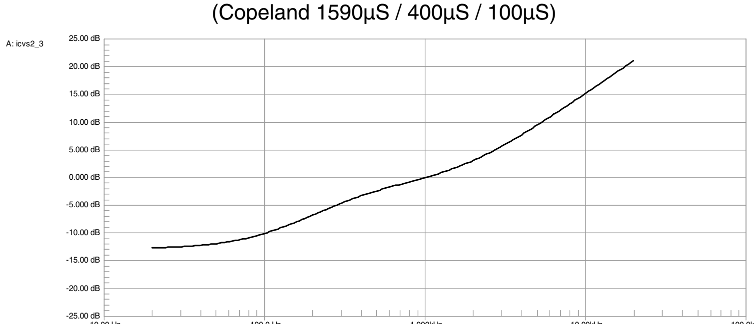
SIMULATION: 50Hz / 500Hz / 1590Hz
(3180µS / 318µS / 100µS)



	SNEPVANGERS et al.	THIS SIMULATION	ERROR
30Hz	–14.00dB	–19.2dB	5.20dB
50Hz	–13.55dB	–17.5dB	3.95dB
100Hz	–11.87dB	–13.7dB	1.83dB
200Hz	–8.38dB	–8.8dB	0.42dB
500Hz	–2.86dB	–3.0dB	0.14dB

Figure 5. *Simulation for 50Hz, 500Hz and 1590Hz (3180µS, 318µS and 100µS). Errors at the lowest frequencies are significant.*

SIMULATION: 100Hz / 398Hz / 1590Hz
(Copeland 1590µS / 400µS / 100µS)



	SNEPVANGERS et al.	THIS SIMULATION	ERROR
30Hz	–14.00dB	–12.5dB	1.50dB
50Hz	–13.55dB	–11.9dB	1.65dB
100Hz	–11.87dB	–10.1dB	1.77dB
200Hz	–8.38dB	–6.8dB	1.58dB
500Hz	–2.86dB	–2.4dB	0.46dB

Figure 6. *Simulation for 100Hz, 389Hz and 1590Hz (1590µS, 400µS and 100µS), a combination suggested by Copeland. Errors are less than 2dB.*

Recording Curve Simulation Model

I have designed a number of phono preamplifiers for RIAA long-playing records. Many years ago I developed a computer simulation model to generate a mathematically-ideal RIAA recording curve, for checking the accuracy of playback equalization circuits. During the development of the archival phono preamp mentioned earlier, I modified that simulation model to generate any recording curve I needed, including the Columbia Lp curve. The program I use for schematic drawing and simulation is CircuitMaker 2000. This program allows you to place measurement cursors on the generated graph for precise level measurements at any desired frequency. The simulation model is shown in the sidebar, along with the procedure for calculating the component values. Those who are not interested in the engineering details can skip the sidebar.

The simulation model was used to generate five graphs using the data shown in Table 2 (Figs. 4 – 8). Accompanying each graph are the measurements made on Snepvangers' graph, the data produced by the simulation, and the errors, or differences between the two. Figure 4 shows the curve generated using 30Hz, 300Hz and 1590Hz for F1, F2 and F3 corresponding to time constants of 5305µS, 530.5µS and 100µS (300Hz is the bass turnover suggested by Tremaine). This combination produced errors of 2.38dB at 200Hz and 4.1dB at 30Hz. Figure 5 shows the graph produced using 50Hz, 500Hz and 1590Hz (3180µS, 318µS and 100µS). The combination produced significant low-frequency errors: 3.95dB at 50Hz and 5.2dB at 30Hz. Figure 6 shows the results for the 100Hz, 398Hz and 1590Hz combination suggested by Copeland (1590µS, 400µS and 100µS). This graph is fairly close to Snepvangers, with errors of less than 2dB. Copeland's interpretation of the graph published by Langford-Smith is shown in Figure 7, with frequencies of 100Hz, 455Hz and 1590Hz (1590µS, 350µS and 100µS). The results are extremely close to Snepvangers, with errors of less than 1dB.

Figure 8 actually contains two curves below 200Hz. The top curve was generated using the frequencies suggested by Eargle and others: 100Hz, 500Hz and 1590Hz (1590µS, 318µS and 100µS). The curve produced by this combination is closer to Snepvangers' graph than any others, with maximum errors of less than 0.3dB. This should establish, beyond any reasonable doubt, the time constants and turnover frequencies used for the Columbia Lp equalization curve.

NAB Confusion

The NAB (National Association of Broadcasters) disc recording characteristic has generated nearly as much confusion as the Columbia Lp curve. Snepvangers included an NAB curve in his graph to illustrate how the new Columbia curve deviated from the NAB curve at low frequencies. Once again, no concrete data on the nature of the deviation – either time constants or turnover frequencies – were offered. The lower curve in Figure 8 is a simulation for the NAB curve using turnover frequencies of 50Hz, 500Hz and 1590Hz (3180µs / 318µS / 100µS). Table 3 shows low-frequency simulation results for this combination, along with two others that have been suggested for the NAB curve (References 13, 14). Note that 30Hz is labeled "N/A" because the NAB specification did not extend below 50Hz. The column labeled "Snepvangers, et al." contains the measurements I made on the NAB portion of the Snepvangers graph using dial calipers. Simulation results and the resulting errors are shown in the other two columns. It is

Table 3. NAB Low Frequency Simulation Results

70.7Hz / 500Hz / 1590Hz
(2250µS / 318µS /100 µS) (References 13 & 14)

	SNEPVANGERS et al.	THIS SIMULATION	ERROR
30Hz	N/A	–16.8dB	N/A
50Hz	–17.2dB	–15.8dB	1.4dB
100Hz	–14.4dB	–12.9dB	1.5dB

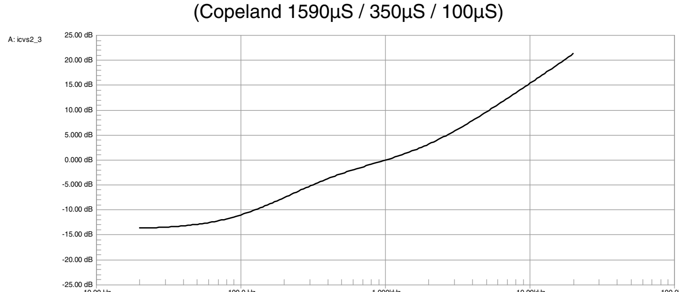
62.5Hz / 500Hz / 1590Hz
(2545µS / 318µS / 100µS) (Reference 14)

	SNEPVANGERS et al.	THIS SIMULATION	ERROR
30Hz	N/A	–17.7dB	N/A
50Hz	–17.2dB	–16.4dB	0.8dB
100Hz	–14.4dB	–13.2dB	1.2dB

50Hz / 500Hz / 1590Hz
(3180µS / 318µS / 100µS)

	SNEPVANGERS et al.	THIS SIMULATION	ERROR
30Hz	N/A	–19.2dB	N/A
50Hz	–17.2dB	–17.5dB	0.3dB
100Hz	–14.4dB	–13.7dB	0.7dB

SIMULATION: 100Hz / 455Hz / 1590Hz
(Copeland 1590µS / 350µS / 100µS)



	SNEPVANGERS et al.	THIS SIMULATION	ERROR
30Hz	–14.00dB	–13.5dB	0.50dB
50Hz	–13.55dB	–12.9dB	0.65dB
100Hz	–11.87dB	–11.0dB	0.87dB
200Hz	–8.38dB	–7.5dB	0.88dB
500Hz	–2.86dB	–2.7dB	0.16dB

Figure 7. *Simulation for 100Hz, 455Hz and 1590Hz (1590µS, 350µS and 100µS), which is Copeland's interpretation of a graph published by Langford-Smith. The results are extremely close to Snepvangers' graph.*

clear from this data that Snepvangers probably interpreted the NAB curve to be the 50Hz / 500Hz /1590Hz (3180µs / 318µS / 100µS) combination which I simulated in the lower curve of Figure 8, since this combination produced the lowest errors when compared to my dial caliper measurements on Snepvangers' graph.

The above results led to a more thorough investigation of the NAB disc recording characteristic. Figure 9 contains the NAB Recording curve as published by Reed (Reference 15), along with a simulation using the 50Hz / 500Hz / 1590Hz combination that Snepvangers' graph suggests. The NAB graph in Figure 9 has caused untold confusion. As noted by Powell and others, the NAB disc recording characteristic is ±16dB at 10kHz, but with the 0dB reference set at 700Hz rather than 1kHz. This is confusing because 1kHz is the reference most commonly used in frequency response graphs, including most disc recording and playback curves. In the simulation shown in Figure 9, I also put the 0dB reference at 700Hz, to make comparisons with the NAB graph more meaningful.

It is important to understand exactly what is meant by the specification "±16dB at 10kHz", particularly what the 0dB reference is for that specification. In order to clarify this, it is necessary to look at the high-frequency portion of the curve by itself. Figure 10 contains a high-frequency pre-emphasis simulation for the Columbia Lp and the NAB recording curves: 100µS time constant, +16dB at 10kHz. The types of filters used in nearly all disc recording equalization circuits are *first-order* filters. This type of filter is actually at a level of +3dB at the turnover frequency, relative to the reference. Since the filter simulated in Figure 10 produces a high-frequency boost, the 0dB reference is at the low end of the frequency spectrum, *not* 1kHz, which is already at +1.4dB. Looking at the curve in Figure 10, the turnover frequency of 1590Hz is at a level of +3dB relative to 20Hz, the latter being the low end of the audible spectrum and the lowest frequency plotted in the simulation. At 10kHz, the curve is at a level of +16dB. For a playback equalizer, all of the "+dB" indications become "–dB", but the same rules apply.

Recording and playback curves for 33 1/3-rpm records normally involve not one, but three turnover frequencies. When the three turnover frequencies are combined into a single curve, the levels at the bass turnover (F2) and treble transition (F3) frequencies will almost never be at ±3dB relative to 1kHz, *especially if those two frequencies are relatively close together as they are in the Columbia and NAB curves*. Consequently, the level at 10kHz will also deviate from the specification if it is measured relative to 1kHz. Note that the extremes of the NAB curve shown in Fig. 9 are at –16dB in the bass and +16dB in the treble. It is reasonable to assume that NAB put the 0dB reference at 700Hz as a matter of convenience, to make the bass and treble symmetrical: –16dB at 50Hz and +16dB at 10kHz.

Let's summarize the main points of the discussion concerning Figs. 9 and 10:

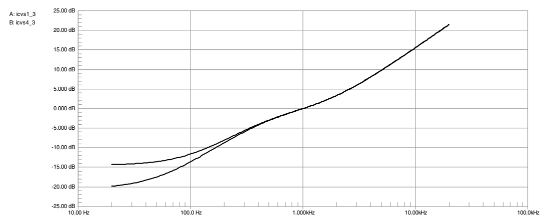
1. +16dB at 10kHz is relative to the low end of the audio spectrum (20Hz), *not* 1kHz!

2. 1kHz is at +1.4dB relative to 20Hz.

3. When this filter is combined with the bass portion of the curve, 10kHz probably won't be at +16dB relative to 1kHz.

4. NAB probably moved the 0db reference to 700Hz to make the bass and treble symmetrical: –16dB at 50Hz and +16dB at 10kHz.

SIMULATION: 100Hz / 500Hz / 1590Hz
(1590µS / 318µS / 100µS)
(50Hz / 500Hz / 16dB @ 10kHz for NAB)

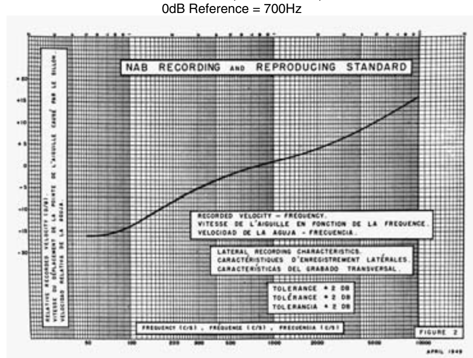


BELOW 200Hz: TOP CURVE IS COLUMBIA; LOWER CURVE IS NAB

	SNEPVANGERS et al.	THIS SIMULATION	ERROR
30Hz	–14.00dB	–14.1dB	0.10dB
50Hz	–13.55dB	–13.6dB	0.05dB
100Hz	–11.87dB	–11.6dB	0.27dB
200Hz	–8.38dB	–8.1dB	0.28dB
500Hz	–2.86dB	–2.9dB	0.04dB

Figure 8. *Simulation for 100Hz, 500Hz and 1590Hz (1590µS, 318µS and 100µS), as suggested by Eargle and others. This combination produced the lowest errors when compared to Snepvangers' graph indicating, beyond a reasonable doubt, that these are the correct turnover frequencies and time constants for the Columbia Lp equalization curve.*

NAB CURVE (Reed P. 242)
0dB Reference = 700Hz



SIMULATION: 3180µS / 318µS / 100µS with 0dB Ref. @ 700Hz
(Snepvangers 50Hz / 500Hz / 1590Hz)

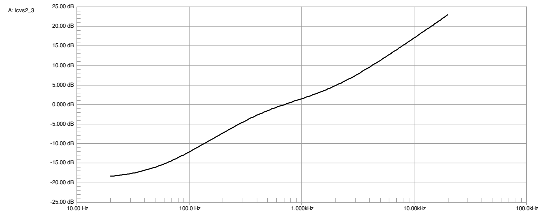


Figure 9. *The NAB graph, published by Reed, is shown in the top illustration. NAB put the 0dB reference at 700Hz, rather than at the customary 1kHz, which has caused considerable confusion over the years. The bottom graph is a simulation of the NAB curve using 50Hz, 500Hz and 1590Hz (3180µS, 318µS and 100µS). The 0dB reference in the simulation has also been placed at 700Hz, to allow meaningful comparisons to the NAB graph.*

The NAB Curve

I carefully measured the NAB curve in Figure 9 with dial calipers. I then ran simulations using four different interpretations of the NAB curve, putting the 0dB reference at 700Hz. Table 4 contains the results. "NAB Graph" contains my measurements on the graph in Figure 9. The simulation results are shown in the other columns. The errors, or

Table 4. NAB Curve Simulations (0dB Reference = 700Hz)

#1 = COPELAND: 2250µS / 275µs / 100µS
(70.7Hz / 578.7Hz / 1590Hz) (Reference 6)

#2 = SNEPVANGERS: 3180µS / 318µS / 100µS
(50Hz / 500Hz / 1590Hz)

#3 = 2545µS / 318µS / 100µS
(62.5Hz / 500Hz/ 1590Hz) (Reference 14)

#4 = 2250µS / 318µS /100 µS
(70.7Hz / 500Hz / 1590Hz) (References 13 & 14)

DEVIATIONS FROM NAB GRAPH FOR **#1, #2, #3** & **#4**
ARE IN PARENTHESES (X.XXdB)

		NAB GRAPH	**#1**	**#2**
50Hz		–15.99dB	–15.08dB (0.91dB)	–16.03dB (0.04dB)
80Hz		–15.04dB	–13.30dB (1.74dB)	–13.58dB (1.46dB)
100Hz		–13.79dB	–12.15dB (1.64dB)	–12.17dB (1.62dB)
200Hz		–7.97dB	–7.69dB (0.28dB)	–7.28dB (0.69dB)
500Hz		–1.85dB	–1.74dB (0.11dB)	–1.56dB (0.29dB)
700Hz	(Ref)	0.00dB	0.00dB	0.00dB
1kHz		+1.28dB	+1.66dB (0.38dB)	+1.49dB (0.21dB)
2kHz		+4.16dB	+5.22dB (1.06dB)	+4.85dB (0.69dB)
5kHz		+10.23dB	+11.76dB (1.53dB)	+11.34dB (1.11dB)
10kHz		+16.15dB	+17.51dB (1.36dB)	+17.06dB (0.91dB)
			(Avg. Error = 0.901dB)	(Avg. Error = 0.702dB)

		NAB GRAPH	**#3**	**#4**
50Hz		–15.99dB	–14.97dB (1.02dB)	–14.29dB (1.70dB)
80Hz		–15.04dB	–12.96dB (2.08dB)	–12.54dB (2.50dB)
100Hz		–13.79dB	–11.71dB (2.08dB)	–11.40dB (2.39dB)
200Hz		–7.97dB	–7.14dB (0.83dB)	–7.05dB (0.92dB)
500Hz		–1.85dB	–1.55dB (0.30dB)	–1.54dB (0.31dB)
700Hz	(Ref)	0.00dB	0.00dB	0.00dB
1kHz		+1.28dB	+1.48dB (0.2dB)	+1.48dB (0.2dB)
2kHz		+4.16dB	+4.84dB (0.68dB)	+4.84dB (0.68dB)
5kHz		+10.23dB	+11.32dB (1.09dB)	+11.31dB (1.08dB)
10kHz		+16.15dB	+17.05dB (0.9dB)	+17.05dB (0.9dB)
			(Avg. Error = 0.918dB)	(Avg. Error = 1.07dB)

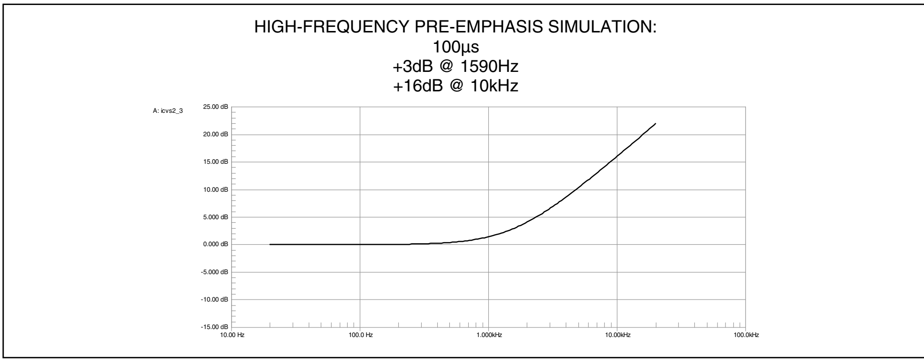


Figure 10. *Simulation of the high-frequency portion of the Columbia Lp and NAB recording characteristics. At 10kHz the response is at +16dB, relative to the low end of the frequency spectrum, not 1kHz. When the high-frequency portion of the curve is combined with the other two turnover frequencies, 10kHz may not appear at +16dB, at least not relative to 1kHz. NAB probably put the 0dB reference at 700Hz as a matter of convenience, to make the bass and treble symmetrical: –16dB at 50Hz and +16dB at 10kHz.*

Figure 11. *This label was used by Columbia for Lp records made between 1948 and 1955. Classical labels were blue, with green used for lighter classical fare, and red or gray for popular music. White labels were used for promotional copies. According to Esoteric Sound, the last record cut with the old Columbia Lp curve was catalog number ML 4895, Offenbach's* Gaité Parisienne *and the Chopin/Glazunov* Les Sylphides *with Eugene Ormandy and the Philadelphia Orchestra.*

differences between the simulation and my measurements on the NAB graph, are given in parentheses. In Figure 9, NAB notes that the tolerance on their graph is ±2dB. Only simulations #1 and #2 – Copeland and Snepvangers – are within that tolerance. Simulations #3 and #4 fall just outside the tolerance. The lowest errors are for the 50Hz / 500Hz /1590Hz combination. Therefore, it is reasonable to conclude that these are the turnover frequencies for the NAB curve, corresponding to time constants of 3180µS, 318µS and 100µS. Readers will note that this NAB simulation shows 10kHz at +17dB, rather than +16. True, but the simulation is well within the ±2dB tolerance of the NAB graph. When the NAB graph was *hand drawn* in 1949, it could not be produced with the accuracy we can achieve with computer simulations, and the author(s) of that graph clearly understood this. Also bear in mind the important point made earlier regarding the actual reference for the ±16dB specification.

It now becomes clear how the Columbia Lp curve was derived from NAB: Columbia simply moved F1 from 50Hz up to 100Hz, leaving F2 and F3 unchanged. Moving F1 up to 100Hz reduced low-frequency rumble when complementary playback curve was applied. As explained in Reference 1, however, this resulted in excessive groove excursions at the lowest recorded frequencies as the bass response of Lp records was extended downward, which is why RIAA settled on 50Hz for F1, as a number of record labels had already done.

Conversion to RIAA

All that remains in this investigation is determining when Columbia made the switch from their original Lp recording curve to the RIAA characteristic. As mentioned earlier, preamplifiers manufactured in the 1940s and 50s generally had variable equalization, allowing the user to adjust the playback curve to match a given record. Prior to the standardization of the RIAA curve, *High Fidelity* magazine published a monthly column in the recording review section called "Dialing Your Disks" (Reference 10). In the Sept. 1955 issue, the recommendation for Columbia Lps is a bass turnover of 500Hz (which they note is "modified"), and a treble roll-off of 16dB at 10kHz. A footnote for Columbia states that "Beginning sometime in 1954, records made from new masters require RIAA equalization for both bass and treble." In the very next issue, Oct. 1955, RIAA equalization is recommended for Columbia Lps. *High Fidelity* also makes exactly the same comments for Epic, Columbia's sister label.

Figure 11 shows the label used by Columbia for Lp records from their introduction in 1948 until they were in the midst of their conversion to RIAA equalization in 1955 (this label was later modified slightly; see Reference 16). Blue labels were used for classical recordings, green for lighter classical material, and red or gray for popular music. White labels were normally used for promotional copies. Nearly all Columbia Lps bearing this label were cut with the old Columbia Lp curve, though there are a small number cut with the RIAA curve during the transition period in 1954-55. Figure 12 shows the famous Columbia "6-eyes" label introduced in 1955. Gray was used for classical music and red for popular music, with white labels used for promotional copies. Nearly all 6-eyes Columbia records should be RIAA, but there are a few during the transition period that were pressed from matrices cut with the old Lp curve. According to Esoteric

Figure 12. *The famous Columbia "6-eyes" label was introduced in 1955. Classical labels were gray and popular were red, with white normally used for promotional copies. Most "6-eyes" records are RIAA.*

Sound (manufacturer of the Re-Equalizer II, a device for adding variable equalization to RIAA preamps), catalog number ML 4895 was the last release cut with the old Columbia Lp curve (Reference 11). This record contained Offenbach's *Gaité Parisienne* and the Chopin/Glazunov *Les Sylphides* with Eugene Ormandy and the Philadelphia Orchestra (Reference 17). As older releases were re-cut with the RIAA curve, Esoteric notes that Columbia began using a smaller Arial font for the matrix numbers. But, the smaller font also appears on some records cut with the old curve. Esoteric also notes that Columbia put a "Hi-Fi Plus" sticker on a number of records bearing the old labels; this was done to indicate a re-cutting with the RIAA curve. Reference 11 contains a great deal of information, including photos of Columbia labels and matrix numbers.

Conclusions

The Columbia Lp equalization curve used time constants of 1590µS, 318µS and 100µS, corresponding to turnover frequencies of 100Hz, 500Hz and 1590Hz (±16dB @ 10kHz). This is the only combination that produces a graph matching Goldmark, Snepvangers & Bachman. The closest fit to the published NAB graph is 3180µS, 318µS and 100µS, corresponding to turnover frequencies of 50Hz, 500Hz and 1590Hz (±16dB at 10kHz). Columbia modified the NAB curve by raising the low-bass turnover point F1 from 50Hz

Generating Disc Recording Curves using Computer Simulation

Figure S1 shows the simulation model used to generate the recording curves discussed in this paper. The simulation model is also known as an *emphasis network*, since it generates a curve gradually rising from the lowest to the highest recorded frequencies. This curve plots the increase in recorded velocity in the actual disc cutting and the corresponding rise in amplitude when the record is played with a magnetic cartridge. Signal generator V1 feeds a sine wave to voltage-controlled voltage source VcVs1 which, in turn, feeds the network comprised of R1, R2 and C1, which generates the low-frequency portion of the curve (F1 and F2). This network is loaded by current-controlled voltage source IcVs1, which generates an output voltage proportional to the current through the low-frequency network. This output voltage is, in turn, fed to the high-frequency network consisting of R3 and C2 (F3). The current through the R2/C2 network is fed to IcVs2, which generates a proportional output voltage. This output voltage appears across load (terminating) resistor Rt, the value of which is not critical.

The procedure for determining the component values in the simulation model is as follows:

1. Determine the F3 frequency from the playback attenuation at 10kHz:

$$F3 = 10000 / (\sqrt{(1/((10^{(-dB/20)})^{2})-1)})$$

where "F3" is the -3dB frequency and "-dB" is the
10kHz attenuation entered as a negative number (see Table 1)

2. If the three time constants are known, proceed to step 4.

3. Calculate the time constants for each of the three turnover frequencies:

$T = 1 / 2\pi F$ (note also that $F = 1 / 2\pi T$)
For F1: $T = 1 / 2\pi * 100 = 1590\mu S$
For F2: $T = 1 / 2\pi * 500 = 318\mu S$
For F3: $T = 1 / 2\pi * 1590 = 100\mu S$

4. Calculate the resistor values for R1, R2 and R3:

$T = RC$, so:
$T1 = (R1 + R2) * C1$
$T2 = R1 * C1$
$T3 = R3 * C2$
$R = T / C$ and $C = 1nF$
$R1 = 318\mu S / 1nF = 318k$
$R2 = (1590\mu S / 1nF) – 318k = 1.272M$
$R3 = 100\mu S / 1nF = 100k$

5. Adjust the scalings of VcVs1 and IcVs1 so that VcVs1 = R2 and IcVs1 = R3

6. Adjust scaling of IcVs2 so 1kHz is at 0dB on the resulting graph.

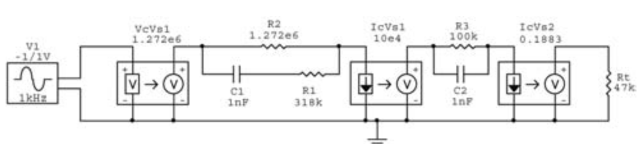


Figure S-1. *This circuit simulation model was used to generate the disc recording curves shown in this article. The component values can be adjusted to produce any desired recording characteristic. Measurement cursors can be placed on the graphs produced by the simulation model, allowing precise determination of levels at any frequency.*

to 100Hz – that is the only difference between the two curves. NAB's decision to put the 0dB reference at 700Hz rather than 1kHz is irrelevant.

Columbia Lps require a special 500Hz bass turnover setting on the playback preamplifier, one that has F1 set at 100Hz. NAB records are the same in the bass region as RIAA recordings, with F1 at 50Hz and F2 at 500Hz (50.05 and 500.5, to be more precise). Both NAB records and Columbia Lps require an F3 of 1590Hz, or –16dB at 10kHz in playback. In other words, NAB transcription discs can be played with the RIAA setting in the bass, and the Columbia setting in the treble.

Acknowledgements

I am grateful to Victor Campos and Dennis Rooney for their helpful suggestions during the preparation of this paper, and to Victor and my wife Ellen for their careful proofing of the manuscript prior to publication.

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Endnotes

1. In his landmark paper "On RIAA Equalization Networks" (*Journal of the Audio Engineering Society*, 1979;June:458-481), Stanley Lipshitz designated the three time constants as F3, F4 and F5. This is because three additional time constants (F1, F2 and F6) must sometimes be considered in the design of playback equalization circuits, even though they were not part of the recording characteristic. The reasons for this are well beyond the scope of this paper. Engineers familiar with Lipshitz's work can easily make the conversion from his terminology to that used in this paper. Others need not concern themselves with this issue. I have used F1, F2 and F3 because I believe it will be the least confusing to most readers.

2. The Columbia trademarked abbreviation for Long Playing was "Lp" with a lower-case "p." Later it became customary to abbreviate "long playing" as "LP." I have retained the original Columbia abbreviation throughout this paper.

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