Chapter 2
RIAA Transfer/Anti-RIAA Transfer

2.1 Introduction

The signal on VRs is coded according to the rules set by the Record Industry Association of America (RIAA). This code is determined by three time constants: T1, T2 and T3. Cutting a VR means that the three time constants encode the signal in a specific way. The reason for this is to handle overloading and noise issues the optimal way.

2.2 Cutting Process with Anti-RIAA

Playing a VR on a turntable means that an amplifier with the three time constants has to decode the signal the opposite way. The transfer as result of the decoding process is often called RIAA weighting and the respective transfer function RIAA(f). Therefore, the result of the process to encode the VR cutting is performed by the anti-RIAA transfer function ARIAA(f).

To demonstrate the whole process without many words the following charts will help to understand. Figure 2.1 shows the basic circuitry[1] to cut a VR and Fig. 2.2 gives the resulting transfer plot, referenced to 0 dB at 1 kHz.

[1]See Sect. 23.3 for more details on the circuitry of an anti-RIAA transfer performing amplifier.

B. Vogel, *The Sound of Silence*,
DOI 10.1007/978-3-642-19774-1_2,

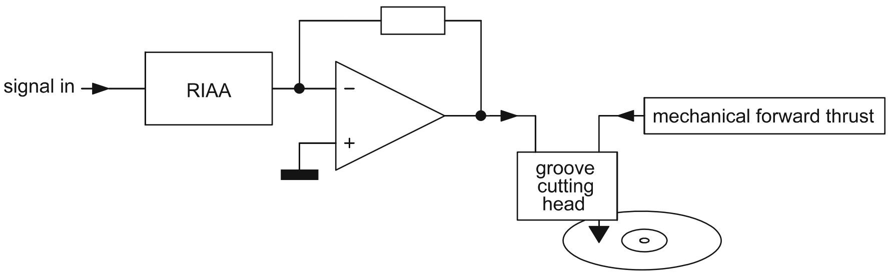

Fig. 2.1 VR cutting process with Anti-RIAA transfer function ARIAA(f)

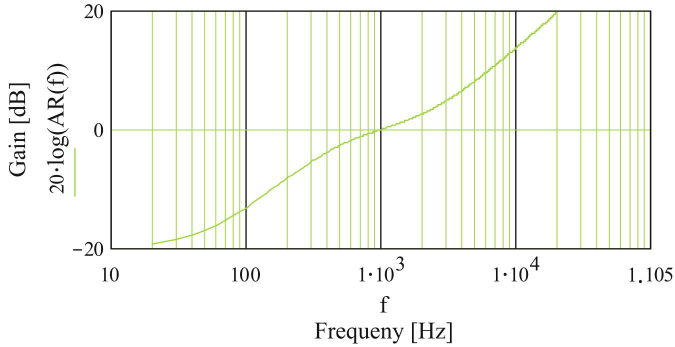

Fig. 2.2 Anti-RIAA transfer function AR(f) (=ARIAA(f) referenced to 0 dB/1 kHz) used to encode the signal on the VR

2.3 Decoding with RIAA Transfer

The RIAA transfer performing amplifier in Fig. 2.3 shows the (active) decoding situation[2] between cartridge and amplifier output. The respective transfer plot is given in and Fig. 2.4.

The result of this rather complex process should be a flat frequency response at the output of the amplifying chain and at the input of the loudspeakers. The horizontal line at 0 dB in Fig. 2.5 shows the result of the sum of the two transfer functions output(f):

Mathematically, the whole process looks a bit difficult, but I guess, relatively easy to understand.

[2]See Chaps. 19 and 20 for more details on active and passive equalization.

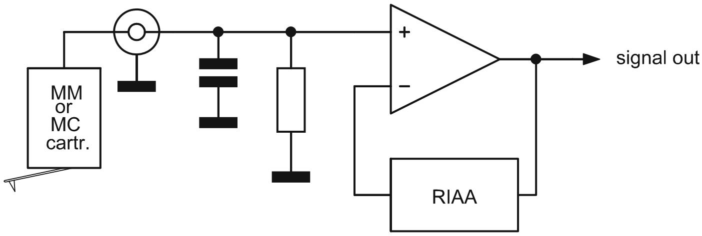

Fig. 2.3 Cartridge-amplifier chain with decoding elements to perform the RIAA transfer function RIAA(f)

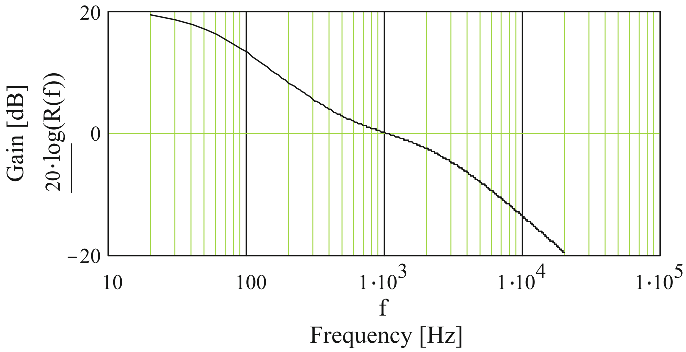

Fig. 2.4 Decoding transfer function R(f) (=RIAA(f) referenced to 0 dB/1 kHz)

2.4 RIAA Transfer: Ideal Situation

Let's start with the three time constants and how they produce the transfer function of the RIAA weighting. By definitiona[3,4] they are:

- $T1 = 3{,}180 \times 10^{-6}$ s with corresponding frequency is 50.05 Hz $= 1/(T1 \times 2 \times \pi)$
- $T2 = 75 \times 10^{-6}$ s with corresponding frequency is 2,122.1 Hz $= 1/(T2 \times 2 \times \pi)$
- $T3 = 318 \times 10^{-6}$ s with corresponding frequency is 500.5 Hz $= 1/(T3 \times 2 \times \pi)$

[3]For the values of the time constants the standard is set by RIAA and DIN 45535/6.

[4]In some regions of the world a fourth time constant also plays a role: $T4 = 7{,}950 \times 10^{-6}$ s (corresponding frequency = 20.02 Hz). This was set by the IEC (Publication 98-1964 + Amendment n. 4, Sep. 1976). It was never standardized and its effects are not described in detail in this book. Nevertheless, an electronic solution will be given in Part V, The RIAA Phono-Amp Engine.

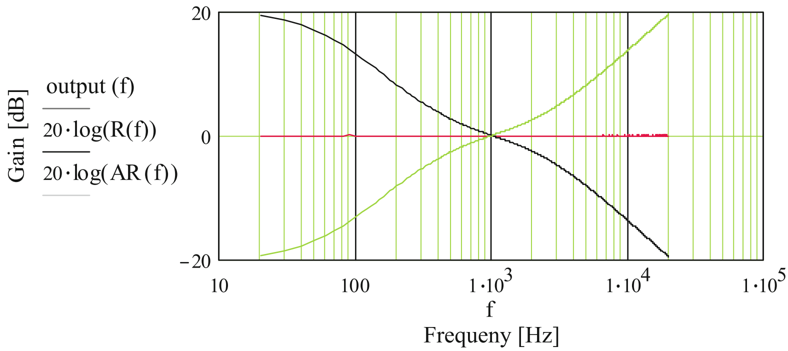

Fig. 2.5 Plot of all three transfers: AR(f) + R(f) = output(f)

Hence, the complex transfer function $H_E(p)$ for the encoding mode (E) looks like:

$$H_E(p) = \frac{(1 + p\,T1)\,(1 + p\,T2)}{(1 + p\,T3)} \tag{2.1}$$

Therefore, the equation for the decoding mode (D) must look like the inverse of it:

$$H_D(p) = \frac{(1 + p\,T3)}{(1 + p\,T1)\,(1 + p\,T2)} \tag{2.2}$$

I call the magnitude of $H_E(p)$ Anti-RIAA transfer = ARIAA(f) and the magnitude of $H_D(p)$ RIAA transfer = RIAA(f). Thus, the magnitude of RIAA(f) becomes:

$$\mathrm{RIAA}(f) = \frac{\sqrt{1 + (2\pi\,f\,T3)^2}}{\sqrt{1 + (2\pi\,f\,T1)^2}\,\sqrt{1 + (2\pi\,f\,T2)^2}} \tag{2.3}$$

This is nothing else but a sequence of two 6 dB/octave lp filters with time constants T1 and T2 followed by an differentiator with the time constant T3.

Now we can calculate any gain at any frequency. But the result will not be very elegant because it will not produce the picture we are used to live with: gain (in dB with reference to 1 kHz) versus frequency. To get this we have to relate the calculation results to the reference point as well as to show the frequency axis in logarithmic scaling.

The reference point in audio is always 0 dB at 1 kHz. Therefore RIAA(10^3 Hz) becomes:

$$\mathrm{RIAA}(10^3\mathrm{Hz}) = \frac{\sqrt{1 + (2\pi\,10^3\mathrm{Hz}\,T3)^2}}{\sqrt{1 + (2\pi\,10^3\mathrm{Hz}\,T1)^2}\,\sqrt{1 + (2\pi\,10^3\mathrm{Hz}\,T2)^2}} \tag{2.4}$$

$$\mathrm{RIAA}(10^3\mathrm{Hz}) = 0.101 \tag{2.5}$$

To get the final – plot-ready – transfer function R(f) which is related to the reference point 1 kHz and to a reference gain of 0 dB (2.3) and the inverse of (2.4) at 1 kHz have to be multiplied:

$$\begin{aligned} \mathrm{R(f)} = & \left(\frac{\sqrt{1+(2\pi\,\mathrm{f\,T1})^2}}{\sqrt{1+(2\pi\,\mathrm{f\,T2})^2}\,\sqrt{1+(2\pi\,\mathrm{f\,T3})^2}}\right) \\ & * \left(\frac{\sqrt{1+(2\pi\,10^3\mathrm{Hz\,T1})^2}}{\sqrt{1+(2\pi\,10^3\mathrm{Hz\,T2})^2}\,\sqrt{1+(2\pi\,10^3\mathrm{HzT3})^2}}\right)^{-1} \end{aligned} \tag{2.6}$$

Hence, the plot in Fig. 2.4 can be achieved with the following equation:

$$20\log[\mathrm{R(f)}] = 20\log[\mathrm{RIAA(f)}] - 20\log\left[\mathrm{RIAA}\left(10^3\mathrm{Hz}\right)\right] \tag{2.7}$$

The plot in Fig. 2.2 is the result of the following equation:

$$20\log[\mathrm{AR(f)}] = 20\log\left[\mathrm{RIAA(f)}^{-1}\right] - 20\log\left[\mathrm{RIAA}\left(10^3\mathrm{Hz}\right)^{-1}\right] \tag{2.8}$$

Consequently, the 0 dB line plot of Fig. 2.5 becomes:

$$\mathrm{output(f)} = 20\log[\mathrm{R(f)}] + 20\log[\mathrm{AR(f)}] \tag{2.9}$$

Table 2.1 is an EXCEL[5] sheet which includes the respective equations to calculate transfer amplitude data for R(f) with reference to 0 dB/1 kHz. The value

Table 2.1 Selected frequencies and calculated (2.6) transfer amplitudes of R(f) with reference to 0 dB/1 kHz

1/A	B	C
2	*Frequency* [*Hz*]	*Transfer amplitude* [*dB*]
3	1,000	−19.911
4		*Transfer amplitude* [*dB rel. 0 dB*]
5	20	19.274
6	50	16.946
7	100	13.088
8	500	2.648
9	1,000	0.000
10	2,122	−2.866
11	5,000	−8.210
12	10,000	−13.734
13	20,000	−19.620

[5]EXCEL is a registered trade mark of Microsoft Inc., USA.

in box C3 is calculated with (2.4). Values in boxes C5–C13 were calculated with (2.6). To calculate AR(f) with reference to 0 dB/1 kHz we only have to inverse the signs in column C, lines 5–13.

2.5 RIAA Transfer: Real Situation

Figures 2.2, 2.4 and 2.5 were created with Mathcad (MCD). A detailed approach to get solutions with this software will be shown on worksheets of the following chapters. But, to demonstrate the very helpful features, I will create a chart showing the deviation from the exact RIAA transfer as the relative error in dB versus frequency for a phono-amp with actual time constants (..a) not far away from the exact ones.

- $T1a = 3{,}183 \times 10^{-6}$ s
- $T2a = 74 \times 10^{-6}$ s
- $T3a = 321 \times 10^{-6}$ s

2.6 Deviation Between Ideal and Real Situation: Calculated

Application of (2.6) with the exact time constants T1, T2, T3 [=R(f)] minus (2.6) with the actual time constants T1a, T2a, T3a [=Ra(f)] will lead to the error plot dev (f) shown in Fig. 2.6:

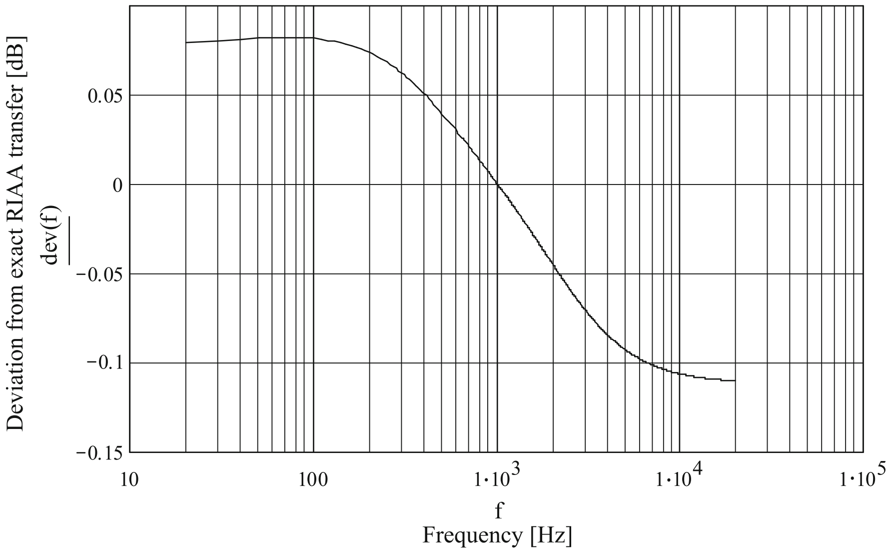

Fig. 2.6 Mathcad calculated deviation dev(f) [dB] versus frequency: exact RIAA transfer minus actual transfer

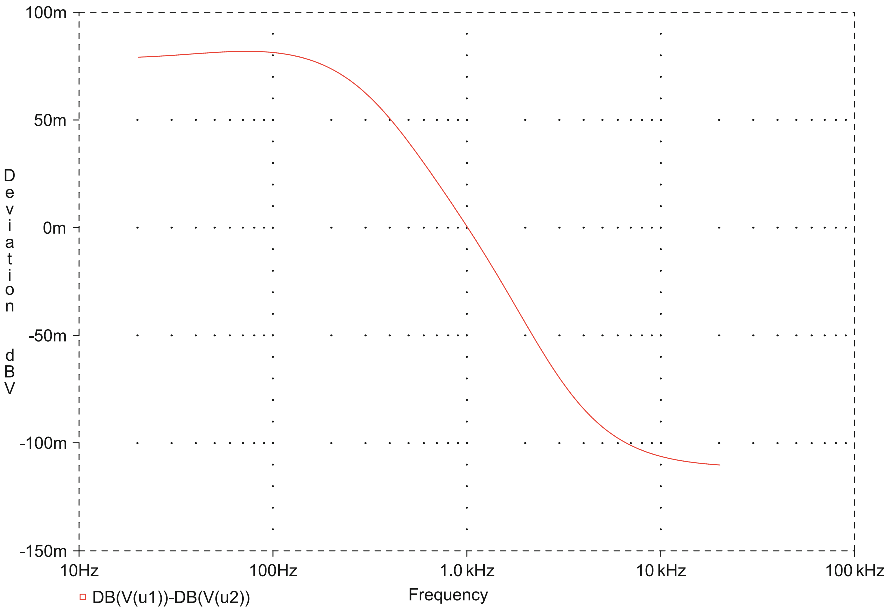

Fig. 2.7 pSpice (MicroSim v8.0) simulated deviation [dB] versus frequency: exact RIAA transfer minus actual transfer

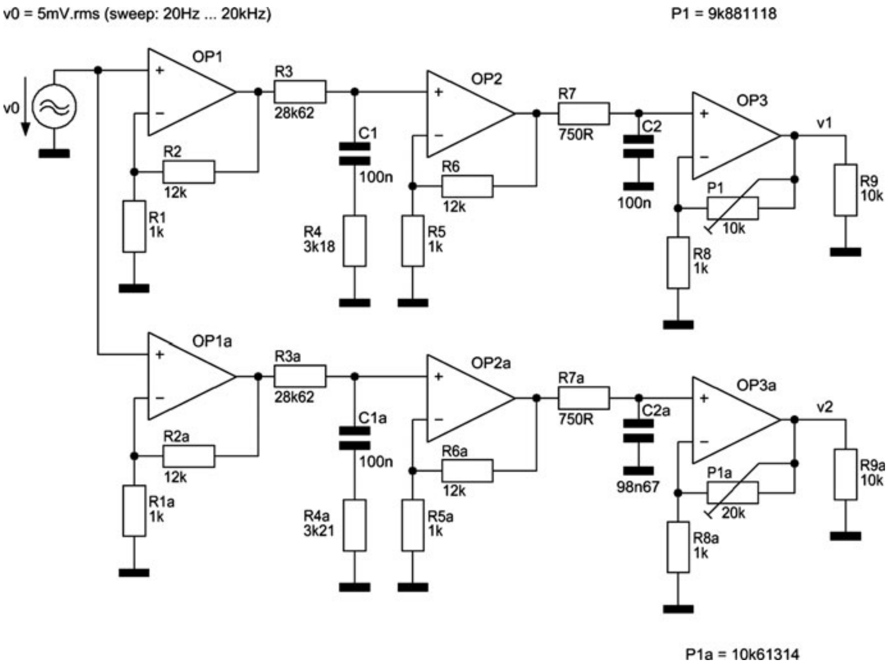

Fig. 2.8 Creation of Fig. 2.7: pSpice simulation schematic to perform a deviation plot between exact RIAA transfer (output voltage v1) and actual RIAA transfer (output voltage v2)

$$\mathrm{dev(f)} = 20\log[\mathrm{R(f)}] - 20\log[\mathrm{Ra(f)}] \tag{2.10}$$

2.7 Deviation Between Ideal and Real Situation: Simulated

Another possibility is the use of a pSice simulation. To get the plot of Fig. 2.7 we need to draw a schematic like the one in Fig. 2.8 – with the following content:

- A first circuit (top) that performs the ideal RIAA transfer:
  v1 = R(20 Hz–20 kHz)
- A second circuit (bottom) that performs the RIAA transfer with actual components:
  v2 = Ra(20 Hz–20 kHz) with
  - T1a = (R3a + R4a) × C1a
  - T2a = R4a × C1a
  - T3a = R7a × C2a
- The gain of both circuits must be trimmed with P1 and P1a to get equal rms output voltages of 0 dBV for v1 and v2 at 1 kHz

  It should not be a surprise that both plots look absolutely equal.