LR Phono Preamps

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Agenda

• A bit about me
• Part 1: What is, and why use, RIAA?
  – Grooves on records
  – The RIAA standard
  – Implementations of RIAA EQ networks and preamps
  – Testing phono preamps
• Part 2: Implementing LR RIAA equalization
  – Example preamp circuits
  – Problems: Inductor imperfections
  – Working around the problems

NOT a discussion about why one would use LR, or if it sounds better than RC!
A bit about me

- I live near Dallas, Texas, USA
  - But I’m not really a Texan!
- Worked as an EE for over 30 years
  - Mostly board-level computer & computer peripherals
  - Lately mostly doing integrated circuit product definition
  - Have a “hobby business” building high-end headphone amps and DIY PC boards for tube audio projects
Part 1: RIAA

What is RIAA, anyway? And why do we need it?
• Sound is recorded on a record by cutting a groove that wiggles according to the amplitude of the recorded signal.

• To play the record, we use a stylus that moves with the groove.
• The cartridge typically uses a magnet and a coil, one of which moves with the stylus. The movement of the magnetic field through the coil generates a small voltage.
Grooves on a record – stereo

- Stereo recording is done with two magnets and coils at a 90 degree angle from one another
Modern phono cartridges fall into two main groups: moving coil (MC), and moving magnet (MM)

MC cartridges have a stationary magnet, and the coil moves with the stylus. MM cartridges are the inverse, with a magnet moving with the stylus and fixed coils.

In a MC cartridge, the coils are very small, so MC cartridges typically have very low output voltage

Typically about 60dB of gain @ 1kHz is needed for MC cartridges - 40-45dB is needed for a MM cartridge.
Groove geometry vs. frequency

- The amplitude of the signal produced by moving a magnetic field through a coil is proportional to the *velocity* of the motion.

- To get the same amplitude out of a phono cartridge at all frequencies, the groove would need to be very wide at low frequencies, and very tiny at high frequencies.

- This would limit the amount of material that could be recorded on a disk (because of the large swing at LF), and generate lots of HF noise (because of the tiny swing at HF).

- What to do?
Phono equalization (EQ)

• One could use a constant-amplitude recording method, which makes the record groove the same physical size at all frequencies

• To do this, the voltage applied to the cutting head must increase with frequency... then the output of a playback cartridge will decrease with frequency

• Playback requires equalization, attenuating the signal with frequency, to get flat reproduction of the original signal

• Constant-amplitude recording has problems: at low frequencies, the large playback gain amplifies LF noise like turntable rumble. And at high frequencies, the cutter velocity becomes very high.

• A better solution is to combine regions of constant-velocity recording with regions of constant-amplitude recording

• RCA introduced the “New Orthophonic” curve in 1953 that did just that

• This is what became the RIAA standard in 1956 that we use today
The RIAA EQ standard

- The standard set by the RIAA defines the EQ curve to be used on records.
- The *recording* EQ curve is flat to 50Hz, then increasing amplitude to 500Hz, flat to 2120Hz, then increasing.
- The *playback* EQ curve is the inverse of this. It has a pole (low-pass characteristic) at 50Hz, a zero (high-pass) at 500Hz, and another pole at 2122Hz.
- The poles and zeros are also referred to by their time constants of 3180µS, 318µS, and 75µS. The frequency is found by $f = 1/(2\pi t)$.
A pole or zero can be created by a resistor, and a reactive component - either a capacitor...

\[ f(-3\text{dB}) = \frac{1}{2\pi R C} \]
Poles and zeros using inductors

• ...or an inductor

\[ f(-3\text{dB}) = \frac{R}{2 \pi L} \]
**RIAA preamp implementations**

- Phono preamps can be implemented several ways:
  - “Passive” preamps put the EQ section in series with the signal
  - “Active” preamps put the EQ in a feedback network around an amplifier
  - A combination of active and passive is also possible

- The EQ function can be performed by any combination of inductors, capacitors, and resistors.
- The amplifier sections can be any combination of opamps, vacuum tubes, or transistors
Passive RIAA EQ networks

- Many other permutations are possible
- In reality, it’s not this straightforward. The nonzero source impedance of each stage interacts with the following stage.
Passive RIAA example

- Below is an example of a phono stage with passive RC EQ (RCA tube manual) with the RIAA EQ highlighted.
Active RIAA tube circuit example

- Below is an example of an phono stage with an active EQ (Dynaco PAS preamp)
More RIAA examples

- These circuits are from Walt Jung’s “Signal Amplifiers”
- Note the two possible transpositions of EQ components (‘’N1” and “N2” networks)
How to test RIAA preamps?

- To test and measure an RIAA phono preamp, one could just apply a voltage to the input, vary the frequency, and measure the output.
- But the small signals involved make this a little difficult.
- The best approach is to use an "inverse RIAA" network. This simulates the output of a cartridge, so the measured output of the preamp should be flat.
- I used one made by Hagerman Technology - www.hagtech.com/iriaa2.html.
- It’s accurate to within +/-0.4dB and has convenient 40dB and 60dB attenuation.
Part 2: LR RIAA equalizers

How to implement LR RIAA?
And avoid some problems...
LR EQ: passive or active

- An LR EQ can be implemented in series with the signal, or in the feedback loop of the amplifier.
- I looked at active LR EQ (in the feedback loop of an opamp), but soon discovered that inductor imperfections made it very difficult to create a stable design.
- Has anybody succeeded in building an active LR EQ?
A tube LR RIAA preamp

- This is Steve Bench’s design from 2004
- Note R4, which (I think) is adding a zero to compensate for the transformer response, and maybe something else too (more later)
An opamp-based LR RIAA preamp

- Here is my initial design of a passive LR preamp:

- The first stage has a gain of 20dB; the second, 41dB
- L1 and R2 form the 50Hz pole, L1 and R3 the 500Hz zero, and L5 and R4 form the 2200Hz pole
- The EQ attenuates about 21dB @ 1kHz, so the net gain is 40dB @ 1kHz
- Exact resistor values were derived from simulation, since there is some interaction between the stages
Circuit simulation: passive LR EQ

- If we simulate my circuit using an inverse RIAA network at the input, it looks very good: within 1/2dB 20Hz – 20kHz!
Circuit measurement: passive LR EQ

- If we build and measure this circuit, it looks OK, but not as good: still down less than 3dB at 20kHz. One *could* live with this...
High frequency response

• HOWEVER.... What if we look out to 100kHz?

• What is this?
Inductor imperfections (parasitics)

- Unfortunately, a real inductor is not just an inductor. It has parasitic resistance (the resistance of the wire), parasitic capacitance, and other non-ideal characteristics.

- The resistance can be modeled as a resistor in series with the inductor; capacitance can be (roughly) modeled as a capacitor in parallel:
Impedance of an ideal inductor

- An ideal inductor has an impedance that varies linearly with frequency, equal to the inductive reactance, which is $2 \times \pi \times f \times L$.
- So the impedance of an ideal inductor (1mH) is a straight line:
Impedance of a real inductor

• ...but add 50pF of parasitic capacitance and it looks like this:
Self-resonance

- This effect of the parasitic shunt capacitance is called “self-resonance”. The inductor and its parasitic capacitance form a parallel resonant circuit, which has a very high impedance at the resonant frequency.
- Generally, the higher the inductance, the lower the SRF (Self Resonant Frequency), since there are more turns of wire in a larger inductor.
- In a passive LR EQ network, self-resonance causes a notch in frequency response at the SRF, because the impedance is very high there...
- ...followed by an increase in gain, because above the SRF, the inductor is now effectively a capacitor, with decreasing impedance with frequency!
Measurement of a real inductor

• I measured the inductor I used, a 520mH pot core part from Cinemag, using a 1k series resistor
  – You can see the LR pole formed by the inductor and the 1k resistor, located at about 300Hz.
  – At ~40kHz, there is a notch – this is self-resonance
  – Above self resonance, the response climbs back to zero dB
Modeling the real inductor

- An ohmmeter and a little trial and error in pSpice tells us what the parasitics of this inductor are.
- The simulation looks exactly like the measurement.
- \( f(SRF) = \frac{1}{2 \pi \sqrt{L \cdot C}} \)
Fixing the inductor

• There are ways to build inductors with less parasitic capacitance, so a higher SRF
  • This typically involves special winding geometries, sectioned windings, insulating layers, or magic!
  • They can cause the inductor to be physically larger, and more expensive, and certainly harder to build
  • There are transformer winders here that can explain more!
• An example of a winding method used to increase SRF is the RF choke – the windings are separated into sections to break up the interwinding capacitances, which gives you a higher frequency SRF than a solenoid-wound coil
Self-resonance in my circuit

- Since the SRF of a larger inductor is typically lower than that of a smaller one, you may think that the larger inductor in my design would be the problem here.
- However, I used the same inductor in both locations. The inductor is tapped – I use the full winding for the 50Hz pole and only a part of it for the 2122Hz pole. But the rest of the coil is still there, so its SRF is not lower than if I used the entire winding – still 40kHz.
Avoiding the SRF with a zero

- See what happens when we add a zero below the SRF:
- There is a barely perceptible dip at the SRF, but no notch!
- At the SRF, the resistor dominates
- So in an LR EQ, the SRF can be avoided... sometimes...
Working around the self-resonance

- Because my first L has a zero (parallel R), the second inductor SRF is causing the notch and gain rise here.
- If we add a resistor (R1 below) across the other inductor and create another zero just below the SRF of the inductor, we can remove the notch.
- Tuning is critical.
- The HF peak is still there, rising until ~400kHz.
The HF peak

- We don’t want too much excessive gain above the audio frequencies, to prevent amplification of unwanted signals (like an AM radio station!)
- Ultrasonic gain can be lowered by adding a high-frequency pole to the system. A small inductor is used, with a very high SRF.
A (mostly) complete simulation

- Still an HF peak at ~400kHz, but its reduced from ~33dB to ~14dB
- A small drop at LF due to the resistance of the new inductor
Final measurement

- The response of the preamp after these changes is within +/-1dB 20Hz – 20kHz
- Channels track within +/- 0.3dB
Final measurement

- Still a rising response above 50kHz
- Peak is only +2.2dB @ 240kHz… better than simulation
Questions?

Still awake?

Thanks!
1kHz square wave
20kHz triangle wave
20Hz triangle wave