LR Phono Preamps

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ETF.13

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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

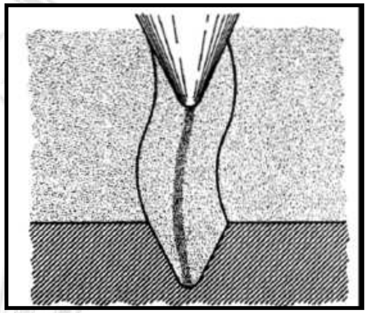
- I live near Dallas, Texas, USA
  - But I’m not really a Texan!
- Worked as an EE for over 30 years
  - Mostly board-level computer & computer peripherals
  - Lately mostly doing integrated circuit product definition
  - Have a “hobby business” building high-end headphone amps and DIY PC boards for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

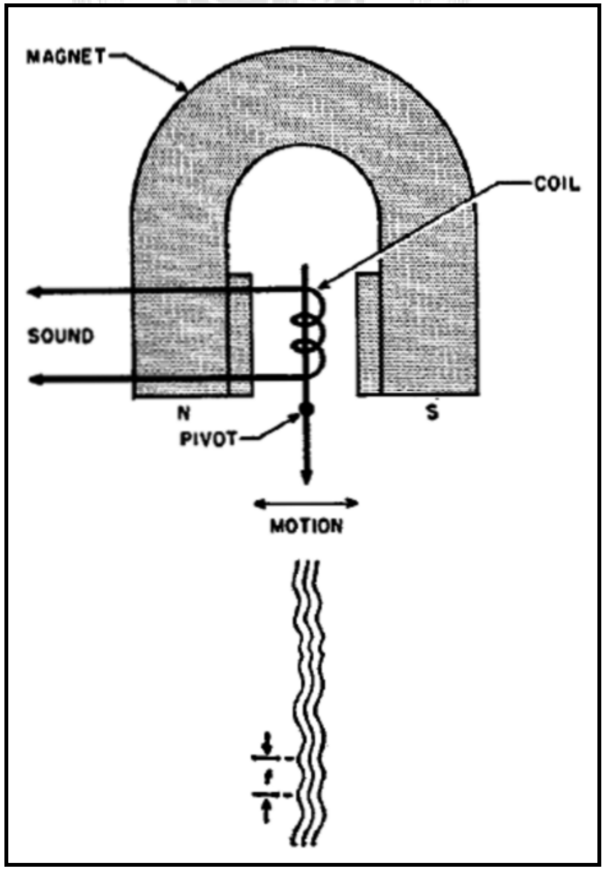
Part 1: RIAA

What is RIAA, anyway?
And why do we need it?

Grooves on a record – the basics

- Sound is recorded on a record by cutting a groove that wiggles according to the amplitude of the recoded signal

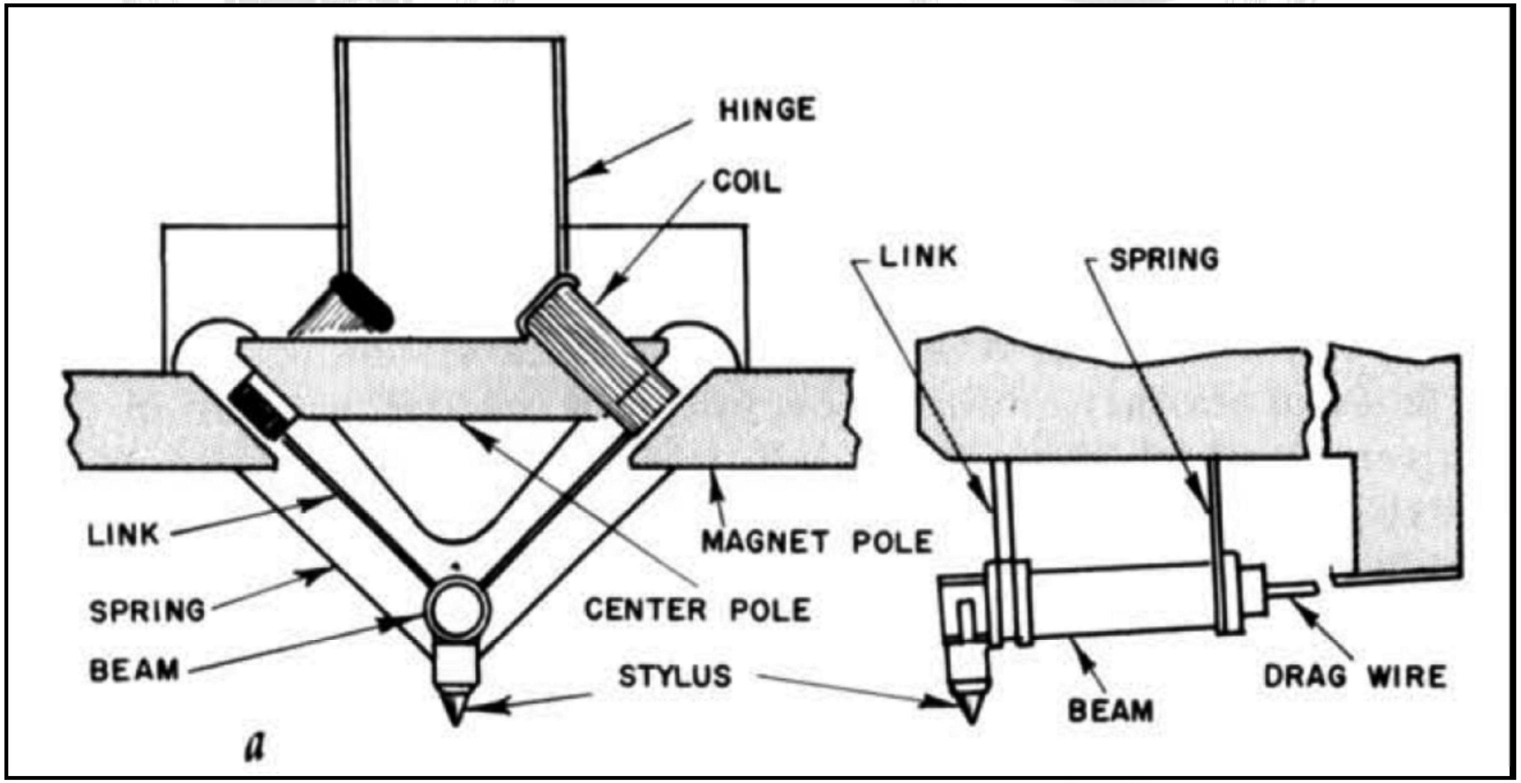




- To play the record, we use a stylus that moves with the groove
- The cartridge typically uses a magnet and a coil, one of which moves with the stylus. The movement of the magnetic field through the coil generates a small voltage.

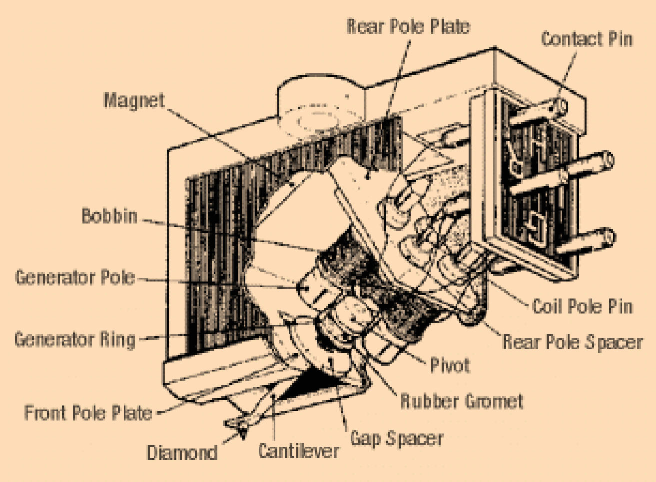
Grooves on a record – stereo

- Stereo recording is done with two magnets and coils at a 90 degree angle from one another



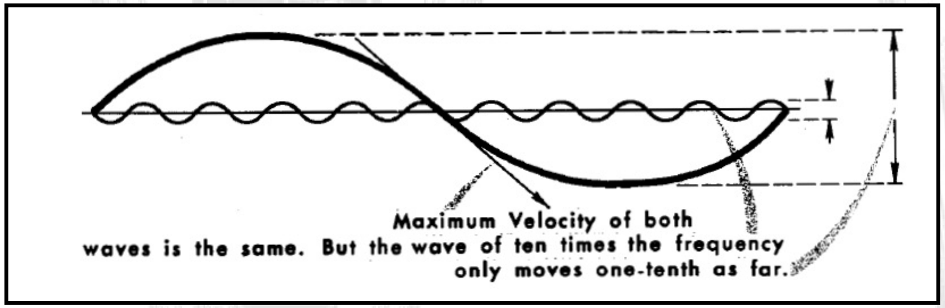
Playback - phono cartridges

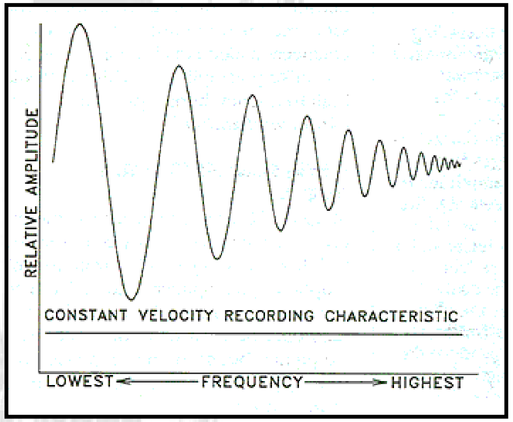
- Modern phono cartridges fall into two main groups: moving coil (MC), and moving magnet (MM)
- MC cartridges have a stationary magnet, and the coil moves with the stylus. MM cartridges are the inverse, with a magnet moving with the stylus and fixed coils.
- In a MC cartridge, the coils are very small, 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**

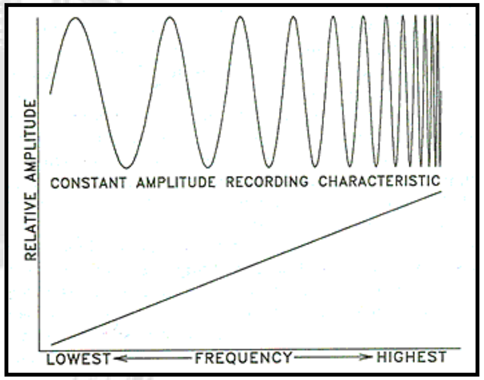


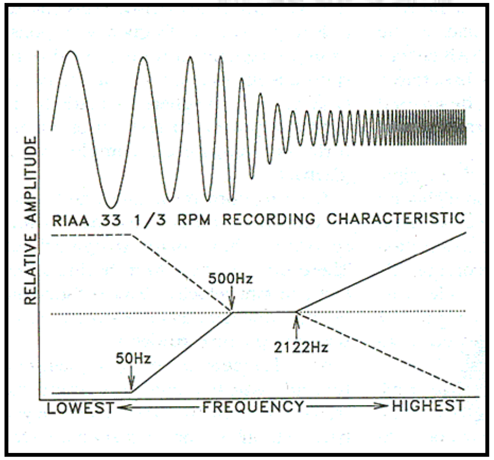


- **To get the same amplitude out of a phono cartridge at all frequencies, the groove would need to be very wide at low frequencies, and very tiny at high frequencies**
- **This would limit the amount of material that could be recorded on a disk (because of the large swing at LF), and generate lots of 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

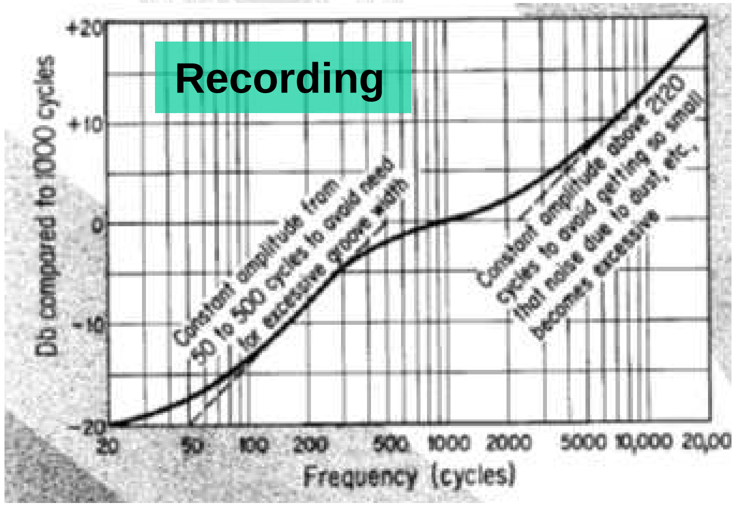


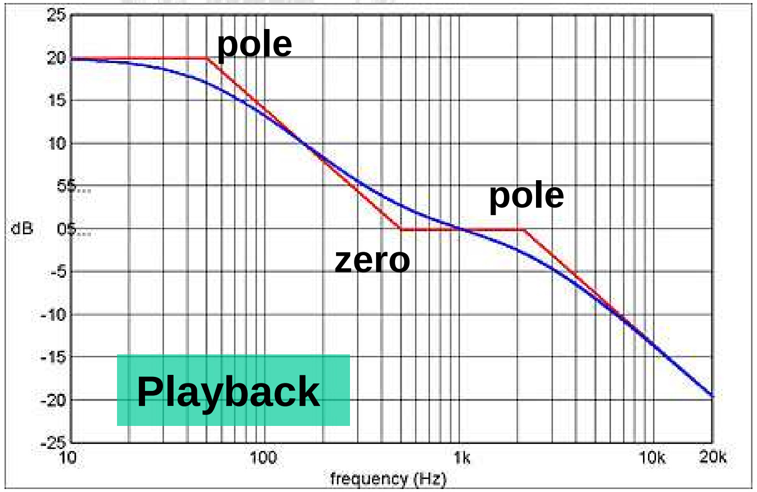


- Constant-amplitude recording has problems: at low frequencies, the large playback gain amplifies LF noise like turntable rumble. And at high frequencies, the cutter velocity becomes very high.
- A better solution is to combine regions of constant-velocity recording with regions of constant-amplitude 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

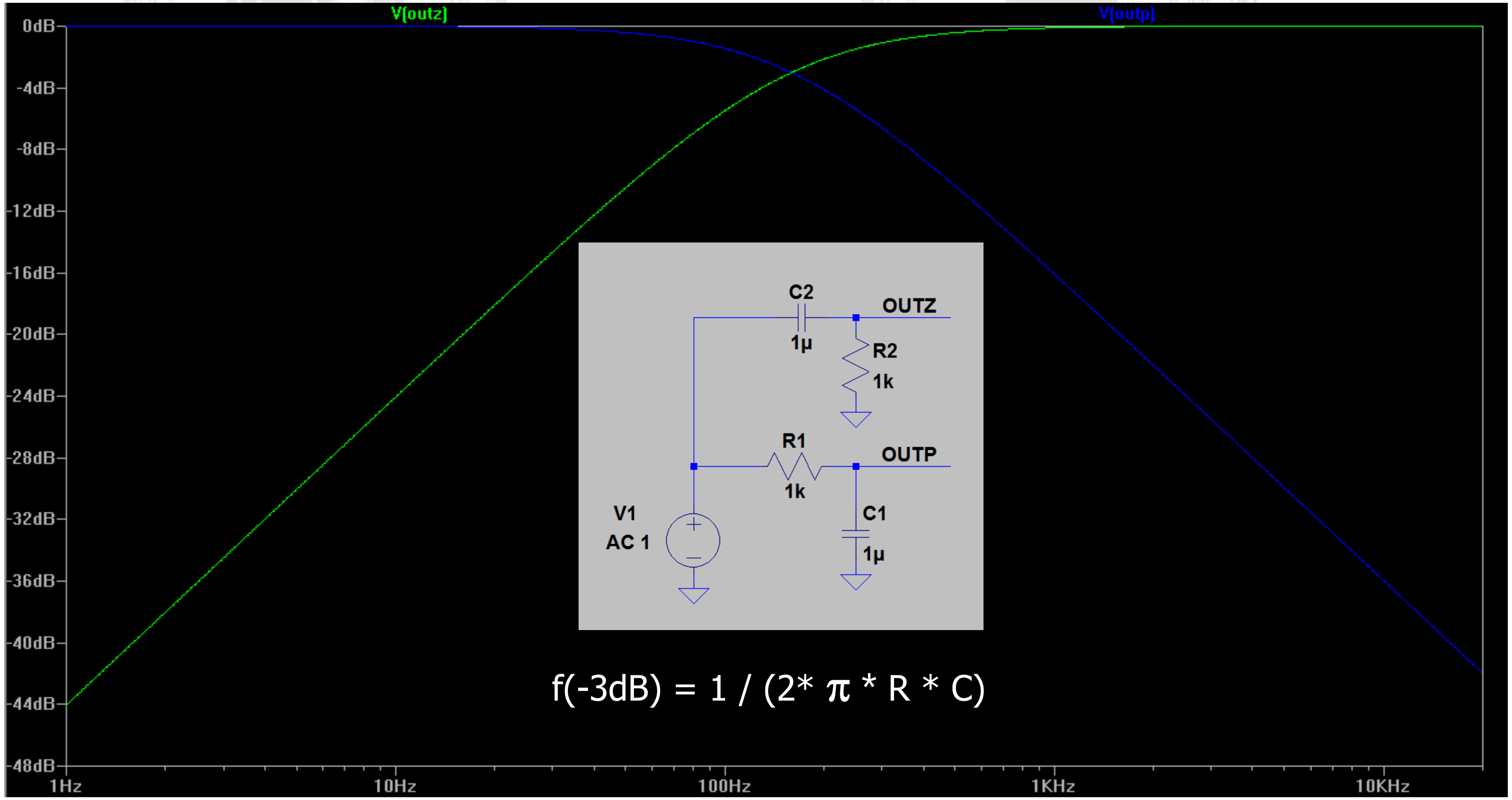
- The standard set by the RIAA defines the EQ curve to be used on records
- The *recording* EQ curve is flat to 50Hz, then increasing amplitude to 500Hz, flat to 2120Hz, then increasing
- The *playback* EQ curve is the inverse of this. It has a pole (low-pass characteristic) at 50Hz, a zero (high-pass) 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 $f = 1/(2*\pi*t)$





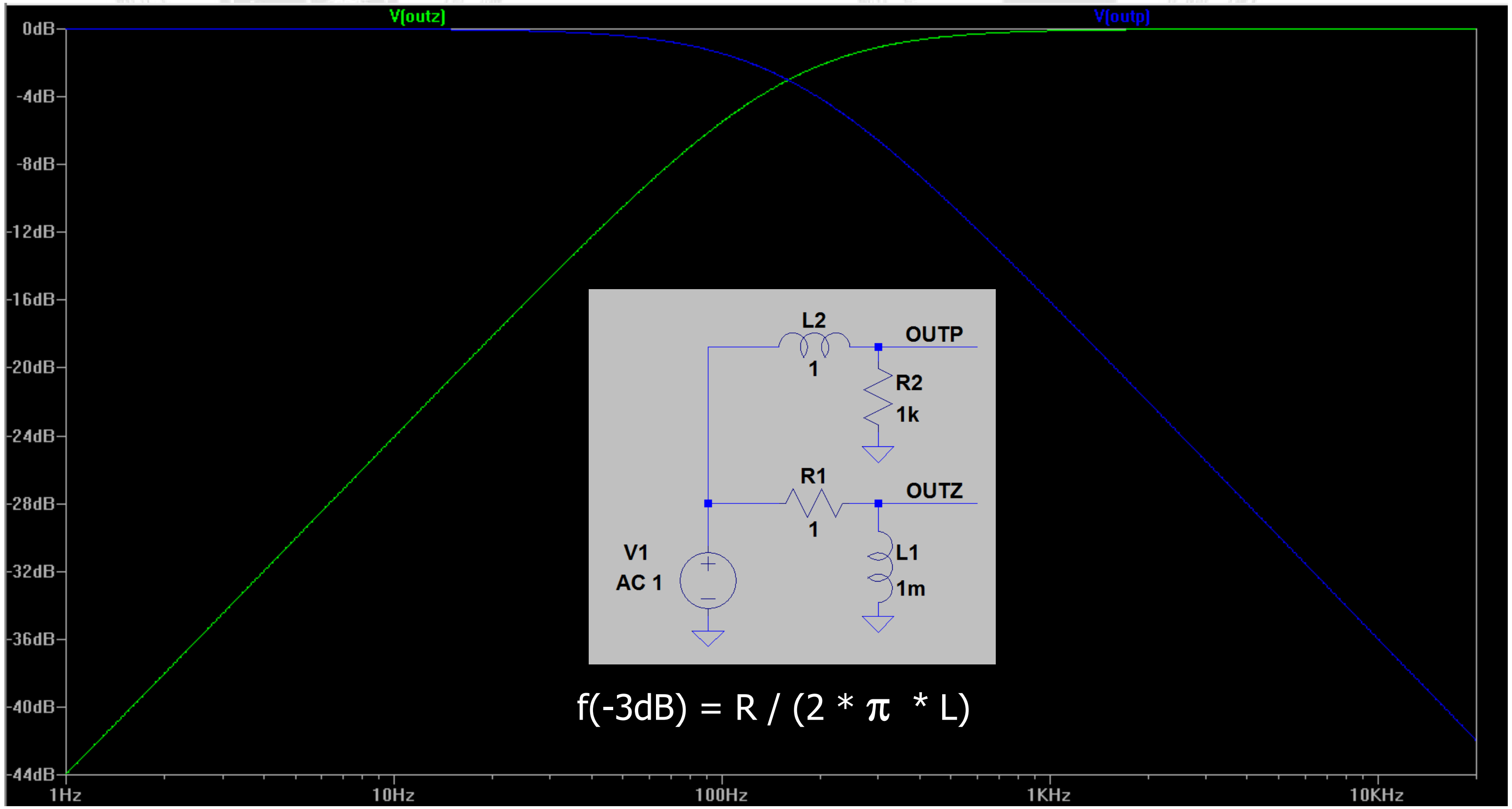
Poles and zeros using capacitors

- A pole or zero can be created by a resistor, and a reactive component - either a capacitor…



Poles and zeros using inductors

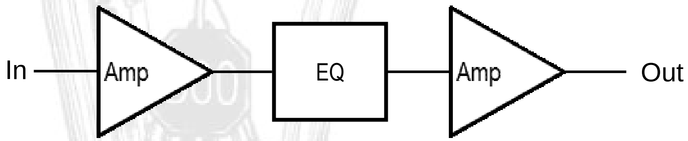
- …or an inductor



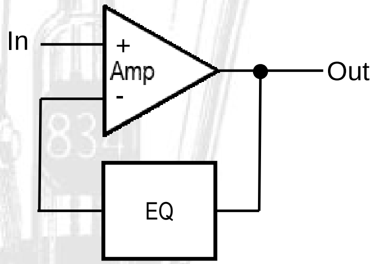
RIAA preamp implementations

- 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

Passive

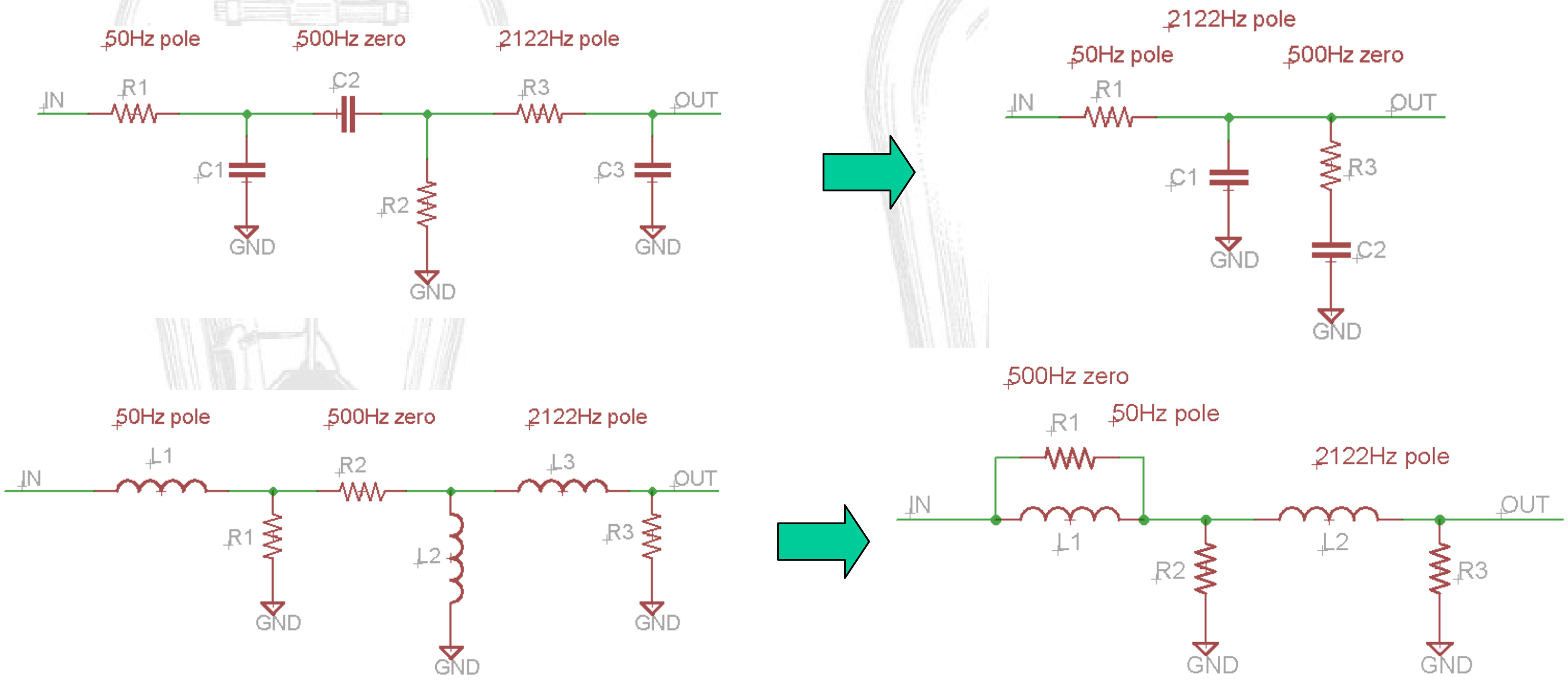


Active



- 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

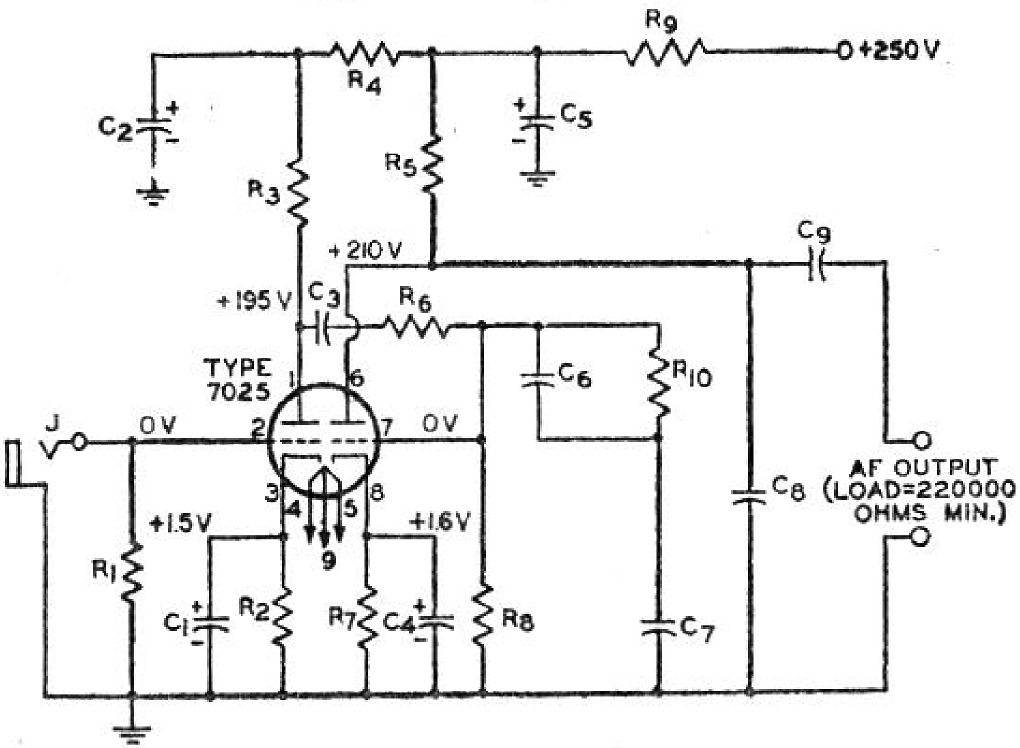


- Many other permutations are possible
- In reality, it’s not this straightforward. The nonzero source impedance of each stage interacts with the following stage.

Passive RIAA example

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

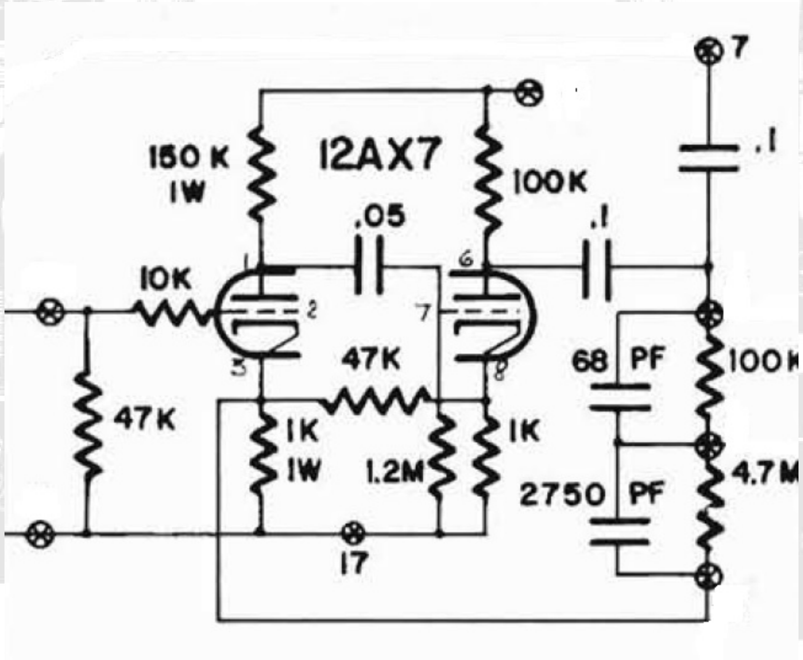
PREAMPLIFIER FOR MAGNETIC PHONOGRAPH PICKUP
With RIAA Equalization



Sensitivity=3 millivolts rms input for output of 0.55 volt at frequency of 1000 Hz.

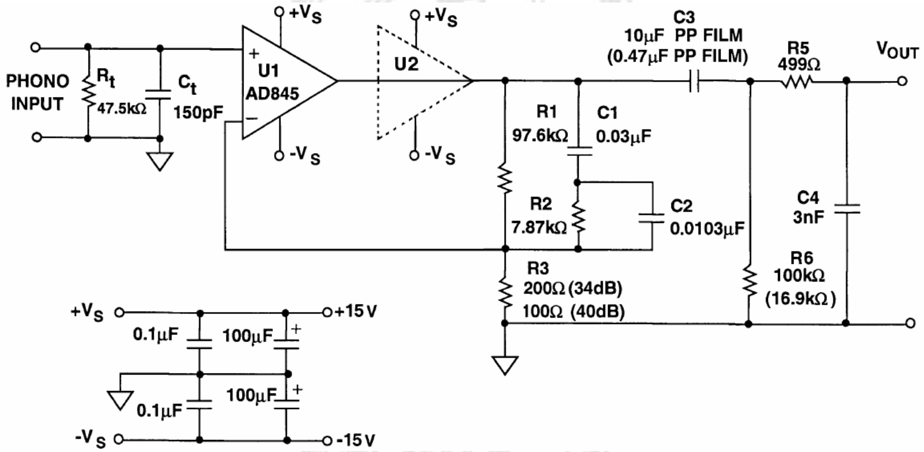
Active RIAA tube circuit example

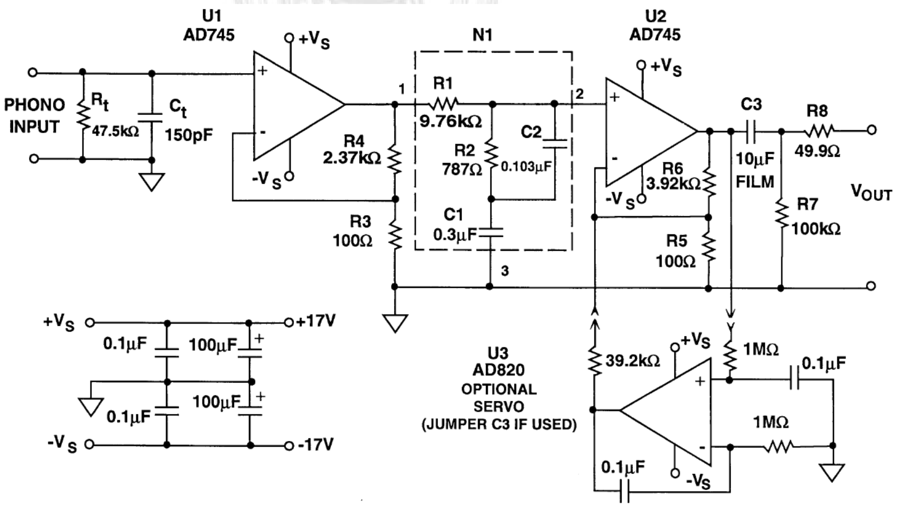
- Below is an example of an phono stage with an active EQ (Dynaco PAS preamp)

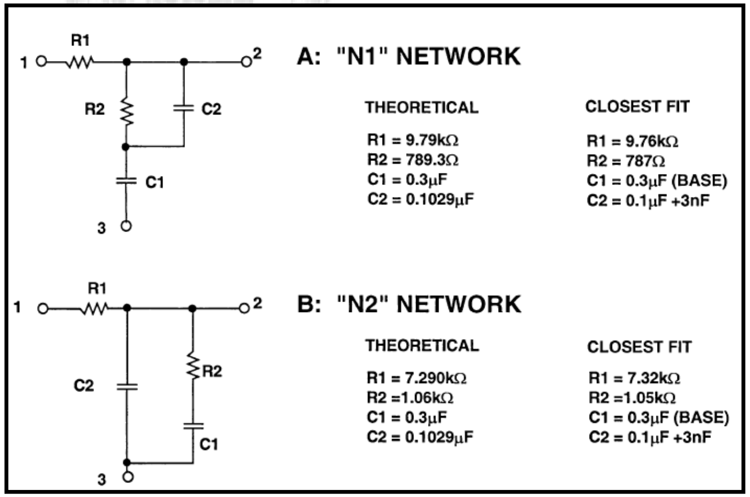


More RIAA examples

- These circuits are from Walt Jung’s “Signal Amplifiers”
- Note the two possible transpositions of EQ components (“N1” and “N2” networks)

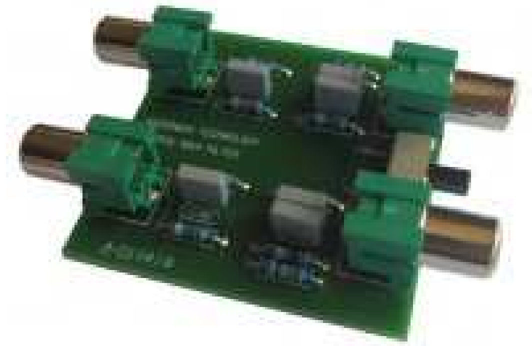


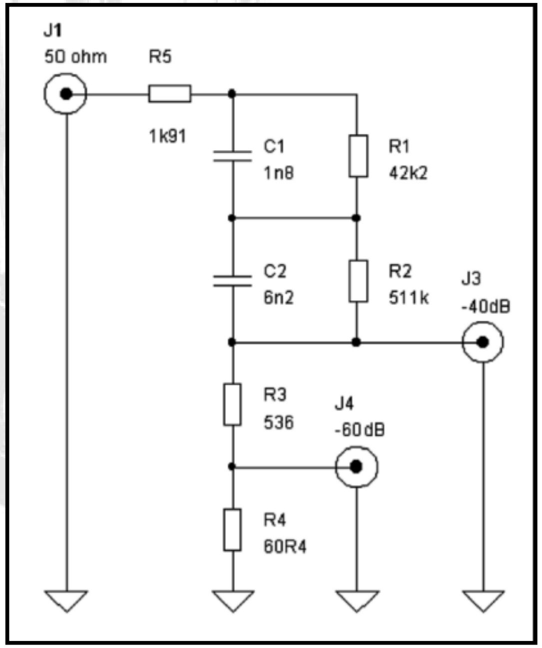




How to test RIAA preamps?

- 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 my Hagerman Technology - www.hagtech.com/iriaa2.html
- It’s accurate to within +/-0.4dB and has convenient 40dB and 60dB attenuation





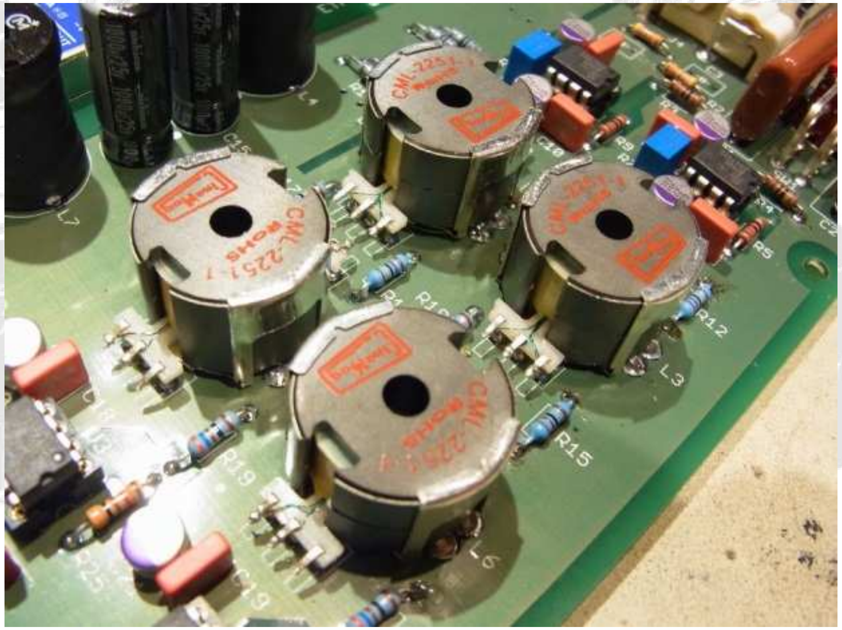
Part 2: LR RIAA equalizers

How to implement LR RIAA?

And avoid some problems...

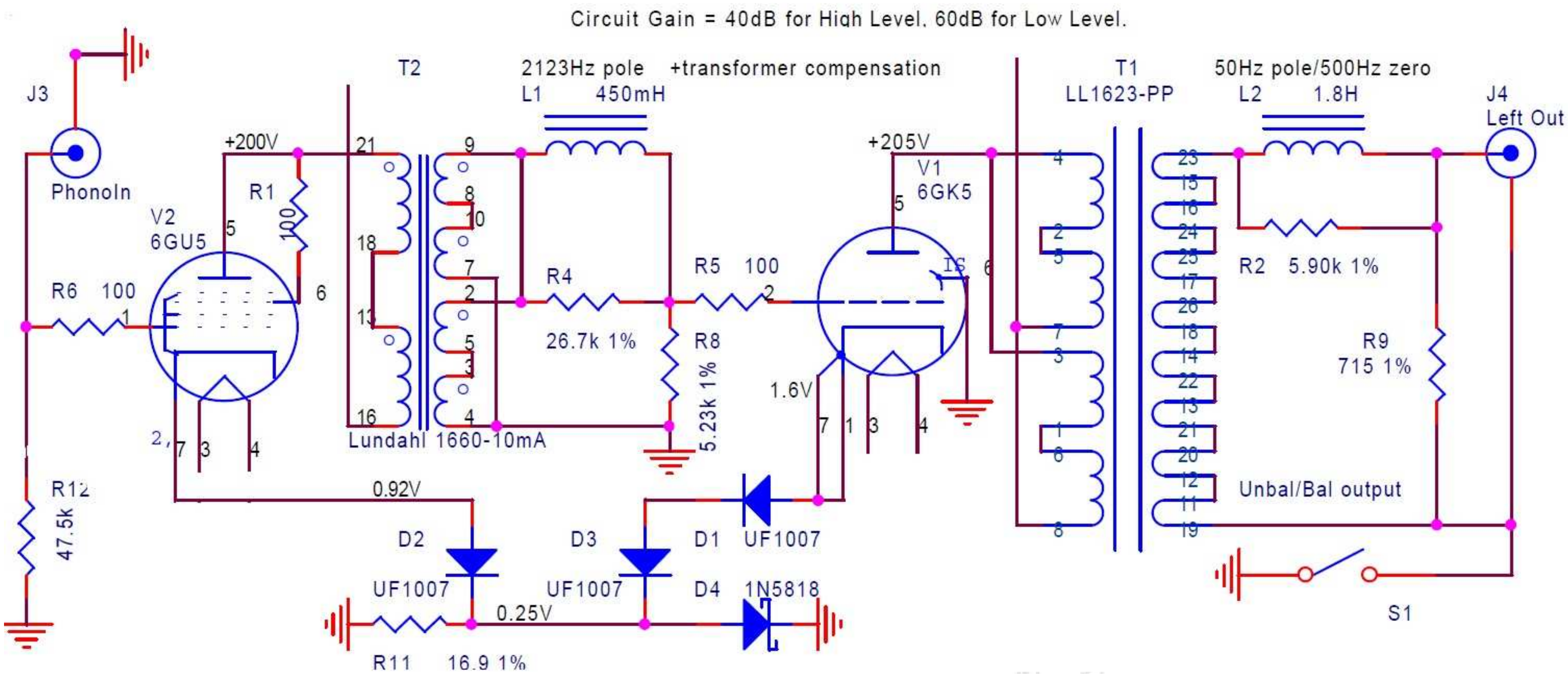
LR EQ: passive or active

- 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?



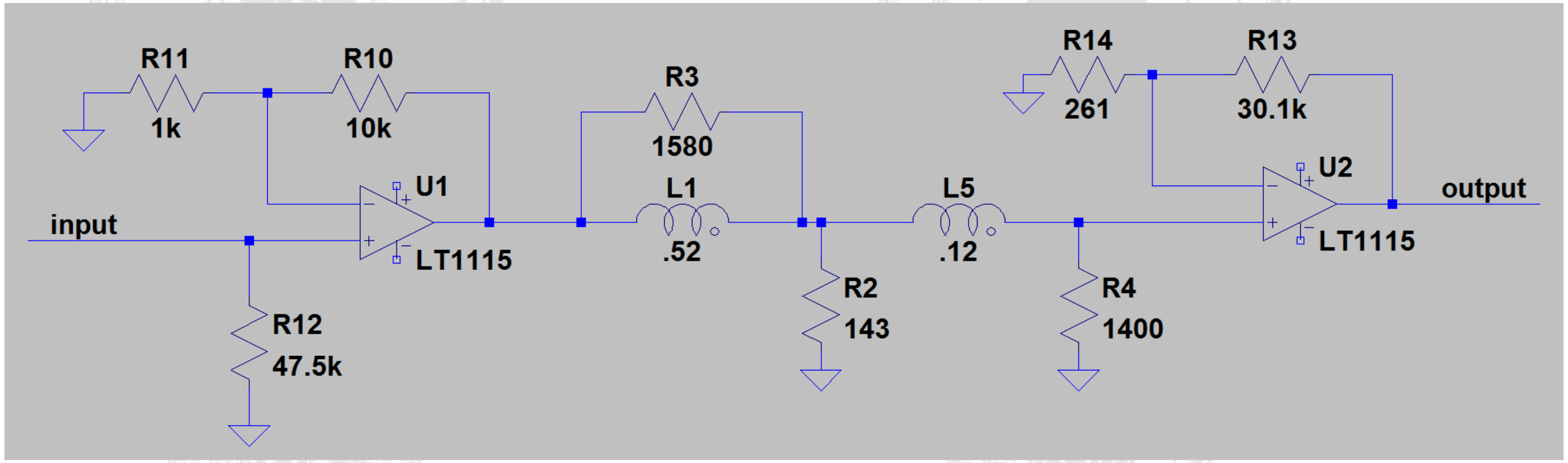
A tube LR RIAA preamp

- 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

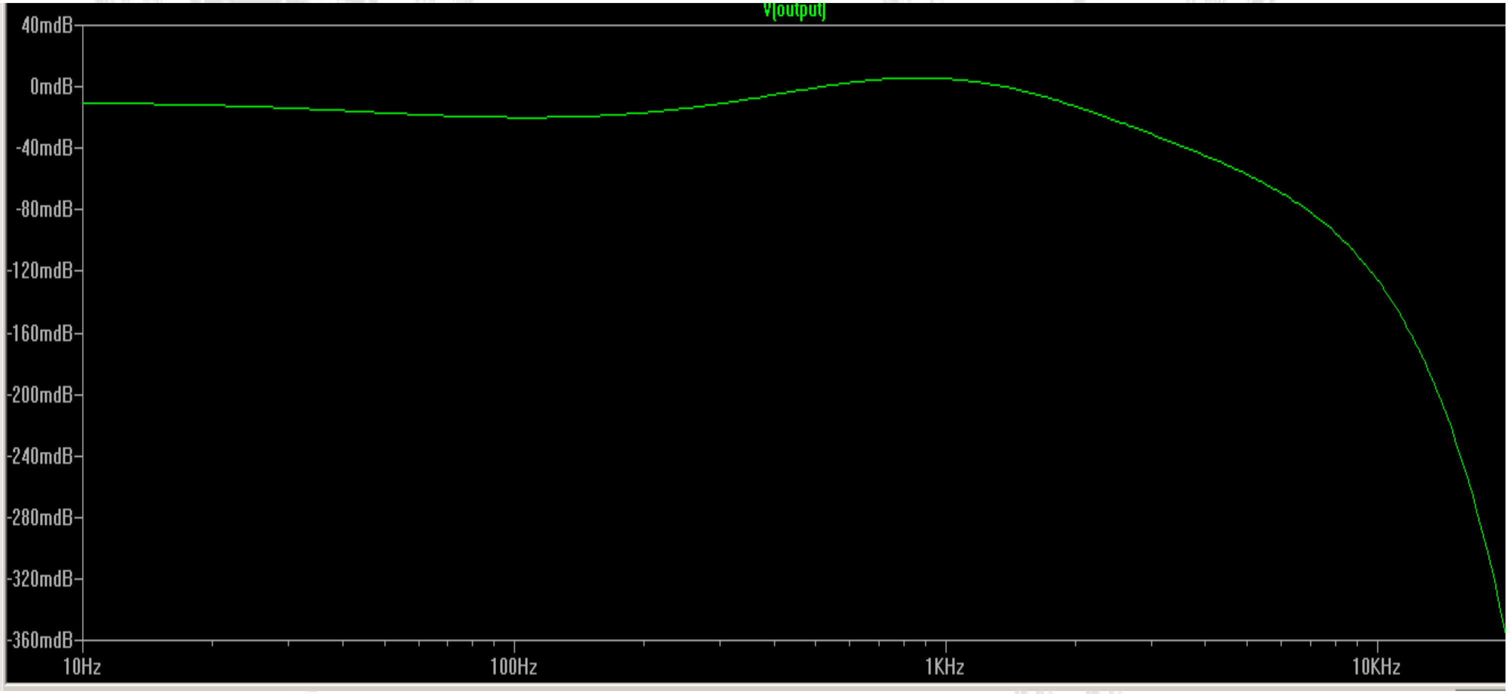
- Here is my initial design of a passive LR preamp:



- 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

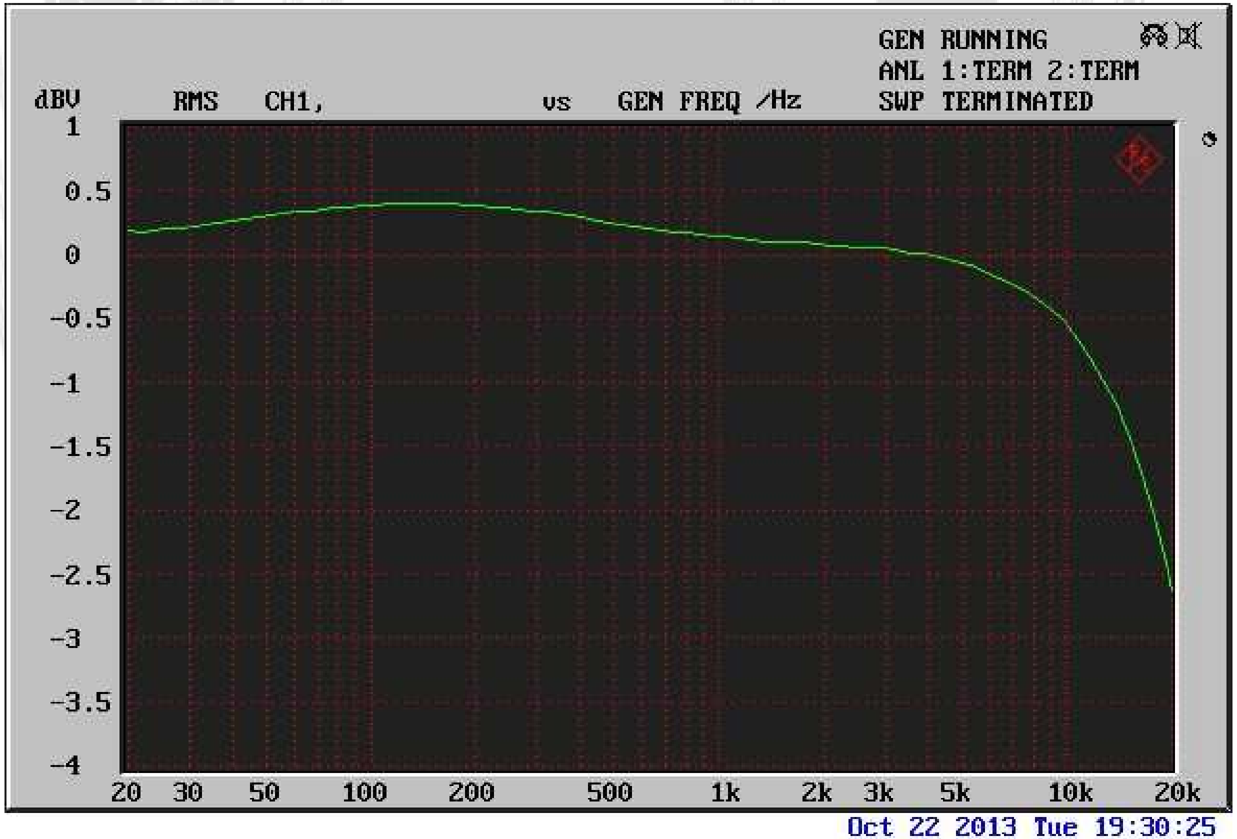
Circuit simulation: passive LR EQ

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



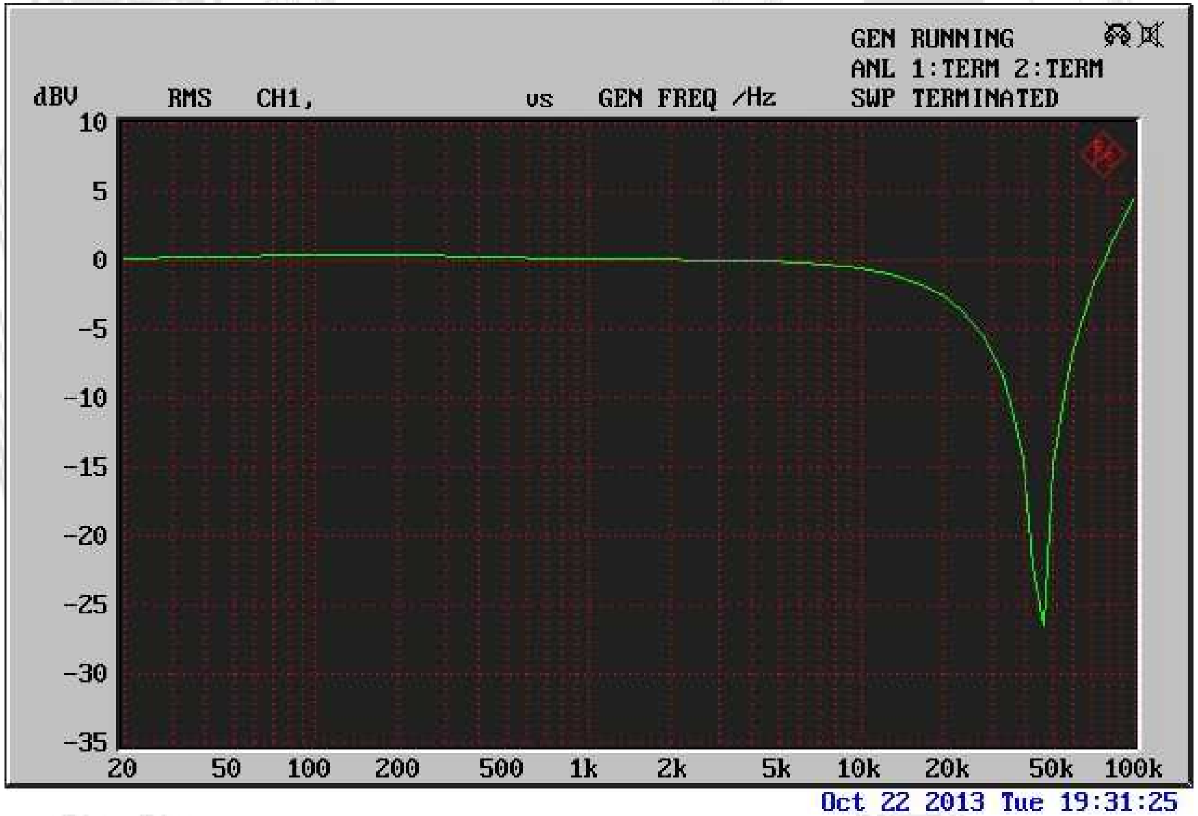
Circuit measurement: passive LR EQ

- **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

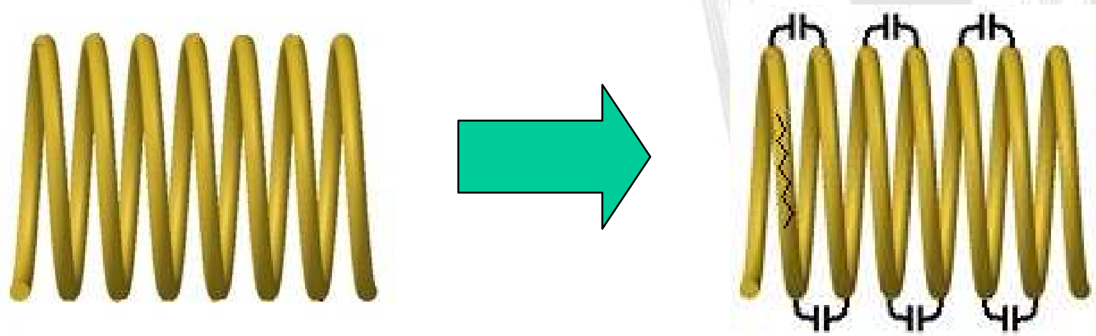
- HOWEVER…. What if we look out to 100kHz?



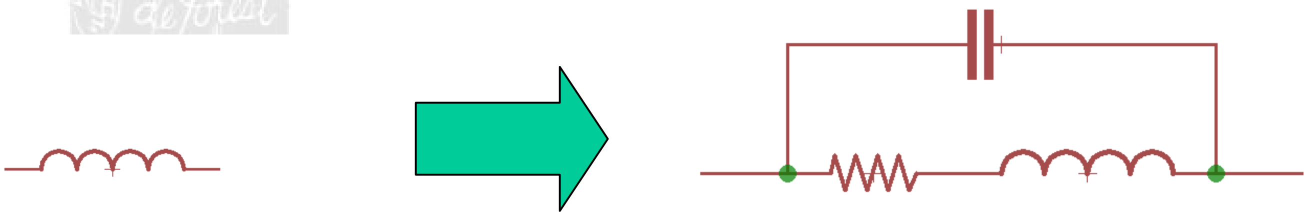
- What is *this*?

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.

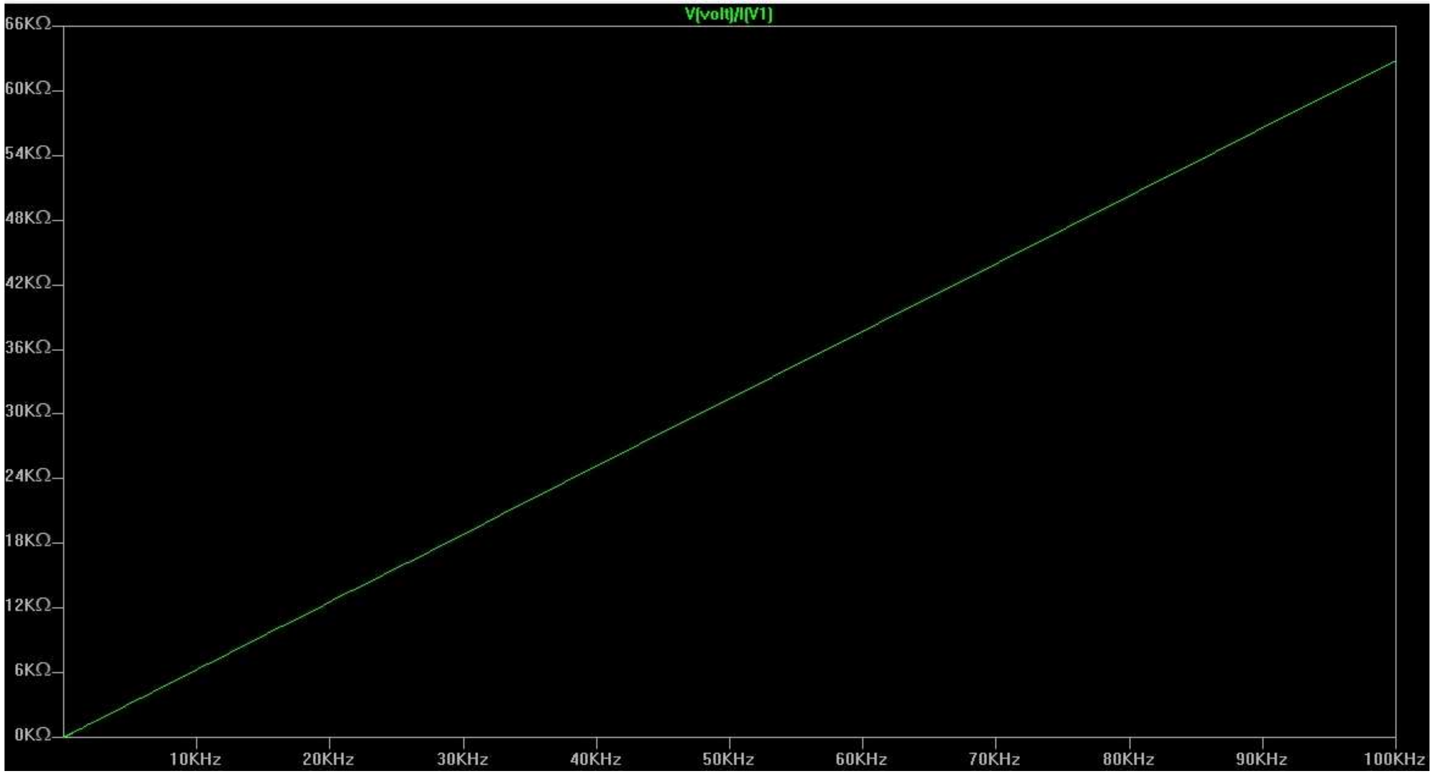


- The resistance can be modeled as a resistor in series with the inductor; capacitance can be (roughly) modeled as a capacitor in parallel:



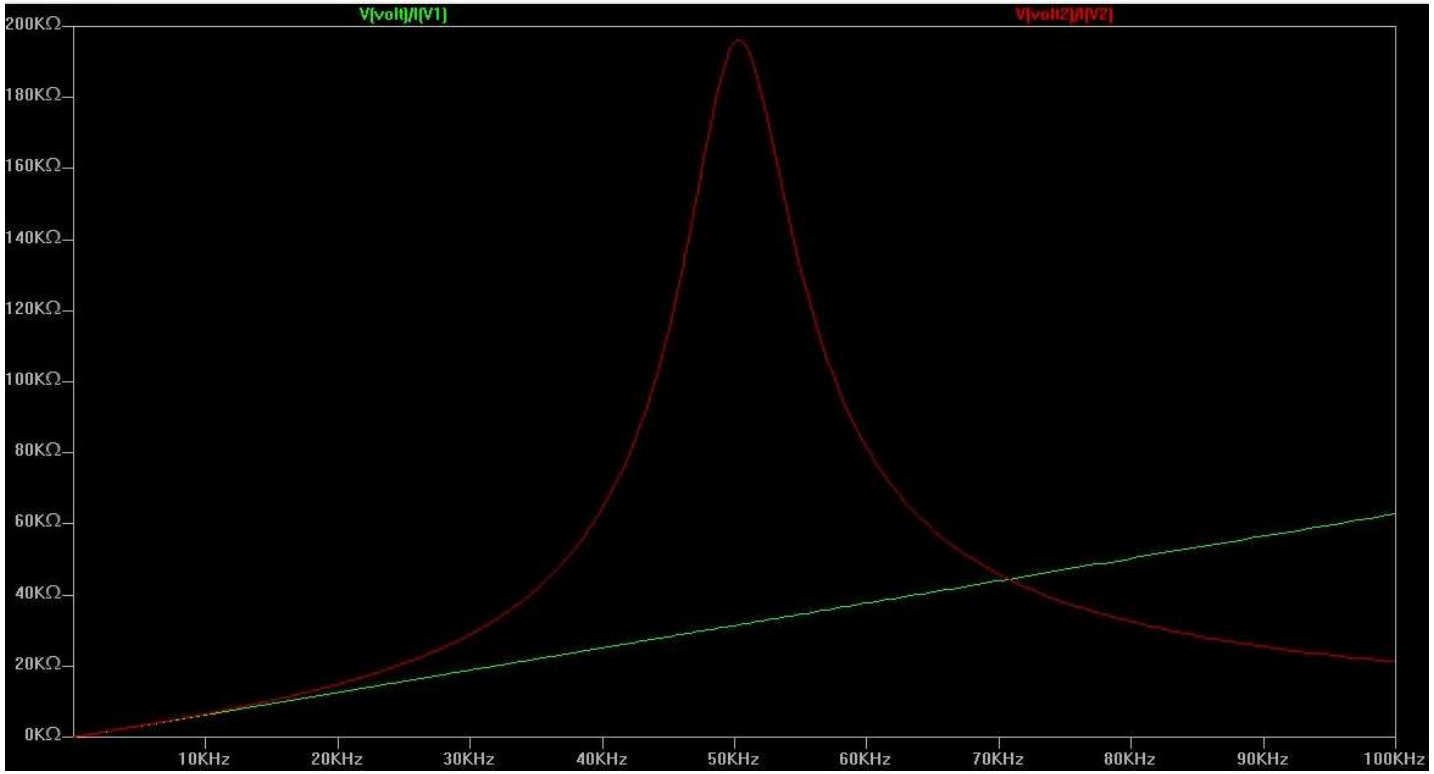
Impedance of an ideal inductor

- An ideal inductor has an impedance that varies linearly with frequency, equal to the inductive reactance, which is $2 * \pi * f * L$
- 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:

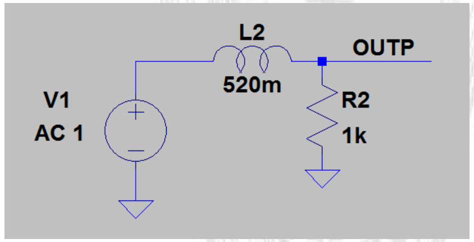


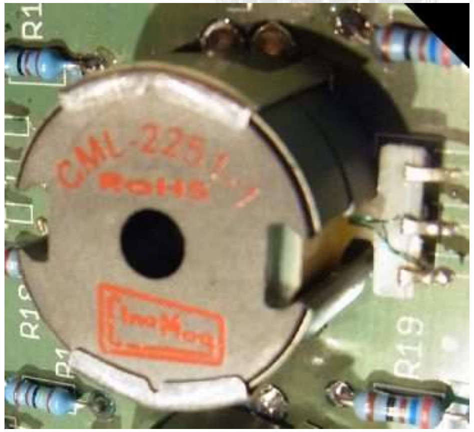
Self-resonance

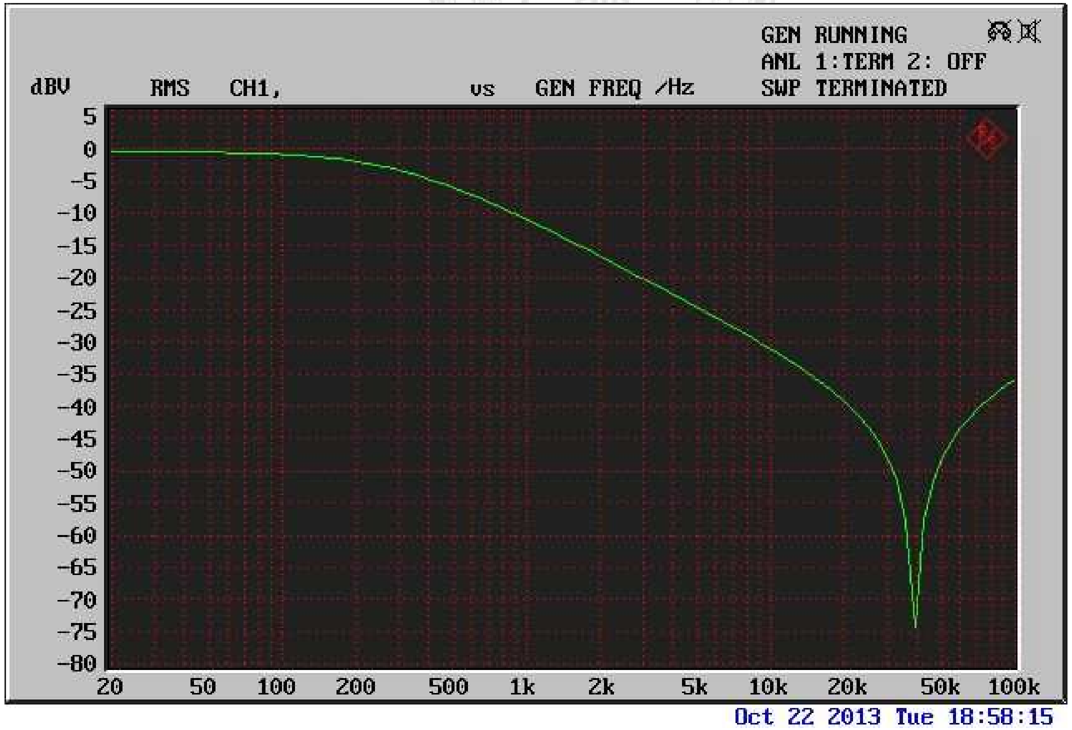
- This effect of the parasitic shunt capacitance is called “self-resonance”. The inductor and its parasitic capacitance form a parallel resonant circuit, which has a very high impedance at the resonant frequency
- Generally, the higher the inductance, the lower the SRF (Self Resonant Frequency), since 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 a 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

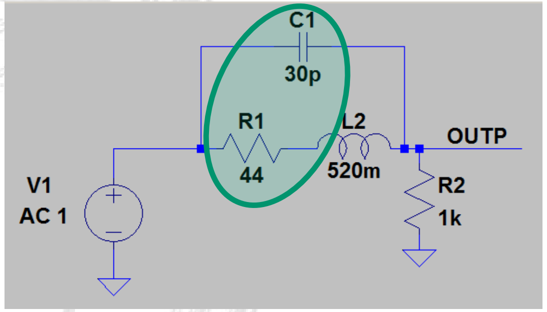


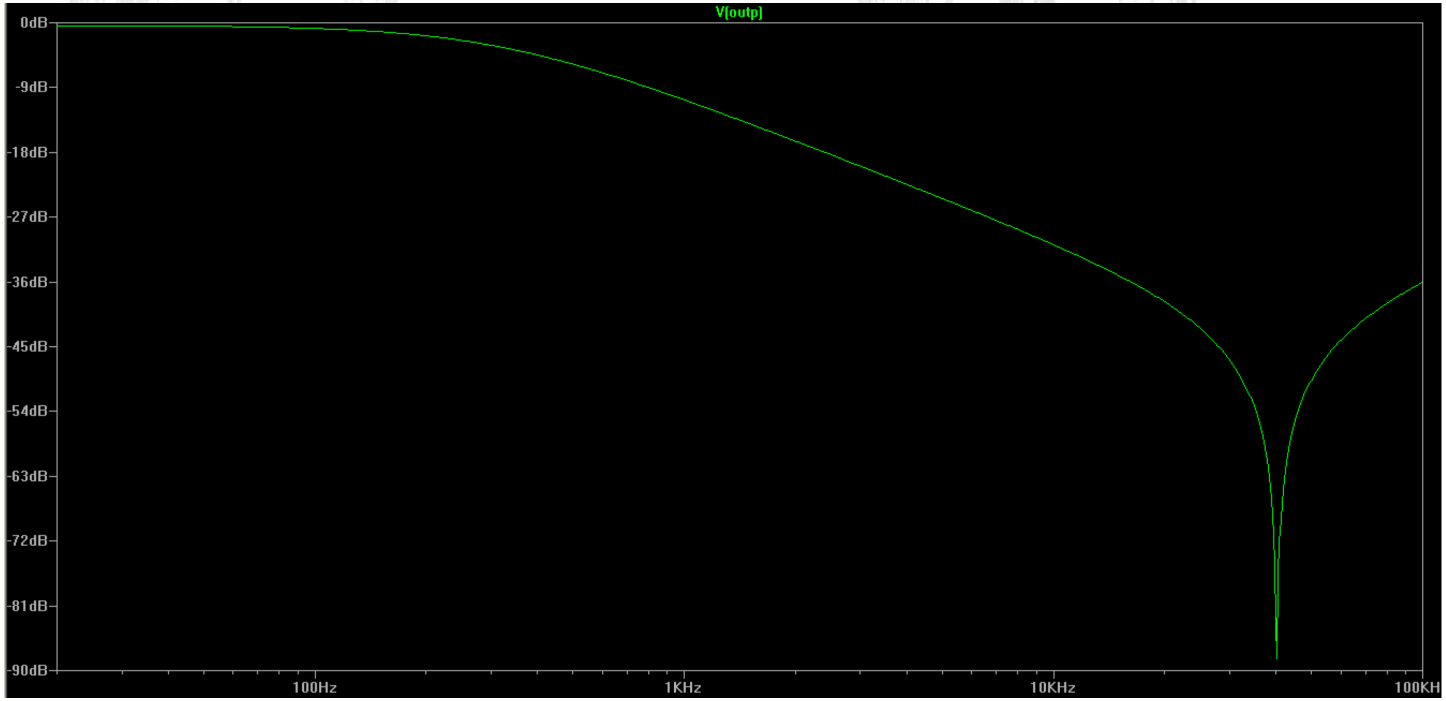




Modeling the real inductor

- 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) = 1 / (2 * π * $\sqrt{L * C}$)

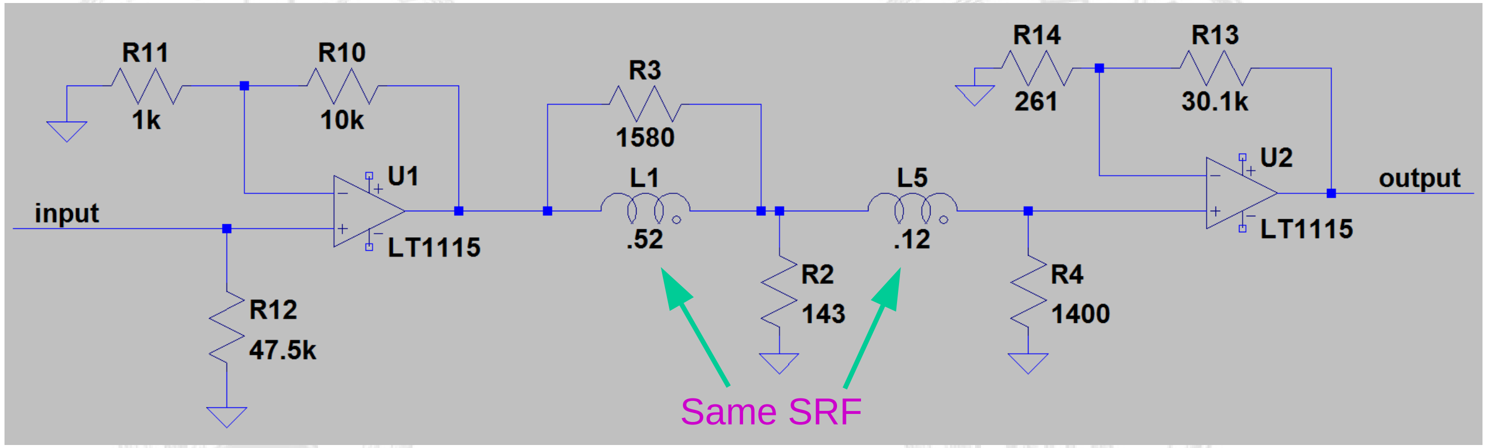




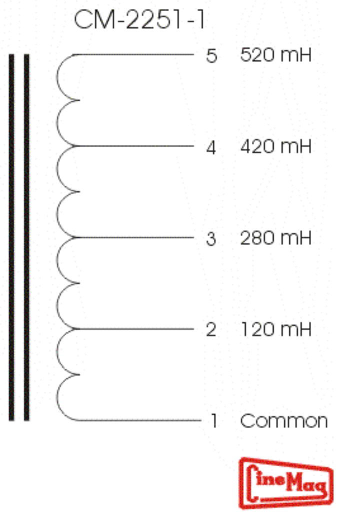
Fixing the inductor

- 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

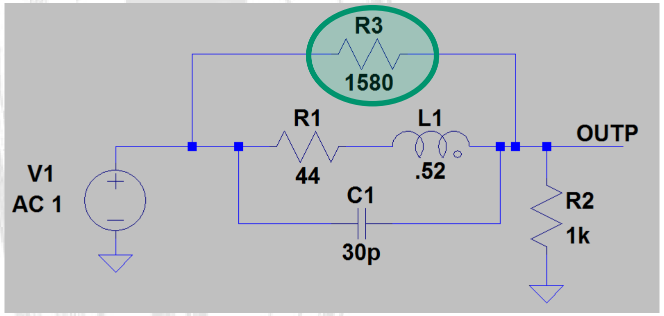


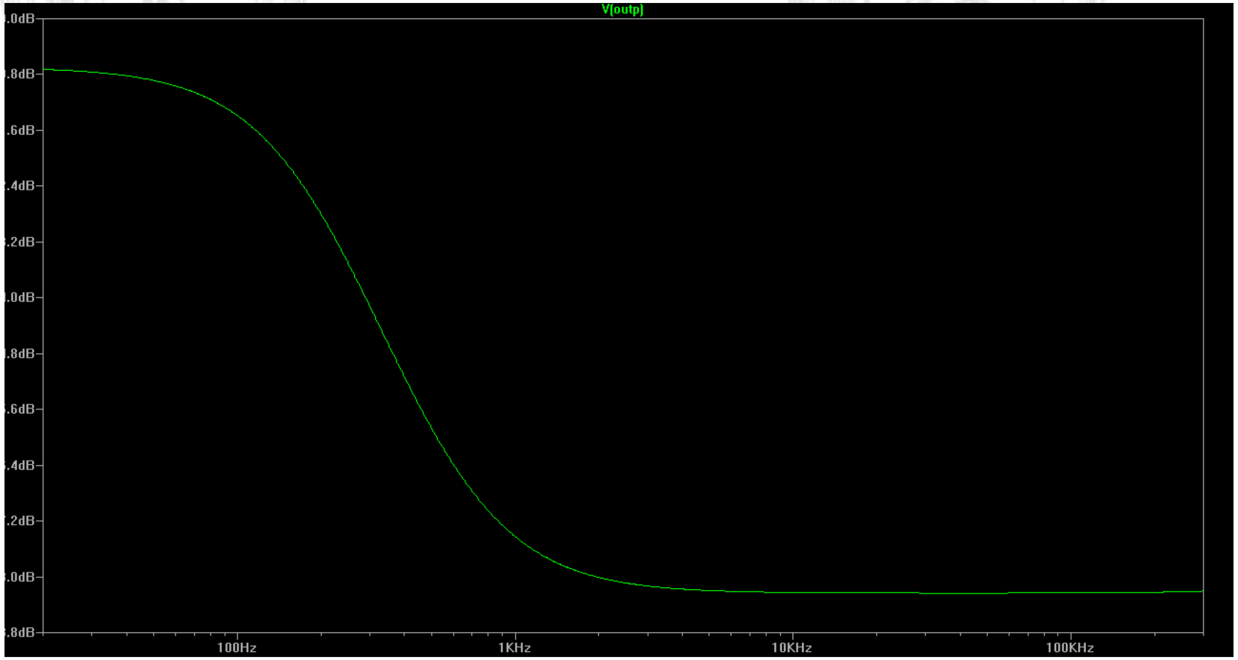
- Since the SRF of a larger inductor is typically lower than that of a smaller one, you may think that the larger inductor in my design would be the problem here
- However, I used the same inductor in both locations. The inductor is tapped – I use the full winding for the 50Hz pole and only a part of 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

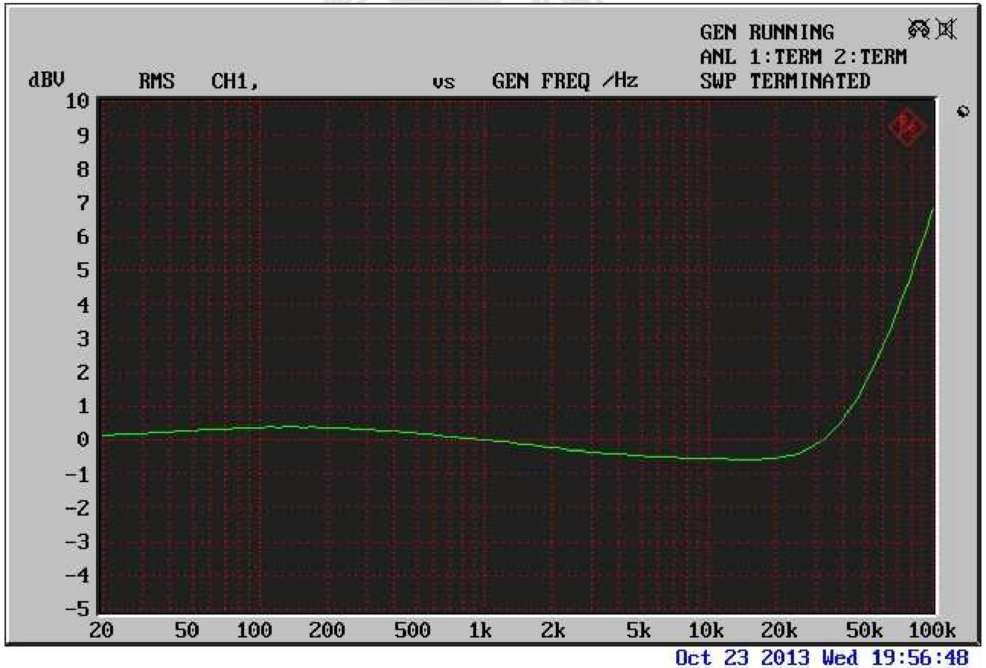
- See what happens when we add a zero below the SRF:
- There is a barely perceptible dip at the SRF, but no notch!
- At the SRF, the resistor dominates
- So in an LR EQ, the SRF can be avoided… sometimes…

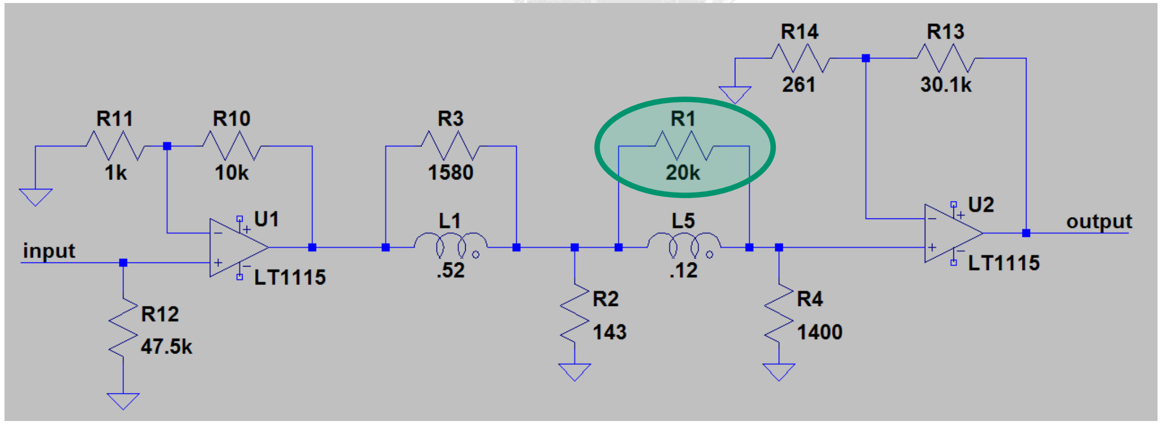




Working around the self-resonance

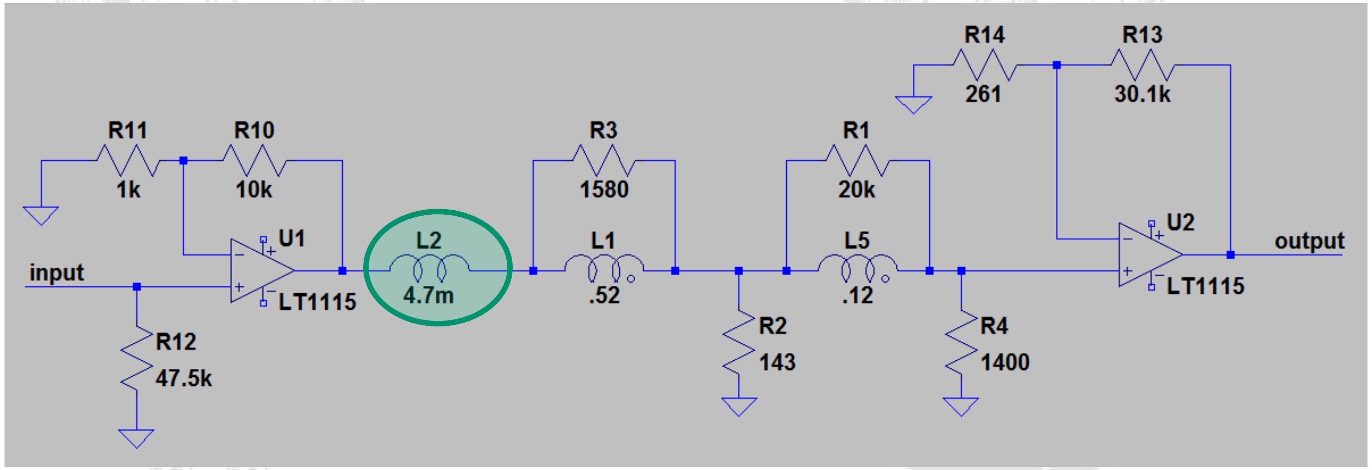
- Because my first L has a zero (parallel R), the *second* inductor SRF is causing the notch and gain rise here
- If we add a resistor (R1 below) across the other inductor and create another zero just below the SRF of the inductor, we can remove the notch
- Tuning is critical
- The HF peak is still there,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





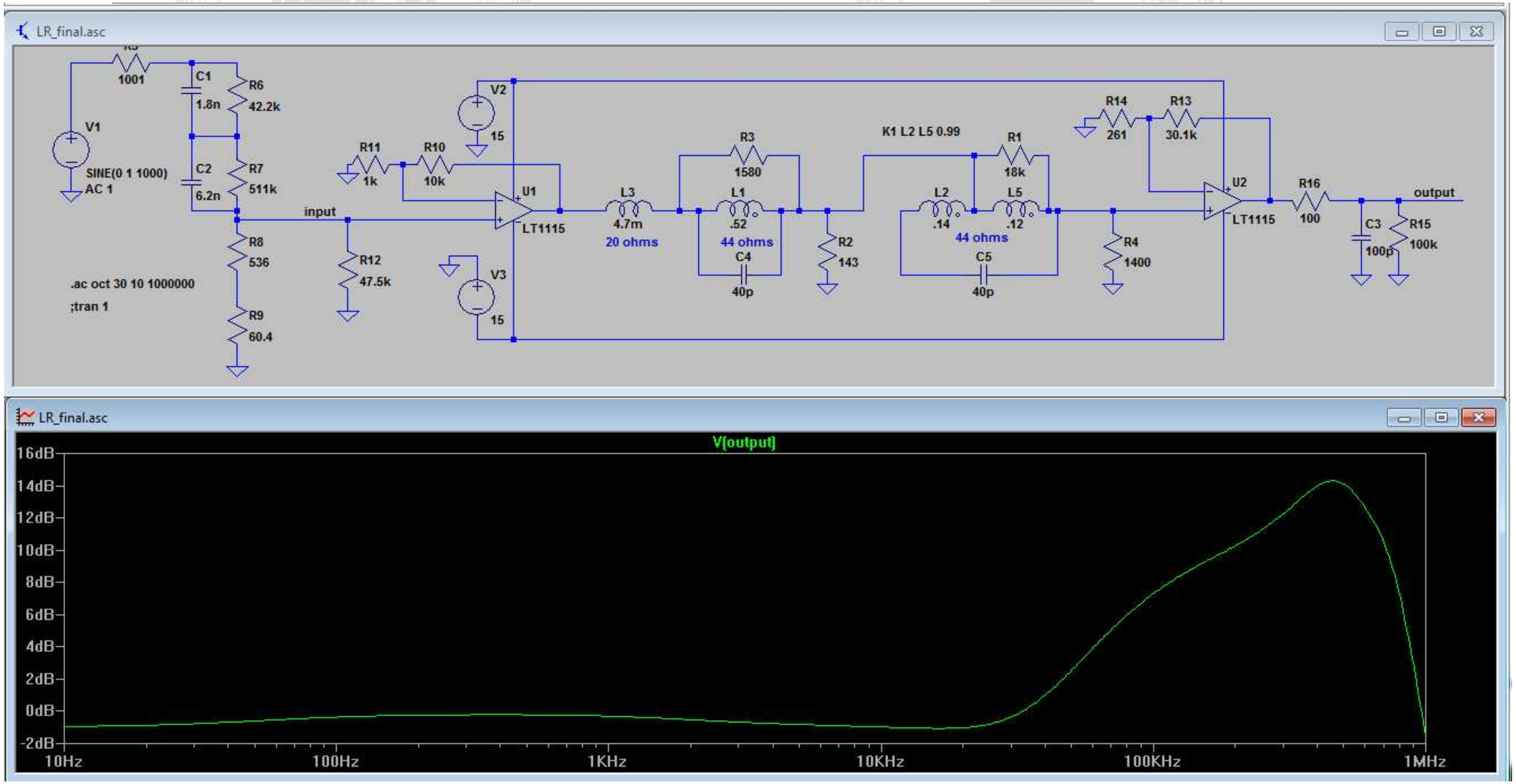
The HF peak

- 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.



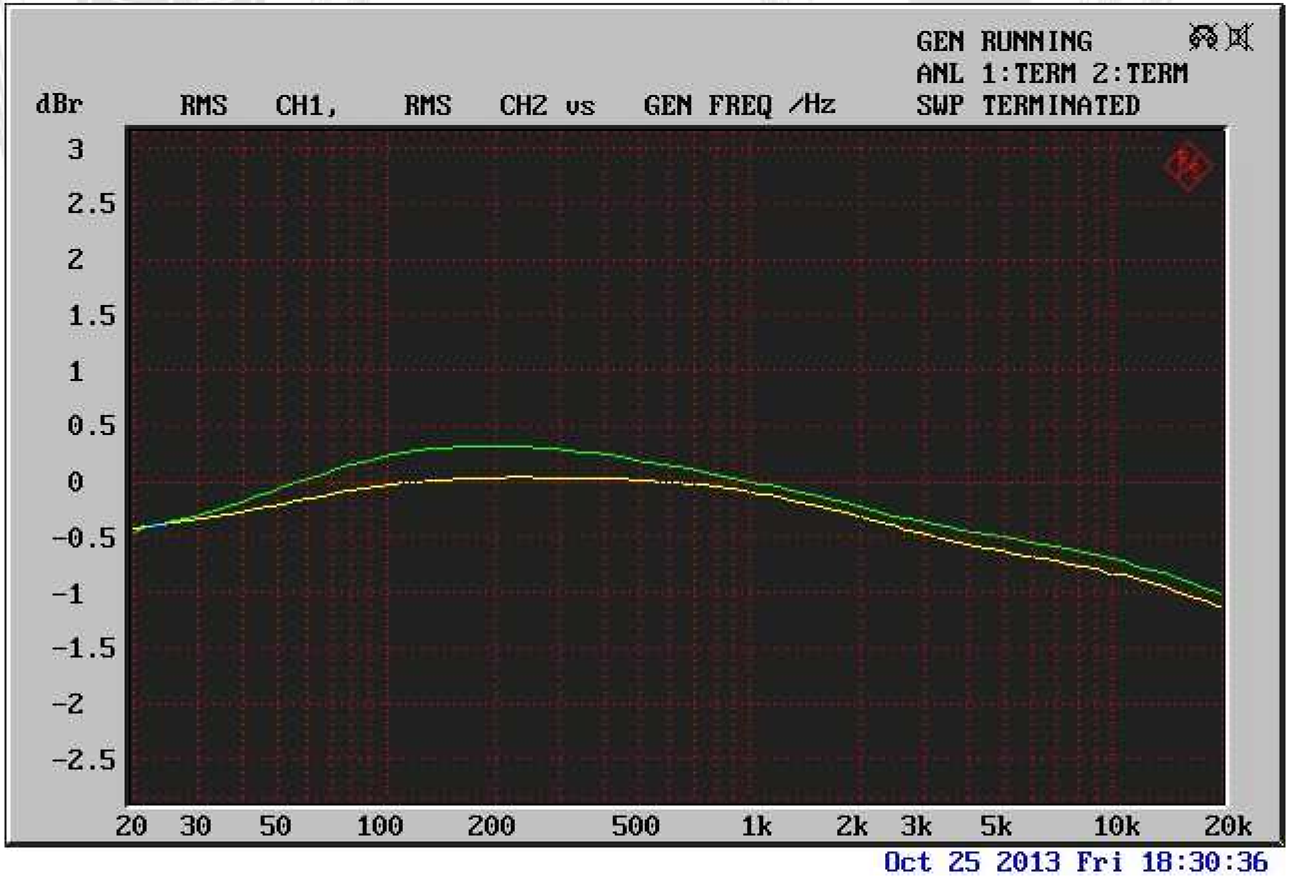
A (mostly) complete simulation

- 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



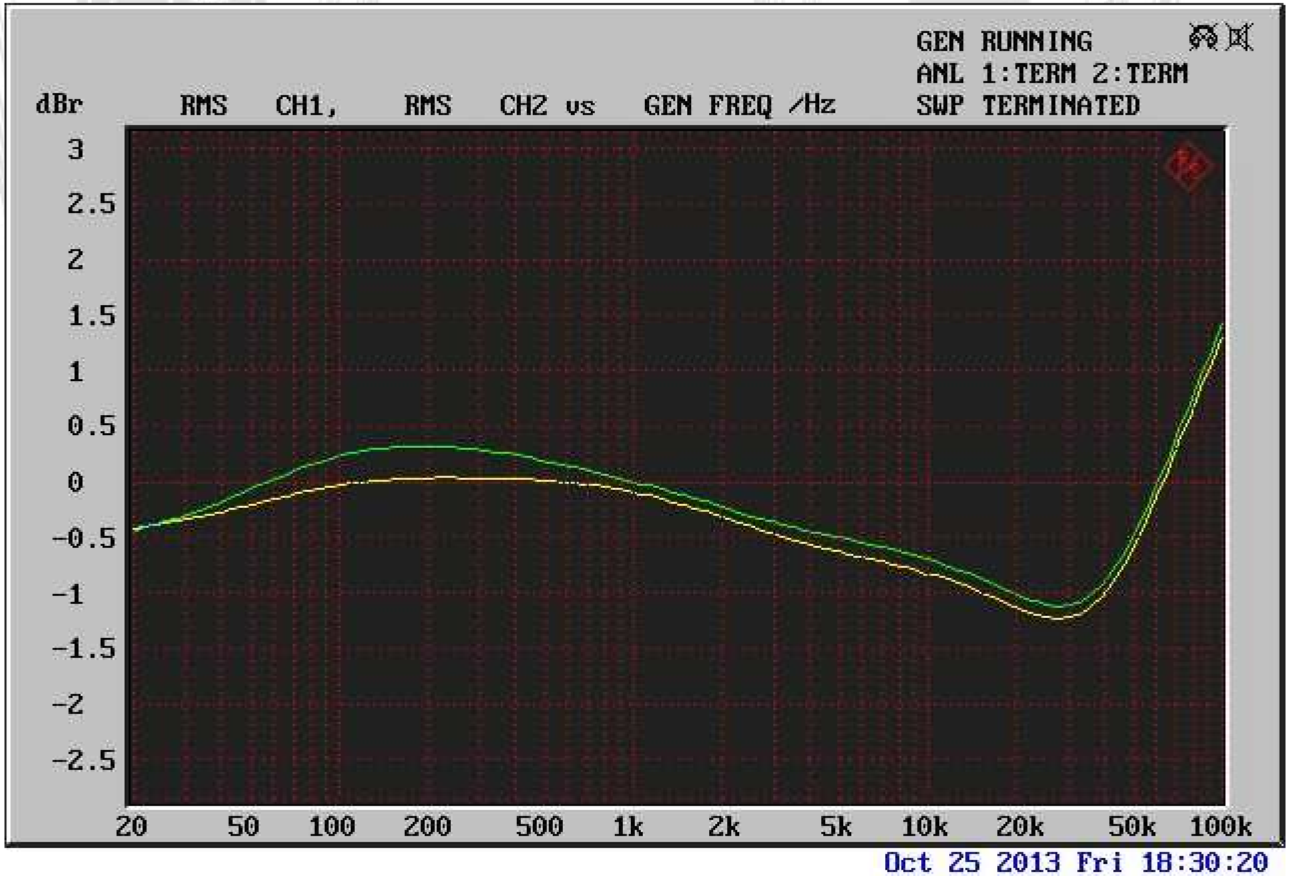
Final measurement

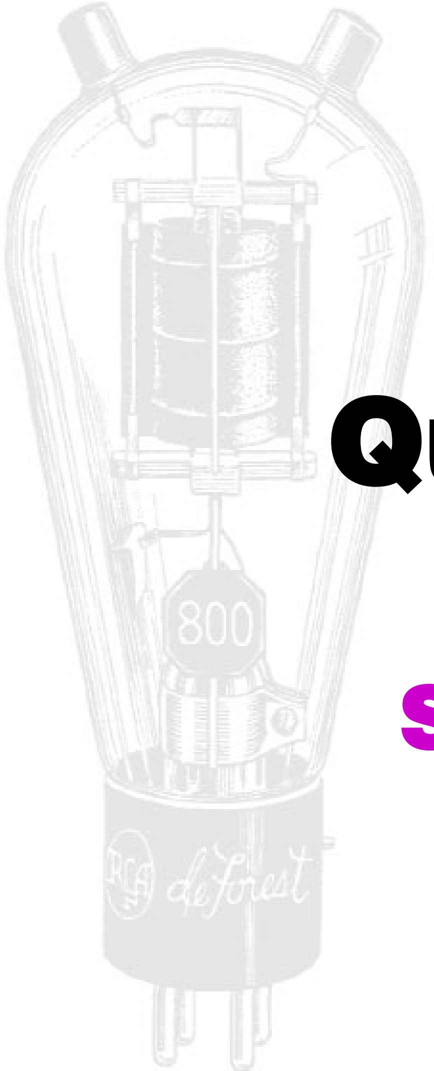
- The response of the preamp after these changes is within +/-1dB 20Hz – 20kHz
- Channels track within +/- 0.3dB



Final measurement

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

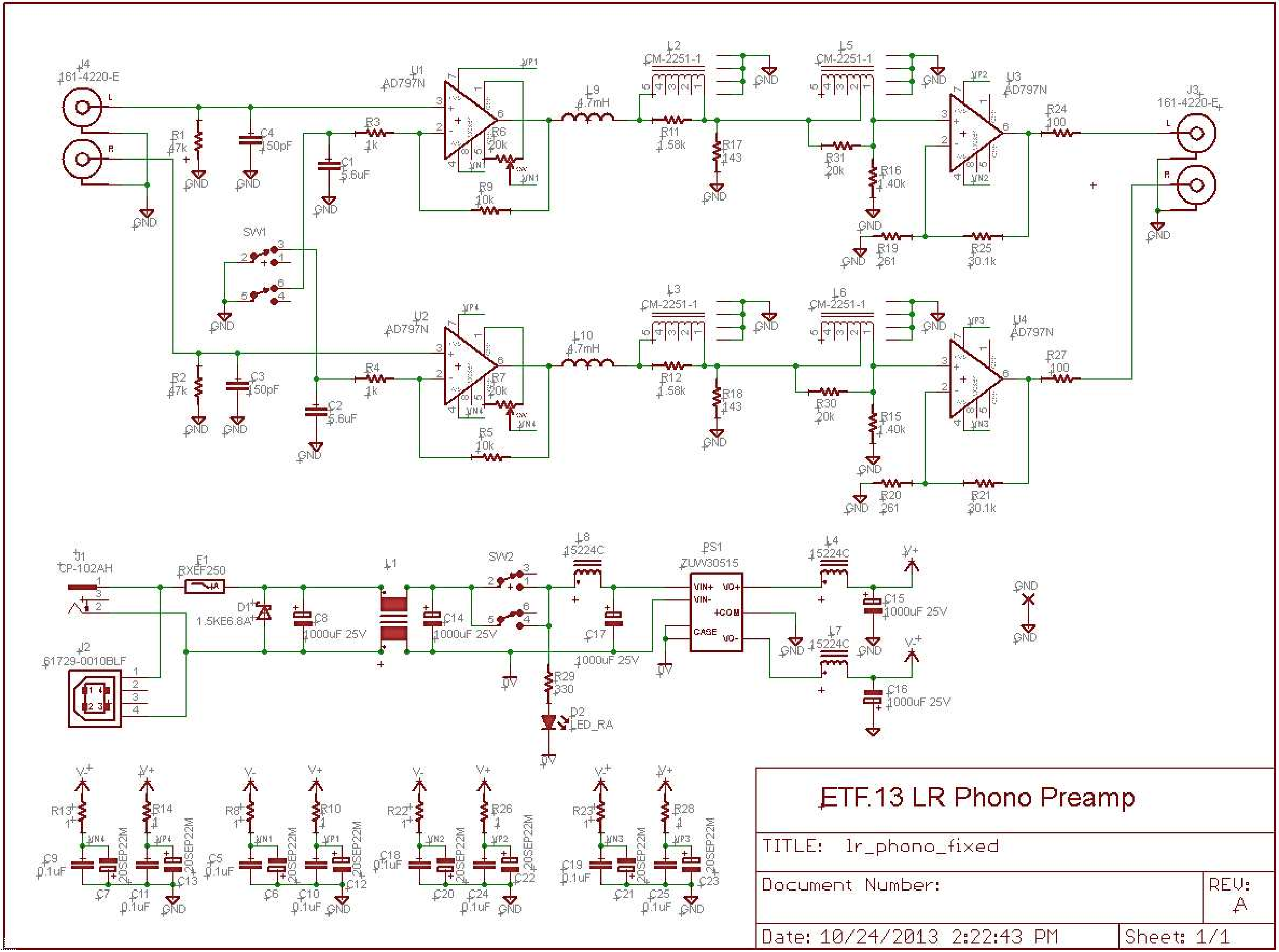




Questions?

Still awake?

Thanks!



ETF.13 LR Phono Preamp

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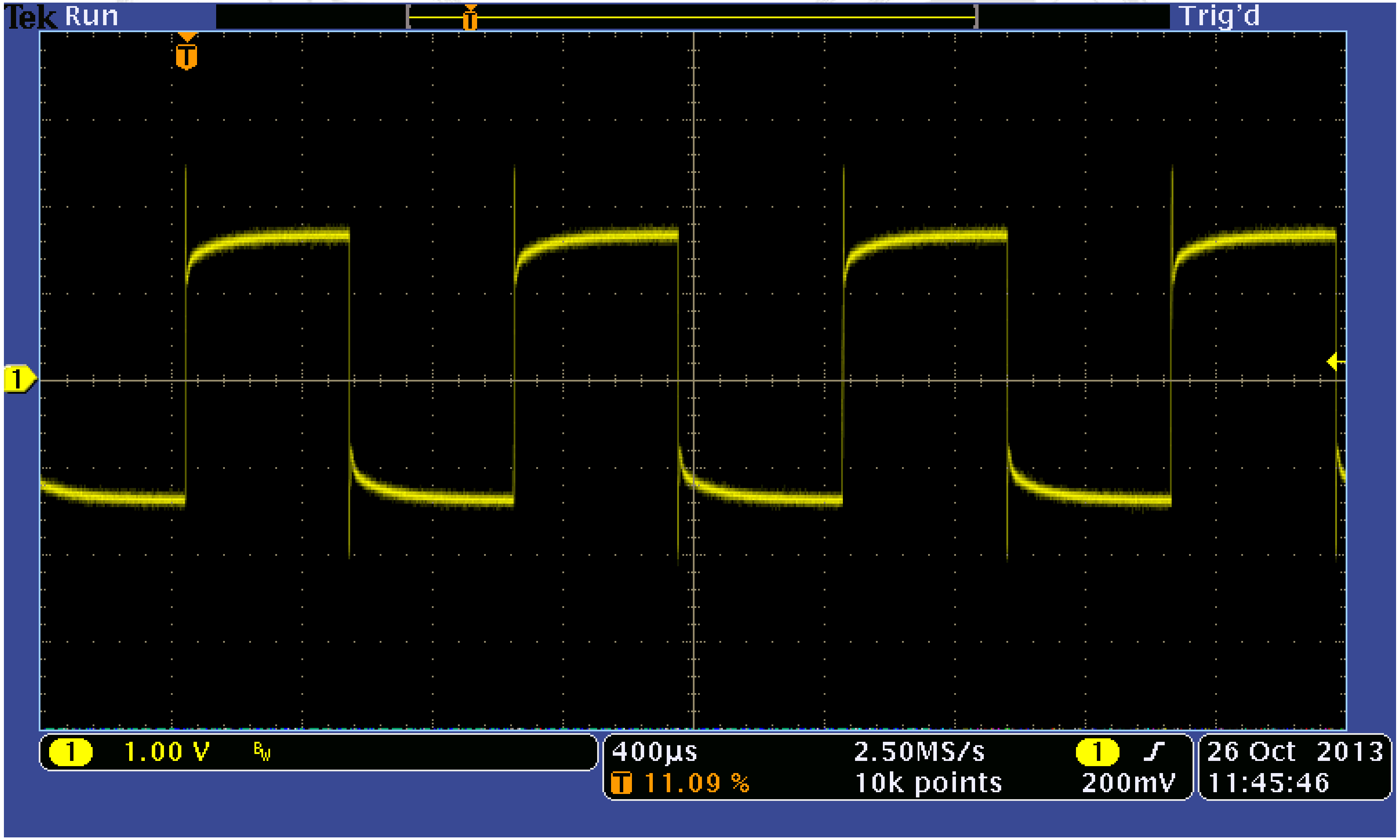
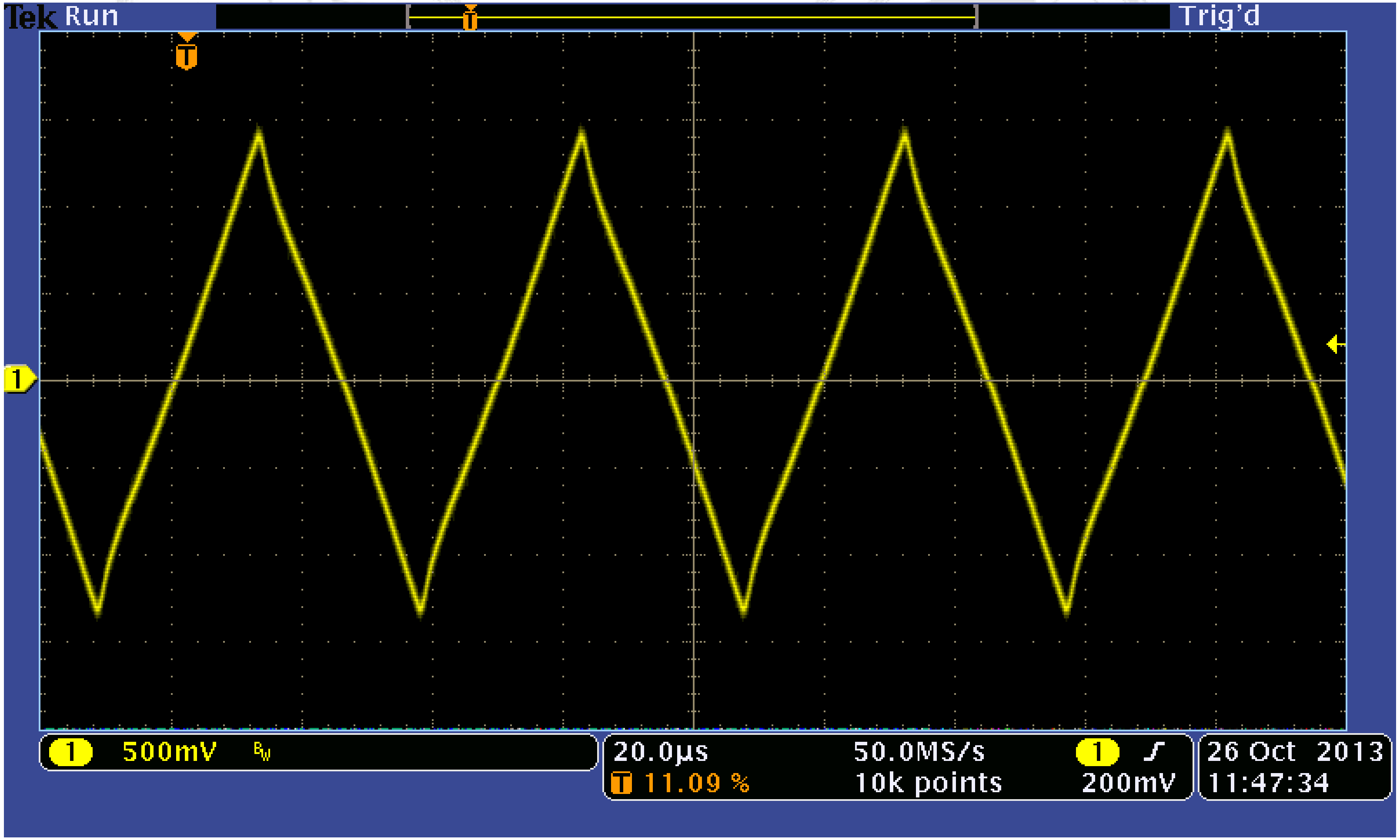
Sheet: 1/1

1kHz square wave



20kHz triangle wave



20Hz triangle wave