All About “Electronic Cooling”

This white paper is about a low noise design technique that some people have called “Electronic Cooling”. We’ll see why shortly. This technique makes the PHONOZ one of the quietest phono preamps available.

Every resistor generates a noise voltage that depends on its temperature and resistance. The hotter the resistor, the noisier it is. Higher resistance values generate more noise voltage. Figure 1 shows the model for a resistor and its noise.

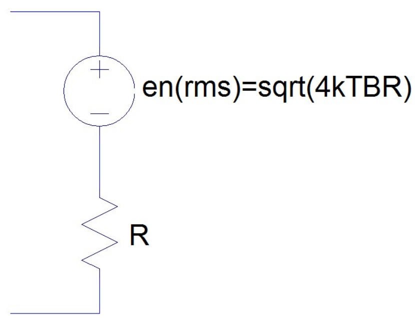

Figure 1 – modeling a resistor and its noise

The rms noise voltage generated by the resistor depends upon:

- T, the resistor’s temperature in degrees Kelvin
- k, Boltzmann’s constant, equal to $1.38 \cdot 10^{-23}$
- B, the bandwidth in Hz over which the noise is measured
- R, the resistance value in Ohms

Given an expression like that, it’s nice to get a value we can refer to in order to check our calculations. In a 1 Hz bandwidth (B=1), a resistor with R=1000 Ohm has a noise of 4.069 nano-volts at a temperature T=300 degrees Kelvin. Note that 300 Kelvin is 26.85 Celcius, or 80.33 Fahrenheit. We’ll call this 4 nano-volts in a 1 Hz bandwidth, or for a general bandwidth B, it’s 4 nV/rt-Hz. Why rt-Hz? Because the B appears under the square root sign.

If we want to calculate the rms noise voltage generated by a 1K Ohm resistor in a 10 kHz bandwidth, we multiply 4 nv/rt-Hz times sqrt(10000), which equals 400 nV in a 10 kHz bandwidth. A 47000 Ohm resistor generates the square root of 47 times as much noise in a 10 kHz bandwidth, or 2.74 microvolts. Can we do any better?

Let’s apply “electronic cooling” as implemented by the circuit in Figure 1. If you look to the right of the dotted line, you see an impedance of 47000 Ohms even though the resistor is 1 Meg. That happens because of something known as “Miller Effect”. If we apply 1 volt on the left side of the resistor, we get -20.27 volts on the right side of the resistor. Therefore, we have 21.27 Volts across the 1 Meg resistor, which causes a current of 21.27 micro-amps for one volt of input. Ohms law says that R=V/I, so we have R=1/21.27e-6=47000 Ohms.

OK, we've managed to make 1 Meg-Ohm look like 47,000 Ohms, but is it any quieter?

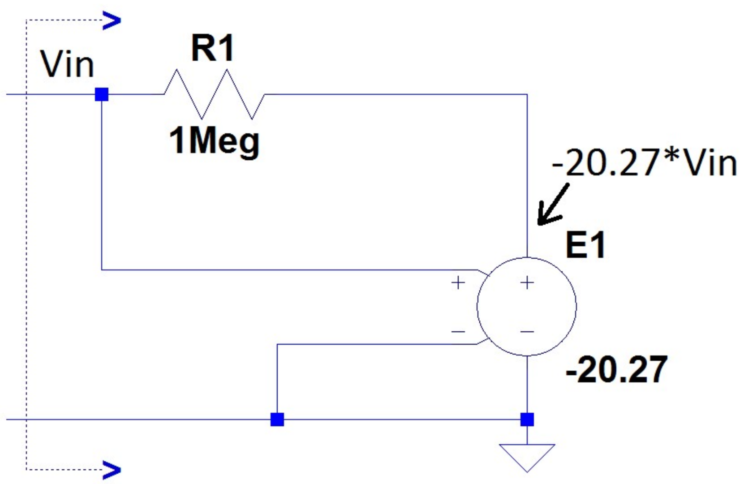

Figure 1 – Electronic cooling impedance transformation

Let's add a model of the noise of a 1 Meg resistor noise, 126.5 nV in a 1 Hz BW, and see what happens.

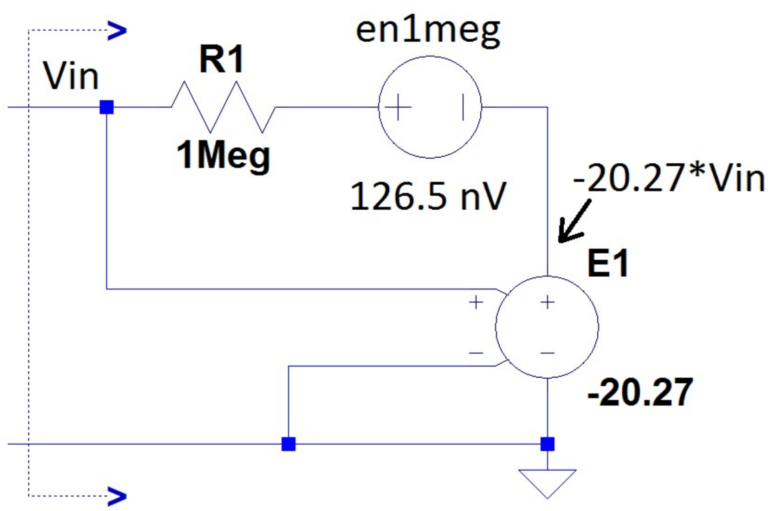

Figure 2 – Electronic cooling noise reduction

We can write a loop equation to find Vin:

-20.27*Vin+en1meg=Vin

Solve it for Vin and we get:

Vin=en1meg/21.27

So the noise of the 1 Meg resistor gets reduced by a factor of 21.27. This is the same as the ratio between the apparent resistance, 47k, and the physical 1 Meg resistor. Now to get a resistor with noise voltage that is 1/21.27 that of 1 Meg, we'd need the resistor to be 1 Meg/(21.27^2)= 2210 Ohms.

So electronic cooling has turned a 1 Meg resistor into a 47 K impedance, but it has the noise of 2210 Ohm resistor! So, why is this "electronic cooling"? Re-examining the noise equation, the other way to reduce the noise is to reduce the temperature.

$$en_{rms} = \sqrt{4 \cdot k \cdot T \cdot B \cdot R}$$

So if electronic cooling makes a 47K resistor have the noise of a 2210 Ohm resistor, then it's equivalent to a temperature that is 2.2/47 times lower than 300K, or 14 Kelvin. That's just 14 degrees above absolute zero! That's cool!

So let's summarize:

1. We can model the noise of a resistor by putting a noise voltage source in series with the resistor.
2. High resistors have more noise than low resistors.
3. Hot resistors have more noise than cold resistors.
4. Electronic cooling can be used to:
   a. Make a 1 Meg resistor look like a 47K resistor
   b. Make that resultant 47K resistor have the noise of a 2.21K Ohm resistor
   c. Reduce the input noise by (in the limit) 13.28 dB

Of course, there are some non-ideal effects that limit this improvement, but this white paper has given the big picture of how electronic cooling reduces noise. This technique makes the PHONOZ one of the quietest moving magnet phono preamps available.