Updated 14-August-2019

Moving Coil Head-Amps

A collection of simulated circuits

www.hifisonix.com

July 2019

Version 1

Will remain a work in progress and updated from time to time.

Contents

- Introduction and Methodology
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  - Arm/Cartridge Resonance Graph

Revision History

- 23-06-2019 – updated Richard Lee's Head Amps with notes provided by the designer; optimized noise performance on some of the single ended bipolar input designs
- 03-07-2019 – extensively updated and added newer designs
- 16-07-2019 – added Fermi and updated graphs
- 31-07-2019 - Updated Weinberg, Newton and added Archimedes; grouped the designs by type

Introduction – MC Head Amps

- In all the simulations, a stimulus of 500uV at 20 kHz is used
- Frequency response, distortion and power consumption were measured.
- The noise performance is quoted at 1 kHz. Where the circuit 1/f performance is markedly different from the others, this is noted – typically, the JFET designs show higher 1/f noise (~300Hz in the sims) than the bipolar input designs. On all the bipolar designs, the 1/f was ~10 Hz. Note also, the standard spice models used do not model the 1/f mechanism accurately.
- While the simulation figures should not be taken as absolutes, they do give some indication of the potential performance of the presented circuits.
- For the bipolar input device simulations, the Zetex ZTX851 and 951 are used as these are the lowest noise readily available transistors (2019).
- For the JFET input circuits, the BF862 model is used. Note that the BF862 is no longer available, but there are alternatives with similar noise performance.
- Attention: On some of the circuits, especially the bipolar input devices ones, further optimization of rbb' to match Rg through the adjustment of the device emitter current is possible – I leave this as an exercise for the reader (to borrow the words of Kendal Castor-Perry).
- I have avoided the temptation to simulate circuits with massive numbers of parallel input devices – this investigation is about practical audio circuits.

Device Models & Sim Methodology

Zetex Device Models

- ZTX951 PNP Device

.MODEL ZTX951 PNP IS=1.3766E-12 NF=1.013 BF=187 IKF=5.0 VAF=66.3

+ISE=1.4E-13 NE=1.41 NR=1.0099 BR=56 IKR=0.9 VAR=33 ISC=1.7E-12

+NC=1.4 RB=1.2 RE=0.020 RC=0.0255 CJC=287E-12 MJC=0.4522

+VJC=0.4956 CJE=1.15E-9 TF=0.83E-9 TR=20E-9

- ZTX851 PNP Device

.MODEL ZTX851 NPN IS =1.0085E-12 NF =1.0001 BF =240 IKF=5.1 VAF=158

\+ ISE=2E-13 NE =1.38 NR =0.9988 BR =110 IKR=5.5 VAR=46

\+ ISC=4.6515E-13 NC =1.334 RB =1.5 RE =0.018 RC =0.015

\+ CJC=155E-12 MJC=0.4348 VJC=0.6477 CJE=1.05E-9

\+ TF =0.79E-9 TR =24E-9

- BF862 JFET

.MODEL BF862 NJF(VTO=-5.083E-1 BETA=3.394E-2 LAMBDA=2.426E-2 IS=1.19E-13 N=1.255 + ISR=3P NR=2 RS=0.5 RD=0.5 BETATCE=-0.5 + VTOTC=-2E-3 ALPHA=1E-3 VK=6.0E2 M=0.6 PB=0.5 + FC=0.5 CGS=9.5P CGD=7.5P KF=8.75E-17 AF=1 + MFG=NXP)

> Attention: The RB specifications for the Zetex devices are not specified in the data sheet. These values were measured by a number of sources on the web and confirmed by various members of the DIY Audio community.

Simulations

- Rgen = 5 Ohms
- Rgen = 10 Ohms
- Measure supply current
- Check Frequency response – only report if anomalous – i.e. 20 Hz-20 kHz +0dB -0.d dB
- Measure distortion

Notes

- An ideal voltage source is used for the power supply since we are only interested in the native noise performance of the different circuits.

Noise Performance of the circuits in pico V/rt Hz

Sorted on Rg = 5 Ohms

Design	5 Ohms	10 Ohms
Weinberg	322	460
James Chadwick	327	462
Archimedes	339	468
Planck	340	466
Newton	353	472
Hawking	373	481
Sommerfeld	378	511
Maxwell	388	502
Heisenberg	408	504
Fermi	459	565
Born	460	560
DeBroglie	470	560
Pauli	470	563
JJ Thompson	480	570
Feynman	483	586
Kip Thorne	490	570
Schrodinger	490	590
Boltzmann	526	612
Julian Schwinger	572	670
Einstein	616	800
Gell-Mann	740	829
Rutherford	758	833
Gamow	804	866
Dirac	1100	1100
Bethe	1116	1240
Faraday	1300	1400
Galilieo	1500	1600
Hugens	2900	3100

These figures include the generator resistance noise – 5 Ohms and 10 Ohms

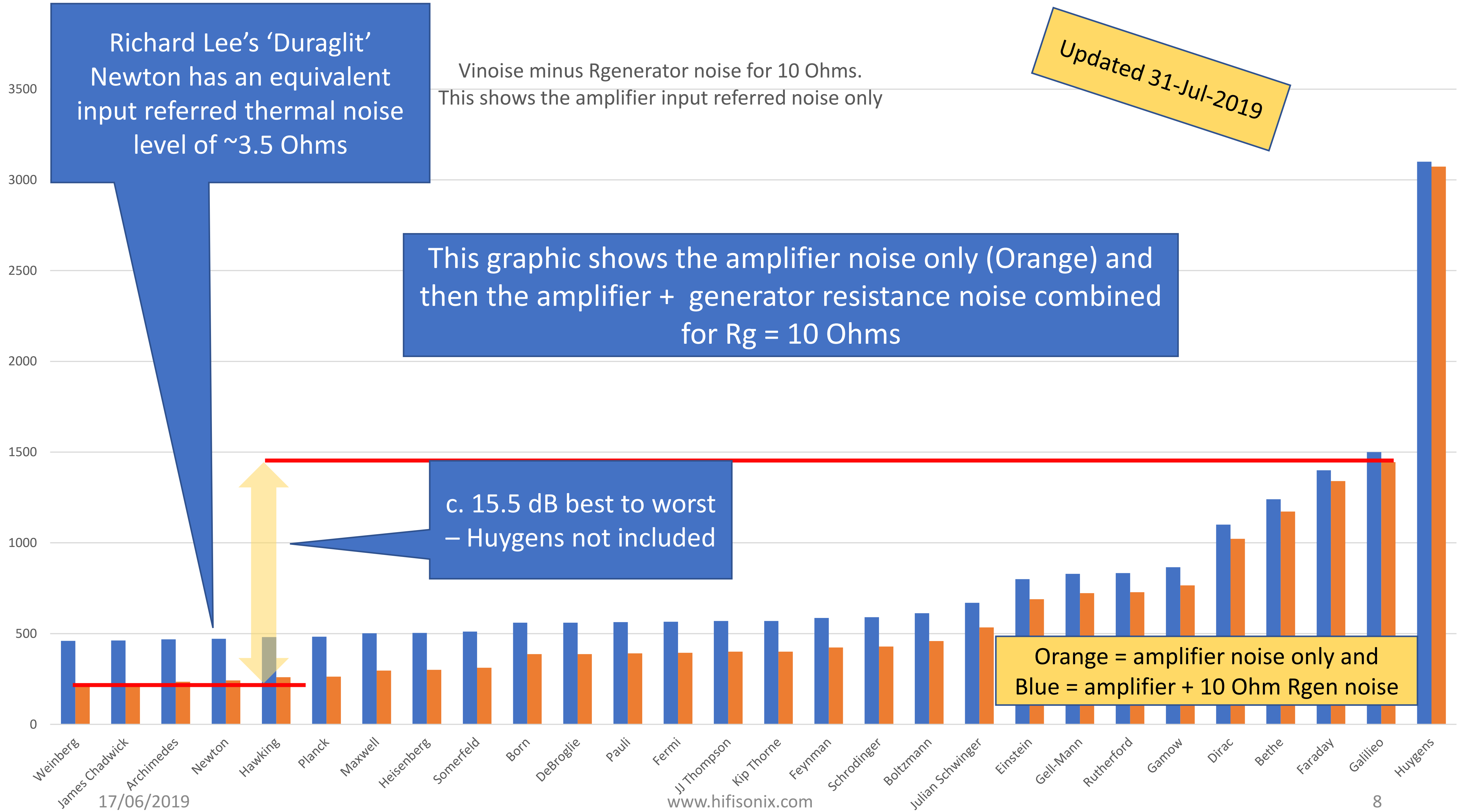
Updated 31-Jul-2019

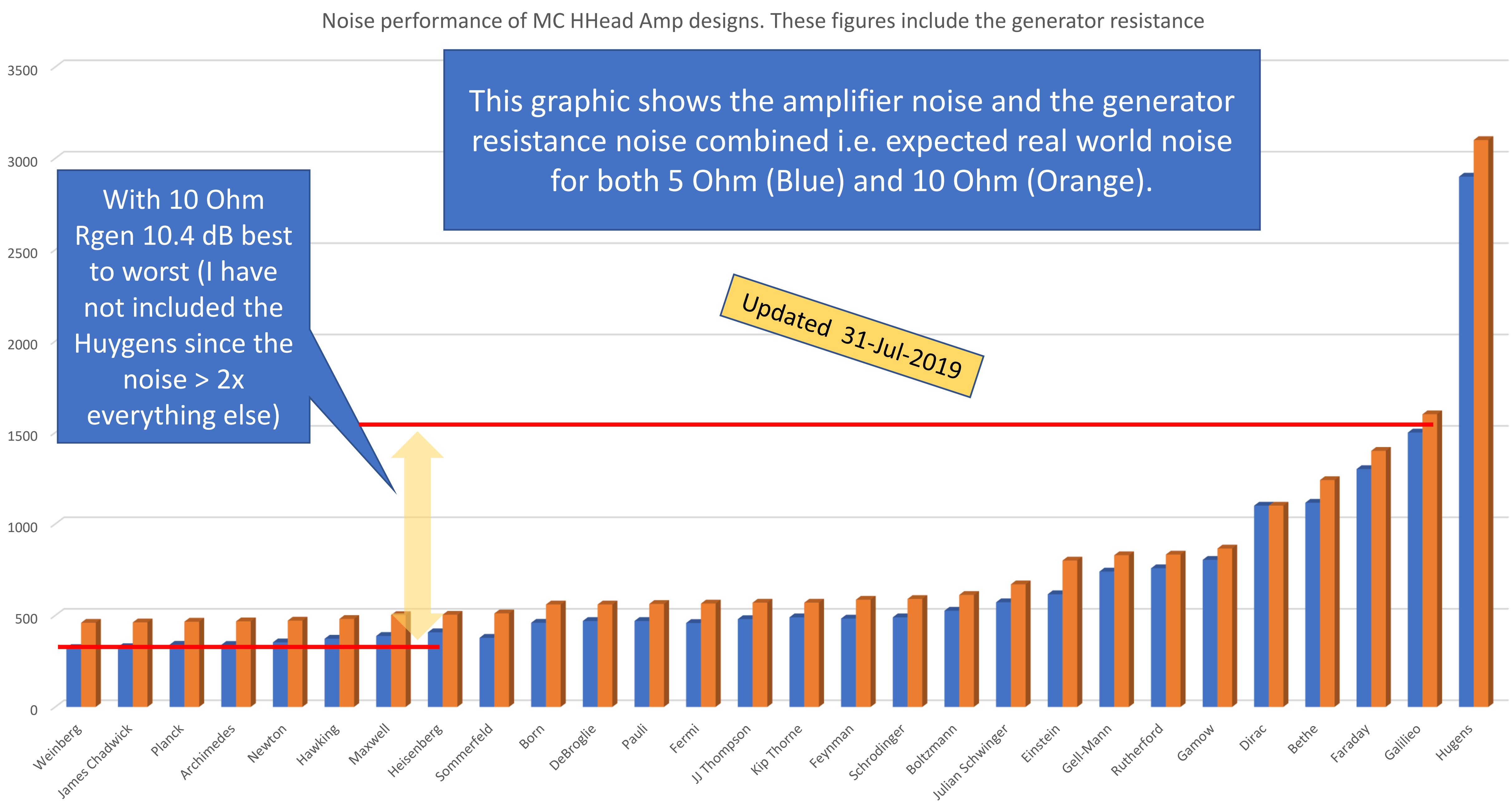
Sorted on Rg = 10 Ohms

Design	5 Ohms	10 Ohms
Weinberg	322	460
James Chadwick	327	462
Planck	340	466
Archimedes	339	468
Newton	353	472
Hawking	373	481
Maxwell	388	502
Heisenberg	408	504
Sommerfeld	378	511
Born	460	560
DeBroglie	470	560
Pauli	470	563
Fermi	459	565
JJ Thompson	480	570
Kip Thorne	490	570
Feynman	483	586
Schrodinger	490	590
Boltzmann	526	612
Julian Schwinger	572	670
Einstein	616	800
Gell-Mann	740	829
Rutherford	758	833
Gamow	804	866
Dirac	1100	1100
Bethe	1116	1240
Faraday	1300	1400
Galilieo	1500	1600
Hugens	2900	3100

Noise Performance

- The difference between the best and the worst in the amplifier only noise (ignoring generator resistance noise) is ~15 dB
- However, when the generator source resistance noise is factored in, the noise differences are less stark and for a 10 Ohm generator resistance, the difference is 10.4 dB.
- As the generator resistance increases, the differences in decrease as the amplifier input referred noise is swamped by the generator resistance noise.
- The next two graphs show the amplifier performance best to worst for both amplifier noise only and the 'real world' noise including the generator resistance.


Richard Lee's 'Duraglit' Newton has an equivalent input referred thermal noise level of ~3.5 Ohms
Vinoise minus Rgenerator noise for 10 Ohms.
This shows the amplifier input referred noise only
Updated 31-Jul-2019
This graphic shows the amplifier noise only (Orange) and then the amplifier + generator resistance noise combined for Rg = 10 Ohms
c. 15.5 dB best to worst – Huygens not included
Orange = amplifier noise only and
Blue = amplifier + 10 Ohm Rgen noise
3500
3000
2500
2000
1500
1000
500
0
Weinberg
James Chadwick
Archimedes
Newton
Hawking
Planck
Maxwell
Heisenberg
Somerfeld
Born
DeBroglie
Pauli
Fermi
JJ Thompson
Kip Thorne
Feynman
Schrodinger
Boltzmann
Julian Schwinger
Einstein
Gell-Mann
Rutherford
Gamow
Dirac
Bethe
Faraday
Gallileo
Huygens


Noise performance of MC HHead Amp designs. These figures include the generator resistance
This graphic shows the amplifier noise and the generator resistance noise combined i.e. expected real world noise for both 5 Ohm (Blue) and 10 Ohm (Orange).
With 10 Ohm Rgen 10.4 dB best to worst (I have not included the Huygens since the noise > 2x everything else)
Updated 31-Jul-2019
3500
3000
2500
2000
1500
1000
500
0
Weinberg
James Chadwick
Planck
Archimedes
Newton
Hawking
Maxwell
Heisenberg
Sommerfeld
Born
DeBroglie
Pauli
Fermi
JJ Thompson
Kip Thorne
Feynman
Schrodinger
Boltzmann
Julian Schwinger
Einstein
Gell-Mann
Rutherford
Gamow
Dirac
Bethe
Faraday
Gallileo
Hugens
5 Ohms
10 Ohms

Noise – how source and amplifier noise add (1)

1. On the next slide is a table that shows how the amplifier noise and the source resistance noise add.
2. Select your total amplifier equivalent noise resistance on the y axis, your source resistance on the x axis and the intersection is the total equivalent input noise. Note: you must manually compute any noise current terms and add them to the voltage noise in RMS fashion – but note that for the simple circuits shown here, you can for the most part ignore current input noise.
3. What is immediately apparent from this is that having an amplifier that is much quieter than the source resistance gives little benefit.

   - For example, if the source resistance is 40 Ohms, a very quiet amplifier with an equivalent input noise voltage of 3.5 Ohms (something like the Hawking designed by Richard Lee in the presentation above) offers only about 1/3rd lower total system noise (0.83nV/rt Hz) noise than an amplifier with an equivalent input noise of 40 Ohms i.e. 1.15 nV/rt Hz.

   - On the other hand, if the source resistance is just 2 Ohms, but the amplifier equivalent noise resistance is 40 Ohms (akin to a JFET input stage), the difference is far more marked and the total system noise will be about 3.2x worse than the source resistance noise - .256 nV/rt Hz versus 0.83 nV/rt Hz.

4. So, as a general rule we can say:- If the amplifier equivalent noise resistance is not more than ~√2 the source resistance noise, it will be just audible since the human ear cannot discern changes of <1.5dB in power level.

Noise – how source and amplifier noise add 2

Generator Source Resistance

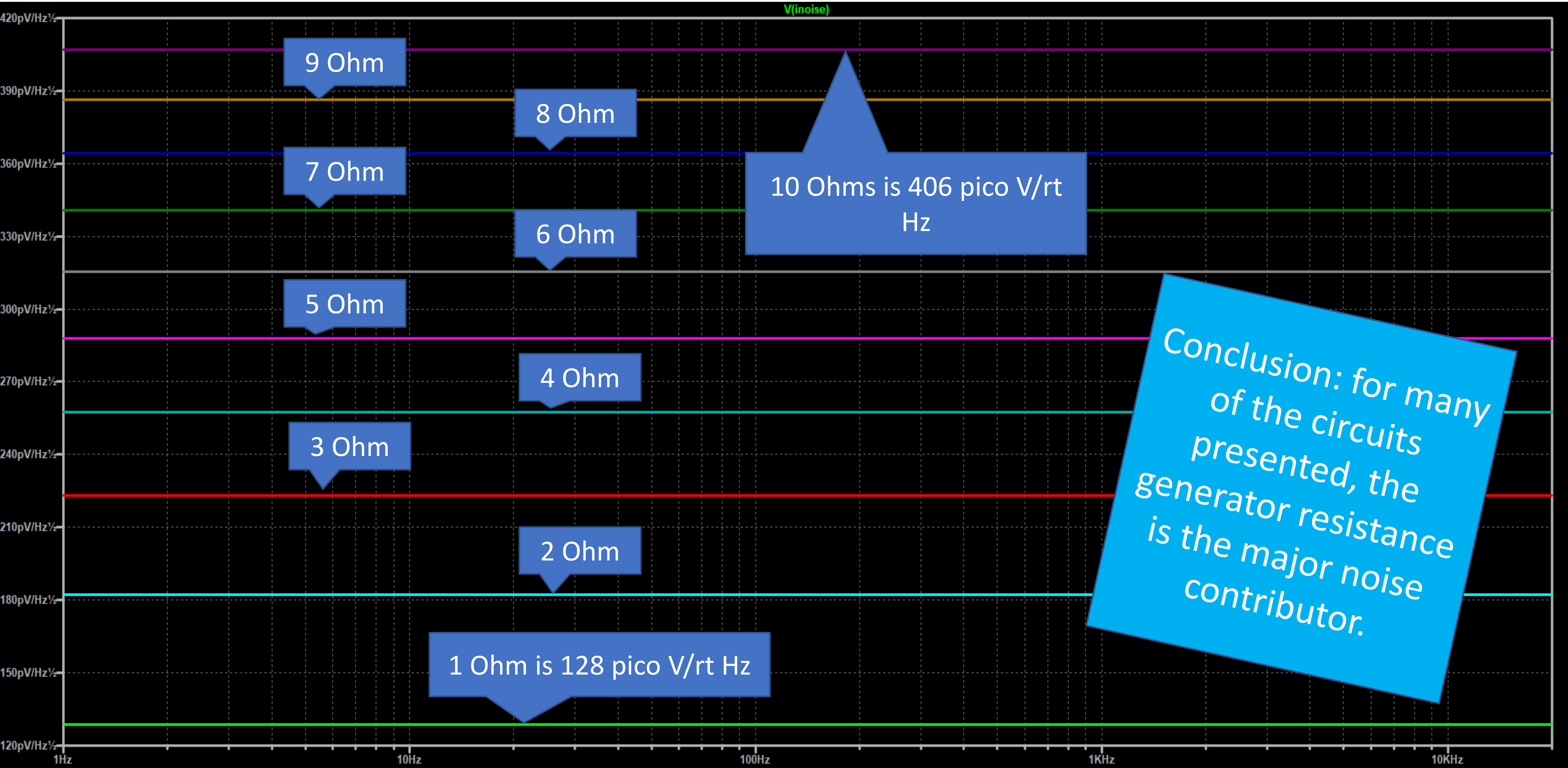
Total* Equivalent Amplifier Noise Resistance

	2	4	6	10	20	40
2	2.56E-10	3.14E-10	3.62E-10	4.44E-10	6.01E-10	8.30E-10
4	3.14E-10	3.62E-10	4.05E-10	4.79E-10	6.27E-10	8.49E-10
6	3.62E-10	4.05E-10	4.44E-10	5.12E-10	6.53E-10	8.68E-10
10	4.44E-10	4.79E-10	5.12E-10	5.73E-10	7.01E-10	9.05E-10
20	6.01E-10	6.27E-10	6.53E-10	7.01E-10	8.10E-10	9.92E-10
40	8.30E-10	8.49E-10	8.68E-10	9.05E-10	9.92E-10	1.15E-09
60	1.01E-09	1.02E-09	1.04E-09	1.07E-09	1.15E-09	1.28E-09

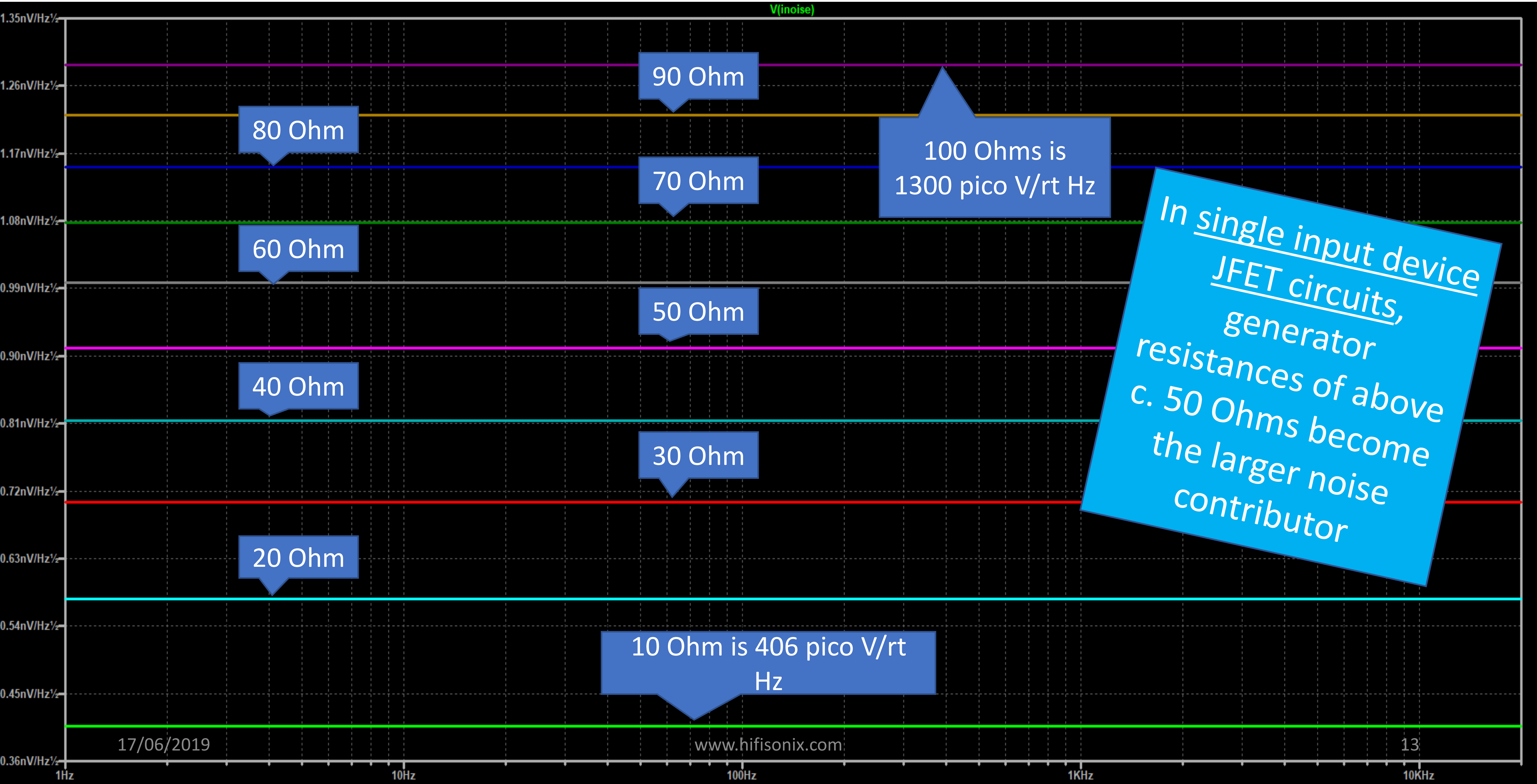
All figures are Volts/rt Hz

*Total equivalent noise = $\sqrt{(Inoise*Rs)^2 + Vnoise^2}$

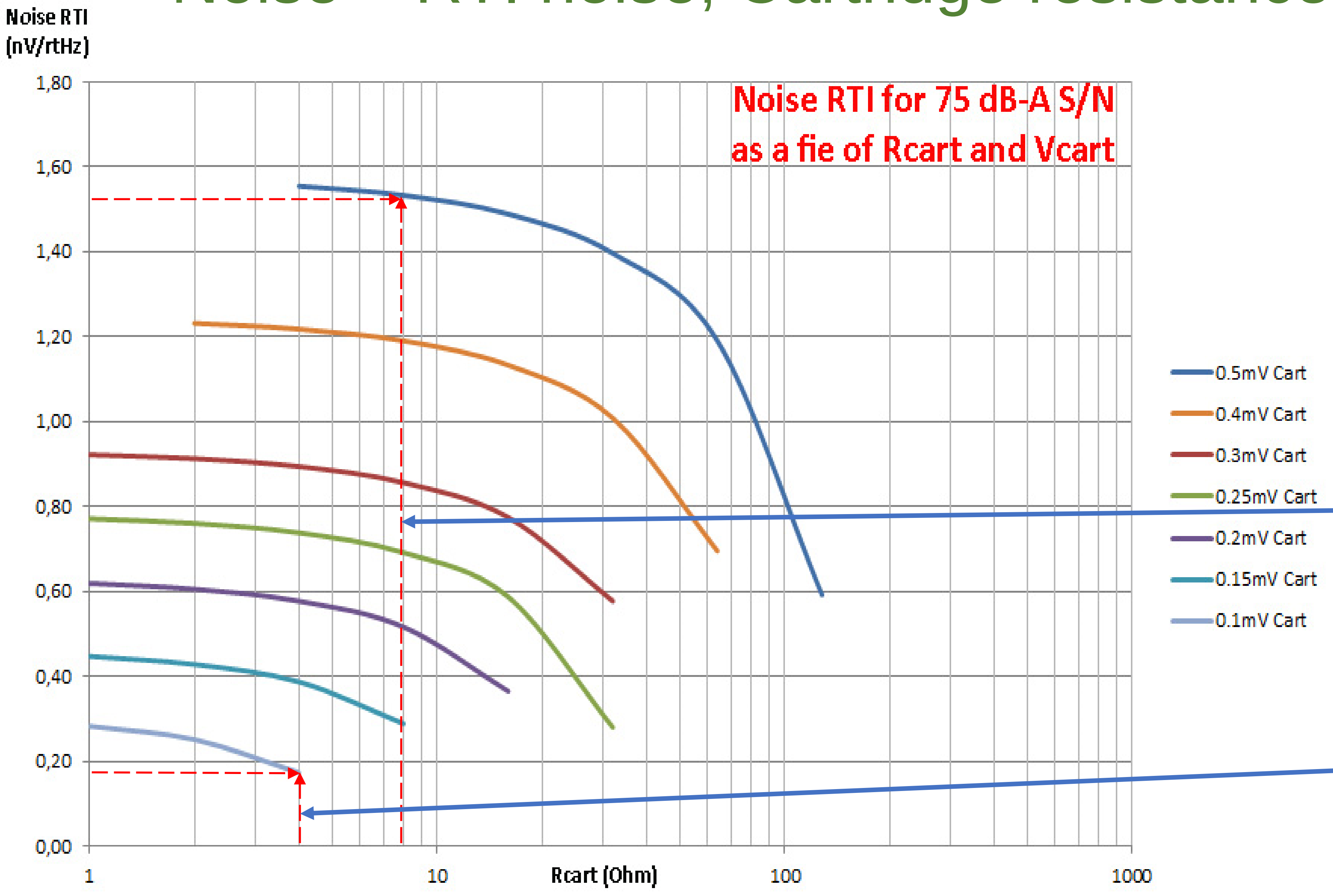
Reference: Resistor Noise Only – 1 to 10 Ohms



Reference: Resistor Noise Only – 10 to 100 Ohms



Noise – RTI noise, Cartridge resistance and Output



This graph by DIY Audio Member *Hans Polak* shows what the Referred To Input (RTI) total noise has to be *equal to or lower* to achieve a S/N ratio of 75 dB for a range of cartridge outputs and their associated generator resistances.

For example, with a cartridge resistance of **8 ohms**, as long as the total RTI input is less than ~1.5nV/rt Hz and the cartridge output is 0.5mV or more, you are good to go. If your cartridge is only 0.1mV output, the cartridge resistance cannot be higher than **3 Ohms** and the total RTI noise no higher than ~180 pico V/rt Hz

The following section presents sim results of a range of MC Head Amplifier circuits

All the designs are named after famous physicists so if you want to discuss a circuit, just refer to its 'physicist' name*.

No attempt has been made to provide loop compensation in the designs where feedback is employed (other than the Galileo which has been built and tested) – this is left up to the reader to investigate (the LTspice XII files are available on the hifisonix.com website on the same page this file is located at). The primary focus of this investigation is to look at noise, current consumption and distortion.

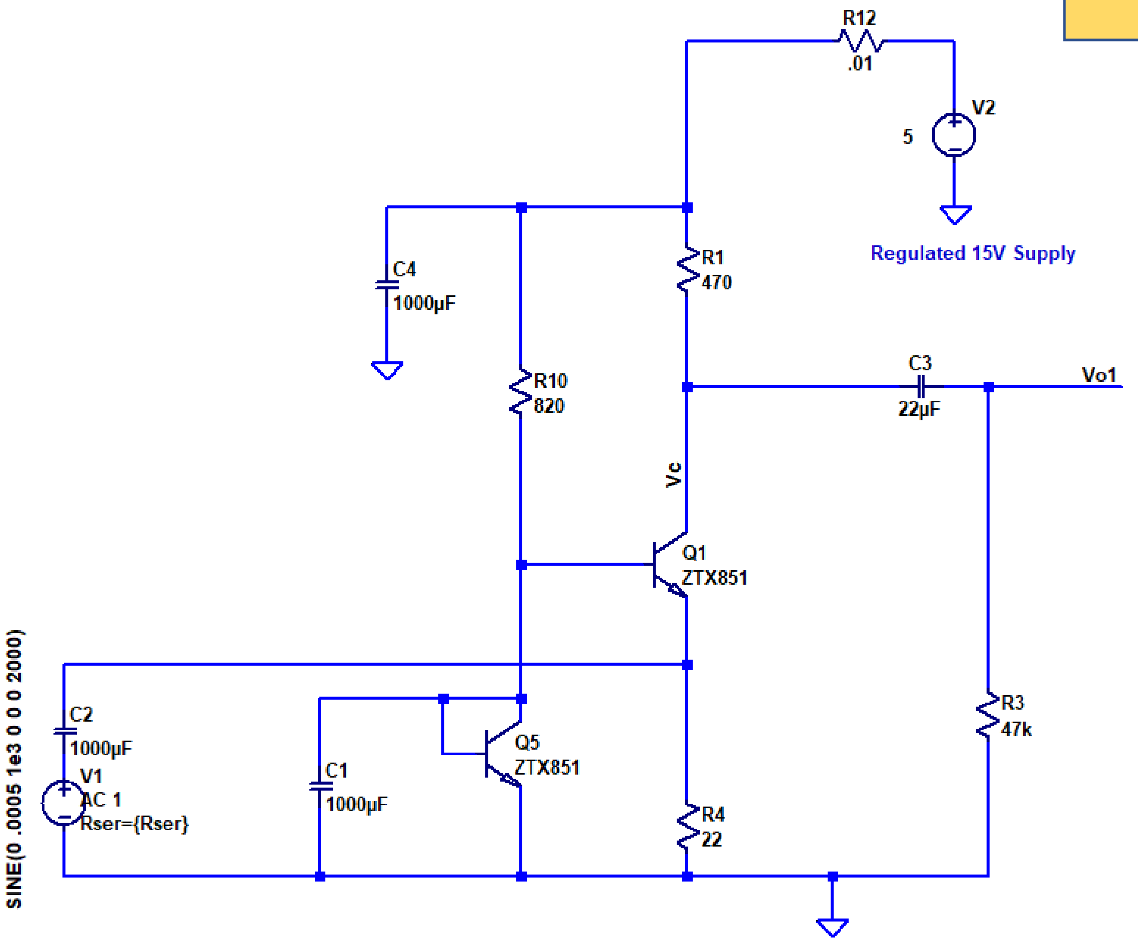
***You can read about these scientists by clicking on the link on the bottom RHS corner**

Simple Single Ended Open Loop Designs

Einstein MC Pre - 616/800 pico V/rt Hz

1/f corner < 10 Hz; current draw c. ~8.5 mA per channel; distortion c. 0.25% @ 20kHz;
4Hz to 2MHz +0dB -3 dB; -1.5 dB at 20 Hz Gain Varies with Generator coil resistance

In all the simulations that follow, the quoted noise INCLUDES the generator resistance noise i.e. it is the real world noise for the circuit with a 5 Ohm and then a 10 Ohm generator resistance




```
.four 1k V(Vo1)
.param plotwinsize = 0
.param numdgt = 15
.noise V(vo1) v1 dec 100 10 20E3
;ac dec 100 1 1000E6
;tran 0 10e-3 2e-3 1e-6
.step param Rser 5 10 5
```

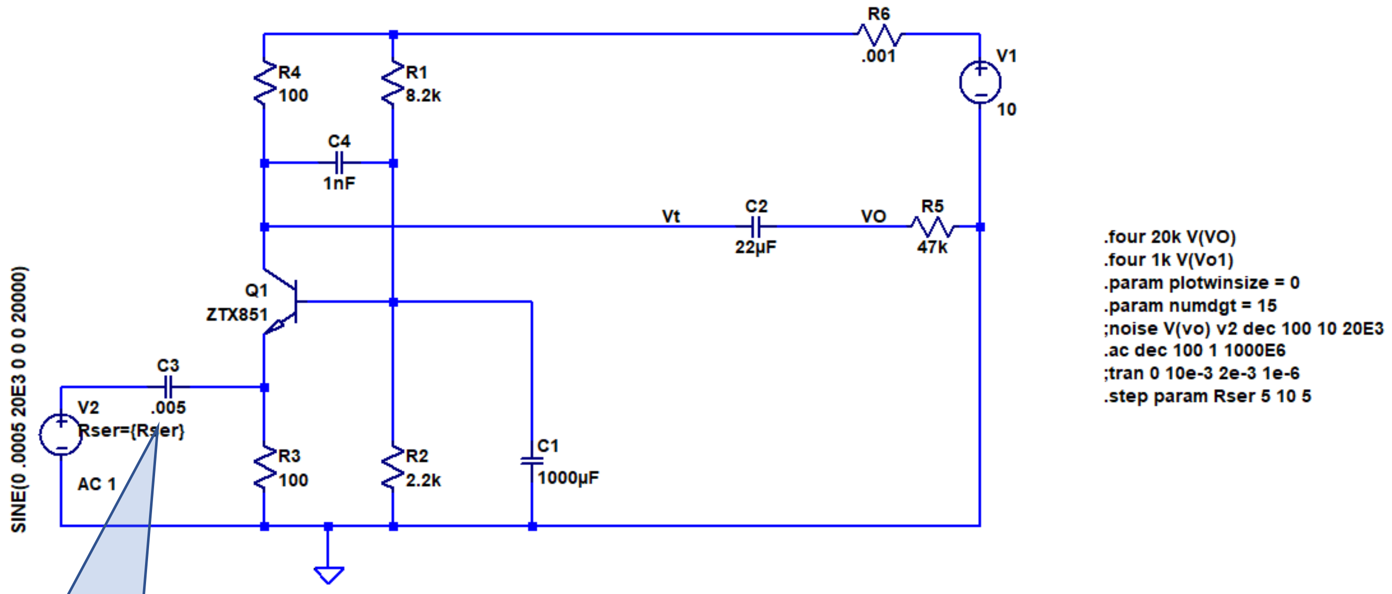
A very simple circuit with good noise performance. Adjust the value of R10 for 3~4mA through R1

https://en.wikipedia.org/wiki/Albert_Einstein

'Maxwell' ultra simple MC Preamp; Distortion 0.033%; Noise 370/509 pico V/rt Hz Isupply = 15mA; -0.5 dB at 20 Hz - requires LARGE C3; Zin is LOW

Gain varies with generator resistance

AV = ~14x



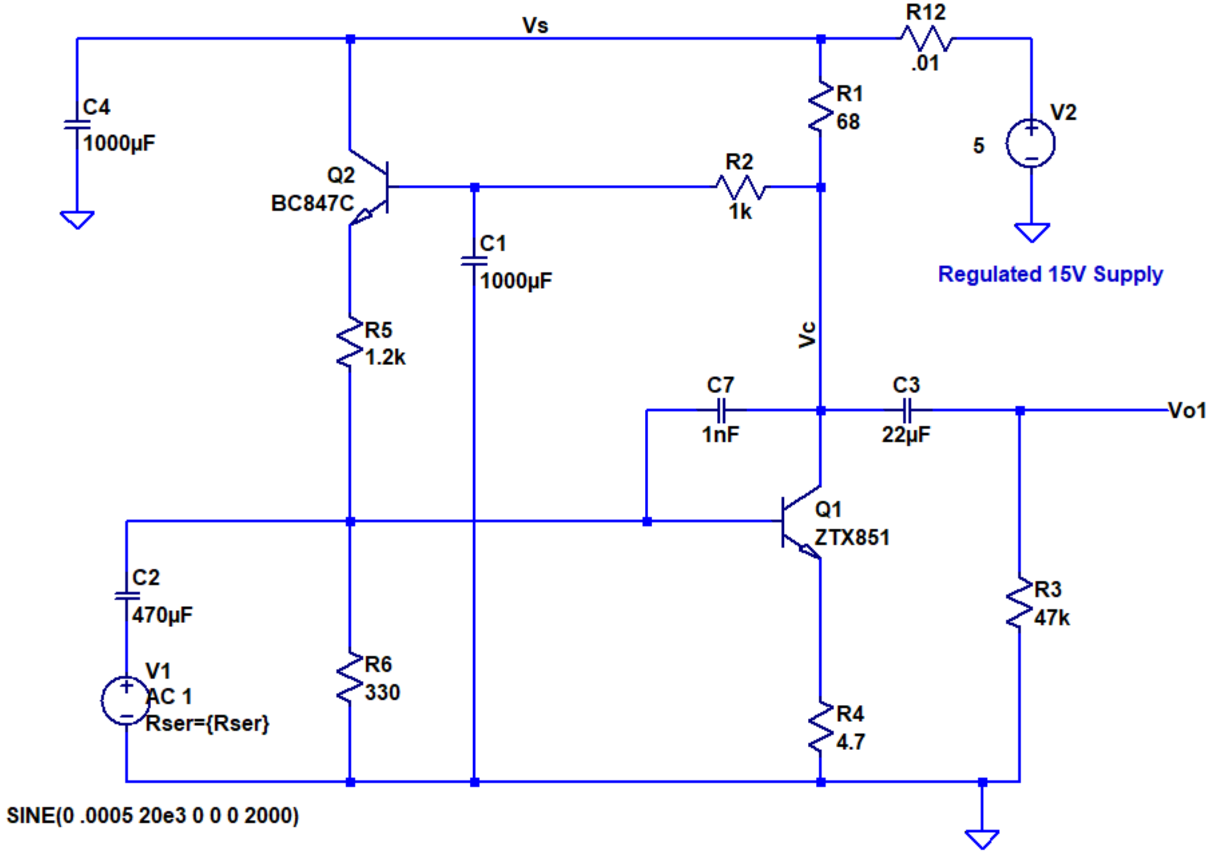
Large electrolytic

Very simple circuit with good noise and distortion performance. Use a 4700uF 10V capacitor for C3

https://en.wikipedia.org/wiki/James_Clerk_Maxwell

Pauli low noise MC preamplifier 470/563 picoV/rt Hz @ 1kHz

1/f corner < 10 Hz; current draw c. 18mA per channel; distortion c. 0.03% @ 20kHz;
2Hz to 2MHz +0dB -3 dB; based on a mic pre from AoE - Horowitz and Hill page 506 3rd Ed



Simple, low noise amplifier with very good performance

.four 20k V(V
.param plotwinsize =
.param numdgt = 15
.noise V(vo1) v1 dec 100 1 20E3
;ac dec 100 1 100E6
.step param Rser 5 10 5

;tran 0 10e-3 2e-3 1e-7

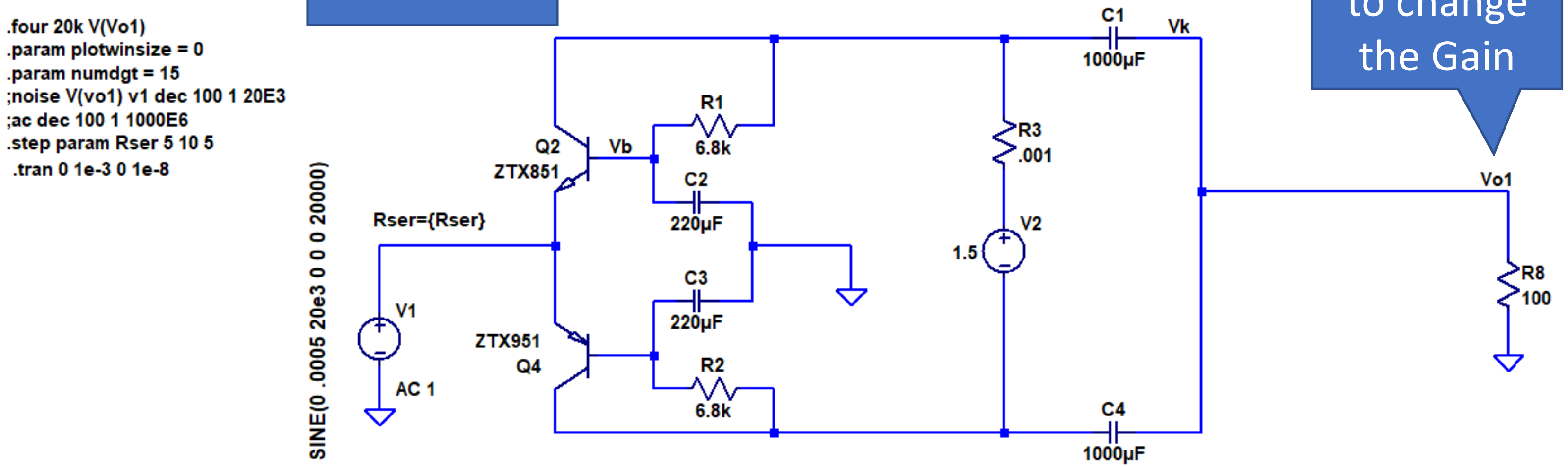
https://en.wikipedia.org/wiki/Wolfgang_Pauli

Simple Balanced Open Loop Designs

'Hawking' 373/481 pico Volts/rt Hz ; Current supply ~5mA; Gain varies with generator source resistance; distortion 0.0068%

AV = ~12x

Adjust the value of R8 to change the Gain



Richard Lee's 'Duraglit Special' design from circa 1980; Note this is battery powered; suits low output, low cartridge coil resistance

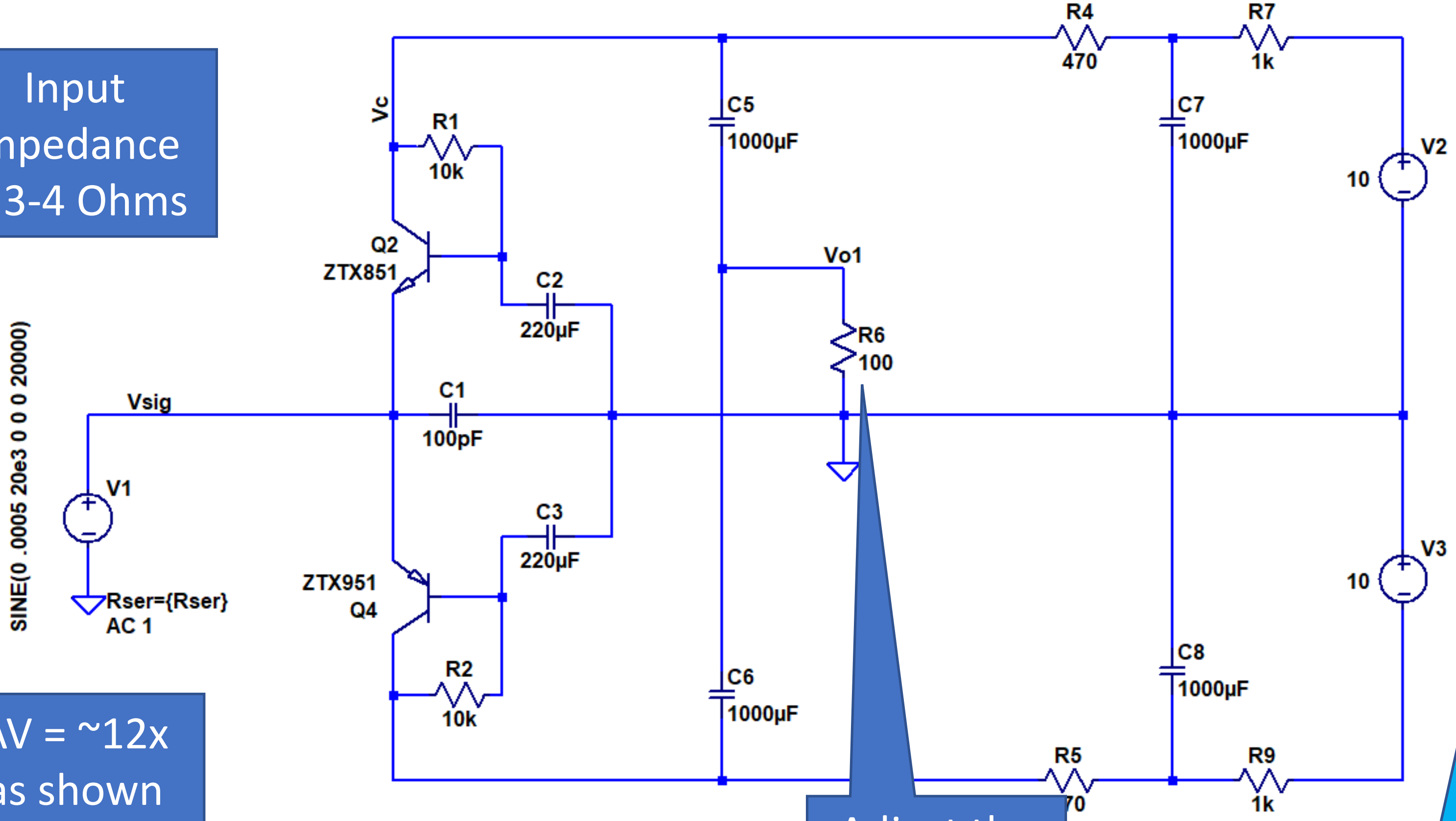
C1 and C4 are set at 1000uF to ensure that the total load (C1, C4 and R8) remains flat down to very low frequencies to avoid LF gain peaking (in this case the -3dB frequency is 1.5 Hz). This applies to all the 'Duraglit' derivatives that follow

https://en.wikipedia.org/wiki/Stephen_Hawking

Newton after Richard Lee's Complementary MC Phono Pre - 353/472 pico V/rt Hz

Isupply c. 6.5mA per rail; distortion c. 0.015% @ 20kHz; 0.5~ 2MHz +0dB -3 dB; Gain Varies with Generator coil resistance.
The ZTX951/851 devices shown offer the best rbb' currently (2019) avaiable and will yield lowest noise voltages
(notes provided by designer R. Lee - updated 23-06-2019).

Input impedance c. 3-4 Ohms



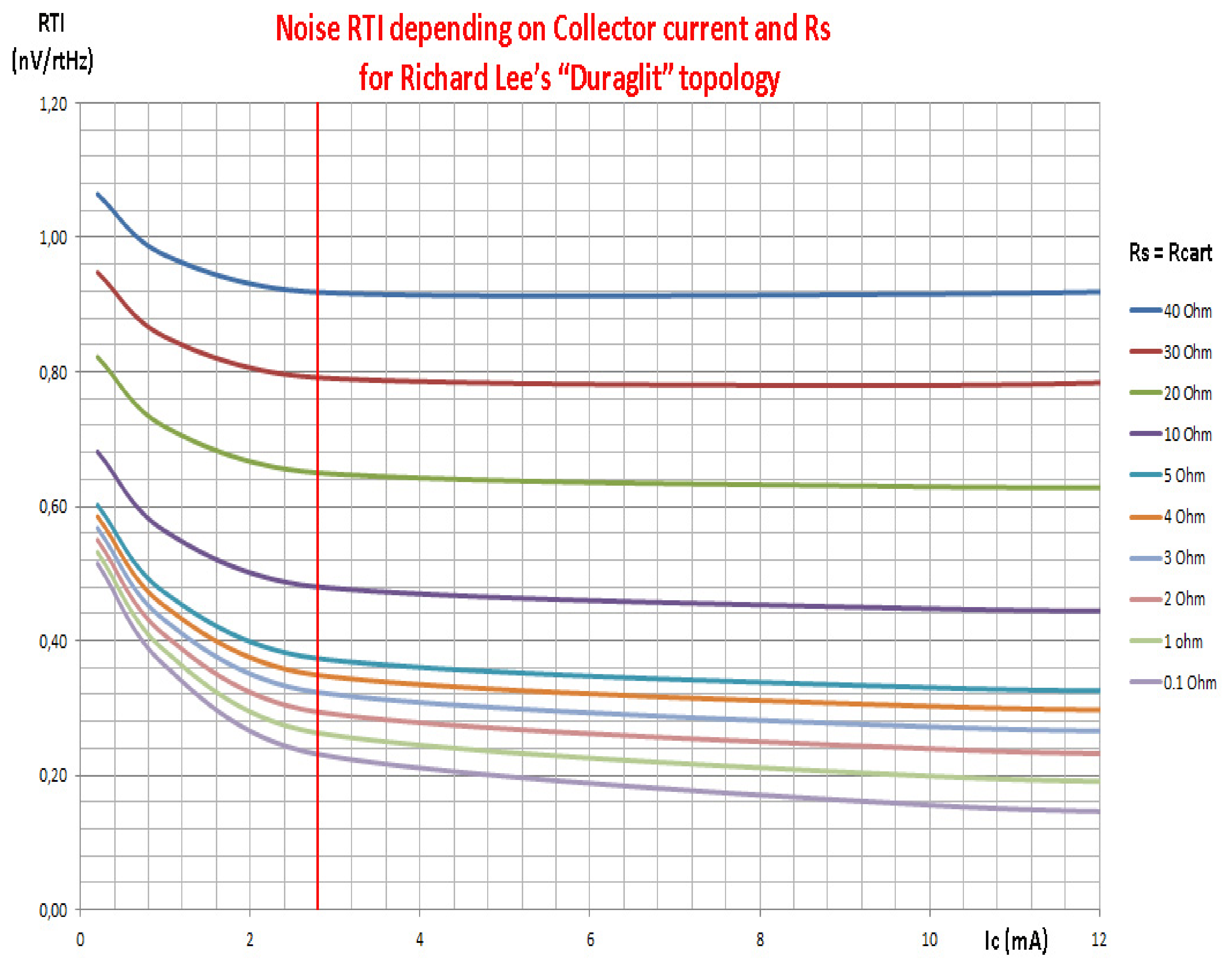
AV = ~12x as shown

Circuit value re-optimized for lowest noise 23 Jul 2019

Adjust the value of R6 to change the Gain

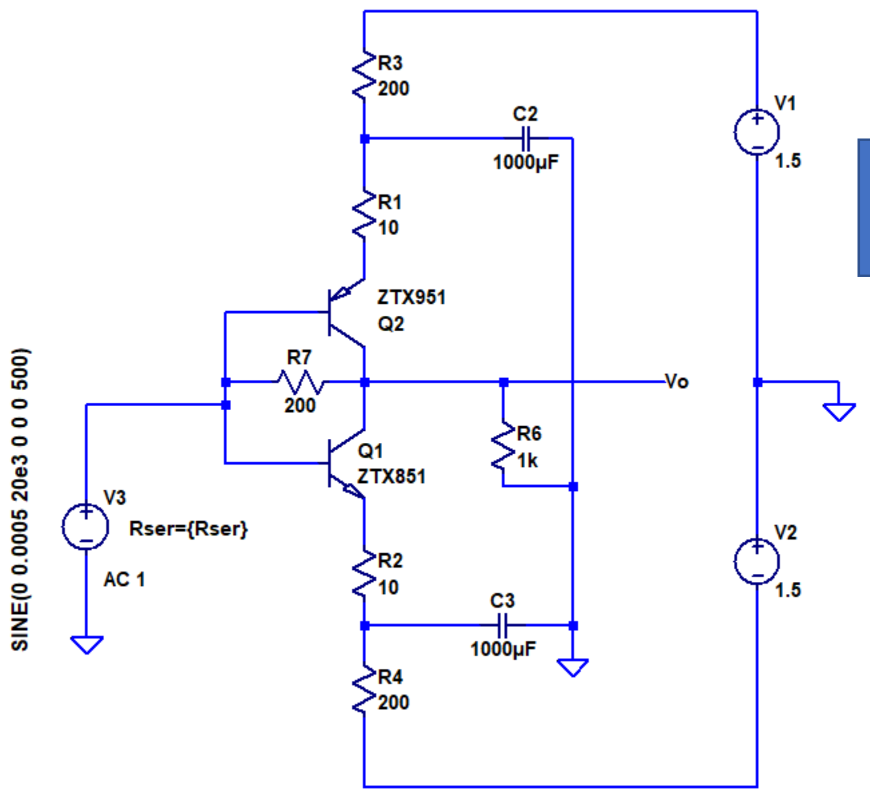
Ultra simple very high performance MC amp – best 'bang for buck' design of the lot; powered off +-10 V rails; optimized for 3~4 Ohm cart resistances. Amplifier only noise is c. 242 pV/rt Hz. With Rgenerator = 3 Ohms. ***total*** noise is 292 pV/rt Hz

https://en.wikipedia.org/wiki/Isaac_Newton



DIY Audio member *Hans Polak's* graphic showing how noise performance of the two previous Richard Lee designs varies with collector current and cartridge generator coil resistance. For all of the cartridge coil resistances, best performance starts with Ic at c. 2.5-3mA with little to be gained in real terms beyond that in higher generator resistance cartridges. For very low generator resistance cartridges (say <5 Ohms), increasing Ic by 3x to 4x will bring some added noise performance improvement

The Schrodinger MC Head Amp (after John Curl); noise 490/590 pico Volt/rt Hz; distortion 12ppm/15ppm; Isupply ~4mA per rail



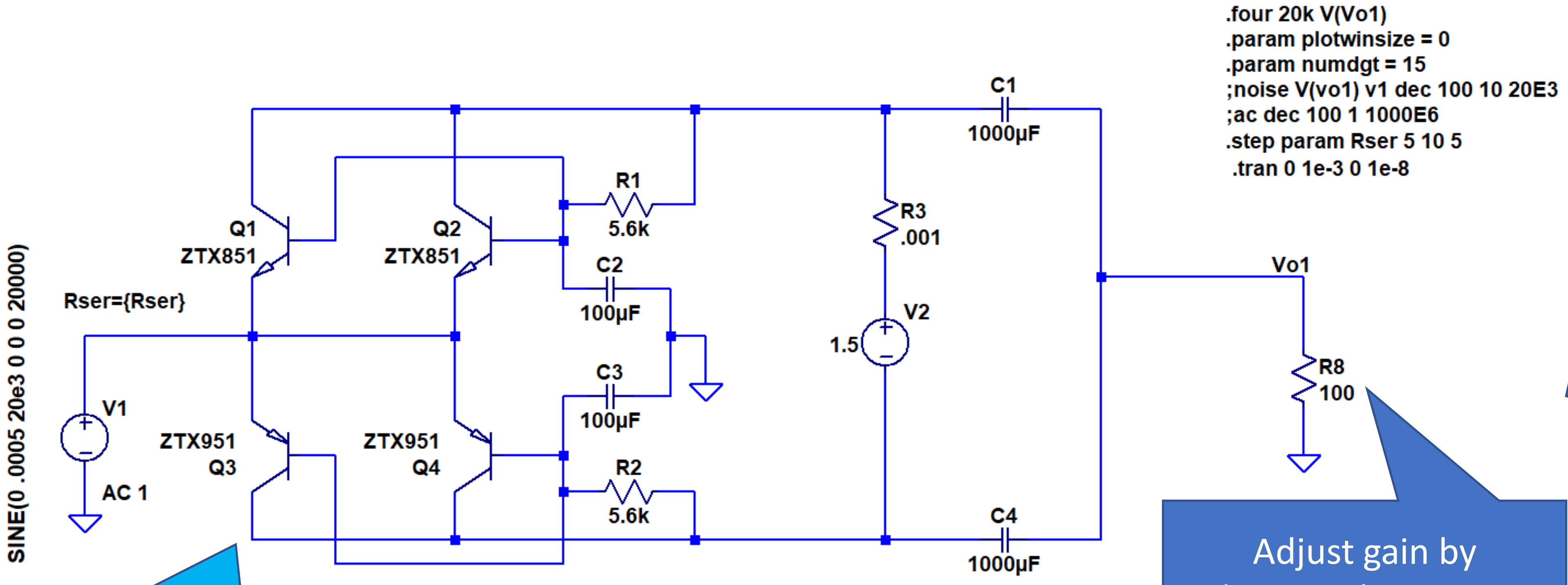
AV = ~12x. Adjust R6 to change gain

```
.four 20k V(VO)
.four 1k V(Vo1)
.param plotwinsize = 0
.param numdgt = 15
.noise V(vo) v3 dec 100 10 20E3
;ac dec 100 1 1000E6
;tran 0 10e-3 2e-3 1e-6
.step param Rser 5 10 5
```

Simple, low power 'current input' virtual earth circuit with good noise performance

https://en.wikipedia.org/wiki/Erwin_Schrödinger

Planck Battery Powered MC Phono Pre; distortion 0.007% noise 340/466 pico V/rt Hz; Current supply ~6.5mA; Gain varies with generator source resistance.



Design developed from the Lee/Leach designs

Match all 4 transistor Vbe’s to better than 1mV

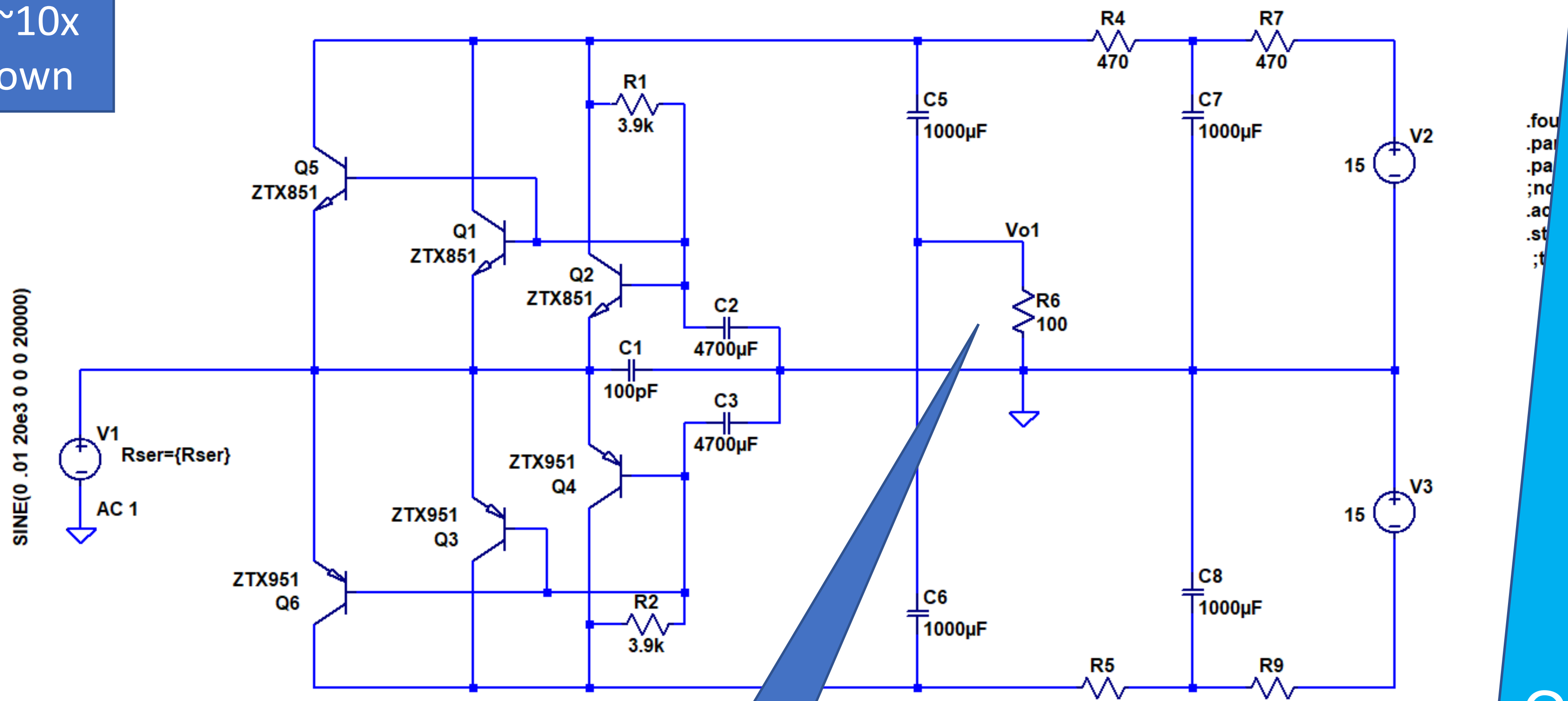
Adjust gain by adjusting this resistor. For the values shown, the gain is 14x (5 Ohm Rg)

https://en.wikipedia.org/wiki/Max_Planck

Weinberg Paralleled Complementary MC Phono Pre - 322/460 pico V/rt Hz

15mA current draw per rail; distortion .035%; gain varies with generator resistance

AV = ~10x as shown



A challenging design that will require all 6 transistor Vbe's to be matched to within 1mV but will yield the lowest overall noise. With Rgenerator = 3 Ohms, ***total*** noise is 255 pV/rt Hz

Adjust the value of R6 to change the Gain

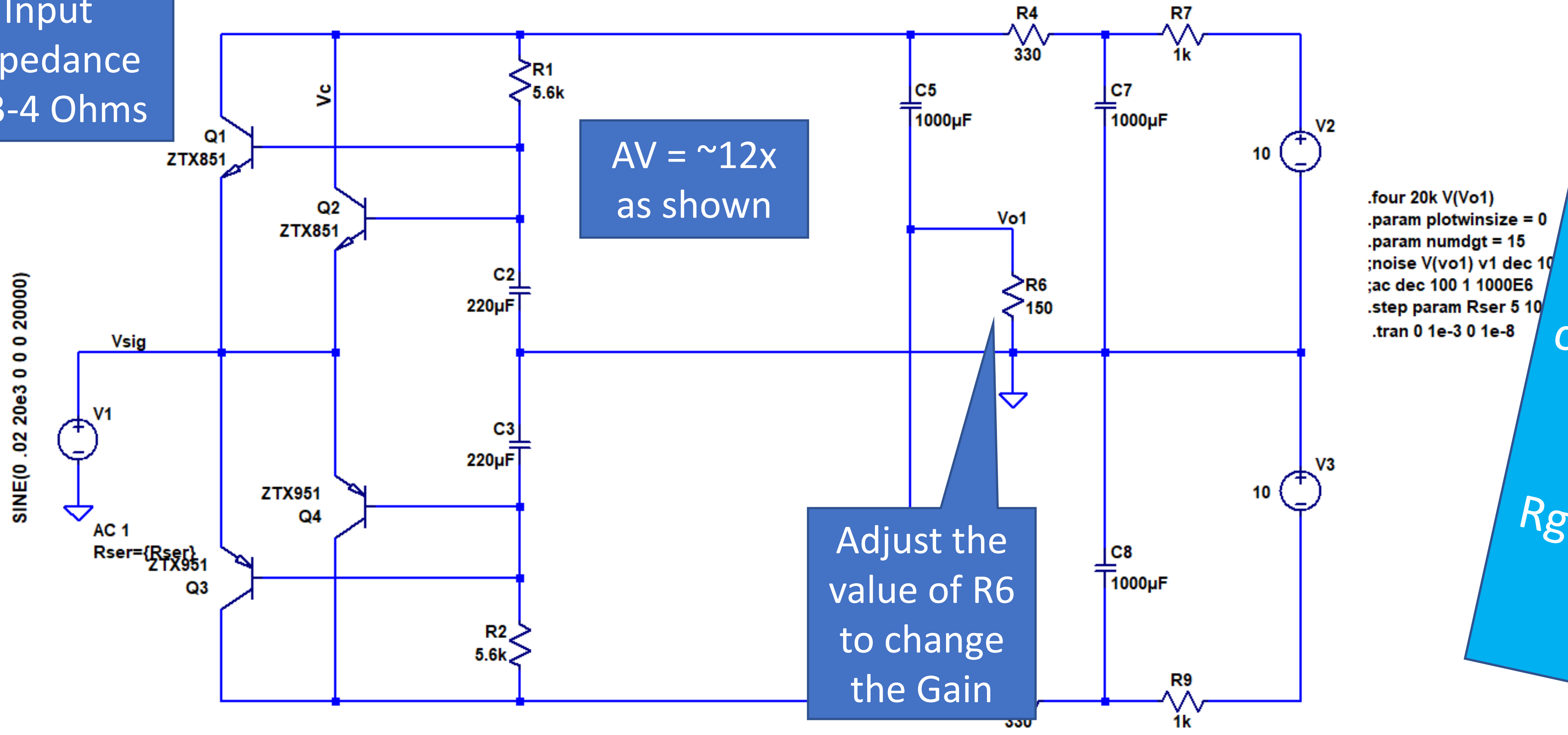
Match the transistor Vbe's to < 1mV

https://en.wikipedia.org/wiki/Steven_Weinberg

Archimedes after Richard Lee's Complementary MC Phono Pre - 353/472 pico V/rt Hz

Isupply c. 6.5mA per rail; distortion c. 0.017% @ 20kHz; 0.5~ 2MHz +0dB -3 dB;
Gain Varies with Generator coil resistance.

Input impedance c. 3-4 Ohms



AV = ~12x as shown

Adjust the value of R6 to change the Gain

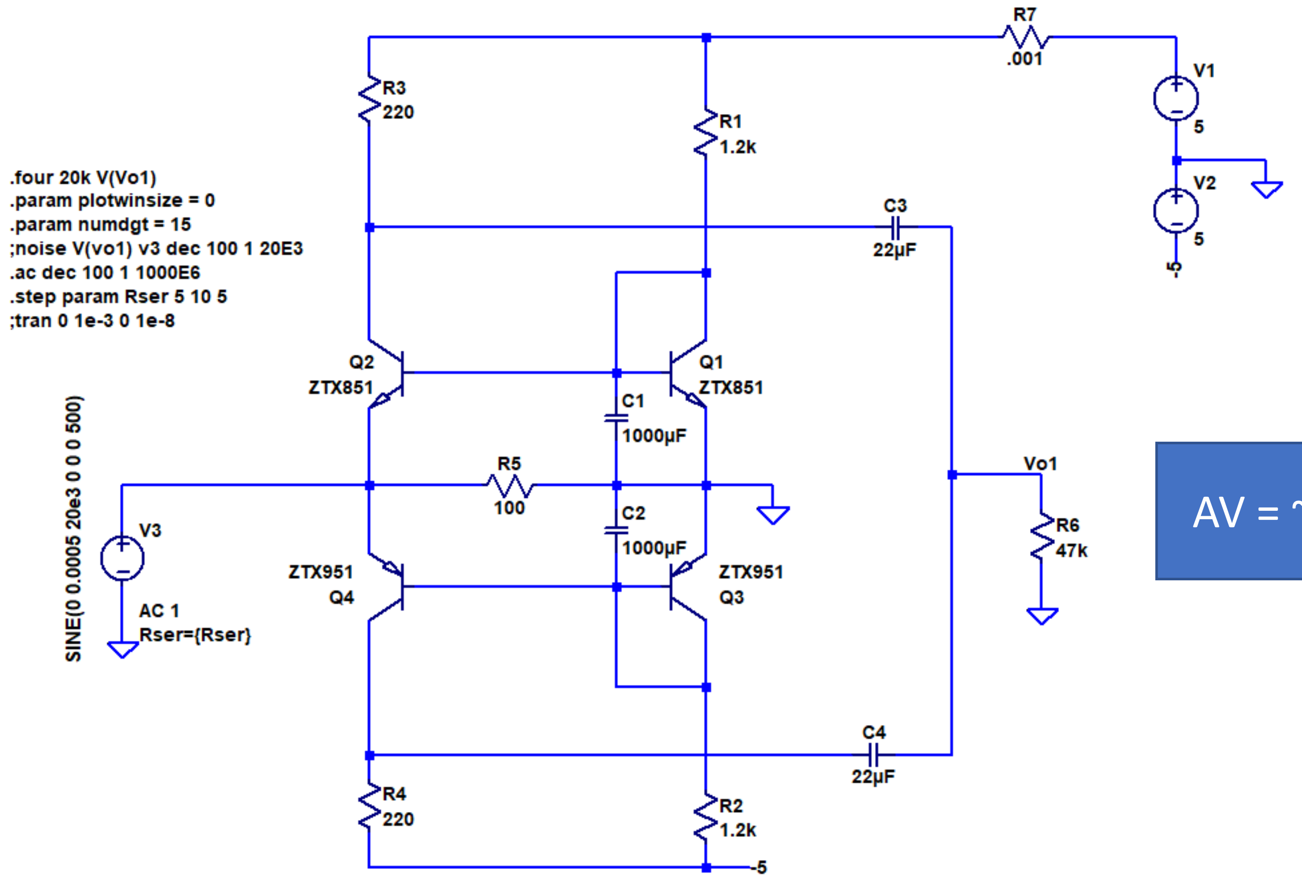
A further development of the 'Newton'. Parallel transistor pairs offer a further slight noise reduction. Amplifier only noise contribution is c. 239 pV/rt Hz and ***total*** noise with Rgenerator = 3 Ohms is 277 pV/rt Hz

Match the transistor Vbe's to < 1mV

www.hifis

https://en.wikipedia.org/wiki/Archimedes

Sommerfeld MC Head Amp (after Jean Hiraga); distortion 0.048/0.08% Isupply 7.5mA; noise 378/511 pico V/rt Hz



AV = ~12x

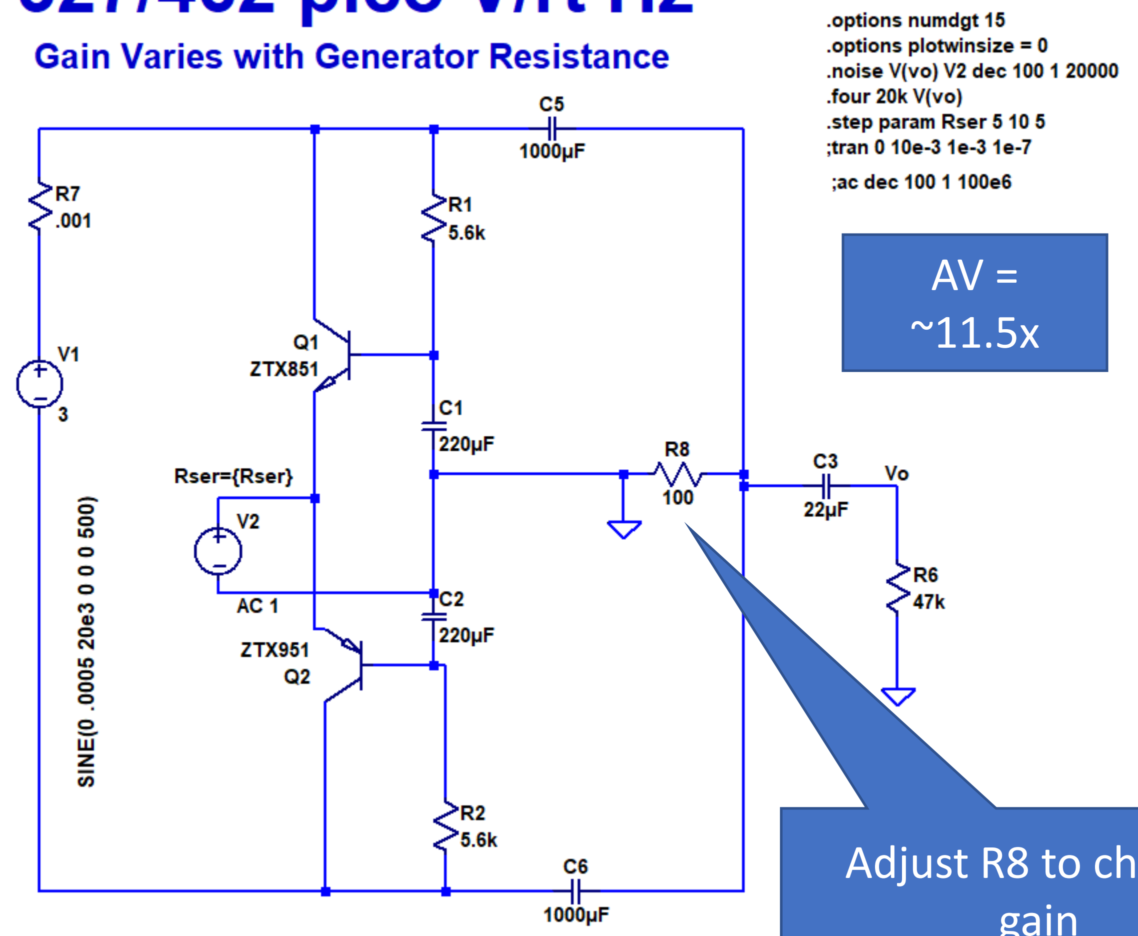
Another very simple circuit with good noise performance. Adjust the value of R1 & R2 for 3~ 4mA through R3 and R4

Adjust value of R3 and R4 to adjust gain; gain varies with generator resistance

https://en.wikipedia.org/wiki/Arnold_Sommerfeld

James Chadwick MC Head Amp; 0.0002% distortion; Isupply = 30mA 327/462 pico V/rt Hz

Gain Varies with Generator Resistance



AV = ~11.5x

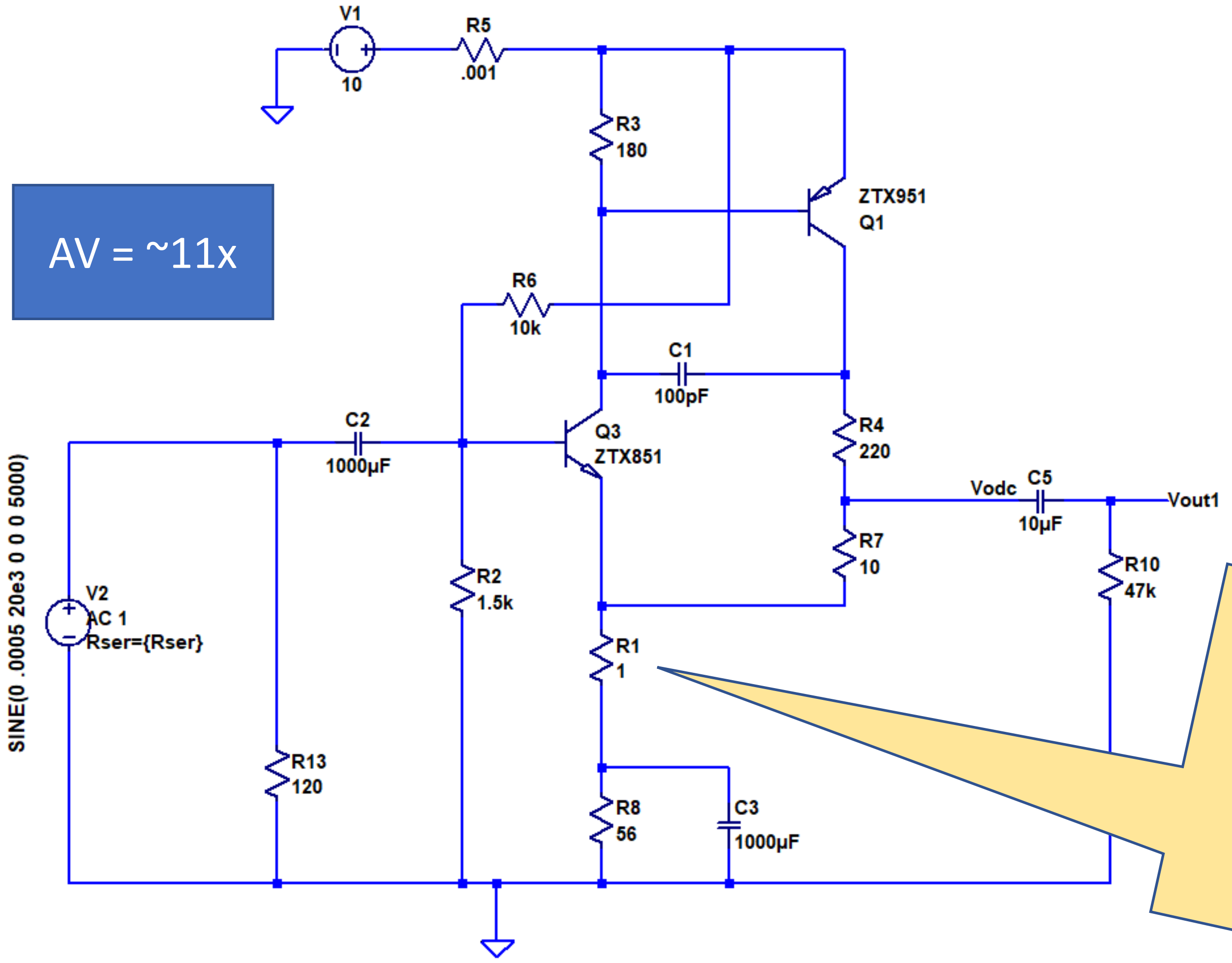
Adjust R8 to change gain

3V battery powered; Ultra low distortion at 2ppm and improved dynamic range – will swing to +-0.9V with <0.04% distortion at 20 kHz

https://en.wikipedia.org/wiki/James_Chadwick

Bipolar Designs With Feedback

Born MC Phono pre; distortion 0.13%; Noise 460/560 pico V/rt Hz; Isupply = 14mA




```
.options plotwinsize = 0
.options numdgt = 15

.four 20k V(Vout1)
.param plotwinsize = 0
.param numdgt = 15

;ac dec 100 1 100e6
;noise V(vout1) V2 dec 100 1 100e3
.step param Rser 5 10 5

.tran 0 1e-3 100e-6 1e-8
```

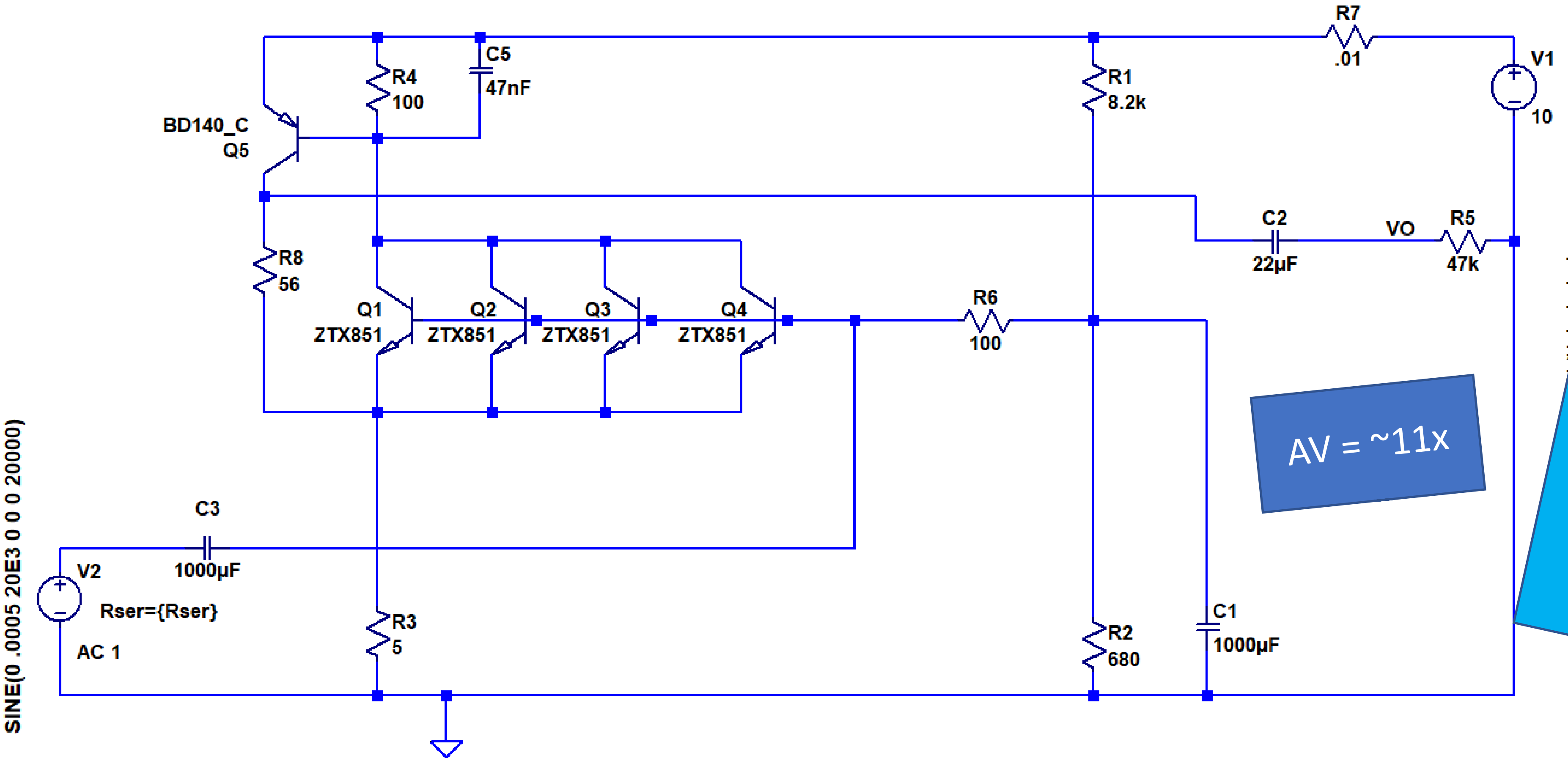
Simple with good performance.

In all of these simple designs with emitter (or source) feedback, the amplifier noise is usually dominated by this resistor.

https://en.wikipedia.org/wiki/Max_Born

'Feynman' MC Pre; 0.01% distortion; Isupply = 44mA; noise = 489/590 picoV/rt Hz; -1 dB at 20 Hz

The gain varies with generator coil resistance. Distortion is primarily 2nds with a bit of 3rds

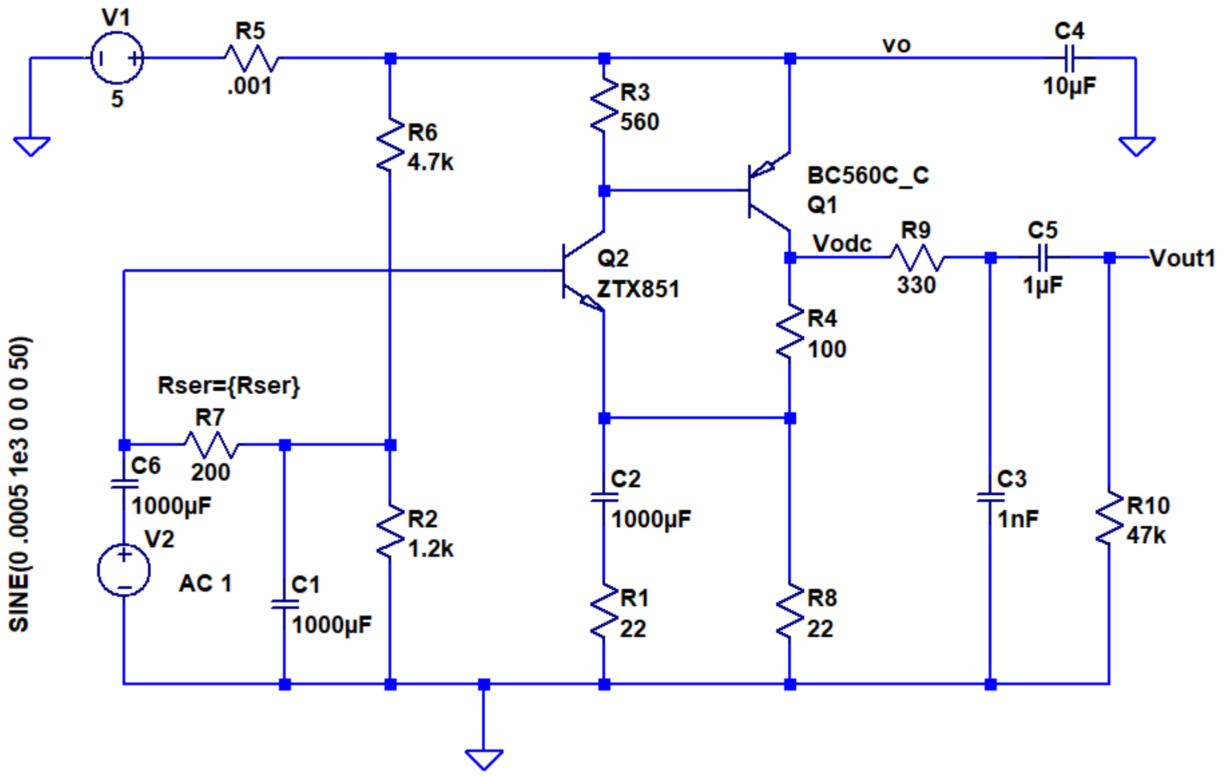


Simple, low distortion design with good noise performance; Match Q1 to Q4 Vbe's to within 1mV

https://en.wikipedia.org/wiki/Richard_Feynman

Rutherford - JLH 1969 MC Pre. Noise 758/833 pico V/rt Hz; Isupply = 22mA/channel; Distortion 0.005%

Design modified with lower R4, R8 and R1 to get lower noise; current consumption 6mA > 22mA per channel



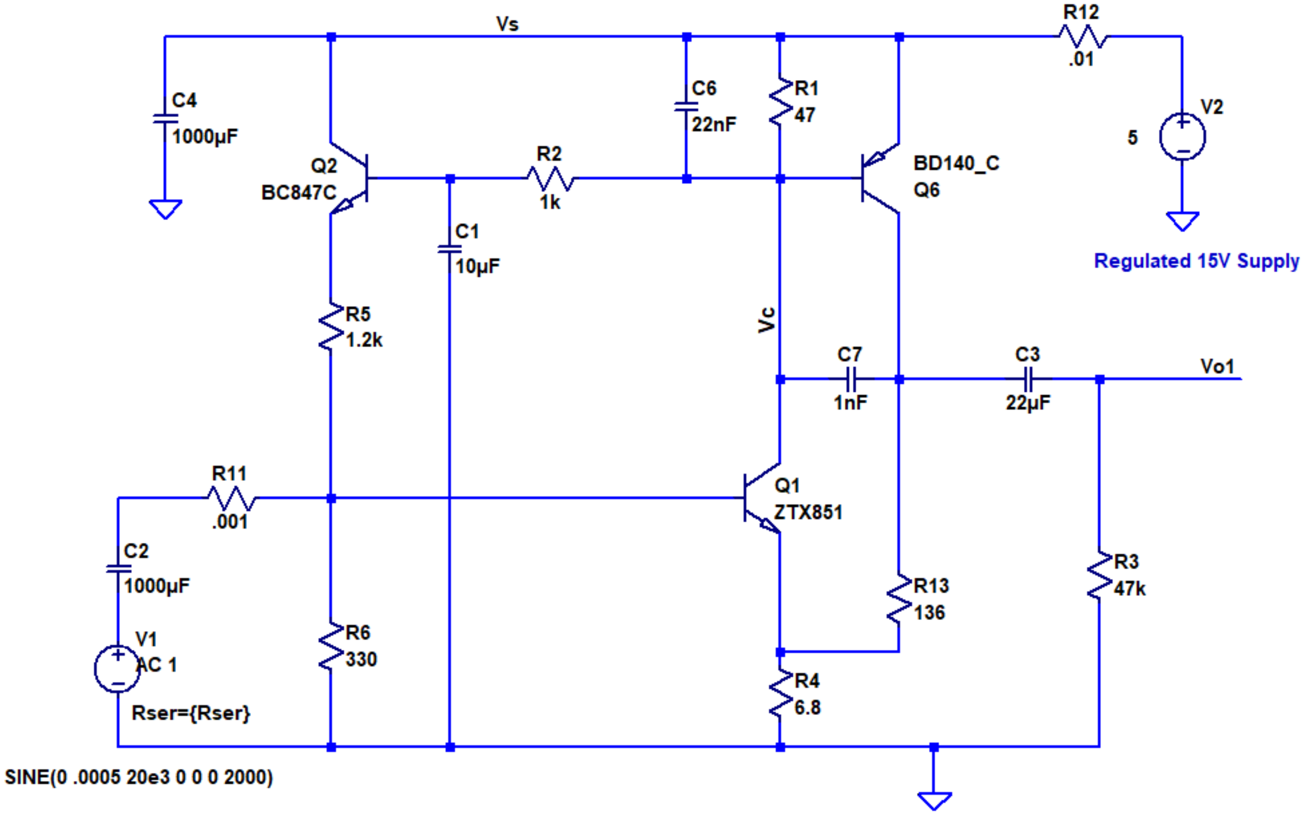

```
.options plotwinsize = 0
.options numdgt = 15

.four 1k V(Vout1)
.param plotwinsize = 0
.param numdgt = 15
.step param Rser 5 10 5
;ac dec 100 1 10e6
;noise V(Vout1) V2 dec 100 1 100e3

.tran 0 10e-3 1e-3 1e-6
```

Simple, conventional low noise amplifier with good performance

https://en.wikipedia.org/wiki/Ernest_Rutherford

Boltzmann Low Noise MC preamplifier 526/612 pico V/rt Hz

1/f corner < 10 Hz; current draw c. 28mA per channel; distortion c. 0.008% @ 20kHz; 2Hz to 2MHz +0dB -3 dB; developed from a design based on a mic pre from AoE - Horowitz and Hill page 506 3rd Ed;

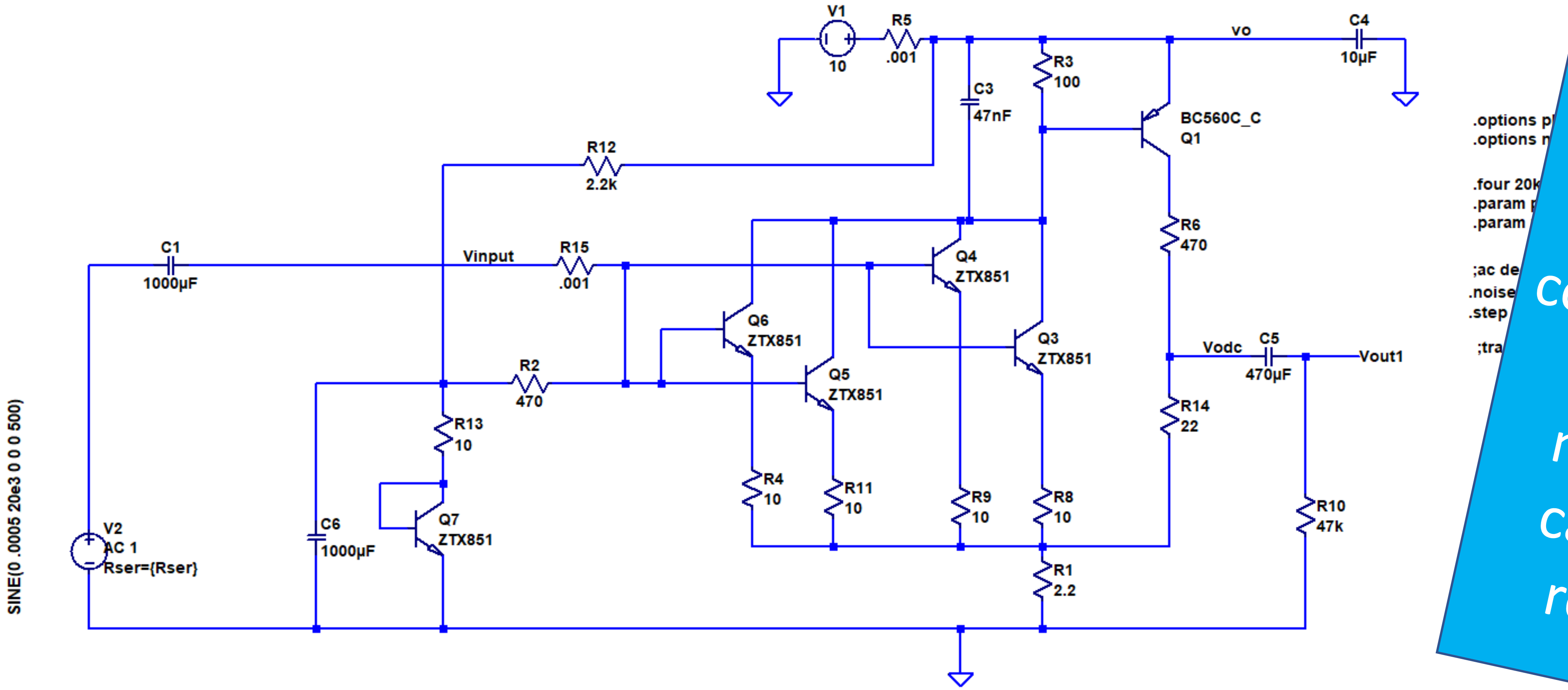


Q1 can be paralleled for lower noise but requires accurate Vbe matching to <1mV across all the devices; Adjust R1 accordingly

https://en.wikipedia.org/wiki/Ludwig_Boltzmann

'Kip Thorne' MC Phono Pre; distortion 0.07%; Isupply = 24mA/channel
Noise = 490/570 pico V/rt Hz

A 10% improvement in noise is possible by omitting input transistor emitter degen resistors but then Vbe must be matched to < 1mV

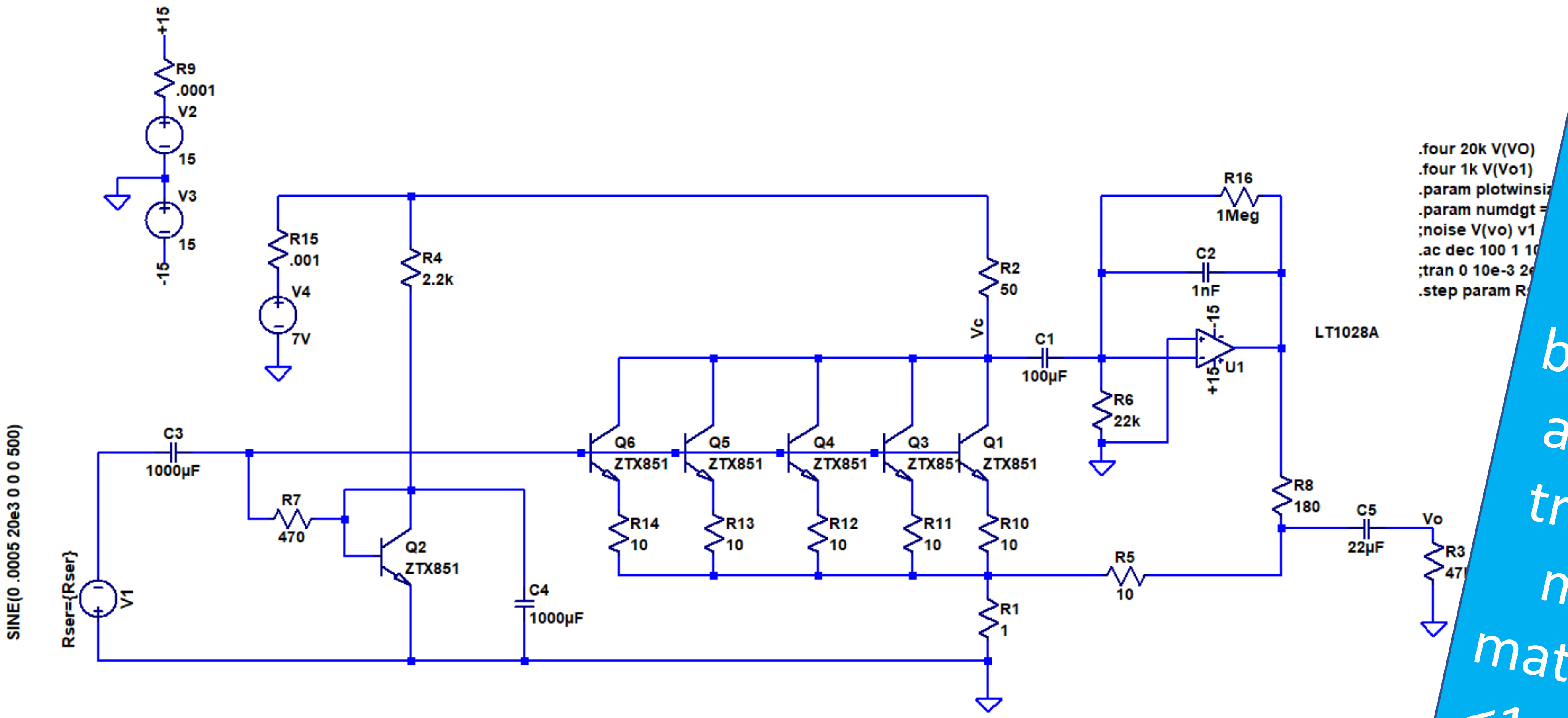


Adjust R12 and/or R13 to change the amplifier transistor collector current to optimize noise for the cartridge DC resistance.

https://en.wikipedia.org/wiki/Kip_Thorne

The 'DeBroglie' MC Head Amp; noise ~470/560 pico V/rt Hz; distortion ~ 70ppm
Isupply 10mA EXCLUDING the opamp; Adjust R4 for 5mA through R2

Match the Vbe of Q1, Q3-Q6 to better than 1mV if omitting R10-R14. The transistor Ic deltas will then be ~60uA per mV difference in Vbe

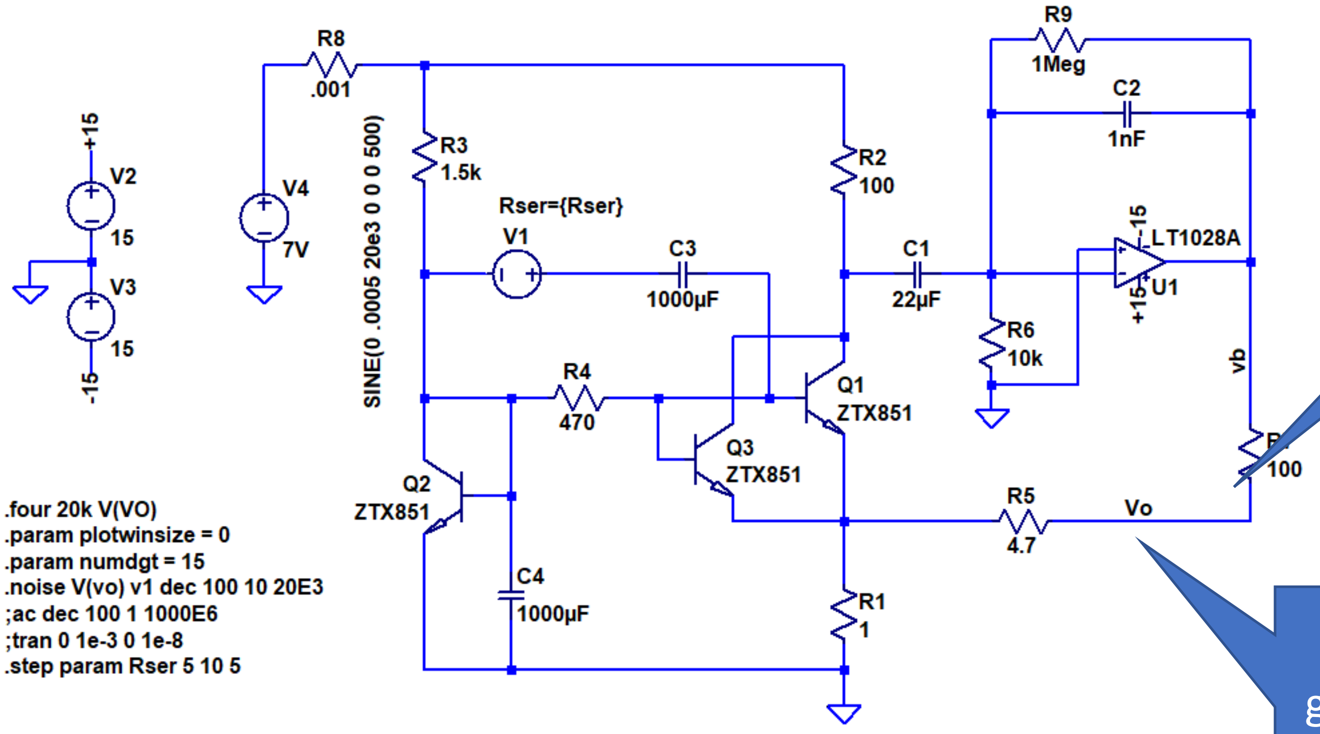


Lower *amplifier only* noise is possible by omitting R10~R14 but Vbe's of associated transistors must be matched for <1mV dVbe

https://en.wikipedia.org/wiki/Louis_de_Broglie

The Heisenberg Low Noise MC-HA; distortion 13 ppm; noise 408/504 pico Volts/rt Hz Isupply 10mA excl. opamp

! ATTENTION: Match Q1 and Q3 Vbe to within 1mV



AV = ~15x

With R5 = 0 Ohms, gain is ~11x and noise improves to 386/487 pico V/rt Hz

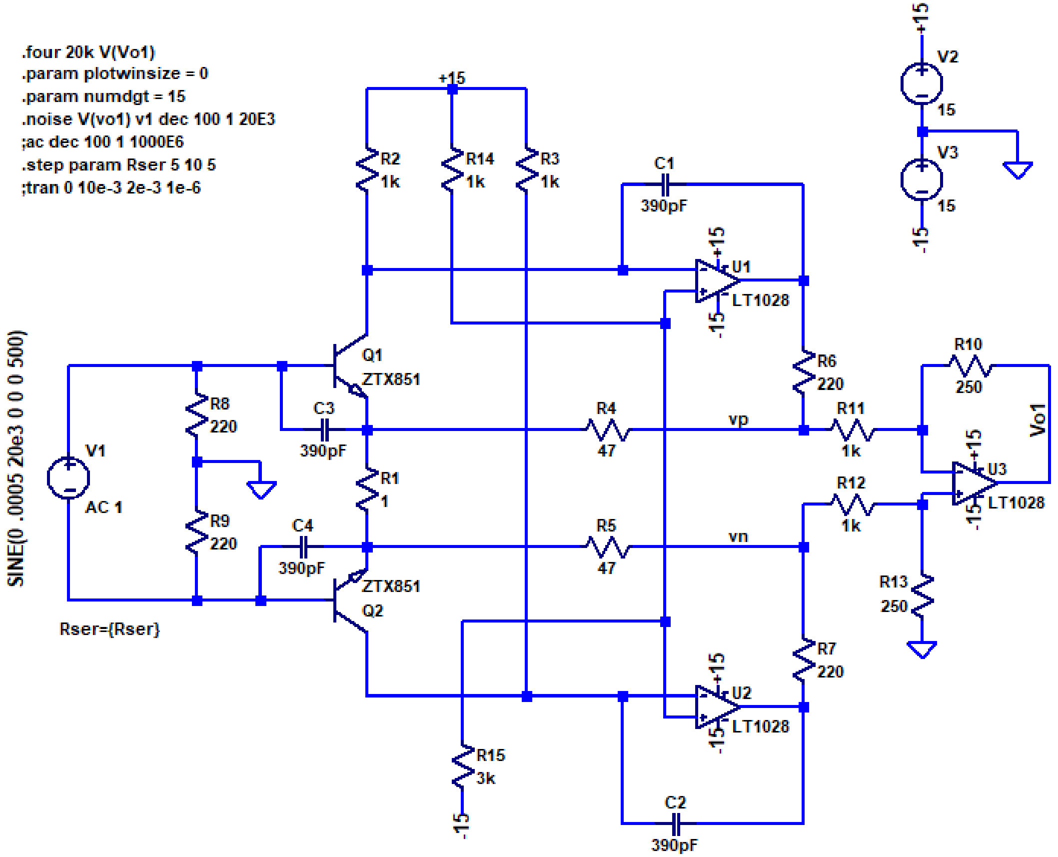
Adjust the value of R3 to change the collector current of Q1 and Q3 to optimize noise to cartridge; match Q1 & Q2 dVbe to < 1mV

https://en.wikipedia.org/wiki/Werner_Heisenberg

J J Thompson MC Head Amp; 480/570 pico V/rt Hz; distortion 0.0017%; DC - 500kHz -3dB

From an idea originally published by Robert Demrow, Analog Devices Inc, 1968 plus work done by W. Kirkwood, 2017

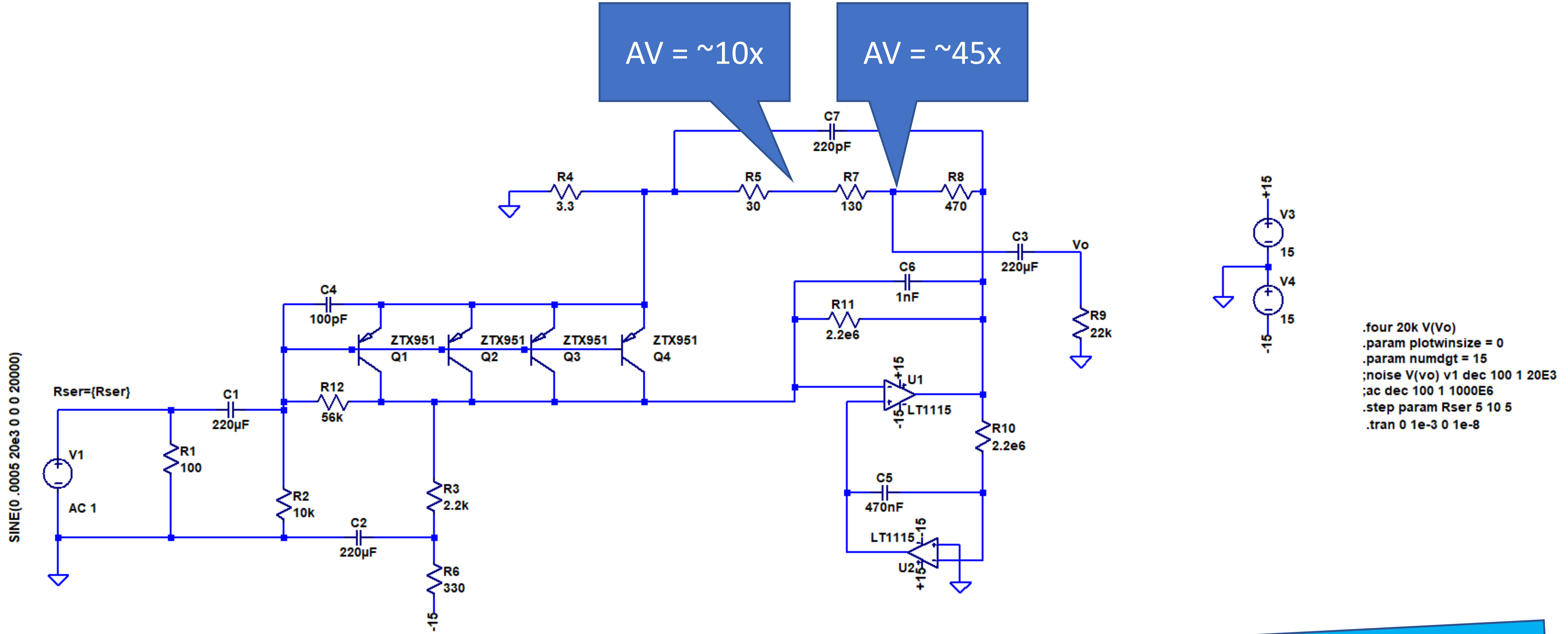
Requires further work to optimize the compensation and frequencey response



Very high performance MC head amp; low noise plus added benefit of balanced input; R1, R4 and R5 set gain; tightly match ALL resistors for best performance

https://en.wikipedia.org/wiki/J._J._Thomson

'Fermi' 459/565 pico Volts/rt Hz ; Isupply c. 20mA; distortion 0.01%
From Rod Elliot site based on a Douglas Self design.



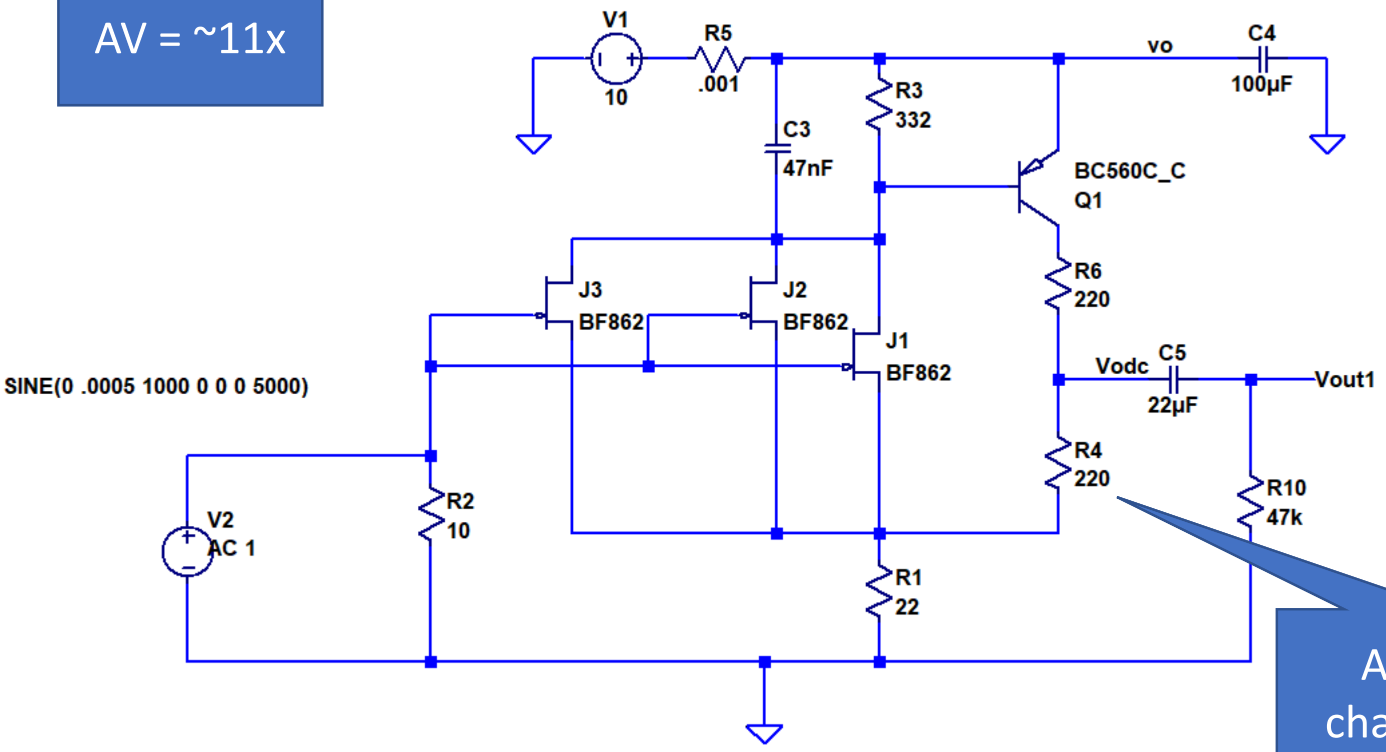
Complex but performance is good. Match Q1-Q4 Vbe for best performance to within 1mV. Adjust C6 to optimize loop and frequency response.

https://en.wikipedia.org/wiki/Enrico_Fermi

JFET Input Designs

Dirac JFET MC Phono; 1.1nV/rt Hz; Isupply = 17mA
Distortion 13ppm; 1/f noise corner of ~100 Hz

AV = ~11x



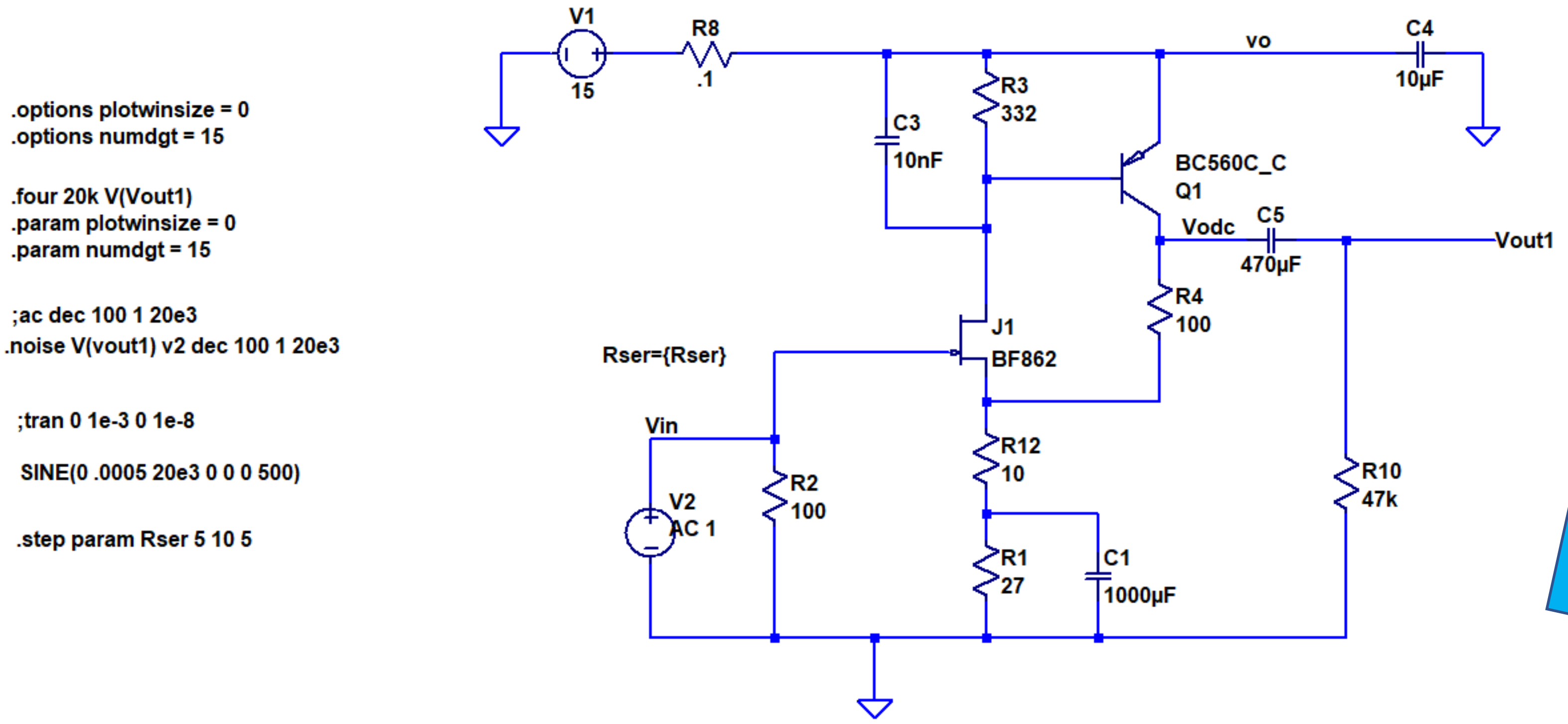

```
.options plotwinsize = 0
.options numdgt = 15

.four 1k V(Vout1)
.param plotwinsize = 0
.param numdgt = 15

;ac dec 100 1 50e5
.noise V(vout1) V2 dec 100 1 100e3

;tran 0 10e-3 0 1e-6
```

Adjust R4 to change the gain

Use ferrite beads in each of the JFET gates to prevent possible HF parasitic oscillation

https://en.wikipedia.org/wiki/Paul_Dirac

Faraday JFET MC Head Amp; distortion ~15 ppm; current consumption 8mA; noise 1.3/1.4 nV/rt Hz

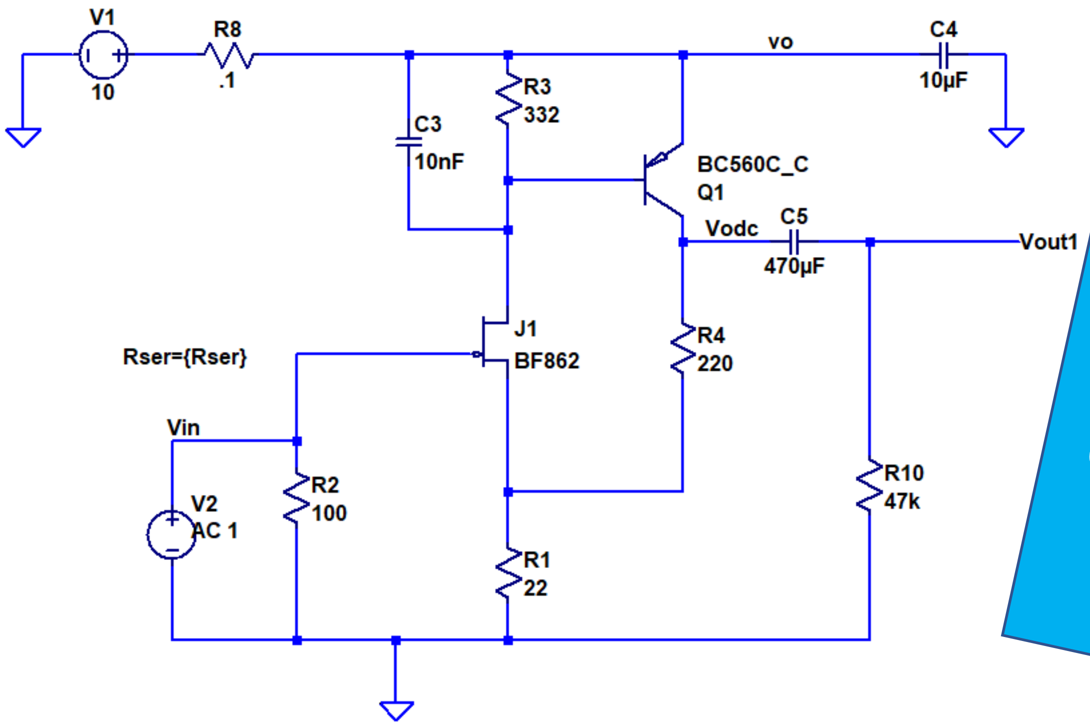


Nice and simple with low distortion; suits MC carts with > 20 Ohms coil resistance

https://en.wikipedia.org/wiki/Michael_Faraday

Galileo JFET MC Head Amp; distortion ~15 ppm; current consumption 13mA; noise 1.5/1.6 nV/rt Hz

```
.options plotwinsize = 0
.options numdgt = 15

.four 20k V(Vout1)
.param plotwinsize = 0
.param numdgt = 15

;ac dec 100 1 20e3
.noise V(vout1) v2 dec 100 1 20e3

;tran 0 1e-3 0 1e-8

SINE(0 .0005 20e3 0 0 0 500)

.step param Rser 5 10 5
```



Nice and simple with low distortion and moderate noise performance. This circuit has been built and works well; suits MC cartridges with 0.5mV output and coil resistances of > 20 Ohms

https://en.wikipedia.org/wiki/Galileo_Galilei

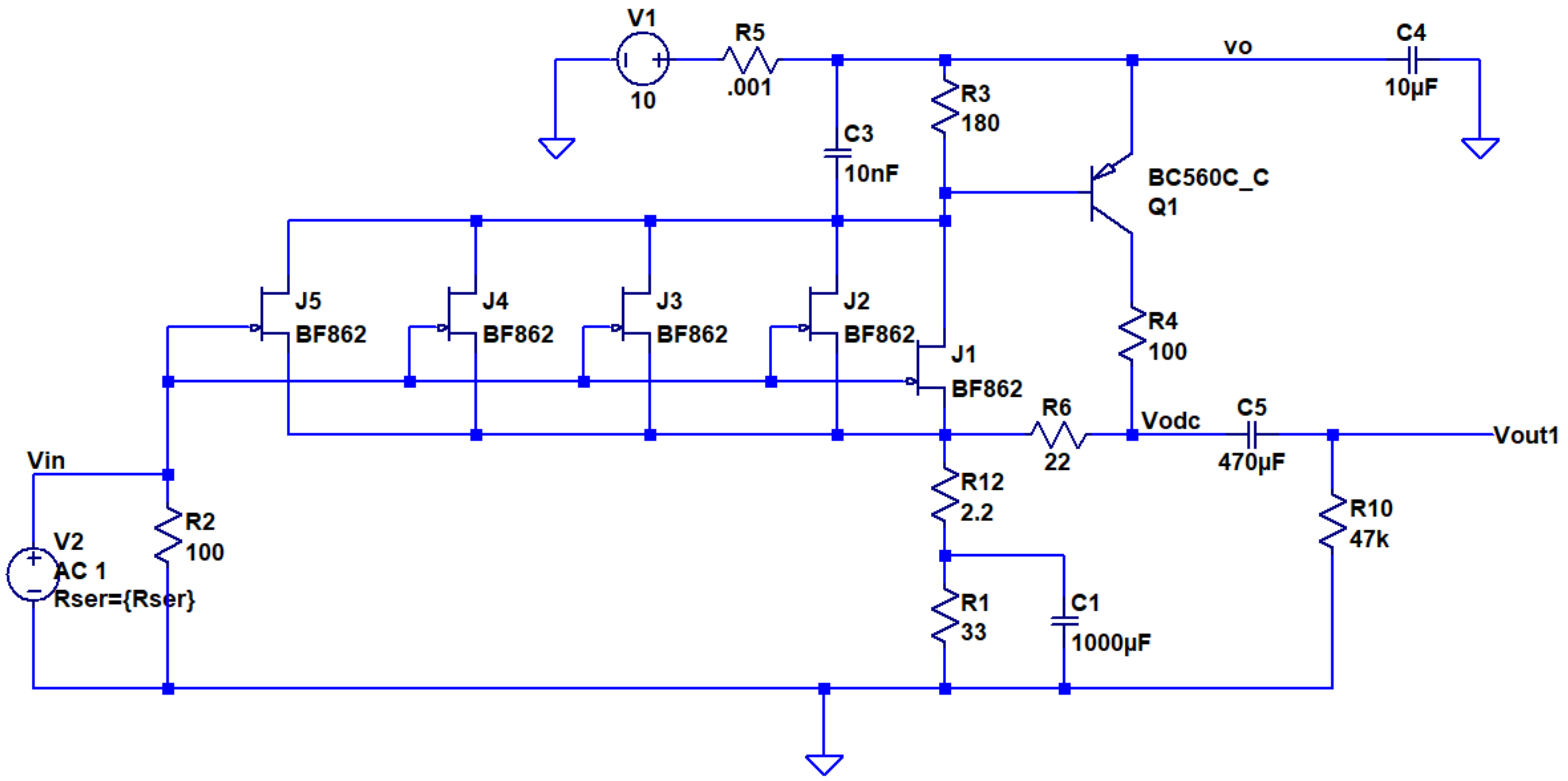
Gell-Mann MC Head Amp; distortion 0.1%; current consumption 8mA; noise 740/829 pico V/rt Hz

.options plotwinsize = 0
.options numdgt = 15

.four 20k V(...

...20e3

Use ferrite beads in each of the JFET gates to prevent possible HF parasitic oscillation



https://en.wikipedia.org/wiki/Murray_Gell-Mann

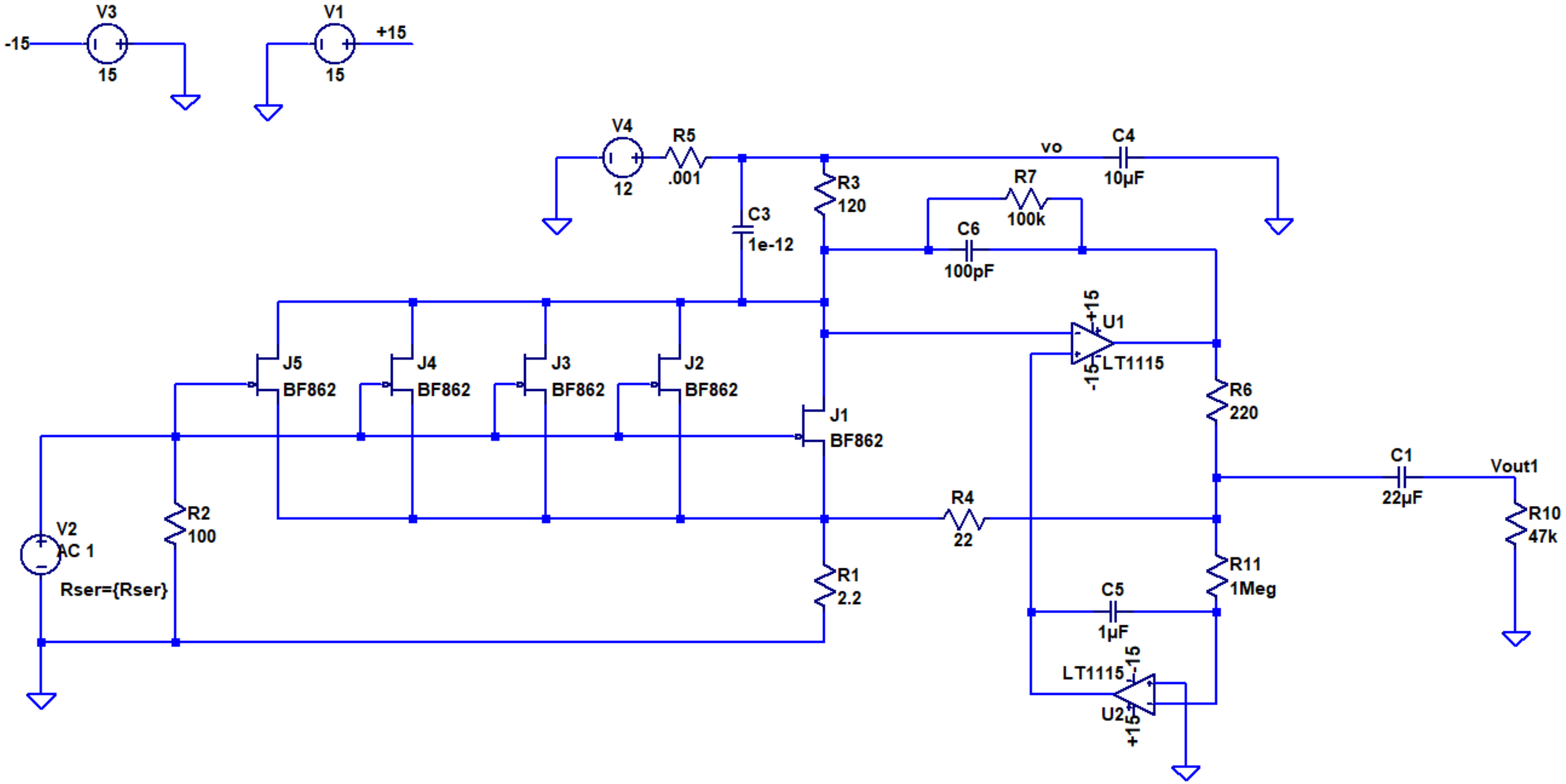
Julian Schwinger JFET MC Front end; 572/670 pico V/rt Hz; distortion ~1ppm
Current consumption ~10mA excl. the opamp

.options plotwinsize = 0
.options numdgt = 15

.four 1k V(Vout1)
.param plotwinsize = 0
.param numdgt = 15
.step param Rser 5 10 5

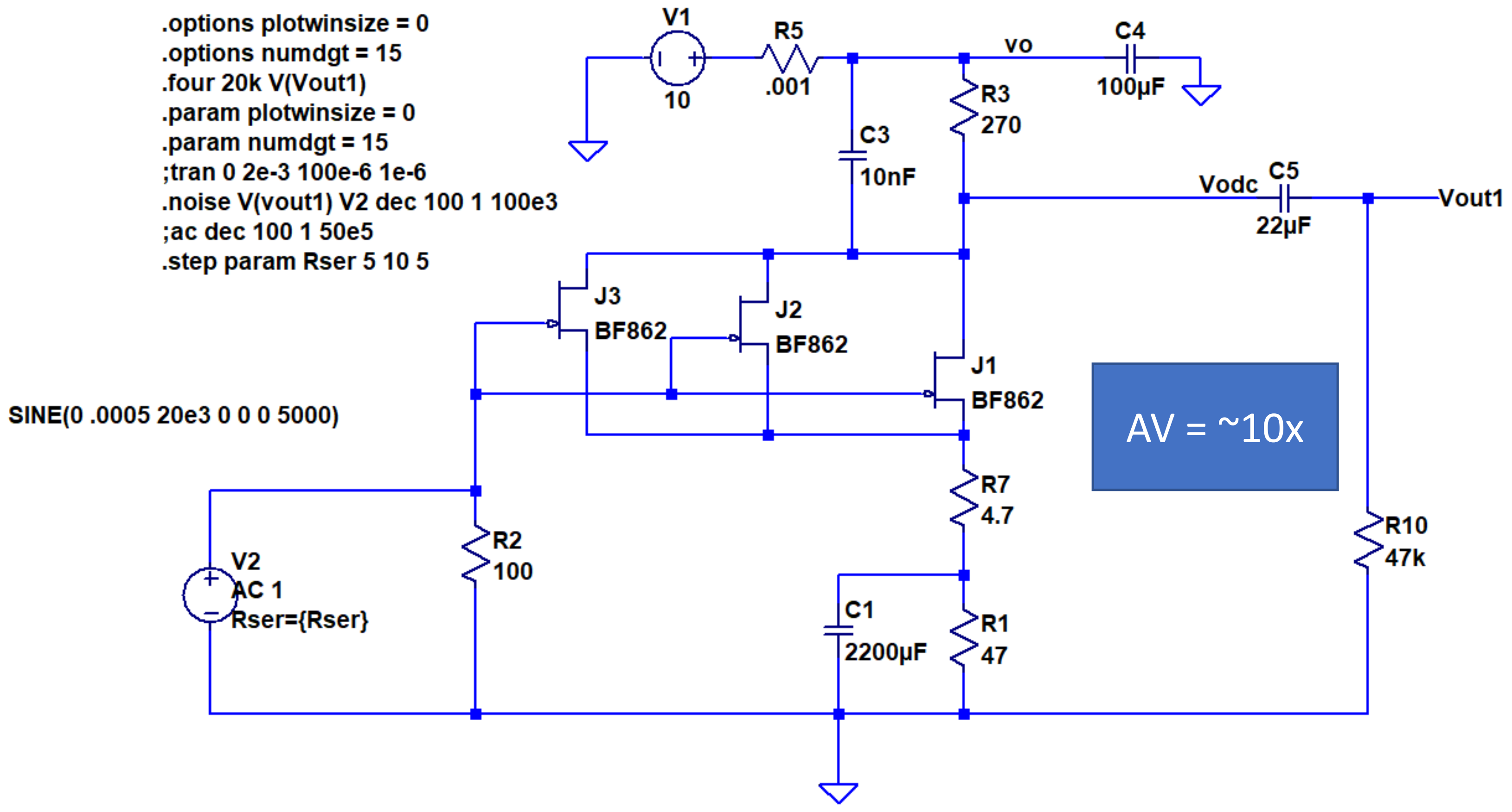
;ac dec 100 1 10e6
SINE(0 .000 0000)
00 10 20e3

Use ferrite beads in each of the JFET gates to prevent possible HF parasitic oscillation



https://en.wikipedia.org/wiki/Julian_Schwinger

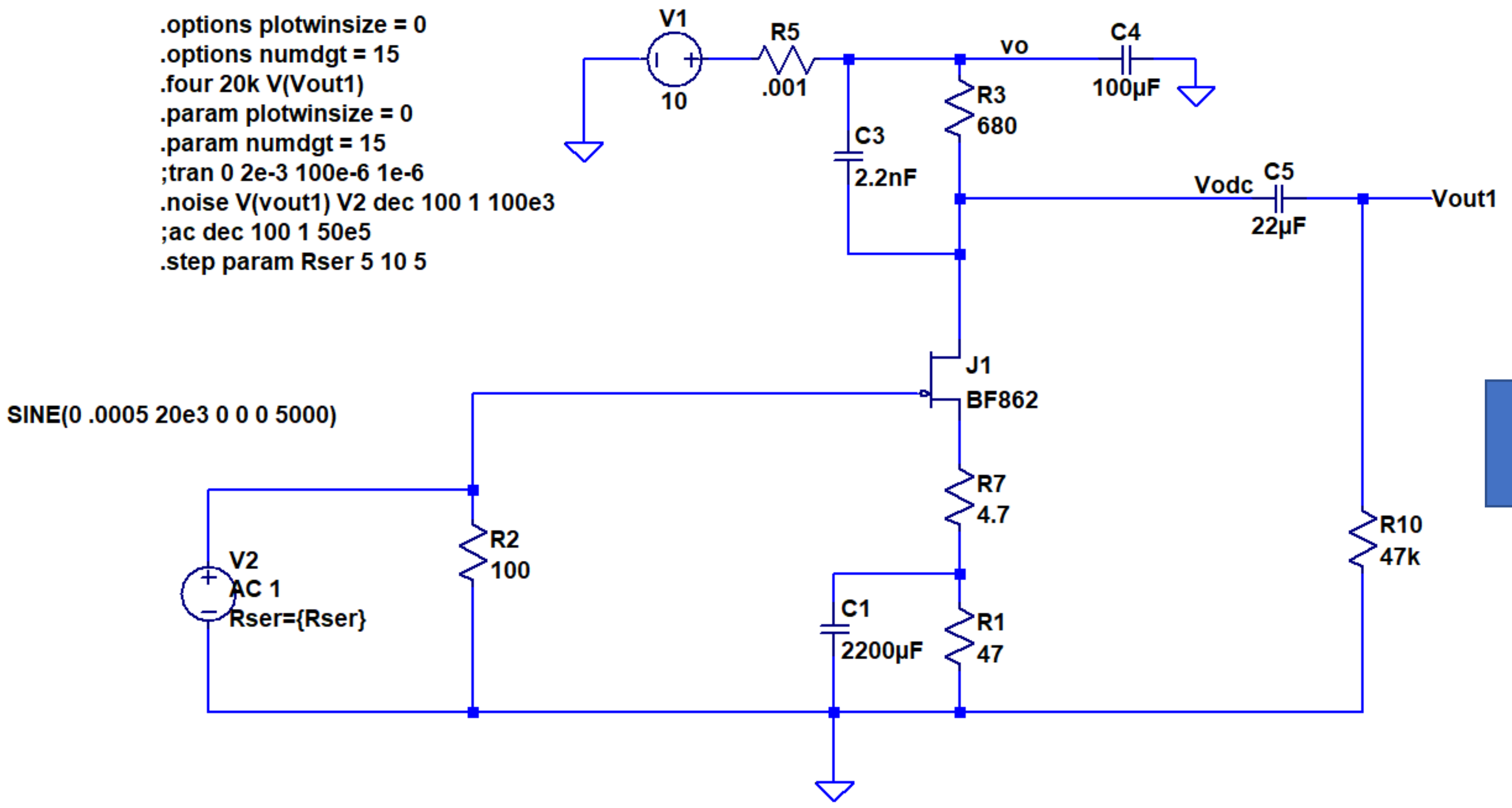
Gamow JFET MC Phono; Isupply = 5.5mA
Distortion 0.03%; 804/866 pico V/rt Hz



Simple with good performance. Use ferrite beads in each of the JFET gates to prevent parasitic HF oscillation.

https://en.wikipedia.org/wiki/George_Gamow

Bethe simple JFET MC Phono; Isupply = 3.8mA
Distortion 0.027%; 1116/1240 pico V/rt Hz



Ultra Simple JFET MC HA

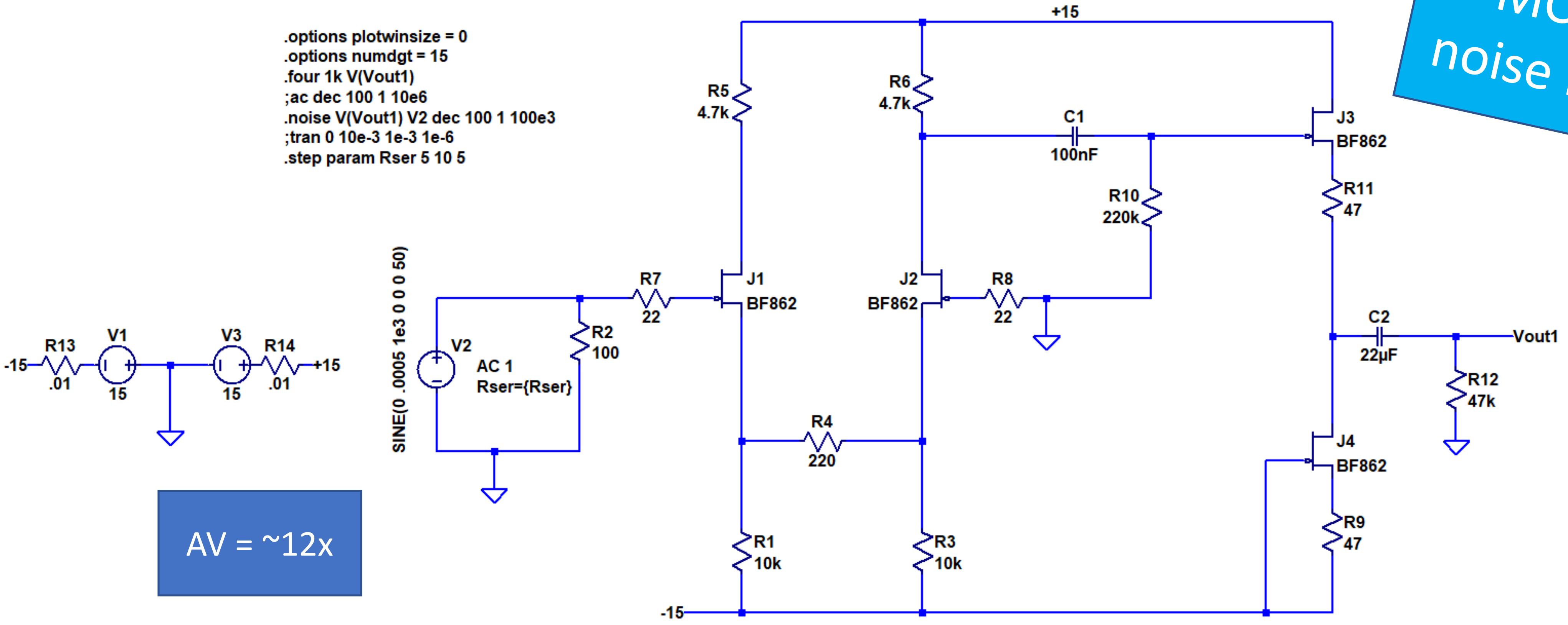
AV = ~10x

https://en.wikipedia.org/wiki/Hans_Bethe

Huygens MC HA; Noise 2.9/3.1 nV/rt Hz; Isupply = 7.5mA; Distortion 0.005%

This is the Piccolo2 JFET MC HA from Hagman Audio Labs

Simple all-JFET MC HA – but noise is very high



AV = ~12x

https://en.wikipedia.org/wiki/Christiaan_Huygens

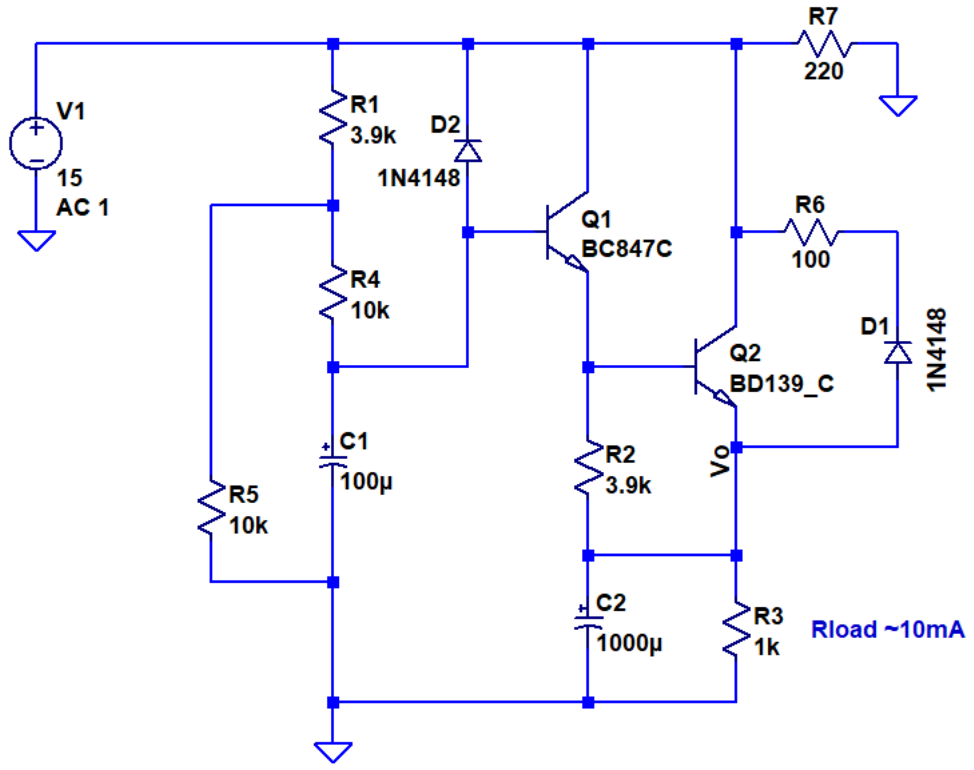
Simple low noise PSU's that can be used with the MC Head Amps.

These circuits would need to be very carefully laid out and well executed to approach the simulated performance. On the opamp based versions, practical circuits would likely need some further work on the loop compensation.

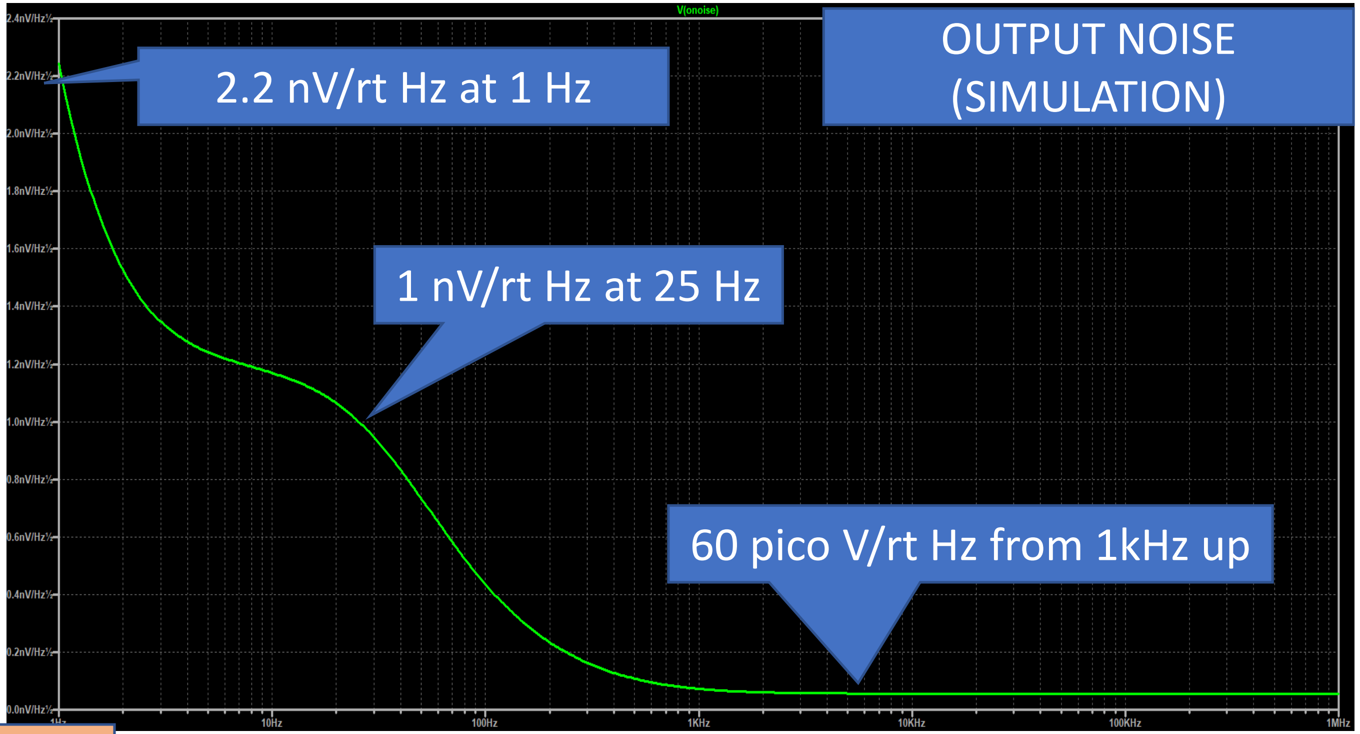
Bohr - Simple cap multiplier PSU for MC Head Amp

Capacitor ESR - and especially C2 - put a lower limit on the noise of this circuit. For the cap shown with an ESR of 120mOhms, it is about 60 pico V/rt Hz. C2 should be a low ESR type, or made up of a number of low ESR types in parallel. D1 allows C2 to discharge quickly as does D2 for C1

For the values of R1 and R5 shown, the output voltage is 9.5V. Adjust accordongly for other output voltages. The upper limit of this circuit with a 15V input supply is about 10V.



;noise V(vo) V1 dec 100 1 1e6
.tran 0 1e-3 0 1e-6

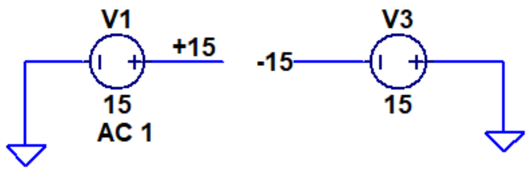


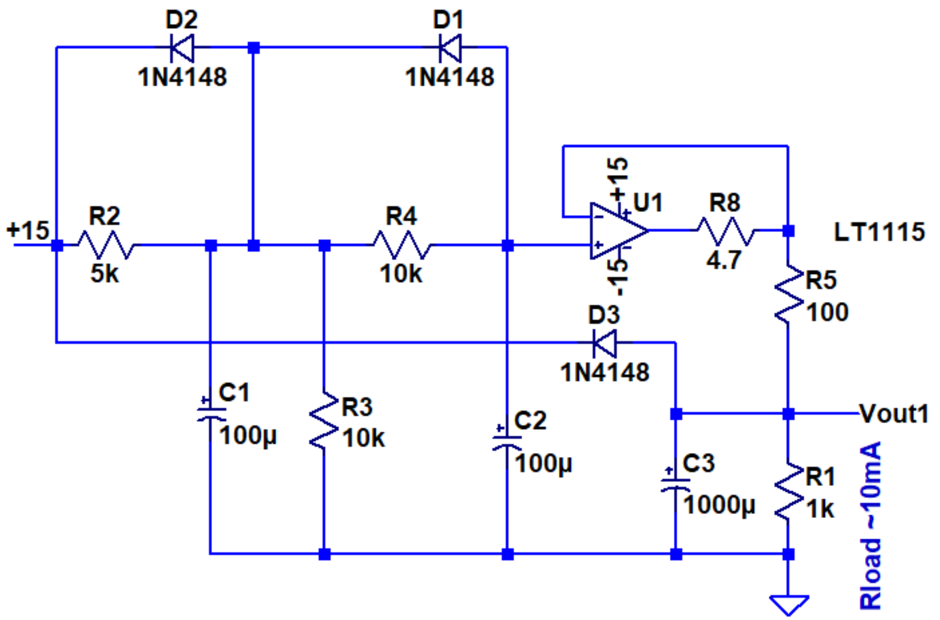
https://en.wikipedia.org/wiki/Niels_Bohr

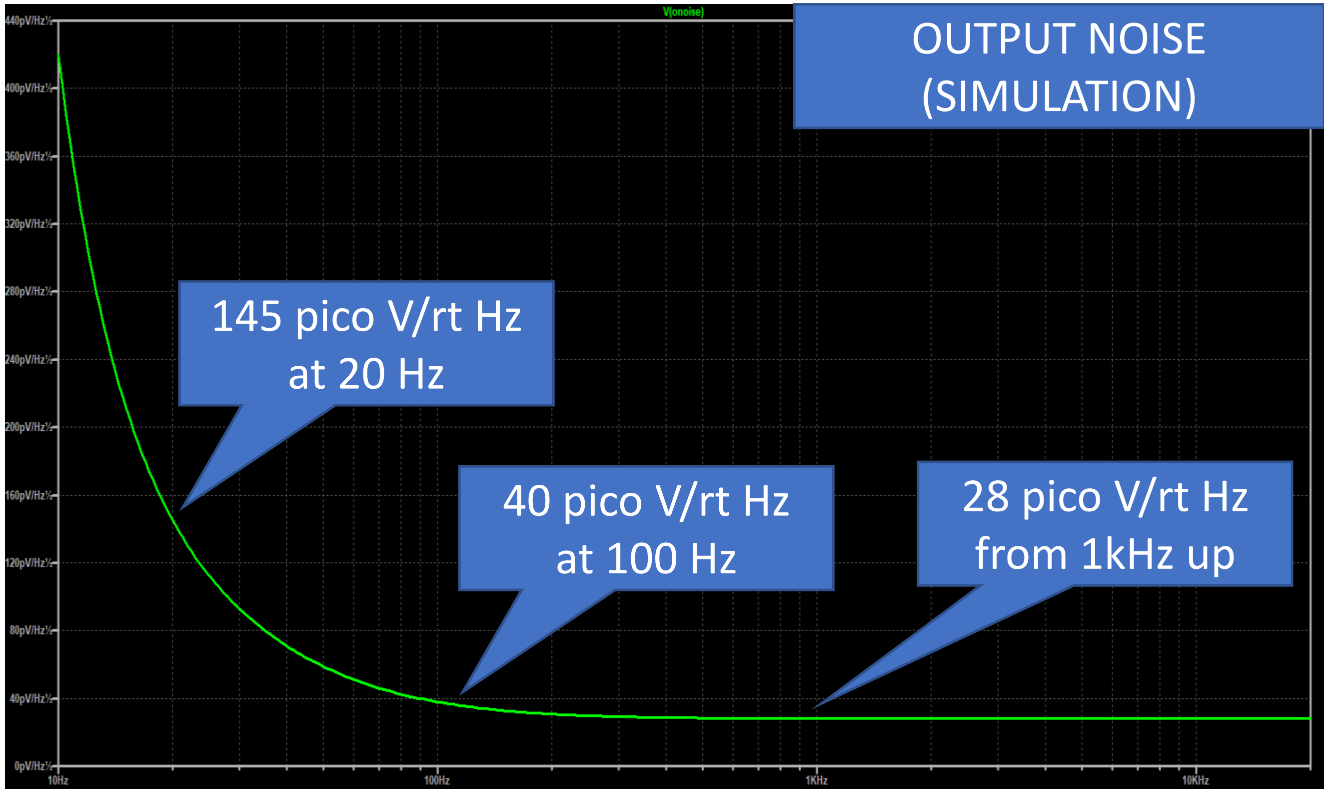
Marie Curie Low Noise 10mA Power Supply

10V output at c. 10mA; PSRR 40 db/Decade 1Hz to 1kHz, thereafter c 120dB to 1MHz.
As with Bohr PSU, ESR of C3 is critical. For the 47mOhm device shown, noise is about 30 pico V/rt Hz from 200 Hz and above

```
.options plotwinsize = 0
.options numdgt = 15
.ac dec 100 1 10e6
;tran 0 10e-3 1e-3 1e-6
;noise V(vout1) V1 dec 100 10 20e3
```



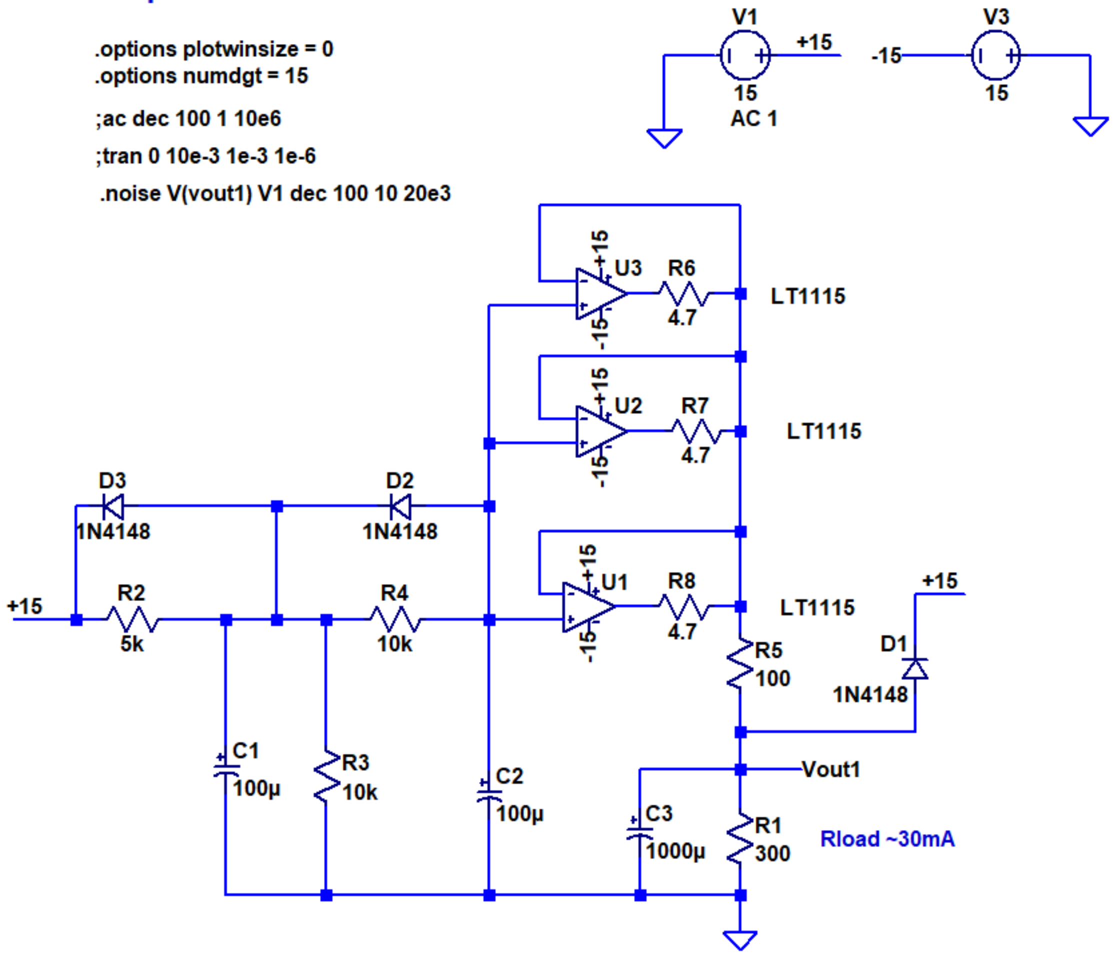


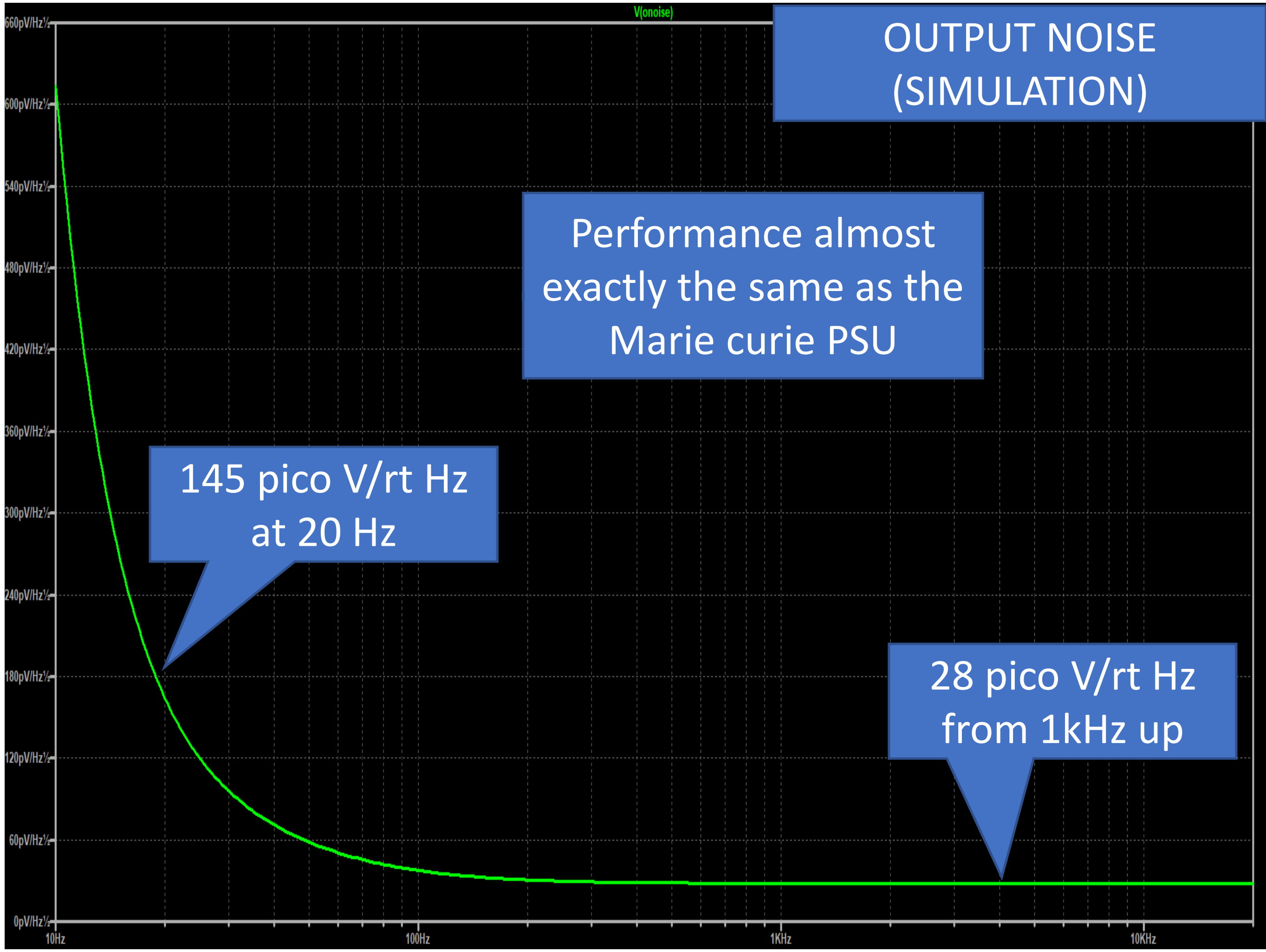


https://en.wikipedia.org/wiki/Marie_Curie

Rontgen Low Noise 30mA Power Supply

10V output at c. 30mA; PSRR 40 db/Decade 1Hz to 1kHz, thereafter c 120dB to 1MHz.
As with Bohr and Curie PSU's, ESR of C3 is critical. For the 47mOhm device shown, noise is about < 30 pico V/rt Hz from 200 Hz and above



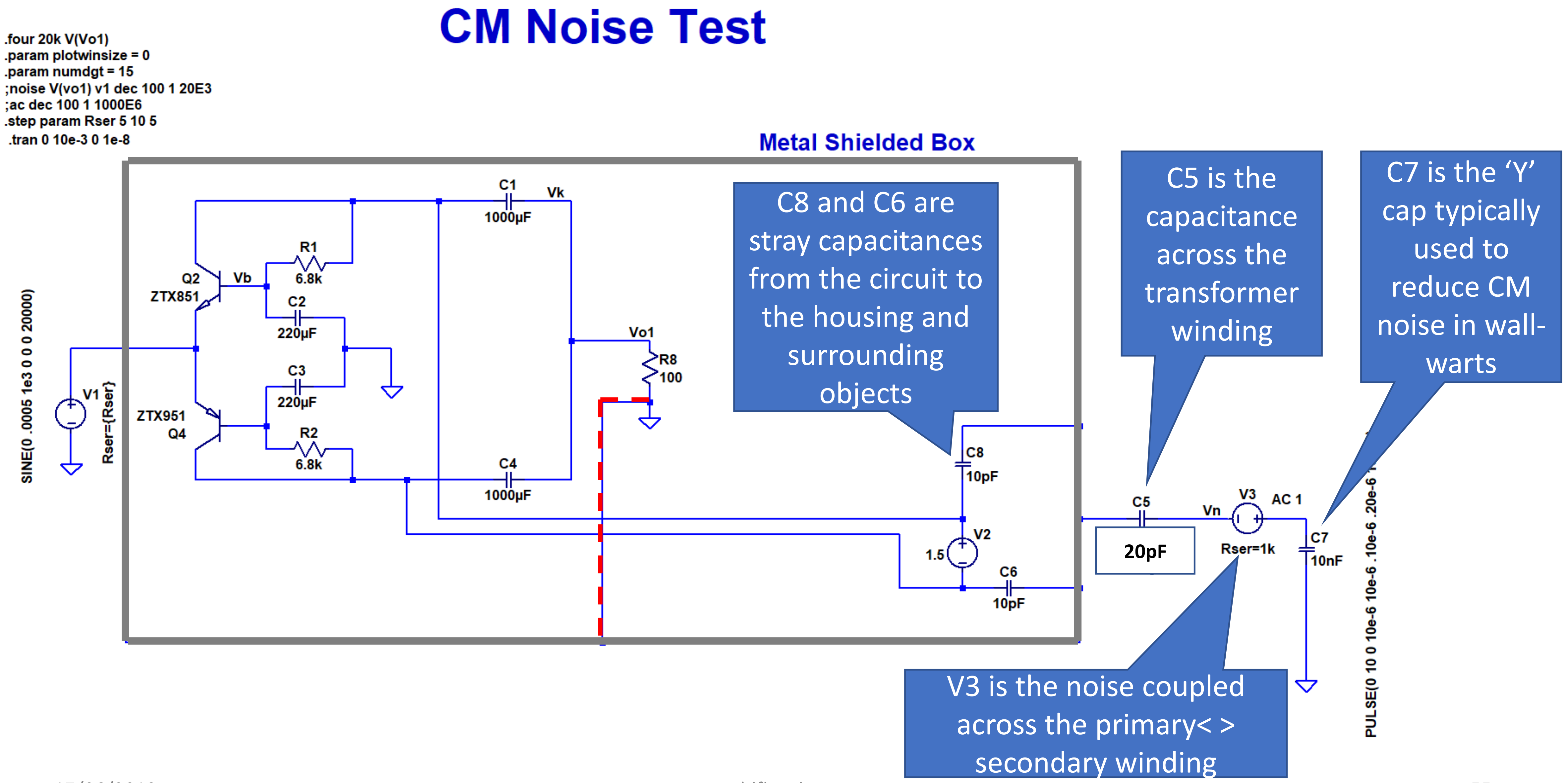


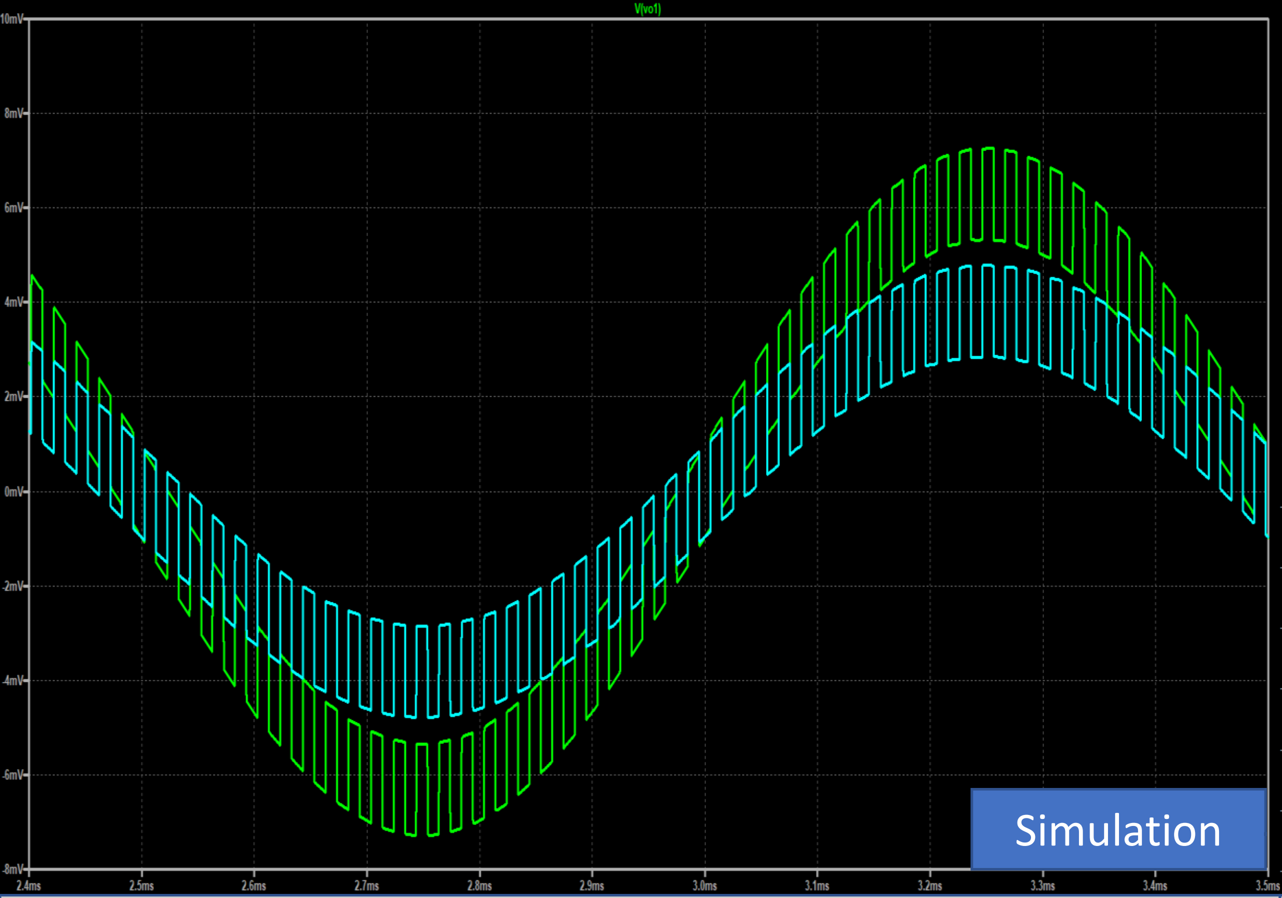
References and Links

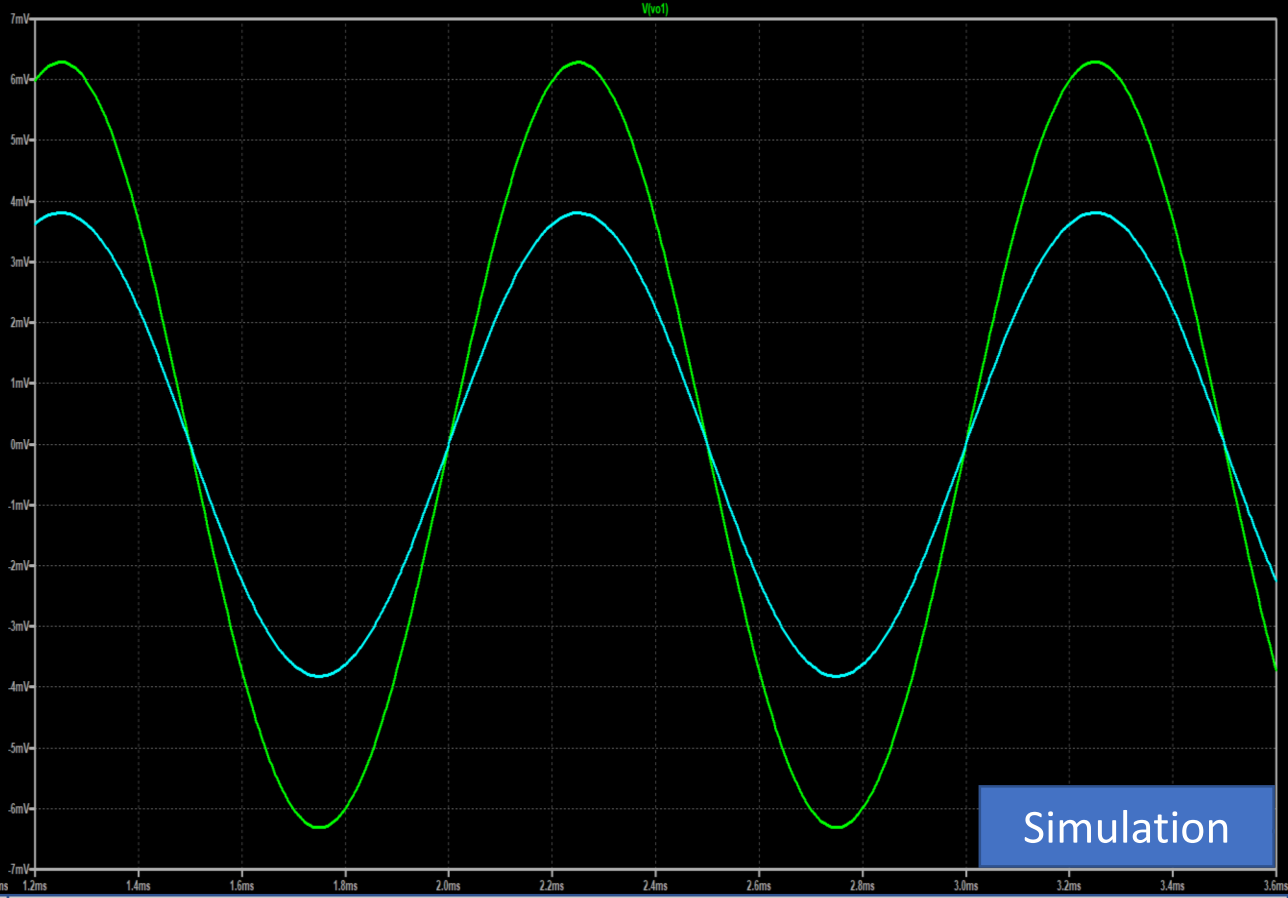
1. Noise in Transistor Circuits – Peter J Baxandall
2. Noise in Semiconductor Devices – Konczakowska and Wilamowski
3. The Art of Electronics 3rd Edition - Horowitz and Hill - Chapter 8 (pages 473 through 590
4. Excellent MIT Physics Dept. Lecture Notes on Noise
5. Opamp noise opamp noise visualizer

Miscellaneous Addenda

Noise in the Hawking and its Derivatives







In the circuit on the previous page, the RED dashed connection from 0V to the metal housing is REMOVED to simulate non-shielded, non-grounded performance. With just 10pF stray coupling between the circuit and the housing and 20 pF between the primary and secondary of the power supply, HF noise (either switching from the use of an SMPSU or HF line conducted noise on the mains) makes the preamplifier unusable.

This simulation is exactly the same as the one on the left, but in this case, the metal box – i.e. shield – has been connected to ***the preamplifier 0V rail*** (dashed red connection on previous page circuit)This effectively shunts the stray capacitances directly to ground and away from the + and – supply rails, completely removing all noise on the output. A decent metal housing is an absolute necessity for these types of MC HA's as is connecting the metal housing to the circuit 0V (dashed RED line in the circuit). Very important note: ***DO NOT*** connect the metal housing to EARTH [Safety Ground] as this will create a severe earth loop.

How to determine arm<>cartridge resonant frequency

2. Cartridge compliance from manufactures specifications

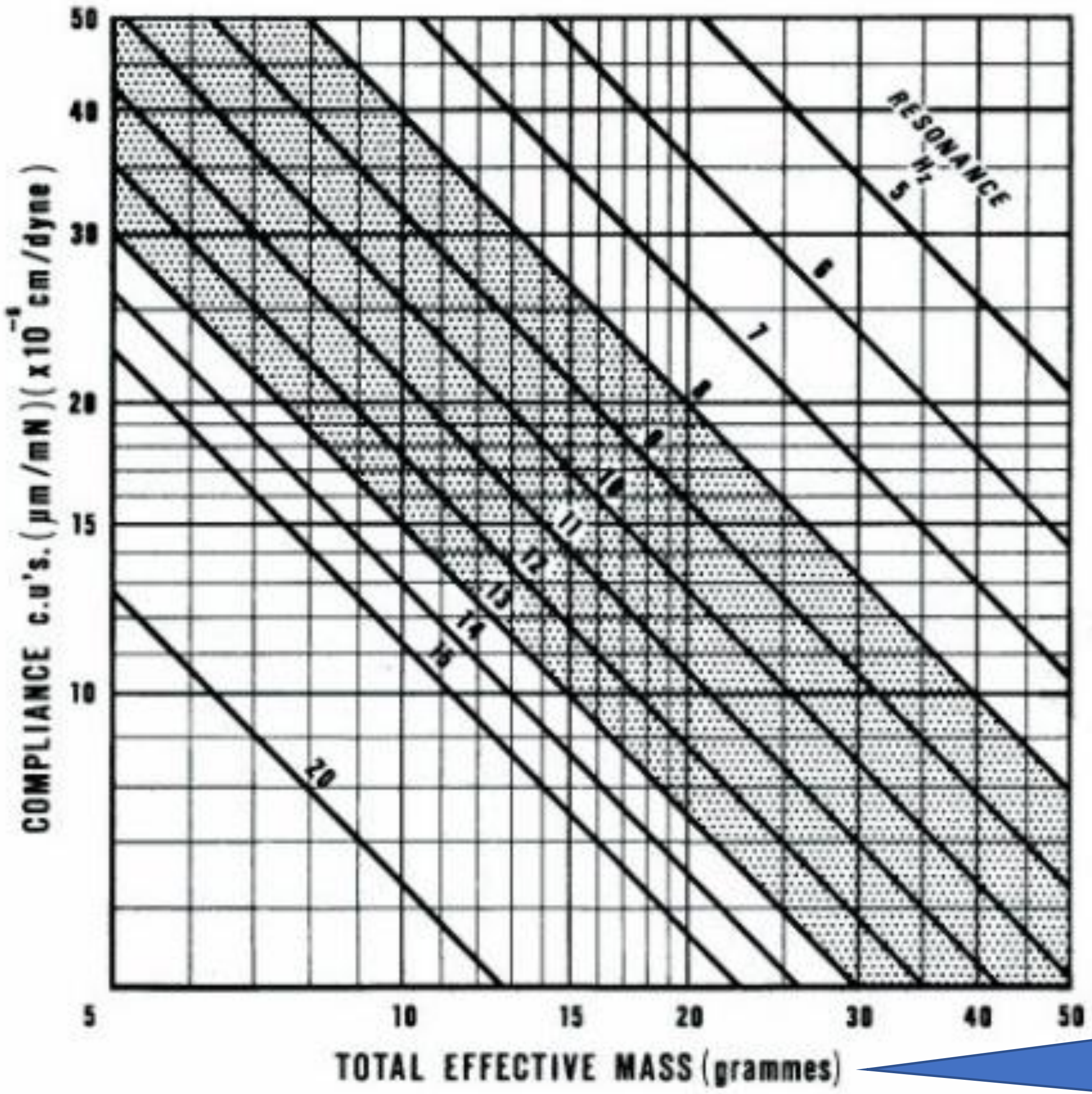


Fig. 1

3. Diagonal line intercept = resultant arm<>Cartridge system resonance

1. Effective arm mass + mass of the cartridge

Graph courtesy SME