Editor's note: these are the appendices for Burkhard Vogel's article in Vol 13:

Challenging BJT Noise

Appendix 1

2SC2547E / 2SA1085E issues

The HITACHI data sheets of its 2SA1083 … 1085 and 2SC2545 … 2SC2547 BJT family [8] claim - and that's the only noise related anchor point we have for these devices - a rather precise 0.5 nV/rtHz input referred noise voltage density at 1kHz, I_C = 10 mA, h_{fe} = 250 … 1200 / 800, and input shorted.

With this information we can calculate the $r_{bb'}$ at eg 1kHz & h_{fe} = 600, hence, with [2] p. 179 or [3] p. 317 we'll obtain (eg via free download of MCD-WS 14.2 from Springer's website about EXTRA Materials: www.extras.springer.com) the $r_{bb'}$ of both devices as follows:

$$0.5 = \sqrt{e_{n.i1}^2 + i_{n.i}^2 r_{bb'}^2 + 4\,k\,T\,B_1\,r_{bb'}}$$

=>

$$r_{bb'} = 13.74\,\Omega \quad \text{at}\,1\,\text{kHz}$$

Next, we go through the x and y finding process à la Section 2. of this article. We'll get

- 2SC2647E: NF(10Hz) = 8.5 dB & NF(1kHz) = 4.9 dB
  x = 0.301 & $f_{c.i}$ = 300Hz

=>

$$r_{bb'.avg} = 14.05\,\Omega \quad \text{in}\,B_{20k}$$

- 2SA1085E: NF(10Hz) = 10 dB & NF(1kHz) = 4.8 dB
  y = 1 & $f_{c.i}$ = 26Hz

=>

$$r_{bb'.avg} = 14.25\,\Omega \quad \text{in}\,B_{20k}$$

With a worst case of 0.51 Ω (≡ 0.158 dB expressed in noise voltage) the differences between (32) and (33) or (34) are rather small. Thus, as of **Figures 20 & 21** these HITACHI devices show rather flat noise density curves in B_{20k}. Practically, they have white noise behaviour.

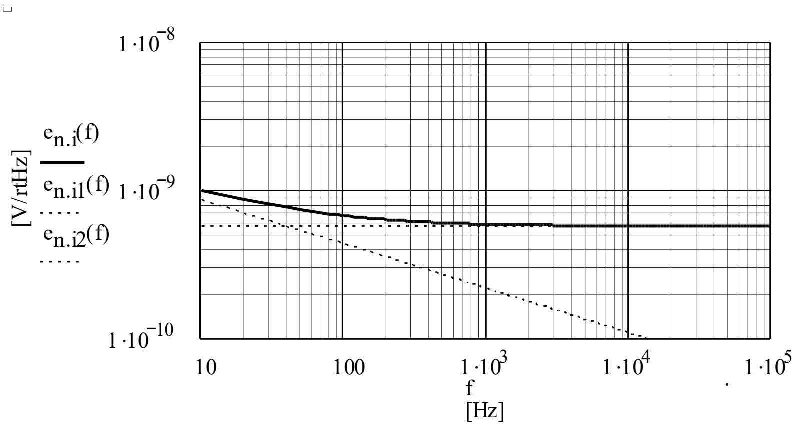

Figure 20 Trace of the calculated input referred noise voltage density of 2SC2647E, incl. its tangents (dotted)

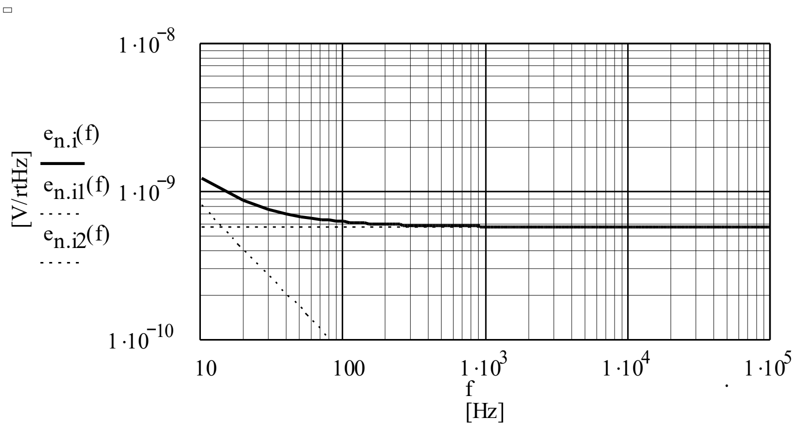

Figure 21 Trace of the calculated input referred noise voltage density of 2SA1085E, incl. its tangents (dotted)

Appendix 2

In 2012 I've sent an LTE to Linear Audio [10] that handles the calculated and measured input referred SNs (after RIAA equalization and A-weighting) of three different input BJTs of the Module 2 Phono-Amp of my RIAA Phono-Amp Engine I, the one with 4 input BJTs paralleled [2,3]. In a second table I've also presented the calculated input referred noise voltage and current densities of the chosen input stage with 4 BJTs parallel connected, including their common emitter resistance of 3.32 Ω.

With the findings of the precedent article

- I have to correct some data of the two tables presented in that LTE
- I additionally present the result of the simulation approach à la **Figure 22**

as follows:

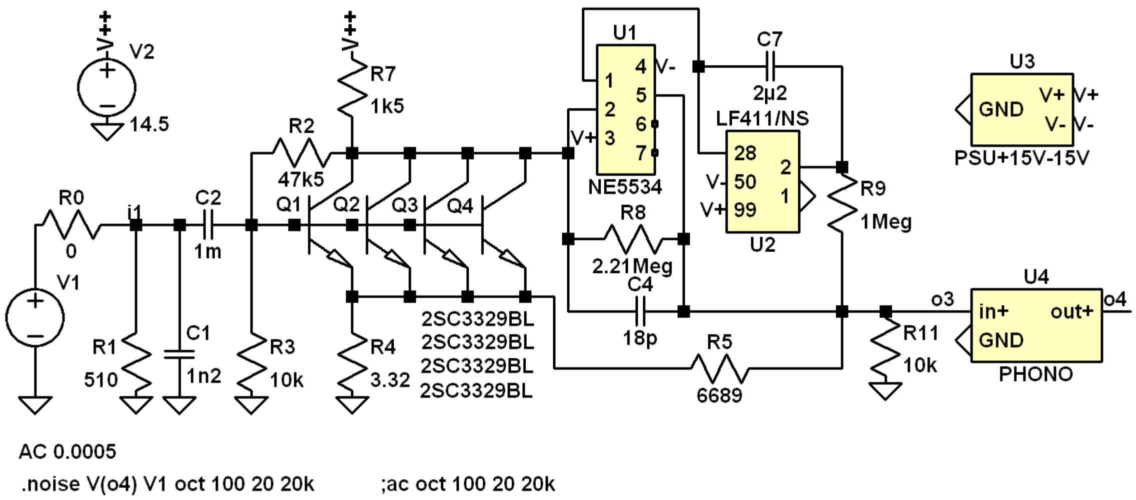

Figure 22 Simulation schematic to get the input referred figures shown in Tables 3 & 4

The simulation approach requires the following adaptations of the generally chosen BC847C. With these changes we can use this type of NPN BJT to form the BJT models of the **Figure 22** i/p devices Q1 … Q4. However, the RB and RBM values are guilty in B_{20k} only!

- SSM2210: BF set to 680 RB set to 29.35 RBM set to 29.35
- 2SC2547: BF set to 550 RB set to 13.6 RBM set to 13.6
- 2SC3329: BF set to 550 RB set to 6.75 RBM set to 6.75

1/A	B	C	D	E	F	G	H	I
2	i/p BJTs		h_{FE}	I_C	$r_{bb'}$	$SN_{ariaa.i}$		
3	type	Ts paral-leled		mA per dev.	Ω per dev.	calculated [dB(A)] ref. 0.5mV at **43Ω**	measured [dB(A)] ref. 0.5mV at **43Ω**	simulated [dB(A)] ref. 0.5mV at **43Ω**
4	1/2 SSM2210	4	680	1.667	30.0	-79.5	-79.2	-79.5
5	2SC2547E	4	550		14.05	-79.8	-80.1	-79.8
6	2SC3329BL	4	550		7.4	-80.0	-80.6	-79.9
7						calculated at **20Ω**	measured at **20Ω**	simulated at **20Ω**
8	1/2 SSM2210	4	680	1.667	30.0	-81.6	-81.4	-81.6
9	2SC2547E	4	550		14.05	-82.2	-82.4	-82.2
10	2SC3329BL	4	550		7.4	-82.5	-82.8	-82.4

Table 3 = LTE-Table 1-impoved
SN comparison of three types of input BJTs,
selected for MC amplification purposes

1/A	B	C	D	E	F	G	H	I	J	K
2	i/p BJTs		h_{FE}	I_C	$r_{bb'}$	$e_{n.i}$	$SN_{ariaa.i}$	$i_{n.i}$	$e_{n.i}$	$SN_{ariaa.i}$
				mA	**Ω**	calculated			simulated	
3–4	type with i/p shorted and i/p referred					noise voltage density [pV/rtHz/ 1kHz]	SN ref. 0.5mV/ 1kHz [dB(A)]	noise current density [pA/rtHz/ 1kHz]	noise voltage density [pV/rtHz/ 1kHz]	SN ref. 0.5mV/ 1kHz [dB(A)]
5	1/2 SSM2210	4 x	680	4 x 1.667	30/4	464.3	-85.6	2.27	468.7	-85.5
6	2SC2547E		550		14.05/4	387.8	-87.2	2.43	392.0	-87.1
7	2SC3329BL		550		7.4/2	349.2	-88.1	2.43	354.8	-88.0

Table 4 = LTE-Table 2-improved
Important calculated and simulated input referred figures
of the three different input devices

In **Table 3** we can see that with inputs loaded the improvements of the BJTs types become very small whereas the 2SC3329 types in **Table 4** show significant deteriorations in columns G & H: from 315.6 pV (in the LTE) to 349.2 pV and from -88.9 dB(A) (in the LTE) to -88.1 dB(A). In both tables the simulation results underline the calculated and measured findings.

Comparison of **Table 3** 20 Ω & 43 Ω differences between simulation and measurement results with the ones of **Table 2** lead to the knowledge that there are higher differences between simulated and measured results in Table 2 than in Table 3. I assume that it has to do with the complexity of the whole amp chain and the chosen fast simulation approach à la **Figure 19** that leads to these **Table 2** differences.

Appendix 3

Author's note: In my main article published in Vol 13, I've described a rather simple method allowing the calculation of 1/f-noise slope exponents 'x' or 'y' plus corresponding corner frequencies $f_{c.i}$. For the math connoisseur the recommended trial and error based so-called successive–approximation approach might look a bit trial-and-error; however, in the meanwhile I found a more math-oriented approach that avoids too many trial and error steps. The new approach is described in this Appendix 3.

Math approaches to find 'x' and '$f_{c.i}$' for the N-type BJT and 'y' and $f_{c.i}$ for the P-type BJT

3.1 NPN: x = ?

Because my Mathcad 11 & 14 softwares didn't find a symbolic solution for 'x' and after many rearrangements of the original article's equations (11) & (12) the following equations allow calculating 'x' up to a specific point [here, it's equation (35)] from which on, to get it right, we can find a solution by application of a graphical approach à la Fig. 23, i.e. by zooming the region around f(x) = 0.

$$f(x)=\left[1+\frac{h}{g}\left(M^{\left(\frac{1}{x}\right)}-1\right)\right]^{x}-N \tag{35}$$

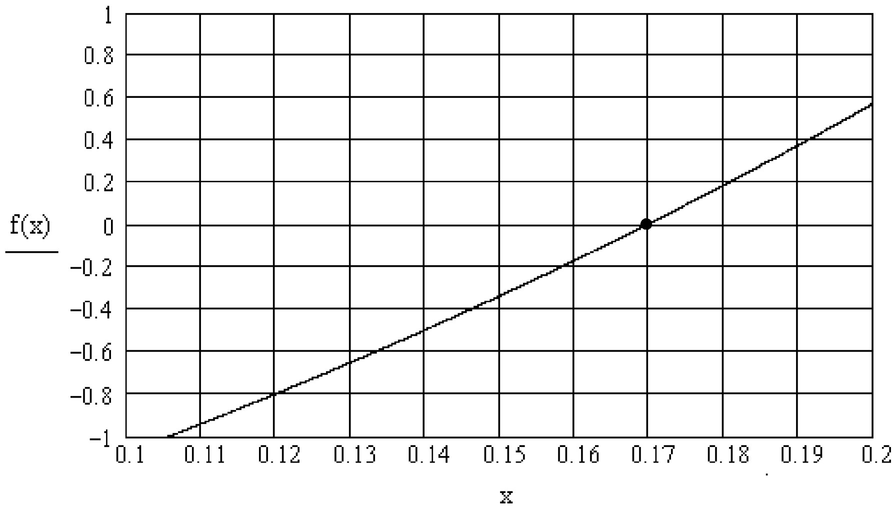

Fig. 23 Graph to get x = 1.6965 at f(x) = 0

$$M=\sqrt{\frac{e_{n.R0}^{2}\left[\exp\left(\frac{NF_{e.1k}}{20}\ln(10)\right)^{2}-1\right]-e_{n.rbb}^{2}}{i_{n.b}^{2}\left(r_{bb}^{2}+R0^{2}\right)+\frac{i_{n.c}^{2}}{g_{m}^{2}}}} \tag{36}$$

$$N = \sqrt{\frac{e_{n.R0}^2\left[\exp\left(\frac{NF_{e.10}}{20}\ln(10)\right)^2 - 1\right] - e_{n.rbb}{}^2}{i_{n.b}^2\left(r_{bb}^2 + R0^2\right) + \frac{i_{n.c}^2}{g_m^2}}} \qquad (37)$$

$$\begin{aligned} g &= 10\,Hz \\ h &= 1\,kHz \end{aligned} \qquad (38)$$

$$NF_{e.10} = 10.2\,dB \qquad (39)$$

$$NF_{e.1k} = 5\,dB \qquad (40)$$

$$i_{n.c} = \sqrt{2\,q\,I_C B_1} \qquad (41)$$

$$I_B = \frac{I_C}{h_{fe}} \qquad g_m = \frac{q\,I_C}{k\,T} \qquad (42)$$

$$i_{n.b} = \sqrt{2\,q\,I_B\,B_1} \qquad (43)$$

$$e_{n.R0} = \sqrt{4\,k\,T\,B_1 R0} \qquad (44)$$

$$e_{n.rbb} = \sqrt{4\,k\,T\,B_1\,r_{bb}} \qquad (45)$$

3.2 NPN: $f_{c.i}$ = ?

Once we've got x we can calculate $f_{c.i}$ = 33.750 kHz as follows:

$$f_{c.i} = h\left[\exp\left(\frac{\ln(M)}{x}\right) - 1\right] \qquad (46)$$

3.3 PNP: y & $f_{c.i}$ = ?

To get M, N, 'y' and $f_{c.i}$ for the PNP type of BJT we have to go through the same process again, however, via equations (11) & (12) by application of adapted $NF_{e.10}$ and $NF_{e.1k}$ values.

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