Borbely EB602/201 Analysed

XEN Audio

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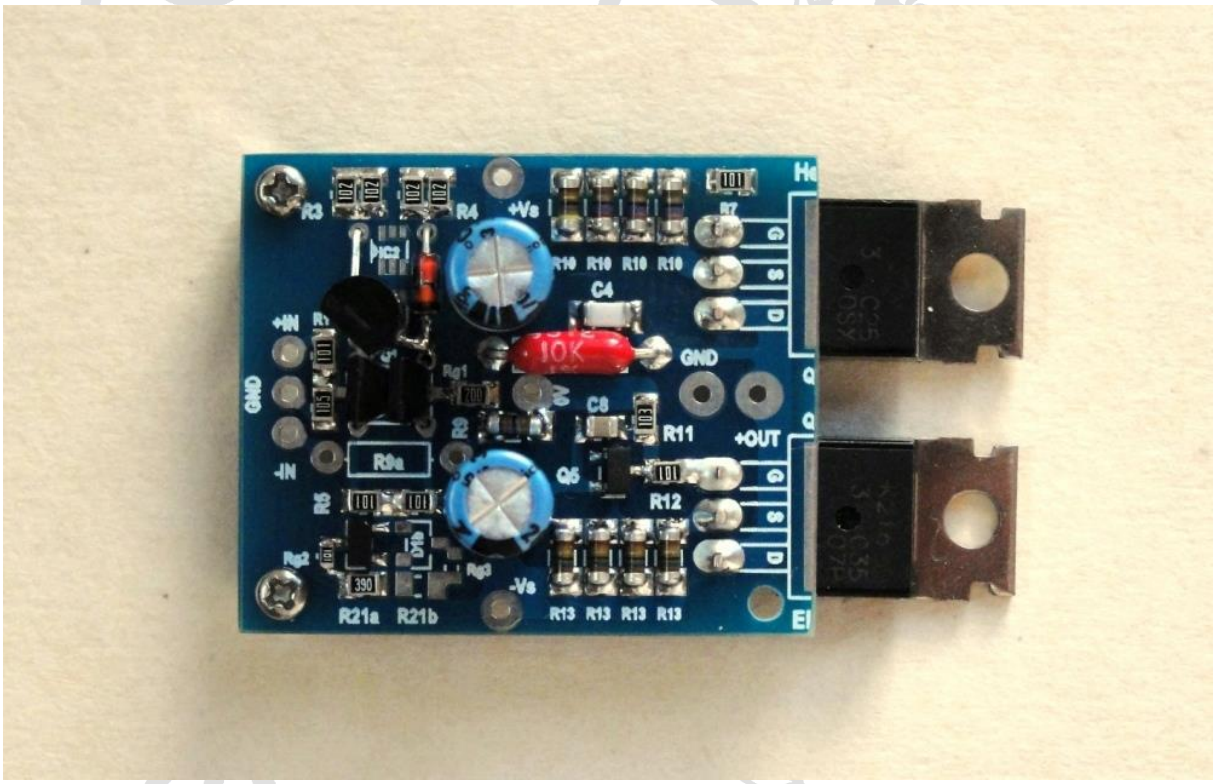

Background

Around 2004, Erno Borbely published his design of a Single-Ended All-FET Headphone Amplifier, the EB602/201. This is essentially based on his previous hybrid headphone amplifier, using a triode tube as input differential pair on +/-15V rails. The Borbely Audio website is unfortunately no longer active, but a very detailed description can still be found in [1].

This simple design has been very popular, and there are many outstanding executions around the world, both commercial and DIY [2, 3, 4]. As the Hitachi / Renesas lateral MOSFETs become obsolete and hence difficult to get, quite a few variants emerged, using IRF vertical FETs, bipolar transistors, or even LM317s, to replace the output devices [5, 6, 7].

However, in his conversation with John Broskie (in 2004 [8]) and again with Jan Didden (in 2009 [9]), he repeated the reasoning behind his choice of Hitachi lateral devices, not based on measurements but rather on sound quality.

This simple, 2-stage, single-ended, pure-Class-A amplifier topology uses a current-mirror-loaded, constant-current-sourced, N-JFET long tail pair as input stage. This in turn drives a single P-channel lateral MOSFET at the positive rail, loaded by a power constant-current source with a N-channel lateral MOSFET. As such, the output stage bias has to be larger than the maximum output current, or the amplifier will clip on current. If the feedback and Zobel networks are removed, the topology can be compared to those found in simple opamps [10]. One cannot help wondering, what makes his design stand out from the rest ?

The following analysis is a humble attempt to try to understand the design choices made by Mr. Borbely. It is of course pure subjective speculation by the author, although Mr. Borbely did kindly review the article and thought it was “a good analysis” of his circuit. Extensive simulations were carried out in LT Spice on the original Borbely circuit, as well as many of its variants, both as a whole or as individual functional blocks.

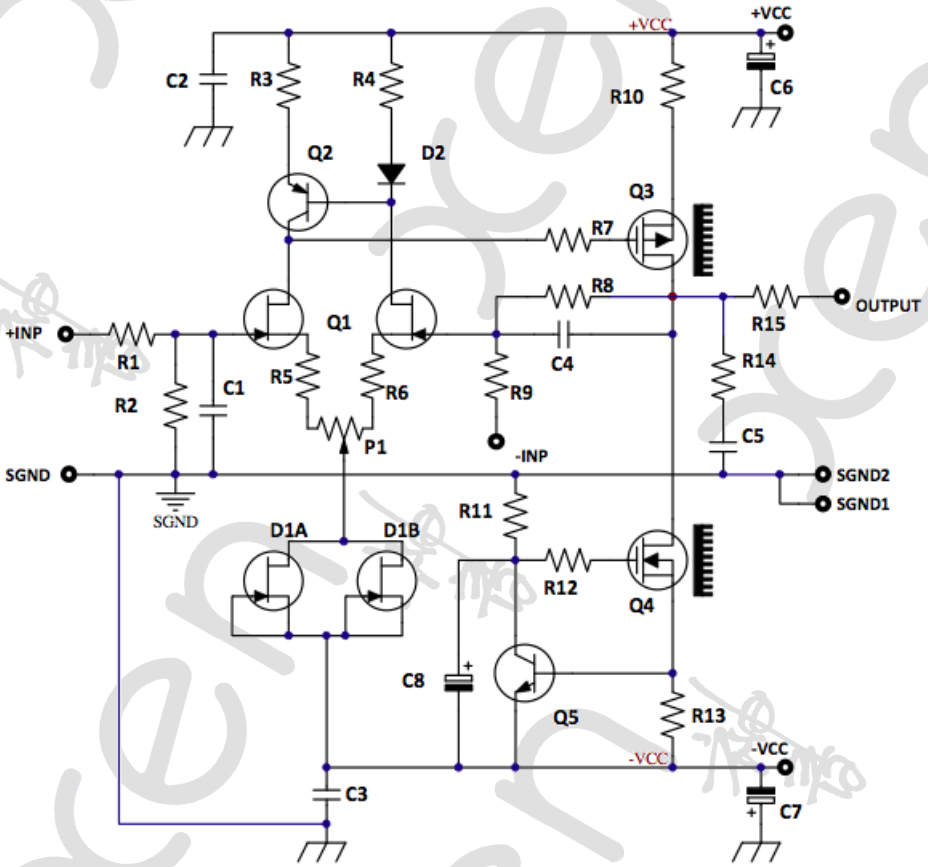

Figure 1 Borbely EB602/201 Schematics

The Functional Blocks

The CCS LTP

One thing to note before we start. In the original EB602 schematics, there is no necessity of any trimming. All the component values can be pre-determined. This is particularly noteworthy, especially with the well-known variations between FET devices.

The circuit evolves from a tube-based hybrid circuit, so it is understandable that it is a single-ended design and not a complementary one, as in the EB1198/116 [11]. The CCS LTP is rather standard of that period, as the 2SK389 dual N-JFET was still easily available. Today, one can still find limited supply of matched pairs of 2SK170 as a direct replacement, or the replacement LSK170. Borbely did mention in [9] that “…. in my experience, they (LSK170) are not as good as the original Toshiba ones.”

Simulations in Spice have shown that same performance can also be obtained using equally low-noise N-JFETs but with lower capacitances and transconductance, by reducing the degeneration resistors