Analysis of TDA2003 and TDA2005 Integrated Amplifiers

Overview:

TDA2003 and TDA2005 are initially produced by SGS-Thompson. The chips were and are still in production by companies as National Semiconductor (LM2005) ST Microelectronics, Unisonic Technologies and some other companies.

This is a second-generation monolithic car stereo circuit. What's makes this chip automotive is the limited supply voltage and ability to drive speakers with lower than 4Ω impedance. Mean high output current.

A simple analysis of the circuit will be made. The analysis will be done with SPICE. The produced models are far from accurate but can give impression how the chips are working. Many of the parameters of the model are estimated by the little available information.

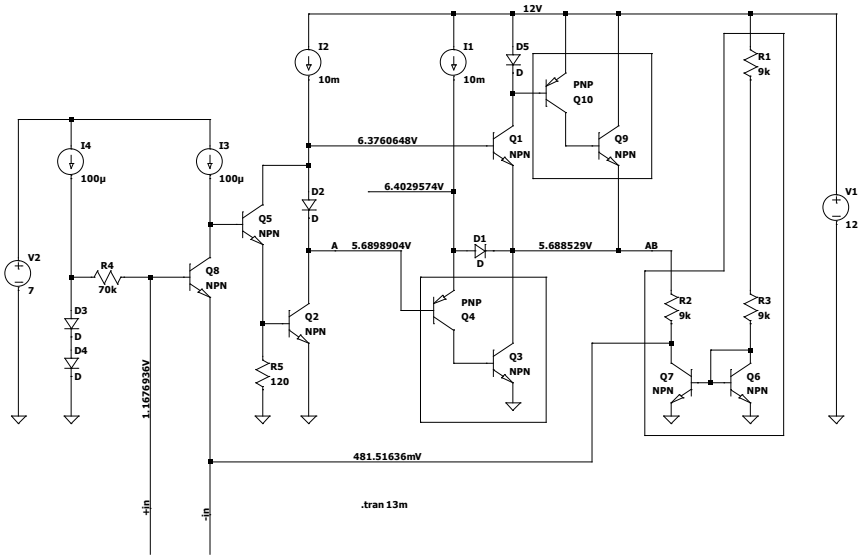
Many thanks to National Semiconductor for their detailed internal circuitry of the LM2005.

Contents

Analysis of the TDA2003:

TDA2003 and TDA2005 have much in common, so some of the conclusions for the TDA2005 will be transferred over TDA2003. The models or the analysis do not pretend to be complete and accurate.

The equivalent circuit:



Output stage:

The output pair is composed by complimentary pairs transistors invented by George Sziklai. The benefit over a Darlington is the input range of the *Vbe*: only one diode drops and better stability.
As the Darlington, the pair cannot saturate more than one diode drop voltage.
The top and the bottom transistors of the output stage are biased separately.
The bottom transistor Q_4, Q_3 is biased by the current generator I_1 and the diode D_1. Of course, the real biasing circuit is far more complicated. Note that the current of the generator I_1 is going to the output.
Looking at bottom transistor only, the input point {A} must have the same voltage as the output point {AB}
The upper transistor Q_{10}, Q_9 is biased by the diode D_5 and the current trough Q_1.
The emitter of the current provider Q_1 for the bias of the upper transistor is also connected to the output. To compensate the Vbe of this transistor the diode D_2 is included in the current path of the driver.

Driver stage:

The stage is made by the transistors Q_2 and Q_5. The current between the transistors is split to get the right bias for the upper arm. The input DC voltage of the stage is *2xVbe*.
After long exploration of the internal circuit of the *LM2005*, the currents I_2 and I_1 appear to be equal.

In all datasheets the output feedback divider is directly connected to the output, and it has *DC* current. The proposed values are around *1kΩ*. My conclusion is that this is done to sink the excessive current of the bias for the bottom arm. With *14V* supply the output must be the half of that voltage. Therefore, the current for the bias is somewhat around *7mA-10mA*.

Input stage:

Simple transistor Q_8 biased at the base with resistor and *1.5V* stable voltage. We can expect *DC* voltage *of 0.7V* on the emitter. The stage can be driven with *AC* signal less than *300mV*. The stage is supplied by internal voltage regulator, made by reverse connected transistor as a Zenner diode. This makes me fell that the voltage is around *7.5V*.
The emitter of this transistor is connected to the output with (measured on TDA2005) R_2*=9kΩ* resistor.

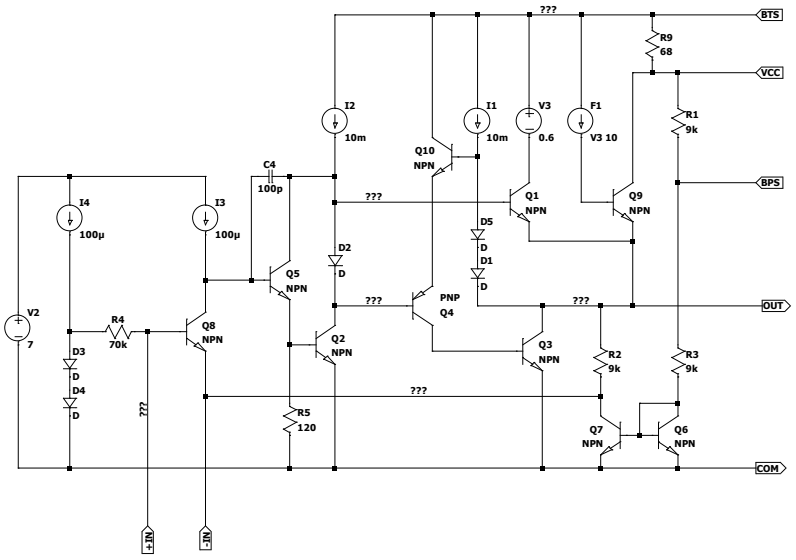
Amplifier DC biasing:

The output must have the half of the supply voltage. The *DC* feedback resistor is R_2. Therefore, the current trough this resistor must produce half of the supply voltage. This is done by the current mirror with Q_7 and Q_6. The supply voltage produces current trough twice than R_2 resistor. The same amount of current will produce the half voltage over the R_2 resistor.

Analysis of the TDA2005:

TDA2005 is the enhanced version of TDA2003. The chip has additional bootstrap inputs and control of the output offset. With bootstrap the output positive peak is higher than the supply voltage. To avoid the clamp of the negative peak the output must be offset up.

TDA2005 single model:

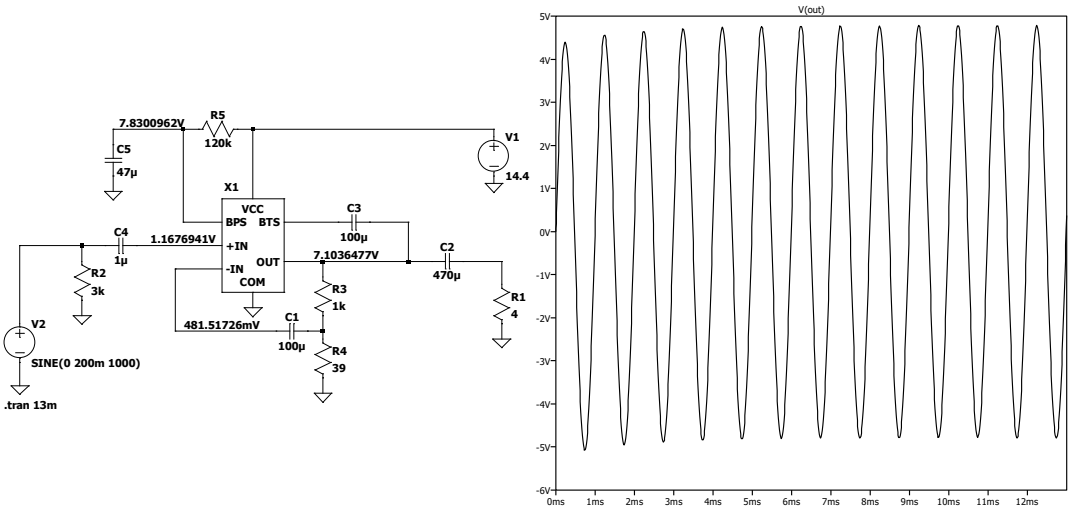


The circuit of the TDA2005 has additional input for the bootstrap (BTS) and for the bias offset (BPS). The classical bootstrap circuit requires resistor to the supply rail. The measured value between BTS pin and VCC pin is R_9*=68Ω*.

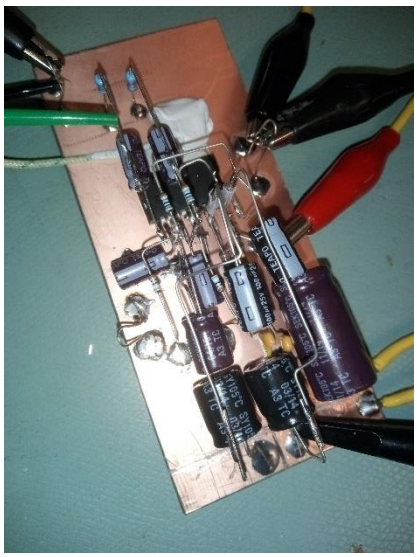
The measured resistor of the DC bias current mirror between pins BPS pin and VCC pin is $R_1=9k\Omega$
In the model, the bias of the bottom leg is closer to the real one.

Verification of the single model.

Using the LTSpice hierarchy features, here are the generated symbol from the above circuit and the results:



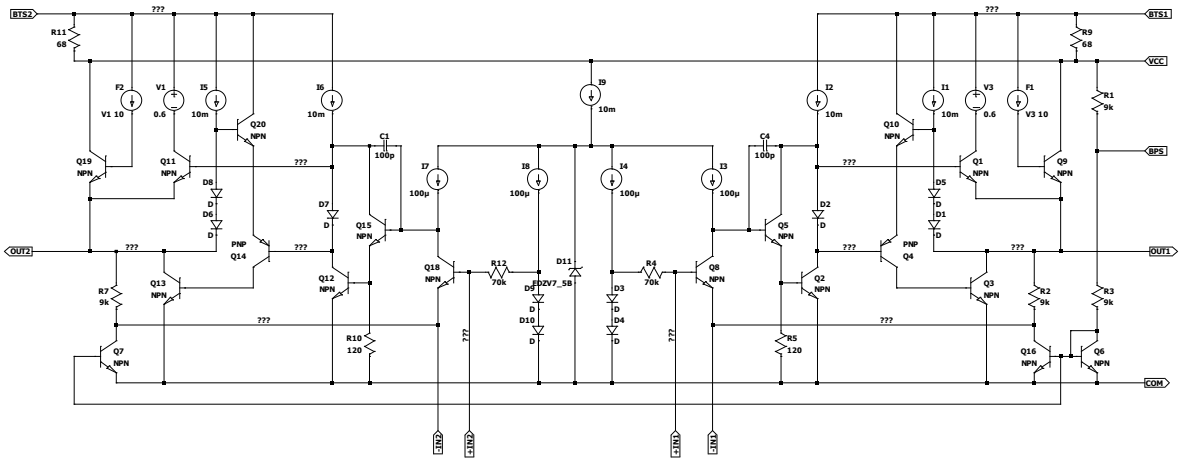
The stereo prototype:



A prototype was built and tested with Van Halen's Right Now.

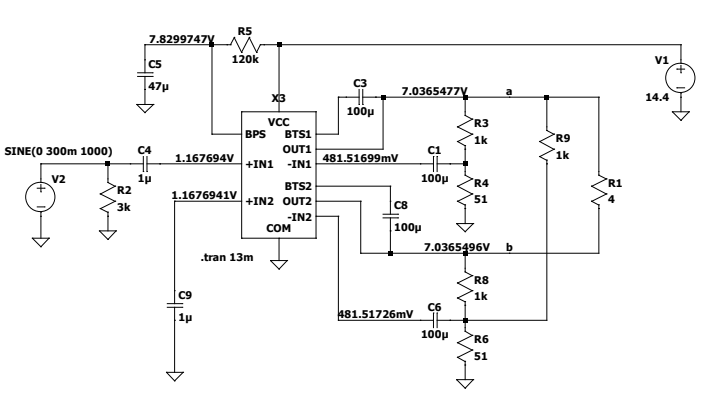
TDA2005 double model:

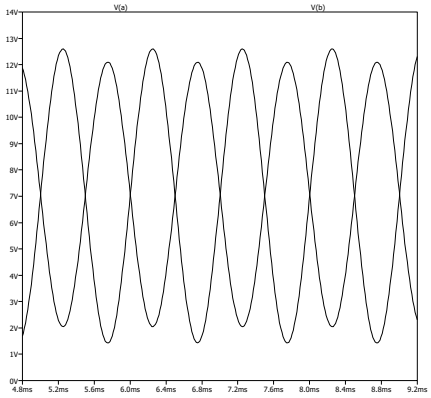
Both amplifiers share one current mirror and is good to see if there is interference.



Also, the bridge mode can be checked this way. In all datasheet examples the amplifiers have only the internal DC feedback. We can assume, that both amplifiers have good enough equality.

Double model simulation:



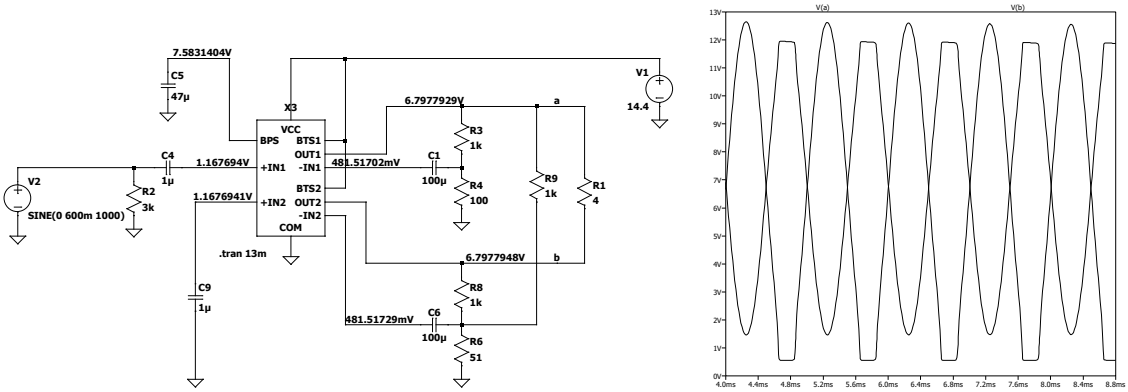


The resistor R_9 and R_8 provide zero point for the output. The input transistor of the following amplifier is trying to keep the voltage on the emitter constant, compensating the output of the *{b}* amplifier in opposite direction of the output of the *{a}* amplifier.
We can see that the outputs are not equal.

Bridge real tests and comparison:

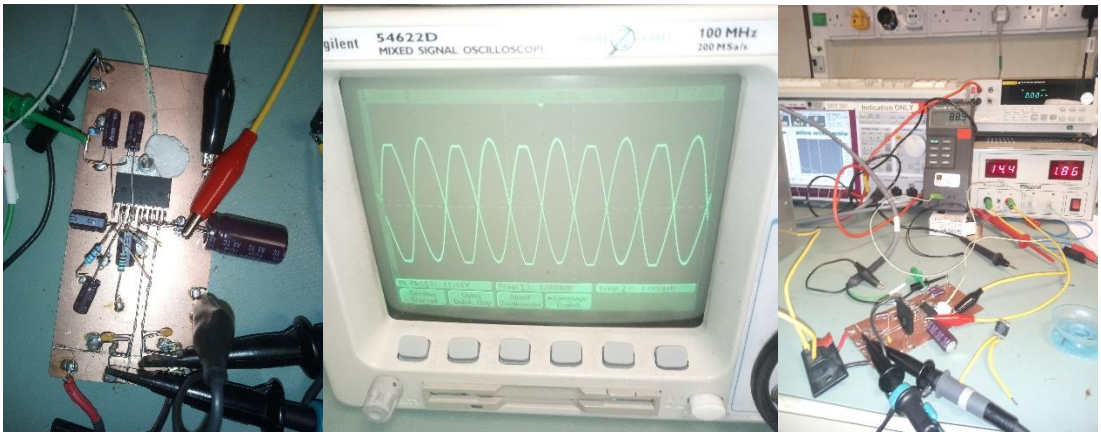
A bridge circuit without bootstrap were build and compared with scope. The goal was to check the saturation of the transistors.

Bridge simulation.



Bridge test bench:

A 3D boards were made and measured. Here are the pictures of the bridge amplifier without bootstrap:



Summary:

The models can verify the DC behaviour, consumption, and the output clamp. The AC characteristics are not measured.

23/11/2021
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