

## Class-AB audio power amplifiers using current driven bipolar power transistors

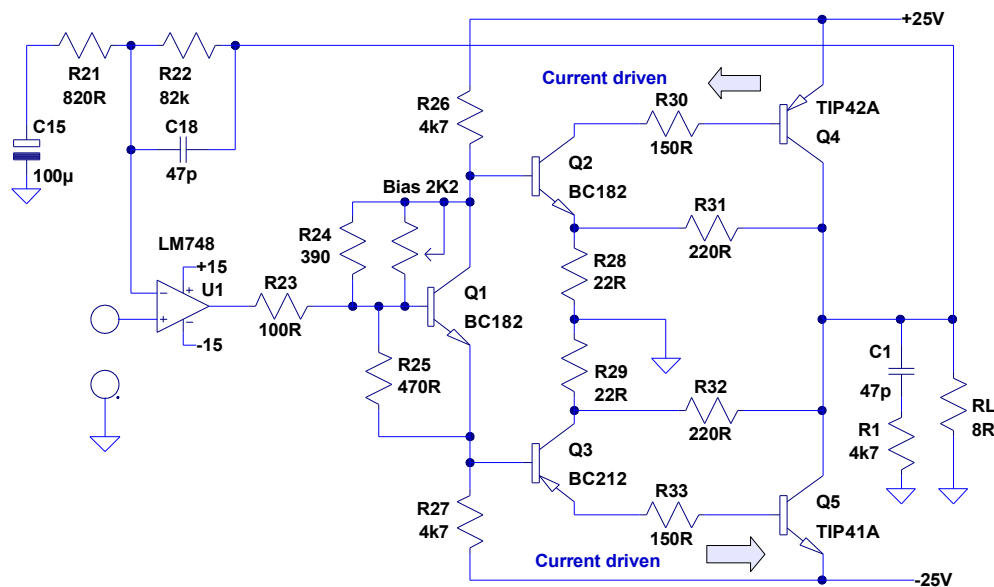
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This article covers a simple modification that overcomes most of the tricky thermal stability issues of regular Class-AB output stages. It uses a common emitter power output stage to remove the power transistors from the Class-B splitting process. That's the first step. The second step is to remove the base-emitter resistors across the power transistors.

This method is not new, it was used in the Practical Wireless 'Texan' [ref 1]. My Square-law Class-AB used it [ref 2] and Win de Jager's 'New Class-B' design used it [ref 3,4]. The Blomley used the first step but not the second step due to slow power transistors [ref 5].

**Figure 1** shows the simplified PW 20W 'Texan' from 1972. It uses current driven power transistors with no the base-emitter resistors on the power transistors. The power transistors are removed from the Class-B splitting/crossover process since they are fed by the driver's collector. The power transistors act as independent current amplifiers.

In this way temperature variations in the power transistors do not affect the optimum bias setting for minimum crossover distortion. We do not need to place the bias voltage generator transistor on the main heatsink because the power transistors do not control the splitting/crossover process. We can mount the driver transistors on a small heatsink of their own and tie the bias voltage generator to the just driver transistors.



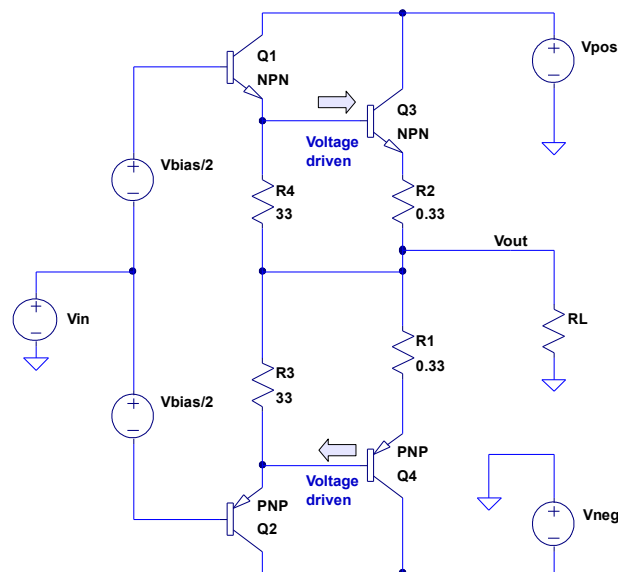
**Figure 1.** The PW 'Texan' uses current driven power transistors without base-emitter resistors on the power transistors.

Compare this to a regular Darlington output stage **Figure 2**. Regular Class-AB output stages use voltage drive to the power transistors. The power transistor's base-emitter's are in series with the driver's base-emitter junctions so any changes in the power transistor's junction temperature affects the optimum bias condition for minimum crossover distortion.

In a regular Darlington output stage the power transistors emitter resistors are indispensable to prevent *short-term* thermal runaway and to prevent current hogging when the power transistors are paralleled [ref 6 Bob Cordell book p299]. See the **Appendix 1** for some calculations.

In a regular output stage the bias voltage generator must be mounted on the power transistor's heatsink to stop *long-term* thermal runaway. Care is needed to get the bias voltage generator's

temperature coefficient correct to maintain an optimum bias condition for minimum crossover distortion. But we can only achieve *long term* tracking. Unfortunately, can't achieve *short-term* tracking due to the time delay from the power transistor's junction to the bias voltage generator on the heatsink. ThermalTrak transistors reduce this time delay from minutes to seconds but they still do not completely eliminate Thermal lag Distortion [ref 6 Bob's book 1<sup>st</sup> Ed. p304-313].



**Figure 2. Regular Darlington power stage.**

In contrast, current driven power transistors do not need *emitter resistors* in the power transistors for thermal stability. Emitter resistors in the driver stage determine the optimum idle current after it is amplified by the power transistor's Beta's ( $H_{FE}$ ). The power transistor's Beta temperature coefficient is about  $+0.4\%/^{\circ}\text{C}$  but this does not affect the *optimum bias condition* because it is determined only by the driver stage. The power transistor's Beta temperature coefficient generates some *short term* gain modulation with signal level changes but the amount of distortion is negligible compared to other nonlinearities from a current source driven output stage.

So with current driven power transistors we overcome most of the tricky thermal problems. But there are some new problems to work through. They are covered next.

### Problems with current driven power transistors

One problem with current source driven power transistors is the current gain (Beta or  $h_{FE}$ ) of each side in push-pull needs to be well matched for low distortion.

Another is the Beta fall at high current generates Large Signal (LSN) distortion.

The third problem with current source driven power transistors is a slow turn-off of the power transistor's with no base-emitter resistors. A slow turn-off causes more power dissipation and distortion at high frequencies due to cross-conduction. With the earlier generation transistors (from the 1970's) their 4 MHz  $F_T$  rating causes cross-conduction dissipation to start increasing from a few kHz which is inadequate for modern audio power amplifiers. We want our power amplifiers to work at full power at 20kHz without gobs of extra dissipation from cross conduction.

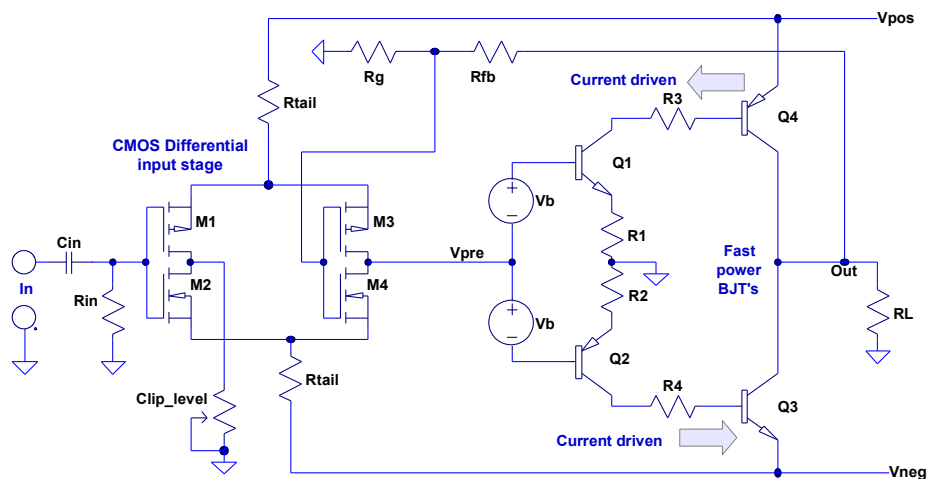
The above problems are not significant problems for regular voltage driven power stages, and that's the main reason why current driven power transistors could not be used in the past.

### Mitigating current drive problems

Modern RET power transistors are a factor of 10 faster than earlier generation power transistors so cross-conduction is no longer a major problem for audio frequencies. These faster power transistors

also offer a factor of 10 lower Beta-fall than earlier generation power transistors and their large signal linearity is no longer a problem. For example, Wim de Jager's design achieves 0.01% distortion at 1kHz and cross conduction is not an issue at 20kHz thanks to very fast power transistors (2SA1095 and 2SC2565) with an  $F_T$  of 80MHz.

**Figure 3** is a simplified circuit for another current-source driven Class-AB circuit that I built recently using relatively fast 30MHz power transistors. I wanted to measure cross conduction at 20kHz to find out if this design can be run at 20kHz without overheating from cross conduction. Amplifiers are rarely run at full output above 10kHz apart from bench testing. Music does not have these high levels of high audio frequencies for a long duration and if it did most tweeters would burn out long before the power amp overheated from cross conduction.



**Figure 3. Simplified current source driven (CSD) Class-AB amplifier circuit.**

I did not use emitter resistors in the power transistors and the bias voltage generator transistors were thermally linked only to the driver transistors and it was thermally stable. I also paralleled two power transistors with no emitter sharing resistors, just individual base resistors, and this too was thermally stable.

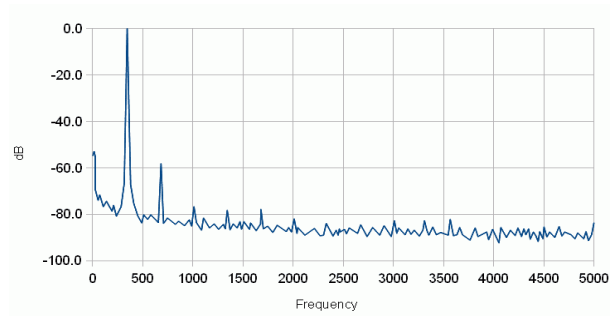
I used ThermalTrak power transistors because I had some at hand. I was able to use their internal diode to monitor differences in their case temperatures to accurately monitor current sharing of paralleled pairs. They shared current evenly.

I tested them to high temperatures with a direct short circuit on the speaker output terminals until an over-temperature cut out turned it off (the fuse was shorted for this test).

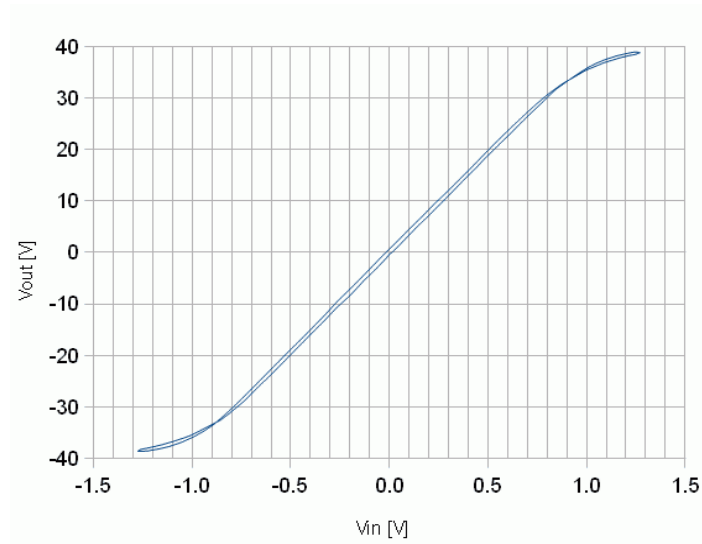
There are several fast power transistors available such as the inexpensive MG6330/MG9410 pair or FJA4313/FJA4213.

[end of snippet]

**Postscript:** On **Mitigating current drive problems** using Miller neutralization – see simulation example here [https://drive.google.com/file/d/1k1v\\_IYy9lw0SW5gj8kWtZ68BDdBMqJJo/view](https://drive.google.com/file/d/1k1v_IYy9lw0SW5gj8kWtZ68BDdBMqJJo/view) file: “Beta\_Rush-CSD-OPS-cct.PDF” July 2019.



***Figure 7. Closed loop 0.1% THD at 333Hz 8W***



***Figure 9. Closed loop XY plot at 333Hz and 30V RMS***