Alex Nikitin, London, October 2007 alexnik@attglobal.net

N-channel D-MOSFET output stage with improved linearity.

In 1992 I came up with the idea of an N-channel only output stage using “Switching” or D-MOSFETs, based upon a bipolar output circuit introduced by John Linsley Hood in his “Simple Class A Amplifier”[1]. **Fig 1** shows the basic topology of this circuit which uses an N-ch phase splitter to drive two N-ch output devices – either in class A or class AB mode.

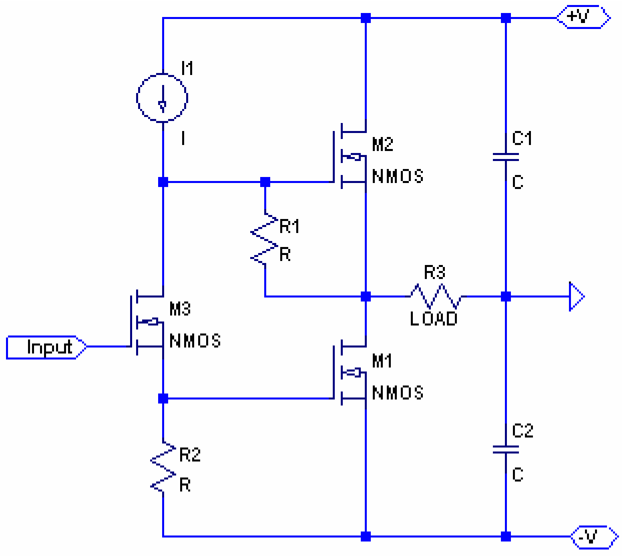

Fig 1: Nch phase splitter

The current from the source I1 is split by FET M3 between two equal value resistors R1 and R2, creating the Vgs voltages for the two output MOSFETs M1 and M2. The sum of the two Vgs voltages is always the same, producing a perfect out of phase drive, required by the push-pull output. The main disadvantage of this topology is its high output impedance without an overall negative feedback (NFB). To improve on it, in 1993 I replaced the N-ch splitter with a P-channel device (See my article in “Radiohobby” magazine #6 1998 [2]). This topology is shown in **Fig 2:**

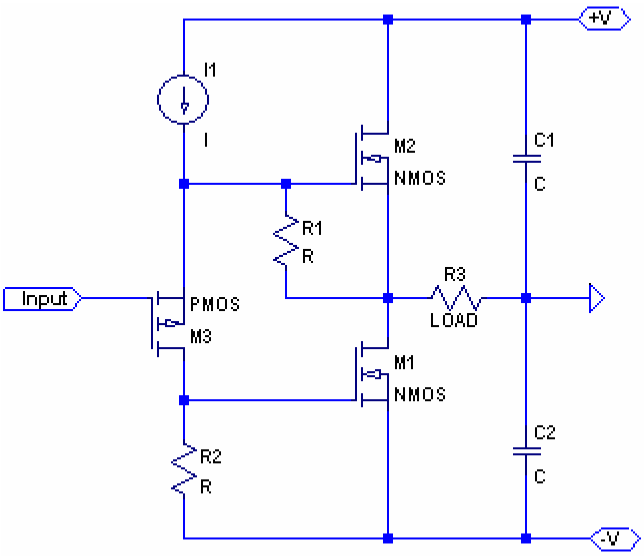

Fig 2: P-ch phase splitter

This circuit is a follower and has a low output impedance, good symmetry and linearity even without an external NFB loop. This configuration was used by me in the first generation of Creek Audio MOSFET-based amplifiers (4240, 5250, A52, 4330) with good measured performance and sonic results. However it required a reasonably high idle current for good linearity. The 4330 output stage was biased at about 70-75 mA, earlier models had even higher idle currents. One of the main reasons for this was that the symmetry of the output drive is provided by FET M3 with a local feedback by R1, reducing the transconductance of the driver. Another problem arises from a nonlinear input capacitance of M2 connected in parallel with R1 thus affecting the local feedback and linearity of the driver, especially in the crossover region and at high frequencies. In 1999 I found a way to substantially improve the performance of this output stage with a very simple modification. Before looking at that new configuration it would be useful to recall one more way of driving a same polarity output stage, known at least from the mid-1970s. It is shown in **Fig. 3**.

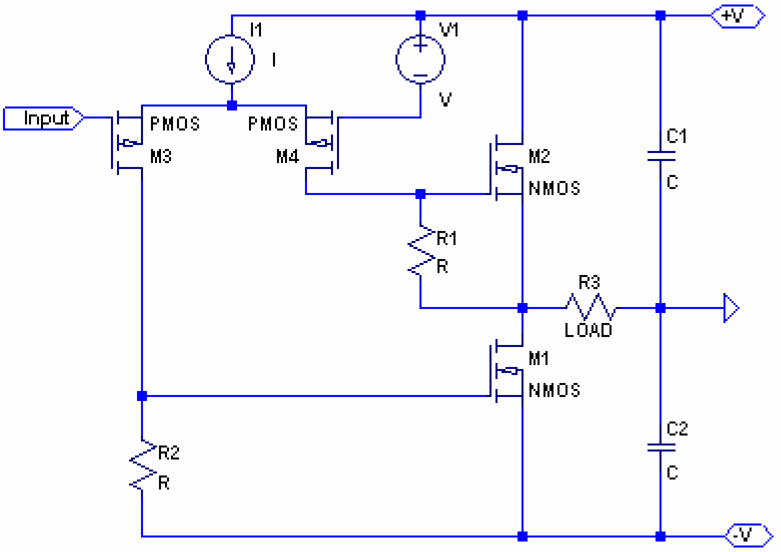

Fig 3: P-ch differential phase splitter

Unfortunately this approach has the same disadvantage as the one in **Fig 1** – high output impedance without an overall NFB loop. Now it is time to show the improved configuration:

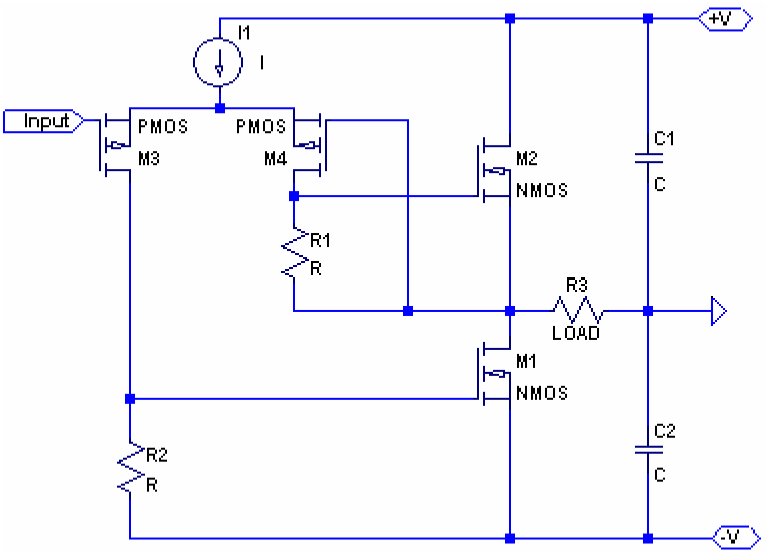

Fig 4: Differential P-ch phase splitter in a local NFB loop

This looks like a cross between the previous two – there is a differential P-ch driver stage, however it is connected so that the output stage is a follower. For this circuit to work the Vth of the output devices should be lower than Vth of the drivers by a good margin. This is easily achieved if the output devices are **low threshold D-MOSFETs** (often called "Logic Level") with Vth<2V and drivers are standard threshold D-MOSFETs [3] with Vth in the area of 3.5-4V. If all the FETs had the same Vth it would be necessary to provide an additional bias voltage for FET M4. The result of this addition is a noticeable improvement in linearity – first, because the open loop gain of the driver stage is higher and second – because the nonlinear input capacitance of M2 is now not a part of the local NFB loop as it was in the circuit of **Fig 2**. During the first tests of this configuration I introduced a jumper link across M4 to convert the circuit into the previous version for comparison. Experiments on the 4330 amplifier showed that the idle current could be reduced by half with the same distortion performance and some improvement in sound quality. That is how the 4330mk2 was born, and then the 5350 and 5350SE amplifiers which used the same approach. **Fig 5** shows a couple of possible improvements to the circuit of **Fig 4**, to make it more symmetrical and better thermally compensated, however I have not tested these. **Fig 6** shows a complete output stage for a 40 W into 8 Ohm amplifier, similar to the one used in the 4330mk2 integrated amplifier.

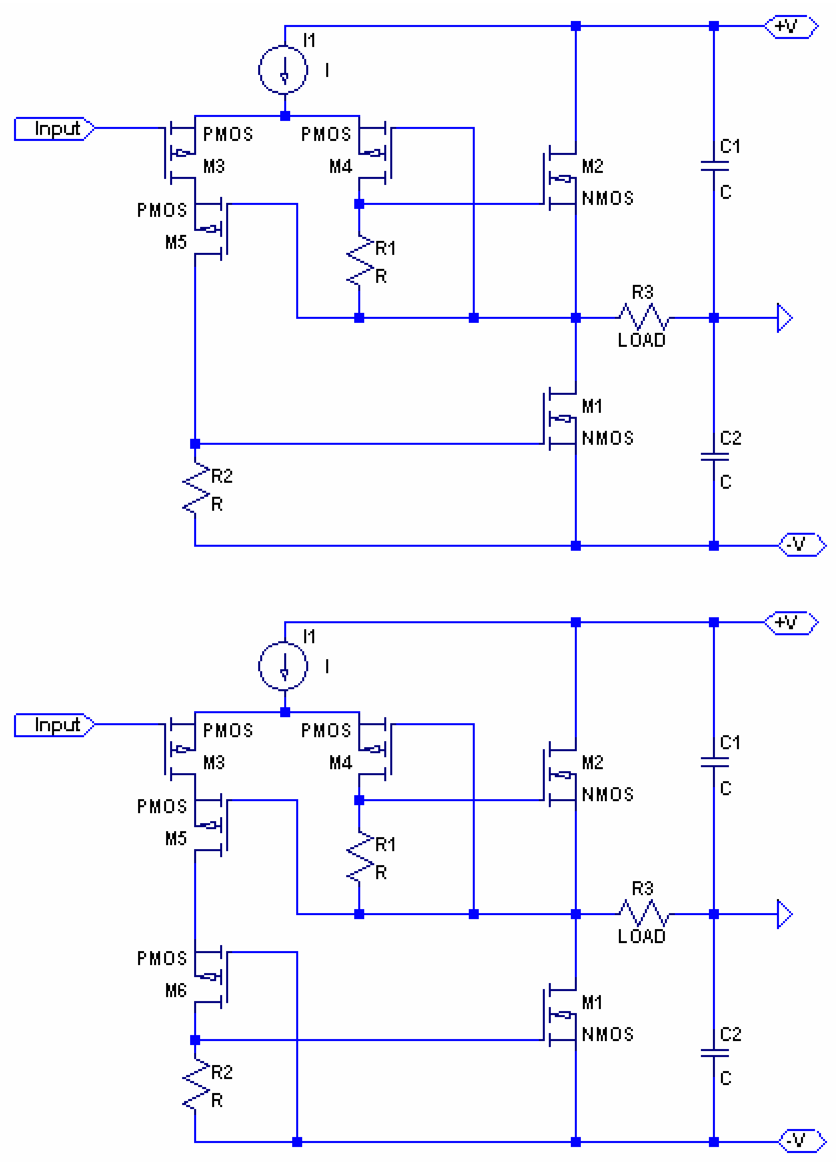

Fig 5: Balancing the power for M3 & M4 and driving conditions for M1 & M2

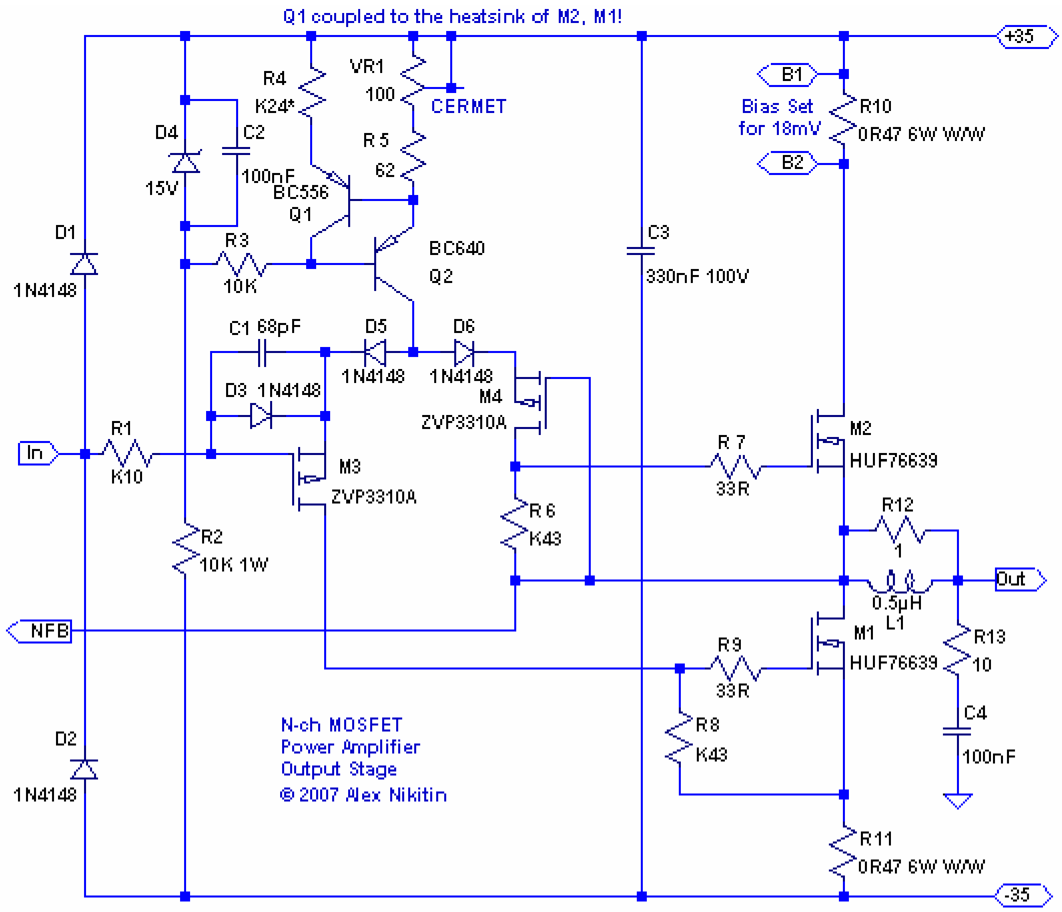

Fig 6: an example of a complete output stage

References:

[1] – “Simple Class A Amplifier”, by John Linsley Hood, “Wireless World”, Apr 1969, p148

[2] – “The history of one circuit”, by Alex Nikitin, “Radiohobby”, Dec 1998 (Russian language magazine published in Kiev, Ukraine).

[3] – “High Performance Audio Power Amplifiers”, by Ben Duncan, Newnes 1996, pp 177-183