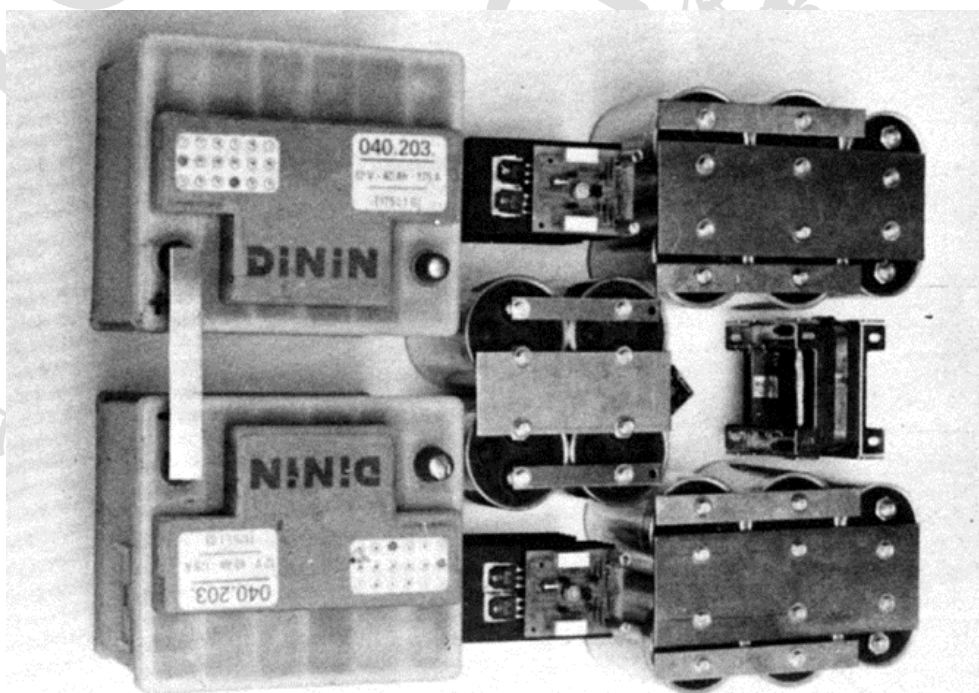


Inrush Limiting for Hiraga Le Monstre Battery Power Supply

XEN Audio

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One of the power supplies we intend to try on the Le Monstre variants is using 2x 12V car batteries, in addition to a pair of 150,000 μ F electrolytic capacitors. The original Le Monstre has a current consumption of about 800mA. So even for 2 channels at 1.6A, a 45Ah battery will allow you to listen all day. There is no real need to connect an additional transformer supply at the same time.

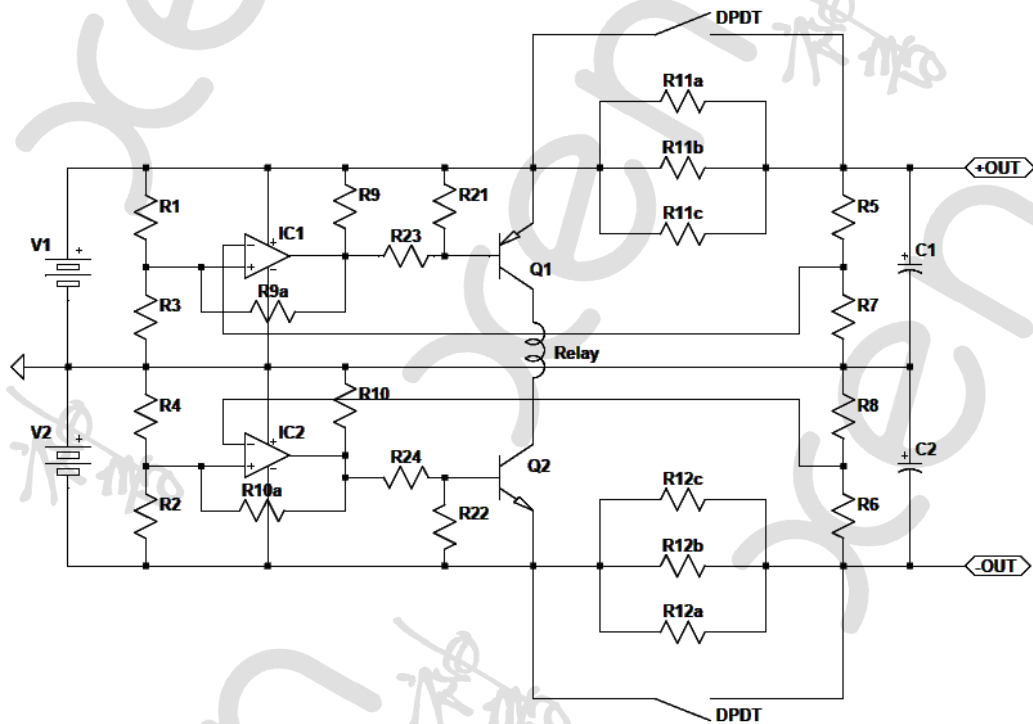
Connecting a 12V 45Ah lead acid battery to a 150mF electrolytic capacitor will result in huge inrush current. NTC Inrush current limiters are commonly used in such situations. But they have a significant drawback in their residual resistance at steady state, especially when the load current draw is low. A CL60 NTC, for example, has a cold resistance of 10R, but still has a residual resistance of 0.2R at 5A continuous current.

The 555 Timer Solution

Another commonly used method is to charge up the capacitors initially via a pair of high-power resistors. A timer circuit then triggers a relay to bypass the latter. Take a resistor of 3R, for example. The instantaneous current at first connection is limited to 4A (and 48W). But as the amplifiers continue to draw 1.6A through them, there will always be a voltage drop of 4.8V across them. That also means that the capacitors can only reach 7.2V before the timer driven relay triggers. As both the car batteries and the electrolytic capacitors have very low internal resistance, the current pulse through the relay will most likely be destructive. The simple solution then is a 2-stage switching, firstly the bypass relay for the resistors, shortly followed by a second relay for connecting to the amplifier power rails.

The timing for the bypass switching depends on the resistor / capacitor combination. 3R and 150,000 μ F gives a time constant of 0.45s, so that the delay for the bypass relay should be set to ~3s to be on the safe side. This can be followed by an additional delay of 1s for the amplifier relay.

The Comparator Solution



Another method can be just to make use of a comparator to compare the capacitor voltage to that of the battery. Once the former has reached e.g. 95% of the latter, the bypass relay can be triggered. However, there is still a small voltage difference between the two, so there is still a surge current at the first instance of electrical contact.

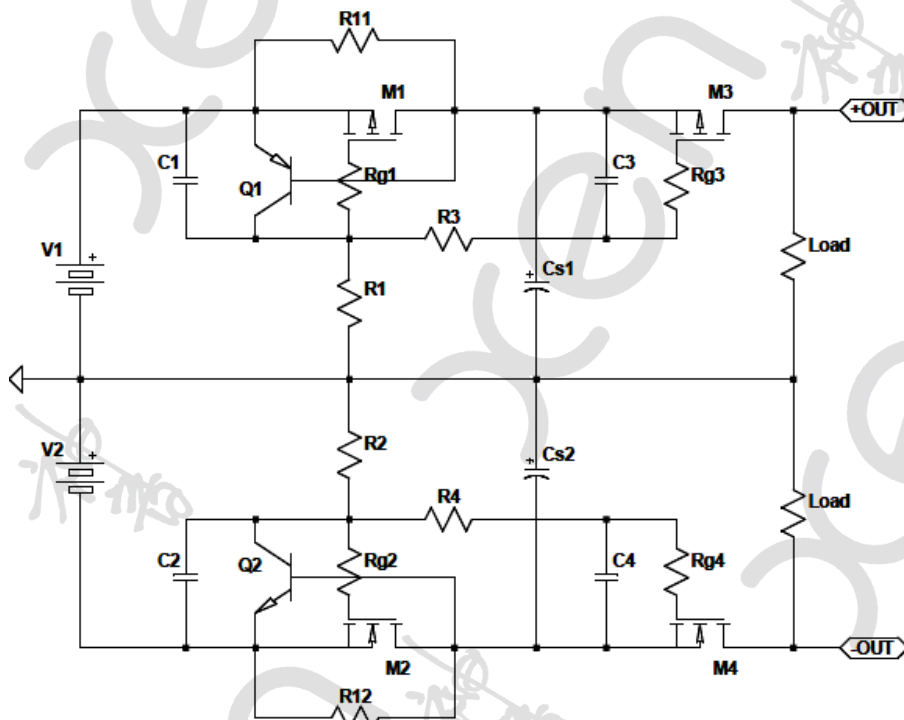
17W ceramic wire-wound resistors are relatively cheap. Taking 3 of them will make a 50W resistor without any need of heat sinks. For a 13.2V supply, the inrush current can be up to 3.8A. So each of the 17W resistors should be 10R. In theory they will survive the load current continuously. One can get away with less power, but the cost saving is minimal and not worthwhile.

The two inputs to the comparator can be half of the battery and capacitor voltages respectively, using simple resistor network as potential dividers. The output of the comparator has pull-up resistors as well as hysteresis feedback. The outputs of the comparators of both positive and negative rails are used to trigger a DPDT bypass relay to short out the inrush resistors. As we wish to make sure both capacitors are fully charged before the bypass, the 24V relay are to be driven across the +/-12V rails via PNP and NPN transistor switches.

A second DPDT relay should be used to switch on the load after a short time delay. Since most relay have a must-on voltage of about 70% of the rated voltage, we can allow 2V drop across each rail with a 100R resistor. These, combined with a 470μF 25V capacitor, will give a delay-time constant of 0.1s. Sufficient to make sure the bypass relay has been activated.

On power down, the incoming voltages drop out, but the capacitors are still partially charged up. Two clamp diodes such as normal 1N4004's can be used to continue to supply the comparator and the relays, until the voltages drop to a level when the relays drop out. The capacitors can be completely discharged by adding two 470R 2W resistors across them. They hardly draw any current during normal operation.

The BJT Clamp Solution



The comparator method still has a small drawback in the surge current at the instance of contact, be it across a much smaller voltage difference. This can be overcome by using MOSFETs for switching. By controlling the rate of V_{gs} change during switching, the MOSFETs can act as a sort of soft switch.

Ryan Brownlee^[1] published a MOSFET based inrush limiting circuit, using a bipolar transistor to clamp the MOSFET gate to the source, turning it off in the process. This clamp is only release when the downstream voltage is $<0.6V$ lower than the upstream voltage. The above-mentioned capacitor across the MOSFET gate-source then allows the latter to first turn on in the resistive regime, before reaching saturation regime at low R_{ds_on} . The surge current can then be kept under control.

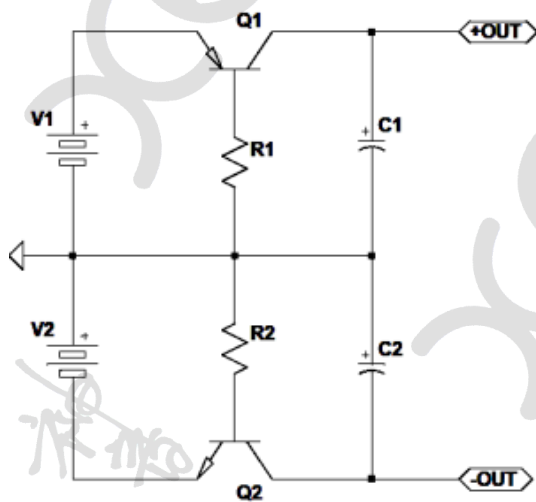
For the amplifier switching, a second MOSFET can be added downstream. This can still use the same BJT clamp from the above, but with added RC network to ensure this switches only after the MOSFET upstream.

The hfe Current Limiter

The MOSFET solution has very low ON resistance, probably lower than the relay, especially over lifetime. But if one would accept an ON resistance of about $0.1R$, there is another VERY simple solution.

The collector current of a bipolar transistor is proportional to its base current. By using a high-current switching PNP on the positive rail, and connecting its base to Gnd via a resistor, the base current, and hence the collector current, can be controlled. Essentially one gets a high current CCS with next to no voltage drop at saturation. So the amp can be hung directly to the caps without the need of a 2-stage switching.

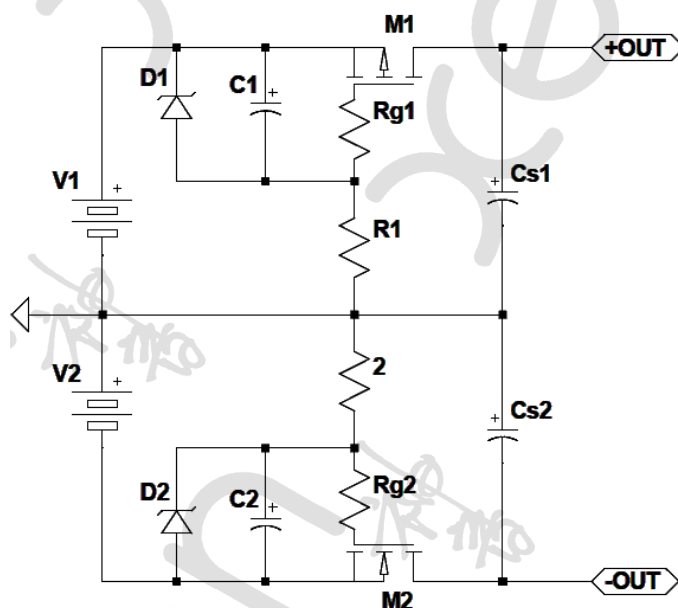
At start up, the bias current is limited by the base resistor to $\sim 2.5\text{A}$, so that the dissipation is below 30W . Once the large rail cap is charged up, the current drops to that required by the amp only, and the voltage drop is $V_{ce}(\text{sat})$.



One needs to match h_{fe} for NPN and PNP, so that the voltages ramp up symmetrically. Or one can also adjust the base resistor values to compensate. The ON resistance is not as low as the MOSFET, but it is pure simplicity. The only danger is that h_{fe} changes with temperature / lifetime, etc., which will affect the synchronisation of the two rails. The BJTs will need to be on heatsinks, or a lump of aluminium.

Note also that because we set the max bias to 2.5A , this is also limiting the current towards the amp. i.e. if the amp needs more, it will have to take it from the caps.

Maybe MOSFETs after all ?



Not entirely happy with the relatively high ON resistance of the BJTs, maybe an equally simple solution with MOSFETs is possible.

As mentioned before, an R-C delay can switch on the MOSFET slowly. If it is slow enough, it can also reduce the peak pulse current, as R_{ds_on} only reduce gradually with increasing V_{gs} in the transition region. The final gate voltage can be clamped with a simple Zener diode, so that the circuit still works with higher rail voltages than the maximum V_{gs} allowed.

Because the NMOS and PMOS are slightly different on both V_{gs} and R_{ds_on} , one of the resistors should be adjusted to synchronise the voltage rise. A small difference in transient voltage is not critical, as the total rise time is less than 1s.

References

1. <https://www.radiolocman.com/review/artical.html?di=647849>