Summary

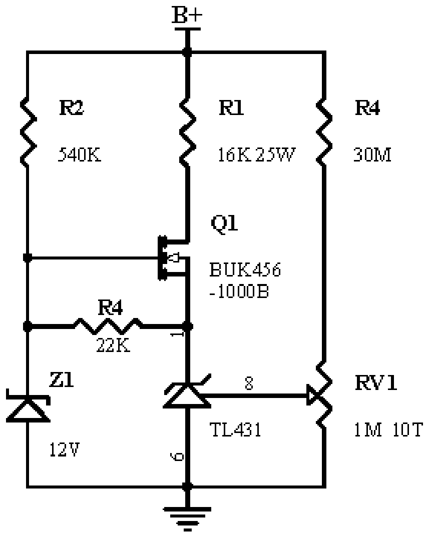
In valve amplifiers, a high-voltage B+ power supply that uses chokes to filter large levels of AC voltage will typically generate an initial over-voltage level prior to the amplifier's valves conducting sufficient nominal load. The level of over-voltage can stress filter and coupling capacitor voltage ratings, as well as other parts.

Heaters in amplifier valves can take tens of seconds to heat cathodes up sufficiently for the various amplifier stages to conduct significant levels of current.

With no initial loading, choke input (LC) filter power supplies, and also CLC filtering where the first C is quite low in capacitance, can charge the B+ rail up to the peak of the available power transformer secondary voltage, a level that can be up to 50% higher than the idle B+ voltage during normal amplifier operation.

Even valve rectified power supplies can impose this initial over-voltage, as valve diodes typically start conducting much sooner than indirectly heated amplifier valves.

This article presents a simple high voltage DC shunt load, to act as a pre-load on the B+ supply until the main amplifier loading is sufficient to drop the B+ voltage to the normal idle voltage level. The shunt load is all electronic, with few components, and has a load turn-on transition voltage range of about 25V. The voltage rating of the load can be up to about 800-900V, and the conducting current up to 100mA.



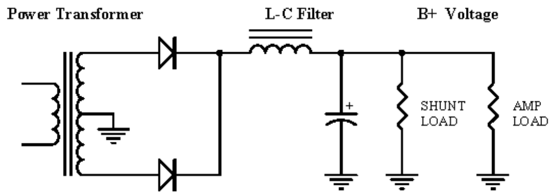
Example circuit for 630VDC 25W shunt load used in a EL34 PP amp with a 560V B+ idle.

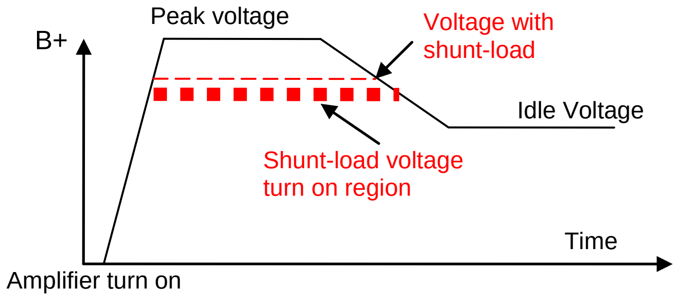
Over-voltage stress

During the initial B+ over-voltage period after amplifier turn-on, all the power supply filter caps may be exposed to the peak B+, as there may be little or no resistive loading within the circuitry. In addition, signal coupling capacitors that connect to valve plate loads can also be subject to peak B+ stress. The power supply rectifying diodes will also experience higher levels of reverse voltage.

Shunt Load Operation

The aim of the shunt load is to restrain B+ voltage to a level somewhat above the normal idle level of the amplifier, prior to the output stage loading the power supply and causing B+ to fall to its idle voltage level.





Idle voltage can vary significantly with mains AC voltage variation, and the idle bias conditions of the output stage. The shunt load should conduct negligible current up to the maximum expected idle voltage level.

The shunt load will progressively turn on over a small range of increasing B+ voltage. Within that turn-on range of B+ voltage, the main power control device, a power FET, will experience its highest power dissipation condition, and should have heatsinking suitable for that maximum dissipation.

Depending on the choke design in the power supply, the main power resistor in the shunt load needs to dissipate a power level similar to half the output power tubes in idle for a PP amp – eg. 10W to 30W. Although the shunt load should only need to dissipate that power level for a short period of time (eg. 10-30 seconds), it should be designed to handle the power continuously.

Without the shunt load, the B+ voltage would rise up to a peak level. For example, a largish power amplifier with 500-550VDC idle B+, could initially have B+ near 800VDC. A suitable shunt load would start to conduct at 600VDC, and B+ settle at about 650VDC with the shunt load FET fully on.

Shunt Load Design

The shunt load effectively applies resistance R1 across B+ when the B+ voltage exceeds a preset high voltage level. The negative side of R1 is pulled down close to 0V when the power mosfet Q1 is turned on, and the TL431 regulator cathode voltage is pulled to a low level (down to about 2V).

The TL431 pulls down its cathode voltage when the reference terminal voltage starts to exceed 2.5V, as determined by the voltage on the wiper of the pot RV1. As the TL431 cathode voltage falls, the gate-source voltage Vgs of Q1 increases, as the gate voltage is fixed to the zener Z1 voltage. When Q1 Vgs exceeds about 3V, the drain source resistance Rds of Q1 falls towards nearly 0Ω, and so the resistor R1 progressively starts to conduct current to act as a shunt load on B+. With Vgs well above 3V, Rds is near 0Ω, and the shunt load looks just like a constant resistor R1 loading B+.

With B+ voltage below the preset level, the TL431 cathode conducts negligible current, and Q1 source voltage is close to the Z1 voltage, so Q1 Rds is high, with negligible current flowing through the shunt load.

Z1 voltage needs to be sufficient to allow Vgs to fully turn the FET on when TL431 cathode is pulled down to about 2V minimum. For a standard FET, a 12V 400mW zener is fine. The zener voltage could be higher as the TL431 cathode can withstand up to 36V, but Vgs for some FETs may have a 20V limit. The zener voltage could be lower, especially when using a logic FET, as the FET doesn't need to be fully enhanced. There may be benefit in lowering Z1 voltage to lower the max TL431 loss, as the TL431 is a small package, and could be configured to pass up to 100mA.

The zener supply resistor R2 needs to keep enough current passing through the zener so that the zener voltage approaches its nominal rating, as well as provide enough current to the TL431 for it to operate correctly and pull the FET source down sufficiently. At least 1mA supply at the shunt load switching voltage is likely to be the minimum needed - so R2 may need to be 1-2W rated. R2 also needs to withstand the max B+ voltage, so two or three resistors may need to be series connected to meet the voltage rating.

The FET gate-source resistor R3 conducts TL431 current sufficient to increase Vgs. To achieve Vgs=10V enhancement, the current through R3=22k needs to reach 0.5mA. But R3 current will reduce zener Z1 current, so the zener voltage may droop somewhat.

The reference voltage divider circuit for the TL431 needs to allow 4uA worst-case current in to the reference terminal. A divider resistance R4 of less than 5MΩ per 100V (ie. up to 30MΩ for 600V) should provide sufficient divider current. Again, R4 voltage rating is an issue, with R4 at least two series resistors.

The FET Vds voltage rating preferably needs to exceed the likely peak B+ voltage without the shunt load operating. The example circuit uses a 1,000V rated FET, and nowadays there are many models with ratings between 600V and 1,000V.

The FET should thermally withstand continuous operation with Vds = ½ B+. At that voltage, R1 is dissipating half the shunt load loss, and Q1 is dissipating the other half – which is the worst-case situation for Q1. In the example circuit, if B+=650V then Q1 current would be 325V/16kΩ = 20mA, and junction dissipation is 7.5W. A TO220 package will need some heatsinking, and suitable high voltage insulation.

Typically, the FET would quickly pass through the worst-case dissipation region as B+ initially rises soon after mains turn-on, and then more slowly as B+ falls when the amplifier power stage starts to conduct significant bias current. The range of voltage over which the FET transitions from fully off to fully on is about 25V in the example circuit. The magnitude of the range depends principally on the FET transconductance and TL431 voltage gain, but may also be affected by TL431 and zener operation at quite low current levels.

R1 should be not too low that the loaded voltage of B+ is near the normal idle B+ voltage. Aim for R1 to be just low enough to force the FET fully on when mains voltage is a bit below nominal (B+ will then be a bit higher at normal mains). Determining a suitable resistance value may need changes, as the voltage regulation of B+ at light loads depends somewhat on the type of inductor used, and require a change in bias current setting. Duncan Tools PSUD2 is a useful tool for determining R1.

Another option

A timed relay can be used to connect the power transformer HV secondaries (like a standby switch) about 30 seconds after amp turn-on. High B+ is then avoided, as the output stage cathodes are up to temperature at the time the diodes start conducting. Bleed resistors across the relay contacts can partially raise B+. This option has the advantage of no high power rated parts, but the relay needs suitable contact voltage ratings.