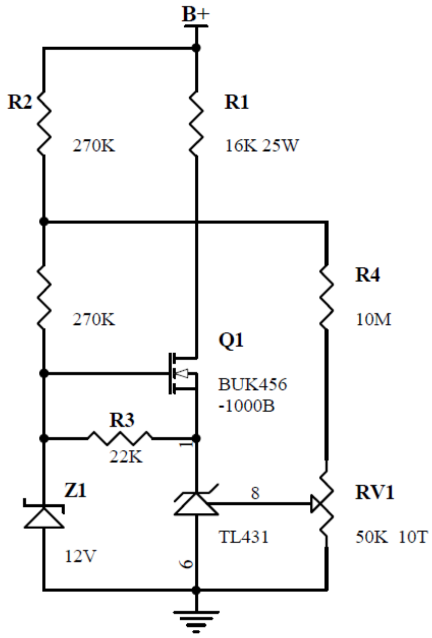
## Summary

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. Even short duration 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 start conducting significant levels of current. Solid-state diodes and directly heated valve diodes start conducting current well before amplifier valves, causing B+ over-voltage for circa ten seconds. Even indirectly heated cathode diodes may start conducting seconds before amplifier valves start to load down the B+ voltage.

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.

This article presents a simple high voltage DC shunt load, to act as a pre-load on the B+ supply until the main amplifier circuitry starts to sufficiently load the power supply and 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 charge up over a number of seconds to peak B+. The power supply rectifying diodes will also experience their highest level of reverse voltage, so are more prone to arcing from cathode to plate. Some amplifiers are designed to handle these stresses, with suitable operating voltage margins on all parts, but many amplifiers are not, or it is too difficult or complicated to restore or repair an amplifier with suitable over-voltage performance.

Some vintage equipment managed this by including a high-wattage wire-wound resistor to conduct enough current for the choke-input filter to operate above the critical inductance condition, to avoid capacitor-input like voltage levels. An uncommon method to increase the effective inductance of the choke, and thereby lower the bleed current necessary to meet critical inductance conditions, is to add a ripple trap R-C filter across the choke.

One common method to avoid turn-on over-voltage stress is to use a timed relay 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 HV diodes start conducting. Bleed resistors across the relay/switch contacts can partially raise B+ prior to normal operation. This option has the advantage of no parts dissipating high power, but requires more intervention into the amplifier's circuitry, and the relay needs suitable contact voltage ratings and multiple poles. This option may also stress output stage valves with significant circuit time constants for charging coupling and cathode bias bypass capacitors after a step application of B+. This option may stress valve diodes, as the diode transient peak current level in the first 100-200ms may be higher.

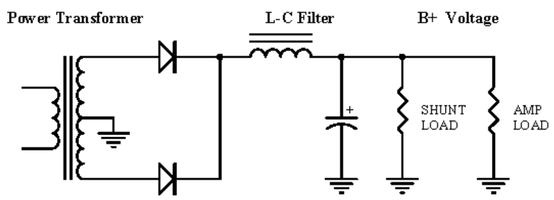
## Shunt Load Operation

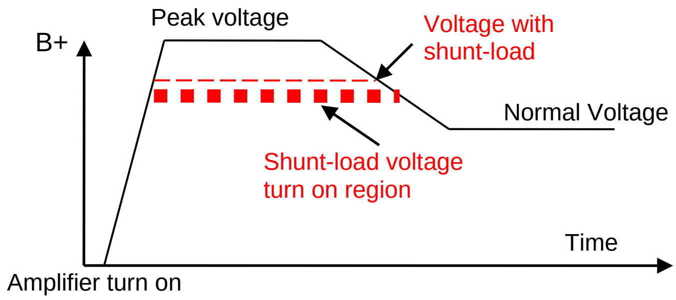
The aim of the shunt load is to restrain B+ voltage to a level somewhat above the normal idle level of the amplifier, prior to the output stage load causing B+ to fall to its normal operating voltage level. The shunt load bleeds enough current through the choke to keep its operation at about the critical inductance operating condition, and hence suppress B+ to just above nominal idle operating level.

Idle voltage could 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 needs to progressively turn on over a small range of increasing B+ voltage, which limits B+ to an acceptable upper limit, whilst sufficiently exceeding the normal idle 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.

Without the shunt load, the B+ voltage may rise up to a peak level, depending on how much bleed resistance exists in the amplifier circuitry. For example, a largish power amplifier with 450-550VDC idle B+, could initially have B+ approaching 700-800VDC. Parts susceptible to that voltage level could include typical 630VDC rated coupling caps, or 600VDC rated electrolytic caps. A compatible shunt load would need to start conducting at 575-600VDC, and limit B+ to about 600-630VDC with the shunt load FET fully on.




Depending on the choke/filter design in the power supply, the shunt load's main power resistor may need to dissipate a significant % of the power normally dissipated by the output power tubes – eg. 20W to 40W in a PP amp. Although the shunt load only needs to dissipate that power level for a short period of time (eg. 10-30 seconds), it should be capable of handling the power continuously.

### 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).

Duncan Tools PSUD2 is a useful tool for estimating R1, by simulating the power supplies output voltage with just R1 as load. Aim for R1 to restrict B+ to the target max level (eg. 630VDC). For the example with B+=630V and R1=16kΩ, resistor dissipation is 25W. 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.

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 is not likely to be fully enhanced. The TL431 Vak is pulled down to 2.5V with significant R1 current, with package dissipation up to 0.25W at 100mA, and so the TO92 with Rja ~ 140 ºC/W could have Tj up to about 85ºC for 50ºC ambient.

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 through R2 at the shunt load switching voltage is likely to be the minimum needed. R2 also needs to withstand the max B+ voltage, so two 270k 0.6W 350V rated resistors connected in series are used.

The FET gate-source resistor R3 conducts TL431 current sufficient to increase Vgs. When Vgs rises above about 3-4V, the TL431 current will increase mainly from Q1 current, so R3 can remain fairly high such that R3=22k is reasonable. Current through R3 will reduce zener Z1 current, so the zener voltage may droop when Vgs is high.

The reference voltage divider circuit for the TL431 needs to allow 4uA worst-case current into the reference terminal. A divider resistance R4 of less than 5MΩ per 100V (ie. up to 30MΩ for 600V) should provide sufficient divider current. R4's high value and voltage rating is alleviated by using the R2 mid-point to allow just one 10MΩ 0.5W 350V resistor.

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.

It is possible that the power supply could operate continuously at the shunt load turn-on voltage – for example due to mains voltage variation or during testing with a variac. Within that turn-on voltage range, R1 dissipates half the shunt load loss, and Q1 dissipates the other half – which is the worst-case situation for Q1, and the FET should thermally withstand that operation. In the example circuit, if turn-on B+=600V then Q1 current would be 300V/16kΩ = 19mA, and junction dissipation is 5.6W. A TO220 package with Rj-c = 1 ºC/W will need an Rc-a < 8 ºC/W heatsink to keep the FET junction below 100º for a 50ºC ambient, and will need suitable high voltage insulation to chassis.

Typically, the FET would quickly pass through its worst-case dissipation region as B+ initially rises soon after mains turn-on, and then pass back through the same region 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.

## Other Applications

One other application is to improve voltage regulation of choke-input filter HV supplies, as commonly used in vintage equipment, especially when triode or pentode-mode post regulation is used that doesn't rely on high-gain feedback regulation of output voltage (eg. the Solartron Vari-Pack SRS153). Even supplies with simple regulation could benefit, such as RTVH March 1960.