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The Kenwood TL-922

Dr Bruce Taylor HB9ANY describes this potent HF bands linear power amplifier.

One of the delights of amateur radio is the possibility of making DX contacts on the HF bands with remarkably low transmitter RF power. But when propagation conditions are poor, or interference or QSB is severe, it can be helpful to maintain a quality R5 QSO by switching in a linear amplifier that can run up to the legal limit. Since Kenwood entered the amateur radio market in 1958, the company has earned a reputation for high quality products that are built to last. Although the first TL-922 power amplifiers, **Fig. 1**, are now well over 40 years old, examples in excellent condition can still be found at swap meets, SK sales and on eBay. And there is very little to go wrong with these fine rigs that can't be repaired by an amateur.

The maximum legal transmitter output power in the US is currently 1.5kW PEP, while in Europe the limit ranges from 400W in the UK, 500W in France, 600W in Switzerland, 750W in Germany, 1kW in Norway and Belgium to 2kW in most countries of the former Yugoslavia. The TL-922 is rated for up to 30 minutes continuous operation at 2kW on SSB, or up to ten minutes continuous key-down at 1kW on CW, RTTY and data modes. The amplifier has a gain of over 10dB and the exciter energy is added to the RF output. When it is on standby the exciter RF input is routed straight through to the antenna connector.

Design

A simplified schematic diagram of the TL-922 is shown in **Fig. 2**. The heart of the unit is a pair of high-gain 3-500Z power triodes operating as a Class AB2 amplifier in the grounded grid configuration, obviating the need for neutralisation. Negative feedback is used to keep the third-order intermodulation distortion below –30dB. The valves have a maximum average anode dissipation rating of 500W and grid dissipation of 20W. They can be operated with an anode voltage of up to 4kV, but in the TL-922 they are run at conservative maxima of 3.1kV on SSB and 2.2kV on CW. Typical measured performance data for an amplifier operating at the UK power limit from 240V AC mains in SSB mode on 14.175MHz are:

- RF output power: 400W
- 2nd harmonic: –43dB
- Higher harmonics: < –59dB
- RF input power: 32W
- HT voltage: 2.9kV
- Anode current: 400mA
- (Quiescent anode current: 200mA)
- Grid current: 80mA
- ALC output: –0.7V
- AC mains input: 8.1A

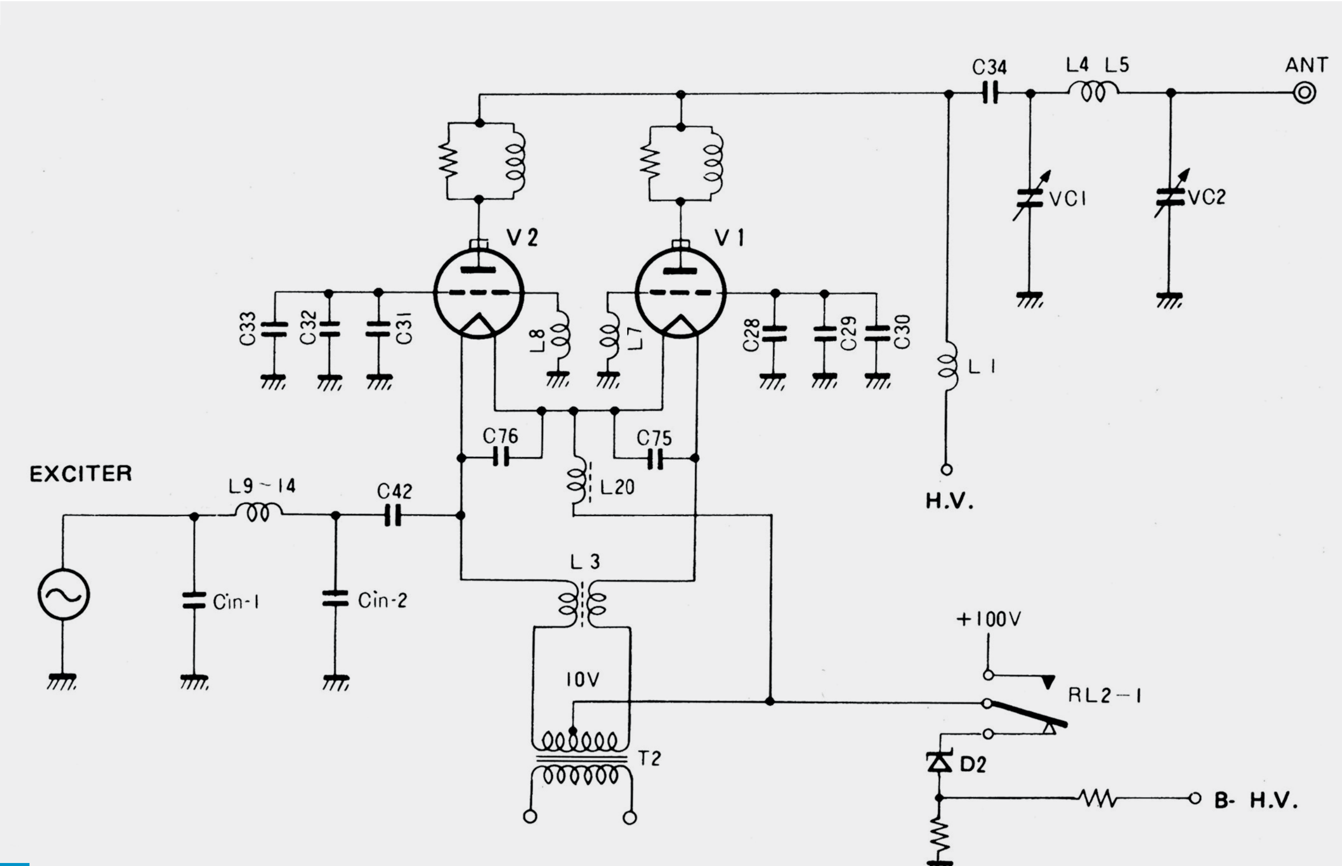
The original 3-500Z valve, **Fig. 3**, was manufactured by the US company Eimac, founded by **Bill Eitel W6UF** and **Jack McCullough W6CHE**, and much of the development work on the valve was done by **Bill Orr W6SAI**, well known for his *Amateur Service Newsletters* and his contributions to the OSCAR satellite programme. Eimac (now part of Communications & Power Industries) no longer manufactures these beautiful glass envelope valves, but only external anode types, and the last batch of Eimac 3-500Zs was of somewhat inferior quality. However, reliable graphite-anode valves were made by Amperex in Holland and France and satisfactory Chinese-made 3-500Zs are readily available from suppliers such as RF Parts and Penta Laboratories/Machlett (URLs below). Today, a matched pair of new Taylor-branded 3-500ZG valves can be purchased for about $360. Note that these valves cannot be rebuilt when they reach end of life.

www.rfparts.com
www.pentalabs.com

I've provided a high-resolution PDF of the full schematic diagram for the 120/240V 'K' version of the amplifier for download here:
https://tinyurl.com/TL922a

The power transformer configuration for the 220/240V 'W' version is provided separately here:
https://tinyurl.com/TL922b

To reduce the current, the filaments of both valves are connected in series and powered by the centre-tapped 10V 15A transformer T2, from which they are isolated by RF chokes L3 and L20. Hence the amplifier can't be operated with only one valve and it's unwise to use a differently branded pair, as they can have minor differences in filament resistance. T2 also supplies the voltages for the front panel lamps and the cutoff bias, relays and ALC. The grids of both valves are DC grounded through 470µH safety chokes L7 and L8 and grounded for RF by 220pF mica capacitors C28 through C33. To set the operating point, the filaments are biased positively with respect to the grids by the 1S265 7.5V Zener diode D2. The low operating bias voltage results in a zero-input quiescent current of about 90-100mA in CW mode and 180-200mA on SSB. This reduces distortion but results in an anode dissipation exceeding 200W in both modes. The bias can be increased by inserting one or more forward-biased rectifier diodes in series with the Zener. In order to prevent the generation of RF noise during standby, the valves are cut off by raising the voltage to about 100V.



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The pi-network output circuit, **Fig. 4**, is designed to drive loads from 50Ω to 75Ω and the high voltage wide-spaced tank capacitor has a smooth 6:1 reduction drive for fine tuning. The input to the amplifier also uses six switched pi-networks, **Fig. 5**, designed to present an impedance of 50Ω to the exciter. The coil cores can be accessed from the top of the chassis on either side of the loading capacitor using a long-reach insulated alignment tool, such as the GC Electronics 8721. A VSWR at the exciter of less than 1.5 should be obtained when they are adjusted for the best match at the band centres, although this may be somewhat dependent on the length of the interconnecting coaxial cable.

Two illuminated meters allow the grid and anode currents of the valves to be monitored, as well as the RF output and the HT voltage. The RF meter gives a relative indication of the voltage at the output antenna connector and its sensitivity can be adjusted by a potentiometer on the rear panel of the amplifier. Forced air cooling of the valves is essential and this is provided by a muffin fan with a thermal delay relay that keeps it running for about two minutes after power off. Although the amplifier weighs 31kg, it is compact and can be carried easily by folding handles that are recessed neatly into the side castings of the case.

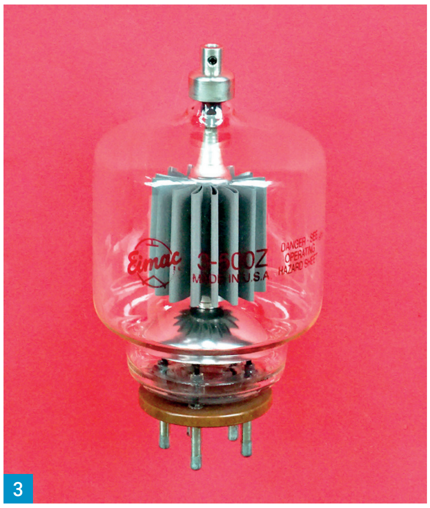
Fig. 1: The Kenwood TL-922 can deliver up to 2kW PEP on SSB and 1kW on CW on 9 bands. Fig. 2: Simplified schematic diagram of the RF section of the TL-922 amplifier. Fig. 3: With forced air cooling the Eimac 3-500Z can support an anode dissipation of 500W.

Variants

Two different versions of the amplifier were manufactured, for operation with a 50/60Hz AC voltage input of 220/240V or 120/240V. The current required for maximum power on SSB is 14A for a 220V or 240V supply and 28A for 120V. To minimise the voltage variation with load, the mains power line to the shack should be of heavy gauge and routed as directly from the switchboard as possible.

The voltage selection is made by jumpers concealed behind a panel on the rear of the cabinet, which can be removed by prising out a pair of snap fasteners. **Fig. 6** shows the jumper locations for 220V (lower) and 240V (upper) operation of the 220/240V version that was normally supplied in Europe. To ensure the correct cooling airflow, be sure to replace the panel. Both of the mains fuses on the rear panel should be the time-delayed type, rated 15A for any of the supply voltage configurations.

To avoid misuse of the amplifier by CB operators, a variant of the 120/240V ver-



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sion designated TL-922A that does not include the 10m range was supplied to some countries. For legal amateur radio use,10m functionality can be restored by reconnecting the bandswitch and removing the additional Phillips-head screw that stops it being rotated beyond the 21MHz position. Minor rewiring of the input coils L13 and L14 is also required to restore the connections shown in the schematic diagram for the 6-band TL-922.

Without any modifications the TL-922 can readily deliver up to 1kW on each of the

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10, 18 and 24MHz WARC bands. Since the amplifier uses low-pass pi-network circuits, the bandswitch should be set to the nearest frequency above the WARC band required, i.e. 14MHz for 10MHz, 21MHz for 18MHz and 28MHz for 24MHz operation. The corresponding tuning control settings are approximately 3.5, 7 and 14. In the UK, an output power of 400W is permitted on a non-interference basis in the lower half of the 6m band from 50 to 51MHz. The TL-922 can be used on this 'magic band' with quite minor modifications to the input and output tuned circuits and the anode parasitic suppressors. Kits of the required components are offered on eBay for less than $10.

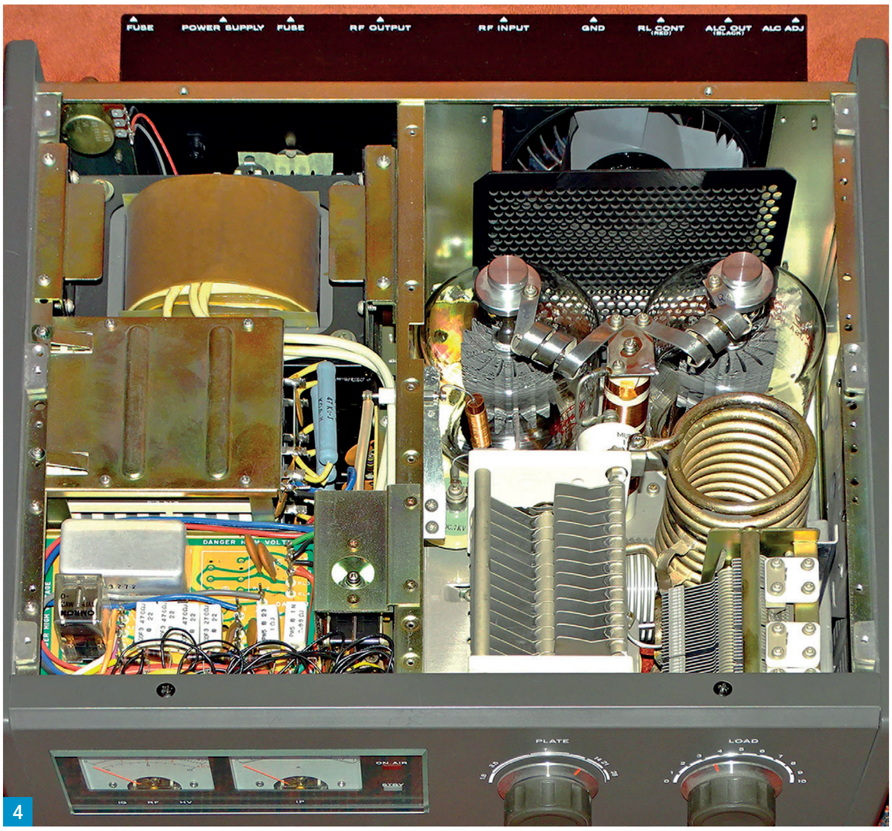
Safety

In view of the lethal voltage of the HT supply in the amplifier, several safety features are incorporated in the design. However, before any intervention the plug should be completely disconnected from the mains supply and bagged to avoid confusion with those of any other equipment on the service bench. When the top cover of the cabinet is removed, a double-pole switch automatically interrupts the mains power supply to the HT transformer, **Fig. 7** (upper). However, mains connections are exposed if the bottom cover is removed.

The eight series-connected 200μF 500V electrolytic capacitors of the HT voltage doubler are mounted in a stack of plastic spacers and enclosed in a metal box, **Fig. 8**, and these capacitors are bypassed by 47kΩ 7W metal film resistors. In addition to balancing the voltage across the capacitors, they serve as safety bleed resistors that discharge the capacitors in 20-30 seconds after the power is switched off.

The full HT voltage is present at the anode caps and parasitic suppressors of the valves, as well as the RF chokes and the doorknob blocking and bypass capacitors, Fig. 4 again. If the top cover of the valve compartment is raised prematurely, a simple spring leaf crowbar grounds the HT supply, discharging the capacitors immediately, Fig. 7 (lower). To conserve the contacts of the SSB/CW switch, which selects the HT tap directly, it's preferable not to change mode with the amplifier power on. The exciter should not be operated in CW mode while the amplifier is in SSB mode and the safety switches in the amplifier should never be defeated.

Because of the fine grid structure of the 3-500Z, Eimac recommended that fault-current limiting should be provided in the anode circuit. Since the TL-922 doesn't incorporate any glitch protection, it can be good practice to insert a 10Ω resistor and



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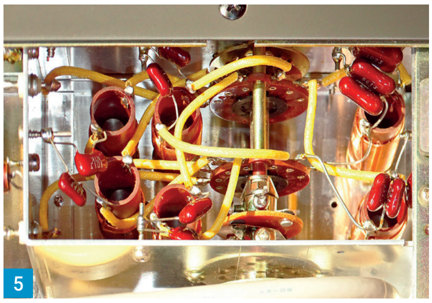
an inexpensive high voltage 1A microwave oven fuse in series with the HT supply to the anodes. A standard 250V instrument fuse is unsuitable as it may arc. Of course, the fuse must be installed on the valve side of the HT crowbar.

A 145°C thermostatic switch protects the HT transformer from overload that might be caused by running the amplifier continuously above its rating. If the switch is activated, it locks the transmit relay in the Standby position. If that happens, the power switch should be left on to allow forced air cooling, and in the meantime the exciter will operate straight through. To avoid arcing and overheating, all the areas in which dust collects should be cleaned regularly by vacuum or compressed air.

After changing bands, the amplifier should first be tuned approximately with reduced exciter power input and then finally with the minimum required normal drive. Take care not to move the bandswitch accidentally while transmitting, or to transmit with no antenna or dummy load connected! A spark discharge device installed at the T/R antenna relay dissipates any momentary high voltage during changeover. The amplifier is rugged. Mine survived a lightning strike to the antenna mast that destroyed two TV sets and a burglar alarm in the house, as well as a Sommerkamp (Yaesu) FT-480R transceiver in the same shack.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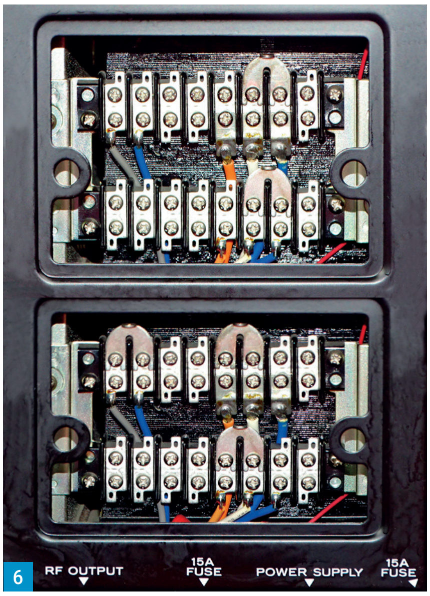
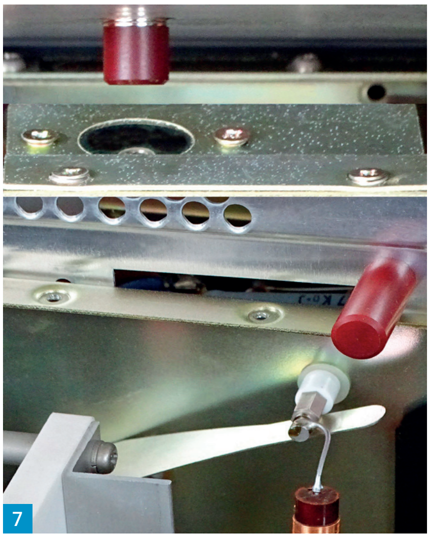
Valve Care

To protect them from shocks and vibration, the 3-500Z valves should be packed separately from the amplifier during transport. They should be stored vertically in dry conditions, as the Kovar that bonds the metal pins to the borosilicate glass is a ferrous alloy that can rust. The radiator anode caps should be fitted before installing the valves, aligning the grub screws with the dimples in the caps and taking care not to overtighten them. Check that the resistors inside the parasitic suppressors are not split, and shape the coils by hand so that they fit accurately between the mounting holes without stressing the glass anode seals of the valves, Fig. 4 again.

Filament voltage has a significant influence on valve longevity. A filament that is not heated sufficiently can suffer emission loss due to surface poisoning by contaminants that render it partly inactive. In continuous commercial service, the ideal regulated volt-





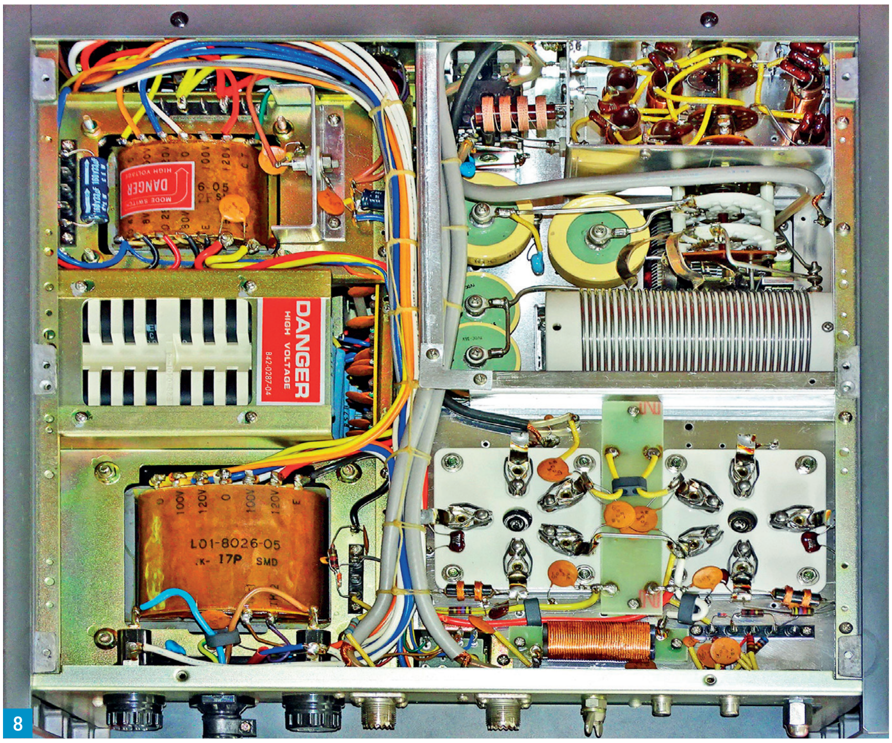


Fig. 4: The power supply is on the left and the RF cage with the output pi-network and 3-500Z valves with their parasitic suppressors on the right. Fig. 5: The six input pi-networks are housed in a fully screened compartment under the chassis. Fig. 6: Jumper locations for 220V (lower) and 240V (upper) operation. Fig. 7: (Upper) Mains input interlock. (Lower) HT safety crowbar.
Fig. 8: The mains transformers and HT box are on the left and the 3-500Z valve bases lower right.

age for valves with thoriated tungsten filaments can be managed by reducing the voltage until just before the RF output begins to decrease and distortion increases. Since this procedure isn't useful for amateur service with unregulated filament supplies, the AC mains jumpers should be selected to give an average heater voltage as close as possible to 5V. Use an accurate true-rms DMM, since the waveform can be significantly distorted, and keep a safe distance from the open amplifier after attaching the test probes right at the valve bases before switching on the power.

The measurements should take account of temperature rise in the amplifier and the local variation in mains voltage, which in winter is typically lowest around 8pm and highest around 4am. When making these measurements the amplifier can be operated upside down, but to avoid the filaments sagging and shorting to the grid it should not be powered while lying on its side, or even with the axis of the valves more than 10° from the vertical. Avoid cycling the filament voltage unnecessarily.

If the local mains voltage is such that the filament voltage can't be set correctly with the few available transformer taps, the jumpers should be set to provide the nearest voltage on the high side of 5V. Resistors of appropriate wattage should then be inserted in the connections from the transformer to the filament chokes at the valve bases. In view of the high current of over 14A, the small voltage drop required can also be achieved simply by replacing the wires from the transformer by lossier ones of a smaller diameter, provided they are protected by sleeving that can support the extra temperature rise.

The negative-going ALC voltage can be varied up to –8V by a preset potentiometer on the rear panel of the amplifier. It's important to adjust the ALC output to the exciter to keep the grid current below 200mA.

3-500Z Revival

A valve that exhibits low emission can sometimes be partially or completely revived by reactivating its filament. The procedure is most successful for the case where the thorium on the surface of the filament has been depleted by running the valve for some time at too low a heater voltage. In a test rig, apply 5V to the filament and connect the grid and the anode together to a 30-40V variable voltage DC power supply. Then allow the valve to 'cook' for many hours with a fan positioned to cool the envelope. As thorium gradually migrates to the surface of the filament, the anode (plus grid) current should begin to rise and the DC voltage should be adjusted periodically to keep it below the specified maximum of 400mA.

If you purchase an amplifier or old stock 3-500Z valves that haven't been used for a considerable time, the valves should also be degassed before the full high voltage is applied to the anodes. This is because gradual leakage at the seals could have caused enough air to enter the envelope for an internal arc to occur when the full HT is applied. The porous graphite anodes used in the 3-500ZG version of the valve are also subject to the slow release of trapped gas over time. Such a flashover would probably destroy the grid chokes and the Zener bias diode, **Fig. 9**, and possibly damage the HT supply as well as the valve itself. The 3-500Z doesn't have the type of flashed getter that produces the characteristic mirror coating on the inside of many smaller valves. Instead, the molybdenum or graphite anode is coated with a porous zirconium alloy that absorbs residual gas molecules when it is heated during normal operation, with an anode dissipation of 250-500W. This power corresponds to the anode glowing from dull red to orange in colour.

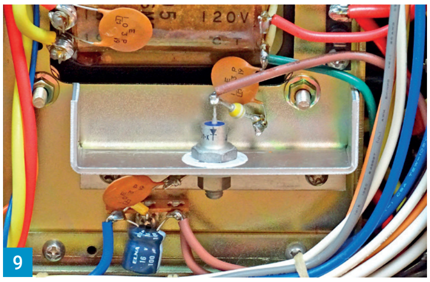
Degassing is best done with a test setup outside the amplifier, using an HT power supply of around 750-1000V. This is low enough for flashover to be unlikely but high enough for the anode to be raised to the gettering temperature of around 1000°C without exceeding the maximum cathode current of 400mA. The anode should be heated up slowly, as the getter absorbs different gases best at different temperatures, and then left to cook for several hours. Be sure to position a fan to keep the temperature of the base seals below 200°C during this operation.

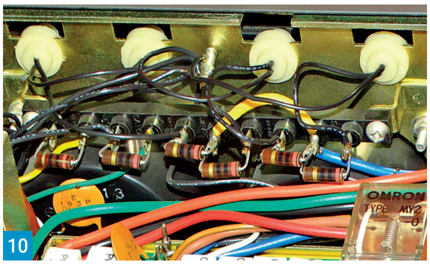
The glass envelope of the 3-500Z allows the characteristic powder blue glow of a soft valve to be seen clearly. It also allows valves to be matched on the basis of their anode colour when delivering high power, something that is not possible with ceramic types. For matching purposes some new Chinese valves have a paper label carrying a number, which is the zero-bias quiescent anode current at an unknown test voltage.

Modifications

The six front panel lamps (two for each meter plus the Standby and On Air indicators) are of a special type (B30-0048-05) that is not readily available. Their life can be prolonged with only a small reduction in brightness by changing the series resistors from 10Ω to 22-27Ω, **Fig. 10**. A more radical approach is to slide the plastic lamp holders out of their retaining slots and replace them by LEDs with current limiting resistors of appropriately increased value. Since most LEDs have quite low reverse voltage limits, a diode or bridge rectifier and reservoir capacitor should be added to rectify the 8V AC supply before making this change. A paper strip can be inserted between the meter LEDs and the meters to act as a light diffuser.

Some TL-922 problems have been attributed to intermittent parasitic oscillations in the region of 125MHz when valves with above-average gain are fitted. Be suspicious of any indication of grid current, or of change in the anode current, when the tuning is varied with no exciter input. Such oscillation could potentially damage the output bandswitch contacts or create a short from the filament helix to the grid cage in a 3-500Z, overheating the filament transformer. A cure may be effected by replacing the coils of the original anode suppressors by ones having a lower *Q*





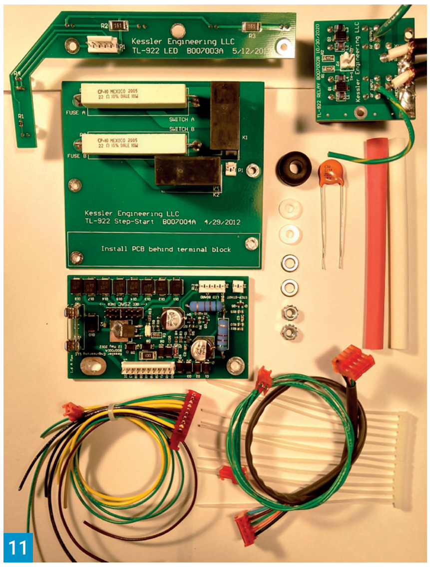


Fig. 9: This 1S265 Zener diode sets the operating point of the valves. Fig. 10: The meter illumination lamps can be replaced by LEDs. Fig. 11: The upgrade kit for the TL-922 by Kessler Engineering includes 4 PCBs and the interconnecting cables.

at VHF. These should have an inductance of around 100μH and can be made from resistance wire. Resistance wire can also be used to replace the short copper wire that connects the plate on the top of the RF choke L1 to the blocking capacitor C34.

Although the standard TL-922 normally performs very satisfactorily, several owners have devised modifications that improve the exciter compatibility or the reliability of the amplifier. **Tom Rauch W8JI** reviews the problems of valve arcing, stability testing and cure at:

www.w8ji.com/Amplifiers.htm

Although **Richard Measures AG6K** is now SK, a detailed description of his numerous TL-922 improvements is still available on the web at:

www.somis.org/QSK922.html

After 'Operate' has been selected, the TL-922 T/R relays are energised by the exciter grounding the Relay Control input to the amplifier. The open-circuit voltage on this line is over 100V, which isn't compatible with some modern exciters that have a low-voltage semiconductor switch rather than physical relay contacts. **Jeff Weinberg W8CQ** of Harbach Electronics (link below) can supply a soft-key interface that transforms the key closure requirement to 0.7V DC at 1.5mA. External relay buffers are available for owners who don't wish to modify their amplifier or exciter.

https://harbachelectronics.com

At initial power up, when the 3-500Z filaments are cold and the HT smoothing capacitors are uncharged, the TL-922 can draw a large inrush current. This can be mitigated by a simple step-start circuit that connects a pair of 22Ω 10W resistors in series with the primary windings of the mains transformers. The resistors can be short-circuited by a relay that is energised by a timer or when the HT rises to about 2/3 of its normal level, which takes less than one second.

The T/R bias and antenna changeover relays in the TL-922 are sturdy, but respond too slowly for satisfactory VOX operation on SSB or QSK on CW. If these modes are required, they can be replaced by fast vacuum relays of adequate power and frequency ratings, mounted to minimise their acoustic noise. The attack and release times of the relays should be sequenced to avoid the RF output relay contacts opening before the exciter input has been cut off.

Don Kessler KI6SZ of Kessler Engineering (link below) offers a modification kit for the TL-922 that adds the step-start, low-voltage soft-key switching and VOX/QSK features, as well as quieter T/R switching, electronic bias control and a LED strip for the front panel lamps, **Fig. 11**. The kit, which costs $360, utilises four printed circuit boards and comes with an excellent detailed installation manual.

https://tinyurl.com/KI6SZ

Whether in original or modified form, the TL-922 is a serious player that can add much enjoyment to amateur radio operation, especially for those who like experimenting with their transmitters. With a possible gain of almost two S-points the amplifier can significantly improve the quality of QSOs when conditions are good, and when conditions are difficult it can help to achieve successful contacts that would otherwise be impossible.