Power supply and control circuits for a 4CX250B amplifier

by A. J. WADE, BSc, G4AJW*

MANY amateurs are now using tetrodes of the 4CX250B family in their power amplifiers, and while such amplifiers usually present little difficulty from the rf point of view—there being several well-proved designs in the literature [1, 2, 3, 4, 5, 6, 7, 8, 9]—many constructors have experienced troubles with power supplies and from the effects of valve flashovers on inadequate power supply and control circuitry. Screen supplies, in particular, are often insufficiently stabilized for linear service, and the fact that the screen supply must be capable of sinking as well as supplying current is not always appreciated.

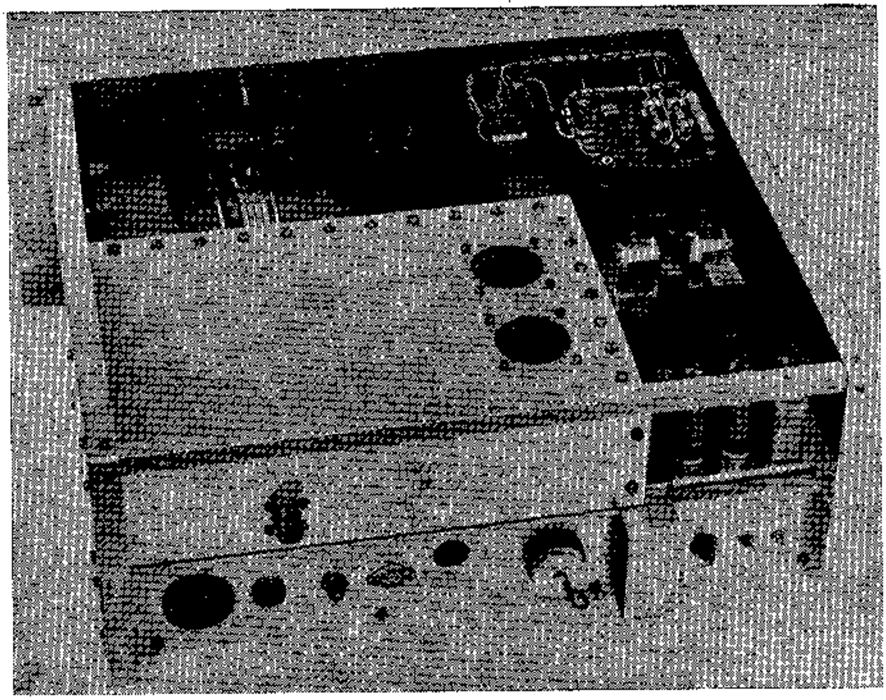
Flashovers from anode to screen can occur quite easily in the 4CX family if the anode voltage is close to its rated maximum and the anode circuit is insufficiently loaded, or if a faulty valve is in use. The flashover can be either internal or external across the ceramic ring, and if precautions are not taken the voltage on the screen pin can rise to 2kV, possibly causing damage to the screen supply or meter circuitry. In some cases flashovers have resulted in failure of the annular decoupling capacitor incorporated in the vhf type of valveholder—a particularly nasty occurrence with these holders becoming even more difficult to obtain.

The circuits presented in this article constitute the author's attempt to design a pa which would operate reliably at high power output, often under arduous contest conditions, which was foolproof in operation and would not blow-up when a valve flashed over. The prototype has now been in use for three years on his linear version of the K2RIW 432MHz pa and has given no trouble at all after the initial bugs were sorted out. This pa retains its original pair of valves and has survived several contests, a dxpedition and a fair amount of general club and home-station use, often operating with 2·5kV on the anodes. The complete design has been duplicated by G8DRE on a 144MHz pa and this was commissioned with few difficulties.

General description

The circuits in Figs 1-3, together with grid and anode circuits for the band(s) required form a pa which is complete except for the high voltage anode supply. No details are given here for the latter since this is very straightforward and in any case usually has to be designed around whatever mains transformer and components the constructor can lay his hands on. It will almost always be built as a separate unit. The control circuit provides a 24V output to drive a contactor or large relay to switch the eht on or off. For a two-valve linear aim to provide between 1·8 and 2·2kV at about 400-500mA continuous rating, but with good dynamic regulation up to 800mA load.

Fig 1 shows circuits for the heater and grid bias supplies together with the control logic and metering arrangements. Switching on the mains activates only the bias and relay



Three-quarter rear view of the author's pa. The psu and control circuits are on the right of the picture, with the heater, relay and bias transformer nearest the front panel. Behind this are RLA and RLB, the bias regulator valve and RLC, the screen supply transformer and the screen stabilizer valves and RLG. The items on the rear apron are (l to r) mains inlet, mains fuse, eht connector, eht contactor skt, rf input socket (recessed), control socket, screen balance pot and the run/set switches

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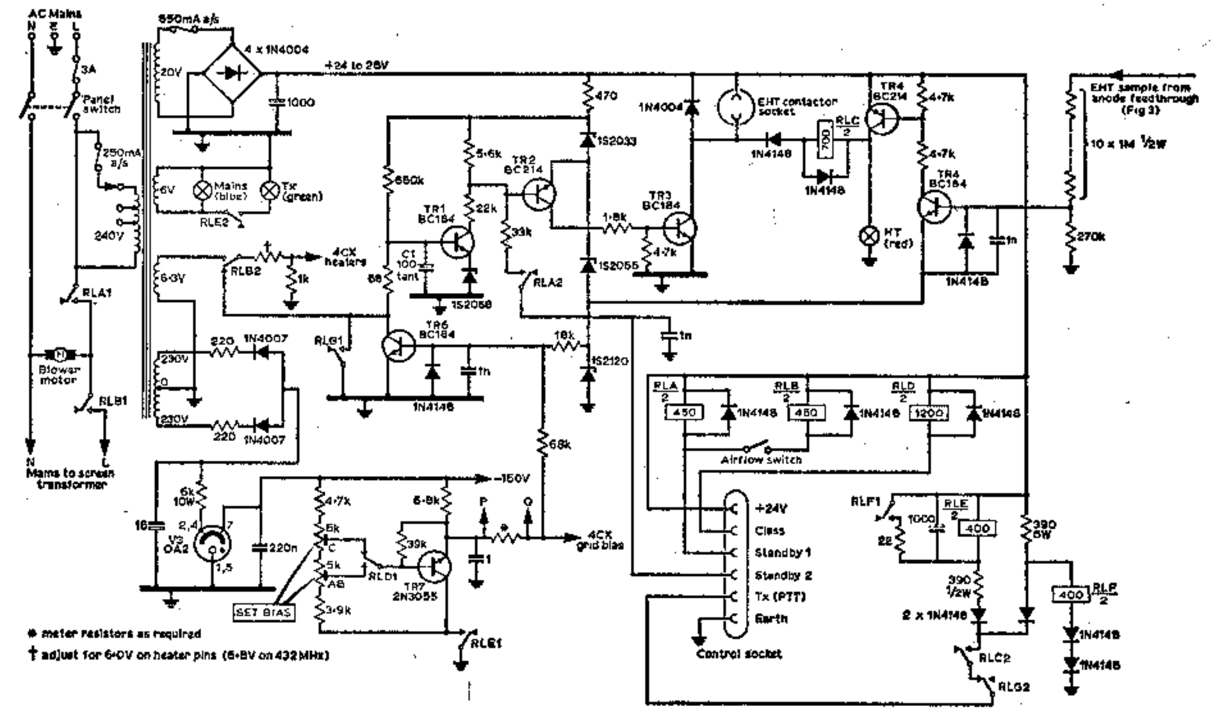
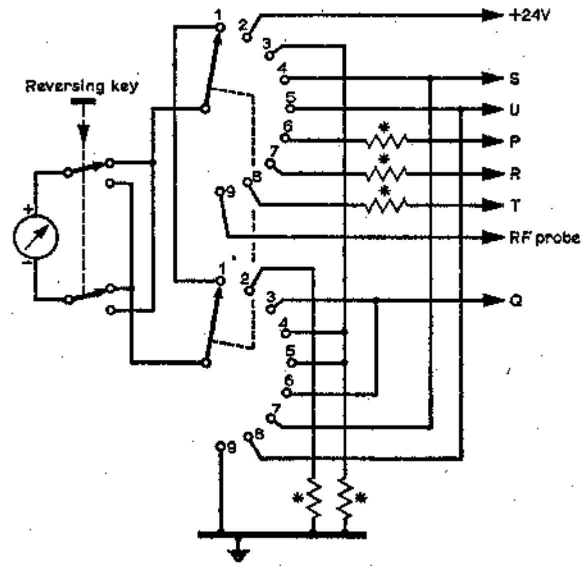


Fig 1. Heater, relay and bias supplies, control logic and metering circuits

Switch positions

1. Off
2. Relay supply voltage
3. Bias voltage
4. No 1 screen voltage
5. No 2 screen voltage
6. Grid current
7. No 1 screen current
8. No 2 screen current
9. RF voltage



supplies—the blower and valve heaters do not come on at this stage. Further action is now initiated remotely via the control socket. Earthing the Standby-1 line switches on the blower. Airflow is sensed by a vane and microswitch arrangement and allows power to be applied to the pa valve heaters. This airflow switch may be thought to be rather a luxury and for fixed station use it probably is—one does not usually have any difficulty in hearing whether the blower is working! However, when operating portable the blower noise is usually inaudible under that of the generator, the howling wind and lashing of rain on the side of the tent, so that, without the switch, the first indication of blower failure would be a dead pair of valves. If any sort of air filter is used, the blower switch is definitely worth having to warn of its blockage.

Application of power to the heaters releases a 1min timer which ensures that the cathodes warm up properly before ht can be applied. Earthing the Standby-2 line produces a 24V signal at the contactor socket which should result in the eht being switched on. The presence of more than about 500V on the incoming eht line switches ht onto the screen shunt stabilizer circuit (Fig 2) and then onto the pa valve screens. Only the −150V grid bias now holds the valves out of conduction.

A shunt stabilizer is used for the screen supply because under certain operating conditions the 4CX250 family can run with negative screen current, ie current flows out from the screen pin, not into it as is usual. This effect is quite normal and results from electron secondary emission at the screen grid. With a linear pa it is usually found that a small negative screen current flows under standing conditions and that it becomes more negative as drive is applied. As the drive is increased the negative current reaches a peak and then falls, eventually becoming positive. Quite large variations in screen current can occur from valve to valve;

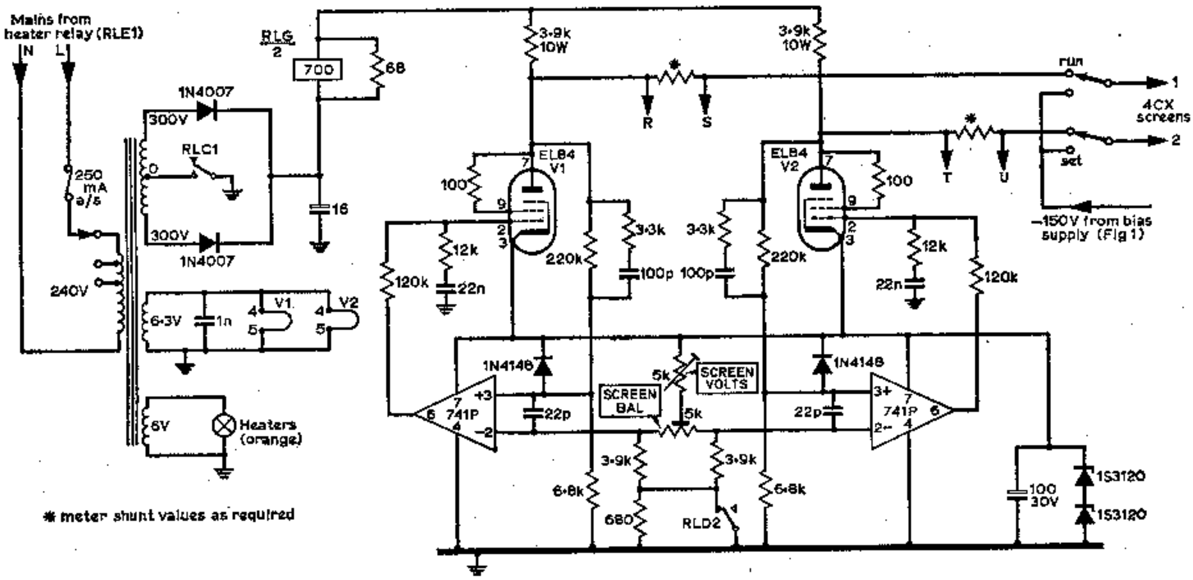


Fig 2. Screen shunt stabilizer circuit

these are not necessarily a sign that anything is amiss. If the screen supply is incapable of sinking the maximum value of negative screen current which occurs, then the screen voltage could rise, increasing the anode current and giving a runaway condition. A series-stabilized supply would need a bleeder consuming an excessive amount of power to guard against this occurrence, so the shunt stabilizer gives a more economical design. Gas discharge regulator valves can provide a simple and adequate shunt stabilizer, but the hard-valve design used here provides a variable voltage output so that both Class AB and Class C operation can be used and the standing currents in a two-valve linear equalized.

Returning an earth on the transmit (ptt) line (Fig 1) lowers the grid bias to about −90V for Class C operation or about −40V for linear service. A short delay is included to allow aerial changeover relays to clear. If drive is now applied the pa will be on the air.

Potentially-damaging fault conditions are dealt with as follows:

Valve or eht flashover: the steep rise in eht current triggers a crowbar thyristor connected to the screens (Fig 3), quickly providing a safe path to earth for the fault current. The short-circuit on the screens is sensed by the screen supply and the relay RLG re-sets the minute timer, thus releasing the eht contactor. Power-up is then automatic after the 60s delay. If, on the author's pa, a screwdriver is dropped into the anode compartment, the eht shuts down without so much as blowing a fuse.

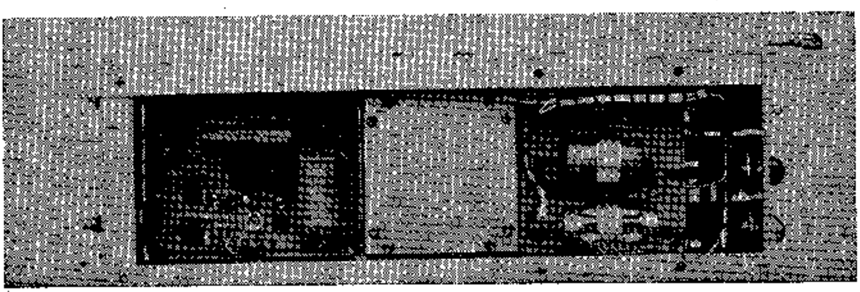
Anode supply failure: screen ht is immediately removed and ptt inhibited. Automatic re-set when eht is restored.

Grid bias failure: the timer is clamped in the re-set condition, thus clearing anode and screen supplies.

Blower failure: all 4CX250 supplies are removed and the timer re-set.

Circuit details

The heater, relay and negative bias supplies in Fig 1 are quite straightforward and readily modified to suit available components. The author's transformer had a rather higher ht winding voltage than was required for the bias supply—hence the 220Ω resistors in series with the rectifier diodes. If a 150-0-150V winding is available these can be omitted. On transmit, the bias is regulated by a simple emitter-follower shunt regulator which is capable of sinking the 50mA grid current from a pair of valves working in Class C. The voltage ratings of the 2N3055 are quite adequate for this circuit, provided that a reputable make of device is employed. There is, of course, no objection to using a higher voltage transistor if this is available. If Class C operation is intended the transistor-heatsink combination must be capable of



Part under-chassis view of the author's pa. The board on the left carries the screen stabilizers, while the logic and bias regulator boards are in the screened compartment in the centre

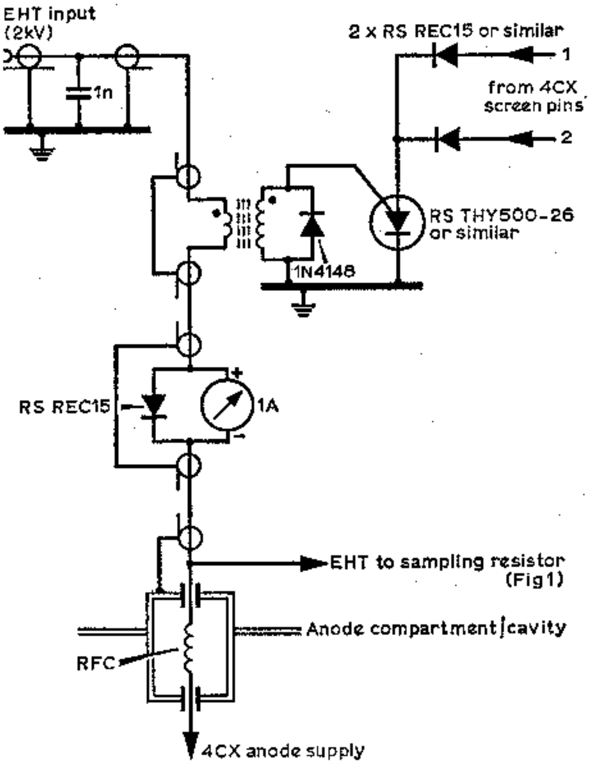
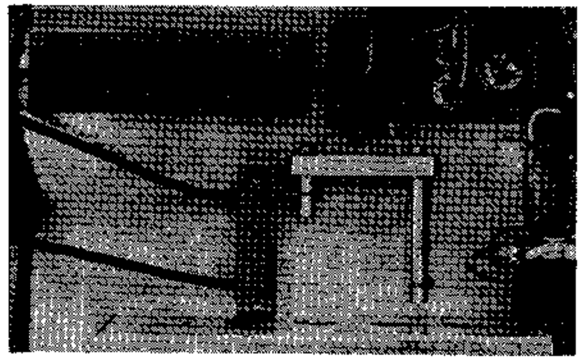


Fig 3. Anode supply wiring and screen thyristor. Trigger transformer details: primary 1t (well insulated), secondary 20t 36swg enam on small ferrite ring (see text)



Close-up of the eht divider chain and screen crowbar in the author's pa. Below these are the string drives for the tuning and coupling flaps

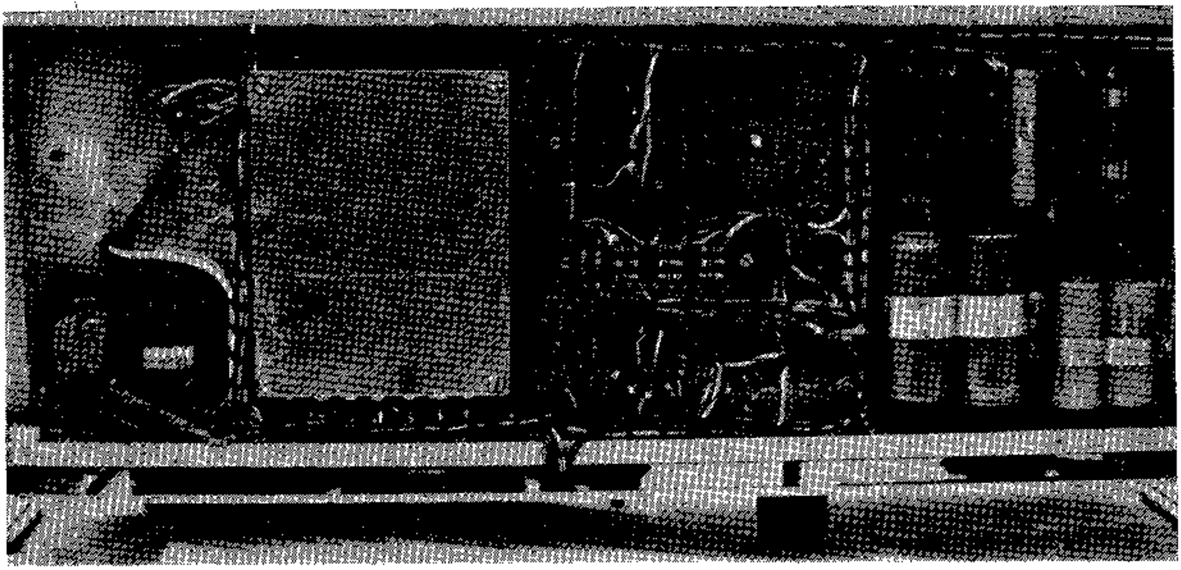
dissipating about 5W. The bias supply is also capable of supplying a few milliamps, and it appears to be quite normal for perfectly healthy valves to draw 1-2mA *positive* grid current when lightly driven in AB1.

Simple relay circuits are used to switch on the blower (RLA) and the heaters (RLB). Note that a second contact on the latter applies mains to the screen supply transformer so that the EL84 heaters come on at the same time. These relays are octal plug-in types. A miniature double-changeover relay (RLD) switches bias and screen voltages between their linear and Class C values. The functions of this relay can be wired to a front panel switch if the remote control facility is not required. The t/r switching arrangement shown is a little unusual and was designed around some surplus twin-capsule A-form reed relays available at the time. A silent changeover is the result. On receive RLE is de-energized and RLF energized. Earthing the ptt line immediately releases RLF so that the capacitor across the coil of RLE is free to charge and after a delay of about 100ms this relay operates and puts the pa onto transmit. When ptt is released RLF re-closes and quickly discharges the timing capacitor, releasing RLE and biassing the pa back. This slow-on fast-off action guards against operation of the amplifier without rf load. No aerial changeover relay is included in the prototype because a masthead receive pre-amplifier is employed; if required, this component can be wired (with a catching diode) between the relay supply and ptt lines.

When relay contact RLB2 applies power to the valve heaters it also removes a near short-circuit from the timing capacitor, C1. After about 1min C1 has charged to 7·4V and TR1 switches on. Resistor values are arranged so that TR2 will not turn on, however, until the Standby-2 (eht on) line is earthed. TR2 turns on TR3 which closes the contactor in the external eht supply. The anode supply is sensed by TR4 and the associated potential divider chain. Its presence turns on TR4, TR5 and the ht indicator and energizes the coil of RLC via TR3. TR6 is normally held off by the grid bias, but should the latter fail this transistor will discharge C1, so switching everything off.

Turning now to Fig 2, contact RLC1 applies power to two identical shunt stabilizer circuits, each of which comprises a triode-connected EL84 driven by a 741 op-amp. The supply for the op-amps is derived from the cathode current of the EL84s, resulting in a self-contained stabilizer which may be found useful in other applications. Each 741 compares a sample of the EL84 anode voltage with a reference derived from the cathode zener, and adjusts the grid voltage for equality. The voltage fed to the screen of each pa valve is thus the voltage at the inverting input of the corresponding 741 multiplied by 226·8/6·8 or about 33. Compensation networks are included to ensure that the loop is stable when operating into the capacitive load presented by the screen decoupling capacitors, and to give a reasonable transient response to load variations. The diodes between the valve cathodes and the non-inverting inputs of the op-amps protect the latter from any overvoltage spikes on the output lines. Two presets are provided; one sets the average screen voltage and the other gives a differential adjustment so that the standing currents in the pa valves of a linear amplifier can be equalized. To facilitate this operation each screen circuit is fitted with a switch which connects the screen grid to the −150V bias so that the valves can be checked one at a time. The standing current should be set to 100mA per valve. Care should be taken not to operate the switches while the pa is drawing anode current otherwise the momentary floating of the screen may cause the crowbar to be triggered. Contact RLD2 provides the necessary increase in screen voltage when changing to linear operation.

The voltage at the tops of the EL84 anode resistors, about 430V in the prototype, should not be less than 400V. There is no objection to using a higher supply voltage, provided that the 3·9kΩ anode resistors are increased in value to keep



Under the chassis of G8DRE's pa. The small board on the left carries the t/r timing components. The screened box houses the semiconductor logic and bias regulator—note the feedthrough decoupled lead-ins. The next unit carries the screen supply transformer, meter shunt board, OA2 and RLA and RLB. To the right are RLC and RLG, run/set switches and a rectifier board

the current in them at about 20-25mA each when the screen voltage is 350. The resistor across the coil of RLG should be selected so that the relay operates reliably when one of the screen output lines is shorted to earth, but does not pull in under normal circumstances; this means that it should operate when the load on the rectifier is 60-70mA. The overall performance of this screen supply is extremely good. The regulation, determined mainly by the slope resistance of the zener in the EL84 cathode circuit, is of the order of 1V and the shunt configuration results in the ability to sink large amounts of negative screen current for short periods. A further advantage is that the maximum screen dissipation rating of the 4CX250B cannot be exceeded, even in the absence of an anode supply.

Fig 3 shows the eht wiring and the screen crowbar thyristor. The trigger transformer in the prototype was wound on a small (about 5/16in dia) ferrite ring of unknown pedigree, and because thyristors vary enormously in their trigger sensitivity, some experimentation may be required here to achieve the right sensitivity. The thyristor should not trigger when the pa is switched onto transmit with full drive applied, or when fairly hard cw keying is used, but a simulated flashover, achieved by connecting a 1,000pF capacitor charged to a few hundred volts across the primary of the transformer (with the anode supply removed), should trigger it reliably. A low voltage supply and a bulb provide a convenient way of checking for triggering, but remember to disconnect the thyristor from the screen circuits for this test. If the trigger sensitivity is too great, reduce the turns ratio of the transformer or shunt the secondary with a lowish value resistor. For the opposite problem try a higher turns ratio or a better thyristor.

The remainder of the anode wiring is straightforward and is mainly a matter of achieving an adequate insulation breakdown voltage. If the equipment is available it is worth testing the whole anode circuit up to 5 or 6kV. A point to watch is that there are no unearthed external metal parts (such as the adjuster screw) on the anode current meter. The protection diode shown for this meter, and its shunt, should be regarded as essential—many a good movement has bitten the dust in this position!

A single multi-function meter is provided for checking other voltages and currents in the circuit (Fig 1). The reversing key facilitates the reading of negative screen current. Ranges and resistor values will depend on the movement used and its scaling. The instrument in the prototype is scaled 0-5 and is arranged to read 0-50V, 0-500V or 0-50mA. The final switch position is fed from a diode probe measuring the rf output, and this can be used for tuning up if a matched load is assured.

Construction

Construction will not be described in detail as most builders will wish to incorporate a few modifications or perhaps to use only parts of the design here. In an amateur project of

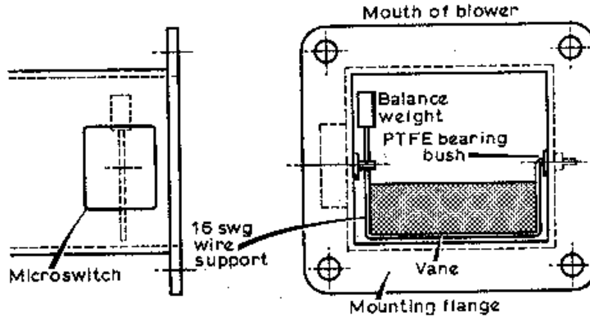


Fig 4. Airflow switch arrangement used by G8DRE

this nature much of the detail will depend on components and materials which are to hand, so no two versions will be the same. No part of the control circuitry is particularly sensitive to layout but reasonable precautions should be taken to prevent rf feedback into the transistorized part of the logic, and into the screen stabilizers. If the grid and anode circuits of the pa are built in efficient rf-tight compartments and power leads are correctly decoupled there should be no difficulties in this respect. In the screen supply the wiring between the 741s and the EL84s must be kept reasonably short and direct.

The eht wiring must obviously be adequately insulated and kept free from sharp spikes which could cause corona. The use of coaxial cable is recommended, and UR43 and UR95 are both quite suitable. The small PET type 101 connector* has been found suitable for the eht lead-in and is available on the surplus market; BNCs are prone to flashover at more than 1·5kV. Remember that the wiring from the screen rings on the 4CX250 valveholders to the crowbar has to carry the fault current from the high voltage supply; it should be kept short and direct to minimize inductance. In this context it is worthwhile including a small resistor in the output lead of the eht supply to keep the peak short circuit current down to 100A or so, and provide a point for dissipating the stored energy in the smoothing capacitors. Without this precaution the fault current can easily be several kiloamps (especially if block paper smoothers are used) and this surge current has to be withstood by the thyristor and the meter protection diode.

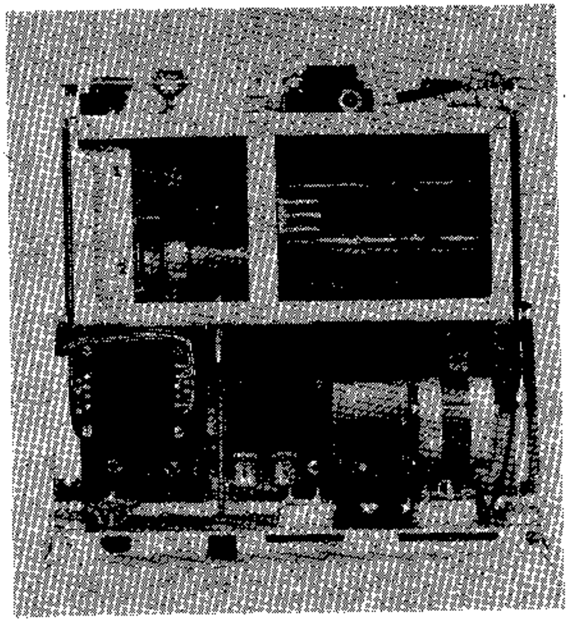
In both the prototypes the control logic and the screen stabilizers are built as small sub-assemblies bolted to the main chassis. Double-sided pc boards (continuous groundplane on the component side) are used for the semiconductor parts of the circuitry. The crowbar thyristor, together with its diodes and trigger transformer, and the eht sampling resistor chain are mounted on separate small pc boards and suitably mounted on the mainframe. The photographs should give a general impression of these layouts.

The airflow switch, if used, is left to the ingenuity of the constructor. The arrangement used by G8DRE is mounted in the throat of the blower and is sketched in Fig 4. The microswitch is of the low-torque rotary type used in coin mechanisms. An electronic version has been suggested, using the cooling effect of the airstream on a bead thermistor, but it has not been developed into a practical design.

Modifications

Many modifications are possible of course. The constructor may wish to re-arrange the control circuits to suit a different combination of mains transformer windings or to conform to individual standards. The screen supply and crowbar are really the main features of this design and should be altered as little as possible. If a single-valve pa is being built only one shunt stabilizer will be needed and the screen balance pot can be omitted, as can the run/set switches and both the diodes between the thyristor anode and the screens.

If conduction-cooled valves are used, the Standby-1 function can be dispensed with, and the heaters run all the time. RLA and RLB will not be required but it may be necessary to add a diode between the relay supply line and



Top view of G8DRE's amplifier, with the anode coverremoved. Screen stabilizers are at the lower left and the crowbar board can be seen on the right, next to RLC. Note the chimney-less method of blowing, as used in the K2RIW design

the top of C1 to ensure that the latter discharges reasonably quickly after switch-off.

Semiconductor types indicated are not critical and the constructor's own pet devices can be substituted, provided that they are adequately rated. TRs 1, 2, 4 and 6 can be virtually any silicon small signal transistors of appropriate polarity and rated at 30V or more. TR3 must be able to carry the operating current of the eht contactor in addition to that of RLC. Note that if this device fails short-circuit the eht will come on regardless of other conditions. TR5 must be able to handle the ht indicator lamp current; the ratings of TR7 have already been discussed. The zener diode in the Fig 1 circuits can be any 400mW type of appropriate voltage, while those in the screen supply must be rated at 1W or more.

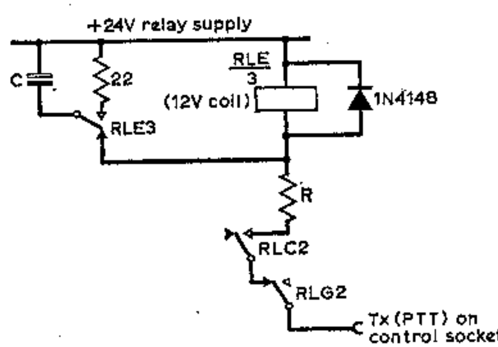


Fig 5. Alternative t/r timing circuit

* Manufactured by Precision Electronic Terminations (EMI) Ltd, Cramptons Road, Sevenoaks, Kent.

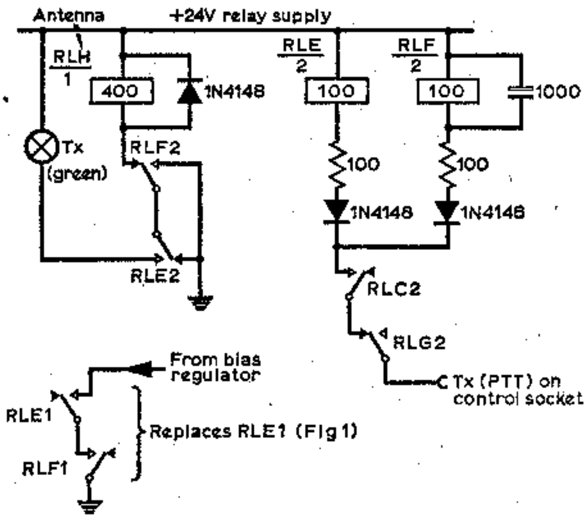


Fig 6. T/r circuit used by G8DRE. RLH1 is the antenna changeover relay (energized on receive in this circuit)

Those who still favour high-level (anode and screen) a.m. may wish to consider applying modulation to the inverting inputs of the 741s in the screen stabilizers. This would enable the advantages of the shunt stabilizer to be retained, avoid large dropper resistors and make for easy adjustment of the proportion of modulation applied to the screens for best linearity. The author has not considered this idea in detail; the pre-regulator screen ht would need to be increased and some modification to the compensation might be desirable. If the modulation for the screens were obtained from an early stage in the modulator it would be necessary to include a network to compensate for phase shifts in later stages and in the modulation transformer.

The ideas in this article are not confined in application to rf amplifiers and could be useful to anyone building a large modulator or high-power audio amplifier.

As mentioned previously, the t/r switching in Fig 1 was designed to use only "make" contacts. If a changeover relay is available the simpler circuit of Fig 5 is suggested. In this the value of R is made equal to the coil resistance of the relay and C is chosen to provide about 100ms delay. Yet another t/r timing circuit is shown in Fig 6; any correspondence on this one should be addressed to G8DRE and not to the author.

Conclusion

This article has dealt in some detail with an aspect of pa construction which is often rather neglected. The circuits here are certainly rather more complex than most arrangements but they are in no way difficult to get going and should result in a reliable pa. The 4CX250 family is a most robust series of valves and they can be run very hard in amateur service, provided that their idiosyncrasies are clearly understood.

The author hopes that he has not discouraged anyone from building an amplifier; there is certainly no substitute for a big pa—except a bigger pa.

Acknowledgements

The author thanks friends and colleagues at GW3UCB for ideas, discussions and comments on this project. In particular he must mention G8DMJ, the reliability of whose pa at one time was an inspiration for this work; G4BRK and G4BRT for repeated (unsuccessful) attempts at destroying the prototype, and G8DRE for being fool enough to prove that the design can be reproduced.

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CATALOGUES RECEIVED

The autumn edition of the **Heathkit** catalogue is now available and contains details of the range of kits obtainable. New kits include a range of frequency counters with an upper limit of 1GHz and a solid-state hf bands cw transmitter, the HX-1675, which has an input of 75W to the final stage. There are several other new kits now available in the audio and instruments fields. Copies of the catalogue are available from Heath (Gloucester) Ltd, Gloucester GL2 6EE, or by callers at the London showroom, 233 Tottenham Court Road, W1 (tel 01-636 7349).

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