Novel Power Supply is also a Series Modulator

Not merely a power supply and a modulator in the one box, but a variable and regulated supply which also performs the function of a transformerless series modulator. Using a novel hybrid circuit technique which combines valves and transistors, it should be of equal interest to both the experienced amateur and the newcomer to amateur radio.

by JAMIESON ROWE

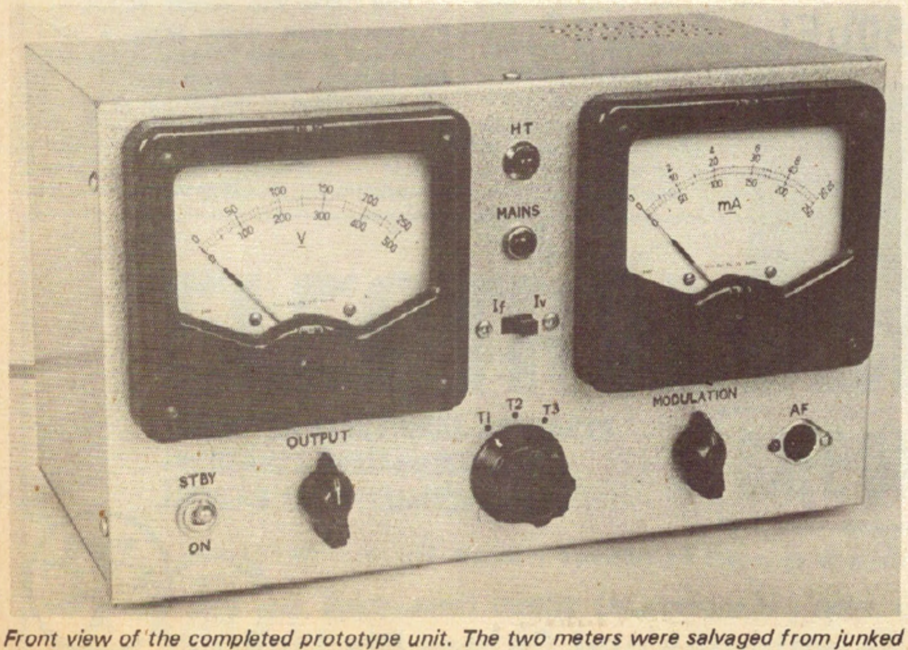
A few weeks ago, I built a small "outboard final" designed to boost the RF output from my existing 144MHz AM transmitter. Rather than make the new final a linear amplifier, I elected to make it a class-C stage in order to obtain the full output for which the valve is rated. This naturally meant that the modulation would have to be disabled in the basic transmitter, and modulation applied to the new final instead to ensure good linearity.

I had planned to supply both modulation and power for the new final from a heavy-duty power supply and class-B modulator unit which had been used for an earlier transmitter. However when I switched this unit on to check that it still worked, I soon found that it was not going to be as easy as I had planned. Among other things, the modulation transformer appeared to have an intermittent short-circuit from secondary to frame. . .

Not having an assortment of modulation transformers from which to choose a replacement, this possiblity was ruled out. And an enquiry regarding new transformers of the appropriate type and rating soon ruled out that possibility also — if only on the score of cost. There didn't even seem to be a suitable old power transformer which I could press into service, either.

With transformer modulation thus fairly definitely ruled out, my thoughts first turned to screen grid modulation. This could certainly be achieved quite easily without a transformer, and with very low power. The easiest way would be to use a voltage amplifier followed by a cathode follower, with the cathode of the follower feeding directly into the PA valve screen as its load.

Unfortunately there is one drawback which this method shares with the other types of "efficiency modulation" — reduced power output. In order to remain within the PA valve ratings, the zero-modulation output must generally be less than the equivalent output for conventional plate modulation. Screen modulation therefore offered little real advantage over the linear amplifier approach, in terms of actual RF (power) output.



Front view of the completed prototype unit. The two meters were salvaged from junked test instruments, but are quite satisfactory.

By a process of elimination I was thus led to consider series modulation. Why not take the idea of screen modulation with a cathode follower a step further? Use a high-power valve or valves in the cathode follower stage, and use it to modulate the supply to both the plate and screen of the PA. With a basic power supply voltage of approximately twice that normally fed to the PA for zero modulation, one should be able to get as much output, within ratings, as with conventional transformer modulation.

Almost immediately after I began working on a design based on this approach, I was struck by the similarity between the circuit I was developing and that of a regulated variable power supply. In fact the logical move was to deliberately combine the two concepts, and design the unit as a regulated variable supply which was also a modulator.

Hence the idea for this project was born. It may not be a completely new design concept, but it is at least original as far as I am concerned.

Before describing the unit itself, I should perhaps give a brief specification of its performance.

The unit as described has two separate HT outputs: a variable, regulated output which may also be modulated with an audio signal, and a fixed voltage output which is unregulated and unmodulated.

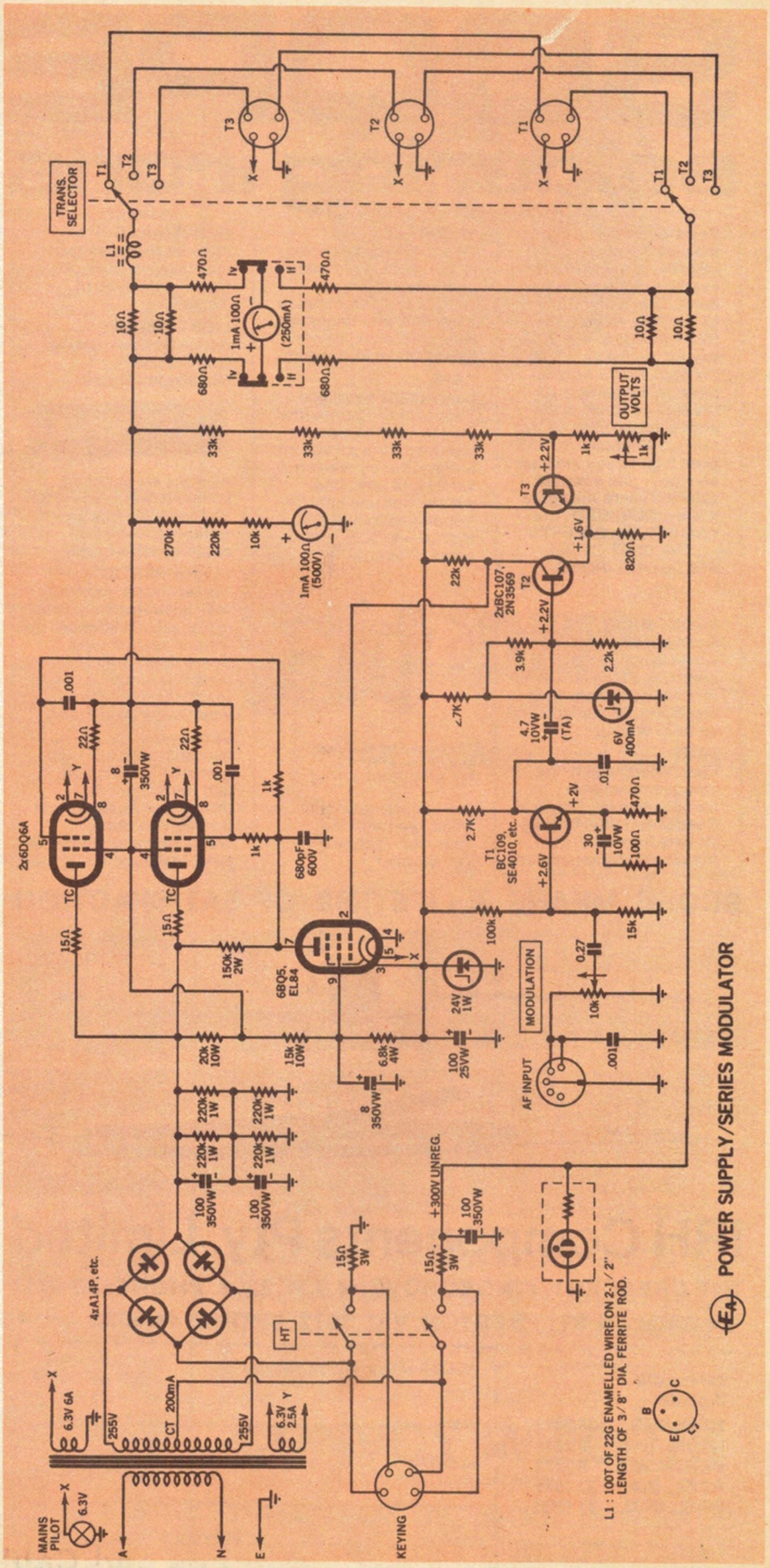
The regulated output is variable between approximately 140 and 300V, to suit a variety of possible transmitter requirements. Its regulation is very good, as may be seen from the curves. Expressed as a percentage, it is better than 0.3% even for current drains well above the limits set by regulator valve dissipation. Ripple output is also very low.

This output may be modulated to approximately 90% by feeding an audio signal of 60mV or more into the "AF input" of the unit. The frequency response of the modulation circuitry is 3dB down at 100Hz and 5kHz, which is more than adequate for amateur and other communications work. Because of the high degree of negative feedback around the modulation circuitry, the modulation is very linear and has low distortion.

As with other series modulators, the unit cannot overmodulate a transmitter in the classic manner possible with transformer modulation. The output voltage can never swing negative on negative modulation peaks, so that a transmitter connected to its output is never cut off. This means that even gross overmodulation (accidental, hopefully!) cannot result in "splatter" of the classical type.

In fact the output from the modulation circuitry of the unit cannot even fall entirely to zero on negative modulation peaks, due to

The circuit of the unit, which is both a power supply and a modulator.



saturation effects. This admittedly means that the transmitter cannot be 100% modulated; but on the other hand it will always deliver at least some RF carrier even during gross overmodulation.

All that happens with overmodulation is that saturation effects cause the modulation waveform to become flattened on either positive or negative peaks — or both — depending upon the quiescent output voltage level.

Naturally this distortion generates additional sidebands on each side of the RF carrier, corresponding to harmonics of the modulating signal. However these are generally not nearly as objectionable as the wideband products generated by splatter transients.

The current capability of the HT regulator / modulator, which is limited by valve dissipation, is approximately 120mA. At 280V output this corresponds to 33W input to a transmitter, so that when used for plate modulation the unit is suitable for use with transmitters of up to about 30W input rating. But there is really no reason why you shouldn't use it as a screen modulator, for higher power transmitters. By using the unregulated HT output to run the PA stage plate and earlier stages, and the regulated / modulated output to run the screen, it could be used with transmitters running up to about 60W input.

The unregulated HT output from the unit is intended for supplying power to either the earlier stages of a valve transmitter, or to the PA stage plate of a higher-powered transmitter when the modulated output is used for screen modulation. This output is approximately 320V for no load, and although unregulated it drops by only about 20V for a load of 175mA. As might be expected the ripple output is rather higher than from the regulated output, but additional filtering can easily be provided if desired, either in the unit itself or in the transmitter.

The unit is fitted with two meters, one of which is used as a voltmeter to monitor the output voltage from the regulator / modulator circuit. The other meter is switchable to measure the current drawn from either the regulated or unregulated outputs.

The two HT outputs from the unit may be fed to any one of three output sockets for connection to transmitters. Each socket is also supplied with 6.3V AC for valve heaters, etc.

For T-R switching the HT outputs of the unit are controlled by a front-panel toggle switch. The two contact sets of this switch are also brought out to a socket at the rear of the unit, to permit remote control from a console or control unit such as that which I described in the August issue.

The unit is quite straightforward in design, as may be seen from the main circuit diagram. It uses only three valves, three transistors, four rectifier diodes and two zener diodes, in a hybrid circuit which I believe is quite novel.

Perhaps the heart of the unit is the series-pass or cathode follower stage, which uses a pair of 6DQ6A horizontal output valves in parallel. These valves each have an 18W plate dissipation rating, so that together they provide a dissipation capability of 36W.

Small separate cathode resistors are used to ensure that they share the load current equally, to equalise the dissipation.

The cathode followers are driven by a 6BQ5 / EL84, which acts as a voltage amplifier. This is driven in turn by transistor T2, which acts as a voltage comparator.

The base of T2 is supplied with a reference voltage of approximately +2.2V, obtained by means of a resistive voltage divider across a 6V zener diode. Its emitter is supplied with a slightly lower voltage, approximately +1.6V, which is produced across the 820 ohm emitter by transistor T3. This transistor is an emitter follower, whose base is connected to a tap on a resistive voltage divider across the HT output of the 6DQ6A cathode followers. Hence the 1.6V at the emitter of T2 is derived from, and proportional to, the HT output voltage.

As the conduction of T2 is determined by the relative magnitude of the voltages at its base and emitter, it therefore effectively compares the two. And this comparison action ensures that the HT output of the 6DQ6A cathode followers is regulated — ie, that it remains substantially constant with loading and mains voltage variations.

If the HT output tends to rise, the voltage at the emitter of T2 also tends to rise, and T2 will accordingly tend to conduct less. Its collector voltage will rise slightly, reducing the bias on the 6BQ5 valve and hence allowing this valve to conduct more current. This will cause the valve plate voltage to fall slightly, reducing the grid voltage on the cathode followers. These valves will then reduce their conduction slightly, restoring the HT output to its original value.

Conversely, if the HT output tends to fall, the voltage at T2's emitter will also tend to fall, and T2 will therefore conduct more. This will increase the negative grid bias on the 6BQ5, reducing this valve's conduction. Its plate voltage and the HT output voltage will therefore rise slightly to again restore the status quo.

The HT voltage level at which this stabilisation action takes place depends upon the setting of the 1k pot in the base circuit of T3. By adjusting the divider ratio, the pot in effect varies the HT voltage level which corresponds to a level of +1.6V at the emitter of T2. Zero pot resistance gives a large divider ratio, and hence maximum HT output, while maximum resistance gives a smaller divider ratio and hence a lower output voltage. The 1k resistor in series with the pot is used to set the maximum division ratio, and hence the maximum HT level (here 300V).

If you were already familiar with regulated power supply circuits you will no doubt have realised already that as described so far the circuit is a fairly conventional regulator. The only difference is that it is hybrid, the reference voltage being derived from a zener diode instead of a gas-discharge tube, while the comparator uses transistors instead of a valve.

So far so good. But how do we arrange for the circuit to act as a modulator as well? The answer is surprisingly simple: by in effect superimposing our audio input on the zener-derived reference voltage. With its reference voltage varying up and down with the audio, the regulator circuit is forced to duplicate the variations on a larger scale at the HT output.

As you can see from the circuit, the audio input is fed to an amplifier transistor T1, via a pot used to adjust the modulation level. From the collector of T1 it is coupled to the base of comparator transistor T2, via a low-leakage tantalum electrolytic capacitor. It's as simple as that, except for a few minor matters which will be discussed shortly.

Before dealing with some of the more subtle aspects of the design, I had better give a brief description of the basic transformer and rectifier circuit.

If we were building a conventional regulated supply, and not one to double as a modulator, the requirement for the basic rectifier circuit would simply be that it should deliver sufficient voltage at the full load current to make up for the voltage drop across the series regulator valves. Its output would thus need to be 400V or so for a regulator intended to deliver up to 300V.

Because the present circuit has to be able to function as a modulator as well as a regulator, its HT output should be able to swing up on positive modulation peaks to TWICE the maximum quiescent output. For a maximum output of 300V, this means that the regulator should be able to deliver voltage peaks of 600V, corresponding to 100% modulation. Naturally this requires that the basic rectifier circuit should deliver at least the same voltage, or ideally somewhat more to again allow for voltage drop in the series regulator valves — say 700V.

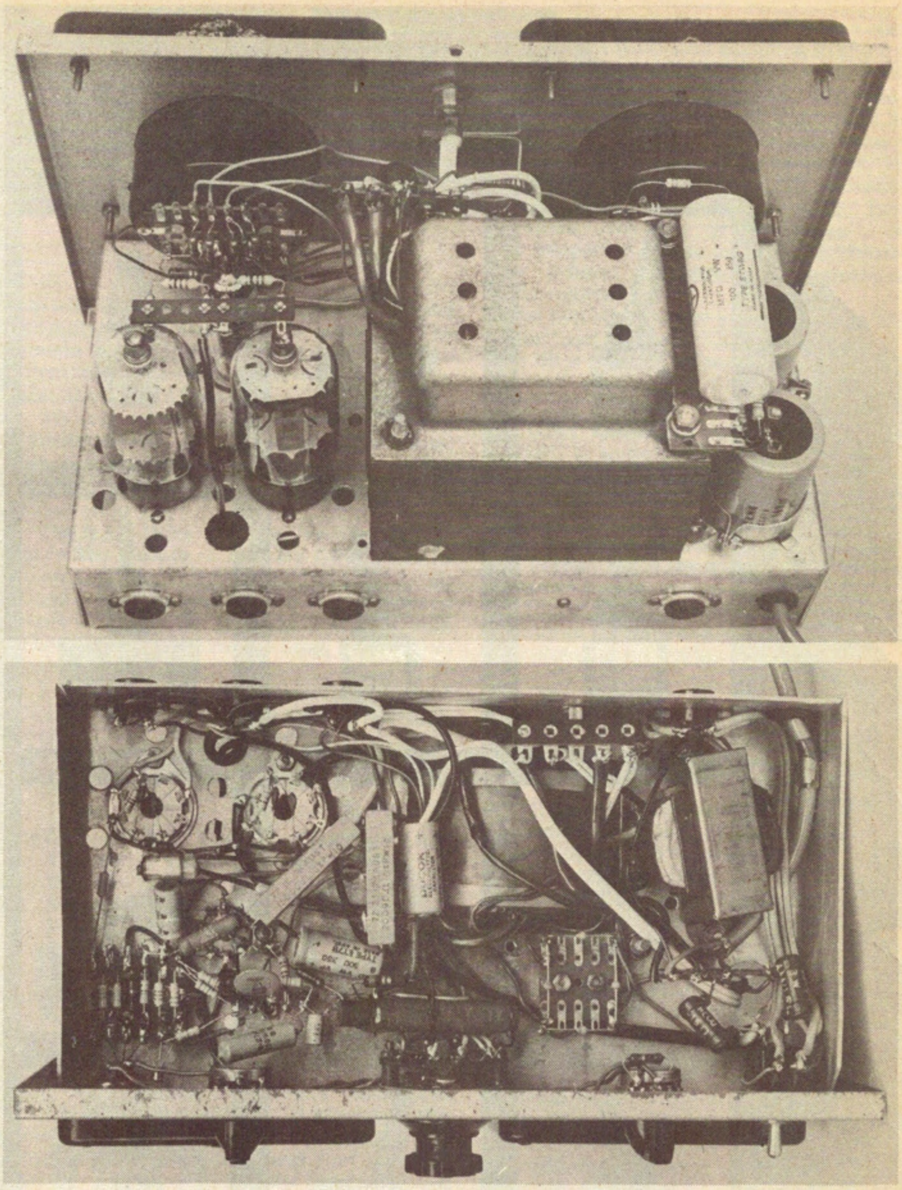
There are various ways of producing a voltage of this order, many of them involving exotic and costly power transformers. However I elected to use a simple approach, and one which uses a straightforward power transformer of the type having a centre-tapped HT secondary made for a conventional full-wave rectifier. By wiring a four-diode bridge rectifier right across the full winding, instead of the two normal diodes, the circuit gives twice the normal output voltage. At the same time the existing centre-tap may be used to provide the unregulated HT output.

The transformer I used in the prototype unit was taken from an old Pye-Tecnico 17-inch TV receiver. It was originally made for Pye by Ferguson Transformers Pty Ltd, and coded PF1149. The HT secondary on this transformer is 225V-0-225V, rated at 300mA, and used with the bridge rectifier feeding two series-connected 100uF capacitors (with shunt resistors to equalise their voltage distribution), it gives a no-load output of 650V. This falls to 620V at a drain of 100mA, which is quite reasonable for the job.

The unregulated supply provided by the winding centre-tap, when filtered by the series 15 ohm resistor and 100uF capacitor, gives a no-load output of 320V. This falls to 300V at 150mA, as may be seen from the curve.

The PF1149 has a heater winding with high-voltage insulation which was originally used to run the heaters of two 6N3 rectifier valves. This winding was rated at 4.2A and is thus ideal for running the two 6DQ6A heaters in the present unit. Before I learned the current rating of this winding, I "played safe" by using it to supply only one of the 6DQ6A heaters, with the other supplied by a separate small heater transformer. This transformer is visible in the underchassis photograph, which was taken before I had the opportunity to remove it.

The PF1149 also has a heavy-duty main heater winding, which provides 12.8V centre-tapped at a rated current of 4.2A. It is thus able to supply some 8.4 amps at 6.3V, more than adequate for the 6BQ5 heater and the heater drains of most modest-sized transmitters. It is for this reason that I have not bothered to switch the heater line to each of the three transmitter outputs on the unit.



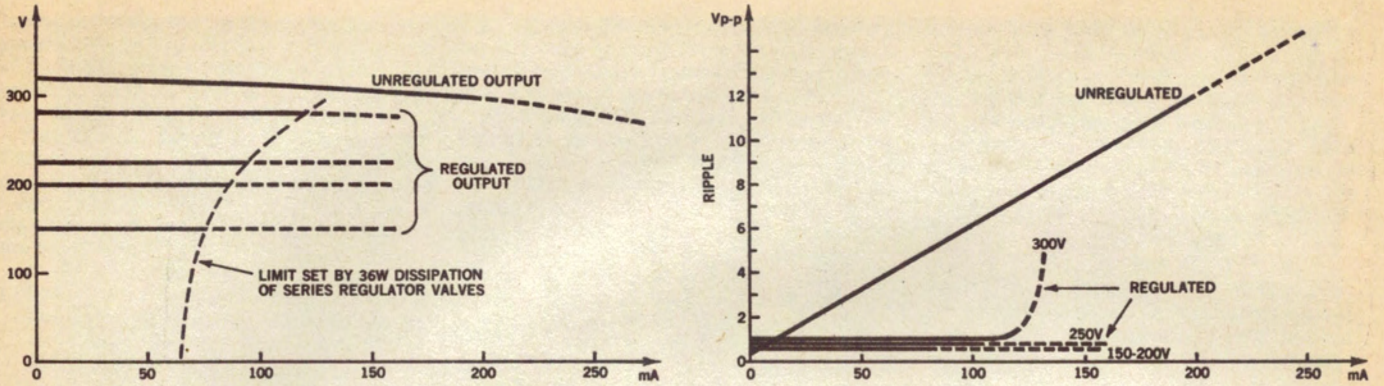
Above-chassis and underneath views of the prototype unit. Note that the small heater transformer shown has since been removed.

All things considered, the PF1149 transformer is more than capable of meeting the requirements of the power supply / modulator. So that if you are able to salvage one from a scrapped Pye TV receiver, as I was, it will do the job very well. There are probably similar power transformers in other old TV receivers which would be equally suitable.

However there may be some readers who will find themselves unable to obtain an old TV chassis yielding a suitable transformer, and perhaps others who in any case would prefer to use a new transformer rather than a used one. For these people, Ferguson Transformers have told me that they are prepared to make a new transformer. This will not be exactly the same as the old PF1149, which is really rather too conservatively rated for this project to justify the cost. Instead Ferguson has designed a new unit, with the specific requirements of the project in view. They will be giving it the code number PF3544.

You may have noted that in the HT rectifier bridge I have used four of the General Electric 1000V PIV "transient protected" or controlled avalanche diodes, type A14P. These cost a little more than the regular type of diode, although not much more now that GE are making them in Australia. At the time of writing they cost about 50c each trade. However in a project of this type where there is a large transformer and the HT is likely to be switched on and off frequently, the greater electrical ruggedness of these diodes is a big advantage.

In fact before I fitted the A14P diodes to the prototype unit, I had used regular 1000V diodes, but two of these blew on a switching



Curves showing the regulation and ripple characteristics of the unit as a power supply. Both regulated and unregulated outputs are shown.

transient about the fifth time I switched the HT off. Since fitting the A14P diodes I have switched the HT on and off many scores of times without a failure.

Having dealt with the basic transformer and rectifier circuit, perhaps I should return as promised to the more incidental aspects of the regulator / modulator section.

When the operation of this section was being described earlier, you may have noticed that there is a 24V zener diode in the cathode circuit of the 6BQ5 valve. This is used to provide a stabilised voltage for the transistors, making use of the cathode current of the 6BQ5 together with the bleed current through the voltage divider used to provide suitable screen grid voltages to the 6BQ5 and 6DQ6A's. The zener also maintains a fixed +24V cathode voltage on the 6BQ5, to allow transistor T2 to control the valve's bias by swinging its grid.

There is a small inductor (L1) in series with the HT output from the cathode follower stage. This consists of 100 turns of 22 gauge or similar enamelled wire, wound as a single layer coil on a 2½in length of 3 / 8in diameter ferrite rod. The purpose of the inductor is to minimise any phase shifts due to shunt capacitance which may be presented across the output terminals by a transmitter.

The regulator / modulator circuit is a feedback amplifier, and its stability therefore tends to be affected by any phase shifts caused by reactive loading. Inductor L1 serves to minimise such phase shifts, and this, together with loop response tailoring provided by the 680pF capacitor shunting the 6BQ5 plate and the .01uF capacitor shunting the collector of transistor T1, stablises the circuit for all likely load situations.

The modulation output will normally connect directly to the "cold" end of the transmitter's PA tank circuit, so that the only shunt capacitance present should be that of the usual RF bypass or feedthrough capacitor, together with the stray capacitance of the interconnecting cable and transmitter wiring. Typically the bypass or feedthrough will be no more than about .002uF, because larger values would start to attenuate the higher modulation frequencies.

The use of inductor L1 makes the modulator circuit quite stable for shunt capacitance values far above this likely figure. In fact the prototype unit is still completely stable even with .047uF shunted across the output. The unit should therefore be capable of operating with virtually any transmitter of up to about 32 watts input intended for high level plate or screen modulation.

The metering circuits should be fairly self-evident from the diagram. The voltmeter is connected permanently across the variable HT output, as the unregulated output remains substantially constant at 300V. The main part of the meter multiplier is made up from two resistors of near-equal value, to share the voltage gradient between them. The current meter is switched between the two HT output circuits to allow convenient monitoring of power input levels.

Also fairly self-evident is the wiring of the HT switch and the T-R keying socket. The HT switch is a DPST type which breaks both the negative side of the rectifier bridge, and also the unregulated output from the transformer centre-tap. This is necessary to ensure complete disconnection of both supplies. The 15-ohm resistor in the negative return of the bridge is to limit diode surge current.

The keying socket connections make it possible to complete both HT circuits externally when required.

I think that just about completes the basic circuit description. However before passing on to a brief description of the physical side of the unit, I should perhaps make a few comments about possible circuit mods and substitutions.

Probably the most likely reason why you may wish to modify the basic design is to increase its output capability, to allow it to operate higher power transmitters.

Assuming you are going to use the old type PF1149 transformer or a similar unit of very husky design, probably the easiest and best way of extending the output capability of the regulator / modulator circuit would be by adding a third 6DQ6A in parallel with the existing two. The 4.2A rating of the insulated 6.3V heater winding of the PF 1149 will easily cope with the additional heater drain, so that the only real circuit change required should be a reduction in the value of the top resistor in the screen grid divider. I have not tried this, but reducing the value from 20k / 10W to 15k / 10W should be a good place to start.

The additional valve would need to have its own 15 ohm series plate suppressor, 1k grid suppressor and 22 ohm cathode resistor, also a .001uF bypass from the grid to the HT output.

By this relatively simple and straightforward modification the current capacity of the regulator would be extended to about 180mA, allowing the unit to be used for full

POWER SUPPLY / MODULATOR PARTS LIST

1 Instrument case and chassis (see text).
1 Power transformer, PF3544 or similar (see text).
2 1mA / 100 ohm meter movements.
1 Rotary switch, 3 pole 3 position.
1 Toggle switch, DPST
4 Miniature 4-pin sockets.
1 240V neon pilot bezel
1 6V incandescent bezel
1 DPDT slider switch

VALVES AND SEMICONDUCTORS
2 6DQ6A or similar.
1 6BQ5 / EL34 or similar.
2 2N3569, BC107 or similar.
1 BC109, SE4010 or similar.
1 6V / 400mW zener diode.
1 24V / 1W zener diode.
4 A14P or similar 1000V transient protected diodes.

RESISTORS
½ watt 5%: 4 x 10 ohm, 2 x 15 ohm, 2 x 22 ohm, 1 x 100 ohm, 3 x 470 ohm, 2 x 680 ohm, 1 x 820 ohm, 3 x 1k, 1 x 2.2k, 2 x 2.7k, 1 x 3.9k, 1 x 10k, 1 x 15k, 1 x 22k, 4 x 33k, 1 x 100k, 1 x 220k, 1 x 270k.
1 x 150k / 1W
4 x 220k / 1W
2 x 15 ohm / 3W
1 x 6.8k / 4W
1 x 15k / 10W
1 x 20k / 10W
1 x 1k linear pot
1 x 10k log pot.

CAPACITORS
1 680pF 600V polystyrene
3 .001uF ceramic
1 .01uF ceramic
1 0.27uF 160V polyester
1 4.7uF 10VW tantalum electro.
2 8uF 350VW electro.
1 30uF 10VW electro.
1 100uF 25VW electro.
2 100uF 350VW chassis mtg electro.
1 100uF 350VW pigtail electro.

MISCELLANEOUS
5-pin DIN socket for audio input, 2 x ceramic octal valve sockets, 1 x ceramic 9-pin socket, 2½in length of 3/8in ferrite rod for stablilising inductor, tagstrips, miniature resistor panel, hookup wire, nuts, screws, solder, etc.
NOTE: Resistor wattage ratings and capacitor ratings are those used for our prototype. Components with higher ratings may generally be used providing they are physically compatible. Components with lower ratings may also be used in some cases, providing the ratings are not exceeded.

plate modulation of transmitters up to about 60W input.

A further increase in current capability could no doubt be achieved by using higher dissipation valves in place of the 6DQ6A's. I have used the valves because they are very easily obtainable at a relatively low cost. More exotic valves will generally involve considerably greater outlay, unless you already have some available or can obtain them from disposals sources. One fairly obvious choice would be the time-honoured 807; a pair of these would be capable of almost as much output as three of the 6DQ6As.

Other valves could be used in place of the 6BQ5, of course, although this is again an easily-obtained type. One could press a 6AQ5, 6BW6 or even an old 6V6 or 6F6 into service here, or perhaps the pentode half of a 6BM8 or 6GW8. It would also be possible to use a lower power type, providing it is rated to withstand 600V peaks on the plate.

The transistors are not unduly critical, and there are many other types which could be used. The main thing is to use silicon NPN types, with a BVceo rating of 25V or higher. T1 should preferably be a low noise type. The 6V zener may be a BZY88 / C6V1 or similar 400mW type, while the 24V diode should be a BZX61 / C24 or similar 1W type.

As I mentioned earlier, it is very desirable to use transient-protected diodes such as the A14P in the HT rectifier bridge. If you do elect to use regular diodes, I would recommend at least 1200V types, or series-connected 800V types with the usual equalising resistors and capacitors. Note that lower voltage A14 diodes may also be connected in series to replace the 1000V type A14P, if this is not available. In this case no equalising resistors or capacitors are needed, as the controlled avalanche action of A14 diodes makes them share reverse current and transients automatically.

The audio sensitivity of the modulator has been deliberately cut back, with the idea that the unit would be used in conjunction with a separate mic preamp / compressor. However if it is desired to use a dynamic mic directly with the unit, its sensitivity may be increased for this purpose simply by reducing the value of the 100-ohm resistor in series with the 30uF capacitor connected to the emitter of T1. Maximum sensitivity may be achieved by removing the resistor entirely and connecting the negative side of the capacitor directly to chassis.

I propose to give only a brief physical description of the unit, because with this type of project most amateurs will have their own ideas on the exact form which it should take.

The prototype unit is built in a fairly small instrument case measuring 12¼in x 7in x 6in (313 x 178 x 153mm). A good deal of the interior of the unit is taken up by the power transformer, with the two 100uF reservoir capacitors for the regulator mounted alongside it at one end of the chassis, and the two 6DQ6As and the 6BQ5 at the other end.

The two meters are mounted on the upper part of the front panel, with the mains and HT pilot lamp bezels between them. Immediately beneath the pilots is the rotary switch used for transmitter selection, with the HT switch and HT voltage control to the left under the voltmeter and the modulation control and audio input socket to the right under the ammeter.

Most of the minor components are mounted beneath the chassis. T2, T3 and the other comparator components are mounted on a 6-lug section of miniature resistor panel immediately behind the audio input connector, with T1 and the other amplifier

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Power Supply/Modulator

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components alongside on a 5-lug tagstrip. A second 5-lug tagstrip behind the rotary switch is used to support the stabilising inductor L1.

The resistors used as shunts and multipliers for the meters are mounted on an 8-lug section of miniature resistor panel attached to the rear of the current meter via its terminals. An 8-lug miniature tagstrip with some of the lugs removed is used to support the two 15-ohm plate suppressor resistors between the two 6DQ6A plate caps.

Before the additional heater transformer was removed from the prototype unit, there was insufficient room beneath the chassis for the 100uF capacitor used for the unregulated HT output. This was mounted on a small insulating panel on the top of the power transformer, as may be seen in the photograph. With the redundant transformer removed, there was no difficulty in mounting the capacitor under the chassis.

The wiring of the unit is not unduly critical, and the reader should encounter few if any problems if he wishes to modify the basic idea to suit some other construction. The main purpose of this article, I feel, has been to present the concept of a modulator / power supply in which bulky and costly modulation transformer is replaced by a couple of easily-obtained valves which combine both the modulation and power supply functions.