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Valve (Tube) Regulated Power Supplies

By Terry Bicknell

Choose one of these tried 'n' true circuits to meet your power supply needs.

How many times have you looked for a special power supply that was better than the ordinary transformer-rectifier-capacitor types and found that they just didn't cut it, or were too expensive on smoothing capacitors? Often you take second best and get on with it. Well, here are some tested systems that don't cost an arm and leg and are easily "tailored" to your needs.

WHAT IS A REGULATED POWER SUPPLY?

A regulated power supply (psu) is one that has its output controlled by a system of feedback involving a controlled element, a reference, and a DC amplifier. It may have either fixed or variable output.

For this article, I consider only the more common uses, that of providing an accurate and stable source of DC supply with a very low impedance, low noise, and low ripple. This is one of the most common uses in audio and instrumentation.

There are three basic types: series regulator, parallel regulator, and a combination of these two. There is also a switchmode or switcher type, but due to the noise and rf output, this is not used much in valve-related audio, as far as I can tell.

WHY USE A REGULATOR?

A good question! A carefully designed standard psu with pi input filtering can give a very good level of ripple rejection—in fact, an output for light loads, in millivolts! However, a regulator needs an output voltage that is constant over all the current range, and a good filter cannot do that. It also has a very low output impedance, which makes it ideal for critical jobs such as instrumentation and dual audio amplifiers. It also should have a very low output noise.

Power and Safety Warning!
Please note that there are lethal voltages in these circuits. Take every precaution to protect yourself when building and testing. In particular, discharge all electrolytics. Neither the author nor the magazine can accept liability for accidents.

Tables A and **B** show typical ripple and noise with a pi input filter psu and capacitor input filter. These are basic type circuits in valve equipment and are used for comparison here. AC mains input is set at 235V AC throughout both tests. In **Table A** the ripple output is excellent at less than 2mV; however, the regulation is less than desirable for a varying load. Note that an ordinary capacitor input filter will produce still far less desirable results, although its output voltage will hold up longer. In **Table B** the basic output voltage regulation of the capacitor input filter is better than the pi type, but the pi has far better ripple rejection.

HINTS AND TIPS

I have built and tested the following series of circuits for this article. Each circuit has a typical set of performance data and some application hints. By the end of the article you should be able to choose a type suited to your immediate need and have some fun building it, too.

The first thing to remember about a regulated psu, or simply "regulator," is that it is very wasteful of energy—not at all green! Because of the high voltages across

TABLE A - RIPPLE FROM A PI INPUT FILTER

Va (RMS)	V(DC)	I(DC)	Ripple (RMS)
333	454	0	less than 2mV
330	436	10	Lightly loaded
329	422	20	>2mV
327	405	30	
324	385	40	
323	372	50	> 5mV

Pi filter components: 500µF + 30H choke + 500µF
% Regulation = 22%

TABLE B RIPPLE FROM A CAPACITOR INPUT FILTER POWER SUPPLY

Va(RMS)	V(DC)	I(DC)	Ripple (RMS)
331	450	0	5mV Greater than for a pi type even
331	445	10	80 when lightly loaded.
329	436	20	150
327	426	30	200
325	416	40	240
323	412	50	300 single 500µF electrolytic

% Regulation = 9.2%

the series tube (or valve), it requires a separate well-insulated heater supply. Also, the amplifier valves will probably need a separate heater supply. The power transformer is becoming complicated with all those LT or LV windings.

You'll also need to look at how you supply the high voltage DC. Will you use the efficient silicon rectifiers, or yet another valve—a large power-gobbling rectifier with yet another separate heater winding? I examine these choices in more detail later.

The next thing to consider is the fact that the series valve requires about 90 to 120V across it to provide you with the regulation range. This means the HV supply will need to meet this, and as a rule of thumb for the transformer HV winding, take the maximum desired output voltage and add 125V—more on that later, too.

The next item of importance is the reference circuit. Do you use a zener diode, which is probably the easiest, or a reference tube such as an OA5 or 6561? I normally use zeners, but their use requires some thought. Most HV zeners above 50V have quite a low power dissipation and require careful consideration from the operating current point of view. Depending from where you take the reference supply, you will need to look at the chosen diode's operating current limits and work well within.

In general, placing the reference circuit in the output of the regulator means that it is being fed from a "regulated" output—included in the feedback loop—and should therefore be more stable and provide a more accurate reference. However, you need to allow for the current drawn, especially if you make a small low power regulator such as the single tube one here. You can also feed the reference from the unregulated DC supply feeding the anode (plate) of the series tube. This has the advantage that the reference current is not part of the output current, and it may allow a wider range of control for simpler circuits.

No work on regulated power supplies is complete without some comments on wiring and current paths. Most of you will not be building a double insulated system, so you'll need to provide a solid frame earth, which needs to be separate from the common ground return and fixed on a separate chassis bolt. You can also solder the electrostatic screen of the power transformer to that point.

Use heavy gauge wire for the power wiring from the rectifiers to the main electrolytic(s) because there is a high circulating current charging the electrolytic in this region. Common ground return paths need to be of a similar gauge, and the output ground needs to be wired directly to the smoothing electrolytic, with no other connections.

It is unwise to have long leads from rectifiers to the smoothing electrolytic, especially if they go via a PCB, because charging current, circulating currents, and common impedance can affect performance. Keep power circulating currents as far away from the main wiring as is practical to avoid stability problems.

In practice, I usually place the output divider (sensing) across the output terminals. This avoids any common impedance from the PCB or direct wiring. The reason is that the DC reference is not the electrolytic nor DC power input, but the output loaded terminals.

I next look at the basic raw DC part of the regulator, its general requirements, and its rectifiers. You'll need a power transformer with at least three low voltage windings for each of series valve, control valve, and perhaps your external circuitry or a separate low voltage transformer. If you choose thermionic rectifiers, you'll need to have another isolated winding.

RECTIFIER CHOICE

You can choose between a valve or semiconductor diode. Diodes are far more efficient, easier to wire, and neater. However, the input electrolytic needs to sustain the maximum peak voltage immediately

TUBE (VALVE) CHOICES

There are many tubes to choose from in the power category, ranging from the specialized 6080 and 6AR7 to the basic EL84 and 6AQ5. The 6080 and 6AR7 are specially designed triodes with good heater cathode insulation and large cathode areas. Workable alternatives to these are the KT66 and KT88 or EL34 (6CA7) as used here. All operate in triode mode.

The triode gives better performance than a tetrode or pentode in the series pass position, because it has a lower anode resistance; however, it requires more drive. For small or specialized regulators, 6AQ5 or ECL86 as used here is quite effective.

Control valves are pentodes for the best performance in simple circuits because of their anode (plate) characteristics. However, they need a lot of care around the selection of Vg2. I have found that a good start for this is at 70% of Vout maximum. I used the EF86 in this article; however, you can also use the 6AU6 and others such as the EF91 and EF94 and even an EF80 (6BX6). In the most specialized circuits ECC83 (12AX7) is used for control DC amplifiers or reference isolation and sensing.

OUTPUT/Series Pass	**Controllers/DC Amps**	**Reference Tubes**
EL34 (6CA7)	6AU6	OA2 150V
KT66 (6L6)	6AK5/5654	OA3 75V
KT88 (6550A)	EF80 (6BX6)	OC3 105V
ECL85 (6GV8)	EF86 (6267)	OD3 150V
ECL86 (6GW8)	EF94 (6AU6)	5651 92V
6V6	12AX7/5751	Not used here
6L6	ECC82 (12AT7)	
807	ECC83 (12AX7)	
6080 (6AS7)		
6098 (6AR6)		

Zeners - Philips series	**Zeners - 1N series**
3W 5% BZT03 C75/A52R	5W IN5378 B 75V "B" series are 5%
75V for circuit 2 and	types and recommended for use here.
3W 5% BTZ03 C100	5W 1N5378 B 100V
100V for circuit 4	5W 1N 5383 B 150V
3W 5% BZT series	
75V and 100V for circuit 3	

after switching on, until the regulator draws current, whereas the valve warms up with the rest of the circuit, which can be less stressful on the smoothing or input electrolytic. The downside to a valve rectifier is the voltage drop across it, which can easily be more than 25V compared to the semiconductor diode's. You may need to calculate this into the DC supply to the regulator. It effectively increases the impedance of the source and may limit action.

As with both types of rectifier, you need some form of current limiting resistor to help protect the rectifiers and electrolytic from peak charging current. This is usually 33 to 150Ω per side; however, it depends upon other factors such as the transformer DC winding resistance and value of the smoothing electrolytic, which always needs to be specified generously and have a low ESR for best performance.

You'd be correct in thinking that perhaps 50Ω of series resistance will degrade the performance of raw DC input. It does, but as with all compromises, the trade-off is in the protection and life of the diodes and the electrolytic as well as limiting that high charging current. The following approximation relates ripple and charging current.

The specification for the transformer needs to be generous, rather than tight, with 5% regulation being better than 10%. This means that the DC input will be more constant with load; therefore, the regulator has less work to do effectively, and thus performance improves.

Calculation of DC regulation factor

$Vr = (V_{nl} - V_{fl}) / V_{fl} \times 100$ (%) ... Ideally 5% or better

where (nl) = no load voltage and (fl) = full load voltage.

A simplified calculation for the series protection resistor

$Rt = Ra + Rsec + \{(Np/Ns)^2\} \times Rp$ ... HT supply resistance

where Ra = resistor in each anode leg

Rsec = resistance of half secondary

$\{(Np/Ns)^2\}$ turns ratio squared

Rp = primary resistance.

Note that the term Ra implies that there is a physical resistor in the anode of each diode leg, the value of which needs to be between 33% and 50% of the total value of the HT supply resistance above, to ensure adequate protection. Generally, I use 33% for tubes and 50% for semiconductor diodes.

Note on ESR: ESR is "effective series resistance." It is a measure of how good the electrolytic is. Low practical ESR values of milliohms are common and needed for a good psu. See maker's spec-sheets. It's not good to use "old type" electrolytics in power-supply units.

To relate the high charging current of the electrolytic to the DC current drawn by the load, check out this approximation between DC current drawn, % ripple voltage, and diode peak current. This peak current is the charging current that flows for less than 1ms at 50Hz, and it can cause some problems with noise.

1% ripple relates to approximately 12 times Idc, charging current, and
5% ripple relates to approximately 5 times Idc, charging current, and
10% ripple relates to approximately 4 times Idc, charging current (where Idc is load I).

There's a critical trade-off in the specification of the power transformer: the quality of the electrolytic (low ESR) and charging current and, hence, regulator performance. The following will give some idea of the trade-offs.

Calculation of supply ripple factor

%Rip = V(RMS)/V(DC out) × 100 (%)

where

V(RMS) = AC ripple output and V(DC) = DC voltage

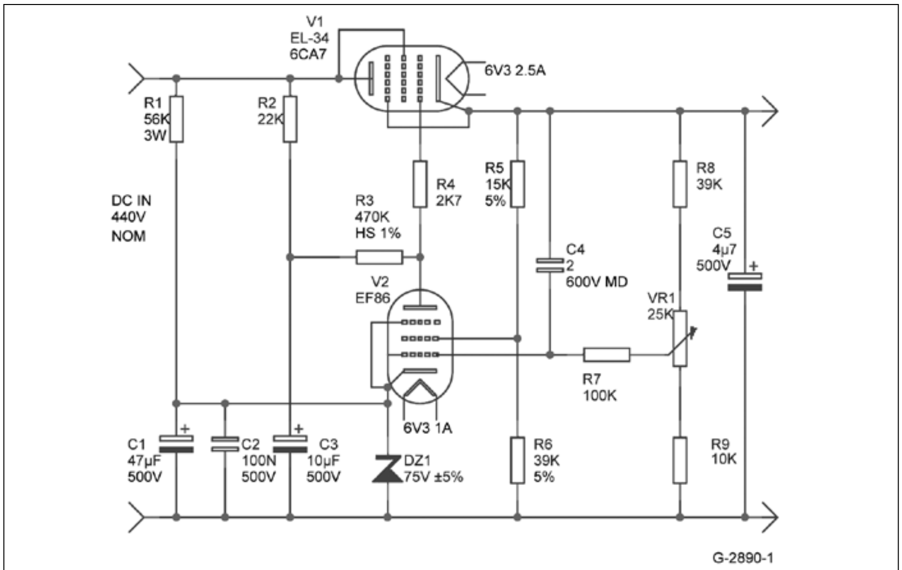

FIGURE 1: Circuit 1. Basic regulator. EL34 (6CA7) and EF86 (6267) plus zener diode.

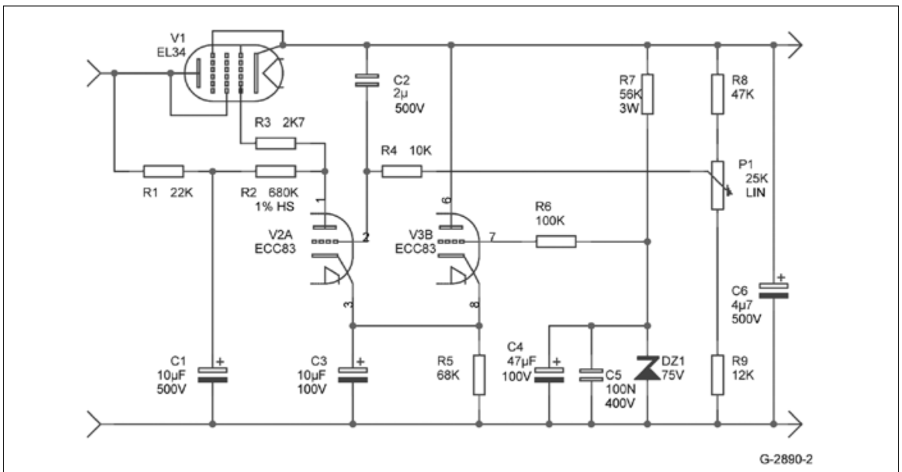

FIGURE 2: Circuit 2. Isolated zener. EL34 and 12AX7 (ECC83).

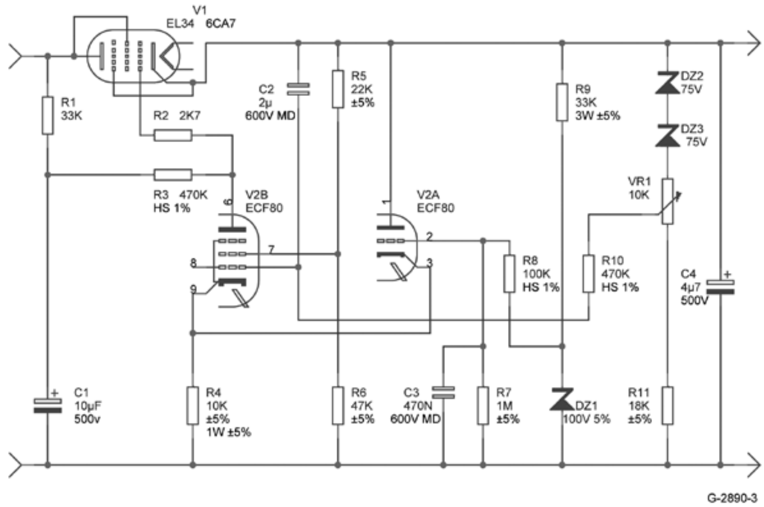

FIGURE 3: Circuit 3. EL34 (6CA7) and ECF80 (6BL8) general-purpose type.

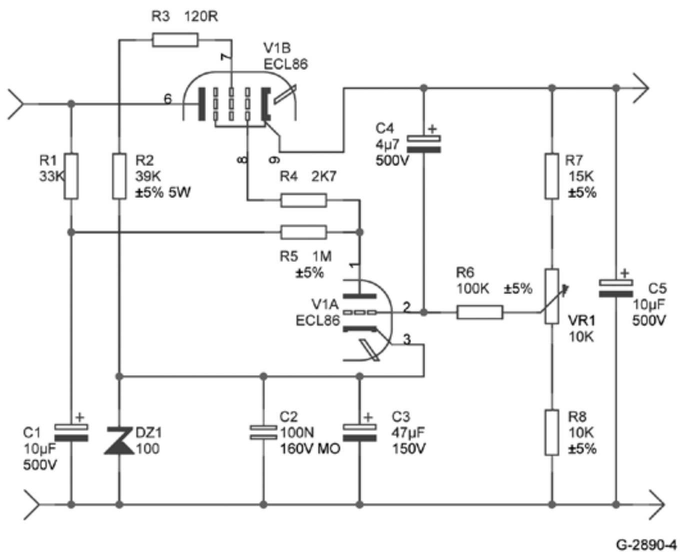

FIGURE 4: Circuit 4. Simple one tube type. ECL86 (6GW8).

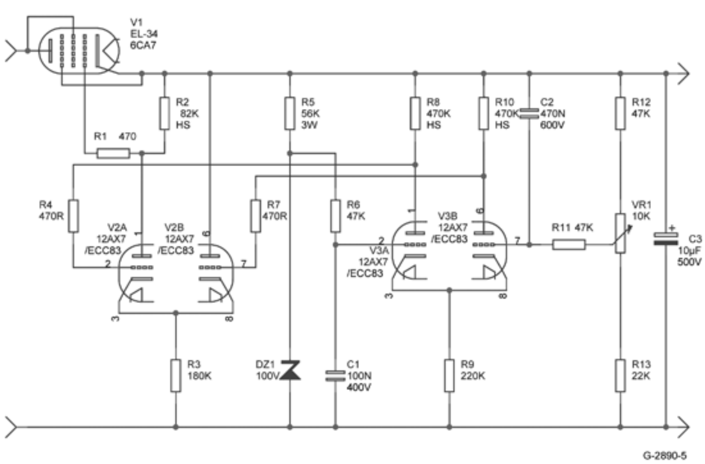

FIGURE 5: Circuit 5. High-performance unit.

DC Voltage Regulation (Vr)

$\%Vr = (V_{nl} - V_{fl})/v_{fl}$ where

V(nl) = no load voltage and V(fl) = full load voltage

The DC regulation at the input is important to maintain the performance of the regulator. Although a slightly larger transformer may be the outcome, it's worthwhile.

THE TESTED CIRCUITS

1. Simple two valve system (series pass and control valve)
2. Three valve circuit—DC amplifier plus isolated zener reference
3. Three valve circuit employing a triode pentode for control
4. Simple low-cost ECL86 regulator
5. A high performance, general-purpose bench unit

For many "one-off" jobs, a simple regulator that can deliver 50mA is all you need. The collection of circuits here offers at least that and, in the case of the last circuit, greatly improves on all desired parameters. These provide enough current to test most small amplifiers and signal line equipment, but not enough to run a power amplifier. Also in the case of the simple one valve circuit, you can build a cost-effective and very compact regulator that gives good performance for its simplicity.

The design of the power transformer will not be shown, because normally this is a specialist job. However, your junk box might provide a solution. You'll need an HT winding capable of approximately twice the desired output current to get the best regulation.

GENERAL OPERATION

For a given output voltage, the output is maintained "constant," or regulated, by means of a basic comparison between the output terminals as set by RV1 and the reference voltage, as set by the zener. Changes due to loading are "sensed" by the output divider networks, of which RV1 is a part, and that change is passed on to the DC amplifier V2. V2 then produces a corresponding but inverted change as drive to the series pass or regulator tube. This change in drive then corrects the effects of the load on the output.

For the circuit in **Fig. 2**, the only real difference is the fact that the zener reference is "isolated" by a cathode-follower circuit. This reduces the loading on the zener, and, because it is in the output circuit, it will be very accurate.

Figure 5 is a special case involving coupled triodes in a very high gain DC amplifier and reference system. V3 (right-most) is similar to other circuits in that there is a DC amplifier connected to the sensing control and a reference connected to the opposite grid of the pair. The difference voltage between the two anodes is then fed to the two middle triodes to produce the drive to the series pass tube and hence the correction needed.

Figure 1 and **Table 1** show a design example for a 50mA regulator with an adjustable output and a range of 100V. The transformer (in all cases here) is required to have 3 × 6.3V windings plus the HT winding, plus an electrostatic screen between primary and secondaries. The basic specifications of these windings would be 6.3 at 1A for the amplifier, 6.3 at 2.5A for the series valve, and a suitable 6.3 for the externals. The HV winding can be a single one or a tapped type depending on your choice of rectifier. This one is center-tapped for use with silicon diodes.

The circuit includes an old 80mA center-tapped transformer I found in my junk box that met the winding spec but was a little light on current at 80mA. It just made 5% Vr at 50mA and was degrading after that. I chose solid-state diodes with a 50Ω protection resistor. You can also use a single winding solution and a bridge rectifier, which, due to its two diode voltage drop, is not as efficient as the center-tapped version chosen, but is easier on transformer specs.

The sample circuits assume the output is centered on 250V.

NOTE: For **Figs**. **1**, **2**, **3**, and **5**, the EL34 is used in triode mode. **Figure 4** uses only an ECL86. The EL34 is not the best choice, but it is freely available and robust enough for this article.

Example:

1. Input smoothed DC measured as 440V.
2. If regulation is 5% then ideal lower limit at 50mA will be approximately

TABLE 1
EL34(6CA7) AND EF86 BASIC REGULATOR

I = 0	180V	230V	280V	Hum and noise
25mA	180V	230V	279.8V	3mV RMS,
30	179.8	229.8	279.7	unless
35	179.9	229.8	279.7	otherwise
40	179.8	229.8	279.7	stated
45	179.8	229.7	279.5 (1)	in
50	179.8	229.7	279.5 (1)	note (1).
55	179.8	229.7	279.4 (1,2)	
60	179.7	229.7	279.4 (1,2)	
65	179.7	229.6	279.3 (1,2)	
70	179.7	229.6	N/A	
75	179.6 (1)	229.6 (1)	N/A	
80	179.5 (1,2)	229.6 (1.2)	N/A	

Note 1: Output hum and noise approached 5mV.
Note 2: Output hum and noise approached 5mV and regulation decreased to more than 0.5V.
Line regulation for ±5% and 10% input based on 235V AC and 280V DC at 40mA.
-10% = 279.8V, -5% = 279.8, 0% = 279.7, +5% = 280.1, and +10% = 280.3V.
Drift: This is tolerable for such a simple system—approximately +0.5V with settling of a similar order during first hour.
Output impedance approximately 5Ω midrange.

These might include a general-purpose basic regulator for which no provision for line regulation is required. Line regulation for the simple circuits is minimal as indicated, so, too, is the drift figure. The useful attributes are simplicity, ease of construction, reliability, with moderate performance and easy-to-obtain parts.

TABLE 2 Three valve circuit EL34 plus ECC83

I = 0	200V (200.5)	250V (250.6)	300V (300.1)	
10	200.4	250.3	300	Noise and hum
20	200.4	250.3	299.9	initially
25	200.2	250.2	299.5	less than 1mV.
30	200.2	250.2	299.3 (1)	
35	200.2	250.2	299.2 (1)	
40	200.1	250.2	299.2 (1)	
45	200.1	250.1	299.1 (1,2)	Noise and
50	200.0	250.1	299.0 (1,2)	hum 5mv.

Note 1: Hum and noise less than 5mV, > 1mV.
Note 2: Regulation considered worse case when > 0.5V at maximum load.
Output impedance: 10Ω midrange.
Drift: Not determined. Settling < 0.5V during first hour.
Line regulation: Not accurately determined, < ±0.8V approximately.

USES
This is another general-use circuit having low-running current with an isolated zener reference. Its range can be changed easily to meet other needs. It has fairly good noise performance. It is adaptable, easy to construct, and reliable.

TABLE 3 ECF80 (6AB8) and EL34(6CA7)

I = 0mA	255	280	300 (299.9)	Hum and noise
25	255.0	280	299.9	less than
30	255.0	280	299.9	1mV
35	255.0	279.9	299.9	up to
40	255.0	279.9	299.9	50mA load,
45	254.9	279.8	299.9	increasing to
50	254.9	279.8	299.9	5mV at maximum
55	254.9	279.8	299.9	output.
60	254.8	279.8	299.8	
65	254.8	279.7	299.7	
70	254.8	279.6	299.7 (1)	
75	254.7 (1)	279.6 (1)	299.6 (1)	
80mA	254.6 (1)	279.5 (1,2)		

Note 1: Hum and Noise initially less than 1mV; at high loads approximately 5mV RMS.
Note 2: Regulation was very good until the top end, where it approached 0.5V.

Line regulation: at 300V and 40mA =	-10%	-5%	0%	+5%	+10%
	299.6	299.7	300	300	300.1

Output impedance: Approximately 4Ω midrange (2 to 8Ω).
Drift: Not determined but settling was > 0.3 and < 1V.

USES
Circuit 3 could be used to supply a permanent load at relatively high current. There was a minimum of drift during the first hour and it has relatively good line regulation. Hum and noise output was very good over the whole range. This is a reliable above average simple design that can be modified easily to give a greater current output with different tube and transformer.

420V.

3. Zener current for a 3W type 30mA maximum diode will operate safely at 5-7mA plus valve current.
4. Maximum valve current (Ia + Ivg2) —800μA.
5. Set series zener R from maximum Vin. 440V and 7mA = 62K, and at 420V I = 6.7mA.

5a. Power rating of 62K is 2.8W—use 4 or 5W type.

6. Set value of potential divider chain at output for 3.75mA = 74K.
7. Set value of screen supply to 70% of Vout. Preferred values of 15K and 39K. 5mA bleed.
8. Determine a value for variable R from 74K total of potential divider (sensing) chain.
   Valve is near to zener voltage, V2 saturation at approximately 98V and cut off at about 93V on g1. This is an initial guide to get approximate values to start; you need to check valve data.

8a. Value of resistance (R lower plus RV1) for 280Vout 26.67K, and for Vout minimum of 180V approximately 38K. Thus chain resolves to: top resistor 39K, RV1 = 25K and lower resistor = 10K.

9. For 280V output V1 will need a grid voltage of the order of 275. This sets the anode voltage of V2, which will be close to Va maximum - cutoff.
10. Minimum Va will be close to 210V, which correlates to minimum Vout of 180.

Does it work? Yes, as the results in **Tables 1-5** attest. The accompanying numbered **Tables** (**1-5**) correspond to the circuits. *aX*

TABLE 4 Single valve ECL86 (6BG8)

I = 0	200 (199.8)V	250.0 V	300 V	
10	199.8	249.9	299.9	Hum and Noise
20	199.7	249.8	299.8	increased
25	199.7	249.8	299.7	above
30	199.6	249.8	299.6	40mA.
35	199.6	249.7	299.6	
40	199.3 (1)	249.7 (1)	299.5 (1)	Regulation
45	199.2 (1)	249.6 (1)	299.2 (1,2)	>0.5V(2)
50	199.1 (1)	249.6 (1)	298.9 (1,2)	>0.5V (2)
H & N	< 5 mV	< 5mV	> 5 mV (2)	

Note 1: Hum and noise less than 5mV but increasing with load.
Note 2: Regulation decreasing, 0.5V or > 0.5V at maximum load.
Note 3: Max cathode current of output section is 65mA.
Output impedance midrange: Approximately 5Ω at 40mA.
Line regulation: Not determined for this circuit.
Drift: Settling during first hour, approximately 0.5V thereafter, < 0.3V.

USES

The uses for this very basic system are generally fixed voltage regulators—a bit like a PCB card regulator—a sub system regulator, or an exceptionally compact regulator for small spaces. The circuit is adaptable and economical in transformer design. This is very reliable and easy to set up and has surprisingly good performance for its simplicity. Many other tubes can be used as long as heater cathode insulation requirements are met.

TABLE 5 EL34(6CA7) + 2 12AX7 (ECC83)

I = 0	250 (250.1) V	300.0V	350 (350.1)V	Hum and noise
20	250.1 <0.1V	300 <0.1V	350.1 <0.1V	< 2mV,
25	250.1			except for
30	250.1			350V range
35	250.1			above 50mA.
40	250.1			Circuit became
45	250.1			critical
50	250.1 <0.1V	300 <0.1V	350.1 <0.1V	due to
55	250.1		350 (1,2)	falling DC input
60	250.1		(1,2,3)	and
65	250.1			voltage
70	250.1		Out	across
75	250.1		of	regulator.
80	250.1 <0.1V	300 <0.1V	Range	
85	250.1			
90	250.1			
95	250.1			
100mA	250.1 <0.1V	300 <0.1V		
	<2mV	<2mv		

Note 1: Hum and noise < 2mV except on high end, see note 2, 3 > 5mV.
Note 2: Regulation decreases rapidly after 350V at 50mA due to DC input.
Note 3: DC input to regulator falling beyond lower limit for this circuit (approximately 415V).
Output impedance: 1Ω or less up to 350V.
Line regulation: +10% +5% 0% -5% -10%
I = 50mA 300 300 300 300 300
Drift: < 0.5V settling in first hour. Thereafter less than 0.2V overall.

USES

This high-performance circuit could be used for a variable supply (with better DC input) or a fixed regulator of high quality and low noise and hum output.