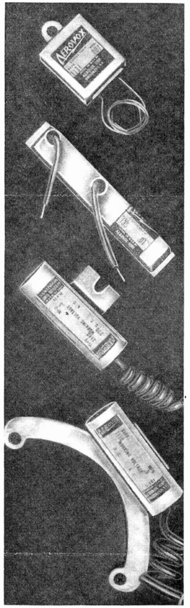

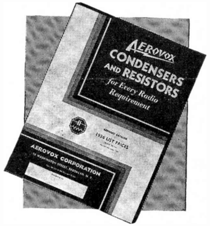

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The Use of Oil Condensers in Amateur Transmitters

By the Engineering Department, Aerovox Corporation

THE design and construction of transmitters employing high voltages requires careful consideration if freedom from breakdowns is to be had. Such breakdowns are the more costly and dangerous the higher the voltage and the power of the transmitter. Therefore the amateur will find it profitable to learn the magnitude of the voltages existing in different parts of his equipment and to choose his parts accordingly.

Apparently, many amateurs are not aware of the actual voltages and currents which occur in their transmitter with the result that they may use parts which are not able to withstand the strain. This article aims to point out the maximum voltages, currents, peak currents, etc. which occur in typical power supplies for transmitters. This is believed to be best fulfilled by taking a set of requirements as an example and working out every step in the design of a power supply.

STATING THE PROBLEM

The most logical order of events would call first for a decision as to the power to be obtained in the output stage. Then the amateur should study the characteristics of the various tubes which might deliver this output and choose the one which he considers most desirable. This decision may be based on suitability of the tube for a particular frequency range or the price of the tube or the power sensitivity or its output for a given plate voltage. This decision alone may considerably influence the total expense of the whole transmitter and should be carefully considered.

The design of a power supply brings its complications only, if the unit is to be subjected to widely varying loads. This appears to happen only in telegraph transmitters and class B stages. However, a little survey has indicated that plenty amateurs have their high voltage supply for class C amplifiers in operation when standing by. Instead of doing the switching in the primary of the high-voltage transformer, it is done somewhere in the load and the whole unit is running without a load. Thus we can take such a arrangement as an example. One of our acquaintances, W2ZZZ, had his mind set on a pair of 304B tubes since they were especially suited for 60 mc. According to the instruction sheets supplied by the manufacturer this tube requires the following voltages and currents when used as a modulated class-C amplifier. D.C. plate voltage, 1000 volts: Plate current, 90 ma. per tube: grid bias,—310 volts; grid current, 17.5 ma.; grid driving power, 7.5 watts; power output 60 watts per tube.

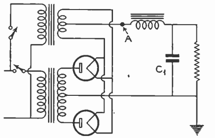

Fig. 1

Assuming that the power supply in question is to supply the plates of these tubes only and that the buffer and oscillator stages have their own supply, the problem is to design a power supply which will deliver 1000 volts at 180 ma. (for two tubes) under load with a ripple of less than 1 percent. The power supply must be designed so that it can run without a load for considerable time.

WHICH RECTIFIER CIRCUIT

The first move is to decide on a rectifier circuit and a suitable rectifier tube. Before this can be done intelligently it is necessary to remember that the conditions stated above imply the use of a bleeder resistor which adds to the load current; also, the filter, the tube and the transformer have voltage drops across them. Therefore, the actual power supply has to be designed for higher voltage and higher current than the original requirements; how much higher will be discussed presently.

There are several possible rectifier circuits: the half-wave rectifier, the full-wave rectifier, the bridge rectifier and the voltage doubler. The half-wave rectifier and the bridge rectifier will deliver the same voltage from the same secondary but the plate voltage and the inverse peak voltage of the bridge rectifier are only half that of the half-wave rectifier. The full-wave rectifier delivers only half the voltage of the half-wave rectifier (for the same total secondary voltage), while the voltage per plate is only half as much, the inverse peak voltage is the same as in a half-wave rectifier circuit. The

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voltage doubler circuit delivers twice as much voltage as the half-wave and four times as much as the full-wave rectifier with only half the voltages across the tubes.

One may eliminate the half-wave and the voltage doubling circuit at once in the present example. The half-wave circuit requires more filtering and larger peak currents in the rectifier. The voltage doubler must be run with condenser input and the currents to be drawn are so heavy that the ratings of the smaller rectifier tubes are likely to be exceeded.

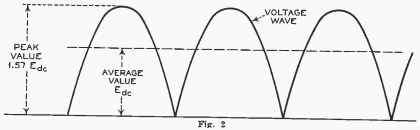

Fig. 2

Table I shows some fundamental relations between currents and voltages in a full-wave and a bridge rectifier. These figures apply to choke input circuits only and assume that the input choke has infinite impedance. In cases where the actual peak current is required the finite inductance of the choke has to be considered; an equation will be given later. The values are given in terms of the average d.c. load current or voltage. The drop in the rectifier and in the transformer is neglected and a transformer with a 1 to 1 ratio is assumed.

It will be seen that the current requirements per tube are the same for full-wave rectifiers and bridge type rectifiers. Since both the current and the voltage requirements for the bridge type are somewhat large for type 83 or 5Z3 tubes, it is more expedient to employ high-voltage rectifiers in a full-wave rectifier circuit.

Table II shows the characteristics of the rectifiers used by amateurs. Keeping in mind that the output voltage is to be more than 1000 volts and that the required a.c. voltage per plate is to be 1.11 times the d.c. output voltage, we find that the table shows the following suitable tubes: RK19, RK21, RK22, 836, 866. In the case of the latter two tubes one must watch the peak inverse voltage and the peak current, both given in table I. So for instance, the maximum obtainable d.c. voltage from a circuit employing 866 in full-wave arrangement is 7500/3.14 = 2400 volts, approx. In the particular transmitter illustrated, the 866 tube was chosen.

When a choke-input filter is used and the choke is above a certain critical value, the voltage appearing at A, Figure 1, is like the graph shown in Figure 2. It is the duty of the first filter section to smooth out the ripple and the voltage across C1 is approximately equal to 1/1.57 of the peaks shown in Figure 2 minus the voltage drop in the choke plus the ripple. If there is a second filter section (Figure 3), the next condenser, C2 is subjected to a lower voltage due to the voltage drop in the second choke. But if the load is removed and no current flows, the condensers (both C1 and C2) will be charged up to the peak voltage of the transformer secondary, 1.57 times the average d.c. voltage at A. In our example that would be over 1600 volts.

In order to prevent the voltage from reaching this maximum, the following condition must be fulfilled according to Terman:

$$\frac{\omega L_1}{R} \geq \frac{\text{peak volts of fundamental ripple component}}{\text{d.c. voltage output}}$$

inserting values for full-wave rectification of 60 cycles, we have

$$L_1 \geq \frac{R}{1125}$$

This equation determines the relation between first choke and bleeder resistance. It is most practical to obtain the choke first. Under full load conditions, the choke must be large enough to prevent the peak current from rising beyond the rating of the tube. This requirement is different from the previous one and, in general calls for a smaller choke. It would be very good to obtain a choke which has the larger of the two values and is rated for the maximum current but this becomes quite expensive. Therefore the swinging choke is used; this device is so designed as to vary its inductance due to saturation when the current varies; thus it can satisfy both requirements.

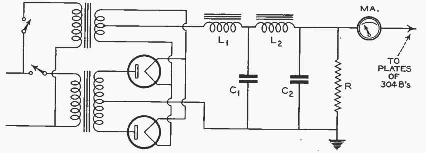

Fig. 3

The next step is to the catalog of the choke manufacturer. It will be seen that a standard size choke with large enough current rating (and do not forget the voltage rating) has an inductance varying between 5 and 25 henries.

Insert the value of 25 henries in the equation above and find the maximum bleeder resistance:

$$R = 25 \times 1125 = 28125 \text{ ohms}$$

It is much better to employ a lower value, if possible. In our case 20,000 ohms was used. This brings the total current to 180 + 50 = 230 ma.

The peak anode current in the tube can now be found from the equation given by Terman:

$$\frac{\text{Peak current with finite inductance}}{\text{Peak current with infinite inductance}} = 1 + \frac{E_1}{E_{dc}} \frac{R_1}{\omega L_1}$$

where E_1 is the peak of the ripple (fundamental), R_1 is the full load resistance

substituting values:

$$\text{Peak current} = 230\left(1 + \frac{.667}{1} \times \frac{1000}{.23} \times \frac{1}{755 \times 5}\right) = 407 \text{ ma.}$$

this is within the rating of the tube.

THE FILTER

It was stipulated that the ripple at 120 cycles should not exceed 1 percent. According to table I there is a ripple of 48.3 percent at the input of the filter. The attenuation in any filter section is given by the equation

$$\text{att} = \frac{1}{\omega^2 LC}$$

under the provision that ωL is very much larger than ωC. Inserting values in the above equation it is seen that the required amount of filtering cannot easily be obtained in a single section unless very large condensers are used. Note that the value of L is 5 henries because we are considering full load conditions.

A standard condenser of 4 mfd. would cut the ripple down to

$$\text{ripple} = \frac{48.3}{755^2 \times 5 \times 4} = 4.3\%$$

A similar calculation will show that the ripple will be cut to .2 percent with a second filter section employing a 10 henry choke and a 4 mfd. condenser. When deciding on the choke and condenser sizes one is cautioned to check that they do not resonate at the frequency of the ripple, for that would increase the hum instead of decreasing it. If the reactance of the choke is much higher than that of the condenser (at least ten times) this condition is fulfilled automatically. The reactance of a 5 henry choke at 120 cycles is 6.28 × 120 × 5 = 3860 ohms approx. The reactance of a 4 mfd. condenser at 120 cycles is 1,000,000 (6.28 × 120 × 4) = 332 ohms. Therefore these values for choke and condenser will be satisfactory and will not resonate at 120 cycles.

Summarizing our efforts so far, the bleeder resistance required is 20,000 ohms able to carry 50 ma., or at least 40 watt rating. A swinging choke 5-25 henry, rated at 230 ma. and insulated for better than 1000 volts. A second choke, 10 henry also rated 230 ma. and over 1000 volts. The two condensers of 4 mfd. should be of the oil-impregnated oil-filled type. The voltage rating had best be decided after the transformer has been chosen.

The chokes in our sample transmitter had resistances of 60 ohms each, which makes the voltage drop in them 120 × .23 = 27 volts approx. The drop in the mercury vapor tube is constant at 15 volts. Now the secondary voltage required each side of centertap is found by referring to table I

$$E_{rms} = 1.11\,(1000 + 27 + 15) \text{ volts}$$

This does not allow for reactance and resistance drop in the secondary itself; for that reason it is good to add about 10 percent. The next standard value of secondary voltage would be 1250 volts, while the current rating should be at least 230 ma. d.c. The actual alternating current in the winding would be .707 × 230 ma. if the inductance of L1 were infinite but it will now be more.

Last but not least come the voltage ratings of the condensers. If there were no surges, a rating of 1.4 × 1250 volts should be safe. When the power is switched on and off there are voltage surges which may reach 2500 volts according to tests made. The lowest rating which could be employed here is 2000 volts; an occasional 2500 volt surge is permissible. The constructor should make sure that his surges are not unreasonably high by means of a test with one of the peak voltmeters described in an earlier issue or by means of the cathode-ray tube. A high-resistance voltage divider can be employed.

Table I

	Full-wave rectifier	Bridge rectifier
Average d.c. output voltage	E	E
Average d.c. output current	I	I
Transformer secondary volts r.m.s.	1.11E per leg	1.11E total
Transformer secondary current r.m.s.	0.707I per leg	I
Transformer primary voltage r.m.s.	1.11E	1.11E
Transformer primary current r.m.s.	I	I
Transformer secondary kva.	1.57EI	1.11EI
Transformer primary kva.	1.11EI	1.11EI
Inverse peak voltage across rectifiers	3.14E	1.57E
Current per tube r.m.s.	0.707I	0.707I
Peak current per tube	I	I
Ripple frequency	2f	2f
Ripple voltage r.m.s.	0.483E	0.483E
Peak voltage of fundamental ripple component	0.667E	0.667E
Peak voltage of second harmonic	0.133E	0.133E
Peak voltage of third harmonic	0.057E	0.057E

Table II
Rectifiers for Transmitters

Type	Description	Cathode Type	Cathode V.	Cathode Amp.	Maximum a.c. volts per plate	Maximum output cur. ma.	Maximum inverse pk. volts	Maximum pk. current ma.
5Z3	Full-wave, high-vacuum	Fil.	5.0	3.0	500	250	1400	....
80	Full-wave, high-vacuum	Fil.	5.0	2.0	350 400 550	125 110 135	.... choke input	....
81	Half-wave, high-vacuum	Fil.	7.5	1.25	700	85	....	....
82	Full-wave, mercury vapor	Fil.	2.5	3.0	500	125	1400	400
83	Full-wave, mercury vapor	Fil.	5.0	3.0	500	250	1400	800
83V	Full-wave, high-vacuum	Htr.	5.0	2.0	400	200	1100	....
836	Half-wave, high-vacuum	Fil.	2.5	5.0	....	....	5000	1000
866	Half-wave, mercury vapor	Fil.	2.5	5.0	....	....	7500	1000
866-A	Half-wave, mercury vapor	Fil.	2.5	5.0	....	....	10000	600
872	Half-wave, mercury vapor	Fil.	5.0	10.0	....	....	7500	2500
872-A	Half-wave, mercury vapor	Fil.	5.0	10.0	....	....	10000	2500
RK19	Full-wave, high-vacuum	Htr.	7.5	2.5	1250	....	3500	600
RK21	Half-wave, high-vacuum	Htr.	2.5	4.0	1250	....	3500	600
RK22	Full-wave, high-vacuum	Htr.	2.5	8.0	1250	....	3500	600