1-25-58 Allan C Mueller

Electronic
TUBES

G-E HAM NEWS

GENERAL ELECTRIC

SPECIAL REPRINT

ABOUT POWER SUPPLIES

BETTER DYNAMIC CHARACTERISTICS MEAN BETTER OUTPUT ON CW, AM AND SSB

Presenting a special reprint of the material on dynamic power supply regulation that was originally published in the January–February and March–April, 1954 issues of G-E HAM NEWS.

What is dynamic regulation in a power supply? Because the literature in this field is exceedingly sparse, perhaps a good way to start is to take two common definitions and directly relate them to the subject at hand, thus:

Static—Relating to forces in equilibrium (as d-c plate voltage and current in a rig transmitting a continuous unmodulated carrier).

Dynamic—Relating to moving forces (as d-c plate voltage and current under typical operating conditions in the average amateur CW, AM or SSB rig).

Keeping these definitions in mind will help in understanding just what goes on inside the conventional plate power supply which ordinarily consists of a center-tapped step-up transformer, rectifier tubes, and a two-section choke-input filter to reduce ripple. Since such supplies have been used since the introduction of the mercury-vapor rectifier, one might think that just about all the "bugs" would have been smoked out by now. Well, many bugs have been eliminated and, as a consequence, manufacturers of transformers and chokes now proudly offer what they term "matched power supplies"—sets of components for which they publish ratings, voltage regulation curves, and ripple output to be expected. These "matched" components make up power supplies that do perform as the published data indicates.

LOSS OF VOLTAGE

However, poor *dynamic* regulation in these conventional power supplies means distortion of signal output—alteration of actual radiated intelligence—almost without exception in CW, AM and SSB rigs. These faults exist no matter how good a *static* regulation figure is indicated by d-c input instrumentation. This comes about in the conventional power supply because transient oscillations excited in the filter rob the rig of voltage during a sizable portion of the time it is sorely needed. Hams who light-heartedly pass this effect off as "instantaneous," thereby implying it is of no consequence, may want to examine their power supplies more critically after studying the test data presented below.

Consider the meaning of the voltage regulation curve usually given for the ordinary rectifier-filter combination. This is a "static" curve, obtained by loading the supply to certain currents, reading the voltages across each load, and then plotting the results. Such a curve is useful, but it tells us only what the *average* voltage will be at any *average* current value—***because the instruments used to measure these values respond only to average quantities.*** Figure 1 shows just such an acceptably good regulation curve in which the voltage drops about 10% or so from no load to full load on an *average* basis.

But is it the average load, voltage and current alone that we are interested in? What kind of loads do our amateur transmitters present to their respective power supplies? Do we transmit intelligence with average loads—or with a complex pattern of instantaneous loads?

VOLTMETERS MISLEADING

Consider the final stage of a CW transmitter. At key-up the load is zero, or, at most, a rather small one. When the key is closed, the maximum load current is drawn. Now does the power supply follow the same curve that was plotted under static or slowly varying loads? An ordinary voltmeter might lead one to think so.

But look at Figure 2! This is a photograph of a cathode-ray oscilloscope which shows how the voltage varies with time in the ordinary power supply when the load is suddenly applied as in keying a CW rig. The solid upper line shows the no-load output of the supply—820 volts; the lower solid line represents zero volts. The lower waving line is a 60-cycle timing wave which permits reading the actual load voltage (represented by the upper oscillating line) at any fraction of a second from the instant the load was applied. The spot on the oscilloscope was started as the key closed to a 200-milliampere load. (The steady current rating on the test supply is 250 milliamperes.)

Note how the load voltage dips suddenly to less than a third of the no-load voltage line, then wildly overshoots the line and oscillates about until it finally settles down to the average loaded voltage of 760 volts—which is the same as the static loaded output voltage shown in the curve of Figure 1 for a 200-milliampere load.

(Incidentally, the ripple under load is visible on the right-hand portion of the load voltage curve of Figure 2, but is fairly small compared with the extravagant excursion of the voltage in the period immediately following the application of the load.)

A d-c voltmeter that was connected across the line at the same time merely dropped from 820 to 760 volts and gave no indication of the actual turmoil immediately after keying!

EFFECT ON CW OPERATION

Is this turmoil anything to worry about? Well, the final stage in a CW transmitter generally runs Class C, and the transient oscillation shown across the power supply modulates each character with that same wave form quite independently of any keying filter that may be provided for click reduction. This, then, is the signal envelope—somewhat poorer than ideal!

How long is a dot or a dash in seconds? That depends on the operator for the most part, of course. But this transient oscillation certainly lasts for a considerable portion of the average CW dot or dash, because as can be seen from the timing wave of Figure 2, the voltage does not settle down to a steady ripple until more than a tenth of a second has elapsed. And as anyone who has played with timing in radio or photography work knows, a tenth of a second is far from what is normally thought of as "instantaneous."

When the load is removed (key up), the power supply voltage behaves as photographed in Figure 3—another wild peak, with the oscillation finally settling down to the no-load line. Of course, in this case there is no "on the air" effect, but the filter condensers and all other connected equipment are subjected once again to this voltage turmoil. This may explain why every once in a while a ham's whole rig is blown to kingdom come when he shuts it off.

The oscillograms shown apply only to single keying actions. Fast keying conditions intensify the transients shown in Figures 2 and 3.

EFFECT ON PHONE OPERATION

So much for CW loads on the common garden variety power supply. Now before the phone men start laughing up their sleeves at their brass-pounding brethren with "hand-modulated" rigs, let's take a close look at Class AB_1, AB_2, and B modulators operated with conventional power supplies.

It is characteristic of these modes of operation to draw average plate current which is a function of the modulating signal. Thus, the modulator load is similar to the on-off type of load experienced in a keyed CW transmitter, and the power supply transient so induced can be a real hazard to good quality. Because of the relatively sluggish action of a d-c plate current instrument (which tends to indicate current flow averaged over about half a second or so) the actual cyclic or syllabic transient load presented to the power supply is much greater than one would be led to believe by just reading the plate milliammeter.

What happens when the power supply behaves as in Figure 1? The answer is high distortion and loss of required peak power because most of the supply voltage just is not there part of the time it is needed by the modulator, and so the modulator tubes cannot draw the peaks of plate current that the grid drive on the modulator stage says should be drawn.

And remember, distortion tests made with steady tones will not show this "dynamic" distortion because the drain on a power supply induced by a steady tone is constant when averaged over one-half of the period of the test tone wave—relatively short compared to a filter transient which lasts more than a tenth of a second.

EFFECT ON SSB OPERATION

Single-sideband transmitters employing Class AB_1, AB_2, or B RF stages present the same type of load to their respective power supplies—and, as a result, also introduce considerable distortion in the radiated signal.

About the only types of emission in common use which do not suffer "on the air" losses as a result of transient filter oscillations are NBFM and FSK. (No transients are excited in the filter because the load is steady.) Linear amplifiers used with AM signals overcome this dynamic power supply regulation problem, but the carrier efficiency of this mode of operation is so low that use of linear amplifiers in amateur AM transmitters is not common. Similarly, constant current (or Heising) modulation for AM is another case where dynamic power supply regulation is not of primary importance. Grid modulation systems—control, screen or suppressor—also side-step the dynamic regulation problem but are inherently low-efficiency systems at best. In all these modes of operation, the only important power supply considerations are adequacy of rating and ripple filtering.

What can be done to improve the dynamic regulation of the conventional power supply? Let us follow the steps that were taken in the shack of W2KUJ to attack the problem.

THE SOLUTION

It became apparent that merely improving the ripple attenuation by adding more filter sections affected the dynamic regulation very little. So the first step was to increase the capacity of the existing filter from 2 microfarads to 5 microfarads per capacitor. The result appears in Figure 4—which shows excellent ripple filtering but only slightly reduced voltage excursions as compared with the transient of Figure 2.

Next, the two 5-microfarad capacitors of the two-section filter were connected in parallel to make a single-section filter (with the two chokes left in series). As shown in Figure 5, the voltage excursions are not greatly changed in magnitude, but have a less complex pattern—comparable, in fact, to that of a simple damped oscillation. But here again, the oscillation is excited in the filter by the suddenly-applied load.

The next step in the test was to use 45 microfarads of capacity as the final element of the filter. The dynamic regulation performance responded nicely, as shown in Figure 6. Note the reduction of magnitude of voltage swing and lowering of the resonant frequency of the filter as compared with Figures 2, 4 and 5.

FINAL DESIGN

This encouraged a final design in which 90 microfarads of capacity rendered the curve shown in Figure 7. Here the dynamic regulation is just slightly greater than the static regulation, which, incidentally, measures 9.34%—quite good enough for almost any amateur transmitter. The "break" characteristics of this final design are pictured in Figure 8. Use of more capacity would improve the dynamic characteristics of the power supply correspondingly because the resonant frequency of the filter would be lowered even farther. (For more detailed theory on the dynamic characteristics of plate power supplies see "Designer's Corner," page 8)

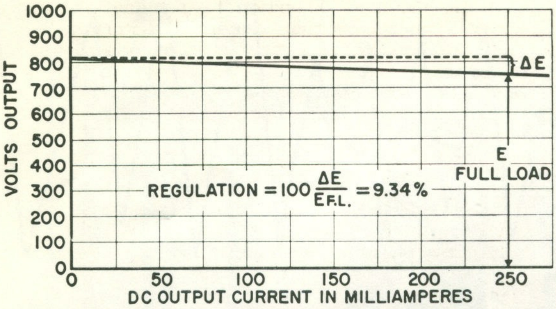


FIG. 1 *Static regulation curve (C_a, C_b any value)*

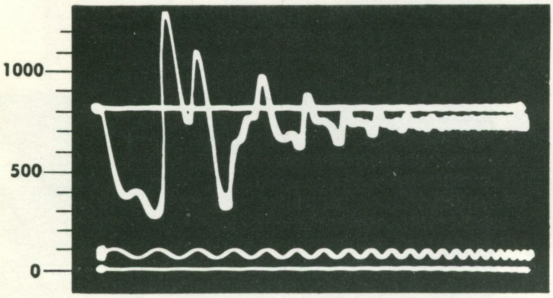


FIG. 2 *Load applied ($C_a = C_b = 2$ mfd)*

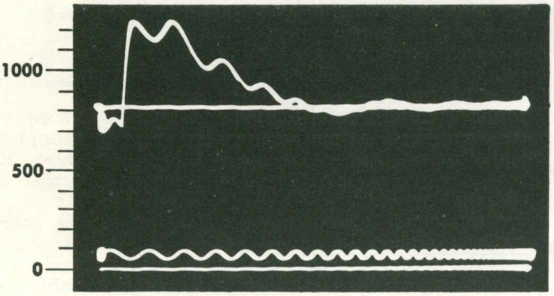


FIG. 3 *Load removed ($C_a = C_b = 2$ mfd)*

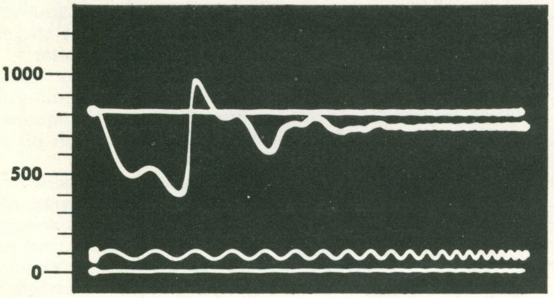


FIG. 4 *Load applied ($C_a = C_b = 5$ mfd)*

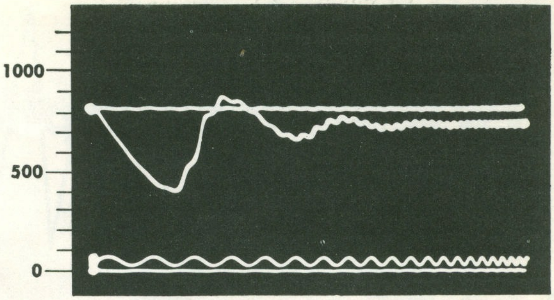


FIG. 5 *Load applied ($C_a = 0$; $C_b = 10$ mfd)*

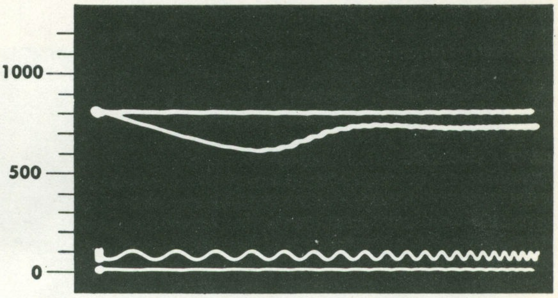


FIG. 6 *Load applied ($C_a = 0$; $C_b = 45$ mfd)*

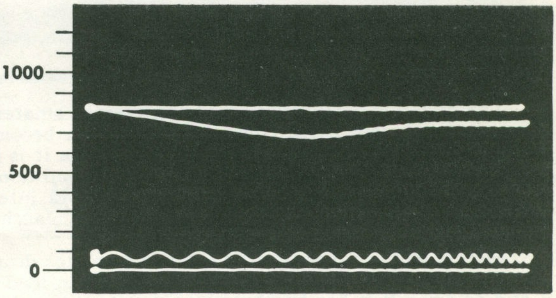


FIG. 7 *Load applied ($C_a = 0$; $C_b = 90$ mfd)*

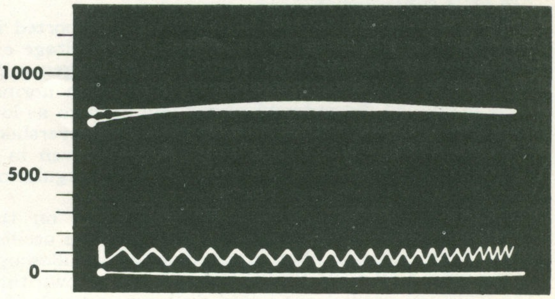
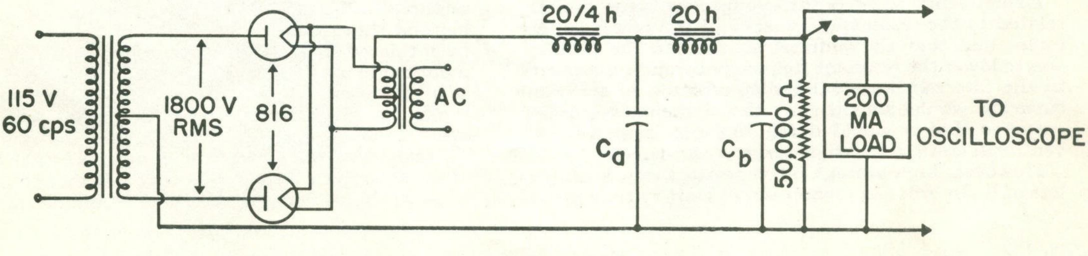
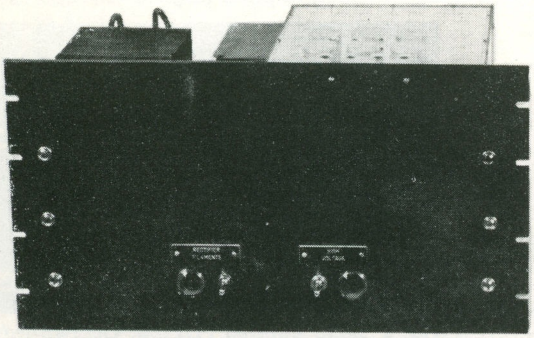


FIG. 8 *Load removed ($C_a = 0$; $C_b = 90$ mfd)*

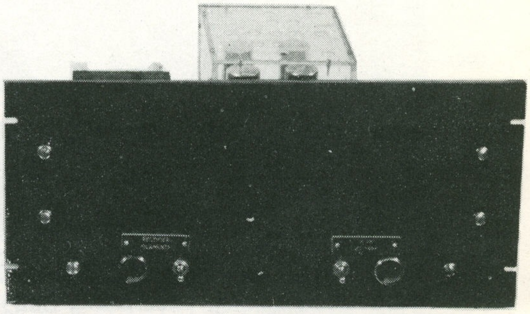
Above data taken with this 750 V/250 ma d-c supply (see text):



two power supplies



1500 VOLT



750 VOLT

The dynamic characteristics of the average amateur power supply are those characteristics which become apparent in the operation of the supply when it is in actual use under average amateur operating conditions. In most amateur operations this means rapid intermittent application and removal of widely varying loads.

Meters will not measure the extensive voltage drops and peaks which are induced by varying the load—and as a result it has become somewhat traditional to regard such voltage excursions as "instantaneous" and "of little consequence."

However, as demonstrated in the tests reported in the last issue of G-E HAM NEWS, these voltage excursions are somewhat more serious than is generally believed. The oscillograms showed that when normal load is applied d-c output voltage will drop to as low as a third of the no-load voltage, then wildly overshoot the no-load level, drop again, and so on—even in a power supply which has an acceptable static regulation figure.

Instantaneous oscillations? That depends on the definition of the word *instantaneous.* As these oscillations were actually photographed on an oscilloscope along with a 60-cycle timing wave, it was shown that the transient oscillations lasted well over a tenth of a second—enough time to competently modulate every CW character and distort at least a fair portion of the first syllable of every word a phone man utters.

Experiments showed the oscillations were directly related to the resonant frequency of the power supply filter—and that the simplest solution to the problem was to lower the resonant frequency by adding capacity to the filter. It was found that addition of sufficient capacity would smooth out the dynamic regulation curve so that it would nearly coincide with the conventional static regulation curve of the supply.

However, high-voltage oil capacitors cost money—lots of it. In order to economize, at least in the sense of not running these newly designed power supplies a great deal higher in cost than conventional supplies of the same ratings, electrolytic capacitors have been specified in series-parallel combinations together with voltage-equalizing resistors.

Electrolytic capacitors generally are, we believe, better than they are cracked up to be in amateur circles. True, they may not last as long as oil capacitors, but as they have been improved considerably since first introduced, it was felt they were well worth trying. Those who still feel squeamish about using electrolytics may, of course, put in oil capacitors of the same value with equally good results. However, it is felt the electrolytics offer more capacity per year, per dollar.

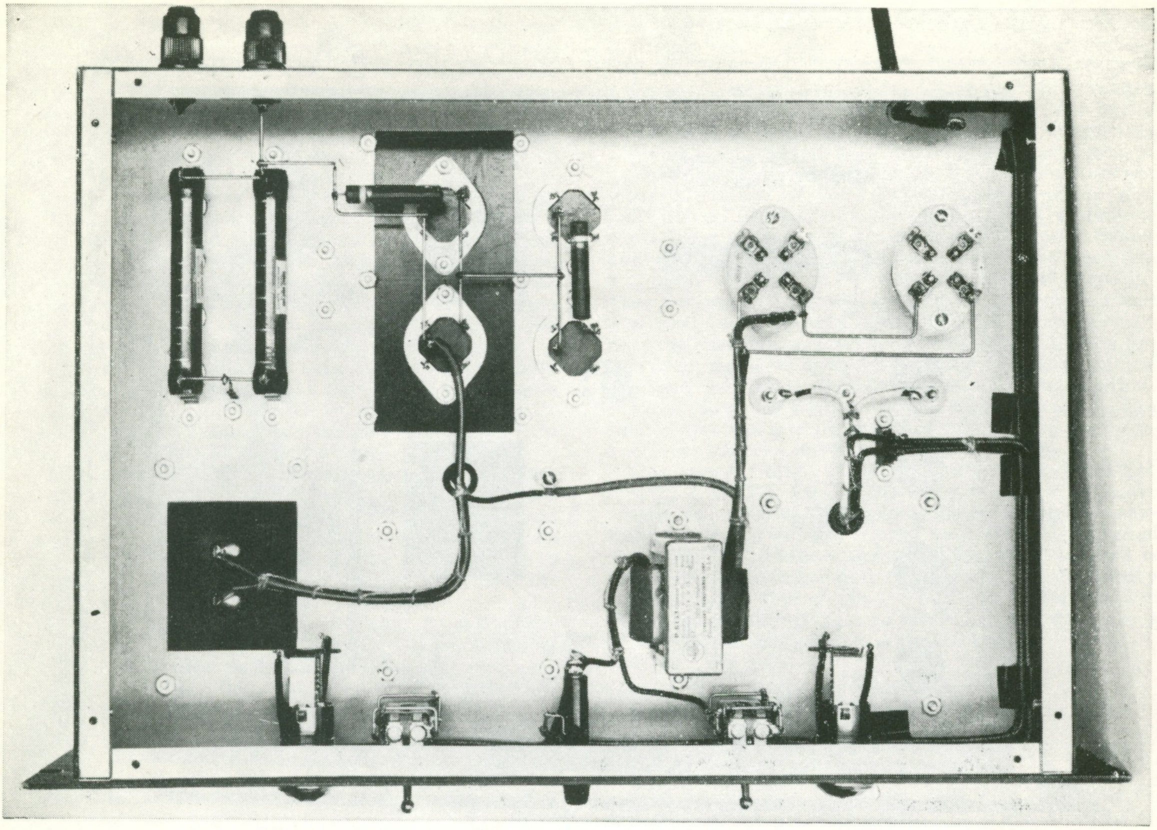
In obtaining the unusually high capacity via the series-parallel methods shown in the circuit diagrams, it is important to make sure that all the equalizing resistors are used. This will insure operation of each capacitor well within its voltage rating.

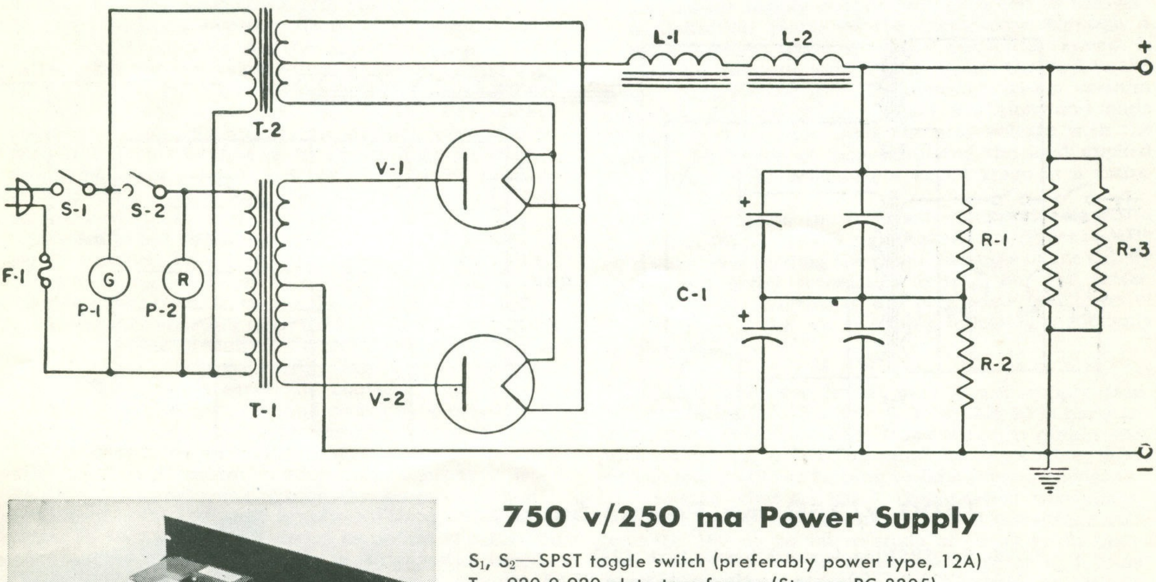
The can of each electrolytic capacitor is its negative terminal. The capacitors in the series arrangement at the negative (chassis) end of the string may be mounted directly on the chassis with the metal mounting rings supplied with each capacitor. However, the remaining capacitors must be installed with cans insulated not only from the chassis but also insulated from the cans of the capacitors higher up in the string. Careful examination of the circuit diagrams will make this clear.

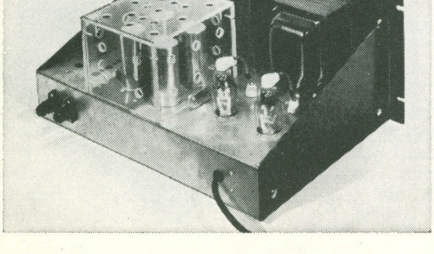
To provide this insulation a variety of mounting methods will suggest themselves to the builder. The method shown here is to mount capacitors that must be insulated on a piece of textolite which in turn is mounted in a hole of appropriate size cut in the chassis.

In addition, it is strongly recommended that a shield be placed over those capacitors whose cans operate above ground. ***This shield is to protect the operator—not the capacitors!*** Remember that the can of an electrolytic capacitor is generally thought of, subconsciously, as being grounded. The builder may have

(continued on page 7, column 1)

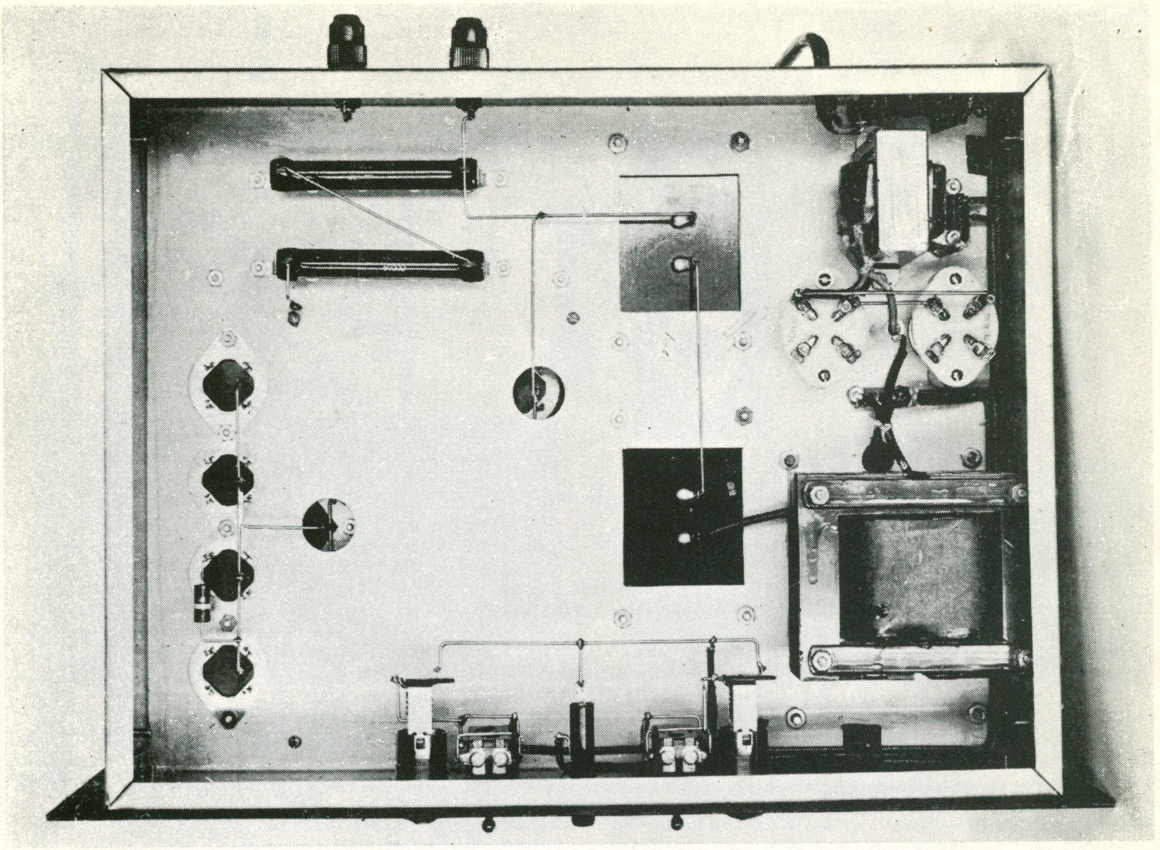


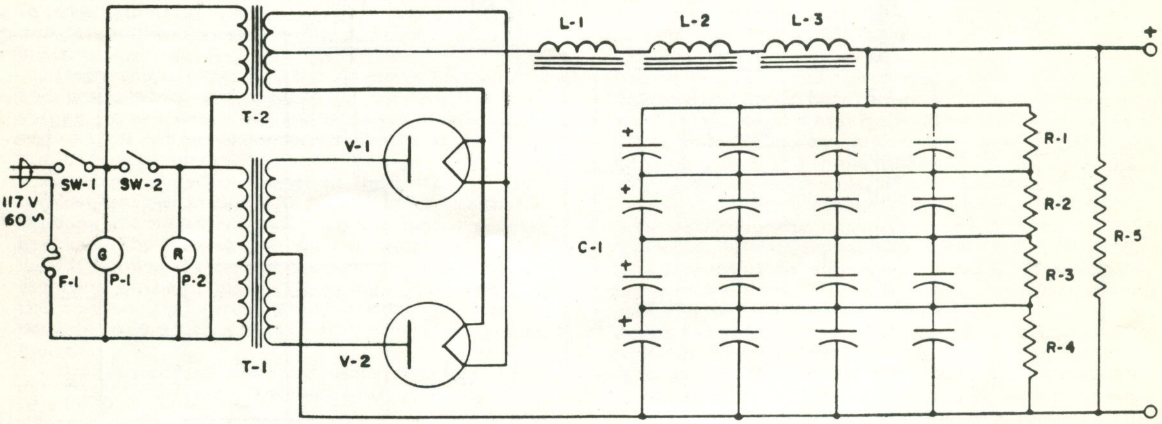




750 v/250 ma Power Supply

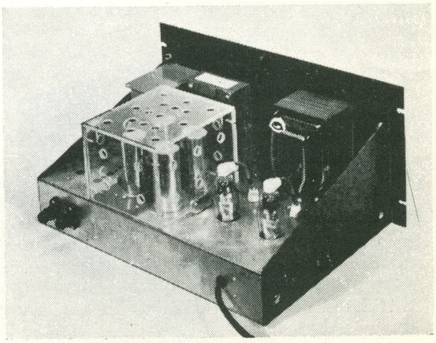
S_1, S_2—SPST toggle switch (preferably power type, 12A)
T_1—920-0-920 plate transformer (Stancor PC-8305)
T_2—2.5 v, 5A filament transformer (Stancor P-6133)
V_1, V_2—GL-816
L_1—20/4 h at 30/300 ma, 80 ohms D-C resistance swinging choke (Stancor C-1720)
L_2—20 h, 225 ma smoothing choke (UTC S-31)
C_1—125 or 90 mfd (4 Sprague TVL-1760 or 1850)
R_1, R_2—200,000 ohms, 2 w composition
R_3—50,000 ohms, 25 w (see text)
P_1, P_2—110 v pilot lamp
F_1—5A slow-blowing fuse





1500 v/250 ma Power Supply

S_1, S_2—SPST toggle switch (power type, 12A)
T_1—1790-0-1790 plate transformer (Stancor PT-8314)
T_2—2.5 v 5A filament transformer (Stancor P-6133)
V_1, V_2—GL-816
L_1—20/4 h at 30/300 ma, 80 ohms D-C resistance swinging choke (Stancor C-1720)
L_2, L_3—20 h, 225 ma smoothing choke (UTC S-31)
C_1—125 mfd (sixteen Sprague TVL-1760)
R_1, R_2, R_3, R_4—100,000 ohms, 2 w composition
R_5—100,000 ohms, 50 w (see text)
P_1, P_2—110 v pilot lamp
F_1—10A slow-blowing fuse



the danger fresh in his mind while he is constructing the power supply and for a relatively short time thereafter. But will he remember, say, a year from now when he opens the rig to service some component that some of those cans are well above ground? And will a visitor to the shack—or the junior operator—inquisitively poking around inside the supply, ever know—*even after he touches one*—that those cans are "hot"?

Take no chances! Time and effort taken *now* to build a shield for these above-ground cans can save a life in the future. The shields shown were fashioned out of sheets of plexiglass drilled with ventilation holes. Such refinement is not necessary, of course. Shields can be fabricated from almost any type of metal. Hardware cloth is inexpensive, easy to handle and when corner joints are soldered it makes a fairly solid shield.

While the sixteen capacitors in the 1500-volt supply may seem like a staggering number, this amounts only to a bank of four-by-four which can occupy as little space as an eight-inch square. Actually, of course, only 12 of these have to be insulated from the chassis.

Remember, the more output capacity, the better the dynamic performance of the power supply will be. If possible, it will be best to use the 125-microfarad capacitors (Sprague TVL 1760, or equivalent). As demonstrated in the previous article, it is difficult to see how one can get too much capacity built into the power supply.

On the other hand, it is important not to overdo the inductance, since the static regulation is proportional to the total d-c resistance of the chokes.

A word about the fact that 225-milliampere smoothing chokes are here used in 250-milliampere power supplies. In a search for chokes of the lowest possible cost and d-c resistance, the design work proceeded on the assumption that the published rating meant, in effect, that this choke has 20 henries inductance at a 225-milliampere load—and might very likely carry additional current. As a test, three of these chokes were put under continuous 250-milliampere loads for 24 hours with no adverse effects. Few amateurs run their power supplies at the so-called "maximum" ratings, but those who regardless of the foregoing wish to put in chokes of higher current rating and are willing to pay the additional cost can do so. The chokes specified in the accompanying circuits were chosen with this in mind—that is, to get as high inductance and as low resistance as possible at the lowest possible cost. If other chokes than those specified are used, the resistance should be checked.

A word about the bleeder resistors used in these two power supplies. To run the resistors as cool as possible, provide a maximum of safety and save space, two methods were tried. In the smaller supply, two 100,000-ohm, 25-watt resistors were used in parallel to obtain the 50,000 ohms required. (While "Dividohms" were used because they were readily available at the time, fixed resistors will serve, of course.) This method doubles the power rating and provides a measure of safety in the event one of the resistors burns out.

Of course, the larger the resistance, the smaller the wire used in a resistor—and the more prone it is to burn out. Frankly, we prefer the second method—employed in the 1500-volt supply—of using two 50,000-ohm, 50-watt resistors in series to obtain the 100,000 ohms of resistance necessary in this power supply. This, too, doubles the power rating and provides as large wire as feasible.

A multitude of refinements can be made on a power supply, of course—one of the most worth while being a safety interlock arrangement in the final installation. However, outside of including fuses, switches and pilot lamps in the accompanying circuit diagrams, refinements have been left to the individual builder to include as suits his purpose. In deviating from the power supplies described herein, however, care should be taken to insure proper insulation at all points.

Wire with insulation suitable for the voltage involved should be used not only in the power supply unit itself, but also in making interunit connections to control panels and transmitters. Adequate mechanical strength should be maintained in the mounting of the heavy transformers and chokes. Input and output connectors can be of any type suitable for the voltages concerned.

The two switches included in the diagrams permit separate control of the rectifier filament power and plate power. The first time the supply is used, a filament warm-up of at least one minute is recommended before applying plate power. This will allow the mercury within the GL-816 tubes to distribute itself properly. This also applies whenever the tubes are removed and replaced. In subsequent operation, it is necessary to allow at least ten seconds for heating the filaments before applying plate power. The power supply should be operated only when the tubes are in a vertical position.

When operated within ratings, these power supplies should give the builder the most satisfactory performance ever experienced with any power supply.

One more thing: **DON'T LOAD THE POWER SUPPLY WITH YOUR BODY!** Be certain to short-circuit the output terminals before working on anything connected with the supply—even when it is turned to the "OFF" position and even if the a-c line cord is pulled out. Remember that 100 microfarads of capacity holds a lot of "soup" and a burned-out bleeder will allow dangerous voltages to remain in the filter for a matter of *minutes* after it is turned off!

- Trapping Transients -

HOW TO PHOTOGRAPH VOLTAGE DROPS

The oscillograms shown on page 3 of this issue of G-E HAM NEWS were taken with a 5-inch cathode-ray oscilloscope fitted with an oscillograph camera.

The power supply output voltage is fed to the vertical deflection plates of the oscilloscope through a voltage divider while a single horizontal sweep is started by the same switch that applies the load to the power supply. The load, incidentally, was a vacuum tube biased to cut off for no-load conditions and made to take load by controlling the grid voltage with the switch. This type of load simulated the load applied to a power supply feeding a keyed stage in a transmitter.

On one occasion the transient voltage developed in the power supply was so high that the multiplier resistor of a voltmeter reading the output voltage of the supply under test arced across and burned out the meter. That time the voltmeter *did* give some indication of the turmoil in the power supply following a suddenly applied load!

* * *

Good dynamic regulation in a power supply (see G-E HAM NEWS, Volume 9, Nos. 1 & 2) is particularly important in an SSB transmitter to obtain the peak output of which the amplifier is capable. And with so many fellows turning to SSB (over a thousand, according to what we hear), the question continually has come up as to just what practical advantage you get with 100 or so microfarads of capacity in your power supply filter. In other words, a lot of fellows ask if 20 or 30 microfarads won't do just as well in practical operation.

The answer lies in the oscillograms of our issue of Volume 9, No. 1. They show the sort of dynamic regulation you get with varying amounts of capacity. They show how performance improves continually as you add capacity. You will note, however, that the performance has improved tremendously by the time the capacitance reaches a value of 45 microfarads. After that, although the improvement continues with additional capacitance, the improvement naturally is smaller.

Designer's CORNER

Some time ago when checking out my SSB transmitter I ran into a dismaying situation.

Checks with a steady audio tone showed the rig was putting out all that could be asked for. But voice peaks measured on the oscilloscope would not come anywhere near the same level. The cause was not easy to determine, but it finally turned out to be tremendous voltage drops in the power supply during a considerable portion of each syllable as a result of filter oscillations. In a more recent test I actually photographed these voltage drops, as pictured in the foregoing article.

The problem is one which involves effective damping of filter resonance or reducing the coupling between the load variations and the resonant system of filter chokes and capacitors—or both—without sacrificing efficiency or static regulation, and without overloading the rectifier tubes or any other power supply component. All this must be done without increasing the cost of the final design appreciably over that of the conventional power supply. It sounds a lot like "eating your cake and having it too," since what we have seen in the oscillograms of Figures 2, 3, 4 and 5 is commonly accepted although rarely suspected performance.

THE SOLUTION

The practical solution of the filter resonance problem involves these basic steps:

1. Reducing the Q of the filter without increasing its series resistance, and
2. Increasing the energy storage in the last filter element.

The first step could be achieved by shunting capacitors and chokes with resistors, but if this is done the peak current handled by the rectifiers would go up, the static regulation would be poorer, and a great deal of power would be wasted in the damping resistors—that is, the efficiency of the power supply would be low.

Since the Q of the choke is $\frac{X_L}{R}$, where X_L is the inductive reactance at a given frequency, and R is the effective series resistance of the choke at the frequency considered, and since the Q of the filter is equal to the Q of the choke (if the capacitor has relatively little effective series resistance), Q can be lowered by decreasing X_L or increasing R. If R is increased the static regulation will suffer as a consequence, so the approach should be through decreased X_L. Since $X_L = 2\pi f L$ a low product of $f \times L$ is desired. In the interest of efficiency and static regulation, practical limits are placed on the value of L, the inductance of the choke, so the factor f is the only one left to be altered.

NEED LOWER FILTER Q

What determines f? The resonant frequency of the filter is the quantity f in question. To a first approximation, $f = \frac{1}{2\pi LC}$, where C is the capacity of the filter condenser with which L resonates. Therefore, the Q of the filter can be lowered by increasing C, and this helps in attainment of the second basic step listed above.

What would have happened if L had been increased by a factor of 9, instead of increasing C by the same factor? The resonant frequency would have been lowered as much, but the series resistance probably would increase by about the same factor (it certainly would if 9 times the number of identical chokes had been used) and the static regulation would be nine times that indicated by Figures 1, 2, 4, 5, 6, and 7, or 84%, a drop from 820 volts, no load, to 131 volts at 200 MA load! The Q would be the same in the filter, but the total performance would be so sadly degraded that such a supply would be valueless except for salvage of parts.

In some cases, the best design would be one in which both the chokes and the condensers were increased in value until suitable dynamic performance was obtained. In high-voltage supplies this begins to pay dividends since the "critical"[1] inductance increases with voltage for a given minimum or bleeder current drain, and high-voltage capacitors begin to get expensive. Static regulation depends on the DC resistance of the chokes (together with the equivalent series resistance due to the plate transformer) but a given total equivalent resistance in the chokes and transformer yields less ***percentage*** voltage drop as the operating voltage is increased.

TWO POWER SUPPLY DESIGNS

We have designed two power supplies which promise to provide excellent dynamic regulation, good static regulation and good ripple filtering. Best of all, these supplies are not expensive ones. The first supply has a continuous rating of 750 volts/250 MA output for moderate and low power applications, while the second is rated at 1500 volts/250 MA. One nice thing about it all is that the builder may utilize the principle we have explained and proven in order to build other supplies which exhibit equally good (or better) dynamic regulation. Either power supply is ideally suited for CW transmitters, Class B modulators, linear amplifiers (such as the Lazy Linear[2] or the Power Peaker[3]), or any application where the voltage and average current requirements are within the ratings given. The final samples of these two power supplies were not completed by the time this issue of G-E HAM NEWS went to press, but construction details will be given in the March-April issue.

—***W2KUJ***

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[1] See G-E HAM NEWS Volume 7, No. 2, page 6; also, the ARRL Handbook. In these treatments only static regulation is considered. Good background material, though.

[2] G-E HAM NEWS Volume 4, No. 4

[3] G-E HAM NEWS Volume 7, No. 5

PARASITICS

In the "Designer's Corner" of the last issue of G-E HAM NEWS (Volume 9, No. 1) the formula for the resonant frequency should, of course, have read:

$$f = \frac{1}{2\pi\sqrt{LC}}.$$

9 7/16 x 6" x 5"
740 Meg ohm Multiplier