amateur service newsletter
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Triode Tubes as Linear R.F. Amplifiers

Many of the common triode transmitting tubes will perform well as linear r.f. amplifiers for single sideband operation. Unfortunately, little operating data for this class of service is available for these tubes, and the radio amateur does not always have the operating curves or other data available to derive proper circuit potentials necessary to achieve low distortion linear operation. The amateur owning a high dissipation transmitting triode, therefore, is often at a loss as to the proper operating parameters for linear service, or he might not know if the tube is really suited for this class of operation. Then, too, good transmitting equipment exists, designed before the advent of SSB, that may be easily converted to single sideband linear service, provided the correct operating potentials can be determined. The purpose of this article is to provide rough guidelines whereby any triode tube may be easily and quickly evaluated as to its useability as a linear r.f. amplifier.

Important Tube Characteristics for Linear Service

Triode tubes[1] may be operated either in grid- or cathode driven service, and may be run in Class-AB-1, Class AB-2, or Class B Mode. The problem, then is to determine **which** triode tubes are most suitable for linear service and in **what** circuit configuration they work best, and finally, to establish the operating potentials which will provide satisfactory results for the user.

Plate dissipation and **amplification factor** are two triode tube characteristics which, in general provide the information to establish the work of the tube as a linear amplifier and which may also suggest the proper circuitry. Other tube characteristics, of course, enter the picture, but by merely examining these two main features, a triode tube may be easily evaluated for linear amplifier service.

Plate dissipation is important because it determines the maximum power limit that the tube may achieve under a given degree of operating efficiency. Linear amplifier efficiency commonly runs between 50- and 65- percent with the remainder of the power being lost as plate dissipation. As a rule of thumb, therefore, 50- to 35- percent of the maximum permissible power input to the tube represents the rated value of maximum plate dissipation. Twisting this idea around, it can be seen that a triode tube having, for example, 450 watts of plate dissipation is probably good for a power input of 900 to 1250 watts, depending upon operating efficiency. Class AB-1 operating efficiency runs close to 50-percent. Class AB-2 efficiency is about the same as Class B; in the vicinity of 65-percent. Thus, knowing the plate dissipation of the tube, we can easily determine approximate maximum power input and power output by first establishing in which class of service the tube is to be operated. It is wise to use "steady state" or single tone condition when making this rough determination of power levels. It is tempting to think that

1 - This discussion deals solely with triode tubes. Similar conclusions may be drawn about tetrode and pentode tubes, but these are not within the scope of this article.

the peak envelope power (P.E.P.) rating may be greater than this level (and it may--!) but this reserve power capability varies between tube types, and can only be determined by experiment at a later stage of the game.

Small transmitting tübes having low values of plate dissipation (3C24, 35T) afford little worth in linear amplifier service as the power capability of these small "bottles" is quite low. The picture changes rapidly as the power capability of the transmitting tube increases, however, and large triode transmitting tubes having high values of plate dissipation are often quite reasonable in cost and are likely candidates for linear service.

Amplification Factor of a triode tube expresses the ratio of change of plate voltage to a given change in grid voltage at some fixed value of plate current. It is determined primarily by the density of the grid structure and the grid-plate spacing of the tube. Amplification factors are expressed in terms of mu (u), and values of u between 8 and 300 are common for triode transmitting tubes. **High-u** tubes are those having an amplification factor of 30 or more, **medium-u** tubes have amplification factors in the range of 10 to 30, and **low-u** tubes fall in the range of 3 to 10.

Amplification factor for many commonly used transmitting triodes is given in most tube manuals and in the transmitting tube section of **The Radio Amateur's Handbook**. This characteristic may be determined experimentally by operating the tube in a quiescent state at normal plate voltage. A small change in the resting bias is made, thus slightly changing the plate current. The plate current is then returned to the original value by making an appropriate change in plate voltage. An amplification factor of 20, for example, means that if the grid potential is changed by one volt, it will take a plate voltage change of about 20 volts to restore the plate current to the original value.

Armed with a knowledge of plate dissipation and amplification factor, an intelligent choice of circuitry may now be made.

Class AB-1, Class AB-2, or Class B Grid Driven Service

These classes of operation are defined by the operating potentials applied to the tube. In general, **any** triode tube in **any** conventional linear amplifier circuit can probably work in **any** of these three modes. Results, however, depend upon circuit design considerations which may be extremely stringent in order to provide a satisfactory degree of linearity for a specific tube in a given circuit. Thus, in order to relax circuit considerations while reaching a desired degree of performance, certain tubes and circuits have been chosen which are widely used in SSB equipments while other tubes and circuits have been cast aside as being economically undesirable.

The Class AB-1 Amplifier is defined as one wherein grid current does not flow over any portion of the operating cycle. That is, grid excitation is held below that value at which the applied **peak** signal level is less than the value of grid bias on the tube. Plate current flows for more than 180 degrees of the r.f. cycle but less than 360 degrees. Once the bias value is exceeded by the driving signal, grid current will flow when the grid is driven positive with respect to the cathode, and the amplifier passes into the **Class AB-2** operating mode. As the peak driving signal level is increased and the bias reduced to substantially cutoff, grid current flows over half the operating cycle, and the amplifier is now operating in the **Class B** mode. As the grid driving signal increases, passing the amplifier stage through the successive operating modes, the instantaneous plate voltage swing increases, and electrode voltages applied to the tube must be varied to allow optimum circuit efficiency and low distortion in each mode of operation. Good and valid reasons exist for each mode of operation, and while it is tempting to jump to the conclusion that all tubes should be operated Class B mode for highest efficiency and output, such is not the case! Other factors affect the choice of operating mode and in doing so, also affect the circuitry and potentials to be used with a particular tube.

In general, a **low-u** triode tube is a preferable choice for a Class AB-1 grid driven linear amplifier. It is easier to obtain maximum plate current swing with this type of triode tube because it is impossible to drive the grid into the positive region of operation (Figure 1). A high-u tube of equal plate dissipation must be driven into the positive grid mode of operation to obtain output comparable to that of a low-u tube driven just to the point of grid current. Of the many triode tubes, the 304TL and the 211 (VT-4C) are common low-u types that perform well in Class AB-1 service. Other low-u triodes that are satisfactory for grid driven linear service are the 75TL, 100TL, 250TL, 806, 450TL and 750TL. Even though large values of driving voltage are required for these tubes, little driving power is required, as the grid never draws current and only circuit losses require that the driving stage supply power to the linear amplifier in question. High-u triode tubes are not recommended for class AB-1 service because the grid must be driven into the positive (grid current) region before appreciable power output can be obtained.

The Class AB-2 amplifier is defined as one wherein the grid current is drawn over a portion of the operating cycle, yet the plate current flows for more than 180°. Grid current flows because the exciting signal has a peak value greater than the fixed operating bias of the tube, and the grid assumes a positive potential when the peak signal exceeds the fixed bias level. Electrons intercepted from the cathode to plate current flow by the positive grid create the grid current, and the power required to create the necessary positive grid swing is derived from the exciting signal that drives the linear amplifier. The impedance the grid presents to the input circuit under conditions of grid current is a function of the ratio of instantaneous grid voltage to current which varies in a nonlinear manner. Thus, unless the r.f. power source (the exciter) has extremely good output voltage regulation, and unless the linear amplifier is properly designed to present a fairly constant load to the exciter, waveform distortion will invariably result whenever this class of amplifier loads the exciter during those intervals of the operating cycle when the grid of the tube is driven positive with respect to the cathode. (**The Class B** linear amplifier represents an extension of the Class AB-2 mode, wherein grid driving power requirement is greater and the demand placed on the driving source is even more stringent).

Class AB-2 grid driven operation of triode tubes should be approached with caution because of this problem, as most radio amateurs do not have the test equipment to properly evaluate and adjust their linear amplifier for this mode of operation. It is possible to swamp a portion of the driving signal by means of low value noninductive resistors placed across the grid circuit of the linear amplifier, and by the use of a high-C grid tank circuit achieve the best possible drive-signal regulation. Both of these methods have been used with good results when properly applied.

In most instances, the increase in output power gained from shifting from Class AB-1 to Class AB-2 operation may not be justified, and more power output may be gained in an easier fashion by operating two tubes in parallel in the Class AB-1 mode. Driving requirements and bias supply regulation problems are thus simplified. These remarks apply equally well to Class B grid driven linear amplifiers, and their use should also be tempered with caution.

Class AB-2 and Class B Cathode Driven Service

High-u triode tubes may be used to advantage in cathode driven (so-called grounded grid) linear amplifier circuits (Figure 2). In this mode of operation, the grid is bypassed to ground and normal Class AB-2 or Class B bias is applied to the stage. No bias is necessary, of course, in the case of zero bias tubes, such as the 811A, 3-400Z and 3-1000Z, and the grid of the tube may be grounded directly. A high-u triode tube should be employed for this style of amplifier, and the inherent feedback of the grounded grid stage combined with the use of a tuned cathode input circuit insure a minimum of driver waveform distortion. Use of a high-u tube is suggested for two reasons: First, the inherent cathode-plate shielding of a high-u tube is better than that of a comparable low-u tube; and second, a high-u tube provides better gain per stage and requires less drive because of less feedthrough power. Tubes such as the 811A, 805, 75TH, 250TH, 450TH and 6C21 work well in this circuit. Resistive loading of the driving circuit is not required as long as there is sufficient "Q" in the cathode tank because of the constant "feed through" power load on the exciter. For most triode tubes, a tuned input circuit having a resonating capacitance C-1 of about 15 mmfd per meter of wavelength is sufficient.

Low-u tubes, on the other hand, require extremely large driving signals in the cathode driven mode, and stage gain is extremely small. Thus, the use of these tubes in this particular circuit configuration is not recommended.

In summary, then, triode tubes to be used for linear amplifier service should have a large plate dissipation, and the power output to be expected from the tube will run from approximately once to twice times the rated plate dissipation. Moreover, high-u triode tubes perform better in cathode driven, class B circuits. Medium-u tubes, falling in the shadowy region (u = 10 to 20) usually are easier to get working in cathode driven circuits, as a general rule.

Bias Supplies

Bias supplies for linear amplifier stages that draw grid current must be capable of good regulation so that the fixed bias does not vary as grid current increases. Shown in Figure 3 is a simple bias supply that will provide a regulated bias variable over the range of -20 to -80 volts. Regulation is 0.001 volt per milliampere of grid current. Between -30 and -80 volts the supply will regulate grid current up to 200 milliamperes. Between -20 and -30 volts, maximum grid current is restricted to 100 milliamperes. The adjustable resistor R-1 is set to produce about 20 milliamperes current through the first regulator tube.

A regulated supply for the -100 to -600 volt range is shown in Figure 4. The tap switch of this supply permits rough bias adjustment over the range, while the potentiometer permits a fine adjustment to be made. Maximum permissible grid current runs from about 100 milliamperes in the vicinity of -100 volts to about 25 milliamperes in the -600 volt region.

Operating Potentials for Linear Service

Once the circuit and class of service have been determined for the particular tube at hand, the proper operating potentials for the tube must be determined. Luckily, much of this data is at hand, although in a disguised form. Most data sheets provide Class AB-1 or AB-2 **audio data**, usually for push-pull operation. As the tube doesn't know if it is being driven by an audio signal or an r.f. signal, this data applies to a significant degree to r.f. linear amplifier service. For a single tube, it is only necessary to divide the indicated currents by two, as the currents are for two tubes. (Actually, only one tube in the push-pull audio service is "working" at one time, but the current meters register currents that are averaged for the two tubes). For example, Figure 5 provides operating data for a 304TL, grid driven, Class AB-1 r.f. linear amplifier, used in the circuit of Figure 1. A plate circuit Q of 15 should be used, and the grid current of the amplifier should be high-C (Q of 15 or better) in order to take care of accidental grid current peaks. Normal grid current is zero. In order to properly load the exciter, it is necessary to swamp the exciter output with a non-inductive load so that the exciter develops nearly full rated output when grid current just starts to flow in the linear stage. The load may be placed across the coaxial line between the exciter and amplifier and consist of a number of 2 watt composition resistors arranged in series-parallel to present a near-52 ohm load. Total wattage rating of the resistor bank should be equal to about one-half the P.E.P. output of the exciter.

Figure 6 provides operating data for a 304TH, cathode driven, Class AB-2 r.f. linear amplifier used in the circuit of Figure 2. At 3000 volts plate potential the 304TH is good for a P.E.P. input close to one kilowatt, and two tubes in parallel can provide the "so-called" two kilowatts P.E.P. Figure 7 provides data for the 450TH in cathode driven, Class AB-2 r.f. linear amplifier service.

It should be noted that steady state conditions are given, and P.E.P. operation should be held to these limits, unless the oscilloscope tells the operator that the tube may be "pushed" a bit before peak flattening or distortion occurs. Use of the oscilloscope should be tempered with caution, however, as it is nearly impossible to read distortion or peak flattening on the "scope" until the degree of intermodulation distortion approaches a level near -20 decibels below one tone of a two tone test signal. By this time, the operator will probably receive a brick through the shack window! To be on the safe side, then, meter readings of grid and plate currents should be one-half or less of those indicated in the tables for **voice peaks**.

FIGURE 5

304TL, GRID-DRIVEN, CLASS AB1 LINEAR AMPLIFIER

D.C. Plate Voltage	1500	2000	2500	3000	volts
D.C. Grid Voltage*	-118	-170	-230	-290	volts
Zero Signal D.C. Plate Current	135	100	80	65	ma
Single Tone Max. D.C. Plate Current	280	275	245	225	ma
Max. D.C. Input	420	550	615	675	watts
Max. Drive Power	0	0	0	0	watts
Plate Load Impedance	1270	2650	4250	6000	ohms
Max. Output	128	245	305	365	watts

FIGURE 6

304TH, CATHODE-DRIVEN, CLASS AB2 LINEAR AMPLIFIER

D.C. Plate Voltage	1500	2000	3000	volts
D.C. Grid Voltage*	-65	-90	-145	volts
Zero Signal D.C. Plate Current	130	100	75	ma
Single Tone Max. D.C. Plate Current	480	380	320	ma
Max. D.C. Input	720	760	960	watts
Max. Drive Power	70	55	60	watts
Cathode Input Impedance**	195	260	385	ohms
Plate Load Impedance	1850	3000	5500	ohms
Max. Output	510	530	715	watts

FIGURE 7

450TH, CATHODE-DRIVEN, CLASS AB2 LINEAR AMPLIFIER

D.C. Plate Voltage	1500	3000	4000	volts
D.C. Grid Voltage*	0	-50	-85	volts
Zero Signal D.C. Plate Current	50	200	150	ma
Single Tone Max. D.C. Plate Current	400	450	335	ma
Max. D.C. Input	600	1350	1340	watts
Max. Drive Power	70	105	70	watts
Cathode Input Impedance**	262	322	350	ohms
Plate Load Impedance	2200	4100	6400	ohms
Max. Output	416	992	1000	watts

NOTE: 1500 volt operation is zero bias service

*Adjust to give stated zero-signal plate current.

**Fundamental frequency component. High-C, tuned cathode tank should be employed to obtain lowest intermodulation distortion.

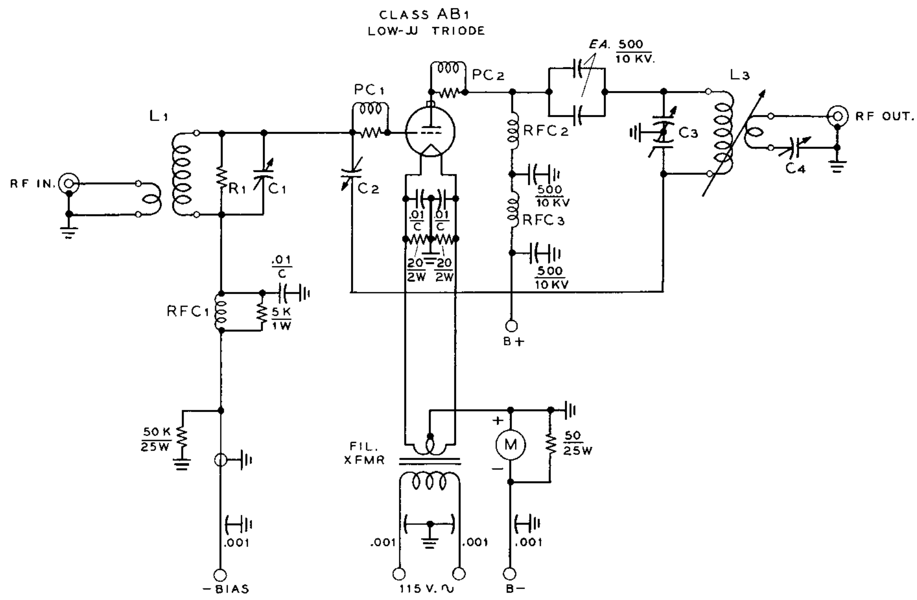

FIGURE 1

TYPICAL GRID DRIVEN, CLASS AB-1 TRIODE LINEAR AMPLIFIER CIRCUIT

C-1, L-1: Grid input circuit (Q = 15). Ratio of L to C chosen so as to match impedance presented by R-1, the loading resistor.

C-2: Neutralizing capacitor. Capacitance approximately twice the grid-plate capacitance of the triode tube. Breakdown voltage equal to three times the d.c. plate voltage.

C-3, L-3: Plate output circuit (Q = 15). Ratio of L to C chosen to match r.f. load resistance of amplifier tube. Handbook charts for Class C Service may be used, provided single tone plate current is used in formulas.

C-4: Series tuning capacitor for link circuit. Approximately 6 uufd per meter of wavelength (See Chapter 6, A.R.R.L. Handbook, or "Radio Handbook").

PC-1, PC-2: Parasitic suppressors. Try two 100 ohm, 2 watt composition resistors in parallel, wound with 5 turns, ½-inch diameter #16 wire, spacewound.

RFC-1: 2-½ mH (National R-100). RFC-2: High voltage choke. B & W #800 or equivalent RFC-3: VHF choke. Ohmite Z-50 or equivalent.

Note: 20 ohm, 2 watt composition resistors placed across filament capacitors to "de-Q" bypass resonances.

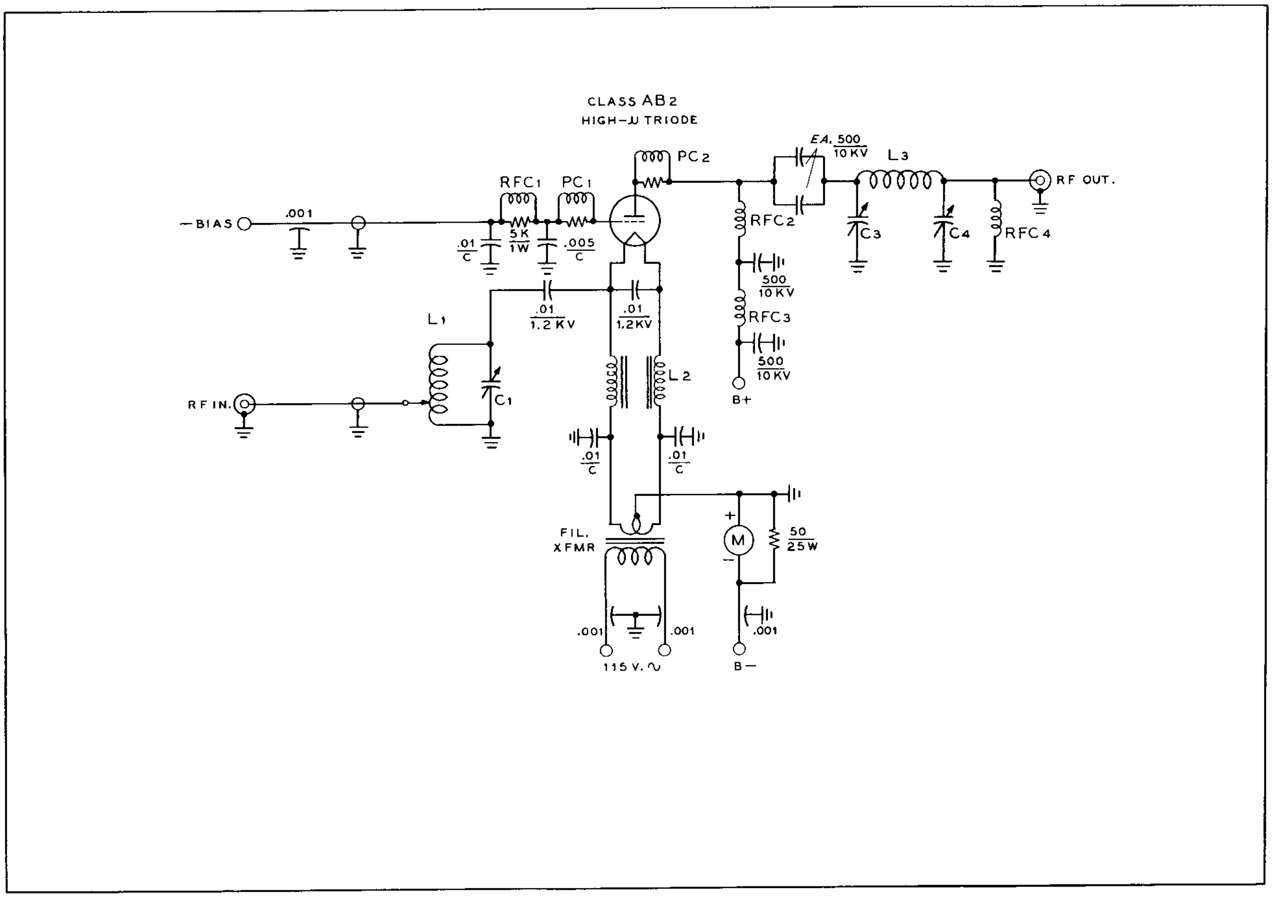

FIGURE 2

TYPICAL CATHODE DRIVEN, CLASS AB-2 TRIODE LINEAR AMPLIFIER CIRCUIT

C-1, L-1: Cathode input circuit (Q greater than 2). Resonates to operating frequency with approximately 20 uuf per meter of wavelength.

C-3, L-4, C-4: Pi-network output circuit (Q = 15). Ratio of L to C chosen to match r.f. load resistance of amplifier tube. For appropriate charts, see A.R.R.L. Handbook and "Radio Handbook". Use single tone plate current in formulas.

L-2: Filament choke. B & W or equivalent.

PC-1, PC-2: Same as Figure 1. RFC-1, RFC-2, RFC-3: Same as Figure 1.

RFC-4: 2½ mH (National R-100).

Notes: Adjust drive tap on L-1 for minimum SWR on coaxial line to exciter. Positive terminal of bias supply is grounded. Grid of tube may be grounded for Class B, zero bias operation with triodes having u of 200 or better.

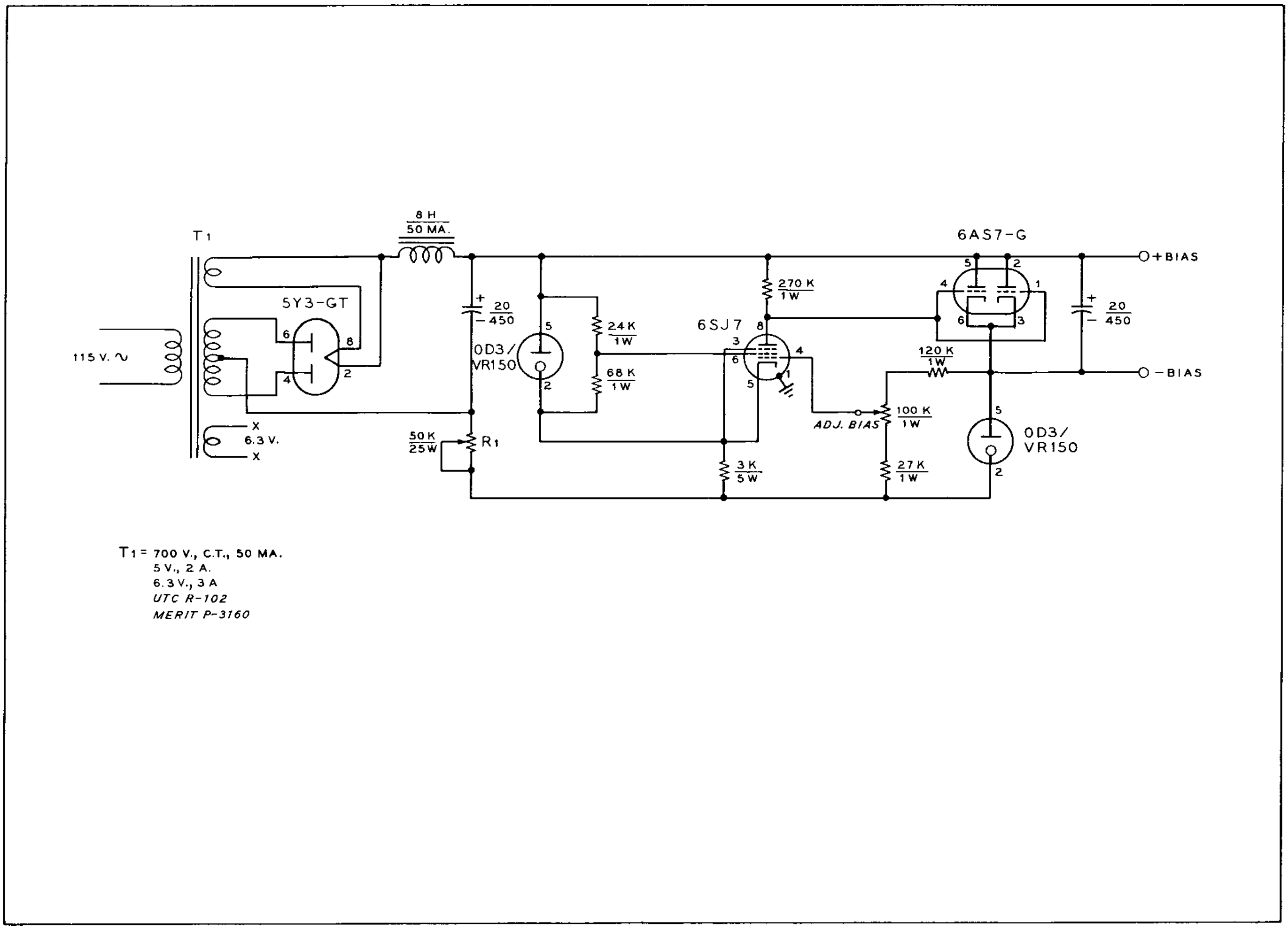

FIGURE 3

LOW VOLTAGE REGULATED BIAS SUPPLY

This simple supply provides a regulated bias voltage variable over the range of -20 to -80 volts. Regulation is 0.001 volt per milliampere. Between -30 and -80 volts, the supply will regulate grid current up to 200 ma. Below -30 volts, maximum grid current is restricted to 100 ma.

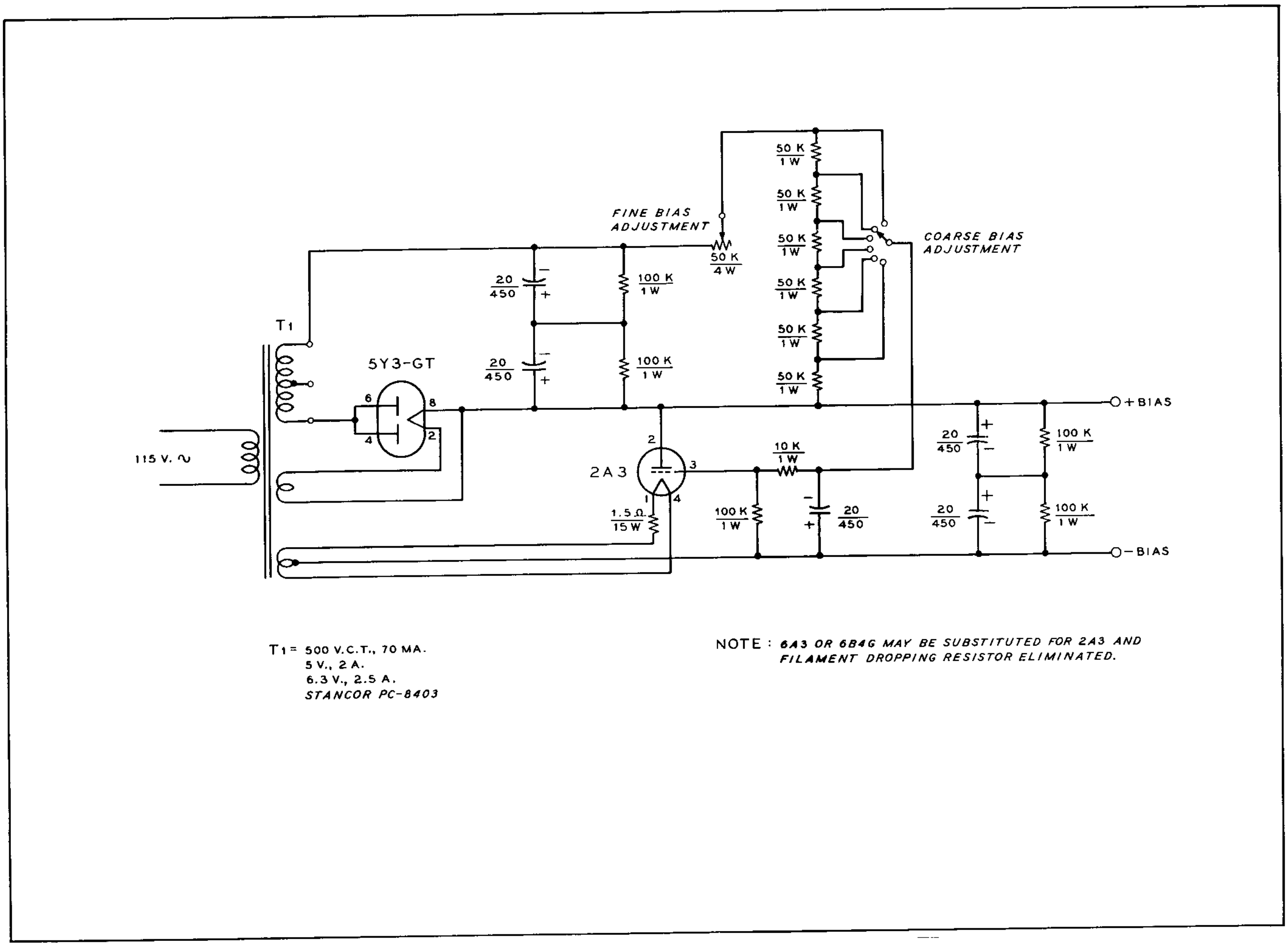

FIGURE 4

MEDIUM VOLTAGE REGULATED BIAS SUPPLY

This series regulated supply acts as a variable bleeder resistor which automatically adjusts its resistance to a value such that grid current flowing through it will develop a constant voltage across the supply terminals. The tap switch permits rough bias adjustment over the range of about -100 to -600 volts, while the potentiometer permits a fine adjustment to be made. Maximum permissible grid current is about 100 ma in the vicinity of -100 volts, dropping to about -25 ma. in the -600 volt region.