A High Output Linear Amplifier

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W9VMQ outlines his experiments with a screen grid driven linear amplifier possessing high plate efficiency and excellent linearity. The arrangement affords near maximum power tube utilization with moderate plate voltages. The circuit requires no bias or screen voltage and the low control grid current makes operation with tetrodes having low grid dissipation ratings possible in a manner more efficient than class AB-1.

The increased use of single sideband transmission by amateurs has developed new interest in linear r.f. power amplifiers. The home brewed final, added to a commercially built exciter for increased output, has become a common amateur construction project.

Amateurs have constructed and used a wide variety of linears, employing many different tubes and classes of operation, and much has been learned that contributes to the data available for practical designs.

The circuits discussed here are the result of experiments made by the author some time ago. The interest at that time was in a simple circuit, using a tube as a variable d.c. resistance with a high peak-current capability. The initial experiments were made with an 814.

It was found that grid bias voltage could be eliminated, and very good control with a wide variation of plate current could be obtained by connecting the control, or number 1, grid to the filament and varying the screen, or number 2, grid voltage from zero to nominal positive potential.

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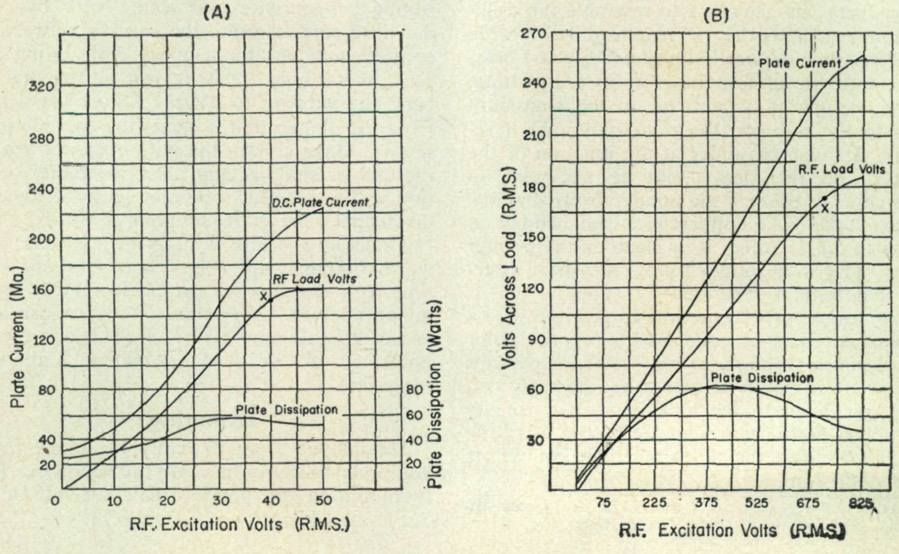
Later the idea occurred to try this method of exciting the tube as a linear amplifier. The circuit worked, but the results were only fair. It was discovered accidentally that the performance improved greatly when a resistance of 10,000 ohms was connected between No. 1 grid and filament, and tests showed very good output and efficiency.

As had been expected, neutralization of the plate-to-screen grid capacitive feedback was found necessary, but the remaining simplicity of the circuit, with no critical grid or screen voltage required, encouraged further experiments. Several screen grid tubes of different types were tried, and all worked satisfactorily.

Tests were made and measurements taken for various excitation levels. The graphs of figs. 1 and 2 were made from such tests. These show

Fig. 1—*Curves comparing d.c. plate current, r.f. plate voltage and plate dissipation for a single 6DQ5 in conventional class AB-1, (A), to a single 6DQ5 in a screen driven pentode circuit (B). The grid bias in (A) was —56 volts and produced an output (at point x) of 112 watts and in (B), with the bias at —9 volts the output at point x was 192 watts. The applied plate voltage was 800 volts in both circuits.*



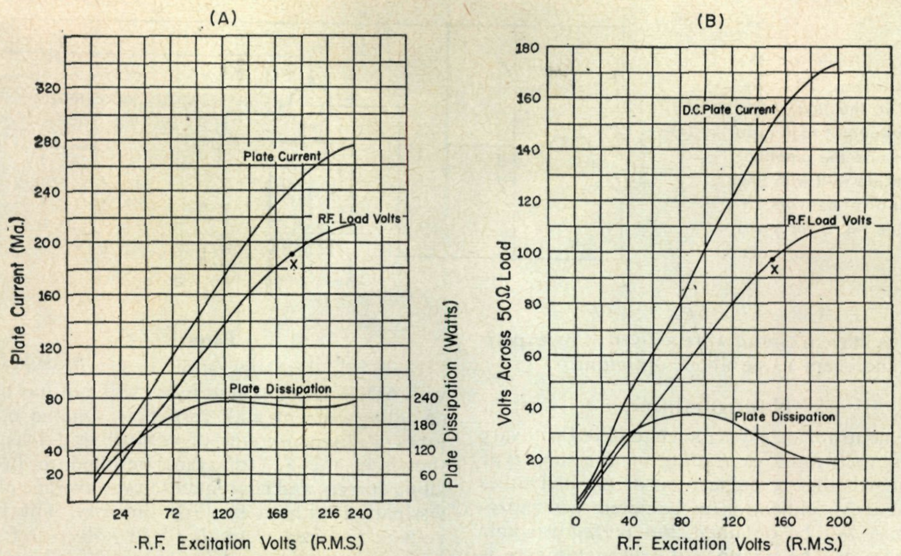


Fig. 2 — Comparison of performance of an 813 in, (A), triode grounded grid and (B) a screen driven pentode. In (A), G_1 was biased at —7.5 volts and G_2 was grounded. In (B), G_1 is biased at —9 volts. Output at point x in (A) is 414 watts and in (B) 584 watts with an applied plate voltage of 2,400 volts.

a comparison in efficiency and output between two screen-driven amplifiers and two standard linear amplifier circuits. Figure 1 shows a comparison between a screen-driven circuit (fig. 1B) and a class AB-1 circuit (fig. 1A) for the 6DQ5. Figure 2 shows the relative performance of an 813 in standard triode connected grounded-grid operation (fig. 2A) and in the screen-driven circuit (fig. 2B). The class AB-1 6DQ5 and the grounded-grid 813 were carefully adjusted for optimum operation to get a fair comparison.

The high efficiency, high output, and excellent linearity characteristics of the circuit are shown by the graphs. The equipment used for measurements was compared with other units of known accuracy, and care was taken to get as accurate readings as possible.

The input impedance of the tube when driven in this way is not linear. Where the driving stage has ample power, no appreciable degradation of the driver linearity appears. The circuit of fig. 3 includes a "linearizing" circuit using a 12AU7 as an automatic, variable swamping resistance. This has effectively corrected some nonlinearity which showed up in this case, due to relatively heavy loading of the output stage of the SB-10 exciter.

Figures 3 and 4 show two practical circuits used with very good results. Necessary component values are shown. The r.f. chokes in the No. 1 grid circuits improve results over those using the grid resistor alone. The values of the grid

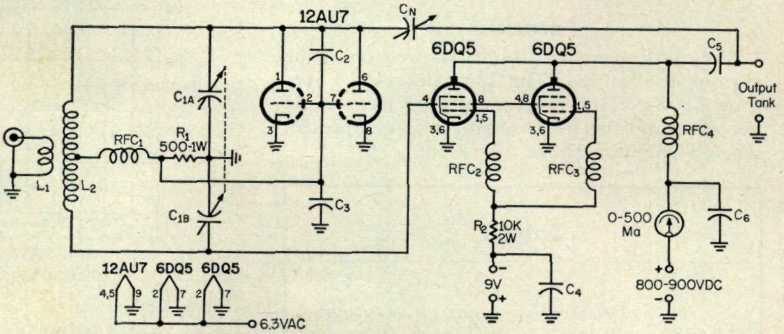
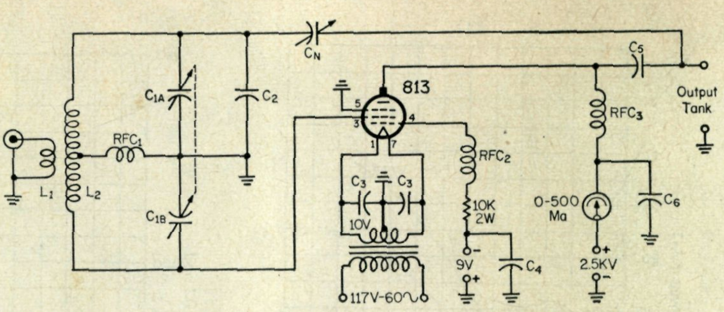


Fig. 3—A practical screen driven circuit employing two 6DQ5s and a 12AU7. The 12AU7 is used to help maintain a linear input impedance by acting as a variable swamping resistor. All L_2 coils wound on 1" diameter lucite rod and center tapped.

$RFC_{1, 2, 3}$—.5 to 2.5 mhy
RFC_4—National R175A
$C_{1, A, B}$—Dual tuning capacitor 25 to 50 mmf per section
C_2—10 mmf 500 v mica or ceramic
$C_{3, 4}$—.002 mf 600 v mica or ceramic
$C_{5, 6}$—.002 mf 1200 v mica or ceramic
C_n—See text

L_1—75 m— 5t, 40 m— 3 t, 20 m— 3 t, 15 m— 2 t, 10 m— 1 t. All wound with #20 hookup wire.
L_2—75 m— 72 t #24 enameled, close wound.
40 m— 34 t #22 enameled, close wound.
20 m— 18 t #18 enameled, spaced 1⅞".
15 m— 13 t #18 enameled, spaced 1⅜".
10 m— 9 t #18 enameled, spaced 1½".

Fig. 4 — Circuit of the screen driven 813 described in the text. As in fig. 3, no output tank data is given and the amplifier will operate well with link coupled or pi network circuits. See fig. 3 for parts list.



resistors in each circuit were arrived at by experiment and seem to be about optimum.

Neutralizing

The neutralizing capacitance required will vary from 1 to 8 mmf, depending on the tube type and on whether a single tube or parallel tubes are used. An indication of complete neutralization may not be obtained, but perfectly stable operation can be obtained if reasonable care is used to prevent coupling between the input and output tuned circuits. It was found that the amplifier could be neutralized on 10 meters and would remain stable on the other four bands through 75 meters with no further adjusting of C_N.

One "sure fire" method of neutralizing, suggested by W8YDR and used by him for 813s, by W8FIS with 4-125As, and by W9EHE with 6DQ5s, is the one of feeding signal from the exciter into the output terminals of the linear and adjusting C_N for minimum No. 1 or No. 2 grid current. (Be sure to remove the plate voltage.)

The Breune or bridge neutralizing circuit was tried with a 4E27A and worked satisfactorily, requiring only a single ended input tuned circuit, but did not work out with tubes not containing a suppressor grid. With tetrodes or beam power pentodes, the plate-to-screen capacitance is not small enough for application of the bridge circuit.

Parasitics

Very little parasitic trouble showed up in the various tubes tried. The separate grid chokes shown in the 6DQ5 diagram of fig. 3 were found necessary to squelch a parasitic that was present when a common choke was used.

Table I

Band	*Driving Power*	*Plate Input Power*	*Output Power*
75	20 Watts	750 Watts	583 Watts
40	20 Watts	750 Watts	577 Watts
20	25 Watts	750 Watts	570 Watts
15	28 Watts	750 Watts	540 Watts
10	32 Watts	750 Watts	520 Watts

Bias

Zero grid bias operation is practical except with 6DQ5 tubes. These tubes will run too high an idling current with zero bias. On the other tubes a slight amount of control grid bias, as shown in the 813 diagram, resulted in lower idling current and consequent lower average plate dissipation without spoiling linearity. The bias voltage required is small (5-10 volts) and not critical.

Input Circuit

Driving voltage may be coupled in capacatively or with a link as shown.

A high L/C ratio in the input tuned circuit broadens the tuning. An input coil for each band, with sufficient inductance to resonate with the tube input capacitance at the center of each phone section, will eliminate input tuning. With link coupling, the link on the input coil for each band can be adjusted to match the output impedance of the exciter being used.

Tests were made to determine the required drive power and performance on the bands 10 through 75 meters, using a single 813. The results are shown in Table I.

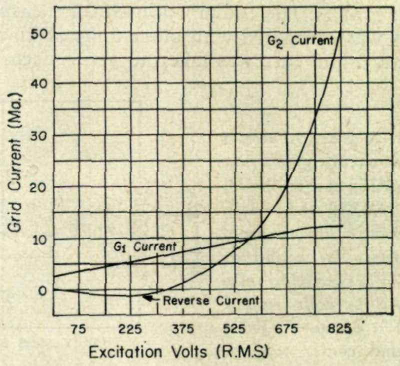


Fig 5—Comparison of the current flow in G_1 and G_2 of an 813 (screen driven) as opposed to the excitation voltage.

Figure 5 shows the measured No. 1 and No. 2 grid currents of the 813 plotted against excitation voltage and corresponding to the other curves of Figure 2-B. The negative voltage developed across the grid resistor is linear with drive voltage and varies at the audio rate when the amplifier is handling a speech generated sideband signal. W8YDR suggests that this current and voltage is the result of trapping of a considerable charge of electrons between the No. 1 and No. 2 grids during the negative half cycle of excitation, and discharging at a rate slow enough to hold the No. 1 grid negative into the next positive half cycle.

Tests with an r.f. voltmeter and an oscilloscope show an r.f. sine wave voltage on the No. 1 grid. Under optimum operating conditions, this voltage is about 1/6 the amplitude of the drive voltage on the No. 2 grid. The method of coupling between the two grids appears to be a combination of capacitive and electron coupling with the amount of coupling essentially the same on all bands.

A comparison between the negative d.c. and r.f. voltages at the No. 1 grid indicated an actual positive potential on the No. 1 grid (with respect to cathode) during part of the r.f. cycle. This grid is positive during less than 180 degrees of the cycle. It seems evident that plate current is flowing in the tube for less than 180 degrees. This would explain the high efficiency obtained. The function of the grid resistor and the choke seem to be 1) to isolate the No. 1 grid from ground for r.f. allowing it to swing positive in phase with the driven No. 2 grid, and 2) to develop a negative voltage on the No. 1 grid which acts as an automatic bias. This automatic bias, varying at the audio rate, results in true class C operation with linearity.

We can see reader's eyebrows raising at the efficiencies indicated by the input and output figures shown on the graphs. The efficiency can be easily checked by observing tube color.[1] For example, at 333 ma on the curve of fig. 2B or at an input of 800 watts, the color of the plate indicates a dissipation of about 125 watts. This works out to an efficiency of 84%. This is peak efficiency with some flat topping, but at the operating point X, well below flat-topping, the overall efficiency is 77.5% with an output of 583 watts to the load.

From a practical standpoint, this circuit has definite performance and economy advantages over any other linear amplifier circuit tried. As an example, at a plate voltage of 2500 and an input of 750 watts, an 813 will deliver almost as much output as two of the same tubes running class AB-1 at 1000 watts input, with the same average plate dissipation per tube in both cases.

A pair of 6DQ5s with a plate voltage of 800 to 900 will deliver in excess of 300 watts output with 400 watts of input and a driving power of 5 to 8 watts, depending on the band in use. The 6DQ5 amplifier is an especially good one for use with low power, home built, or commercial exciters in the ten to twenty watt class. An SB-10 driving a pair of 6DQ5s has been very effective, and W9EHE is using a similar amplifier, with a 20-A, to put a very robust signal in here at a distance of 100 miles under day and night conditions.

The 6DQ5s can be operated with plate voltages as high as 1250 volts with higher grid bias (approximately -12 volts) without sacrificing linearity or efficiency, giving the same input power level (400 watts for 2 tubes) with less driving power.

Performance of the circuit at lower than nominal plate voltages is exceptionally good. The following table shows results of tests with an 813 (Table II).

Table II

Plate Voltage	*Plate Current*	*Input*	*Output*
2000	295 ma	590 Watts	460 Watts
1600	288 ma	445 Watts	342 Watts
1200	270 ma	325 Watts	245 Watts

All figures for output are based on r.m.s. voltage measurements across a 50 ohm dummy load with steady carrier input of the desired level. The dummy load circuit included an r.f. ammeter and a series variable capacitor, as shown in fig. 6 for tuning out the circuit reactance, including that of the link. The ammeter readings were used as a check, at the higher power levels, when calculating power in the load. The load resistance consisted of twelve 115 watt, 600 ohm Globar type CX resistors, in parallel.[2]

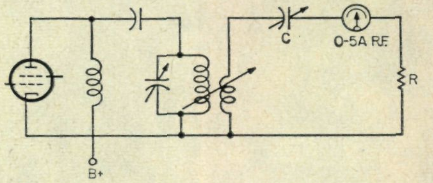


Fig. 6 — Circuit used to measure the power output.

Output tuned circuit values are not shown in the diagrams; standard values apply here as in any other circuit of similar power rating and indicated plate resistance. Link coupled-parallel tuned, or pi-network tank circuits can be used. Smaller diameter coils for the input tuned circuit can be used on the high frequency bands. The input circuit can be designed for band switching with a series of coils or with a single tapped coil.

[1]Plate dissipation as determined by color is rather loose, and it would be better if the proper color for a given dissipation were first ascertained. This can be done by hooking up the tube without drive, and in fact no tuned circuits either. Then use fixed bias to set the plate current for a power input equal to the maximum rated dissipation. Now note the color of the plate, which can be used as a reference. Plate color for other dissipation amounts can also be obtained in the same manner.—*Ed.*

[2]Glanzer, K., "A 1500 Watt Dummy Load", *CQ*, March, 1961, page 30.

(*Continued on page 108*)

YL *[from page 105]*

the YL nets and other YLRL activities that go on throughout the year, and be sure to encourage non-YLRL members to send in their logs. Contest dates are Sept. 26-27-28, 1961; complete rules in separate box.

YLRL Anniversary Party

W1ZEN has set the dates for the 22nd YLRL Anniversary Party. Mark them now on your calendar: CW—Oct. 25-26, 1961; Phone —Nov. 8-9, 1961. All licensed YL and XYL operators throughout the world are invited to participate and all bands may be used. Complete rules will be published here in October *CQ*.

33, W5RZJ

High Output Linear *[from page 45]*

The plate dissipation figures for the grounded-grid curves of fig. 3 were obtained by subtracting the feedthrough power in the output circuit from the measured output, and subtracting this from the plate input power. The values for feed-through were arrived at by measuring the r.f. voltage from filament to ground (E_k r.f.) and dividing this by the output tank r.f. voltage (E_{tank}), then multiplying the measured output power by this percentage or:

$$\text{Feed through power} = \text{Output power}\frac{E_k \text{ r.f.}}{E_{tank}}$$

This method may not be strictly accurate, but it seemed to agree closely with dissipation estimates made at several levels by the plate color comparison method.

The question of harmonic generation and TVI, as a result of class C operation of the tube has no doubt occurred to the reader. It can be answered only by stating this amplifier seemed to be as free from harmonics and TVI as any other circuit tried here. ■

Look at S.S.B. *[from page 54]*

fast attack, slow-decay a.v.c., and many other topics that are quite appropriately part of the complete and detailed s.s.b. story.

And don't get the erroneous idea that every fellow who can split an infinitive runs a cool 2000 watts, p.e.p. My power input is about a pint and it will be for many years to come—not because I wouldn't like more, but only because it's all I can afford. I mention this in the hope that it will stress that this has been presented for all amateurs and not just a select segment.

Whether DX fiend or local rag-chew devotee, it is earnestly hoped that all a.m. men who have not "gone s.s.b." will give some serious, unprejudiced thought to doing so. Listen around on the bands to s.s.b.; note its effectiveness through QRM and QRN. If at all possible, go to a friend's shack and try out s.s.b. for yourself. Consider carefully the great saving in critical radio-spectrum space.

Last, but certainly not least, keep in mind that when too many hams have no desire to improve the state of the art and to add to their own knowledge through advanced modes and techniques, then amateur radio will, like the proverbial old soldier, slowly QSB away. ■

OSCAR Flyover *[from page 59]*

sending traffic on the proposed flight to the Southern California gang, the bulk of radio tracking reports were taken by W6KGC and sent to the OSCAR group. K6KCB kept a constant monitor on 80 meter c.w., 75 meter phone and 2 meters, and stood by on the NTS to receive any tracking reports on Sunday evening.

A great many amateurs took part in the OSCAR flyover and supplied key support at critical times. Some of the more notable "assists" were W6FON, K6YKG, K6VWV, W6DMN, K6QJZ, K6OZL, K6MYK and others. Also of great service was WA6OKK who acted as second operator at WA6HVN.

Results of the flight were most encouraging. Approximately 50 stations were worked by the aircraft, and these reported reception of the beacon directly to the plane. WA6GMZ reported reception of the beacon when the plane was over Gorman, California, a distance of nearly 280 miles from Black Mountain. In addition, K6BPI in San Diego heard the OSCAR signal when the plane was over Newhall, California, a distance of about 140 miles. It was apparent that the beacon could be heard over distances of this order without the need of exotic receiving equipment. It would seem that when OSCAR I is in orbit, hundreds of miles above the earth, the area of reception on each pass-by will be enormous.

Tracking results were encouraging. Using simple equipment, it was possible to provide correlation within 5 degrees at a distance of 200 miles. The best report checked within 2 degrees at 210 miles.

May we thank the following nets for their help in the OSCAR Flyover both before the test, when communications was being organized and QSTs were sent, as well as during the flight: Mission Trail Net, Sixth Regional Net, Northern California Net, Southern California Net, American Legion-Golden Bear Net, Northern California Traffic Net, Channel Cities Net, San José CD Net, and Santa Clara Operational Area Net.

A few interesting sidelights.

The large number of amateurs who stood by ready to help if required.

The speed with which the operation formed up with so very little advance notice.

The cooperation between the phone nets and c.w. nets on the flyover was little short of phenomenal and made the flyover successful. It could not have been done, because of the shortness of time, without this close cooperation. ■