Space-Charge-Grid Amplifier

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A new low-power amplifier using the space-charge-grid tubes first publicized as audio output tubes almost four years ago.

FROM TIME IMMEMORIAL, it seems, the audio enthusiast has been searching for wider frequency range and lower distortion in his amplifiers. These desirable features are expensive, and cost is an important consideration to the average audio fan. So, the effort has gone on to get the most for the least. The amplifier to be described represents what is believed to be the highest quality yet attained for the required financial investment. The remarkable performance is made possible by two important components: a new and radically different tube type and a high-quality low-cost output transformer.

In spite of its well known limitations which increase cost, the triode tube has for years been the standby of the audio crowd. The beam-power tube overcame a number of the limitations of the triode, but many builders never accepted the beam power tube as the equal of the triode. Thus the argument has raged for some years on the beam tube vs. the triode, with good points on both sides. Now, the National Union Radio Corp. has developed for commercial use a new tube type which combines the best features of the triode and the beam tube, and which opens a new era in high-quality amplifiers. This tube is known

Fig. 1. Separate chassis for the amplifier and power supply simplify mounting in many applications.

as the NU 2160 and is a space charge tube. Its plate family of curves resembles those of triodes, but its efficiency and drive requirements are like a beam power tube.

The space charge tube has been described in the literature, but for the benefit of those who do not have access to the references, its characteristics are briefly summarized. The space charge tube is a tetrode, with a cathode, two grids, and a plate. The grid nearest the cathode is operated at a positive d.c. voltage with respect to the cathode, the effect being to counteract the negative space charge and produce a larger cloud of electrons at the plane of the first grid. This cloud acts as a virtual cathode. The second grid is then the control electrode, being operated with a negative bias in the conventional manner. The operation of the space charge tube is similar to a triode with a large effective cathode. It should be pointed out that it is not possible to connect an ordinary tube as a space charge tube because so doing would cause excessive current in the first grid. In the NU 2160 the current

in the first grid has been lowered by mounting a pair of side rods between the space charge grid and the cathode, and connecting these rods to the control grid. The side rods thus shield the space charge (No. 1) grid from the cathode except in the vicinity of the lateral wires of the grid. They also have an effect in reducing harmonic distortion.

The positive voltage on the space-charge grid is supplied from the plate supply through a 10,000-ohm resistor. The space charge grid is *not* bypassed, and the omission of the bypass capacitor produces three beneficial effects: the power output is increased slightly for a given average cathode current, the output is less affected by changes in external load impedance, and the odd harmonic distortion is reduced. It has been mentioned that the plate current family resembles triode curves. To this must be added the fact that the plate resistance is low—2,500 ohms—the μ of 16 is medium, and the transconductance is 6.500 micromhos. The uniformity and regularity of the plate family indicate that these parameters are fairly constant and therefore the distortion is low. The tube is operated with a bias of about 18 volts on the control (No. 2) grid so that operation out of a resistance-coupled stage or phase inverter is very practical.

Through the courtesy of National Union, the writer was provided with a pair of NU 2160's for experimental use. At the present time. National Union is marketing this tube through radio parts distributors under the new designation 6BL5GT/2160 at a price of $18.00. Because of this high price. most of the discussion of this tube for audio amplifier applications is purely academic. since better amplifiers could be built at much lower cost.

Design of Amplifier

Examination of the data sheets provided with the tubes, showed that the tube was ideal for a low-cost amplifier, the power output as calculated being of the order of 6 watts for two tubes in push-pull. The Peerless S-508-A output transformer, originally designed for type 6V6 tubes, has ratings as to plate current and primary impedance which suit it to the 2160. Its design, based on the 6V6 plate resistance, means that it will perform even better at low frequencies with the low-plate-resistance space-charge tube. Its physical size is small, and its price—scarcely higher than a large replacement type transformer—puts it within the reach of the most modest budget. This transformer has low insertion loss, wide frequency response, and ability to deliver power at frequency extremes. The performance data on the complete amplifier to be given later attests to this.

The amplifier itself is simple and with the possible exception of the space-charge stage is conventional. As will be seen from *Fig. 2* it consists of a pentode amplifier stage using a type 6SJ7, direct coupled to a 6J5 split-load phase inverter which drives the output
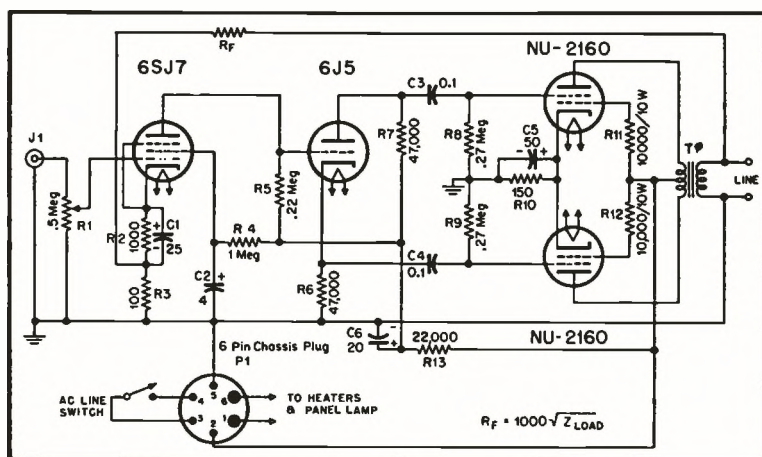

Fig. 2. Schematic of the space-charge-grid amplifier chassis.

tubes. The circuitry of the pentode stage is conventional, the only precaution being to use an adequate bypass capacitor on the screen. The split-load phase inverter is also well known and conventional. The writer has found it to be about as good a circuit as is available, having none of the drawbacks sometimes ascribed to it. One of the big advantages is that it lends itself so well to direct coupling from a preceding stage. Use of direct coupling extends the frequency response of the stage to d.c. and eliminates coupling networks which can cause phase shift and low-frequency attenuation. There are only two coupling capacitors in the amplifier, from the phase inverter plate and cathode to the power amplifier grids. The low-frequency response in the entire amplifier is very good, much better than the transformer curves alone might lead one to believe. It should also be pointed out that the direct coupling system used here is almost automatic in its action to provide optimum operation for both stages once the plate voltage of the preceding stage is brought close to the positive voltage on the phase inverter cathode. There is plenty of good clean signal from the phase inverter to work directly into the space charge control grids and give full power output.

Output Stage

The space-charge-tube circuit differs from the usual push-pull beam-power circuit in one respect. Two 10,000-ohm 10-watt resistors are used to provide the space charge grid voltage. It is nec-

essary to use a separate resistor for each tube. As has been pointed out previously, these space-charge grids are *not* bypassed. The cathodes are tied together and go to ground through a 150-ohm resistor, which is heavily bypassed. The tubes are operated more Class AB₁ than recommended by the manufacturer, as tests with intermodulation equipment showed that reducing the bias increased the distortion slightly at the higher output levels.

Inverse feedback around the amplifier is sufficient to reduce hum, noise, and distortion almost to the vanishing point at the usual levels. The source impedance is lowered to 2.5 ohms on the 16-ohm tap. Connections are available on the output transformer to match loads of from 4 to 16 ohms. Values for the feedback resistor for various load impedances are given in *Fig. 2*.

Construction

The amplifier is constructed on an aluminum chassis 5 × 7 × 3 in. There is plenty of room for all parts, most of which are mounted on two terminal boards. One board is used for the pentode and phase-inverter components, while the other holds the coupling capacitors and resistors for the space charge tubes. A ground bus is used with connection to the chassis at the input so as to avoid chassis currents and hum. The controls are simple—a volume control, a pilot lamp and an a.c. line switch.

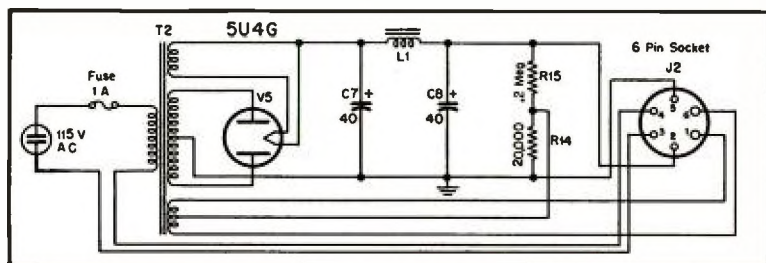The power supply, *Fig. 3*, is simple and conventional. The power trans-

Fig. 3. Schematic of the power-supply chassis.

former is rated at 120 ma, and the amplifier draws just about that current. After 12 hours continuous use in 75° F. ambient, the transformer is just warm. A 6-wire cable is used to connect the power supply to the amplifier. The a.c. power line is run to the amplifier so that there is no possibility of the power supply becoming energized, without its load being connected even if the a.c. power switch is not installed. If no switch is desired, terminals 3 and 4 of the plug must be wired together.

The two-chassis system was employed for this unit—one chassis being used for the amplifier and another for the power supply—so that the amplifier can be placed wherever desired and the power supply can be located at some remote point. Furthermore, they can be placed side by side, end to end, or even stacked if required. One large chassis can be used if the amplifier and power supply are to be constructed as a single unit.

Performance

At the beginning it was stated that this amplifier was intended as a high-quality, low-cost unit. It is believed that this has been accomplished, as will be seen from the performance data. The NU 2160 was not intended as a high-power tube, and hence the power output is limited when compared with 6L6 tubes. The useful power output of the amplifier in a load resistor connected to output transformer secondary is about 5.5 watts, based upon the point where the intermodulation begins to climb rapidly. This power rating compares very favorably with the data sheet which gives the power in a resistive load connected from plate to plate as 6 watts for 2 per cent harmonic distortion, as shown in *Fig. 4*. The single-frequency sine-wave output power before the waveform begins to be distorted (about 5 per cent) is 7.5 watts. The power output as a function of frequency is given in *Fig. 5*. It is the power output at frequency extremes that makes an amplifier sound good and which is reflected in the low intermodulation distortion. Power output at frequency extremes is a function of the output transformer, as tube manufacturers do not put frequency restrictions on their audio power tubes, their measurements being made on a resistive load connected directly to the plates.
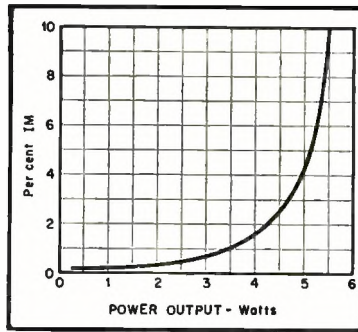

Fig. 4. Intermodulation distortion curves for the amplifier indicate its excellence for low-power applications.

The absolute gain of the amplifier is 81 db, and is practically constant from 20 to 20,000 cps., the maximum departure being about 0.2 db at the limits. It must be pointed out again that frequency response is not nearly as important in the "ear appeal" of an amplifier as power output as a function of frequency. The output transformer used has a rated frequency response of no more than 1 db down at 30 and 15,000 cps, yet the amplifier frequency response is much better. The answer lies in the fact that inverse feedback improves the frequency curve. However, inverse feedback will not help power output measurements as a function of frequency to a great extent. Hence the power curve is more important.

The total noise level, including hum, is −51.2 dbm which is −88.7 db below the rated output of 5.5 watts. The distortion was measured with an intermodulation set using frequencies of 40 and 2000 cps. Up to within 1 db of the rated power the IM distortion is no more than 2 per cent, and at 2 db below rated power the IM is 1 per cent or less. These are entirely negligible amounts. An efficient speaker with 0.1 watt input at 1000 cps will produce a sound level of around 83 db. This sound level has been classified on the *Electronic Industries* sound level chart as "very loud radio in home." At a power output of 0.1 watt the IM distortion in this amplifier is about 0.15 per cent and at a 10 db higher level, which is roughly representative of peaks in the program
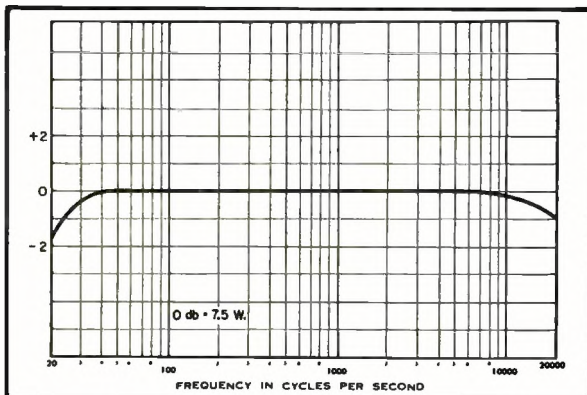
material, the IM distortion is 0.25 per cent. Thus at all usable levels, the IM distortion is too small to worry about.

The total cost of the parts to build this amplifier and power supply, using the transformers specified for its performance and other parts of first grade is about $35.00. This does not include the space-charge-grid tubes. which add up to another $36.00. making the entire amplifier rather more costly than many amplifiers of considerably better performance. However. if the demand for the tube should ever increase to the point where its cost became comparable to that of a 6V6. the performance of this amplifier would recommend it.

It was not intended that this amplifier take the place of a deluxe amplifier, such as the Musician's Amplifier, where the ultimate in quality is desired and where the performance requirements are rigorous. This amplifier "folds up" at power levels where the Musician's Amplifier is still below 2 per cent IM. However, this amplifier is especially commended for the average home, especially when cost is an important consideration. At the 1950 Audio Fair it was compared on A-B test with larger amplifiers of equal quality and until the level became so loud that it was deafening, there was no audible difference. In the author's home it has done everything that a home amplifier is called upon to do. There is not enough gain to operate directly from a magnetic pick-up cartridge but with a preamplifier, many of which have been described in these pages, it reproduces all that is on a record. There is, however, plenty of gain for an FM tuner.

PARTS LIST

C_1	25 µf, 25 v. electrolytic
C_2	4 µf, 450 v. electrolytic
C_3, C_4	0.1 µf, 600 v. paper
C_5	50 µf, 50 v. electrolytic
C_6	20 µf. 450 v. electrolytic (FP type)
C_7, C_8	40–40 µf. 450 v. electrolytic (FP type)
L_1	Peerless C-325-A filter choke. 10 H. at 120 ma; d.c. resistance, 240 ohms
R_1	0.5 meg, audio taper vol. control
R_2	1000 ohms, 1 watt
R_3	100 ohms, ½ watt
R_4	1.0 meg, 1 watt
R_5	0.22 meg, 1 watt
R_6, R_7	47,000 ohms, 1 watt (5% or matched)
R_8, R_9	0.27 meg, ½ watt
R_{10}	150 ohms, 10 watt
R_{11}, R_{12}	10,000 ohms, 10 watt
R_{13}, R_{14}	22,000 ohms, 1 watt
R_{15}	0.22 meg, 1 watt
T_1	Peerless S-508-A output transformer. Pri. Z: 8000 ohms plate-to-plate; Sec. Z: 4, 8, 12, 16 ohms. Frequency response ±1 db from 30 to 15,000 cps.
T_2	Peerless R-480-A power transformer. 350–0–350 v. at 120 ma; 5 v. at 3 amps; 6.3 v. at 5 amps.
V_1	6SJ7
V_2	6J5
V_3, V_4	National Union 6BL5GT/2160
V_5	5U4G

Fig. 5. Curve showing power output vs. frequency over the range from 20 to 20,000 cps.

0 db = 7.5 W.

FREQUENCY IN CYCLES PER SECOND

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