The Purple Cow

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Every so often one encounters an amplifier which has been built by its designer with little regard for cost, but with the sole aim of creating the finest unit possible. Some of the design features in this example should be studied for their value in other applications aside from the over-all unit.

LOOKS "FUNNY," DOESN'T IT? It *is* "funny"! How can one expect good high-frequency response with the 4.7-megohm resistor for the plate load on the pentode section of the 6U8? That is a story of some length. The circuit under discussion is that of the "starved" amplifier, and is the first-stage section of this unit.

It should be noted from *Fig. 1* that the circuit operates in an unconventional manner. The pentode is starved for plate current and receives but little screen potential. The writer has used the old 6SJ7 tubes under similar operating conditions and obtained made-good gains of 3500 to 4500.

The plate of the pentode is directly coupled to the grid of the triode which is connected as a cathode follower. With this arrangement there is no Miller effect to add to the shunt plate-load reactance across the plate resistor for the pentode. This results in pushing out the high-frequency response of the combination far beyond what one might expect.

The output signal of the triode is in phase with the signal in the plate circuit of the pentode and therefore the pentode screen receives degenerative signal from the tap on the follower load resistor. Positive screen-grid operating potential is also obtained from the same tap. The extremely high gain of the composite tube is thus "plowed back" through the screen, trading gain for stability, wide-band performance and low over-all distortion. The composite tube envelope delivers a made-good gain of 100 and is only down 3 db at 40 kilocycles. Constructed as shown, this stage contributes almost no hum to the over-all output at full volume.

The stage was designed to make up for the high insertion loss experienced when using the IRC level control for Fletcher-Munson compensation. This loss at the mid frequencies is about 40 db. The maker of the control states that an amplifier operating without the control must have sufficient over-all gain so that comfortable room volume is obtained from a setting of the volume control such that the resistance to chassis ground from the moving arm tap is 1.1 per cent of the total resistance of the control.

The position of the tap on the cathode load resistor can be adjusted so that the screen of the pentode receives increasing amounts of negative feedback signal. In this way the gain of the amplifier can be adjusted to accommodate pickups of different average output voltages.

Care must be exercised in the construction of this first amplifier so as to provide full static shielding for the circuits of the pentode and triode sections. Use of d.c. for the heater is strongly recommended. The schematic shows one way of obtaining it by passing the 480-ma output-stage current through the heater. If hum troubles are experienced from strong electromagnetic fields, the 6U8 can be enclosed in a Mu metal shield or one turned out on a lathe from block or bar stock steel.

No effort was made to determine the minimum acceptable decoupling in the plate circuits. The writer wanted the ultimate—a "purple cow"—and economy was not a primary consideration. It was played straight across the board for safety and minimum noise and hum.

The Phase Splitter

The phase splitter is a conventional "long-tailed pair." It will be noted that both triodes receive the same operating voltages. The signal developed in the plate circuit of the triode to which the signal is first applied develops a signal across the cathode resistor and this drives the second triode because its grid is grounded by the 0.25-μf capacitor as far as signal is concerned.

The unusual part of the arrangement is that there is a potentiometer in the plate circuits of these triodes. This permits exact equalization of output signals by varying the made-good gains of the separate triodes. More or less load resistance can be inserted and removed from each triode of the inverter to accomplish this desired result.

This feature, together with the provision in the output stage for static balance of plate currents, results in minimum of total distortion.

This type of phase splitter is quite popular in European amplifiers and maintains its performance over a wide band.

The Exciter Stage

The plate loads for the exciter tubes are composed of triodes in a circuit configuration that resembles that of the cascode amplifier. More careful examination of the action in the stage will reveal the basic difference and the unusual capabilities of the same. The special features have been verified by experimental investigation from "jury rigs" of the circuit.

When there is a *positive*-going signal at the grid of the lower tube, there is an increasing plate-current demand. The increasing plate current on the side under discussion causes an increasing IR drop across all of the resistors in this circuit. It is therefore apparent that there is an increasing drop across the cathode resistor of the upper tube of the pair. This drop is of such phase or direction that the upper tube is then getting an increasing *negative* going signal.

We have just established that either side of the exciter is thus putting out a push-pull signal although the applied signal is single sided. Either side of the composite exciter delivers a single sided output signal.

In a true push-pull stage the plate current for class A operation will remain constant with applied signal and no overload even if the signals are d.c. The circuit being explained has this characteristic. The lower tube calls for increasing plate current under the before assumed conditions while the upper tube calls for a decreasing plate current in the same common circuit. With correct adjustment the plate current will remain constant as long as the signal handling abilitiy is not exceeded even if the applied signal is steady state or d.c.

Apparently the upper tube produces the signal by an IR drop across its dynamic plate resistance, the current remaining constant and the plate re-

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sistance changing as required to give the changing product—the output signal desired. This signal is taken from the cathode of the upper tube.

If all of the above is true, it would be expected that the stage would exhibit the tendency to cancel even harmonic distortion. That it does so can be shown easily with a 'scope and suitable single-frequency signal generator. With increasing signal a sine wave at the output of either side shows distortion as the overload point is approached. As this point is approached, the cathode resistor for the upper tube can be adjusted in value to obtain only symmetrical distortion in the output, which means that the arrangement is passing only odd harmonic distortion. Again this is physical support of the contention that the arrangement is a true simulation of the transformer-coupled push-pull output stage.

The schematic does not show this and the working circuit is not so arranged, simply because the use of equal (upper and lower) cathode resistors results in equal plate voltage distribution across the tubes. This, together with the fact that the final tests were satisfactory, resulted in the decision not to unbalance the cathode resistors for ultimate even-harmonic reduction.

Reference to the tube manuals will show that the 6SN7-GTA is quite capable of operating with plate potentials of 450 volts and that the permissible plate dissipation is such that the resistors could be unbalanced for ultimate reduction of the even-harmonic distortion. This would be done if it were necessary to enter competition with the design.

For "ultra-minimum" distortion, the upper-tube cathode-load resistor should be made to have a resistance equal to about 15 to 20 per cent less than that resistance of the lower-tube cathode re-

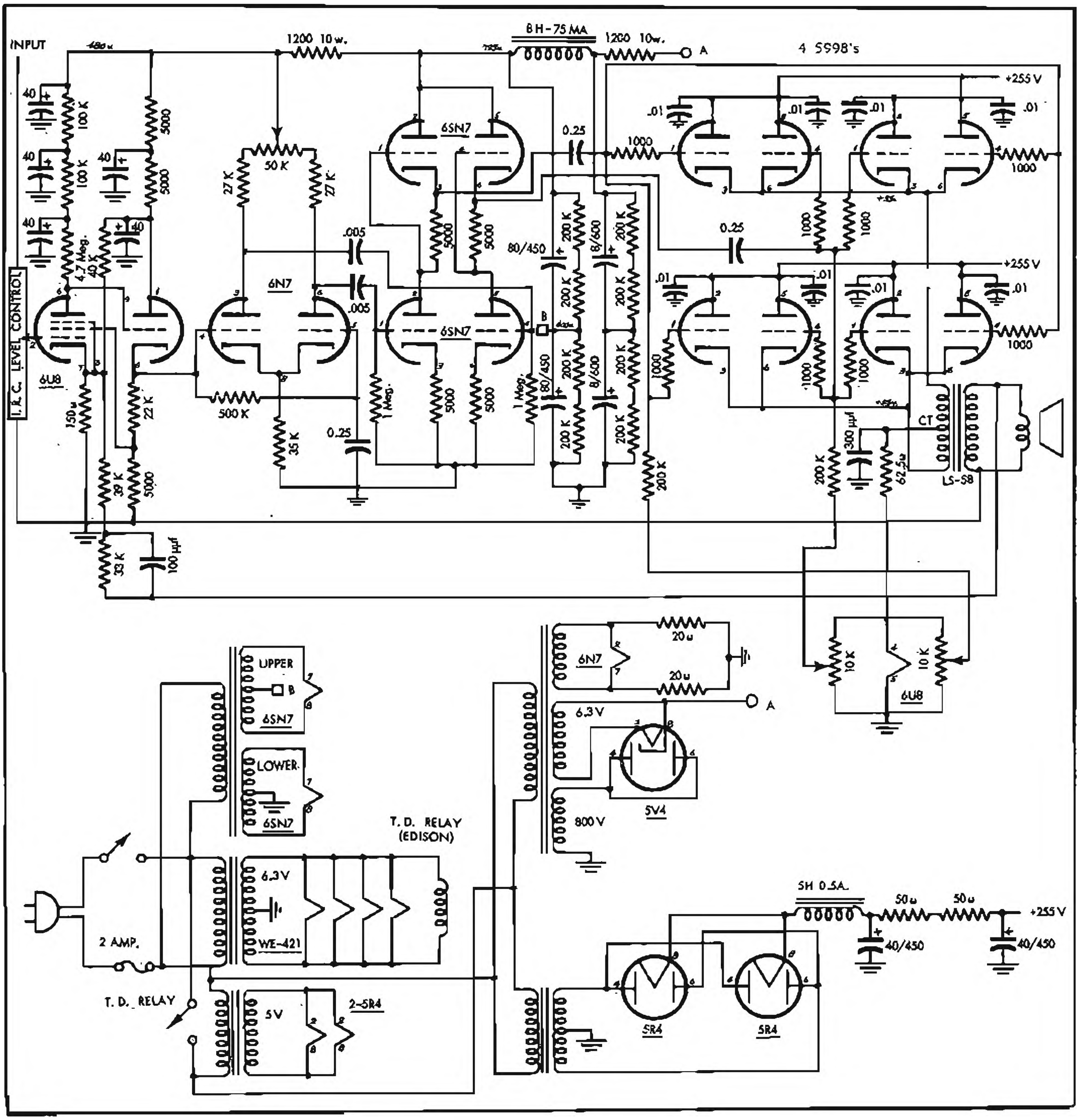


Fig. 1. Complete schematic for the "Purple Cow" amplifier which employs four heavy-duty double triodes in a cathode-follower output stage for reliable and high-quality performance.

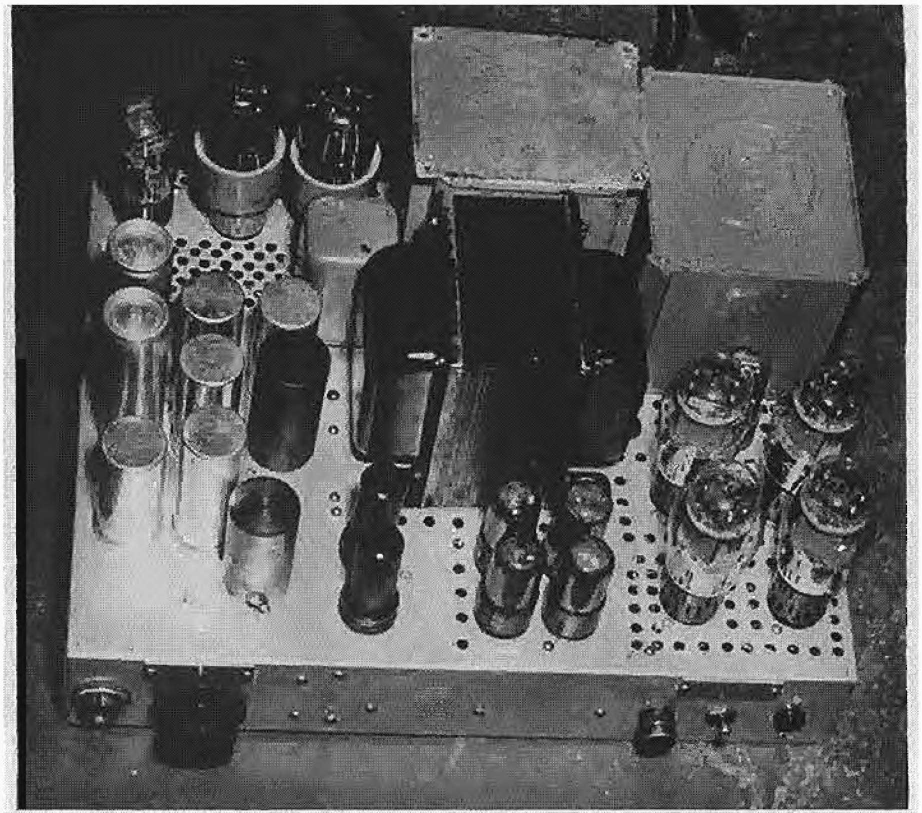


Fig. 2. Top-of-chassis view of the amplifier described by the author. Note solid steel shield over input tube just in front of the bank of electrolytic capacitor cans.

sistor. This again has been found true by experiment and trial.

It is interesting to note that the arrangement causes the curvatures of the grid-voltage/plate-current characteristics of the exciter tubes to be opposed just as these are in the transformer-coupled push-pull stage. Also note the additional degeneration present in the circuit due to the unbypassed cathode resistor of the upper tube.

Measurements show that for the same operating conditions at or near the overload point, the circuit described reduces the IM distortion by factors of from 20 to 90 per cent over the conventional resistor-loaded stage.

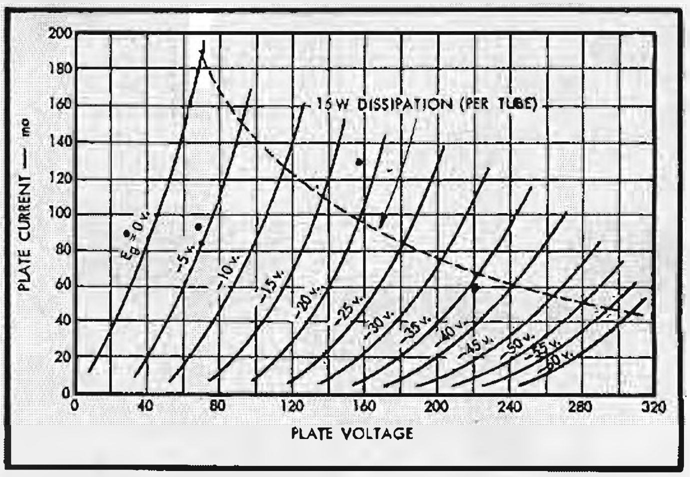
If these facts are true, as they appear to be, we may conclude that the complete exciter requires a push-pull signal for its operation and that when such signal is supplied, each half of the signal is converted at each side of the exciter input into a new push-pull signal. The separate output-stage grids are therefore excited by separate push-pull signals.

The Cathode-Loaded Output Stage

It is not necessary to "sell" the advantages of cathode loading. Our best engineering minds list but one disadvantage for this arrangement—that of the high excitation required at the input of the stage.

Several things can be done to overcome this objection and when these have been accomplished we have the ideal amplifier.

Fig. 3. Plate family for the 5998 tube.



One obvious thing to be done is to get the greatest gain possible from the stage. Since the stage is excited by a signal equal to the output swing plus the grid swing, we can reduce the grid swing required by selecting power output tubes having the optimum characteristics.

Figure 3 shows the plate curves for the Western Electric 421A, with which the writer was familiar. This tube is no longer made by W.E., but the Tung-Sol 5998 is essentially identical. Operating with a supply voltage of 220, the 5998 will swing 60 ma with 36 volts on the grid, indicated as the operating point on the curves. This would indicate that the 5998 would be an excellent tube for a high-power cathode-loaded output stage. (For still higher power requirements, one could turn to the 6528, which has an allowable plate dissipation of 30 watts per plate; or 60 watts per tube; another similar type is the 7242, with 100 watts rated dissipation in its single triode section.)

The working arrangement shown on the schematic shows each side of the composite output tube (four triodes per side) to have 32,000 micromhos of transconductance. The gain of the stage is from 0.8 to 0.9 over the working range. This simply means that practically all of the exciting or input signal is developed across the output transformer primary. This results in a cathode-loaded output stage that is relatively easy to drive.

Figure 1 shows the precautions to be exercised in handling the high transconductances obtained. The output tubes must not get the idea that they are plate loaded at some extremely high frequency or oscillation will result. All leads are to be kept short and close to the chassis. Do not neglect the decoupling shown at the grids and plates of the tubes.

There is one additional thing that we can do to decrease the excitation required in a cathode-loaded output stage and this trick picks up the efficiency quite appreciably. The reflected resistance from the speaker load should equal the dynamic plate resistance of the composite output tube. This is the practical application of the law that states that for maximum transfer of power the load resistance should be made equal to the generator resistance.

The U.T.C. LS-58 output transformer, when operated in the push-pull parallel hookup, will reflect a primary impedance of 1500 ohms with a 30-ohm secondary load. An 8-ohm speaker connected to this tap will be reflected across the primary as a 400-ohm load which is an exact match for the 5998 composite output, both halves.

The schematic, *Fig.* 1, shows an amplifier with the output stage having an idle dissipation of about 105 watts and with a maximum usable output of 46 watts—about 43 per cent efficiency. The output stage, while strictly class A, is quite efficient and takes no back seat to other acceptable circuit arrangements.

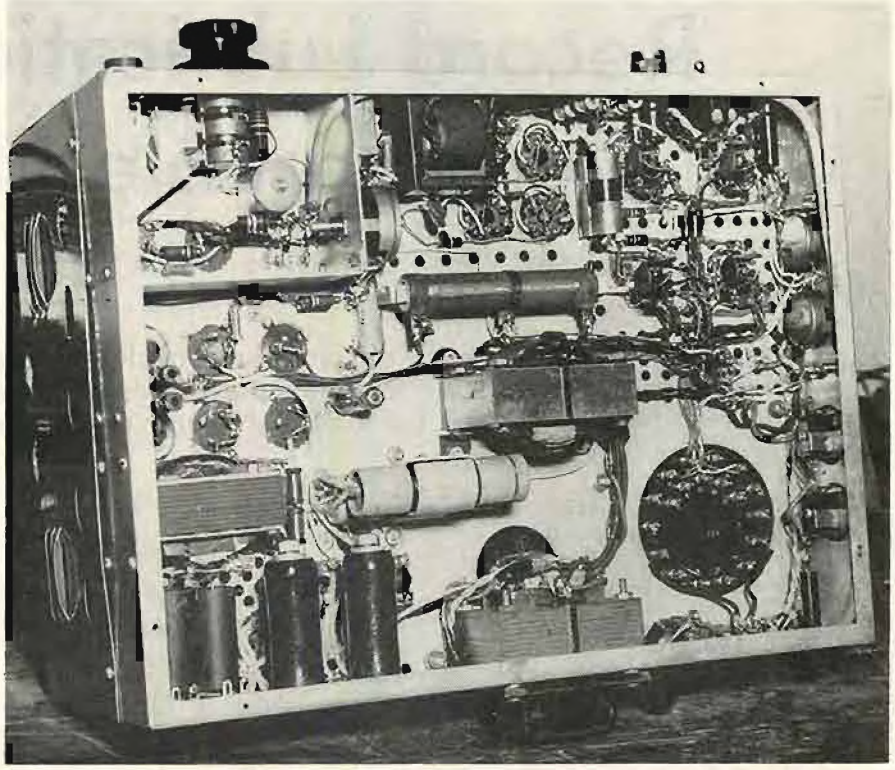


Fig. 4. Under-chassis view of amplifier. Actual configuration and parts placement will depend on power supply components selected.

The 5998 tubes seem excellent in quality and very hard. The circuit was wired and the current balance arrangement set for no compensation. When the rig was first turned on, the plate currents exactly balanced and have remained in balance despite several hundred hours of subsequent operation.

The cathode-loaded output stage is used in the complete amplifier in a type of Williamson circuit. The IM distortion figures on the completed amplifier are as follows.

At 10 watts, 0.38 per cent; at 20 watts, 0.82 per cent; at 30 watts, 1 per cent; at 46 watts, 1.9 per cent. This data should establish that this cathode-loaded output stage with its special exciter has overcome the classical objection to the circuit.

Notes on the Complete Amplifier

The use of .005-μf coupling capacitors to the grids of the exciter stage seems out of order. It will be noted that the time constants of the RC coupling here and at the grids of the output stage differ by 10 to 1.

The small coupling capacitors were chosen by experiment. With the 100-μμf capacitor in the feedback loop disconnected, the feedback voltage over the five stages was increased until the amplifier oscillated. With .01-μf coupling capacitors to the inputs of the exciter, oscillation at a very low frequency appeared with 28 db of feedback. With .005-μf coupling capacitors, the feedback could be increased to 33 db before oscillation set in, this time at about 100 kc.

It was decided to have 18 db of safety factor and accordingly the over-all feedback around the five-stage loop was set at 15 db and this amount will be obtained if the schematic is followed with a similar construction. The over-all frequency response is flat down to 10 cps as determined by single-frequency checks.

Working into an 8-ohm resistive load, the amplifier reproduces a 10-kc square wave without appreciable distortion, but to obtain this end, the 100-μμf capacitor in the feedback loop must be used. It will also be necessary to avoid strictly the use of any of the carbofilm resistors or any similar resistor in the signal handling circuits as these are slightly inductive at high frequencies. These were used in the original construction but were replaced with composition resistors when "ringing" appeared on the flat tops of square waves in these tests.

The output transformer is a U.T.C. LS-58 and better results might be obtained by employing a special output transformer using grain-oriented core materials and designed specifically for this application. The author knows of no such transformer available at this time.

A signal of 0.1 volt at the input will drive the amplifier to its full output of 46 watts, 19.2 volts across 8 ohms. With the level control full on, the idle noise and hum output is about 80 db below full output. Despite the high over-all gain this is a very quiet amplifier, and this quality is appreciated during the soft passages of musical compositions.

The power supplies are not all that could be desired as these were set up from the scrap box materials available and adjustments required were made as shown by knocking down the output voltages by use of dropping resistors. Since the amplifier is class A throughout, it is understandable that such an arrangement is entirely satisfactory. Any further unorthodoxy apparent in examining the power supply and the heater arrangements was brought about by necessity; the components employed were those at hand and their use is reflected in the unusual circuitry associated with them.

The 5V4 rectifier experiences peak inverse voltages slightly in excess of its rated capabilities over about 30 per cent of the cycle but has given no evidence whatever of being in trouble. A third 5R4GY would avoid this problem.

Any amplifier using the IRC level control must have its over-all gain so adjusted that the output is balanced at whatever level is desired—loud or soft. If the amplifier has too much gain the output will be too heavy or "bassy" and it will sound dull and uninteresting. If there is insufficient gain the output will be thin and lack body, tending to sound shrill.

One practical means for proper adjustment of gain in using this control is to make sure that there is sufficient surplus over-all gain in the amplifier in the first place and then operate with the control wired in as required. Additional attenuation can be inserted with a composition resistor located between the input terminal and the high side of the IRC control. The value of this resistor is then chosen by trial, and the correct value results in having the output balanced regardless of the setting of the control. The illusion obtained as the control is operated to reduce the volume is that the music is simply being played more softly but that all of the instruments are being reduced in volume alike.

The performance as judged by listening tests is pleasing, crisp, and sparkling, with robust body and abundant clean bass. Record or needle scratch is so low that listeners often make unsolicited comment about its absence.

What is next expressed is the writer's personal opinion and will not be debated. Since the damping factor is very high indeed there may be some who might inquire as to the desirability of reduction by using a series resistance in the voice-coil circuit. No good speaker operating in a correct enclosure will require this treatment. The writer uses a Bozak system and these systems require no such series resistance. The amplifier must "boss" the speaker for best reproduction, and it accomplishes this best with high damping factors.

To simplify the presentation of the circuit on the schematic the exciter and inverter stages are shown as being composed of single triodes. The photographs do show that these stages are made up from triodes in parallel. This is done to reduce the effect of reflected plate and grid shunt reactance due to the Miller effect always present when coupling triode amplifiers into triode amplifiers. By this means the high-frequency response is carried out to extreme limits.

Acknowledgement

The author acknowledges the assistance of Mr. Donald Ismert who assisted in the "jury-rigging," performed all the measurements, and did the necessary photography. Æ

PARTS LIST

2	8-μf 600-volt electrolytic capacitors
5	10- to 40-μf 50-volt electrolytic capacitors
2	80-μf 450-volt electrolytic capacitors
2	40-μf 450-volt electrolytic capacitors
1	300-μf 150-volt electrolytic capacitor
3	0.25-μf 600-volt paper capacitors
8	.01-μf disc ceramic capacitors
2	.005-μf disc ceramic capacitors
1	100-μμf mica capacitor
2	20-ohm ½-watt resistors
1	150-ohm ½-watt resistor
8	1000-ohm ½-watt resistors
4	5000-ohm ½-watt resistors
1	33,000-ohm ½-watt resistor
1	39,000-ohm ½-watt resistor
2	100,000-ohm ½-watt resistors
10	220,000-ohm ½-watt resistors
1	470,000-ohm ½-watt resistor
2	1.0-megohm ½-watt resistors
1	4.7-meg ½-watt resistor
1	5000-ohm 1-watt resistor
1	22,000-ohm 1-watt resistor
2	27,000-ohm 1-watt resistors
1	35,000-ohm 1-watt resistor
1	5000-ohm 5-watt resistor
1	1200-ohm 10-watt resistor
1	18,000-ohm 10-watt resistor
1	40,000-ohm 10-watt resistor
1	62.5-ohm 25-watt resistor
1	50-ohm 50-watt resistor
1	50,000-ohm wirewound potentiometer, 3 watts
2	10,000-ohm wirewound potentiometers, 1 watt
1	IRC Loudness Control

1 Edison Model 501 time delay relay, 45 seconds
1 6U8 tube
2 6N7 tubes
4 6SN7 tubes
4 5998 tubes
1 5U4G tube
2 5R4GY tubes

NOTE: Many transformer and choke combinations are possible. It is suggested that the constructor consult with his parts supplier before beginning work on the power supply. The author can furnish transformer part numbers and manufacturer's name to any interested parties. Æ