RADIOTRONICS

Vol.16 December 1951 No.12

The editors and all concerned with the production of Radiotronics extend to readers their very best wishes for a happy Xmas and New Year.

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Volume 16 **December 1951** **Number 12**

By the way—

We would remind readers that all subscriptions to Radiotronics expire with this issue. If they have not already done so, subscribers should immediately return the subscription form enclosed with the October issue, together with the necessary remittance to this office to avoid missing any of the 1952 issues. We would emphasise this, as quite a few readers failed to renew their 1951 subscriptions until April or May and were unable to be supplied with earlier issues. DON'T DELAY—ACT TO-DAY.

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The January issue will be largely devoted to an article on phototubes and their application.

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High Quality LP Reproduction

Introduction

With the advent of the microgroove record, a considerable upsurge of interest in high quality amplifiers has been evident.

Many enthusiasts have built the Radiotronics A515 amplifier and have added the preamplifier and tone correction circuits suggested by Williamson, in their search for higher fidelity.

For the majority of home constructors, A515 plus its ancillary equipment has one important drawback — the cost involved. Additional disadvantages are size and weight.

In view of this, it was considered that the design of a lower-cost audio system capable of good reproduction, and its detailed description in this journal would interest a fair proportion of our readers.

Design requirements

Before proceeding to the actual design, the specifications for the amplifier must be laid down.

These include,

(a) audio power output,
(b) frequency response,
(c) distortion limit.

At the same time, the following factors should be kept to a minimum,

(d) cost,
(e) circuit complexity,
(f) size.

Each of these in turn is considered to obtain a clear picture.

Audio output

With the increased acoustic efficiency of modern permanent-magnet loudspeakers, the need for a large power output is not as great as formerly. Bearing this in mind, it is suggested that an audio output of about two watts should be satisfactory. This assumes that the user is listening to LP music in a quiet average-size living room. There are several ways of achieving this output and they shall be reviewed briefly.

A single-ended output stage using a triode, beam-tetrode or pentode could be used. The advantage of this method is simplicity as no phase-inverter stage is required. However, the output transformer primary has to carry a large, unbalanced d.c. current which makes its design difficult, cost high, and size large, if good low-frequency response is required. The distortion in the output stage is of the order of 5 to 10%, although this could be reduced by inverse feedback.

The alternative of a push-pull output stage, has much to commend it. Percentage distortion is small, as even harmonics are cancelled out. Similarly, power supply hum is balanced out and the residual noise level is thus low. Beam-tetrodes and pentodes, however, develop high-order odd harmonics which are objectionable if even of very small amplitudes, and which are not reduced by the push-pull connection. It is possible to render these components small by a large amount of feedback, but it is felt that a better approach to the problem would be to commence with a low-distortion push-pull triode-output amplifier and add a smaller and more readily-controllable amount of feedback to achieve the desired result. This avoids the instability troubles which seem to plague the home-constructor owing to his lack of suitable test equipment required for thorough checking. The choice of a low-power output also leads to a considerable decrease in cost, as both the power supply and output transformer can be made appreciably smaller.

Frequency response

It is felt that a lower and upper limit of 50 and 10,000 cycles respectively should provide a satisfactory measure of realism for the average listener using modern equipment. Extending this range further in both directions calls for a much more expensive output transformer and a more elaborate baffling arrangement. Unless a very high quality pickup is used, an upper limit of 10,000 cycles will afford much cleaner reproduction, than with a top limit of say, 20,000 cycles, by the elimination of unwanted distortion, noise and spurious responses. When playing older 78 r.p.m. records, a means of limiting the response to about 5,000 and 7,000 cycles as necessary, is very convenient. A method of accomplishing this will be described later. It should be realised that a wide frequency response alone is no criterion of the relative merit of an audio system. It is far better to limit the range deliberately and enjoy a minimum of distortion within that range, than to endure the distressing harmonics and unwanted intermodulation components often present in the upper 10,000 cycle band of amplifiers specified as "flat to 20,000 cycles."

Distortion

Some authorities have suggested that an amplifier be termed "high-fidelity" if its measured r.m.s. harmonic distortion is not more than ½% and if its intermodulation distortion is not greater than 2%. Be this as it may, the lower the total of distortion components, the better. Admittedly the speaker and pickup contribute more distortion than a good amplifier, but that should not be a deterrent from designing the electrical system to have as little distortion as possible. As we have chosen a push-pull triode amplifier, it should not be at all difficult to limit the distortion to well under 1·% by the judicious use of feedback.

Under this heading also, can justly come hum and noise. A level of 65 db below full output should not be exceeded, but if possible this figure should be reduced to better than 70 db for the discriminating listener if the additional expense entailed is not great. The necessity for a high-gain preamplifier is obviated if a pickup with an appreciable output voltage is selected. This thus removes a further likely source of hum and noise.

Concerning the remaining factors, the size can be kept small by the use of miniature Radiotrons throughout. The total number used can be kept to a minimum if the output valves need only a small driving voltage, and if a preamplifier is not required. By the same token the circuit then becomes quite simple and straightforward and the overall cost, lower.

ASSOCIATED EQUIPMENT

(a) Pickups

There are several different types of LP pickups on the local market with the promise of more to follow. Of those at present available, the Acos GP 20 crystal pickup would seem to be the most suitable for the purpose in mind. By means of interchangeable heads, it is possible to play either 78 or 33⅓ r.p.m. records as desired. Its output voltage is higher than other comparable LP pickups and its response, when equalised, is good to at least 10,000 cycles, which is the upper limit of interest. In addition the GP20 is in the medium-price class and further it does not require a matching transformer — itself a source of hum pickup.

(b) Speaker

There are several good quality speakers on the local market that would be eminently suitable for use with the amplifier system as outlined above. The limiting factor when selecting a particular unit will probably be the financial outlay and manufacturers' literature should be consulted closely before purchasing in view of this.

(c) Baffle

While a horn is the best method of speaker loading, this is difficult for the average person to construct. A vented baffle or alternatively an infinite baffle (being a speaker mounted in the wall of a room) is more practicable and most speaker manufacturers supply full constructional details of these for use with their products.

(d) Tone compensation

The circuits designed for compensation of recording characteristics by the makers of pickups are recommended for general use, rather than circuits culled from other sources. For limiting the higher frequencies a low-pass filter is adjudged as being a good method of accomplishing this. By suitable switching, the upper frequency limit can be varied to suit the listener's taste without the overall volume level changing as with the normal resistance-capacity type of tone control.

It is hoped to present the amplifier design in our February issue, subsequent issues including constructional details of the filter unit, vented baffle, etc.

New RCA Releases

The new **Radiotron 6X8** — a 9-pin miniature tube containing a medium-mu triode and a sharp-cutoff pentode — is designed especially for use as a combined oscillator and mixer tube in television receivers utilizing an intermediate frequency in the order of 40 Mc/s. In such service, a single 6X8 gives converter performance comparable to that obtainable from a 6AG5 as mixer and one unit of a 6J6 as oscillator.

The low grid-No.1-to-plate capacitance of the pentode mixer unit of the 6X8 minimizes feedback problems encountered in mixer circuits operating at an intermediate frequency of about 40 Mc/s especially the troublesome feedback encountered on channel No. 2 because of the small difference between the channel frequency and the intermediate frequency. The low output capacitance of the mixer unit permits the use of a high-impedance plate circuit with resultant increase in mixer gain.

The 6X8 offers versatility to designers of A-M/F-M receivers. The pentode unit may be used in the A-M section as a pentode mixer to provide high gain, and in the F-M section either as a pentode mixer or as a triode-connected mixer depending on signal-to-noise considerations. The triode unit of the 6X8 makes a satisfactory oscillator for either the A-M section or the F-M section.

Radiotron 6BQ7 is a medium-mu twin triode of the 9-pin miniature type designed for use as the first r-f amplifier tube in very-high-frequency television-receiver tuners or as a low-noise intermediate-frequency preamplifier tube in ultra-high-frequency television receivers employing a crystal mixer.

Having very high transconductance, low input capacitance, low input loading, as well as low plate-to-cathode capacitance, the 6BQ7 can be used to advantage in the direct-coupled r-f stage of television receivers utilizing a driven grounded-grid amplifier circuit or in the cascode type of circuit. Use of the 6BQ7 in such circuits provides a reduction in noise with resultant improved receiver sensitivity.

The very high transconductance — 6,000 micromhos obtained at a plate current of only 9 milliamperes — permits high gain and reduced equivalent noise resistance. The low input loading minimizes induced grid noise and makes practical a high input-circuit gain even in the high-frequency channels. Furthermore, variation of the gain-control bias voltage produces a relatively small change in input loading so that antenna termination is substantially constant. The low plate-to-cathode capacitance contributes to stability in grounded-grid service.

Each of the triode units of the 6BQ7 is effectively shielded from the other. Consequently, either unit will give stable performance when used in high-frequency applications such as push-pull grounded-grid amplifiers, driven grounded-grid circuits, and counter circuits.

Pickup Input Circuits

Compensating for 78 and 33⅓ r.p.m. recording characteristics.

by R. L. WEST, B.Sc., A.M.Brit., I.R.E., and S. KELLY.

Much disappointment can be avoided by a simple understanding of the principles underlying the design and selection of input arrangements for standard 78 r.p.m. and 33⅓ r.p.m. long-playing records. An exhaustive treatment is not intended, but it is hoped that this article will help the beginner to avoid the commoner pitfalls.

Most pickups fall into two main types — crystal (or piezoelectric) and magnetic — the latter covering ribbon and moving coil, as well as moving-iron armature and "variable reluctance" types. Crystal pickups are always of high-impedance; they are thus suitable for more or less direct connection to a grid circuit. Magnetic pickups are sometimes wound with a large number of turns of wire to generate the relatively large voltage required for the grid circuit; this can introduce electrical resonance (of self capacity and inductance of coil) unless great care is taken in the design. For high-fidelity pickups it is normally more convenient to use fewer turns (only *one* in the ribbon) as these produce very small e.m.f.'s but are capable of delivering a much larger current. Since it is voltage and not current that matters at the grid circuit a suitable step-up transformer is normally used. The following remarks assume the use of a transformer where necessary and apply mainly to the high-impedance (secondary) side.

Effect of load

The input impedance of a valve is usually very high compared with the generator impedance and can be neglected; the value of the grid leak will therefore be dictated by the load impedance requirements of the pickup.

Magnetic pickups have internal impedance which is principally L and R in series, whereas crystal types are principally C and R in series and R is usually very small. Fig. 1 shows the effect of load resistance and assumes constant output voltage on open circuit. In each case the dotted characteristic represents the effect of a lower value of load resistance.

Incidental capacitance

(*i*) *Screened lead between pickup (or transformer secondary) and amplifier*:—Again the internal impedance has to be introduced (see Fig. 2). By way of simplification the small resistive component has been omitted from the crystal case but should be included in the event of using very high cable capacities. The slight peak shown in the magnetic case is seldom noticeable since the internal R and the external R (not shown) damp it very thoroughly.

(*ii*) *Screened lead after the volume control*:—This is a common trap for beginners and is often overlooked by those who should know better! The Fig. 2 (c) shows the effective circuit, and the resulting top loss with intermediate settings of the volume control, which can be very considerable, particularly if a high-value volume control is used. The effect disappears as the slider approaches the "bottom end" and turns into an example of the previous type when the slider approaches the "top end". The use of a compensating condenser C_C as shown sometimes helps a little but note that a capacity varying between C_L and $C_L/2$ is now permanently across the input, and only when the slider is half way (electrically) is the "compensation" correct! Far better, if enough gain is available, to use circuit of Fig. 2 (d). Here the very low output resistance will "swamp" the capacity of most normal screened lead requirements.

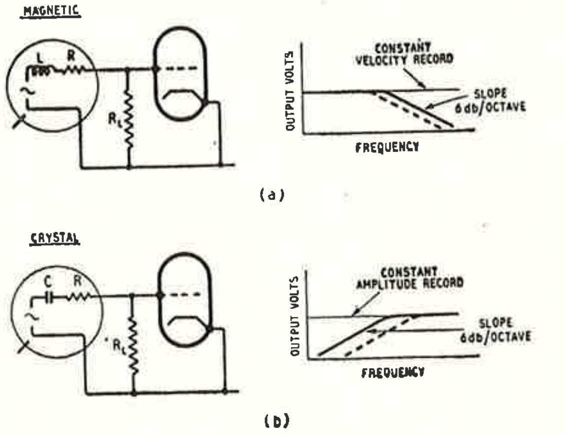

Fig. 1. Effect of resistance on output from magnetic and piezoelectric pickups.

Pickup resonances

Low resonances, say under 1,000 c/s, include those due to the tone arm torsional resonance and the effective mass of the whole pickup resonating with the armature mounting compliance. If these are excessive within the working range, the pickup can be considered unsatisfactory, since it will be found that very heavy tracking pressures are necessary to keep the needle in the groove at these frequencies, with consequent increase in record wear. Electrical correction is no remedy.

The most noticeable high-frequency resonance is where the stylus and/or armature flexes. This ranges

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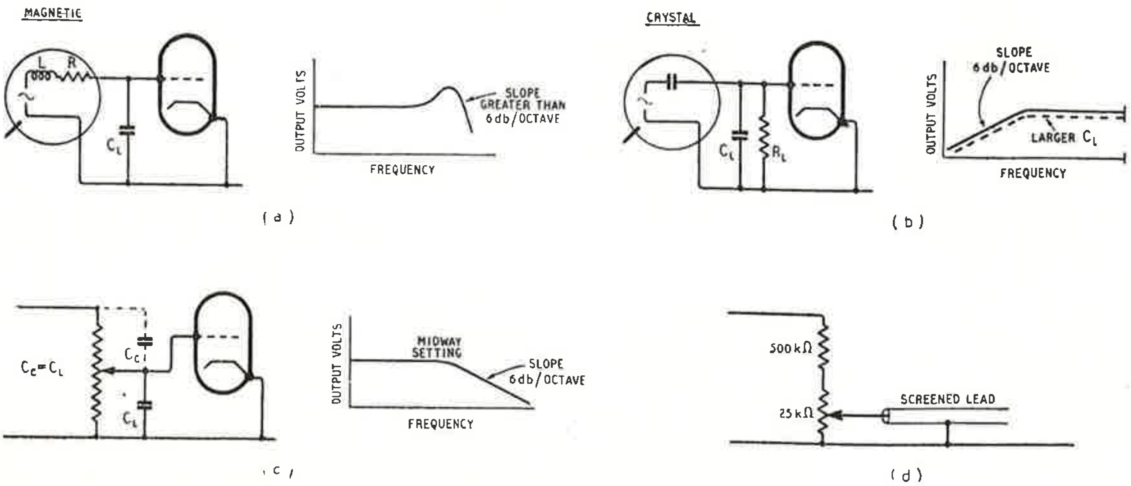

Fig. 2. Illustrating the effect of external capacitance on the response of magnetic and crystal pickups.

from about 3,500 c/s in the older pickups to well above audibility in some modern ones. The "height" of the resonance varies, from 12 db or more in the case of an undamped system, down to a barely perceptible rise if sufficient damping is added and in the right place. This is the resonance which if within the audible range, considerably augments needle scratch. Above this resonance, the output usually falls off very rapidly (see Fig. 3a).

A simple treatment for magnetic types is to use a rather lower load than normal, and so produce top attenuation at the rate of 6 db per octave. This improves the general balance — Fig. 3 (b) — and assists the electromagnetic damping.

A more elaborate circuit uses a tuned series filter — Fig. 3 (c). *R* is seldom needed as the pickup impedance is usually sufficient. As a rule R_2 can likewise be dispensed with since there is some resistance in the inductance. It is better to over-emphasise the correction in order to reduce to a minimum surface noise due to the armature resonance. "*L*" can be an air-cored or dust-cored choke of between $\frac{1}{4}$ and 1 henry. An ordinary laminated core usually exhibits a marked change of inductance with signal strength at these very low operating levels.

The older crystal types usually had an overall output of the type shown in Fig. 3 (d). Here it will be seen that the overall balance is sufficiently good for average domestic use.

Results can be improved by a tuned filter, a parallel-tuned (rejector) circuit is the simplest to use. In Fig. 3 (e), "*L*" would be the same component as in the magnetic case.

Choice of load

In general, the higher the load resistance, the greater the voltage developed by the pickup. For magnetic types the load can be several megohms if the top resonance frequency is very high, the grid circuit capacitance low and no top attenuation desired at this point. The makers' recommendations will have taken these factors into consideration.

For the older crystal types it is usually necessary to use a load under one megohm in order to attenuate the bass response somewhat — unless one is trying to get bass from a small cabinet! Values of $\frac{1}{2}$ megohm to 100,000 ohms are most common.

Hum — causes and cure

There are two main sources of hum — by induction from an alternating magnetic field such as from the mains transformer or gramophone motor, and by electrostatic induction from wiring and components usually connected to the mains or other high voltage a.c. sources.

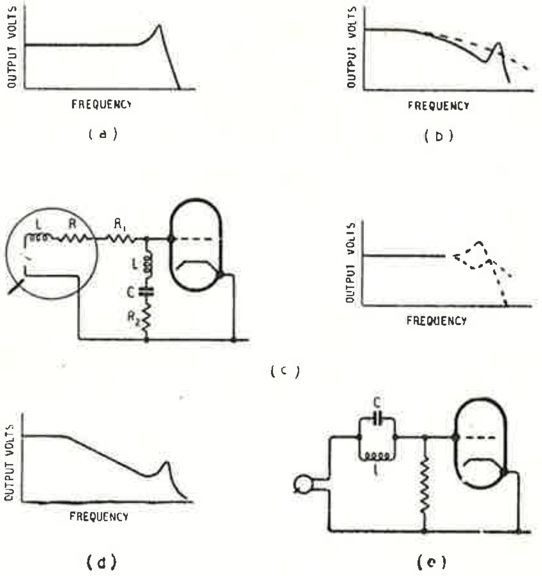

Fig. 3. "Top" resonances in magnetic and crystal pickups.

Magnetic hum introduced into the leads and wiring represents only a very small e.m.f., since only one complete turn is involved. This can be troublesome when a step-up transformer follows the lead in question, how troublesome depends on the transformer turns ratio and the e.m.f. generated by the pickup.

The best treatment is to twist tightly these low-impedance leads all the way from the pickup coil itself right up to the transformer input terminals. For the secondary connections, ordinary screened leads are sufficient, but it is advisable to keep all these leads as far from stray magnetic fields (including heater wiring) as possible. The transformer hum problem is dealt with later. On the high-impedance side the magnetic and crystal types experience mainly hum from electrostatic induction. The cure is simple — just plain good screening everywhere, and this precludes mains switches on volume controls, unless they are well shielded.

Rumble

This consists usually of vibrations originating from the motor with the main components between about 5 to 30 c/s. Magnetic pickups are seldom troubled with rumble since their output is proportional to velocity which falls with frequency for a given amplitude — hence very little output occurs at these low frequencies.

Crystal pickups, on the other hand, usually show up the motor deficiencies on this score, since the output voltage is proportional to amplitude. In a recent design (Acos GP20) a velocity type characteristic has been introduced below about 30 c/s and the trouble is considerably reduced.

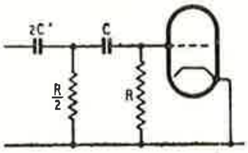

Fig. 4. Simple "rumble" filter.

Where necessary, a simple high-pass filter, such as that shown in Fig. 4, gives useful rumble attenuation without spoiling the bass response. This attenuates at 12 db/octave and gives a more rapid rate of fall at small values of attenuation than the more usual circuit, having equal capacities and equal resistances. Using the circuit shown, values of $C = 0.01\ \mu F$ and $R = 0.5\ M\Omega$ have proved satisfactory.

Pickup transformers

(*a*) *Step-up ratio* — In general as high a step-up ratio as practical is used. Suppose the grid leak-cum-load has been chosen as 1 MΩ, then the actual load on the pickup will be $10^6/N^2$ where N is the turns ratio. The larger N, the smaller is the load, so one must not make N too large by trying to increase the output voltage too far, or severe top loss will occur. If the d.c. resistance of the pickup is, say, 25 ohms, then its impedance at 1,000 c/s we know must be more than this, say 50 ohms, and the load should be much greater still, say, 100 ohms if minimum top loss is desired. This makes N equal to 100. If top loss is definitely desired N could be increased to, say, 200. This will not quite double the output voltage since the lower load will cause a larger voltage drop (at all frequencies) in the resistive component of the pickup impedance.

(*b*) *Choice of primary turns* — For any given ratio and core, too few primary turns, i.e. low inductance, will lead to loss of bass.

At the lowest frequency involved the primary reactance must be equal to or greater than the pickup impedance or load, whichever is the larger. A rough and ready rule, which is liable to err only on the generous side is to put the same number of turns on the primary as there are in the pickup coil, be it one or many.

(*c*) *Core material* — In the interest of minimum distortion (due to hysteresis), at the very low signal levels involved, a nickel alloy such as Mumetal is by far the best material. Not much will be needed, a ¼-in. square core section should be ample for any design.

(*d*) *Screening* — Enclosure in any earthed metal can will look after the electrostatic component. From the magnetic point of view the best method is to select a spot as far as possible from the mains transformer, smoothing choke and motor. Use a Mumetal can, which should be earthed, care being taken to prevent the transformer core from touching the can, and remembering that the magnetic properties of Mumetal deteriorate if the material is stressed by cold working in any way. Any residual (magnetic) hum can be reduced by orienting the transformer in the can, or the can as a whole. In severe cases, a second Mumetal can, to enclose without touching the first, may be necessary.

Mechanical feedback

On occasions, when the loudspeaker is in the same cabinet as the turntable, mechanical feedback will occur when the pickup stylus is in contact with the record. This is usually due to flimsy cabinet construction or to attempting a very large low-frequency output. Each case must be treated on its merits, but trouble of this nature emphasises the desirability of a separate speaker. When this is not practicable cases may be dealt with by rubber or felt mounting for the whole baseboard, stiffening the baseboard, tightening or slackening slightly the motor mounting, or even reducing the bass response at the extreme low frequencies.

Simple pickup measurements

Very little apparatus is necessary to carry out useful checks on frequency characteristics. A standard frequency record, preferably the type with bands of fixed frequency ranging from, say, 30 c/s up to 14,000 c/s or more, a fixed resistor of 5 to 10-watt rating equal to the nominal speaker load, an a.c. voltmeter (rectifier type) of range 0 to 5 V or 0 to 10 V.

Most modern amplifiers employ sufficient feedback to be virtually flat over the audio range, so, with a resistive load in place of the speaker and the voltmeter across that, they make a very nice valve voltmeter, provided the volume control is not disturbed after the initial setting.

A response curve can then be obtained quite easily by converting voltage ratios to the voltage at, say, 1,000 c/s into decibels by the usual formula:

Decibels = 20 × log. ratio — or by referring to decibel tables or abacs if these are available.

Be careful not to overload the amplifier when taking these readings. Knowing the maximum power output of the amplifier and remembering that Watts $= V^2R$ calculate the highest reading V you can allow to be seen on the voltmeter.

In the absence of an LP test record, the circuit can be checked satisfactorily using a 78-r.p.m. standard frequency record, run at 78 r.p.m. and using the correct stylus. To the readings obtained, when converted to decibels, add the bass-cut figures quoted on the record, then the final curve should look like the inverse of curve C in Fig. 6 if equalization is correct. This method is quite accurate except for the top resonance, if any.

Controls for a pickup

Two controls are really sufficient — a top attenuator, preferably switched in 4 or 5 stages, to cover age, origin, and condition of 78-r.p.m. records, and a changeover switch to effect the major 78 — LP change. A three-position switch is useful, in the form 78-LP-Radio. The more ambitious might like to expand it to:—78 NORMAL — 78 FFRR — LP — Radio, but the extra top of the Decca FFRR can be dealt with quite adequately by the normal top control.

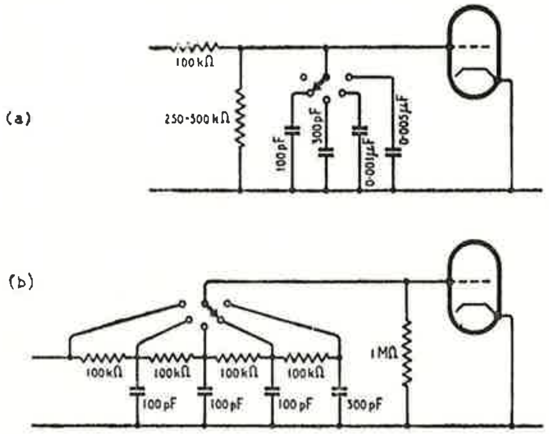

Fig. 5. Top cut controls (a) with variable cut-off frequency, (b) with variable attenuation slope.

Two top cut circuits are shown. Fig. 5 (a) is the conventional one with 6 db/octave attenuation starting higher or lower in the scale according to the capacity chosen. With the values given attenuation starts, according to the switch position, at frequencies in the neighbourhood of 10, 6 and 3 kc/s and for really bad records at about 300 c/s. Fig. 5 (b) varies the slope from 5 to 20 db/octave with a little variation of the starting point, which is in the region of 1,000-2,000 c/s.

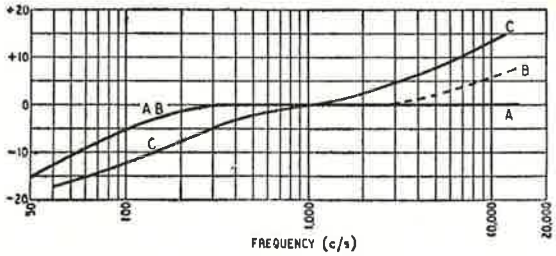

Fig. 6. Principal commercial recording characteristics plotted on the basis of equal velocity at 1,000 c/s. A. standard 78 r.p.m.; B, Decca FFRR, 78 r.p.m.; C, Decca long playing.

A 78/LP changeover is suggested, rather than using the top and bass controls; this enables the changeover to be made with a single operation. Further, exact equalization of LP recordings is not possible with simple cut/boost controls, and it is in any case desirable that the whole of the variable top and bass control range should be available for special conditions.

78 r.p.m. — (*i*) *The recording characteristic.*—

Fig. 6 shows (A and B) the two recording characteristics produced in this country in terms of velocity against frequency.

(*ii*) *Correction circuits.*—The magnetic types require a bass lifting circuit of the type shown in Fig. 7 (a). In reality it "attenuates-everything-but-the-bass," a matter of 10 times for both sets of values given, so that adequate gain must be available in the amplifier.

R_1	R_2	R_3	C
100kΩ	10kΩ	≥ 500kΩ	0·05µF
200kΩ	20kΩ	≥ 1MΩ	0·05µF

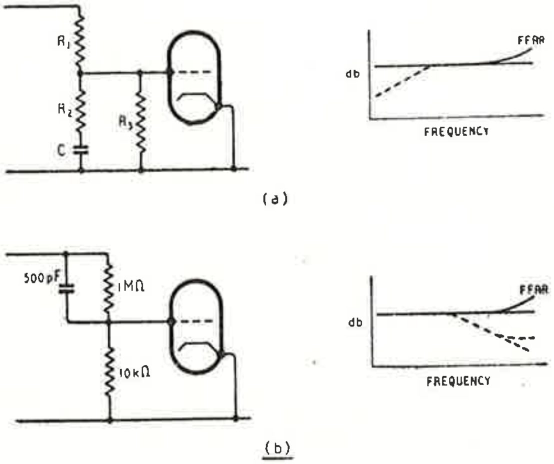

Fig. 7. Simple compensating circuits for 78 r.p.m. recordings (a) magnetic (velocity) pickups, (b) crystal (amplitude) pickups. The dotted curves indicate voltage output before correction.

The circuit of Fig. 7 (b) for the crystal type is similar in this respect. With the older crystal types it must be used with discretion, though, on account of the rather large high-note resonance. An elaboration of this circuit which was recommended for use with the Acos GP12 is shown in Fig. 8. This pickup followed closely the theoretical amplitude operation of piezo crystals.

With the later types of crystal pickup, such as the Acos GP20, the high-frequency response does not follow this law, but has an internally-compensated response which approximates to a velocity law at high frequencies when terminated by a resistive load. For those who would like to improve the response, a circuit is shown in Fig. 9.

None of these circuits include top correction for the difference between standard and FFRR characteristics, but this will be covered by the suggested top control.

A complete circuit for a magnetic pickup is shown in Fig. 10, and for an Acos GP20 in Fig. 11. This latter includes the anti-rumble circuit of Fig. 4.

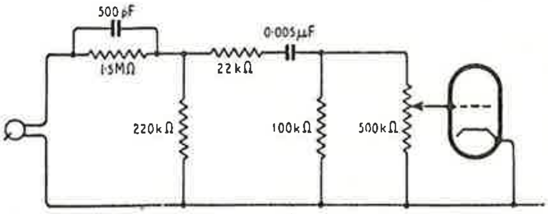

Fig. 8. Correction circuit for the Acos GP12 pickup on 78 r.p.m. records.

Long-playing (33⅓ r.p.m.)

The successful adaptation of standard pickups for microgroove recording is dependent on the recognition of several factors. If the pickup will not track standard 78 r.p.m. test recordings satisfactorily at 14 grams or less, it is improbable that the same pickup (with a correct radius stylus, of course) will track long-playing records at 7 grams. The tracking problem is not only important at the low frequencies, but also at the extreme high frequencies, where the velocity of the microgroove recording approaches that of the standard record, although the tracking weight of the pickup is considerably less and mechanical impedance of the armature is rising rapidly.

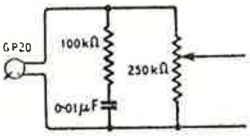

Fig. 9. Correction circuit for Acos GP20 pickup on 78 r.p.m. recordings.

Assuming, however, that the pickup is satisfactory in this respect, there is no reason why it should not give satisfactory results on microgrooves, providing it is correctly equalized. It should be noted that the effective resonance frequency of the armature system is usually decreased by about half an octave on microgroove compared with standard records, so that if any resonance is at all apparent in the upper register on standard records it will, in general, be more prominent and at a lower frequency on microgrooves.

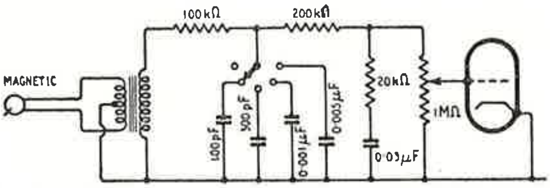

Fig. 10. Complete compensating circuit (78 r.p.m.) for magnetic (velocity) pickups.

Frequency correction — As examples, two high fidelity magnetic pickups and a similar type crystal pickup are presented herewith. The open-circuit response characteristic of the Decca Model D2, 3-pin type, magnetic pickup is given in Fig. 12 (A). It will be seen that this response, in the mid and lower registers, approximates to the recording characteristic, Fig. 6 (C), but in the higher frequencies rises rather more steeply because of the lowered resonant frequency of the armature system. The electrical network, shown inset, corrects the response shown in curve B. Although this final response is not in the "straight line from d.c. to infinity" beloved by the pedants, it is well within ± 2db. The components in question were radio-tolerance units. It may be pointed out that the 500 pF terminating condenser and the 4,000 Ω resistance may have to be varied with individual pickups to get a satisfactory balance between the middle and upper frequencies. This equalizer has been successfully used with a variety of pickups of up to 5,000 ohms impedance (connected direct or taken on the secondary of the coupling transformer) which normally require a load resistance of quarter to half megohm.

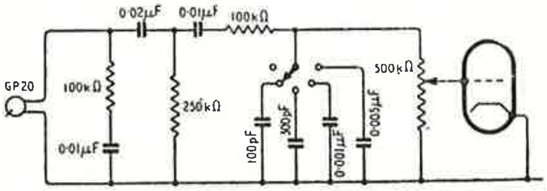

Fig. 11. Complete compensating circuit (78 r.p.m.) for Acos GP20 pickups.

The best of the moving-coil pickups show a resonance of at least 20 kc/s on standard 78-r.p.m. records and even when played on microgroove records the resonance is seldom lower than 15 or 16 kc/s and the pickup response is very nearly that of the record. With care the low-frequency resonance can be below 30 c/s and the low-frequency response will also be very nearly that of the recording characteristic. The Leak moving-coil pickup and its transformer are shown as being representative of this type of instrument. The open-circuit response is given in Fig. 13 (A); when connected with the appropriate equalizer network the response shown at B is obtained. The high-frequency "roll-off" is controlled by the 0.015-µF condenser; decreasing it to 0.01 µF will increase the 10-kc/s response by about 4 db. This condenser can be adjusted to meet individual requirements. If the low-frequency end is considered excessive a condenser can be inserted between the

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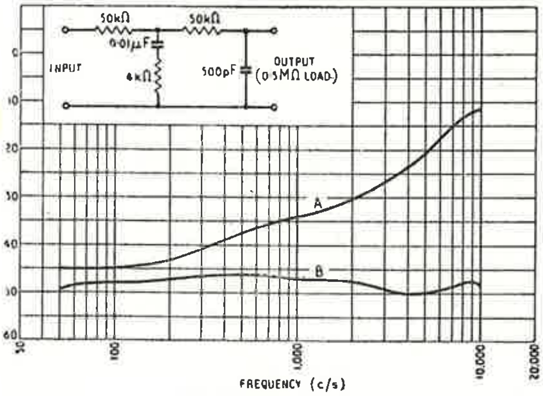

Fig. 12. Output of high-impedance Decca Model D2 (3-pin type) moving-iron pickup on 33⅓ r.p.m. test record; A, without correction; B, with equalizer circuit shown inset.

Restricting Frequency Range in Speech Amplifiers

This is a case of where you can get something for nothing, or at least, close to nothing. Before giving the punch line, though, let's examine the situation from the beginning.

Phone stations on the ham bands seem to fall into three categories regarding their speech quality. The first are the stations that will have no audio equipment in the shack unless it is capable of a flat response from 20 cycles to 15,000 cycles. Their quality is superb, and your ears would tell you so if it were possible to have a receiver and a reproducing system capable of handling this audio range at a time when propagation conditions allowed undistorted reception. These amateurs are taking up needless space in the limited ham spectrum by their activities, but as long as their carrier is inside the band edge by twenty to twenty-five kilocycles (in order to keep those wide sidebands inside the band) then, the FCC will not bother them, at least not yet.

On the other extreme is the second group, small though it be. These amateurs wish to have a transmitter that is as effective, communication-wise, as possible. Those who are on A-M phone tailor their speech amplifier equipment until it transmits the narrowest possible audio range, leaving only enough audio range for complete understandability. A more rabid group goes even further, by partially eliminating the carrier and then transmitting only one sideband. These amateurs deserve a lot of applause, but we needn't bother to applaud them, because they did this not for applause but because they want their money's worth out of their equipment.

Which brings us to the third group, which must certainly include the majority of the world's phone men. This group is made up almost entirely of Mr. Average Phone Man and others of his ilk. Mr. Average Phone Man has a speech amplifier and a modulator which he copied faithfully from some handbook or some radio magazine. When he finished the audio end, he connected it to his c-w rig, got on the air, and asked the first ham he contacted the age-old question, "How's my modulation?" Aside from the fact that Mr. Average Phone Man should have checked his modulation with a scope, while transmitting into a dummy load, instead of depending on the advice of another Mr. A. P. M., this situation is quite normal and is to be expected.

All right, you say, this is old stuff, so where's the pitch? Here it is. Why continue to waste power by transmitting certain audio frequencies if these audio frequencies are unable to help the other fellow hear you, especially when you can almost get rid of these unwanted high and low frequencies at practically no cost? To be specific about cost, the change can be made by the use of four 600 volt paper or mica condensers.

Before explaining how and where to put which condensers, let's make certain that another point is clear. This article has nothing to do with speech compressors, speech clippers, or sharp cutoff low-pass filters. The latter will do an excellent job of tailoring the speech range, but these filters may be rather elaborate. Speech compressors and speech clippers, on the other hand, do not affect in any way the band-pass characteristics of an amplifier unit. They may, however, affect the fidelity from a distortion standpoint. This is especially true of speech clippers.

One other point might also be explained here. The changes to be described are suitable for practically any type of speech amplifier. However, a restricted bandwidth is not assured if these changes are made in an amplifier which is used for NBFM. If the swing is not carefully adjusted the bandwidth may still be excessive. In other words, it is worthwhile to make these changes in an NBFM speech amplifier, but the effect will be nullified if the signal is permitted to swing too far frequency-wise, due to improper adjustment.

Here, then, is what you may do to restrict the audio range of your speech amplifier in an economical way. First, attenuate the low audio frequencies by changing the value of two of the interstage coupling condensers and second, attenuate the high audio frequencies by adding a condenser from plate to ground on two of the audio stages.

The calculations to determine the proper size of condenser for each point are not difficult. It is first necessary to decide on the audio range you wish to cover. Let us assume that you want an audio characteristic which is down somewhat at 300 cycles on the low end and 3,500 cycles on the high end. To be more exact, this is one which will be down 6 db at 300 and 3,500 cycles, when changes are made to two of the stages. These two frequencies — 300 and 3,500 cycles — will be used in the calculations.

The next step is to examine the circuit diagram of your speech amplifier. Most amplifiers consist of a pentode preamplifier, driving a triode or pentode amplifier, driving a phase inverter or transformer coupled amplifier which in turn drives the output stage. We are interested only in the first two tubes. We want to put a condenser from the plate of the first tube to ground, and one from the plate of the second tube to ground. Also, we wish to change the values of the condensers which are between the plate

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of the first tube and the grid of the second tube, and between the plate of the second tube and the grid of the third tube.

If the third tube is a phase inverter, it is best not to attempt to change the coupling condenser between the second and third tubes. The reason is beyond the scope of this article but it might be necessary to change the grid circuit of the phase inverter in order to get the proper effect from the changed coupling condenser. In this case, the coupling condenser can be changed between the microphone and the input tube. This is completely satisfactory if a dynamic microphone is used. If a crystal microphone is used, a different approach is necessary. Again this is not within the scope of this article, so that you will have to be satisfied with changes on only one tube, instead of two.

The final step before starting the calculations is to check the value of the grid resistor to which the new coupling condenser will connect. This will be the grid resistor for the second and third tubes unless, as stated above, it is necessary to put one coupling condenser between microphone and grid, in which case examine the grid resistors for the first and second tubes. These resistors should be no greater than 250,000 ohms. If they are of a greater value, decrease them so they are 250,000 ohms or less. Incidentally, the grid resistor for the second tube is usually the gain control.

The proper value of coupling condenser will now be one whose capacitive reactance, at 300 cycles, is equal to the grid resistance in the grid circuit of the stage to which it connects. These words mean, simply, that the condenser value in micro-farads is equal to: $\frac{1,000,000}{(1884)\ (R_G)}$ where R_G is the value of the grid resistor in ohms. This assumes that the low frequency point selected was 300 cycles. The figure of 1884 is 300 times 2 times π. As an example, if the grid resistor is 250,000 ohms, the condenser should be 0.0021, so use a 0.002 μF condenser. Make this calculation for both stages, and replace your present coupling condenser with the calculated value of condenser if it is not already that value. The low frequency audio tones are now taken care of.

Before starting the calculation of the plate to ground condensers, find out the plate resistance (R_P) of the two tubes involved. Most handbooks have this figure. Next, check the circuit diagram and get the value of the plate load resistor which you are using. This is the resistor which connects directly to the plate at one end and is bypassed to ground (and connects to B plus) at the other end. Next, get the value of grid resistor on the tube which follows the tube whose value of R_P you just looked up. Now, calculate the effective parallel resistance of these three factors, that is, of R_P, the plate resistance, of R_L, the plate load resistance, and R_G, the grid resistance, by the formula:

$$\frac{1}{R_T} = \frac{1}{R_P} + \frac{1}{R_L} + \frac{1}{R_G}$$

For example, assume that a 6J5 tube uses a plate load resistor of 50,000 ohms. The plate resistance of a 6J5 is approximately 7,000 ohms. Assume also that the grid resistance of the next stage is 250,000 ohms. The effective resistance of these three in parallel is 5,990 ohms. Call this R_T for the 6J5 stage. Incidentally, the R_P for triodes is low, as shown above. For pentodes, R_P will be very high.

The proper value of shunt condenser to connect from plate to ground is one whose capacitive reactance, at 3,500 cycles, is equal to R_T. Stated again simply, the value in micro-farads is:

$$\frac{1,000,000}{(22,000)\ (R_T)}$$

This assumes that the high frequency point selected was 3,500 cycles. The figure of 22,000 is 3,500 times 2 times π. As an example, if R_T is 5,990 ohms, then the plate to ground condenser calculates out to be 0.0076 μF so use a 0.0075 μF condenser. Connect it to the plate of the tube and to a convenient ground point. Make this calculation for both stages. This takes care of the higher frequency audio tones.

Let us now examine the change we have brought about in the speech amplifier and also examine what we have gained from this change. To do this, we shall have to assume that the response of the speech amplifier, before the change, was fairly uniform from 150 to 6,000 cycles. This is the sort of response which might be expected in a speech amplifier following general circuit practice. In addition, the response was probably only five or six db down at 100 and 10,000 cycles.

When you used your speech amplifier, before the change, you were modulating your carrier with all the complex audio tones that existed in the microphone output, over the 100 to 10,000 cycle range. Your sideband power, which is all that the other ham is using to hear your signal, was therefore spread over a wide frequency range. It so happens that it takes a fair amount of modulator power to components which are not necessary for intelligibility.

By making the change in your speech amplifier, you now still have the same power in your sidebands, assuming that the percentage of modulation is the same, but you now have a great deal more power available to transmit the range of frequencies that really count, those between 300 and 3,500 cycles. Effectively, therefore, you have a "louder" signal, because you have increased power at the audio frequencies to which the other ham listens. In round numbers, the increase in signal strength is about 6 db, which is the same as a four to one increase in carrier power, or the same as putting up an antenna with a 6 db gain over the one you were using.

To get an idea of the response curve which is obtainable, let us look at a speech amplifier which uses, for example, a 6SL7 dual triode for the first two stages, driving a third stage which has a 250,000 ohm grid leak. Assume that the aforementioned

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Fixed Station or Mobile

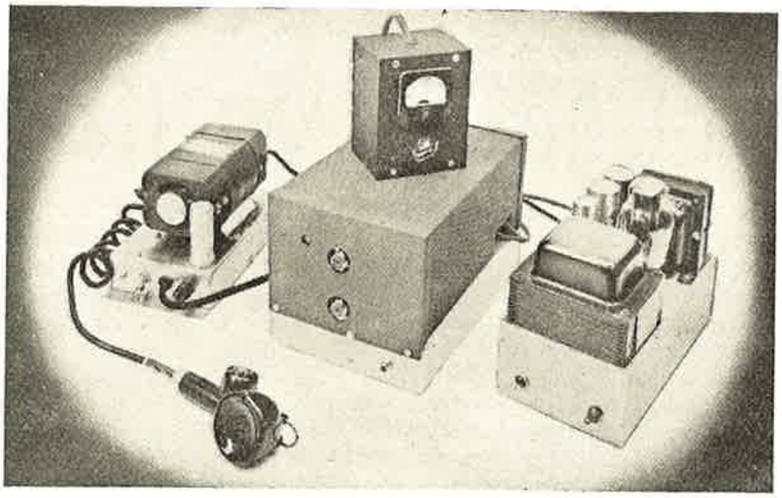

Fig. 1.

As shown in the schematic diagram a 6AK6* is employed as a crystal oscillator-tripler stage. Starting with an 8-Mc/s crystal, this stage provides a 24-Mc/s signal to the second 6AK6 which triples to 72 megacycles. A 5763 miniature beam-power amplifier is used as a doubler and a 2E26 operates as the final amplifier at 144 megacycles. For maximum power efficiency, a 1635 is used as a class B modulator. A 6N7-GT may be employed to obtain the same modulator output, but the 1635 has the advantage of requiring less heater power and a lower zero-signal plate current. The first audio amplifier utilizes one half of a 12AU7 as a grounded-grid stage to obtain a good match to the carbon microphone, and also to provide a convenient source of voltage for the microphone.

Meter circuit

Metering the grid circuits of the frequency multipliers and the final amplifier, and the plate circuits of both the final amplifier and the class B modulator is accomplished by means of an external test meter.

As shown in Fig. 2, the test-meter circuit consists of a 0.1 mA meter, a two-section six-position switch, and two resistors. Connection of the test meter to the transmitter is made by means of a cable and plug.

When the meter switch is set to any one of the first three positions shown in Table 1, the 3,900-ohm multiplier resistor and the milliammeter are connected in series between ground and a point on a voltage divider in the grid circuit. The meter deflection is proportional to the flow of grid current.

In positions 4 and 5 of the meter switch, the meter and the 910-ohm resistor, in series, are connected across a 10-ohm shunt (R_{23} for position 4, or R_{22} for position 5) to indicate the final-amplifier or modulator plate current, respectively. The test meter is connected between ground and a 1N34 rectifier in the antenna-coupling circuit in position 6 of the meter switch.

Construction

The transmitter is constructed on a 7 by 11 by 2-inch chassis; it is so arranged that the r-f section is on one side of the chassis (refer to Fig. 3) and the modulator and power plugs on the other side. Separating these two sections, on the underside of the

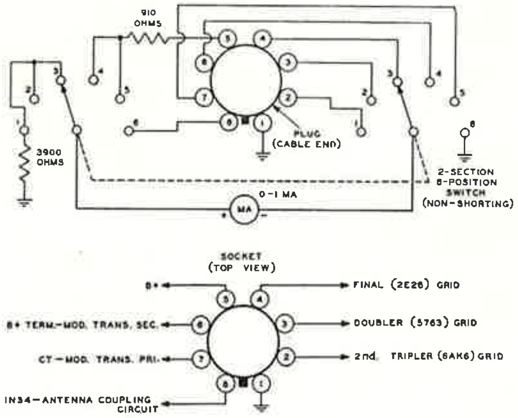

Fig. 2. Test meter circuit.

Table 1 — Test-Meter Calibration Data

Switch Position	Indication	Full-scale Deflection
1	2nd tripler (6AK6) grid current	5 ma
2	Doubler (5763) grid current	5 ma
3	Final (2E26) grid current	5 ma
4	Final (2E26) plate current	100 ma
5	Class B mod. plate current	100 ma
6	RF power output	15 watts

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*** Radiotron type 6AM5 is suggested as an alternative to type 6AK6.**

COMPACT 2-METRE TRANSMITTER

This versatile two-metre transmitter meets the requirements of extreme reliability, minimum stand-by power consumption, ease of adjustment, and portability. It may be operated either from a 240-volt a.c. line or from a 6-volt storage battery; this transmitter provides an output of approximately 10 watts.

Employs:

- **Popular 2E26**
- **Radiotron Miniatures**

By GEORGE D. HANCHETT, Jr.

chassis, is a strip of aluminium to which a resistor board is fastened. All of the resistors, with the exception of the 5763 grid resistor, R_{10}, are mounted on this board. Such mechanical support of the resistors provides the necessary ruggedness for mobile operation.

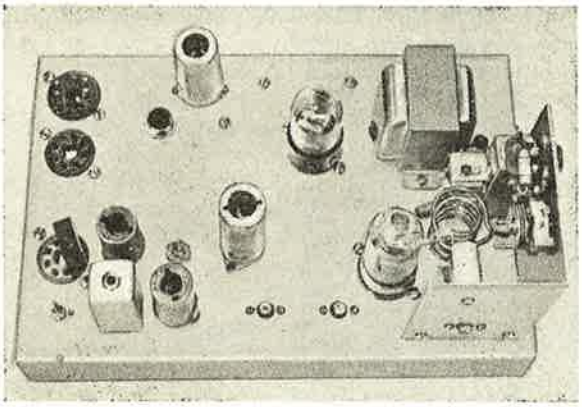


Fig. 3. Top view of the transmitter.

By-passing in the frequency multipliers and the final amplifier is accomplished with single- and dual-section ceramic capacitors. The metering leads are brought to an octal meter jack for connection to the external test meter.

The arrangement of the components in the output tank circuit is shown in fig. 4. The bracket for this tank circuit is made from a 4 by 5-inch piece of aluminium. The output link coil is connected to a coaxial relay so that in the non-energized position, the antenna will be connected to the associated receiver.

Adjustment

The tuning of the transmitter is a simple process. With only the two 6AK6's in place, connect the transmitter to the 300-volt supply. Connect the test meter to the unit and set the selector switch to the second tripler-grid position. Vary the inductance of L_1 to obtain oscillation, and then adjust the primary and secondary of T_1 for maximum meter deflection. The grid current of the second 6AK6 should be approximately 2 mA.

Insert the 5763 into the transmitter and adjust L_2 to resonance as indicated by maximum 5763 grid current when the test meter is set in position 2. At resonance the grid current of the 5763 should be approximately 1 mA. Adjustment of L_2 should be made as rapidly as possible, so that the 5763 plate circuit (which will probably not be in resonance) does not draw excessive current for a sustained period.

Switch the test meter to the 2E26 grid position (3) and plug in the 2E26. To protect the 2E26

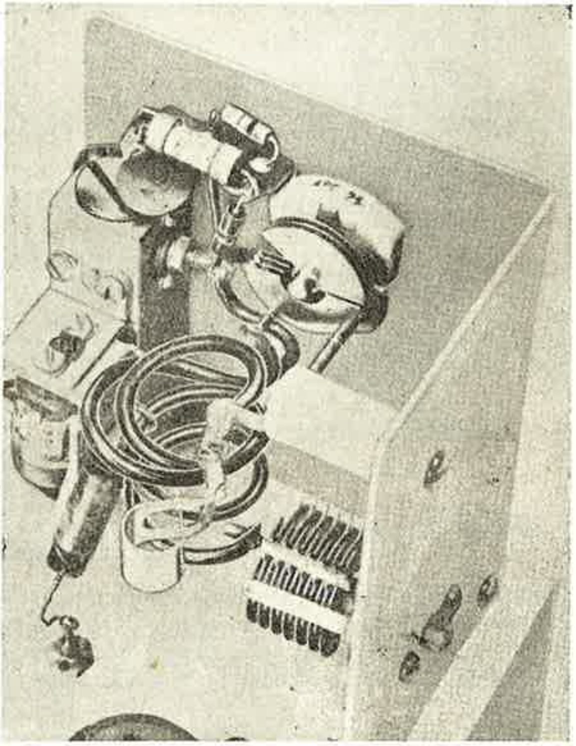
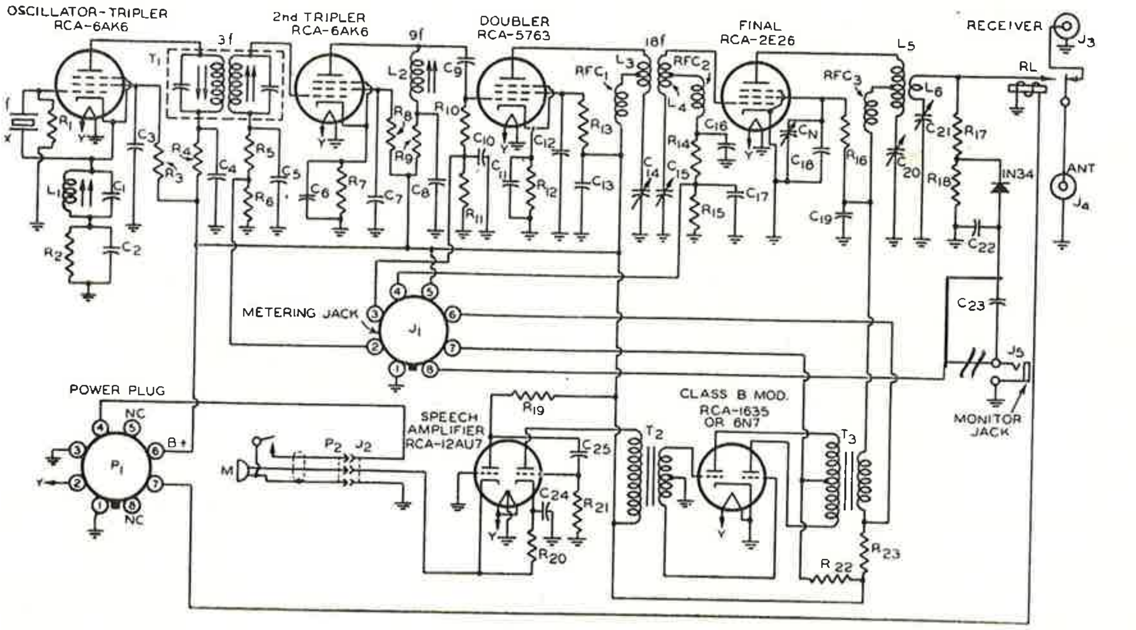


Fig. 4. Close-up view of the tank circuit.



Transmitter

C_1	100 μμf.
C_2	0.005 μf, disc ceramic.
C_3, C_4	Twin 0.004 μf, disc ceramic.
C_5	0.005 μf, disc ceramic.
C_6, C_7	Twin 0.004 μf, disc ceramic.
C_8	0.005 μf, disc ceramic.
C_9	10 μμf.
C_{10}	0.005 μf, disc ceramic.
C_{11}, C_{12}	Twin 0.004 μf, disc ceramic
C_{13}	0.005 μf, disc ceramic.
C_{14}	25 μμf, air padding.
C_{15}	25 μμf, air padding.
C_{16}	100 μμf.
C_{17}	0.005 μf, disc ceramic.
C_{18}	47 μμf.
C_{19}	470 μμf, feed-through type.
C_{20}	25 μμf, air padding.
C_{21}	25 μμf, air padding.
C_{22}	0.005 μf, disc ceramic.
C_{23}	0.01 μf, 400 wv.
C_{24}	25 μf, 25 wv, electrolytic.
C_{25}	0.005 μf, disc ceramic.
C_N	4-30 μμf, ceramic.

J_1	8-pin octal socket.
J_2	Amphenol connector PC2F.
J_3	Coaxial connector type N } part of coax relay R_L.
J_4	Coaxial connector type N } part of coax relay R_L.
J_5	Phone jack.

L_2	5 turns 14E on ½-in. diam, spaced to fill winding space of 11/16 in. on National XR50 form.
L_3	5 turns 14E on ½-in. diam; space between turns equal to wire diam.
L_4	3 turns 14E on ½-in. diam; space between turns equal to wire diam.
L_5	3 turns 10E on ¾-in. diam; spaced to occupy 1½ in.
L_6	Single turn 10E on 1-in. diam.

M	Carbon microphone with "push-to-talk" switch.

P_1	8-pin octal plug.
P_2	Amphenol connector MC2M.

R_1	100,000 ohms, ½ watt.
R_2	1,000 ohms, ½ watt.
R_3	47,000 ohms, ½ watt.
R_4	1,000 ohms, ½ watt.
R_5	33,000 ohms, ½ watt.
R_6	1,000 ohms, ½ watt.
R_7	1,000 ohms, ½ watt.
R_8	47,000 ohms, ½ watt.
R_9	1,000 ohms, ½ watt.
R_{10}	82,000 ohms, 1 watt.
R_{11}	1,000 ohms, ½ watt.
R_{12}	68 ohms, ½ watt.
R_{13}	22,000 ohms, 1 watt
R_{14}	33,000 ohms, 1 watt.
R_{15}	1,000 ohms, ½ watt.
R_{16}	20,000 ohms, 1 watt.
R_{17}	15,000 ohms, ½ watt.
R_{18}	10,000 ohms, ½ watt.
R_{19}	47,000 ohms, ½ watt.
R_{20}.	1,000 ohms, ½ watt.
R_{21}	470,000 ohms, ½ watt.
R_{22}, R_{23}	10 ohms, ½ watt.

RFC_1 } RFC_2 } RFC_3 }	40-in. length of 32E wound/ on ¼-in. diam. form.

R_L	Advance 8500, 6-volt type or equivalent.

T_2	Thordarson T20D76 or equivalent.
T_3	Thordarson T21M52 or equivalent.

Fig. 5. Schematic diagram of the transmitter.

Note: The connection from pin 8 on the metering jack should be changed from J_5 to the junction of C_{22} and C_{23}.

during the initial tune-up, disconnect the series screen resistor, R_{16}, from the plate supply. Then adjust C_{14} and C_{15} for maximum grid current in the 2E26; the 2E26 grid current should be approximately 1.5 to 2.0 mA.

At this point in the initial tuning procedure, the final amplifier should be neutralized as follows: rotate C_{20} through its entire range and observe the downward kick of the test meter (switch set in position 3, the 2E26 grid-current position). Then adjust neutralizing capacitor C_n until the downward deflection of the meter needle is minimised when C_{20} is rotated through its range. Reconnect the screen-grid resistor to the plate supply and set the

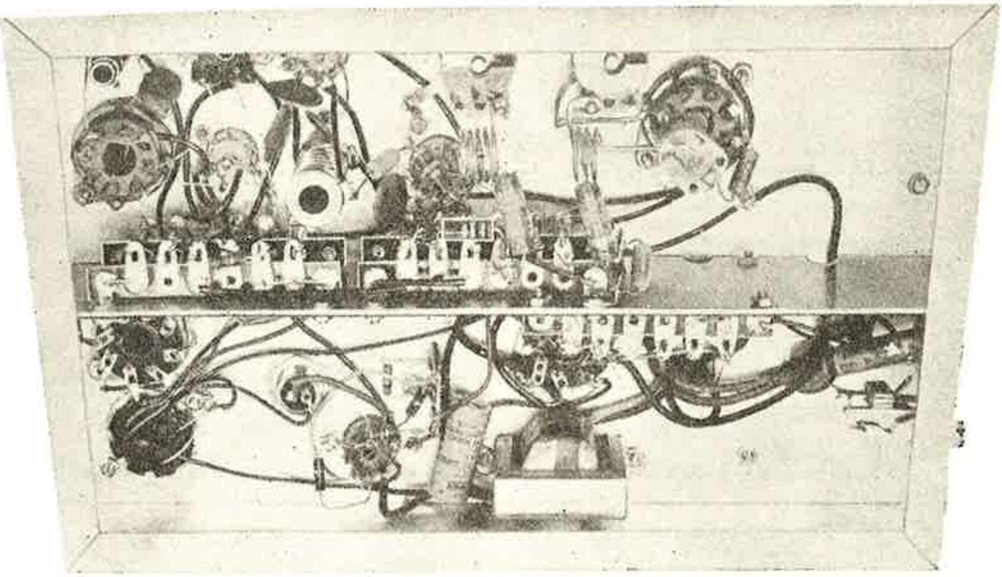


Fig. 6. Bottom view of the transmitter. The resistor board provides the necessary mechanical support for mobile operation.

meter selector switch to the 2E26 plate-current position (4). Capacitor C_{20} should then be adjusted for resonance.

After these adjustments have been made, connect the antenna to the transmitter and set the test meter switch to the output position (6). Capacitor C_{21} should be adjusted for maximum output. When a 52-ohm coax cable is used, a meter reading of approximately 0.4 mA indicates 10 watts of r-f power. Finally, readjust L_1, T_1, C_{14}, C_{15} and C_{20} for maximum power output.

The 1635 class B modulator tube and the 12AU7 speech-amplifier tube should then be plugged in and the microphone connected to the transmitter.

A.C. power supply

The power supply for a.c. operation is shown to the right of the transmitter unit in fig. 1; the schematic diagram for this supply is shown in Fig. 7. This supply is constructed on a 5 by 10 by 3-inch chassis. It employs a conventional full-wave rectifier and filter circuit, plus a selenium rectifier which supplies 6 volts d.c. for relay operation. The relay shown in Fig. 7 is a control relay which simultaneously grounds the centre tap of the high-voltage winding of the power transformer and applies energizing voltage to the antenna relay when the microphone switch is closed.

Genemotor power supply

For mobile and emergency operation, the power unit shown in the upper left-hand corner of Fig. 1 should be connected to the octal chassis connector P_1, located on the transmitter. This supply employs a Genemotor which operates from a 6-volt storage battery to provide a plate voltage of 300 volts. The output of the Genemotor is filtered with a single 4-μF capacitor. A control relay is also included in this supply as shown in the schematic diagram, Fig. 8. When the microphone switch is pressed, this relay connects the ungrounded input terminal of the Genemotor to the "hot" side of the storage battery, and simultaneously applies energizing voltage to the antenna relay. A 5 by 9½ by 2-inch chassis is required for the construction of this power supply.

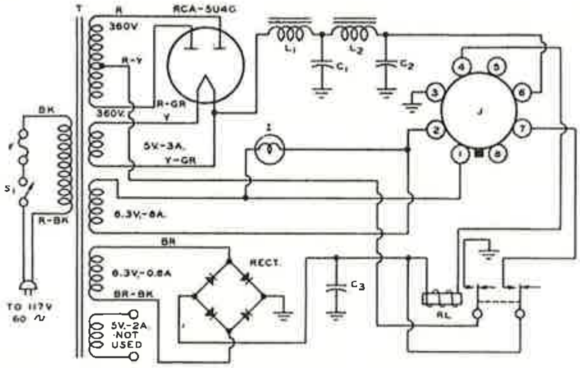
Installation notes (mobile operation)

For mobile operation, the transmitter and the Genemotor supply should be fastened securely to a shock-mounted support. A piece of ¾-inch plywood and four shock mounts will serve as a simple vibration-proof mounting.

Table II — Currents and Voltages for Normal Operation*

Meter Indication	Oscillator Tripler (6AK6)	Second Tripler (6AK6)	Doubler (5763)	Final (2E26)	AF Amp (½ 12AU7)	Driver (½ 12AU7)	Modulator (1635)
E_b (v)	275	265	300	300	300	300	300
I_b (ma)	12	15	35	60	4	7	6 (min.) 40 (max.)
I_{c2} (ma)	2.3	3.0	2.5	5.0	—	—	—
E_{c2} (v)	195	165	250	200	—	—	—
I_{c1} (ma)	0.7	2	0.9	1.6	—	—	—
E_k (v)	12	20	1.5	0	4	11	0

* *For rf output of 10 watts.*



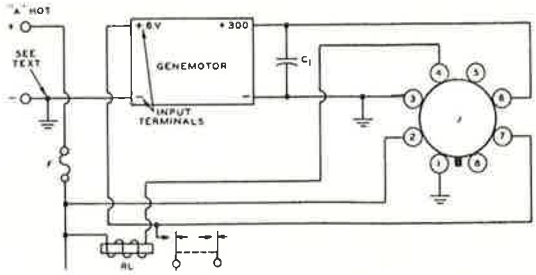
AC Power Supply

C_1	40 μf, 450 wv, electrolytic.
C_2	80 μf, 450 wv, electrolytic.
C_3	3,000 μf, 15 wv, electrolytic.
F	5-ampere fuse.
I	6-v, 150-ma pilot lamp.
J	8-contact octal socket.
L_1	Choke, 3 henrys at 225 ma, Peerless C-315-X or equivalent.
L_2	Choke, 5 henrys at 200 ma, Stancor C-1646 or equivalent.
R_L	Relay, 6v (dc), Advance 500 or equivalent.
RECT	Selenium rectifier, 600 ma, 25v, Federal 1017
S_1	SPST Toggle Switch.
T	Power transformer, RCA 201T8.

Fig. 7. Schematic diagram of the power supply for the fixed station installation.

Connection to the car battery should be made through a heavy conductor to minimize voltage drop.

Check the polarity of the auto battery and determine the polarity of the grounded terminal. As shown in Fig. 8, the negative input terminal of the Genemotor is grounded. If the positive terminal on the battery is grounded, reverse the input connections to the Genemotor.



Genemotor Power Supply

C_1	4 μf, 450 wv, electrolytic.
F	30-ampere fuse.
G	Carter Genemotor 325-A or equivalent: Input 6v, 21 amp; output 300v, 250 ma.
J	8-contact octal socket.
R_L	Relay, 6v(dc), Advance 500.

Fig. 8. Schematic diagram of Genemotor power supply for the mobile installation.

Heater voltage should be controlled by means of a 6-volt, SPST relay with ¼-inch contacts connected in series with the "A hot" input terminal of the Genemotor supply and the ungrounded battery terminal. Energizing voltage to the coil of this relay may be controlled by a SPST toggle switch located at the operating position.

Operation

With the a.c. power supply connected to P_1, heater voltage will be applied to the tubes in the transmitter when the power supply switch is turned on. Closing the microphone push-to-talk switch will simultaneously apply plate voltage to the transmitter tubes and cause the antenna-transfer relay to operate, regardless of the power supply employed.

PICKUP INPUT CIRCUITS *(continued from page 253)*

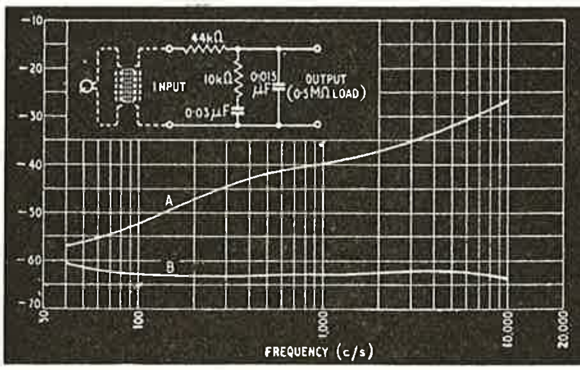


Fig. 13. Low-impedance Leak moving-coil pickup and transformer on 33⅓ r.p.m. test record; A, without correction; B, with equalizer circuit.

transformer secondary and the 44,000 Ω resistor. A value of 0.25 μF will give a reduction of about 6 db at 50 c/s. The "roll-off" at low frequency can be adjusted to suit conditions by varying the value of this condenser, lower values increasing the attenuation.

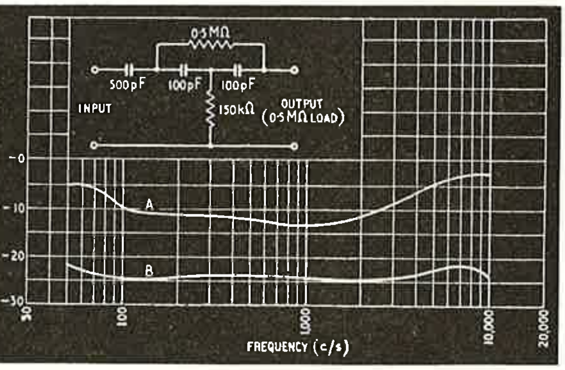


Fig. 14. Cosmocord GP20 crystal pickup on 33⅓ r.p.m. test record; A, without correction; B, with "bridged T" equalizer circuit.

The case of the crystal pickup is shown in Fig. 14, the unequalized response being shown at A and the equalized at B. It will be seen that a modified "bridged T" network is used, and, within reason, the equalizing is independent of the pickup impedance. In all cases the terminating resistance should be

(Concluded on page 264)

A Single-Ended Push Pull Audio Amplifier

By ARNOLD PETERSON and DONALD B. SINCLAIR

Many types of audio-amplifier systems are in use to-day. They range from the very simple and low-cost units in small radios and most television receivers to the complicated and expensive high-quality systems. The choice of the particular type of amplifier is generally dictated by a compromise between cost and performance, and new developments in circuits and components can shift the choice from one type to another.

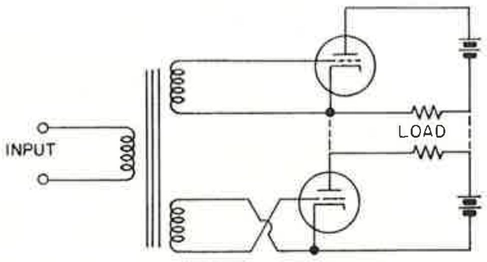


Fig. 1. Circuit to illustrate principle of operation of the push-pull output system. The grids are driven out of phase, and the a.c. load currents add while the d.c. load currents subtract.

The circuit development to be described here is one which will possibly upset the balance of cost and performance for all but the cheapest amplifiers, and from an optimistic point of view it could lead to important changes in the design of loudspeakers, power output tubes, output transformers, and radio and television receivers of moderate and high prices.

This development was prompted by a desire to devise a comparatively simple means of utilizing the higher efficiency of Class AB operation without having the serious switching transients that usually occur at high frequencies. That this objective was accomplished will be shown by the material to be presented here. In addition, the following points will be made: First, this circuit is also a desirable one for Class A operation of push-pull triodes or beam-power tubes. Second, it simplifies the application of feedback from the output stage to preceding single-ended stages. Third, it provides an important step in the solution to the problem of eliminating all coupling transformers in power amplifiers. Ultimately we may expect to drive a loudspeaker directly from the output tubes without any coupling transformer.

The basic plan of the output system is shown in Figure 1. Two triode-amplifier stages are shown. The lower one is a simple amplifier supplying a resistance load in the plate circuit. The upper one is similar except the load and the d.c. plate supply have been interchanged. It is important to notice that this amplifier is not a cathode follower, since the a.c. grid voltage is applied between the grid and cathode. If the two tubes are identical in characteristics and the supply voltages and loads are the same, the d.c. plate current in the two loads will be identical. Then if the connections shown by the dotted lines are made, the two currents will cancel because they are in opposite directions. When equal a.c. signals are applied to the two circuits, the a.c. components in the loads are equal. These two components would also cancel, when the connections are made, if the grid driving voltages were in phase. But with oppositely phased voltages on the grids the a.c. plate currents add in the load. We see here that the tubes are in series for the d.c. plate supply and in parallel for a.c. signals. However, this first circuit has the serious disadvantage of requiring a driving transformer with its associated expense and difficulties in maintaining proper balance at high frequencies.

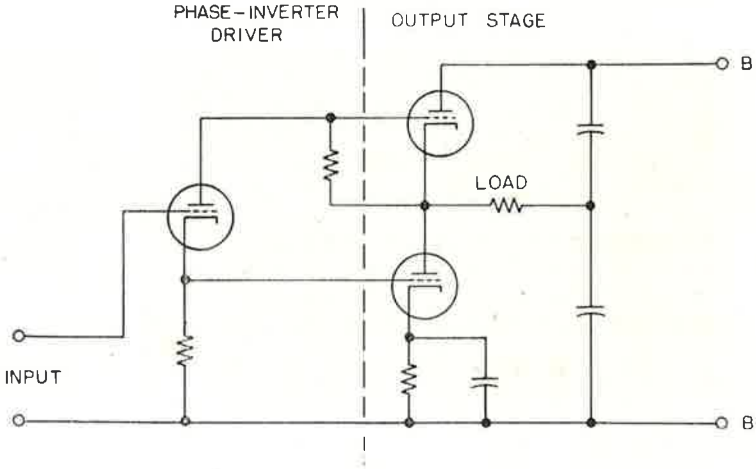


Fig. 2. Method of driving output stage by a phase inverter. Each of the output tubes is driven from grid to cathode.

In order to avoid a driving transformer it is necessary to devise a phase-inverter stage that will supply the voltages in the correct phase and at the proper electrodes. One such phase inverter is shown in Figure 2. This driver stage receives its plate-

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supply voltage from the midpoint of the two series-connected output stages. It has equal resistors in the plate and the cathode. Then a change in its plate current, produced by a signal on the grid, will result in equal voltages being developed across these resistors. The voltage in the cathode circuit is developed between the cathode and grid of the lower tube. An equal and oppositely phased voltage is developed between the cathode and grid of the upper tube. It is important to notice that this upper grid is not driven with respect to ground. If it were, the upper tube would act as a cathode follower, and the balance of the two tubes would be destroyed.

This driver is shown direct-coupled to the output stages. This direct-coupling is frequently desirable even though it is not essential except for a d.c. amplifier. The d.c. voltage drop across the resistor in the driver plate develops a negative bias for the upper output tube. The voltage drop in the lower resistor is in the wrong direction for supplying negative bias. In the circuit shown the proper bias is obtained by the voltage drop in the cathode resistor of the lower output tube which supplies a voltage equal to twice the bias required for a single tube. Other methods for supplying this bias are readily devised.

The amplifier circuit shown here uses no transformers at the output or between stages for Class A or Class AB_1 operation of push-pull triodes. By using some of the newer low-impedance tubes, the optimum output load resistance can be made quite low, because the tubes drive the load in parallel. As an extreme example, the use of the two halves of a single type 6AS7-G would lead to an optimum load impedance of about 280 ohms. While this value is still far from the usual 8- or 16-ohm impedance of a loudspeaker voice coil, something can be done to raise the voice-coil impedances so that the voice coil can be driven directly without a matching transformer. To a first approximation the voice-coil impedance can be increased without affecting the loudspeaker efficiency. As a practical matter the limit is determined by the smallest aluminium or copper wire that can be handled in a production setup. It is probable that the voice-coil impedance of large loudspeakers can be raised to the level required. Furthermore, it is entirely possible that a suitable ring-armature drive for small cone speakers can be developed. Then there should be no difficulty in winding this type for an impedance of almost any desired level.

In order to determine to what extent one should go to eliminate coupling transformers, it is useful to review some of their characteristics. Audio power transformers are generally expensive, heavy and bulky. They usually limit the low-frequency capabilities of an amplifier by increasing the distortion and reducing the output at low frequencies. They have only a moderate efficiency, with the small transformers having a maximum efficiency of only about 75%. In general, the elimination of coupling transformers appears to be an important step forward if it can be done. There would be some increases in cost of other items, but it seems probable that a net reduction in cost for a given performance can be obtained, but it will depend on future developments in loudspeakers and tubes.

Two characteristics of the circuit of Figure 2 limit its range of operation. One is the inherent negative feedback, and the other is the effect of capacitance from the plate of the driver stage to ground. Since the plate voltage of the driver tube is taken from the output, the output voltage is fed back to this stage. This feedback is negative, and it can be considered useful for reducing distortion. However, when it is desired to avoid the associated loss in gain, the feedback can be minimized by using a pentode driver.

The impedance level at the plate of the driver stage is in effect multiplied up by the gain of the output stage. That is, the frequency characteristic of the drive for the upper tube is determined by the *R-C* combination of the total capacitance from the plate to ground, and the plate resistor multiplied in value by one more than the gain of the output stage. For the audio-frequency range the resulting drop in output can be kept very small. But, if an attempt is made to use an amplifier of this type over the video range, this effect will be serious.

Many minor variations can be made in this basic circuit depending on the application. For example, the load is shown connected in a balanced fashion to the output stages to make it easier to see the principle of operation. Actually, it is usually more useful to have one end of the load grounded to B- and to feed the other end from the midpoint through a series-blocking capacitor. Another variation that is sometimes useful is *R-C* coupling from the driver to the output tubes instead of direct coupling. Still another variation is in the method of furnishing proper bias to the various tubes.

One objection that might be raised to this circuit is that the required plate voltage for the output stage is twice normal. The development of the high-voltage selenium rectifier with voltage-doubler circuits has made this point less objectionable at the present time. Another factor is the development of the low-impedance or high-perveance tubes for television use. Their use in this circuit permits the production of relatively high powers with moderate total plate voltage.

This amplifier shows triodes in the output stage and driver. It should help to fulfil the dream of some idealists who look for an all-triode transformerless audio system. However, many designers of audio amplifiers are interested in using beam-power tubes with their possibilities of high gain and high efficiency. How these can be used in the present circuit will now be discussed.

The main problem in using these beam tubes is in the method of supplying the proper voltage for the screen of the upper tube. The d.c. voltage of the screen is normally near that of the plate, and the screen should be at cathode potential for the signal voltage. If the screen of the upper tube is supplied through a dropping resistor from the plate supply, then the by-pass to the cathode puts the dropping resistor in parallel with the load and some signal power is lost. In some cases this loss in power can be made small. In other applications the voltage for the upper screen can be fed through the load, so that no signal power is lost. This feed might be through the primary of a matching transformer.

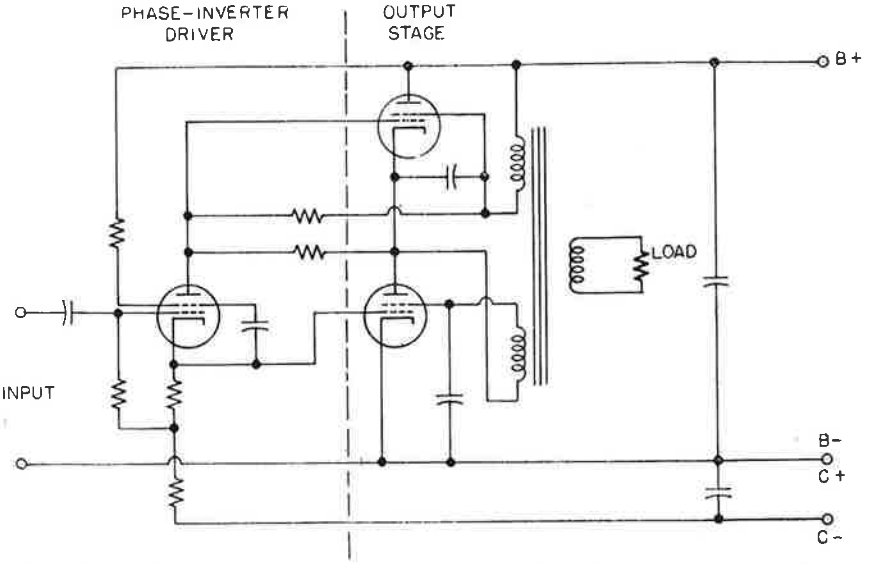

Fig. 3. Method of supplying proper screen voltagesfor beam power tubes. The d.c. screen currents flow through the two windings in the opposite sense so that there is no net d.c. flux from the screen currents.

Since loudspeakers with high-impedance voice coils are not available at present, we still need to use an output transformer for driving a speaker. How this transformer can be used for supplying the screen voltages is shown in Figure 3. The primary is in two sections. One section is connected from the plate supply to the upper screen, which is by-passed to its cathode at the midpoint where the plate and cathode of the two output tubes are connected together. The other section is connected from the screen of the lower tube, which is by-passed to ground, to the midpoint. The d.c. screen currents flow through the windings in the opposite sense, so that there is no net d.c. flux from the screen currents in the windings.

By following the transformer connections it can be seen that the two sections of the primary are connected in parallel, for signal voltages, by the by-pass capacitors. Because of this parallel connection, the two halves of a standard push-pull transformer can be used to obtain the required impedance level for this single-ended circuit. Furthermore, because these windings are connected in parallel by the capacitors, the circuit does not depend on close magnetic coupling between the two sections of the primary. This point is important, since in Class AB operation, the usual push-pull connection does have serious switching transients unless the coupling between the two halves of the primary is very good. In order to verify this point experimentally, the circuit shown was set up, using a Type 6AK6 pentode to drive a pair of Type 6L6 beam-power tubes. The operation was with fixed bias as shown, Class AB$_1$, and with no feedback. An output of 50 watts was obtained with a plate efficiency of 59%. The output waveform was independent of the magnetic coupling between the halves of the primary. To illustrate this the next figure shows a photograph of some pertinent waveforms. For this case, two separate chokes were used in place of the transformer so that the magnetic coupling was essentially zero. The operating frequency shown here is 20 Kc/s, and the power level is 50 watts. The upper trace is the output voltage, and the lower trace is the cathode current in the lower tube. It is clear that current is flowing in each tube for only slightly longer than one-half cycle, and there is no sign of a switching transient. Thus the general behaviour of the circuit is verified.

This output of 50 watts was obtained within the plate dissipation ratings of the Type 6L6 of 38 watts for two tubes. But the screen ratings were exceeded to obtain this output with Class AB$_1$ operation. However, this output can be obtained within the ICAS ratings of the Type 1614, the transmitting version of the Type 6L6. Using two Type 1614's with two cascaded stages of Type 6AK6's in this less than 0.1% harmonic distortion for all output circuit, and with negative feedback, we have obtained levels up to 50 watts. To obtain this low level of

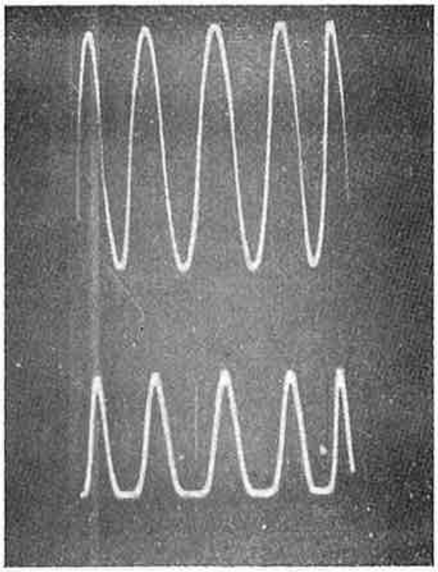

Fig. 4. Upper trace is the waveform of the output voltage for the circuit of Fig. 3, and the lower trace is the cathode current in the lower tube. Both traces were obtained at a 50-watt power level and at 20 Kc/s.

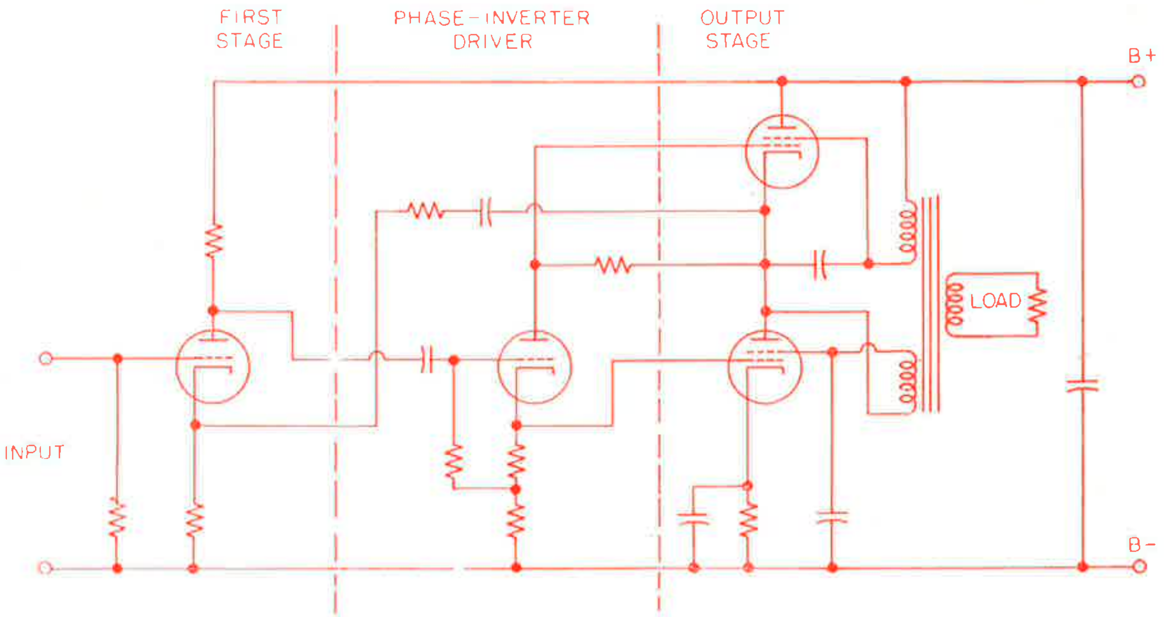

Fig. 5. Circuit to illustrate one method of applying feedback. The feedback is taken from the junction of the two output tubes to the cathode of the first stage.

distortion, feedback of 25 to 30 db is necessary, and the method of obtaining stable operation with this feedback will now be discussed.

One method for applying negative feedback to an amplifier of this type is shown in Figure 5. Since the output is single ended, the feedback can be made directly from the midpoint of the output stage to a preceding single-ended stage. In the three-stage amplifier shown, the feedback is applied to the cathode of the first stage. Because of the direct coupling of the phase-inverter driver there is little danger of low-frequency motorboating with feedback. Furthermore, since the feedback does not have to be taken from the secondary of the output transformer, there is less danger than usual of high-frequency oscillations. Or, expressed differently, greater amounts of negative feedback can be used, when applied as shown, with stable operation, than can be used with feedback from the secondary of the usual output transformer.

The usual feedback from the secondary tends to correct for the drop in response at the high-frequency end by the feedback system. This feedback forces the output system to operate at higher levels than normal at high frequencies to produce the uniform output desired. Unless the transformer is very good, with feedback from the secondary, the result may be high distortion at high frequencies. This distortion is usually exhibited as intermodulation of high-frequency signals, and *this effect* is *not* present with feedback from the primary as shown here.

The feedback shown in this circuit puts the secondary of the transformer outside the feedback loop. High frequency corrective networks can be used, if necessary, at the secondary without being concerned about phase shift.

In conclusion, the circuits shown have the advan- obtaining push-pull operation. If these circuits are accepted in the audio-amplifier field, we can expect to see the decline in importance of the output transformer. We can expect to see the development of high-impedance voice coils for speakers, which, with high-perveance tubes in the output stages, will permit the elimination of the output transformer and the building of better audio systems at lower cost.

PICKUP INPUT CIRCUITS

0.5 MΩ. If the input impedance of the amplifier is other than this value a simple potential-divider matching arrangement should be used.

It may be found, especially with cheaper type turntables or units that have been modified from 78 r.p.m., that motor rumble is excessive. Should this be the case, the high-pass filter unit described earlier may be used successfully, but should be connected between the equalizing unit and its load resistance.

In conclusion, the authors are indebted to Messrs. Decca Radio and Television, Cosmocord and H. J. Leak & Company for information regarding characteristics of records and pickups.

RESTRICTING FREQUENCY RANGE

changes have been made. Now let us apply a pure tone at 1,000 cycles, the midband frequency, and measure the output of the speech amplifier. Next, apply a pure tone of 300 cycles. The output will be down 6 db, or four to one in power. The same thing is true for a 3,500 cycle tone. A pure tone at 150 cycles (and at 7,000 cycles) will be down 14 db, or twenty-five to one in power.

Thus, while the curve obtained is not of the sharp cutoff variety, it will give essentially the same results, and will certainly sound the same to the ear. Further, it was obtained at practically no cost.