Some Tested Circuits for 807's as Audio Amplifiers

The 807 seems to be regarded by many as suitable only for power outputs of 50 watts and more when used as a push-pull audio amplifier. In order to demonstrate that this view is not correct, we have performed some experiments, and as a result have developed a number of circuits in which the tube demonstrates its worth for powers ranging from 10 to 20 watts and for the highest quality. These powers are realized with very modest H.T. power requirements, and should be of much interest to gramophone enthusiasts, public address workers, and amateur transmitters alike.

Since the publication not so long ago in the "Wireless World" of Mr. Williamson's high-fidelity amplifier, which used KT66 beam-tubes as triodes with a large degree of negative feedback, there has been a very great amount of interest in this class of amplifier. This interest has not been based simply on theoretical grounds, but mostly on really outstanding practical performance. It has been found, for instance, that, contrary to the accepted idea, an amplifier whose distortion is in the region of 0.1 per cent. rather than 2 to 3 per cent., which has hitherto been regarded as the lowest that is detectable by ear, really does sound different. It appears, therefore, that the ear finds difficulty in distinguishing between, say, 2 per cent. and 5 per cent. distortion, but can quite readily tell the difference between 2 per cent. and 0.1 per cent. What does not seem to have been fully realized is the fundamental principle by means of which Mr. Williamson has achieved his desirable result, and thereby demonstrated a new fact in relation to high-fidelity reproduction.

BASIC PRINCIPLE OF THE "WIRELESS WORLD" AMPLIFIER

Since anyone who is interested in quality reproduction is inherently given to examining circuits of different types, and to evaluating their worth by comparison with other circuits which purport to have good features, it is not altogether surprising if some such enthusiasts have missed the point that is basically responsible for the superior performance of Mr. Williamson's amplifier. It cannot be found by a simple examination of the circuit, which, apart from an obvious concern about balancing the push-pull part with great care, is not particularly unusual to look at. The key is to be found in the fact that the negative feedback used amounts to as much as 20 to 30 db. Now, this is a relatively enormous amount of feedback, especially when it is realized that it is connected from the secondary of the output transformer back to the cathode of the first stage of the amplifier. The fedback loop therefore includes virtually the whole of the amplifier, and its distortion, whether generated in the voltage amplifying stages, the power output stage, or the output transformer, is beneficially affected in proportion to the amount of feedback that is used. Now there is nothing new in this, as a principle. Similar types of amplifiers have been suggested almost as long as there has been negative feedback. The question is: why has it taken so long for an amplifier to be designed which can use as much feedback as this one does, without introducing difficulties for the constructor?

The answer is to be found in the fact that, although the benefits of negative feedback are well known, and although it is common knowledge that the greater the degree of feedback the greater the benefits conferred by it, a grave practical difficulty occurs when large amounts of feedback are attempted, and especially over a number of stages. It is this—that, unless suitable precautions are taken (and these are not always easy to apply), the feedback does not remain **negative** at all frequencies. It can become zero and can even change itself round and become positive feedback. When this happens, it is largely a matter of luck whether or not the amplifier breaks into oscillation—a far from desirable result!

To enlarge upon this a little further, it can readily been seen why this situation can arise. For the feedback to be absolutely negative, it must be 180 degrees out of phase with the signal voltage at the point where the feedback is applied. This is easily obtained in the middle frequency range, because here the only phase shift caused by the amplifier circuit is the 180-degree phase change per stage which occurs because of the way in which the valve works. However, at low and high frequencies, the phase shift per stages becomes greater or less than 180 degrees. In a single stage, this does not matter so very much, because the phase shift cannot exceed 90 degrees, with the result that the feedback can never become positive, though it can reduce itself to zero. This means that, at the frequency at which this occurs, there is no feedback, and so there is no reduction of amplifier gain. The response curve of the amplifier therefore rises sharply at high and low frequencies, and exhibits a peak at some frequency in both the high and low range at which the feedback has been reduced to zero by the phase shift. At the peaks, the gain of the amplifier may not be as high as the mid-frequency gain without feedback, because the peaks may, and in all probability will, occur at frequencies where the gain without feedback has decreased in the normal course of events.

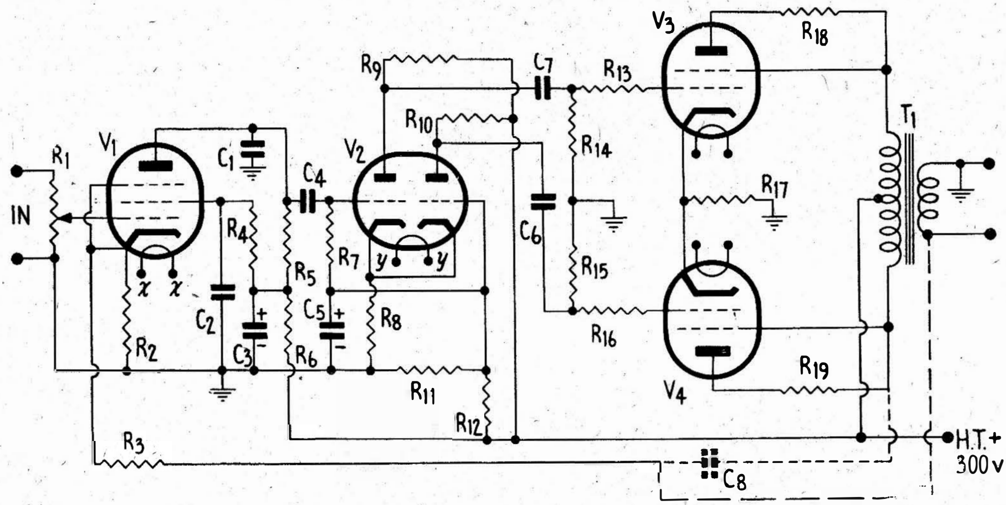
The situation above has been used to illustrate what happens when feedback is applied round one stage only. If it is applied round two stages, however, it is possible for the feedback voltage to lag or lead by a maximum of 180 degrees. This makes it possible for the feedback not only to reduce to zero, but even to become positive in sign. This is another way of saying that the amplifier is now **regenerative**, and so can oscillate, if the gain is great enough at the frequencies where regeneration occurs. Similarly, the situation is even more difficult when the feedback is applied over three or four stages. The more stages are included in the feedback loop, the smaller the phase shift PER STAGE that is needed to turn the feedback from negative to positive. Also, the greater is the likelihood of there being enough gain for oscillation at the frequency where positive feedback occurs.

The above considerations lead to two simple conclusions regarding feedback amplifiers:

(1) The more stages are included in the feedback loop, the less the phase shift per stage that can be tolerated.

(2) For a given number of stages within the feedback loop, the less the phase shift, the more feedback can be used without danger of instability.

The two points stated above are really different ways of stating the same fact, and the second one gives the key to the success of the "Wireless World" amplifier designed by Mr. Williamson. Thus, what he has done is to design a circuit (including output transformer) which has very much less phase shift than the usual three-stage amplifier. As a result, he has found it possible to apply 20 to 30 db. of feedback and thereby to reduce the circuit distortion by a similar degree. Suppose, for example, that the circuit distortion without any feedback is 2.5 per cent. at full output, this means that the distortion with feedback applied will be reduced to 0.1 to 0.25 per cent. at full output, and to correspondingly smaller figures at lower outputs.



COMPONENT LIST

R_1, 1 meg. pot.
R_2, 1600ω.
R_3, 250k. (min.) (see text).
R_4, R_7, 250k.
R_5, R_9, R_{13}, R_{16}, 100k.
R_6, R_{11}, 25k.
R_8, 20k.
R_{10}, 120k.
R_{12}, 50k.
R_{14}, R_{15}, 500k.
R_{17}, 275ω 2 watts.
R_{18}, R_{19}, 50ω.
C_1, 100 μμf.
C_2, 0.5 μf.
C_3, C_5, 8 μf. 450v. electro.
C_4, 0.05 μf.
C_6, C_7, 0.1 μf.
C_8, 4 μf. 500v. oil-filled.
V_1, 6J7 or EF37.
V_2, 6SN7.
V_3, V_4, 807.
T_1, 9000ω to voice-coil.

APPLICATION OF THIS PRINCIPLE TO 807 AMPLIFIER CIRCUITS

We have gone to some lengths in illustrating the basic principle underlying the design of the "Wireless World" amplifier, both from the point of view of its general interest and also in order to show that there is nothing mysterious about the "super-excellence," if such it may be termed, of this amplifier. The principle that has been stated shows, among other things, that it is by no means essential to use KT66's. There is no fundamental reason why any other valve which has suitable triode characteristics should not be employed. Nor need an amplifier of the kind we are discussing necessarily use triodes in the output stage. Others, notably Hilliard, in America, have shown that pentodes or beam tubes, with suitable circuits, can and do produce an answer that is at least as good as that given by triodes.

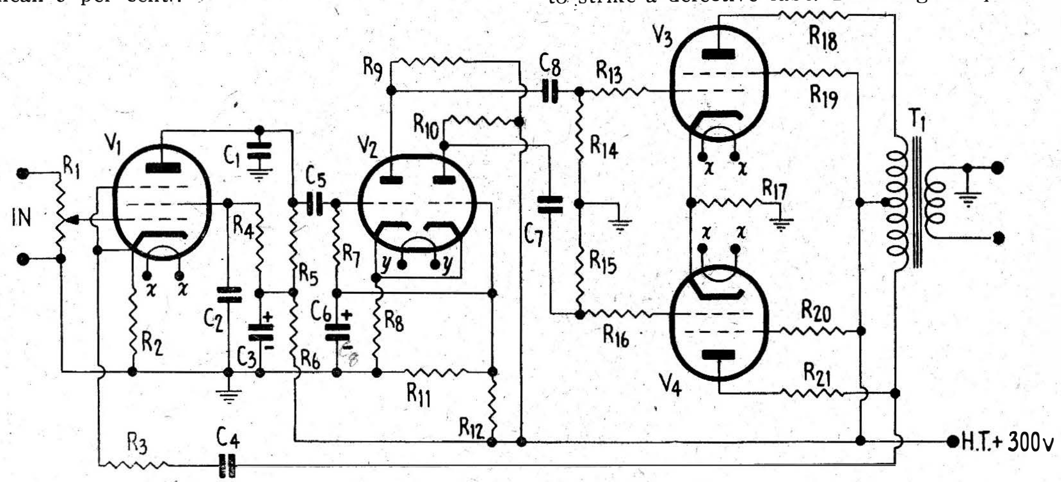
We have therefore developed a basic circuit for using 807's in the output stage, with almost as much feedback as is used in the Williamson amplifier, and either as triodes or as tetrodes. These circuits are presented below.

POWER OUTPUT CONSIDERATIONS

The first circuit to be described is one in which the 807's are connected as triodes and with an H.T. supply of 300 volts at 100 ma. This arrangement gives a measured power output of 10.7 watts, and enables 16.25 db. of feedback to be used, either from the secondary of the output transformer or from one plate of the output stage, back to the cathode of the first stage. This figure is not quite as high as that quoted for the "Wireless World" amplifier, but, even so, it is much greater than the amounts of feedback usually seen in amplifiers of this nature, and is great enough to reduce amplifier distortion to under 0.5 per cent. at all levels smaller than the maximum power output quoted. Readers should not assume, because of the 10.7 watt rating of the circuit, that triode-connected 807's are incapable of giving more output than this. They are; but in designing this amplifier circuit we have done more than simply consider the greatest possible power output. In fact, a large number of our readers, we are convinced, will not want an amplifier with a higher output than this. It is, to our way of thinking, about the ideal size of amplifier for home use, in that more than 10 watts can rarely be made use of fully, owing to the small size of the room in which it has to work. At the same time, 10 watts is ample power, even for a large room. This being the case, the limitation of the power of the triode amplifier to 10 watts enables the H. T. power supply to be cut down, both in voltage and current. Three hundred volts at 100 ma. is not large enough to be too expensive for the average constructor, and represents a real economy over what would be needed to give the amplifier a power output of 20 or even 15 watts. Also, the supply is not a difficult one to build, because the current drain at full output is only a few milliamps more than at no signal. The regulation of the supply is therefore quite unimportant, and costly low-resistance chokes are not needed.

To take care of those who have a real need for a high-fidelity amplifier with up to 22¼ watts, we have re-arranged the circuit as shown in Fig. 2. This time the 807's are used as tetrodes, the maximum feedback is 17.5 db., and the power input is 22.25 watts, maximum undistorted. And by "undistorted" we do not mean 5 per cent.!

in respect to the low-frequency feedback limit. However, we will discuss this point further when we come to talk about the adjustment in practice of the feedback network. The first stage in the amplifier is a pentode voltage amplifier, and uses either a 6J7 or an EF37. The latter tube is specially constructed to be free from microphonic effects, and its use in this position should not be strictly necessary, since the feedback reduces the overall gain of the circuit to the point where the input voltage for full output is 0.75v. for the circuit of Fig. 2, and not very different from this in the circuit of Fig. 1. Used at this input level, there should not be trouble from microphonics unless one is unlucky enough to strike a defective tube. This stage is quite conven-



COMPONENT LIST

R_1, 1 meg. pot.
R_2, 1600ω.
R_3, 250k. min. (see text).
R_4, R_7, 250k.
R_5, R_9, R_{13}, R_{16}, 100k.
R_6, R_{11}, 25k.
R_{10}, 120k. (see text).
R_{12}, 50k.
R_{14}, R_{15}, 500k.
R_{17}, 120ω 2 watts.
R_{18}, R_{19}, R_{20}, R_{21}, 50ω.
V_1, 6J7 or EF37.
R_8, 20k.
V_2, 6SN7.
V_3, V_4, 807.
T_1, 4750ω to voice-coil.
C_1, 100 μμf.
C_2, 0.5 μf.
C_3, C_5, 8 μf. 450v. electro.
C_4, 0.05 μf.
C_6, C_7, 0.1 μf.
C_8, 4 μf. 500v. oil-filled.

The H. T. requirements for the second amplifier are only 300 volts at 150 ma., which is a 50 per cent. increase in D.C. input power for an increase in output power of more than 100 per cent. This is the main advantage of the tetrode connection, since beam tetrodes are more efficient than triodes as power converters. The 22.25 watts given by this amplifier are enough to 100 per cent. modulate a 100-watt carrier, using cathode modulation!

VOLTAGE AMPLIFIER CIRCUITS

A glance at Figs. 1 and 2 will show that the voltage amplifying sections of both amplifiers are substantially identical. Comparing the results, as so far presented, with those of the "Wireless World" amplifier, we find that the ones described in this article are not capable of taking quite so much feedback as the former. However, we do not take a serious view of this, because these circuits use almost as much, and it is unlikely that the results will be noticeably different. In our circuit, we have not gone to the trouble to make the intitial stage direct-coupled to the second stage, which in our case is also the phase inverter. The difference in performance, slight though it is, can be put down mostly to the omission of this direct coupling, particularly

tional except for the omission of the cathode bypass condenser. This has to be done in order that the feedback voltage can be developed across the cathode resistor. It also helps to reduce distortion in this stage, since it provides a certain amount of degeneration in the tube circuit itself, irrespective of the main feedback connection. The second stage uses a 6SN7 as a cathode-coupled phase-inverter, which has useful gain as well. This circuit has been used a number of times before in these pages, and a fairly full discussion of its operation was given in the issue of June, 1948. By making the common cathode resistor high enough, it is possible, without further precautions, to achieve a well enough balanced output for most purposes. However, in an amplifier which attempts to reach high-fidelity standards, it is desirable to have exact balance between the sides of a push-pull system. The cathode-coupled circuit is capable, with care, of being exactly balanced, and so is admirably suited to our purpose. It is for giving exact balance that the halves of V_2 have been shown with unequal plate loads. The first half (i.e., the section that is fed directly by V_1) has a load resistor of 100k. ohms, while the other half, which does not get quite the same input voltage, has a plate load of

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120k. ohms. It is realized that the resistors used will have tolerances of between 10 and 20 per cent., and that on this account specifying these values will not necessarily mean that perfect balance will be got if any two resistors are chosen at random, but, if desired, the extra piece of load resistance can be obtained by using identical 100k. resistors for both halves of the valve and by connecting a variable resistor of, say, 50k. ohms in series with the load resistor of the second half of V_2. Exact balance can then be obtained by adjusing this variable resistor until a 'scope shows that the outputs from the two halves are equal.

THE OUTPUT STAGES

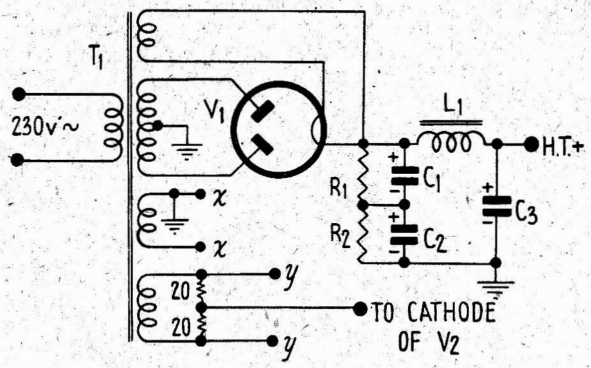
The output stages in the two amplifiers are, of course, different. In Fig. 1, the triode amplifier, it will be noted than the screen grids are connected to the plates of the valves, and NOT to the control grids. This makes it necessary to take quite a long lead through the chassis from the socket to the top-cap plate connection; it can also be seen that the two elements are not directly inter-connected, but that a small resistor is placed between each screen and plate. This is by way of a screen stopper, preventing parasitic oscillations. Also included are grid stoppers, for the same reason. On no account should either be omitted. If the feedback links are disregarded, the output stage can be said to be very ordinary in its circuit. Cathode bias is used, and the bias resistor is left unbypassed. There is no necessity for such bypassing, as the audio currents from the individual valves are out of phase, and to the extent that the output stage is properly balanced, there is no audio frequency voltage to be found across the cathode resistor.

On Fig. 1, there have been shown alternative connections for the negative feedback. One way of making the connection is to earth one side of the output transformer secondary and take a lead from the other side, through the feedback resistor, R, to the cathode of V_1. The degree of feedback is governed by the relative sizes of the feedback resistor and the V_1 cathode resistor. Since the latter is fixed, this leaves the former as the sole variable. The other method of connection is to use a large coupling condenser (in this case 4 mfd.) from the plate of the appropriate valve to the feedback resistor. These alternatives have been suggested in order to give the constructor some choice in selecting an output transformer. If the latter is included in the feedback chain, the phase-shift in it is added to that of the rest of the amplifier; thus, when a high-fidelity output transformer is used, it is possible to connect the feedback from its secondary. If a cheaper one is used, it may not be possible to employ enough feedback from the secondary, on account of either motor-boating or high-frequency oscillation. In this case more satisfactory results will be obtained by using the alternative connection.

On Fig. 2, no alternative method has been indicated, as with the tetrode circuit, the best arrangement was found to be the one shown. This is not at all serious, as the distortion arising in a really high-quality transformer is very slight, so that if feedback is not put round it, it does not matter very much.

VALUES OF COUPLING CONDENSERS AND GRID RESISTORS

In the ordinary run of audio amplifiers, when no feedback is used, the exact values of the grid resistors in resistance-coupled stages, and of the coupling condensers, are not usually regarded as very important. The main thing is to have the grid resistors small enough for good high-frequency response, and the coupling condensers large enough, in relation to them, for good low-frequency response. (Of course,



Power supply suitable for either of the amplifiers mentioned in the text.

T_1, 350-0-350v. 150 ma. 6.3v., 6.3v., 5v.
L_1, 30H., less than 300ω resistance. V_1, 83v. or 83.
R_1, R_2, 1 meg. C_1, C_2, C_3, 16 μf. 450v.

Note: For triode amplifier T_1 need be rated only at 100 ma.

there are other things that enter into the choice of values, but these are the most important items.) However, when feedback is placed round a number of stages in an amplifier, as here, the frequency response of each stage, and therefore the value of these components, has to be carefully matched. Thus, if the low-frequency response is carried too far down, the result may be motor-boating. Similarly, high-frequency oscillation may occur if the high-frequency response is not good enough, and equally, under some circumstances, if it is too good.

A WARNING

For these reasons, it is necessary to warn intending builders that **the values recommended for the two circuits given in this article should be adhered to quite strictly.** For example, if any attempt is made to increase the size of the coupling condensers, trouble will almost ertainly be experienced from motor-boating. This is due to the increase in response of the amplifier at frequencies so far below the audio range as to be quite useless—namely, below ten cycles per second. Thus there need be no fear that the response of the amplifiers is not already good enough at the extremes of the audio range. In the case of the low end, the measured response is flat down to 20 c/sec., and exhibits a very slightly rising characteristic down to 15 c/sec.

FIXING THE VALUES IN THE FEEDBACK CIRCUIT

The values we have given for the feedback resistor are minimum values. That is to say, the smaller this resistor, the greater the feedback, with the result that the resistor in question cannot be reduced beyond a certain point. It is possible that with different mechanical arrangements from the one used by us in our experimental work on the amplifiers, the amount of feedback that can be successfully used will differ from our figure. This is not very likely, in our opinion, but it is as well to be prepared for all possibilities. The best way to fix the value of the feedback resistor is to put a resistive load on the secondary of the output transformer and to examine the output waveform on an oscilloscope. The feedback is then increased by decreasing the value of the feedback resistor until either motor-boating or H.F. oscillation is encountered. Usually, one of these will occur first; which one, it is not very important, as the onset of either represents the limit to which feedback can be taken. If motor-boating does not occur, it is necessary to see that no high-frequency oscillation takes place until **after** full audio output has been obtained. This is easily seen when the output waveform is examined, as the onset of distortion in the audio waveform is recognized separately from the high-frequency oscillation, which appears as "fuzz" on the trace, usually at one spot on the output wave. If this occurs AFTER full audio output has been obtained, it does not matter, since the amplifier will presumably not be run at a higher level than this. The value of the feedback resistor is adjusted until the oscillation does not take place before the amplifier is overloaded by the signal proper. Motor-boating shows up on the 'scope as a slow periodic shift in the position of the pattern. The shift is, of course, in the Y direction, since the motor-boating is nothing more than a very low-frequency oscillation. The values of coupling condensers and grid resistors in the two circuits given here have been chosen to allow as much feedback as possible to be applied, so that there is little point in attempting to better them.

CONCLUSION

In this article we have placed rather more emphasis than usual on the theoretical aspects of the circuits, and have given no specific instructions as to the physical lay-out to be used. This does not mean that the circuits have been made to work very well indeed, or that they are in the nature of experimental circuits which may need some trouble on the part of the constructor before they can be regarded as satisfactory. These two basic amplifiers have been fully tested in our laboratory, with very fine results, and we have no hesitation in recommending them to anyone who is looking for a circuit which will make use of 807's in the best pos-

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R. & E. ABSTRACT SERVICE

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(Philips Tech. Review, 6, pp. 39-45, 1941). Additional application: preserving rectifiers for automatic telephone exchanges. —Philips Technical Review (Holland), Vol. 9, No. 8, p. 231.
Direction-finder for locating storms. Description of apparatus used on frequency of 10 kc. to indicate direction taken by a storm. Employs two loop antennae, at right-angles to each other. These loops, through amplifiers, are connected to vertical and horizontal plates respectively of C.R.T. Flashes on screen indicate direction from which static received. Circuit diagram given.—Electronics (U.S.A.), May, 1948, p. 106.

QUALITY BROADCAST RECEIVER

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"narrow," since this reduces the high-frequency components of the noise, which are the most disturbing ones. In this respect, the selectivity switch is used just as a tone control would be. To sum up, the best quality of reception will be in the "broad" position, unless there is interference present, and, except for tuning, the set need be at "narrow" only when noise, from one source or another, is troublesome.

We may say in conclusion that the quality of reception given by the set will be a revelation to all who construct it; our own staff, who are notoriously sceptical in such matters, seem to have decided, with no dissentients, that it makes their own receivers sound a little shabby!

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sible manner for outputs from 10 to 20 watts. There is nothing in the circuits which makes either of them difficult to handle, and the usual lay-out for a push-pull amplifier can be followed with every expectation of success. An arrangement of valves and power supply components such as we have recommended for the majority of amplifiers that have been fully described in this journal will do admirably for these circuits, too.