Puzzled About Amplifiers?

NORMAN H. CROWHURST

Is a triode amplifier better than a pentode amplifier, or vice versa? The author shows you that either type of tube can be incorporated into an excellent amplifier if the design is correct—and then he tells you about some of the design problems.

If you follow the reports of certain consumer testing organizations, you may be puzzled why it is a certain manufacturer's product can be rated as "best buy" one year, while the following year the same product is rejected as "unacceptable, not worthy of further test." The answer to that question does not appear to be a technical one so we won't attempt it here. However, there are differences in amplifier performance which make a very similar question—that *is* technical—quite pertinent. What really is the best type of amplifier circuit?

This question repeatedly occurs in various guises, so it is not untimely to review it. One still hears from people who have triode amplifiers and who tell us that their neighbors and friends testify the "good old amplifier" still gives performance comparable with the best modern one.

Others who hear reports like this want to know just what the score is. If the "good old triode" was the best kind of output stage for an amplifier, why is it that manufacturers universally adopted pentodes or tetrodes in various types of output circuits?

When we examine the difference between the two types of tube we find that the pentode is more efficient and consequently, for a specific amount of dissipation, or dollars' worth of tubes, it is possible to deliver a larger output power. Also, having a higher gain than the older triode tubes, it is easier to apply a greater amount of feedback and thereby reduce distortion to a lower figure. Consequently a modern amplifier, using the same dollars' worth of components, can quote a higher power output with lower distortion than the "good old triode" amplifier.

One would imagine that such statistics, which are measurable objectively, should be more reliable than the opinion of a number of people who listen to modern amplifiers against the older triode counterpart and who still aver that the triode sounds as though it does a better job. However, a serious investigation of the technical performance of amplifiers, beyond just the simple specifications usually quoted, turns up a number of reasons for this difference.

In the first place, the transfer characteristic of pentodes contains *much higher order* harmonics than the triode type characteristic which, single-ended, produces predominantly second harmonic and, in push-pull, produces a relatively small amount of third and not much above this. A pentode-type output, in contrast, produces third and fifth harmonics and sometimes even seventh in quite sizable proportion. True the feedback reduces these dramatically, but the amount of feedback necessary to do a real cleaning up job on the harmonic and intermodulation distortion can also produce other troubles. These occur under a variety of circumstances.

Blocking

One of them is what happens at overload. Measurements merely tell how pure an amplifier is up to a certain point. They do not say what happens when a sharp peak momentarily drives the amplifier beyond this point, as can often happen with program material. The average "good old triode" amplifier merely lopped off the high peak and carried on working. More recent work with transistor circuits, which achieve the same results by somewhat different methods, has shown that such peak clipping can become quite drastic before it is appreciably audible.

But many amplifiers employing a large amount of feedback, particularly those using pentode output tubes, do more than clip off the peak. When such a high peak comes through, it throws the amplifier out of balance in such a way as to block the signal that immediately follows it. This produces a noticeable interruption or breaking up in the program. As the amplifier comes back into action, after the blocking, it distorts because the tube that was blocked does not suddenly come back to its correct operating condition. Thus the effect of the sudden peak is to block the amplifier and allow it to come back with a sort of strangled effect. This is generally given the name "break up."

Let's take an example. A 25-watt amplifier is capable of handling a peak power of 50 watts. The average power in a program signal may not be more than 2 to 5 watts. But such average program material may well include a peak here or there that runs up to what should be 60 watts, 10 watts beyond the maximum handling capacity of the amplifier. This is what causes the trouble. Each such peak momentarily overloads and blocks the amplifier so that, for a fraction of a second thereafter, it will not even handle one watt and then it comes back into action distorting the 2- to 5-watt level that follows the momentary peak.

Obviously such an amplifier will not appear to give as much good, clean output as one that handles say 15 watts and then clips for a moment. Even though the corresponding peak may still run up to what would be 60 watts, this just gets lost and the following 2- to 5-watt level is amplified without further distortion. Using the latter amplifier, the level could probably be turned up so it runs at from 6 to 15 watts instead of 2 to 5 watts, an increase in level of about 5 db, which is quite noticeably louder, and yet will still sound clean as compared with the 25-watt amplifier working at an average output of 2 to 5 watts. This comparison is illustrated at *Fig.* 1.

Are we to conclude then that, in spite of the better figures a pentode will give, it does not really produce better results than the triode? Not at all. A pentode properly used can produce quite good results and still retain the advantages, apparent in the figures, of better efficiency and improved gain which also enable the distortion to be satisfactory reduced.

The twin-coupled amplifier[1] described in these pages in November, 1957, is an example of this. A great many readers have written in saying that they have compared this amplifier with others, using much larger nominal outputs, and

* 216-18 40th Ave., Bayside 61, N. Y.

[1] Louis Bourget, "Stereo-monaural companion amplifier for the Preamp with Presence," AUDIO, Nov., 1957.

that the twin-coupled gives superior performance, both as to apparent undistorted output and general cleanness. And yet the twin-coupled circuit uses the output tubes strictly as pentodes with a variety of unity coupling. This well illustrates that pentodes *can* be operated in such a way as to achieve the benefits of their improved efficiency and give performance that is quite acceptable to critical listeners.

The Best Circuit

What then is the best of the modern output circuits? This is a question quite often asked and one to which there is no direct reply. It depends on how well each type of output circuit is designed or used.

For quite a while, there seemed to be a belief among amplifier designers that optimum performance is achieved if all the stages reach overload point at about the same level of amplification. Another school of thought recommends that the earliest stages have quite a nice margin (which is easier to do), while the drive and output stages should run into overload pretty well at the same point. Often it has been recommended that the output stage should overload before all earlier stages, because this means that only one stage is responsible for producing distortion instead of many stages running into distortion conditions at the same time.

Each of these recommendations may have its point, considering the amplifier without feedback. But when feedback is applied, as it is on all modern amplifiers, the situation is considerably altered.

Feedback theory is usually confined to the condition where the amplifier is assumed to have all its gain. Unfortunately, as soon as clipping occurs the amplifier does not have all its gain. This does not necessarily introduce any instability, but it can result in the sudden appearance of signals having excessive amplitude.

For example, suppose, at maximum output, the input is really 1 volt but is held down at the grid of the first stage to an effective 0.1 volt because there is 0.9 volts of feedback. Then the onset of clipping results in a signal that suddenly looks like the 1 volt it really is because the 0.9 volts signal gets chopped off short. This results in a high peak being amplified by the early stages of the amplifier until some stage fails to handle it. An increase of actual input from 1 volt to 1.1 volts in a waveform at the first grid that suddenly shoots up from 0.1 volt to 0.2 volts, and proportionately through successive stages. (*Fig.* 2)

What happens due to this sudden peak then depends on further details in the amplifier design. If this sudden peak produces overload at a point where there is direct coupling, say between an amplifier and phase-splitter stage, the ampli-

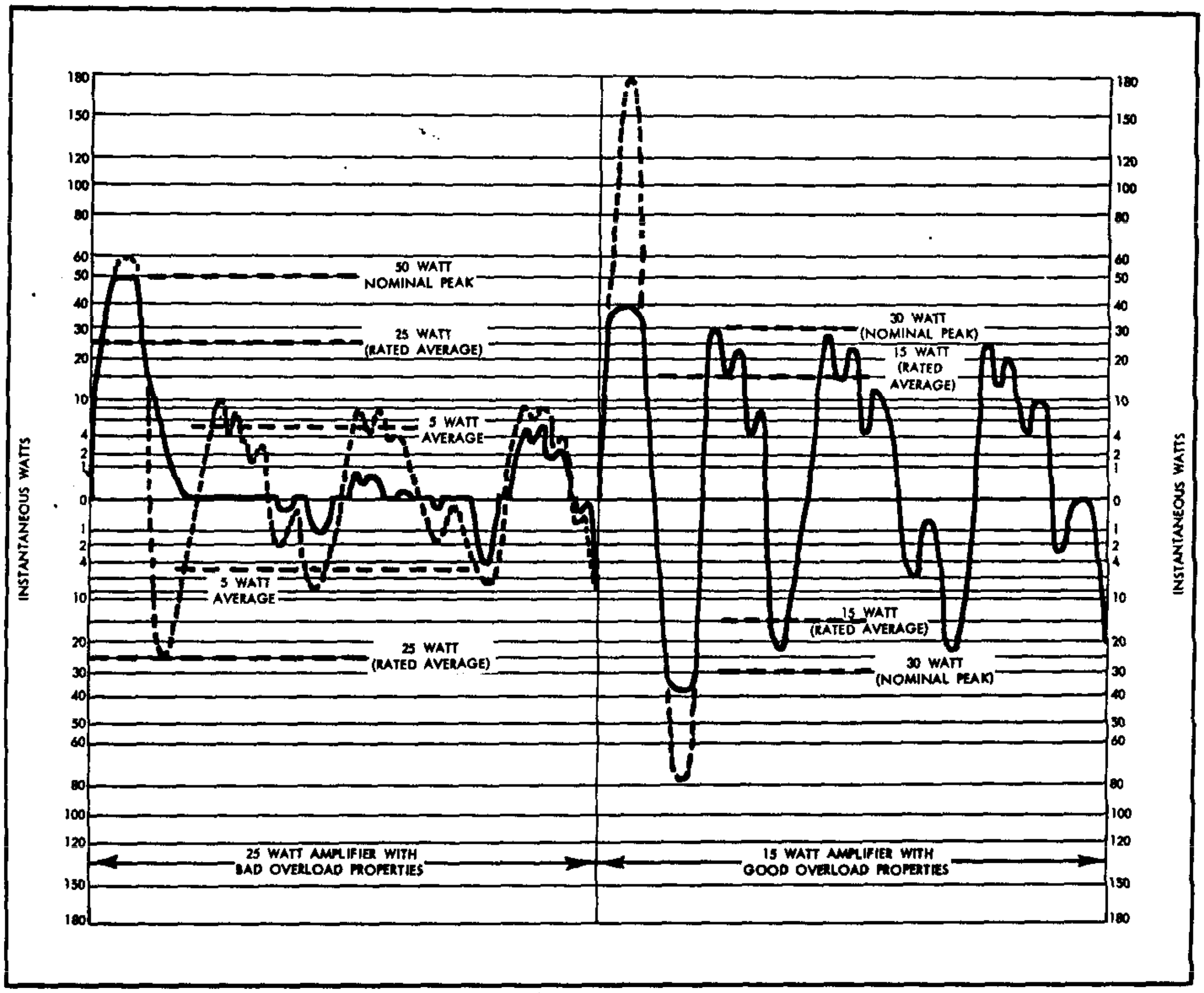

Fig. 1. Comparison of the same transient waveform amplified by (left) a 25-watt amplifier with bad overload characteristic, and (right) a 15-watt amplifier with good overload characteristic. In each case, the solid line represents the actual waveform, while the dashed line shows the correct waveform where the amplifier departs from it. The 15-watt amplifier is handling the same waveform at three times the power level.

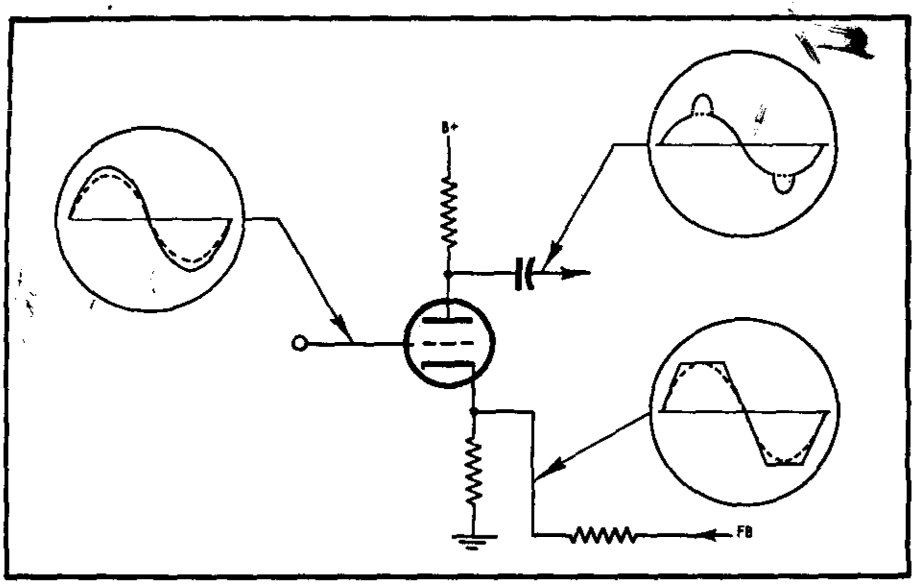

Fig. 2. What happens in any feedback amplifier when clipping occurs. This shows the waveforms associated with the input stage. Dashed line is the waveform at maximum undistorted signal level. Solid line at a level 10 per cent above this.

fier will not be disturbed by it. As soon as the peak disappears the amplifier reverts to its normal operating condition and carries on amplifying normally.

But if this peak reaches its limit of amplification at a stage that is resistance/capacitance coupled, a grid may be driven a long way positive, causing a negative charge to appear on the grid side of the coupling capacitor after the peak disappears. This biases that stage momentarily back beyond cutoff and causes blocking. As the stage drifts back into its normal operating condition some distortion is evident before the amplifier resumes proper operation.

Another place where the trouble can occur, if the amplifier is "held up" right through to the grids of the output stage, is that the sudden removel of amplification due to clipping results in an excessive postive drive at the grids of the output stage. These are almost invariably resistance/capacitance coupled and consequently, immediately following the excessive peak, the output stage is momentarily over-biased so as to produce crossover distortion if not complete blocking for the moment.

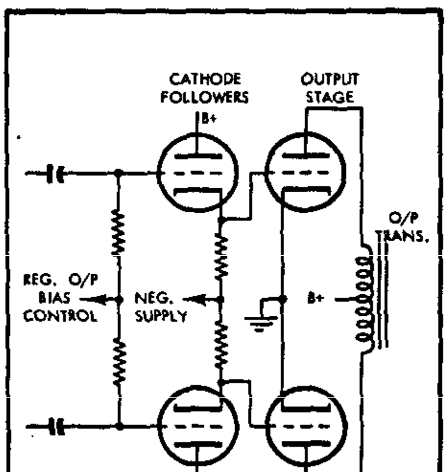

Fig. 3. One way to obviate output-stage blocking is to use direct-coupled cathode followers between drive and output, as shown here.

The Cures

There are two ways of obviating this. One is to use a cathode follower, direct coupled to the output stage with appropriate negative supply to enable the cathode follower to have an even more negative return than the necessary bias voltage for the output stage (*Fig.* 3).

The other is much simpler and almost as effective. It consists of interposing what at one time would have been called a grid-stopper resistor between each coupling capacitor and the output tube grids. It does not serve the one-time function of stopping parasitic oscillation in the grid circuit, but does prevent the large grid-current flow that momentarily occurs during the high peak condition and thus avoids the radical overbias condition after the peak (*Fig.* 4).

These are some general measures to obviate the sudden overload troubles that beset high-feedback pentode-type amplifiers. But what about some of the other types of circuits, Ultra-Linear, unity-coupled, Circlotron, single-ended push-pull, and so on? "Which of these would you recommend as best?" is a not uncommon question. Here again it is not so much a question of choosing the best circuit as seeing that the one you do choose is correctly used.

In the case of Ultra-Linear the choice of the tube operation is virtually one between pentode and triode. The tappings on the transformer primary "split the difference" between connecting the screen to B+ or directly to plates. The first is pentode, the second is triode. Connecting them to a tapping results in Ultra-Linear. This achieves practically the efficiency of a pentode while maintaining the linearity or low-order distortion of a triode.

This would seem to be ideal. The difficulty is that, to work perfectly, the transformer must maintain the correct tapping, both in voltage and phase, *at all audio frequencies*. This is not too difficult for the low-frequency end but, at the high-frequency end, stray leakage inductances between different parts of the winding, along with winding intercapacitances, can really play havoc with an Ultra-Linear circuit resulting in some quite weird waveforms at some specific frequencies.

The solution to this is to have a correctly designed Ultra-Linear transformer that avoids any spurious deviation from correct tapping up to a frequency beyond the audio range and also beyond the cutoff of the transformer as a primary-to-secondary transformer. This is not impossible, but only relatively few transformers manufactured under the name of Ultra-Linear achieve this objective.

The McIntosh version of the unity-coupled circuit relies on the famous bifilar-wound output transformer.[2] The fact that the high-voltage and ground-voltage primaries are wound with the wire actually side-by-side achieves a very intimate coupling between the winding connected to cathode and that connected to screen of the same tubes. To try and achieve this version of the unity-coupled circuit without a bifilar-wound transformer would be asking for trouble.

Of course, it is also necessary to use the various refinements developed with that circuit for avoiding the other kind of blocking we discussed earlier. In the case of the McIntosh circuit the output tubes are driven by cathode-follower direct-coupled stages.

[2] Norman H. Crowhurst, "Realistic engineering philosophy," AUDIO, Oct., 1959.

(*Continued on page 88*)

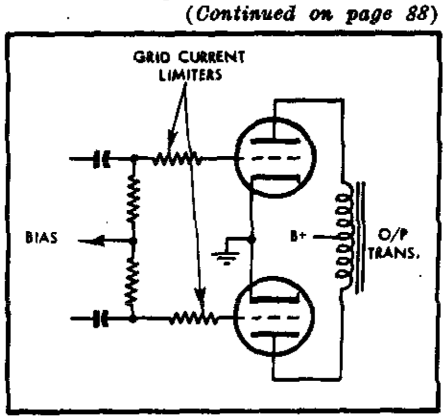

Fig. 4. A simpler method of at least reducing the effect is the use of grid-current-limiter resistors, shown here in the output-stage grids. They can also be used at any stage that causes blocking.

STATEMENT REQUIRED BY THE ACT OF AUGUST 24, 1912, AS AMENDED BY THE ACTS OF MARCH 3, 1933, AND JULY 2, 1946 (Title 39, United States Code, Section 233) SHOWING THE OWNERSHIP, MANAGEMENT, AND CIRCULATION OF

AUDIO, published Monthly at Lancaster, Pa., for October 1, 1959

1. The names and addresses of the publisher, editor, managing editor, and business managers are: Publisher: Charles G. McProud, 204 Front St., Mineola, N. Y.; Editor: Charles G. McProud, 204 Front St., Mineola, N. Y.; Managing editor: none; Business manager: Henry A. Schober, 204 Front St., Mineola, N. Y.

2. The owner is: Radio Magazines, Inc., 204 Front St., Mineola, N. Y.; Henry A. Schober, 204 Front St., Mineola, N. Y.; Charles G. McProud, 204 Front St., Mineola, N. Y.

3. The known bondholders, mortgagees, and other security holders owning or holding 1 per cent or more of total amount of bonds, mortgages, or other securities are: none.

4. Paragraphs 2 and 3 include, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting; also the statements in the two paragraphs show the affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner.

(Signed) HENRY A. SCHOBER, Business Manager.

Sworn to and subscribed before me this 9th day of September, 1959.

(Seal) Donald F. Mattone, Notary Public.

State of New York. No. 30-7766600. Qualified in Nassau County. Term expires March 30, 1960.

AMPLIFIERS

(from page 26)

An alternative approach is the twin-coupled amplifier referred to previously. This uses completely separate transformers but employs large capacitance from screen to cathode to achieve tight coupling at the higher frequencies. The double transformer achieves sufficiently close coupling for the low frequencies, which is not difficult.

The Circlotron circuit utilizes a comparatively ordinary output transformer and only needs one of them. Its disadvantage is the fact that it needs two high-voltage suppliers. While this may not be any more expensive (probably is less expensive, in fact) than using two output transformers or a more expensive single one, it does have the disadvantage that the high-voltage suppliers are virtually attached to the plates and cathodes of the output stage. This means that capacitances in the supply circuit and the power transformer are effectively in the audio circuit of the amplifier which can introduce complications in that direction.

So each circuit has its critical factors and it is only by taking careful account of the various critical factors in each circuit, watching out for the possibilities of blocking, or other spurious conditions—the things that can happen due to the difference between practical program material and the kind of signals used for measuring amplifier performance—that a satisfactory amplifier can be produced. Using any basic circuit as a starting point it is possible to design out the various bugs that spoil amplifier performance.

So, rather than saying that any one particular circuit is basically the best circuit, it is better to look a little closer and see how well the circuit has been designed as regards avoiding some of the spurious things that can happen in amplifiers. Æ

MICROPHONE PREAMP

(from page 50)

J_2	Output connector, Amphenol 91-860
Q_1	2N133 transistor
Q_2	2N132 transistor
R_1	5600 ohms, ½ watt
R_2, R_8	120k ohms, ½ watt
R_3	560k ohms, ½ watt
R_4, R_5	100 ohms, ½ watt
R_6, R_9	10,000 ohms, ½ watt
R_7	390k ohms, ½ watt
R_{10}	20,000 ohms, ½ watt
	2 Penlite batteries
	Miscellaneous hardware
	Insulated mounting board, 3×5 in.
	Aluminum box, 5×3×1½ in.