OBJECTIVES IN HIGH FIDELITY AMPLIFIER DESIGN

AnHigh Fidelity Amplifier Built to Unusual Ideas of Response Curves

By Richard S. Burwen

To design an amplifier having high fidelity characteristics one must first establish an objective as to the type of response curve to work for. Which gives the most pleasing effect to the ear? Is a straight-line voltage characteristic at the speaker most desirable?

These questions constituted the key idea around which the amplifier covered in this article was developed, after two years of assiduous experimentation. The result is something remarkably pleasing to the ear, an instrument of extreme range with tone so rich, so full and brilliant as to be fairly described as high high-fidelity response.

We must start at the outset with the conception that perfect re-creation of the original sound is impossible. What comes out of the speaker is really a new and different sound; and that sound must be given qualities by means of design features in the instrument itself that make the result pleasing to the ear regardless of what the response curves may say. The idea is comparable to the retouching of a photograph.

~~If~~ When you look at the response curves reproduced with this article you ~~would~~ may at first glance say they indicate tremendous distortion. But for reasons to be discussed they do in fact indicate tone that has great ear appeal.

Two factors are primarily responsible for the unusual tone: (1) tremendous boost of frequencies at the extreme ends of the range; (2) proper balance among the high, low and middle frequencies.

Let us at this point refer to fig. 1 which is the joint response of the amplifier and its associated broadcast receiver. Following the line marked "normal" which is the response with controls in "normal" position, there is indicated a boost of 12.5 db at 25 cps and a boost of 35 db at 15,000 cps.

At this point it might be well to emphasize that the curves are from readings of an output meter across the voice coil of the speaker and not across a resistive load. It seemed this was the logical method of correlating electrical response with sound effects in an experimental development because frequency response varies with the particular speaker used.

In discussing the reasons such a curve can represent brilliance and full, rich, balanced tone quality, let us start with a consideration of the high frequency end. Brilliance of tone results from reproducing effectively the overtones. It is by effective amplification in the region between 5,000 and 10,000 cps that brilliance in the output sound is created. In spite of the limitations of transmission through which many of the harmonics fail to be transmitted, we can by making the most of the frequencies that are present compensate to a large extent for the missing elements.

Without such boost the sound output at the high frequencies tends to fall off with increasing rapidity. When translated into sound the steep boost shown in the curve is not what it seems. A large part only compensates for loss. Beyond that it helps to compensate for the missing harmonics at the extreme high end.

The effect of this amplification is well demonstrated in listening to certain of the transcribed programs, whose transmission range is even more limited than live programs. Because of the increased amplification of the harmonics, some of these programs sound as brilliant as live transmissions.

It should theoritcally be desirable to compensate likewise for lost frequencies above the 10,000 mark by means of an increasing slope. Above 10,000, however, it is difficult to accomplish and is actually unnecessary. To the ear there is little difference between music containing 15,000 cycle harmonics and about 10,000

that which is limited to 10,000. Further, there is nothing transmitted/even on FM that materially adds to the quality of the reproduction; at least, such is the writer's conclusion after recent listening tests on FM with an amplifier having a rising characteristic of at least 40 db per octave at the extreme frequencies. The major increase was that of background hiss.

It is important to emphasize that while boosting in the 5000-10,000 zone we must be careful not to boost much in the 3000 cycle region. At 3000 both apparatus and ear are pretty efficient. Boost in this region will produce screechy effects and destroy the element of balance. But beyond that point go as far as you like. The writer in his experiments increased step by step the slope of the curve to the greatest possible extent.

Now on the bass end somewhat similar reasoning holds true. If you will again refer to fig. 1 you will notice the rise in the line begins at 100 cycles and most of the boost is below it. Since it is at these extreme low frequencies that efficiencies fall off, we can, so long as it is confined to this region, stand what ~~looks on the chart like a highly exaggerated effect~~. To the ear the effect is not exaggerated. We have brought up in the reproduction the low ~~boom~~ vibration of the bull fiddle and the rumbling, ~~vibrating effects~~ of the low organ notes. In our own amplifier the meter actually indicates substantial output as low as 5 cps.

There is an important relationship ~~definite connection~~ between the efficiencies at both ends of the scale; for it is only because of reaching the extremes on the low end that it is possible to maintain them on the other. No characteristic of an amplifier is more important than balance among the bass, middles and highs. If you cut off at one end you must also cut off or cut down at the other. Right here is another reason for brilliance; because it is unnecessary to cut down or reduce the amplification of the highs to offset lack of reproduction at the low end, those overtones which occur in the middle of the range and at the beginning of the high ~~low~~ frequency end are retained in proper balance. We can afford to repeat that it is ~~the presence~~ effective amplification of overtones that makes for brilliance.

While paying attention to the right and left, the middle must not be forgotten, for it is easily possible to get a type of reproduction that is mostly highs and lows while to the ear it ~~then~~ appears the middle frequencies are lacking altogether. The ear must judge when this proper balance has been attained.

From ~~the fact of~~ confining the bass boost to the low lows occurs a most important result. It is the answer to a defect of reproduction ~~problem~~ that has had little discussion in print. That effect is the common heaviness on voice, that thickening effect which produces the typical "radio voice." Why is it the ~~typical~~ good" home receiver may provide a pleasing bass effect on music and yet ~~when the announcer comes on~~ gives you ~~get~~ a typical "radio" effect, however, more especially when the speaker is a deep-voiced person? Some of this ~~must~~ of course be attributed to the transmission, but ~~more~~ most of the answer is ~~in~~ the bass boost goes ~~going~~ too high up in the frequency scale. Distortion ~~has been~~ are created at frequencies just above the lowest which is not apparent to the ear on music because the effect is not unpleasant, but it does show up strongly when the deep-voiced speaker comes on the air.

Most voices don't go below 100 cps. By keeping ~~most of the~~ rise below this frequency, ~~most~~ most voices sound very natural indeed even though the music is rich and full of bass. For ordinary purposes it is unnecessary in our amplifier to do much with the tone controls. You are listening to the deepest vibrations of the organ; the announcer comes on-yet he sounds quite natural, with only a trace of that heaviness on the deepest voices. Now comes a ~~news~~ all-voice broadcast and still you don't feel impelled to trouble yourself to throw the bass control into a lighter position.

This same factor is likewise responsible for another surprising quality in the music. It seems to have surprising clarity. Because the bass does not overrun and obliterate the medium low and middle frequency instruments, they seem to stand out individually.

Having discussed the type of reasoning behind the design, some of which developed on the way as a result of experiments with straight-line characteristics, let us delve into what features of the design make the desired curves possible.

Feedback was the key idea adopted, but feedback in a special way. It was obvious that for feedback to accomplish the kind of results indicated it had to be selective ~~feedback~~. The final scheme, the net result of many experimental hookups, is <u>a selective feed-back system with a phase-shift effect which makes it negative at intermediate frequencies and positive at extreme high and extreme low frequencies</u>. There are other items but this is the one that produces the major contribution to the effect. This feedback system is shown in fig. 2. Let us follow this circuit, set off in heavy lines.

Taking voltage from across the voice coil, it feeds it back in series with the cathode of the second triode section of the 7F7 tube. The network consists essentially of two parts -- a high-pass filter and a low-pass filter. The high-pass section comprises C15, C16 and C17, each of 100 mf in the line, and across the line are resistors R19 of 200 ohms and R20 of 100 ohms. Plus R12 of 100 ohms in the cathode circuit. The low-pass section consists of chokes CH 2 and CH3 with a 500 ohm resistor R21 across the first and .02 condenser ~~C14~~ C18 across the second, plus C19 across the feedback line.

This is selective feedback, the selection arising from the same kind of attenuation that takes place in the coupling condenser of a resistance-coupled amplifier stage, where frequencies fall off at a rate varying with the size of the condenser. The values of 100 mf in combination with 100 ohms effectively feed back negatively down to 50 cycles; at the same time the two choke combinations making up the low-pass section limit the amount of feed-back at the high frequencies. The net result is decreased amplification of the middles from 50 cycles up to around 3000, in effect boosting the amplification outside that range.

Instead of one, there are three condensers in series. The trio provide sharper cut-off at the low frequency end; but more important, there is a phase-shifting action which makes the feedback positive at the extreme low frequency end, and due to the chokes, slightly positive at the other.

The boost on the bass end is considerable. Partly responsible is ~~the fact that~~ the resonant frequency of the speaker, which falls in its range. From fig. 3 it will be noted there is a maximum boost of 44 db at 20 cycles. Each of the three condensers and its associated resistor causes a certain amount of phase shift at frequencies where the reactance of the condenser is appreciably large in comparison to its following resistor - that is, at frequencies below 50; and in passing through three such condenser combinations there is a gradual reversal of phase that nicely solves our problem of getting a large amount of boost.

That this positive effect is present is shown by the ~~fact that as a result of the feedback the~~ chart. Gain at the bass end is much greater than the loss of gain at the middle frequencies. Values of filter components were selected to give greatest possible rise at both ends while at the same time maintaining the amplifier stable.

To control the bump at the bass end a six position switch S2 is used. It simply shunts a different value of condenser or a resistor and condenser in series across the high-pass filter section. Its six positions range from full effectiveness to complete short circuit. From "normal" position 2 it can attenuate 4 db or boost 38 db at 30 cycles.

For treble tone control potentiometer R10 is used. The feedback filter was adjusted to provide "normal" with this control at center, providing thus ability both to increase and decrease high frequency response. The taper on this control should be one in which the condenser is shunted across 9/10 of the resistance at mid-position. At 3000 cycles this control can boost 5 db or attenuate 9 db. Its effectiveness is most noticeable between 1000 and 4000. The effect of R10 is shown in the curve of fig. 4.

To take full advantage of the abilities of the amplifier it was necessary to take care not to lose any quality in the receiver itself. The receiver diagrammed in fig. 5 was therefore specially designed to go with it — a simple TRF receiver which because of its broad-tuning characteristic gives little cutting of sidebands. It has two 6SK7 tuned stages feeding into a resistance-coupled diode detector and has automatic volume control, with a large time-constant to prevent low frequency degeneration. Resistors have been incorporated across the grid coils to stop any leaning toward oscillation which would decrease band width and create hiss. There is practically no loss in the high frequency region due to selectivity or bypass effects, and no station hiss, even on weak stations.

Included with the receiver is a triode audio pre-amplifier stage. At this point we have taken advantage of a further opportunity to increase the compensation provided in the amplifier by inserting another filter circuit. From the diagram in fig. 5 it will be noted this filter is in two parts - one before the pre-amplifier stage and one immediately beyond it. One consists of a resistance-capacity equalizer to boost both bass and treble. The other section consists of a number of things which will be best described in connection with the three-position progfam switch.

In "normal" or "high fidelity" position we have in the circuit R44 and C45 to boost treble. In center position we have added into the circuit a 10 KC beatnote filter. Due to the purposely broad tuning of the receiver, beat notes are prevalent at night and this is a necessity. In position3 both highs and lows are cut down by inserting C40 and C41 in the line and R43 and C46 across the line, at the same time shorting out the original R44 and C45 used with position 1. The beat-note filter remains in the circuit likewise in "voice" position.

The reduction in gain preceding the audio amplifier stage is just sufficient to lower signal strength on strong stations to a point where no overloading of the stage occurs. For broadcast reception then the volume control can be placed at the input of the main amplifier with its consequent elimination of crosstalk.

In fig. 1 to which we have previously referred is the final combined curve of receiver and amplifier. By comparison of figs. 1, 3 and 4 it will be noted there is a material change in the character of the curve at both ends over that of the amplifier itself. Bass and treble boosts are increased. The 10 KC filter gives an attenuation of about 20 db and there is attenuation to -14 db at 100 cycles in the "voice" position.

After the receiver comes the problem of the phonograph. The writer has made hundreds of experiments with ~~all kinds of~~ equalizer combinations, checking results with listening tests and response measurements on all kinds of records and with a number of different types of pick-up. In determining the kind of system that will best please the ear the matter is complicated by considerations of scratch elimination, distortion and rumble. It is possible to get many kinds of response from different kinds of equalizer hookups. Individually many of them sound apparently pleasing. Again the ear must be the judge of what is best after comparison. Actually an equalizer that gives pleasing tone with ~~kind~~ one kind type of record may not be so good with another. Records vary much in their characteristics.

The response curves shown in fig. 6 are those which the writer has decided are best for the average record. The two curves are ~~these of~~ standard test records, Victor 84522-A and Columbia 10003M. With equalizers adjusted to produce these curves, good clean-cut performance is obtained without scratch or distortion, especially when using a pick-up with jewel point. The same curve with steel needle is less brilliant.

Note the dip in the 250 cycle region on the curve of the Victor record, which has the same recording characteristics as commercial records. This dip makes the music sound lighter and less muffled. It is made necessary for purposes of balance because of slicing off the highs.

There is gradual attenuation from 800 to 4000 cycles, at which point there is an abrupt slicing off. The line between 800 and 4000 is perfectly straight and gives an apparently more brilliant rendition than a "roll-off."

ith this curve there is still a surprising amount of brilliance. That much is lacking, however, is revealed in experiments with equalizers permitting higher ranges. On exceptionally good records such equalizers can be used with enhanced fidelity. For example, a curve flat up to 10,000 or rolling off from 800 to 10,000 is much more brilliant; for violin solos a curve having a dip of 8 db at 3000 and a rise of 10 db at 8000 was found to be especially brilliant, although accompanied by a prominent but not too objectionable hiss. Actually, the writer has developed for his own use a series of six equalizers controlled from a six-position switch, each giving a different type of curve and adaptable for different types of records.

Another interesting indication developed by the experiments was that different pick-ups though adjusted to produce identical response curves gave different sound effects to the ear. No single equalizer circuit can therefore be prescribed for different pick-ups. That which the writer settled on after many experiments is shown in fig. 7. It is strictly a trick circuit and naturally matches only this particular pick-up, an Audak PRO-2 Microdyne magnetic having a 200 ohm impedance.

The three resonant circuits interact to provide the sharp cutoff at 4000. The filter after the tube is not exclusive to this particular hook-up. It also uses phase shift to obtain the sharp difference between 100 and 200 cycles. The bass frequencies flow through a low-pass filter while a parallel path for the middle and high frequencies is provided by the .003 condenser ~~C3~~ C57. Phase shift in each of these two parallel circuits at 250 cycles is opposite to that of the other. When the two outputs combine there is a canceling effect at 250 so that a sharp difference between the outputs at 250 and 100 occurs with the use of only a simple resistance-capacity equaliser.

It is apparent so far that by adopting the principle of inserting special filters into the circuits connecting the inputs we are adapting each device to the amplifier in a manner that improves performance. This is no less true when it comes to connecting the FM receiver. Again the purpose of the filter is to boost both low lows and extreme highs, by attenuating the other frequencies through the filter.

In FM transmission the highs are boosted at the sending end to improve signal-to-noise ratio and then cut down by a bypass in the receiver. The high frequency bypass in the FM receiver was removed and the new filter interposed as shown in fig. 8. It consists of a simple RC equalizer. The response curve is in fig. 9. It shows a ~~50~~ 45 db rise at 15,000 cps.

The writer's outfit is constructed on a 6 x 7 x 2 chassis for the amplifier while the broadcast receiver with its pre-amplifier is built on a 5 x 7 x 1½. Connection between the two is by a cable into an octal socket. The output transformer and the selective feedback network is external to the main chassis. Similarly the phonograph preamplifier and its filter is built into a separate metal box. The layout grew with the experiments and is pretty crowded. In copying I recommend larger chassis which will make possible better mechanical arrangements.

[illegible] woofer + 2 tweeters are used. The tweeters are [illegible] connected to the large speaker through a 25 mf electrolytic condenser

The amplifier proper with power supply consists of only three tubes. The high quality output is obtained from a single 6L6G. There is nothing special about the output transformer -- it is just an ordinary 10w universal. The secondary tap has been selected not according to specification but to provide maximum power at 20 cycles. (Due to losses in the transformer maximum power at 20 cycles is less than the 3 watts normal output of the amplifier.) The three inputs have individual gain controls, permitting mixing and fading. Hum is barely perceptible.

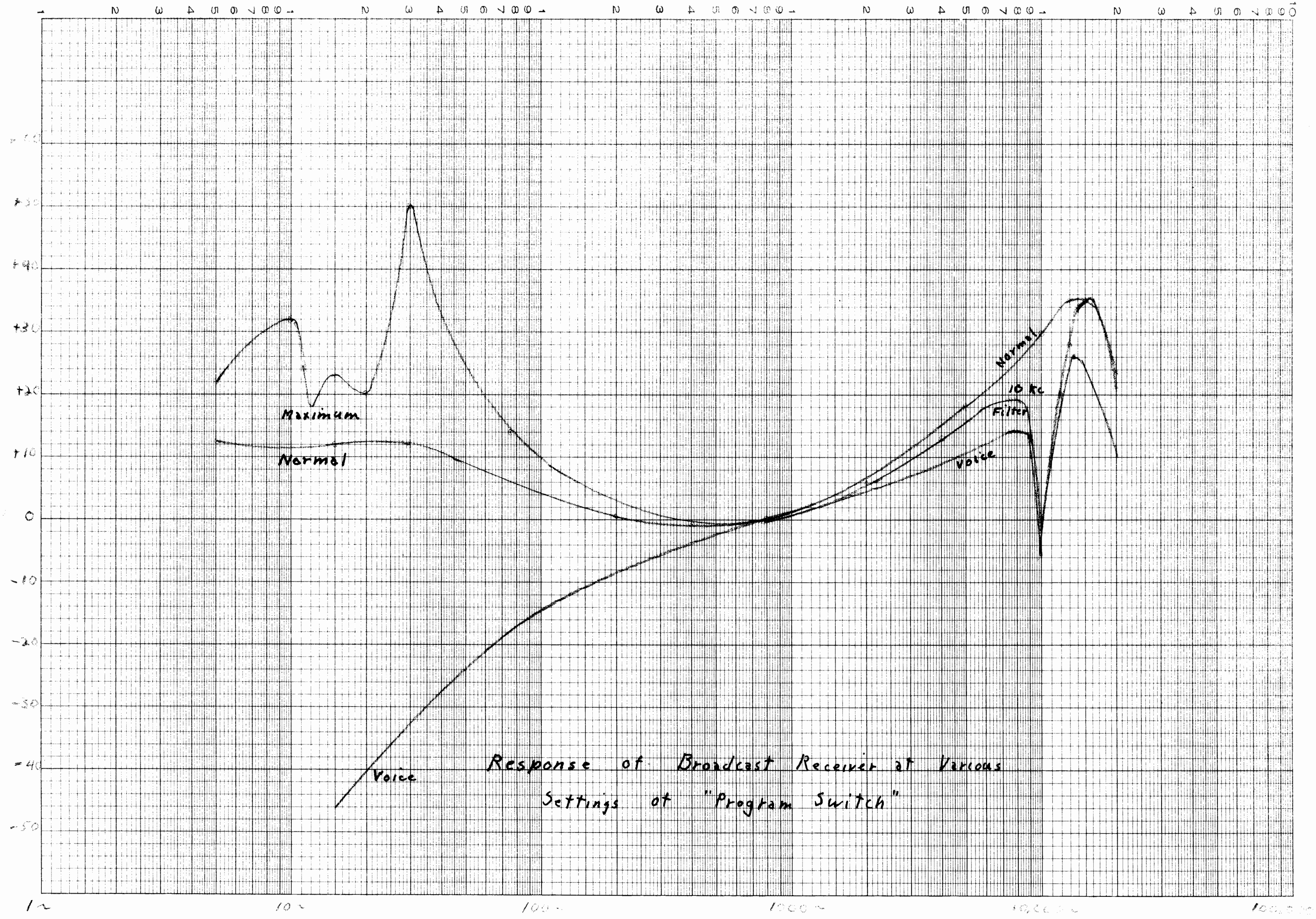
The usual "bugs" appeared during development. The chief problem was that of maintaining stability. Originally there were actually five different kinds of oscillation and motor-boating encountered at once. By appropriate shielding, adjusting values of coupling condensers and inserting decoupling filters in the power supply system, these troubles were one by one eliminated. ~~The receiver is provided with a 1000 ohm adjustable cathode bias resistor to adjust gain for the size of the antenna.~~

The type of speaker used made a difference in stability. If a 12" speaker is used the 200 ohm resistor should be replaced by 100 ohms; more positive feedback will then occur at low frequencies without oscillation because the resonant frequency of the smaller speaker is higher.

Because of induced hum the output transformer was mounted separately from the amplifier; line condensers and an external ground were connected. Originally the gain control on the phonograph input was 1.5 meg. Capacity effect between the resistance element and ground caused loss of high frequencies and it was changed to a .5 meg. which overcame the trouble.

With these bugs removed the amplifier is stable, hum and background noise are down to an extremely low level and are governed almost entirely by the characteristics of the transmission itself. It could be expected a copy would work without the appearance of such troubles.

The reasoning back of this amplifier and the outstanding results it produces indicate that straight-line electrical response is not a desirable objective in amplifier design. ~~It may be that straight-line accoustical response is, but to get it the response curves taken at the amplifier must curve and slope.~~ The curves represented in this article may not be the ultimate ideal and undoubtedly would be modified for other reproducers, but in the writer's opinion they do illustrate an important principle of design that leads to improvement in present-day radios and amplifiers.



Response of Broadcast Receiver at Various Settings of "Program Switch"