Positive Feedback for A-F Curve Shaping

L. P. HANER*

Part 1. Describing a 15-watt power amplifier with unique high-fidelity characteristics for use in a home entertainment center.

PERHAPS the most pertinent stimulus behind this study has been the realization that a serious paradox exists in our understanding of the requirements of an audio reproducing system. The classical school of thought would have us acquire 10-watt amplifiers with flat response from 20 to 20,000 cps and low harmonic distortion. Several years ago Fletcher and Munson published data on human hearing characteristics which have been given lip service but limited real concern. More recently, we have become concerned with transient response and intermodulation distortion. We are all aware of the shortcomings of our sources of electronically reproduced sound. Highly damped speakers with wide-range response and a smooth characteristic are becoming more and more desired. Microphones, records, transmitters, pickups, amplifiers, transmission lines, and practically all the multitude of steps, thru which the signal must pass, exact their toll—on both ends of the audio spectrum. Obviously, something should be done about it. Herewith, I present my solution—partial though it may be.

First, look for a moment at todays audio amplifiers. They must have a *flat* characteristic thru the audio spectrum. In order to produce maximum speaker damping, low-mu triode output tubes are often used. Occasionally the cathode follower is utilized, or, in its stead, negative feedback from the voice coil of the speaker. Admittedly, these solutions attain a high degree of smooth, clean, accurate reproduction. Now, look at that which is missing. There has been very little consideration for ear characteristics. We've sacrificed valuable gain and power to obtain speaker damping. We ignore the speaker cabinet unless we make highly specialized acoustically perfected units which do not fit the home. It should be self-evident that the only time a really *flat* response is desired is where the sound is reproduced at the same acoustic level it was originally played. Furthermore, if you listen to sound at even moderate volume levels, the response curve should *not* be flat. Note the Fletcher-Munson curves in *Fig.* 1. Just where we want higher level reproduction everything has a failing characteristic.

* *Wilmington, Delaware.*

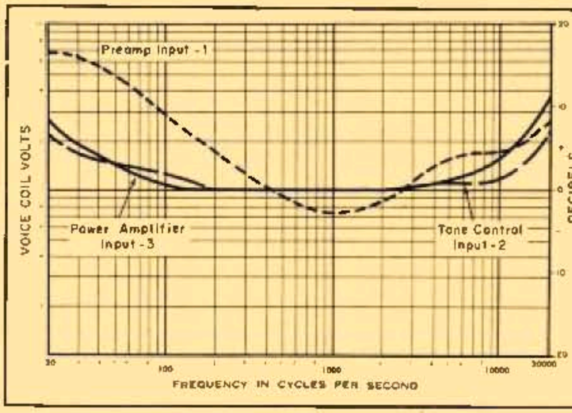


Fig. 3. Response curves of complete installation with tone controls in "flat" position.

A few ways are open to us for compensating some of the shortcomings of sound reproducing systems. Good components in a well designed amplifier are essential. Good wide-range speakers in a proper baffle are also essential. The amplifier design itself probably allows the greatest latitude for compensation. Most tone controls or compensators of the dual type are developed to operate from a central frequency, providing adjustable boost or attenuation above and below a central point in frequency. Invariably, this type of compensation rolls off at the extreme ends and therefore only partially fulfills the hearing requirement. It then becomes necessary to employ additional means of compensation—fixed and basic to the main amplifier section. Beyond this it is desirable to make the overall system as positive and stiff as possible. The sound emanating from the speaker should, except for purposeful compensation, be an exact replica, at different volume, of the amplifier input voltage. No embellishments should be added unintentionally and without control by the speaker or amplifier. Unless particular care is exercised, amplifiers and speakers have a strong tendency *not* to reproduce the signal exactly. Pentode and beam power amplifiers are noted for it. Even the best speakers have a multitude of major and

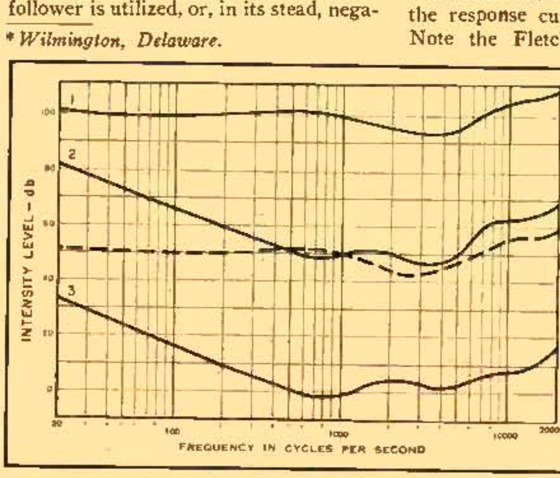


Fig. 1. Simplified Fletcher-Munson curves, to show effect of deficiencies in response curves.

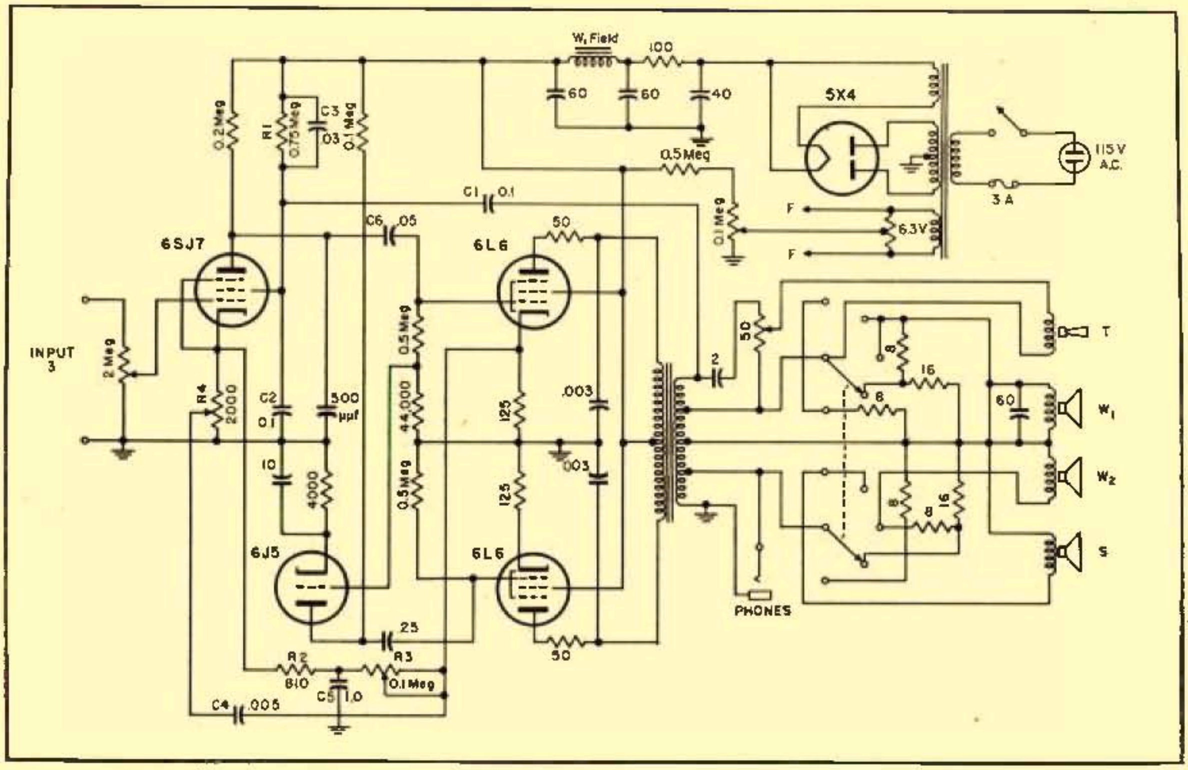


Fig. 2. Output amplifier, power supply, and speaker connection used in the author's installation.

minor resonances which are further complicated by the baffle and its enclosure. There are ways for overcoming these deficiences to a large degree. Negative feedback from the voice coil reduces the generator impedance of the amplifier and damps the resonances in the speaker. In addition, the voltages set up in the voice coil by its own microphone characteristics provide a compensation source for cabinet resonances and bad room acoustics. The speaker then becomes more integral with the amplifier and reproduces only what is fed to it. Sufficient negative feedback to do this effectively reduces the pentode amplifier gain to such a value that some think a low-mu triode without feedback suffices because of its inherent low plate resistance and, hence, low generator impedance.

The use of positive feedback along with negative feedback goes a long way towards correcting the deficiencies in the pentode amplifier. Further reduction of generator impedance and increased damping becomes possible. In other words, the higher gain allows more negative feedback to be utilized for a given reduction in overall gain. The non-linear characteristics of the output stage, the output transformer, the speaker, and the cabinet become less and less a factor in the acoustic output. They become compensated and respond more positively and absolutely in accordance with the input signal to the amplifier. Poor component quality in the output transformer, speaker, and cabinet, while more easily tolerated, is not advisable, but conditions are much less critical.

Such an amplifier has been developed and is described in this article. This amplifier is part of a home entertainment center—including AM, FM, TV, a 3-speed record changer, a wire recorder, and a separate 45-r.p.m. record changer. It drives three speakers ordinarily—two 12-inch woofers and a tweeter. Switching of another 12-inch speaker in the recreation room is possible; played along with or without the speakers in the entertainment-center cabinet. The TV set may be used in the living room at the same time one of the music sources is being heard in the recreation room. The

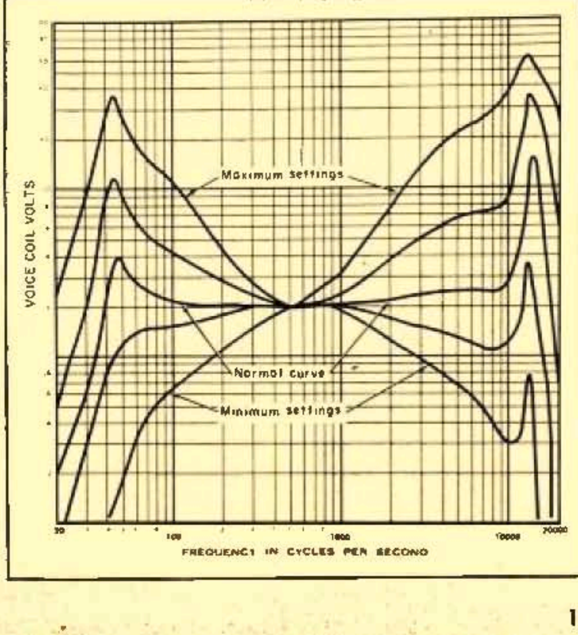


Fig. 4. Curves possible with tone-control arrangement provided, and by adjustment of positive-feedback.

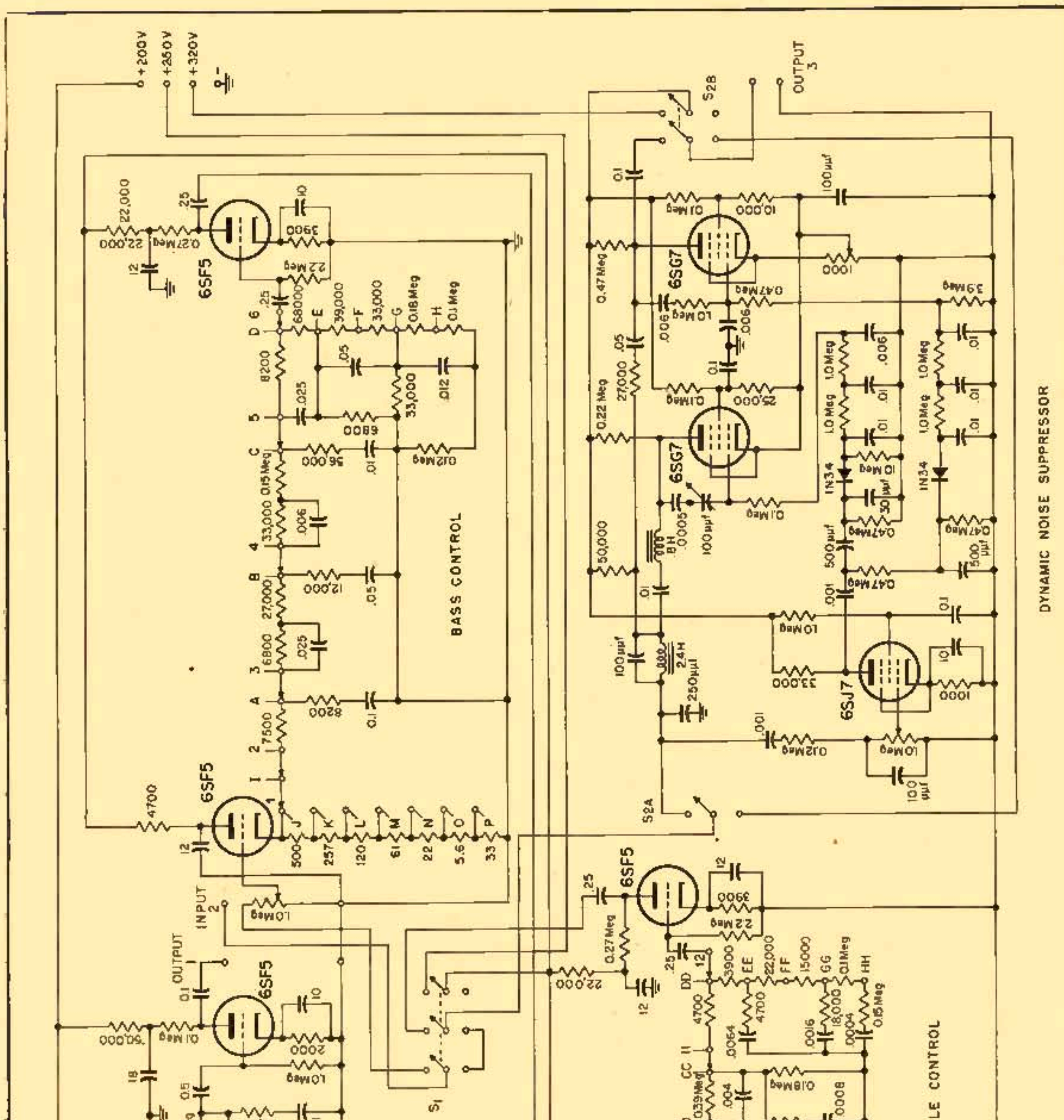
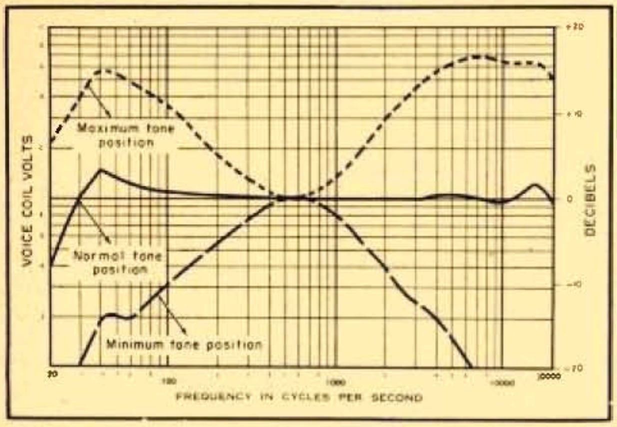


Fig. 8. Schematic of complete input equipment, with dynamic noise suppressor and modified preamplifier. Letters and numbers referring to circuit points are connected to switches, and table of Fig. 10 shows connections to obtain various response curves.



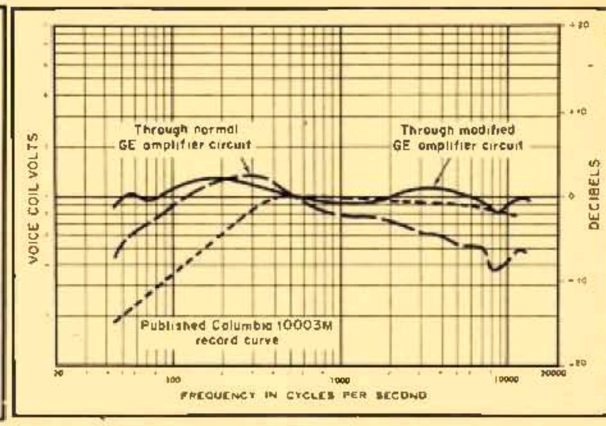


Fig. 5 (left). Range of control possible with tone controls. Fig. 6 (right). Frequency-response of normal G-E preamplifier and of modified circuit. Curve of record characteristic shown for comparison.

switching system, the preamplifier, and the power amplifier are described, and performance data is given.

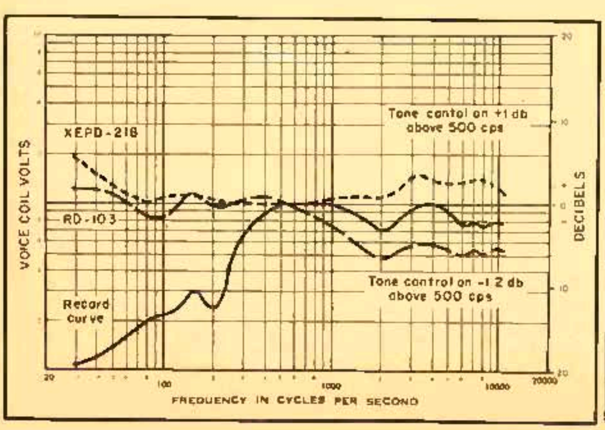
The Power Amplifier

The power amplifier consists of a 6SJ7 pentode stage driving two 6L6 beam power tubes in push-pull, class A. A conventional 6J5 phase inverter is used. The output transformer is a UTC type LS-57. Its secondary is connected to four speakers thru a switching system in such a way that a variety of selections is possible. One of these speakers is in another room. The load impedance is held essentially constant thru the use of substitute resistors. A fifth speaker is connected only to the TV receiver. In this way TV programs can be put thru this amplifier or played separately thru a separate amplifier and speaker.

The circuit for this power amplifier is shown in *Fig. 2*. Negative feedback is secured from the 30-ohm output transformer winding back to the 6SJ7 screen grid thru the capacitor C_1. The capacitors C_2 and C_3 provide the proper feedback voltage division on the screen grid. Resistor R_1 and capacitor C_3 are adjusted for minimum hum and were selected by experiment using a 2-megohm potentiometer for R_1 and a capacitor decade for C_3. Positive feedback is secured through two tuned resonant loops connected between a 6L6 cathode and the 6SJ7 cathode. It is *essential* that the positive feedback be connected at a point ahead of the negative feedback return. Otherwise, maximum reduction in generator impedance *cannot* be obtained by using positive feedback in conjunction with negative feedback. One of the positive feedback loops is tuned to a high audio frequency, and the other is tuned to a low audio frequency. The high-frequency feedback circuit is tuned by capacitor C_4 and interstage coupling capacitor C_6. Capacitor C_5 and resistor R_2 are used to tune the low-frequency feedback loop. Other capacitances and resistances are influential but these comprise the components which can be readily adjusted to put the resonant frequencies at the points desired. Potentiometers R_3 and R_4 control the amount of feedback in these loops. The amount of feedback and the resonant frequency used is adjusted to provide the desired shape of the overall frequency-response curve. Invariably this has been well below the positive feedback level which causes oscillation. At the point of oscillation, extremely high peaks occur in the frequency response curve. These may be flattened by proper use of by-pass capacitors across the 6L6 cathode resistor from which the feedback voltage is obtained. A similar capacitor should be placed across the other 6L6 cathode resistor to maintain balance. Resistors across capacitors C_4 and C_5 also flatten these peaks, should it be necessary. These methods provide excellent means of shaping the basic frequency-response curve of the amplifier. At present, the low-frequency peak is set at 18 cps, and the high frequency peak is set at 20,000 cps.

After more than a year of testing and

[*Continued on page 44*]



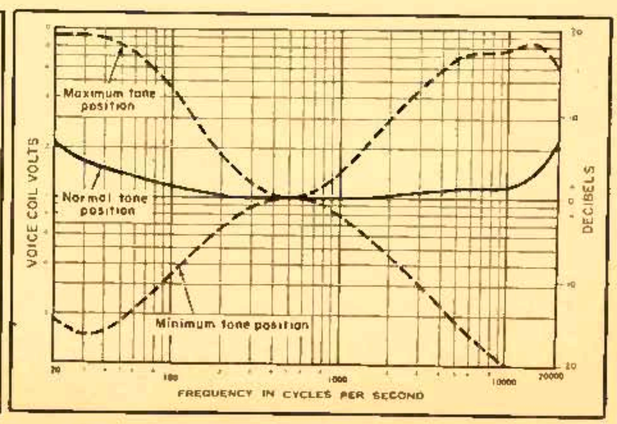


Fig. 7 (left). Response curves for RD-103 and XEPD-218 records. Fig. 9 (right). Normal and maximum curves for the equipment as finally adjusted.

POSITIVE FEEDBACK

[*from page 19*]

study, it was considered most satisfactory to provide a frequency response characteristic similar to that shown in *Fig.* 3, labelled INPUT-3. If the frequency range of the source of signal extends thruout the audio spectrum, this curve seems best. However, on sources having limited frequency response characteristic, the NORMAL CURVE shown in *Fig.* 4 was excellent. If these peaks are in the range of frequencies being very actively reproduced, an unnatural effect is experienced which is not normally recognized except by experienced and critical listeners. The NORMAL curve in *Fig.* 5 was a satisfactory listening curve to use as a basic characteristic. The chief advantage of the one shown in *Fig.* 3 seemed to be in the bass end. While "stage-property moving" and the blast of air in pronouncing p's was more noticeable, the overall result was more realistic and pleasing. Measuring the amount of positive and negative is difficult since there are two positive feedback loops. However, voltage readings for negative feedback before and after disconnecting were taken and are shown in Table I. The voltages were read on a vacuum tube voltmeter.

TABLE I

Frequency—cps	Voice Coil Volts connected	Voice Coil Volts disconnected
18	0.4	0.1
30	0.4	0.6
100	0.4	1.6
500	0.4	1.6
1000	0.4	1.4
5000	0.4	1.3
10000	0.4	0.9
20000	0.4	0.1

By moving the arm on the potentiometer R_1 to the ground end, the decrease in voice-coil voltage at 500 cps was from 1.0 to 0.47 volts. This does not entirely disconnect the low-frequency positive feedback loop and there is still positive feedback. Since the high-frequency loop is most effective at a very high audio frequency, the positive feedback at that frequency is accordingly higher. From these measurements and circuit considerations, it is estimated that the negative feedback at 500 cps is of the order of 30 db, with the positive feedback being of the order of 20 db. In other words, positive feedback employed in this way allows 30 db of negative feedback and permits only 10 db loss in the overall amplifier gain. Reduction in generator impedance is equivalent to 30 db of negative feedback. This changes at the ends of the audio spectrum. It is actually possible to obtain *negative* generator impedance. This is exemplified by the case where the feedback was adjusted on this amplifier in such a way as to produce a dip in the frequency response characteristic where the fundamental resonance of the speaker would normally produce a peak. The best feedback adjustment provides a smooth curve through this region. This indicates that practically zero generator impedance exists. A further illustration of this is shown in a test where the frequency-response curve was taken by measuring voltage across the voice coil of the speaker and then re-running the test after substituting an equivalent resistance of 8 ohms. These data are given in Table II.

TABLE 2

Frequency	Volts at voice coil	Volts at register
20	2.62	2.68
30	1.79	1.82
50	1.41	1.39
100	1.10	1.10
200	1.02	1.02
500	1.00	1.00
1000	.98	.98
1500	1.02	1.02
2000	1.04	1.04
3000	1.05	1.05
5000	1.16	1.12
7000	1.27	1.13
10000	1.53	1.38
15000	2.28	2.28
20000	3.73	4.71

A further indication is that no variations in volume level are heard as the

CLASSIFIED

Rates: 10¢ per word per insertion for noncommercial advertisements; 25¢ per word for commercial advertisements. Rates are net, and no discounts will be allowed. Copy must be accompanied by remittance in full, and must reach the New York office by the first of the month preceding the date of issue.

WANTED TO BUY OR SWAP: Used high-quality equipment in perfect condition. Amplifiers, tuners, recorders, speakers, 2- or 3-speed changers. J. Colbert, 85–08 168th Place, Jamaica 3, N. Y.

FOR SALE: Custom radio-phono assembly in one-piece solid walnut cabinet, with Hallicrafter S-47 AM-FM chassis, JAP-60 speaker, Webster 100-27, GE dual pickup, 7-cu.ft. infinite baffle chamber, Kimsul lined; $410. New York area only. Box CF-2, AUDIO ENGINEERING.

FOR SALE: UTC-LS7 driver transformer, $15; or will trade for Hi-Fi output transformer, 10,000Ω plate-to-plate. UTC-LS61 or 63, Peerless S-265-Q, etc. Ralph Majeski, 3860 N. River Road, Salem, Ore.

WANTED: Used Magnecorder, Presto, or Ampex portable tape recorder. State condition and price. Hal Roper, 628 Page Ave., N.E., Atlanta, Ga.

PROFESSIONAL DIRECTORY

oscillator input is swept thru the audio spectrum. Voltage observed at the voice coil varies exactly as shown in the curves of *Fig.* 3, 5, and 9—that is, smoothly and without peaks or dips.

Using a Hewlett-Packard audio oscillator, a Dumont 208B oscillograph, a Dumont electronic switch as a square-wave generator, and other miscellaneous equipment found in an industrial electronics laboratory, several distortion indicating tests were made. A Clarkstan 104–1, 60–10,000 cps sweep-frequency record, a Columbia 10003M test record, and a Columbia LP RD103 test record were also used. These tests were augmented by a large number of critical listening tests involving musicians, radio engineers and consultants, and audio enthusiasts.

Square waves from 50 to 500 cps were reproduced faithfully with sharp corners and no tendency to "ring" at either end of the square wave. The sweep-frequency characteristic obtained from the Clarkstan record reproduced the curve in *Fig.* 3 accurately except that the high-frequency end was down slightly. The marker pips were sharp and distinct. The high-frequency loss increased towards the center of the record and was presumed to be the record characteristic. Frequency-response reproduction of the Columbia 10003M and RD-103 records are shown in *Figs.* 6 and 7.

A-B tests were run in competition with a well known custom-built all-triode amplifier, considered by many to be the best that can be bought. Both amplifiers drove a Bozak B-201 speaker. Both were driven by a Presto turntable using a Pickering pickup on LP demonstration transcription. The positive-feedback amplifier seemed to be cleaner on the high-frequency end of the audio spectrum. More damping of the extreme lows also seemed evident, although there was some variation in the opinion among the listeners on this point. No A-B tests were run on live-music FM broadcasts, which, through this amplifier, are the most life-like of any electronically reproduced music to which the author has listened. Remarkable "presence" is felt.

(To be concluded in the March issue)

ERRATA

A. E. Richmond, author of the article "Rapid Attenuator Calculations Using the Vector Slide Rule" in the December 1950 issue, reports the following errors on page 46:

The formula at the middle of the column should have the fraction bar inserted, to read $\theta = \cosh^{-1}\sqrt{Z_1/Z_2}$.

Step 4 of the calculation procedure should read "To determine this minimum loss in decibels, *multiply* θ by 8.686. Use Scales C and D."