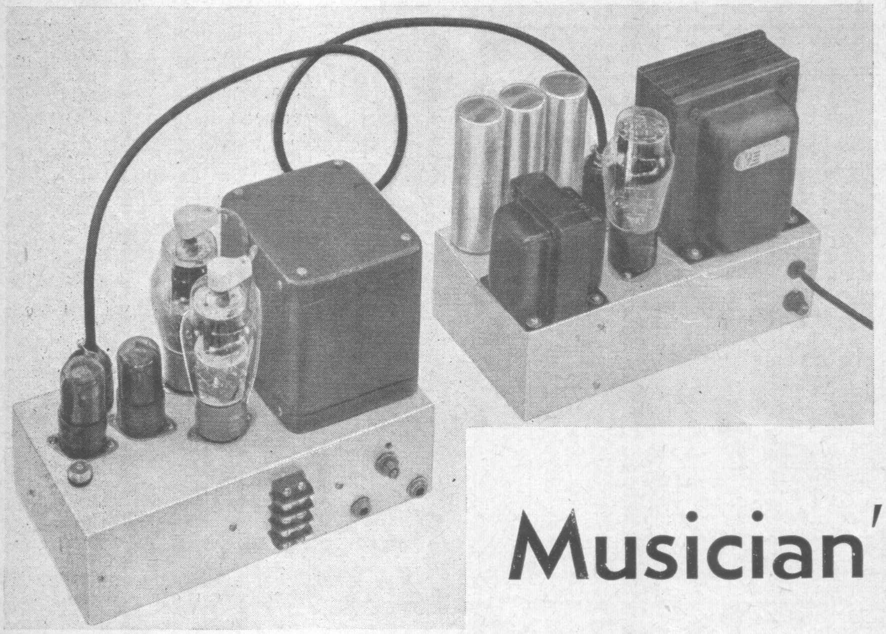

Fig. 1. The two chassis comprising the amplifier patterned after the "Williamson."

DAVID SARSER*

and

MELVIN C. SPRINKLE**

Musician's Amplifier

An adaptation of a famous English circuit which has already earned an enviable reputation for quality.

Amplifiers are something like women—there are a lot of 'em. And—like women—amplifiers come in all sizes, shapes, and degrees of appeal. The readers of radio magazines have seen dozens of different amplifier designs, and audio enthusiasts are as vociferous in praise of their pet circuits as Kentucky colonels about their pet way of making a mint julep.

The writers of this article—one a professional violinist in Toscanini's NBC Symphony, owner of the famous Lamoreux Stradivarius, and a builder of amplifiers, the other a professional electronic engineer whose avocation is serious music—have both made a baker's dozen of amplifiers, but have felt that most of these amplifiers in one way or another never completely recreated a satisfactory "studio sound."

The writers, then, have pooled their resources and have come to the conclusion that there should be a simple, easy-to-make, and thoroughly foolproof circuit which gives out with that intangible something called "presence effect." In doing so, we are going to duck controversies regarding beam-power tubes versus triodes, transformers versus resistance coupling, and all the other perennial areas of enthusiastic conflicts and ideologies. All we're really after—how simple it sounds!—is to reproduce music in the home which sounds the same way it does in the concert hall or broadcast studio.

Recently, we heard about the "Williamson" circuit which has been widely publicized in England and Australia as the absolute tops for obtaining natural reproduction. It was written up in *Wireless World* (an English publication) for April and May, 1947. This circuit has become so popular in England that it was reprinted with minor modifications in the August, 1949, issue of the *Wireless World.*

Having studied the Williamson circuit and having read the comments on its intermodulation distortion in Audio Engineering for September, 1948, we became interested in the possibilities of the amplifier.

Strictly from the technical point of view, the output tubes are 807's with triode connection. The 807 has much to recommend it as an audio tube. It is a standard type, available everywhere, and though it is usually considered to be a transmitting tube, its price makes it no more expensive than other tubes used by amplifier constructors. It has a fairly high plate dissipation, and draws enough plate current to provide adequate audio power. It is a cathode type, rather than direct heated and hence the completed amplifier has no hum even when used with efficient speakers with fine bass response such as the Altec Lansing 604B.

The output transformer presented somewhat of a problem as the original circuit called for a transformer not manufactured in this country. If it were specially made to Williamson's specifications the cost would be prohibitive. A careful survey and trial on various transformers available through jobbing channels disclosed that one transformer—the Peerless S-265Q—would best meet the rigid specifications for performance.

The resistance network in the cathode circuit of the 807 tubes contains a variable resistor P_1, which is set to give equal current in each tube. A closed circuit jack is provided in the cathode circuit of each 807 to permit insertion of a milliammeter when making this adjustment, and the plate current should be balanced by P_1 to exact equality, at 50 ma per tube.

The original Williamson diagram contained a series resistor to adjust the total plate current drain of both tubes. After building several of these amplifiers it was decided to omit this control and substitute a fixed resistor, since once it is set it is never changed.

The driver stage consists of a single 6SN7GT tube connected in push pull and resistance coupled to the 807's. Here one of the points of superiority of the 807 is evident. Most low-mu triodes such as the 2A3 and its six-volt counterpart, the 6B4G, have a high bias of the order of 60 volts and, hence, require a driver stage capable of putting out signals whose peak values are of this magnitude. As a result, resistance coupling to low-mu triodes is not practicable unless elaborate precautions are taken to supply adequate driving voltage with low distortion, a difficult task. The triode-connected 807 requires about 35 volts bias and thus the use of 6SN7 as a driver becomes practical. The first two stages are unique as they consist of a single 6SN7 tube using the first section as a voltage amplifier which is directly coupled to a "cathodyne" or split load type of

* 548 *Riverside Drive, New York 27, N. Y.*
** 5 *Melrose Ave., Bergenfield, N. J.*

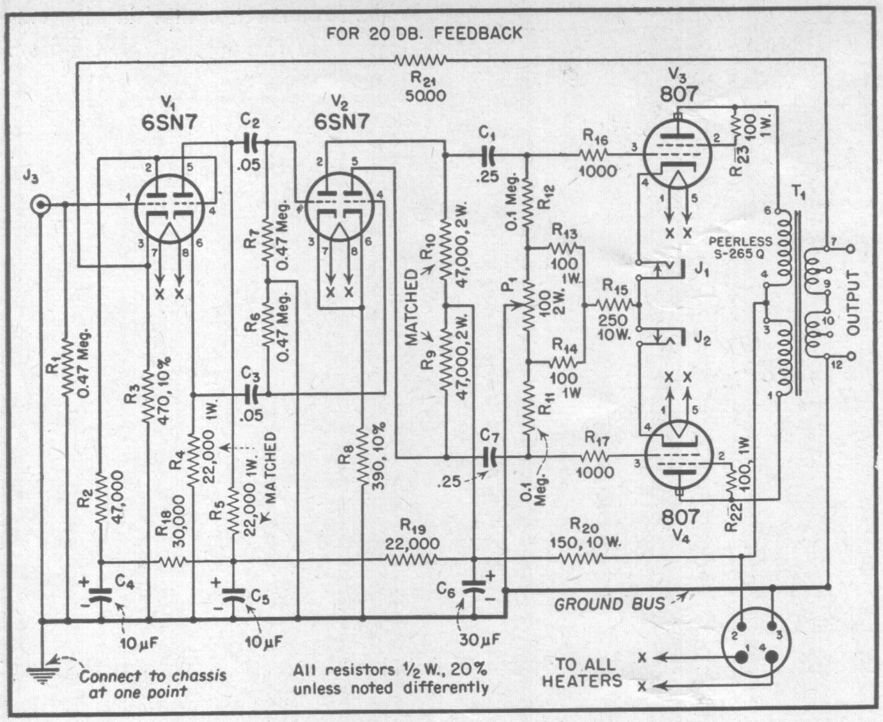

Fig. 2. Schematic of the amplifier section.

phase inverter. Use of this type of phase inverter permits direct coupling, as the positive voltage on the phase inverter grid is offset by the high positive voltage on its cathode. Direct coupling to the phase inverter permits the extension of the low-frequency response in this stage to d.c. and eliminates coupling networks which can cause phase shift and low-frequency attenuation. It will be seen from the schematic, *Fig.* 2, that there are only four coupling capacitors in the entire amplifier, two on each side of the push pull system. Thus the response of this amplifier at low frequencies is remarkably good.

Inverse Feedback

It will be noted that inverse feedback is used in this amplifier. Inverse feedback has been used with beam power amplifiers, but the circuit is not confined to this type of amplifier. Our amplifier incorporates approximately 20 db of feedback which is put around four stages and the output transformer. With this much feedback there is absolutely no trace of supersonic or subaudible oscillation, a tribute to the design of the output transformer. Feedback greatly improves the linearity and response of the amplifier and reduces the source impedance looking back into the output terminals to the unbelievably low figure of about ⅔ of an ohm on the 16-ohm output tap. When this amplifier is used with highly damped, high-efficiency speakers, the clarity of reproduction is more than satisfactory.

In connection with source impedance, there are two schools of thought. One group holds that the source impedance should be made as low as possible by using triode tubes, by the use of inverse feedback, or possibly both. The other group maintains that the source impedance should be low, but not necesarily as small as possible—their claims being based upon listening tests. This second group feels that a representative value of source impedance should be from 0.5 to 1.0 times the load impedance; thus on a 16-ohm tap the source impedance would be between 8 and 16 ohms. This amplifier has been constructed so that the source impedance is very low and those persons who prefer a slightly higher value may increase the feedback resistor (R-21) to approximately 22,000 ohms, or they may insert a resistor in series with the speaker voice coil should they prefer to retain the effects of the high feedback in this amplifier.

The power supply, *Fig.* 3, is built on a separate chassis to eliminate hum and also to provide a more compact construction, which simplifies installation. It is conventional with the exception that high grade 600-volt oil-filled capacitors are used in the filter. The recommended power transformer is designed for continuous operation with a drain of 200 ma in the plate supply. In practice it is found that after the amplifier has been on all day the transformer is just moderately warm.

Construction Details

Construction of this amplifier is simple. The amplifier and power supply are both placed on a 5 x 10 x 3 chassis; there is plenty of room for parts with complete accessibility for service should it be required. All resistors and capacitors are mounted on a terminal strip which is mounted on one side of the chassis as shown in *Fig.* 4. This type of construction, long used by professional amplifier builders, has been much neglected by amateur constructors and its use is encouraged to provide neatness as well as ease of construction and repair.

In order to reduce hum and undesired coupling between stages to a minimum, a grounding bus is used. This begins in the amplifier where the B— from the power supply enters the chassis, connects to the grounded side (terminal 12) of the output transformer secondary and then is carried along on the terminal strip toward the input, picking up cathode circuits and filter capacitor cans as it goes. It is grounded to the chassis at only one point near the input connector. Use of a grounding bus in amplifiers is also well known to professionals, and a large part of the difficulties encountered by amateur constructors is due to haphazard ground connections. The layout of parts is shown in *Fig.* 5.

At this point it might be well to review a few of the beliefs held by amateur constructors of amplifiers. Many amplifier designs which have appeared in magazines have had their virtues

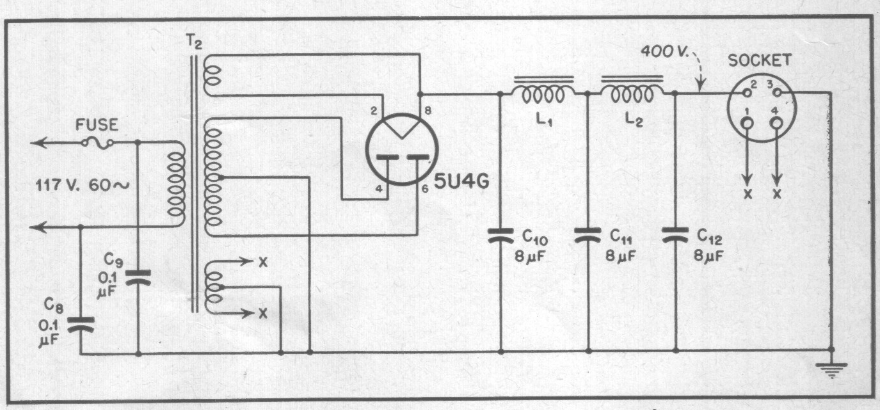

Fig. 3. Schematic of the power supply.

extolled solely on the basis of frequency measurements. The measurement of frequency response is an important property of an amplifier, but it is not the *only* property which contributes to naturalness in the reproduced sound. Frequency response is a measure of how the gain of the amplifier changes as a function of frequency. If, for example, the absolute gain is 75 db at 1,000 cps and 70 db at 10,000 cps, then the amplifier is said to be down 5 db at 10,000 cps. For this reason frequency response measurements are usually made at low output levels.

Power Output vs. Frequency

One important property of an amplifier which has long been neglected in the previous literature on the subject is power output at various frequencies. Magazine articles and manufacturers' literature will state that an amplifier will put out "10 watts." Sometimes they state the frequency and the degree of distortion that was present when this measurement was made. The importance of power output over the audible spectrum is so great that it cannot be over-emphasized, and it is this factor which is to a large degree responsible for naturalness of reproduction and freedom from distortion. Full power output over a wide band of frequencies is largely determined by the output transformer, the most important component in an audio amplifier.

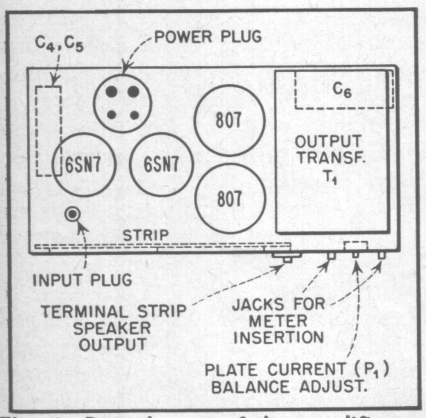

Fig. 4. Parts layout of the amplifier on a 5 x 10 chassis.

The manufacturers of output transformers more often than not fail to make any statement as to the power output of amplifiers using their transformers at various frequencies. Regarding the transformer we used, the manufacturer states that the output will be down no more than 3 db from midrange power at 20 cps and at 20,000 cps. Audio enthusiasts who make measurements of power at various frequencies from 20 to 20,000 cps would be amazed to see the very poor power characteristic of a favorite amplifier.

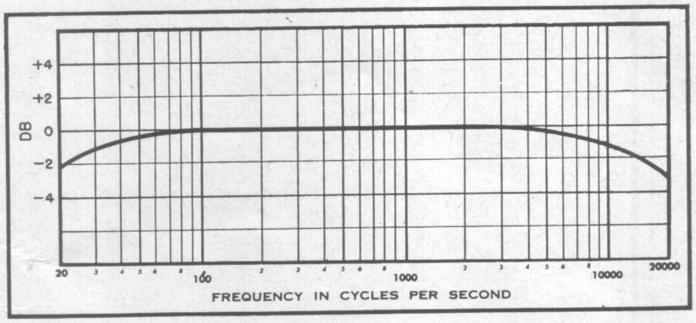

Fig. 6. Relative power output with respect to frequency.

Performance

The absolute gain of this amplifier, with about 20 db of feedback, is 70.8 db. The frequency response was measured by feeding in a signal at constant level from an audio oscillator, the signal being fed through a series resistor of 500,000 ohms which is equal to the input impedance of the amplifier. This is the customary way of measuring amplifiers professionally. The output was measured across a 16-ohm non-inductive resistor and high grade meters were used which had a minimum of frequency error. Under these conditions the amplifier is flat from 20 to 80,000 cps. There is a rise of 3.4 db at 96,000 cps and the output begins to fall at about 100,000 cps. In the revised article, Mr. Williamson states that his amplifier is flat from 20 to 100,000 cps, but he does not state the manner in which the response was measured.

The amplifier performs exceptionally well when tested with square waves. This test consists of feeding square waves into the input and observing the wave form on an oscilloscope at various points throughout the circuit. If the output waveforms have sharp corners and no tilt on top and bottom the following things can be said about the amplifier:

1. The frequency response is flat to at least 20 times the fundamental frequency of the square waves.
2. There is no time delay; i.e., the phase shift through the amplifier is proportional to frequency.
3. There is no spurious oscillation produced by steep-wave-front signals, such as the usual music and speech programs.

Square wave testing is a sensitive method of testing amplifiers, especially with regard to phase shift, and it was found that this amplifier passed without distortion square waves having fundamental frequencies from 20 cps to 5,000 cps. These signals were passed through the entire amplifier and not just one stage. This confirms the frequency - response measurements and showed that there is uniform time delay for all frequencies between 20 and 100,000 cps. It is entirely possible that the startling realism in reproduced music is due to the excellent phase characteristics of the amplifier, as a non-linear phase characteristic disturbs the arrangement of harmonics in complicated signals such as program material.

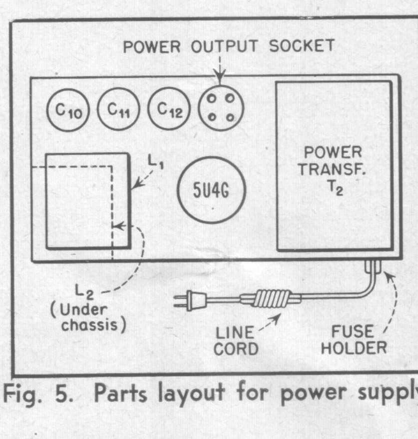

Fig. 5. Parts layout for power supply.

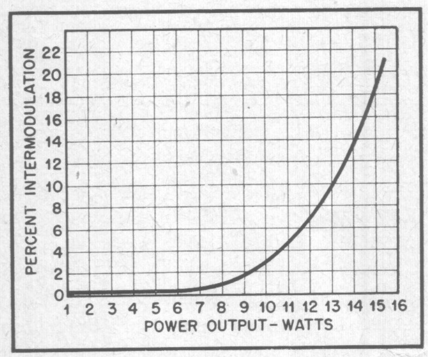

Fig. 7. Intermodulation distortion curve plotted against power output.

Mr. Williamson does not state the power characteristics of his amplifier, but does say that the power output is 15 watts. As our output tubes are not exactly the same as the KT66 valves originally used, we cannot make accurate comparison, but with 807 tubes and a 400-volt plate supply it will deliver 12.2 watts to the load resistor at 1,000 cps at 7 per cent intermodulation distortion. As may be seen from *Fig.* 6, the power begins falling off at low frequencies and is approximately 0.7 db down at 40 cps and 2.1 db down at 20 cps. It is down 2.1 db from full power at 15,000 cps and down 3 db at 20,000 cps. This power curve on the surface may appear to be excessive, but tests run by the authors on several well-known makes of audio amplifiers have shown the power to be down as much

[*Continued on page 53*]

MUSICIAN'S AMPLIFIER

[*from page 13*]

as 20 db at 20 and 20,000 cps. The overall intermodulation distortion curve is presented in *Fig. 7*.

On the surface it may appear that 12.2 watts is rather poor output from two 807 tubes, but it must be remembered that the 807's are triode-connected and the efficiency of triodes is much less than that of tetrodes. Moreover, the power output compares very favorably with that from type 2A3 or 6-volt equivalent triodes. The power ratings given in the tube manual for these types are the power developed in a load resistor connected plate to plate, while our power measurement was of *useful* secondary power. Those who have built "10 watt amplifiers" using 2A3 or equivalent tubes might find it very enlightening to measure the undistorted power in a resistor connected in place of their speaker. We have found that the power of 12 useful watts is more than enough for home volume, even when operating with a 10 db safety factor.

The intermodulation distortion in this amplifier was checked on Altec Lansing intermodulation equipment, using frequencies of 40 and 2,000 cps. It was found to be extremely low at powers up to about 8 watts. As a matter of fact, the IM distortion for ordinary room volume powers was less than .2% which is entirely negligible. As pointed out in Audio Engineering for September 1948, the power read on the IM equipment may be converted to equivalent single-frequency power, the usual way of rating an amplifier, by multiplying the IM meter power by the factor 1.47. This has been done in the published curve and it will be noted that the amplifier does not begin to exhibit serious distortion until sine wave power of 12.5 to 13 watts is reached. Thus the power curve for various frequencies, as reproduced in this article, is for substantially distortionless reproduction. If the reader wishes to be conservative in his amplifier performance, the power output as read from the curve should be divided by the factor 1.47 in order to get the IM *meter* power for a given amount of distortion.

When this amplifier is connected to a wide range speaker system and fed with good program material (e.g., local, live FM transmission) the resulting realism is so startling that it must be heard to be appreciated. The intermodulation distortion is so low that when a full symphony orchestra is playing, the various instruments are easily detected. The thud of the bass drum and the tinkle of the triangle are reproduced naturally at low levels, together with other sounds, even the squeaking of chairs and shuffling of feet. One very prominent musician, who is a composer, arranger and conductor and in whose home one of these amplifiers has been installed, said: "You not only can hear the difference between the flute and clarinet, but you can also separate the first and second clarinets when they play together".

Controls

It will be noted that the circuit diagram does not show any gain control. It is the authors' contention that an ideal amplifier should be one which can be tucked in some corner and forgotten while gain control and equalization should be accomplished in a separate control unit. The equalization and gain controls together with a phonograph preamplifier may well be a part of an FM tuner. If it is desired, however, to incorporate a gain control, the 0.5 meg grid resistor of the input stage may be replaced with a 0.5 meg left hand taper volume control. No equalization (tone controls) should be added to this amplifier, as the feedback loop goes from the output transformer to the first stage, and the large amount of feedback will negate any equalization introduced within the feedback loop. If equalization is desired it must be incorporated before the volume control. There is such power available at both the bass and treble end so that when the bass and/or treble boost is used, the results are positive and free from distortion at all comfortable levels. When bass boost is added the foundation music is solid and free from thuds.

To a couple of fiddlers—one who fiddles all day on a Stradivarius, the other who fiddles all day with amplifiers, *this* amplifier is the best that we have yet heard. We suggest that you build one and judge for yourself.

PARTS LIST

C_1, C_7—0.25 µf. 400 v. paper.
C_2, C_3—.05 µf, 600 v. paper.
C_4, C_5—10 µf, 450 v. electrolytic.
C_6—30 µf, 500 v. electrolytic.
J_1, J_2—Closed circuit jack, Mallory A-2 (*Must* be insulated from chassis).
J_3—Input connector. Amphenol 75-PC1M (R_1 is mounted inside this connector).
J_4—Power cable connector, Amphenol 86-RCP4 (4-pin male chassis plug).
P_1—100 ohm, 2W. wire wound potentiometer.
R_1, R_6, R_7—0.47 meg, ½ W.
R_2—47,000 ohms.
R_3—470 ohms, ½ W. 10%.
R_4, R_5—22,000 ohms, 10%, (matched).
R_8—390 ohms, ½ W. 10%.
R_9, R_{10}—47,000 ohms, 2 W. 10% (matched)
R_{11}, R_{12}—0.1 meg, ½ W.
R_{13}, $_{14}$, R_{22}, R_{23}—100 ohms.

R_{15}—250 ohms, 10 W. wire wound.
R_{16}, $_{17}$—1000 ohms, ½ W.
R_{18}—27,000 ohms.
R_{19}—22,000 ohms.
R_{20}—150 ohms, 10 W. wire wound.
R_{21}—5000 ohms, 10%.
T_1—Peerless S-265-Q.

Power Supply

C_8, C_9—0.1 μf, 600 v. paper.
C_{10}, C_{11}, C_{12}—8 μf, 600 v. oil filled.
F_1—Littelfuse 342001 fuse extractor post with 3AG fuse, 2 amps.
J_5—Power cord socket, Amphenol 77MIP4 (4-hole socket).
L_1, L_2—Peerless C-325-A. 10 H, 120 ma, d.c. resistance 240 ohms.
T_2—Peerless R-560-A. 800 v. CT at 200 ma; 5 v at 3 a; 6.3 v at 6 a.

Power Cable

1—Female connector, Amphenol 78-PF4.
1—Male connector, Amphenol 86-PM4.
4-wire cable, of required length.

All resistors are 1-watt, 20% tolerance, unless otherwise specified.

Additional Test Records

In order to complete the catalog of test records which appeared in the September issue, the following types are described — having been released after the original list was prepared.

CLARKSTAN

102M 12-inch, 33-1/3 rpm. Vinylite, SF. Microgroove audio sweep-frequency record, similar to 1000A but for long-playing microgroove records, covering range from 70 to 10,000 cps and recorded with NAB characteristic. Sweep repetition rate, 20 per second.

2000S 12-inch, 78.26 rpm. Vinylite, SF. Steady-state frequency record; recorded CV above 500 cps, constant amplitude below. Frequencies: 500 cps, 10, 9, 8, 7, 6, break, 5, 4, 3, 2, and 1 kc; 700, break, 500, 300, 200, break, 100, 70, and 50 cps, followed by 1000 and 500 cps.

2001S/2002S 12-inch, 33-1/3 rpm. Vinylite, DF. Microgroove steady-state frequency record. Frequencies: 1 kc; 10, 9, 8, 7, 6, break, 5, 4, 3, 2, 1.5, and 1 kc; 700, break, 500, 400, 300, 200, 150, break, 100, 70, 50, and 1000 cps. One side recorded with NAB modified characteristic; other side recorded CV above 500 cps, constant amplitude below.

101 12-inch, 33-1/3 rpm. Vinylite, SF. Intermodulation test record, 1:4 ratio, 7 kc and 100 cps recorded with NAB characteristic.

Clarkstan frequency records may be obtained from most radio jobbers, or from the Clarkstan Corporation, 11927 West Pico Blvd., Los Angeles 34, Calif.