The New WLW AGC Amplifier*

R. J. ROCKWELL†

Summary—**Since the inception of radio broadcasting, the control of audio level has been a constant problem. This paper discusses some of the shortcomings of presently-used circuitry in limiting and automatic gain control amplifiers and describes a new approach to the problem of level control, which provides both slow gain increase and decrease along with fast limiting action while maintaining wide frequency response and extremely low distortion under all operating conditions.**

Introduction

RADIO broadcasting has for its objective the faithful reproduction in the listener's home of those sensations of sound to which they would be subjected at the scene of the broadcast. A completely faithful reproduction of sounds in the home is never realized in practice, and in many cases this would be actually undesirable. Probably one of the greatest defects in currently reproduced sounds is the lack of auditory perspective. A practical approach to the problem should take into account the degree of fidelity which will provide a reasonably satisfactory reproduction of various kinds of program material in any average home. For example, it is clearly undesirable to attempt to accurately reproduce a symphony orchestra with its full 70-db volume range in the listener's home; the minimum noise level in an average residence is about 25 db above 10^{-16} watts per square cm (the noise of an average whisper at a distance of 4 feet is 20 db) so that the peak audio power of a symphony orchestra reproduced with its full volume range of 70 db in the average listener's home would be 95 db above 10^{-16} watts per square cm. This sound intensity is equivalent to the noise reproduced by a riveter at a distance of only 40 feet.

The transmitted volume range is usually less than the volume range of the original program, because the audio control operator usually adjusts gain in such a way that the fortissimo parts of the program are reduced and the pianissimo parts are increased. There are several reasons why this is done; first, the listener does not wish to reproduce a wide volume range such as encountered in a symphony orchestra, since the fortissimo parts of the program would be entirely too loud when the pianissimo portions are made just audible above room noise. Second, the permissible volume range is limited to approximately 50 db by the broadcast and receiving equipment, even in the most favorable cases.

From the above, it should be clear that a transmitted volume range of approximately 50 db would be desirable for the reproduction of program material in the home. For these reasons, Crosley Broadcasting Engineers have been vitally interested in amplifiers which would automatically convert a 70-db volume range to a 50-db volume range without noticeably altering the expression desired by the conductor.

Many previous automatic amplifiers have been designed by Crosley over the past 25 years and almost all commercial models have been studied and tested. It is believed that the amplifier described in this report is the first real accomplishment that has been made in this area; its action definitely excels that of an expert operator who slowly raises and lowers the gain as needed, returning the control to normal during extended quiet periods and while switching programs. This slow automatic control is followed by a fast-acting automatic attenuator to suppress occasional peaks.

Past History

To the best of our knowledge, WLW was the first broadcast station to use an automatic amplifier; this was as early as 1935. This is substantiated by our early patent position in this area.

Since that date, many improvements have been incorporated in our circuitry, and several commercial types have appeared on the market.

Among these commercial types are amplifiers incorporating circuits which are intended to delay the signal until gain correction is effected, amplifiers using both slow and fast gain reduction, those which convert the signal to a modulated and demodulated carrier so as to suppress "thump," etc.

Inherent in most of these types, as well as our older models, is the objectionable increase in background noise during quiescent portions of the program, followed by an objectionable fast-gain reduction as program is resumed, and/or other degrading and objectionable effects.

Since our recent venture into high-fidelity transmission with the new WLW Cathanode Transmitter, it has become necessary to improve all other associated equipment, particularly the AGC amplifier.

Redesign

From our own experience, and from tests conducted on commercial units, we realized that the first step in redesign was to analyze all shortcomings of presently available equipment. From this analysis, mandatory specifications and requirements were determined in order to be acceptable in the new WLW high fidelity system. These are shown in Table I.

* Received by the PGA, January 8, 1960.
† Crosley Broadcasting Corp., Cincinnati 2, Ohio.

TABLE I
DESIGN SPECIFICATIONS

Input Level
Adjustable, −20 dbm to 0 dbm

Output Level
Adjustable, −5 dbm to +15 dbm

Frequency Response
±0.5 db, 20 to 20,000 cps, for any condition of AGC action

Signal-to-Noise Ratio
Min. 70 db below normal output

Harmonic Distortion
Max. 0.5 per cent for any condition of AGC action

AGC Characteristics
Normal input signals cause no change in the slow-increase, slow-decrease, or fast-decrease circuits.
Low-level signals cause the gain to increase slowly, as needed.
High-level signals cause the gain to decrease slowly, as needed.
Slow-gain decrease range: 10 db
Slow-gain increase range: 10 db
Fast-gain decrease range: 20 db

Time Constants
Slow-gain increase attack time
Slow-gain increase release time

Slow-gain decrease attack time
Slow-gain decrease release time } To be determined by listening tests

Fast-gain decrease attack time
Fast-gain decrease release time

Metering
Illuminated input VU meter permanently connected following input gain control.
Illuminated output VU meter permanently connected ahead of output gain control.
Illuminated matching meter. Normally zero left with center go-no-go tube current scale and increase-decrease DB scale from zero center.

Manual Controls
Input level control 20 db, in 1-db steps, unbalanced T.
Output level control 20 db, in 1-db steps, unbalanced T.
Electrical meter center (AGC expansion).
Electrical meter center (AGC compression).
AGC ON-OFF switch
Selector switch-tube check, AGC monitor.

Basic Circuit

The complete circuit diagram for the new WLW AGC amplifier is shown in Fig. 1, and photographs of the amplifier are shown in Figs. 2–4. The basic amplifier consists of two 6SN7 amplifier stages and a push-pull 6L6(5881) output stage operating Class A.

AGC Action

Between the first and second 6SN7 amplifier stages, V_1 and V_2, is an electronic bridge circuit incorporating a 6SN7 tube, V_2, whose grids are controlled by rectified signal. The variable resistance of this tube provides an automatic electronic variable attenuator. Three separately-acting 6AL5 rectifiers, V_8, V_9, and V_{10}, sense the signal level conditions and automatically control the grids of V_2.

Electronic Bridge Attenuator

The action of the electronic bridge attenuator is as follows: The output of the first amplifier stage, V_1, is fed into the top and bottom of the bridge, a voltage division occurs on the right side of the bridge through 68K and 22K ohm resistors R_1 and R_2 as one leg and 220K resistor R_3 as the other leg. Since R_1 and R_2 total lower resistance than R_{13}, the output voltage at the right side of the bridge will be fed mostly from the top input terminal. As positive dc is applied to the grid of the control tube V_2, its resistance decreases, thus reducing the voltage at the junction of R_1 and R_2 which lowers the output voltage at the right side of the bridge. Exactly the same effect occurs at the left bridge output terminal with respect to input voltage fed to the bottom of the bridge. Since, in a bridge circuit of this type, a linear increase of positive grid voltage produces an exponential reduction of audio output voltage, the control capability is greatly extended and flattened.

Slow Gain Increase-Decrease

It will be noted that two of the three signal rectifiers, V_8 and V_9, are connected in dc opposition.

Rectifier V_8 which produces negative dc control voltage is supplemented with a negative 13-volt threshold so as to bias V_2 to a quiescent static current, which results in a no-signal gain reduction of 10 db. As signal is increased from a very low value, this rectifier starts to cut off V_2, approaching complete cutoff at approximately 10 db below normal input, thus producing approximately 10 db slow gain increase. Just previous to cutoff, as signal level is further increased, the positive dc control rectifier, V_9, overcomes its threshold bias and, since this rectifier involves a series resistance of only 100K ohms, it takes precedence over the negative rectifier, V_8, whose resistance is over 1 megohm. The control tube, V_2, therefore becomes more conductive and slowly reduces gain, as shown in Fig. 5. It may be noted that further action of the negative rectifier circuit, above normal signal level, is clamped by a biased diode, so as to not interfere with the action of the slow-gain decrease circuit. The attack time of the slow-decrease circuit is approximately 20 msec, with a 30-second release time. The attack time of the slow increase circuit is 7 seconds, with a release time of 30 seconds. This characteristic was incorporated so as to simulate the action of a human operator who would cautiously increase a low-level signal yet rapidly decrease an excessive signal.

Fast Gain Decrease

In Fig. 5 it can be seen that the fast-gain decrease action parallels the slow gain increase-decrease action, but at a signal level about 4 db higher. The fast circuit utilizes the same 6SN7 control tube, V_2, as does the slow circuit, but is controlled from a short time constant rectifier (V_{10}). A high peak signal will cause the fast-

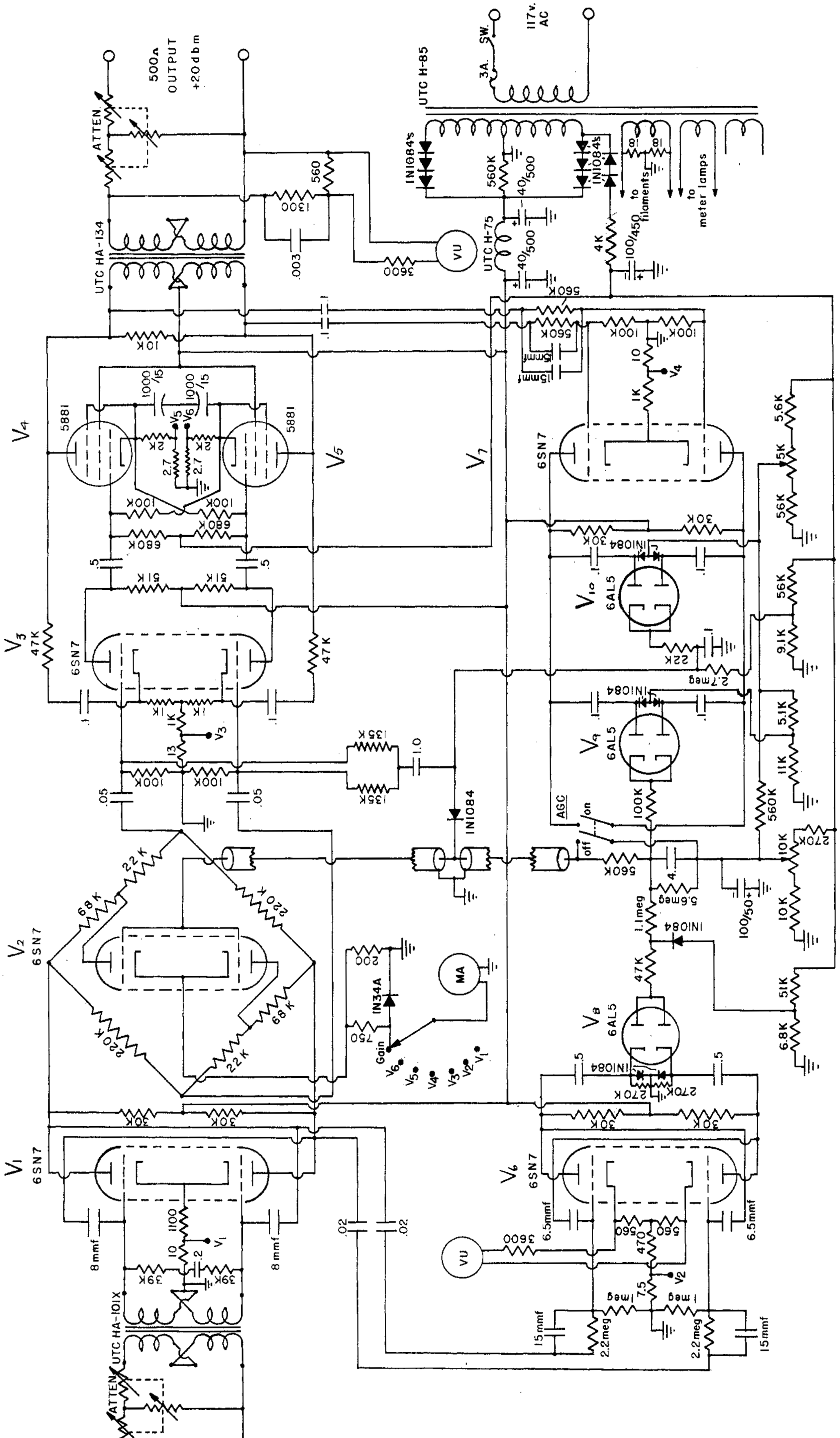

Fig. 1—Amplifier circuit diagram.

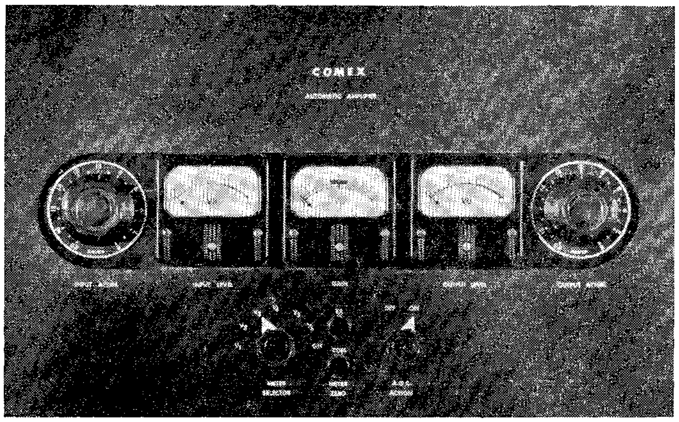

Fig. 2—Amplifier, front view.

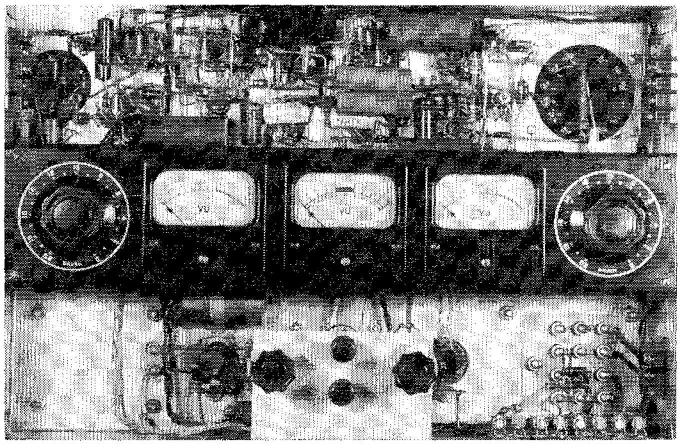

Fig. 3—Amplifier, front view with panel removed.

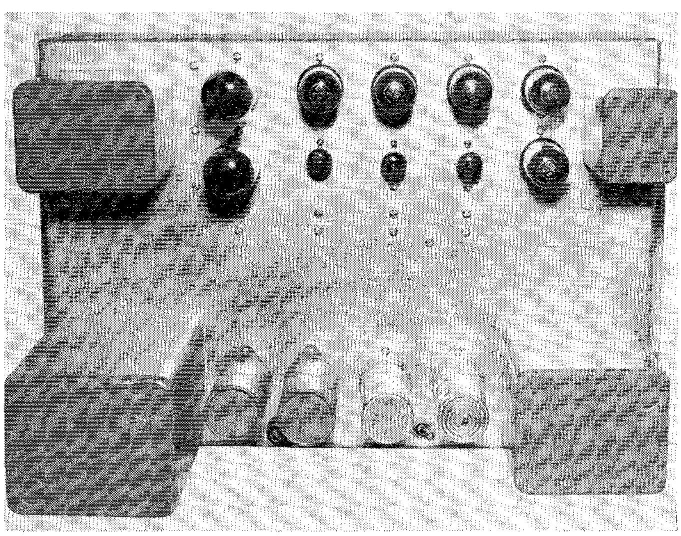

Fig. 4—Amplifier, rear view.

gain decrease circuit to take temporary control from either the slow-increase or slow-decrease circuits, but it is rapidly biased out of operation by the slow-decrease rectifier.

It will be noted that the fast dc surges from the short time constant rectifier are applied to the second amplifier grids through a 1-mfd condenser and 135K ohm dropping resistors; these positive pulses effectively neutralize the negative pulses resulting from fast plate-voltage reduction as the control tube increases plate current. This simple method of "thump" suppression eliminates the costly interstage transformer previously used to prevent parallel negative grid surges in conventional circuits; this condenser also provides the slow recovery time for the fast-decrease circuit. The attack time of the fast-decrease circuit is approximately 3 msec, and the release time if 1.5 seconds.

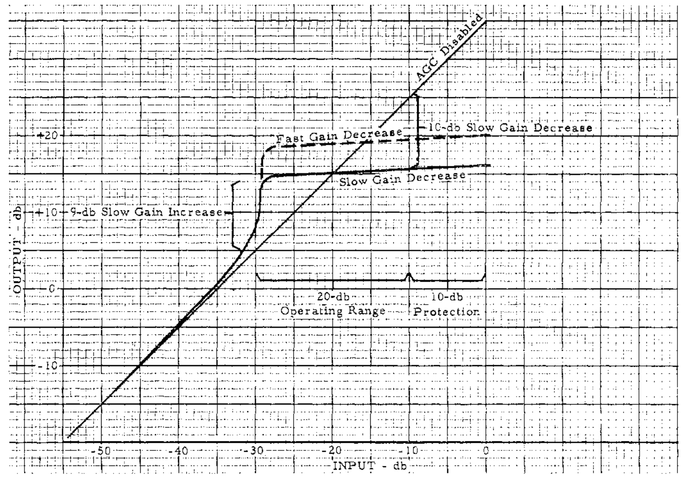

Fig. 5—Performance characteristic of WLW AGC amplifier.

Frequency Response

Frequency response of this unit, under any condition of gain increase or decrease, is essentially flat from 10 cps to 30,000 cps, as shown in the curves of Fig. 6. These extreme specifications were met by careful neutralization of all high-resistance grid circuits and correction for input and output transformer characteristics.

Distortion

Several factors contribute to the very low distortion. Most conventional circuits use the rectified signal to control bias on a low-level stage. This is obviously a departure from proper bias, and reasonable distortion is only possible at very low signal levels. The gain control circuit, herein described, easily maintains distortion less than 0.5 per cent under all conditions of gain control up to 10 db above normal input, as shown in Fig. 7. All signal rectifiers are isolated from amplifier stages by isolation stages V_6 and V_7, so as to isolate rectifier distortion. It will be noted from the circuit diagram that the output amplifier's grid bias resistors return to opposite cathodes and that negative bias is fed directly to the grids through very high resistance (680K ohms), at high negative voltage. This novel arrangement provides nearly perfect balancing of anode current of unmatched tubes, thus reducing dc saturation of the output transformer, resulting in approximately 10 to 1 distortion re-

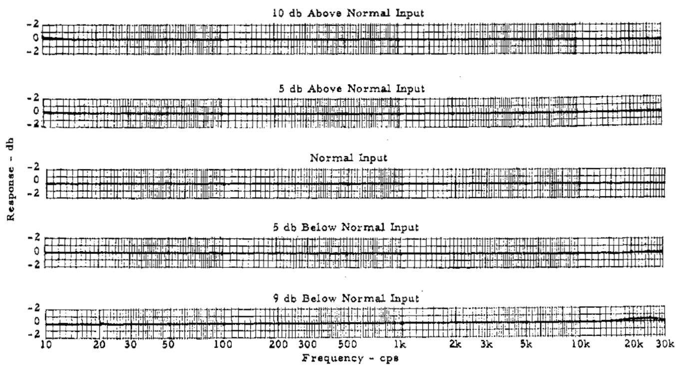

Fig. 6—Frequency response at various input levels.

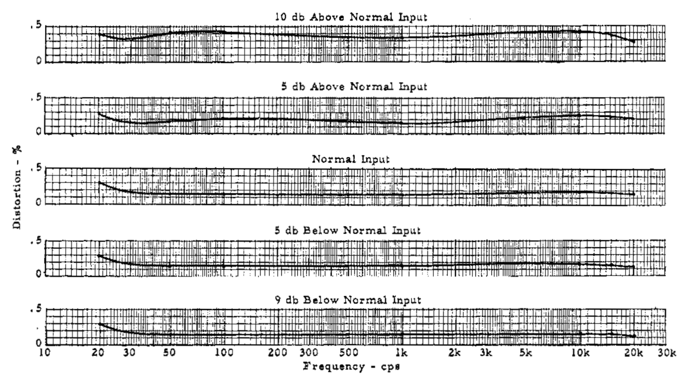

Fig. 7—Distortion at various input levels.

duction at 20 cps. Distortion values in the order of 0.25 per cent are obtained. Functionally, the cathode of a high-current tube will be more positive than the cathode of a low-current tube. With this circuit, the higher positive cathode voltage feeds through the grid resistor to the opposite low-current tube grid, thus increasing its current. Conversely, the cathode of the low-current tube biases the grid of the high-current tube to lower current. This compensating action is improved by using higher than normal cathode resistors in order to effect more dc correction.

Frequencies as low as 20 cycles per second were held within this very low distortion at plus 20 dbm output by using very high (2000 ohms) cathode resistors in the output stage and compensating with positive grid bias. This permit tube currents to balance closely, thus greatly reducing transformer dc saturation. Conventional 330-ohm cathode resistors resulted in 20-cycle distortion near 2 per cent with carefully selected output tubes and random tubes produced much higher distortion.

Operation

The equipment utilizing the circuits described will automatically perform the following functions:

1) Normal input signals cause no change in the slow-increase, slow-decrease, or fast-decrease circuits.

TABLE II

Measured Performance Characteristics

Input Level		
Adjustable, −20 dbm to 0 dbm		
Output Level		
Adjustable, −5 dbm to +15 dbm.		
Frequency Response		
±0.5 db, 10 to 30,000 cps, for any condition of AGC action		
Signal-to-Noise Ratio		
80 db below normal output (AGC Off)		
78 db below normal output (AGC On)		
Harmonic Distortion		
Less than 0.5 per cent for any condition of AGC action		
AGC Action		
Normal input signals cause no change in the slow-increase, slow-decrease, or fast-decrease circuits.		
Low-level signals cause the gain to increase slowly, as needed.		
High-level signals cause the gain to decrease slowly, as needed.		
Slow-gain decrease range:	15 db	
Slow-gain increase range:	9 db	
Fast-gain decrease range:	24 db	
Time Constants		
Slow-gain increase attack time: approximately	7	seconds
Slow-gain increase release time: approximately	30	seconds
Slow-gain decrease attack time: approximately	20	msec
Slow-gain decrease release time: approximately	30	seconds
Fast-gain decrease attack time: approximately	3	msec
Fast-gain decrease release time: approximately	1.5	seconds

2) Low-level signals cause the gain to increase slowly, as needed.
3) High-level signals cause the gain to decrease slowly, as needed.
4) During conditions 1 through 3, occasional peaks result in fast-gain decrease with slow recovery until the slow circuits take precedence.

Setup

The setup for the amplifier is very simple and can be accomplished with a mid-frequency tone source, as follows:

1) Apply mid-range tone and set input meter to 100 per cent with input attenuator.
2) Set selector switch to position GN and AGC switch to "OFF" position and set center meter to zero with control marked "EX."
3) With AGC switch in "ON" position, again set center meter to zero with control marked "COM."

The amplifier is then ready for program use.

The presence of this amplifier in the WLW high-fidelity system is completely undetectable to the ear, yet chart recordings of modulation percentage show a definite higher modulation level as a result of its use, as shown in Fig. 8.

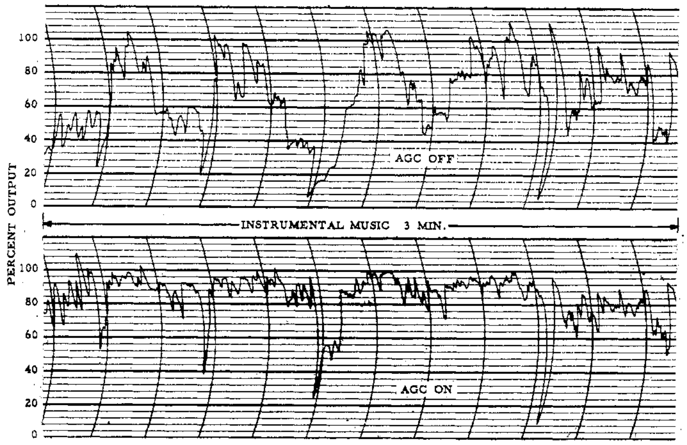

Fig. 8—Chart recording of rectified output.

ACKNOWLEDGMENT

The success of this project was, to a large degree, due to the contribution of Mr. E. B. Dooley, Staff Engineer, Crosley Broadcasting Corp. The first two paragraphs contain portions of memorandum from K. A. Norton to A. D. Ring in May, 1939, incorporated with Mr. Ring's permission.

The Distortion Resulting from the Use of Center-Tapped Transformers in a Class B Power Amplifier*

R. G. DE BUDA†

Summary—**The transformer-coupled Class B amplifier is investigated with regard to harmonic distortion caused indirectly by the self-resonance of the transformer primary. For undistorted Class B operation, the short-circuited flow of even harmonic unbalanced mode currents is essential. When these harmonics are at a frequency at which the transformer primary is close to self-resonance, the flow is impeded and harmonic plate voltages will appear. A slight circuit asymmetry or nonlinearity will permit the harmonic voltages to couple into the load, as harmonic distortion. By a similar effect negative feedback circuits can increase distortion by an amount for which formulas are given.**

INTRODUCTION

In this paper, the push-pull transformer-coupled Class B amplifier of Fig. 1 is discussed, which may, for instance, be used in the final audio stage of a high-level modulated RF transmitter; and a mechanism is investigated by which the transformer causes nonlinear distortion of the output signal.

These nonlinear distortions occur at certain narrow frequency bands at or near the upper end of the audio band, so they are certainly not related to low-frequency saturation effects of the transformer core. The Class B amplifier is assumed to have an ideally linear characteristic. On the surface it would appear that assuming ideally linear elements only, there can be no distortion. But this overlooks the fact that a Class B tube, regardless how "linear," has a sharp nonlinearity at the commutation from cutoff to the conducting state.

If the three-winding transformer in Fig. 1 has a finite leakage inductance between the halves of the primary, then the voltage wave induced across tube 2 by the current flowing through tube 1 will not exactly fit the voltage wave across tube 2 while tube 2 conducts. Thus, the commutation of Class B operation gives rise to quasi-transients which have been reported by Sah in 1936.[1]

* Received by the PGA, February 15, 1960. Presented at the IRE Canadian Convention, Toronto, Can., October 8, 1959.
† Canadian General Electric Co., Ltd., Toronto, Can.

[1] A. P.-T. Sah, "Quasitransients in class B audio frequency push-pull amplifiers," Proc. IRE, vol. 24, pp. 1522–1541; November, 1936.