



Audio Engineering Society,
Box F, Oceanside, N. Y.

AUDIO engineering society

Containing the Activities and Papers of the Society, and published monthly as a part of AUDIO ENGINEERING Magazine

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Automatic Audio Gain Controls

J. L. HATHAWAY*

A discussion of the development and application of program-controlled circuits in broadcasting, with a description of a general-purpose AAGC amplifier in regular use.

THE PURPOSE OF THIS PAPER is to cover briefly the history of Automatic Audio Gain Controls at the National Broadcasting Company. With this equipment line levels may be held more constant, the average level increased many fold, and the listening public—both radio and television—subjected less to sudden drastic changes of sound volume. The new automatic control incorporates a number of improved features as compared to those which are currently employed for adjusting gain as a function of program level, thereby eliminating undue volume fluctuations. Such control equipments are not only called Automatic Audio Gain Controls, or AAGC's but compressors, limiters, program regulators, and a number of other descriptive names, some complimentary and some uncomplimentary. Improper maintenance or operation, as well as unsuitable design, accounts for most of those in the latter category, but judging from the fact that there are in the United States thousands of units giving satisfactory daily service, it is obvious that results are generally well worth while. Even in the field of television, sound transmission is greatly improved through the use of a good AAGC, such as the new Type ND-333.

Early Experiments

Laboratory development of Automatic Audio Gain Control systems has been underway off and on for twenty years, sometimes directed toward solving particular operating problems and other times emphasizing control system improvements. Some of the units developed are relatively complex, while others are extremely simple, such as that shown on Fig. 1. Here a small tungsten filament lamp was connected in a low-im-

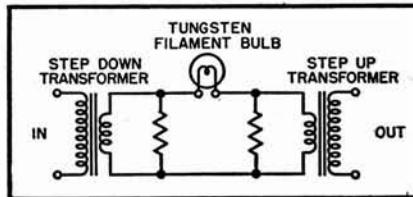


Fig. 1. Earliest form of simple AAGC used in 1929.

pedance circuit so that its resistance variation caused over-all changes of attenuation. Such a tungsten bulb changes resistance by more than 10 to 1, hot to cold, implying a possible attenuation change as great as 20 db. This arrangement *should* be highly effective when preceded by an amplifier of sufficient gain and power handling capacity to heat the filament on program peaks to at least a dull glow. However, its usefulness is restricted by poor timing characteristics. An ordinary small filament has similar heating and cooling thermal lags, and timing determined by these lags has been found completely unsatisfactory for good control. Because heating is *too slow*, around 125 milliseconds, high-level spurts of program are allowed to pass unattenuated and are readily heard. Because cooling is *too fast*, certain desirable program level fluctuations, such as those occurring in speech, are reduced or removed almost completely.

During early experimental work, without known prior art, the importance of utilizing extremely dissimilar gain reduction and gain recovery times was not appreciated. Then in 1934 a circuit was tried having a gain reduction or "attack" time of around 10 milliseconds, together with a recovery time of slightly over one second. After only a short period of careful listening, it was obvious that this combination was superior to anything previously tested, and in fact that first breadboard setup did a worth

while job of controlling gain. Various attack and recovery times were then tried with engineers acting as guinea pigs. When the attack time was greater than about 30 milliseconds, short bursts of high-level peaks were audible, and the over-all effect was not as pleasing as with attack times below 10 milliseconds. In going below 10 milliseconds, there was no appreciable change in over-all effect until the attack time was made less than 200 microseconds. With such a short attack time, the sound quality was the same as that for a time of around 1 millisecond, but on programs of local origin the level was appreciably lower due to extreme crests of high-frequency peaks causing greater gain reduction. The *recovery* time most desirable seemed a matter of properly fitting the particular application. Where greatest possible average level was desirable, rapid recovery—around 1/3 second—seemed best. Where least noticeable effect by the automatic action was called for, a recovery time somewhat greater than 1 second seemed preferable.

Early Application

Shortly after the initial experimentation on time constants, a number of rack mounted units were constructed and placed in service in New York, Cleveland, and Chicago. Some of these served to regulate levels in automatic announce booths whereby news flashes could be placed on the air without waiting for control engineers to reach the studios. Others were for use on regular studio or field pickup programs to aid and supplement the control engineer's efforts in feeding proper level onto the telephone lines. Also a portable unit was used with great effectiveness in the gondola of the stratosphere balloon during its record-breaking flight in 1935, and by the following year we were getting

*National Broadcasting Company, New York.

Automatic Audio Gain Control systems into our special events beermug and pack transmitter designs. Since then, more or less hand-tailored controls have been employed in a wide variety of applications, including television sound and broadcast transmitters, disc recorders, tape recorders, film recorders, and field and studio amplifiers. Many of these units have different characteristics, sometimes because of the nature of the application, and sometimes because of the difficulties involved in building circuits with optimum characteristics in portable equipment.

Characteristics and Measurements

Many characteristics of Automatic Audio Gain Control—such as frequency response, input and output impedance, signal-to-noise ratio, and harmonic distortion—are similar to those of ordinary amplifiers. It is essential in the measurement of some of these either to block out the control circuit or else to employ a signal level which is safely below the threshold of control. Measurements of recovery and attack times require radically different technique. Recovery time may be determined by watching a VU meter connected to the output of the unit under test and measuring time for it to reach steady state reading after suddenly reducing to normal a tone signal which has been 10 to 20 db above normal. Attack time is readily determined by means of an oscilloscope, preferably one equipped with a P7 screen and a triggered single-sweep circuit. Here, the scope is connected to the output of the Automatic Audio Gain Control and tone applied to the input at just under threshold level. This level is suddenly increased (usually by 6 to 20 db), and the scope displays the over-all effect. Figure 2 is a drawing made from typical oscilloscope patterns, (A) showing a good AAGC in proper adjustment, and (B) showing either a good one far out of adjustment or a poor one even at its best adjustment. The drawings show tone applied at just under threshold control level, followed at time 0 milliseconds by a 12 db increase. At (A), perfect balance results in complete cancellation of all "thump" or "plop" component, the signal being symmetrical about the axis. After about 1 millisecond, complete stability is reached at a level some 2 db above that at the start. (B) illustrates a condition of misbalance, the dotted line average representing a severe plop component above the axis and lasting for many milliseconds. A plop of this magnitude is readily audible and has a secondary effect—also audible—of depressing the gain to a subnormal level because of the excessive control potential caused by the misbalance. Thus, for a large fraction of a

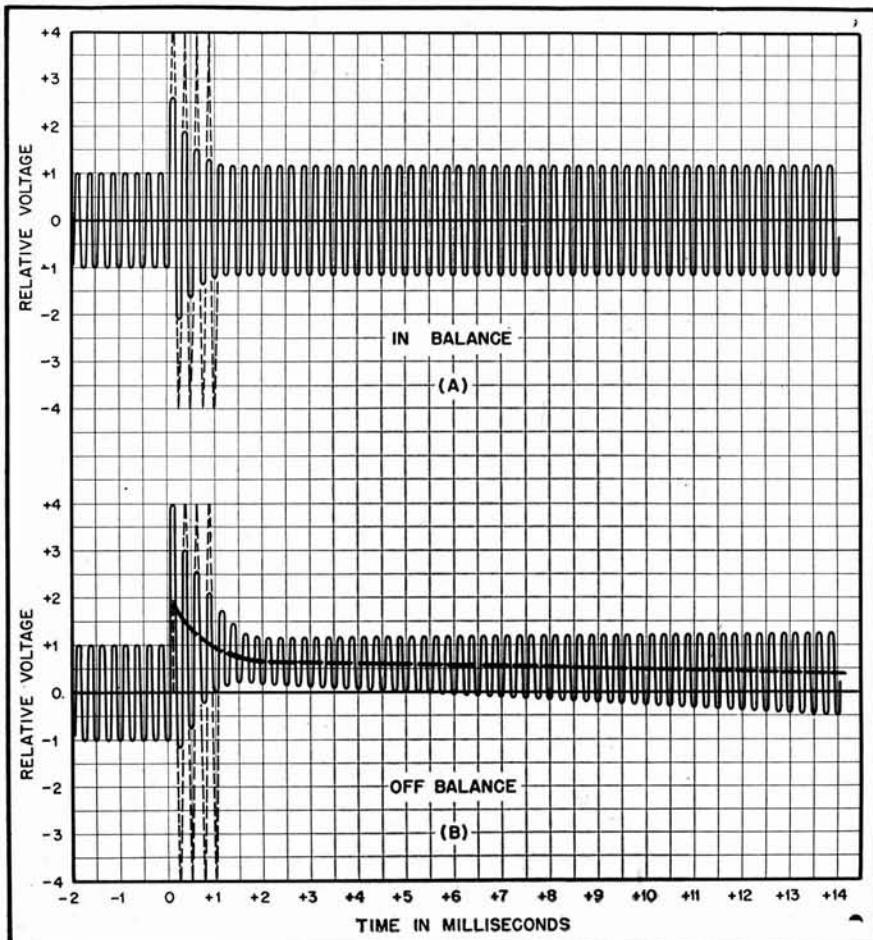


Fig. 2. Drawing made from typical 'scope patterns to show effect of "plop" generation. (A) shows signal passing through well-balanced amplifier as a result of an increase in level of 12 lb. (B) shows same signal passing through a poorly balanced amplifier, resulting in an average value differing from the axis, or zero.

second, depending upon the recovery time, the *high-level* input peak has actually caused a *low-level* output. Complete stability should be reached within the recovery time, although this is not shown in the figure.

Unbalances of push-pull tubes or circuit components are responsible for plop generation. Its seriousness in relation to program is obviously a function of program level at the controlling tubes. Thus a given misbalance with low program level might be quite objectionable, whereas it would be completely insignificant if the tubes were operated at higher program level. Therefore, in good AAGC design, with given tube parameters, the program level at the threshold of control must be as high as possible in order to minimize plop. At the same time, it cannot be excessive, since harmonic distortion becomes equally objectionable.

Control Characteristic

"Control Characteristic" refers to the effectiveness of an Automatic Audio

Gain Control in reducing excessive level variations assuming no undue wave form distortion or plop generation. Figure 3 illustrates three different types of control characteristics. Where complete high-level limitation is called for, as at a broadcast transmitter, it is desirable to utilize a so-called "limiter" characteristic, curve 3. Something less drastic, such as the modified limiter of curve 1, should be employed as a supplementary aid to a control operator, and the unit should, in this application, be located in the circuit following the manual controls, but preceding the volume indicator and loudspeaker so that the operator sees and hears the combination of both manual and automatic control. For operatic and symphonic programs intended for music lovers, the control effect should be much less, as in the so-called "Compressor" characteristic of curve 2.

Amount of Gain Reduction

A common question related to Automatic Audio Gain Control application is "How much gain reduction?" This is

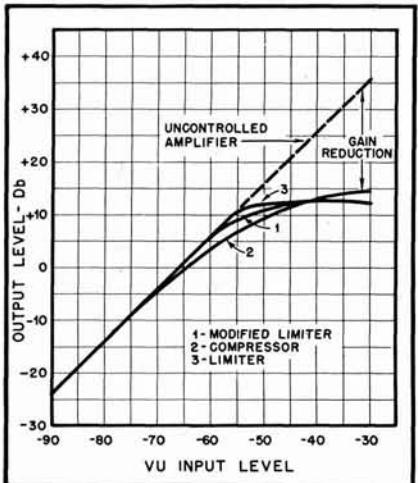


Fig. 3. Typical control characteristics obtained in various forms of automatic amplifier circuits.

not a simple question and a simple reply is too incomplete, some applications calling for greater gain reduction than others. For example, where no manual control is exerted, the extreme input variations can at times account for as much as 20 db of gain reduction. Controls at broadcasting transmitters are not normally subjected to such extreme variations, since manual control has been previously exerted, but even so, surprisingly large variations do exist, as a result of different control operators, different types of programs, and different amounts of telephone lines. This was pointed out two years ago in data taken to chart these variations at our N. Y. broadcasting station. With all adjustments fixed, the number of gain reduction peaks and their amplitudes were counted by a two-man team for several ten-minute periods throughout the day and evening and the results tabulated. Three of these periods are charted on Fig. 4. Two of them depict extremes and

show a surprising difference, the one from Hollywood obviously having passed through a long-peak-ironer before arriving in N. Y. This ironer was more effective some days than others, but generally functioned in dual manner. First it slightly compressed all extremely high levels at each of many repeaters. Second, it eliminated all frequencies above 5 kc, thus accounting for much of the difference between average and peak potentials.

Use With Pre-emphasis

The use of Automatic Audio Gain Control in disc recording circuits has been found highly advantageous because it permits increased level with corresponding improvement in signal-to-noise ratio and at the same time provides for greater reliability. Where the NAB recording characteristic is utilized, a rather special condition results, calling for a special control. In recording with this characteristic, high frequencies are electrically pre-emphasized by a circuit of 100 microseconds time constant, meaning about a 10-db rise at 5 kc and a 16-db rise at 10 kc. If the automatic control is located in the circuit after pre-emphasis, all peaks, including those occasionally caused by extreme high frequencies, are eliminated, which might seem desirable. However, listening tests indicate that this is far from desirable because the program gain control becomes highly unsatisfactory whenever extreme highs exist. This is caused by the level ducking unpredictably during some of the highest passages at the very time the ear expects greatest level. That is, the medium-frequency components which largely determine loudness are suddenly depressed just when they should be the strongest. This condition does not prevail if the Automatic Control is operated prior to pre-emphasis in the circuit. In

this situation a different degradation occurs in the form of occasional high-frequency cross modulation due to overloading by the pre-emphasized components, especially so because of the usual high-frequency recording and reproducing troubles. There is no general rule as to which is the lesser of these two evils, since each leads to degraded sound reproduction. However, tests and usage over many years have shown that a midway condition is entirely satisfactory. For such an arrangement the Automatic Audio Gain Control may be located either ahead of or following the pre-emphasis, whichever is the more convenient. If *ahead*, the amplifier within the AAGC unit feeding potential to the rectifier should be "half way" pre-emphasized. If *following*, the rectifier-amplifier should be de-emphasized "half-way," or about 8 db at 10 kc. This latter arrangement works out very easily in most cases through the use of a single small capacitor shunting the side amplifier or rectifier feed circuit.

To be concluded next month

BALTIMORE GROUP TO MEET SEPT. 6

The Baltimore Audio Engineering Association will meet on September 6 at 8:00 p.m. in the Academy Room of the Emerson Hotel. The main feature of the evening will be a lecture and demonstration by Melvin C. Sprinkle, sponsored jointly by the Peerless Electrical Products division of Altec Lansing Corporation and the Wholesale Radio Parts Co., Baltimore jobbers.



Employment Register

POSITIONS OPEN and AVAILABLE PERSONNEL may be listed here at no charge to industry or to members of the Society. For insertion in this column, brief announcements should be in the hands of the Secretary, Audio Engineering Society, Box F, Oceanside, N. Y., before the fifth of the month preceding the date of issue.

• **Audio Technician.** Employed in audio field at present; experienced in development and construction. Enthusiastic, good troubleshooter and maintenance man; wide knowledge of serious music. Desire position in studio, lab, or custom installation firm. Box 801.

• **Audio, TV Field Engineer.** 10 yrs practical experience in maintenance of professional audio, TV, and radar equipment; design and maintenance custom home music systems. Member AES; Assoc AIEE. Good tech. educ. bkgnd; exc. references; exp. customer relations; extremely conscientious. Presently mgr. TV service lab and field service technician, electronic organs: Desire field work hi-fi audio or TV. Prefer Washington, D. C. area; consider other. Box 701.

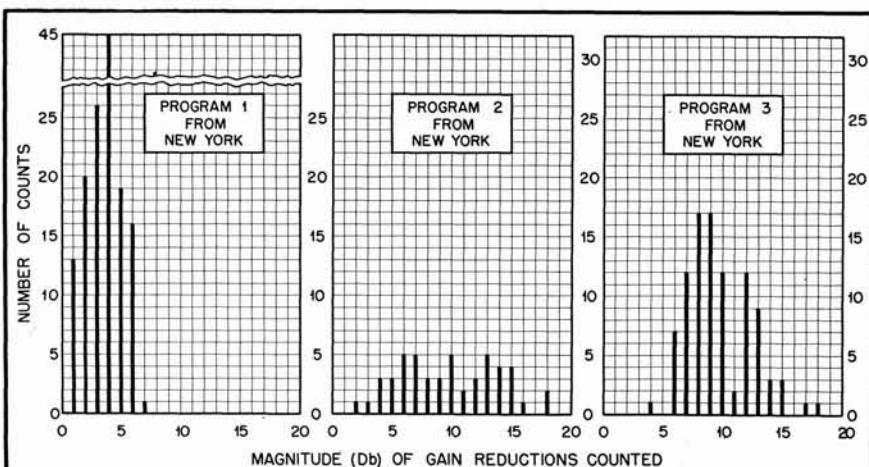


Fig. 4. Actual counts of gain reduction peaks occurring in programs from different sources.



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Automatic Audio Gain Controls

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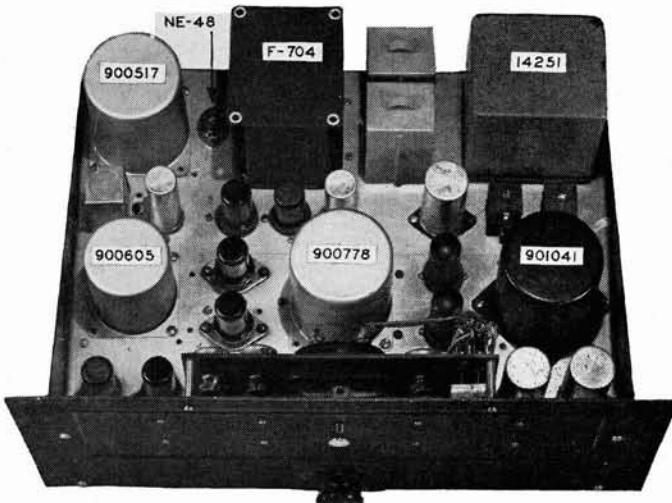
A discussion of the development and application of program-controlled circuits in broadcasting, with a description of a general-purpose AAGC amplifier in regular use.

MANY OF THE AAGC's in service are necessarily of compromise design. For example, in extremely portable battery-operated equipment, such as radio mikes or pack transmitters, it is hardly practical to utilize all of the refinements of a high-quality studio control unit. A tiny transmitter cannot devote sufficient filament power or bulk to push-pull control tubes and balancing transformers so that a single-sided system is generally used. This leads to a condition of regeneration or degeneration, depending on the number of stages, and also to creation of severe plop components. The general cure for both of these ailments is the same—the use of an extremely slow attack time around 50 to 100 milliseconds. Although it might seem that this would render the control virtually useless, such is not the case. Tests on high-level input to units incorporating even this imperfect control show that great benefit is derived as compared to similar equipments without any form of automatic control. Without the control, overmodulation becomes serious and causes the "rasping" type of distortion which is disagreeable and at the same time intelligibility is reduced. With the control, the rasping distortion is eliminated, and quality, except for a few slight plops, is generally good. Furthermore, average level may be increased many db when the AAGC is employed.

Dual Controls

Applications wherein extremely wide level variations are likely to occur call for double-action control. Our studio units are of this type and some of these are used without manual assistance as, for example, in news flash booths. The philosophy leading to the development of these dual controls was basically as

Fig. 5. Top view of ND-333 AAGC amplifier.



follows: with normal input, a limiter type of control would be thoroughly satisfactory. But suppose a speaker were close to the microphone and also had louder-than-normal voice—the microphone output might easily be 20 db or so above normal. This condition frequently exists in practice, especially when the speaker must override a high ambient acoustical noise level. Thus, peak gain reductions of 20 to 22 db are not uncommon, and this is too much for an ordinary limiter since gain rises too rapidly during slight pauses, producing a continual rising and falling effect which removes syllable emphasis and creates an unnatural and displeasing sound. If, however, control adjustment were made slowly in the microphone circuit ahead of the limiter, the rapidly rising gain during pauses would be evident only during the first few spoken words, that is, during the transition period prior to attenuation of average level by the first circuit. Thereafter the input level would be held down to just slightly above normal. If long pauses existed, the input would slowly restore gain towards maximum. Thus the func-

tioning of such a double circuit might be likened to a person's neck and eye action wherein he glances only with the eyes at objects which are to be viewed but momentarily. When prolonged viewing is called for, the neck automatically turns to relieve the eyes of most of their displacement after which the eyes are in better position for continued viewing. The slow averaging of the dual control is thus similar to neck action, whereas the rapid limiting is similar to eye action.

Units employing two controlled stages have served satisfactorily in studio operations for the past twelve years. These operate with the first stage functioning on average level. The second stage, having a rapid attack time, is always available for conventional limiting. Recently, in order to simplify and further improve this double action, designs have utilized a double-time-constant circuit operating in a single controlled stage. Here two radically different time constant RC circuits are operated in series in such manner that a small capacitor is quickly charged by a single peak in the control rectifier. A much larger capacitor is slowly charged, requiring many peaks to

* National Broadcasting Company, New York.

accumulate an appreciable charge. But if a high signal level persists for a sizable fraction of a second, the voltage across the larger capacitor becomes equal to or even greater than that across the smaller, due to the ratio of discharge resistors. Therefore, after only a few short program bursts, most of rectified control potential appears across the small capacitor and recovery rate is rapid—about 0.5 second for 90 per cent recovery. However, after continued peaks most of the rectified potential accumulates across the large capacitor, allowing the rapidly acting circuit to relax in its activity. The resulting recovery rate after prolonged peaks is relatively slow—about 2 seconds for 50 per cent recovery and 8 to 12 seconds for 90 per cent recovery. Again it should be brought out that limiting action, with this type of double time constant circuit, is always available for holding down unduly high level peaks. Such a dual control is desirable for any of the various applications where extreme portability is not required.

The most recent AAGC developed at NBC, Type ND-333 studio control unit, is pictured on Fig. 5. It is operated in place of a regular studio amplifier, having sufficient gain for operation between the mixer output and the program bus.

It has a maximum voltage gain of 81 db, will control programs at as low as -75 VU, and has a maximum output power of around 4 watts at 15 ohms impedance. It is a rack mounted unit, powered from either a house battery supply or the 115-volt a.c. line. All controls except the meter switch are located behind the hinged front panel door in order to reduce the likelihood of undue tampering.

Three different control characteristics are remotely selectable to suit the particular program material, two relays mounted on the chassis providing for this remote selection. The *modified limiting* characteristic previously described is used for all programs of local origin, with the exception of symphony and opera. For these, the *compression* characteristic is available. The *nemo* or *limiting* characteristic is for the programs from outside the studio where the program has previously undergone automatic gain control. Thus, no additional control is introduced for normal level peaks. To achieve this, a connection may be made at the control console's *nemo* switch in order to select automatically this *nemo* characteristic for outside programs, causing the unit to act like an ordinary amplifier unless some unreason-

ably high peak occurs in the program.

The two controlled tubes in this particular unit are 6SA7's, which should be properly balanced for transconductance. Assuming normally good tubes, this balance is readily achieved by means of a balance checking switch and adjusting system. When the balance switch is pressed, a 60-cps signal is applied in phase to the control grids of the 6SA7's, and the balance potentiometer may be adjusted for minimum output meter reading. Balance checks by this means show that ordinary tubes give excellent balance and produce no audible plop or any discernible dissymmetry on an oscilloscope. Furthermore, correct balance produces the condition of minimum harmonic distortion as indicated on a distortion meter.

Above 50 cps, distortion is extremely low, even for conditions of high input levels and gain reduction. Measured curves are shown on Fig. 6, and these are representative of ordinary good tubes.

After reaching what was believed to be the stage of complete development, one of these controlled amplifiers was placed in studio operation and used on a great many different N. Y. programs with excellent results. Then a complaint

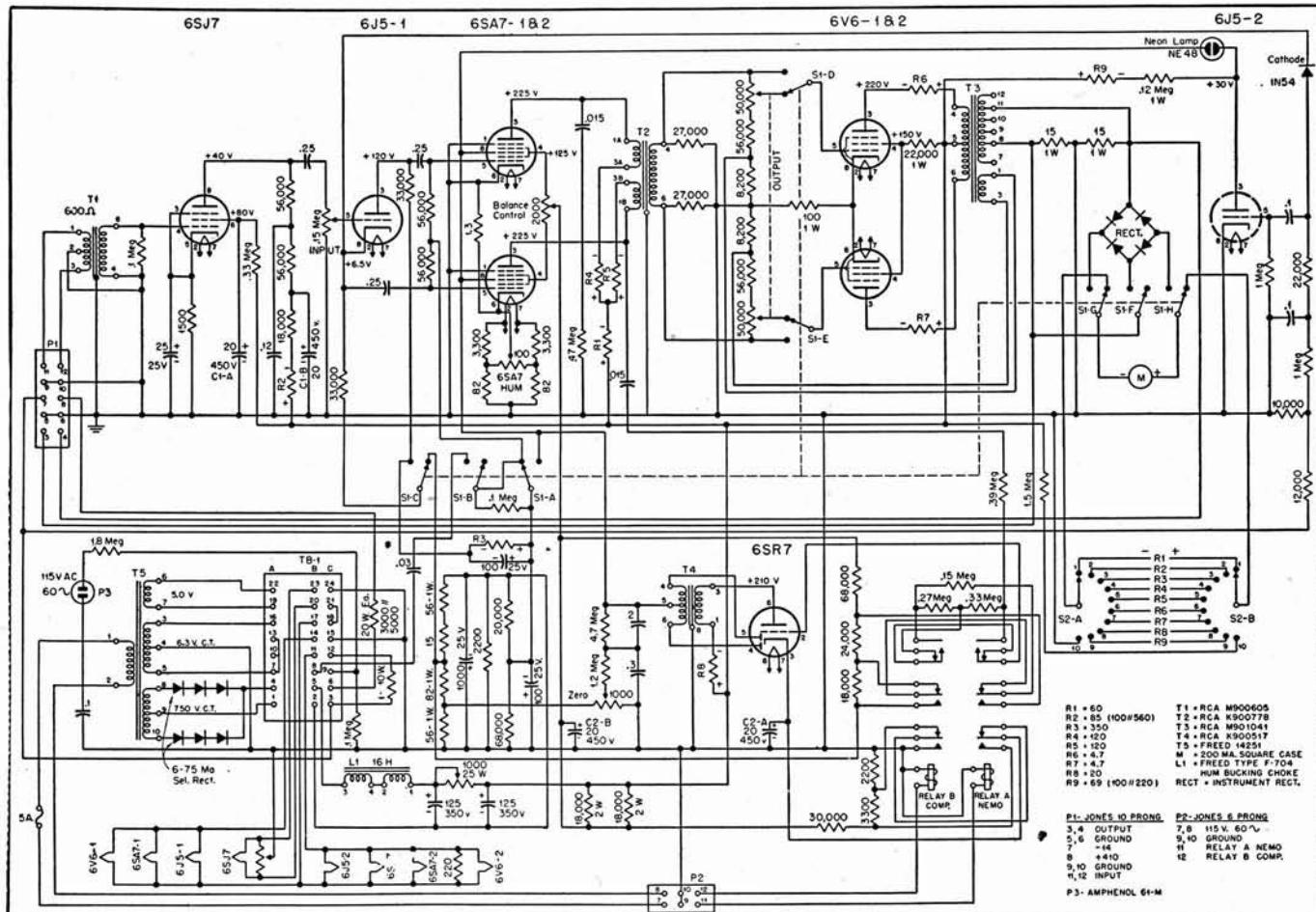


Fig. 7. Complete schematic of ND-333 Automatic Audio Gain Control Amplifier.

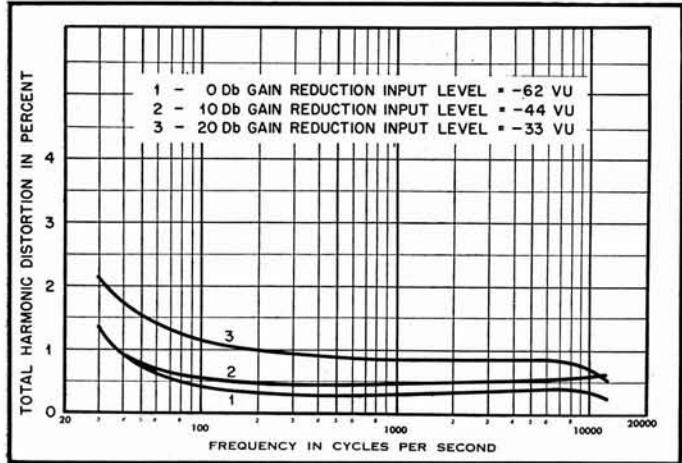


Fig. 6. Harmonic distortion curves for ND-333 amplifier under different operating conditions.

was received which could not be overlooked. The producer on one of the dramatic shows believed that the unit was holding pistol shots down too low in level. He liked its action otherwise but wanted to hear the sound-effect shots louder and have them indicate full scale on the VU meter—the engineer had always been able to achieve this without the automatic control. He agreed that the broadcasting station limiter would reduce most of the excessive peak level but still wanted a more realistic effect in the control and clients booths. Therefore, a short study of pistol shot acoustical characteristics was conducted by viewing oscilloscope patterns. The main portion of the pistol shot proved to be extremely short, in the order of 15 milliseconds. Such a short burst at normal amplitude does not sound loud, nor does it register fully on a VU meter. In order to make it indicate and sound full, the amplitude must be increased several fold. With this in mind, a special circuit was invented and installed in the unit to create the desired effect. Figure 7 is a complete schematic of the ND-333 AACG, showing the pistol shot accentuating circuit at the upper right portion. A crystal rectifier converts a sample of the high-intensity sound potential to a negative d.c. pulse which is coupled to the grid of a triode amplifier. The crystal is biased to conduct only when the input level is 24 db above threshold, a condition existing only on pistol shots as far as we can determine, assuming some degree of manual control. The negative pulse on the grid results in a positive plate pulse, which in turn ignites the neon lamp and momentarily decommissions the control circuit.

ND-333 Application

The new studio control unit is highly effective and multifold in purpose. It permits 6- to 8-db higher average output onto the telephone lines feeding both

the local and remote broadcast transmitters. It permits a more even over-all control of level, and unless its action is purposely overridden by the control engineer, makes it unnecessary for millions of listeners to continually jump to adjust the volume controls on millions of radio receivers throughout the country. It gives improved television sound through increased transmission level and uniformity. It prevents excessive levels on telephone long lines, which otherwise cause severe distortion. Broadcasters sometimes feel that the long-lines personnel are supercritical of level. It must not be too high or too low or they call master control to insist on something being done about it. At Radio City some of these AACG units have been available for just this type of emergency. An engineer on a complicated show may have ten or more microphones to keep properly mixed—a producer shouting instruction, a script to follow, and in addition a PA system to control as well as over-all output level. When "long lines" calls master control and they in turn call this one-armed paper hanger two or three times to bring up level or hold down peaks, he becomes slightly confused. Then, in the deliberate atmosphere of the transmission room, someone says "Here's a rubber amplifier for him," silently inserting patch cords to replace the uncontrolled studio amplifier. Calm returns to the master control room, no more calls come from the supercritical long liners, and in the control booth the operator suddenly has no more trouble delivering a sufficiently high level without the VU meter hitting hard off scale. Above all, thanks to Automatic Audio Gain Control, the listener whose baby sleeps upstairs hears every word of his favorite program without worry of a floor walking session.

In conclusion, a great deal of credit and thanks should go to Mr. Raymond Lafferty of the NBC Engineering Development Group for his skill and diligence in the development and application of the ND-333.



Employment Register

EMPLOYMENT OPPORTUNITIES may be listed here at no charge to industry or to members of the Society. For insertion in this column, brief announcements should be in the hands of the Secretary, Audio Engineering Society, Box F, Oceanside, N. Y. before the first of the month preceding the date of issue. Replies to box numbers should be addressed to AUDIO ENGINEERING, 342 Madison Ave., New York 17, N. Y.

★ Positions Open

● Positions Wanted

★ BRAZIL: We have an opening for an electronic engineer who would like to come to Brazil and become a partner in an old established high-class service organization. Want man with all around knowledge of receivers, amplifiers, test equipment, electronic heating, and general application of electronics. Capital required, about \$5000. São Paulo is the fastest growing city in South America. Genial climate. Food plentiful. Assured future for a good man of about 30. Knowledge of Portuguese not essential. References exchanged. Box 1001.

★ Wireman, instrument, capable of building models and occasional short production runs of precision electronic devices. Must be able to work with minimum of supervision. Permanent; write giving salary expected, family status, availability. Box 1002.

★ WANTED: Signal Corp Center, Fort Monmouth, N. J. has openings in the following Civil Service positions:

Military Instructors—Microwave relay, radar, radio electronics, fixed station radio, central office techniques, teletype installation and maintenance, repeater and carrier, dial central office maintenance, theory of electricity. \$3100-4600.

Electronic Engineers—Participate in design, development, modification, construction, and testing of electronic equipment—radio, radar, wire communications, instrumentation, sonar, etc. Responsibility depending upon experience and ability. \$3100-6400.

Technical Writers—Write, edit, prepare technical publications, handbooks, circulars, instruction books, etc. Edit and revise scientific manuscripts on radio, radar, electronics, communications, and photography. Write instruction manuals on theory, operation, and maintenance of Signal Corps equipment; determine media and method of presentation of material; prepare charts, graphs, schematic diagrams etc. \$3100-5400.

Applicants for any of these positions should write Chief, Civilian Personnel Branch, Signal Corps Center, Fort Monmouth, N. J., submitting a completed Standard Form 57, "Application for Federal Employment" (obtainable at any first or second class post office) for review before going to Fort Monmouth for a personal interview.