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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.

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-impedance 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.

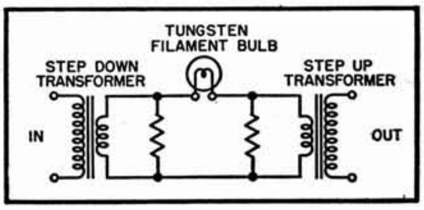

Fig. 1. Earliest form of simple AAGC used in 1929.

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 breadbroad 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 progams 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

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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 charactetristics, 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 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.

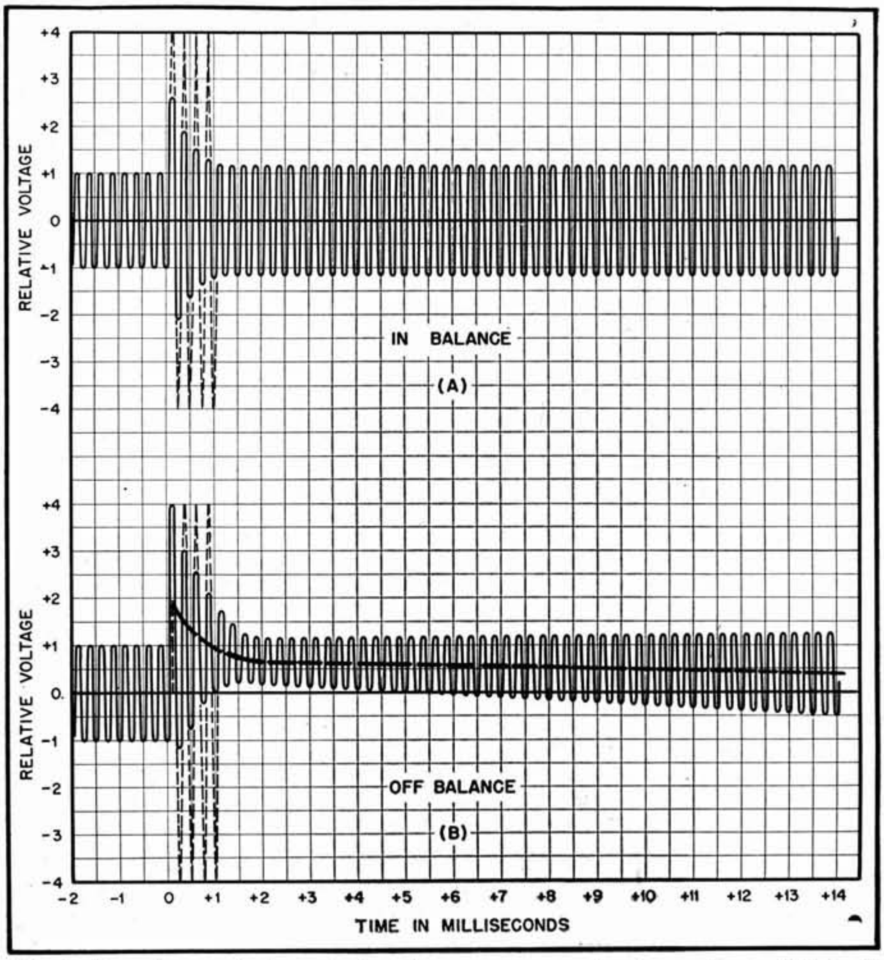

Fig. 2. Drawing made from typical 'scope patterns to show effect of "plop" generation. (A) shows signal passing through well-balanced amplifier as a result of an increase in level of 12 lb. (B) shows same signal passing through a poorly balanced amplifier, resulting in an average value differing from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

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