BBC

ENGINEERING DIVISION

MONOGRAPH

NUMBER 77: MARCH 1969

The Automatic Control of Sound-signal Level in Broadcasting Studios

by

D. E. L. SHORTER, B.Sc.(Eng.), F.I.E.E.

W. I. MANSON, B.Sc.(Eng.)

(Research Department, BBC Engineering Division)

BRITISH BROADCASTING CORPORATION

PRICE FIVE SHILLINGS

BBC ENGINEERING MONOGRAPH

No. 77

THE AUTOMATIC CONTROL OF SOUND-SIGNAL LEVEL IN BROADCASTING STUDIOS

by

D. E. L. Shorter, B.Sc.(Eng.), F.I.E.E.

W. I. Manson, B.Sc.(Eng.)

(Research Department, BBC Engineering Division)

MARCH 1969

BRITISH BROADCASTING CORPORATION

FOREWORD

THIS is one of a series of Engineering Monographs published by the British Broadcasting Corporation. About six are produced every year, each dealing with a technical subject within the field of television and sound broadcasting. Each Monograph describes work that has been done by the Engineering Division of the BBC and includes, where appropriate, a survey of earlier work on the same subject. From time to time the series may include selected reprints of articles by BBC authors that have appeared in technical journals. Papers dealing with general engineering developments in broadcasting may also be included occasionally.

This series should be of interest and value to engineers engaged in the fields of broadcasting and of telecommunications generally.

Individual copies cost 5s. or 5s. 9d. by post, while the annual subscription is £1 post free. Orders can be placed with newsagents and booksellers, or BBC PUBLICATIONS, 35 MARYLEBONE HIGH STREET, LONDON, W.1.

CONTENTS

PREVIOUS ISSUES IN THIS SERIES

No.	Title	Date
1.	*The Suppressed Frame System of Telerecording*	JUNE 1955
2.	*Absolute Measurements in Magnetic Recording*	SEPTEMBER 1955
3.	*The Visibility of Noise in Television*	OCTOBER 1955
4.	*The Design of a Ribbon Type Pressure-gradient Microphone for Broadcast Transmission*	DECEMBER 1955
5.	*Reproducing Equipment for Fine-groove Records*	FEBRUARY 1956
6.	*A V.H.F./U.H.F. Field-strength Recording Receiver using Post-detector Selectivity*	APRIL 1956
7.	*The Design of a High Quality Commentator's Microphone Insensitive to Ambient Noise*	JUNE 1956
8.	*An Automatic Integrator for Determining the Mean Spherical Response of Loudspeakers and Microphones*	AUGUST 1956
9.	*The Application of Phase-coherent Detection and Correlation Methods to Room Acoustics*	NOVEMBER 1956
10.	*An Automatic System for Synchronizing Sound on Quarter-inch Magnetic Tape with Action on 35-mm Cinematograph Film*	JANUARY 1957
11.	*Engineering Training in the BBC*	MARCH 1957
12.	*An Improved 'Roving Eye'*	APRIL 1957
13.	*The BBC Riverside Television Studios: The Architectural Aspects*	JULY 1957
14.	*The BBC Riverside Television Studios: Some Aspects of Technical Planning and Equipment*	OCTOBER 1957
15.	*New Equipment and Methods for the Evaluation of the Performance of Lenses for Television*	DECEMBER 1957
16.	*Analysis and Measurement of Programme Levels*	MARCH 1958
17.	*The Design of a Linear Phase-shift Low-pass Filter*	APRIL 1958
18.	*The BBC Colour Television Tests: An Appraisal of Results*	MAY 1958
19.	*A U.H.F. Television Link for Outside Broadcasts*	JUNE 1958
20.	*The BBC's Mark II Mobile Studio and Control Room for the Sound Broadcasting Service*	AUGUST 1958
21.	*Two New BBC Transparencies for Testing Television Camera Channels* (*Out of Print*)	NOVEMBER 1958
22.	*The Engineering Facilities of the BBC Monitoring Service*	JANUARY 1959
23.	*The Crystal Palace Band I Television Transmitting Aerial*	FEBRUARY 1959
24.	*The Measurement of Random Noise in the presence of a Television Signal*	MARCH 1959
25.	*A Quality-checking Receiver for V.H.F. F.M. Sound Broadcasting*	JUNE 1959
26.	*Transistor Amplifiers for Sound Broadcasting*	AUGUST 1959
27.	*The Equipment of the BBC Television Film Studios at Ealing*	JANUARY 1960
28.	*Programme Switching, Control, and Monitoring in Sound Broadcasting*	FEBRUARY 1960
29.	*A Summary of the Present Position of Stereophonic Broadcasting*	APRIL 1960
30.	*Film Processing and After-processing Treatment of 16-mm Films*	MAY 1960
31.	*The Power Gain of Multi-tiered V.H.F. Transmitting Aerials*	JULY 1960
32.	*A New Survey of the BBC Experimental Colour Transmissions*	OCTOBER 1960
33.	*Sensitometric Control in Film Making*	DECEMBER 1960
34.	*A Mobile Laboratory for UHF and VHF Television Surveys*	FEBRUARY 1961
35.	*Tables of Horizontal Radiation Patterns of Dipoles Mounted on Cylinders*	FEBRUARY 1961
36.	*Some Aspects of Optical Lens Performance*	APRIL 1961
37.	*An Instrument for Measuring Television Signal-to-noise Ratio*	JUNE 1961
38.	*Operational Research on Microphone and Studio Techniques in Stereophony*	SEPTEMBER 1961
39.	*Twenty-five Years of BBC Television*	OCTOBER 1961
40.	*The Broadcasting of Music in Television*	FEBRUARY 1962
41.	*The Design of a Group of Plug-in Television Studio Amplifiers*	APRIL 1962
42.	*Apparatus for Television and Sound Relay Stations*	JULY 1962
43.	*Propagational Factors in Short-wave Broadcasting*	AUGUST 1962
44.	*A Band V Signal-frequency Unit and a Correlation Detector for a VHF/UHF Field-strength Recording Receiver*	OCTOBER 1962
45.	*Vertical Resolution and Line Broadening*	DECEMBER 1962
46.	*The Application of Transistors to Sound Broadcasting*	FEBRUARY 1963
47.	*Vertical Aperture Correction using Continuously Variable Ultrasonic Delay Lines*	MAY 1963
48.	*The Development of BBC Internal Telecommunications*	MAY 1963
49.	*Apparatus for Measurement of Non-linear Distortion as a Continuous Function of Frequency*	JULY 1963
50.	*New Methods of Lens Testing and Measurement*	SEPTEMBER 1963
51.	*Radiophonics in the BBC*	NOVEMBER 1963
52.	*Stereophony: the effect of cross-talk between left and right channels*	MARCH 1964
53.	*Aerial distribution systems for receiving stations in the l.f., m.f., and h.f. bands*	JULY 1964
54.	*An Analysis of Film Granularity in Television Reproduction*	AUGUST 1964
55.	*A Review of Television Standards Conversion*	DECEMBER 1964
56.	*Stereophony: the effect of interchannel differences in the phase/frequency and amplitude/frequency characteristics*	DECEMBER 1964
57.	*Drop-out in Video-tape Recording*	JUNE 1965
58.	*Sine-squared pulse and bar testing in colour television*	AUGUST 1965
59.	*The acoustic design and performance of a new free-field sound measurement room*	SEPTEMBER 1965
60.	*Colorimetric Analysis of Interference in Colour Television*	FEBRUARY 1966
61.	*Sporadic E Ionization and Television Interference*	MARCH 1966
62.	*Automatic monitoring*	APRIL 1966
63.	*The design of transmission lines and single-stage switching circuits for a line-store standards converter*	AUGUST 1966
64.	*Data for the acoustic design of studios*	NOVEMBER 1966
65.	*Tristimulus spot colorimeter*	DECEMBER 1966
66.	*VHF aerial gain calculation using tables of mutual resistance between the radiating elements*	FEBRUARY 1967
67.	*Pulse sound: A System of Television Sound Broadcasting Using Pulses in the Video Waveform*	MARCH 1967
68.	*Recent research on studio sound problems*	JULY 1967
69.	*A Survey of the Development of Television Test Cards Used in the BBC*	SEPTEMBER 1967
70.	*The dynamic characteristics of limiters for sound programme circuits*	OCTOBER 1967
71.	*The Programme Effects Generator*	NOVEMBER 1967
72.	*Colour Sensitometric Parameters in Colour Film Telerecording*	MARCH 1968
73.	*Sonic booms and other aircraft noise in studios*	APRIL 1968
74.	*The non-linear characteristics of klystron amplifiers*	JUNE 1968
75.	*Pulse-code modulation for high-quality sound-signal distribution*	DECEMBER 1968
76.	*The Variable Inductance Frequency Modulator*	DECEMBER 1968

THE AUTOMATIC CONTROL OF SOUND-SIGNAL LEVEL IN BROADCASTING STUDIOS

SUMMARY

In order to keep the level of the sound signal leaving a broadcasting studio within the limits that can be satisfactorily transmitted, it is necessary from time to time to vary the gain of the amplifier chain following the microphone. This adjustment is normally carried out by a skilled operator, and although various attempts have been made to devise an automatic gain-control system to perform the task, none has been entirely satisfactory.

The monograph surveys the principal obstacles to be overcome in producing an acceptable automatic device to replace a human control operator. Reference is made to recent work carried out on the subject in the BBC and elsewhere and some suggestions for future development are put forward.

1. Introduction

The level of the sound received by a microphone in a broadcasting studio cannot in general be predicted with great accuracy; moreover, the range of levels encountered is greater than can be satisfactorily transmitted through the broadcasting chain. It is therefore customary to employ in each studio a skilled operator who observes the readings of a level-indicating meter, listens to the programme on a loudspeaker, and regulates the gain in the amplifier chain accordingly. The operator's task is (i) to keep the maximum indicated signal level from exceeding a prescribed upper limit, (ii) to prevent the minimum level from falling for long periods below a prescribed lower limit, and (iii) within these limits to make both maximum and minimum levels appropriate to the nature of the programme. To achieve these ends, gain adjustments over a range of as much as 20 dB may be necessary (though, as a rule, not all of this range is required in any one programme).

From the earliest days of broadcasting, the possibility has been considered of replacing the human operator by some form of automatic gain-control device to regulate the signal level. Admittedly, the action taken by an operator is based to a large extent on his assessment of the artistic effect that the programme is intended to convey, and this requires a degree of knowledge and understanding which is unlikely to be reproducible in any practicable automatic device. However, in view of the economy in human effort that might be achieved by even a partially successful automatic control arrangement, the situation has from time to time been reconsidered in the light of current developments in electronic technology.

In the course of some work[1] carried out in 1965 and 1966 on the dynamic characteristics of limiters for overload protection, it was found that devices of this kind incorporating certain refinements in design could be made to fulfil some of the simpler requirements for automatic gain control in studios. As an extension of this work, consideration was then given to the problems of automatic control in more difficult cases, in order to discover how far the field of applications of limiters and similar devices could profitably be extended by further improvements in instrumentation, and, in pursuit of this object, some exploratory experiments were carried out.

The present monograph is devoted to a survey of the problems and possibilities of automatic gain control, with reference to some experimental findings, together with suggestions for future lines of development.

2. Field of Application of Automatic Gain-control Devices

Before the inherent potentialities and limitations of automatic gain-control devices are considered, it must be pointed out that the present investigation is concerned only with gain regulation as a necessary evil, to be carried out as rarely and as unobtrusively as possible. The use of automatic gain regulation for the deliberate production of special effects, as in 'pop' programmes, is subject to entirely different terms of reference and will not be considered here. Moreover, the question may be asked, whether the action taken by the operator should in fact be regarded as the ideal, to be imitated as closely as possible. On the one hand, the operator is constantly confronted by a choice between various evils and, since the ultimate aim of the transmission is to satisfy a human audience, a human being should be the best judge of what ought to be done in any given circumstances. On the other hand, if an automatic device can be programmed to recognize each combination of circumstances and make the same decisions as would an operator, it might be possible to implement those decisions more effectively.

Finally, it is necessary to consider how far—if at all—the shortcomings of an automatic gain-control device are likely to be tolerated in practice. For the purpose of the present discussion, such a device can be said to fail if it produces an obtrusive and unpleasant effect of a kind that could not be attributed by the listener to the idiosyncrasy of a particular operator. Failures of this kind, unlike those due to technical faults or human errors, must be regarded as systematic rather than random in their occurrence. Each one will represent the inability of the automatic device to cope with a particular set of circumstances; however rare those circumstances may be, the fact that they will inevitably lead to failure would probably make the device unacceptable to many users, and it is unlikely that a finite rate of failure, in the sense defined above, would be tolerated in service. An automatic device would therefore be used only in circumstances in which its limitations are never apparent; the nature and extent of these limitations will be dealt with in the sections which follow.

Musical and dramatic programmes generally employ more than one microphone, and the operator who carries out the mixing operation simultaneously controls the overall level. It might therefore be argued that automatic level-control devices need never be used for these programmes, but will be required only for such items as news, talks, and interviews. Automatic level control may, however, fulfil a useful function in dealing with any recorded material—for example, items originating outside the BBC—which is non-standard in signal level or has a dynamic range which is too great. Further, there may be occasions in which it would be advantageous to separate the function of mixing from that of overall level control—as was done in the early days of broadcasting; the latter task might then be delegated to an automatic device, leaving the operator free to concentrate on the mixing. This arrangement would be attractive in local broadcasting stations where mixing may be carried out by individuals not primarily concerned with engineering requirements.

3. Limitations of Control without Advance Information

In order to regulate the level of an incoming programme signal without detriment to the intended artistic effect, it is desirable to have advance information in order that changes can be anticipated. A script or score may be provided, but even without these a skilled operator can normally make a sufficiently accurate forecast, from the nature of the sounds heard, to avoid gross errors.

An operator having foreknowledge of a sudden large change in signal level, and wishing to preserve as much of this change as the dynamic range of the transmission system will permit, may find it necessary to raise or lower the gain of the circuit in advance. To carry out this operation unobtrusively, however, the necessary change of gain must be spread over a period of seconds—perhaps tens of seconds; any automatic device which is to produce the same effect would therefore have to incorporate some means of delaying the programme signal by a comparable amount without appreciable impairment of quality. To meet this requirement in the present state of the art would be very difficult, the more so because of the unrestricted dynamic range of the signal arriving from the microphone. Fixed delay networks of practicable dimensions and cost can give at most a few tens of milliseconds, while existing magnetic recording systems have too low a signal-to-noise ratio for the purpose. If the sound signal were coded into digital form, logic devices could be used to store the information. However, to accommodate the full dynamic range of uncontrolled programme, the signal-to-noise ratio of the digital system would need to be at least 12 dB greater than that required for programme signals after control,[2] and as a result, a code having at least 14 bits per sample[3] would be necessary. To allow for audio-frequency components up to 15 kHz the signal would have to be sampled and coded at a rate of at least 30 kHz,[3] so that, for every second of delay, a storage capacity of the order of $\frac{1}{2}$ megabit would be required—enough for a large computer. It seems likely that developments in digital recording will eventually provide an economic solution; the present discussions, however, will be restricted to automatic control devices which are incapable of anticipating requirements by an appreciable time interval.* With such devices it will be necessary to accept some loss of impact in a programme containing sudden large changes in volume, and to tolerate such anomalies as an abrupt fall in the level of an orchestral accompaniment where gain is reduced on the entry of a loud solo instrument. The highest standard of performance which can be expected is in fact that of a quick but unimaginative human operator, having no script or score before him, who cannot understand or make predictions from what he hears.

4. Regulation of High Signal Levels

4.1 *Use of Limiter for Overload Protection*

For an automatic gain-control device, as for a human operator, the first requirement, as indicated in Section 1, (i), is to protect the transmission chain against overload by restricting the maximum signal amplitude to a prescribed level, but in this respect, at least, the automatic device is the more effective of the two. The statement that the operator prevents the signal level from exceeding a prescribed value represents a slight over-simplification. The expertise of the operator includes the ability to assess, perhaps unconsciously, the statistical distribution of the level fluctuations and to set the gain so that the probability of the prescribed limit being exceeded is low. The result of this operation in practice is that around 1 per cent of the 'peaks'[4] registered on a quasi-peak reading instrument having an integration time† of 10 ms do in fact exceed the nominal maximum permitted level. By contrast, an electronic overload protection device can, if necessary, be made to take action on a signal lasting only a few tens of microseconds; although the required gain reduction has to be spread over a few hundred microseconds to avoid the generation of audible modulation products,[1] a corresponding electrical delay can be introduced ahead of the variable-gain element so that the prescribed maximum output level is not exceeded. Thus, the automatic protection of a transmission chain against overload does not in itself present any great problem.

For the purpose of the present discussion, the action of a limiter used in the manner just described may be illustrated by the steady-state output/input characteristic of Fig. 1, curve (*a*). The maximum allowable output signal level is

* In the design of protective limiters, it may be necessary, in order to prevent the output level from momentarily exceeding the permitted maximum, to delay the signal by a few hundred microseconds, thus allowing any necessary gain reduction to be effected in advance; as far as the ear is concerned, however, the action appears to be simultaneous with the signal that gave rise to it.

† The integration time of a quasi-peak indicating instrument is defined as the minimum duration of a switched sinusoidal signal required to produce a reading 80 per cent of that obtained with a steady signal of the same amplitude.

determined by the overload point of the succeeding transmission chain; the maximum input level however is, by the terms of reference, not precisely known and is therefore represented by a hatched region.

As long as the maximum gain reduction required does not exceed about 3 dB and the time for which this reduction takes place does not amount to more than a few per cent of the total, neither the quality nor the dynamic range of the programme will be appreciably affected; in these circumstances, the gain-recovery time* is not critical, but is usually made about ½ second. If, on the other hand, a limiter is required to exercise a much greater degree of gain control, so that the dynamic range of the programme is appreciably compressed, the gain-recovery time becomes an important factor.

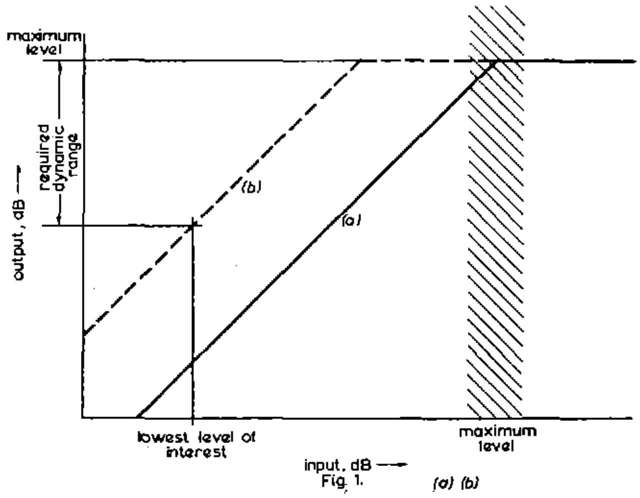

Fig. 1 — *Steady-state output/input characteristics*

(*a*) Limiter used for overload protection
(*b*) Limiter used to compress dynamic range of programme

4.2 *Use of Limiter for Compression at High Signal Levels*

Fig. 1, curve (*b*), shows how a limiter can be used to reduce the dynamic range of the programme signal by raising the level of the quiet passages, thus partially satisfying requirement (ii) of Section 1. Additional gain is provided to bring the weakest input signal of interest up to the desired output level; for input signals of high level, the gain is then automatically reduced so that the prescribed maximum output is not exceeded.

The principal shortcoming of this and similar devices as a substitute for a human operator is the objectionable effect of short-term gain fluctuations, which naturally increase with the degree of gain regulation. Reference has already been made to the effect of the sudden reduction in gain which, in the absence of adequate signal delay, must from time to time take place. In addition, a variety of other effects are observed, which depend on the rate at which the gain, once reduced, can return to normal.

If the gain recovery is spread over a long period—say 3 seconds or more—the mean programme level may be depressed for an unnecessarily long period following some isolated peak in the signal level; moreover, in the event of a sudden drop in level, as, for example, when a loud voice is followed by a quiet voice in a discussion, the compensating gain increase takes place too late to be fully effective.

If, on the other hand, gain recovery is completed within about ½ second, the quality of speech may be adversely affected; the rise in gain between words, or even between syllables, may exaggerate breath noises or certain initial consonants.* Sounds in the background—music or crowd noises, for example—will fluctuate in level as the gain changes, producing an effect which is even more obtrusive than the change in the speech quality. On music, the rapid rise of gain may interfere with the natural slow decay in the sound of instruments such as the piano, or of an orchestra in a reverberant hall.

With a further reduction in the gain-recovery time, to $\frac{1}{10}$ second or less, the sudden fall in the level of the background on the arrival of an isolated high-amplitude peak may be less obtrusive; apart from this, most of the abovementioned defects are aggravated. In addition, certain sustained signals, the crest value of which fluctuates in a random fashion, produce corresponding inverse fluctuations in gain which are then heard as a fluttering effect; this phenomenon can be very objectionable in choral passages.

There is no single relationship between gain recovery and time which will enable all of the above-mentioned impairments to be avoided on all types of programme. The best compromise to date has been achieved by means of a circuit, described in the earlier publication already cited[1] in which the effective recovery time-constant of the gain-control system is caused to vary between about 30 milliseconds and 10 seconds according to the level and duration of the signals; this arrangement can be used to exercise level control involving up to about 16 dB of gain reduction without the gain-recovery phenomena referred to above becoming obtrusive.† In practice, the effective control range of this and similar devices is limited to about 8 dB by the audibility of studio background noise, such as clock ticks and ventilation rumble, during prolonged pauses when the circuit gain is automatically raised to its maximum value. (With a human operator, these sounds would be heard only during the quietest passages of the programme.) Experiments carried out during the present investigation suggest, however, that this difficulty might be overcome by making the recovery time-constant return to a high value during pauses in the programme.

* It should be noted that the gain of a limiter, once having been reduced by the action of a signal, takes a finite time to recover after the signal has ceased. Under operating conditions, therefore, the output produced by the weaker signals may at times be lower than that indicated by the steady-state characteristics.

* This latter effect can be mitigated in extreme cases by application of high-frequency pre-emphasis to the control chain of the limiter[5] (an artifice known in the film industry as 'de-essing').

† The foregoing remarks apply equally to a protective limiter which has to compensate for gross errors of level control or line-up in the preceding chain.

5. Regulation of Low Signal Level

5.1 *Compression at Low Signal Levels*

The form of gain control described in 4.2 operates primarily on signals in the upper part of the dynamic range, the gain for signals of lower level being only indirectly affected in consequence of the finite recovery time of the system. The result is open to objection on artistic grounds. Intentional differences in maximum level—for example, as between speech and music—are largely removed; moreover, in the case of a crescendo in music or dramatic speech, the level is at first allowed to increase but later held constant. It is therefore desirable that variation of gain with signal level should extend also to the lower end of the dynamic range.

In the present investigation, a number of attempts were made to produce an automatic gain-control device which would raise the gain for low-level signals without greatly affecting the upper end of the dynamic range. The most effective arrangement found was a combination of two limiters having their respective input and output terminals in parallel. The first of these limiters functioned primarily as an overload protector, having the steady-state output/input characteristic shown in Fig. 2, curve (*a*). The second limiter had a higher gain in the quiescent condition and was set to operate at a lower signal level, giving the steady-state characteristic shown in Fig. 2, curve (*b*).* The resultant output/input characteristic of the system is shown in Fig. 2, curve (*c*). The low-level limiter was necessarily in almost constant operation over a wide range of gain, and a variable-recovery time circuit, of the type already described, was therefore provided. The complete device was thought to be sufficiently promising to merit consideration in any future work.

The steady-state characteristic of Fig. 2(*c*) is not very different from the combination of limiter and compressor† already used in some studios, as well as at medium-wave transmitters, and illustrated in idealized form by Fig. 2, curve (*d*). These devices have gain recovery times of ½ second or less and are therefore subject to the effects of rapid gain fluctuation, described in 4.2. With the characteristic of Fig. 2(*d*), however, large changes of gain take place less frequently than with the characteristic of Fig. 1(*b*), and the overall effect is consequently more acceptable. There is no reason, moreover, why devices, such as those referred to in 4.2, for automatically varying the gain recovery characteristics of a limiter should not be applied to a compressor or to a compressor/limiter combination.

5.2 *Noise Gates*

All the gain-regulating devices referred to so far have

* A somewhat similar arrangement, employing a limiter operating at low signal levels, is used in a commercial compandor[8] produced in 1966.

† In current nomenclature, the term *compression* is used to describe the action of any signal-processing device, the steady-state output/input characteristic of which has, within the working range, a region where the slope is less than unity. The term *compressor* is however reserved for those devices in which the output increases with the input throughout the working range, limiters being thus excluded. It should be noted that as a result of this convention, a limiter which is being used to produce compression cannot, without grave risk of confusion, be referred to as a compressor.

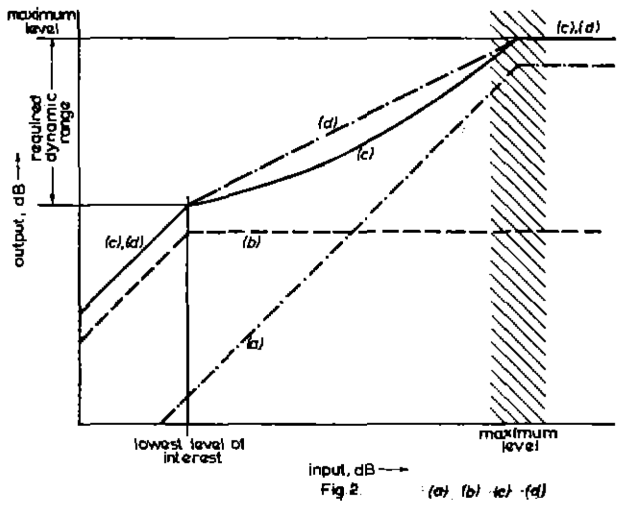

Fig. 2 — Steady-state output/input characteristics

(*a*), (*b*) Limiters used for high- and low-level control respectively
(*c*) High- and low-level limiters with inputs and outputs paralleled
(*d*) 2:1 compressor combined with protective limiter

maximum gain at low signal levels; their useful operating range is therefore limited by the rise in the level of background sounds during programme pauses. To avoid this difficulty, a number of automatic gain-control devices are designed to reduce gain whenever the incoming signal falls below a prescribed threshold. Fig. 3 shows the steady-state output/input characteristic of a compressor/limiter combination, similar to that of Fig. 2(*d*), to which this artifice—known as a 'noise gate'—has been applied. In the example shown, the gain at very low signal levels has been made equal to the gain at a point O in the middle of the range to be covered; thus, the lower part of the characteristic, extrapolated as shown by the dotted line, intercepts the upper part of the curve at O. The input signal level, corresponding to point G, below which gain is reduced, is referred to as the 'gating' level.

Most gating circuits are designed to be capable of operating at syllabic rate or faster. At the start of a signal, the rise of gain is made fast enough to avoid giving the hearer the impression that something has been missed; when the signal ceases, the return to the low-gain condition is made fast enough to avoid audible persistence of the noise which it is desired to suppress. With such rapid operation, an unpleasant amplitude flutter is inevitably produced if either the signal or the noise level hovers around the gating region of the output/input characteristic.

In some commercial automatic gain-control devices, however, a form of slow gating has been adopted. In a sustained quiet passage of programme in which the signal lies above the gating level, the gain rises over a period of seconds to its maximum value; if the signal later ceases or fails to reach the gating level, the gain is held at maximum for a waiting period of 5 to 10 seconds and is then slowly reduced to normal. However, this slow speed of operation, while avoiding the effects of syllabic gain fluctuation, leads to other difficulties. Consider a sudden transition from

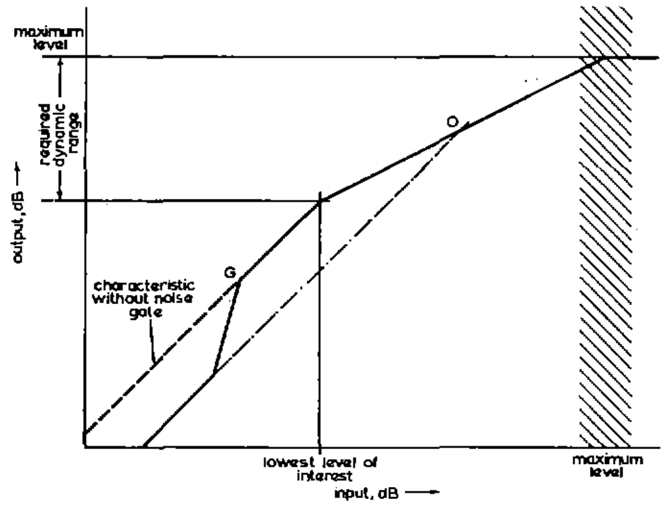

Fig. 3 — Steady-state output/input characteristic: compressor/limiter with noise gate

loud to quiet programme in which the final level of the incoming signal is still above the gating point. In such a case, a human operator might well choose, in a speech programme, to raise the level of the quiet passage by a single, carefully timed, increase in gain; in a programme of music, however, he might decide to preserve contrast by allowing at least the first part of the quiet passage to remain at its original level, and if he increased the gain at all he would do it at a rate so slow as to be imperceptible. In the same circumstances, the automatic device described above would leave the first part of the quiet passage unchanged but thereafter would raise the gain in a few seconds, i.e. at a rate fast enough to be obtrusive; the result would be unsatisfactory for both speech and music.

Gating devices in general rely on an adequate separation between the lowest signal level and the highest noise level. The safety margin is rarely very great, and to avoid the danger of anomalous operation in which noise is intermittently raised in level or a quiet signal suppressed, careful setting-up adjustments before each programme are usually necessary. In any case, a gated system must inevitably fail with music which starts or ends very quietly, as for example, the popular composition which imitates the effect of a military band approaching and receding.

6. Regulation of Intermediate Levels

A human control operator, as well as taking action to prevent excessively high or low signal levels being transmitted, has to decide whether the programme at the moment is intended to be loud or quiet so that he may set the level at the appropriate point within the permitted range.

This action—function (iii) in Section 1—is the most difficult of all to carry out by a piece of automatic equipment, since it requires the rapid recognition of the nature of the programme. To recognize automatically the characteristics, other than level, which distinguish quiet music from loud music, or quiet speech from loud speech, is unlikely to be practicable in the foreseeable future (some idea of the magnitude of the problem may be obtained by contemplation of the literature on automatic speech recognition). The most that can be done at the moment is to distinguish speech from music; further reference to this possibility will be made in Section 7.

Whatever the nature of the programme, however, the average level of the controlled signal should not lie so near to the prescribed upper or lower limit that an unexpected increase in the former case or a decrease in the latter would necessitate a sudden change of gain. Abrupt gain changes should be kept as small as possible, since they produce an audible discontinuity in the level of any background sound, such as a crowd noise or musical accompaniment. It is therefore desirable, in an automatic gain-control device, to provide means for assessing the average level as soon as possible after the start of the programme and gradually to regulate the gain accordingly. In the course of the present investigation, a slow-acting automatic gain-control system was made to regulate the proportion of time for which the signal level lay above a prescribed figure. It is thought that a system of this kind, operating over a limited control range and used in conjunction with some of the quick-acting devices already discussed, could avoid some of the worst anomalies arising from abrupt gain changes. Alternatively, the two devices could be combined, the working point of a single variable-gain device being modified in accordance with the long-term history of the signal level.

7. Future Development

7.1 *General*

From the foregoing it will be seen that the quality impairment (using the term in its broadest sense) introduced by applying automatic gain control to sound signals increases with the degree of gain variation required. From experience so far, the situation may be roughly summarized as follows:

(*a*) If the range of control is less than about 6 dB, then any one of a number of known automatic devices will be acceptable on most programmes.

(*b*) If the range of control is greater than about 12 dB, any one of the existing automatic devices will produce objectionable effects on many types of programme material.

(*c*) If the control range is greater than 6 dB but less than 12 dB, the result depends on the type of programme. For any one class of programme material, the acceptable range of control may be substantially extended by adopting a particular form of static and dynamic characteristic, which, however, may be quite unsuitable for some other type of item.

It follows that future development should aim at (i) avoiding the need for large gain variations during any one programme, and (ii) altering the characteristics of the controlling device as required to produce optimum performance for the type of item being transmitted.

7.2 *Restriction of Required Control Range*

The full range of gain control required in studio equipment dealing with live speech and music together with a variety of commercial disk recordings could be as much as 20 dB. On the other hand, individual programmes would probably not require more than 10 dB of automatic gain adjustment, so that, given the necessary information, the remaining 10 dB could be preset.

For the transmission of news, talks, or interviews in the absence of technical staff, the distance from speaker to microphone could be roughly predetermined by fixing the position of seats and desks. In other cases, an approximate allowance for distance could be made by providing an attenuator with the dial marked in units of length; the setting of such a control makes no greater demand on non-technical personnel than does the use of a flash-gun in photography. The automatic gain-control device would then have to deal only with variations in level due to the difference between individual voices and to movements of the speaker about his mean position. If, however, a speaker in an unattended studio can give a preliminary test for level adjustment, the effect of both distance and voice level can be taken into account; an automatic device could readily be made to assess the signal level over a period of 10 to 15 seconds—discounting pauses—and then introduce an appropriate degree of fixed attenuation for the duration of the performance.

Commercial disk recordings (with the possible exception of 'pops') will probably have been played through at least once before going on the air, and the opportunity could then be taken to determine, by human or electronic means, the maximum or average reproduced signal level. The result could be stamped on to the record label in some form of binary code, using magnetic ink; on replay, the coded information could be automatically read off and used to control a fixed attenuator. For records not provided with advance information in this way, the maximum reserve gain of the system would be introduced and the automatic gain control would have to operate over a correspondingly greater range. It is assumed that recordings produced within the BBC will have been standardized in level, and that in cases where it has not been thought worth while to do this, the effects of wide-range automatic control will be tolerated.

7.3 *Adaptation of Control Characteristics to Programme Content*

It has been pointed out that the shortcomings of automatic gain-control devices can be mitigated by suiting their characteristics to the nature of the programme material. In some cases, the necessary change can be brought about by some existing operation, such as the switch from 'announcer' to 'grams'. The possibility of automatically recognizing the difference between speech and music has also been considered by several workers, the motive in one case being to regulate the directional characteristics of a loudspeaker according to the nature of the programme[7] and, in others, to suppress the advertising announcements interposed in a commercial radio service.[8,9] In both the cases cited, discrimination was based on the rate of change of the signal-envelope amplitude, which is in general more rapid in speech than in music. For the purpose of the present investigation, experiments were carried out with a device of this kind, and it was found possible to obtain in most cases a reliable speech/music decision within a few seconds of the start of the programme. This performance is poor compared with that of the human ear and brain (which can unerringly tell speech from music in, say, a half-second burst of signal); it is thought nevertheless that the information obtained could be utilized to avoid some of the worst errors in automatic control, by dividing the programme material into a few broad categories, and varying the static and dynamic characteristics of the automatic gain-control device to produce the best compromise performance in each case.*

7.4 *Criteria for Signal Level*

Throughout this report the term 'level' has been used in a general sense without specifying whether, for example, the r.m.s. or crest value of the signal waveform is meant. When considering the maximum level which can be allowed without producing over-modulation of the transmission system, the crest value of the waveform is relevant, though there may be some reservations in the case of peaks of very short duration. In the regulation of lower signal level, and in the suppression of studio noise by gating, some quantity more closely related to the loudness of the reproduced sound would be more appropriate. Thus, a complete automatic control system should incorporate in its control circuits a 'loudness detector' including aural sensitivity weighting,† to control low and intermediate signal levels, together with a peak signal rectifier to actuate an overload protection device.

8. Conclusions

The difficulties, both fundamental and instrumental, in devising an automatic gain-control system to replace a human operator have been considered and the prospects for the future have been assessed.

It is concluded that, while a universally usable automatic gain-control system needs to simulate human attributes to a degree which appears either impossible or uneconomic in the foreseeable future, a number of devices of this kind having more limited capabilities can be envisaged. To make the best use of such devices, the range of automatic control should be restricted to that necessary to cover level variations within a single programme or programme item, other variations being taken up by preset attenuators; in addition, both the static and the dynamic characteristics should be changed as required (possibly by automatic means) to suit the type of programme.

* Suggestions have been made by Belger and Jakubowski[10, 11, 12] for the use of a speech/music discriminator to avoid anomalies in automatic level control.

† It may be noted that the American Broadcasting Company has used a limiter[13] having empirically designed weighting networks in its control circuits, in the hope of defeating the efforts of advertisers to make their contributions sound louder or more arresting than the remainder of the programme. The technique described may well be capable of wider application.

9. References

1. Shorter, D. E. L., Manson, W. I., and Stebbings, D. W. **The dynamic characteristics of limiters for sound programme circuits.** BBC Engineering Monograph No. 70, October 1967.
2. Godfrey, J. W., Editor. **Studio engineering for sound broadcasting.** BBC Engineering Training Manual, Iliffe, 1955, p. 53.
3. Shorter, D. E. L., Chew, J. R., Howorth, D., and Sanders, J. R. **Pulse-code modulation for high-quality sound-signal distribution.** BBC Engineering Monograph No. 75, December 1968.
4. **Some statistical parameters of the quasi-peak voltage of BBC sound programmes.** BBC Research Department Report No. L-064, Serial No. 1966/20.
5. Frayne, J. G. and Wolfe, H., 1949. **Elements of sound recording.** New York, John Wiley, 1949, ch. 10, p. 173.
6. Dolby, Ray M. **An audio noise reduction system.** Journal of the Audio Engineering Society, **15**, 4 October 1967, pp. 383–8.
7. Enkel, F. **Lautsprecheranlage mit schallquellen-gesteuerter Richtcharakteristik.** Gravesaner Blätter 1958, *11/13*, pp. 10–13.
8. Gross, F. D. **Music/speech discriminator.** Electronics World, *69*, 4 April 1963, pp. 36–8 and 73–4.
9. Heller, S. **Technical reports: Commercial killers.** Radio-Electronics, xxvi, 8 August 1955, pp. 50–2.
10. Belger, E. and Jakubowski, H. **Möglichkeiten zur Erhöhung der Sprachverständlichkeit bei Mittelwellen-Fernempfang.** Rundfunktechn. Mitt. *11*, 5 October 1967, pp. 266–72.
11. Jakubowski, H. **Das Problem der Programmlautstärke.** Rundfunktechn. Mitt., *12*, 2 April 1968, pp. 53–8.
12. Belger, E. and Jakubowski, H. **Ein Programmgesteuerter Musik-Sprache-Schalter.** Rundfunktechn. Mitt., *12*, 6 December 1968, pp. 288–91.
13. Morris, R. M. **Automatic control of aural program loudness.** I.E.E.E. Trans. on Broadcasting, BC-13, 1 January 1967, pp. 37–40.

Published by the British Broadcasting Corporation, 35 Marylebone High Street, London, W.1. Printed in England by The Broadwater Press Ltd, Welwyn Garden City, Herts. SBN 563 08492 8