CHAPTER 16

VOLUME EXPANSION, COMPRESSION AND LIMITING

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Section Page

SECTION 1: GENERAL PRINCIPLES

(i) Introduction (ii) An ideal system (iii) Practical problems in volume expansion (iv) Distortion (v) General comments.

(i) Introduction

The maximum volume range of any sound reproducer is the difference in decibels between the maximum sound output and the level of masking by background noise which latter may include hum, random noise, needle scratch or microphone noise.

The volume range transmitted by a broadcast station may vary from a low value up to at least 60 db for a F-M transmitter (F.C.C.), the value depending on the type of programme. In the case of an A-M transmitter the maximum volume range is about 50 db—see Chapter 14 Sect. 7(iv).

If the original sound has a volume range greater than the maximum volume range of the transmitter, it is usual to compress it in some way. The compression may be accomplished manually by the control engineer, or automatically by a device known as a peak limiter or a volume compressor.

A similar case arises with recorded music, where the maximum volume range may be as low as 35 db for shellac lateral-cut disc records.

Many types of programme have a maximum volume range less than 35 db, and therefore do not require compression. However, most broadcast transmitters have an automatic peak limiter permanently operating, while it has even been found beneficial to use volume compression in F-M broadcasting (Ref. 29).

If reproduced music is to have the same volume range as in its original form, some kind of volume expander is required. But, as will be shown later, volume expansion cannot be applied indiscriminately and cannot be perfect.

One advantage of the use of volume expansion is that it reduces the background noise, other than room noise. This is a considerable advantage when the source is a disc record.

A serious shortcoming of automatic volume expansion is that the circuit can never duplicate the original volume range because it has no way of knowing what these original levels were—it will make the loud portions louder and the soft portions softer, but always by the same amount for a given input level. Thus the expander circuit might increase every signal that is 10 db above the average volume level to 15 db above the average, but the level in the studio might have been higher or lower than this.

The amplitude ratios of a soft and a loud note when rendered simultaneously cannot be compressed or expanded by any system. If the loud note causes a certain compression in the transmitter, the soft note will be compressed in the same ratio and may fall below the noise level (Ref. 33).

(ii) An ideal system

In an ideal system the transmitter would broadcast two separate carrier frequencies, one modulated with the music and the other modulated with some signal indicating the degree of compression being used at each instant. In the case of disc recorded music it would be necessary to have two grooves and two pickups. In each case the reproducer would incorporate a volume expander in which the degree of expansion is controlled by the second (indicating) signal.

Alternatively, only a single modulated carrier may be used provided that the expander characteristic in the receiver is the inverse of the compression characteristic in the transmitter. In addition, the time lags of the compressor and the expander should be equal. This is an ideal which cannot be reached at the present time owing to the lack of standardization and the use of manual controls.

There are serious technical problems both in the compression and expansion operation, but these are considered in Sections 2 and 4 respectively.

(iii) Practical problems in volume expansion

At the present time most broadcast stations employ some form of automatic volume compression, while compression is also used in recording on discs. The problem facing the receiver and amplifier designer is how to make the best use of volume expansion under conditions where it is impossible to reach the ideal.

(A) Orchestral reproduction

This subject is dealt with in a general manner in Chapter 14 Sect. 7(iv) and (v).

It is in orchestral reproduction that volume expansion can be employed to its full advantage. Experience indicates that the operation of the volume expander in the upwards direction should be as rapid as practicable (see Sect. 4) but that the fall should be very gradual—up to 1 or 2 seconds or even more, the optimum rate varying with the type of music and with the listener's choice.

Most competent audio-frequency engineers agree that automatic volume expansion is capable of giving more realistic reproduction of recorded orchestral music when used under the best possible conditions, even though it is known to have many technical defects. The usual amount of volume expansion used in such cases is 12 to 20 db maximum, with the maximum expansion variable at the desire of the listener.

(B) Average home listening

The average home radio receiver, used for a variety of purposes including speech, background music, drama and miscellaneous programmes, is usually better without expansion. Expansion might beneficially be used on orchestral programmes provided that the audience is prepared to listen intently, the room noise level is sufficiently low, and the neighbours do not object. These conditions are the exception rather than the rule.

On the other hand, volume expansion with manual control is well worth incorporation into a home gramophone amplifier.

(C) Background music

Music which is intended to form a background should be compressed and not expanded. The maximum dynamic range may be from 25 db down to possibly 10 db (Ref. 45).

(D) Factory music

Factory music must be heard above a very high noise level without becoming inaudible for any appreciable period. It should be compressed and not expanded, with a maximum dynamic range from 20 db down to possibly 5 db in exceptionally noisy locations.

References to General Principles : 3, 20, 29, 33, 34, 45, 48, 59.

(iv) Distortion

Apart from the harmonic and intermodulation distortion and extraneous noises produced by the compressor and expander, which may be kept low by good design, there are some special features which require consideration. Some of these are described in Sect. 2(iv) in connection with volume compression.

(v) General comments

There is an extraordinarily wide variety of devices for both volume compression and volume expansion, but in many cases the information published is too meagre to permit comparisons between the different methods. There is the additional problem that some of the designs may not be suitable for quantity production, on account of unduly critical adjustments and/or critical selection of valves.

The subject is a very complicated one, and the present unsatisfactory state of the " published art " has forced the author to refrain deliberately from giving much comment. The methods and circuits described in the following sections have been compiled mainly from very limited sources, often from a single article, and the information and claims based solely on the articles, to which full references have been given.

SECTION 2 : VOLUME COMPRESSION

(i) Introduction (ii) Peak limiters (iii) Volume limiters (iv) Distortion caused by peak limiters or volume limiters (v) Volume compression (vi) Volume compression plus limiting (vii) Compression of commercial speech.

(i) Introduction

In this Section it is intended to approach the subject from the point of view of the radio receiver or amplifier designer.

Volume compressors may be divided into three groups :

(A) Peak limiters

A peak limiter is an amplifier whose gain will be quickly reduced and slowly restored when the instantaneous peak power of the input exceeds a predetermined value The output for all inputs in excess of this value is substantially constant.

(B) Volume limiters

A volume limiter is an amplifier whose gain is automatically reduced when the average input volume to the amplifier exceeds a predetermined value, so that the output for all inputs in excess of this value is substantially constant. A volume limiter differs from a peak limiter in that it is controlled by the average volume instead of by the instantaneous peaks.

(C) Volume compressors

These are used for the purpose of compression over a substantial part of the entire operating range.

(ii) Peak limiters

Peak limiters are used principally in broadcast transmitters. They are intended to prevent overmodulation and to increase the average level of the programme. The latter result follows automatically if the input is increased and the peak limiter left to look after the peaks.

FIG. 16.1.

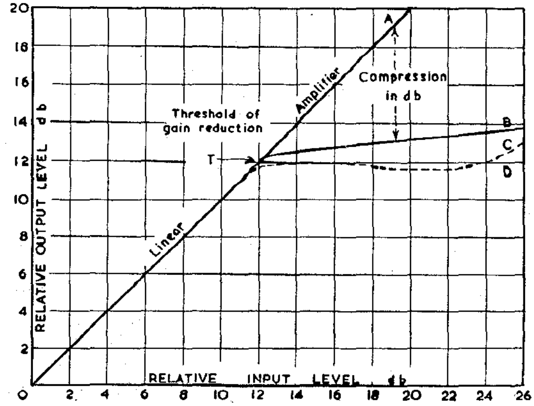

Fig. 16.1. *Compression characteristics (B, C, D) of typical peak limiter or volume limiter.*

Some static limiter characteristics are shown in Fig. 16.1. Curve OA is the curve of a linear amplifier. Curve OTD is that of an " ideal " limiter, with point T as the threshold of limiting. It will be seen that the output does not rise above a level of 12 db, no matter how great the input may become.

Curve OTB is that of a practical peak limiter, the curve TB indicating by its slope a compression ratio of 10 to 1 (both being measured in db). The compression in db at any point is as indicated by the arrows.

Curve OC is that of a peak limiter having " over-control " (Refs. 36, 40, 44) which does not exceed 100% modulation (line TD) until the compression reaches 12 db.

With peak limiters a volume expander cannot be used to give correct compensation for the compression.

Most of the earlier and simpler forms of peak limiters have a comparatively slow " attack " time, that is the time taken for the limiter to operate on a sudden increase in input level—usual times are 1 or 2 milliseconds. A slow attack time results in overmodulation and distortion for short intervals following each transient. More recent examples of good design (Refs. 36, 38, 40, 44, 63) claim to have " attack " times less than 100 microseconds, while some (Refs. 36, 40, 44) incorporate a time delay filter in the signal circuit which is claimed to permit almost instantaneous operation. Tests have been carried out under dynamic conditions to demonstrate the performance of various types of limiters (Refs. 4, 40, 63). It is good practice for the " attack " time of a peak limiter to be less than 200 microseconds, while still shorter times (e.g. 100 microseconds or less) are desirable.

The recovery times in most cases are manually controlled, with times up to 2 or even 3 seconds, but automatic control has also been used to lengthen the recovery time so as to avoid " pumping " when several programme peaks occur in rapid succession (Ref. 36). The recovery time is not made longer than necessary, since it causes reduced modulation percentage.

One design (Ref. 86) has a subsidiary series *CR* circuit that has only a slight effect with a single sharp peak, thereby giving a fairly short recovery time (0.33 sec.) but with a sustained peak the recovery time increases to 2 seconds.

If a fixed value of recovery time is used, the most suitable range is from 0.5 to 1.5 seconds, and " pumping " may be avoided by restricting the limiting action to 4 or

6 db. A preferable arrangement incorporates a double value of recovery time, in which a longer recovery time occurs on sustained or repetitive peaks, and a short recovery time on brief, non-repetitive peaks (e.g. Ref. 72).

Careful listening tests with modern peak limiters having very short "attack" time, indicate that differences in quality can only be discerned when the limiting action (compression) reaches 5 db with a good modern type (Ref. 63) or 8 to 10 db with the nearly instantaneous type (Ref. 44).

Some broadcast stations unfortunately abuse the limiter by increasing the percentage modulation to such an extent that the distortion is distinctly audible in any good receiver.

References to peak limiters : 4, 36, 37, 38, 40, 44, 63.

(iii) Volume limiters

These are very similar in most respects to peak limiters, and the same general remarks hold for both. Examples of volume limiters are Refs. 12, 29.

(iv) Distortion caused by peak limiters or volume limiters

(A) Distortion caused by slow attack time

This is definitely audible in some types of programmes when the attack time is greater than 100 microseconds.

(B) Transient waveform distortion

This occurs in some types of limiters during limiting (Ref. 40). It may only affect part of one cycle, or it may continue over many cycles.

(C) Thump

Control current surges caused by rapid changes in input level may or may not be audible as a thump. Careful design is necessary to reduce the trouble. One design is claimed to have a very high signal/thump ratio (Refs. 36, 40, 44).

(D) Non-linear distortion

In the best designs the total harmonic distortion is below 1% and the intermodulation distortion below 3% under all conditions, over the whole a-f range.

(E) "Pumping"

This has already been described above.

(F) Sibilant speech sounds

The high frequency components in speech (sibilant sounds) are normally at a much lower level than the low frequency components. When volume compression is applied to speech, the control voltage derived from sibilants alone is much less than that from vowel sounds. Consequently the amplifier gain is higher for sibilants alone than for other speech sounds, leading to accentuation and distortion of the sibilants. This trouble may be avoided by incorporating a suitable equalizer in the control circuit (Ref. 9).

(G) Effect of pre-emphasis

Pre-emphasis, as used in certain recording systems and in F-M broadcasting, sometimes tends to give overmodulation with high frequency peaks. It is therefore advisable to place the pre-emphasis network ahead of the limiting amplifier. In such cases the limiting should be held to low values such as 2 or 3 db (Refs. 4, 44).

(v) Volume compression

Volume compression is distinguished from limiting in that it extends over the whole, or a substantial part of, the entire operating range. The compression characteristic may either be a straight line (A) or a smooth curve (B) shown typically in Fig. 16.2 ; in both examples an input range of 60 db is compressed to an output range of 40 db.

Either type of compression characteristic may be used satisfactorily in conjunction with an expander provided that the expansion characteristic is the inverse of the compression characteristic.

Some examples of volume compressors are Refs. 2, 31, 66—see also the a.g.c. circuit of Ref. 39. The attack time of a volume compressor should be fairly slow—this will permit the attack time of the expander to be made the same value. A compressor for use with recording is described in Ref. 69.

FIG. 16. 2

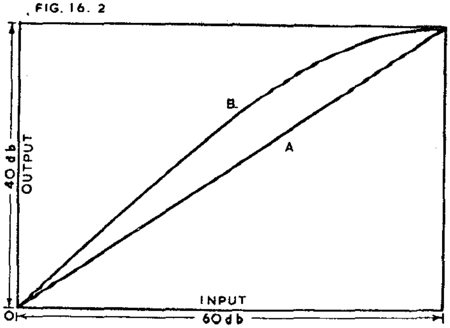

Fig. 16.2. *Compression characteristics of volume compressors.*

(vi) Volume compression plus limiting

In broadcast transmitters it is desirable to adopt both volume compression and limiting—volume compression for use with discretion depending on the type of programme; limiting for all programmes to permit a high percentage modulation to be used without peaks exceeding 100%.

One combined equipment has been designed (Ref. 39) incorporating a memory circuit which holds the gain constant for a predetermined time to preserve the dynamic range of the programme.

References to Section 2 (Volume compression, general): 2, 4, 5, 9, 12, 29, 31, 32, 36, 37, 38, 39, 40, 44, 63, 66, 69, 85, 89.

(vii) Compression of commercial speech

The comments above apply to good fidelity systems. For commercial speech, some form of " level governing amplifier " (W.E. Co.) or " constant volume amplifier " (British Post Office) is commonly used in complex systems. However, for simple systems, it is difficult to improve on an efficient speech clipper (see Sect. 6).

SECTION 3: GAIN CONTROL DEVICES

(i) Remote cut-off pentodes (ii) Pentagrids and triode-hexodes (iii) Plate resistance control (iv) Negative feedback (v) Lamps (vi) Suppressor-grid control.

Gain control devices are used in both volume compressors and expanders to provide a gain which is a function of the input signal.

(i) Remote cut-off pentodes

This is an application of audio a.v.c., and remote cut-off pentodes are capable of being used in both applications. The predominant (second) harmonic distortion does not exceed 1% with valve type 78 having a load resistance of 50 000 ohms, with an input of 0.15 volt (Ref. 62). The distortion may be reduced by push-pull operation and by limiting the input voltage to a low level.

A method of testing valves for the preselection of remote cut-off pentodes is described in Ref. 70.

It is the author's opinion that, despite all the troublesome features, the push-pull circuit using suitable selected remote cut-off pentodes, gives the most satisfactory control performance. This control stage must be followed by a " combining circuit " such as a push-pull transformer or centre-tapped-choke, either in the plate circuit or in the following grid circuit—the latter being preferable. See also remarks in Sect. 4(iv).

(ii) Pentagrids and triode-hexodes

Type 6L7 pentagrids are capable of handling higher input voltages than pentodes for the same distortion. The predominant (second) harmonic distortion does not exceed 1% with valve type 6L7 having a load resistance of 50 000 ohms, with an input of 0.5 volt (Ref. 62). The input signal is applied to the remote cut-off grid (No. 1) here operated at fixed bias, and the control voltage is applied to the sharp cut-off grid (No. 3). See Refs. 14, 35.

Type 6A8 pentagrids may also be used, with the signal applied to the oscillator grid (No. 1) and the control voltage applied to the signal grid (No. 4). See Ref. 14.

Type 6K8 triode-hexodes may be used, with the signal applied to No. 1 grid and the control voltage applied to No. 3 grid. See Ref. 14.

Many other types of multi-grid valves may also be used.

(iii) Plate resistance control

The plate resistance of a valve is a function of the grid bias voltage. A triode has a sharp change from a fairly low value at normal bias voltages to a high value when approaching cut-off, and infinity beyond cut-off. This effect has been applied in a volume compressor (Ref. 12).

(iv) Negative feedback

The gain of an amplifier may be controlled by means of a negative feedback network in which one element is the plate resistance of a valve whose grid is connected to the control voltage. One application (Ref. 31) gives less than 1.8% total harmonic distortion under all conditions, with an output of 12 volts.

FIG. 16.3

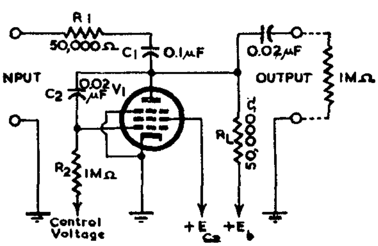

Fig. 16.3. Pentode with negative feedback used as shunt resistance in an attenuator to provide gain control.

Another application of negative feedback is Fig. 16.3 which employs a remote cut-off pentode with negative feedback provided by capacitance C_2 from plate to grid. By this means the effective plate resistance with feedback becomes approximately $1/g_m$. Thus a valve with a range of mutual conductance from 2000 to 2 micromhos may be used as a resistance varying from 500 to 500 000 ohms. The ratio between output and input voltages is given by

$$R_L/(g_m R_1 R_L + R_1 + R_L).$$

With the values given in Fig. 16.3, a variation approaching 33 db is obtainable when V_1 has a maximum g_m of 2000 micromhos (Ref. 62). The dominant (second) harmonic distortion is less than 0.2% for an input voltage of 2 volts.

FIG. 16.4

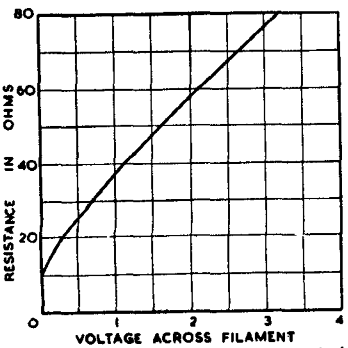

Fig. 16.4. Resistance characteristic of typical 4-6 volt 0.04 A metal filament lamp used in volume expanders (Ref. 45).

(v) Lamps

Metal filament (dial) lamps may be used as control devices in volume expanders. A typical tungsten filament lamp has a resistance at maximum brilliancy of about 10 times that at room temperature (Fig. 16.4). See Sect. 4(ii) for applications of metal filament lamps in expanders.

Note: Carbon filament lamps have a resistance which is less when at maximum brilliancy than at room temperature.

(vi) Suppressor-grid control

The control voltage may be applied to the suppressor grid of a suitable pentode valve. This is used in Figs. 16.11 and 16.12.

References to suppressor-grid control: 7, 10, 16, 27, 33, 46.

SECTION 4: VOLUME EXPANSION

(i) Introduction (ii) Expanders incorporating lamps (iii) Expanders utilizing feedback (iv) Expanders incorporating remote cut-off pentodes (v) Expanders incorporating remote cut-off triodes (vi) Expanders incorporating suppressor-grid controlled pentodes (vii) Expanders incorporating valves with five grids (viii) Expanders incorporating plate resistance control.

(i) Introduction

Volume expansion is very similar to volume compression, and the same control methods are used for both, but the control voltage is of opposite polarity. In fact, an expander/compressor may be designed with a switch to change from one to the other (Fig. 16.14).

The desirable characteristics which a volume expander should have are:

1. Negligible non-linear distortion.
2. The degree of expansion should be under control.
3. The degree and control of expansion should be independent of the volume level at which the amplifier is operated.
4. The expansion should result in the upwards expansion of loud passages and the downwards expansion of soft passages.
5. The attack time should be short—times from 0.2 to 200 milliseconds are in common use, but the shorter times are preferable (say not exceeding 20 milliseconds).
6. The recovery time should be adjustable from a fraction of a second to 1 or 2 seconds.
7. There should be no audible thump or transient distortion with sudden large transients.
8. There should be no appreciable reduction in maximum power output.
9. The overall gain should not be reduced seriously by the expander.
10. The shape of the expansion characteristic should provide some expansion at low output levels, the amount of expansion steadily increasing all the way to maximum power output.

For most purposes an expansion of 10 or 12 db is satisfactory, although some prefer up to 15 or even 20 db.

It is preferable to introduce the expander into the amplifying chain so that minimum amplification follows it. It is therefore desirable to select a type of expander which is capable of a fairly high output voltage. It is preferable for tone controls to precede the expansion unit.

Electronic methods of volume expansion may be divided into two groups, those in which the control voltage is derived from the output voltage, and those in which it is derived from the input voltage, suitably amplified. The former method is cheaper and employs fewer valves, but it has a less desirable shape of expansion characteristic and may be unstable. The latter method is used in Figs. 16.10 to 16.15 inclusive, and is preferable in order to avoid thumps and blocking effects.

When the control voltage is derived from the input voltage, a " side-chain " amplifier is used (e.g. Fig. 16.10) with the final stage transformer-coupled to a suitable full-wave rectifier and load network.

(ii) Expanders incorporating lamps

Small metal filament lamps are sometimes used in volume expanders, the variation of about 10 to 1 in resistance (see Fig. 16.4) giving sufficient range of control. The simplicity and cheapness of some of these volume expanders make a strong appeal, although there are many shortcomings. If the lamps are placed in the voice coil circuit there is a loss of something like 50% of the power output. It is difficult to find lamps with characteristics suitable for all applications. It is not possible for the listener to control either the amount of expansion or the time constant. The degree of expansion falls rapidly as the operating level is reduced, and an appreciable amount of expansion can only be achieved at maximum power output. The more complicated designs overcome a few of these defects.

A lamp with a 40 mA current has an attack time of about 30 milliseconds and a recovery time of about 150 milliseconds (Ref. 45).

(A) Lamps in voice coil circuit

The simplest form is Fig. 16.5 in which the lamp is shunted across the voice coil, but this is only effective with a pentode valve without voltage feedback, and the distortion due to mismatching is severe except at one level. It is not used in practice.

FIG. 16.5

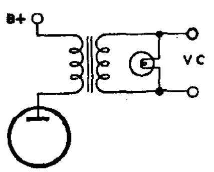

Fig. 16.5. *Simplest form of volume expander using a lamp*

FIG. 16.6

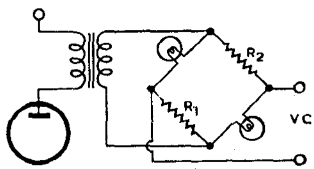

Fig. 16.6. *Bridge type of volume expander using lamps.*

FIG. 16.7

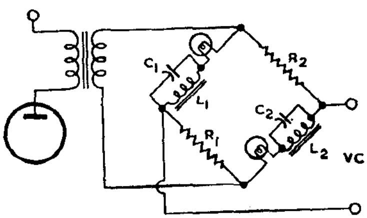

Fig. 16.7. *Bridge type of volume expander using lamps which provides bass boosting at low levels.*

The bridge circuit of Fig. 16.6 is quite practical, and may be used with any type of output valve. At maximum volume this may possibly have an efficiency of 66%. With the addition of two inductors L_1 and L_2 and two capacitors C_1 and C_2 (Fig. 16.7) it may be used to provide bass boosting at low output levels only (Refs. 50, 51, 52, 61). Correct load matching is arranged for maximum output, leaving the low level condition to look after itself.

A suggested application of both carbon and metal filament lamps is Ref. 53.

(B) Volume expander in stage preceding loudspeaker

The loss of power caused by lamps in the voice coil circuit may be avoided by incorporating the expander in an earlier stage. This necessitates a low power amplifier (driver) stage which provides enough power to operate the expander, say 3 watts, followed by a step-up transformer to the output stage, which may be a high-power push-pull amplifier. The volume control should follow the expander, or else two volume controls should be used (Ref. 54).

(C) Lamp-controlled feedback

This is undoubtedly the best form of expander using lamps, although it suffers from most of the limitations of the lamp. An expansion of about 10 db is practicable and Fig. 16.8 shows one form which it may take. Refs. 22, 34, 45.

References to expanders incorporating lamps : 22, 33, 34, 45, 50, 51, 52, 53, 54, 55, 61.

FIG 16.8

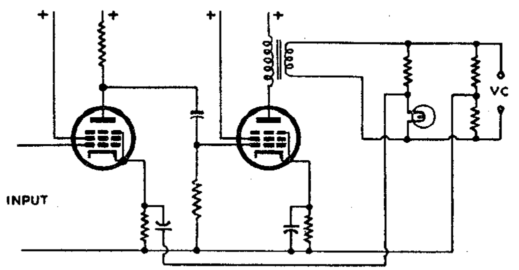

Fig. 16.8. Lamp-operated negative feedback volume expander (Ref. 22).

(iii) Expanders utilizing feedback

Two designs have been developed by Stevens (Ref. 58) and subsequently received attention (Ref. 22) but have certain limitations.

An improved form is shown in Fig. 16.9 which gives an expansion of 29 db, with minimum gain of 200 times. The distortion is not visible on a C.R.O. with an output of 30 volts r.m.s. The attack time is 50 milliseconds and the recovery time about 1 second ; the latter may be adjusted by varying R_{10}. For further details see Refs. 22, 24 and 68.

(iv) Expanders incorporating remote cut-off pentodes

This is the oldest type of volume expander and a very satisfactory one, the valves being types suitable for use as i-f amplifiers or audio a.v.c. stages in receivers. It is possible to obtain a good control characteristic and any reasonable degree of expansion, to provide independent volume and expansion controls, and to arrange the time constants of the circuit to give the desired attack and recovery times. In order to avoid non-linear distortion, the controlled stages should operate with input voltages not greater than 0.15 volt, with a load resistance of 50 000 ohms. The controlled stages are nearly always arranged in push-pull—this eliminates even harmonic distortion and reduces intermodulation distortion. Push-pull operation is particularly valuable in reducing " thump " with large transients ; it also reduces any residual ripple that may come through from the rectifier. A further advantage of push-pull operation is that cathode and screen by-pass capacitors

FIG 16 9

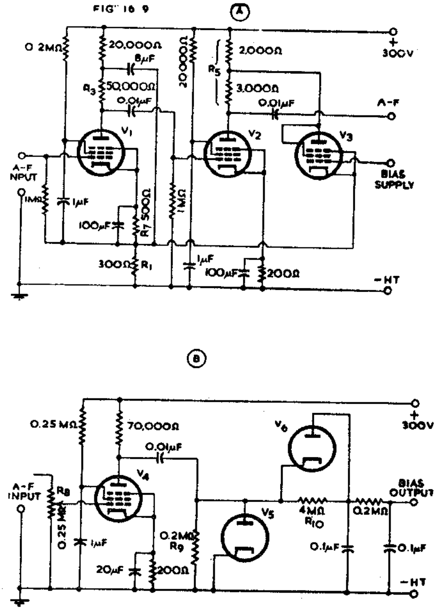

Fig. 16.9. Volume expander using negative feedback ; (A) amplifier (B) circuit for supplying control bias to the amplifier (Refs. 22, 24). $V_1 = V_2 = V_3 = V_4 =$ SP41 ; V_5 and V_6 together = 6H6.

FIG. 16.10

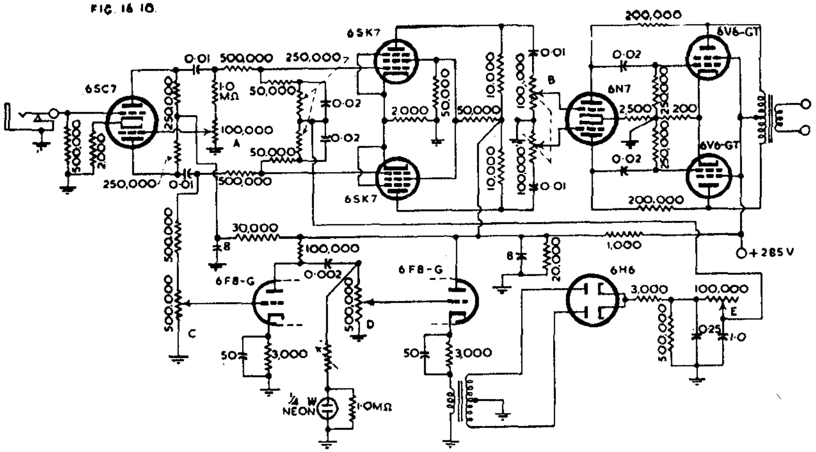

Fig. 16.10. *Volume expander incorporating remote cut-off pentodes (Ref.* 23). *Controls A = balance, B = volume, C = input level, D = expansion, E = time constant.*

may be omitted, thus eliminating time delay in the adjustment of electrode voltages. Valves used in each push-pull pair must be very carefully matched for plate current and mutual conductance at several points over the operating range of grid bias voltages. Owing to the limited input-voltage which may be used, there should be one voltage amplifier stage between the controlled stage and the power amplifier.

An example of good design is Fig. 16.10 (Ref. 23). The minimum attack time is about 10 milliseconds and the recovery time of the order of 1 second. The expansion curve (db versus voltage) is approximately linear up to a d.c. control voltage of 20 volts, which gives 10 db expansion. The 6SC7 stage is common to both sections. The 6SK7 push-pull stage is the controlled stage ; this is followed by the 6N7 voltage amplifier stage which is coupled to the 6V6-GT power amplifier. The signal to feed the rectifier is taken from the plate circuit of the 6SC7 stage, amplified in two stages (6F8-G), the second being a cathode follower, and rectified by the 6H6. The direct voltage from the 6H6 filter circuit is applied to the signal grids of the 6SK7 valves.

In any expander of this general type, whatever may be the method of controlling the gain, it is necessary to prevent the transients in the output of the individual expander valves from becoming so large as to cut off the following stage. This can be accomplished by transformer coupling, by a direct-coupled phase inverter (as in Fig. 16.13) or by the use of low values of load resistances and coupling capacitances (as Fig. 16.10). With the third method it is necessary to incorporate an equalizing network to give a flat overall frequency response.

Refs. 22 (Part 1), 23.

(v) Expanders incorporating remote cut-off triodes

Any remote cut-off pentode may be connected as a triode (screen, suppressor and plate tied together) to form a triode which may be used in a similar manner to a pentode, except that the gain will be lower. It has been stated that a single valve has 0.37% total harmonic distortion unexpanded, 0.64% expanded, predominately second harmonic, when the output level is − 25 db (i.e. 0.056 volt). For further details see Refs. 1, 42.

(vi) Expanders incorporating suppressor-grid controlled pentodes

A sharp cut-off pentode of suitable design may be used for controlling the gain—the English Mazda AC/SP1 and the American 6SJ7 are typical examples. One example of this application is Fig. 16.11 (Refs. 7, 10) which has an attack time of about 1 millisecond, and a variable recovery time of about 1 second maximum. Resistors

FIG 16 11

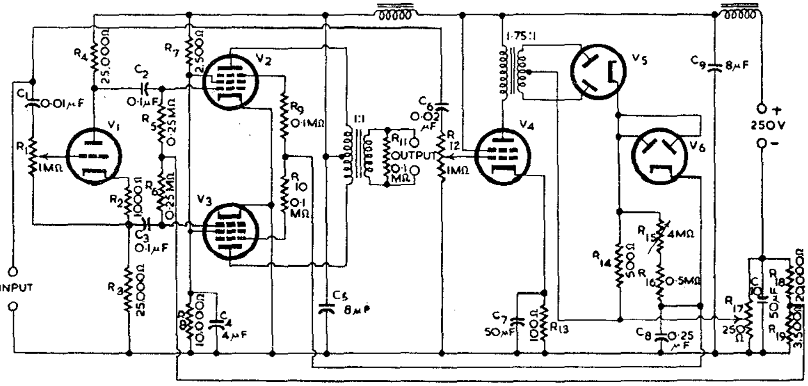

Fig. 16.11. *Volume expander incorporating push-pull suppressor-controlled pentodes (Ref. 7).* $V_1 = MH_4$, $V_2 = V_3 = AC/SP1$, $V_4 = KT41$, $V_5 = V_6 = AZ3$.

R_9 and R_{10} prevent the suppressor grids from being driven positive. With the moving contacts of R_{12} and R_{17} at the chassis ends, R_1 should be adjusted in conjunction with the volume control of the main amplifier so that the latter will just be fully loaded with the loudest signal. R_{17} is then adjusted to give the desired expansion. R_{12} is advanced until the loudest signal just causes the suppressors to be at cathode potential. Any further alteration in volume level should be made by R_1. Some suggested modifications are given in Refs. 10, 16.

A second example is Fig. 16.12 (Ref. 27) in which the need for push-pull operation and for a transformer is avoided by an ingenious device. V_1 is the suppressor-controlled stage while V_2 is a " dummy " designed to balance the plate and screen currents of V_1 so that the current passing through each load resistor is constant. The maximum signal input to the expander stage is about 0.25 volt, and the maximum signal output of the expander is of the order of several volts, for low distortion. The controlled range is about 15 db. The diode rectifier incorporated in the suppressor circuit prevents the suppressor from being driven positive. The time constants are such that 75% of final gain is achieved in the fast position in approximately 20 milliseconds, and in the slow position 60 milliseconds. The recovery times are about 0.5 and 1.2 seconds.

References 27, 46.

FIG. 16.12

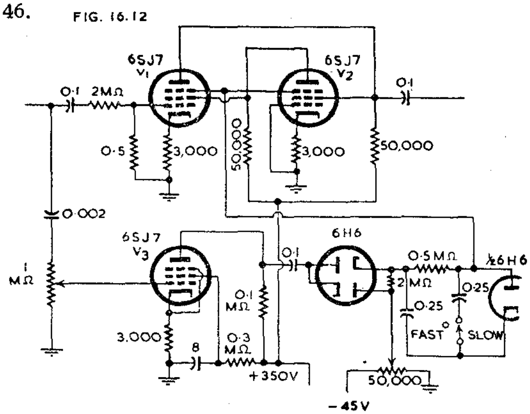

Fig. 16.12. *Single-ended surgeless volume expander incorporating suppressor-grid control (Ref. 27).*

(vii) Expanders incorporating valves with five grids

(A) Incorporating type 6L7

This valve type has two signal input grids, grid No. 1 having a remote cut-off characteristic, and grid No. 3 having a sharp cut-off characteristic. Normally the signal is applied to No. 1 grid which operates at a fixed bias of about − 10 volts, grid No. 3 is operated with a static bias of approximately − 18 volts, the screen is maintained at 100 volts and the static plate current is from 0.12 to 0.15 mA. The expansion available is about 20 db, and the maximum input is 1 volt, or say 0.5 volt for reasonably low distortion. There may be difficulty with hum, owing to the low signal amplification with small input voltages. There must be a careful compromise between time of " attack " and suppression of the ripple voltage produced by the bias rectifier. Particularly when the input level is low, the transient voltages on No. 3 grid become audible as clicks or thumps. These remarks apply to the old form of single valve design (Refs. 13, 35, 55, 64).

An improved form is shown in Fig. 16.13 (Ref. 21) which makes use of push-pull 6L7 control valves and direct-coupling to the following 6SJ7 phase inverter. The attack time is 12 milliseconds and the recovery time adjustable from 0.07 to 0.9 second.

References to 6L7 expanders : 19, 21, 35, 55, 64.

FIG. 16.13.

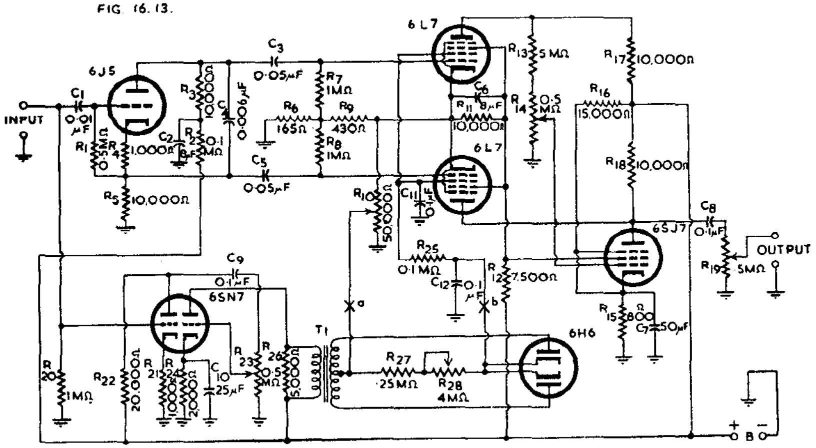

Fig. 16.13. *Volume expander incorporating push-pull* 6L7 *control valves* (*Ref.* 21).

(B) Incorporating 6A8

The input signal is applied to Grid No. 1 (oscillator grid) and the amplified voltage for control purposes is taken from a volume control in the plate circuit of Grid No. 2 (anode grid), rectified by a separate rectifier and then applied to Grid No. 4 (control grid). Ref. 14 ; also Ref. 56 (incorporating MX40).

(C) Incorporating triode-hexode (6K8)

The input signal is applied both to Grid No. 1 of the hexode and to the grid of the triode, and the amplified voltage for control purposes is taken from a volume control in the triode plate circuit, rectified by a separate rectifier and then applied to Grid No. 3 of the hexode. Ref. 14.

(D) Incorporating type 6SA7, 6BE6, or 7Q7

One possible application is Fig. 16.14 (Ref. 25) in which push-pull 7Q7 valves form the controlled stage. The maximum expansion is 18 db, attack time 3 milliseconds and recovery time 0.5 second. The push-pull signal is applied from the phase splitter to the No. 3 grids of the 7Q7 valves, while the control voltage is applied to the No. 1 grids in parallel. In the original article this expansion circuit is incorporated

FIG 16 14

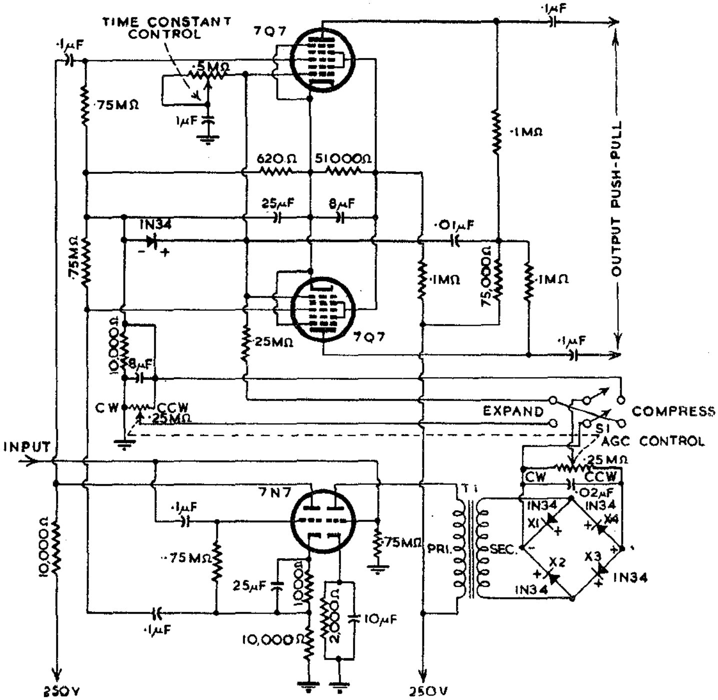

Fig. 16.14. Volume expander/compressor incorporating push-pull 7Q7 (= 6SA7 = 6BE6) control valves and 7N7 (= 6SN7-GT) as phase splitter and control amplifier with 1N34 germanium crystal diode rectifiers (Ref. 25).

in a complete 30 watt amplifier with 4% total harmonic distortion at zero expansion which is increased to 5.5% with maximum expansion.

(viii) Expanders incorporating plate resistance control

The plate resistance of a valve may be varied either by varying the grid bias or by applying feedback. In either case it may be used to shunt across a network and thereby to control the overall gain.

Some possible applications are described in Refs. 22 (Part 1 Fig. 3), 41, 43 and 55 (Fig. 6). A good design is Fig. 16.15 (Ref. 43) in which a rapid attack is combined with a recovery time which may be varied from 0.5 to 10 seconds. The maximum expansion is 12 db, and the intermodulation distortion is always less than 1.75%. The expansion characteristic (db versus db) is almost linear. The push-pull 6J5 valves form a Class A_1 amplifier with a normal load of 15 000 ohms across each valve. The 6P5 (= 76) valves form the controlling stage and place an additional shunt load from a high value to 10 000 ohms per valve. The maximum input voltage is 3 volts peak, grid to grid. If a high impedance input circuit is desired, transformer T_1 may be replaced by a phase splitter stage (Fig. 6 of Ref. 43). The close approach to linearity in the expansion characteristic is obtained by arranging 6 db more expansion than necessary, and then reducing the overall gain by 6 db through negative feedback.

Some alternative applications are discussed in Ref. 13.

FIG 16.15

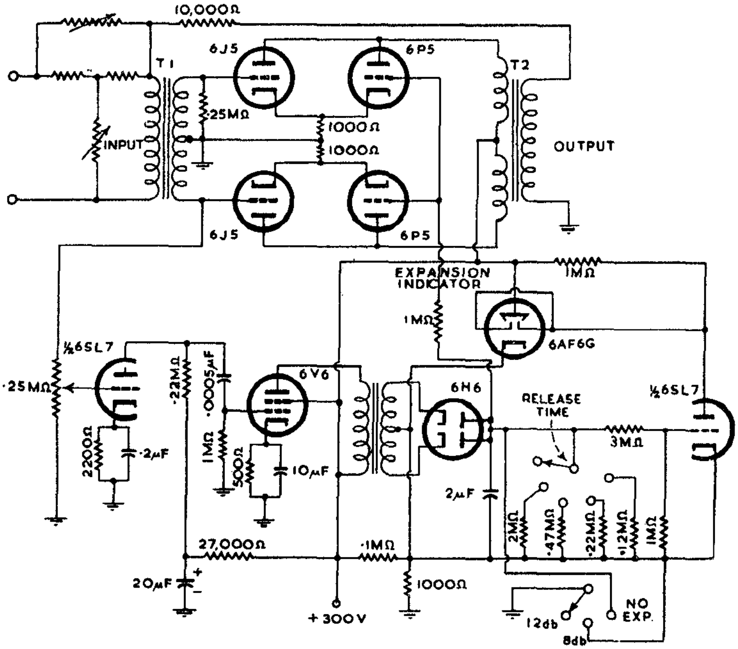

Fig. 16.15. *Volume expander incorporating plate resistance control* (*Ref.* 43).

SECTION 5 : PUBLIC ADDRESS A.V.C.

Audio a.v.c. may be applied to an a-f amplifier so as to permit the speaker to move his head without causing a serious drop in sound output level from the loudspeaker. The usual method is to incorporate into the amplifier a control valve, at such a level that the input voltage to the control valve is about 0.5 volt for type 6L7 or 0.15 volt for a remote cut-off pentode. Other methods of control can, of course, be used. The control voltage may be derived from a suitable point on the main amplifier, preferably through an isolating stage, with a full wave rectifier and filter in the usual way. A typical example is Ref. 65.

References to public address a.v.c. : 39, 65, 92.

SECTION 6 : SPEECH CLIPPERS

In the case of speech it is practicable to clip the peaks without seriously affecting the tonal qualities of the voice, and with a bearable degree of distortion. With a suitably designed speech clipper it is possible to operate at a higher average level than with a limiter, owing to the long recovery time which is necessary with the latter. A speech clipper is practically instantaneous in its action.

When peaks have been clipped there should be a minimum of phase distortion in the remainder of the amplifier, at least up to 8000 c/s. The response should be flat from 200 to 4000 c/s, but there must be treble attenuation above 4000 c/s—at least 25 db at 10 000 c/s. The treble attenuation may be provided by a single constant *k* section filter, since the harmonics are attenuated sufficiently before they are shifted far enough in phase to increase appreciably the peak amplitude of the wave. At the bass end, satisfactory results are obtained if the response following the clipper stage is attenuated 3 db or less.

The Plex amplifier (Ref. 37, Fig. 3) is capable of 20 db peak clipping before the distortion becomes serious. The average increase in power level is about 12 db.

An alternative design of speech clipper incorporated in a speech amplifier is given in Fig. 2 of Ref. 28.

FIG. 16.16

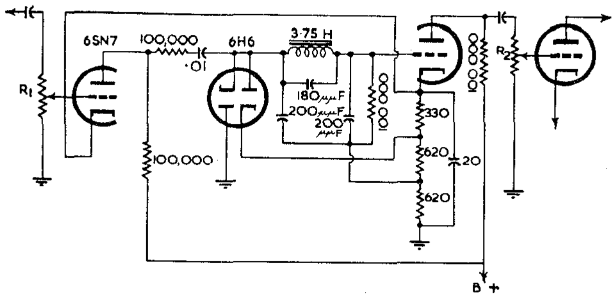

Fig. 16.16. *Simple form of speech clipper suitable for an amateur transmitter. The* 3.75 *H choke must have low d.c. resistance and good a-f characteristics* (*Ref.* 28).

A much simpler form of speech clipper, but one good enough for use with amateur transmitters, is shown in Fig. 16.16 (Ref. 28).

" Infinite " peak clipping has been used successfully, giving articulation from 50 to 90%. If preceded and followed by suitable frequency-tilting filters, the articulation may reach 97% with a quality sounding very much like normal speech. See Chapter 14 Sect. 11(ii), also Ref. 71 of this chapter.

References to speech clippers : 28, 37, 63, 71.

SECTION 7 : NOISE PEAK AND OUTPUT LIMITERS

(*i*) *Introduction* (*ii*) *Instantaneous noise peak limiters* (*iii*) *Output limiters* (*iv*) *General remarks.*

(i) Introduction

Limiters are restrictive devices to mitigate the effects of undesired electrical disturbances of an impulsive nature such as static and ignition noise on the output of an A-M receiver.

(ii) Instantaneous noise-peak limiters

(A) Series noise-peak limiters

These are highly effective in radio receivers. Fig. 16.17 is a simple series limiter which only requires four additional components as shown inside the dash-dash rectangle. Threshold bias is derived from the rectified carrier.

FIG. 16.17

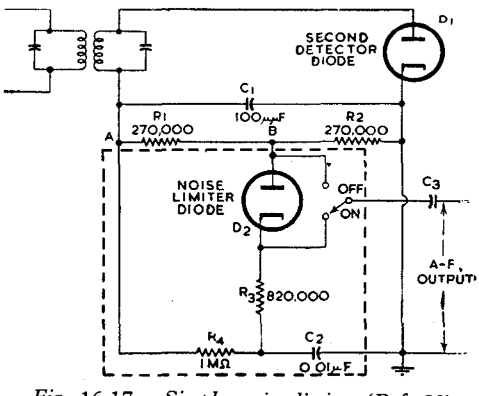

Fig. 16.17. *Simple series limiter* (*Ref.* 30).

When a 6H6 valve is used for both diodes, the hum may be reduced by earthing the end of the heater which is closer to the diode D_2. The hum may still be troublesome even with this precaution.

A circuit giving lower hum is Fig. 16.18; if a limiter on/off switch is used, two different values of C_5 will be required.

FIG. 16.18

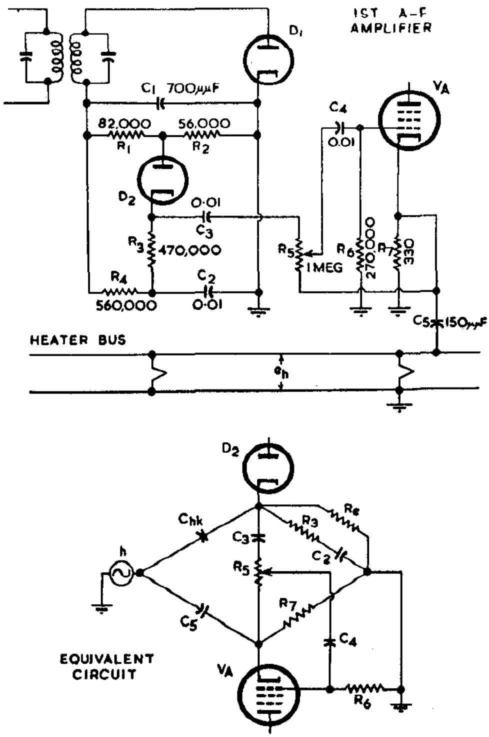

Fig. 16.18. *Hum-reduction version of simple series limiter with equivalent circuit to show bridge configuration (Ref.* 30).

(B) Series-type noise limiter with threshold adjustment

In this form the limiter threshold can be varied from about 65% modulation down to substantially zero, on half of the modulation cycle (Fig. 16.19). Diode D_3 may be added to buck the thermionic potential of the limiter diode and thereby improve the effectiveness at low carrier levels; this is at the cost of increased distortion.

(C) Low-loss series-type noise limiter (Fig. 16.20)

This provides the a-f amplifier with a higher percentage of the a-f voltage across the detector diode load (2 or 3 db improvement).

FIG. 16.19

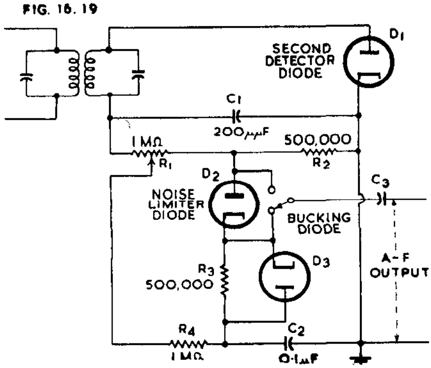

Fig. 16.19. *Series-type noise limiter with threshold adjustment (Ref.* 30).

FIG. 16.20

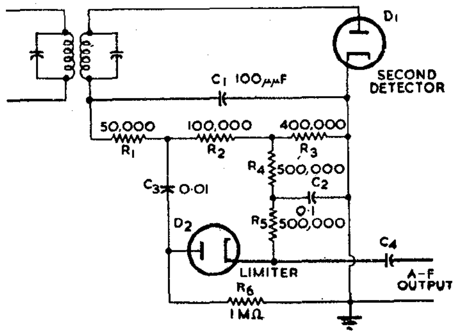

Fig. 16.20. *Low-loss series limiter.* (*Ref.* 30).

(D) Balanced-detector noise limiter (Fig. 16.21)

This functions as a balanced bridge arrangement for detector voltages above the limiting threshold, with unbalance at all other times. It must be adjusted manually for each carrier level. This is not a very satisfactory form of limiter.

FIG. 16.21

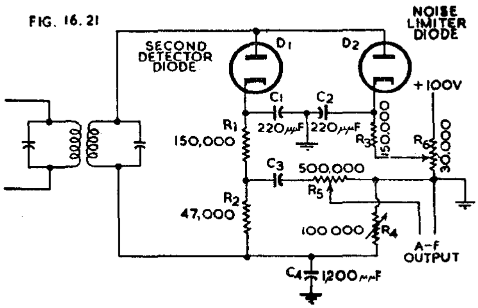

Fig. 16.21. *Balanced-detector noise limiter* (*Ref.* 30).

(E) Automatic balanced-detector noise limiter (Fig. 16.22)

The additional diode is operated from a tertiary winding on the final i-f transformer. Limiting does not take place at modulation depths below 100%. This is an improvement on Fig. 16.21 but it also is limited in performance.

FIG 16.22

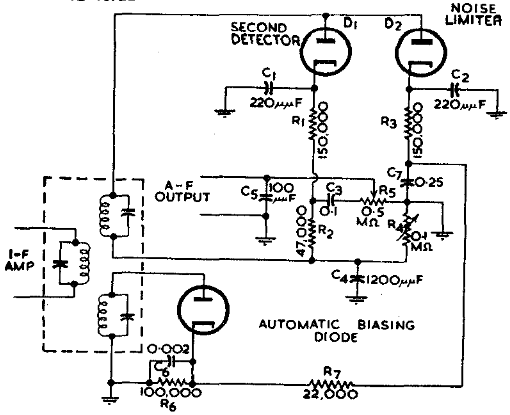

Fig. 16.22. *Automatic balanced-detector noise limiter.* (*Ref.* 30).

FIG. 16.23

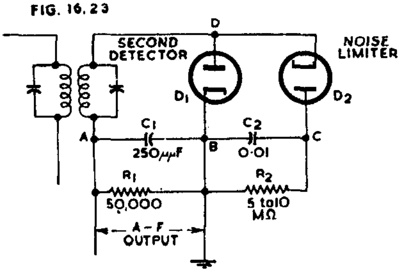

FIG. 16.24

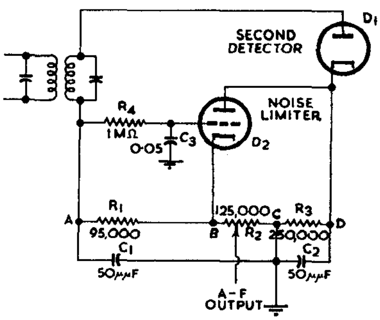

Fig. 16.23. *Balancing-type noise limiter* (*Ref.* 30).

Fig. 16.24. *Triode shunt-type noise limiter* (*Ref.* 30).

(F) Balancing-type noise limiter (Fig. 16.23)

This uses a limiter diode with reversed polarity, shunted across the detector diode. The modulation distortion is quite high, even on relatively low modulation depths. This circuit gives effective limiting of noise peaks. It provides about twice the normally obtainable a.v.c. voltage when the direct potential across R_2 is utilized.

(G) Triode shunt-type noise limiter (Fig. 16.24)

This circuit employs the plate resistance of a triode shunted across a portion of detector diode load, the magnitude of the shunt resistance being controlled by the grid and plate voltages, which act in conjunction with differential time-constants. The percentage of modulation at which distortion begins depends on the triode used, the values of R_1, R_2 and R_3, the time-constants involved, and the absolute carrier level. The higher carrier levels produce no distortion and no limiting. Serious distortion has been observed with 10% modulation at low signal levels. Effective limiting action is restricted to a narrow range of carrier input levels, generally above 10 Mc/s in carrier frequency.

FIG. 16.25

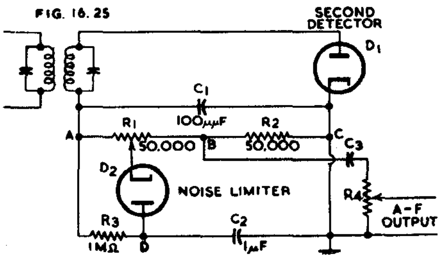

Fig. 16.25. *Diode shunt-type noise limiter* (*Ref.* 30).

(H) Simple diode shunt-type noise limiter (Fig. 16.25)

This is the simplest form of limiter, but the performance is not very good; some improvement is evident on pulse type interference on signals above 10 Mc/s.

(I) Modified shunt-type noise limiter (Fig. 16.26)

This limiter begins to cause distortion at about 100% modulation for the values shown. This form is much more effective than the simple shunt limiter, although not so good as the simple series-type limiter at the lower carrier frequencies.

FIG 16.26

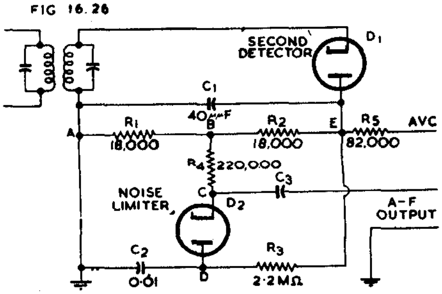

Fig. 16.26. *Modified shunt noise limiter* (*Ref.* 30).

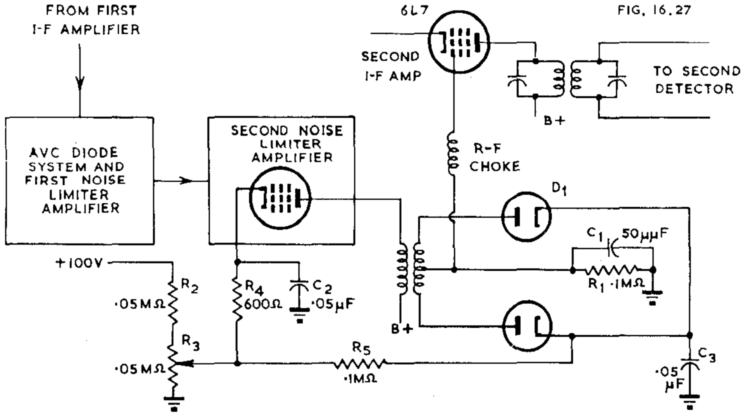

Fig. 16.27. *Degenerative noise limiter, acting between first and second i-f stages* (*Ref.* 30).

(J) Degenerative noise-limiter (Fig. 16.27)

Degenerative feed to the i-f amplifier prior to final detection is used in this circuit. A portion of the output from the first i-f amplifier is amplified in the first and second noise-limiter amplifiers, and the resulting i-f output is coupled into a full-wave rectifier having R_1 as a load resistance. The direct voltage developed across R_1 provides the bias for the grid of a 6L7 serving as second i-f amplifier. Front panel control R_3 provides a positive delay voltage for the diode cathodes, to prevent rectification until the signal or noise peaks exceed this bias. This limiter requires manual adjustment of the threshold of operation, and is useless on fading signals. Modulation distortion is determined by the delay bias obtained from R_3 or by an accessory a.v.c bias if provision is made for automatic biasing.

(iii) Output limiters

(A) R-F output limiter

This method, using low voltages on r-f amplifier plates and screens, is mainly used for telegraphy (Ref. 30).

(B) A-F saturation-type output limiter

This method gives control of the maximum output of the a-f power amplifier by suitably adjusting the plate, screen and grid voltages. A low-pass filter filters out distortion produced in the output stage. A similar result may also be achieved in an a-f voltage amplifier by controlling the screen voltage of a pentode valve. These are mainly used for modulated c-w (Ref. 30).

(C) Logarithmic compressor (Fig. 16.28)

This circuit is a two-stage a-f amplifier with negative feedback, having two diodes connected in series with the feedback path in such a way as to provide a path for both positive and negative half-cycles of the feedback voltage. Potentiometer R_{10} provides bias to the diodes for setting the limiting level.

Using the diodes in this manner is equivalent to varying the feedback percentage from a low value to a maximum as the instantaneous feedback voltage rises, with the reverse effect as the instantaneous feedback voltage falls. This circuit produces considerable distortion on speech or music but does not destroy intelligibility. Noise interference is reduced substantially, and almost as effectively in some cases as with a series noise-peak limiter.

FIG 16.28.

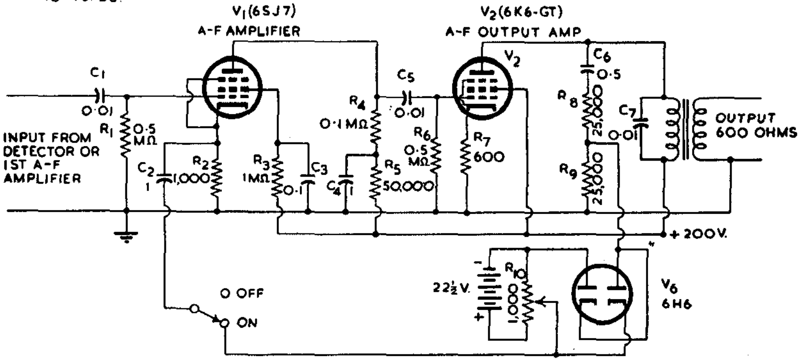

Fig. 16.28. *Logarithmic compressor* (*Ref.* 30).

(iv) General remarks

Satisfactory protection against blocking may be provided by arranging for the stage preceding the final i-f amplifier to overload before the final i-f amplifier, then for each preceding stage to overload in turn.

A linear detector (or second detector) is desirable when handling a high noise level.

It is desirable to have control of the a-f gain of the stage following an instantaneous limiter—shunt limiters operate better with low following a-f gain. Ref. 30.

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