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COMPLETE SPECIFICATION

Improvements in Noise Reduction Systems

I, RAY MILTON DOLBY, a citizen of the United States of America, of Dolby Laboratories, 590 Wandsworth Road, London, S.W.8., England, formerly of Crabtree Hall, Crabtree Lane, London, S.W.6., England, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

Introduction

This invention relates to compressors and expanders and noise reduction systems of the type in which a signal is subjected to amplitude compression before being fed through transmission or recording and playback apparatus which introduces noise and thereafter to complementary expansion. For convenience the apparatus which introduces the noise will be called the "information channel". In audio systems the noise is usually hiss and hum, but it may also take the form of rumble, clicks, crosstalk and so on. The main noise problem in video systems is high frequency noise which leads to a grainy picture.

Many noise reduction systems are known, including the use of pre-emphasis at the lower and upper parts of the audio range. This simple approach is of limited use because overloading must be avoided when the audio signal includes a substantial amount of energy in the high or low frequency ranges. Recording is sometimes effected on two channels, one recorded at a level up to 30dB above the other. On playback the high level channel is automatically selected for low level passages and vice versa but this technique is of limited applicability and necessarily uses two channels instead of one. Other systems use non-linear circuits but these

introduce intermodulation distortion in audio systems. It is also known to control a low-pass filter automatically in response to signal level to filter out hiss during low-level passages only. In using compressors and expanders it is known to vary the degree of expansion on playback automatically in response to the signal level.

All of these prior proposals suffer from limited applicability, limited effectiveness or from undesirable side effects such as distortion, and it is the object of the present invention to provide a system of general applicability which avoids these defects.

General Principles

In a conventional limiter or compressor the operating law is determined by a variable gain device, together with its control circuits, through which the full signal passes. In the present invention on the other hand, the signal is split into two components: 1) An unaltered component which contributes mainly the high level signals and 2) a low level differential component from a limiter circuit. The overall compression characteristic is derived by adding the two components together.

This differential technique has several advantages. Distortion is reduced, since the limiter contribution is negligible at high levels. Tracking accuracy problems between compression and expansion are practically eliminated, since the compression law is largely determined by the limiting threshold and the addition proportions of the two components, factors which are readily controlled. Thus a favourable property of the method is a relative insensitivity to errors in level between compression and expansion. The method is also advantageous under dynamic and transient signal conditions. For example

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it is possible to hold overshoots to negligible values, thereby avoiding overloading of the information channel.

According to the present invention a signal compressor comprises a straight-through signal path and means for adding to the output thereof the output of a further path which includes means for amplifying the input signal and means for limiting the output of the further path to a fractional part of the maximum amplitude of the input signal to be treated by the compressor.

The effect of this arrangement is that, at high signal levels, the output of the compressor is substantially unchanged from the input signal, but at low levels the amplifier in the further path effects compression. The limiting means can be linear which makes the compressor suitable for use in audio applications.

The signal expander is complementary to the compressor, the said further path being connected between the output of the expander and means for subtracting the output of the further path from the input signal.

If then the input signal to the compressor is x , the signal in the information channel is y and the output signal of the expander is z we have $y = (1 + F_1)x$

$$\text{and } z = y - F_2x \text{ or } z = \frac{y}{1 + F_2}$$

where F_1 and F_2 represent the transfer characteristics of the further paths in the compressor and expander respectively. Therefore we have

$$z = \frac{1 + F_1}{1 + F_2} x \text{ and if } F_1 = F_2 \\ z = x \text{ as required.}$$

Note that this result is obtained without the need for high amplification, as would be the case if the complete compressor were enclosed within a feedback loop.

Although $z = x$, noise introduced by the information channel is acted upon by the expander only thereby effecting substantial attenuation thereof at low signal levels, e.g. 10dB noise reduction. The form of F_1 is that of a substantial multiplier at low signal levels, decreasing at higher levels, so that the output of the further path is substantially constant at higher levels. The characteristic of F_1 can even make the output of the further path a decreasing function of x at higher levels, as later described.

Preferably the said further path has band-pass characteristics (which may be high pass or low pass characteristics at the top and bottom of the overall frequency range respectively) so as to enable the noise reduction to be effected selectively in a particular part of the frequency spectrum which may be subject, for example, to hiss or hum or, in a video system, to high frequency noise.

Furthermore in most applications it is desirable to use a plurality of the further paths to deal selectively with different bands, so that high amplitude signals in one band do not prevent the noise reduction process in another band in which there may be low level signals.

In the case of a colour television signal, significant reduction of moire patterns, as well as wide-band noise reduction, may be achieved if the further paths take account of the colour sub-carrier and preferably also its sidebands.

The expander may of course be used to improve the quality of a signal which was not previously subjected to the action of the compressor. There may also be occasions when the compressor is used without the expander to provide special effects. In general, however, a complete noise reduction system will include both the compressor, feeding the information channel, and the expander, fed by the information channel.

In a modification of the invention two information channels are used, one for the straight-through signal from the compressor and one for the output of the further path thereof or the combined outputs of the several further paths. This approach is of use when it is desired in a compatible system to have the un-compressed signal separately available.

In a system in which phase is preserved, e.g. a video system, the output of the or each further path may be limited by a simple diode circuit which automatically shifts the filter cutoff frequency to narrow the pass band when the filter output rises above a certain level.

In an audio system a linear limiter is used, being controlled by a smooth signal to prevent the introduction of distortion. The linear limiter may then, however, be followed by a non-linear limiter which is effective during the finite time taken by the smoothed signal to build up thereby preventing overloading of the information channel in this interval. In this arrangement the non-linear limiter acts without introducing audible distortion because of the shortness of the interval and because of the low amplitude of the limiter output as compared with that of the main channel. Alternatively the linear limiting action may be effected by the use of a variable cut-off frequency filter whose cut-off frequency is automatically shifted to narrow the passband when the filter output rises above a certain level.

Figures

The invention will be further described by way of example with reference to the accompanying drawings, in which:—

Fig. 1 is a block diagram of a compressor for video signals,

Fig. 2 is a block diagram of the complementary expander,

Figs. 3 and 4 are circuit diagrams of two filter and limiter circuits used in the compressor and expander,

Fig. 5 shows a modified form of Fig. 3,

Fig. 6 is the circuit diagram of a modified filter and limiter circuit for use in a colour television system,

Fig. 7 is a block diagram of an audio compressor,

Fig. 8 is the circuit diagram of a limiter used in the compressor of Fig. 7,

Fig. 9 shows a modification of part of Fig. 8,

Fig. 10 shows another modification of part of Fig. 8,

Fig. 11 is a diagram of a modified filter and limiter for the audio compressor, and

Fig. 12 shows certain explanatory characteristic curves, curves relating to compressors being shown at (a), curves relating to compressors with attenuation at (b) and curves relating to expanders at (c).

Video Noise Reduction System — Monochrome

Referring to Fig. 1 a monochrome video compressor is shown in which the signal in a straight-through path 18 is added in circuit 20 to the outputs of two further paths 9 and 11 provided for reducing noise (in conjunction with an expander) in the 100kc/s—1mc/s and 1mc/s to 4mc/s. bands respectively, these ranges being of the order required for a normal television video signal. The outputs of paths 9 and 11 are added in an adder 19 before being fed to the adder 20. For a noise reduction of 10dB amplifiers 13 and 14 amplify the low level input signals by 6.7dB (2.16 times), set by attenuators 16. Each path includes a combined filter (selecting the corresponding band) and limiter 10, 12 which prevents the outputs of the limiter circuits from exceeding, say, 1% of the maximum input signal level. At low signal levels the high frequency components at the compressor output will be 10dB (3.16 times) up on the input level but at full input level the value of the added components will be only 2.16% of the peak to peak signal, negligible overshoot thus being introduced.

The expander shown in Fig. 2 restores the signal since the two signal paths 9 and 11 are now connected between the output and input of the subtracting means 21. The paths 9 and 11 are identical to those in Figs. 1 and 2. This expander circuit attenuates high frequency components at low signal levels in the high frequency bands and hence attenuates the high frequency noise which causes graininess. While the attenuation is not present when the high frequency signal level is high, the noise is not then noticeable as it is

masked by the picture detail represented by the high frequency signal components. The same masking effect is responsible for the success of the audio systems, later described, in reducing perceptable noise. Two further paths 9 and 11 are shown by way of example in the expander and compressor of Fig. 1 and 2. If only a single path were used for the whole band of 100kc/s to 4 mc/s, high amplitude signals up to 1mc/s would frequently prevent the reduction of noise above 1mc/s.

In practice it is not necessary to have a separate amplifier in each path 9 and 11. A single amplifier common to both paths may precede the two filter and limiter circuits 10 and 12.

Fig. 3 shows the preferred circuit for the filter and limiter 12. A simple RC network 24, 26 gives high pass characteristics (i.e. above 1mc/s) and diodes 28 limit the output to small excursions above and below ground. The circuit 10, Fig. 4 has an added RC circuit 30, 32 to define the 1mc/s upper cut-off; the components 24 and 26 have values appropriate to a lower cut-off frequency of 100kc/s.

The diodes 28 are preferably high conductance germanium diodes to minimise the voltage drop thereacross, e.g. to about 0.1 to 0.2 volts. Even so the input signal voltage must be at a high level if limiting is to be operative at say 1% of the maximum input. An input voltage of 40 volts peak to peak, with a bias of a fraction of a volt is satisfactory. The modification shown in Fig. 5 reduces the drive requirement, as would be convenient in transistor circuits. The diodes 28 are connected to the filter output point 34 through a capacitor 35 and are returned to the output of a feedback amplifier chain comprising amplifier 36, gain-setting attenuator 38 and emitter follower 40. The voltage swing required at the input is reduced by the factor of the gain of the feedback loop, the effect of which is to shift the limiting threshold in the opposite direction to changes in the input signal level.

It is important to notice the direct connection of the limiting diodes to the filter(s) at point 34, no buffer amplifier being interposed. The filter capacitor charging current is supplied mainly by the diodes for high amplitude transients. The recovery time of the circuit is therefore less than if a buffer were used, in which case the capacitor charging current would be supplied only by resistor 26. The filter components resume their normal, linear functions as soon as the transient has passed and the capacitor has been appropriately charged. The driver stage should be able to deliver sufficient current to charge the capacitor fully within about 0.1 microseconds after the passage of a full-peak to peak input step.

Expanders of the types which have been described may also be used to reduce the noise in video signals which have not previously been subjected to the action of a compressor. Although this practice leads to loss of low level detail the loss is surprisingly un-noticeable in normal viewing. When transmitting from a noisy video recording, for example, the operator may increase the gain of each path 9 and 11 sufficiently to reduce noise to an acceptable level. It will also be appreciated that, when both compressor and expander are used, it is not necessary to match the characteristics of their respective further paths very closely.

Video Noise Reduction System — Colour

The invention may be applied to colour video signals and is of advantage not only for the reduction of wideband noise, but for reducing moire patterns which arise from interaction between the colour sub-carrier and the f.m. carrier system of the video recorder.

The compression and expansion may be applied to the R, B and G signals individually, or better to the Y, I and Q signals or to the composite colour signal when, as will frequently be the case, component signals are not available separately. In all cases it is necessary to exclude the colour sub-carrier from each further path (to the extent of at least 50db attenuation), otherwise the sub-carrier will choke the compressor and expander and make noise reduction impossible when composite signals are being processed. Therefore, a low pass filter (cut-off at approximately 2mc/s) is required in each channel, suitable precautions being taken to avoid oscillation in the feedback loop used in the expander. Typically then, noise reduction can be obtained from say 100kc/s to 2mc/s in the R, B and G channels or from 100 kc/s to 2mc/s in the Y channel and from 100kc/s to the upper limits of the I and Q channels. A similar approach in the case of the composite signal will give noise reduction from 100kc/s to 2mc/s in the Y channel only but even this is of advantage since the spurious intermodulation products which give rise to moire patterns are contributed mainly by the Y channel.

If the cut-off frequency is raised to permit the passage of sub-carrier sidebands, say to within 400 kc/s of the sub-carrier frequency, the noise reduction coverage will be increased but at the expense of introducing "dead time" (calculated to be of the order of 3 microseconds) whenever there is an abrupt change in the sub-carrier amplitude or phase. "Dead time" refers to time in which the output of the further path remains at the limiting level although the signal level has fallen below this level. Based on the 525 line N.T.S.C. standard, noise reduction would be obtained in the Y channel from 100kc/s to

3.58mc/s minus 400kc/s=3.18 mc/s, in the I channel from 400kc/s to 1.5cm/s and in the Q channel from 400kc/s to 500kc/s. The dead time prevents noise reduction following large, abrupt colour transitions but the burst of noise is likely to be masked subjectively by the colour transition, as well as by the brightness change probably accompanying it.

The sideband choking effect may be compared with the previously described behaviour of the monochrome system in which a buffer amplifier is used between the filter circuit and the limiter. In neither case do the diodes enter into the filter network's readjustment to the new conditions imposed by the incidence of a transient. It was seen that when the diodes are allowed to interact with the filter the filter becomes non-linear with high amplitude transients and is forced to accommodate itself quickly to new conditions. This situation suggests that some analogous arrangement should be possible for response to a carrier and its sidebands.

The idealized behaviour is obtained by a subcarrier trap having a high Q (narrow bandwidth) when the colour sidebands and high frequency Y components have low levels, full noise reduction action being possible under these conditions. When the colour sidebands and/or high frequency Y components exceed a predetermined level, the Q of the trap is lowered momentarily, thereby dissipating the energy introduced by the sidebands and not allowing its storage in reactive elements. As soon as the sideband energy is extinguished, the Q of the circuit is raised and the noise reduction action is resumed.

One suitable circuit is shown in Fig. 6. In addition to a capacitor 60 and resistor 62 defining the lower frequency of the noise reduction band, as in Fig. 3, a parallel-tuned sub-carrier trap consisting of inductor 54 and capacitor 56, is included in the series signal path and a series trap, consisting of inductor 54A and capacitor 56A, shunts the signal path. Either one of the two traps may be eliminated, but in the general case both are present. Low level sideband components are transmitted to the output with undiminished level, the trap(s) being unable to follow such changes while in linear operation. The parallel resonant circuit will be forced to accommodate itself to any large and abrupt change in the amplitude or phase of the carrier (appearance of sidebands) by the action of the diodes 28, while such large amplitude components are not even allowed to reach the series trap, again by the action of the diodes.

Noise reduction then covers the Y channel from 100kc/s upwards except for a sharp notch at the sub-carrier frequency. The I and Q channels are covered from a frequency depending on the bandwidth of the trap(s), e.g. 50kc/s, to their top ends.

The foregoing discussion has related pri-

marily to the N.T.S.C and PAL type of system but much is applicable to the SECAM system. However some modifications would be necessary to cover the latter system since the sub-carrier is frequency modulated. For example the trap 54A, 56A of Fig. 6 could be replaced by a plurality of such traps in parallel, (or of the parallel traps in series), together covering the whole sub-carrier deviation band. Alternatively the f.m. sub-carrier could be tapped off, limited and fed back to cancel the sub-carrier in the composite signal in the further path of the compressor or expander.

Instrumentation Noise Reduction Systems

Similar techniques to those discussed for monochrome video signals may be used to deal with wideband instrumentation applications, the frequency ranges of the further paths being suitably modified. Where carrier frequency systems are used it is preferable to split the signal into separate bands, each with its own noise reduction system. A poorer alternative, in which several carriers are treated by a single noise reduction system, is to use a circuit such as that of Fig. 6 with a plurality of traps 54, 56 54A, 56A tuned to the different carrier frequencies. Where no wideband signal component is treated in addition, the capacitor 60 is eliminated. Noise reduction ceases in all channels whenever significant sideband components appear in any one channel.

Audio Noise Reduction Systems

Turning now to audio signals, the only fundamental difference from video systems lies in the need for linear limiting, owing to the lack of preservation of phase in audio information channels. A noise reduction path is necessary for a high frequency band, say 5kc/s to 20kc/s and usually for a low frequency band, say 30c/s to 150c/s. For a high quality system further paths are preferably provided to cover say 150c/s to 1.5kc/s and 1.5 kc/s to 5kc/s. The resulting compressor circuit is shown in Fig. 7 and includes a straight-through path 64, adder 84, amplifiers 74 for the four paths, each with its attenuator 86, filters 66, 68, 70 and 72 for the four bands, separate, linear limiters 76, 78, 80 and 82 and further path combining means 85. Below the limiting thresholds suggested gain for the paths are similar to those used with video, yielding a noise reduction of the order of 10dB.

The corresponding expander is not shown as its construction will be immediately apparent by analogy with Fig. 2. Indeed, as a practical matter, a single unit may be built with provision for switching or strapping connections to convert the unit to either a compressor or expander as required. The feed-

back connection required in the expander precludes the use of filters having fast changes in phase shift with frequency. The filters 66 etc. may be conventional.

Each limiter may commence to act at about 40dB below peak level, full limiting being achieved at about -30dB. Because the contributions of any of the noise reduction paths at high signal levels are negligible, they cannot cause distortion or significant overshoots under transient signal conditions.

As an optional feature, the output of each limiter may be caused to decrease as the level increases above -30dB, as later described, the output falling to a negligible value at say -10dB. This feature is desirable where high levels of noise reduction, say 15dB, may be required.

Fig. 12 shows compressor operating laws at (a), curve A being the law of a conventional compressor which operates on the full signal. Curve D represents the unaltered component of the straight-through path of the present invention and curve E represents the low level differential component from a limiter circuit. The characteristics D and E add to give the overall compression characteristic B.

Fig. 8 shows a suitable limiter circuit the component values being appropriate to path 1, i.e. limiter 76.

The use of the exponential voltage-current characteristic of semiconductor diodes is a convenient way of providing a variable resistance which can readily be controlled by a d.c. bias current. Since in the present invention the limiters pass only low signal levels, distortion generated by the diodes is negligible.

Referring to Fig. 8, the dynamic resistances of diode D_1 and D_2 are controlled by the current passing through silicon transistors Q_1 and Q_2 . Resistive voltage dividers are formed by R_3 and D_1 and by R_4 and D_2 , the balanced connection cancelling out the signals produced by the control current. When Q_1 and Q_2 are in the cutoff condition the input signal will be passed to the output at essentially unaltered level, while if a control voltage is applied to Q_1 , the dynamic resistance of the diodes will be reduced and the output signal will be attenuated.

Capacitors C_1 , C_2 , C_3 , and C_4 are for coupling purposes only, having no frequency discrimination or time-constant effects. Resistors R_1 and R_2 tie the d.c. voltages of the outputs of the input capacitors securely to the supply voltage and ground, respectively. Capacitors C_3 and C_4 add together the voltages of the two attenuation circuits, while capacitors C_1 and C_2 are adjusted to cancel out the control signal.

The amplifier 94 drives the full wave rectifier circuit T_1 , D_3 , and D_4 , charging the smoothing capacitor C_5 . Resistor R_5 , in com-

bination with C_7 , produces a time constant of one second, which is suitable for the signals handled by the low frequency channel.

In the circuit as shown the onset of the limiting action will be quite abrupt. By the use of a simple diode-resistor circuit between the emitters of Q_1 and Q_2 , a smoother limiting characteristic can be obtained, which is of advantage for good tracking between the record and playback circuits and for obtaining characteristics which are more consistent from unit to unit.

The essential signal to the amplifier 94 is that provided by feedback connection 93. The feed-forward connection 95 is optional and provides for the above-mentioned cut-off of the output at about -10dB .

In order to ensure that the compression characteristic in a particular band is determined only by the frequencies in that band, it is possible to introduce appropriate band-pass filters into each of the control amplifiers 94. This approach may be useful where the filters 66 etc. used on the inputs of the limiters do not provide sufficient rejection, sharper filters here being precluded by the feedback configuration used in the expander.

Control Signal Smoothing

It is important to note that the use of separate circuits for the four different frequency bands not only allows noise reduction to take place in one band irrespective of the signal level in another band but also permits the limiter time constants to be suited to the frequencies handled. For example path 4 may have a recovery time constant as small as a few milliseconds, (compared with times of the order of one second ordinarily associated with compression or limiting). When each time-constant is made suitable to the range of frequencies which it controls, the usual noise modulation effects are absent.

The simple smoothing capacitor C_7 of Fig. 8 requires many cycles of the input waveform to discharge and in fact yields a limiter recovery time which is only marginally acceptable. If the time constant is shortened to overcome this defect, ripple appears in the control voltage and distorts the compressed signal.

In order to overcome this problem, the circuit shown in Fig. 9 may replace the capacitor C_7 and resistor R_7 in Fig. 8.

A suitable RC decay time constant (R_7 , C_7) is chosen, and the capacitor C_7 is split into two parts C_{7A} and C_{7B} , these being fed by two series resistors R_8 . The series resistors are so chosen that with the capacitors the ripple voltage is reduced to the desired value. Unfortunately, the circuit then has an attack time which is far too great. However, when diodes D_2 and D_1 are connected in parallel with the Resistor R_8 , the fast rise time is restored without affecting the decay time. The

diodes D_2 and D_1 are chosen to have voltage-current characteristics allowing effective filtering of the ripple component while being suitably conducting for larger amplitude excursions.

In the non-linear integrator described above there is a limit to the amount of filtering which can be achieved for a given recovery time. Under these limiting conditions the ripple voltage will increase if the recovery time is reduced even more. For the purpose of allowing a reduction in recovery time a further refinement has been devised (Fig. 10). A pre-integrator consisting of resistor R_9 and capacitor C_8 is arranged to have the desired decay time-constant R_9 , C_8 ; the pre-integrator can also be of the type shown in Fig. 9, yielding a smoother output wave without disadvantage. The output of the pre-integrator feeds an emitter follower 96, which serves as a low impedance driver for a further integrator circuit. Owing to the diodes D_2 and D_1 the capacitor C_8 is charged or discharged quickly, following the input wave, for large excursions. A fast attack time is hence preserved and the decay time is caused to follow that of the pre-integrator. But under equilibrium conditions the diodes are in an essentially non-conducting state, and the integrator R_{10} , C_8 smoothes the wave to any degree desired.

The main feature of the above described non-linear integration scheme is that low-frequency distortion and the generation of modulation products can be held to low values. Furthermore, the compression action does not tend to be controlled by short transients but by more extended aspects of the signal, a property which is important for yielding a good noise reduction effect.

While the response time of the above circuit is progressively reduced with increasing variations in signal amplitude, overshoots will be produced if the incoming amplitude transitions are large enough. In the present system the amplitudes of such overshoots are reduced by following the linear limiter with a conventional, non-linear limiter. Such a non-linear limiter 87 is shown in path 4, only of Fig. 7 but is preferably included in all paths. The effect of the non-linear limiter is to clip symmetrically the output of the linear limiter 82 when a large suddenly applied signal passes therethrough. Overshoot is thereby limited to say 1 or 2dB with a full amplitude signal. The non-linear limiter does not introduce audible distortion, even on the most difficult types of programme material, such as piano, because the limiter output is small compared with the signal in the main path and because the distortion is of such short duration.

Variable Cut-off System

In a modified embodiment of the audio

compressor or expander paths 2 and 3 in Fig. 7 are omitted and the limiting action in paths 1 and 4 is achieved by moving the top and bottom cut-off frequencies of the respective bands respectively down and up whenever the path output exceeds a certain level. Further description will be confined to path 4, the converse treatment in path 1 being apparent therefrom. Thus, at low levels at high frequencies, path 4 may boost signals from 2kc/s upwards. If a high amplitude signal occurs above this frequency, the cut-off frequency of the filter shifts upwards. Fig. 11 shows a suitable filter and limiter circuit for achieving this.

The elements C_{10} , L_1 and R_{11} form a conventional high pass filter. A voltage controlled resistance 108, which may be similar to the balanced diode circuit D_{11} , D_2 etc. shown in Fig. 8, is in parallel with R_{11} and is biased so as normally to present high impedance. However, the output signal is amplified at 110 and rectified and filtered by circuit 112 to provide a control signal for the resistance 108 such that the resistance falls as the signal amplitude increases. This action shifts the filter cut-off frequency upwards. Preferably the slope is 12dB/octave when resistance 108 is high impedance, to prevent incorrect operation being caused by high amplitude components below 2kc/s; but for reasons of economy the slope may fall to 6dB/octave as the cut-off frequency rises without detriment. The time constants of the rectifier-filter circuit 112 may be of the order of 100 milliseconds for the high frequency channel and a few tenths of a second for the low frequency channel.

The variable cut-off filter may take a number of other forms, and the controlled element itself may include Hall effect devices, reactance tubes, voltage controlled capacitances, light controlled resistors transistors or field effect transistors.

Methods of providing a complete cut-off effect are possible as in the case of the limiter of Fig. 8. One method would be to monitor the a.c. current passing through the voltage controlled resistance 112. When the current exceeds a certain value a voltage derived from this current is fed into the control circuit, which thereby lowers the resistance still further. The output signal is then cut off, and will remain so until the input voltage or frequency distribution has changed in such a way as to reduce the sampled current.

Other refinements include the introduction of frequency discriminating networks either in the control amplifier 110 or in the output of the circuit of Fig. 11 for the purpose of lowering the threshold voltage for very high or very low frequencies, which is sometimes necessary in order to prevent overloading of some types of highly equalized recording systems.

The audio compressors and expanders described above may be used in many fields, including tape recording, disc recording, motion picture sound recording, radio relay systems, sound broadcasting and telephone networks. For example, master tapes can be produced with a high S/N ratio, even after repeated dubbing, and it is possible to manufacture commercial discs or pre-recorded tapes with the noise-reduction characteristic for subsequent playback on a domestic noise-reduction system.

Noise-reduction systems based on the compressors of Fig. 7 and Fig. 11 with their corresponding expanders has been tested under the most stringent conditions and do not introduce any detectable degradation of programme material of the most difficult kinds.

Related Devices

Related devices or systems based on the principles of the present invention may be mentioned.

A full band noise reduction system may be used in some cases. Such a system takes the form of path 4 of Fig. 7, omitting the filter 72, using curves B and H in Fig. 12 in recording and playback respectively. In other cases, full coverage of the audio frequency band may not be needed and a single path with an appropriate filter to deal with say hiss or rumble may be used. A narrow band filter may be used to deal with noise at a specific frequency, such as hum or a whistle, the filter being made tunable if required. Such a narrow band path may be used in addition to the paths providing full band coverage, as in Fig. 7. The narrow band path encompassing the narrow path is blocked by high level signals. Where the noise level is high and of a wideband nature it is helpful to use a large number of narrow band paths.

The use of separate information channels for the direct signal and the signals from the noise reduction path(s) has been briefly mentioned. In effect, referring to Fig. 7, this arrangement is equivalent to removing the adding circuit 84 from the compressor to the expander and is illustrated schematically by showing a switch 83 for feeding the output of the adder 85 to an auxiliary output for transmission or recording in a channel parallel to that of the straight-through signal. This modification has application in compatible VHF (FM) transmissions, (the noise reduction signal being modulated as a sub-carrier), compatible disc recordings (the two channels being recorded separately by the techniques used in stereo recording), and compatible tape recordings. In such tape recordings the noise reduction channel can be recorded at a higher level on a narrow track outside the region scanned by the normal head, which reproduces only the direct signal. For noise reduction operation, an additional head scans

the narrow track or a head of extra width head scans both this and the direct signal track.

For non-critical applications however, the transmitted or recorded signal is almost compatible in any event, it being possible to dispense with the expander if a simple passive network is used to correct the bass and treble boost effectively introduced by the compressor. For the parameters used in the present system such a network should provide a 6dB/octave roll-off starting at about 100c/s at the bass end and about 2 or 3kc/s at the treble end.

The invention also facilitates the reduction of distortion, especially high frequency distortion in disc recording, in that a lower recording level may be used without sacrificing signal to noise ratio, recording being in accordance with curve G in Fig. 12(b). Even at low frequencies it may be advantageous to use the invention to permit a lower recording level and hence a higher density of information, as by a finer groove pitch for example in disc recording.

For reducing traffic or turntable rumble an expander may be used with a single noise reduction path including a low pass (e.g. 80c/s) filter and both linear and non-linear limiters as in Fig. 8. However a more abrupt expansion law is used, as in curve J of Fig. 12(c). When low frequency signals are absent the system yields an attenuated low frequency response, the limiting threshold being set at a value a little higher than the rumble amplitude. If they are present at all, low frequency signal components will probably have amplitudes higher than the limiting threshold and will therefore be passed with little or no attenuation.

Though the rumble-reducing expander does not presuppose the use of a compressor, the corresponding compression law to J is shown at C in Fig. 12(a) and is obtained by adding to the straight-through characteristic D a noise reduction path characteristic F. Characteristic F results from a higher loop gain and a sharper limiting threshold than in the case of the curve E appropriate to the circuit of Fig. 8.

An expander may also be used, without a compressor for hiss reduction. However this matter is not so clear-cut as the case of rumble reduction, since, unlike low frequencies (which are fundamentals), high frequency signal components (which are harmonics) may have any amplitude whatever. To avoid noticeable alternations of the frequency response it is therefore necessary in the high frequency case to derive the control signals for the limiter from lower frequency fundamentals, which can be used as a likely indicator of the presence of high frequency components.

A hiss reduction system can be arranged

in the same way, following curve J, as the rumble reduction system, except for filters. In the filter position shown in Fig. 7 a 2,000 c/s high pass filter, for example, can be used, the output of this filter containing sufficient fundamentals to give a rough indication of the presence of higher harmonics. A 5,000 c/s filter would then follow the limiters, this filter controlling the frequency range of the hiss reduction action. (In other applications it may be desirable to make the band selected for deriving the control signal narrower than the band acted upon by the limiters.)

In an alternative arrangement, the 5,000 c/s signal filter can be placed in the filter position of Fig. 7, and the control voltage for the limiter can be derived from a sharp 2,000 c/s filter fed in parallel with the signal filter or from the input.

For the reduction of discrete frequency noise, without the use of a compressor, band-pass filter and limiter channels following curve J of Fig. 12(c) are provided for each interfering frequency, each having an appropriate threshold setting. When a signal appears at one of the noise frequencies the noise reduction action is momentarily blocked, but the interference is then effectively masked by the signal.

In certain applications it is convenient to have some automatic way of closing down recording or transmission channels which are momentarily unused. The required automatic attenuation action can be obtained with an operating law as shown in Fig. 12(c) curve J, no filter being used. The limiter threshold is set at a value just above the noise level of the system or at any other level above which the signal is deemed to be significant. The most valuable property of such an automatic attenuator is that it would have instantaneous attack time with negligible distortion of the initial wavefront.

In some recording applications it is convenient to be able to boost the high and low frequencies during low level passages according to the Fletcher-Munson curves, in order to compensate for the low level frequency response characteristics of the ear. This operation can be accomplished, using a suitable filter, with a compressor having a law of the type shown in Fig. 12(a) curve B, but the exact shape used must be chosen, together with the response of the filter, to give the best overall fit to the Fletcher-Munson curves. It is also possible to obtain the required characteristics by means of separate low and high frequency channels; this approach is preferable from the point of view of optimising the decay time constants.

Although it is preferred to construct the expanders in the manner hereinbefore disclosed, it will be appreciated that an expander may be formed in the conventional

way by including a complete compressor in the feedback loop of a high gain feedback amplifier.

WHAT I CLAIM IS:—

- 5 1. A signal compressor comprising a straight-through signal path and means for adding to the output thereof the output of a further path which includes means for amplifying the input signal and means for limiting
- 10 the output of the further path to a fractional part of the maximum amplitude of the input signal to be treated by the compressor.
- 15 2. A modification of the signal compressor according to claim 1, omitting the adding means and including means for applying the outputs of the said straight-through and further paths to different information channels.
- 20 3. A signal expander comprising a main signal path including subtracting means arranged to subtract from the input signal the output signal of a further path whose input is connected to the output of the subtracting means, the further path including means
- 25 for amplifying the output signal of the subtracting means and means for limiting the output of the further path to a fractional part of the maximum amplitude of the input signal to be treated by the expander.
- 30 4. A signal expander according to claim 3 for use with a signal compressor according to claim 2, further comprising adding means for adding the signals in two information channels to provide the said input signal to the subtracting means.
- 35 5. A signal compressor or expander according to any of claims 1 to 4, wherein the said further path includes a filter limiting the frequencies passed thereby to a particular
- 40 frequency band.
- 45 6. A signal compressor or expander according to claim 5, wherein there is a plurality of further paths whose filters select different frequency bands.
- 50 7. A signal compressor or expander according to claim 5 or 6, wherein the filter in the or each said further path, is directly connected to a limiter circuit.
- 55 8. A signal compressor or expander according to claim 7, wherein the limiter circuit is included in an amplifying feedback loop.
- 60 9. A signal compressor or expander according to any of claims 5 to 8, for use with a carrier system signal, wherein the or each filter includes at least one tuned trap circuit tuned to one or more selected frequencies for removing carriers at such frequencies while permitting compression or expansion of the carrier sidebands, and a broadband signal if such also be present.
- 10. A signal compressor or expander according to any of claims 5 to 8, for use with a broadband signal extending up to a

carrier signal, wherein the or each filter has an upper cut off frequency below the carrier frequency.

11. A signal compressor or expander according to any of claims 1 to 5, wherein the or each further path includes a linear limiter controlled in response to the output signal of the limiter to effect a progressive limiting action on the signal passing through the limiter as the input amplitude increases.

12. A signal compressor or expander, according to claim 11, wherein the linear limiter is additionally controlled in response to the input signal so as to increase the progressive limiting action as the input amplitude further increases.

13. A signal compressor or expander according to claim 11 or 12, comprising means which rectify and smooth the output signal of the limiter or this output signal and the input signal to provide a control signal for the linear limiter.

14. A signal compressor or expander according to claim 13, wherein the smoothing means comprise shunt capacitors fed by series resistors each of which resistors has in parallel therewith a non-linear device permitting rapid charging of the capacitors.

15. A signal compressor or expander according to claim 13, wherein the smoothing means comprise a first smoothing circuit feeding a series resistor and shunt capacitor, the resistor having in parallel therewith oppositely poled non-linear devices.

16. A signal compressor or expander according to any of claims 11 to 15, wherein the linear limiter is followed by a non-linear limiter.

17. A signal compressor or expander according to any of claims 11 to 16, wherein the or each said further path includes filters so arranged that the signal in response to which the linear limiter is controlled covers a different frequency band from the signal at the limiter output.

18. A signal compressor or expander according to any of claims 1 to 6, wherein the or each further path includes a filter which is automatically variable in response to the amplitude of the output signal of the filter so as to narrow the pass band of the filter and thereby to suppress signals exceeding a certain amplitude.

19. A noise reduction system comprising a compressor according to any of claims 1, 2 and 5 to 16 in combination with an expander according to any of claims 3 to 16, the said further paths of the compressor and expander having substantially identical characteristics.

20. A signal expander comprising a compressor according to any of claims 1, 2 and 5 to 16 included in the feedback loop of a high gain feedback amplifier.

21. A signal compressor or expander substantially as described with reference to Figs.

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way by including a complete compressor in the feedback loop of a high gain feedback amplifier.

WHAT I CLAIM IS:—

5 1. A signal compressor comprising a straight-through signal path and means for adding to the output thereof the output of a further path which includes means for amplifying the input signal and means for limiting the output of the further path to a fractional part of the maximum amplitude of the input signal to be treated by the compressor.

10 2. A modification of the signal compressor according to claim 1, omitting the adding means and including means for applying the outputs of the said straight-through and further paths to different information channels.

15 3. A signal expander comprising a main signal path including subtracting means arranged to subtract from the input signal the output signal of a further path whose input is connected to the output of the subtracting means, the further path including means for amplifying the output signal of the subtracting means and means for limiting the output of the further path to a fractional part of the maximum amplitude of the input signal to be treated by the expander.

20 4. A signal expander according to claim 3 for use with a signal compressor according to claim 2, further comprising adding means for adding the signals in two information channels to provide the said input signal to the subtracting means.

25 5. A signal compressor or expander according to any of claims 1 to 4, wherein the said further path includes a filter limiting the frequencies passed thereby to a particular frequency band.

30 6. A signal compressor or expander according to claim 5, wherein there is a plurality of further paths whose filters select different frequency bands.

35 7. A signal compressor or expander according to claim 5 or 6, wherein the filter in the or each said further path, is directly connected to a limiter circuit.

40 8. A signal compressor or expander according to claim 7, wherein the limiter circuit is included in an amplifying feedback loop.

45 9. A signal compressor or expander according to any of claims 5 to 8, for use with a carrier system signal, wherein the or each filter includes at least one tuned trap circuit tuned to one or more selected frequencies for removing carriers at such frequencies while permitting compression or expansion of the carrier sidebands, and a broadband signal if such also be present.

50 10. A signal compressor or expander according to any of claims 5 to 8, for use with a broadband signal extending up to a

carrier signal, wherein the or each filter has an upper cut off frequency below the carrier frequency.

65 11. A signal compressor or expander according to any of claims 1 to 5, wherein the or each further path includes a linear limiter controlled in response to the output signal of the limiter to effect a progressive limiting action on the signal passing through the limiter as the input amplitude increases.

70 12. A signal compressor or expander according to claim 11, wherein the linear limiter is additionally controlled in response to the input signal so as to increase the progressive limiting action as the input amplitude further increases.

75 13. A signal compressor or expander according to claim 11 or 12, comprising means which rectify and smooth the output signal of the limiter or this output signal and the input signal to provide a control signal for the linear limiter.

80 14. A signal compressor or expander according to claim 13, wherein the smoothing means comprise shunt capacitors fed by series resistors each of which resistors has in parallel therewith a non-linear device permitting rapid charging of the capacitors.

85 15. A signal compressor or expander according to claim 13, wherein the smoothing means comprise a first smoothing circuit feeding a series resistor and shunt capacitor, the resistor having in parallel therewith oppositely poled non-linear devices.

90 16. A signal compressor or expander according to any of claims 11 to 15, wherein the linear limiter is followed by a non-linear limiter.

95 17. A signal compressor or expander according to any of claims 11 to 16, wherein the or each said further path includes filters so arranged that the signal in response to which the linear limiter is controlled covers a different frequency band from the signal at the limiter output.

100 18. A signal compressor or expander according to any of claims 1 to 6, wherein the or each further path includes a filter which is automatically variable in response to the amplitude of the output signal of the filter so as to narrow the pass band of the filter and thereby to suppress signals exceeding a certain amplitude.

105 19. A noise reduction system comprising a compressor according to any of claims 1, 2 and 5 to 16 in combination with an expander according to any of claims 3 to 16, the said further paths of the compressor and expander having substantially identical characteristics.

110 20. A signal expander comprising a compressor according to any of claims 1, 2 and 5 to 16 included in the feedback loop of a high gain feedback amplifier.

115 21. A signal compressor or expander substantially as described with reference to Figs.



1, 2, 3 and 4 of the accompanying drawings.

22. A signal compressor or expander substantially as described with reference to Figs. 1, 2, 3 and 4 as modified by Fig. 5 of the accompanying drawings.

23. A signal compressor or expander substantially as described with reference to Figs. 1, 2, 3 and 4 as modified by Fig. 6 of the accompanying drawings.

24. A signal compressor or expander substantially as described with reference to Figs. 7 and 8 of the accompanying drawings.

25. A signal compressor or expander substantially as described with reference to Figs.

7 and 8 as modified by Fig. 9 of the accompanying drawings.

26. A signal compressor or expander substantially as described with reference to Figs. 7 and 8 as modified by Fig. 10 of the accompanying drawings.

27. A signal compressor or expander substantially as described with reference to Figs. 7 and 11 of the accompanying drawings.

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