

CIRCUIT ARRANGEMENT FOR MODIFYING DYNAMIC RANGE

The present invention is concerned in general with circuit arrangements which alter the dynamic range of signals, namely compressors which compress the dynamic range and expanders which expand the dynamic range. The invention is particularly useful for treating audio signals but is also applicable to other signals.

Compressors and expanders are normally used together (a compander system) to effect noise reduction; the signal is compressed before transmission or recording and expanded after reception or playback from the transmission channel. However compressors may be used alone to reduce the dynamic range, e.g. to suit the capacity of a transmission channel, without subsequent expansion when the compressed signal is adequate for the end purpose. In addition, compressors alone are used in certain products, especially audio products which are intended only to transmit or record compressed broadcast or pre-recorded signals. Expanders alone are used in certain products, especially audio products which are intended only to receive or play back already compressed broadcast or pre-recorded signals. In certain products, particularly audio recording and play back products, a single device is often configured for switchable mode operation as a compressor to record signals and as an expander to play back compressed broadcast or pre-recorded signals.

The amount of compression or expansion may be expressed in dB. For example, 10 dB of compression means that an input dynamic range of N dB is compressed to an output range of (N-10) dB.

The present invention relates in particular to a circuit arrangement for modifying the dynamic range of an input signal and comprising a first circuit with a bi-linear characteristic (where "linear" in this context denotes constant gain) composed of:

- 1) a low level linear portion up to a threshold,
- 2) an intermediate level non-linear (changing gain) portion, above the threshold and up to a finishing point, providing a predetermined maximum compression ratio or expansion ratio, and
- 3) a high level linear portion having a gain different from the gain of the low level portion.

The characteristic is denoted a bi-linear characteristic because there are two portions of substantially constant gain.

In practice, the threshold and finishing point are not always well defined "points". The two transition regions where the intermediate level portion merges into the low level and high level linear portions can each vary in shape from a smooth curve to a sharp curve, depending on the control characteristics of the compressor and expander.

It is also pointed out that circuit arrangements with bi-linear characteristics are distinguished from two other known classes of circuit arrangement, namely:

(a) a logarithmic or non-linear circuit arrangement with either a fixed or changing slope and with no linear portion: the gain changes over the whole dynamic range.

(b) circuit arrangements with a characteristic having two or more portions of which only one portion is linear ("uni-linear").

A circuit arrangement with a bi-linear characteristic has particular advantages and is widely used. The threshold can be set above the input noise level or transmission channel noise

1 level in order to exclude the possibility of control of the
2 circuit by noise. The high level portion of substantially
3 constant gain avoids non-linear treatment of high level signals
4 which would otherwise introduce distortion. Moreover, in the
5 case of an audio signal, for which the circuit must be syllabic,
6 the high level portion provides a region within which to deal
7 with the overshoots which occur with a syllabic circuit when the
8 signal level increases abruptly. The overshoots are suppressed
9 by clipping diodes or similar means. Only bi-linear character-
10 istics are capable of providing this combination of advantages.

11 The majority of the known circuits with a bi-linear
12 characteristic in use today in consumer audio products provide
13 10 dB of compression and expansion which is adequate for
14 many purposes. However, this leaves some noise audible to some
15 listeners and, for highest fidelity, more compression and
16 expansion is desirable, say 20 dB. It is difficult to provide
17 such a large amount of compression or expansion without encoun-
18 tering problems which affect the quality of the signal.

19 Circuits are known and commercially available which
20 provide 20 dB of compression or expansion, and even more, but
21 these are usually constant slope logarithmic circuit arrangement
22 in which there is a constantly changing gain over the whole
23 dynamic range or nearly the whole dynamic range. Such circuits
24 suffer from higher distortion and signal tracking problems at
25 very low and very high signal levels than the bi-linear circuits
26 in which the change of gain is restricted to an intermediate
27 portion of the characteristic and overshoot problems are more
28 severe than with bi-linear characteristic arrangements. Known
29 constant slope companders employ compression ratios in the range
30 1.5:1, 2:1 and 3:1, but 2:1 is most common.

31 Compression ratio is defined as the ratio of the
32 incremental input dynamic range to the incremental output

dynamic range. The expansion ratio for a complementary expander is the inverse of the compression ratio. If the compression ratio is 3:1, the expansion ratio is 1:3. It is convenient to utilize the concept of the inverse expansion ratio which, for the example just given is 3:1, i.e., it corresponds to the compression ratio. For simplicity, discussion herein will be confined largely to the compression ratio with the understanding that the same considerations apply, making appropriate changes, to the expansion ratio.

A high compression ratio has a disadvantage in that it is difficult to ensure complementarity between the compressor and the expander; in particular level errors or errors in the frequency response of the transmission or recording medium lead to correspondingly multiplied errors at the output of the expander.

It is known (e.g. US-PS 2,558,002, US-PS 4,061,874 and Japanese Patent Publication 51-20124) to increase the amount of compression available by connecting in cascade a plurality of compressor stages. These known circuits (controlled impedance device, diodes, etc.) multiply the compression ratios of the individual stages so that a high compression ratio results, with the disadvantage explained above. For example, one circuit with a compression ratio of 2:1 and the other with a compression ratio of 3:1 will yield an overall ratio of 6:1. The resulting expansion ratio of 1:6 would place a heavy burden on the uniformity of the transmission channel. Another consideration is the demands that are made upon whatever circuit is effecting the change of gain required to establish the compressor or expander characteristic. It is relatively easy to make a circuit effect accurate gain changes over a range of 10 dB but significantly more difficult to make the same circuit effect accurate gain changes over a range of 20 dB. It is thus difficult to establish a controlled, reproducible characteristic for use in a compander

1 system. The 51-20124 publication concludes that a plurality of
2 series compressors (and expanders) are not suitable as a noise
3 reduction system for high fidelity reproduction systems.

4 It is also known (US-PS 3,902,131 and US-PS 3,930,208)
5 to cascade a plurality of compressor stages that operate in
6 mutually exclusive frequency ranges. While such arrangements
7 may not result in any increase in compression ratio over that of
8 a single stage, they do not provide any increase in compression.

9 In the light of all these considerations it is the
10 object of this invention to provide an increased amount of
11 compression or expansion without an undesirably large increase
12 in the compression ratio and without making excessive demands
13 upon any circuit involved in effecting a change of gain.

14 A further object is to provide an increased amount
15 of audio compression or expansion without producing an
16 undesirably large increase in the overshoots produced under
17 transient signal conditions.

18 A close examination of bi-linear circuits shows
19 that they not only have the previously enumerated advantages
20 but a further one as well--namely, a way of solving the high
21 compression ratio problem and, in the case of audio circuits,
22 also a way of solving the high overshoot problem.

23 Note that the superposition of the linear regions
24 does not amplify the compression ratio in these regions; the
25 compression ratio is increased only in the limited region in
26 which dynamic action takes place. Therefore, I have found it
27 possible to separate the areas of dynamic action in such a
28 way as to obtain the required overall increase in compression,
29 while at the same time not altering the overall maximum com-
30 pression or expansion ratio significantly.

The arrangement according to the invention is defined in
claim 1, to which reference should now be made.

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1 A further feature of this arrangement is that the
2 overall result is bi-linear, with all of the attendant advan-
3 tages. Thus the action staggering possibility of bi-linear
4 devices represents a further hitherto unrecognized advantage of
5 this class of device.

6 The above stated objects are met in accordance with the
7 invention which is characterized in that a first circuit, which
8 has a bi-linear input-output characteristic, is followed by one
9 or more further circuits which also have bi-linear characteristics
10 at any given frequency within a frequency range common to the
11 circuits. The thresholds and dynamic regions of the circuits
12 are set to different values so as to stagger the intermediate
13 level portions of the characteristics of the circuits to produce
14 a change of gain over a wider range of intermediate input levels
15 than for any of the circuits individually, and to produce an
16 increased difference between the gains at low and high input
17 levels, but with a maximum compression or expansion ratio which
18 is substantially no greater than the maximum compression ratio
19 of any single circuit, by virtue of the staggering.

20 In the case of audio circuits, if the circuits have
21 overshoot suppression (limiting) elements, then it is also
22 possible to stagger their thresholds along with the stagger of
23 the syllabic thresholds. The overshoots of the lower level
24 circuits, or stages, are correspondingly reduced, with minimal
25 overall overshoot of the several stages. This is in contrast
26 with conventional logarithmic compressors in which large over-
27 shoots are inherently produced.

28 Each of the circuits may introduce an alteration of
29 the spectral content of the signal -- for example, a low level
30 treble boost in the case of a compressor. Thus each succeeding
31 stage may be actuated by a signal of progressively changing
32 spectral content. In the case of complex signals, this has the

1 virtue of spectrally spreading out the chances for error in the
2 decoding function. In the case of a tape recorder with an
3 uneven frequency response characteristic, for example, the
4 spectral shifting tendency reduces the overall dynamic and
5 frequency response errors of the decoded result.

6 Consideration will now be given to the amount of
7 staggering required. For simplicity, reference is made to a
8 series connection of two compressor circuits. The compression
9 ratio of each of the first and second circuits will rise from
10 unity at the respective threshold to a maximum and this will be
11 called the rising flank of the compression ratio. The ratio
12 will then fall back to unity and this will be called the falling
13 flank. Strictly speaking the falling flank may approach unity
14 asymptotically but for all practical purposes it may be con-
15 sidered to have reached unity when it is at some value differin
16 only by an arbitrary small amount from unity.

17 The staggering of the intermediate level portions of
18 the first and second circuits results in the falling flank of o
19 circuit overlapping the rising flank of the other circuit. At
20 least to a first approximation, the difference between the two
21 thresholds can be made such that the overlap of flanks results
22 in an overall compression ratio which does not substantially
23 exceed the maximum compression ratio of either circuit by itself

24 Preferably, the threshold of the second circuit is
25 lower than that of the first circuit (if more than two circuits
26 are used, each further circuit preferably has a progressively
27 lower threshold), in the case of a compressor and vice versa in
28 the case of an expander. In principle the order can be reverse
29 with the first compressor circuit having the lower threshold.
30 In the case of more than 2 circuits, the order of threshold
31 levels among them, in principle, can be scrambled and arranged
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1 in any order so long as the intermediate level portions of the
2 circuits are properly staggered.

3 Thus the ideal stagger is considered to be that which
4 causes the falling flank of one circuit to overlap the rising
5 flank of the other circuit in order to restrict, so far as
6 possible, the level region in which dynamic action occurs in the
7 overall series connected device while at the same time avoiding
8 any substantial increase in the maximum compression or expansion
9 ratio over that of a single device. Then, for example, if the
10 maximum compression ratio of each circuit is 2:1, the compression
11 ratio of the overall circuit arrangement will rise to 2:1,
12 maintain this value over the overlap, and then fall back to
13 unity. Thus, ideally, there is no increase at all above the
14 ratio of 2:1, in contrast to the prior art arrangements of
15 cascaded compressor stages which multiply the ratios to 4:1.

16 In practice it may be difficult to achieve an optimum
17 overlap at all frequencies but it can be seen that, providing a
18 reasonable approximation is made to the ideal, the overall maxi-
19 mum compression ratio can be prevented from rising excessively
20 above 2:1 in the example given. It may in a practical circuit
21 arrangement perhaps rise to 2.5:1.

22 A low maximum compression ratio (e.g. 1.5:1) permits
23 an expander to track the compressor more easily to provide good
24 complementarity with signal channels having somewhat unreliable
25 gains and/or frequency responses. However, a low compression
26 ratio spreads the dynamic action over a wider range of levels,
27 causing greater susceptibility to noise modulation for a given
28 maximum amount of noise reduction difference in gain at low and
29 high input levels. Hence, there is a trade off between undesir-
30 able effects caused both by high and low compression ratios.
31 Consequently, the ideal compression ratio will depend on the
32 system environment and the system design goals.

1 The ability to stagger bi-linear stages provides the
2 designer with an additional way in which to optimize an overall
3 circuit. In so doing, the shapes of the compression character-
4 istics of individual stages can be designed with staggering
5 specifically in mind. The transient characteristics of the
6 circuits are also taken into account and the opportunity is
7 preferably taken to stagger the overshoot suppression threshold
8 in audio compressors and expanders so as to result in minimal
9 overall overshoot.

10 A well known type of circuit, called "sliding band",
11 which can be used for each of the first and second circuits,
12 creates the specified desirable characteristic for the case of
13 high frequency audio compression or expansion by applying high
14 frequency boost (for compression) or cut (for expansion) by way
15 of a high pass filter with a variable lower corner frequency.
16 As the signal level in the high frequency band increases, the
17 filter corner frequency slides upwardly so as to narrow the
18 boosted or cut band and exclude the useful signal from the boost
19 or cut. Examples of such circuits are to be found in US-PS Re
20 28,426, US-PS 3,757,254, US-PS 4,072,914, US-PS 3,934,190 and
21 Japanese Patent Application 55529/71.

22 Accordingly, each of the first and second circuits
23 be such a "sliding band" circuit. In principle the quiescent
24 corner frequencies of the two sliding band circuits can be
25 different and use can be made of this to provide a degree of
26 compression or expansion which is higher in one part of the
27 treated frequency band than in another. However, in accordance
28 with an important further development of the invention the
29 corner frequencies are made substantially identical. This
30 leads to the advantage of sharper discriminations between the
31 frequency region where boost or cut is being applied and the

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1 region where it is not applied and accordingly a sharper
2 discrimination between the region where noise reduction is no
3 longer taking place, because of the appearance of a significant
4 useful signal, and the region where noise reduction remains
5 effective.

6 On the other hand, circuits are also well known in
7 which the frequency spectrum is split into a plurality of bands
8 by corresponding band-pass filters and the compression or expan-
9 sion is effected in each band by a gain control device (whether
10 an automatically responsive, diode type of limiting device or a
11 controlled limiting device) in the case of a compressor, with
12 some form of reciprocal or complementary circuitry for an
13 expander. Examples of such circuits are to be found in US-PS
14 3,846,719. These split band or multi-band circuits have the
15 advantage of independent action in the various frequency bands
16 and, if this property is required, such circuits may be employed
17 as the first, second, or more stages in the circuit arrangement
18 of the invention.

19 In principle, one of the first and second circuits may
20 be a multi-band circuit and the other may be a sliding band cir-
21 cuit. This will be of interest in a special situation in which
22 it is, for example, desired to enhance the degree of compression
23 or expansion in one portion of the total frequency band, the
24 sliding band circuit and one or more of the band-splitting
25 channels acting over this portion of the frequency band.

26 It is known to construct bi-linear compressors and
27 expanders, of both sliding band and split band type, by the use
28 of only a single signal path. However, it is generally preferred
29 to construct such devices by providing a main signal circuit
30 which is linear with respect to dynamic range, with a combining
31 circuit in the main circuit, and a further circuit which derives
32 its input from the input or output of the further circuit and

1 has its output coupled to the combining circuit. The further
2 circuit includes a limiter (self-acting or controlled) and the
3 limited further circuit signal boosts the main circuit signal
4 the combining circuit for the case of compression but bucks the
5 main circuit signal for the case of expansion. The limited
6 further path signal is smaller than the main path signal in the
7 upper part of the input dynamic range. The main and further
8 circuits are preferably and most conveniently separately
9 identifiable signal paths.

10 Such known compressors and expanders are particularly
11 advantageous because they enable the desired kind of transfer
12 characteristic to be established in a precise way without
13 problems of high-level distortion. The low level portion of
14 substantially constant gain is established by giving the further
15 path a threshold above the noise level; below this threshold the
16 further path is linear. The intermediate level portion is
17 created by the region over which the further path limiting
18 action becomes partially effective and the high level portion
19 substantially constant gain arises after the limiter has become
20 fully effective so that the further path signal ceases to
21 increase and becomes negligible compared to the main path
22 signal. At the highest part of the input dynamic range, the
23 output of the circuit arrangement is effectively only the signal
24 passed by the linear main path, i.e. linear with respect to
25 dynamic range. In dual path audio circuits the provision of
26 overshoot suppression is particularly convenient.

27 Examples of these known circuits are to be found in
28 US-PS 3,846,719, US-PS 3,903,485 and US-PS Re 28,426. There are
29 also known analogous circuits which achieve like results but
30 wherein the further path has characteristics inverse to limiting
31 characteristics and the further path output bucks the main path

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1 signal for compression and boosts the main path signal for
2 expansion (US-PS 3,828,280 and US-PS 3,875,537).

3 Any of these known bi-linear circuits may accordingly
4 be employed as the first and second circuits of the circuit
5 arrangement according to the invention in order to obtain the
6 advantages inherent therein and also to provide a good way of
7 establishing the desired amount of staggering. This is done by
8 setting the thresholds and dynamic regions of the two further
9 paths appropriately.

10 As mentioned previously, it is not essential to create
11 the desired form of bi-linear characteristic by such "dual path"
12 techniques. Alternatives exist, operating with single paths, as
13 described in US-PS 3,757,254, US-PS 3,967,219, US-PS 4,072,914,
14 US-PS 3,909,733 and Japanese Patent Application 55529/71, for
15 example. Although these alternative circuits usually are not
16 capable of producing such good results as dual path circuits, or
17 may be less convenient and thereby less economical, they can
18 produce generally equivalent results. Accordingly, these known
19 circuits can also be used as one or more of the circuits of a
20 circuit arrangement according to the invention. If desired, one
21 of the first and second circuits can be a dual path circuit and
22 the other a single path circuit.

23 The invention will be described in more detail,
24 by way of example, with reference to the accompanying drawings,
25 in which:

26 Figure 1 is an exemplary set of curves showing com-
27plementary bi-linear compression and expansion characteristics.

28 Figure 2 is a block diagram showing the present
29 invention in general terms.

30 Figure 3 is an exemplary graphic depiction of the
31 areas of dynamic action and how they can be separated in series
32 connected compressors or expanders.

1 Figure 4 is a further simplified form of Figure 3.

2 Figure 5 is a series of idealized bi-linear character-
3 istic curves illustrating a general technique for staggering t
4 thresholds of series circuits.

5 Figure 6 is a schematic circuit diagram of a prior a
6 sliding band compressor.

7 Figure 7 is a schematic circuit diagram of a prior a
8 sliding band expander.

9 Figure 8 is a schematic circuit diagram of a modifi-
10 cation to Figures 6 and 7.

11 Figure 9 is a chart recording showing the response
12 below the compression threshold of two series compressors
13 and expanders according to an embodiment of the invention.

14 Figure 10 is a chart recording showing the response
15 below the compression threshold of a prior art compressor
16 and expander according to Figures 6, 7 and 8.

17 Figure 11 is a chart recording of the input-output
18 response as a function of frequency of a compressor having
19 series devices according to an embodiment of the invention.

20 Figure 12 is a chart recording of the input-output
21 response as a function of frequency of a prior art compressor
22 having a single device.

23 Figures 13-15 are a series of probe tone curves
24 illustrating the sliding band action of an embodiment of the
25 invention and the circuit of Figures 6 and 8.

26 Figure 16 shows characteristic curves below the
27 compression threshold of a further embodiment of the invention

28 Figure 17 shows characteristic curves similar in
29 nature to those of Figure 11, but for a further embodiment of
30 the invention.

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1 Figure 18 shows characteristic curves similar in
2 nature to those of Figures 11 and 17, but illustrating excessive
3 bunching.

4 Exemplary bi-linear complementary compression and
5 expansion transfer characteristics (at a particular frequency)
6 are shown in Figure 1, indicating (for the compression charac-
7 teristic) the low level portion of substantially constant
8 gain, the threshold, the portion where dynamic action occurs,
9 the finishing point, and the high level portion of substantially
10 constant gain.

11 Figure 2 shows the present invention in general terms:
12 a first bi-linear compressor 2 receives the input information
13 and applies its output to a second bi-linear compressor 4
14 connected in series, which has its output applied to a noisy
15 information carrying channel N. A pair of series connected
16 bi-linear expanders 6 and 8 receive the input from channel N at
17 expander 6 and provide a noise reduction system output at the
18 output of expander 8. The areas of dynamic action of the series
19 devices are separated or staggered with respect to each other
20 within the frequency range that is common to the devices.
21 Although the figure shows two devices on each side of the
22 information channel N, two or more can be employed: the inven-
23 tion contemplates two or more series bi-linear compressors or
24 expanders. When configured as a complementary noise reduction
25 system, like numbers of series bi-linear compressors and
26 expanders are provided.

27 The order of stages having particular characteristics
28 in the compressor is reversed in the expander. For example,
29 the last stage of the expander is complementary to the first
30 stage of the compressor in all respects--steady state and time
31 dependent dynamic response (frequency, phase and transient
32 response under all signal level and dynamic conditions).

1 An exemplary graphic depiction of the separation or
2 staggering for two bi-linear devices is shown in Figure 3, which
3 plots compression ratio versus input amplitude level (horizontal
4 axis) for a compressor or expander operating at a particular
5 frequency. For clarity, the curves are shown in idealized form
6 as a practical matter the curves are somewhat asymmetrical in
7 practical embodiments of applicant's A-type and B-type noise
8 reduction systems, (US-PS 3,846,719 and US-PS Re 28,426, respec-
9 tively). Curve 12 refers to the dynamic action of one compres-
10 sor or expander (the high level stage). Curve 10 is that of a
11 further compressor or expander (the low level stage), with a
12 separated area of dynamic action. If the high level stage is
13 first in the series of compressors (second in the series of
14 expanders), the curve 12 represents the variations of compress-
15 ion ratio of the first (compressor) stage as a function of the inp-
16 ut level to the first stage and curve 10 is the variation of the
17 compression ratio of the second (compressor) stage as a function
18 of the input level to the first stage. The top curves are those
19 of compressors, the bottom curves those of expanders. In this
20 example, the areas of action in response to input amplitude
21 level are separated such that the product of the two curves
22 results in an overall characteristic having a compression ratio
23 or expansion ratio which does not exceed 2:1 (1:2) between the
24 two maximum compression points 10b and 12b (10a and 12a) of the
25 two devices.

26 Thus, even with two devices in series, the end region
27 of operation still remain fixed, the maximum compression and
28 maximum expansion ratios are not increased beyond those of single
29 devices and the advantages of single bi-linear devices are
30 retained. Consequently, any errors occurring within the range
31 of dynamic action caused by the devices in series should not exceed
32 those of a single device.

1 Most bi-linear devices determine the fixed end regions
2 of constant gain by means of fixed, pre-set circuit elements,
3 such as resistors and capacitors, which are inherently stable
4 and cannot introduce dynamic errors, waveform distortions and
5 the like. Consequently, only in a transitional area of opera-
6 tion, between the linear, constant gain regions, can any dynamic-
7 ally active portions of the circuits introduce signal errors.

8 Note that in the representation of Figure 2, the
9 dynamic action of a conventional logarithmic compressor or
10 expander becomes a horizontal line; line 11, for example, is
11 the characteristic of a 2:1 compressor, line 13 is that of a 1:2
12 expander. It is clear, in this analysis, that there is no oppor-
13 tunity for separating or staggering the actions of such devices.

14 For purposes of analysis and to obtain a first order
15 approximation of necessary threshold levels to provide optimum
16 staggering in accordance with the invention, it is useful to
17 idealize Figure 3 even further. Assume therefore that each
18 compressor (and expander) immediately reaches its maximum
19 compression ratio at a threshold level and holds that ratio
20 until it reaches a finishing point at a higher level where its
21 dynamic action abruptly stops. Then a series of compressors and
22 expanders depicted in the manner of Figure 3 appear as contiguous
23 rectangular curves such as shown in Figure 4. As an example,
24 three bi-linear characteristic compressors and expanders are
25 connected in the series. The low level device, which is
26 preferably the third compressor (first expander), has the lowest
27 threshold (T_3) shown at -62 dB, with its finish point (F_3)
28 at -46 dB which is the threshold (T_2) of the medium level
29 stage. The medium level stage has its finishing point (F_2) at
30 -30 dB which is the threshold (T_1) of the high level stage.
31 The high level stage has its finishing point (F_1) at -14 dB.
32 All levels are with reference to the overall input. It is

1 further assumed that each stage affords 8 dB of compression and
2 a maximum compression ratio of 2:1.

3 Figure 5 depicts idealized characteristic curves (over-
4 all input versus output) for compression based on the example of
5 Figure 4 (the mirror image expansion curves are omitted for
6 clarity). The drawing shows how the dynamic action of each stage
7 occurs next to that of its adjacent stage resulting in an overall
8 compression ratio of 2:1 while obtaining 24 dB of compression.

9 Based on observations of Figures 4 and 5, a single
10 equation sets forth the relationship between threshold levels
11 (T), finishing point (F), maximum compression ratio (C) and
12 gain (G) of any particular stage:

13
$$T = F - \frac{CG}{C-1}.$$

14 Using this equation the threshold levels for each stage can be
15 determined to a reasonably close approximation by an iterative
16 process. For example, if an overall finishing point (F_1) of
17 -14 dB is desired with a stage gain of 8 dB and a maximum
18 compression ratio of 2, the equation shows that the high level
19 threshold (T_1) is -30 dB. This value is then used as the
20 finishing point (F_2) of the middle level stage to determine
21 that its threshold should be -46 dB, and so on. Thus each stage
22 is referred back to the result of the previous stage in this
23 analysis. However, the calculated threshold is the overall
24 threshold, referred to the input of the series. To obtain the
25 threshold of a particular circuit referred to its own input, the
26 cumulative signal gain up to that point is taken into account.
27 For example, the threshold of the lowest level stage of Fig. 5
28 is -46 dB when referred to the input of that stage.

29 The equation can also be solved for the finishing
30 point F, the compression ratio C, or the gain, G. Thus, the
31 designer can determine his circuit parameters based on his
32 design goals. Such goals may include requirements that the

1 lowest level threshold be above the noise floor, that the
2 highest level finishing point be low enough to permit the use of
3 overshoot protection and that the overall maximum compression
4 ratio not exceed a particular value.

5 In practical circuits, the threshold and finishing
6 point are not always well defined points as they are in this
7 analysis. As discussed in the introduction, the regions in which
8 the intermediate level portion of the characteristic merge with
9 the low level and high level linear portions may be smooth or
10 sharp depending on the characteristics of the circuits that
11 control the dynamic action. Thus, in practice, the threshold
12 region of one circuit will overlap with the finishing point
13 region of another circuit.

14 Consideration of the above equation and Fig. 5 shows
15 that for the particular case of a 2:1 compression ratio, half of
16 the threshold staggering is provided by the signal gains of the
17 stages and that the other half must be provided by an altered
18 bias on the control element and/or an altered control amplifier
19 gain (increased gain for lower threshold). Similarly, for
20 1.5:1 and 3:1 compression ratios, respectively, $1/3$ and $2/3$ of
21 the staggering, respectively, is provided by the stage gains and
22 $2/3$ and $1/3$ of the staggering, respectively, must be provided by
23 the control circuitry.

24 In both Figures 1 and 5, 0 dB is a nominal maximum or
25 reference level. In practice, a headroom of some 10 to 20 dB
26 is provided above the 0 dB level.

27 As mentioned earlier, it is usually preferable for
28 the high level stage to be first in a compressor series and the
29 low-level stage to be last. However, a reversed arrangement
30 is also possible. In the reversed case the control amplifier
31 of the first stage needs a high gain in order to achieve the
32 required low threshold. This low threshold then applies even in

1 the presence of high level signals, which in the case of sliding
2 band systems known in the prior art usually leads to poor noise
3 modulation performance of the overall system. In this reversed
4 arrangement each stage must provide sufficient control amplifier
5 gain to achieve the threshold required of that stage. Moreover,
6 each threshold is essentially fixed and independent of the opera-
7 tion of the other stages. This is a consequence of the fact that
8 the signal gain of each earlier stage has fallen substantially to
9 unity when the threshold is reached for the corresponding suc-
10 ceeding stage. The calculation of the thresholds required for
11 optimal staggering in the reversed case is the same as that in
12 the preferred case. However, the threshold of each stage referred
13 to its own input becomes the same as the overall threshold.

14 In contrast to the reversed situation, in the preferred
15 arrangement (in which the high level stage is first in the
16 compressor chain, and the low-level stage is last), there is a
17 useful interaction between the stage gains and the thresholds.
18 The thresholds of the downstream stages are partly determined by
19 the signal gains of the preceding stages. Thus in a 2 stage
20 system with 10 dB of low level gain per stage, the control ampli-
21 fier gain requirement of the second stage is reduced by 10 dB, by
22 virtue of the low-level signal gain of the first stage. When a
23 high level signal appears, the 10 dB gain of the first stage is
24 eliminated and the threshold of the low level stage is effectively
25 raised by 10 dB. With sliding band companders this improves the
26 noise modulation performance of the noise reduction action.

27 In the preferred arrangement the gains of all preceding
28 stages are fully effective up to the threshold of any particular
29 succeeding stage. Thus, in contrast with the reversed order
30 system described above, the preferred arrangement takes best
31 advantage of the prevailing signal gains of the individual
32 stages. Namely:

1 1. Under very low level (sub-threshold) signal
2 conditions the control amplifier gain requirement
3 of each stage is reduced by an amount equal to the
4 cumulative signal gains of all preceding stages.
5 In the example of Fig. 5, the control amplifier
6 gain required of the lowest level stage, to achieve
7 a threshold of -62 dB, is thus reduced by 16 dB
8 relative to that required if that stage were
9 operating independently or in the reversed configura-
10 tion described previously. Similarly, the control
11 amplifier gain of the mid-level stage is reduced by
12 8 dB, thus leading to the most economical circuitry.
13 2. A signal dependent variable threshold effect is
14 achieved, whereby with sliding band stages, noise
15 modulation effects are reduced. The effective
16 thresholds of the low level stages are progressively
17 raised with increasing signal level at a particular
18 frequency. At high signal levels (on the high level
19 linear portion of the transfer characteristic) the
20 effective threshold of the lowest level stage is
21 raised by a level equal to all the low-level (sub-
22 threshold) stage gains up to that point. In the
23 example of Fig. 5 the threshold of the lowest level
24 stage, normally -62 dB under low level signal condi-
25 tions, is thus raised by 16 dB, to -46 dB, under high
26 level signal conditions. Similarly, the threshold of
27 the mid-level stage is raised to -38 dB.

28
29 In a first practical embodiment of the invention,
30 employing series sliding band devices, the compressor 2 and
31 expander 8 of Figure 2 are essentially standard B-type sliding
32 band devices as set forth in US-PS Re 28,426, while compressor 4

1 and expander 6 have modified response characteristics. I have
2 found that, with the noise generated by cassette tapes, a work-
3 able result is obtained when the second device (in the compres-
4 sion mode) not only has a staggered input amplitude level
5 response but also has a cut off frequency some two to three
6 octaves lower than that of a standard B-type device. More speci-
7 fically, the threshold levels of the second device are lowered,
8 both of the syllabic filter/limiters and of the overshoot
9 supression limiter, to effect staggering, and the corner fre-
10 quency of the fixed filter is lowered by two to three octaves.

11 Details of the B-type circuit are set forth in Figures
12 6, 7 and 8 which are the same as Figure 4, 5 and 10 respectively
13 of US-PS Re 28,426 and further details of said circuits, their
14 operation and theory are set forth therein. The following
15 description of Figures 6, 7 and 8 is taken from US-PS Re 28,426.

16 The circuit of Figure 6 is specifically designed for
17 incorporation in the record channel of a consumer tape recorder,
18 two such circuits being required for a stereo recorder. The
19 input signal is applied at terminal 10 to an emitter follower
20 stage 12 which provides a low impedance signal. This signal is
21 applied firstly through a main, straight-through path constituted
22 by a resistor 14 to an output terminal 16 and secondly through a
23 further path the last element of which is a resistor 18 also
24 connected to the terminal 16. The resistors 14 and 18 add the
25 outputs of the main and further paths to provide the required
26 compression law.

27 The further path consists of a fixed filter 20, a
28 variable cut-off filter 22 including a FET 24 (these constituting
29 the filter/limiter), and an amplifier 26 the output of which is
30 coupled to a double diode limiter or clipper 28 and to the
31 resistor 18. The non-linear limiter suppresses overshoots of

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1 the output signal with abruptly increasing input signals. The
2 amplifier 26 increases the signal in the further path to a level
3 such that the knee in the characteristic of the limiter or
4 overshoot suppressor 28, comprising silicon diodes, is effective
5 at the appropriate signal level under transient conditions.
6 The effective threshold of the overshoot suppressor is somewhat
7 above that of the syllabic filter/limiter. The resistors 14 and
8 18 are so proportioned that the required compensating degree of
9 attenuation is then provided for the signal in the further path.

10 The output of the amplifier 26 is also coupled to an
11 amplifier 30 the output of which is rectified by a germanium
12 diode 31 and integrated by a smoothing filter 32 to provide
13 the control voltage for the FET 24.

14 Two simple RC filters are used, though equivalent LC
15 or LCR filters could be used. The fixed filter 20 provides a
16 cut-off frequency of 1700 Hz, below which diminishing compression
17 take place. The filter 22 comprises a series capacitor 34 and
18 shunt resistor 36 followed by a series resistor 38 and the FET
19 24, with its source-drain path connected as a shunt resistor.
20 Under quiescent conditions with zero signal on the gate of the
21 FET 24, the FET is pinched off and presents substantially
22 infinite impedance; the presence of the resistor 38 can then be
23 ignored. The cut-off frequency of the filter 22 is thus 800
24 Hz, which it will be noted is substantially below the cut-off
25 frequency of the fixed filter 20.

26 When the signal on the gate increases sufficiently for
27 the resistance of the FET to fall to less than say 1 K, the
28 resistor 38 effectively shunts the resistor 36 and the cut-off
29 frequency rises, markedly narrowing the pass band of the filter.
30 The rise in cut-off frequency is of course a progressive action.

31 The use of a FET is convenient because, within a
32 suitable restricted range of signal amplitudes, such a device

1 acts substantially as a linear resistor (for either polarity
2 signal), the value of which is determined by the control voltage
3 on the gate.

4 The resistor 36 and FET are returned to an adjustable
5 tap 46 in a potential divider which includes a temperature
6 compensating germanium diode 48. The tap 46 enables the compression
7 threshold of the filter 22 to be adjusted.

8 The amplifier 26 comprises complementary transistors
9 giving high input impedance and low output impedance. Since
10 the amplifier drives the diode limiter 28, a finite output
11 impedance is required and is provided by a coupling resistor
12 50. The diodes 28 are, as already noted, silicon diodes
13 and have a sharp knee around 1/2 volt.

14 The signal on the limiter and hence on the resistor
15 can be shorted to ground by a switch 53 when it is required to
16 switch the compressor out of action.

17 The amplifier 30 is an NPN resistor with an emitter
18 time constant network 52 giving increased gain at high frequencies.
19 Strong high frequencies (e.g. a cymbal crash)
20 will therefore lead to rapid narrowing of the band in which
21 compression takes place, so as to avoid signal distortion.

22 The amplifier is coupled to the smoothing filter 32
23 through the rectifying diode 31. The filter comprises a series
24 resistor 54 and shunt capacitor 56. The resistor 54 is shunted
25 by a silicon diode 58 which allows rapid charging of the
26 capacitor 56 for fast attack, coupled with good smoothing under
27 steady-state conditions. The voltage on capacitor 56 is applied
28 directly to the gate of the FET 24.

29 A complete circuit diagram of the complementary
30 expander is provided in Figure 7, but a full description is not
31 required as substantially as the circuit is identical to Figure

32 ///

1 6, component values, are therefore not for the most part shown
2 in Figure 7.

3 The differences between Figures 6 and 7 are as follows:

4 In Figure 7, the further path derives its input from
5 the output terminal 16a, the amplifier 26a is inverting,
6 and the signals combined by the resistors 14 and 18 are applied
7 to the input (base) of the emitter follower 12, the output
8 (emitter) of which is coupled to the terminal 16a. To ensure
9 low driving impedance, the input terminal 10a is coupled to the
10 resistor 14 through an emitter follower 60. Suitable measures
11 must be taken to prevent bias getting in the expander.

12 The amplifier 26a is rendered inverting by taking the
13 output from the emitter, instead of the collector, of the second
14 (PNP) transistor. This alteration involves shifting the 10 K
15 resistor 62 (Figure 6) from the collector to the emitter (Figure
16 6), which automatically gives a suitable output impedance for
17 driving the limiter. The resistor 50 is therefore omitted in
18 Figure 7.

19 It should be noted that it is important in aligning
20 a complete noise reduction system to have equal signal levels
21 on the emitters of the transistors 12 in both compressor
22 and expander. Metering terminals M are shown connected to
23 these emitters.

24 Figure 8 shows a preferred circuit, for replacing the
25 circuit between points A, B and C in Figures 6 and 7. When the
26 FET 24 is pinched off, the second RC network 22 is inoperative,
27 and the first RC network 20 then determines the response of the
28 further path. The improved circuit combines the phase advantages
29 of having only a single RC section under quiescent conditions
30 with the 12 dB per octave attenuation characteristics of a
31 two-section RC filter under signal conditions.

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1 In the practical circuit, using MPF 104 FET's, the
2 resistor 36a is necessary in order to provide a finite source
3 impedance to work into the FET. In this way the compression
4 ratio at all frequencies and levels is held to a maximum of
5 about 2. The 39 K resistor 36a serves the same compression
6 ratio limiting function in the improved circuit as the resistor
7 36 in the circuit of Figure 6 or Figure 7. In addition, this
8 resistor provides a low frequency path for the signal.

9
10 Modifications to Figures 6, 7 and 8

11 As mentioned previously, in the first practical
12 embodiment of the present invention, compressor 4 and expander
13 of Figure 2 employ devices of the type shown in Figures 6, 7
14 8 with modified characteristics. The altered cut off frequency
15 and lowered threshold are accomplished, respectively, by modifying
16 the characteristics of the fixed filter (fixed filter 20 of
17 Figure 6) and also the control amplifier gain by altering its
18 pre-emphasis characteristics (emitter time constant network 52
19 of amplifier 30 in said Figure 6). The threshold of the over-
20 shoot suppressor is lowered by the application of suitable DC
21 biases (in the forward direction) to the diodes 28. The
22 impedances of the variable filter (variable filter 22 in Figure
23 6 and 8) are left generally unaltered in order to retain a
24 suitable match to the characteristics of available voltage
25 controllable variable circuits elements. Suitable modifications
26 of the B-Type sliding band circuit shown in Figures 6, 7 and
27 are to change the value of the 3.3 K resistor in fixed filter
28 to a value of 18 K in order to lower its cutoff frequency two
29 three octaves. For an increase in the control amplifier gain
30 the value of the capacitor in the amplifier 30 emitter time
31 constant network 52 is increased from 0.15 to 0.60 μf (or from
32 0.1 to 0.4 μf if the suggested 0.1 μf value is used). Biases

1 about plus and minus 1/4 volt in the forward direction are
2 applied to silicon diodes 28, thereby reducing the overshoot
3 suppression level by several decibels.

4 Variable filter 22 has an all pass frequency charac-
5 teristic in response to the quiescent control voltage and thus
6 the overall filter cut off is lowered two to three octaves.
7 Increasing the capacitor value in the emitter network of control
8 amplifier 30 increases the amplifier gain at any given frequency.
9 As explained above and in US-PS Re 28,426, as the control
10 voltage (from amplifier 30, rectifier 31 and smoothing filter
11 32) increases, the cut off frequency of the variable RC Filter
12 22 rises. Thus, with larger values of capacitance in network
13 52, the variable filter responds by moving up in frequency
14 from its quiescent value in response to lower level signals,
15 thus staggering the level response or threshold from that in the
16 unmodified B-Type circuit.

17 The level response can be staggered in numerous ways in
18 addition to changing the emitter network of the control ampli-
19 fier. Other possibilities include changing the bias on the
20 control element, otherwise altering the gain of the control
21 amplifier, altering the relative signal levels between the
22 filter path and the control signal derivation path, and so on.

23 Certain details of the circuit of Figures 6, 7
24 and 8 have evolved over the years and more modern forms of the
25 circuit have been published and are well known in the art.
26 Reference to the specific circuit in US-PS Re 28,426 is made for
27 convenience in presentation.

28 Figure 9 shows an actual chart recording plot of
29 response below the compression threshold of the two series
30 connected compressors, the first being modified as described
31 above; the expander response is also shown. Compare to Figure 10
32

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(which is Figure 12 of US-PS Re 28,426) showing an actual chart recording plot of response below the compression threshold of single compressor or expander according to Figures 6, 7 and 8.

Figure 11 is a chart recording of the input-output response of the series compressors as a function of frequency. Inspection of the response plots shows the two dynamic areas for the curves indicating the two staggered areas of action. While the observability of the dynamic areas in these curves is useful to demonstrate the staggered action of the devices, in practice it is preferred that the curves are as smooth as possible, without discernible dynamic areas or "bumps." Parallel lines A and B are drawn through the threshold regions: Line A referring to the standard circuit and line B to the modified circuit. Compare these curves to Figure 12 (which is US-PS Re 28,426) which plots similar response curves for a single unmodified B-type sliding band compressor. Figure 11 shows that the compressor comprising series devices provides essentially twice as much compression which is distributed over a greater frequency and level area.

The variable band action of the staggered action series devices can be seen in Figure 13 and 14, showing a chart recorder probe tone response of said series connected compressors. Compare to Figure 15 (which is Figure 15 of US-PS Re 28,426) which is an actual chart recording obtained from the circuit of Figure 6 incorporating Figure 8. The variable band action is shown by plotting the compressor frequency response means of a low-level probe tone (the level of which is below the compressor threshold) in the presence of a high-level signal; the probe is detected at the compressor output by means of a tracking filter. The high-level signal causes the compressor circuitry to operate, the graph showing the effect on the turnover frequency of the filter.

1 Figure 13 shows the response for a probe tone at
2 -65 dB and 200 Hz signal tones at levels ranging from -28
3 dB and below to +10 dB. Figure 14 is for a 500 Hz signal
4 tone at levels ranging from -34 dB and below to +10 dB.

5 In a further practical embodiment of the invention,
6 giving improved performance, the compressor 2 and expander 8 of
7 Figure 2 are both modifications of standard B-type devices.
8 Both series devices have their corner frequency lowered by two
9 octaves in order to provide a sharply rising low-level response
10 characteristic. Dynamic action staggering is provided by
11 decreasing the thresholds (both syllabic and overshoot suppression) of the second (in the compressor mode) device.

13 A feature and useful advantage of the invention is
14 that the frequency responses of the individual circuits are
15 compounded. If the most sharply rising noise reduction characteristic is desired, this is accomplished by the use of circuits
16 having the same low level (quiescent) frequency response
17 characteristics.

19 Accordingly, in the improved embodiment, the choice of
20 identical filter characteristics at about 2 octaves below that
21 of the standard B-type device results in a characteristic that
22 rises rapidly above about 300 Hz. Thus, the system becomes
23 capable of achieving substantial noise reduction in the critical
24 300 Hz to 2 kHz range, a region in which tape noise is discern-
25 able once noises above 2 kHz have been reduced. There is
26 negligible audible noise contribution from the tape below about
27 300 Hz. By providing only minimal noise reduction action below
28 300 Hz, the system avoids the manipulation of fundamental signal
29 frequencies and improves the complementarity of the system in
30 practical tape recorders, which, for example, may have frequency
31 response errors due to head bumps and the like. Moreover, by

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1 avoiding the compression of low frequency signals, system
2 compatibility is improved because the boosting of low frequency
3 signals would result in annoying rumble and bass enhancement
4 when encoded tapes are played on systems not having complement
5 expanders.

6 Referring once again to Figures 6 and 8, the two
7 series devices in the practical embodiment under discussion
8 both have the resistor in fixed filter 20 changed from 3.3
9 K to 13 K, which causes the overall lower cut off frequency
10 of the filters 20 and 22 to shift about 2 octaves lower to about
11 375 Hz. In the second device, the capacitor in the emitter
12 network 52 of control amplifier 30 is increased in value by a
13 factor of about 4 as in the previously discussed embodiment.
14 This results in a staggering of threshold levels of roughly 10
15 to 15 dB (depending on signal level and signal frequency).
16 Appropriate biasing is introduced in the diode limiter circuit
17 28 to lower the overshoot suppression level.

18 In a modification of the last described practical
19 embodiment the capacitor 34 in filter 22 can be increased in
20 value to 0.01 μ f in order to promote consistency in character-
21 istics from unit to unit and to improve the noise modulation
22 characteristics. In that case, due to the substantially equal
23 time constants of fixed filter 20 and variable filter 22, the
24 arrangement is equivalent to a single pole variable filter and
25 the fixed filter can be eliminated. In that case the resistor
26 36a (which has a value of 47 K in modern forms of the B-type
27 circuit) is placed in shunt with the source-drain path of FET
28 so as to provide a quiescent corner frequency of about 375 Hz.
29 It is, however, desirable to retain the fixed filter in the h
30 level circuit so that the circuit can be switched to operate
31 itself as a standard B-type circuit.

32 ///

1 As a practical matter, a consumer product embodying
2 the improved systems just described will be compatible with
3 existing non-encoded and B-type encoded software (e.g., tapes
4 and FM broadcasts). The improved systems incorporate a standard
5 B-type device and, hence, can be switched to operate as a B-type
6 device for full compatibility. On the other hand, when recorded
7 tapes become available encoded with the improved system, existing
8 B-type consumer systems may observe excessive high frequency
9 information or "brightness" which can be treated by adjusting
10 the high frequency tone control in the same way that non-equipped
11 consumer systems presently treat B-type encoded software.

12 The standard B-Type circuit described in US-PS Re
13 28,426 has a maximum compression ratio of about 2:1. This
14 compression ratio has proven to be a good practical choice for
15 consumer cassette tape compander systems. In the series con-
16 nected circuits of the embodiments described above, each circuit
17 retains a maximum compression ratio of about 2:1 and the maximum
18 compression ratio of the overall combination of series circuits
19 is about 2:1 at most input signal levels and frequencies.
20 However, in practical embodiments, it is difficult to avoid
21 somewhat greater ratios, e.g. 2.5:1, in a small range of levels
22 and frequencies. This can be tolerated if the compression ratio
23 is not more than about 2.5:1 (or about 1-1/4 times that of each
24 circuit) and if the range of levels and frequencies in which it
25 occurs is not large.

26 Another specific embodiment of the invention depicted
27 generally in Figure 2 is to configure one compressor and
28 expander as a split band device⁺, such as described in US-PS
29 3,846,719 and US-PS 3,903,485, and the other compressor and
30 expander as a sliding band device. *One suitable split band or
31 multi-band device is described in the Journal of the Audio

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1 Engineering Society, Vol. 15, No. 4, October, 1967, pp. 383-388.

2 Split band devices in accordance with the parameters in that
3 paper have become well known as A-type devices.

4 In a practical embodiment, an A-type compressor
5 receives a flat input signal and provides its output to a
6 specially tailored sliding band device. It is most advantageous
7 to locate the A-type device so as to receive an unprocessed
8 input signal because it is designed to process a flat input
9 signal. Placing the sliding band device first would have
10 the disadvantage of changing the flat input signal to a form
11 less suited for the A-type device input. On the reproducing
12 side, the sliding band expander receives the channel N signal,
13 processes it and applies it to the A-type expander.

14 Figure 16 shows curves similar to Figure 9 for the
15 low signal level response of an A-type compressor alone, the
16 sliding band compressor alone and the combined compressor
17 response. The expansion response curves are complementary
18 in the manner of Figure 9. The A-type device provides 10
19 dB compression up to about 5 kHz, above which the increase
20 in level rises smoothly to 15 dB at 15 kHz. Advantage is
21 taken of this rising response of the A-type characteristic to
22 desensitize the sliding band characteristic at high frequencies
23 (see the high frequency portion of the "sliding band" curve in
24 Figure 16); this is advantageous in reducing the effects of high
25 frequency channel-response uncertainties, hereinafter described
26 in greater detail. Thus, the combined response curve climbs
27 smoothly to 20 dB where it remains essentially level to about
28 kHz where it drops off. The sliding band device is designed to
29 have operating thresholds and resulting areas of dynamic action
30 which are well clear of those of the A-type circuit.

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Figure 17 shows a series of response curves at different levels for the series A-type and sliding band compressors. These curves present the same type of information as Figure 11. The shaded area C indicates generally the dynamic regions resulting from action of the A-type device; shaded area D from action of the sliding band device. This arrangement results in a maximum compression ratio which at any level or frequency does not exceed about 2:1 and therefore is relatively free of error amplification effects in practical tape recording channels.

It will be understood that for exemplary purposes a standard A-type device is connected in series with a special sliding band device. However, in principle, the A-type device can be modified to shift its areas of dynamic action so as to provide the best fit with the action areas of the sliding band device.

* The precise amount of staggering or shifting necessary in this and other configurations set forth herein will depend on the parameters of the signal processing devices used. The goal in staggering the areas of dynamic action is to minimize bunching effects in the response curves.* Bunching is an indication of large compression or expansion ratios. For example, see Figure 18 which shows excessive bunching; that is, at some frequencies and levels a 10 dB change in input level results in a 2-1/2 dB change in output -- a 4:1 ratio. Optimally, with appropriate staggering, a 2:1 ratio is never substantially exceeded in a cassette compander system throughout most of the range of levels and frequencies. In other types of transmission systems higher compression ratios may be acceptable.

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CLAIMS

1. A circuit arrangement for modifying the dynamic range of an input signal, comprising a first circuit with a bi-linear characteristic composed of a low level portion of substantially constant gain up to a threshold, an intermediate level portion, above the threshold, of changing gain providing a maximum compression ratio or expansion ratio, and a high level portion of substantially constant gain different from the gain of the low level portion, and at least one further circuit, which also has a bi-linear characteristic within a frequency range common to the circuits, in series with the first circuit, the intermediate level portions of the characteristics of the circuits being staggered within a frequency range common to the circuits such as to provide a change of gain over a wider range of intermediate input levels than for any of the circuits individually, and an increased difference between the gains at low and high input levels, but with an overall maximum compression or expansion ratio which is substantially no greater than that of any single circuit, by virtue of the staggering and an overall characteristic which is also bi-linear.
2. A circuit arrangement according to claim 1, wherein the circuits are compressors and the thresholds thereof are set to different values in order to stagger the intermediate level portions of the characteristics of the circuits.
3. A circuit arrangement according to claim 1, wherein the circuits are expanders and the thresholds thereof are set to different values in order to stagger the intermediate level portions of the characteristics of the circuits.
4. A circuit arrangement according to claim 1, 2 or 3, wherein the falling flank of the compression or expansion ratio of each of the circuits overlaps the rising flank of the compression or expansion ratio of another of the circuits to the extent that the overall compression or expansion ratio in the overlapping region does not substantially exceed the maximum compression or expansion ratio of the adjacent circuits.



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5. A circuit arrangement according to claim 4, wherein each of the circuits has a maximum compression or inverse expansion ratio of substantially 2:1 and the maximum ratio for the complete circuit arrangement does not substantially exceed 2:1.

6. A circuit arrangement according to any of claims 1 to 5, wherein at least one of the circuits comprises a variable filter providing a boost or cut in a high or low frequency region of the signal band, and responsive to signals in that region to cause the filter corner frequency to slide in the sense narrowing the boosted or cut region.

7. A circuit arrangement according to claim 6, for audio signals, wherein the or each variable filter has a rectifying, smoothing and amplifying control circuit providing a control signal to a controlled impedance device of the filter to effect the sliding of the filter corner frequency.

8. A circuit arrangement according to claim 7, wherein each circuit comprises a variable filter.

9. A circuit arrangement according to claim 8, wherein the control circuits of the variable filters have different gains such as to establish the different thresholds of the circuits.

10. A circuit arrangement according to claim 8 or 9, wherein the quiescent corner frequencies of the variable filters are substantially the same.

11. A circuit arrangement according to claim 10, wherein the boost or cut is provided in a high frequency region and the quiescent corner frequencies of the variable filters are in the region of 300 to 400 Hz.

12. A circuit arrangement according to claim 8, 9, 10 or 11, wherein in at least one circuit the variable filter is in series with a fixed filter having a narrower pass band than the variable filters in the quiescent state.



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13. A circuit arrangement according to claim 12, wherein at least two circuits have a variable filter in series with a fixed filter and the corner frequencies of the fixed filters are substantially the same.
14. A circuit arrangement according to claim 13, wherein the boost or cut is provided in a high frequency region and the fixed filters have a corner frequency in the region of 300 to 400 Hz.
15. A noise reduction arrangement comprising a compressor arrangement according to claim 2 or any of claims 4 to 14 insofar as dependent thereon and an expander arrangement according to claim 3 and any of claims 4 to 14 insofar as dependent thereon, wherein the threshold of each successive compressor circuit is lower than the threshold of the previous circuit and the threshold of each successive expander circuit is higher than the threshold of the previous circuit.
16. A noise reduction arrangement comprising a compressor arrangement according to claim 2 or any of claims 4 to 14 insofar as dependent thereon and an expander arrangement according to claim 3 and any of claims 4 to 14 insofar as dependent thereon, wherein the threshold of each successive compressor circuit is higher than the threshold of the previous circuit and the threshold of each successive expander circuit is lower than the threshold of the previous circuit.
17. An arrangement according to any of claims 1 to 16, wherein at least one of the circuits is a dual-path circuit comprising a main path which is linear with respect to dynamic range, a combining circuit in the main path, and a further path which has its input connected to the input or output of the main path and its output connected to the combining circuit, the further path providing a signal which, at least in an upper part of the frequency band, boosts or bucks the main path signal by way of the combining circuit, but which is so limited that, in the upper part of the input dynamic range, the further path signal is smaller than the main path signal.



18. An arrangement according to any of claims 6 to 16 and claim 17, wherein at least one of the circuits is a dual path circuit with the variable filter in the further path thereof.

19. A circuit arrangement according to claim 1 wherein the approximately threshold level T of a given stage is determined by the relationship

$$T = F - \frac{CG}{C-1},$$

where F is the finishing point of the stage, whereat the intermediate level portion ends and the high level portion starts, C is the maximum compression ratio of the stage and G is the gain of the stage.

20. A circuit arrangement according to any of claims 1 to 14, wherein the circuit arrangement is for modifying the dynamic range of audio signals and wherein each circuit includes an overshoot suppressor having a threshold level, the threshold levels being staggered among the circuits such as to provide a reduction in the overshoots of the overall circuit arrangement.

21. An arrangement according to claims 15 and 20, wherein the threshold of the overshoot suppressor of each successive compressor circuit is lower than that of the previous circuit and the threshold of the overshoot suppressor of each successive expander circuit is higher than that of the previous circuit.

22. An arrangement to claims 16 and 20, wherein the threshold of the overshoot suppressor of each successive compressor circuit is higher than that of the previous circuit and the threshold of the overshoot suppressor of each successive expander circuit is lower than that of the previous circuit.

23. A circuit arrangement according to claim 11, wherein there are two bi-linear circuits, each having a low level gain of substantially 10 dB.



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24. A circuit arrangement according to any of claims 1, 2, 3, 4, 15 and 16, wherein there are three bi-linear circuits, each having a low level gain of substantially 8 dB.
- 5 25. A circuit arrangement according to claim 6, wherein one of the circuits comprises said variable filter, and wherein there is one further circuit comprising a plurality of band pass filters each in combination with a limiting device.
- 10 26. An arrangement according to any of claims 1 to 25, wherein all of the first and further circuits have substantially the same maximum compression ratio or expansion ratio.
- 15 27. An arrangement according to claim 1, wherein each of the first and further circuits includes a control circuit responsive to the level of a signal within the first or further circuit itself to control the compression or expansion provided thereby.
-