

CIRCUIT ARRANGEMENTS FOR REDUCING MEDIA OVERLOAD
EFFECTS IN SIGNAL RECORDING AND TRANSMISSION SYSTEMS

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5 The present invention is concerned in general with
6 recording and transmission systems and with circuit arrangements
7 which alter the dynamic range of signals handled by such
8 systems, namely compressors which compress the dynamic range
9 and expanders which expand the dynamic range. The invention
10 is particularly useful for treating audio signals but is also
11 applicable to other signals, including video signals.

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

30 More specifically, the present invention relates to
31 compressors and expanders which, in addition to providing
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1 compression or expansion, also effect level dependent equaliza-
2 tion. In magnetic recording, the need for such equalization
3 arises because of the tendency of magnetic tape to saturate,
4 particularly at high frequencies. Various proposals have been
5 made for achieving the equalization, several being discussed in
6 Rundfunktechn. Mitteilungen, Jahrg. 22 (1978) H. 2, pp 63-74.
7 A need for equalization can also arise with other recording or
8 transmission media which are susceptible to high level satura-
9 tion or overload effect at certain frequencies.

10 One possibility (but which fails to provide level
11 dependent equalization) is to provide a high-frequency roll-off
12 circuit after the compressor and a compensating boost circuit
13 before the expander. An alternative is to put the roll-off
14 circuit before the compressor and the boost circuit after the
15 expander. A disadvantage of any such technique is that signals
16 at all levels are subject to the same roll-off action (and
17 subsequent boost) so that there is a significant decrease in the
18 amount of noise reduction which is obtained. It is suggested in
19 the Rundfunktechn. Mitteilungen article that the loss of noise
20 reduction can be tolerated if the amount of noise reduction
21 without such techniques is as high as 20 dB. This is only
22 partially true. In practice, particularly with respect to some
23 Compact Cassette tapes, tape saturation effects extend down as
24 low as 2 kHz and the change in equalization required to take
25 account of this will lead to a significant increase in audible
26 noise.

27 Attempts have been made to overcome this problem by
28 making the response of the roll-off and boost circuits level-
29 dependent (US-PS 4,072,914). In the case of the roll-off
30 circuit the roll-off is steeper at high levels than at low
31 levels. For the boost circuit, the boost characteristic is

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1 likewise steeper at high levels than at low levels. A disad-
2 vantage of this approach is the consequential increase in
3 circuit complexity.

4 In the Rundfunktechn. Mitteilungen article there is
5 also a proposal to put a high-frequency boost circuit in front
6 of the control circuit of both the compressor and the expander
7 but it is also there pointed out that the resulting roll-off is
8 only noticeable in the medium level signal range, whereas it is
9 desired to obtain the effect principally at high levels. In
10 video recording systems high frequency saturation problems may
11 be caused by the recording pre-emphasis used. A similar problem
12 exists in FM broadcasting.

13 It is therefore one object of this invention to
14 provide a better solution to the problems discussed above,
15 namely a solution which is both effective and simple.

16 Although not discussed in the prior art there is a
17 related problem in that low frequency equalization (roll-off in
18 the compressor and boost in the expander) is desirable if the
19 compression and expansion are effective at low frequencies also.
20 Low frequency compression and expansion are useful for hum noise
21 reduction and may be achieved using wide band compressors and
22 expanders or compressors and expanders with circuits operating
23 independently at low and high frequencies. At low frequencies,
24 the primary objective of equalization is to counteract the
25 effect of the 3180 usec (+3 dB at 50 Hz) recording boost built
26 into many magnetic tape recorders, which causes low frequency
27 tape saturation problems, e.g. with organ music.

28 Another object of the invention is to provide a means
29 whereby the required equalization can be effected additionally
30 at low frequencies, if required.

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1 A further object of the invention is to increase the
2 headroom and accordingly, the dynamic range of recording media
3 subject to saturation.

4 The starting point of the invention is a compressor or
5 expander comprising a main signal path which is linear with
6 respect to dynamic range, a combining circuit in the main path,
7 and a further path which has its input connected to the input or
8 output of the main path and its output connected to the combin-
9 ing circuit, the further path providing a signal which, at least
10 in an upper part of the frequency band, boosts or bucks the
11 main path signal by way of the combining circuit, but which is
12 so limited that, in the upper part of the input dynamic range,
13 the further path signal is smaller than the main path signal.

14 The upper part of the frequency band typically extends
15 up from a value of some hundreds of Hertz, say a value of 300 -
16 400 Hz, although a higher value may be used. In the upper part
17 of the input dynamic range, say -10 dB to +10 dB, relative to a
18 reference level, the further path signal is small relative to
19 the main path signal.

20 Such compressors and expanders are well known and
21 widely used, examples being described in US-PS 3,846,719, US-PS
22 3,903,485 and US-PS Re 28,426. They are designated dual path
23 compressors and expanders. The further path signal boosts the
24 main path signal in the compressor but bucks the main path
25 signal in the expander. A Type I configuration (for example as
26 in US-PS 3,046,719) is generally used for audio applications and
27 a Type II configuration (for example as in US-PS 3,903,485) is
28 generally used for video applications.

29 In the case of the compressor the invention is
30 defined in claim 1 and uses a frequency dependent circuit connected only in
31 the main path and providing a reduction in frequency response
32 in the part of the frequency band affected by saturation.

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1 In the case of the expander the invention is defined
2 in claim 4 and uses a frequency dependent circuit connected only in the main
3 path and providing an increase in frequency response in the
4 part of the frequency band affected by saturation.

5 The frequency dependent circuit in the main path is
6 connected between the further path take off point and the combin-
7 ing circuit, in both compressors and expanders, both Type I and
8 Type II.

9 The invention also provides a complete noise reduction
10 system comprising the compressor and the expander.

11 The said part of the frequency band affected by
12 saturation is usually the upper extreme -- that is, said upper
13 extreme is whatever upper frequency is regarded as the top end
14 of the audio frequency band in any given practical case, whether
15 this is 15 kHz or 20 kHz or some other value, in the case of
16 audio, or such as 4 - 6 MHz in the case of video.

17 In an audio development of the invention, where the
18 compressor or expander also acts at low frequencies, the fre-
19 quency dependent circuit also provides a reduction (compressor)
20 or increase (expander) in frequency response in the lower part
21 of the audio frequency band (e.g., extending downward from about
22 one hundred Hertz towards its lower extreme, which extreme is
23 typically in the region of 20 Hz.

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

27 Fig. 1 shows a representative response curve of a
28 cassette tape recorder/reproducer.

29 Fig. 2 shows an explanatory characteristic curve.

30 Fig. 3 is a block diagram of an embodiment of the
31 invention in the context of Type I compressors and expanders.

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1 Fig. 4 is a block diagram of the invention in the
2 context of Type II compressors and expanders.

3 Fig. 5 is a block diagram of an embodiment of the
4 invention in the context of a dual stage compander system for
5 magnetic tape recording.

6 The problem of high frequency saturation is common to
7 all magnetic tape and optical film recorders. It may also occur
8 in pre-emphasized recording and transmission systems of many
9 kinds, including FM broadcasting systems. Although it is most
10 severe in low speed tape recorders, particularly those using low
11 cost tape formulations, it affects the ability to record at
12 higher levels even in high quality professional magnetic tape
13 and optical film recorders. That is, the recording medium does
14 not accurately record the high level, high frequency signals
15 applied to it. The main audible effect is intermodulation
16 distortion and a reduction in high frequency content of the
17 recording. However, in the context of the present invention,
18 such saturation is especially undesirable because with certain
19 combinations of signal levels and frequencies it upsets the
20 playback complementarity of the expander. Hence, the expander
21 will inaccurately decode the played back signal to some extent
22 depending on the degree of saturation. The main audible effect
23 is usually an exaggeration of the high frequency loss by the
24 expander but it may also include a spurious modulation of
25 mid-frequency signals.

26 The illustrated embodiment is considered primarily
27 in the context of a cassette tape recorder recorder/reproducer
28 although the invention is applicable as well to professional
29 quality magnetic tape, optical film recording and recording and
30 transmission systems in general.

31 Fig. 1 shows the response of a well above average
32 Compact Cassette recorder/reproducer. At a recording level of

1 -20 dB the response is substantially flat out to 20 kHz. At
2 higher recording levels the effects of high frequency tape
3 saturation become apparent, causing a substantial high frequency
4 roll off at a record level of 0 dB. Typical cassette units
5 exhibit substantially greater saturation effects.

6 The most straightforward way of reducing the above
7 saturation effect is to change the recording equalization in
8 such a way that the tape is not driven so hard in the frequency
9 range in which saturation is troublesome. The playback equali-
10 zation is then altered in a complementary way. Unfortunately,
11 in cassette recording, saturation effects may extend down to
12 frequencies as low as 2 kHz or so as Fig. 1 suggests. The
13 required change in equalization would thus result in a signifi-
14 cant increase in audible noise.

15 The circuit described below effectively permits a
16 treatment to reduce high frequency saturation without sacrificing
17 any significant noise reduction in the treated frequency range.
18 The same technique may be used to reduce low frequency tape
19 distortion where a full-range noise reduction system is employed.
20 In particular, note that in a dual path compressor or expander
21 circuit the output of the circuit at very low signal levels is
22 provided mostly by the further or noise reduction path. In the
23 case of one such device providing 10 dB of dynamic action, the
24 contributions of the main and noise reduction paths are in the
25 ratios of 1 and 2.16, respectively. At high signal levels the
26 roles of the two paths are reversed; the main path provides the
27 predominant signal component, and the further path contribution
28 is negligible.

29 The saturation or distortion reduction effect is based
30 on the above observations. Namely, an equalizer providing the
31 required reduction in high or low frequency drive is placed in

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1 the main path of the compressor. As shown in Figure 2, which
2 shows the operation of a high frequency distortion reduction
3 circuit, at high signal levels essentially the full effect of
4 the equalization is obtained, with a consequent reduction in
5 high frequency saturation. However, at low levels, the equali-
6 zation effect is reduced, since the contribution of the noise
7 reduction path becomes significant. If, for example, the
8 antisaturation network provides for as much as a 12 dB attenua-
9 tion at a particular frequency, then, ignoring phase considera-
10 tions, the low level effect will be

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$$0.25 \times 1 + 2.16 = 2.41 = 7.6 \text{ dB}$$

12 That is, a 12 dB reduction in high level recording drive is
13 obtained for a 2.4 dB loss in noise reduction effect. Such a
14 high degree of distortion reduction would be required only at
15 the highest frequencies, at 15 kHz, for example. At lower
16 frequencies the required reduction in saturation would be less,
17 with a correspondingly reduced loss of noise reduction effect.
18 At low frequencies, the primary objective would be to counteract
19 the effect of the 3180 usec (+3 dB at 50 Hz) recording boost
20 built into many tape recorders, which causes low frequency tape
21 saturation problems, e.g. with organ music, as already mentioned.

22 In audio applications, the requirements of a suitable
23 anti-saturation network may be determined as follows. The maxi-
24 mum usable output level of the tape, optical film, FM channel,
25 or otherwise, is determined at low to medium frequencies and at
26 higher frequencies up to the highest frequency of interest. The
27 resulting maximum output level curve is compared to a plot of
28 energy distribution as a function of frequency for normally
29 encountered music and speech sounds. Such a plot is presented
30 in my paper Journal of the Audio Engineering Society, Vol. 21,
31 No. 5, June, 1973, pp. 357-362. The difference between the

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1 two curves is an indication of the required high level anti-
2 saturation characteristics. Once such characteristics are
3 determined and implemented, the resulting compression character-
4 istic curves should be checked to determine if the anti-
5 saturation network has caused an increase in compression ratio
6 at any frequency or level. If so, appropriate changes can
7 be made in the limiting characteristics of the noise reduction
8 path and/or, where several series connected compressors (or
9 expanders) are used, the anti-saturation characteristic can be
10 distributed among the devices.

11 Similar considerations apply in the case of video
12 devices. In video recorders high frequency pre-emphasis is
13 frequently used, which can result in FM overmodulation problems.
14 The overmodulation tendency of any particular recording system
15 can be measured and an appropriate kind and degree of anti-
16 saturation can be provided. If compressors and expanders of the
17 types described in US-PS 3 046 719 and US-PS 3 903 485 are used,
18 there will be a further overmodulation tendency produced by
19 small residual overshoots (a few percent) from the compressors.
20 These overshoots can be compensated by the present invention.
21 (In audio systems there is also a tendency to compensate residual
22 overshoots).

23 While it would be possible to operate with only the
24 antisaturation network in the encoder unit, it is preferable
25 to provide a complementary correction on the playback side, so
26 that flat frequency response is maintained at all levels. The
27 following analysis shows the type of correction required.

28 Referring to Figure 3, which shows the Type I dual
29 path compressor and expander configurations, let the input
30 signal to the compressor be x , the signal in the information
31 channel be y , and the output signal of the expander be z . Let
32 F_1 and F_2 be the transfer characteristics of the further

path of the compressor and expander, respectively, and F_{AS} be the transfer characteristic of the antisaturation network. Let F'_{AS} be the required compensating characteristic in the decoder.

$$y = (F_{AS} + F_1)x$$

$$\text{and } z = yF'_{AS} - zF_2F'_{AS}$$

$$\text{thus, } z = \frac{F'_{AS}F_{AS} + F_1F'_{AS}}{1 + F_2F'_{AS}} x$$

Inspection shows that $z = x$ if $F_1 = F_2$ and $F'_{AS} = \frac{1}{F_{AS}}$.

A similar derivation applies to the Type II configuration shown in Figure 4:

$$y = F_{AS}x + F_1F_{AS}y$$

$$\text{and } z = F'_{AS}y - F_2y$$

$$\text{thus } z = \frac{(F'_{AS} - F_2)}{\frac{1}{F_{AS}} - F_1} x$$

Inspection shows that $z = x$ if $F_1 = F_2$ and $F'_{AS} = \frac{1}{F_{AS}}$.

The above shows not only that the two noise reduction networks should be identical, as is known from the applicant's prior art, but that the antisaturation compensation network in the decoder should have an inverse characteristic to that of the network employed in the encoder. Simple corrections can be achieved passively, such as by RC combinations, while more complex ones can employ feedback techniques, especially to achieve the inverse characteristics required in the decoder.

Referring now to Figure 5, a block diagram of the present invention is shown embodied in a dual stage Type I configuration primarily for use in magnetic tape recording and reproduction.

The illustrated embodiment employs cascaded compressors 52 and 54 to obtain an enhanced amount of compression

1 and, correspondingly, cascaded expanders 56, 58. The invention
2 is applicable as well to single stage dual path compressors and
3 expanders. Each compressor has a main path 10 including a
4 combining circuit 12 which adds to the main path the output of
5 the further path N_1 , N_2 , whose input is connected to the
6 input of the corresponding main path. The expanders have
7 main paths 14 and combining circuits 16 which subtract from the
8 main path signal the output of the further path N_2 , N_1 , whose
9 input is connected to the corresponding main path output.

10 Such compressor and expander configurations are well
11 known in themselves and will therefore not be described in great
12 detail. However there are two main forms for the further path
13 N_1 or N_2 . One alternative (Figs. 7 and 8 of US-PS 3,846,719)
14 is a filter followed by a controlled limiter which is caused to
15 limit progressively, as the signal level rises, by a rectified
16 and smoothed control signal. Another alternative (US-PS
17 Re 28,426) is a sliding band high pass filter whose pass band is
18 progressively narrowed by the control signal so as to exclude
19 large signal components from the output of the filter, which is
20 preferably in series with a fixed high pass filter. Advantageous
21 corner frequency values for the sliding band filters are about
22 375 Hz in the quiescent state but become progressively narrower
23 high pass in response to the control signal.

24 The first and second compressors 52 and 54 each
25 have high frequency and/or low frequency (and/or any other
26 particular frequency or frequency range) anti-saturation net-
27 works 74, 76 affecting the main signal components. On the
28 reproduce side of the tape recorder T, the first and second
29 expanders 56 and 58 have complementary networks affecting the
30 main signal components. Alternately, such compensation may
31 be provided in only one of the compressors and in only the

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1 corresponding expander. The compensation, may, for example,
2 take the form of a gentle high frequency roll off in the encoder
3 (compressor), increasing at very high frequencies, say above 10
4 kHz, and complementary boost in the decoder (expander).

5 Because the high frequency channel overload reduction
6 is applied only to the main signal components, the low level
7 components in the side channels are unaffected and thus the
8 overload reduction does not greatly affect the noise reduction.
9 Consequently, the channel overload reduction can extend down to
10 the mid-frequency range.

11 The antisaturation networks in the encoders, 74, 76,
12 and the complementary networks in the decoders, 78, 80, are
13 located in the main signal paths. This arrangement results in
14 very little loss of noise reduction effect, since the bulk of
15 signal at low levels is provided by the noise reduction side
16 chain. Therefore it is possible to provide antisaturation
17 networks that taken together have a gradual high frequency roll
18 off, 3-6 dB/octave, for example, (and complementary boost
19 in the decoder) extending quite far down in frequency, for
20 example to 2-3 kHz, to deal with saturation effects without a
21 high degree of noise reduction loss. The frequency response at
22 0 dB in Figure 1, shows, for example, a fall off of high fre-
23 quency response from saturation beginning about 2 kHz. Since
24 the antisaturation networks are in the main channels, which
25 carry the high level signals, only those signals which cause
26 saturation are affected. As shown in Figure 1, low level
27 signals do not cause significant tape saturation.

28 Optionally, half of the 3-6 dB/octave roll off is
29 provided in each network 74 and 76 and half of the complementary
30 boost is provided in each network 78 and 80. If all of the roll
31 off and boost is placed in single networks 76 and 78, then the

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1 associated compressor or expander will have an increased com-
2 pression or expansion ratio in the particular level and frequency
3 region associated with that compressor or expander. However, in
4 a consumer system the use of a single network is adequate.

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CLAIMS

1. A compressor having level dependent equalization for use in a signal transmission system in which the compressed signals are applied to a transmission channel which is susceptible to high level saturation or overload effect in part of the frequency band in which the compressor compresses the dynamic range of signals, comprising a main signal 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 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, about -10 dB to + 10 dB relative to the 0db reference level of the compressor, the further path signal is limited to a value which is small relative to the main path signal, and frequency dependent circuit means connected only in that portion of the main path between the combining circuit and the input or the output of the main path where the further path has its input coupled for providing a response characteristic which substantially reduces the saturation or overload effect in at least part of the frequency band in which the effect occurs and in which the further path boosts the main path signal, the said response characteristic affecting the compressor characteristic at high levels for signals in the said upper part of the input dynamic range, wherein the overall response characteristic of the compressor at high levels is substantially that of the frequency dependent circuit means.
2. A compressor according to claim 1, wherein the compressor is an audio compressor and the frequency dependent circuit means produces a reduction in frequency response in the upper part of the audio frequency band.



3. An audio compressor according to claim 2, wherein the compressor also acts at low frequencies and the frequency dependent circuit means also produces a reduction in frequency response in the lower part of the audio frequency band.

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4. An expander having level dependent equalization for use in a signal transmission system in which compressed signals are received from a transmission channel which is susceptible to high level saturation or overload effect in part of the frequency band in which the dynamic range of signals has been compressed, comprising a main signal 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, 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, about -10 dB to + 10 dB relative to the 0dB reference level of the expander, the further path signal is limited to a value which is small relative to the main path signal, and frequency dependent circuit means connected only in that portion of the main path between the combining circuit and the input or the output of the main path where the further path has its input coupled for providing an enhanced response characteristic which applies in at least part of the frequency band in which the saturation or overload effect occurs and in which the further path boosts the main path signal, the said response characteristic affecting the expander characteristic at high levels for signals in the said upper part of the input dynamic range, wherein the overall response characteristic of the expander at high levels is substantially that of the frequency dependent circuit means.

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5. An expander according to claim 4, wherein the expander is an audio expander and the frequency dependent circuit means produces an increase in the frequency response in the upper part of the audio frequency band.

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6. An audio expander according to claim 5, wherein the expander also acts at low frequencies and the frequency dependent circuit means also produces an increase in frequency response in the lower part of the audio frequency band.

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7. A noise reduction system comprising a compressor according to claim 1 and an expander according to claim 4.

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8. A noise reduction system according to claim 7, wherein the compressor and expander act at audio frequencies and the frequency dependent circuit means produce a reduction in frequency response in the compressor and a complementary increase in frequency response in the expander in the upper part of the audio frequency band.

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9. An audio noise reduction system according to claim 8, wherein the compressor and expander also act at low frequencies and the frequency dependent circuit means also produce a reduction in frequency response in the compressor and a complementary increase in frequency response in the expander in the lower part of the audio frequency band.

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