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NETWORKS FOR SUPPRESSING MID-FREQUENCY
MODULATION EFFECTS IN COMPRESSORS,
EXPANDERS AND NOISE REDUCTION SYSTEMS

The present invention is concerned in general with circuit arrangements which alter the dynamic range of audio signals, namely compressors which compress the dynamic range and expanders which expand the dynamic range.

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.

Transmission channels are known to have frequency dependent characteristics. Consequently the frequency spectrum of received or played back signals is altered and when compressed

1 expansion of the signals is degraded by the transmission channel
2 frequency characteristics.

3 In compander type noise reduction systems, complemen-
4 tarity requires not only that the expander have essentially the
5 inverse characteristics of the compressor, but also that the
6 transmission channel between the compressor and expander preserve
7 relative signal amplitudes at all frequencies within the
8 bandwidth of signals compressed. As received at the expander,
9 changes in the relative levels caused by the transmission
10 channel are indistinguishable from signal processing by the
11 compressor. Hence, errors in the transmission channel cause the
12 expanded signals to differ from the input signals to the com-
13 pressor. Such differences can be significant and audible
14 depending on the spectral content of the signals. With high
15 compression/ expansion ratios, errors in the transmission
16 channel become more significant. Typically, the most audible
17 effect is not the direct effect on very high or very low fre-
18 quency signals themselves, but rather the modulation effect on
19 signals between the bandwidth extremes that is caused by failure
20 of the extreme high and low frequency signals to reach the
21 expander. For discussion purposes this effect will be referred
22 to as the mid-band modulation effect.

23 In wideband companders an amplitude error at the
24 controlling frequency will manifest itself to the same degree in
25 all other portions of the spectrum. This may or may not be
26 acceptable. In sliding band companders, as described hereafter,
27 the controlling frequencies are at the bandwidth extremes,
28 errors at such frequencies are substantially multiplied at
29 mid-frequencies. (Conversely, if the controlling frequencies
30 are at mid-frequencies, as they usually are, then any errors at
31 the frequency extremes are reduced; this is an advantage of
32 sliding band companders.)

1 "Transmission channel" as used herein is defined
2 to include all portions of the system between a compressor and
3 an expander.

4 In the case of noise reduction systems that record
5 compressed signals on relatively narrow bandwidth media such as
6 slow speed magnetic tape, e.g. Compact Cassettes, it is particu-
7 larly difficult to provide accurate complementary expansion of
8 the compressed signals. This is due to the inability of such
9 systems to provide a flat signal amplitude response particularly
10 at low and high frequencies. However, such problems exist even
11 in professional compressor/expander systems. The inadequacy
12 occurs after the compressor and can be caused by the recorder,
13 the tape, the playback unit or any combination thereof, including
14 bandwidth limitation filters. Similarly in other systems, such
15 as FM or satellite broadcasting, the errors occur after compres-
16 sion in the transmitter, the broadcast signal carrying media,
17 the receiver or combinations thereof.

18 In practical compressor-expander systems it has been
19 found necessary to incorporate sharp cutoff filters before the
20 compressor and before the expander. The filters are at least
21 low pass, but preferably also include high-pass sections. Such
22 band-limitation filters have corner frequencies at the edges of
23 or outside the useful bandpass of the system in order not to
24 limit the system bandwidth. Such filters have several functions:

- 25 a) Attenuation of subcarrier components and the 19
26 kHz pilot tone used in FM broadcasting, in order
27 to avoid bias "birdie" beats (whistles) and
28 mistracking of encode and decode noise reduction
29 processor circuits.
- 30 b) Attenuation of the tape recorder bias which may
31 leak in the signal circuits, in order to avoid
32 encoder/decoder mistracking.

1 c) Attenuation of rf or supersonic components in the
2 encoder input signal which may otherwise result in
3 audible intermodulation products and/or bias
4 "birdies."

5 d) Attenuation of supersonic tape noise or other
6 transmission channel noise at the decoder input,
7 in order to avoid encoder/decoder mistracking.

8 e) A signal bandwidth definition to promote comple-
9 mentarity in response of the encoder/decoder.

10 In professional applications it is desirable to
11 employ a high frequency bandwidth limitation filter (e.g. at
12 20-25 kHz) and preferably also a low frequency bandwidth
13 limitation filter (e.g. at 20 Hz).

14 Strictly speaking, if an ideal channel exists between
15 the encoder and decoder, then the input filter to the decoder
16 should be disconnected, as its inclusion may result in some
17 signal situations in a slight noncomplementarity (the encoder
18 signal is subjected to one stage of filtering; the decoder is
19 subjected to two stages of filtering). However, removal of the
20 decoder input filter is not practical because of considerations
21 a) to e) above. Therefore, even when there is a good channel
22 between the encoder output and decoder input, the presence of
23 the very necessary decoder input filter (for protection purposes)
24 results in an inherently non-complementary system under certain
25 signal conditions. Because of this it is helpful to consider
26 the expander input filter to be an integral part of the trans-
27 mission channel.

28 It is an object of the present invention to provide
29 for the suppression of the adverse effects on complementarity
30 in compander type noise reduction systems caused by errors in
31 transmission channel amplitude response.

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1 Stated in other words, it is an object of the present
2 invention to provide for the suppression of the adverse effects
3 on complementarity in compander type noise reduction systems
4 caused by errors in amplitude response that occur between the
5 compressor and expander.

6 It is a particular object of the invention to suppress
7 non-complementarity effects at very high (low) frequencies that
8 produce audible effects at mid-frequencies (to reduce the
9 mid-band modulation effect).

10 A further object of the invention is to suppress such
11 adverse effects in systems in which the bandwidth of compressed
12 signals exceeds the bandwidth in which the transmission channel
13 amplitude response is relatively flat.

14 It is yet a further object of the invention to suppress
15 such adverse effects in audio tape systems employing Compact
16 Cassette or other bandwidth restricted media, including the
17 audio portion of video cassettes and video discs.

18 It is a further object of the invention to reduce the
19 non-complementary modulation of low level medium frequency (e.g.
20 500 Hz - 1 kHz, or so) signals when present with extremely high
21 frequency signals (e.g. above 10 kHz) in such audio tape systems.

22 It is a further object to reduce non-complementary
23 effects introduced by the use of expander input filters.

24 It is yet a further object of the invention to reduce
25 the above effects in sliding band systems of the type described
26 hereinafter.

27 In bandwidth restricted systems the frequency bandwidth
28 of compressed signals approaches or exceeds the usable bandwidth
29 of the record/playback transmission channel and thus such
30 systems are especially susceptible to errors in record/playback
31 frequency response, particularly in the region of the high and
32 low frequency band edges.

1 There are two aspects to the problem: 1) the com-
2 pressor output bandwidth may exceed the bandwidth in which
3 the record/playback response is relatively flat in that self-
4 contained audio device, and 2) the compressor output bandwidth
5 of the device used in preparing prerecorded tapes or discs may
6 exceed the bandwidth in which the audio device playback respons
7 is flat.

8 While errors may theoretically occur anywhere in the
9 spectrum, as explained further below, the invention is directed
10 to suppressing the effect of errors at the bandwidth extremes o
11 the system, particularly to suppressing the mid-band modulation
12 effects caused by such errors.

13 The invention which is the solution to the mid-band
14 modulation problem is rather surprising in its simplicity. Mor
15 specifically, the signals processed by the compressor are
16 subjected to an abrupt high (and/or low) frequency drop-off wit
17 a corner frequency well within the useful bandpass of the
18 system, somewhat below (above) the frequency at which the
19 transmission channel or record/playback response has substantia
20 errors. Signals processed by the expander are preferably
21 subjected to a complementary boost so that an overall flat
22 frequency response is maintained. If lack of overall flat
23 frequency response is acceptable, the invention may be incorpo-
24 rated only in the compressor portions of the compander system.

25 Thus, in accordance with the present invention, a por
26 tion (or portions) of the signal spectrum in which transmission
27 channel or record/playback response has errors is (are) attenu-
28 ated to a level such that the attenuated portion is substantial
29 excluded from controlling the compression and expansion.

30 In accordance with the invention, the spectral
31 content of the signals processed by the compressor is altered

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1 or skewed ("spectral skewing") such that the compressor action
2 is significantly less susceptible to the influence of signals
3 beyond the abrupt roll-off frequency.

4 One preferred embodiment of the invention is to locate
5 a suitable filter (or network) in the signal path of the com-
6 pressor input (and preferably a complementary filter in the
7 signal path of the expander output). This approach is preferred
8 because it requires the least amount of circuit components
9 and it operates at all signal levels. However, an equivalent
10 arrangement is to employ two filters: one in the control
11 circuit path of the compressor and the other in the signal path
12 of the compressor output. Similarly, in the expander, one
13 filter is located in the control circuit path and the other in
14 the signal path of the expander input. Further alternatives are
15 possible in the case of a dual path compressor or expander (for
16 example as disclosed in US-PS 3,846,719 and US-PS Re 28,426): a
17 suitable filter may be located only in the input of the processor
18 side path so as to affect both the signals passing therethrough
19 and also the control circuit of the side path or the equivalent
20 two filter arrangement may be employed where one filter is
21 placed in the side path control circuit path and the other in
22 the side path signal output path.

23 It is known in compander systems to provide a roll off
24 at high frequencies in the compressor side of the system and to
25 provide a complementary boost in the expander side of the system
26 in order to reduce tape saturation, for example (US-PS 3,846,719,
27 US-PS 4,072,914, Rundfunktechn. Mitteilungen, Jahrg. 22 (1978)
28 H.2, pp. 63-74.) However, the roll off is gentle and is not suf-
29 ficient to keep high level signals at high (low) frequencies in
30 the uncertain response region of the system from affecting the
31 compressor as is accomplished with the present invention.

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1 It is known from the above disclosures to place anti-
2 saturation filters at various places in the signal path; before
3 and after the compressor/expander and within the compressor/
4 expander including at the same time in its control circuit.
5 Thus there are many possible locations of antisaturation filters
6 in the compressor and expander signal paths that will serve the
7 purpose of reducing the high frequency signals applied to the
8 recording tape. In contrast, the circuitry according to the
9 present invention must be more precisely located because it is
10 intended to affect the compressor and consequently the expander
11 by altering the frequency spectrum of signals that the compressor
12 processes.

13 Although the present invention is not directed to
14 alleviating saturation effects it nevertheless will assist in
15 avoiding tape saturation to some extent. However, because the
16 corner frequency of the abrupt drop-off is ordinarily located at
17 a frequency above (below) the region in which saturation begins
18 to occur, tape saturation is preferably treated by other means
19 as for example as described in Audio, May, 1981, pp. 20-26.

20 As with the known anti-saturation arrangements, the
21 present invention does result in a loss of noise reduction
22 effect in the region in which the signals are abruptly attenuated
23 as a function of frequency. However, the corner frequency of
24 the abrupt drop off for the upper frequency end of the system is
25 at a relatively high frequency in the region in which the human
26 ear is much less sensitive to noise. With respect to use of the
27 invention at the low frequency end of the system, the ear is
28 also less sensitive and also there should be essentially no
29 audible noise at such frequencies in properly engineered systems
30 even with reduced noise reduction. The invention contemplates
31 spectral skewing only at the high and/or low frequency extremes
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1 because in practical systems those frequency regions are the
2 only ones in which the transmission channel amplitude response
3 has significant errors. A further reason is that an impairment
4 of the noise reduction can be tolerated at these extremes due to
5 the response of the human ear.

6 In another known system, a 12 dB/octave bandpass
7 filter having corner frequencies of about 20 Hz and 10 kHz
8 is employed in the control circuit of a wide band consumer
9 audio tape compander type noise reduction system (sold under the
10 trademark "dbx II"). However, this arrangement does not achieve
11 the results of the present invention because no filter is
12 provided in the signal path and a high level high (low) frequency
13 signal beyond 10 kHz (or below 20 Hz) is amplified in accordance
14 with the level of whatever signals are present within the band-
15 pass of the control circuit. Hence, such an arrangement
16 provides excessive amplification of high level, high (low)
17 frequency signals (outside the 20 Hz - 10 kHz band) when high
18 amplitude signals within the 20 Hz - 10 kHz band are not present,
19 resulting in overdriving the transmission channel.

20 It is also known in a video noise reduction system
21 (US-PS 3,846,719) to provide a variable-Q notch filter responsive
22 to chroma level, centered on the color television subcarrier
23 frequency, in order to prevent the chroma signals from choking
24 the compressor and expander and thus eliminating noise reduction
25 at frequencies below the color subcarrier frequency. Thus, the
26 filter center is within the bandwidth extremes of the signals in
27 the system and within the predictable response of the system
28 transmission channel and, moreover, is not for the purpose of
29 overcoming record/playback response errors, which purpose
30 underlies the present invention.

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It is further known to provide 12 dB/octave low pass, bandpass and high pass filters in the side paths of dual path compressors and expanders (US-PS 3,846,719; Journal of the Audio Engineering Society, Vol 15, No 4, October 1967, pp 383-388). However, these filters are for an entirely different purpose, namely band splitting of the noise reduction action in separate side paths, and do not affect the upper or lower frequency extremes of the compressor input signals.

Likewise, the sharp cut off band limitation filters described earlier have corner frequencies purposely located outside the useful system bandwidth because they are not intended to affect the upper or lower frequency bandwidth extremes.

Heretofore, it has been considered undesirable to substantially alter the frequency spectrum within the usable system bandwidth. For example in professional recording it is considered unthinkable to locate the corner frequency of any upper band-limitation filter below 20 kHz. Similarly, in FM broadcasting, a 15 kHz upper bandpass limit is rigorously maintained throughout all the audio signal stages.

Although the present invention is not limited to use with any particular type of noise reduction companding system and it will improve the operation of all types of companders, including wide band companders, it is particularly useful for use with sliding band noise reduction systems. An example of such a system is to be found in US-PS Re 28,426. In such known sliding band circuits, high frequency audio compression or expansion is achieved by applying high frequency boost (for compression) or cut (for expansion) by way of a high pass filter with a variable lower corner frequency. As the signal level in the high frequency band increases, the filter corner frequency slides upwardly so as to narrow the boosted or cut band and exclude the useful signal from the boost or cut.

1 In sliding band devices one effect of uncertainties
2 in record/playback response is the resulting modulation of low
3 level medium frequency signals when high frequency signal in the
4 region of record/playback uncertainties are present at the
5 compressor input. In dual path sliding band devices of the type
6 such as described in US-PS Re 28,426, this effect can be sup-
7 pressed by providing the abrupt high frequency drop-off in the
8 side path of the device. While such a configuration provides
9 the abrupt drop-off only at medium and low signal levels, it is
10 adequate to substantially satisfy the objects of the invention
11 in dual path devices of both the sliding band type (US-PS Re
12 28,426) and the fixed band type (US-PS 3,846,719).

13 The invention will be described in more detail, by
14 way of example, with reference to the accompanying drawings, in
15 which:

16 Figures 1-4 are block diagrams showing alternative
17 placements of the spectral skewing network(s) according to the
18 invention.

19 Figure 5 is a response curve showing generally the
20 characteristics of a high frequency spectral skewing network
21 and complementary de-skewing network for use in a cassette
22 tape recorder/reproducer.

23 Figure 6 is the standard CCIR noise weighting
24 characteristic curve.

25 Figures 7-10 are representative response curves of
26 typical cassette tape recorder/reproducers.

27 Figures 11-16 are representative curves useful in
28 understanding the invention.

29 Referring now to Figures 1-4, generalized block
30 diagrams are shown to illustrate the various locations where
31 spectral skewing networks according to this invention can be
32 located.

1 In Figure 1, which shows the simplest and preferred
2 embodiment, the spectral skewing network (having a low or high
3 frequency section) or networks (having both low and high fre-
4 quency sections) 2 is (are) located in the input signal path to
5 a compressor 4, the output of which is applied to a transmission
6 channel N. On the reproduce side of the channel N, a comple-
7 mentary expander 6 acts on the reproduced signal and applies it
8 to an optional spectral de-skewing network(s) 8 that has (have)
9 a characteristic(s) complementary to the network(s) in the
10 compressor input path. This location of the network is par-
11 ticularly advantageous where the compressor and expander each
12 include two or more series devices such as described in Audio,
13 May, 1981, pp. 20-26.

14 Figure 2 illustrates an equivalent configuration,
15 which in practice is not preferred because it is more complex,
16 requires additional circuitry and is more expensive. In this
17 equivalent configuration a spectral skewing network(s) 10 is
18 placed in the compressor control circuit and a further spectral
19 skewing network(s) 12 in the compressor signal output path. If
20 the optional de-skewing is employed in the reproduce side, a
21 complementary de-skewing network(s) 14 is employed in the
22 expander signal input path and a spectral skewing network(s)
23 10, that has the same characteristics as the network(s) 10 in
24 the compressor control circuit, is placed in the expander 6
25 control circuit. The characteristics of networks 4 and 12 may
26 differ somewhat from that of network(s) 2 and from each other to
27 obtain the same overall results as network(s) 2. This observa-
28 tion applies also to networks 14 and 16. Where compresor 4 and
29 expander 6 each include series devices, such as described in the
30 Audio article, a spectral skewing network(s) 10 is required only
31 in the control circuit of the first compressor device and a
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1 network(s) 12 is located only in the output path of the first
2 compressor series device, and (optionally) a network(s) 14 only
3 in the input path of the last expander series device with a
4 network(s) 16 only in its control circuit.

5 Figures 3 and 4 illustrate placement of the spectral
6 skewing networks in the side paths of dual path compressors
7 and expanders. Such compressor and expander configurations
8 are well known in themselves and will therefore not be described
9 in great detail. However, there are two main forms for the
10 further path N (20). One alternative (Figs. 7 and 8 of US-PS
11 3,846,719) is a filter followed by a controlled limiter which is
12 caused to limit progressively, as the signal level rises, by a
13 rectified and smoothed control signal. Another alternative
14 (US-PS RE 28,426) is a sliding band high pass filter whose pass
15 band is progressively narrowed by the control signal so as to
16 exclude large signal components from the output of the filter.
17 Advantageous corner frequency values for the variable filters
18 are about 375 Hz in the quiescent state but become progressively
19 narrower high pass in response to the control signal. Dual path
20 compressors and expanders (singly or in series) can also be
21 employed in in the configurations of Figs. 1 and 2.

22 In Figure 3 the spectral skewing network(s) 18 is
23 (are) placed in the input signal path of the noise reduction
24 side path circuitry 20 of the compressor 22 and (optionally)
25 the expander 24. In Figure 4, an equivalent configuration is
26 shown in connection with a sliding band type compressor 26 and
27 expander 28. In this equivalent configuration, a spectral
28 skewing network(s) 28 is placed in the side path control circuit
29 30 which controls a frequency variable shelf or sliding band
30 filter circuit 32. A further spectral skewing network 34 is
31 placed in the side path output. Optionally, the same networks
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1 are located in the expander side path. The configurations of
2 Figures 1 and 2 are preferred to those of Figure 3 and 4 because
3 the former act at all signal levels and hence also reduce channel
4 overload or tape saturation effects at the band extreme(s).

5 Although in Figures 3 and 4 only a single side path is
6 shown, several side paths may be employed such as in, for
7 example, US-PS 3,846,719. Further, the side paths may be
8 configured such that the compressor side path has a feedback
9 configuration and the expander side path a feedforward con-
10 figuration, as, for example in US-PS 3,903,485. Where series
11 dual path devices are employed in a compressor and expander,
12 such as the type described in Audio, May, 1981, pp. 20-26, it is
13 sufficient to employ a spectral skewing network(s) in the first
14 series device in the compressor and (optionally) in the last
15 series device in the expander, although the configuration of
16 Figure 1 herein is preferred.

- 17 The spectral skewing characteristic has preferably:
- 18 a) A drop-off corner frequency within the region in
 - 19 which the transmission channel or tape recorder
 - 20 response, including that of the expander band-pass
 - 21 filter, is reasonably dependable -- that is,
 - 22 somewhat below (above) the frequency at which
 - 23 the transmission channel or tape recorder response
 - 24 is uncertain or begins to roll off.
 - 25 b) An abrupt drop-off, to provide a well defined
 - 26 limit for the frequencies controlling the circuit
 - 27 c) A well defined shape following the drop-off, so
 - 28 as to permit the easy creation of the reciprocal
 - 29 characteristic during reproduction or playback
 - 30 to retain an overall flat frequency response (if
 - 31 desired).

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1 d) A shape which takes optimal advantage of the low
2 level noise sensitivity characteristic of human
3 hearing - that is, frequency response drop-off
4 as steep and as deep as possible without intro-
5 ducing a noticeable increase in noise level when
6 employing the reciprocal characteristic during
7 playback.

8 While the spectral skewing characteristic effectively
9 reduces the noise reduction action above (below) the sharp
10 corner frequency, if the frequency is above about 8 kHz (or
11 below about 50 Hz), the increased noise will not be audible in
12 view of the human ear's response to low-level high and low
13 frequency noise, especially if the noise level is extremely low
14 as it is when the present invention is used in a tape recording
15 compander. This somewhat surprising aspect of the invention has
16 been verified experimentally.

17 Justification for this treatment can also be found in
18 the shape of the CCIR noise weighting curve, shown in Figure 6.
19 The curve follows the low-level noise sensitivity of the human
20 ear. Note that the sensitivity is low at low frequencies, and
21 also falls off very rapidly above a peak at about 6-7 kHz.
22 Thus, there is a reduced psycho-acoustic need for maintaining
23 substantial noise reduction at frequencies above 8-10 kHz. This
24 is the high frequency counterpart of the observed ability of
25 noise reduction systems to provide a subjectively large amount
26 of noise reduction even though the low frequencies may be
27 treated little if at all. Good engineering can eliminate hum,
28 which in cassette tape recording is the only low frequency noise
29 which is subjectively troublesome.

30 In professional noise reduction systems, in which
31 low frequency noise reduction is provided as an insurance

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1 against unexpected hum problems, there is usually little need
2 for any noise reduction below the lowest hum component likely to
3 be encountered (i.e. 50 Hz).

4 Especially at the high frequency end of the spectrum,
5 the use of a spectral skewing network does not obviate or
6 replace an overall band limitation filter, sometimes popularly
7 known as a "multiplex filter" ("MPX"). The reasons have been
8 given previously. As discussed, a band limitation filter,
9 usually used in both recording and playback, has several func-
10 tions only peripherally related to those in these discussions.
11 Therefore, even in the case of an ideal signal channel, it is
12 desirable to have in encoding and decoding both:

- 13 1) bandwidth limitation filters; and
- 14 2) spectral skewing and de-skewing networks.

15 The spectral skewing network(s) (2, 10, 12, 18, 28, 34)
16 provide an abrupt shelf, dip or drop-off as shown in Figure 5.
17 The dashed lines are intended to show that the ultimate high
18 frequency (low frequency response) need not be precisely as
19 shown in the solid lines.

20 One suitable form of the spectral skewing network(s)
21 (2, 10, 12, 18, 28, 34), is a sharp low-pass (high-pass) filter
22 with an 18 dB/octave slope, and having a corner frequency within
23 the rapidly declining portion of the CCIR noise weighting curve
24 (Figure 6) and below (above) the upper cut off frequency of the
25 transmission channel. A corner or cutoff frequency of about
26 8-10 kHz (50 Hz at the low frequency end) would be suitable for
27 a high quality tape deck having a useful but uncertain response
28 out to some 15 kHz (or 30-60 Hz at the low frequency end).

29 The network could also take the form of a shelf
30 network with about a 10 dB floor such as shown in Figure 5.

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1 Another suitable form of the network is a notch filter
2 with a center frequency of about 16 kHz (20 Hz), a Q such
3 that a corner frequency of about 8-10 kHz (40 Hz) is obtained,
4 and a depth of some 10 dB. A double tuned (stagger tuned) notch
5 filter can also be used, especially in professional applications,
6 in order to provide a wider overall notch, the second notch
7 being placed some fraction of an octave above the first notch
8 (say 1/3 octave).

9 A depth of some 10-15 dB has been proven experimentally
10 to eliminate the mid-band modulation effect in the most difficult
11 cases. However, a depth of as little as 6 dB has been found to
12 make a substantial improvement in the mid-band modulation
13 effect, particularly when the drop-off is very abrupt such as 18
14 dB per octave.

15 If a flat overall response is desired, the same
16 network and/or complementary networks 8, 10, 14, 18, 28,
17 and 34 are employed in the reproduce or playback portion of
18 the system.

19 Referring particularly to the characteristics of con-
20 sumer Compact Cassette audio tape recorder and playback devices,
21 in order to appreciate the invention more fully, reference is
22 made to Figures 7-9 which show representative measured high
23 frequency response curves at input levels low enough to avoid
24 tape saturation for several typical Compact Cassette recorders.
25 Figure 10 shows representative high frequency response curves
26 at several input levels for another typical Compact Cassette
27 recorder. Note that in Figure 7, the recorder response falls
28 off rapidly beyond 10 kHz. In Figure 8, there is a rise in
29 response starting about 10 kHz with a pronounced peak at about
30 17 kHz. The response in Figure 9 has a high frequency peak at
31 15 kHz with a rapid fall off of response beyond that frequency.

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1 The response in Figure 10 for a level of -20 dB, which avoids
2 saturation, is nearly ideal, being substantially flat out to
3 20 kHz. Such a good response is, however, rare.

4 Thus, the selection of a high frequency spectral
5 skewing network corner frequency of about 10 kHz is a good
6 choice for such devices because the response curves in Figures
7 7-10 show that for levels below saturation, the typical recorder
8 in good adjustment has little deficiency in response below 10
9 kHz. Hence, the spectral skewing network will ensure, at most
10 levels, that there will be essentially no level discrepancy in
11 the playback control signal caused by uncertainties in response
12 at extremely high frequencies. A corner frequency of about 10
13 kHz is a good choice for such devices because, in addition, tha
14 frequency is on the steeply declining portion of the CCIR noise
15 weighting curve (Figure 6) and thus some loss of noise reduction
16 can be tolerated by the human ear.

17 In selecting a suitable corner frequency for a spectr
18 skewing network, the designer can select approximate frequencies
19 different from 10 kHz based on the parameters of his system. For
20 example, in the case of a higher quality transmission channel, a
21 higher corner frequency may be acceptable. With respect to
22 Compact Cassette devices of the type whose characteristics are
23 shown in Figures 7-10, acceptable high frequency corner frequen
24 can range from about 8 kHz to perhaps 11 or 12 kHz. Also, while
25 a filter of about 18 dB/octave is desirable to assure that high
26 level high (low) frequency signals do not control the compressor

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1 a drop-off as little as 12 dB/octave will substantially meet the
2 objectives of the invention for most signals. Attenuations much
3 sharper than 18 dB/octave present difficulties in providing
4 complementary de-skewing and are more costly.

5 The required filter drop off rate depends in part on
6 the sensitivity of the compressor to signals beyond the filter
7 cut off frequency. Consider, for example, the dual path sliding
8 band compressor as disclosed in US-PS Re 28,426. In that
9 device, high frequency pre-emphasis is used in the compressor
10 control circuit such that if a signal such as shown in Figure 11
11 is applied to the compressor (such a signal might be generated
12 by a wideband percussive sound), the control circuit pre-emphasis
13 causes the signal to have an energy spectrum as shown in Figure
14 12. The pre-emphasized signal spectrum has a peak. After
15 rectification, this peak provides the DC control signal which
16 controls the compressor's sliding band action.

17 Figure 13 illustrates the uncertain frequency responses
18 of the tape recorder channel, shown for four representative
19 Compact Cassette tape recorders a, b, c and d. The effect
20 on the spectrum of Figure 12 is to cause four different spectra
21 to be present in the control circuit of the expander (decoder),
22 resulting in four different DC control signals. Clearly, errors
23 in decoding will result.

24 In such a case, a desirable spectral skewing network
25 characteristic causes the expander (decoder) to generate the same
26 DC control signal in each case such, as shown in Figure 15. A
27 network characteristic having a corner frequency at about 10 kHz,
28 such as shown in Figure 5 is suitable. Note that the network
29 does not eliminate the sliding of the frequency band; indeed,
30 it may be only slightly reduced. However, the sliding (or
31 compression as in the band splitting system of US-PS 3,846,719)
32 now becomes recoverable during playback.

1 It should be appreciated that the primary object of
2 the invention can be seen in Fig. 15 - namely to assure the same
3 peak in the spectrum of the AC control signal is present at the
4 rectification point in both the compressor and the expander.

5 With respect to sliding band systems of the type just
6 mentioned, the spectral skewing network is particularly useful
7 in suppressing mid-frequency modulation caused by the presence
8 of high level, high frequency signals in the compressor that are
9 not recovered and applied to the expander. This modulation
10 effect, which occurs very rarely in actual music sources,
11 relates to the basic operation of the sliding band device with
12 imperfect signal channels: a predominant signal effectively
13 controls the sliding band frequency characteristic and may cause
14 audible effects when that signal is at a high frequency which is
15 not recovered in playback. When that predominating signal is at
16 a high frequency, significantly above the frequency of a low
17 level mid-frequency signal, the mid-frequency modulation effect
18 is audible if the high frequency signal is intermittent such as
19 with percussive sounds, brushed cymbals, for example, and is not
20 reproduced at the same level by the tape recorder. In that case
21 the mid-frequency signals are modulated in amplitude, even after
22 decoding, because the high frequency signal causes the sliding
23 band frequency response to vary without complementary expansion
24 in the playback decoder. It should be noted that this effect is
25 basically not a tape saturation effect; it might be caused by
26 inaccurate biasing and equalization or by gap loss, poor
27 azimuth and the like. However, it is clear that the effect will
28 be worse if there is also saturation in the controlling frequency
29 region.

30 This problem of low-level, mid-frequency modulation
31 effects may be better understood by reference to Figure 16,
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1 which shows the results when a series of probe tone curves using
2 a 15 kHz signal at levels from 0 to -60 dB and below and a
3 sweeping low-level probe tone at -65 dB are recorded and played
4 back on a sliding band system.

5 Note that when a dominant 15 kHz signal increases
6 in amplitude from -60 dB to e.g. -50 dB, the output of the
7 compressor changes by about 2 dB. This 2 dB change must be
8 accurately preserved in the recording process because of the
9 dependance of the mid-frequency dynamics on this dominant signal
10 (a change of some 10 dB is produced in the region of 1 kHz).
11 Thus any error in playback in the controlling frequency region
12 is multiplied substantially in the mid-frequency region.

13 If a noise reduction system treats low frequencies,
14 then there will be a corresponding effect at low frequencies.
15 Extremely low frequency rumble in the input signal to the
16 compressor may actuate the compressor circuitry. If the
17 recorder does not reproduce the rumble components, then signal
18 modulation effects at the expander output will be evident.

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CLAIMS

1. An audio signal compressor for use in a signal transmission system in which a compressed signal is transferred to an expander by way of a transmission channel liable to exhibit an uncertain relative signal amplitude response in the region of the high
5 and/or low frequency extremes of the useful bandwidth of signals applied to the compressor, the compressor comprising means whereby its compression is controlled in response to frequency and amplitude level characteristics of the applied signals, and further comprising filter means for substantially excluding said
10 high and/or low frequency extreme regions from controlling the compressor and for attenuating said high and/or low frequency extreme regions in the compressed signal, the filter means acting abruptly above a high corner frequency and/or below a
15 low corner frequency and the or each corner frequency being within the frequency region in which the human ear can hear signal components but where the ear has reduced sensitivity to low noise components.
2. A signal compressor according to claim 1, wherein the filter means act below an abrupt low corner frequency of about 50 Hz.
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3. A signal compressor according to claim 1 or 2, wherein the filter means act above an abrupt high corner frequency of 8 kHz to 12 kHz.
- 25 4. A signal compressor according to claim 1, 2 or 3, wherein the or each corner frequency has a slope of 12 dB/octave to 18 dB/octave.
- 30 5. A signal compressor according to any of claims 1 to 4, wherein the filter means comprises a band rejecting network having at least one steep drop-off with a corner frequency located to attenuate said high and/or low frequency extreme regions.

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6. A signal compressor according to claim 5, wherein the network is located in the input signal path to the compressor.

5 7. A signal compressor according to claim 5, wherein the means whereby the compression is controlled comprise a control circuit responsive to the frequency and amplitude of applied signals for controlling compression, and one band rejecting network is located in the control circuit and a further band rejecting network is located in the output signal path of
10 said compressor.

8. A signal compressor according to any of claims 5 to 7, wherein the or each band rejecting network comprises a low pass filter in the high frequency extreme region and/or a
15 high pass filter in the low frequency extreme region.



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9. A signal compressor according to any of claims 5 to 7, wherein the or each band rejecting network comprises a notch filter in the high and/or low frequency extreme region.

10. A signal compressor according to any of claims 5 to 7, wherein the or each band rejecting network comprises a shelf network in the high and/or low frequency extreme region.

11. A signal compressor according to any of claims 5 to 10, wherein the or each band rejecting network has a depth of at least 6 dB in the high and/or low frequency extremes.

12. A signal compressor according to claim 11, wherein the depth is from 6 to 10 dB.

13. A signal compressor according to any of claims 1 to 4, wherein the compressor has 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 boosts the main path signal by way of the combining circuit, but which is limited to a value smaller than the main path signal, the filter means being located only in the further path of the compressor.

14. A signal compressor according to claim 13, wherein the filter means comprises a network located in the input signal path of the further path.

15. A signal compressor according to claim 13, wherein the said means whereby the compression is controlled comprise a control circuit in the further path responsive to the frequency and amplitude of applied signals for controlling compression, and wherein the filter means comprise a band rejecting network located in the control circuit and a further band rejecting network located in the output signal path of the further path.



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16. A signal compressor according to claim 14 or 15, wherein the or each network comprises a low pass filter in the high frequency extreme region and/or a high pass filter in the low frequency extreme regions.

17. A signal compressor according to claim 14 or 15, wherein the or each network comprises a notch filter in the high and/or low frequency extreme region.

18. A signal compressor according to claim 14 or 15, wherein the or each network comprises a shelf network in the high and/or low frequency extreme region.

19. A signal compressor according to any of claims 1 to 18, in combination with an expander for expanding the dynamic range of signals compressed by the compressor and received via the transmission channel, the expander comprising a circuit arrangement for boosting the attenuated high and/or low frequency extreme regions to provide a substantially flat overall frequency response.
