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Method and apparatus for compensating for chrominance saturation

The present invention relates to a method and apparatus for use in video processing systems to compensate for colour saturation, particularly after
5 luminance processing has been performed.

Background to the Invention

The human eye is able to interpret very many different colours. Colour may be considered to be the combined effect of three distinct components or
10 properties of light: hue, saturation and brightness. Hue is the name of the colour, and places the colour in its correct position in the electromagnetic spectrum. Saturation is the degree of intensity, or strength, of a colour. Brightness describes differences in the intensity of light reflected from, or, transmitted by, a colour image.

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In colour television systems, video signals are represented by three components: Y (luminance), and two chrominance components (Cb, Cr). The signal is thus referred to as YCbCr. The luminance component (Y) contains the brightness information, and the chrominance components (Cb, Cr) contain
20 the colour information.

The YCbCr system is defined in CCIR601, which relates to a worldwide digital video standard. In an 8-bit digital system, Y has a normal range of 16 to 235, and Cb and Cr have a range of 16 to 240, with 128 equalling 0.

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The YCbCr colour space is represented graphically in Figure 1. The values of Y, Cb and Cr are shown without the offsets described above i.e. the range of Y is 0 to 219, and the range of Cb and Cr is -112 to 112. In the colour space as illustrated, the hue is represented by the phase angle with respect to the
30 Cb axis. The magnitude of the chrominance components vector, in combination with the luminance Y, provides a measure for colour saturation

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Description of the Prior Art

In prior art video processing systems, many quality enhancements are applied to the luminance component. Linear and non-linear mapping functions are applied to the raw luminance signal to yield an improved luminance value and
5 so, an improved picture. However, this process leads to a perceptual change in the viewed colour saturation. This can result in images which are not optimal. Prior art compensation systems operate by adjusting the gain of the chrominance signals to offset the change in colour saturation. Specific solutions use the change in gain in the luminance signal to derive a
10 corresponding change in the gain to the chrominance signals.

Image quality improvement by linear or non-linear processing of the luminance signal leads to a noticeable change in the output colour saturation, which directly affects the quality of the viewed image. Increasing the
15 luminance signal alone results in a decreased colour saturation rendering viewed colours somewhat pastel in appearance. Decreasing the luminance signal alone results in increased colour saturation rendering viewed colours more unnaturally vivid, which in some cases can appear over-saturated and uncomfortable to watch.

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The problem with adjusting image quality by processing the luminance component alone means that a degree of post processing of the chrominance signals is generally required in order to compensate for colour saturation changes.

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Figure 2 shows a prior art solution to the problem of processing the luminance component. The input luminance signal Y_{in} is received by a luminance processor 101, which outputs a processed luminance signal Y_{out} . Y_{in} and Y_{out} are also fed into a gain generator 102 which determines the amount of gain
30 applied to Y_{in} and adjusts the input chrominance signals Cb_{in} and Cr_{in} accordingly, in multipliers 103 and 104, respectively, to yield Cb_{out} and Cr_{out} .

A problem with such a compensation system is that it does not account for human perceptions of different hues, and treats all hues equally.

The present invention aims to provide a method and apparatus which addresses and ameliorates the problems described above.

5 Summary of the Invention

According to the present invention, there is provided a method of colour saturation compensation in a video signal, including the steps of: processing a luminance signal component of the video signal; determining whether the processing of the luminance signal results in a change in chrominance saturation;
10 saturation; if the step of determining reveals that the chrominance saturation has changed, applying a chrominance compensation signal to the chrominance signals to counteract the effects of chrominance saturation, wherein said step of applying a compensation signal include the steps of: generating a compensation signal which is dependent on hue and luminance
15 ratio (output luminance signal / input luminance signal).

Preferably, said hue is determined according to the relationship:

$$\text{Hue} = \tan^{-1}(\text{Cr}_{\text{in}}/\text{Cb}_{\text{in}})$$

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where Cr_{in} and Cb_{in} are the input chrominance signals.

Preferably, the hue may be approximated by the following steps: dividing the absolute value of the smaller of Cr_{in} and Cb_{in} by the larger of Cr_{in} and Cb_{in} ;
25 determining in which of eight 45° regions of CbCr space a present sample resides by processing sign bits of Cb, Cr and the difference between the absolute values of Cb and Cr; limiting the resultant value such that it lies in the range 0 to 360 as a valid hue.

30 Preferably, the smaller of the absolute value of Cb or Cr is divided by the larger of the absolute value of Cb or Cr, wherein the result of the division is processed such that the result of the division process is augmented such that

it lies in the correct region according to the sign of Cb, the sign of Cr and the sign of $|Cb| - |Cr|$.

5 Preferably, the compensation signal is derived from hue information, said hue information forming an input to a weighting factor calculation process which calculates a weighting factor for a particular hue, said weighting factor being multiplied by the luminance ratio to yield the compensation signal.

10 Preferably, said compensation signal is constrained so as not to exceed a maximum allowable gain.

Preferably, said weighting factor calculation process includes calculating a weighting factor described as a linear approximation to a non-linear function.

15 Preferably, the linear approximation takes the form of a plurality of line segments defining a relationship between hue and weighting factor.

20 Preferably, the plurality of line segments includes six discrete line segments having relating hue to weight according to the table of Figure 14.

Preferably, the weighting factor may be modified by an amount determined by a user-defined quantity.

25 According to a second aspect of the present invention, there is provided apparatus to perform the method and associated features of the first aspect of the present invention.

30 Embodiments of the present invention apply a compensation gain to modify the chrominance components, Cb and Cr, based on a particular hue. Embodiments are able to compensate colour saturation on both over-saturated and de-saturated cases.

In a preferred embodiment, the hue-based compensation gain signal is obtained by multiplying the ratio of the output and input luminance with a hue-based weighting factor which varies depending on the hue. The hue-based weighting factor is indicative of the relationship between the ratio of changed saturation and the hue of the corresponding sample.

Brief Description of the Drawings

For a better understanding of the present invention and to understand how the same may be brought into effect, the invention will now be described by way of example only, with reference to the appended drawings in which:

Figure 1 shows a representation of YCbCr colour space;

Figure 2 shows a prior art approach to chrominance saturation compensation;

Figure 3 shows an overview of an embodiment of the invention;

Figure 4 shows a graph plotting chrominance saturations at two luminance values;

Figure 5 shows a graph plotting the relationship between ratios of changed saturations and hue;

Figure 6 shows a plot of a hue-based weighting function;

Figure 7 shows a functional block diagram of the present invention;

Figure 8 shows the relationship between chrominance components and hue;

Figure 9 shows eight defined regions in CbCr space;

Figure 10 shows a table detailing the eight regions of Figure 9 together with their sign values and hue calculations;

Figure 11 shows a block diagram of the internal structure of a hue estimator;

Figure 12 shows a block diagram of the internal structure of the multiplexer of Figure 11;

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Figure 13 shows the linear approximation of the weighting function as six individual line segments; and

Figure 14 shows a table listing the gradients and offsets for the six lines of Figure 13.

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Description of the preferred embodiment

Figure 3 shows a general overview of an embodiment of the present invention. This embodiment utilises the chrominance and modified luminance signals to enhance the chrominance saturation. The input luminance signal Y_{in} is received by the luminance contrast enhancement circuit or process 201 and modified according to known luminance enhancement techniques. Such techniques may include using a luminance mapping function to enhance the luminance signal. The skilled man will be aware of such techniques. The modified luminance signal, Y_{out} , is the output from circuit or process 201.

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Figure 3 also shows a colour saturation compensation circuit or process 202, which receives as inputs Y_{in} and Y_{out} as well as the chrominance input signals Cr_{in} and Cb_{in} .

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The colour saturation compensation circuit or process may be arranged as a hardware circuit in custom or general circuitry, or may be arranged to operate a software process on a suitably programmed or configured processor, such as a DSP.

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Circuit or process 202 operates on its 4 input signals to create two output signals Cb_{out} and Cr_{out} which are colour saturation compensated chrominance signals. The output chrominance signals are essentially generated by

multiplying the input chrominance signals with a hue-based compensation gain, the derivation of which is described here.

At an overview level, the present invention may be described by the following
5 equations:

$$Cb_{out} = CGain * Cb_{in} \quad (1)$$

$$Cr_{out} = CGain * Cr_{in} \quad (2)$$

10 CGain is the compensation gain which may, in turn, be represented by the equation:

$$CGain = Weight(hue) * Y_{out}/Y_{in} \quad (3)$$

15 Weight(hue) is the hue-based weighting factor, the derivation of which will shortly be described.

As a result of the luminance enhancements performed on the luminance signal, the resulting colour saturation can be acceptable, over-saturated or de-saturated. Embodiments of the present invention seek to address the
20 problems caused by over-saturation and de-saturation.

In the case of de-saturation, the compensation gain is limited in the range of :

25 $1.0 < CGain < MaxGain$

where MaxGain is the maximum allowable compensation gain.

In the case of over-saturation, the compensation gain is limited in the range
30 of:

$$0 < CGain < 1.0$$

In order to take advantage of perceptual differences in colour saturation as it applies to different hues, a hue-based weighting factor, $Weight(hue)$, is derived to improve compensation gain according to the hue of a given sample. Different colours have different ratios of changed saturation when their luminance changes. In this context, the ratio of changed saturation is defined as the ratio of colour saturation after luminance processing to colour saturation before luminance processing.

Figures 4 and 5 are intended to illustrate the relationship between the ratios of changed saturation and hue in a particular example. Figure 4 shows Hue as a value (0-360) on the x-axis, and saturation on the y-axis. The graphs show two lines representing different saturation values for a given hue, for different luminance values. The dashed line represents a larger luminance value than the solid line. It can be seen from Figure 4 that for a fixed luminance value, different hues have different saturations. When the luminance value of a colour increases, its saturation decreases, as can be inferred by the dashed line sitting below the solid line in Figure 4.

Figure 5 shows a curve plotting ratio of saturations on the y-axis against Hue on the x-axis. This curve illustrates that when the luminance is changed, its saturation will be changed, but that the ratio of changed saturation is dependent on the particular hue. For instance, in this example, the ratio of changed saturation of 'red' (hue = 100) is larger than the ratio of changed saturation of 'yellow' (hue = 177). For this reason, different compensation gains are required for different hues.

Embodiments of the present invention provide a hue-based weighting function, $fweight(hue)$, which relates a particular hue to a corresponding weighting factor. The function is derived from the curve of the relationship between the ratio of changed saturation and hue, as is shown in Figure 5.

Figure 6 shows an example of the function curve using certain experimental values. The final weighting factor can be adjusted by a user-defined

parameter WGain. The adjusted weighting factor is described by the following equation:

$$\text{Weight}(\text{hue}) = \text{WGain} * (\text{fweight}(\text{hue}) - 1) + 1 \quad (4)$$

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Figure 7 shows a detailed view of an embodiment of the invention. It's main feature is an enhanced detailed view of the colour saturation compensation block 202 of Figure 3, which is shown within the dotted box.

- 10 The embodiment of Figure 7 receives three input signals: Y_{in} , Cb_{in} and Cr_{in} . It generates three output signals: Y_{out} , Cb_{out} and Cr_{out} . The luminance processing is performed by circuit or process 201.

- A circuit entitled 'Luma Ratio' 301 is provided which receives as inputs Y_{in} and Y_{out} . It is operable to divide Y_{out} by Y_{in} to yield LGain, which is the luminance ratio. This ratio, LGain is compared in comparator 302 with '1'. If LGain is larger than '1' then the luminance has increased, and colour saturation has consequentially decreased. If LGain is less than '1' then the luminance has decreased, and over saturation detector 310 is used to determine whether the colour is over-saturated or not.
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- An OR gate 308 is provided which is operable to select an input of multiplexer 309. OR gate 308 is arranged to output a '1' in the event that LGain is >1 and the colour is de-saturated or if LGain is <1 and over-saturation is detected. In either of these events, the input chrominance signals will require compensation.
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- The compensation signal CGain is applied to a first input of the multiplexer 309, and '1' is applied to the other input. If the output of OR gate 308 is 1, then the CGain input of the multiplexer 309 is selected. This has the effect of applying the CGain signal to multipliers 311, 312 which each act on the input chrominance signals to produce the output chrominance signals.
- 30

If the output of OR gate 308 is '0', then the '1' input to multiplexer 309 is selected, applying '1' to the multipliers 311, 312, with the net effect that the output chrominance signals are unchanged from the input signals.

- 5 The over-saturation detector 310 is operable to detect whether a particular colour sample is over-saturated or not, If the value of the sample's saturation is >1 then the colour is over-saturated. Otherwise, the colour is not over-saturated. The degree of colour saturation can be calculated in RGB space according to the following equation:

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$$\text{Saturation} = (\text{Max}(R, G, B) - \text{Min}(R, G, B)) / \text{Max}(R, G, B) \quad (5)$$

where R, G and B are red green and blue signals respectively. To convert YCbCr signals to RGB signals, the following equations may be used:

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$$\left. \begin{aligned} R &= Y + 1.366 * Cr \\ G &= Y - 0.700 * Cr - 0.334 * Cb \\ B &= Y + 1.732 * Cb \end{aligned} \right\} \quad (6)$$

- Since the value of $\text{Max}(R, G, B)$ in (5) is always positive, the detection of over saturation can be carried out by detecting the sign bit of $\text{Min}(R, G, B)$. If it is negative, then the saturation value is >1 and the colour is over-saturated. If the sign bit is positive, then the colour is not over saturated.
- 20

- In order to calculate CGain for a particular hue, it is necessary to calculate a hue value from the input chrominance components. Hue calculator 303 receives as inputs Cb_{in} and Cr_{in} . Using Cartesian components, the hue is related to the chrominance components as shown in Figure 8. Cb and Cr are shown as mutually perpendicular axes. The hue is given by the phase angle of the chrominance vector, with respect to the Cb axis, as shown. The magnitude of the vector in combination with the luminance is a measure of the colour saturation. The hue can be calculated using the following equation:
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$$\text{Hue} = \tan^{-1}(Cr/Cb) \quad (7)$$

where $\tan^{-1}$ is the arctan function. Equation (7) returns the real inverse tangent of Cr/Cb in the range 0 to 360° using the signs of both arguments to determine the quadrant of the returned value. Normally, for an inverse tangent
5 function, $\tan^{-1}(x)$, when its independent variable, x , is ranged from 0 to 1, the function can be approximated by a linear function: $\tan^{-1}(x) \approx x \cdot 180/\pi$ and is ranged from 0 to 45°. Thus, the required angular information can be extracted from the quotient defined by $|Cr|/|Cb|$ (when $|Cr| < |Cb|$), or $|Cb|/|Cr|$ (when $|Cr| > |Cb|$) combined with the sign information from Cr and Cb .

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According to this, the the four quadrants of $CbCr$ colour space can be divided into 8 regions of 45°. Each region can be identified by the sign bits of Cb , Cr and $(|Cb| - |Cr|)$. The hue angle in each region can be defined by the quotient of $|Cr|/|Cb|$ (when $|Cr| < |Cb|$), or $|Cb|/|Cr|$ (when $|Cr| > |Cb|$). For example, in Figure 9, region (1) is defined by Cb and Cr both
15 being positive with $|Cb| > |Cr|$. The quotients of $|Cr|/|Cb|$ correspond to the tangents of angles from 0 to 45°. As the chrominance signals move into region (2), $|Cb| < |Cr|$ and Cb and Cr remain positive. The quotients of $|Cb|/|Cr|$ correspond to the angles from 0 to 45° with respect to the + Cr
20 axis.

Similarly, as the chrominance signals traverse each quadrant, the values represented by the quotients correspond to angles in the range 0 to 45° to 0, because only the magnitudes of Cb and Cr are applied to the divider and the
25 smaller value is always divided by the larger. The table of Figure 10 indicates the regions, the range of hue angles, the quotient values, the sign bits of Cb and Cr and $|Cb| - |Cr|$ samples in the respective regions. In the Sign column, '0' represents positive and '1' represents negative. The final column, 'Hue', illustrates a simple method of determining hue from the sign bits and the
30 quotient values.

Figure 11 shows a schematic of the internal structure of the hue calculator
303 shown in Figure 7. The chrominance input signals Cb_{in} and Cr_{in} are

respectively applied to absolute value circuits 801, 802 which output only the magnitude of the input signals. $|Cb|$, the output of circuit 801 is passed to subtraction circuit 803 as subtrahend. $|Cr|$, the output of circuit 802 is passed to subtraction circuit 803 as minuend. The output of circuit 803 equals the
5 difference between the two input signals, i.e. $|Cb| - |Cr|$. The sign bit of the calculation indicates which input signal to the subtractor 803 has the largest magnitude.

Switching circuit 804 receives $|Cb|$ and $|Cr|$ as major inputs and a signal
10 indicative of the sign of $|Cb| - |Cr|$ as a control input. The control input ensures that the switch is operative such that the larger input signal is always directed to the following divider circuit 805 as divisor, and the smaller input signal is always directed to the divider circuit 805 as dividend.

15 Divider circuit 805 acts on its input signals to generate a quotient value which is input to a multiplexer 807. The internal construction of multiplexer 807 is shown in Figure 12. The multiplexer 807 receives as an input the output of the divider 805. This input signal is augmented in multiple adder units to generate a series of possible angle values which are all fed into translator 901, which is
20 in effect a further multiplexer. The control inputs to translator 901 are derived from three digital signals representing the signs of Cb , Cr and $|Cb| - |Cr|$. These sign bits are decoded in logic decoder 806 to create the three control bits required to select one of the eight inputs to translator 901. In effect, the circuit of Figure 12 puts the results of the table of Figure 10 into effect.

25 The output of multiplexer 807 is fed into a limiter 808 to ensure that the eventual Hue output is limited in the range 0 to 360.

Referring to Figure 7, the output of the Hue calculator 303 is next passed to a
30 Weight Calculator 304 which has as a further input $WGain$. Weight calculator 304 implements weighting function, $fweight(hue)$. As can be seen from Figure 6, $fweight(hue)$ is a non-linear function which has 360 independent variables. To avoid the hardware complexity required by using a look up table to store all

results for all 360 variables, the non-linear function is approximated using six line segments. The approximation is shown in Figure 13. Each line in the approximation is defined by the equation:

5
$$fweight(hue) = K * hue + B \quad (8)$$

where K is the gradient of the line and B is the offset.

The parameters of the six lines (L1 – L6) are shown in the table in Figure 14.
10 Using the function's value $fweight(hue)$ and user-defined WGain, the hue based $weight(hue)$ can be calculated using equation (4).

The ideal compensation gain CGain is obtained by multiplying the adjusted weight, $weight(hue)$, by the luminance gain, LGain, at multiplier 306. The
15 maximum gain estimator 305 is arranged to output a maximum allowable gain, MaxGain, to limit the range of the compensation gain which may be applied. This avoids any danger of colour change. In an 8-bit digital system, chrominance signals are defined to have a range of 16-240, with 128 being equal to 0. The maximum value of the chrominance components is 112. Thus,
20 MaxGain can be defined by the equation:

$$MaxGain = 112 / \max(abs(Cb_{in}), abs(Cr_{in})) \quad (9)$$

where $\max(abs(Cb_{in}), abs(Cr_{in}))$ is the maximum value of $(abs(Cb_{in}))$ and
25 $abs(Cr_{in})$, and $(abs(Cb_{in}))$ and $abs(Cr_{in})$ are the absolute values of Cb_{in} and Cr_{in} respectively.

Embodiments of the present invention may be realised in software using a suitable programmed processor, especially a DSP. Alternatively,
30 embodiments may be realised in hardware using either discrete components or, preferably, a custom integrated circuit, such as an ASIC.

The present invention includes and novel feature or combination of features disclosed herein either explicitly or any generalisation thereof irrespective of

whether or not it relates to the claimed invention or mitigates any or all of the problems addressed.

CLAIMS

1. A method of colour saturation compensation in a video signal, including the steps of:

5 processing a luminance signal component of the video signal;

determining whether the processing of the luminance signal results in a change in chrominance saturation;

10 if the step of determining reveals that the chrominance saturation has changed, applying a chrominance compensation signal to the chrominance signals to counteract the effects of chrominance saturation, wherein said step of applying a compensation signal include the steps of:

15 generating a compensation signal which is dependent on hue and luminance ratio (output luminance signal / input luminance signal).

2. A method as claimed in claim 1 wherein said hue is determined according to the relationship:

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$$\text{Hue} = \tan^{-1}(\text{Cr}_{\text{in}}/\text{Cb}_{\text{in}})$$

where Cr_{in} and Cb_{in} are the input chrominance signals.

25 3. A method as claimed in claim 2 wherein the hue may be approximated by the following steps:

dividing the absolute value of the smaller of Cr_{in} and Cb_{in} by the larger of Cr_{in} and Cb_{in} ;

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determining in which of eight 45° regions of CbCr space a present sample resides by processing sign bits of Cb, Cr and the difference between the absolute values of Cb and Cr;

limiting the resultant value such that it lies in the range 0 to 360 as a valid hue.

4. A method as claimed in claim 3 wherein the smaller of the absolute value of Cb or Cr is divided by the larger of the absolute value of Cb or Cr, wherein the result of the division is processed such that the result of the division process is augmented such that it lies in the correct region according to the sign of Cb, the sign of Cr and the sign of $|Cb| - |Cr|$.

5. A method as claimed in any one of the preceding claims wherein the compensation signal is derived from hue information, said hue information forming an input to a weighting factor calculation process which calculates a weighting factor for a particular hue, said weighting factor being multiplied by the luminance ratio to yield the compensation signal.

6. A method as claimed in claim 5 wherein said compensation signal is constrained so as not to exceed a maximum allowable gain.

7. A method as claimed in claim 5 or 6 wherein said weighting factor calculation process includes calculating a weighting factor described a linear approximation to a non-linear function.

8. A method as claimed in claim 7 wherein the linear approximation takes the form of a plurality of line segments defining a relationship between hue and weighting factor.

9. A method as claimed in claim 8 wherein the plurality of line segments includes six discrete line segments having relating hue to weight according to the following table:

Line Segment	Hue range	Gradient	Offset
L1	0-52	-0.0014	1.2314
L2	53-100	+0.0002	1.1525
L3	101-177	-0.0028	1.4797

L4	178-235	+0.0015	0.7513
L5	236-280	-0.0003	1.1637
L6	281-360	+0.0023	0.4163

10. A method as claimed in any one of claims 5 to 9 wherein the weighting factor may be modified by an amount determined by a user-defined quantity.
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11. Apparatus arranged to perform any one of the preceding method claims.
12. Apparatus as claimed in claim 11 including a processor.
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13. Apparatus as claimed in claim 12 wherein the processor is a Digital Signal Processor (DSP).
14. Apparatus as claimed in claim 11 including a custom integrated circuit
- 15 such as an ASIC.