

Automatic gain control circuit, eg. for use in a hard disk drive.

The invention relates to an automatic gain control circuit for amplifying an input signal so that it has a specific correspondence with a reference value, the circuit comprising

- input means for receiving the input signal,
- 5 - variable gain amplifier means for amplifying said input signal in response to a gain control signal,
- peak detector means for detecting peaks in said amplified input signal, the peak detector means having an attack time constant and a decay time constant, so as to supply a peak detector output signal which is representative of the amplitude of the peaks in said amplified
- 10 input signal,
- comparator means for comparing the peak detector output signal with said reference value so as to derive an error signal therefrom,
- integrator means for integrating the error signal so as to obtain said gain control signal, and to a hard disk drive apparatus provided with the automatic gain control circuit.

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An automatic gain control circuit as defined in the opening paragraph is well known in the art and can, as an example, be used in a servo demodulator circuit in a hard disk drive.

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- The invention aims at providing an improved automatic gain control circuit. In accordance with the invention, the automatic gain control circuit is characterized in that the peak detector means comprising means for controlling said decay time constant in response
- 25 to said error signal, and that at least in a situation when the peak detector output signal is larger than said reference signal, said means for controlling said decay time constant is adapted to decrease said decay time constant for increasing error signals, and that at least in said situation when the peak detector output signal is larger than said reference value, the following relationship is maintained between the attack time constant T_a and the decay time

constant T_d of the peak detector means:

$$T_d = c.T_a^p,$$

- 5 where c is a positive constant and p is a constant larger than 1.

The invention is based on the following recognition. A hard disk comprises a plurality of servo patterns prerecorded on the hard disk. A servo pattern comprises a burst of eg. 40 dibits for AGC control, followed by a timing reference portion which is eg. 8 dibits long and which comprises a timing mark, a Gray code which is eg. 13 dibits long and
10 subsequently followed by a plurality of servo bursts, each burst being comprised of a number of dibits. In the AGC circuit in accordance with the invention, one or more peak detectors are used to detect the amplitudes of the peaks present in the input signal. When starting reproduction, the HDD is first switched into a search mode in which the timing marks should be detected. When in lock, the detection system has a timing window for gating the servo
15 patterns positioned on the hard disk. In the search mode, however, the timing window is not yet enabled, so that the AGC circuit 'sees' all kinds of signals, such as not only the servo patterns but also the actual data recorded on the hard disk. Known AGC circuits are unable in this situation to detect as an example the timing mark in the first servo pattern read from the hard disk. One of the measures to improve the behaviour of the AGC circuit is the use of
20 the claimed relationship between the attack and the decay time of the peak detector. This results in an optimal behaviour of the peak detector, as the peak detector climbs directly to the peaks in the input signal.

Suppose that the attack time constant is larger than the optimal attack time constant that satisfies the above relationship, the peak detector cannot climb to the peaks of
25 the input signal. When the attack time constant is smaller than the optimal time constant, convergence is correct, but the operation is noisier than needed.

The parameter p in the above equation is a constant which is substantially equal to 2. For the constant c , it can be said that the value of the constant c depends on the shape of the pulses that occur in the input signal to the peak detector. For purely sinusoidal pulses
30 at the input of the peak detector, the value of c is substantially equal to 20 or a little higher. For more Lorentzian type pulses at the input of the peak detector, c is much higher. Generally it can be said that the following relationship holds for the said constant c :

$$20 \leq c \leq 200.$$

It should be noted in this respect that, for the value range of the parameter c , as given above, the attack and decay time constants should be expressed in numbers of dibits, or said in a different way: in numbers of periods of the servo frequency of the signal in the servo bursts. In this situation, the attack and decay time constants are dimensionless parameters, and so is the parameter c . It speaks for itself that the attack and decay time constants could have been expressed in 'seconds'. In that situation, c has a different value range than given above, and is expressed in the dimension of 1/second.

This automatic gain control circuit may be further characterized in that in said other situation, the means for controlling said attack time constant is adapted to decrease said attack time constant for increasing error signals.

In the search mode, as the time window for windowing the servo patterns is disabled, detection of the timing mark may be not well possible. This for the reason that the AGC control function will be fully active. By maintaining its gain value, obtained from the dibits in the AGC control area, at substantially the same value thereafter, the detection of the sector timing mark has been possible.

It should be noted here that the locking of the AGC to the dibits in the AGC control area is considered to be the first mentioned situation and the situation where the gain value should be maintained at substantially the same value, eg. during a drop out, is considered to be the other situation.

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These and other aspects of the invention will be apparent from and elucidated with respect to the embodiments described hereafter in the figure description, in which

figure 1 shows an embodiment of the automatic gain control circuit,
figure 2 shows a half wave rectified sinusoid and the output signal of the peak detector unit in the circuit of figure 1,
figure 3 a servo pattern, as present in a track on a hard disk, and
figure 4 shows the input and output signal of a peak detector in the peak detector unit in the automatic gain control circuit.

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Figure 1 shows an embodiment of the automatic gain control circuit, which is provided with an input terminal 2, for receiving an input signal. This input signal can be the

signal read from a hard disk. The input terminal 2 is coupled to an input 6 of a variable gain amplifier 4. An output 8 of the amplifier 4 is coupled, via a lowpass filter 10, which could be considered to be included in the amplifier 4, to an input 12 of a peak detector unit 14. An output of the peak detector unit 14 is coupled to a first input 18 of a comparator unit 20, which has a second input 22 coupled to a terminal 24 at which a reference value V_{ref} is available for supply to the input 22. An output 26 of the comparator unit 20 is coupled to an input 28 of an integrator unit 30. An output 36 of the integrator unit 30 is coupled to a control signal input 38 of the variable gain amplifier 4.

The variable gain amplifier 4 amplifies the signal applied to its input 6, in response to the gain control signal applied to its control signal input 38, and supplies an amplified signal to its output 8. The peak detector unit 14 detects peaks in said amplified signal, and supplies an output signal V_p at its output which has a relationship with the amplitude of the peaks in said amplified signal. In a preferred embodiment of the peak detector unit 14, the unit 14 comprises two peak detectors, one peak detector for detecting the peaks of positive polarity and the other peak detector for detecting the peaks of negative polarity. The two peak amplitude values obtained are added together so as to obtain an output signal which is representative of the peak-to-peak value of the signal applied to the input of the peak detector unit 14. This detection is less insensitive to the influences of baseline wander in the signal.

The comparator unit 20 compares the peak detector output signal V_p with said reference value V_{ref} so as to derive an error signal e therefrom. More specifically, the comparator unit 20, subtracts V_{ref} from V_p so as to obtain said error signal e . The error signal e is integrated in the integrator unit 30. Thus results in a control signal applied to the control signal input 38, so as to control the gain the variable gain amplifier 4. The gain in the amplifier 4 is controlled in such a way that the error signal e is controlled towards a small value (zero).

The peak detector unit 14 has an attack time constant T_a and a decay time constant T_d . The attack time constant T_a governs the behaviour of the peak detector unit 14, when a sudden rise in the amplitude of the input signal occurs and the decay time constant T_d governs the behaviour of the peak detector unit 14, when a sudden decrease in the amplitude of the input signal occurs.

In order to optimally detect the peaks in the peak detector unit 14, a relationship exists between the attack time constant T_a and the decay time constant T_d , which relationship will be explained hereafter.

Figure 2 shows a half wave rectified sinusoid, as a function of time, that is supplied as input signal to the peak detector unit 14. This half wave rectified sinusoid could be obtained from a sequence of subsequent dibits to be described later that are present in the AGC portion P_1 or in the servo burst portion P_4 , see figure 3. Figure 2 further shows the output signal V_p of the peak detector unit 14, as a function of time. The peak detector unit 14 attacks during the time interval between the time instants t_0 and t_1 , and between the time instants t_2 and t_3 , and decays during the time interval before the time instant t_0 , between the time instants t_1 and t_2 and after the time instant t_3 . For an optimal peak detection, the behaviour of the peak detector unit 14 is such that, each time, the peak detector unit 14 attacks towards precisely the maxima in the half wave rectified sinusoid.

A calculation reveals that this requirement leads to the following relationship between T_a and T_d :

$$T_d = c.T_a^p,$$

where c is a positive constant and p is a constant larger than 1.

More specifically, p is a constant substantially equal to 2. For the constant c , the following relationship holds:

$$20 \leq c \leq 200.$$

For the example of the half wave rectified sinusoid, it appears that c has a value smaller than 50. In more realistic situations, and eg. dependent of the filter characteristic of the lowpass filter 10, the input signal to the peak detector unit 14 is not ideally sinusoidal. In such situations, c will have a much larger value, between 50 and 200.

It should be noted here, that the attack time constant of the peak detector unit 14 is defined as the time interval, starting at the time instant when a positive going step shaped input signal from a zero amplitude towards a specific step amplitude is applied to the input of the peak detector unit 14, until the time instant when the output signal of the peak detector reaches the said specific step amplitude. Further, the decay time constant of the peak detector unit 14 is defined as the time interval, starting at the time instant when a down going step shaped input signal from a specific step amplitude towards a zero amplitude is applied to the input of the peak detector unit 14, until the time instant when the output signal of the peak detector reaches the said zero amplitude.

In an embodiment of the automatic gain control circuit, where the attack and the decay time constants are fixed, those constants should thus satisfy the above relationship in order to function optimally.

In this respect, it should be noted that the relationship between the attack time
5 constant and the decay time constant of the peak detector unit is non-linear for the attack time, more specifically quadratic for $p=2$. In the latter case, this means that, if the attack time constant and the decay time constant are expressed in 'seconds', that c has the dimension of 1/second. The value range for c given above is not valid in this situation.

One could express the attack time constant and the decay time constant in a
10 dimensionless way, namely by expressing the attack time and the decay time in number of periods of the servo frequency, or in number of dibits, to be explained hereafter. The period of the servo frequency is in fact equal to $1/(t_3-t_1)$, which equals the length of a dibit, see figure 2. In the dimensionless expression for the attack time constant and the decay time constant, the constant c is dimensionless as well, and satisfies the value range given above.

15 In a further elaboration of the embodiment described thus far, the attack and decay time constants are controllable in their value. To that purpose, the circuit further comprises a control signal generator unit 34 which has an input 32 coupled to the output 26 of the comparator unit 20 and which has two outputs 40 and 42 coupled to control signal inputs 44 and 46 respectively of the peak detector unit 14.

20 More specifically, one of the two time constants is controlled in response to the error signal e , and the other one of the two time constants is derived from the first one, using the relationship described above. The control signal generator unit 34 thus generates a first control signal from the error signal e , which is supplied via its output 42 to the control signal input 46 of the peak detector unit 14, and which is meant to control one of the time
25 constants, let us assume the decay time constant, and generates a second control signal, either from the error signal, or from the first control signal, which second control signal is supplied via its output 40 to the control signal input 44 of the peak detector unit 14, so as to control the other one of the time constants: that is, the attack time constant, such that the above relationship between both time constants is maintained.

30 The use of the automatic gain control circuit in accordance with the invention will now further be described in an application where the circuit is used in a demodulator circuit for demodulating the servo patterns prerecorded on a hard disk.

Figure 3 shows schematically the contents of a servo pattern. The servo pattern in a track on the hard disk comprises an AGC portion, denoted P_1 , used for setting the time

constants in the automatic gain control circuit, a timing reference portion P_2 , for bringing a data detection circuit (not shown) in correct timing relationship with the information read from the track, a Gray code portion P_3 , which identifies the tracks by an increasing number, when going from the centre towards the edge of the disk, and a servo burst portion P_4 , which is used for enabling a track servo control, so as to correctly position a read head on the track in a direction transverse to the track. The AGC portion P_1 comprises a burst of a plurality of eg. 40 dibits. The timing reference portion P_2 comprises is eg. 8 dibits long, but comprise a timing mark comprised of one or more dibits. The Gray code portion P_3 is eg. 13 dibits long and the servo burst portion P_4 comprises a plurality of servo bursts of a number of eg. 11 dibits each.

First, the functioning of the control signal generator unit 34 will be described in a situation when the error signal e ($e = V_p - V_{ref}$) is positive. In this situation, the control signal generator unit 34 generates control signals to control the attack time T_a constant and the decay time constant T_d , such that with increasing error signal amplitude, both time constants are decreased, whilst the above defined relationship between both time constants is maintained. Decreasing the attack and decay time constant in the peak detector 14 can be realized by increasing the attack current and the decay current in the peak detector for charging and decharging respectively of an internal capacitor (not shown) in the peak detector 14.

Second, the functioning of the control signal generator unit 34 will be described in a situation when the error signal e ($e = V_p - V_{ref}$) is negative. Such situation takes place when a drop out occurs, or in the portion P_2 of the servo pattern, when no dibits are present. In this situation, the control signal generator unit 34 generates control signals to control the attack time T_a constant and the decay time constant T_d , such that with increasing (ly negative) error signal amplitude, the attack time constant is decreased, whilst the decay time constant remains constant. As a result, when (as an example) the timing reference dibit(s) arrive(s), it(they) can be properly amplified and can thus be detected. This behaviour further can improve the detection of the Gray code.

For obtaining the correct timing, the timing marks in the time mark region P_2 can be detected in a pulse detection unit 48, shown schematically in figure 1. The pulse detection unit 48 will further be used to detect the Gray code pulses.

The detection of the amplitudes of the servo bursts can be realized by a servo burst detector unit 50, also shown schematically in figure 1. The amplitudes of the various bursts in the portion P_4 are an indication of how far the read head (not shown) is positioned

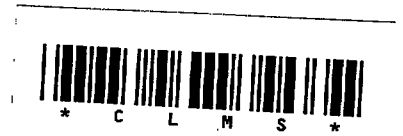
off track. When the head is mispositioned, this head position can be corrected accordingly.

In order for the automatic gain control circuit to function properly, it should be noted that a further requirement exists between the time constant of the automatic gain control circuit, which time constant is defined as the time constant of the circuit, assuming that the peak detector unit 14 has no delay (that means: a time constant equal to zero), and the time constant of the peak detector 14. This further requirement is that the time constant of the automatic gain control circuit is substantially equal to the decay time constant of the peak detector 14.

Figure 4 shows an example of the input signal V_i and the output signal V_o , as a function of time, of the peak detector in the peak detector unit 14 that detects the positive peaks in the input signal, when the AGC circuit is in the search mode. More precisely, figure 4 shows the portions P_1 and P_2 of the servo pattern read from the hard disk. What can be seen in figure 4, is that a disturbance is present in the AGC portion, and that the attack time constant of the peak detector is controlled such that the output signal climbs relatively fast to the peaks in the AGC portion. Further, the decay time constant of the peak detector is controlled such that upon decreasing peak amplitudes, the peak detector can easily follow the peaks. Further, in the portion P_2 , the decay time constant is increased so that the output signal of the peak detector remains at a substantially constant level, so that the timing pulses, as well as the following Gray code pulses can be detected correctly.

Whilst the invention has been described with reference to preferred embodiments thereof, it is to be understood that these are not limitative examples. Thus, various modifications may become apparent to those skilled in the art, without departing from the scope of the invention, as defined by the claims. It should thus be noted that, although the invention has been described with reference to an automatic gain control circuit for a hard disk drive, the automatic gain control circuit could be used in other reproduction systems, such as other magnetic recording systems.

Further, the invention lies in each and every novel feature or combination of features.

CLAIMS

1. An automatic gain control circuit for amplifying an input signal so that it has a specific correspondence with a reference value, the circuit comprising

- input means for receiving the input signal,
- variable gain amplifier means for amplifying said input signal in response to a gain control
5 signal,

- peak detector means for detecting peaks in said amplified input signal, the peak detector means having an attack time constant and a decay time constant, so as to supply a peak detector output signal which is representative of the amplitude of the peaks in said amplified input signal,

10 - comparator means for comparing the peak detector output signal with said reference value so as to derive an error signal therefrom,

- integrator means for integrating the error signal so as to obtain said gain control signal, characterized in that the peak detector means comprising means for controlling said decay time constant in response to said error signal, and that at least in a situation when the peak
15 detector output signal is larger than said reference signal, said means for controlling said decay time constant is adapted to decrease said decay time constant for increasing error signals, and that at least in said situation when the peak detector output signal is larger than said reference value, the following relationship is maintained between the attack time
20 constant T_a and the decay time constant T_d of the peak detector means:

$$T_d = c.T_a^p,$$

where c is a positive constant and p is a constant larger than 1.

2. Automatic gain control circuit as claimed in claim 1, characterized in that p is a
25 constant substantially equal to 2.

3. Automatic gain control circuit as claimed in claim 1, characterized in that the following relationship holds for the said constant c :

$$20 \leq c \leq 200.$$

4. Automatic gain control circuit as claimed in claim 1, characterized in the peak detector means comprises means for controlling said attack time constant, said means for controlling said attack time constant being adapted to derive said attack time constant from said decay time constant using said relationship.

5 5. Automatic gain control circuit as claimed in claim 1 or 4, characterized in that, in another situation when the peak detector output signal is smaller than said reference signal, the means for controlling said decay time constant is adapted to maintain said decay time constant at a substantially constant value.

6. Automatic gain control circuit as claimed in claim 5, characterized in that, in
10 said other situation, the means for controlling said attack time constant is adapted to decrease said attack time constant for increasing error signals.

7. Automatic gain control circuit as claimed in claim 1, characterized in that said peak detector means comprises first and second peak detectors for detecting peaks of positive and negative polarity, the peak detector means being adapted to generate a peak detector
15 output signal which has a relationship with the peak-to-peak distance in said amplified input signal.

8. Hard disk drive apparatus for reading information from a hard disk, the apparatus being provided with

- said hard disk,

20 - drive means for driving said hard disk,

- read means for reading information from said hard disk,

said hard disk drive apparatus further being provided with the automatic gain control circuit as claimed in anyone of the preceding claims.

9. Hard disk drive apparatus as claimed in claim 8, characterized in that said
25 apparatus comprises servo demodulator means for detecting timing pulses and servo bursts included in servo patterns accommodated on the hard disk, said servo demodulator means comprising said automatic gain control circuit.

