THE GC5016 AGC CIRCUIT FUNCTIONAL DESCRIPTION AND APPLICATION NOTE

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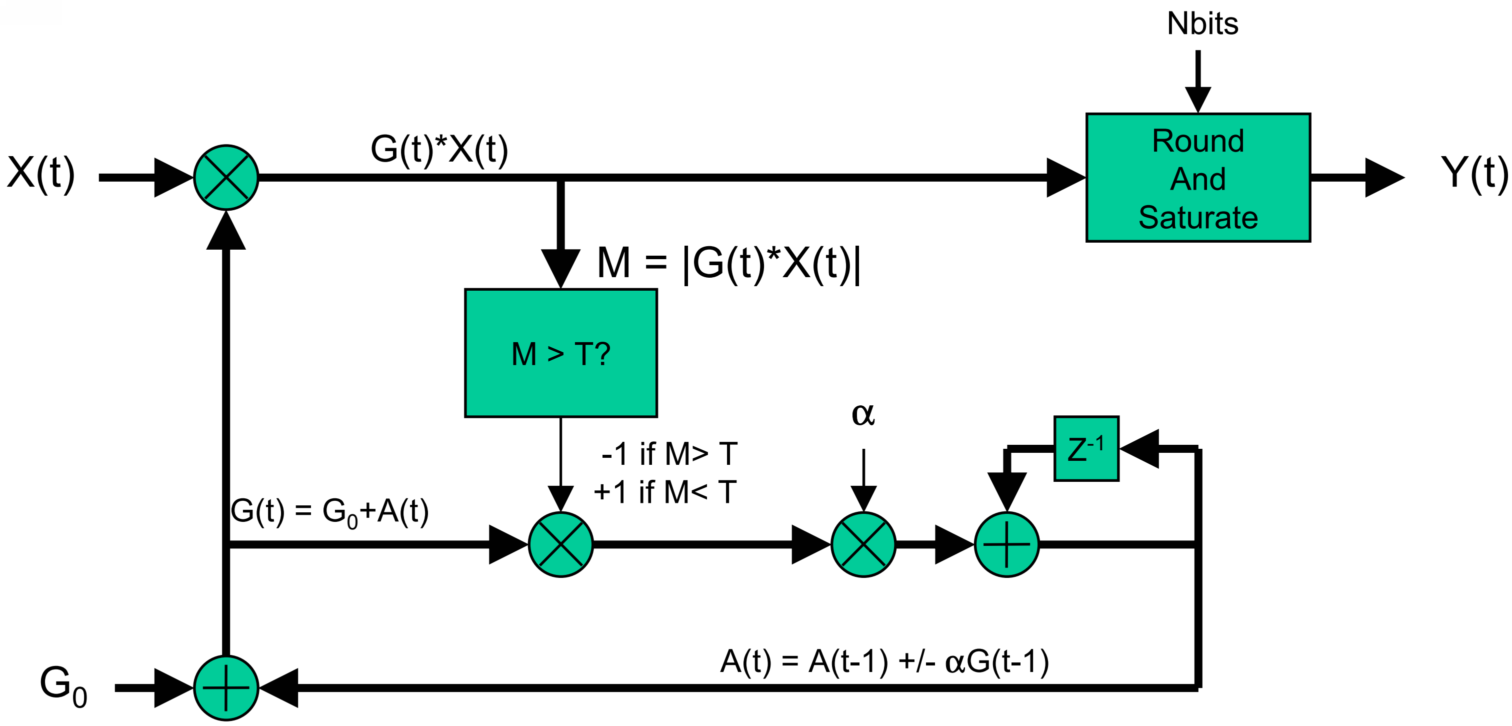
FUNCTIONAL BLOCK DIAGRAM



FUNCTIONAL DESCRIPTION

- Mathematical Equivalent:

  $$G(t) = (1 +/- \alpha)\ G(t-1)$$

- Gain is separated into nominal and adaptive parts:

  $$G(t) = G_0 + A(t)$$

- The circuit adapts **A(t)**, not **G_0**, allowing a default gain of **G_0** to be specified.
- The adaption loop:

  Increases the gain when the magnitude (**M**) is less than threshold

  Decreases the gain when the magnitude (**M**) is greater than threshold

- The adaption loop will stop when **A(t)** reaches a maximum negative value or maximum positive value. This is used to limit the gain adjustment to fall within a desired range.
- The loop operates in four modes: fast attack, fast decay, slow attack and slow decay
- The loop adapts twice for each complex sample, once for the magnitude of the I-half and once for the magnitude of the Q-half.

ADAPTION TIME CONSTANTS

- The adaption loop gain "α" can take on four values:
  - $\alpha_z = 2^{-(Dz+3)}$ for fast attack when the signal is too weak
  - $\alpha_s = 2^{-(Ds+3)}$ for fast decay when the signal is too strong
  - $\alpha_B = 2^{-(D_B+3)}$ for slow attack when a sample is below threshold
  - $\alpha_A = 2^{-(D_A+3)}$ for slow decay when a sample is above threshold
- The four user specified values D_{Zero}, D_{Sat}, D_{Above} and D_{Below} are used to set the attack and decay time constants
- The loop converges exponentially with a time constant equal to $2^{(D+2.75)}$ updates:
  - At two complex samples per "chip", and two updates per complex sample, the effective time constant is $2^{(D+0.75)}$ chips for CDMA systems.
  - The time constants for UMTS (3.84MChips/sec) and CDMA2000 (1.2288MChips/sec) are shown on the next slide.
  - Note: The time constant is how long it takes the AGC to converge to within 63% of a required gain change. It takes four time constants to converge to within 98% of the change.

ADAPTION TIME CONSTANTS (Continued)

Value of D	Time constant (Complex Samples)	Time constant for UMTS (us)	Time constant for CDMA2000 (us)
0	4	0.5	2
1	7	1	3
2	13	2	5
3	27	4	11
4	54	7	22
5	108	14	44
6	215	28	87
7	431	56	175
8	861	112	350
9	1,722	224	701
10	3,444	448	1.4ms
11	6,889	897	2.8ms
12	13,777	1.8ms	5.6ms
13	27,554	3.6ms	11.2ms
14	55,109	7.2ms	22.4ms
15	110,218	14.3ms	44.8ms

FAST ATTACK MODE FOR WEAK SIGNALS

- If the signal is very weak, then the AGC goes into a fast attack mode to increase the gain rapidly.
- A "zero detect counter" is used to select the fast attack mode:
  - The zero detect counter increments when the magnitude is less than a weak signal threshold (T_W), and decrements otherwise.
  - T_W can be selected as 1/16th, 1/32nd, 1/64th, 1/128th, or 1/256th of full scale.
  - The zero detect counter stops at zero or 15.
- The "weak signal" fast attack time constant D_{Zero} is used when the counter exceeds the zero detect threshold (T_Z) which is typically set to 5 or 6.
- The fast attack mode is entered for T_Z= 5 when there are at least 6 weak values in a row, or at least 11 of the last 16 values were "weak".
- The fast attack mode is entered for T_Z= 6 when there are at least 7 weak values in a row, or at least 12 of the last 16 values were "weak".

FAST DECAY MODE FOR STRONG SIGNALS

- If the signal is too strong, then the AGC goes into a fast decay mode to decrease the gain rapidly.
- A "saturation detect counter" is used to select the fast decay mode:
  - The saturation detect counter increments when the magnitude is greater than or equal to full scale and decrements otherwise.
  - The saturation detect counter stops at zero or 15.
- The "strong signal" fast decay time constant D_{Sat} is used when the counter exceeds the saturation detect threshold (T_S) which is typically set to 5 or 6.
- The fast decay mode is entered for T_S= 5 when there are at least 6 saturated values in a row, or at least 11 of the last 16 values were saturated.
- The fast decay mode is entered for T_S= 6 when there are at least 7 saturated values in a row, or at least 12 of the last 16 values were saturated.

AGC INDUCED NOISE LEVEL

- The gain is adjusted every sample using the update equation:

$$G(t) = (1 \pm 2^{-(D+3)})\, G(t-1)$$

- The AGC output data is then:

$$\begin{aligned} Y(t) &= X(t)G(t) \\ &= X(t)(1 \pm 2^{-(D+3)})\, G(t-1) \\ &= X(t)G(t-1) \pm 2^{-(D+3)}X(t)G(t-1) \end{aligned}$$

  The term **$X(t)G(t-1)$** is the desired output, and **$\pm 2^{-(D+3)}X(t)G(t-1)$** is the noise term.

- The signal to noise ratio is then

$$\begin{aligned} SNR_{AGC} &= 10\log[\, \langle (XG)^2 \rangle / \langle (2^{-(D+3)}XG)^2 \rangle]\ dB \\ &= 10\log[2^{2(D+3)}]\ dB \\ &= 6(D+3)\ dB \end{aligned}$$

- Hence the noise induced by the AGC is always 6(D+3) dB below the desired signal.
- For most CDMA signals an in-band SNR of 30dB is more than adequate, so $D \geq 2$ for D_{Below} and D_{Above} is adequate.

SETTING THE AGC TARGET THRESHOLD

- The AGC circuit is typically used to set the output RMS signal level relative to the full scale output word. This is commonly called the crest factor (CF).
- For example, if the targeted crest factor is 6 dB, then the AGC's target threshold should be set so that the RMS signal level will be 6dB below full scale.
- If $D_{Below} = D_{Above}$, then the target threshold will be the median magnitude of the signal's amplitude distribution, I.E., the AGC will drive the output signal level to the point where half of the samples are above the threshold and half are below.
- The target threshold in this case is set to be equal to the desired RMS magnitude times the ratio of the median magnitude to the RMS magnitude of the signal's statistics.
- For Gaussian signals, which includes UMTS (WCDMA), CDMA2000 or any CDMA modulated signal, the median magnitude is 0.6745 times the RMS magnitude.
- For narrowband signals, such as tones, the median value is equal to the RMS level.
- The magnitude is calculated as a value between 0 and 255 where 0 means the magnitude is less than $1/256^{th}$ full scale, and 255 means the magnitude is greater than or equal to full scale.
- The AGC threshold setting for various crest factors is shown in the next table.

AGC THRESHOLD SETTINGS

Crest Factor in dB	Desired RMS Magnitude	Threshold for UMTS/CDMA Signals	Threshold for Narrowband signals
0	255	172	255
1	227	153	227
2	203	137	203
3	181	122	181
4	161	109	161
5	143	97	143
6	128	86	128
7	114	77	114
8	102	68	102
9	90	61	90
10	81	54	81
11	72	48	72
12	64	43	64
13	57	39	57
14	51	34	51

A COMMON THRESHOLD FOR MIXED SIGNAL OPERATION

- If the AGC input contains a mix of Gaussian signals and narrowband signals, such as a CDMA signal with a narrowband interfering signal, and the objective is to drive the output level to a constant RMS value or crest factor, then the median threshold will not work
- If D_{Above} is less than D_{Below}, which means the loop gain α_A is larger than the loop gain α_B, then the AGC will drive the output signal so that more samples are below threshold than above. The ratio of samples below threshold to those above when the loop converges is equal to $\alpha_A/(\alpha_B+\alpha_A)$. For example, if $\alpha_A = 4\alpha_B$, then 4/5ths, or 80% of the output samples will be below threshold.
- This ratio of α_A to α_B can be used in the AGC loop to drive the RMS levels of two different signals to be equal using a common threshold. For any two signal types, there will always be value β such that both signal types will have the same ratio of magnitudes above and below β times their RMS levels. One can then set $\alpha_A/(\alpha_B+\alpha_A)$ equal to the ratio and the threshold equal to β times the desired RMS level.
- For Gaussian signals and tones, both will have 80% of their values below 1.28 times their RMS levels. This means that one can set $\alpha_A=4\alpha_B$, and set the threshold to be 1.28 times the desired RMS level, and then both signals will converge to the same RMS level.

A COMMON THRESHOLD FOR MIXED SIGNAL OPERATION (Continued)

- Hence, the AGC will drive a mixed CDMA plus tone signal to the desired RMS level by setting $D_{Below} = D_{Above} + 2$, and setting the threshold to 1.28 times the desired RMS magnitude using the following table.

Crest Factor in dB	Desired RMS Magnitude	Threshold for UMTS/CDMA Signals
3	181	232
4	161	206
5	143	183
6	128	164
7	114	146
8	102	131
9	90	115
10	81	104
11	72	92

- The SNR due to the AGC noise in this case is $6(D_{Below}+2.5)$ dB
- The AGC loop's attack time constant is set by D_{Below}.
- The AGC loop's decay time constant is set by D_{Above}.

AGC DYNAMIC RANGE

- The objective of the AGC is to add gain to weak signals so they can be output using 8 our fewer bits and still be demodulated.
- The dynamic range is the ratio of the strongest signal that can be demodulated to the smallest.
- The total dynamic range is the amount of gain that can be added to the signal plus the dynamic range available in the output words.
- The AGC can add 42 dB of gain to weak signals.
- The dynamic range of the output words is $(6 \cdot N_{BITS})-CF-SNR_{MIN}$, where N_{BITS} is the output word size, CF is the crest factor, and SNR_{MIN} is the minimum SNR required to demodulate the signal. Typically N_{BITS} is 8, CF is 8, and SNR_{MIN} is 10 dB, giving 30dB of available dynamic range.
- This gives a typical dynamic range of 42dB + 30dB = 72dB

EXTENDING THE AGC DYNAMIC RANGE

- The AGC dynamic range can be extended if an external saturate circuit is used
- 6dB of dynamic range can be added for each MSB that is checked for overflow and used to saturate the output values to plus or minus full scale
- For example, the 8 bit output mode of the GC5016 can be used to generate 6 bit outputs with 54 dB of slew range if the upper two bits are checked for saturation
  - If bit 7 (the MSB and sign bit) == bit 6 == bit 5, then no overflow has occurred and bits 0-5 are output
  - If the bits do not match, then bit 7 is output as bit 5, and the opposite of bit 7 is output for bits 0-4. (i.e., the output is either 011111, or 100000
- The AGC target thresholds need to be divided by 2 for each bit saturated
  - For the 8 bit to 6 bit mode the desired threshold needs to be divided by 4

Using the CMD5016 Program to Set Up the AGC Circuit

- The cmd5016 program will automatically set up the AGC circuit
- The user specifies the desired adaption time constant in microseconds using the cmd5016 keyword “agc_tc”
- The user specifies the desired output crest factor in dB using “agc_cf”
    - Note the user sets up the extended dynamic range mode described on the previous page by increasing the agc_cf in 6dB steps for each 6dB of extra dynamic range. The cmd5016 will then set the appropriate threshold.
- The user specifies the agc mode (CDMA, Narrowband, or Mixed) using the agc_mode keyword.
- The cmd5016 program will then set all of the agc parameters discussed in this application note
- See the application note “Automatic Gain Control Mode Settings”.

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