APPROACH TO SOLVE THE AGC API ISSUE IN THE TACTICAL SDR DOMAIN
A WAVEFORM PROVIDER PERSPECTIVE

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ABSTRACT

In the tactical radio domain receiver designs are dominated by the extraordinary requirements of up to 150 dB signal dynamic range at the antenna input caused by a peer to peer communication principle in the presence of collocated transmitters.

Even with state of the art receiver technology, covering such high dynamic ranges within the entire analog receiver chain from antenna input to the analog to digital converter (ADC) can only be performed by appropriate dynamic compression methods.

Usually such dynamic compression is implemented by a combination of fast and often nested automatic gain control (AGC) loops.
This paper

first highlights major differences between the AGC principles of legacy receiver and SDR receiver concepts,

then emphasizes on the SDR specific AGC challenges from a receiver designer's point of view,

after moves the focus on AGC to a WFA designer's point of view,

now from this viewpoint introduces two alternative AGC API concepts,

and finally proposes a platform API combining both concepts.

1. INTRODUCTION

For legacy receivers designers tend to locate the major dynamic compression at the final intermediate frequency (IF) stage close to the ADC. In this stage the signal bandwidth is limited to the instantaneous bandwidth of the waveform. So, signals from other transmitters operating in adjacent channels are already removed by the IF filter. Thus, the AGC loop dynamic behaviour can be optimized to the usually well known dynamic behaviour of the waveform as well as to the predictable channel dynamic caused by fading due to the relative velocity of transmitter/transceiver and/or reflector(s).

Finally, after this narrowband AGC loop the final level variation of the received signal at the ADC can be limited around an optimum ADC input level close to ADC full scale.

In the SDR world the situation looks quite different: Instantaneous bandwidth ranges to be hosted on one SDR channel may vary by several decades (e. g. from 5 kHz to 5 MHz) whereas a rather limited number (typically 2...3) of different IF filter bandwidths are selectable. Thus, in the general case 10 to even 100 adjacent channels may pass the final analog filter causing a heavy signal load at the ADC. In the usual operating scenario the wanted signal at the IF centre frequency is received from a far away transmitter whereas several collocated ones may dominate both the signal level at the ADC input and the receive signal strength indicator (RSSI) outputs used to control the AGC loop.

Thus the AGC loop dynamic behaviour has to be optimized to the dynamic behaviour of the receive scenario caused by both friendly and hostile transmitters inside the theatre.

For waveform application (WFA) portability reasons there is a strong demand to define a widely applicable AGC API which on the one hand copes with the capabilities of various AGC-loop concepts (respectively SDR receiver designs) but on the other hand generalizes the individual API methods in a way that their impact on the receive signal distortion can easily be predicted by the WFA supplier without the need of an interior view of the individual receiver/AGC design.

2. AGC PRINCIPLE IN LEGACY RECEIVER

Figure 1 shows a rather generic AGC behavioural model. In this paper the notion *behavioural model* is used for block diagrams showing only those functional receiver blocks impacting the waveform processing through gain variation.

The major dynamic compression is performed after the IF filter. Here the IF filter bandwidth matches the (usually constant) receive signal instantaneous bandwidth. Thus, the IF filter suppresses signals from transmitters operating in adjacent channels, characterized by the so called *adjacent*

channel selectivity of the IF filter. In consequence, the AGC loop dynamic behaviour exclusively matches to both the dynamic behaviour of the waveform and the dynamic of the channels between the own network subscribers and the receive antenna.
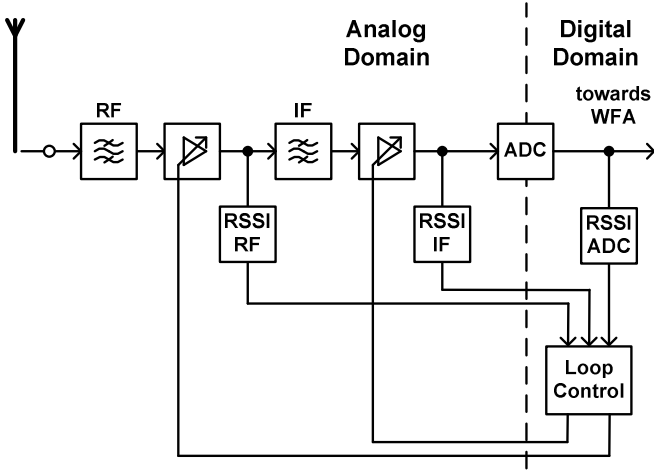

Figure 1: Generic AGC behavioural model

Due to these well known behaviours as well as due to the fact that the dynamic behaviour of the IF signal is anyhow constrained by the narrow signal bandwidth AGC loops can be optimised to compensate the level changes at the IF filter output in a way that the level variation at the ADC can be kept quite limited. Thus, dynamic requirements to the ADC are rather relaxed and the AGC processing in the digital domain of the receiver needs only coping with rather moderate level variations.

3. AGC PRINCIPLE IN SDR RECEIVER

Also within a SDR receiver the major dynamic compression is as far as possible performed after the IF filter, but in general the IF filter bandwidth does not match the wanted signal bandwidth. Thus, signals from other transmitters operating in adjacent channels are also contained within the IF signal in front of the ADC as already mentioned. The typical collocation situation has to cope with a wanted signal from a far away transmitter dominated by an interfering signal from a friendly transmitter in close proximity separated only by a few channels from the wanted one.

A priori knowledge of the dynamic behaviour of the signal mixture in the IF band is rather vague compared to the legacy receiver case:

Not only the dynamic behaviours of the waveforms operating in the adjacent channel may dramatically differ regarding their statistical parameters, but also the channels of the various received signals may be of different type.

4. SDR AGC CHALLENGES

For illustration of the challenges to the SDR receiver and AGC designs let us consider a SDR connected to a static satellite dish and hosting a satellite communication waveform in the lower UHF range. Level variations of the wanted receive signal are mainly caused by weather condition changes like rain and therefore are rather slow.

Concurrently in the same scenario there are also airborne communication systems active. Due to fast fading caused by their high velocity as well as due to their fast movement through the side lobes of the antenna elevation diagram fast level changes of several tens of dB at the antenna input are quite usual. If such interfering transmitters operate just a few channels distant from the wanted signal they will completely pass the IF filter in front of the ADC. A properly acting AGC loop will therefore modulate the amplitude level of the wanted receive signal inversely to the aggregate receive level of the interfering signal mixture.

Thus, the ADC has to cope with a high level difference between the input level of the wanted signal and the summed level of various dominant signals within its input frequency range, resulting in extraordinary spurious free dynamic requirements to the ADC. The WFA dealing with the sampled receive signal will on the one hand have to compensate the signal variations of the wanted signal by WFA internal AGC methods and on the other hand have to cope with distortion effects caused by the above described mechanism.

Moreover, in order to mitigate such distortion effects the WFA has to properly control the AGC behaviour even in real time.
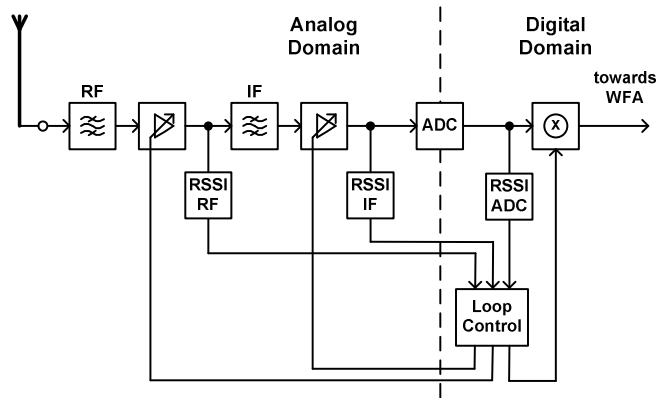

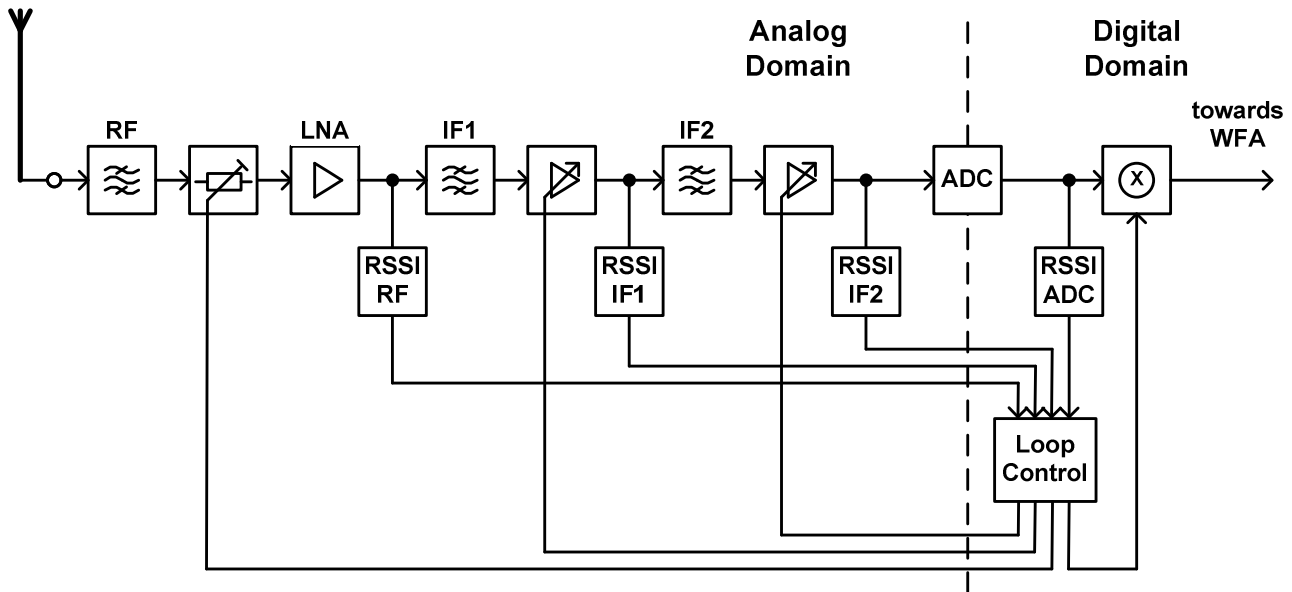**Figure 2: Level compensation behavioural model**

Figure 3: Multi stage gain variation

In order to avoid level variations of the wanted signal caused by dominant receive signals in adjacent channels a level compensation mechanism can be added in the receiver chain as illustrated in figure 2. This mechanism inserts a gain in the digital domain (implemented as multiplier) inversely to the aggregate gain actually set by the AGC control loop in the analog domain. So, the IQ signal after the inverse gain is directly proportional to the receive level at the antenna input. Moreover, in case the receiver is appropriately calibrated receive levels at the antenna connector can even be computed in absolute values within the WFA, e. g. in [dBm], providing the WFA with simple methods to detect channel access.

5. WFA VIEW ON AGC

Provided that a SDR receiver combines the compensation measure illustrated in figure 2 with a high dynamic ADC method it seems that a WFA could completely ignore the receiver AGC behaviour as it always receives a wanted signal proportional to the receive level at the antenna input. After (matched) channel filtering the same assumptions on the dynamic behaviour of the wanted signal (including its channel) could be taken as in the case of the legacy receiver/AGC design. Thus, applying equivalent AGC methods (as in the legacy receiver case) in the digital domain should solve the SDR AGC issue!

Is this a valid assumption?

Unfortunately not: In the above first glance view the impact of the analog (mainly IF) filters in the receive chain have been neglected!

As long as there is no filter between any gain varying stage and the ADC, no filter impact on the AGC behaviour has to be considered. Unfortunately it is rather difficult to cover a typical 150 dB input level swing within a static gain analog chain. Thus, within a state of the art receiver amplification (and therefore also gain variation) is distributed among various stages and therefore also the (IF) filtering, as indicated in figure 3.

In such a distributed gain topology, IF filters are also located between gain varying stages and the ADC. Here an instant level change at the amplifier output (due to gain switch) leads to a continuous level adjustment at the proximate filter output according to the filter specific impulse response. Analog filter impulse responses are usually of infinite (IIR) type. Their convergence speed behaves reciprocal to the filter bandwidth. As the inverse gain in the digital domain changes its level instantaneously a residual gain (respectively signal level variation) is visible after the inverse gain (multiplier) block.

This effect can be modeled as a receiver internal impulsive interference source correlated in time with the level swing of any individual gain change. The delays between the gain changes in the analog and the ones in the digital domain have to be designed for minimum aggregate interference energy at the inverse gain output.

Depending on the nature of the AGC loop control algorithm the described (by nature impulsive) interference source effect can be transformed into a more continuous interference source effect, when gain adjustments are performed incrementally or even continuously.

Whether the impulsive interference source or the continuous interference source model is favourable depends on the vulnerability nature of the individual waveform.

We can imagine that a waveform, which is transporting analog modulated voice, may be less resistant to impulsive interference than a waveform transporting convolutional coded data.

This example indicates that it would be favourable to give the WFA some control of the AGC.

At this point it has to be emphasized that the amount of control shall be limited to transparent and easily understandable degrees of freedom and that the WFA designer shall handle this control with care in order to minimize the probability that at the end of the day the resulting (self) interference effects are even worse than without WFA control.

6. AGC API CONCEPT

The above explanations make it obvious that proper AGC parameter handling strongly depends on an appropriate behavioural model describing the impact of the parameter configuration in a (from WFA point of view) transparent way. Through such a model behind the AGC application programming interface (API) the residual interference energy/power shall be characterized.

For sake of WFA portability there is a strong demand to define a widely applicable AGC API, which on the one hand copes with the capabilities of various AGC concepts (respectively SDR receiver designs) and on the other hand generalizes the individual API methods in a way that the impact on the receive signal distortion can easily be predicted by a WFA supplier without the need of an interior view of the individual receiver/AGC design.

As already indicated, the WFA should have means to configure the AGC to behave either as impulsive or as continuous interference source.

In the impulsive interference source model the AGC intends to minimize the number of gain changes. This behaviour can be achieved by fixing gain as long as the IF input to the AGC is floating within a predefined level range, limited by an upper and a lower input level below ADC full scale. So, in the following this AGC behaviour is called *floating level behaviour*.

In the continuous interference source model the AGC intends to minimize the individual gain steps, thus stepping as often as possible up to a (quasi) continuous gain swing. This behaviour can be achieved by correcting any input level swing by a reciprocal gain swing, thus quasi fixing the IF input to the ADC. So, this AGC behaviour is called *constant level behaviour*.

Figure 4 illustrates the floating level behaviour of the output parameters *gain* and *ADC input* dependent on the input level at the antenna.
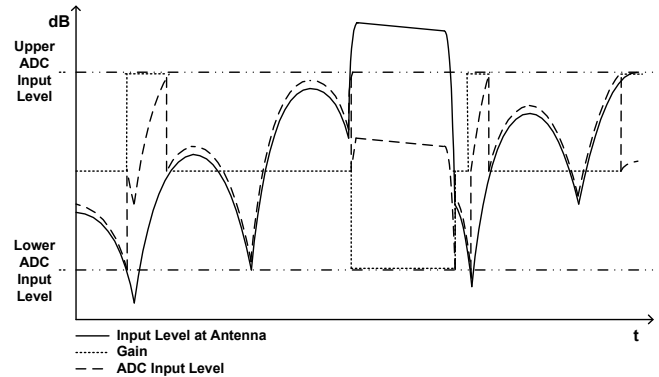

Figure 4: Floating level behaviour

Floating level behaviour is characterized by long periods of fixed gain, combined with a swing of the ADC input proportional to the input level at the antenna, interrupted by abrupt gain and ADC input changes as soon as the ADC input exceeds the predefined ADC input swing range.

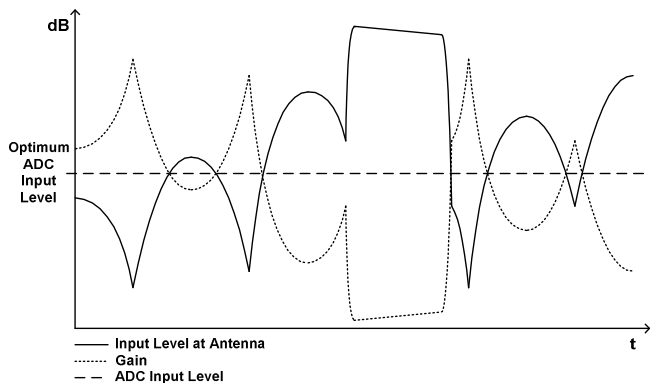Figure 5 illustrates the respective constant level behaviour.

Figure 5: Constant level behaviour

Constant level behaviour is characterized by a swing of the gain reciprocal to the input level at the antenna, whereas the ADC input is constant at a predefined optimum ADC input level.

It has to be mentioned that figures 4 and 5 only illustrate the principle. In reality the behaviour of the mentioned parameters may somehow deviate depending on the gain control loop structure and parameters.

To configure the floating level behaviour the WFA shall be able to define the ADC input level range, e. g. by setting the upper ADC input level and the lower ADC input level in $[dB_{FS}]$.

To configure the constant level behaviour the WFA shall be able to set the (optimum) ADC input level in $[dB_{FS}]$.
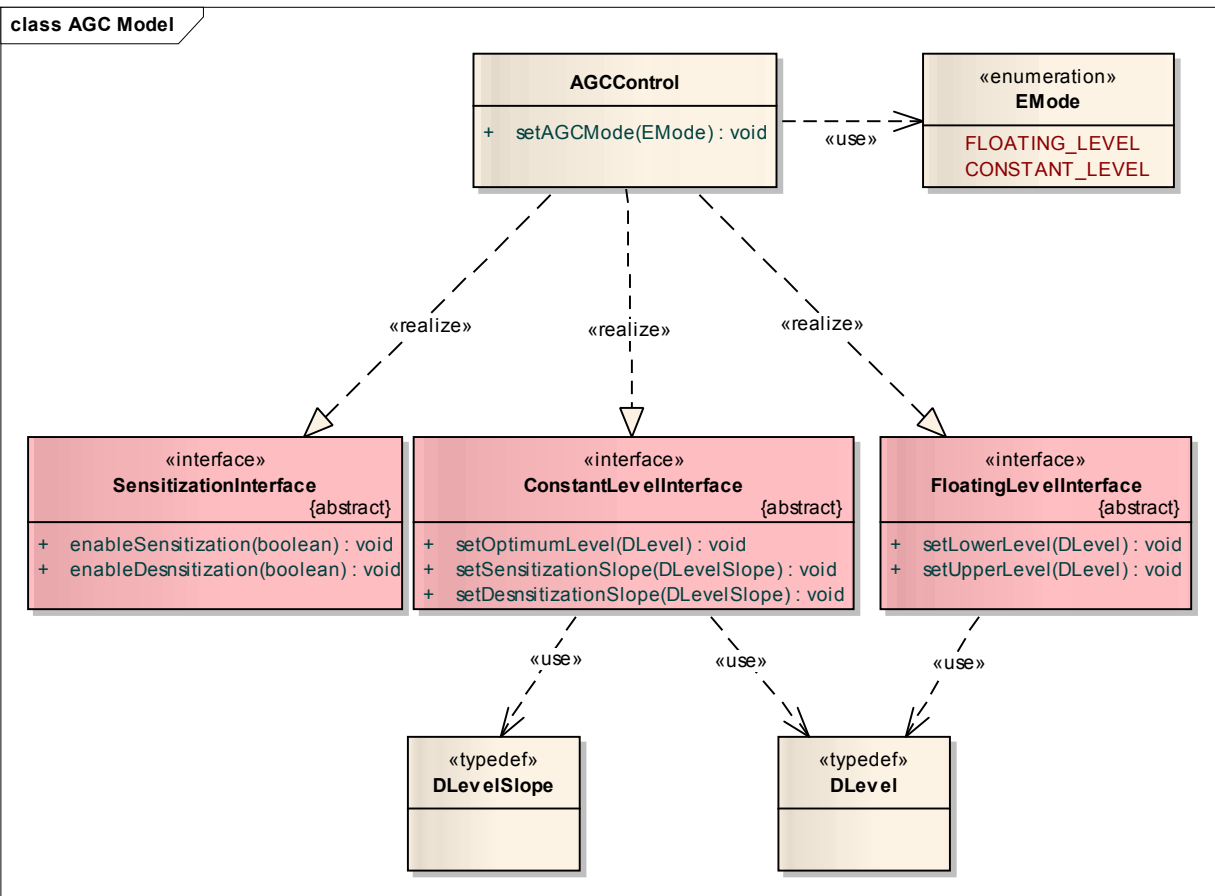
Figure 6: API summary

As gain swing in general causes (self made) distortion on the receive signal the WFA shall have access to several methods to control this distortion effect such as to limit gain adjustment speed (gain slope), measured in [dB/s]. Such gain slope limitation should be desirably independently for sensitization and desensitization swing. Fixing gain during certain vulnerable/sensitive phases of the waveform is also desirable. Such gain fixing shall operate under time bound control of the WFA. Optimally such fixing should also be controlled independently for sensitization and desensitization.

7. AGC API SUMMARY

Figure 6 summarizes the proposed AGC API.

- *setAGCMode*: *Selects* between
  - o FLOATING_LEVEL: Floating level behaviour
  - o CONSTANT_LEVEL: Constant level behaviour

In case of FLOATING_LEVEL:
- *setUpperLevel*: Specifies the upper boundary of the floating ADC input level [dB$_{FS}$]
- *setLowerLevel*: Specifies the lower boundary of the floating ADC input level [dB$_{FS}$]
- *enableSensitization*: Enables/disables gain increase
- *enableDesensitization*: Enables/disables gain decrease

Remark: In case of FLOATING_LEVEL, gain in/decrease speed shall be as fast as possible.

In case of CONSTANT_LEVEL:
- *setOptimumLevel*: Specifies the optimum ADC input level [dB$_{FS}$], i.e. the ADC level to be quasi fixed (= constant) by the AGC algorithm
- *setSensitizationSlope*: Specifies the maximum gain increase speed [dB/s]
- *setDesensitizationSlope*: Specifies the maximum gain decrease speed [dB/s]
- *enableSensitization*: Enables/disables gain increase
- *enableDesensitization*: Enables/disables gain decrease

This API contains both static and dynamic parameters. The static parameters are usually unique for a particular waveform (respectively waveform mode) and must only be changed in case of waveform (mode) change. Dynamic parameters have to be changed at a certain instant of time (time bound) relative to the (expected) receive signal of the wanted signal. The only mandatory dynamic parameters are *setSensitization* and *setDesensitization*.

8. CONCLUSION

A platform API suited for configuration and real time control of the AGC located within any tactical SDR receiver has been introduced. This API takes into account that even decades of adjacent channels may pass the IF analog filter in front of the ADC:

It provides a flexible, but transparent AGC loop dynamic behaviour control adaptable to the dynamic behaviour of the receive scenario. It allows a WFA supplier to control the impact on the receive signal distortion according to either an *impulsive* or a *continuous* noise model without any knowledge of the individual receiver design, thus ensures waveform application portability onto any tactical SDR platform.