

Figure 1: General architecture showing the evaluation platform and waveform components in the RX showing AGC control of the SDR

The waveform is designed to be platform independent for flexibility and portability. To accommodate different SDR chipsets used in either proprietary or commercial-off-the-shelf (COTS) platforms, there is a platform adapter module (PAM) which serves as an interface between the SDR ADC and the PHY input as shown in Figure 1. The TX-RX interface (trx_int) is bidirectional, allowing data transfers from PHY to the SDR DAC in the TX mode. For the AGC to operate, the gains of the 3 amplifiers in the RX portion of the AD 9361 are adjusted via a customized SPI bus. When the AGC is active, the PHY sends out via the radio front end controller (RFE ctrl) module, a message to the PAM, the relative gain needed for adjustment. The message is then decoded by the RFE message decoder and sends out via the SPI bus, information to program the respective front end amplifier gains.

All transmitted bursts start with two Zadoff-Chu CAZAC [1] preambles, a header and followed by payload data. The primary use of the CAZAC preamble is for synchronization and thus enables the correlator in the receiver to detect the start-of-frame. Secondary functions include estimations of carrier frequency offset, symbol timing offset and preamble power for the AGC.

The length of the each burst can vary from 5 ms to 12 ms depending on the intended payload. The MAC controls the type of burst to transmit or receive in a 30 mS TDMA slot.

B. AGC Operation

The signal into the waveform is derived from the 12-bit ADC in the SDR receiver platform. The waveform nominal operation for optimum performance of QPSK is set to -3 dB below the ADC full-scale (dB_{FS}) to allow for peak-to-average power (PAPR) variations due to the root-raised cosine (RRC) pulse shaping of the transmitted waveform. When the AGC is in operation, the waveform measures the received signal after the waveform preamble has been detected and sends to the platform the relative gain needed, and will be set by the platform by adjusting the programmable gain amplifier(s) in the platform to maintain the -3dB_{FS} drive level into the waveform.

The waveform's PHY performs the received signal power measurement as follows. On receiving the command to start receive mode from the MAC, the waveform's PHY listens for the 2 preambles that is sent out at the start of every transmit burst. The ADC in the platform samples the received signal at 4 times the transmitted output symbol rate. Using cross correlation between the received waveform and a reference CAZAC preamble, the synchronization module declares preamble detection is achieved when the cross correlator output peaks to indicate the detection of the received preambles and derives the Start-of-Frame time instance from the detected peaks. The waveform then computes the power in the 2nd preamble and this power is a direct measure of the received signal strength.

The measured second preamble power is fed into a look-up table which outputs the relative gain value that is needed to be reduced or increased from the existing platform gain. This look-up table is derived from a *characterization* process of the

second preamble power over a set of fixed/preset platform gain settings across a range of signal-noise-ratios (SNR). The preamble power vs SNR over a set of fixed platform gain settings for the waveform is shown in Figure 2.

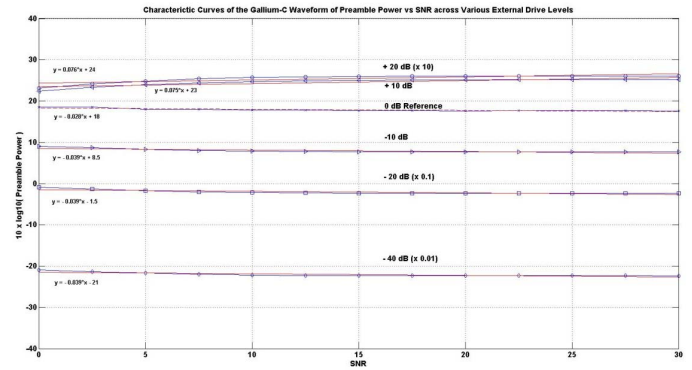


Figure 2: Characterization of preamble power vs SNR at preset external gain settings

From Figure 2, it can be seen that the characteristic curve at each fixed external drive level from -40 dB to 0 dB_{ref} is almost flat across SNR. Above 0 dB_{ref}, the effect of ADC saturation is clearly seen. At this juncture it is important to note that it is not possible to measure power beyond the full-scale range of the ADC. At this saturation point, the AGC can only instruct the platform gain to be reduced progressively until the signal level falls into the operating range of the ADC.

At drive levels below the 0 dB_{ref}, external gain must be increased to bring the drive back to the reference level with one exception where the external gain is already at maximum value when operating at the fringe /edge of the coverage area. Here the level into the receiver will drop but the receiver system has enough dynamic range to maintain performance.

Using a reference SNR of 10 dB from Figure 1, a set of values for preamble powers is obtained for various external drive levels as depicted in Figure 3

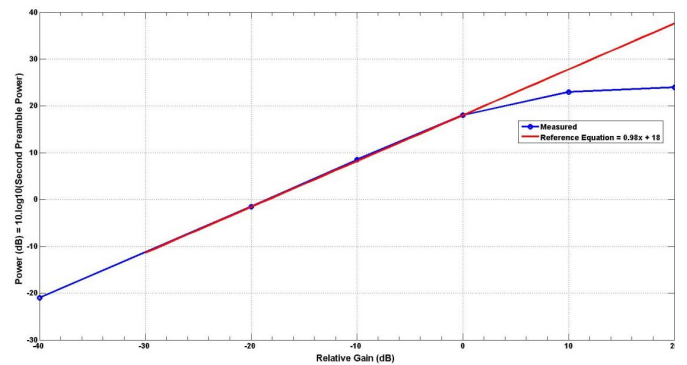


Figure 3 : Preamble power vs relative gain at reference SNR of 10 dB

The preamble power (dB) is linear between -40dB and 0dB relative gain and is expressed by the equation $y = 0.96 * x + 18$. This equation gives the preamble power (dB) for any relative

received signal strength. In operation, it is the preamble power that is measured and the estimate of relative signal strength is required. By rearranging the equation, the relative signal strength (x) can be computed for any value of y in the linear region where $x = (y - 18)/0.96$. Due to compression beyond the 0 dB relative gain, the curve deviates from the linear equation and eventually flattens out at +24 dB Preamble Power. When the ADC is overdriven, the maximum relative gain available for compensation at each burst is approximately 10 dB. This inability to resolve the overdriven state results in a slower settling time as it reduces the gain in 10 dB steps. The settling time is also slower in low SNR conditions due to detected noise power uncertainty.

The final desired output of the waveform to the platform is the required relative gain compensation value and this is the complementary (*negative*) value of the relative signal strength. The relative gain compensation transfer curve is shown in the blue trace in Figure 4.

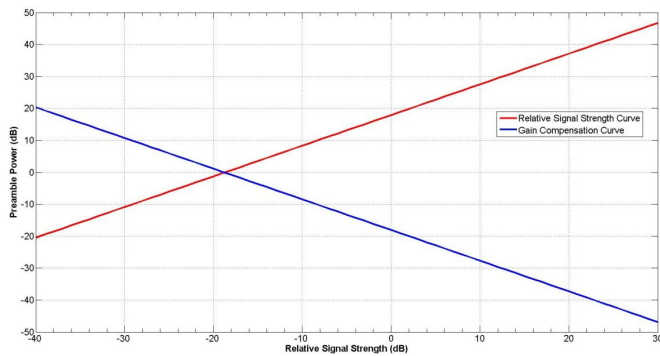


Figure 4 : Relative gain compensation versus measured preamble Power

III. MAC CONTROL FOR AGC OPERATION

The PHY/RF controller stores the previous gain value based on the ID of the source node. Before the start of each receive slot, the MAC will indicate to the PHY/RF controller the ID of the source node for this slot. The PHY/RF controller will then load the previously stored gain value for this source node at the start of the receive slot before the transmission begins. When the transmission of the burst begins, the preambles are first received and detected. Based on the measured power of the detected preambles, the gain adjustment is derived and set for the reception of the payload in the current burst. This new gain value is also stored so that it can be used at the start of the reception of the next burst from this source node.

During network camping, the SU will be in receiving mode for an interval of time. This interval is known as the scanning window in which the SU scans for the MU beacon. The scanning window must be sufficiently large in order for the SU to receive and successfully decode at least one MU beacon. At the start of the scanning window, the gain is reset to its maximum value. As the SU receives the first burst from the MU, it tries to detect the preambles. If the preambles are detected, the gain adjustment is derived and set. At this point of time, the gain may still not be at the optimal level and thus the

burst may not be decoded correctly. However, the currently set gain value is used to receive the next burst and the process is repeated iteratively until the gain value reaches a level where the burst can be correctly decoded and the MAC is able to receive the MU beacon. Assuming that a maximum of 10 iterations is required to reach the optimal receive gain level in the worst case (i.e. under severe overloading) and the MU is transmitting a beacon at every epoch interval, the scanning window should be at least $10 \times$ epoch duration.

When the SU is camped, it starts to transmit its own beacon. At this time, the SU is already synchronized with the MU with regards to the time slots. The MU has separate receive slots for receiving the beacons from each of the SUs. The PHY/RF controller will also maintain separate gain values for each SU. Before the MU receives the decoded beacon from the SU, it will periodically reset the gain to the maximum value. This reset interval is set at $16 \times$ the epoch duration, which is greater than the scanning window. During this interval, if the SU is transmitting, the MU uses the detected preambles to adjust the receive gain to the optimal level in order to decode the SU beacon correctly. Once the decoded SU beacon is received, the MU will stop resetting the gain value.

After the SU camps, camp error occurs when either the SU or the MU is unable to receive the beacon from the other node for a period of time. This timeout for camp error is set at 10 s in the implementation.

At 1/4 of this timeout period, if the MAC does not receive any beacon, it attempts to recover the beacon by resetting the receive gain to its maximum value. This triggers the process of iteratively adjusting the gain value back to its optimal level. If at the end of the timeout period, the beacon is still not received, a camp error indication is issued.

IV. PHY OPERATION AND THE SIMULATED TRANSIENT RESPONSE OF THE AGC SYSTEM

The correlator used in receiver PHY is based on the CAZAC sequence and designed to be robust and tolerant to severe overload conditions. In the case of severe overload, the signal into the correlator is clipped but the correlator will still work to detect the preambles as shown in Figure 5 for the case of 100 dB over drive and a low SNR of 5 dB. The correlator peaks at its maximum possible value at the 1st preamble in this specific example.

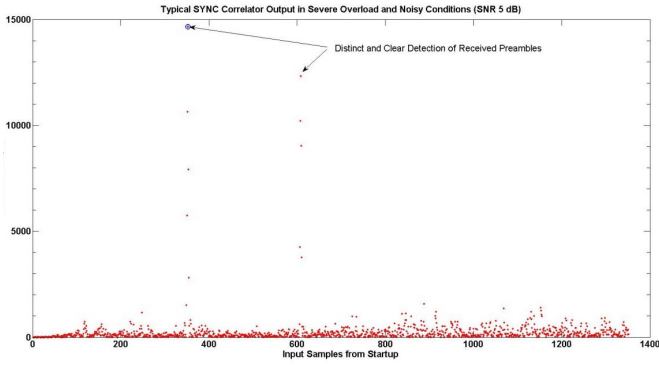


Figure 5 : Typical SYNC correlator output for detection of start-of-frame preambles

In the scenario where the receiver is 1 m away from the transmitter, the free-space loss at 2.4 GHz is approximately -40 dB and with a radiated TX power of +29 dBm, the expected signal strength at the receiver antenna is -11 dBm. This is a very large signal compared to the RX sensitivity level of -95 dBm signal power needed for a Bit Error Rate (BER) performance of 1×10^{-6} . There is a difference of 84 dB and will cause the front-end amplifiers and the output of the ADC to severely clip. The gain(s) of the platform amplifier(s) must be reduced to the 0 dB_{ref} optimum input level required by the waveform. The simulated transient response of AGC system at various SNR's under severe overloading is shown in Figure 6.

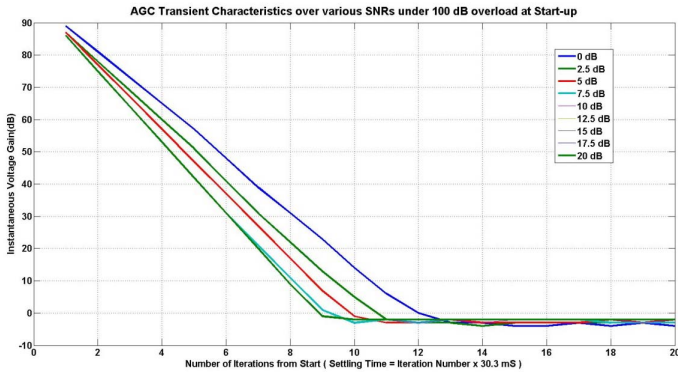


Figure 6 : Transient response of AGC to severe overloading of 100 dB_{ref} at start-up.

At a *usable* SNR of 5 dB (red trace in Figure 6), the AGC settles at the 10th iteration and beyond. At higher SNRs, the response settles in 9 iterations. If it is assumed that a preamble is detected at least once every 30mS, the settling duration at an SNR of 5dB is 300 mS. In the RX implementation, the duration between reception of a synchronization sequence (consisting of a set of 2 preamble sequences) at the start of each burst and the next set is not fixed and depends on the mode of operation. During *network camping* mode at start-up, the MAC listens for the beacon at every epoch period of 180mS and the AGC system may take up to 1.8 seconds to reach steady state. The period can be shorter than 1.8 sec as the MAC can camp when it detects no CRC errors if the SNR of the received signal is greater than 7.5 dB (Table 1). Once the system has camped, the

MAC reverts to its normal mode of operation where depending on the frame number in the slot structure, the number of synchronization sequences received in the burst can be between 2 and 3 within 30 mS which will shorten the AGC settling duration further.

The settling period under severe overload conditions will not be perceivable and will not affect the system performance in the intended point-to-multi-point application. Such overloads could only occur at very close range operating scenarios such as during over-the-air lab tests or close proximity checks. The instantaneous BER performance in AWGN at various AGC iterations and SNR values is shown in Table 1.

TABLE 1: INSTANTANEOUS BER IN AWGN CHANNEL AT VARIOUS AGC ITERATIONS (1-12) AND SNR (0-20 dB) IN OVER-DRIVEN CONDITION AT START-UP

SNR	Instantaneous Bit Error Rate in AWGN channel at various AGC Itera											
	1	2	3	4	5	6	7	8	9	10	11	12
0	0.490	0.477	0.476	0.467	0.489	0.468	0.473	0.480	0.484	0.490	0.503	0.377
2.5	0.394	0.382	0.404	0.335	0.390	0.346	0.328	0.296	0.251	0.276	0.049	0.055
5	0.032	0.060044	0.090611	0.137918	0.044396	0.05786	0.055313	0	0	0	0	0
7.5	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
12.5	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
17.5	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0

It is clear from Table 1 that the instantaneous BER at an SNR of 2.5 dB improves significantly at and above the 11th iteration. At 5 dB SNR and beyond the 7th iteration, the instantaneous BER is zero. It is also interesting to note that the instantaneous BER is zero at the 1st iteration for overdriven signals having SNRs of 7.5 dB and greater. This is an indication of a robust RX system performance in over-driven signal conditions.

In another scenario where the system detects an *under* driven situation, the AGC system will compensate by requesting to increase the gain of platform amplifier. The transient response for this under driven scenario is shown in

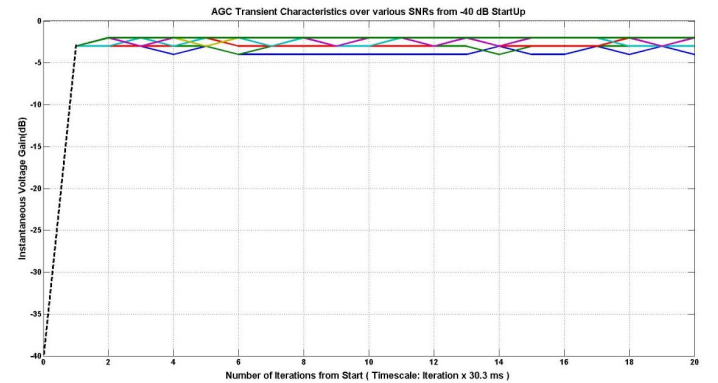


Figure 7: Transient response of the AGC to an under driven system at -40 dB_{ref} at start-up

As the *under* driven condition works in the *linear* region of Figure 3, the response is extremely fast and the AGC system is able to compensate almost instantaneously at the 1st iteration to reach the desired steady state value. This occurs in less than 30ms, assuming at least a single synchronization sequence is detected. The instantaneous BER performance at the various AGC iterations is shown in Table 2

TABLE 2 : INSTANTANEOUS BER IN AWGN CHANNEL AT VARIOUS AGC ITERATIONS IN UNDER DRIVEN CONDITION AT START-UP

SNR	Instantaneous Bit Error Rate in AWGN channel at various AGC Itera											
	1	2	3	4	5	6	7	8	9	10	11	12
0	0.502	0.371	0.422	0.414	0.410	0.400	0.400	0.409	0.389	0.388	0.434	0.418
2.5	0.512	0.089	0.093	0.109	0.105	0.053	0.088	0.067	0.108	0.111	0.087	0.055
5	0.502	0	0	0	0	0	0	0	0	0	0	0
7.5	0.484	0	0	0	0	0	0	0	0	0	0	0
10	0.494	0	0	0	0	0	0	0	0	0	0	0
12.5	0.488	0	0	0	0	0	0	0	0	0	0	0
15	0.504	0	0	0	0	0	0	0	0	0	0	0
17.5	0.496	0	0	0	0	0	0	0	0	0	0	0
20	0.509	0	0	0	0	0	0	0	0	0	0	0

From Table 2, it can be seen that the BER performance above 2.5 dB SNR improves substantially after the 1st iteration and for SNRs above 5 dB, the BER is zero.

Further, in order to make the system robust, the waveform remembers the absolute platform gain when a transmission from a specific MU or SU was received successfully. Based on the transmission and reception schedules, the last stored absolute gain value will be recalled and requested to be set *before* the start of receive mode operation for the transmission from that particular SU or MU. This mechanism ensures that subsequent transmissions from that particular SU or MU do not go through the iterative AGC settling process to be successfully received.

V. CONCLUSION

This paper describes the operation and performance of an AGC scheme used in a real-time point-to-multi-point

implementation. It is shown that the AGC is robust in operation and works as expected in over and under driven conditions to attain a steady state optimum drive level into the waveform for best BER performance and is sufficient for the intended point-to-multi-point application.

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