Automatic Gain Control Characterization for OFDM Scheme

A Project Report

submitted by

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THESIS CERTIFICATE

This is to certify that the thesis titled **Automatic Gain Control Characterization for OFDM Scheme**, submitted by VENUGOPAL MUKUND KULKRNI, to the Indian Institute of Technology, Madras, for the award of the degree of Master of Technology, is a bona fide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

KEYWORDS: Automatic Gain Control; Orthogonal Frequency Division Multiplexing; Long Term Evolution; Time Division Duplex; Analog-to-Digital Converter

AGC is an important part of a communication receiver as it maintains the output power level constant by minimizing quantization noise and avoiding receiver saturation. AGC has got a self regulating adaptive mechanism to keep output power constant by varying the gain for different input power levels. The received power levels in Wireless communication (in particular OFDM scheme) show a wide dynamic range ; necessitating the efficient and speedy AGC subsystem response . The Step sizes used in iterative gain updation as well as the sample interval lengths used in estimating the output power level are natural and inherent parameters which characterize the performance measures of any AGC. There need to be study done to emphasize quantitatively the effect of these parameters on performance characteristics of AGC specifically in the context of OFDM as a wireless modulating scheme.

The convergence delay ,transient SQNR and the steady state error are considered here as performance measures. by varying step sizes as well as the sample integration intervals performance trade off s are brought out. AGC Involving highly dynamic operating characteristics, instigated simulation study to be followed in deriving the behavioral response . Further ,based on above observations; strategizing AGC to react to the sudden input variations as would be encountered in case of an obscuration or while entering into an enclosed area is thought over. Similar sudden power variations are observed in TDD mode of LTE scheme ,where there is a periodical change of received power as changeovers occur between receiving and transmitting modes.

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CHAPTER 1

BACKGROUND

1.1 AGC Working

When we come to the discussion on AGC, the main purpose of AGC is to prevent amplifier output from saturating the ADC, at the same time enhance SQNR of low strength signals.

AGC in its basic structure contains a Variable Gain Amplifier(VGA), whose gain is controlled by the control voltage ,which in turn generated by difference operation of estimated rms output and desired reference value.As a design requirement VGA gain should have sufficient dynamic range to handle variations in input power. Usually VGA has linear in dB response and its settling time is far smaller than the sampling time. The ADC digitizes the output of VGA to derive the RMS estimate of output. Sample length for estimate depends on accuracy requirement.

AGC is implemented using recursive relation, which continues till the output reaches reference value.Gain is recursively updated in steps to arrive at a gain corresponding to reference output. The RMS output value is compared with reference output value and the difference is applied inturn to variable gain amplifier.According to recursive formula new gain update is proportional to difference between previous estimated output and reference output ,multiplied by step_factor.Higher the step factor larger is gain change and faster is the convergence. But higher step size creates more error in steady state. Where as for smaller step_factors gain changes will be smaller and take longer time to converge.Advantage of small step_factor is in terms of lower steady state error.

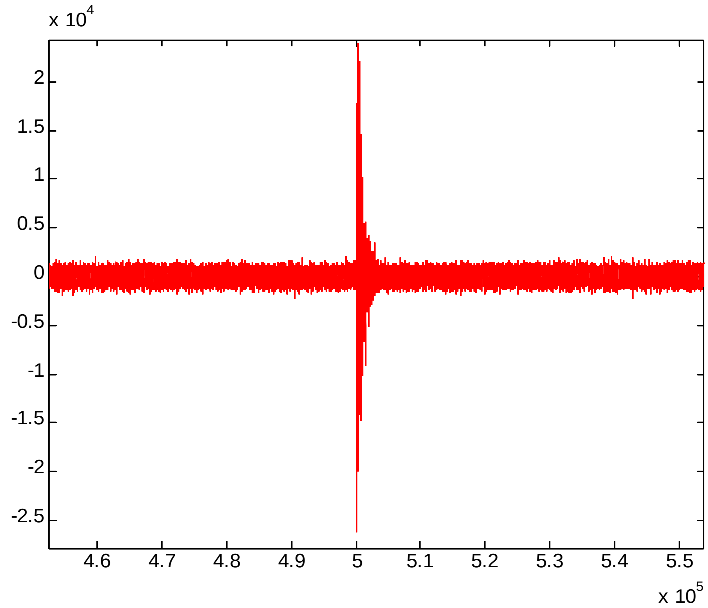

Figure 1.1: AGC Response

1.2 OFDM

OFDM signal is a combination of several sub-carriers with very small sub-carrier spacing, in the order of KHz, equal to $f = \frac{1}{T}$. Multiplexing such hundreds of symbols (BPSK/QPSK/16-QAM) into different sub-carriers in the same time interval is possible. This Hyper-symbol is referred to as one OFDM symbol. Baseband equivalent of an OFDM signal is given by

$$x(t) = \sum_{k=0}^{N_c-1} a(k)^m e^{j2\pi\Delta ft} \tag{1.1}$$

defined in the interval $mTs < t < (m+1)Tu$. Where Tu is time period of the OFDM symbol, N_c is number of sub-carriers that are to be multiplexed, $a(m)$ is set of the sub-symbols in mth OFDM symbol and $\Delta f = 1/Tu$. It is important to note that the information that is modulated from an OFDM signal is in frequency domain. One of the biggest advantages of the OFDM signal is that it can be implemented easily by using IFFT module. It be constructed by the following discrete time signal and then giving it to an Digital to Analog converter.

$$x(n) = \sum_{k=0}^{N-1} a(k)' e^{j2\pi kn/N} \tag{1.2}$$

$$a(k)' = a(k) \qquad for\ 0 < k < N_c$$

$$a(k)' = 0 \qquad for\ N_c \leq k < N$$

N is chosen as a nearest greater integer to N_c and also can be expressed in the form 2k. Sampling rate of the system is given by $fs = N\Delta f$. Note that superscript m, which indicates the symbol number, is left out for convenience. A Cyclic Prefix (CP), which is a copy of the last part of the samples is appended to the front of the serial data stream before Radio Frequency (RF) up conversion and transmission. The CP combats the disrupting effects of the channel which introduce Inter Symbol Interference (ISI) .

1.3 Literature survey and present scenario

There are several AGC schemes as available in wireless receivers. They will be employing a step wise gain compensation to achieve reference output.If the step size would be maintained constant result in incurring huge delay in settling down and increasing error rates.

Various publications and papers presented in this scheme (Tavares and Piedade (1990),Jang and Choi (2010),Wang *et al.* (2007) and Perels *et al.* (2008)) ,were surveyed.They follow basic AGC with simpler modifications which can be classified as under. One of strategy is to Adapt, two levels of AGCs with first level utilizing smaller integration length making AGC to converge to approximate gain quickly to evaluate few of OFDM parameters and then go for second level AGC with longer integration length to have finer gain adjustment ,when AGC output is used in estimating channel . The second strategy is to vary the step size adaptively within few iterations of gain adjustment to give a faster convergence as well as low steady state error together.In above publications the results of factual parameter behavior is scarcely presented than qualitative observations .So a study in this aspect is made to present the behavior of AGC and build an optimum strategy to respond to a sudden change in input variance also discussed.

CHAPTER 2

AGC Performance measures

Using convergence delay, Transient SQNR and steady State error as important measures, better performance of these has got direct implication on overall efficiency of AGC. Convergence delay being of utmost concern has been widely addressed to reduce the same. Overshoots and the transient being unavoidable part of AGC response, various methods are adapted to reduce the same. Transient SQNR is being addressed as even during transition period the information content and the detectability of that information should not suffer. It is of more prominence where the change of input received power are frequent.Where as the actions taken to reduce convergence delay have reverse effect steady state performance.Steady State Error is has prolonged effect as it is seen over longer period.

2.1 Convergence Delay

Speed of convergence or delay from instance of input change till AGC response approaches less than 5% around reference output value; depends on several factors .As overshoot is seen at the instance of change the extent of overshoot depends on previous gain and present input.This is Case where both are random information .For a high current gain, applied to previously received lower input power, suppose suddenly encounters a change of higher input power, the resulting over shoot will be larger. Further difference term used to calculate the updated gain will also be higher introducing a gain change of larger amount resulting in faster convergence. In case of smaller output changes gain changes will be slower.But the controllable parameters which can be adjusted so that the convergence delay can be reduced, are the integration length and step_factor

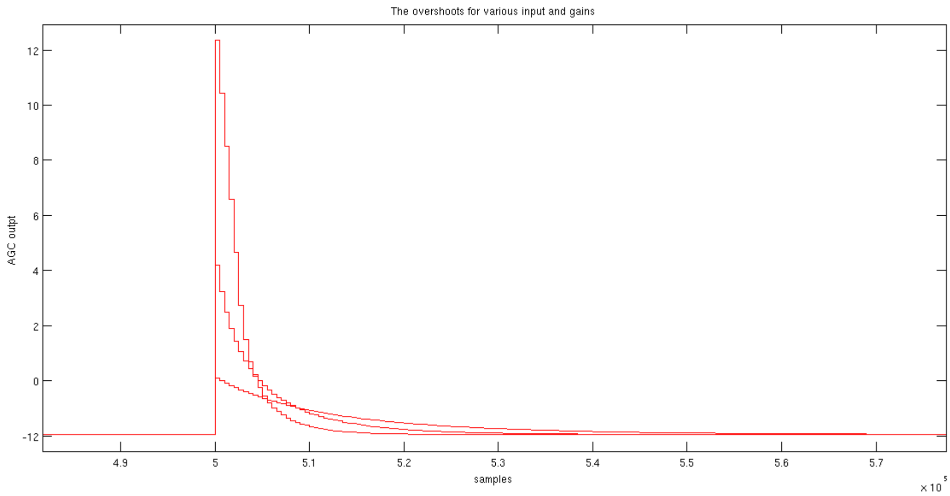

Figure 2.1: Convergence Delay

INTEGRATION LENGTH

Integration length is the number of samples utilized in deriving the output strength value. There can be output estimation done in terms of average absolute value or an RMS value giving the estimate of output power. Trade off affecting the convergence delay is the number of samples utilized in calculating estimate. Lesser number of samples will Yield into faster convergence delay.But lesser is the number of samples used poorer will be the estimation accuracy which being fundamental relation between accuracy and integration length. In later chapter the effect of varying size of integration length is discussed.For instance if convergence takes K iterations with N samples in each integration length, then the total delay in terms of samples would be $N \times K$. So there is a linear relation between integration length and delay.

STEP_FACTOR

Step_factor is the parameter which multiplies to difference term in gain updation relation controlling the amount of gain change. For a given RMS output value for higher step_factor faster would be the convergence delay.In later chapter it could also be found that for given input change we can derive max step_factor for which output converges fastest.

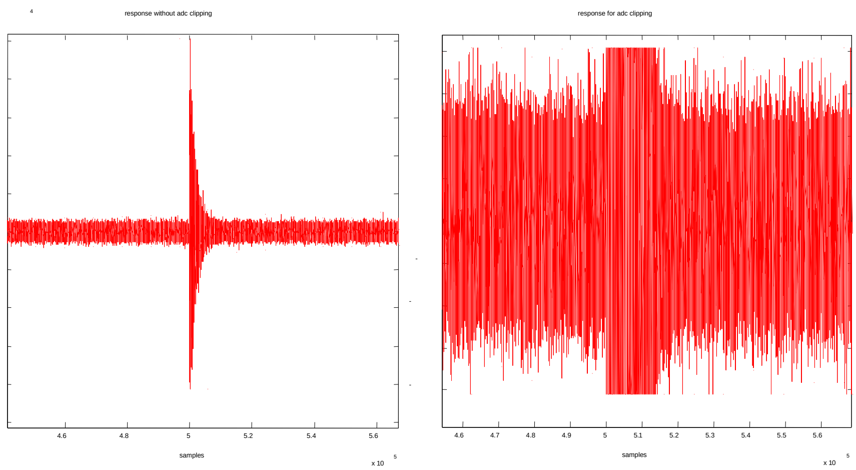

Figure 2.2: Transient Response

2.2 Transient SQNR

Transient SQNR is defined as the Average SQNR of AGC output starting from change in level of output till it subsides to 5% of reference value.Transient SQNR depends on several factors. The extent of overshoot depends on previous gain and present input.Then output will iteratively converge to the reference value.The clipping effect will be dominant in SQNR calculation for overshoot beyond ADC clipping levels. For smaller step_factors and shorter integration lengths the output will come out of clipping level much faster .The following plot shows higher SQNR levels for given 12dB change in input for various step_factors.

2.3 Steady state error

Steady State error is calculated after settlement of the output transient response.The SSE is RMS error between original input and the AGC output.In steady sate AGC output suppose to be scaled version of input. Following plot show the effect of larger Step_Factor to that of smaller ones.Figure clearly shows for larger Step_factor the SSE is higher and for smaller Step_Factors it is reduced.We can explain the observation as thus, In process of applying updated gain based on the previous estimated output;which in a way trying to correlate the previous output with Incoming input samples(which is useful for slowly varying envelope).The correlation is more prominent for larger Step_Factor.But for OFDM modulated signals which manifests randomness sample to sample, trying to correlate produces higher error.For smaller step_factors the Updation of gain based on previous estimated output is minimal almost as a costant gain being multiplied.which we can say is having least correlation from previous output value.Thus smaller step_factor produces smaller steady state error. Further effect of same error on detected output remains to be determined.

Effect of integration length on SSE:As discussed earlier shorter integration length results in reduced accuracy in estimated output and higher Steady state error.But shortest integration length is taken to be 50 whose effect on accuracy is noted in next chapter.integration lengths 500, 2000, 5000 are considered to the effect of on SSE .

CHAPTER 3

Simulation Study

3.1 Considerations

3.2 Input modelling

The received OFDM signals follow Gaussian distribution with mean zero.The variance of the Gaussian distribution indicates the received power.Received input considered is at base band after down conversion.The dynamic range of the input considered for AGC operation is ten times the dynamic range of ADC.

3.3 Reference output

12 bit-ADC being widely used in wireless application, same is chosen here for simulation.As we know there are two types of errors induced due to ADC. One is because of clipping of saturating signals and other is due to mere quantization of signals in linear region of ADC.Lower Strength signals get worse affected by quantization noise, where as higher strength saturating signals suffer due to clipping. So there is always a need to scale the received input so to maximize the SQNR.This output level of ADC is taken as reference output.

To find out input corresponding to maximum SQNR ADC output ,Initial Gaussian input of 0dB variance (the power corresponding to voltage Vmax of ADC is taken as reference power; all input and output powers are further normalized with this power) is scaled to various variances spanning the dynamic range of ADC and in each case Average_SQNR is noted.The scaled variance for which average SQNR is max is taken to be Ref output. .For chosen 12-bit ADC, above analyses resulted in giving -12dB to be the AGC reference output power.

3.4 Effect of Step_factor

AGC will respond to the changed input based on fed back rms output .This will go on as an iterative pro cess .Gain is increased iteratively in steps so that error in steady state is reduced.There are several ways in which steps sizes are designed. In a basic Iterative process for applying gain represented as.

$$Gain\_present = Gain\_previous + step\_factor(Ref\_output - Est\_output) \quad (3.1)$$

Step_factor is the parameter which decides speed of convergence.Higher step_factor even though results in faster convergence but results in larger steady state error.Vice versa is true for smaller step_factor. An analyses[3] on a feedback AGC the, the optimum step_factor depends on both ref value and input.for given reference value we can arrive at table of optimum step_factors covering entire dynamic range of input with suitable resolution .This set will give the fastest convergence. Following is table derived for various input levels. The performance measures were analyzed for various input power

Input power level in dB	Max_Step_factor
-48	9.7656e-005
-42	4.8828e-005
-36	2.4414e-005
-30	1.2207e-005
-24	6.1036e-006
-18	3.0518e-006
-12	3.0518e-006
-6	7.6294e-007
6	1.9073e-007
12	9.5368e-008

levels by varying step_factors suitably for each case

For input power of -24dB;Step_factors=[6.1036e-006,3.0518e-006,3.0518e-006]

For input power of 0dB;Step_factors=[3.814e-007,1.9163e-007,9.5368e-008]

For input power of 12dB;Step_factors= [9.5368e-008,4.8343e-008,2.4176e-008]

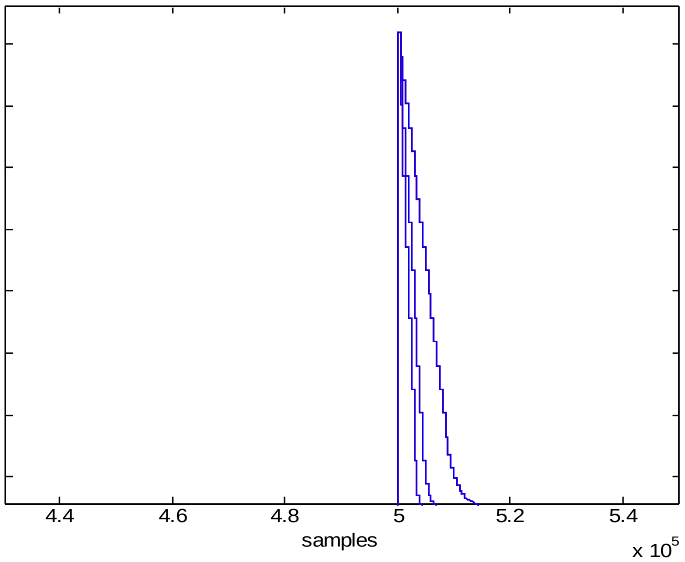

Figure 3.1: Response of AGC to Varying Step_factor

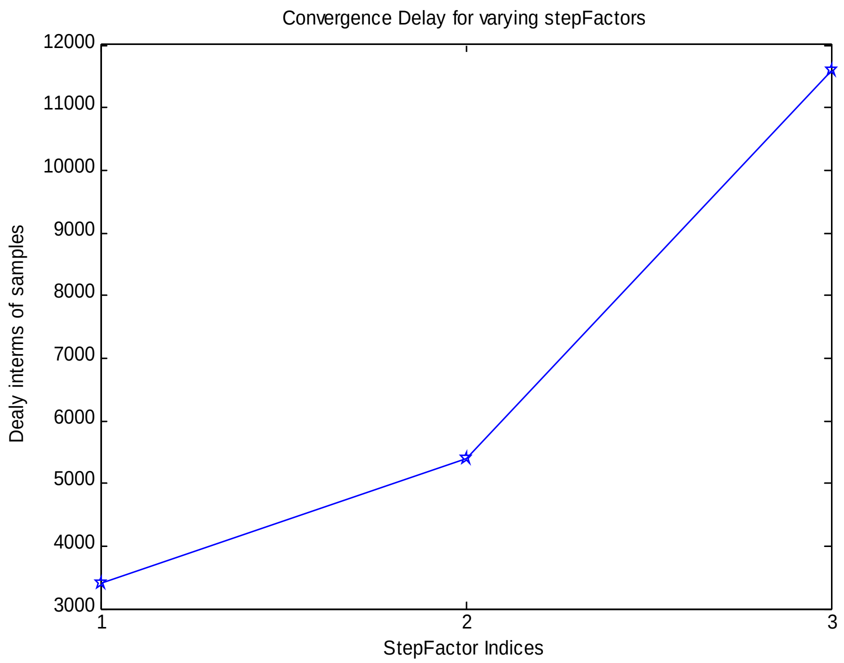

Figure 3.2: Convergence Delay with varying Step_factors at -24dB input power

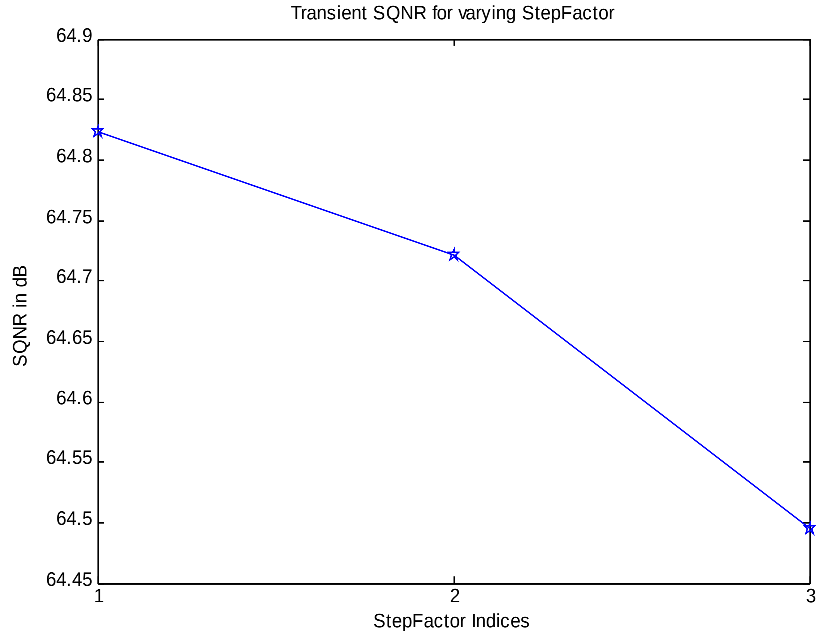

Figure 3.3: SQNR Changes with varying Step_Factors at -24dB input power

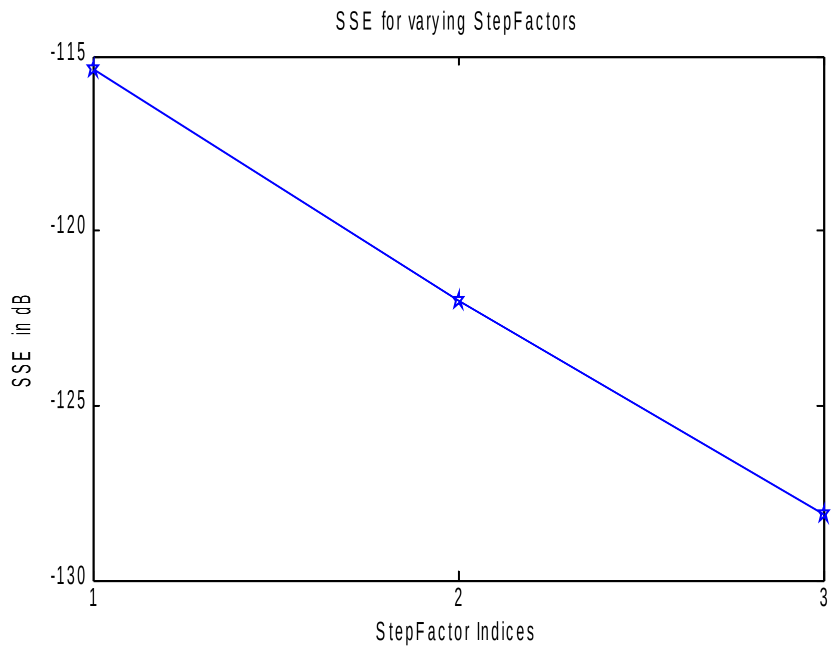

Figure 3.4: Steady State Error with varying Step_factors at -24dB input power

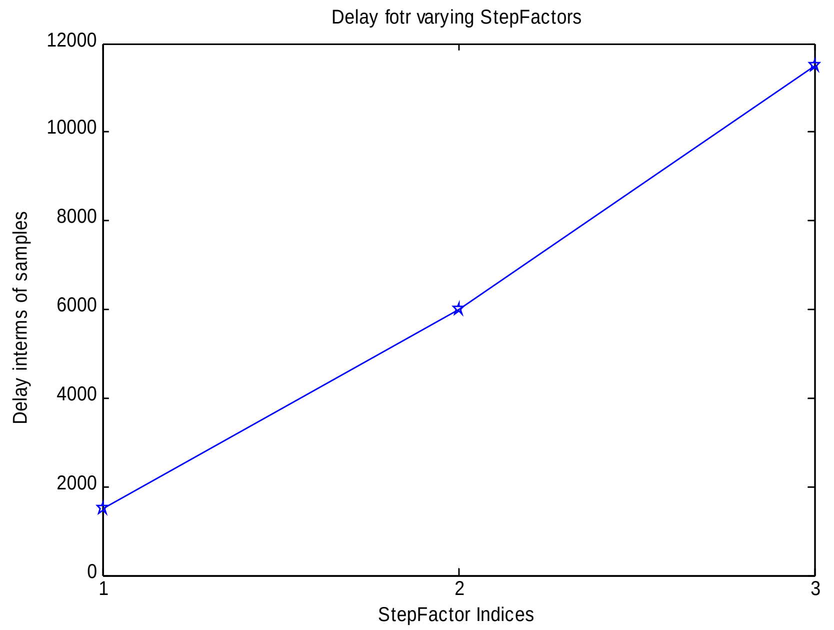

Figure 3.5: Convergence Delay with varying Step_factors at 0dB input power

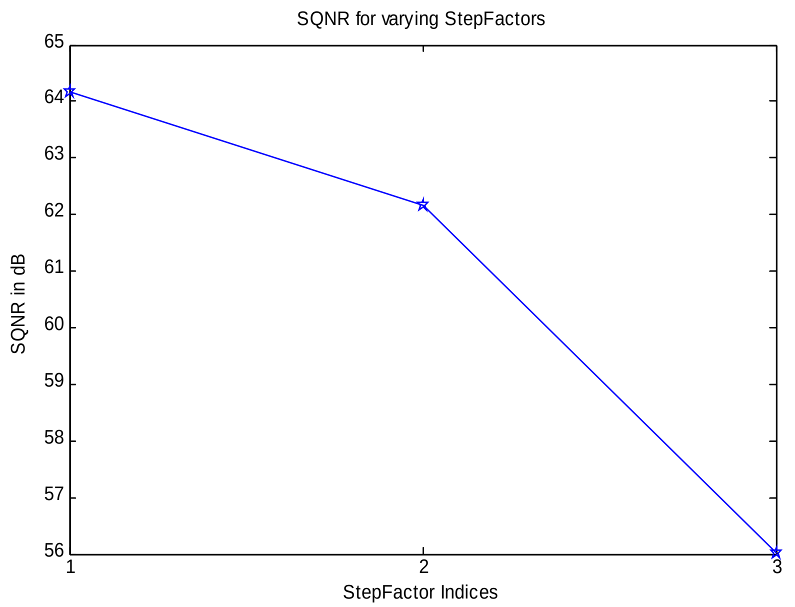

Figure 3.6: SQNR Changes with varying Step_Factors at 0dB input power

Figure 3.7: Steady State Error with varying Step_factors at 0dB input power

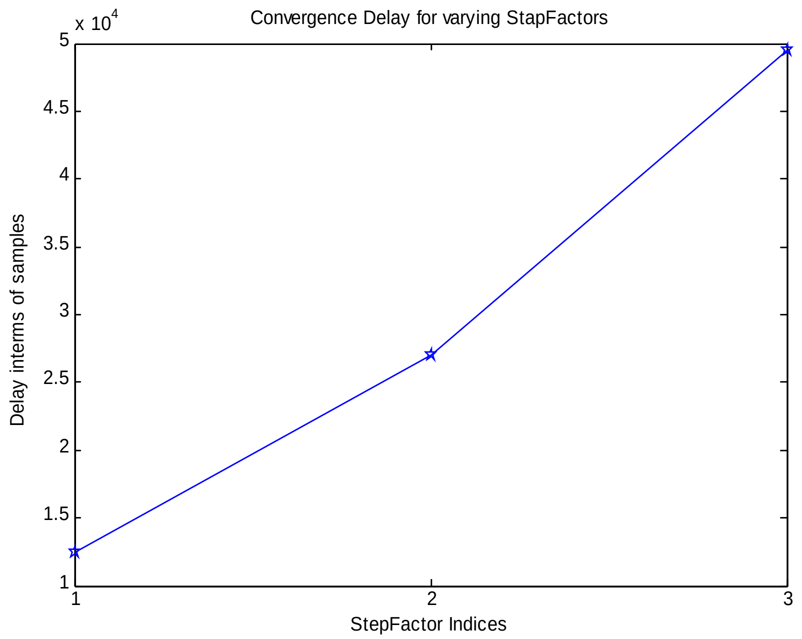

Figure 3.8: Convergence Delay with varying Step_factors at 12dB input power

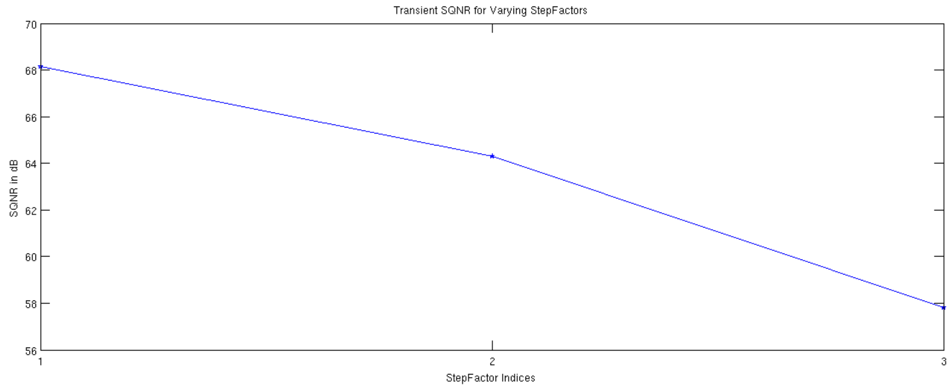

Figure 3.9: SQNR Changes with varying Step_Factors at 12dB input power

Figure 3.10: Steady State Error with varying Step_factors at 12dB input power

3.5 Integration length

Integration length is another controllable parameter which affect performance characteristics.Intuitively shorter integration length gives faster transient response;same time suffers in accuracy of output estimate.Longer integration length incurs more delay but generate more accurate output estimate;Shorter integration lengths are useful when there is fast response expected, like the sudden changes in received power as in scope of work.Longer length are use full in tracking slower envelope changes due to Doppler.Shortest integrating length has a statistical constraint depending on which we derived number of samples to be 50 samples with 8% of accuracy of estimated value.Other way the longest integration length is limited by the cut-off frequency as AGC acts as the High pass filter for the Doppler envelopes.

Various integration lengths giving estimate RMS value with different accuracy as stated below

Integration lengths (in terms of samples)	Accuracy in % of estimated value
50	8%
500	2.5%
2000	1.2%
5000	0.8%

So we can expect that with same accuracy Steady state error will also get affected.Analyzing the effect on convergence delay caused due to the integration length of N samples with K iterations would result in $N \times K$ sample delay. Where as Transient SQNR would remain constant for the following reason.For an overshoot of same amount and step_factor remaining same, longer integration length AGC response remains in clipped region for longer time with overall transient response also lasting for longer time.Where as due to shorter integration length AGC response comes out of clipped region faster.But same time transient response involved will also be shorter.So if we calculate average SQNR in the transient period of respective integration lengths it is would to be same.But if we consider advantage of shorter integration lengths having faster convergence and take SQNR for fixed number of samples covering both transient responses, trade off can be clearly seen as being presented in following plot. For input power of -24dB For input power of 0 dB

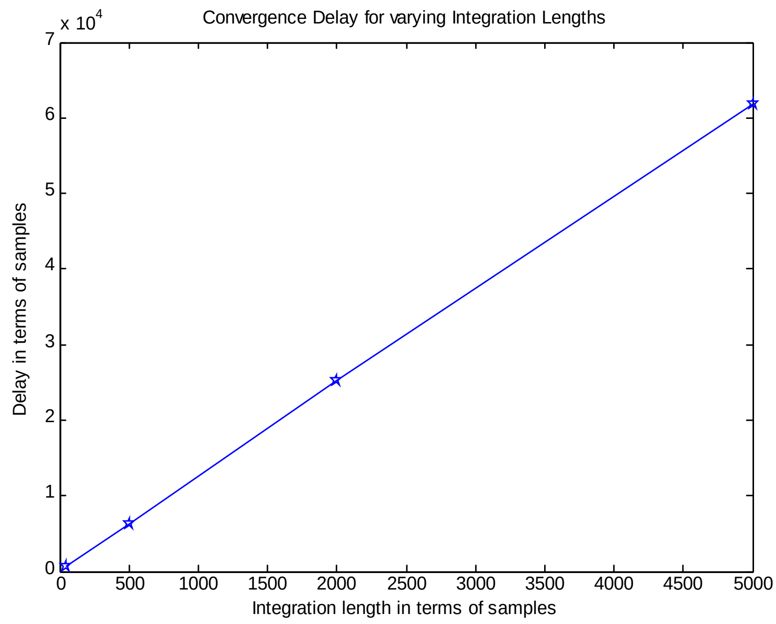

Figure 3.11: Convergence Delay with varying Integration at input power -24dB

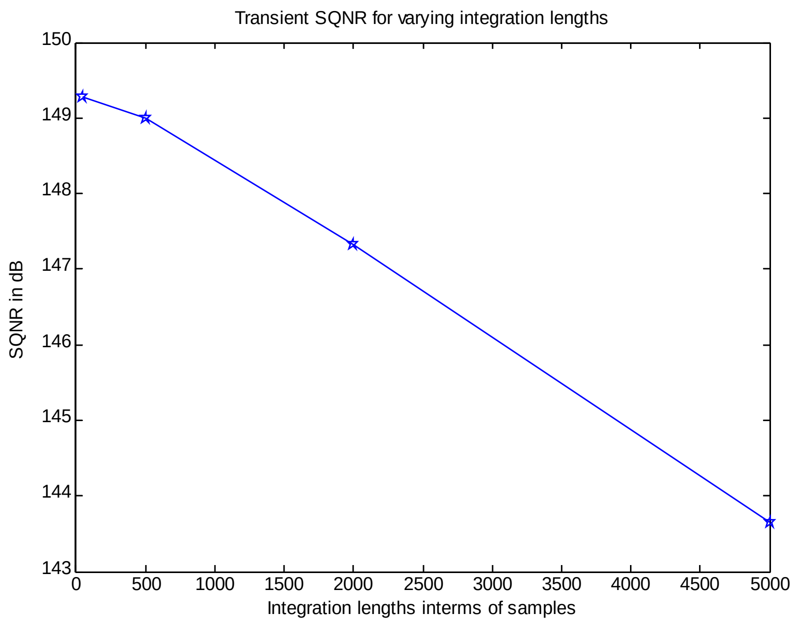

Figure 3.12: Transient SQNR with varying Integration lengths at input power -24dB

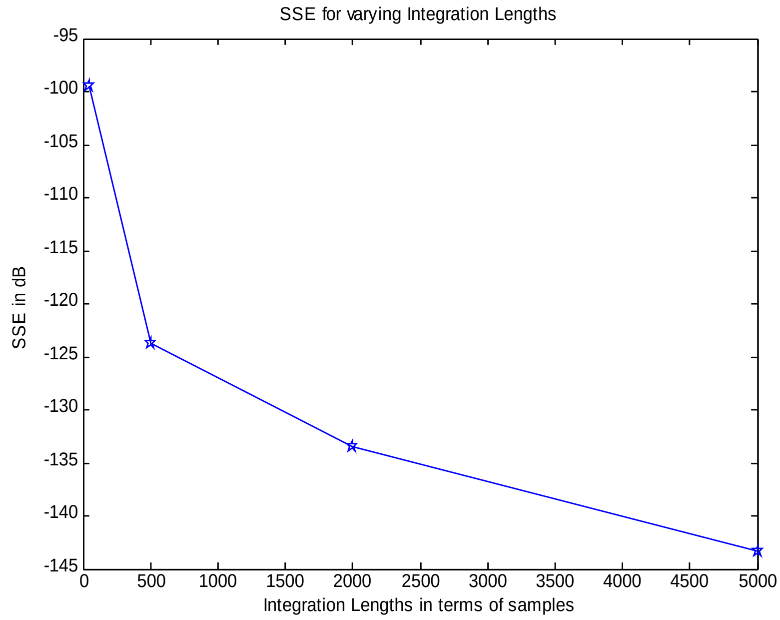

Figure 3.13: Steady Sate error with Varying Integration lengths at input power -24dB

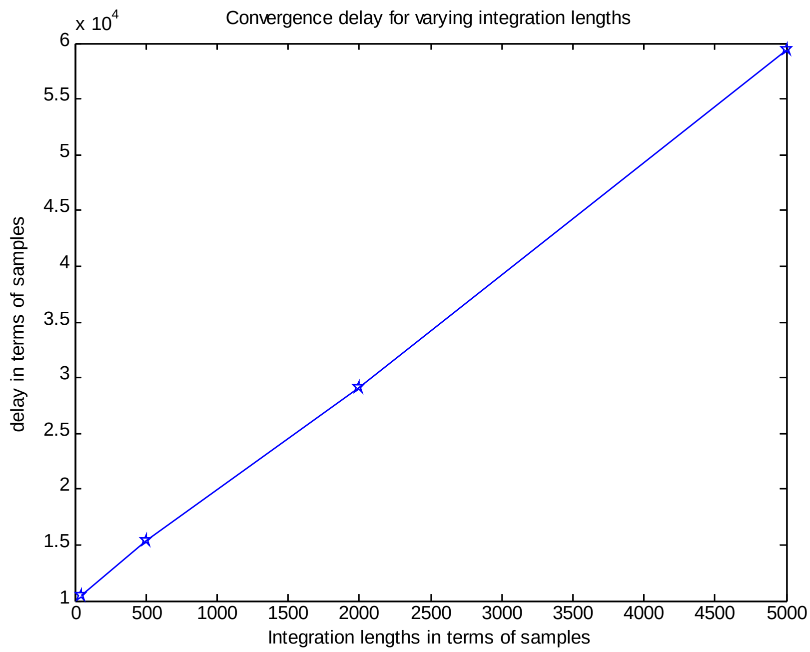

Figure 3.14: Convergence Delay with varying Integration at input power 0dB

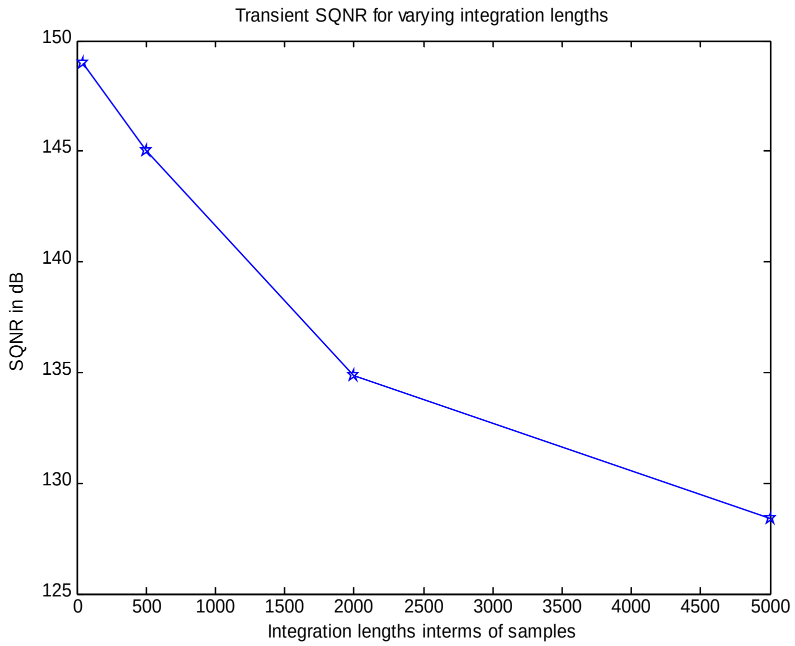

Figure 3.15: Transient SQNR with varying Integration lengths at input power 0dB

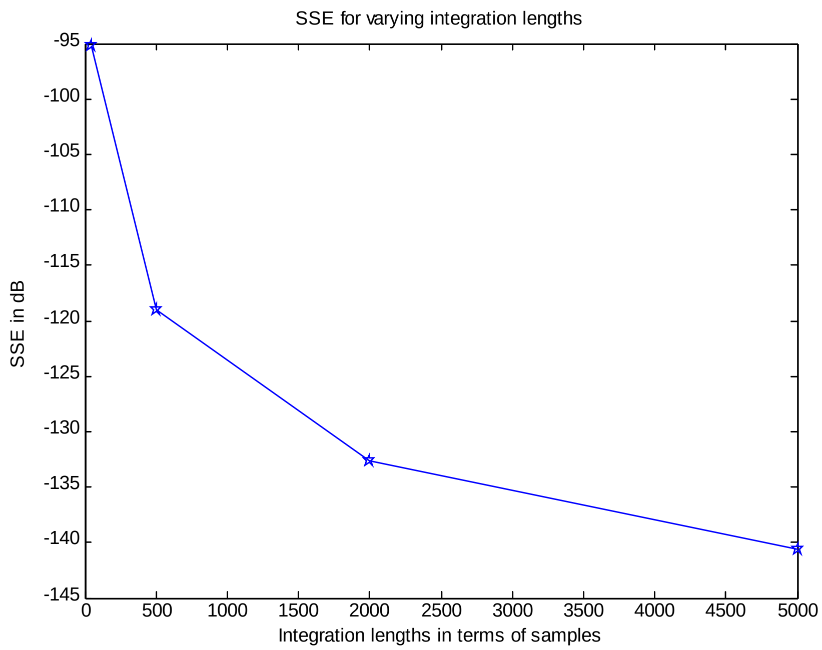

Figure 3.16: Steady Sate error with Varying Integration lengths at input power 0dB

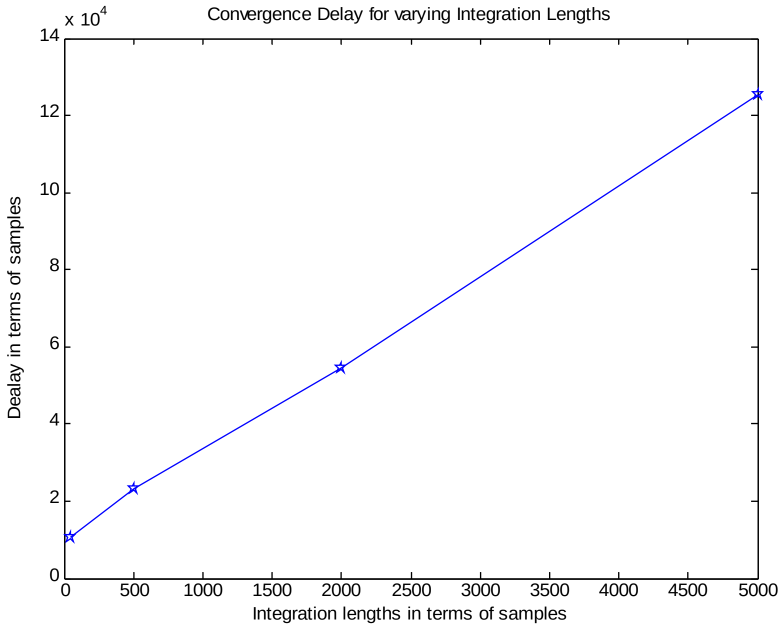

Figure 3.17: Convergence Delay with varying Integration at input power 12dB

For input power 12dB

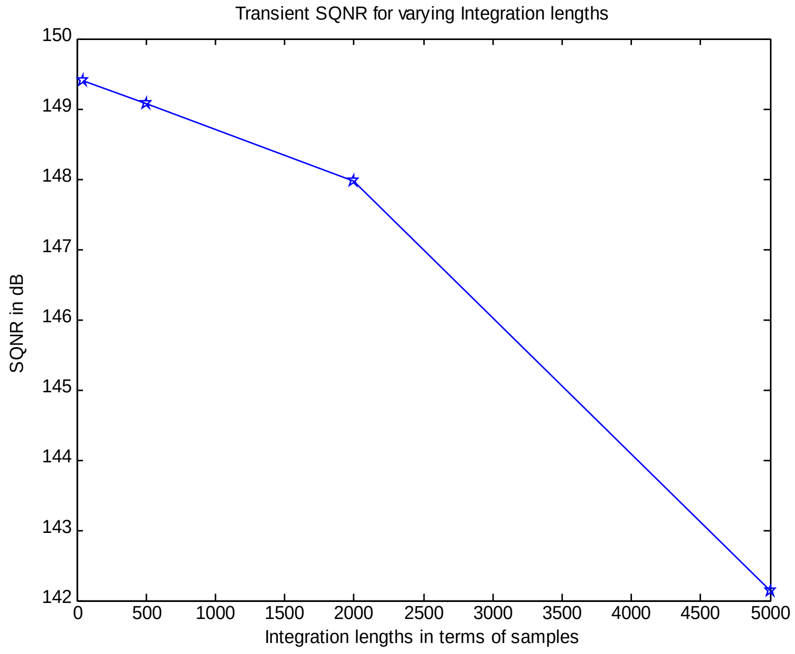

Figure 3.18: Transient SQNR with varying Integration lengths at input power 12dB

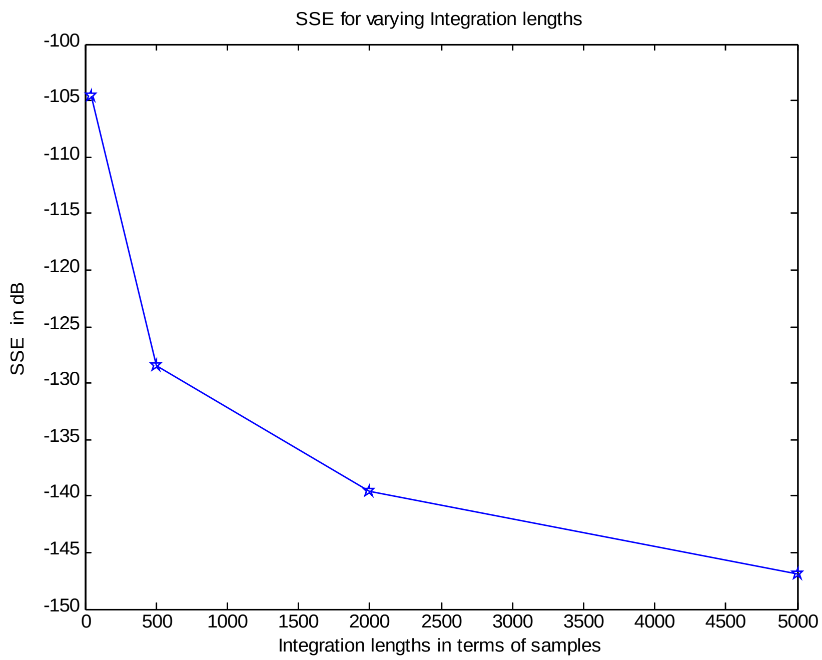

Figure 3.19: Steady Sate error with Varying Integration lengths at input power 12dB

CHAPTER 4

Strategy For Sudden changes

4.1 TDD structure

LTE frame is of 10ms duration, which is divided into ten 1ms subframes.LTE frame is partitioned for uplink and downlink as shown in figure. Down link and Uplink in TDD are sharing time resources in one of several configurations allowed in LTE scheme.LTE down link is based on OFDM modulation.

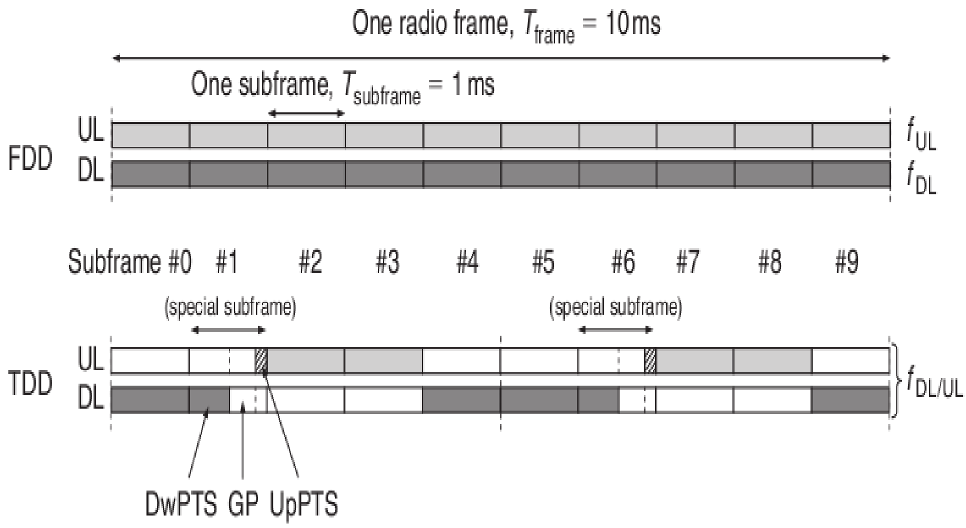

Figure 4.1: Timing Structure of TDD

4.2 Proposed Strategy for handling sudden change

The situations where the received power levels vary suddenly is approximated with a step envelope modulated OFDM signal.The situation occurs when there is a huge obscuration preventing transmitted power, soon after line of sight environment or receiver enters in an enclosed area reducing the received power. Similar situation is seen in TDD mode of operation,where there is a periodical change over between transmitter and receiver operating alternatively as explained in previous chapter.Even though the change is approximated with step change,practically change is smoothened by diffraction at the obscuration edges;also sudden variation is limited by bandwidth of receiver chain. In TDD mode the change is periodical and occurs at known instance.Similarly in obscuration kind of situation ,while defining problem it is assumed that there exists a parallel channel running which indicates about instant of change .Thus as soon as change detection signal is received ,the integration length is reduced to the minimum length option as 50 samples.This option estimates the output level in least time with an accuracy of 8% of estimated value.

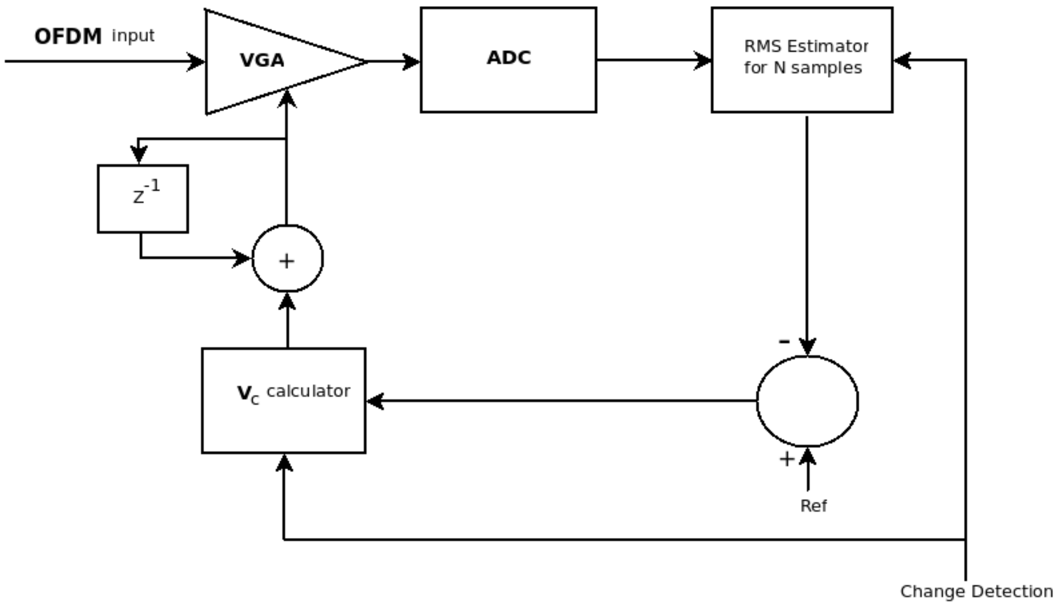

Figure 4.2: Block diagram of Adaptive AGC

As soon as 50 samples are collected, output RMS value is calculated and corresponding optimum step factor is applied in updating gain. So the convergence would be fast.During this phase Integration length is kept 50 samples only.Every time the RMs value estimated is compared with reference to be within 2dB of reference output.If so then step_factor is changed to a value ,which would be slowest step_factor considered. The performance evaluation of the scheme is done as under. The input varied from standard deviation 0dB to that of -24dB at an instant of 500000 sample.A change detection signal is sensed and the step_factor changed to 4.8828e-004 from steady state step_factor of 4.7684e-007. In first experiment the integration length is kept at higher value as 2000 samples and it is not adapted with the change.We can see in zoomed up plot that because of max_step_factor in about 4 to 5 iteration output returned to reference output.

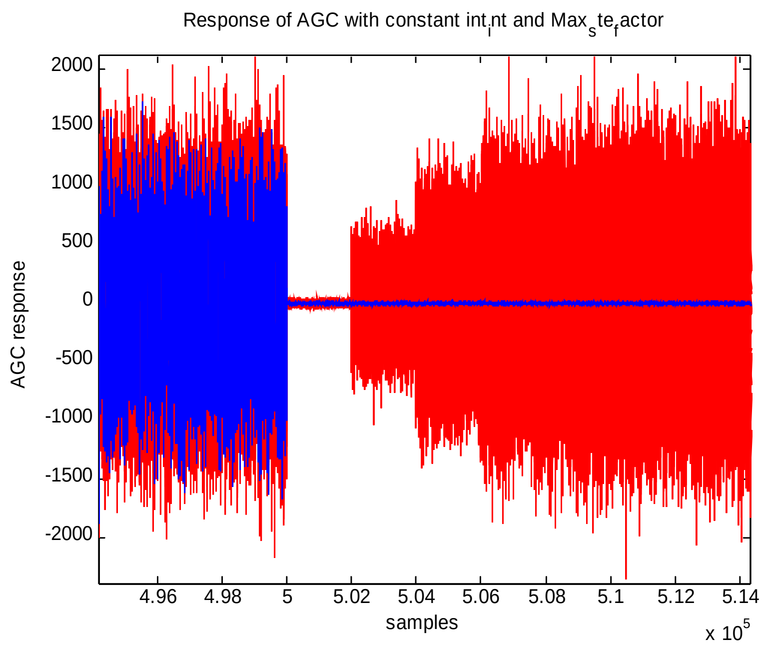

Figure 4.3: Adaptive AGC Response 1

In second experiment both step_factor and integration lengths were made adaptive resultant convergence delay has decreased to almost 50x5 =250 samples.As soon as it has converged to less than 2dB integration length and step_factor are brought back to earlier values.

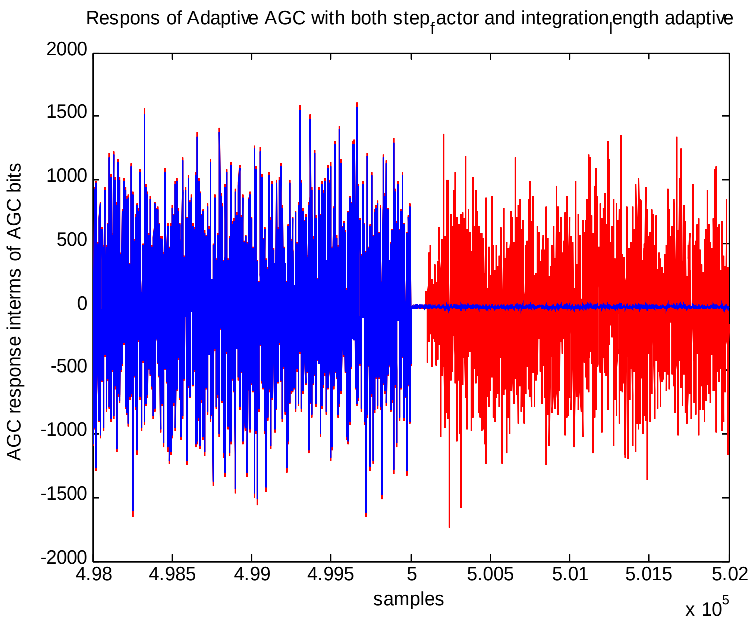

Figure 4.4: Adaptive AGC Response 2

Further following is comparison of performance measures between normal and adaptive AGCs

For a input change from 0 dB power to -24dB power

Convergence Delay for Adaptive AGC = 300 samples (6 iterations of 50 samples)

Convergence Delay for normal AGC = 46000 samples(23 iterations of 2000 samples)

Transient SQNR for Adaptive AGC = 77.85 dB

Transient SQNR for normal AGC = 70.58 dB

SSE for Adaptive AGC = -66.7 dB

SSE for normal AGC = -67.3 dB

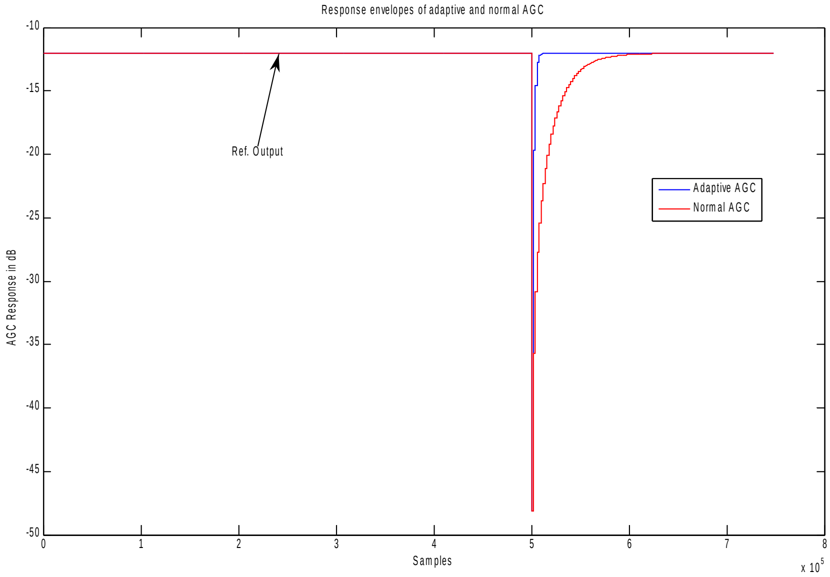

Figure 4.5: Convergence delay for Adaptive and normal AGCs

Input power changed to 13dB

Convergence Delay for Adaptive AGC = 400 samples (8 iterations of 50 samples)

Convergence Delay for Adaptive AGC = 300 samples (6 iterations of 50 samples)

Convergence Delay for normal AGC = 46000 samples(23 iterations of 2000 samples)

Transient SQNR for Adaptive AGC = 77.85 dB

Transient SQNR for normal AGC = 70.58 dB

SSE for Adaptive AGC = -66.7 dB

SSE for normal AGC = -75.3 dB

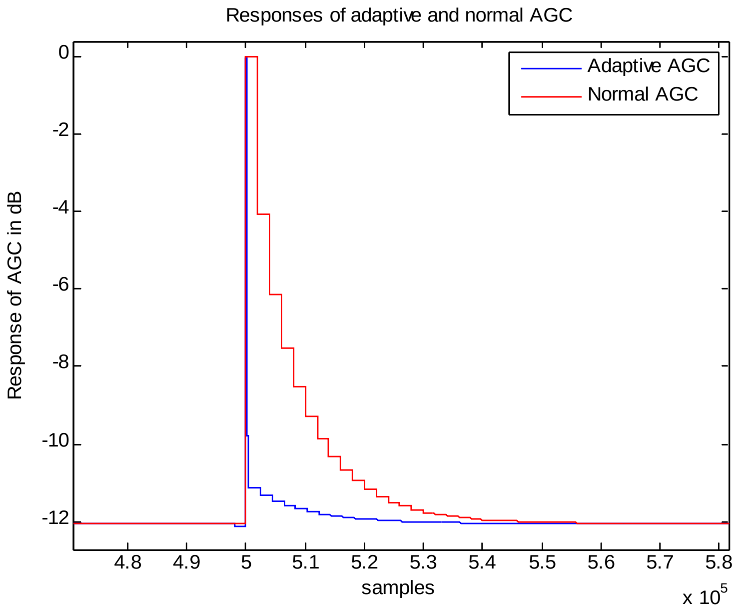

Figure 4.6: Convergence delay for Adaptive and normal AGCs

CHAPTER 5

Conclusion and scope for future work

The particular work is presented as detailed behavioral study of AGC for OFDM input. The Convergence delay , Transient SQNR and Steady State Error are Taken as performance measures to bring out the trade offs.A Strategy is also presented to handle a sudden variation in input power level. In this strategy way to achieve faster Convergence keeping Steady State Error low is presented.

As a continued work lot of scope exists in designing iterative gain updating as well as setting up of initial gain value. This can be used as study before practically implementing scheme and proving its veracity.

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