Reduction of Saturation Error Value of PAL Television System Using Inverse Matrix Generator Model

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ABSTRACT

Reduction of Saturation Error Value of PAL Television System Using Inverse Matrix Generator Model, is aimed at the need to improve received picture quality in the event of distortion in the transmitted picture that could cause differential phase difference on received image signals which is the cause of saturation error. Saturation error leads to darkening of the picture colour and, thus, introduction of huge hue changes from the original. This thesis highlights the effects of saturation error to television image viewing, it analyses various methods that could be adopted to reduce saturation error, and it provides a unique model that reduces or eliminates saturation error of PAL colour television system. The model utilizes an inverse matrixes generator that is combined with a zero-window comparator and a low-pass filter network to ensure that saturation error of PAL television is reduced or eliminated. An analysis of the inverse matrix generator model using MatLab simulink shows that it adequately reduces saturation error by 99%; thus, presenting itself as a unique model that can be used to improve the quality of pictures and images when transmitted under poor condition, causing a differential phase error to be introduced into the system.

Keywords: PAL, Saturation, Amplitude, Hue, Inverse Matrix.

1.0 INTRODUCTION

Saturation is the amount of whiteness of a hue or colour **(Biebuma, 2000)**. When this value is distorted, it can not give the true hue or colour information to the receiver as it is transmitted. Thus, the receiver is given marginally distorted colour information. More so, the picture appears dimmer than the transmitted picture. This fluctuation can be unpleasant to the eyes. Saturation reduction is a characteristic of PAL colour system. Thus, reduction of saturation error value is a worthwhile proposition.

The Journal, Engineer's Guide to Decoding and Encoding, examines PAL, NTSC and SECAM block diagram circuitry individually and their respective encoding and decoding techniques. While it is explicit in its analysis on the role the individual systems play in the overall colour television system, there is no solution to the saturation loss problem in PAL system **(Watkinson, 1994)**. It does not consider also, the user preference for the saturation drop in the colour system.

The journal, Analogue TV Systems: Migration from Monochrome to Colour, highlights the technical details of how television migrated from monochrome to colour. It analyses the spectrum of the luminance signal as well as the vectors of the chrominance signals. It also shows the block diagram implementation of the monochrome and colour television **(Yao, 2003)**. However, solution was not given for the saturation error introduced in the PAL colour system.

The journal, Digital Audio and Video Broadcasting Technology: A Practical Engineering Guide, analyses how each colour systems add up with the monochrome to give the respective colour television system. It goes further to state the various factors affecting colour television systems and how the signals can be measured in various parameters **(Fischer, 2010)**. The journal, thus, failed to state the technique or procedures for reducing saturation error in the received PAL system television.

Thus, this report is targeted at establishing a model and method that is unique in improving saturation of the received colour in PAL to near optimum by way of reducing the saturation error value.

The internal mechanism of PAL standard makes it possible for saturation error to be introduced if there is a differential phase difference in the transmitted picture signal as shown in equation (1).

$$f(t)=\frac{1}{2}\left(\sin\left(wt+\theta+\beta\right)+\sin\left(wt+\theta-\beta\right)\right)=\sin\left(wt+\theta\right)\cdot\cos\beta \quad \ldots..(1)$$

Here, β is the differential phase introduced into the system and cos β which is the dynamic amplitude that is modulated as the saturation of the colour signal reduces with increased differential phase change **(Wikipedia, June 2013)**.

2.0 RELATED WORKS

The patent by **Freyberger et al (1986)** of the United States patent with number 4568967 proposes a model for digital colour signal processing to include a multiplier which multiplies two demodulated digital colour difference signals by a digital colour-saturation signal to provide three time-division-multiplexed signal pairs, each of which is added to the digital luminance signal by an adder. The color-saturation-signal input of the multiplier is preceded by a second multiplier to which the color-saturation signal and multiplier factors stored in a memory are applied. These multiplier factors are permanently stored by the manufacturer of the color television receiver or can be adjusted during the operation of the receiver. The three adders are followed by three digital-to-analog converters which provide the analog color signals. The disadvantage of this model is that it does not maximize the saturation but increases it to a defined level.

Smith, A. V. (2004), in his patent with number US6674487B1, establishes a model for hue correction using a saturation control. This model is achieved by a colour space value adjusted based on a hue angle and a saturation value, and a second colour space value adjusted based on the defined hue angle and the saturation value. The second colour space values are processed to obtain a hue–adjusted colour space value. This model works perfectly for NTSC colour system that can treat each horizontal scan lines uniquely to obtain the individual colour make-up unlike PAL. It is difficult to obtain the individual hue until after demodulation in PAL. The demodulated colours are already distorted as there is an ingrained saturation reduction. Also, it would lead to reduction of vertical saturation by half.

Another patent by **Lin Chien-Hung et al (2005)** with number US6961098B2, proposes a model of TV encoding with a function of adjusting hue. This model has a function for adjusting hue for receiving a first and second colour mixture signals comprising a first and second multiplexer which is representative of a hue angle and its inverse or negative, a Sin-Cos generator, a first and second multiplier circuit and an adder. While this patent can work perfectly for NTSC as it requires a minimum interface to incorporate the model, for PAL, it will require a great deal of overhauling of the standard procedures for PAL or could add huge deal of cost and interface materials to effect. Also, this model deals with individual hues while PAL deals with colour differences. Thus, the power dissipation will be higher and power/current inefficient.

It should be noted that any model that is used on NTSC colour system, if used in PAL would lead to omission of images of the even number lines that are in phase alternation with the odd number lines. This procedure would lead to decrease or reduction of vertical resolution by half. According to **Fischer (2010),** television system especially NTSC and PAL experience various forms of distortions during its transmission that could result in phase error. According to **Wikipedia (January, 2014),** PAL system is susceptible to vertical resolution loss in the bid of avoiding phase error. Phase error can not be avoided by television systems. The essence, then, of the experimental work is defeated because it has introduces another problem, that of reduced vertical resolution.

Biebuma (2000) defines saturation as the amount of whiteness of a colour or light. **Smith (2004)** defines saturation as the depth or intensity of the colour. Also, **Anthony (2010)** defines colour saturation as the amount of gray in the colour. That is to say, the more saturated the colour is, the less gray it has and vice versa. Anthony’s definition is an inverse of how Biebuma defined colour saturation. Biebuma’s definition of saturation is on the top scale of the amount of whiteness (lesser gray). Thus, both can agree that the more saturated a colour is, the whiter (or lesser gray) it is and from Smith the more intense it is, and vice versa.

Biotech (2006), while discussing the disadvantages of PAL notes that in the process of holding a stable hue through its line inversion technique, the saturation becomes variable. He acknowledges that while the variable saturation effect can not be ignored, the eye can more readily accommodate it to hue variation.

In a series of experiments, **Edward et al (2009)** investigated the role of color in human perception of naturalness by asking subjects to rate the naturalness of the color saturation for different images. It was found that observers could easily differentiate unnaturally over or under-saturated images from their original natural counterparts with certain accuracy. Moreover, they observed that this ability is not based on the observers' memory of specific pictures nor is it based on high-level knowledge about object color (memory color) since observers could correctly judge natural color saturation for images they had never seen before and for objects with native colors (e.g. oranges) and non-native colors (e.g. cars).

Anthony (2010), in his journal relates that saturated pictures are exciting and dynamic and tend to be attractive. He asserts that in a work environment, it can slow down the performance of tasks. He notes that it is the reason why under-saturated colour icons are used as command button to make work efficient. However, in terms of viewing, under-saturated picture is boring and unattractive. This view is supported by **Jon (2010)** that it can affect viewers' mood.

Considering the effects of saturation error to picture viewers, **wikipedia (August 2014)** defined colour saturation as the colourfulness of a colour relative to its own brightness; and, defining colourfulness as the degree of difference between a colour and gray. It also defined chroma as the colourfulness relative to the brightness of another colour that appears white under similar viewing conditions. It can thus be concluded that saturation error can have an adverse effect to the colourfulness of the received picture images.

3.0 METHODOLOGY

The methodology for the research of this paper is in stages of Mathematical model of design, flowchart of design approach, computer modelling and simulation of design.
The methodology of achieving the set objective is set out in the sequence of events listed below:

- Input signal sinusoid representing the PAL picture signals.
- Low-pass filtering for envelope detection.
- Passage through a zero-window comparator to exclude all zero input signals.
- The passage into the Inverse Matrix generator.
- A multiplier with original signal to give a corrected and optimal final output signal.

The above sequence of design approach ultimately leads to a model that is adopted to reduce the saturation error from a given value to its optimum value.

3.1 Mathematical Model of Inverse Matrix Generator

The model generated for the design in reducing the saturation error of PAL television colour system is derived systematically in stages as shown below:

Given $Q(t) = A\sin wt$ ……………………………………………(2)

Where A=amplitude of sinusoid signal, Q(t) = Input picture signal
Then at the low-pass filter, its transfer function is given as:

$$G(s) = \frac{X(s)}{F(s)} \quad \text{……………………………………………..(3)}$$

Where X(s) = output Laplace signal and F(s) = Input Laplace signal
Hence, using a simple low-pass filter,

$$G(s) = \frac{1}{s+1} \quad \text{……………………………………………(4)}$$

This yields a first-order linear differential equation as follows:
Equating (3) and (4) and cross multiplying, then,

$$sX(s) + X(s) = F(s) \quad \text{…………………………………………(5)}$$

Using an inverse Laplace transform on equation (5) to get the impulse response in the time domain, then,

$$\frac{dx(t)}{dt} + x(t) = f(t) \quad \text{………………………………………(6)}$$

Applying the power square law to the input signal to detect the envelope,

$$f(t) = Q(t)^2 \quad \text{……………………………………….(7)}$$

Solving equation (6) using an integrating factor and application of the techniques of integration, taking into account an initial condition of t = 0, and substituting of variables from equations (2) and (7) then,

$$x(t) = \frac{A^2}{2}\left\{\left(1 - \frac{\cos 2wt - 2w\sin 2wt}{1+4w^2}\right) - \left(e^{-t}\left(1 - \frac{1}{1+4w^2}\right)\right)\right\} \quad \text{…….(8)}$$

Then,

$$A = \sqrt{\frac{2x(t)}{\left(1 - \frac{\cos 2wt - 2w\sin wt}{1+4w^2}\right) - \left(e^{-t}\left(1 - \frac{1}{1+4w^2}\right)\right)}} \quad \text{……… …..(9)}$$

Let $$c = \left(1 - \frac{\cos 2wt - 2w\sin 2wt}{1+4w^2}\right) - \left(e^{-t}\left(1 - \frac{1}{1+4w^2}\right)\right) \quad \text{……(10)}$$

Thus $$A = \sqrt{\frac{2x(t)}{c}} \quad \text{……………………………………… …… .(11)}$$

$x(t)$ is the output from the low-pass filter in an impulse response time domain which is shown to detect and output only amplitude (A) of the input signal $Q(t) = A\sin wt$. Details are shown in Table 1.

The initial variable value of c in table 1 is the result of the low-pass filter action.
Hence,

$$B(t) = \frac{Q(t)}{A} \quad \text{………………………………………………… ..(12)}$$

Where B(t) = final output signal, Q(t) = Input signal and A = Input amplitude
The reciprocal of A in equation (12) is generated by the inverse matrix generator.

3.2 Sequence of Design Approach

The flowchart showing the design procedure and approach is shown in Figure 1.

3.3 Simulated Design of the Inverse Matrix Generator

3.3.1 Modelling of Saturation Amplitude Extractor

The block diagram model of the Saturated amplifier extractor is shown in Figure 2.

From the mathematical model developed in figure 2, in extracting the saturation amplitude value, the square law is applied to obtain a DC component in the spectrum which is passed into a low-pass filter.

A low-pass filter is implemented using the transfer function since it is difficult implementing the circuit design in the simulation. The transfer function used here for the low-pass filter is of cut-off angular frequency of 1 rad/s corresponding to 0.02546Hz. This helps the circuit to filter out any time-varying signals and its harmonics to leave behind an almost perfect DC signal that is needed. When implemented by circuit simulation, the transfer function is converted to an op-amp with an RC network to give the necessary low-pass filter cut-off frequency.

Let A sin*wt* be a sinusoidal saturation obtained after PAL phase correction, where A = cosβ and β is the phase differential error introduced to the system.

Then, $$(A\sin wt)^2 = A^2\sin^2 wt = \frac{1}{2}A^2(1-\cos 2wt) = \frac{1}{2}A^2 - \frac{1}{2}A^2\cos 2wt \quad \text{……..(13)}$$

The result of the squaring as shown in equation (13) is passed into a low-pass filter where $\frac{1}{2}A^2$ is passed through while the sinusoid is blocked by the filter. Therefore, $\frac{1}{2}A^2$ is doubled then square rooted to obtain the value A. This principle is what is implemented in the block diagram of figure 2.

The value A is a very important value as input into the inverse matrix generator. The value A can be dynamic as picture fields vary sinusoidally. Thus, A gives a variable and dynamic input into the d input of the inverse matrix generator for an x or z output to be achieved.

3.3.2 Modelling of the Zero-Window Comparator

It is note worthy that zero can be an input value into the inverse matrix generator. A zero value can be either there is an absence of signal or a large error leading to minimum saturation. However, a zero input will yield an infinite inverse as the reciprocal of zero is infinity. Infinite value makes the system unstable. Thus, a zero-window comparator ensures that a zero value is not given as input into the inverse matrix generator.

It is important here that a zero input gives a non-zero output and a non-zero input gives a zero output. The zero-window comparator input and output is then passed into an analog **summer** which comprises an op-amp. The value gotten from the summer is then passed into the inverse matrix generator.

Figure 3 above I developed shows the block diagram model of the zero-window comparator. This will enable proper integration as a whole to design a comprehensive workable system.

The following are the possible outcome of the zero-window input, output and summer output .

As shown in table 2, the summer outputs the same zero-window input values for non-zero inputs. However, when zero-window input is zero, its output and summer output gives a nominal 5v. This ensures that the same value for non-zero saturation amplitude value enters the inverse matrix generator input and a nominal 5v enters the inverse matrix generator input in place of zero volts. This 5v can be converted to IRE scale of TV.

3.3.3 Modelling of the Inverse Matrix Generator and Error Correction

Figure 4 below I developed in line with inverse matrix equation shows the block diagram implementation of the inverse matrix generator using mathematical model.

The inverse matrix generator has 4 inputs *a*, *b*, *c* and *d* corresponding to 1, *b*, 0, *d* respectively. The value of *b* is chosen by the designer to use as output moderator (mostly the standard 0.70v or 100 IRE) while *d* serves as dynamic saturation amplitude input that has been gotten from the zero-window comparator and analog summer.

It has also for outputs *w*, *x*, *y*, *z* with *w* and *y* as 0 and 1 respectively while *x* is *b* multiple of the reciprocal of *d* (-*b*/*d*) and *z* is the reciprocal of *d* (1/*d*). The designer can choose *x* or *z* as it final output source. The output *x* is chosen if 1v or 140 IRE standard is super-saturated amplitude so that *b* can moderate it by multiplying. I chose *z* as my output source, taking the optimum amplitude as 1v.
To correct the reduced saturation amplitude to optimum 1v, the output *z*, from the inverse matrix generator is multiplied with the original erroneous saturation signal (that has been used to extract its saturation amplitude). The result is a 1v saturation amplitude signal as shown in the equation below:

Error saturation signal = $\cos\beta \cdot \sin wt = A\sin wt$ ……………….(14)

Where A = cosβ = constant = saturation amplitude

Error correction: $A\sin wt \times \frac{1}{A} = 1 \cdot \sin wt$ ………………………..(15)

The output source *z* produces $\frac{1}{A}$ output which is passed into a multiplier with the saturation signal to give a corrected saturation.

Figure 5, I developed below from a comprehensive application of the mathematical model equation, shows the complete implementation of the various blocks and circuits that implements the saturation error value reduction. Here, the various detailed blocks are masked into simpler or single blocks. Here also, input b is taken as 0.70v equivalent to approximately 100 IRE.

When output *x* of the inverse matrix generator is used instead of *z*, the corrected amplitude becomes 0.70sin*wt*. This ensures that the picture signal is never over-saturated to enable a clipping of signal. The attached oscilloscope does not in any way contribute to the system workability, but helps to measure the signals at the end point of connection. This helps us to see if our desired output is generated.

4.0 RESULTS AND DISCUSSIONS

The simulation methods used in this thesis work are predominantly MatLab simulink and Proteus electronic design software. MatLab simulink is very helpful in designing a system and its subsystem models and effectively simplify the design model. When run, the individual subsystems each are executed producing results that are combined to give a desired end result.

The saturation value generated by PAL colour television system is a sinusoid with dynamic time-varying amplitude and frequency (depending on the hue transmitting at that instant). Thus, a sinusoid with a time-varying amplitude and frequency can be simulated using a steady-state amplitude and frequency instead and tested against worst conditions of the amplitude and frequency. It can, thus be said that the worst case amplitude is zero and the worst case frequency is zero or purely dc.

The chosen simulated sinusoid to represent the sinusoid generated by PAL colour television as it corrects a given phase error is 0.6sin300t. This implies that it is assumed that a properly saturated colour signal must have amplitude of 1 given simply as sin300t. The angular frequency chosen is 300 rad/s signifying a frequency of 47.7Hz. This frequency is low enough to be studied within a given short time span of the simulation. This frequency is representative of whatever frequency that the PAL colour system generates. A frequency of 0Hz indicates a dc value.

4.1 Performance Evaluation for Saturation Amplitude Extractor

As shown in figure 5 earlier, the error saturation sinusoid is passed through a low-pass filter network. The low-pass filter network ensures that it extracts only the dc component of the error saturation sinusoid which at the output is the amplitude of the error saturation sinusoid equal to 0.6. This is indicated in figure 6 below.

As indicated in figure 6, any sinusoid (be it of dynamic amplitude) shall have its amplitude extracted and passed into the zero-window comparator subsystem. From the figure above, a low-pass filter has a curve from the start-up until it gets to a steady value point which is indicated by the steady-state value of the error saturation amplitude. This transient from zero until the steady-state point has a little effect on the system. But the effect is minimized as it occurs just only at start-up which is less than 2 seconds. Thus, the eye can comfortably ignore the effect of the start-up transient.

The table indicating the value of the low-pass filter output x(t) within the first 10s is shown below as Table 3.

4.2 Performance Evaluation of the Zero-Window Comparator

The zero-window subsystem passes as its input the output of the low-pass filter network. This subsystem ensures that no value zero goes into the inverse matrix network. The graph of figure 7 shows the output of the zero-window subsystem.

As shown in figure 7, the zero-window comparator gives an output of 1 for zero input and zero for non-zero input. From Figure 6 and figure 7, at startup, the output of the low-pass filter network is zero and rise steady to 0.6, whereas, the output given by the zero-window comparator is a step fall from 1 to 0. This indicates that the system is sensitive to even slight or infinitesimal change from zero as its input and then gives an output of zero but reserves 1 exclusively for input of 0.

Figure 8 above shows a comparison of the low-pass filter output (figure 8a) and the summer output (figure 8b). The zero-window subsystem output is passed into a summer that produces a pseudo version of the error saturation amplitude. As seen in figure 8, the error saturation amplitude is shown in the LPF scope which is a result of the low-pass filter network. This is contrasted with the result shown in the summer. The summer output is a pseudo version of the low-pass filter output. It appears similar except that at startup it assumes 1 and not 0. This ensures that no value of zero enters the inverse matrix generator.

It is important to note that a zero value entry into the inverse matrix network will lead to instability of the system as an infinite output is expected to be generated, which is not feasible.

4.3 Performance Evaluation of the Inverse Matrix Generator

The inverse matrix generator is a two-port subsystem with 4 inputs and 4 outputs signifying a 2x2 input to 2x2 inverse output. Two of these inputs are fixed with $a = 1$ and $c = 0$. The input b is a modifier whose value is used as a factor of the d input when giving its output as x. The value for b is chosen as 0.70, which is the equivalent saturation safe limit for colour outputs. The input d is the dynamic time-varying error saturation amplitude. Thus, it has no fixed value but has the value from the summer.

When the value equal to zero enters the d input, the system becomes unstable because of the infeasible infinite value it is expected to generate. The zero-window and summer ensured that this problem did not arise. The inverse matrix thus, outputs $w = 1$ and $y = 0$ as a fixed output while x vary as a multiple of b and z. Output z is the reciprocal of input d.

4.4 Saturation Error Reduction in PAL Television

The output z from the inverse matrix generator is the final moderation of the error saturation sinusoid before it is corrected and its error reduced. The output z from the inverse matrix generator is passed into a multiplier with the error saturation sinusoid to effectively give a sinusoid with optimum unity amplitude.

The Figure 9 below shows a comparison of the error saturation sinusoid and the corrected saturation sinusoid.

As shown in figure 9 above, the error saturation sinusoid signal is corrected from amplitude of 0.6(from figure 9a) to 1(seen in figure 9b). This is almost a **100% error correction** or reduction to **zero error value** as our target of amplitude equal to unity has been achieved.

From figure 9 also, we can observe super-saturation within the first 2 seconds. This super-saturation can be reduced if the moderator output b of the inverse matrix generator is used to clip the amplitude at approximately 0.70 and by appropriate choice of low-pass filters that makes a signal passage resemble a rectangular voltage passage instead of a slope that rises steadily to peak voltage. However, the effect of the super-saturation is resolved by the eye because the super-saturation amplitude is not too large from unity and the duration is infinitesimal (about 2 seconds). Noteworthy, is the fact that modern televisions automatically clip the saturation of any amplitude above unity to 1. Thus, super-saturation is automatically eliminated.

The table 4 below indicates the final output amplitude of the input signal after passing through the model above for various input amplitude.

5.0 CONCLUSION

A model presented in this report provided a unique method of saturation error reduction and elimination with the use of an inverse matrix generator. This model is a purely detachable model type whereby it incorporation into the system do not require excessive alteration of existing television model. What is required is possibly an extension port with a power source and a signal source (PAL signal with saturation error) which is demarcated to give signal input and signal output source into the television. If attached externally, it can only correct saturation error of the television signal; otherwise, the original signal is passed. Also, if attached internally, becomes just a little addition to the circuit for saturation error correction of PAL colour system.

The inverse matrix generator model acts like a stabilizer to the saturation of colour signals. It extracts the amplitude of the saturation input signal through its low-pass filter network as it undergoes a power square law. It also passes the output into a zero-window comparator that ensures only a non-zero input into the inverse matrix generator. The inverse matrix produces a reciprocal of the input that is used to multiply the original signal, thus, eliminating the saturation error.

This model is a stabilizer with purely electronic components devoid of mechanical delay and inertia like the relay etc. Thus, this model does not add considerably to the signal delay. Its delay is attributed to the delay of the least components which more or less is a couple of milliseconds delay.

The model increases the input saturation error from 0.6v to 1v. Since 1v is the desired result, the error reduction is given as desired output minus actual output. Therefore 1v – 1v = 0. This means that there is a zero value of error reduction. This is also a 99% error reduction as all error is eliminated giving a 100% desired output.

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Table 1 The values of the factor c

Sinwt	w(rad/s)	t(s)	C
Sin 300	300	1	0.6307
Sin 600	300	2	0.8661
Sin 300	300	5	0.9947
Sin 3000	300	10	0.9985
Sin 6000	300	20	0.9985
Sin 9000	300	30	0.9985
Sin 1200	300	40	0.9985

Table 2 Possible values of zero-window inputs, its corresponding outputs and summer outputs

Zero-window Input (v)	Zero-window Output (v)	Analog Summer (v)
1	0	1
- 1	0	- 1
0	5	5
0.8	0	0.8
- 0.8	0	- 0.8

Table 3 The outcome of low-pass filter envelope detector

Time (t (s))	Low-pass filter Output x(t)
1	0.50
2	0.55
6	0.60
10	0.60

Table 4: Comparison of various inputs and final output of model equation

Input picture amplitude	Final Output amplitude from model
0.1	1
0.2	1
0.3	1
0.4	1
0.5	1
0.6	1

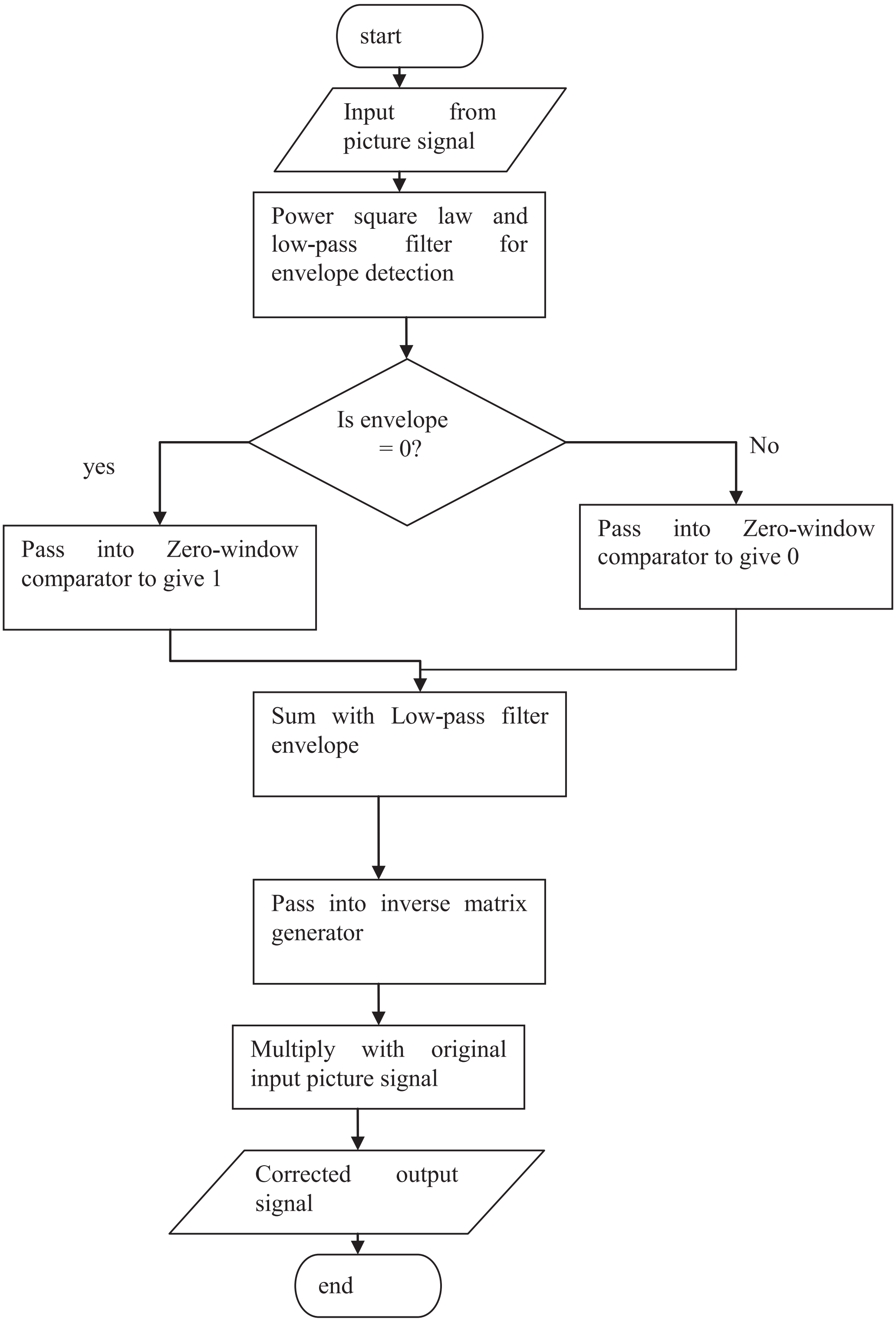

Figure 1 Flowchart showing the design implementation

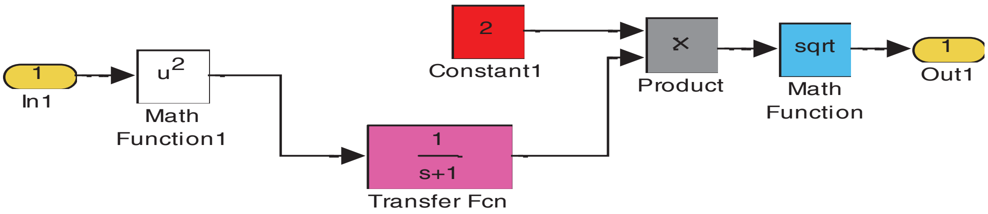

Figure 2Block diagram model of saturation amplitude extractor extraction

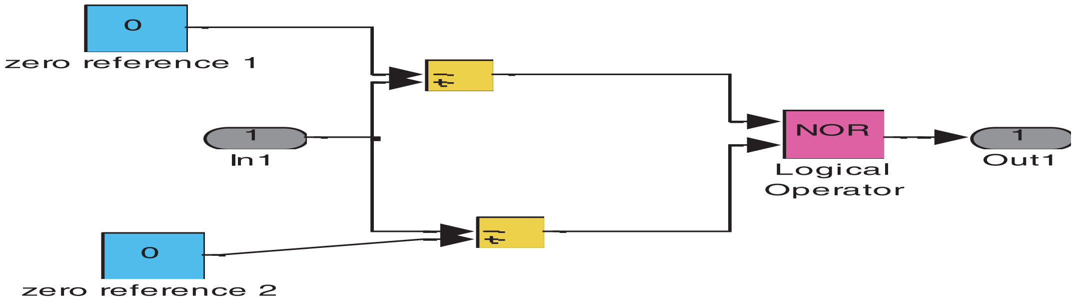

Figure 3 Block diagram model of zero-window comparator circuit

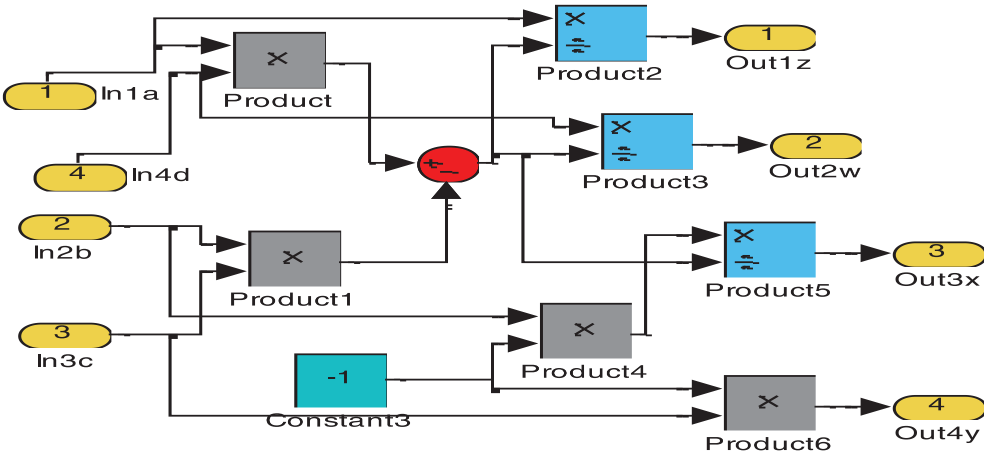

Figure 4 Block diagram model of inverse matrix generator

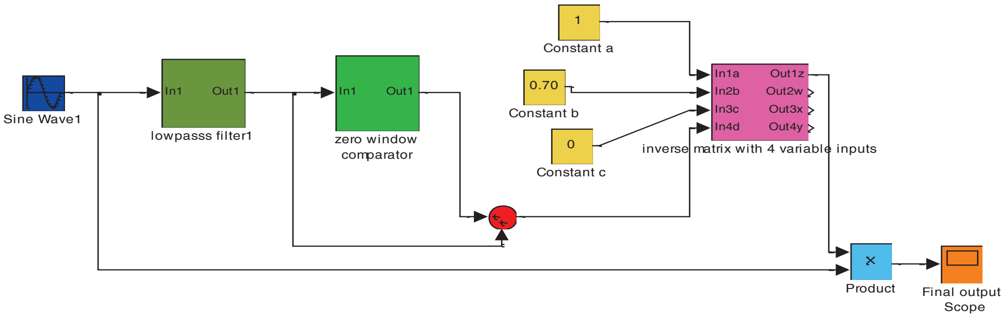

Figure 5: Block diagram showing the complete saturation error correction implementation

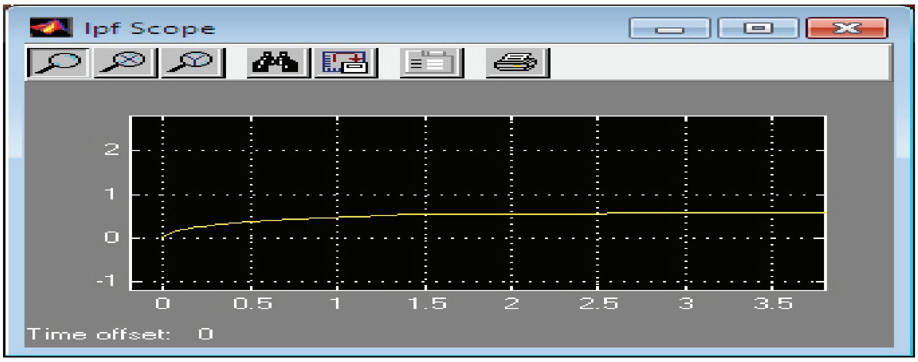

Figure 6 Error saturation amplitude extracted by low-pass filter network

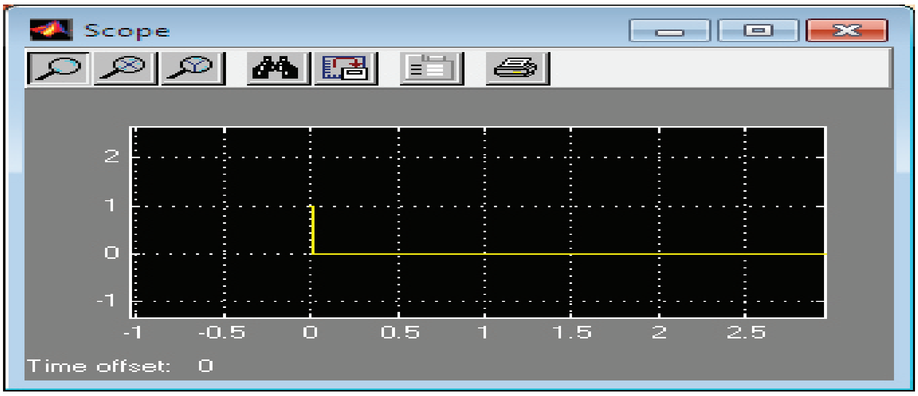

Figure 7 The zero-window comparator output

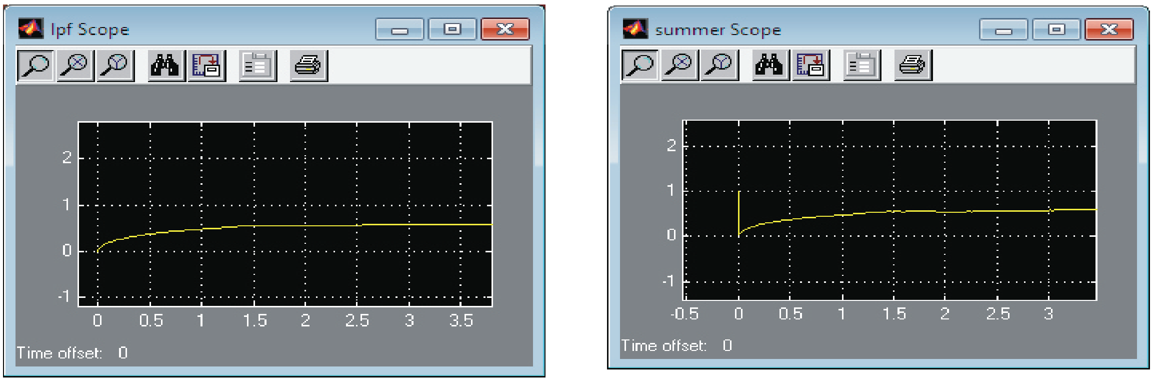

Figure 8a Figure 8b

Figure 8 : Comparison of low-pass filter and summer outputs.

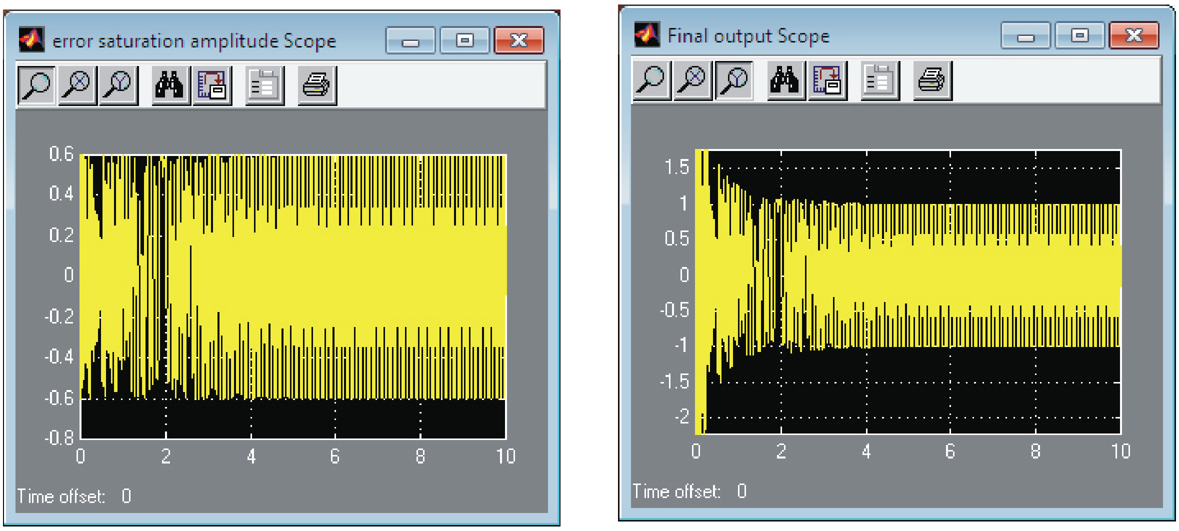

Figure 9a Figure 9b

Figure 9 Comparison of error saturation sinusoid and corrected saturation sinusoid