TARGET LOCALIZATION USING RETICLE SEEKER

By

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ABSTRACT

Reticle systems, which are widely used in IR seekers, are considered to be a classical approach for estimating the target position within the specified field of view. In this thesis, a thorough study has been made and various approaches for target localization for a simple wagon wheel reticle have been explored. For target detection, a conventional PLL-approach and a relatively new adaptive DSP algorithm for enhanced performance were tested. However, for increased efficiency, a new technique based on the reticle geometry and scan profiles is proposed. Furthermore to solve the problems such as loss of modulation rosette, scanning has been used. It is used to construct the image of the scene and hence provides an opening for the various imaging techniques, which can then be used to find the target, track it and to segregate it from the flares and other such decoys.

DEDICATED

TO MY PARENTS AND MY SIBLINGS

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First of all, all praise to Allah, who is the sole creator and sustainer of the universe. I can never thank him enough for all the bounties that he has bestowed upon me.

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1. INTRODUCTION

The purpose of an infrared (IR) guided tracker is to track the source of IR .With the help of operator; it must perform the following functions to achieve this objective:

- Acquire the target
- Track the target
- Navigate to an intercept with the target
- Destroy the target

For military utility the tracker must be simple to employ, reliable and relatively inexpensive so that they maybe fielded in quantity. Reticle based missile seekers have been successfully filling this role in operational use for almost 50 years. Currently, there are hundreds and thousands of operational reticle –based IR seekers worldwide. Pseudo imaging seekers have augmented the reticle bases seekers, but they are essentially a variation on the theme. Imaging seekers, designed around staring focal plan array detectors, are beginning to transition into operational use and will gradually begin replacing reticle seekers in operational inventories. However, the simplicity, reliability, ease of construction, and relatively low cost of reticle seekers ensure that they will remain with us for a long time [1].

The advantages of the reticle seekers are, few detectors are used, simplicity and low cost, [2, 3, 6, and 7]. Owing to a spatial filtering effect of the reticle, the IR reticle tracker may exclude unwanted background signals, [2-4]. However, the major drawback of the reticle based trackers has been proven to be overly sensitivity on the IR countermeasures such as flares and jammers, [5-7]. It has been shown in [8,9] that an optical system based on a nutating reticle can be modified to resolve the multisource limitation problem, [5].

Many different seeker and sensor technologies exist, from early reticle based sensors through pseudo-imaging systems such as the rosette scanner [20]-[28] to imaging and spectral imaging devices. Figure 1 shows an approximate timeline for when these technologies were developed. Reticle based sensors[1]-[17] were developed early in the timeline resulting in a great number of reticle patterns and modulation scheme types being utilized including amplitude, frequency, pulse-position, pulse-width and various combinations of these modulation types . Of these the systems that use amplitude modulation (AM) and frequency modulation (FM) reticles are most widely used and various studies have been conducted regarding their relative merits. The patterns used for AM and FM reticles vary greatly and the type of modulation produced not only depends on the reticle pattern but also on the way in which the reticle and scene are combined. In general there are two scanning schemes, called spin-scan and conical-scan or con-scan. Spin-scan systems typically use AM reticles and con-scan systems typically use FM reticles. The main difference between spin-scan and con-scan can be linked to the way in which the scene and reticle are combined. The earlier IR missile seeker types included spin-scan, rear-aspect and hot spot tracker mechanisms to “bang bang” the control surfaces. These missile seekers evolved into conical-scan trackers with all –aspect tracking capability and proportional navigation guidance. The reticle used in an infrared (IR) seeker separates an IR target from its background and produces appropriate modulation signals that make possible a variety of signal processes for guidance and/or target tracking. Reticle seekers are classified into two types: rotating and stationary reticle seekers.

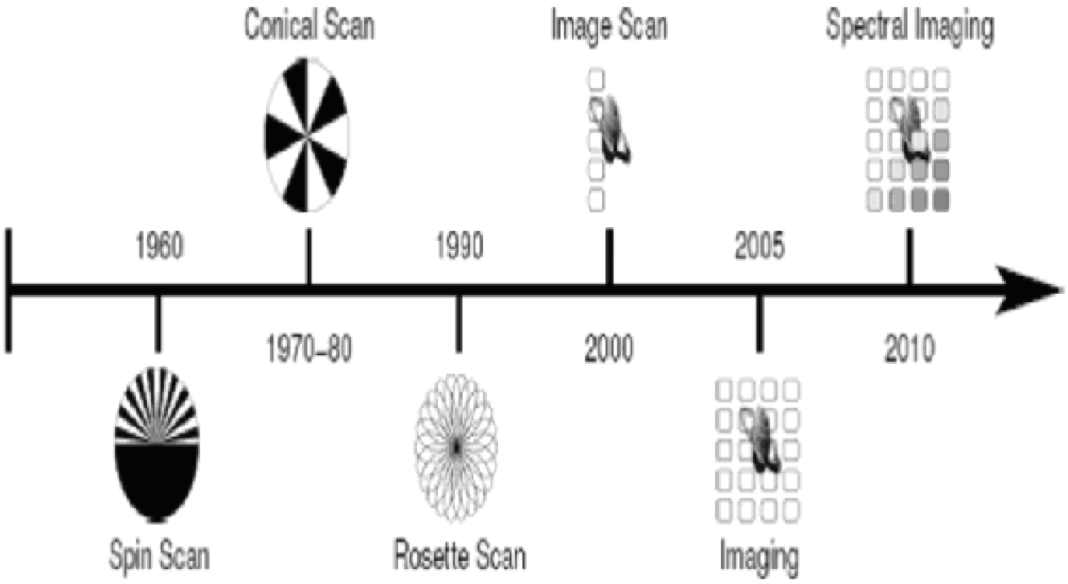


Figure 1. 1: **A time line of seeker technologies showing the early spin-scan and conical scan systems eventually giving way to more sophisticated imaging systems**

1.1 Literature review

Several papers have studied different reticles and the output of the reticle system[2]-[3],[11],[12]. Fisher et al provided a summary of the method of operation, the performance characteristics and the applications of existing IR-tracking devices. Applications are studied from the standpoint of important physical considerations: target size, spectra radiance, background radiance etc[13] .Carpenter compared the characteristics of both AM and FM reticle systems in terms of signal to noise ratio[3]. In addition, Deyerle explained various IR seekers including spin-scans and presented counter-countermeausres (CCM) to detect and reject flares[30]. Driggers et al[9][10] presented the methods of obtaining AM and FM for determining target locations with spinning reticles. This study showed that multiple parameters including the amplitude or the frequency according to angle radius and phase can be integrated into a single reticle. Chao et al. integrated the point and the spot model for the design of fm reticles. These analytical results derived from the two models can be used to determine the total number of spokes, the angular velocity, the allowed amount of eccentricity, and the zone of modification [32]. Many papers [1] to [9] describe the output signal detected behind different reticles. This output signal depends on several parameters related to the input signal form and to the reticle pattern. A detailed study of the output signal when the input signal has a Gaussian profile has been done by Porras, Alda, and Bernabeu[31].The paper by Anderson and Callary [11] describes a computer model of optical trackers. The paper by G.Olsson[15] presented a simulation method of reticle based on image–processing system and signal processing. The paper describes a simulation method of reticles based on images of reticles as well as targets and countermeasures. There is no Fourier transform involved. The paper also describes the signal processing required to achieve the pointing error from the reticle output signal.

Hyun-Ki Hong [33] proposed a scheme that used an improved reticle seeker based on the segmented focal plane array. Sung-Hyun Han presented an algorithm based on the instantaneous frequency estimation in case of a fixed reticle system.

Surng-Ghabb Jahng proposed moment technique for rosette scan [25]. The conventional Infrared counter-countermeasure (IRCCM) using the moment technique took an average of the target position over scan frame time. This method distinguished the target from the flare by setting the detection threshold at the average intensity of the previously detected target signal. The flare may have a similar intensity level to the target signal, since its intensity varies with time. In that case the RSIS could not discriminate the target from the flare, resulting in eventual failure to track the target. Surng-Gabb Jhang [26] then incorporated K-Means Algorithm in Rosette scanning. The conventional IRCCM using the KMA classified the pixels of the detected image into two clusters: the target and the flare, and then tracked only the target cluster. This method posed a problem. It recognized multiple flares as a single one because the KMA can handle a limited number of clusters only. This causes the RSIS to fail to track the target. Later in his paper [35], he presented a new IRCCM technique using an iterative self-organizing data analysis (ISODATA) technique, in order to distinguish the real targets from either multiple or single flares. Unlike the

KMA, the ISODATA algorithm can handle an arbitrary number of clusters, as might be encountered when observing multiple flares. The conventional RSIS mistakes the flare for the target during the time interval in which the flare intensity is close to the target intensity. However, using the ISODATA algorithm, an improved RSIS can classify all of the clusters in the TFOV and then compute their centroids.

1.2 Motivation

The reticle is one of the key components for tracking the hostile aircraft; therefore its pattern design is a highly guarded secret. The motivation for this thesis was to prepare the ground for future work. Although a lot of work has been done on reticles but not much information is available. The aim was to perform a thorough search on the reticle seekers and to get an insight into the reticle system. Different techniques needed to be implemented and their respective problems were to be highlighted.

1.3 Overview of the thesis

Chapter 2 presents the basic concepts of Reticles and its various features. In this chapter the operation of the reticle is briefly discussed.

Chapter 3 describes the modeling of wagon wheel reticle. It describes the various steps for the implementation of the seeker system. It gives a brief overview of the steps involved in simulation of the reticle system.

Chapter 4 discusses the conventional method for target localization based on the phase lock loop. Results after implementing this method in Matlab/Simulink are presented.

Chapter 5 presents the results of implementing the DSP algorithm in Matlab. It also highlights the advantages of using this method in contrast to the conventional method.

Chapter 6 describes a new method for target localization based on a geometrical method.

Chapter 7 brings in image processing into target localization. Various techniques based on image processing are described in this chapter. This chapter gives an important insight into the reticle system.

Chapter 8 describes rosette scanning of the field of view. The idea is to acquire an image of the scene containing the target so that imaging techniques can then be applied detect the target and hence for target tracking.

Chapter 9 highlights the problem associated with the various techniques discussed in the thesis.

Chapter 10 summarizes the whole thesis and states future recommendations.

2. CONCEPTS

2.1 Reticle

The term reticle has been defined as "a pattern located in the focal plane of an instrument to measure or locate a point in an image." A reticle is essentially a modulator that ‘chops’ the scene using sequentially arranged transparent and opaque spokes on a circular element in front of the detector .the detector sees the scene chopped by the reticle at the spin rate times the number of reticle spokes. The reticle design allows the sensor to detect when it is spinning past the zero point, allowing the angle of arrival of target sources to be determined. Reticles have been used and are still used in a multitude of operations from commercial applications or surveying to military applications of bore sighting surveillance and fire control systems. The general case that most people are familiar with is the simple sight on a rifle or gun.

Reticles can be used to locate points or regions of interest within a scene, providing some form of spatial information. To provide spatial information the reticle must contain at least one transparent and one opaque region and the reticle must move with respect to the scene in order to transform spatial information into temporal or time varying, information. If the reticle moves over the complete scene then at some time some points on the scene will transmit though the reticle and at other times they will not. A photoelectric detector placed behind the reticle will translate the spatial intensity variations in the scene into time variations in the output of the detector. To illustrate this consider the simple reticle containing two quarter circle transmissive regions, and two quarter circle opaque regions shown in Figure 2.1(a) combined with a single ideal point source used as the image scene. If the reticle is rotated then the output of the detector will alternate between high and low states as shown in Figure 2.1(b). If the number of transparent and opaque regions is increased then the number of high and low states in the output from the detector also increases, as shown in Figures 2.1(c) and 2.1(d).

The reticle pattern is critical to the operation of the sensor since it determines the type of signal that will be output from the detector. The output signal must then be interpreted, usually by electronics, to determine the desired characteristic or characteristics of the scene. Missile seekers, for example, are designed to determine the location of a target in the scene. Early seekers were designed as “hot-spot” seekers in which the hottest target in the scene was interpreted to be the desired target. These hot-spot seekers were easily fooled by other hot sources such as the sun, or flares, resulting in more research into sophisticated seeker and reticle designs for single [25, 27, 36] and multiple sources [35, 50].

2.2 **Operation**

Figure 2.2 shows a simple reticle system. Energy emitted from the target is gathered by the optical system and focused through spinning mirrors onto a fixed reticle. Reticles as described earlier are disks which have alternate bands of opaque and transmissible material. The energy passing through the reticle is focused on the detector element which outputs pulses whose amplitude corresponds to the received target energy. The pulse frequency known as the carrier frequency is a product of spin rate of the reticle and the number of Transmissive/opaque spoke pairs in the reticle. When the mirrors are first spun, a phase reference is established to encode the angular position of the target. The missile seeker uses the phase reference to determine the angle of the target to keep the seeker telescope pointed at the target and to correct the missile fly out to intercept the target. The seeker always acts to centre the target within its IFOV but in doing so; it creates the tracking information that allows guidance laws to be applied to guide the missile to the target.

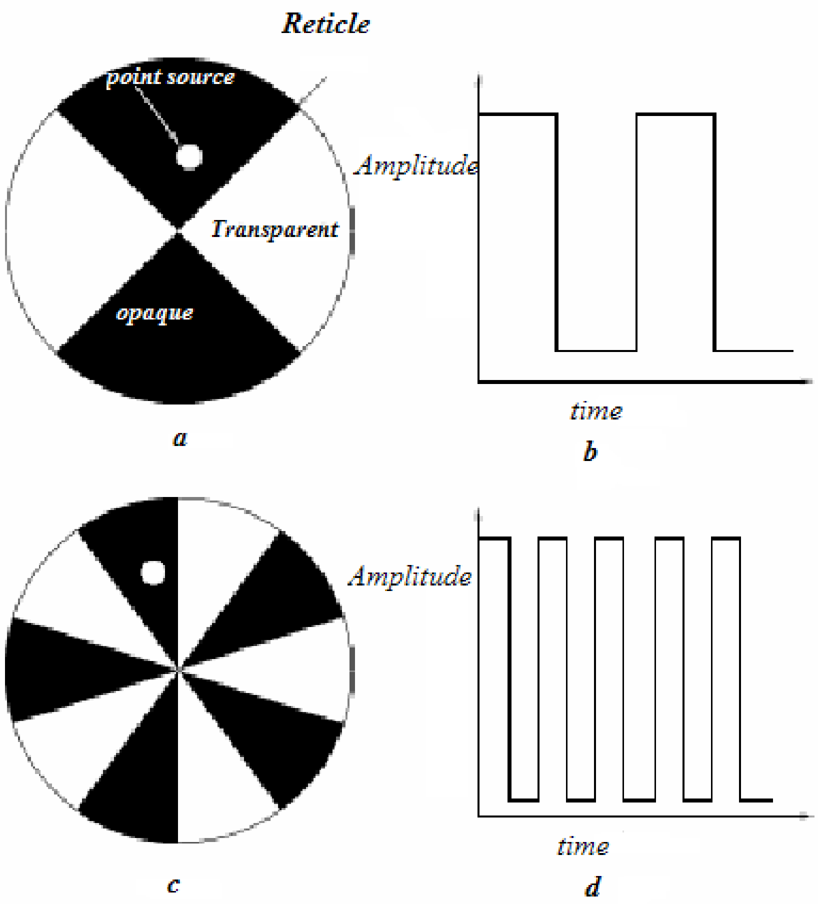

Reticle
point source
Transparent
opaque
Amplitude
time
a
b
Amplitude
time
c
d

Figure 2. 1

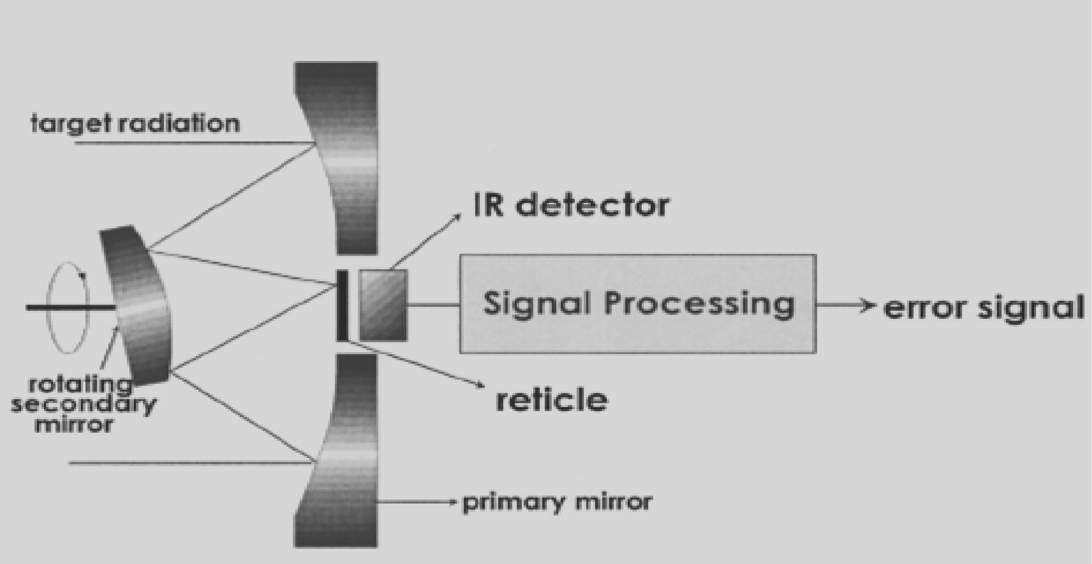


Figure 2. 2

2.3 Spin Scan and con-scan

In a spin-scan system (Figure 2.5 (a)) the reticle is spun about its centre relative to a fixed scene whereas in con-scan system (Figure 2.5(b)) it is the reticle that is fixed and the scene is nutated about the reticle Spin-scan systems may also be called spinning or rotating reticle systems. Con-scan systems may also be called fixed reticle or nutating systems. A spin-scan system will always image an on bore sight target onto the centre of the reticle, and off bore sight targets traverse along a circle that is concentric. Conical-scan systems are quite different in that an on bore sight target may never traverse the centre of the reticle, but rather a concentric circle, and an off bore sight target will traverse a circle that is not centered at the origin of the reticle but at a point offset from the origin. Figure 2.4 shows how an off bore sight point source traverses a reticle in a spin-scan and con-scan system. In the spin scan system the source follows a circular concentric path because the reticle is spinning about its centre. The radius of the circle is related to how far off the optical bore sight the source is located. In the con-scan system the source still follows a circular path, but it is no longer concentric with respect to the centre of the reticle. This type of offset scanning is called nutation and the offset radius about which the scene nutates is related to how far off the optical bore sight the source is located.

In general con-scan systems will be frequency modulation systems since nutation that is offset from the origin will generally result in a frequency modulated signal. Spin-scan systems, however, can be either amplitude or frequency modulation systems depending on the reticle pattern used. In this context the naming of reticles as either AM or FM is misleading since it is the combination of reticle and the method that the scene is scanned that determines the modulation characteristics, and the names AM and FM more suited to the type of processing electronics used to decode the detector output. To avoid confusion it is more useful to name a system as a combination of the reticle and scanning system, such as AM-spin-scan or FM-con-scan.

Centre spun spin-scan seekers are relatively insensitive when the target is in the centre of the seeker scan (i.e. when the telescope is pointed directly at the target and thus no Tracking error).this is because the point target tends to bleed energy into all the spokes at once, eliminating the pulse signal output of the detector. an error signal is generated only when the target falls away from the centre of the reticle, causing the missile to fly an undulating path toward the target .this fight path gave rise to the name ‘Sidewinder’ for the original 9 AAM developed in the China lake Naval weapons centre in the early 1950s.centre null systems lend themselves well to simple bang –bang control systems in rolling missiles. However the disadvantages of such a system are imprecise control, yielding relatively large circular error probable (CEP) impact areas, and aerodynamic energy wasted in the bang –bang system resulting in shorter-range missiles. Another disadvantage is that the seeker becomes more susceptible to clutter or countermeasure when the target is in the null state. Am spin –scam seekers respond to a flare moving out of null while the target buried at the centre has little influence. Seeker designers moved toward conical scan trackers that provide a continuous update on target position to improve target tracking and reduce susceptibility to countermeasures.

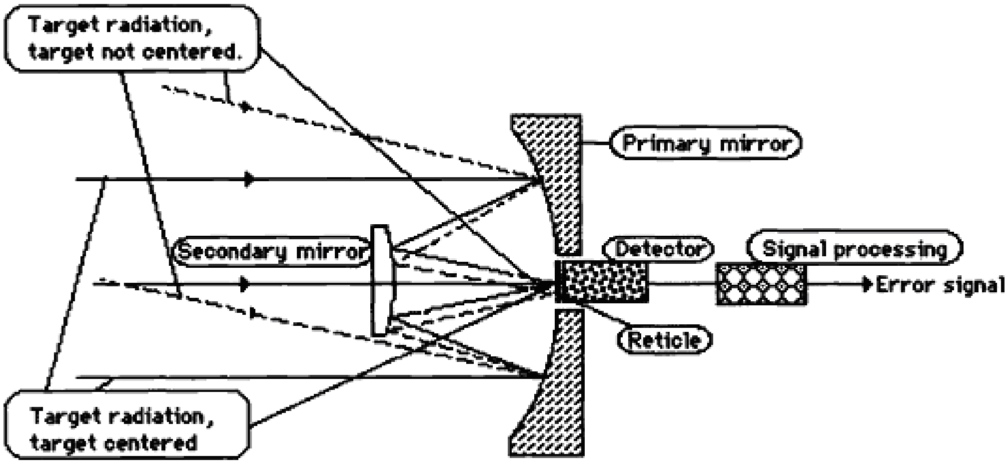


Figure 2. 3: The principle of a spinning reticle seeker

The optics are called *folded Cassegrain*. The optical axis of the seeker and the centre of the reticle coincide. The reticle modulates the scene irradiance in the focal plane of the collecting optics. The output detector signal is usually amplitude modulated.

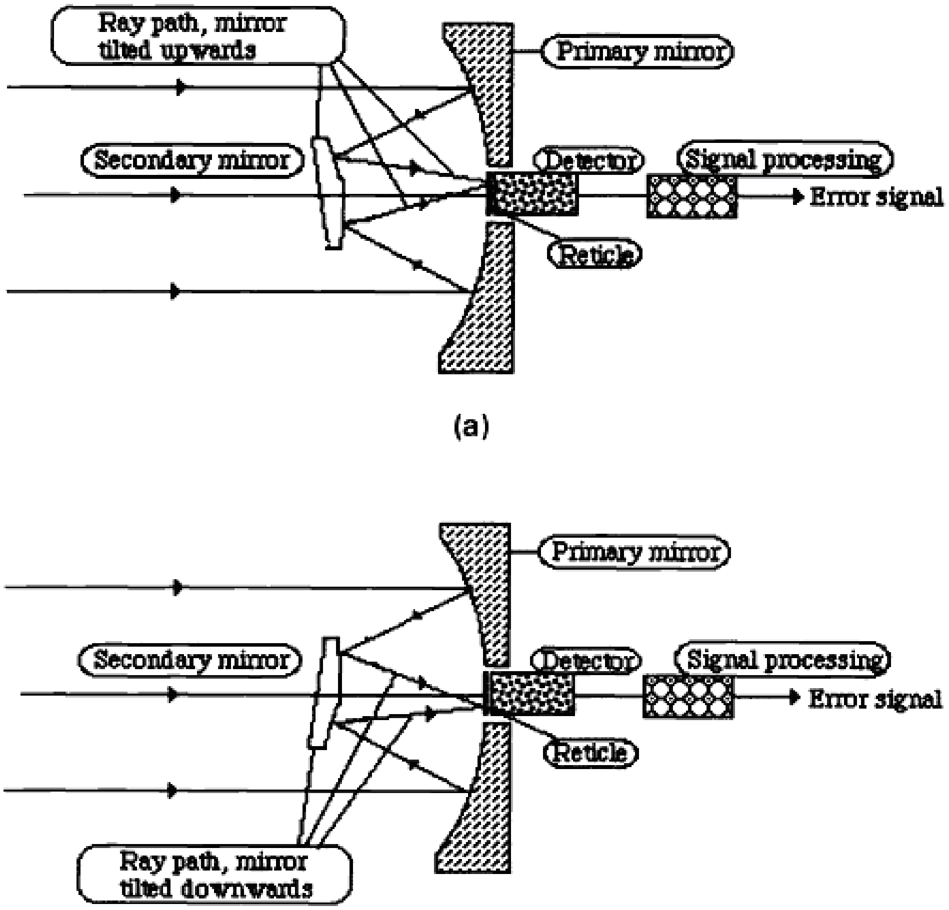


Figure 2. 4: Example of a reticle seeker with a fixed reticle and off-axis rotating mirror

The secondary mirror is tilted and rotating and thus “moving” the target across the reticle pattern, usually resulting in a FM output signal. The optical axis of the seeker and the centre of the reticle do not coincide. The secondary mirror is shown into different positions (a) tilted upward and (b) tilted downward, due to its rotation

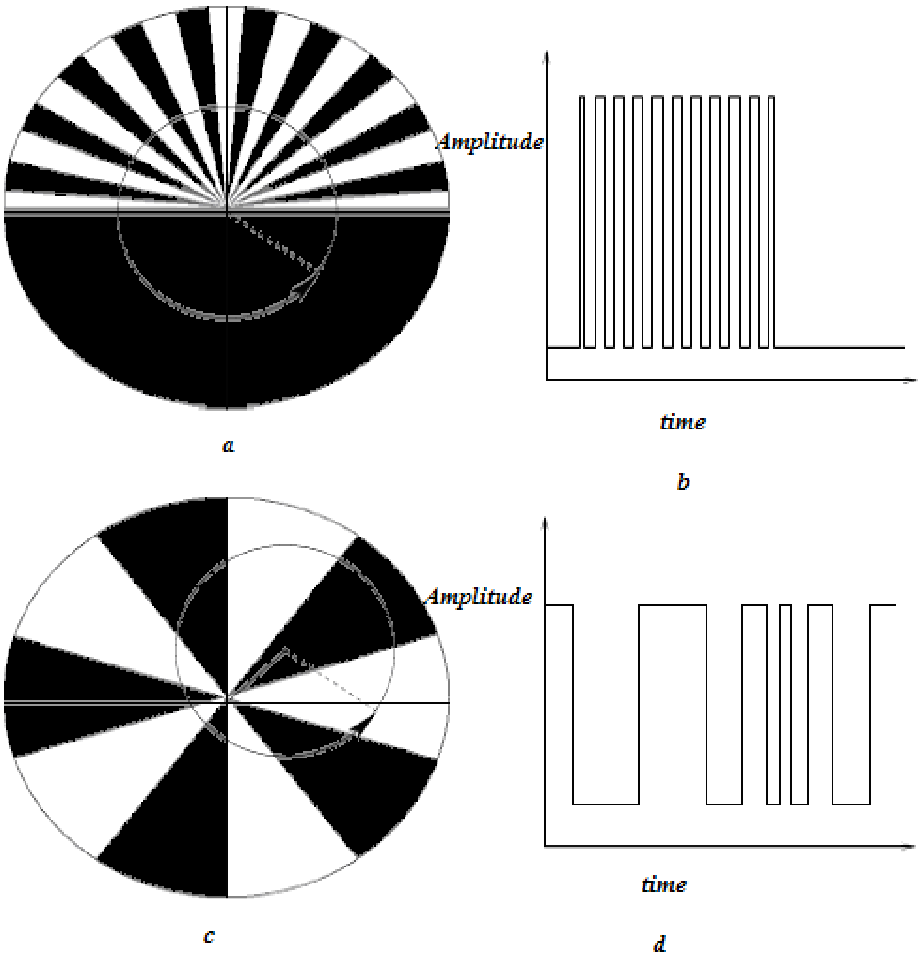


Figure 2. 5: A point source traced across a rising sun using spin-scan (a) system and a wagon wheel using conical-scan(c) system. The spin scan system information is contained in the amplitude of the signal (b) whereas the information for the conical-scan system is contained in the frequency variations of the signal (d)

2.4 Target

IR missiles acquire and track IR electro-optical energy emitted by the target aircraft. The emission primarily originates from the engine(s).All objects or surfaces emit IR energy in levels and bands associated with its absolute temperature and the surface emissivity. Most real target s are complex emitters with multiple IR sources operating at different temperatures and emissivity levels. The missile seeker perceives the target as a hot point source of energy in contrast to the background until it closes to a range where the target expands across the seeker field of view (becoming an extended source).reticle seekers inherently track point source more effectively than extended sources, giving them a margin of protection against clutter and background sources. The missile seeker prefers to view the target against benign, uniform cool background, such as clear blue sky, which yields maximum signal to noise level. Unfortunately for the seeker design, the missile seeker must deal with the real world of clouds and extended ground IR sources. Clouds reflect the light of the sun and can present very warm, extended background sources that can compete with the target aircraft signatures. The ground can be uniform warm or cold, or present hot point source target such as buildings etc.

2.4.1 Target localization:

Target localization is defined as finding the spatial coordinates of the object in an image or in a scene. These coordinates can be found out by finding the amplitude and phase of the demodulated signal using phase detector.

2.5 Extended source Elimination

The effects of extended background sources may be reduced by using a very small IFOVs and/or signal processing. Figure 2.5 shows a reticle with half the disk Transmissive. The output of the amplifiers from an extended source will be a steady state voltage, assuming the source completely fills the seeker field of view. This is because the extended source is transmitting through more than one reticle spoke at a time, yielding an elevated output equal to that of the spoked area. The target pulses ride on top of the direct current (DC) signal. in the signal processor a narrow band-pass filter centered on the carrier frequency strips the DC signal, leaving only the target pulses.

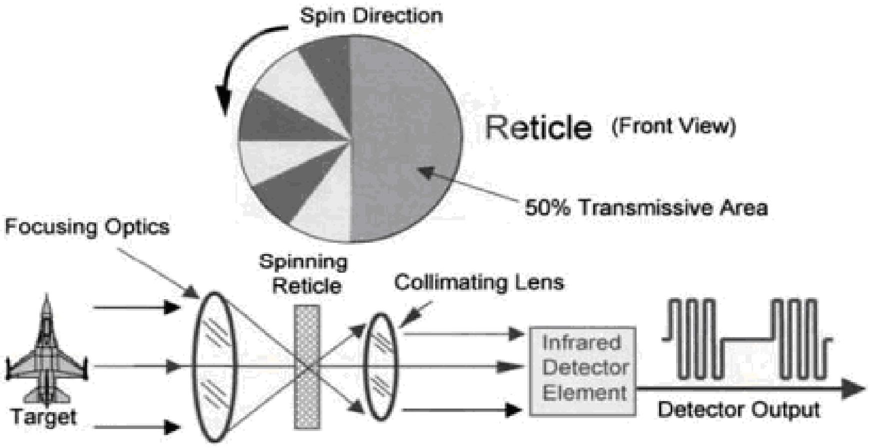


Figure 2. 6:Reticle system with extended source background rejection

3. SYSTEM DESIGN

To study the behavior of the reticle seeker the reticle system was modeled using Matlab. The stationary reticle seeker (SRS) was used to overcome the disadvantages of the rotating seeker, such as the loss of carrier signal for very small errors and the lack of target position information for large errors.

3.1 Modeling of Reticle

Wagon wheel was chosen for the simulation purposes.Simulatons were done in Matlab/Simulink.the Reticle was made in matlab and later on was filled with balck and white color in paint .If the component is transmitted, the pixel value of the reticle is 1. A pixel value of 0 corresponds to no transmission.

A prototype, stationary wagon wheel reticle is illustrated in Figure 3.1. The reticle consists of N pairs of spokes and has a radius corresponding to field angle (R_R). Nutation scanning is used, in which the target image is scanned around a circle of fixed radius (R_N) at the nutation frequency (f_N). The center of the nutation circle corresponds to the target position in the FOV; the nutation circle of an on-axis target is concentric with the reticle.

3.2 Modulation

When the target is located at the null position, figure 3.2 (on axis (1)), the image scans a circle concentric with the reticle, producing an un modulated signal with a constant carrier frequency. This frequency is the product of the number of spoke pairs and the spin frequency.

$$\mathbf{Freq_{carrier} = no.\ spoke\ pairs \times Freq_{spin}} \tag{3.1}$$

The wagon wheel reticle produces a FM signal (2), for a slightly off-axis target as long as the target image is maintained on the reticle over the entire nutation cycle. However, when the target position error becomes larger than (R_R-R_N), the target image deviates from the reticle during a portion of the nutation cycle. Then, the reticle produces a FM/AM signal [(3) and (4)], indicating the on-off AM of the FM signal.

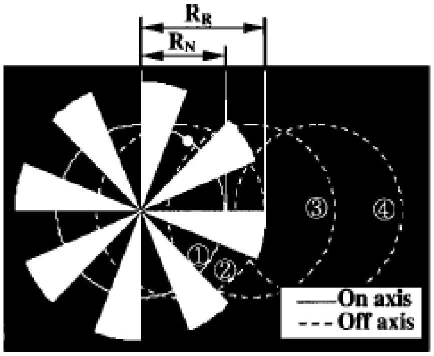


Figure 3. 1

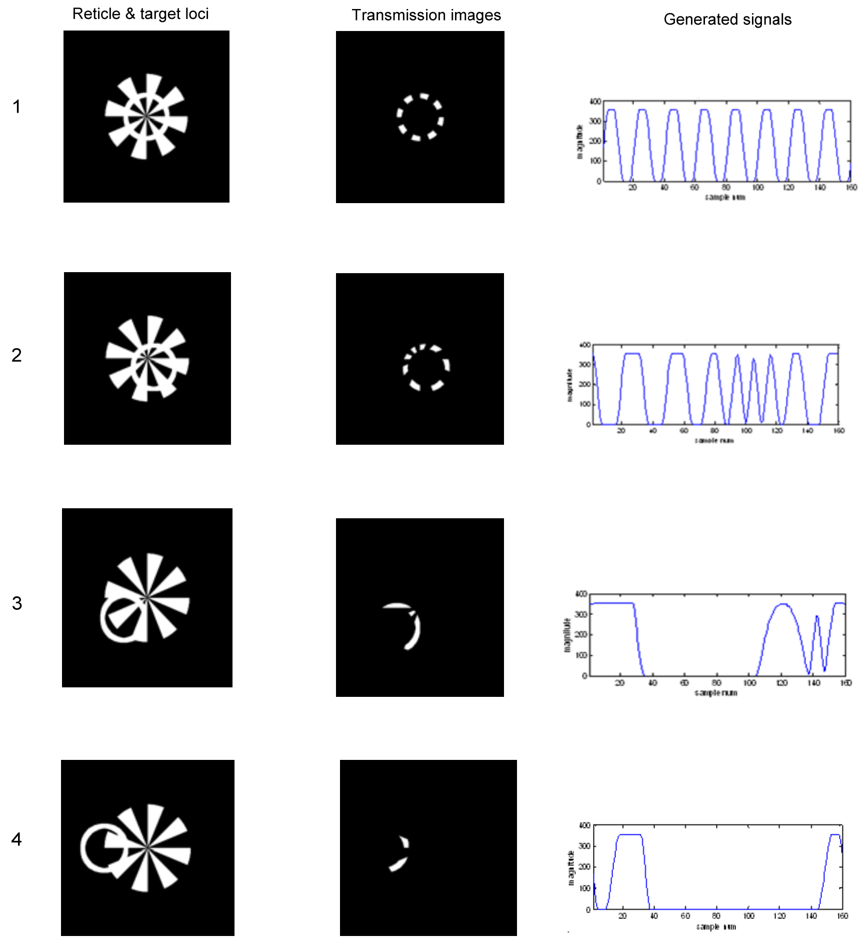


Figure 3. 2: The above figure shows target locus and corresponding generated signals

3.3 **Generating the Signal:**

To model the signal ,the image of the target(pixels representing the target are white) is taken and moved over the reticle in a circular fashion with the spin frequency of 100Hz in a fixed step for example 1 degree.the radius of the circle is known .Note that the centre of this nutating circle represents the target position.As the target moves over reticle,the target pixels and that of the reticle are compared and AND togather .only those pixels of the reticle are chosen for the AND operation which are masked by the target.these pixels are then summed and hence represent the ouput value of the signal at that instant.

3.4 **Signal Classification**

Now note that as long as long as the target image is maintained on the reticle over the entire nutation signal,the output signal is a narrow band FM signal.as soon as comes off the reticle FM/AM signal is produced.By counting the number of transition points [1 to 0 and 0 to 1] the modulation signals can be classified into AM/FM region.for example for a wagon wheel comprising of 10 spoke pairs will have 20 transition points in FM region while it is less than 20 in the FM/AM region.

3.5 **Demodulation**

Once the nature of the modulation has been determined, an appropriate demodulation technique is selected. This demodulated signal contains the information regarding the target’s radial and directional position. Thus the demodulated signal is then transferred to the phase detector, which measures the phase of the signal modulation with respect to the reticle phase reference.

3.6 **Phase and Amplitude Detection**

The amplitude and the phase of the demodulated signal correspond to the radial and angle position of the target .For phase and amplitude detection State-space recursive least-squares is used (SSRLS).

3.6.1 SSRLS

There are various ways of determining the phase and the amplitude of a signal. Due to the superior performance and excellent tracking performance of SSRLS, it is used for determining the target position.

In the current scenario SSRLS is needed to track a sinusoidal wave r(t)=a $\sin(\omega t+\phi)$ with unknown amplitude 'a 'and phase ϕ and known frequency ω. The discrete state-space model

$$x[k+1] = Ax[k]$$
$$y[k] = Cx[k] \tag{3.2}$$

With sampling time T for the continuous signal is

$$x[k+1] = \begin{pmatrix} \cos(\omega T) & \sin(\omega T) \\ -\sin(\omega T) & \cos(\omega T) \end{pmatrix} x[k]$$

$$x[0] = \begin{pmatrix} \sin(\phi) \\ \cos(\phi) \end{pmatrix}$$

$$y[k] = \begin{pmatrix} a & 0 \end{pmatrix} \tag{3.3}$$

Here the states may be defined as

$$x_1[k] = a\sin(\omega T + \phi)$$
$$x_2[k] = a\cos(\omega T + \phi) \tag{3.4}$$

Note that the two states x1 and x2 can then be used in the simple trigonometric formulas to determine the amplitude and the phase of the signal.

Simulink model of SSRLS is shown in the figure 3.3

3.7 <u>Loss of Modulation Depth:</u>

The reticle is a selective modulator that is most efficient against a point source target. Thus the reticle system performs well for the single target that is smaller than the smallest bar width of the reticle. Figure 3.4 shows the cases of loss of modulation depth. For full modulation depth, it is necessary that the target size is less than or equal to the smallest reticle bar width. In figure 3.4 as the target size becomes larger than the bars of the reticle, the modulation depth decreases because the target overlaps into the next transmissive area. Another problem takes place when multiple targets are located in the field of view. To solve these problems a double reticle system can be used. It comprises of two FM frequency vs. radius reticles. with the use of reticles, namely a stationary and a spinning reticle, full modulation is achieved although the target is too large for full modulation by a single reticle system .however as the stationary reticle always blocks the incoming target signal, total field of view of the double system is reduced to half that of the system.

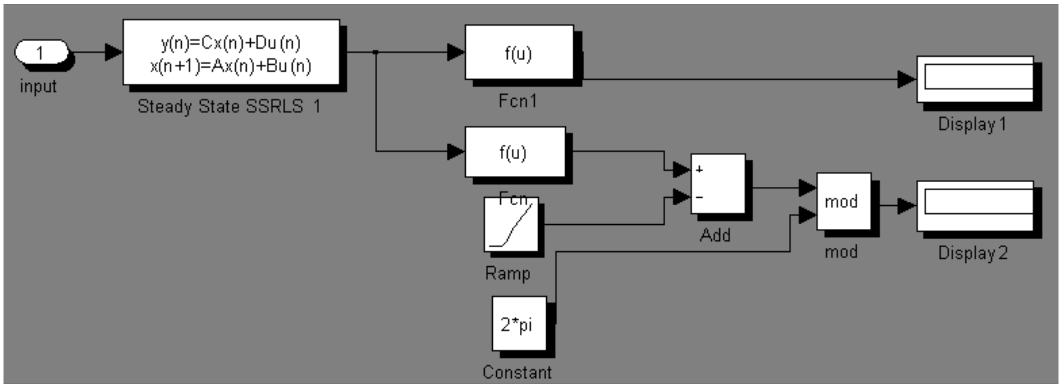


Figure 3. 3: SSRLS

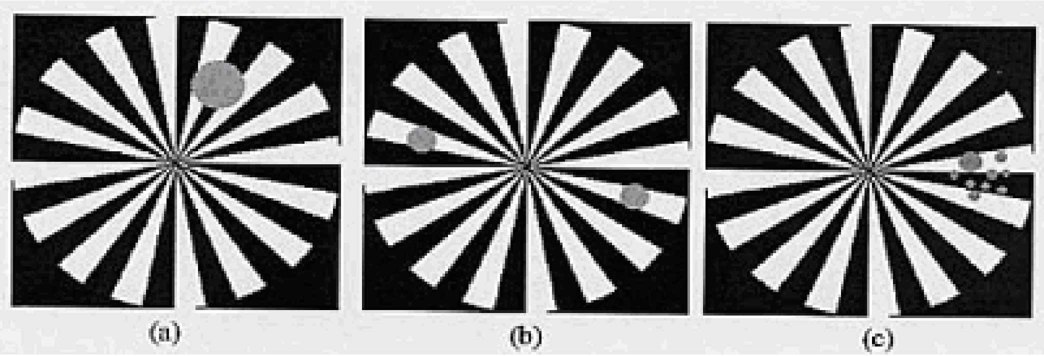


Figure 3. 4: In the case of loss of modualtion depth (a)a large target,(b)multiple targets,and (c)the target having CMs;flares.

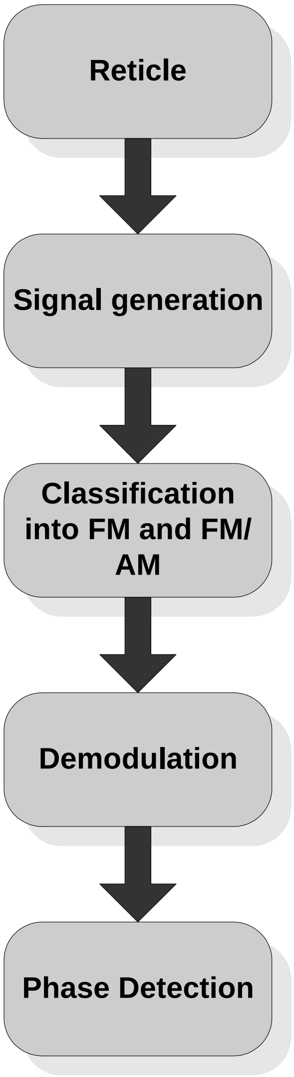


Figure 3. 6: Flow chart showing various steps invoved in the reticle seeker

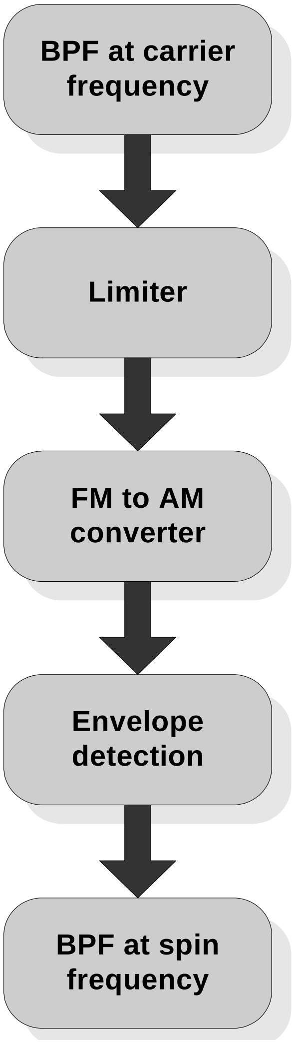


Figure 3. 5: Demodulation circuitry of the seeker

4. CONVENTIONAL METHOD BASED ON PLL

4.1 Phase Locked Loop Fundamentals,

A Phase Locked Loop or a PLL is a feedback control circuit. As the name suggests, the phase locked loop operates by trying to lock to the phase of a very accurate input signal through the use of its negative feedback path. A basic form of a PLL consists of three fundamental functional blocks namely

- A Phase Detector (PD)
- A Loop Filter (LF)
- A voltage controlled oscillator (VCO)

With the circuit configuration shown in Figure 4.1

The phase detector compares the phase of the output signal to the phase of the reference signal. (In an analog PLL the comparator is simply a multiplier and the simplest form in digital is the XOR gate).If there is a phase difference between the two signals; it generates an output voltage, which is proportional to the phase error of the two signals. This output voltage passes through the loop pass filter. The low pass filter in a PLL filters out the unwanted double frequency component which contains no useful information. The constant phase offset is then passed on to the voltage-controlled oscillator setting it to and keeping it at the correct frequency.

Due to this self correcting technique, the output signal will be in phase with the reference signal. When both signals are synchronized the PLL is said to be in lock condition. The phase error between the two signals is zero or almost zero at this.

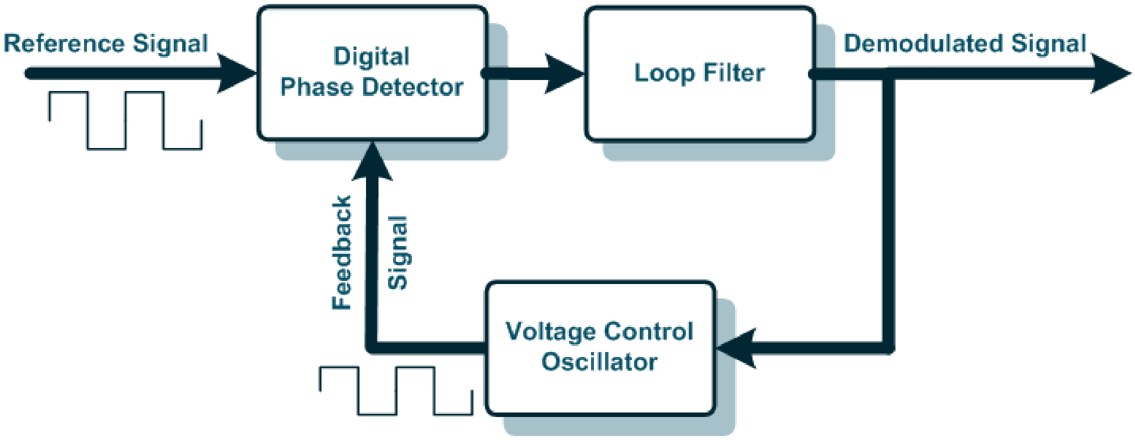


Figure 4. 1:: A classical Digital Phase Lock Loop

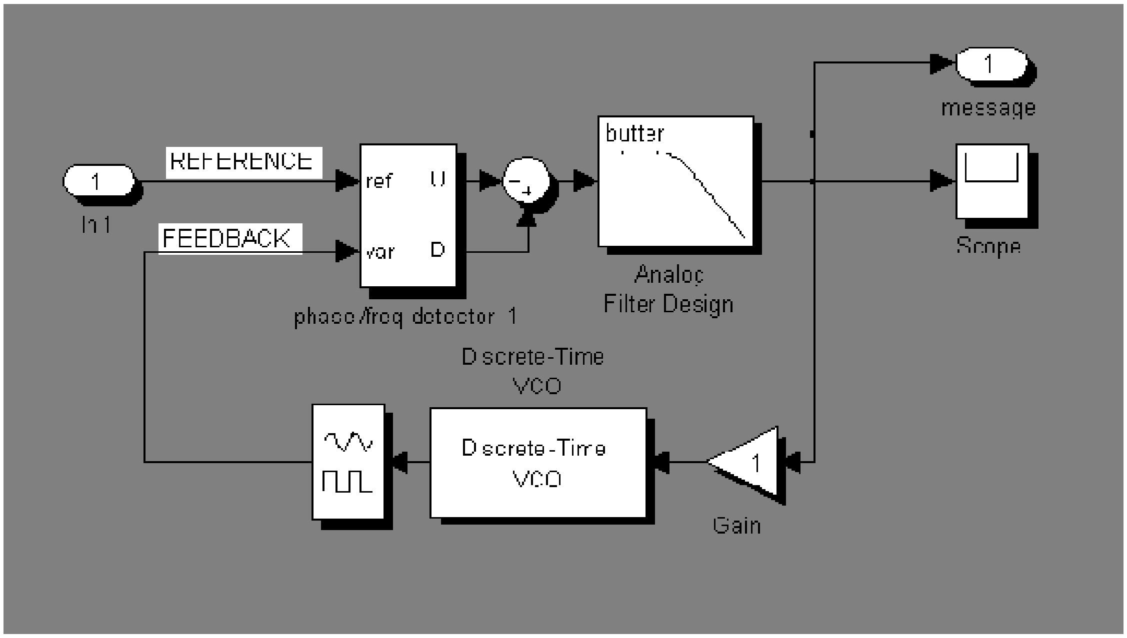


Figure 4. 2:: Simulink Model of Phase lock loop

4.2 **Target Localization with PLL**

The signal generated by the image processing is first converted into a binary signal before fed into the PLL.This binary signal is then fed into the phase detector along with the feedback signal from the VCO.

Now instead of an analogue phase detector a digital phase detector(DPD) is needed.Hence instead of using a Linear PLL,a digital PLL (DPLL)is used.In case of DPLL there are three options for the DPD i.e

- EXOR gate
- J-K flip flops
- Phase frequency detector (PFD)

The EXOR gate is the simplest and easiest to implement but there are few drawbacks.it can be used only when the input and the feedback signal have the same duty cycle and are symmetrical.Seconldy it is used only when the two frequencies are fairly high and very close togather.

Due to the superior paerformnace and the ability to track both the phase error and the differnces in the frequency,PFD is chosen for implementation.schematic and the truth table of PFD is shown in the table 4.4 and figure 4.5.

The error signal produced by the PFD is then passed through the low pass filter before being fed into the VCO.The output of the low pass filter basically represents the demodulated signal.this demodulated or the error signal contains the information regarding the location of the target.this demodulated signal is then passed through a bandpass filter with the centre frequency at the spinning frequency i.e 100Hz.the resulting error signal gives the position of the target.the phase gives the direction and the amplitude gives the radial position of the target.to determine the phase and the amplitude the output of the bandpass signal is passed through the SSRLS.the whole method is summarized in the flow chart shown in the figure 4.3

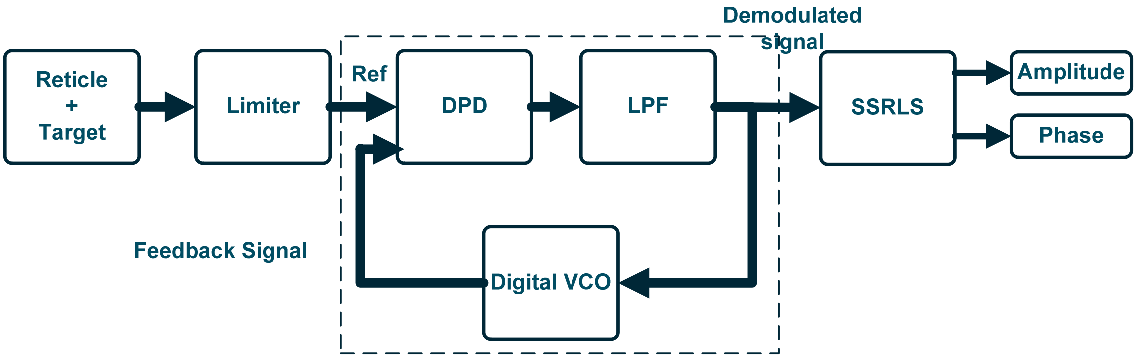


Figure 4. 3: Flow chart showing various steps invoved in target localization using PLL

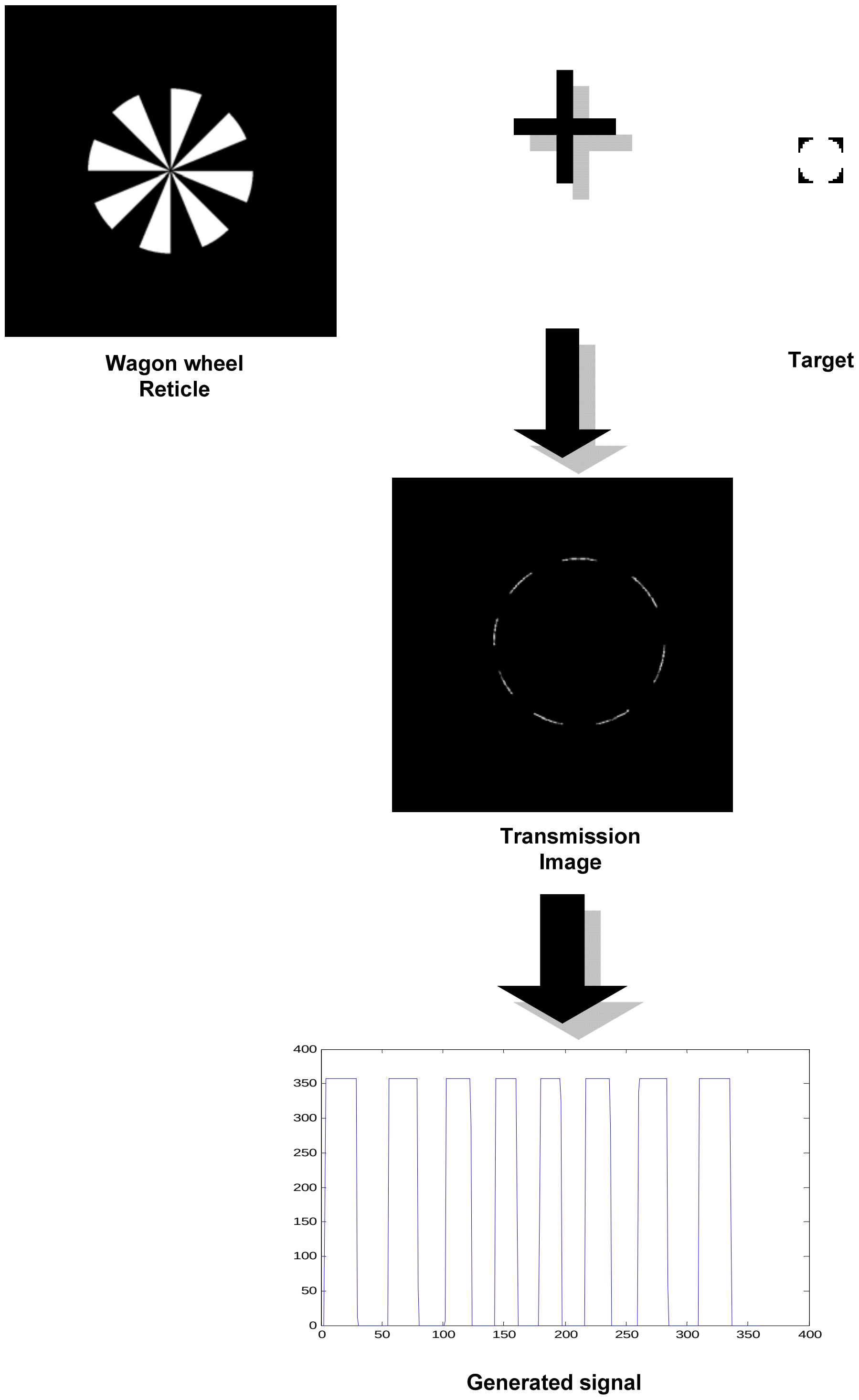
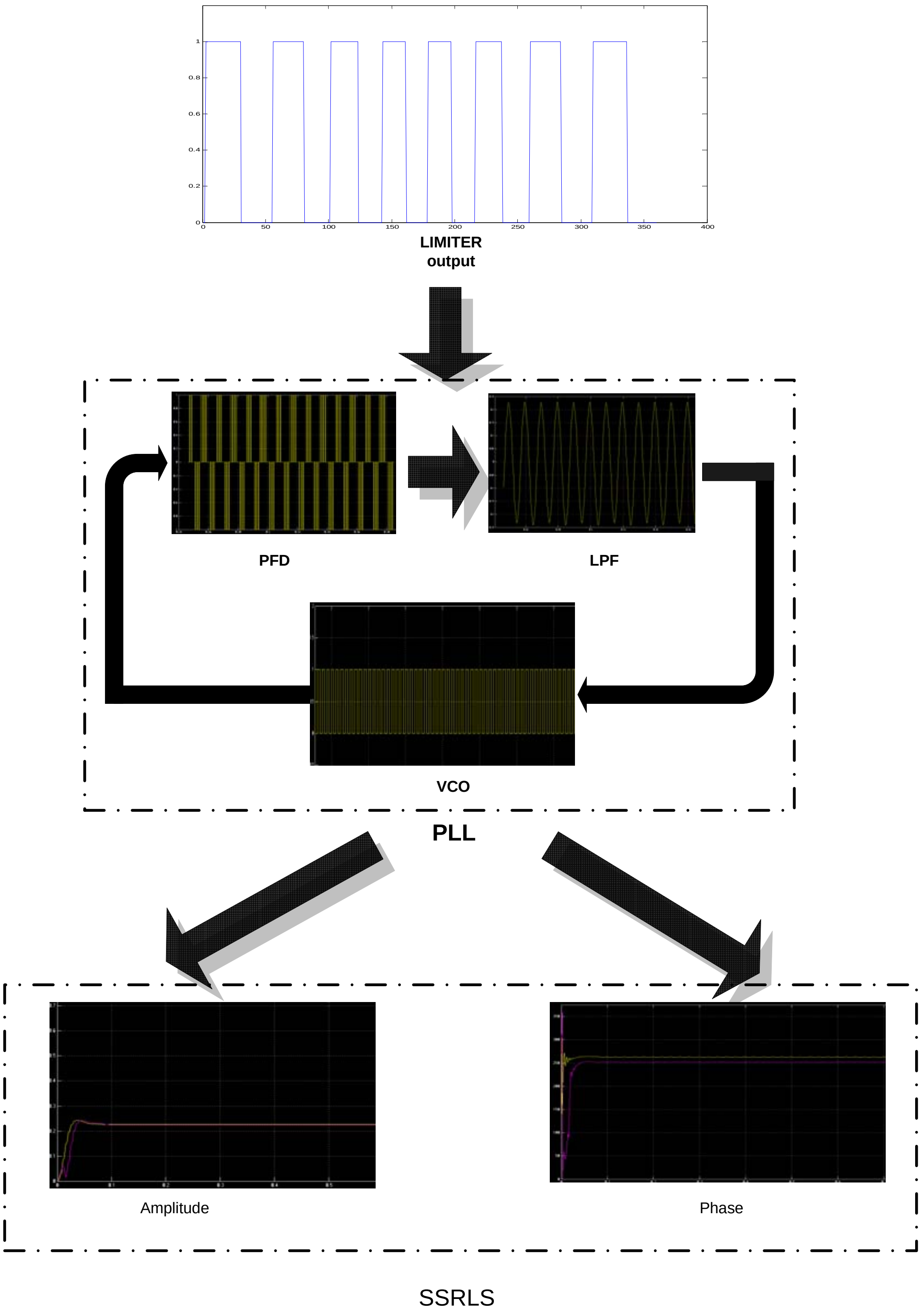


Figure 4. 4: Step by step simulation of the reticle system using PLL


1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
350
400
LIMITER
output
PFD
LPF
VCO
PLL
Amplitude
Phase
SSRLS

STATE	INPUT		OUTPUT	
Pump Down (states: 2 → 1 → 2)	R	FB	U	D
2	0	0	0	0
2 → 1	0	1	0	1
1 → 2	1	0	0	0
2	0	0	0	0
Pump Up (states: 2 → 3 → 2)				
2	0	0	0	0
2 → 3	1	0	1	0
3 → 2	1	1	0	0
2	0	0	0	0

Table 4. 1: Operational State

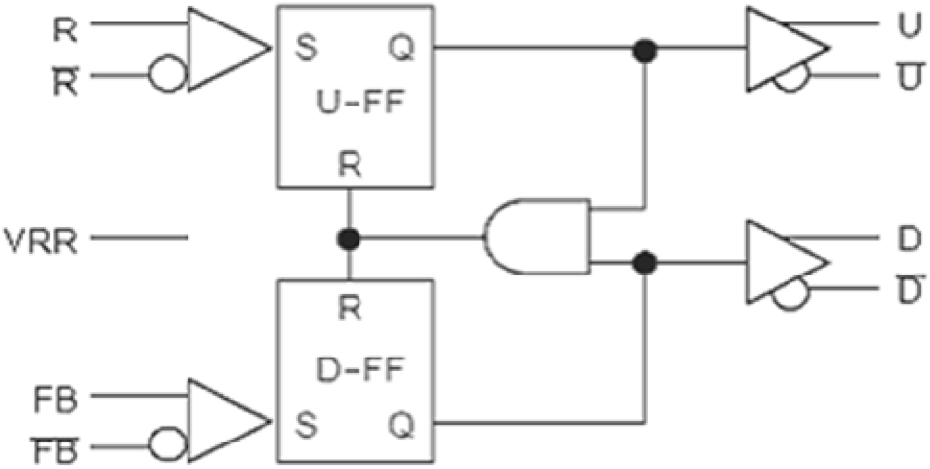
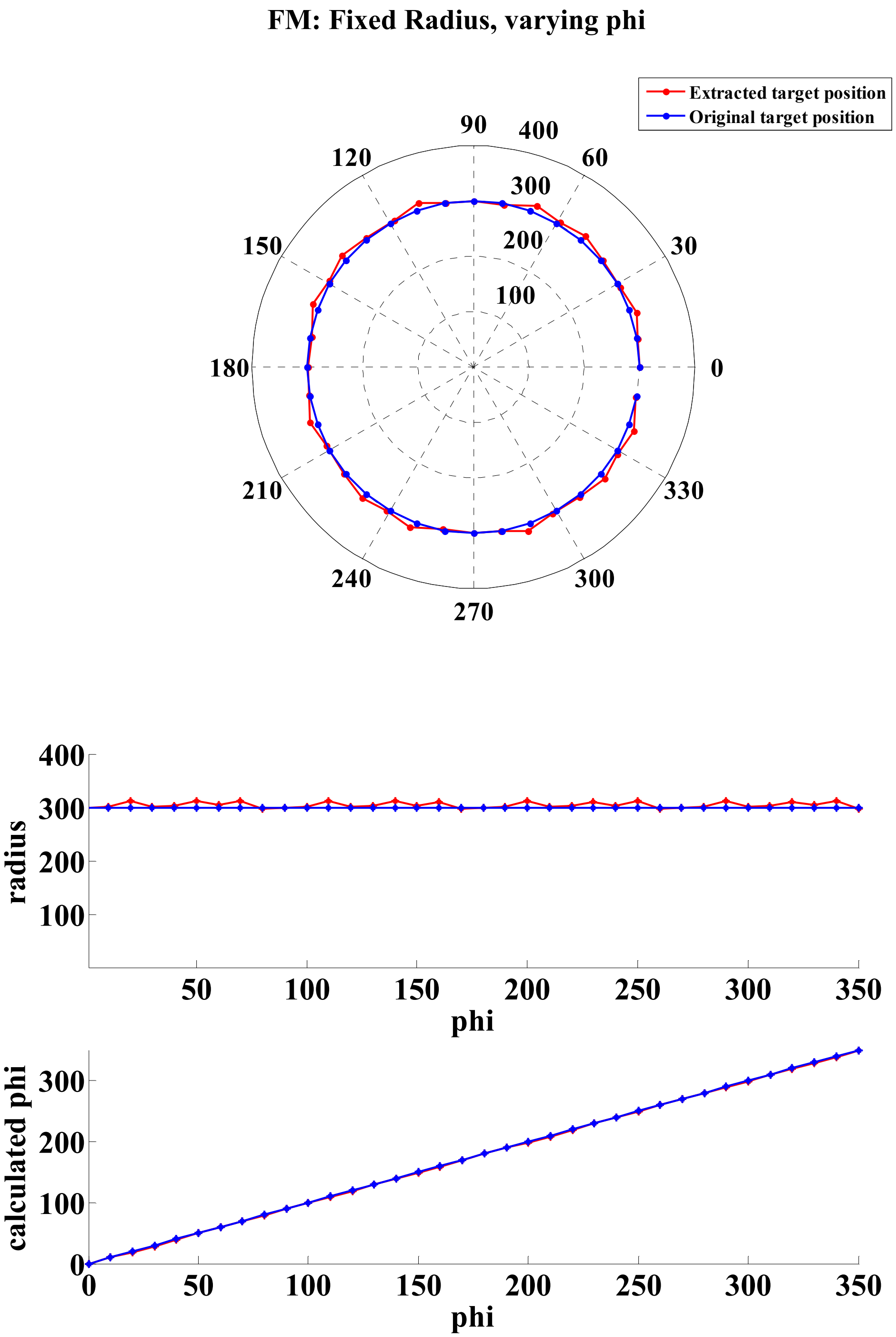


Figure 4. 5: Logic diagram of PFD

4.3 **Results:**



FM: Fixed Radius, varying phi

Figure 4. 6: shows various target position at fixed radius, Rd=300 and varying phi i.e. phi is incremented in steps of 10

5. TARGET LOCALIZATION USING ADAPTIVE DSP ALGORITHM

5.1 Introduction

To improve the performance of SRS, an adaptive DSP algorithm was proposed by Jeoung-Su Oh .The algorithm classifies the modulation signals into the FM and the FM/AM signals and applies different signal processing techniques to each modulation signals. As this is based on the digital techniques, it is easy to implement various digital signal processing techniques as compared to implementing the signal processing techniques in the analog technology.

5.2 Algorithm

The incomming signal modulated by the reticle and the optical part needs to be demodulated .In conventional analog algorithms ,PLL or the frequency discriminator are used to demodulate the FM signal. Whereas in this algorithm a different method is used.Here an envelope signal is obtained directly and simply by taking the instantaneous value to be inversely proportional to the pulse width of the binary signal,so its amplitude corresponds to the instantaneous frequency .note that this new envelope detector serves as the FM-to-AM converter,fullwave rectifier,and envelope detector of a conventional algorithm,silmultaneously.Meanwhile a simple AM demodulation is done for the FM/AM signal.In case Of FM/AM signal the signal from the reticle is directly fed into a bandpass filter centred at the spin frequency.the output of this BPF is then fed into SSRLS for phase and amplitude detection.The complete algorithm is depicted in the block diagram shown in the figure.

The most obvious advantage of this algorithm is that there is no need to use to the conventional demodulating techniques.and as this algorithm is digital ,it is easy to implement it on the harware as compared to the analog techniques.

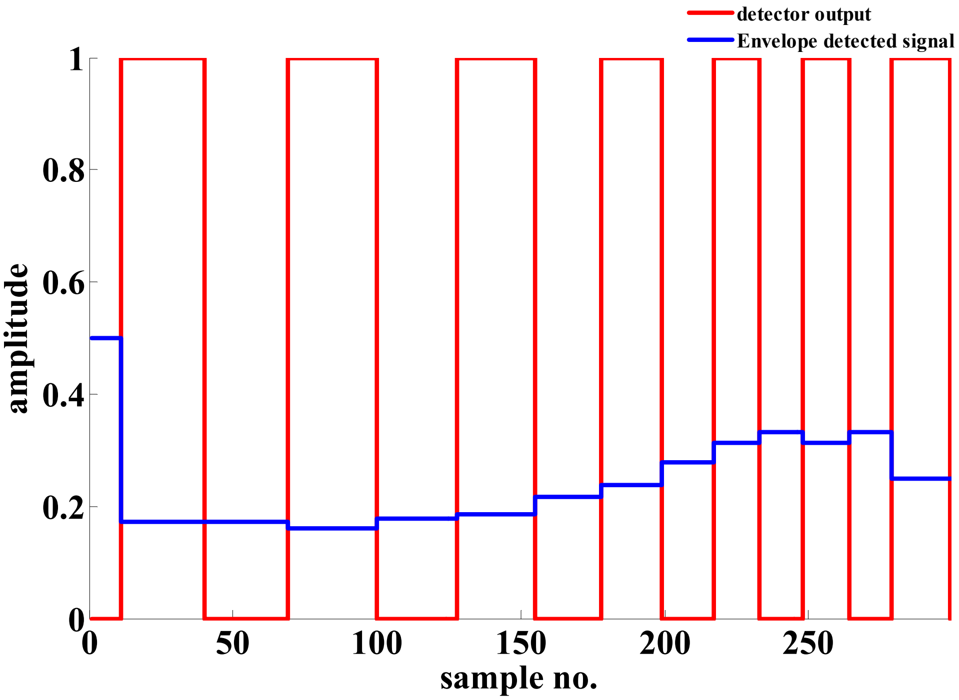


Figure 5. 1: Envelope detected signal

5.3 <u>Results</u>

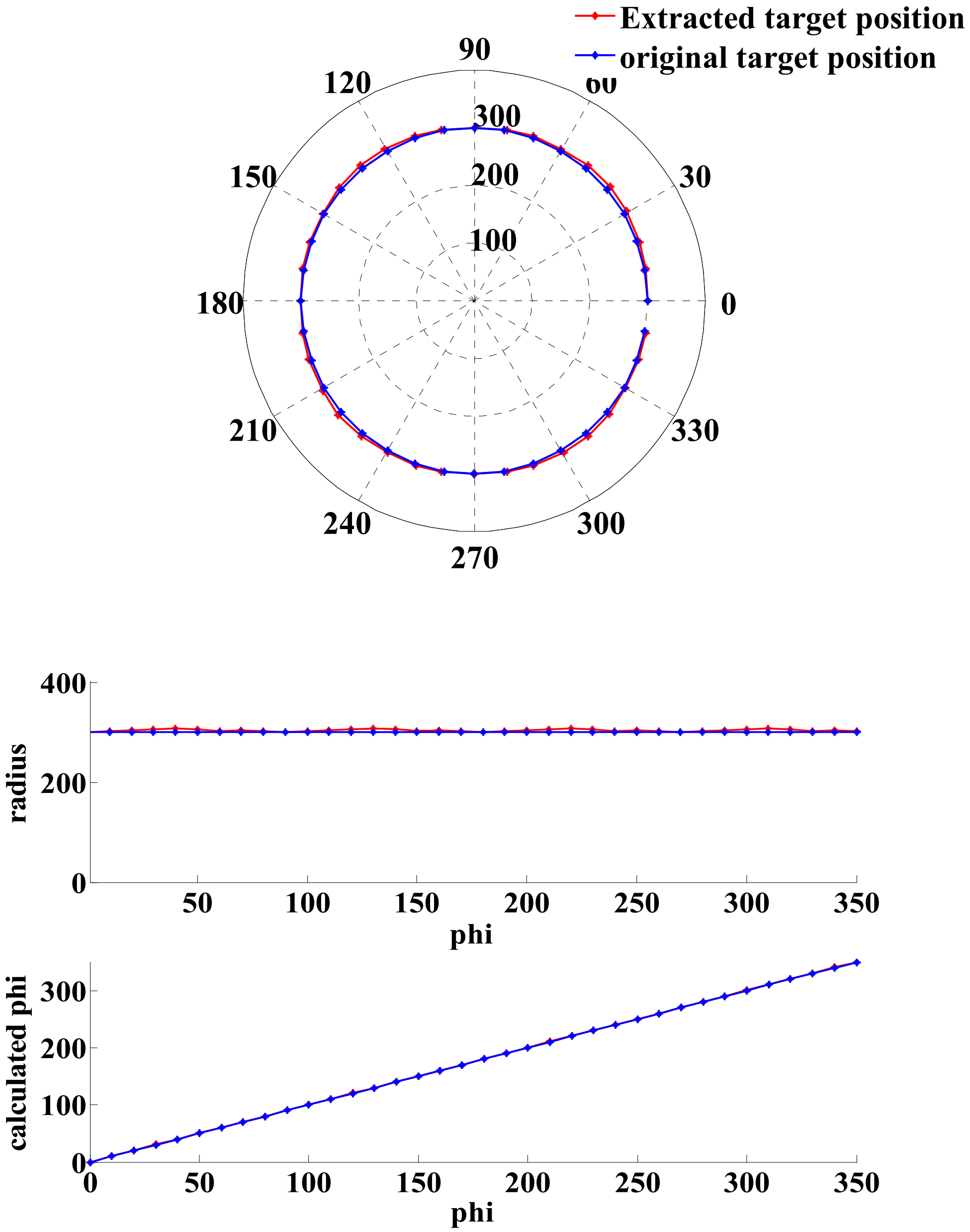


Figure 5. 2: Shows various target position at fixed radius, Rd=300 and varying phi i.e. phi is incremented in steps of 10

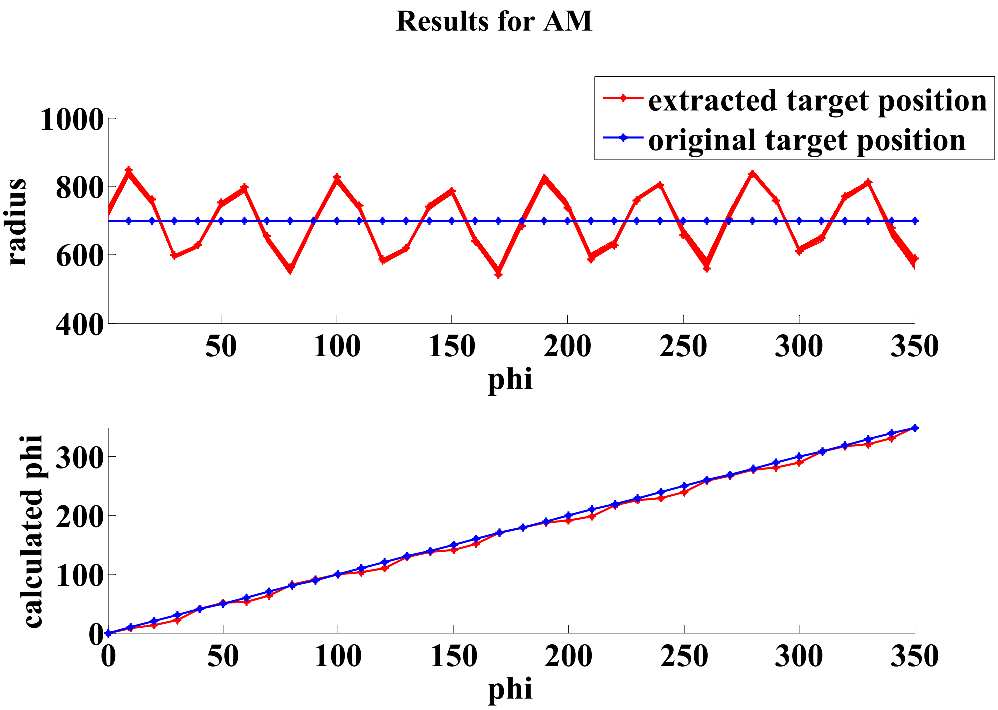


Figure 5. 3: Rd=700 and phi is incremented in steps of 10

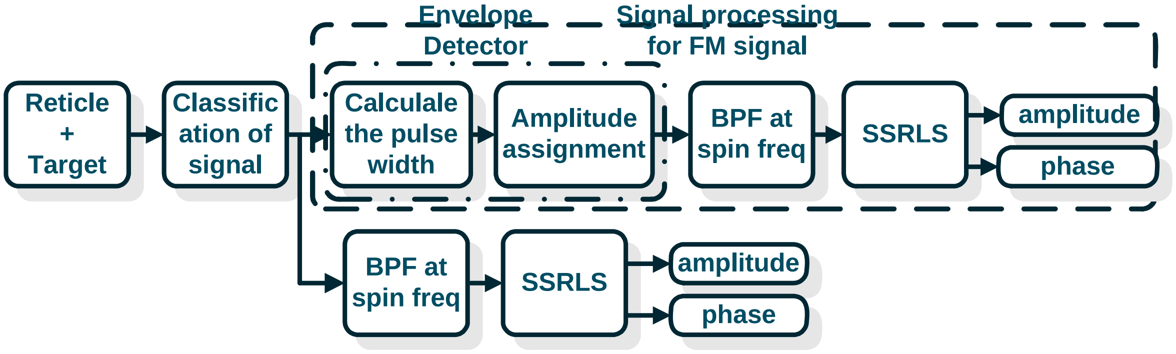


Figure 5. 4: Block diagram showing various steps involved

6. GEOMETRICAL METHOD FOR TARGET LOCALIZATION

6.1 Introduction

As the technology advances day by day, it is becoming increasingly important to come up with a technique that is able to detect and to lock on the target very quickly. Keeping this in mind, technique based on the reticle geometry has been proposed.

6.2 Geometrical method for FM signal

The radius of scanner locus and the magnitude of step are known; therefore the instantaneous value of the angle can be determined with reference to the centre of the scanner.

For example,

Let the radius of the scanner locus (R_d) =100

And the scanner moves in steps of say 1.8 degrees. It is assumed that scanner moves in clockwise direction .Ten by looking at the binary signal (generated from the reticle and passed through the limiter) can be used to determine the instantaneous value of the theta i.e sample number 50 corresponds to 1.8 X 50=90. The reticle with 8 pairs of spoke will produce 16 transitions (0 to 1 and vice versa) in its output signal. These transitions correspond to the points where the scanner moves from white to black region and vice versa. Note here that transition numbers remain 16 as long as the target is in the FM region. (Geometry of the reticle is such that as long as target is in the FM region all the spokes will intersect the scanner locus).By looking at the figure 6.1 it is observed that line '1' of spoke 1 will cut the scanner locus at point a and then again at b .This corresponds to 8 transitions. Now this behavior is exhibited by all the lines making up the spokes of the reticle as long as the scanner locus remains on the reticle for complete revolution.

Any point lying on a plane can be defined by radius 'r' and angle 'phi' in polar plane. Note that Rd is known and the phi is calculated from the method mentioned earlier. The important point to keep in mind is that the coordinates of the calculated points are with reference to the centre of the scanner locus i.e they are defined with respect to the origin defined at the centre of the scanner locus and not with the respect to the reticle centre, which is in fact the true origin.

Once the two points lying on the same line are known, then using the equation of line, a chord can be defined. In this manner all the chords can be defined for the respective spokes. By inspecting the figure 6.1it can be observed that the intersection of these chords is basically the centre of the reticle .hence the intersection of all the chords is determined using the Least mean square technique. Here the thing to remember is that the instead of finding the centre of the scanner (which represents the target position and direction), the reticle centre is calculated with respect to the origin at the centre of the scanner locus. The length of line joining the two origins basically represent the radius ‘r’ and is independent of the fact that which one of the two points is taken as the origin. However the angle ‘phi’ is dependent on the origin. Hence after simple algebraic manipulations phi with respect to the origin at the centre of reticle can be determine. Hence the scanner centre is calculated.

6.3 AM/FM Region

Many attempts were made to find such geometrical relationship for AM/FM region. But unfortunately none of them were successful. If such a technique can be devised, it will definitely prove to be a land mark in the history of conical seekers.

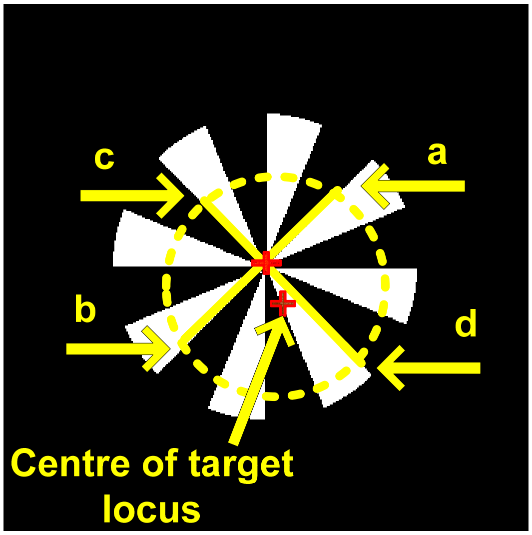


Figure 6. 1

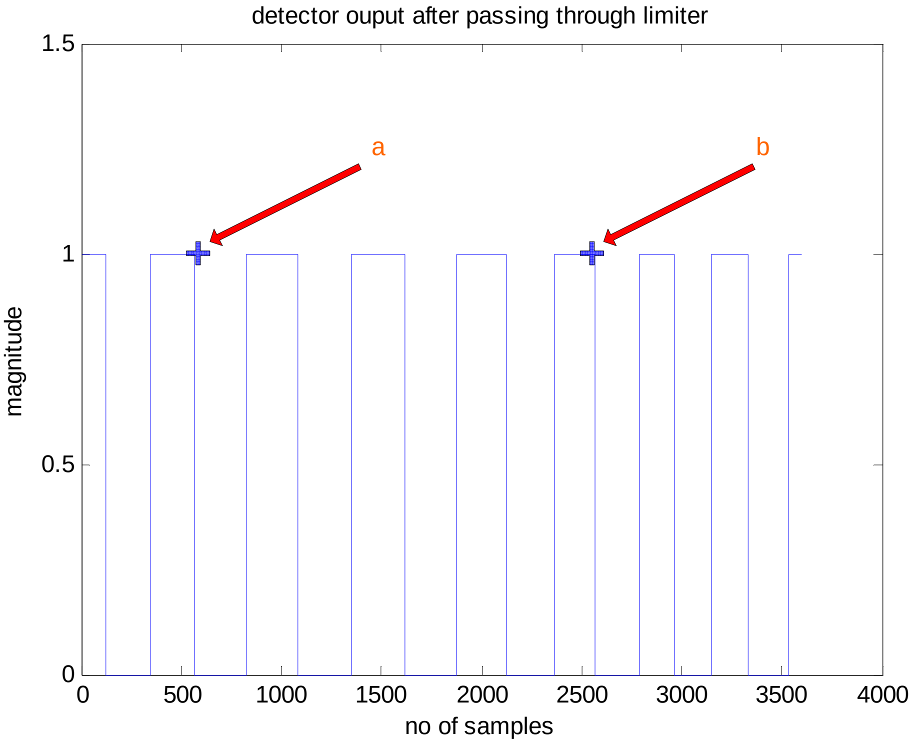


Figure 6. 2

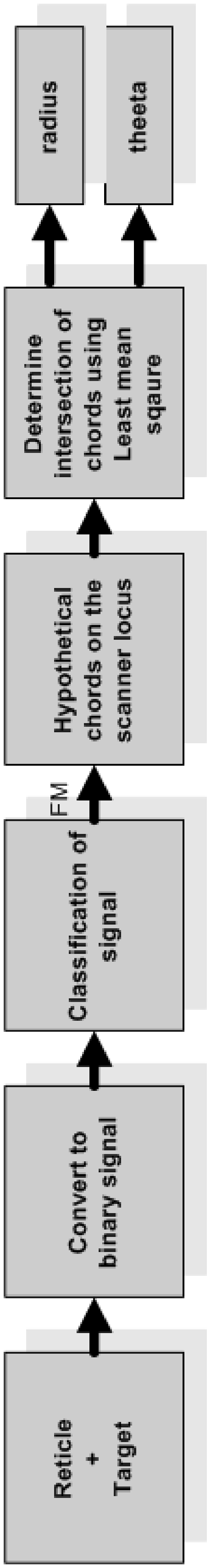


Figure 6. 3: Block Diagram showing various steps involved

6.4 Results

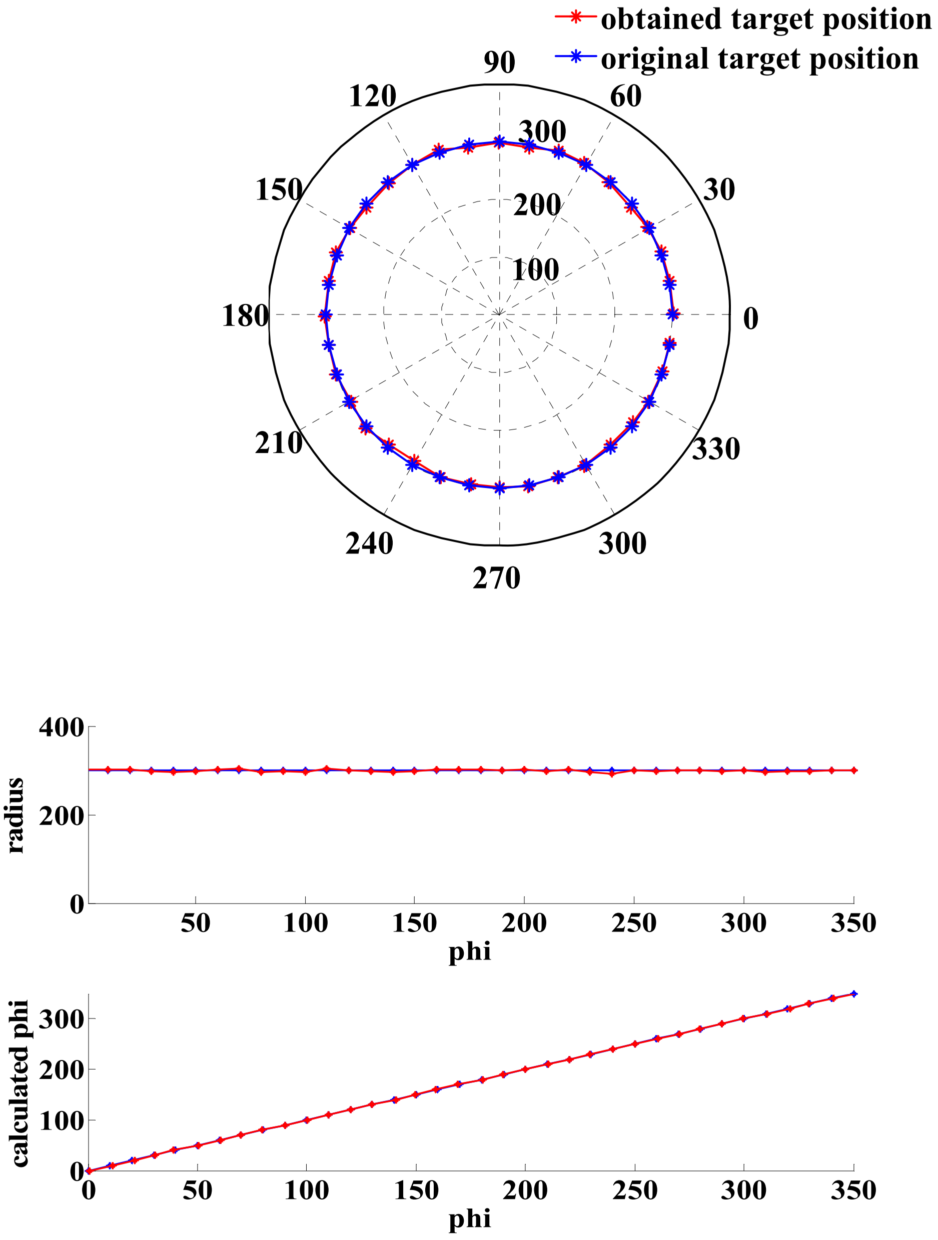


Figure 6. 4: shows various target position at fixed radius, Rd=300 and varying phi i.e. phi is incremented in steps of 10

7. SIGNAL MATCHING FOR TARGET LOCALIZATION

Image processing has opened up a lot of doors for target detection and tracking. It has rescued the engineers where the other techniques have failed miserably. Not only it has provided solutions for otherwise seemingly impossible tasks but has also made things easier to handle and most importantly to visualize various scenarios. This was basically the inspiration for exploring the domain of image processing for target localization. The biggest advantage of using imaging in the seekers is that; image seekers are inherently highly resistant to flare countermeasure. Flares will not easily decoy them. Because the point source simply does not look like an expanded aircraft with an exhaust plume. Furthermore, implementation of software processing with discriminating algorithms within the seeker would discriminate between the real IR target and flare decoy.

Image processing was incorporated initially for signal generation as discussed in chapter 2 of this thesis. Later on various methods were developed based on image processing. Though none of them were fruitful in accurate target localization but they provided many important results and gave an insight of the reticle system. Which can however be used in future for development of some efficient technique. These methods are discussed one by one.

7.1 Signal Matching:

The most obvious technique is based on the signal matching. In this the incoming signal as produced by the reticle is matched with that of the reference signals. The reference signals are generated for all the possible pixels positions in an image. These are then saved separately and any incoming signal is compared with all the signals. The most important thing is the matching criterion because a signal generation is dependent on the size of the target. If the size of target changes then either new set of reference signals need to be generated for a particular target size or some sort of matching criterion is needed. As the mentioned method is computationally heavy, boundaries for possible target locations are defined. This is done in the following manner.

The signal matching technique is joined with the geometrical method i.e a combination of geometrical and signal matching are used for target localization. Firstly depending on the number of transitions, signal is classified into FM or FM/AM signal. If the signal is pure FM, then geometrical method is used. However if the signal is AM then the signal matching technique is used. In this manner computations are greatly decreased.

7.2 **Moving image and stationary Reticle:**

As the name suggests, in this method the complete image containing the target is moved over the canvas containing the reticle. The image is moved over the canvas in a circle of fixed radius 'R'. The image containing the target is broken into sub blocks of 16 X 16 where each block consists of fixed number of pixels. Reference signals are generated by assuming that the target is represented by 1 complete block. The target is placed at each block (one at a time) and resulting signal is stored as the reference signal corresponding to that particular target position. In this manner a total of 256 reference signals are generated and stored. For signal matching correlation is used. But as seen from the figure 7.2 not much information can extracted from the figure. This suggests that some other matching criterion needs to be developed.

Once again complete matching i.e. incoming signal is compared with the reference signals and where complete 1 to 1 matching occurs can be used. But this has serious limitation. Complete matching is only possible if the target size is same as what was used for the reference signal generation. A change in the target size results in a different signal for same target position. So either a way is developed in which the target size remains the same as that what is considered while making the reference signal or some other method is needed.

One thing that is certain is that the target signal is high only in the places where the respective reference signal is also high i.e. it is not possible that for a particular location the respective target signal is high in a place where the respective reference signal is low .in this manner one can limit the possibilities of signal match. Apparently this is visualization is equally applicable to target sizes less than the block size (used for generating the reference signals).To implement this; the reference signal and the target signal are XOR and their sum is plotted. Where the value is minimum, that corresponds to target position. However there is no unique minimum. This is evident from Figure 7.3.

(a) **(b)** **(c)**

Figure 7. 1

(a) Shows the segmentation of Image into blocks of 8 x 8. (b) and (c) show possible target positions.

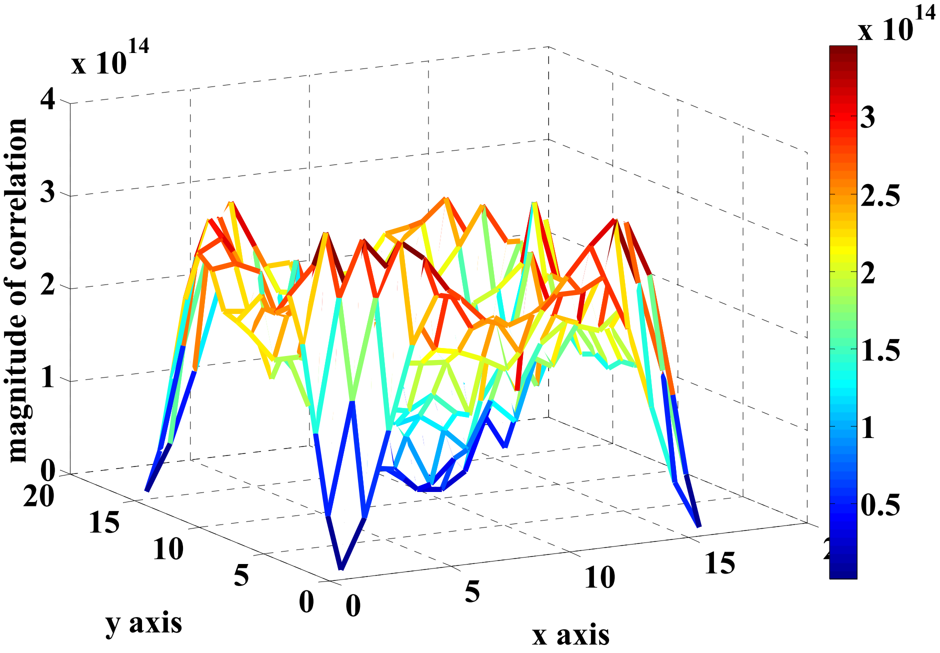


Figure 7. 2: Result of Correlation. Note that there is no distinct peak

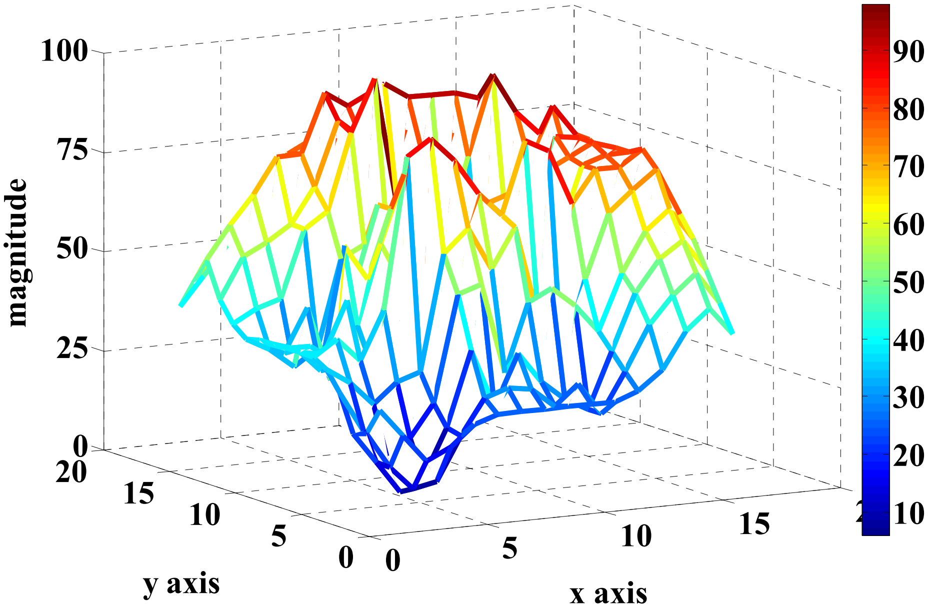


Figure 7. 3: Result after taking the XOR of the Reference signal with the signal from the target.

8. ROSETTE SCAN

8.1 Introduction

Imaging missile seekers are being used by several adversaries because of their minimum cost and low –cost technology insertion. Imaging seekers do not use a reticle. Instead, they use an array of detector elements that detect IR energy from the scene and generate a spatial map of that scene. An image can be formed with a two-dimensional array of detectors that stare constantly at the scene.

The rosette scanning infrared seeker (RSIS),mounted on the thermal tracking missile, is a tracker in which a single infrared detector scans the total field of view (TFOV) in a rosette pattern, as shown in Fig. 8.1. To reduce detector noise, the size of the instantaneous field of view (IFOV) should be small. If the IFOV is designed too small, however, it may not achieve full scan coverage (FSC). Therefore, in this case the invisible regions cause the performance of the RSIS to deteriorate.

The infrared seeker, mounted on the thermal tracking missile, identifies a position of the target by detecting and processing the thermal energy radiated from the target. Among the various IR seekers, the rosette scanning infrared seeker (RSIS) is a tracker in which a single detector scans the total field of view (TFOV) in a rosette pattern. The rosette pattern is achieved by means of two counter-rotating optical elements such as prisms, tilted mirrors, or off centered lenses. The RSIS offers positioning and imaging information about the target to the servo system of the missile. In general, the small instantaneous field of view Provides the high resolution for an incoming target image and the low interference of background signals and detector noise. If the IFOV is designed too small, however, it may not achieve full scan coverage. The invisible region causes the performance of the RSIS to deteriorate.

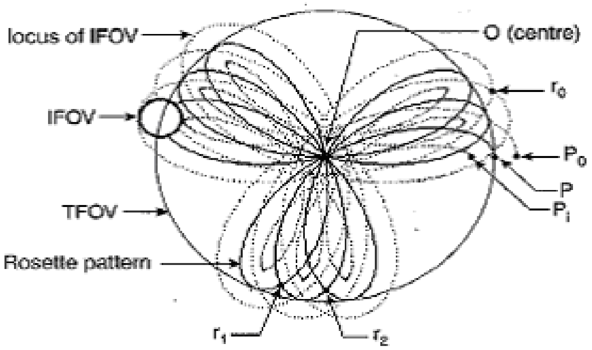


Figure 8. 1: Locus of IFOV along the Rosette pattern

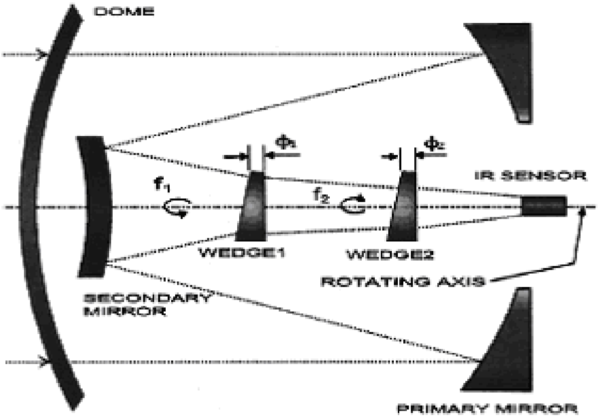


Figure 8. 2: Scheme of RSIS

8.2 The General Properties of the RSIS

A rosette scanning infrared seeker (RSIS) is the device mounted on the infrared guided missile. It offers the positions and images of target to missiles' servo system by scanning a total field of view (TFOV) in a rosette pattern with a single detector. An instantaneous field of view (IFOV) is a diameter of the detector moving along the path of the rosette pattern.

The IFOV has the property that its smaller size provides the less interference of background signals and detector noise. If its size is too small to cover the TFOV, however, it produces the invisible regions in the TFOV and decreases the performance of the seeker. For full scan coverage (FSC), it is necessary to design the small IFOV without the invisible regions as possible.

The rosette pattern of the RSIS can be achieved by means of two counter-rotating optical elements such as prisms, tilted mirrors, or off-centered lenses. Figure 8.2 shows the scheme of the typical RSIS using wedge prisms with apex angle f1 and f2, respectively.

Resolution of the detected images by the rosette scan seeker depends on the size of the IFOV and the number of scanning lines or the petals. The smaller the IFOV and the larger petal numbers, in general, provide the rosette scan seeker with better resolution. However, this is not a rule applicable to all cases.

The rotating optical elements spin at frequencies $f\,1$ and $f\,2$, the values of which determine the scan pattern parameters such as the number of petals and the petal width. The loci of the rosette pattern at any time *t*, in Cartesian coordinates, can be represented by

$$\mathbf{x(t) = \frac{\delta}{2}(\cos 2\pi f_1 t + \cos 2\pi f_2 t)}$$

$$\mathbf{y(t) = \frac{\delta}{2}(\sin 2\pi f_1 t - \sin 2\pi f_2 t)} \tag{8.1}$$

Where $\boldsymbol{\delta}$ stands for the deviation angle between the optical elements and the radius of the TFOV. If $f\,2\,/\,f\,1$ is a rational number, then the pattern is closed. Then the parameters f 1and $f\,2$ have a greatest common divisor *f*, such that

$$\mathbf{N_1 = f_1/f}$$

$$\mathbf{N_2 = f_2/f} \qquad (8.2)$$

Are both positive integers. Moreover, N1 and N2 are the smallest integers satisfying

$$\mathbf{\frac{N_2}{N_1} = \frac{f_2}{f_1}} \qquad (8.3)$$

The total number of petals in the pattern is

$$\mathbf{N = N_1 + N_2} \qquad (8.4)$$

The rosette period T is

$$\mathbf{\frac{1}{f} = \frac{N_1}{f_1} = \frac{N_2}{f_2}} \qquad (8.5)$$

The RSIS offers a 2D image of target by scanning a total field of view (TFOV) in a rosette pattern with a single detector. The small size of the IFOV provides the high resolution of an incoming image and the low interference of background and detector noise. If the IFOV is designed too small, however, it may not achieve full scan coverage (FSC). Therefore, in this case the invisible region causes the performance of the RSIS to deteriorate. The size of IFOV should be minimized to lessen interfering background signals and detector noise, but be large enough to provide full scan coverage. There are various conventional methods available for deigning of the size of IFOV. One is to design the IFOV small by making lessen the size of the TFOV. This method makes narrow a total detectable region of the RSIS since the TFOV also is reduced in a small size. Hence this method is not used.

In order to design a small IFOV, that can achieve FSC, the size of IFOV is represented by the following formula.

$$\boldsymbol{\omega_p = \delta\cos(\pi/\Delta N).\sqrt{2 - 2\cos(2\pi/N)}} \qquad (8.6)$$

where

$$\mathbf{\Delta N = N1 - N2}$$
$$\mathbf{\Delta N \geq 3} \tag{8.7}$$

The parameter **ΔN** also stands for the petal width. As the number of the parameter increases, the petal width becomes wider.

As shown in figure 8.3 and figure 8.4 if the parameter **ΔN** is 3 or more, then the petals have an intersected point or more, otherwise, the petals do not have an intersected point.

8.3 **Application**

The Rosette scan is modeled in MATLAB. The aim is to acquire an image of the target scenario. Using the Cartesian equations, the locus of the rosette scan is constructed. Keeping the importance of the size of IFOV, wp is calculated using the formula. Different values for N1 and N2 are taken. The constraints on the values of N1 and N2 are kept in mind while taking different values.

Rosette scan can be visualized as hole through which one is looking at a scene. Only the region lying within the circumference of the hole is visible. As in at any instant only a portion of the scene is available. Thus using this information and storing it in the memory, the whole image can be constructed.

The important thing that should be kept in mind is that the speed of the scanner should be very fast. This is essential because otherwise the target would have moved a considerable distance as compared to the target image that has been constructed.

8.4 **Image construction**

Binary images (image comprising of 0 and 1 only) are taken for simulations. The idea is to construct an image of the given scenario. For this pixels lying within the IFOV are taken, they are summed together .Then there average is calculated i.e.

Avg = (sum of all the pixel values lying within the boundaries of IFOV)/(total number of pixels in IFOV).

Once the average value is calculated, thresholding is applied to the average vale. If the value of average is greater than 0, then it is assigned a value of 1 else it remains 0.any values greater than 1 is also truncated to 1.An image or for that matter literally speaking, a canvas is taken .The instantaneous value of IFOV is known .so going on to the canvas, at the same position as that of the centroid of IFOV, the pixels corresponding to IFOV are assigned the average value calculated earlier. In this manner the canvas pixels are assigned the values. The pixels that are outside TFOV of the rosette scan are set to 0.Now the thing to keep in mind is; that this constructed image on the canvas is not exact replica of the target scenario. It’s somewhat a dilated version of the scene.

8.5 **Image processing:**

Once the image has been acquired, comes the task of finding the coordinated of the target and further down target tracking and differentiating the target from flares. For this various algorithms for object detection and tracking are available. A somewhat precise image of the target can be acquired out of the dilated image (canvas).To separate the target from the flares many methodologies are available such as moment technique, K means algorithm and most importantly ISODATA technique. All these techniques are based on image processing. The latter two are based on the clustering where as the former is based on the intensity.

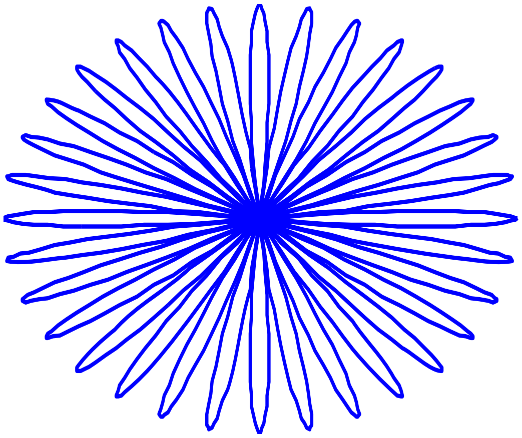


Figure 8. 3: Rosette pattern with non-intersecting petals

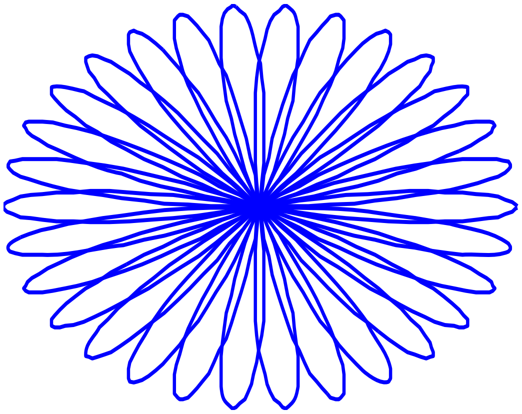
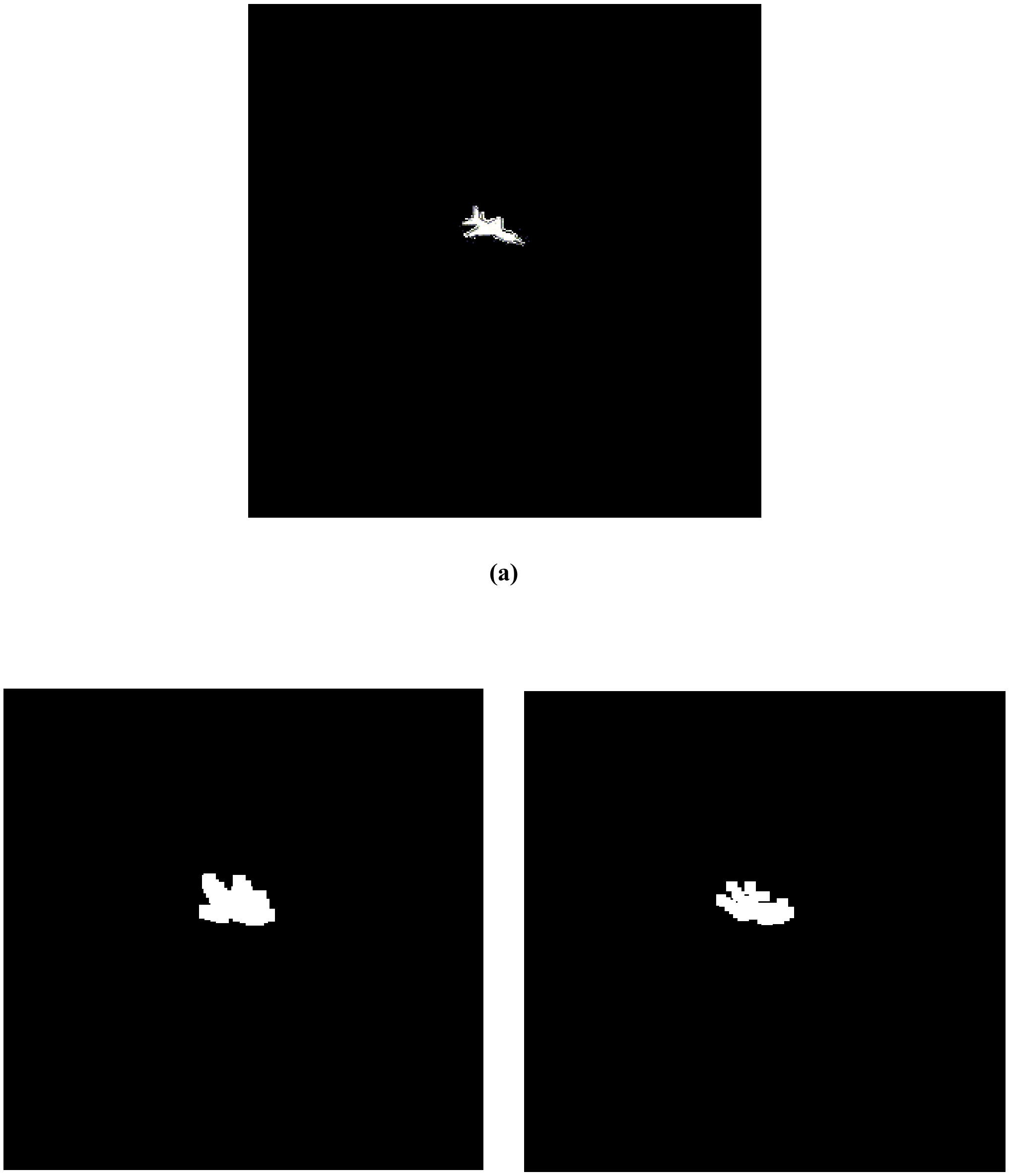


Figure 8. 4: Rosette pattern with intersecting petals

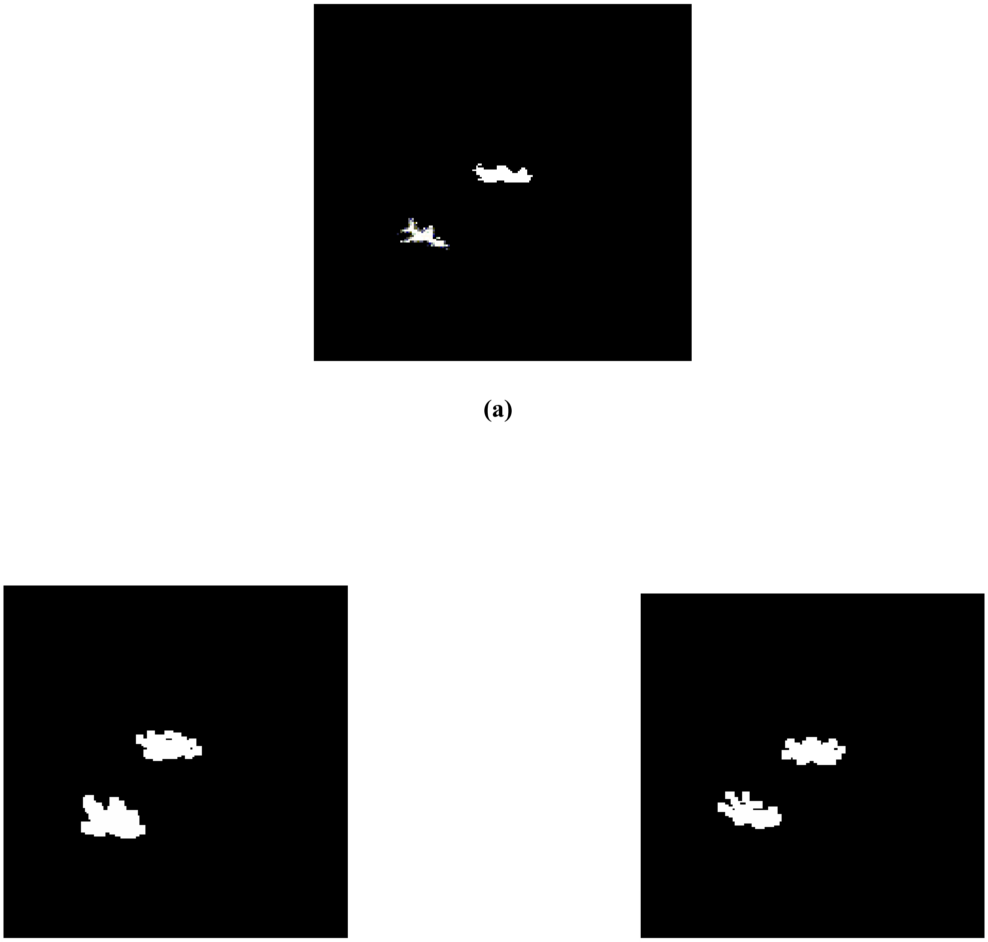
8.6 **Results**



(a)

(b) (c)

Figure 8. 5: (a) shows the target.(b) and (c) show images obtained with different petal number.



(a)

(a)

(c)

Figure 8. 6: (a) shows the target.(b) and (c) show images obtained with different petal number

9. CONCLUSIONS AND FUTURE RECOMMENDATIONS

9.1 Different Reticles

Various types of the reticles are available. However as the reticle design and working is the most important part of the seeker, its working is kept as a secret. Therefore not much literature is available. Hence there is a need to explore them and to simulate them. Two types of Reticles are shown in figure 9.1.

9.2 Different target sizes

The reticle is a selective modulator that is most efficient against a point source. So the reticle system performs well for a single target that is smaller than the smallest bar width of the reticle. As the Size of the target effects the modulation and hence the detector output signal, Algorithm and electronic circuitry of the reticle can be modified to cater for the size.

9.3 Modification of the centre of the reticle

The centre of the reticle can be modified to obtain accurate results. An example of such modification is shown in the figure 9.2.

9.4 Object identification

Imaging techniques can be used to identify the object and to track it.

Differentiating the target and flares/multiple target detection

IR missiles need sophisticated circuit technology and exotic signal processing capability to detect the presence of flares and to reject them as false targets while allowing the seeker to continue tracking the real target. The IRCCM techniques for possible integration into a missile seeker must include two critical components: the first is ‘Flare switching’, which detects the presence of a flare in the seeker FOV and activates the second component called the ‘response’ circuit, which asks the missile seeker to take immediate action to reject the radiation from a flare.

9.5 **Focal plane arrays:**

A staring array, staring-plane array, focal-plane array (FPA) or focal-plane is an image sensing device consisting of an array (typically rectangular) of light-sensing pixels at the focal plane of a lens. FPAs are used most commonly for imaging purposes. Keeping the limitations of IR seekers in mind ,it is suggested that work on them be done.

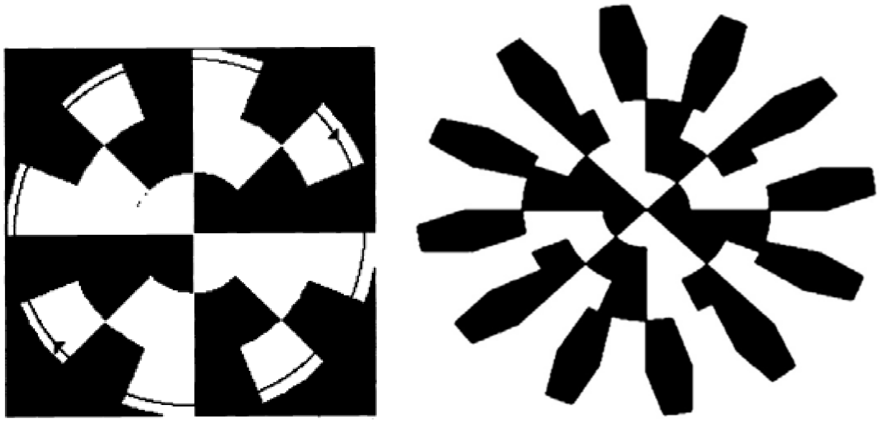


Figure 9. 1: Different Reticle designs

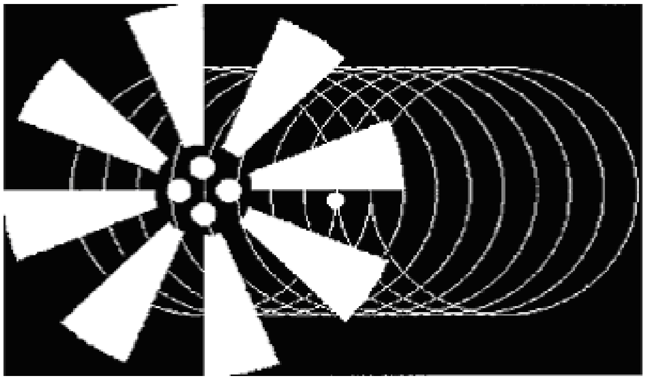


Figure 9. 2: Modified wagon-wheel Reticle and circular path of a target image at various positions.

10. PROBLEMS AND SHORT COMINGS

10.1 **High signal**

At close proximity signal remains high throughout and hence gives no information. This means that when seeker approaches the target it cannot rely on Reticle for tracking. Hence the seeker uses approximations to engage onto the target.

10.2 **Phase lock loop**

In case of PLL, careful designing is needed in order to deal with various problems of PLL such as jitter etc. Control of PLL involves careful designing and the stability of PLL is an important aspect. Another very important thing that should be kept in mind is that designing of PLL on computer is one thing and implementing it on hardware is another. Several things need to be considered while implementing it on hardware.

It has been observed that PLL can be used to get results as long as the target is on the reticle i.e. the output signal of the detector is FM. In case of AM or off axis PLL cannot be used.

10.3 **Signal matching**

In case of signal matching technique some sort of matching criterion is needed, so that the efficiency can be increased. Comparing the signal pixel by pixel is very time consuming. And in case of reticle seeker timing is a very crucial parameter.

10.4 **Geometrical method:**

This technique has definitely provided a different approach to the seeker problem and has opened the door for such geometrical relationship for the reticles.

The method purposed is really efficient and fast and provides very accurate results. However this technique is reticle specific i.e. it is only applicable on wagon wheel In case of geometrical technique, when AM region is encountered it is difficult to identify the cords. However by noting the number of transitions one can identify when the AM region is encountered however the attempt to find a geometrical technique for the AM region did not prove to be fruitful.

10.5 **Practical issues**

1) The opaque regions of the reticles are usually thin films and may be vulnerable to damage by absorption.
2) The detector may also be damaged/inhibited by absorption, or saturation may occur.

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