Millimeter Wave Sensor for third Generation Antitank Guided Missiles And Precision Guided Munitions

B.S.V. Prasad, D.R. Jahagirdar, Rani Surender S., Nidhi Gupta,
Vinod Kumar Singh, Neelesh Tayade, K. Sridhar Babu, J.V. Prasad, Sujatha Ravichandran, V.G. Borkar, and Rajatendu Das
Directorate of RF Systems, Research Centre Imarat, Hyderabad.
INDIA-500069

ABSTRACT

A coherent millimeter wave (MMW) active sensor has been configured with all weather capabilities for the third generation antitank guided missiles (ATGMs) with fire and forget and top attack capabilities. To meet the stringent dimensional and weight constraints and beam width requirements of ATGM, a W-band system has been designed with trans-twist planar reflector array mono pulse antenna and compact comparator. The main subsystems of the sensor are a GFPC Radome, a parallelogram linkage based stabilization system, a coherent two channel mono pulse transmitter receiver and signal processor. The sensor has been designed to typically operate in a lock-on before launch mode based on apriori target range and bearing designation. The paper covers the system description and critical design issues, and presents the performance results achieved so far.

Key words: Glass filled poly carbonate, Line off sight Errors, Bore sight, Range tracking and Angle tracking.

1. INTRODUCTION

The basic requirement of the ATGMs is to have top attack trajectory and all weather capability that make them highly suitable weapons against tanks. The ATGM can either be launched from ground or a helicopter against a tank. Particularly the third generation ATGMs are characterized by their “lock on before launch” and fire and forget capability. To meet the above requirements the missile should be fitted with a Seeker that can always track the target while on flight and helps the missile home on to the target with top attack. Due to the constraints imposed by the missile-carrying platform (e.g. helicopter or ground based system), the size and weight of the missile should be as small as possible. Consequently, with the missile size and weight the seeker size and weight also should come down. In addition to the size and weight, the seeker should have ECCM and all weather capability. To meet the above mentioned requirements coherent pulsed millimeter wave radar has been chosen at W-band as Seeker. The W-band seeker has the following characteristics that make it suitable for anti tank applications.

2. SYSTEM DESCRIPTION

The System block diagram is given in fig 1. The subsystems of seeker are (a) Glass Filled Poly Carbonate (GFPC) Radome, (b) Trans-Twist Antenna, (c) Servo stabilization system, (d) Coherent Trans receiver, (e) Coherent detector and (f) signal processor. The transmitter sends the W-band signal in pulsed form through the trans-twist antenna and the target echo received through the same antenna is down converted to the IF band in the dual channel receiver subsystem. The IF signals are coherently detected by I & Q detector[1,2]. The detected signals are digitized and processed in the signal processor for range and angle tracking of the target. The signal processor[1] implements various algorithms like False alarm rate receiver through cell averaging, coherent pulse integration for SNR improvement, range tracking and angle error generation. It also provides variable gain for the coherent detector and channel selection (azimuth and elevation) for the receiver.

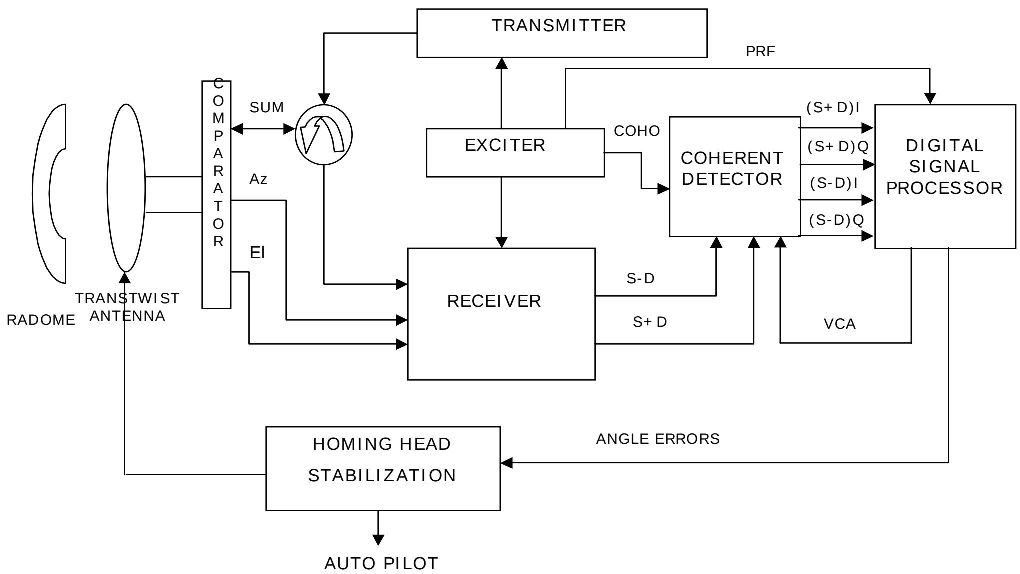

Fig 1. Block Diagram of coherent MMW Seeker.

The target echo return contains both the range and angle information of the target. The range information is obtained by round trip delay and angle information is obtained from the mono pulse antenna system. The signal processor extracts this information and performs the range tracking and also generates line of sight error signals (Azimuth and elevation). These error signals are given as input to the stabilization system, which in turn ensures the antenna to be at bore sight. Thus closed loop angle tracking is performed in both azimuth and elevation planes. The stabilization system also isolates the missile body disturbances to ensure the line sight between antenna and target.

For extracting the angle error information of the target, coherent processing based on the mono pulse principle[1] is used. The antenna is a trans-twist antenna with four horn mono pulse feed and a compact comparator. The exciter generates the basic Coho, stalo and PRF signals for transmitter, Receiver, coherent detector and signal processor. The transmitter uses injection locked amplifiers with IMPATT diodes for the required Tx power. The Stalo signals are frequency multiplied to generate the W-band signals for transmitter and receiver. The receiver is a two-channel mono pulse receiver which time multiplexes the angle information of elevation and azimuth planes on the same channel. The time multiplexed azimuth and elevation difference signals are added to the SUM signal in the receiver to generate S+D (sum and difference) and S-D signals. The difference signal D is the time multiplexed signal of azimuth and elevation line of sight error signals. The S+D and S-D signals are down converted to IF range in the receiver and amplified to the required level by IF amplifiers. The coherent detector is an In phase and Quadrature Phase detector that takes the S+D and S-D signals as input and generates the respective two pairs of I (In Phase) and Q (Quadrature Phase) signals along with providing variable gain to the signal. The signal processor performs coherent integration followed by non-coherent integration to extract the maximum gain in the stipulated time interval. It also implements detection and error computing algorithms along with providing automatic gain control to the coherent detector for increasing the dynamic range of the system.

The basic working of the angle tracking system is illustrated in fig 2. In the antenna the sum (S) and difference (D) signals are formed using mono pulse, where the D signal contains the information about the angular error off boresight. The relative phase of S and D signals contains the information about the direction of angular error.

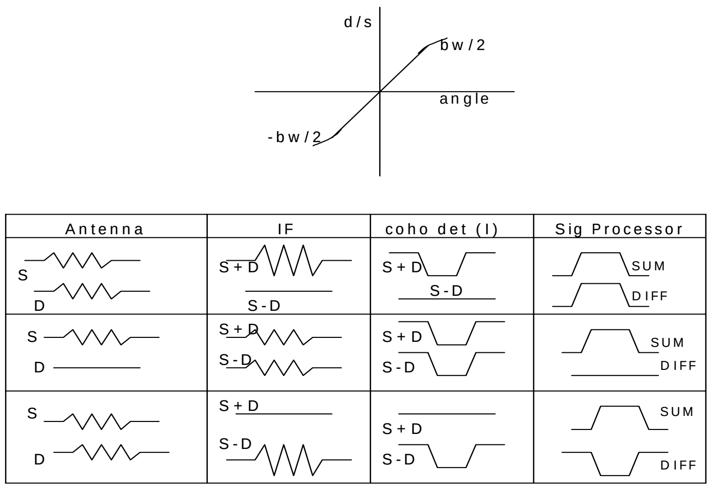

Fig 2. Basic working of the Angle tracking system.

Since we are using the coherent system, the phase information of the return signals are preserved in the receiver, coherent detector and signal processor. The antenna generates both elevation and azimuth difference signals, so in addition to the sum signal there are two difference signals generated at the output of the antenna. However the two difference signals are time multiplexed so that the receiver is a two-channel system instead of three-channel system. This has reduced the hardware size of the receiver that is very important for a missile borne system. The down converted IF signals are coherently detected using I and Q demodulator. After detection the signal processor separates the sum and difference signals. The ratio D/S (i.e. difference /sum) is given as angular positions of the target.

3. CRITICAL DESIGN ISSUES

From the performance point of view, the following issues are critical to the system.

3.1. Null Depth

Ideally at boresight, the difference (D) output from the antenna should be zero and sum output should be maximum. However the D out put is never zero but exhibits minimum value at or near bore sight. The minimum magnitude of the D relative to the S signal is called the Null Depth of the system. Some times the difference minimum may not be exactly at bore sight but some off set angle from bore sight. For an efficient angle tracking performance of the seeker, it is necessary that null depth should be high and difference minimum occurs only at bore sight. The depth of the Null also decides the sensitivity of the system during the angle tracking along the line of sight (LOS) and also the speed at which the antenna is brought back to LOS (in terms of the well defined mono pulse slope parameter)[4]. A typical value for this parameter is of the order of 30 dB.

3.2. Phase Imbalance

Despite being a coherent system phase imbalance do occur and degrade the performance. The critical imbalance to be tackled is between (S+D) and (S-D) channels. If α is the phase imbalance in radians between S and D, then one can take one signal as S and the other as $D\cos\alpha$. Then the angular error output[3] becomes $2DS/(S^2+D^2\sec^2\alpha)$. For large values of D say (D=S) the ratio becomes $2/(1+\sec^2\alpha)$ which is less than the true value of 1. Hence RF phase imbalance has the effect of compressing the angular error curve. As this effect is significant proper phase trimming of S and D channels is very essential. We have adopted an innovative method of balancing the phase between sum and difference channels (both elevation and Azimuth), which will be explained in the results sub section.

3.3 Gain Imbalance

The gain imbalances between S and D channels affect the angular error output significantly. It can be easily shown[1] that if the gain of the two channel has a ratio of p, then the angular error output becomes $(1-p)/(1+p)$ at bore sight which is nonzero. So the gain imbalance shifts the bore sight of the system from true position. To overcome the problem of imbalance either commute the channels (S+D) and (S-D) or attenuate one channel properly to reduce the imbalance. A typical imbalance that can be tolerated is of the order of 1 dB.

3.4 I/Q Errors

The critical errors in coherent I/Q detection[5] are (a) non orthogonality between the channels (b) Imbalance of the gain between the two channels (c) DC offset present in the channels. The gain imbalance and non-orthogonality will present a false target along with the original target. The DC off set manifests by showing a DC signal in the FFT output. A typical gain imbalance that can be tolerated is of the order of 1 dB and non-orthogonality tolerance is less than 0.5^0.

4. INDOOR TRIALS

The seeker with all subsystems integrated has been tested for its performance evaluation in the laboratory. The indoor test set up is shown in fig 3.

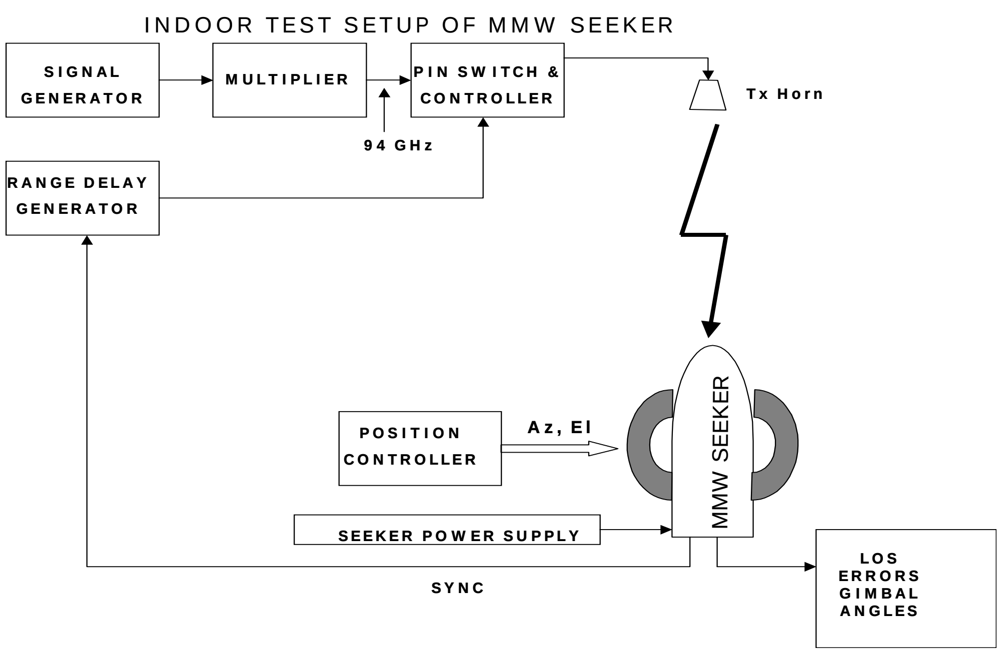

Fig. 3. Indoor test setup of MMW SEEKER

The seeker is operated in receive only mode. The target is emulated using a signal source with a frequency multiplier, which multiplies the source frequency to W –band (94 GHz). The W-band signal is pulsed by using PIN switches, which are switched by tapping the delayed PRF from the Seeker. The delayed PRF is for the purpose of emulating the desired range and it is generated by a pulse generator triggered with the PRF signal from the Seeker. The pulsed W-band signal is then transmitted to the Seeker by a calibrated horn Antenna. The distance between the transmitting horn and the Seeker is 7 meters. The transmitting horn is kept on a fixed platform and the Seeker is mounted on an electro-mechanical positioner whose position in azimuth and elevation can be controlled precisely. The seeker has successfully tracked in range and angle. The Gimbal angle freedom of $\pm 12^0$ is established in azimuth.

5. RESULTS

The aim of the indoor trials is to establish the complete functionality of the seeker that becomes the first step towards integrating it in the missile and carrying out the flight trials against the real target. The major achievements of the indoor trials are discussed below.

5.1. Phase Trimming

The seeker transmits and receives at W-band i.e. the corresponding wavelength of 3.2 mm. So 3.2-millimeter path length corresponds to 360^0 phase change. In order to retain the phase of the return echo, the path length between the two channels should be identical. However due to smaller wavelength even a 0.3 mm difference in the path lengths of the two channels gives rise to the phase difference of 36^0. Without phase matching, the two IF outputs will be asymmetric around bore sight in elevation as well as in azimuth. This will result in poorer angle tracking by the seeker. Inserting the dielectric material in the sum, difference azimuth and difference elevation channel wave-guides solved the phase matching problem. Fig 4 shows the IF1 and IF2 outputs over the entire beam width of 2^0 after phase trimming. The symmetry of IF1 and IF2 outputs around the boresight can be seen.

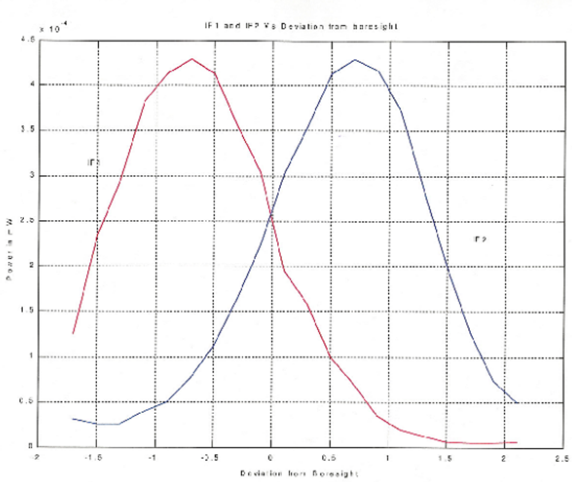

Fig 4. Phase trimmed IF1 and IF2 outputs around boresight.

5.2. The difference to sum ratio

Normally all mono pulse processors calculate the ratio of voltages or difference of phases rather than calculating absolute values of voltage and phase. So instead of using the difference amplitude directly, the ratio of difference amplitude and sum amplitude along with the relative phase is used which is normally called the normalized difference signal or difference to sum ratio (d/s ratio) for obtaining the target angle position in both azimuth and elevation. When the target is at bore sight, the difference signal is zero and correspondingly d/s ratio is zero. Away from bore sight the difference signal build up reaches to peak at 3 dB down from the antenna beam width peak. For a single point target the sum signal and difference signal have the same phase (say θ) or out of phase (180^0+θ) because they are obtained by four individual beams whose outputs ideally should have the same phase. So if the relative phase angle between sum and one of the difference channels is θ, the difference to sum ratio is taken as (D/S) cos θ on one side of the bore sight and (D/S)cos(180+θ) on the other side of the bore sight.Ideally θ is zero, so the cosine factor is +1 on one side and -1 on the side of the bore sight. In essence the D/S ratio not only provides how far the target is away from bore sight axis but also provides sense (above or below of bore sight for elevation and left or right of bore sight for azimuth). This D/S ratio so calculated is shown in fig 5.

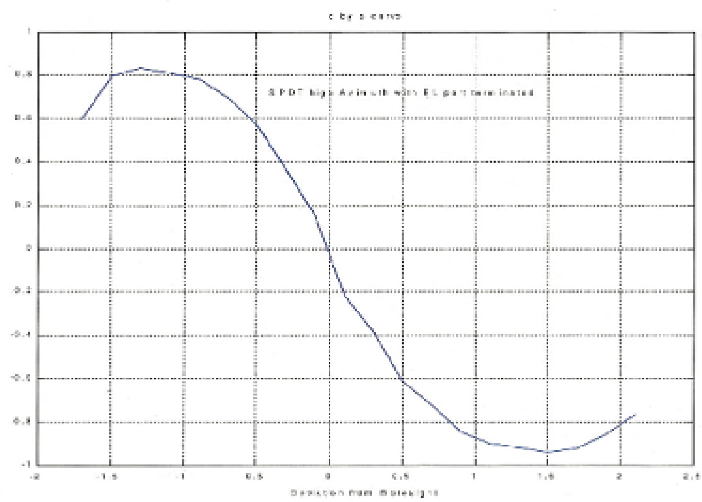

Fig 5. D/S ratio for one of the difference channel.

5.3 Los Error and Gimbal Angle

The stabilization system is in position mode (i.e. at bore sight) and the LOS errors monitored at every 0.2^0 within the beam width to see if they follow the 0.1^0/V scale factor. Then the sense between the signal processor and servo system is checked and the LOS errors are given as input to the stabilization system to complete the closed loop tracking. Closed loop tracking requires the LOS errors to be zero while the gimbal angle increases in such a manner so as to maintain the line of sight with the target. The fig 6 shows the LOS errors going to zero from 8 Volts (which is due to the position of the seeker being 0.8^0 away from LOS).

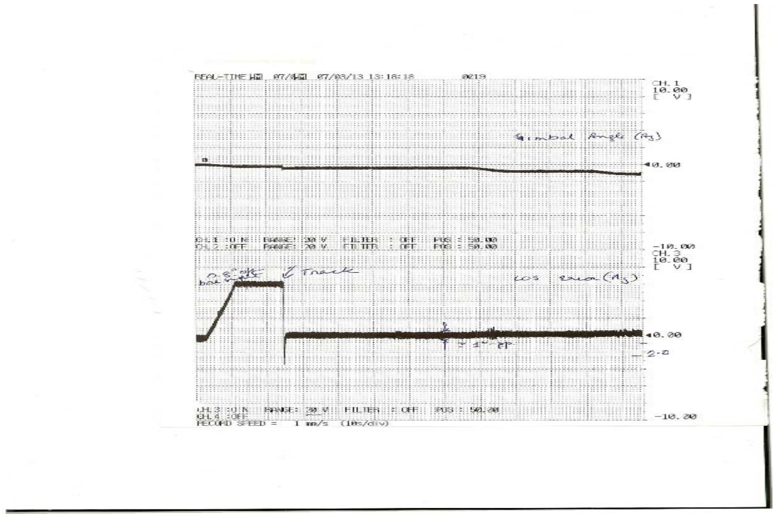

Fig 6. The seeker correcting LOS error upon closing the loop.

Fig 7 shows the movement of the gimbal in terms of the voltage over range of $+12^0$ to -12^0 movement of position. The gimbal angle is increasing with a scale factor of 300 mv/deg.

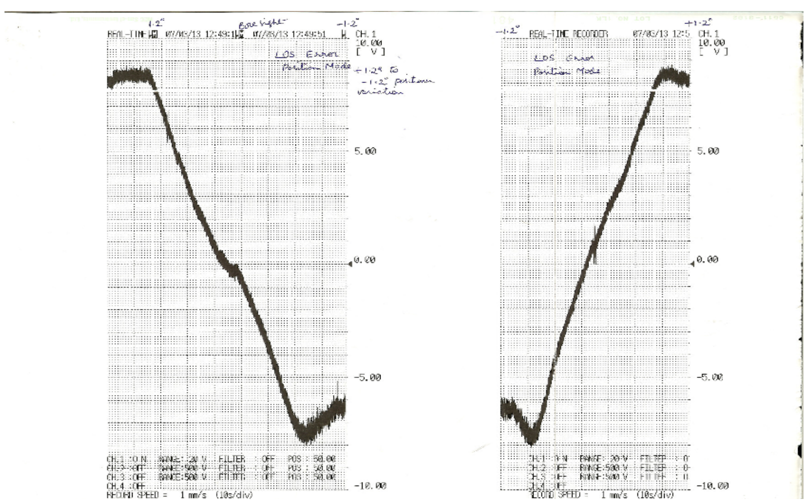

Fig 7. Gimbal movement in $+12^0$ to -12^0 while in closed loop.

5. CONCLUSION

In the indoor trials the functioning and performance of the W-band seeker is completely established. The seeker has been checked particularly for closed loop performance and it has tracked the emulated target.

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