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A Missile Jamming Design for Aircraft Defence Using Infrared Automated Counter Measures

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Abstract: Infrared guided missiles possess a greater threat towards aircrafts in the scenario of defence. Securing aircrafts from such attacks requires an active directed infrared counter measure. Since DIRCM systems require the parameters of the missile signals to be known in advance, they suffer when attempted to be applied in real time. This paper proposes anInfrared Automated Counter Measures (IRACM) system with an equippedmissile alert equipment (MAE) capable of estimating the signal parameters once the signal is detected. Jamming is performed by which the missiles are subjected to miss the target along the field of vision by updating the jammer frequency based on the signal parameters. Since IR flashes in IRACM are emitted directly towards the missiles, it is considered more efficient when compared with the flare methods which emits in all directions. The experimental results of proposed method reveal that the system performs well in estimating missile signal parameters and the jamming effect is influenced by the estimated parameters.

Keywords: Infrared Automated Counter Measures, missile alert equipment, DIRCM.

1. Introduction

The advancement in IR technology has led to the development of IR guided missiles as a main armament in the space. The heat signatures emitted by aircraft engines are detected by IR missile for tracking an aircraft to attack [1]. The components of an IR missile mainly include a detector that is capable of detecting as well as tracking a target. In particular, Reports on war environments around 20 years reveal that the damage caused by such missiles is about 90% [2]. Hence considering the impacts of damages, defence strategies are established and they fall into two broad categories namely, flare methodsas well as jammer methods.Jamming signal exerted by flare methods is of high radiation power including objects for protection. Flare methods are found to be weak in facing attacks and limited in their capability of load amount as well as continuity in launching. Modern missiles are designed in a way to overcome such flares and target.Jammer methods are subdivided into omni-directional and directed jammer methods [3]. Since the former system emits in all directions, they consume more power and are inefficient. Therefore, DIRCM systems are developed to overcome such pitfalls [4]. In DIRCM, the variable frequency of jammer signal has influence over missile guidance system. Hence, it is found to an important technique among defence community for protecting military forces from opponent missiles. As DIRCM is more effective than the present flare method or the omni-directional jammer method, its development and research are progressing nowadays.

Numerous missiles are being launched and each possesses difference in the nature of their signals. However, existing DIRCM systems expect the signal parameters to be fed prior to the attack.It refers to the fact that the systems can only be able to jam missiles whose parameters are specified on them. This describes the impossibility of DIRCM systems to be implemented in real time applications. Thus, systems with capability to analyse the signal at the time of detection must be implemented such that jamming can be performed by updating the frequency based on the results of analysis.

This paper establishes anIRACM system with MAE attached to it. MAE is capable of detecting the incoming hazardous signal and estimating the parameters of those detected signal. The major contributions of this paper are 1) anIRACM system is implemented with MAEto detect themissile signal and calculate the signal parameters 2) update the jammer frequency with respect todetermined parameters and perform jamming. Since the directed jammer method uses higher luminance lamps or laser for applying jamming energy into missile seeker, it consumes less energy and can emit jamming source continuatively.

The rest of this paper is organised as follows. In section 2, briefly reviews related literature. Then, background information and formulation of the problem forcounter measures on IR guided missiles are presented in Section 3. In Section 4, the proposed work describing the working of the DIRCM system is presented. Section 5 presents a report of the obtained simulation results obtained.

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2. Literature Review

With the advancement in missile technology, the need for counter measures in order to safeguard aircrafts is greatly demanded. Several researches have been done in the respective field. A decoy of aircraft resembling the IR characteristics of the target is used in [5] to mislead the missile. It analyses the defence strategy by combining a series of defence moves with the decoy. The authors have proposed that, contrasting horizontal-S maneuver to barrel roll maneuver provides best avoidance maneuver. Comparison of anti- jamming of missile and avoidance strategies of the decoy provided the best defence strategy. However the model is simple and does not coincide with reality. The jamming effects of spin-scan and con-scan reticle seekers are analysed in [6]. The jamming effect is found to be better only when the frequencies of jammer and reticle are similar. The jamming effect was analysed by examining target positions with changes of a frequency and intensity of the jammer signal. But the frequency features of the seeker in advance.

In contrast, the authors of [7] had proposed that the parameters Intensity, frequency and phase influence the effect of jamming. The effect of the seeker was studied based on the variation in these constraints. It also requires the seeker frequency earlier. The tracking error rates are determined for active and flare methods and compared with unjammed tracking for determining the jamming effectiveness [8]. However they were found as short term solutions. Genetic programming with some manoeuvres was proposed in order to address countermeasure problems [9]. The paper established a general framework for uncertainty conditions in order to solve problems of strategy optimization. The author has formulated the MCO problem as a representative example of a broad class of strategy optimization problems. But GP requires more computation to find solution. The analysis of jamming effects in [10] shows that the jamming is better when both jammer and spinning frequencies are same. Signal processing of both reticle seekers were understood.The simulator included a tracking process of target in field of view (FOV) of seeker and a guidance loop for an approach of a missile. Jamming effect was analysed by examining target position according to changes of frequency and intensity of jammer signal. They cannot be applied in real time because the characteristics of missiles must be known before the DIRCM signal is added. Since type of seekers is eminent in determining the jammer signal towards the missile, research has been done in type of reticle and their signal processing [11]. The increase in jam to signal ratio increases the jammer effect of against con-scan seekers. It was found that the type of jammer signal influences the jammer frequency. A simulation system with the model of each components and the interaction between them is described in [12]. It was said that low power counter measures such as jamming and dazzling requires prior idea about the missile sensor. Hence the internal behaviour of dazzling was designed by heuristic modelling based on experiments. It worked well in flares but it was found complex to design DIRCM interactions.

Most existing systems required the parameters of the missiles to be known in advance. Hence a system that computes the parameters by itself once when the missile signal approaches is demanded.

3. Methodology Background

3.1 Infrared Homing

Light emitted from infrared target is used as system guidance to identify and track the target in infrared homing. Heat seekers are missiles that use infrared seekers as hotter bodies to radiate IR of more strength. As devices with passive nature, IR seekers provide little idea about their target tracking which differentiates them from the radar. Thus, making it appropriate for sneak attack in case of visually encountered attacks or utilises forward IR for long range distance or identical cuing systems. Hence heat seeker is made tremendously dangerous. However counter measures are applied on them, which includes spraying flare after targets in order to make fake source of heat. It is possible only when the missile is detected by the pilot, and establishes counter measure. This is considered highly ineffective in modern scenario even when the missile is detected. Directional methods of jamming work well on such seekers.

3.2 DIRCM as a countermeasure

Aircrafts are safeguarded from IR missiles using DIRCM system. It is a brief and small sized system. The system is designed in such a way to be more protective against vulnerable missiles in the view of safeguarding aircraft from attacks that happens in the field of battle. It is regarded as highly modernized and improved when compared with conventional IR counter measure. It establishes counter measures directly towards the point of view of the attack and hence it is used as a term in general to indicate counter measure. There are two modes through which the DIRCM can work such as active and standby mode. Jamming is initiated by manually choosing the active mode. DIRCM defend attacks depending on two different systems. First system detects the malicious missile using an ultraviolet sensor. The other system contains a transmitter through which IR energy is directed towards the missile seeker. A compact pod comprises both of the systems that is present on the lower side of the fuelage of jet.

Energy source in DIRCM is mounted on a mobile turret. It is tied with a warning system and plume of missile in order to operate well and to exactly hit the missile seeker. The seeker is subjected to an attack by the modulated signal, and a set of seekers are defeated by different iterations of the modulated scheme. The victory of counter action depends upon the mechanism used to track the enemy and better analysis of the capability of missile. More power is required for DIRCM in order to defeat advance system of tracking.

1) When a missile is fired, different source of energies is produced along with the spectrum. Warning system of DIRCM detects ultraviolet energy and transmits a signal towards the transmitter.

2) As the signal arrives the transmitter, it tracks the approaching rival using a pointer assembly.
3) A lamp of higher intensity infrared energy is then fired into the missile seeker.
4) In addition to missile blinding, the beam enters into the guidance system of the seeker and produces an error signal in order to make the missile to feel that it is not following the intended route.
5) The guiding system adjusts the path of the missile in response.
6) However, the missile enters into a state that it thinks it has no threat afterwards.
7) The process takes place in shorter span between two and five seconds and the crew on aircraft is not responsible of these actions.
8) When a height of 18000 feet is reached by the aircraft, the guardian system stops operating because it is the maximum height of missiles.

4. Proposed Work

The framework of proposed simulation is discussed in detail in this section. The block diagram is initially described. Then the parameters of the detected missile signal are estimated and its position is determined. Finally, the implementation of jamming is presented.

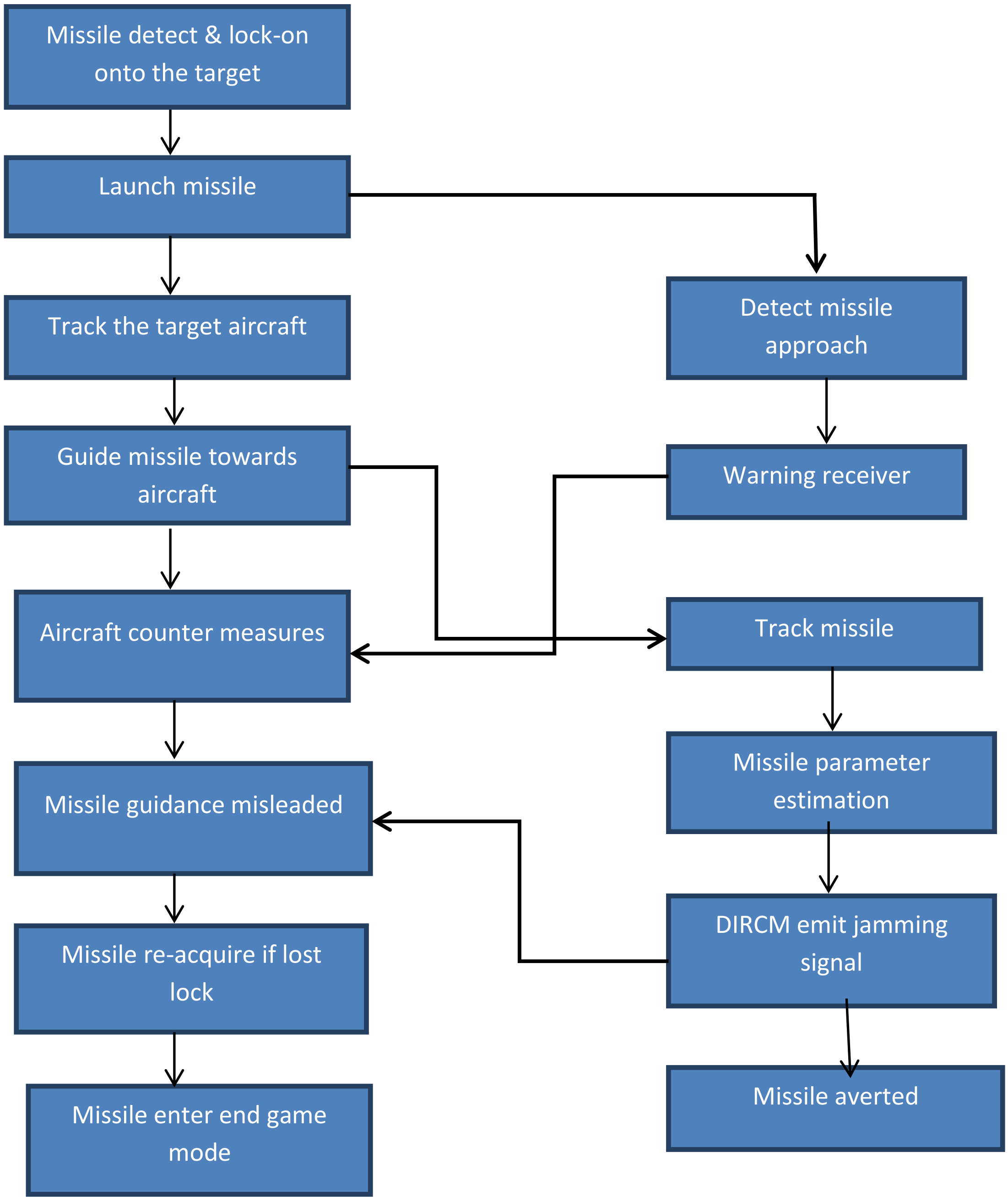

Fig.1: Block diagram of proposed system

This work proposes a counter measure technique in order to safeguard an aircraft from attacking missiles. The block diagram for the proposed work is shown in fig.1. The core of the proposed framework isIRACM system with MAEthat is capable of estimating the parameters at the time of detection. All forms of energies are produced when an IR guided missile gets fired into the electromagnetic spectrum. When the missile approaches the aircraft, MAE detects the signal and determines the direction and type of missile. Then the signal is processed which involves parameter estimation including frequency, duration and bandwidth of pulse, elevation and azimuth angles. Once estimations are made, jammer frequency against missile is generated based on the parameters.Jammer frequency is generated so that it must be stronger than that of the missile frequency to be more effective. The jammer frequency is then applied towards the missile.It establishes effect on the guidance system of the missile and causes an error signal to build making the missile's guidance system think it's off course. Finally, the missile is averted and enters into the end game mode.

4.1 Estimation of parameters

Parameters of the missile signal includesPulse repetition interval, Center frequency, Bandwidth, Pulse duration, Direction of arrival, Position of the missile. Estimation of parameters requires the signal to be analysed in detail including the location, direction of the missile etc. MAEobstructsan impinging signal, and various signal processing mechanisms are used for extracting characteristics of the wave and position of the foe. MAE chain includes an antenna of phased array, an envelope detector, a signal processor and a receiver. The envelope detector and receiver are responsible for the estimation of signal's frequency band. It is then followed by the signal processor, which treats the sub band signal detected. Along the direction of sub band signal arrival,Beam steering is applied, andpseudo Wigner-Ville transform, a mechanism for analysis time-frequency is used in association with Hough transform to estimate the parameters of wave. Initially,Wigner-Ville transform derives the time frequency characterization of the signal intercepted. Hough transform works well even in the presence of noise and hence enhancement of time frequency analysis can be done. Parameter estimating is then carried out.The position of the missile can be estimated with the help of single- baseline approach and arrival angle.

Algorithm

Consider,
missile frequency fs $\leftarrow$ *4e9*
freqlim $\leftarrow$ *[1.7e9 1.9e9]*
Aircraft frequency, fc
rectangular array for MAE
size $\leftarrow$ *[10,10]*
ElementSpacing $\leftarrow$ *repmat((c/2e9)/2*
bandwidth of each frequency sub-band
stepFreq $\leftarrow$ *100e6*
Compute the number of sub band
numChan $\leftarrow$ *fs/stepFreq*
Calculate original starting frequency as.
detfBand $\leftarrow$ *fs*(detInd-1)/(fs/stepFreq)*
fs $\leftarrow$ *stepFreq*
The frequency estimation function for SIGNAL is
$PSI\left(e^{j\omega}\right) \leftarrow \frac{1}{\sum_{i=p+1}^{M}|e^{H}v_i|^2}$
Locate emitter
altimeterElev $\leftarrow$ *position of MAE*
Compute the pseudo Wigner-Ville transform
$PW(t,f) \leftarrow \int_{-\infty}^{\infty} \omega(\tau/2)\omega(-\tau/2)x(t+\tau/2)x(t-\tau/2)e^{-j2\pi\tau f}\,d\tau$
Implement a median filter
filImag $\leftarrow$ *medfilt2(twvNorm,[7 7])*
Parameter Estimation
Calculate the true angles
Azimuth angle
$tan\alpha = \frac{\sin L}{cos\varphi_1 tan\varphi_2 - sin\varphi_1 cosL}$
Elevation angle
$\alpha s \leftarrow 90-\theta s$
Zenith angle
$Cos\theta s \leftarrow sin\Phi sin\delta + cos\Phi cos\delta cosh$
Distance $\leftarrow$ *(time) * (velocity)*

Bandwidth, $B \leftarrow \frac{f_H - f_L}{f_c}$
pulse Repitition $\leftarrow$ *abs(t1,4 – t1,2)*
Center frequency $\leftarrow$ *detfBand +* $f_{2,1}$

4.2 Jamming

Once the parameters are estimated, jammer frequency is generated by IRACM system. It is generated on the basis of estimated parameters so as to have the jammer frequency more effective than that of the missile. It means that the jammer frequency must be greater than the frequency of the missile. The generated frequency is applied towards the missile to perform jamming. It establishes effect on the guidance system of missile and causes an error signal to build into the missile's guidance system. The path of the missile gets diverted from the aircraft. Finally, the missile is averted and enters into the end game mode.

5. Simulation Results

The simulation results obtained from the proposed framework are presented in this section. The direction of the aircraft is initially unknown to the missile. Hence the missile guidance system performs scanning around the space for aircraft. Generally, missiles possess a nature of transmitting set of pulse along every direction prior to migrating to the next location. So, without losing generality, the missile is considered to transmit at an angle of zero degree both azimuth and elevation. The time frequency characterisation of 8 pulse train received at the aircraft is shown in fig.2. Since MAE possess no knowledge about the transmit time, the delay in first pulse is unknown eventhough the train of pulses are transmitted at particular delay.

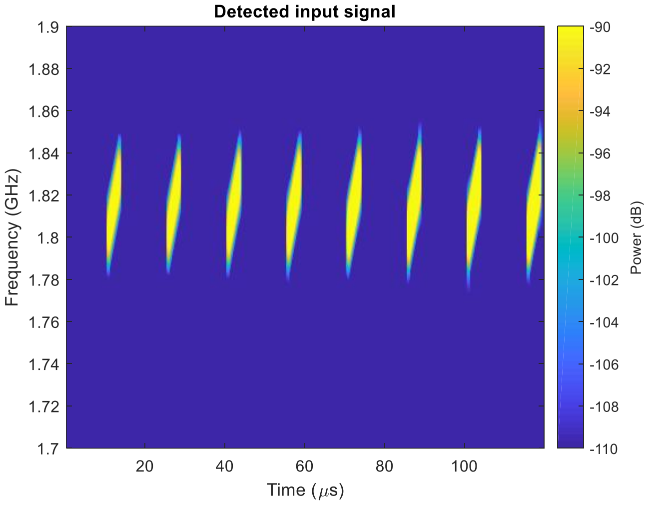

Fig.2 Detected missile signal

In order to reduce the burden of sampling the overall bandwidth received by MAE, signal is broken into sub-bands each of bandwidth ranging 100 MHz so that down sampling can be performed by considering each sub band of frequency 100 MHz. The initial eight bands produced by by filter bank is displayed in fig.3.

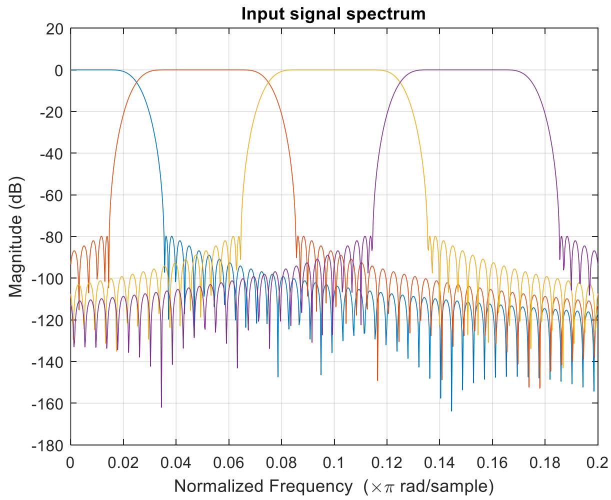

Fig 3. Sperctrum of the detected missile signal

A three dimensional data called sub data is received. Fast time is reprented as the first dimension, sub bands are indicated in the second dimension and the elements received along the receiving array correspons the third dimension. The number of elements received is 100 for a 10x10 antenna configuration of MAE. Due to the low transmission power and high noise at the receiver, it is hard to distinguish missile signal from noise. The SNR (signal-to-nose ratio) can be enhanced by summing up the power received for getting better power estimation in every sub band. Th band found to be containing power as maximum is identified as the one used by the missile.

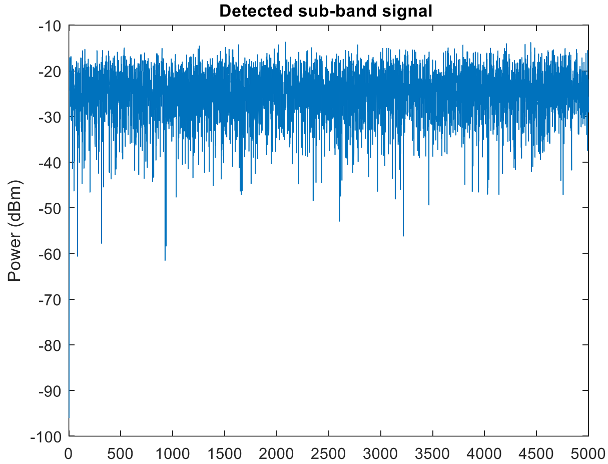

Fig 4. Sub bands of the missile signal

Sub data is transformed into a matrix of two-dimension. Fast time samples are provided in the first dimension and the data of 100 channels received are contained in the second dimension. Carrier frequency of the signal detected is found by calculating the starting frequency of the sub band detected. Information regarding the altitude can be obtained from the reading in the altimeter of aircraft and the missile location can be obtained by the arrival direction of triangulate. Fig.5 represents the missile location.

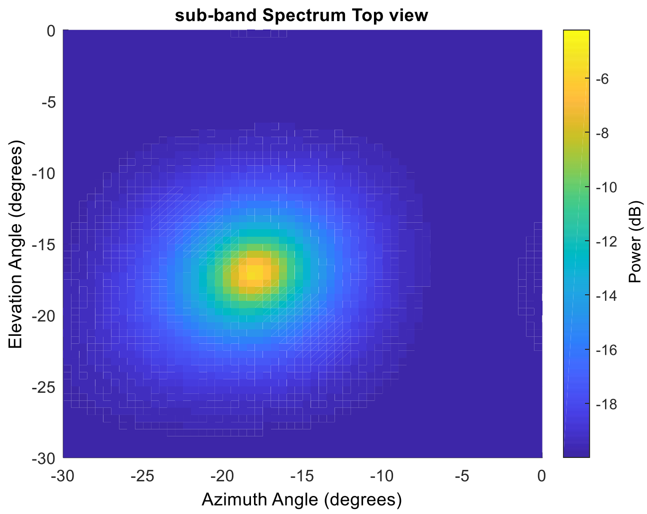

Fig 5. Top view of the sub band spectrum

Fig.6 displays the analysis of time frequency of the signal. When compared with the smeared out spectrogram,The Wigner distribution is found to provide betterauto term localisation. However, appearance of cross terms is resulted when applied to multiple frequency signal because of their quadratic character.

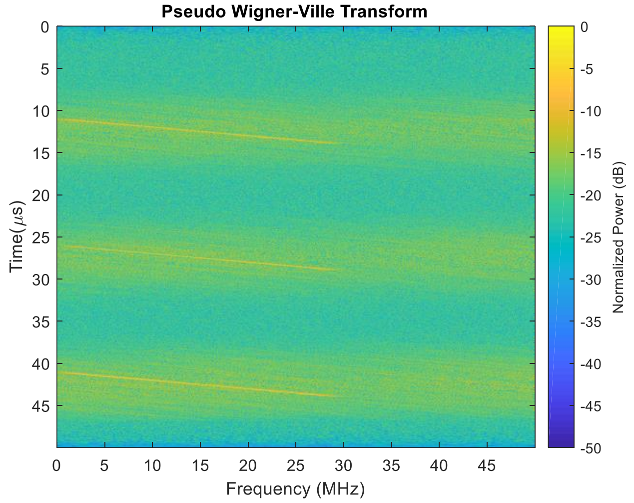

Fig 6. Pseudo Wigner Ville applied on missile signal

Using Hough transform, the binary pseudo Wigner-Ville image are first transformed to peaks. This way, instead of detecting the line in an image, we just need to detect a peak in an image. To use Hough transform, it is necessary to convert the time frequency image into a binary image. Data smoothing is performed on the image and then use imbinarize to do the conversion. The conversion threshold can be modified based on the signal-noise characteristics of the receiver and the operating environment.

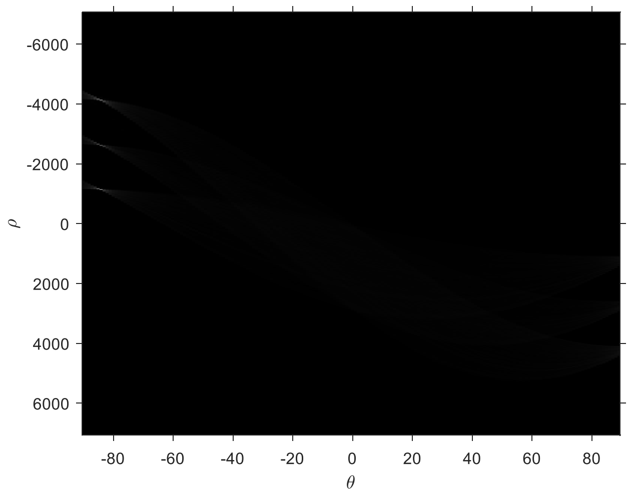

Fig 7. Hough transform

The peak positions are extracted using hough peaks. Using these positions, houghlines can reconstruct the lines in the original binary image. Thus the beginning and the end of these lines help us estimate the waveform parameters.

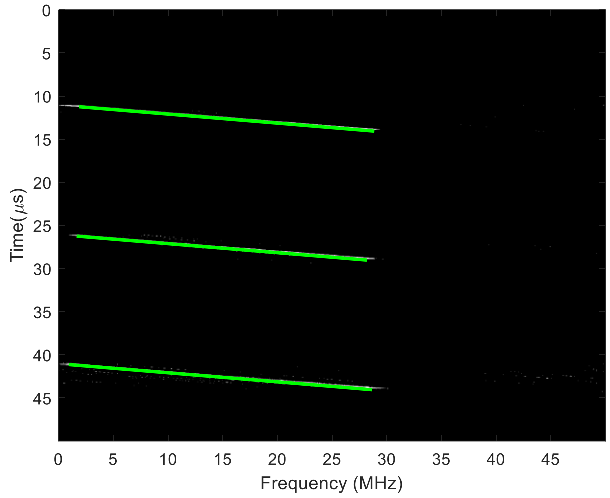

Fig 8. Hough transform detected lines

Here, the airccraft is assumed to be moving with a fixed speed of 325m/s and a reciprocated course of 50 cm above the starting position of missile. The experimental results reveal that missile acqusition is found after 0.69 seconds before initiating the attack. The guided closed loop starts as it reaches the time interval of 0.89 seconds.Due to the influence of detected target at 3.46 s, the closest point is evaluated at 0.25 m. The simulation reference is visualised in the form of animation blocks.

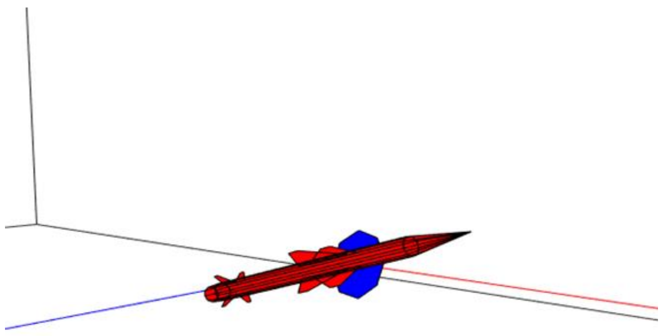

Fig 9. Jamming of missile

The following figure depicts the overall performance of the system with respect to the time. The acceleration of the system is obtained by dividing the thrust produced by the aircraft by the weight of the system. It is found to be better. Angle of incidence is found to be constant over time but may vary at some circumstances. Speed of the aircraft with the proposed IRACM system is expressed in terms of Mach number. It is obtained by considering both the speed of the aircraft with the speed of sound. The aerodynamic side slip and the directional stability of the system is found to be stable.

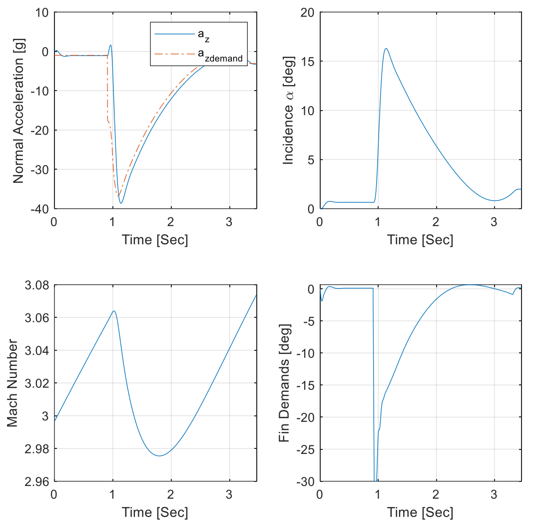

Fig 10. Overall performance

The following figure.11 illustrates the changes in modes of the system It illustrates the different angles including the true look angle and gimbal angle of the IRACM system.

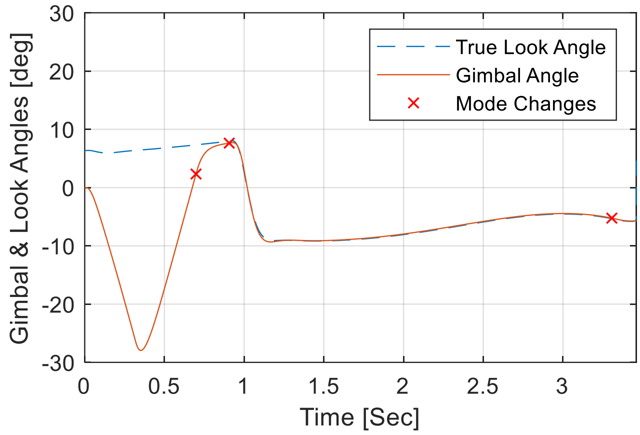

Fig 11. Changes in mode

The path of the aircraft and the missile are depicted in the following figure. The path is usually powered by the gravitational force and in some cases it is influences by the resistance of air if the system is found to be available in the air medium.

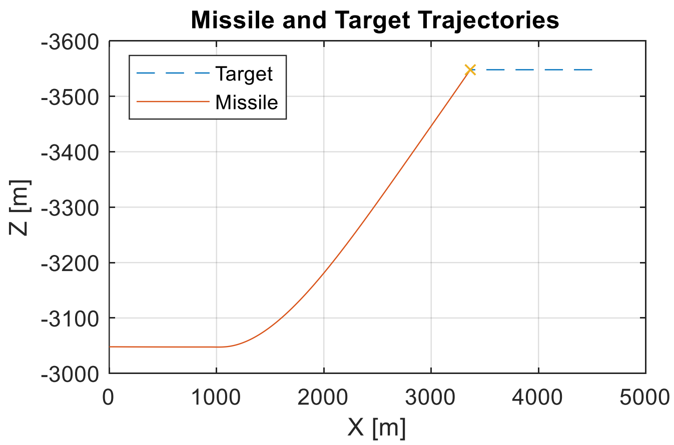

Fig 12. Path of missile and aircraft

The variance in the average phase error with respect to the change in jammer frequency is shown in the following diagram. B refers to the intensity of the relative IR jammer. From the figure, it is known that the increase in jammer frequency considerably increases the effect of jamming performed towards the missile.

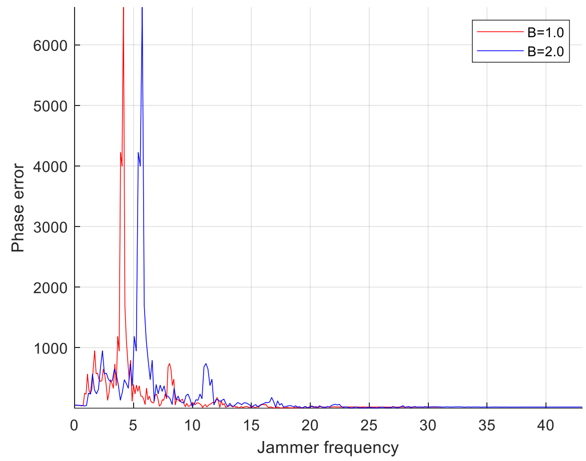

Fig 13. Variance of average phase error for the jammer frequency

The performance of the system in view of the jammer frequency is illustated in the figure. It is found that the jammer frequency exerterd by the system gets stronger when the missile frequency is high. Jammer frequency is more when the opposing frequency is high. This is due to the reason that jammer must be high inorder to mislead the missile's guidance system.

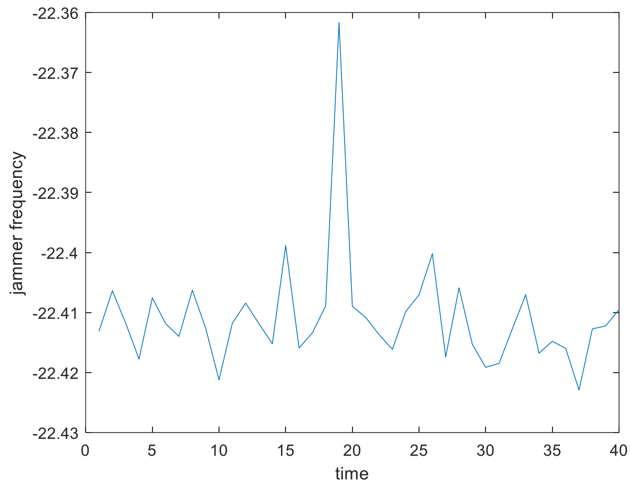

Fig 14. Performance in terms of jammer frequency

Fig. 15 shows the comparison between the variance of the average phase error and the jammer frequency fj. It is also presented in tabular form in Table 1. This comparison is made between IRACM and DIRCM technique given by Bae et al in [10]. The phase error error is found to be reduced in the IRACM system so that it is considered better than the DIRCM.

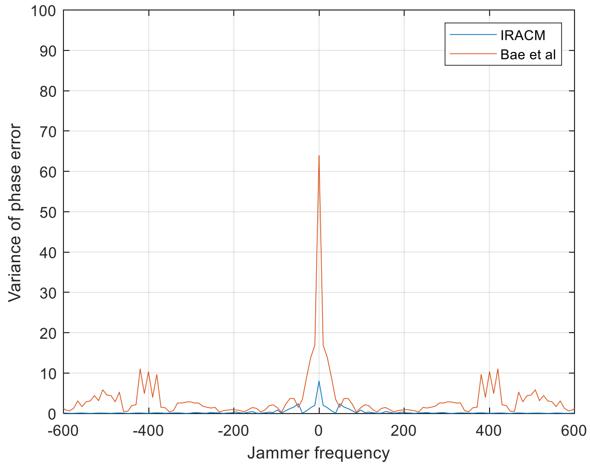

Fig.15 Comparison of jammer frequency with phase error

Table 1: Jammer frequency comparison

Jammer Frequency	Variance of phase error	
	Bae et al	IRACM
-600	-0.2645	0
-500	5.0264	0
-400	10.052	0
-300	2.6455	0
-200	0.7936	0
-100	1.8518	0.79365
0	63.756	7.14286
100	1.0582	0.52910
200	0.5291	0.52910
300	2.6455	0
400	9.2592	0
500	4.7619	0
600	0.2645	0

Fig.16 and Table 2 shows the plot of number of rotations of the missile seeker against the phase error. The comparison is made between IRACM and that of the system given by Kim et al in [6]. The phase error is identified to be reduced in IRACM when compared with [6]. Since the error is low, the system can withstand any kind of missile seekers.

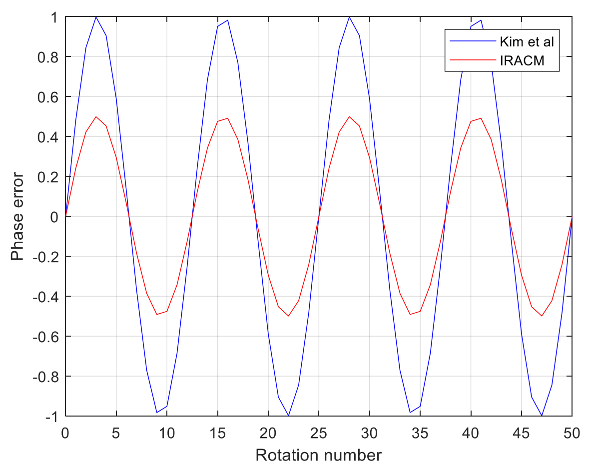

Fig 16. Comparison of rotation number with phase error

Table 2: Rotation error comparison

Rotation Number	Phase error	
	IRACM	Kim et al
0	0	0.03058
5	0.29108	0.60048
10	-0.46948	-0.95670
15	0.47417	0.94495
20	-0.30985	-0.54164
25	-0.01408	0.00471
30	0.29577	0.60754
35	-0.47417	-0.95432
40	0.46948	0.96144
45	0.03286	-0.59574
50	0	-0.06821

6. Conclusion

DIRCM systems that are being used nowadays perform jamming only when the missile parameters are fed into it in advance. This nature of such systems faces difficulties to utilise them in applications as missile parameters cannot be known earlier. By taking such systems into view,aIRACM system with MAE is presented in order to estimate the missile signal parameters at the time of detection. The system is designed with a phased array antenna, a channelized receiver, an envelope detector, and a signal processor for analysing the signal. Jamming was performed based on the calculated parameters by updating the strength of jammer frequency. The jammer frequency is subjected to intrude into the guidance system of the missile. Thus, the missile is diverted from the way along the aircraft. The simulation result demonstrates the efficiency of the proposed system in terms of jammer frequency. The deviations in jammer frequency with response to intensity are also demonstrated.

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