

## Research Article

### GPS Jamming: Strengthening Anti Jam GPS System with Adaptive Phase Only Nulling Using Cuckoo Search

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**Abstract:** Global Positioning System (GPS) signals are spread spectrum, modulated with very low average power caused by background noise. Signal received is mostly 165 dB down than thermal noise level. Such signals are easily jammed either through intentional noise sources (jammer) or unintentionally from broadcasting stations harmonics or other out of band sources. This study proposes to reveal how a nulling antenna with adaptive spatial filtering technique can efficiently mitigate intentional and non-intentional interference. A beam forming antenna array is an antennas set whose outputs are weighted by complex values and combined form array output. The complex valued weights effect is to steer the array pattern's main lobes to desired directions which may be unknown and hence antenna weights are adjusted adaptively till some array performance measure is improved, revealing proper lobe or null placement. This study proposes a Cuckoo Search (CS) algorithm based new optimization method for multiple interference cancellation design that increases gain to desired signal and improves jamming rejection performance.

**Keywords:** Anti-jamming, Cuckoo Search (CS), Global Positioning System (GPS), jamming, null steering

#### INTRODUCTION

Global Positioning System (GPS) is an earth-orbiting-satellite based navigation system which provides users globally with 24 h precise time, traceable to global time standards and precise position in three dimensions. The GPS is operated by United States Air Force under the Department of Defence (DoD). It was designed for and is under the control of the US military (Dana, 1997). Though there are thousands of commercial and recreational civil users globally, DoD control impacts many GPS planning, operation and user aspects.

GPS positioning is trilateration based which determines position by measuring distances to points at identified coordinates. A trilateration requires 3 ranges to 3 known points. Nevertheless, GPS point positioning requires 4 "pseudo ranges" to 4 satellites. GPS segments are four (Blewitt, 1997):

- Space Segment includes constellation of GPS satellites which transmit signals to user.
- Control Segment is responsible for monitoring and operation of Space Segment.
- User Segment includes user hardware and processing software to position, navigate and time applications.
- Ground Segment includes civilian tracking networks providing User Segment with precise ephemerides, reference control and real time

Services (DGPS) that mitigate "selective availability" effects.

Recently, GPS jamming is of concern to users. Civilian applications safety concerns and military operational concerns continue to escalate. But, GPS downlink vulnerability to jamming is not new, having existed from system inception. Papers discussing vulnerability date back over twenty years (Rash, 1997). GPS performance characterization and receiver testing against jamming was performed by many civilian and military entities. No standard test methodology to define how accurate or repeatable GPS jamming testing should be. Only recently was there an attempt to standardize military's navigation testing facilities and testing processes.

Once jamming presence is established, a GPS receiver with AJ features adapts to jamming environment in which it is. GPS receiver's next defense aimed at reducing jamming levels contaminating signal processing functions are embodied in filter's differing levels and types. During high levels of jamming, a receiver may not maintain both code and carrier tracking. A receiver normally can maintain code tracking even when carrier tracking is not possible. When only code tracking is available, receiver will slew locally generated carrier and code signals based on predicted and not measured Doppler shifts. Such predictions are performed by receiver processor, which

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Wideband jamming power is diluted over a broad frequency interval (matched to spread spectrum bandwidth of targeted signal/receiver). Though wideband jamming is regarded for low power spectral density, it is practically impossible to filter it out through embedded receiver signal processing techniques. A fraction of jamming signal that makes it through a GPS receiver (and into base band processing functions) becomes additive to noise floor, degrading output Signal-to-Interference power Ratio (SIR) and corresponding receiver operation.

Continuous Wave (CW) and Narrowband (or spot) noise tone jammers cause degradation to receiver SIR and degradation/denial of GPS navigation the same as wideband noise. Effectiveness of such jamming techniques is greater than wideband noise as they lead to higher power spectral densities at receiver outputs, as they are highly concentrated signals in frequency domain. Wideband pulse jammers convey high peak power interference signals at low duty cycles to harm/saturate receiver front ends. A jammer designed with GPS receiver architecture knowledge is an intelligent jammer which generates complex waveforms like pulse signals or sweep CW signals making RFI detection tough. Jammers are narrowband or broadband. Narrowband anti-jamming techniques include adaptive filtering, time-frequency, adaptive antennas and subspace processing. Time frequency domain techniques and spatial processing using antenna arrays suit combating broadband jammers (Mukhopadhyay *et al.*, 2007). Time-frequency methods like Short Time Fourier Transform (STFT) based processing, filter-banks, wavelet transforms or subspace processing suit low cost, low power and small form factor applications.

Antenna arrays are expensive and large and so their applications are restricted to fixed location GPS systems, or systems on ships or aircraft. Missile systems have space constraints making antenna arrays unsuitable. Another constraint is environment. For systems on aircraft or missiles, it is imperative to switch over to changing environment due to motion speed. STFT based techniques suit such applications. Adaptive antennas can be used in rapidly changing environments.

Basic to any AJ receiver design are capabilities to detect jamming and characterizing jamming features. Jamming detection is accomplished by comparing signal levels to noise floor in receiver, before code correlators. At this stage, GPS signal amplitude is below noise floor. Detection of significant signal amplitude now indicates jamming or other interference. Automatic Gain Control (AGC) measurements characterize jamming signal amplitude (Kandangath, 2003).

A phase-only adaptive algorithm modifies quantized phase weights based on the array's total

output power. When no interference is present, then algorithm minimizes desired signal (Haupt, 1997). To prevent desired signal degradation, algorithm is turned on at low array signal-to-interference-plus-noise ratios or when nulling phase shifts are small. By using some least significant bits of phase shifters for adaptive nulling, damage the algorithm, can do to main beam is limited.

An anti-jam GPS receiver must be operational at "cold" start, i.e., start with no information about position and orientation (Zhang and Amin, 2012). Here, though GPS satellites positions may be found at GPS almanac, GPS receiver cannot determine steering vectors associated with satellites until jammers are suppressed. Blind anti-jamming array processing techniques, like Minimum Variance (MV), achieve very good jammer-suppression performance.

This study proposes a novel Cuckoo Search algorithm based optimization method for multiple interference cancellation design. The proposed system increases gain to desired signal and improves jamming rejection performance.

## LITERATURE REVIEW

An efficient hybrid model based method with breeding and subpopulations, between Genetic Algorithm (GA) and modified particle swarm optimizer for linear antenna arrays pattern synthesis with prescribed nulls in interference direction and multi-lobe beam forming by complex weights of array elements was proposed by Chaker (2014). Usually, pattern synthesis technique generating a desired pattern is a nonlinear optimization problem. The new method was based on hybrid model algorithm while linear antenna array synthesis was modeled as a multi-objective optimization problem. Multi-objective optimization was concerned with vector of objectives functions maximization in directions of desired signals that were subject to many constraints. Many numerical results with imposed single, multiple and broad nulls sectors were issued and compared to published results to prove the proposed method's performance.

An efficient Bees algorithm based method for pattern synthesis of linear antenna arrays with prescribed nulls was presented by Guney and Onay (2007). Pattern nulling was achieved by controlling each array element's amplitude alone. Numerical examples of Chebyshev pattern with single, multiple and broad nulls imposed at interference directions were given to show algorithm's accuracy and flexibility.

An optimal radiation pattern obtained for linear antenna array using Particle Swarm Optimization (PSO) technique was presented by Zuniga *et al.* (2010). Phase shift weights set were generated to steer a beam to any direction while keeping nulls in interferer's direction. Fitness function which ensured phase shift weights calculations was presented. Comparison between standard GA and PSO was studied and results showed that latter achieved better and more consistent radiation

pattern than GA. Also, many experiments showed that PSO being capable of solving problem using less fitness functions evaluations on average.

A novel anti-jamming GPS receiver structure that preserved GPS signal phase continuity was proposed by Zhang and Amin (2012). The proposed technique's effectiveness was verified by simulation. Anti-jamming techniques are critical to maintain GPS systems integrity and functionality in various applications. One problem with existing array-based anti-jamming GPS receivers was errors introduced in carrier phase, affecting GPS solution.

Adaptive filters, both temporal and spatial were considered in detail and experimented on both labs and field trial and whose results illustrate key issues were presented by Trinkle and Gray (2001). GPS systems proliferated, especially in aviation where FAA felt it was useful for enroute navigation and CAT 1 non precision landing approaches. Relatively low interference power levels that jammed GPS receivers needed to improve system against intentional or unintentional interferences. Many methods could do so. At signal input level, use of adaptive A/D converters might prevent digital receivers saturating. Next, adaptive filtering techniques using single or multiple element antennae coupled with spatial and temporal digital processors rejected narrowband and broadband interferences. Also other digital signal processing algorithms could reject specific interferences from a spread spectrum system. Finally at systems level, both GPS and INS receivers may be tightly/loosely coupled to improve GPS accuracy and robustness when jamming signals are present. The benefits and drawbacks of the above methods in various generic implementations were overviewed and compared.

How nulling antenna or controlled reception pattern antenna with adaptive spatial filtering technique mitigated international and non-international interferences was proposed by Kundu and Ghosh (2008). A beam forming antenna array is an antennas set whose outputs were weighted by complex values and combined to form array output. Complex valued weights effect was to steer the array pattern's main lobes to desired directions which might be unknown and so antenna weights are adjusted adaptively till some measure of array performance improved, indicating proper lobe or null placement. An adaptive algorithm to adjust an antenna array's complex weights was presented that nulls high power signals while allowing receiving GPS signals as long as signals were from different directions.

A blind beam forming technique for GPS receivers described by Zheng (2008) improves GPS receiver performance by mitigating interference and enhancing GPS signals separately. It has a 3 stage structure. Technique was based on subspace and multiple

independent beam forming techniques. A signal model was constructed. Specific emphasis was on projection matrix derived from subspace technique. Interference and phase error effect on this technique was discussed and technique was tested and compared to null steering and MMSE technique through simulated data for many interference environments. Also, the new technique applied to real data showed advantages over simple null steering.

A smart array antenna system that improved performance through spatial filtering was proposed by Debbat and Bendimerad (2012). Smart array antennas supported by strong signal processing algorithms automatically changed beam pattern in accordance with changing signal environment. Adaptation was achieved by multiplying incoming signals with complex weights and summing them together to get desired radiation pattern. Adaptive array optimization was NP-hard. A Pachycondyla Apicalis algorithm (API) based technique was presented to solve the issue. Many patterns illustrative examples with imposed single and multiple null directions showed the present method's versatility.

A new optimization method based on PSO algorithm for a linear phase array's multiple interference cancellation design was proposed by Hsu *et al.* (2010). A linear phase array is a linear array antenna with phase only perturbations. Adaptive array antenna suppressed interferences in interfering directions using optimization techniques so that it increased SIR. PSO could solve combinatorial optimization problems. PSO was applied to find weighting vector, which ensures pattern nulling optimization for new adaptive antenna. The Person Name technique cancelled multiple interferences for different incident directions in everyday wireless communication systems. An example demonstrated the proposed phase-only perturbations approach based on PSO. Simulation demonstrates the proposed method's effectiveness.

An efficient method for pattern synthesis of linear antenna arrays with prescribed null and multi-lobe beam forming was proposed by Mouhamadou *et al.* (2006). Multi-lobe pattern and adaptive pattern nulling was achieved by controlling each array element's phase. The new Sequential Quadratic Programming (SQP) algorithm based method and linear antenna array synthesis were modeled as multi-objective optimization problem. Multi-objective optimization was concerned with maximization (or minimization) of objectives functions vector in directions of that were subject to many constraints (in this case, constraints were imposed as null in direction of interfering signal). To verify the technique's validity, many illustrative examples of uniform excited array patterns with main beam were placed in direction of useful signal and null was placed

in direction of potential interferers and multi-beam patterns demonstrated.

### METHODOLOGY

Adaptive array processing techniques attempt to fix the shortcomings of the antenna switching concept by using arrays of small antenna elements than full directional apertures. So, this makes installing practical, on even small weapon platforms. Also, implementation of phased-array processing is crucial to multiple jammer suppression that can restore GPS receiver operation in widespread jamming environments. Phase control is provided in Adaptive arrays to every element of their multiple element antennas.

The new anti-jamming GPS algorithm provides stable GPS signal phase output being robust to the operational environment's imperfect knowledge (calibration errors). It provides precise estimation and GPS phase change compensation without involving NCO or a similar device. The adaptive algorithm calculates complex weights by solving optimization problem. Many optimization criteria were proposed, most being based on minimizing array output power subject to some constraint. The most common constraint was simply to set one beam former weights to unity. This criterion is termed "Power Inversion" and will be the focus of this section. It steers deep nulls in direction of interferences and attempts to maintain a uniform beam pattern in other directions.

By maintaining uniform beam pattern, other than in interference direction, it is hoped that GPS signals will be preserved. Other single beam former criteria that use platform attitude and GPS signal DOA information achieve performance improvement over simple power inversion array especially in situations where satellite DOA is close to interference (Trinkle and Gray, 2001). But, in most situations, involving antenna arrays of less than 8 elements, a simple power inversion array achieves as well as more sophisticated adaptive algorithms. This is because gain of spatial filter needs to be optimized in direction of at least 4 satellites simultaneously.

The simplest and earliest, adaptive beam forming technique is the null steering beam former. The idea of null steering is to put null in direction of interference. There are two techniques depending on how nulls are steered. One is priori knowledge based on directions of desired signal and interference and the other one is based on the statistics of the received data at the array. There is another null steering technique where it is based on statistics of received array data (Civicioglu and Besdok, 2013). This approach works by steering deep nulls in directions of interfering sources and attempting to maintain uniform beam pattern in other directions. This method does not need a priori information of angular directions of desired signal and interferences.

Optimization is an applied science which explores best parameters values to a problem taken under specified conditions. Optimization plans to get relevant parameter values to enable an objective function generating minimum or maximum value. An optimization problem starts with an objective function design. This must correctly define related problem mathematically and clearly express relation between problem parameters (Zheng, 2008). Meta-heuristic optimization algorithms use 2 basic strategies when searching for global optimum; exploration and exploitation. While exploration succeeds enables an algorithm each best local solutions in search space, exploitation expresses ability to reach global optimum solution which is likely to exist around local solutions get. A meta-heuristic algorithm must be able to rapidly converge to the global optimum solution of the related objective function.

For a linear array of N antennas, let  $(a_1, a_2, \dots, a_n)$  represent the normalized current excitation and  $(p_1, p_2, \dots, p_n)$  represent the nth element position with respect to the center of array. Let the angular velocity  $v = \sin(\theta)$ , where theta represent the broadside scanning angle.

To produce null in the direction of interference, every phase of the array element is controlled to suppress the sector levels of the array pattern in the prescribed directions of interference. Using the phases of the current excitations of the antenna, the new pattern can be defined as:

$$F(v) = \psi s(v) \tag{1}$$

Where  $\psi$  is a vector containing the element's phase perturbations:

$$\psi = \begin{bmatrix} e^{j\psi_1} \\ e^{j\psi_2} \\ \cdot \\ \cdot \\ e^{j\psi_n} \end{bmatrix} \tag{2}$$

$$S(v) = \begin{bmatrix} a_1 e^{jd_1 v} \\ a_2 e^{jd_2 v} \\ \cdot \\ \cdot \\ a_n e^{jd_n v} \end{bmatrix} \tag{3}$$

Obtaining the ideal phase is NP Hard. In this study Cuckoo Search Optimization is proposed to find the ideal phase values. The goal of Cuckoo Search is to optimize the value  $\psi$  at every iteration such that the

objective function is minimized. The  $k^{th}$  iteration during the Cuckoo search algorithm can be represented in Eq. (4):

$$\psi_k = [e^{j\psi_1^k}, e^{j\psi_2^k}, e^{j\psi_3^k}, \dots, e^{j\psi_N^k}]^T \quad (4)$$

Let  $\delta_i(v)$  denote the new location in the  $i^{th}$  suppressed sector and  $\delta_0(v)$  denote the error in the nulling regions, then the approximated perturbed pattern in every iteration can be expressed as:

$$F_k(v) = \begin{cases} F_0(v) + \delta_0^k(v) & v \in R_0 \\ \delta_i^k(v) & v \in R_i \quad i=1,2,\dots,I \end{cases} \quad (5)$$

where,

$R_0$  : The angular region of the nulling regions

$R_1$  : The  $i^{th}$  angular sector of the  $i^{th}$  interference

The objective functions used in this study is defined by:

$$Fitness = \frac{e^M}{\left( \prod_{n=1}^M |F(v)|^2 \right)} \quad (6)$$

where,  $|F(v)|$  is the output power in the direction of the null and  $M$  is the number of detected interference. If more than one interference sources are present then the total output power is the product of powers in the direction of interferers. The fitness function proposed is such that the termination criteria reduce as the number of interference increases. This is proposed to avoid the local minima problem.

**Cuckoo Search (CS) optimization algorithm:** CS is a meta-heuristic algorithm inspired by the cuckoo species due to their special lifestyle and aggressive reproduction (Kaveh *et al.*, 2012). These species lay eggs in nests of other birds with an amazing ability to select recently spawned nests and remove existing eggs that increase hatching probability. The host takes care of eggs presuming they are its own. Some host birds combat this parasitic cuckoos behaviour and throw discovered eggs or build nests in new locations. The cuckoo breeding analogy is used to develop a new design optimization algorithm. A generation is represented by a host nests set. Every nest carries an egg (solution). Solutions quality improves by generating a new solution from existing solution and modifying characteristics. Solutions number is fixed in every generation. Pseudo code for cuckoo search is as follows (Yang and Deb, 2009):

Table 1: Mapping between cuckoo search optimization algorithms

Initial nests	The initial random beam steering phase shift values	25
Best nest	The best phase shift value i.e., the value with lowest fitness	-
New nest	The new solutions generated after the best nest is chosen from the current iteration	-
Lower bound for phase shift	Seven bits are used for encoding	2.81°
Upper bound for phase shift	The maximum shift allowed is obtained by changing only the last 3 bits	16.81°
Termination condition	Fitness value less than $10^{-4}$ or 500 iterations	-

Begin

Objective function  $f(x)$ ,  $x = (x_1, \dots, x_d)^T$   
 Generate initial population of  $n$  host nests  $x_i$  ( $i = 1, 2, \dots, n$ )  
 while ( $t < \text{MaxGeneration}$ ) or (stop criterion)  
 Get a cuckoo randomly by Levy flights  
 evaluate its quality/fitness  $F_i$   
 Choose a nest among  $n$  (say,  $j$ ) randomly  
 if ( $F_i > F_j$ ),  
 replace  $j$  by the new solution;  
 end  
 A fraction ( $pa$ ) of worse nests are abandoned and new ones are built;  
 Keep the best solutions (or nests with quality solutions);  
 Rank the solutions and find the current best  
 end while  
 Postprocess results and visualization  
 End

In the proposed method, find the best nest-Get the current best initial solution (the best solution in initial solution of 25). Generate new nests while keeping the best nest-Create new search solutions within the upper bound and lower bound. Update iteration number. Find the best nest-If the new search solutions contain better fitness, update the solution. Iterate till termination condition is reached.

Mapping between Cuckoo Search Optimization (CSO) Algorithms is shown in Table 1.

## RESULTS AND DISCUSSION

The proposed algorithm is implemented in 8 element array and 16 element arrays. In the experiments conducted, the interference location is not known to the algorithm and the algorithm starts the search randomly using the initial bee population. The termination condition was to achieve a null at the interference. Beam forming when interference detected at two locations of  $-20$  and  $70^\circ$  and main steering lobe at  $10^\circ$  for the two scenarios is shown in Fig. 1.

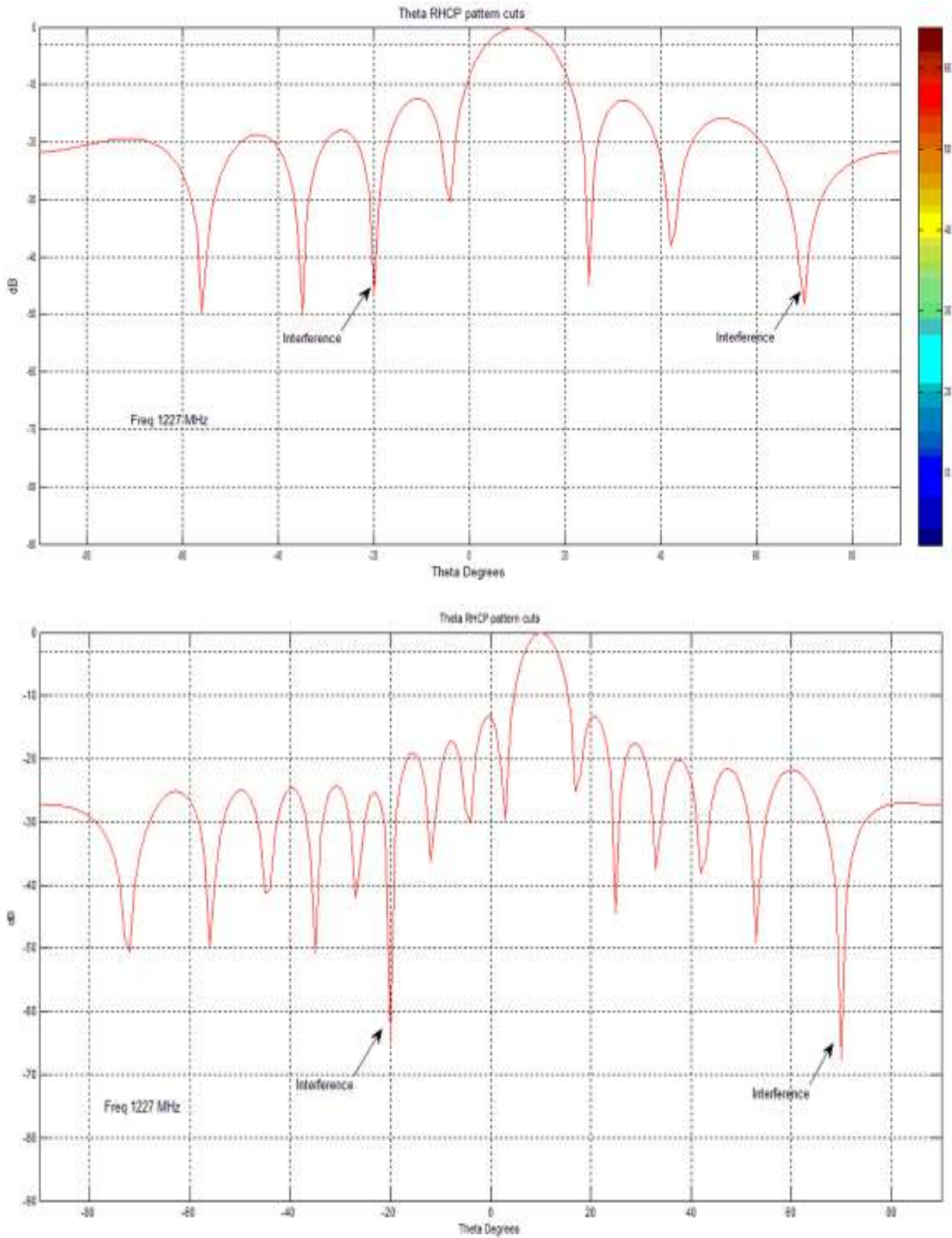


Fig. 1: Beam forming after 100 iteration

The mean squared error for each iteration is shown in Fig. 2. It can be observed that after 49 iterations the

solution converges even when the number of interference is more than one.

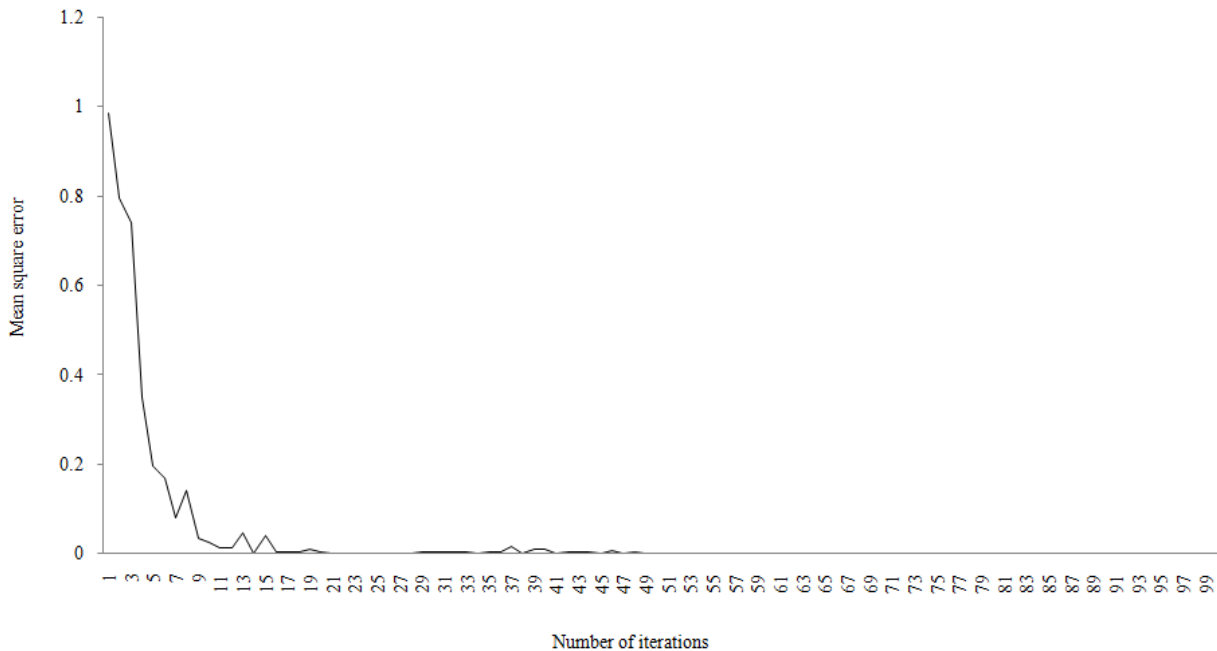


Fig. 2: Mean squared error

### CONCLUSION

Global Positioning System (GPS) is a satellite based navigation system to locate positions anywhere on earth. GPS receivers are susceptible to interference, due to low signal powers receipt. GPS is based on a group of satellites orbiting the earth continuously. These satellites equipped with atomic clocks, transmit radio signals that have exact location, time and other information. This study proposed a new CS algorithm based optimization method for interference cancellation design and improved jamming rejection. The new algorithm not only identified interference angle but also was able to effectively null the same.

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