The Study of CFAR(Constant False Alarm Rate) process for a helicopter mounted millimeter wave radar system

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Abstract : This paper describes constant alarm rates process of millimeter wave radar that exits on non-stationary target detection schemes in the ground clutter conditions. The comparison of various CFAR processes such as CA(Cell-Average)-CFAR, GO(Greatest Of)/SO(Smallest Of) –CFAR and OS(Order Statistics)-CFAR performance are applied. Using matlab software, we show the performance and loss between detection probability and signal to noise ratio. When rang bins increase, this results show the OS-CFAR process performance is better than any others and satisfies the optimal detection probability without loss of detection in the homogeneous clutter.

1. INTRODUCTION

In the radar system for air-to-ground target detection such as power lines, non-stationary target signal detection in the clutter environment condition may be a very difficult task. In such a condition, the clutter is relatively large so that a desired false alarm rate cannot be achieved. In order to suppress the clutter and maintain the constant false alarm, the various detection schemes are reported by authors. And many detection schemes are mainly developed for microwave radar system. In spite of the advantage of small-size components, high resolution image and no signal interfere existing, the effective detection schemes are not reported by the millimeter wave radar system.

With increasing the data base of MMW radar measurement, it is appropriate to review the information and apply it to MMW radar design and performance evaluation method. The Georgia Tech Research Institute has played an active role in measurement data at 35GHz(Ka-band) and 95GHz(M-band). At MMW frequencies, the consideration of environmental effects and clutter on radar performance is important. Comparative observations on the effect of clear air, rain and frozen hydrometeors are required. Paying particular attention to the attenuation and backscatter associated with rain and hydrometeors. Ground clutter has proven to impact significantly the effectiveness of MMW radar systems.

Components Cost often necessitate the choice of only one radars requiring an analysis of the design and performance radar system. According to electronics industry has been developed to the MMW frequency, the possibility of the radar operation expanded to the higher frequencies.

Depend on the scenario of the helicopter flight operation, returned signal and ground clutters, radar receiver system employs the square law detector followed by the returned signal from RF(Radio Frequency) parts. We are assuming the swelling 1 mode for radar returns from target and Gaussian statistics from background clutter. Based on the theses statistical distributions, we are analyzing the CA-CFAR, GO/SO-CFAR, OS-CFAR processes in the homogeneous background clutter.

2. MMW RADAR SYSTEM

The scenario proposed for this paper is helicopter mounted MMW radar system that is attempting to detect the obstacles on the mountains. Fig. 1. shows the general geometry problem. A helicopter is flying over terrain with millimeter wave sensor scanning the ground ahead searching obstacles. The problem has happened to detect the obstacles in the presence of atmosphere attenuation, rain attenuation and ground clutters. At the MMW frequency, it is important to consider the environmental effects and clutter on the radar performance and helicopter flight safety. Observation on the effects of clear air and rain are required. Ground clutter has proven to impact significantly the effectiveness of MMW radar systems. This frequency is advantage of high antenna gain with small aperture, high angular tracking accuracy, reduced electronic countermeasures vulnerability, reduction in multi-path and ground clutter at low elevation angle, improved multiple target discrimination and target identification, and mapping quality resolution possible. Disadvantage of component cost high, component reliability and availability low, short range propagation and higher attenuation [1].

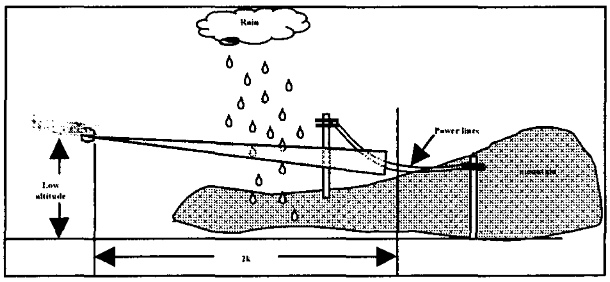

Fig. 1. System Scenario

We design the helicopter mounted millimeter wave radar system. That is consisted of the lens antenna, gimbal system, transmitter, non-coherent receiver, DSP(Digital Signal Processor) system and cockpit display system. Table 1. summarizes the parameters of each proposed MMW radar system. Frensnel Lens antenna that is used to be MMW radar system has the advantage of the less side lobe than the reflector antenna. 4 beam forming switch in the feed has possibility of operation from reaching high voltage. It is possible to use the 4 beam forming at the elevation angle. Antenna diameter limitation results in the aerodynamic and mounting the helicopter weight. Antenna scan rate must have azimuth -90°~+90° and elevation 26°. A raster scan pattern is envisioned in which antenna scan from left to right. In order to transmit 2.5kW power, we use the E2V technology magnetron and solid-state modulators. Magnetron operates 2.5kW peak power at 35±0.2GHz. The modulator and high voltage power supply for radar transmitter are critical elements, and must be properly specified and designed. Overall frequency stability for non-coherent systems is dependent on the performance of the modulator and power supply. Pulse width, PRF, operation voltage and current, and size and weight restricts are affect modulator design. [3].

Table 1. Radar Parameters[3]

Factor	Values	Remark
Frequency(f)	35GHz	
Peak Power(P)	2.5kW	
Pulse Width	150nsec	
Antenna Gain	>35dBi	
Beam Width	2°	
Azimuth angle	-90°~+90°	
Pulse width	150nsec	
Bandwidth	7MHz	
RCS	5dBsm	2km
Detection Range	2km	
Probability of false alarm rate(P_{fa})	10^{-6}	
Rain attenuation	2.6dB/km	10mm/hr
Noise Figure	< 4dB	
ADC	> 12bits	

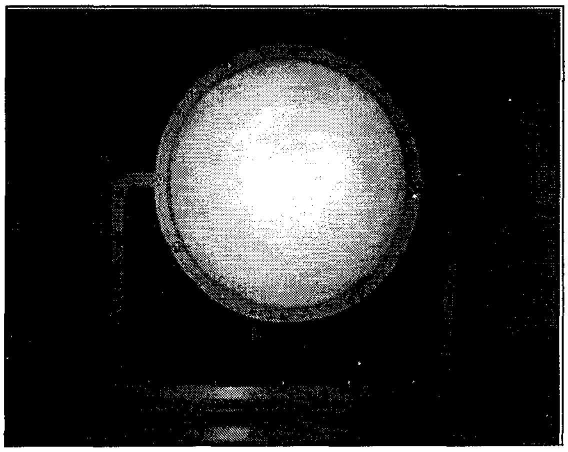

Fig. 2. MMW(35GHz) Lens Antenna[3]

Non-coherent receiver performs the single conversion system and provides the IF frequency (60MHz) to the signal process part. Detection range varies from collision detection mode to weather mode, according to the various flight modes. In the front stage of LNA (Low Noise Amplifier), STC (Sensitivity Time Control) is another gain control mode in which the gain of the receiver is varied as a function of time. It followers to be the detection range variable. After single conversion process is performed, Non-coherent envelop detector process provides the 60MHz IF frequency signal and IF signal to Signal process section. SPS(Signal Processing Section) consisted of 14bits ADC(Analogue Digital Conversion) on PMC module, 4 Tiger SHARC DSP(Digital Signal Process)s that are performing the Non-Coherent Integration, CFAR(Constant False Alarm Rate) process and video output data and SBC module, Digital I/O board. These are mounted in the 3U rack[2].

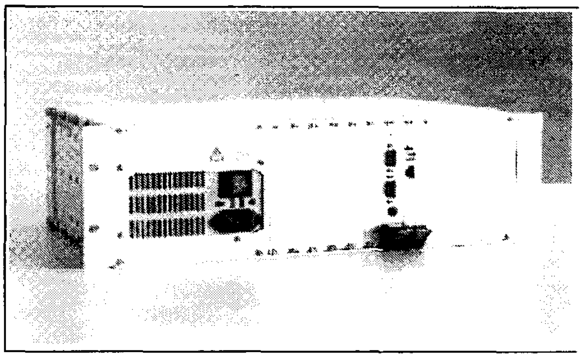

Fig. 3. 3U Rack mount for Signal Processing[2]

3. CFAR PROCESS SCHEMES[6]

Returned signal power from clutter and receiver noise is difficult to be mathematical expression. A fixed threshold detection scheme cannot be applied to the radar returns in individual range cells if the false alarm rate is controlled. An attractive class of schemes that can be used to overcome the problem of clutter are the constant false alarm rate (CFAR) processing schemes which set the threshold adaptively based on local information of total noise power.

Basically, the cell averaging CFAR processor sets the threshold by estimating the mean level in a window of N range cells. The CA-CFAR processor is the optimum CFAR processor in a homogeneous background when the reference cells contain independent. As N size increases, the detection probability approaches the optimum detector which is based on a fixed threshold.

The CA-CFAR procedure uses the maximum likelihood estimate of the noise power to set the adaptive threshold under the assumption that the underlying noise distribution is exponential. This performance is affected when the assumption of homogeneous reference window is violated. This leads to serious degradation in detection probability. When a clutter edge exits on the reference cell with target return in the test cell, severe masking of targets results due to increase in threshold. However, if the test cell contains a clutter example, the threshold is not high enough to achieve the design false alarm rate because the noise estimate also includes values from relatively clear background.

Modified CA-CFAR schemes have been proposed to overcome the problems associated with nonhomogeneous noise backgrounds. These split the reference window into leading and lagging parts symmetrically about the cell under test. The noise power is no longer estimated, therefore, some loss of detection in the homogeneous reference window is introduced compare with the CA-CFAR processor. Hasen[7] has proposed the greatest of (GO) the sums in the leading and lagging windows, Moore & Laurence[8] have shown that during clutter power transitions a mirror increase can be expected in the false alarm rate of GO-CFAR processor in the worst case. However, the GO-CFAR detector is incapable of resolving closely spaced targets.

In order to prevent the suppression of closely spaced targets, Trunk[10] proposed a SO-CFAR processing scheme, which sums the leading and lagging windows used to estimate the noise power.

Recently, OS (Ordered Statistics) CFAR has been introduced to alleviate these problems to some degree. The ideas from the fact that OS schemes have proven very effective in rejecting impulsive noise and preserving edges in applications. The OS processor estimates the noise power simply by selecting kth largest cell in the reference window of size N. Rohling[11] has noted that the false alarm probability of the OS processor is independent of the total noise power in the exponential noise model. The OS CFAR processor is unable to prevent excessive false alarm rate at clutter edges, unless the threshold estimate incorporates the ordered sample near the maximum, that is unless k is very close to N, but in this case the processor suffers greater loss of detection performance.

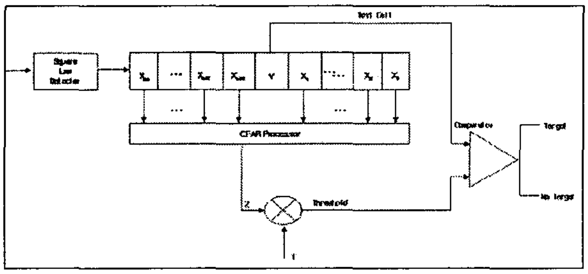

Fig. 4. Block diagram of CFAR processor

The square-law detected video range samples are sent serially into a shift register of length N+1 = 2n+1 as show in Fig. 4. the statistic Z which is proportional to the estimate of total noise power is formed by processing the contents of N reference cells surrounding the cell under investigation whose content is Y. A target is declared to be present if Y exceeds the threshold TZ. T is a constant scale factor used to achieve a desired constant false alarm probability for a given window of size N, when the total background noise is homogeneous. In order to analyze the detection performance of a CFAR processor in homogeneous background noise, we assume that the square-law detector output for any range cell is exponentially distribution with probability density function (PDF)

$$f(x) = (1/2\lambda)\exp(-x/2\lambda) \qquad (1)$$

Under the null hypothesis H_0 of no target in a range cell and homogeneous background, λ is the total background clutter-plus-thermal noise power, which is denoted by μ . Under the alternative hypothesis H_1 of present of a target, λ is $\lambda = \mu(1+S)$, where S is the average signal-to-total noise ratio (SNR) of target. We assume that a Swerling 1 mode for the radar returns from the target and Gaussian statistics for the background. We also assume that the observations in the N+1 cells, including the cell under test, are statistically independent. Therefore for the cell under test the value of λ is

$$\lambda = \begin{cases} \mu & under \quad H_0 \\ \mu(1+S) & under \quad H_1 \end{cases} \qquad (2)$$

The optimum detector sets a fixed threshold to determine the presence of a target under the assumption that the total homogeneous noise power μ is known a priori. In this the false alarm probability (P_{fa}) is given by

$$P_{fa} = P[Y > Y_0 | H_0] = \exp(-Y_0/2\mu) \qquad (3)$$

Y0 is the fixed optimum threshold. The optimum detection probability P_D^{opt} is given by

$$P_D^{opt} = P[Y > Y_0 | H_1] = \exp(-Y_0/2\mu(1+S)) \qquad (4)$$

Substituting (3) into (4), we get

$$P_D^{opt} = [P_{fa}]^{1/(1+S)} \qquad (5)$$

There is an inherent loss of detection probability in a CFAR processor compared with the optimum processor detection performance in homogeneous noise background. The CFAR processor is able to set the threshold by estimating the total noise power within a finite reference window. The optimum processor is able to set a fixed threshold under the assumption that the total noise power is known. It is obviously of value to have some idea of the loss of detection power for a proposed CFAR processor relative to the optimum processor for a homogeneous noise background. This loss of detection probability will vary with the false alarm rate and window size. There are two different methods that may be employs to measure the CFAR performance. The conventional method is to compute the SNR needed for CFAR processing scheme beyond the optimum processor to employ a fixed detection probability.

3.1. CA(Cell-Average) CFAR Process scheme

In the case of CA-CFAR processor from Fig. 5, total noise is estimated by the sum of N range cells in the reference window. This is sufficient statistic for the noise power μ under the assumption of exponentially distributed homogeneous noise background. We have

$$Z = \sum_{i=1}^{N} x_i \qquad (5)$$

Xi is range cells surrounding the cell under test. We express exponential density to gamma density with $\alpha = 1$ in PDF.

$$f(y) = \beta^{-\alpha} y^{\alpha-1} \exp(-y/\beta)/\Gamma(\alpha) \qquad (6)$$

The cumulative distribution function (cdf) corresponding to this pdf is denoted. The probability of detection Pd for the CA-CFAR processor yield

$$P_D = [1 + T/(1+S)]^{-N} \qquad (7)$$

The constant scale factor T is computed from (7) by setting S=0:

$$T = (P_{fa})^{-1/N} - 1 \qquad (8)$$

It is obviously that above detection and false alarm probabilities are fndependent of μ .

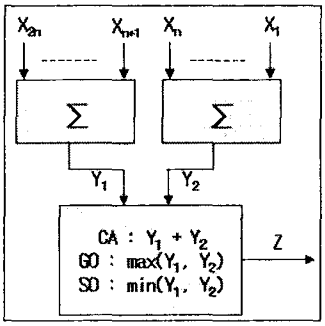

Fig. 5. Block diagram of Mean-Level CFAR

3.2. GO(Greatest Of)/SO(Smallest Of) CFAR Process scheme

Excessive numbers of false alarms in the CA-CFAR scheme at clutter edge and degradation of detection probability in multiple target environments are the prime motivations for exploring other CFAR schemes that discriminate between interference and the primary targets. Two such techniques have been investigated that are modifications -of the CA-CFAR technique. However, each of these schemes is capable of overcoming only one of the above two problems, with additional loss of detection power.

A modified detection scheme is proposed and known as the greatest of (GO) CFAR procedure. The total noise power is estimated form the larger of two separated sums computed for the leading and lagging window, as shown in Fig. 5. we have

Subheadings are in bold letters and placed flush on the left-hand margin of the column

$$Z = \max(Y_1, Y_2) \qquad (9)$$

Where,

$$Y_1 = \sum_{i=1}^{n} X_i, \qquad Y_2 = \sum_{i=n+1}^{N} Xi \qquad n = N/2 \qquad (10)$$

With n=N/2. In general, the pdf of Z defined is given by

$$f_Z(z) = f_1(z)F_2(z) + F_1(z)f_2(z) \qquad (11)$$

Where, f and F are pdf and cdf of random variable Y_1 and Y_2. For homogeneous background, the false alarm rate probability is

$$P_{fa} = 2(1+T)^{-n} - s\sum_{i=0}^{n-1} \binom{n+i-1}{i} (2+T)^{-(n+i)} \qquad (12)$$

Where, T is the constant multiplier which depend on the reference window size N and design P_{fa}. The detection probability P_d is found by simply replacing T with T/(1+S) in (12).

The smallest of (SO) CFAR scheme has been introduced by alleviate the problems associated with closely spaced targets leading to two or more targets appearing in the reference cell. In the SO-CFAR scheme the noise power estimate is the smallest of the sums Y_1 and Y_2 in Fig.5.

$$Z = \min(Y_1, Y_2) \qquad (13)$$

In this case the pdf of Z is given by

$$f_Z(z) = f_1(z)[1 - F_2(z)] + f_2(z)[1 - F_1(z)] \qquad (14)$$

Therefore, we conclude the OS-CFAR scheme

$$P_{fa} = M_{Y1}(T/2\mu) + M_{Y2}(T/2\mu) - P_{fa}^{GO} \qquad (15)$$

Where, $M_{Y1}(T)$ and $M_{Y2}(T)$ are the mgfs of Y_1 and Y_2. P_{fa}^{GO} is the GO-CFAR probability of false alarm. the above expression explains the relationship between the SO-CFAR and the GO-CFAR performance. And detection probability of the SO-CFAR scheme is given by replacing the T with T/(1+S).

OS(Ordereḑ Statistics) CFAR Process scheme

Rohling[11] has proposed by an alternative CFAR procedure in which the threshold is obtained from one of the ordered samples of the reference cell. The range samples are first ordered according to their magnitudes, and the statistic Z is given to be kth largest sample.

Rohling[11] has shown that the OS scheme does fall in the class of CFAR schemes for the exponential noise model. Therefore, without loss of generally we simply set $\lambda = \mu = 1/2$.

The detection probability of OS-CFAR can be expressed by

$$P_d(S) = k\binom{N}{k}\int_0^{\infty}(1-\exp(-z))^{k-1}$$
$$\times \exp(-(N-k+1+T/(1+S))z)dz \quad (16)$$
$$= \prod_{i=0}^{k-1}(N-i)/(N-i+T/(1+S))$$

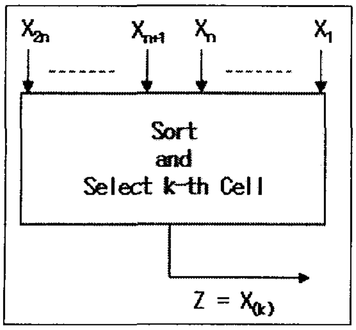

Fig. 6. Block diagram of OS- CFAR

The constant T is now a function of k. the P_{fa} is given by setting S=0 in (16). The value of T for a given k is computed by solving iteratively for fixed N and P_{fa}.

The ADT of the OS processor is given by differentiating the mgf with respect to T and expresses

$$ADT = T\sum_{i=0}^{k-1} 1/(N-i) \quad (17)$$

Where, N is number of range bins. T is the scale factor of the OS-CFAR scheme.

4. RESULT OF SIMULATION

Based on the above chapter, we have performed the simulation the detection probability in (4), (7), (12), (15) and (16). we are considering the simulation in homogenous clutter background. Depend on the signal process equipment, the number of range bins is determined. Our project selected 14bit ADC and data size for cruise flight. Fig. 7 shows the detailed the range bins.

Parameter		Operation Mode				Remark
		Mode 1 (Take-off)	Mode 2 (Cruise)	Mode 3 (Landing)	Mode 4 (Weather)	
System Parameters	Operation Freq.	35 GHz	35 GHz	35 GHz	35 GHz	
	Unamb. Range	31.25 km	31.25 km	31.25 km	125 km	c/2PRF [m]
	Detection Range	2 km	8 km	2 km	70 km	
	PRF	4.8 KHz	4.8 KHz	4.8 KHz	1.2 KHz	
	PRI	208.3 us	208.3 us	208.3 us	833.3 us	1/PRF
	Pulse-width	150 nsec	150 nsec	150 nsec	600 nsec	
	Range Resolution	22.5 m	22.5 m	22.5 m	90 m	cτ/2 [m]
	No. of Sample Data	89	356	89	778	Range / Range Resolution (초수신기)
	Sample Size	1424	5696	1424	3112	No. of Sample Data • No. of Integrated pulse (16개)
	Sampling Frequency	60MHz	60MHz	60MHz	15MHz	
	Range Accuracy	2.5 m	2.5 m	2.5 m	10 m	c/2f[illegible]
	A/D Resolution	14 bit	14 bit	14 bit	14 bit	
	Range BIN	800	3200	800	7000	Range / ADC Range Accuracy
	Data Size	179,200 bit 22.4 KHz	716,800 bit 89.6 KHz	179,200 bit 22.4 KHz	1,568,000 bit 196 KHz	Range BIN • No. of Integrated pulse • A/D Resolution
	비고	- 4빔 - 각 빔마다 16 펄스 적분	- 4빔 - 각 빔마다 16 펄스 적분	- 4빔 - 각 빔마다 16 펄스 적분	- 1빔 - 16펄스 적분	A/D에서 DSP로 14 bit 데이터 전송에 걸리는 시간과 그 데이터를 처리하는 DSP의 계산시간이 [illegible] 보임. 단, DSP에서 SBC로의 데이터 전송은 [illegible] 데이터로 1 range cell에 대한 [illegible] 전달되므로 전송속도 및 용량에는 문제없음.

Fig. 7. The number of rang bin for flight status [2]

From the Fig.8, it shows the detection probability performance in homogeneous region of CA, CAGO/SO, OS-CFAR schemes. And it performs the various schemes as function of primary target SNR at P_{fa}=10^{-6} for different window size N.

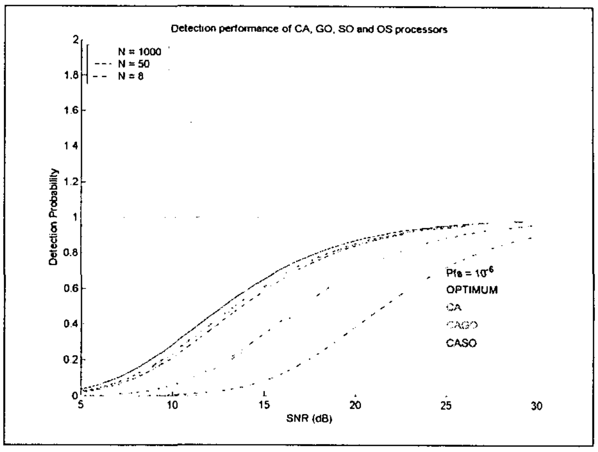

Fig. 8. Detection performance of CA, GO, SO and OS CFAR

As the result of simulation, the performance of OS-CFAR scheme is highly dependent on the range bin size. For the range bin N small, this scheme loss is quite large compared with CA, CAGO/SO-CFAR schemes. But decrease for increasing N. and other CFAR scheme except the OS-CFAR is constant value.

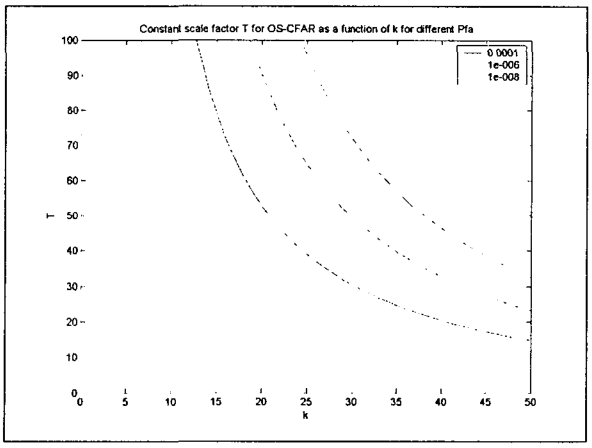

Fig. 9. Constant scale factor T for OS-CFAR

It is important to define the kth parameter in OS-CFAR scheme. Then, the Fig. 9 shows the value of T and ADT as function of k for probability of false alarm rate. As k increases, T decreases accordingly. For higher k values the noise estimate Z is one of the reference range samples that have relatively large magnitude, based on the Fig. 6.

It is clear the ADT exhibits a board minimum for larger values of k. therefore, any reasonable k for which the ADT is relatively low may be chosen for estimating the noise power without loss the detection performance in uniform noise background.

5. CONCLUSION

This paper presented non-stationary target detection under the homogeneous clutter, using the range bin parameter of helicopter mounted MMW radar system. We are assuming that target is swelling 1 mode and clutter's statistics is exponentiaL distributions. These assumptions are based on the microwave frequency clutter. Many authors are reported by the microwave frequency clutter. distributions. But not reported by MMW frequency clutter.

According to the result of simulation, we suggested the performance of OS-CFAR was highly increased. And better than any other CFAR schemes which were divergence when the range bin was increased. So, we have to apply various CFAR schemes to in the helicopter mounted MMW radar system. And we will confirm the result data between simulation and test.

In the latter, We are considering target detection in the non-homogeneous clutter background. That is more difficulty to detect between target and noise. And studying the clutter distribution at 35GHz frequency region.

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