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Improvement in Target Detectability through MISO RADAR

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ABSTRACT

Through intensive study, it has been explored that multiple-input single-output (MISO) antenna systems have the potential to dramatically improve the performance of communication systems over single antenna systems. With the idea of implementing WiMAX MISO Communication Technology for overcoming the challenges offered by hostile channel and environmental effects, it leads the Technocrats to utilize this Technology in RADAR operations. In conventional RADAR, the target's radar cross section (RCS) measurement at very low SNR level is very difficult and degrades the overall radar performance. The novelty of MISO RADAR is that it provides measures to overcome those degradations and provide higher range, cross range resolution. This paper explores enormous potential of MISO RADAR regarding the probability of target detection in low signal to clutter ratio (SCR) level.

Keywords

Uniform Linear Array (ULA), Signal to clutter ratio (SCR), Radar cross section (RCS), clutter, range, cross range, Cell Averaging, Constant False Alarm Rate (CFAR).

1. INTRODUCTION

MISO (multiple-input single-output) radar refers to an emerging sensing technology that employs multiple transmitters and single receiver. Unlike the traditional SISO (single-input single output) radar, which can only transmit scaled versions of a signal waveform, the MISO radar is capable of transmitting arbitrary waveforms. This provides extra degrees of freedom in the design of the radar systems [1] [2]. These additional degrees of freedom support flexible time-energy management modes, lead to improved angular resolution etc. Also MISO radar has the ability to improve radar performance in terms of radar cross section (RCS) diversity [3], handle slow moving targets by exploiting Doppler estimates from multiple directions [4], and support high accuracy measurement of target location and identification [5].

Firstly, the case of a MIMO RADAR modeling has been taken into account with theoretical derivations and analysis. So, let us consider that a narrowband plane wave with carrier frequency f_c (= 2.5 GHz) impinging from angle θ. We have simulated the model by using Agilent SystemVue and set the RF as 2.5 GHz. The radio environment is simulated by adding the Target along with the Rayleigh type Clutter. Under this circumstances, the received signal of the n^{th} antenna can be expressed as

$$b_k(t) = \beta y(t) e^{j\frac{2\pi}{\lambda} dk \sin\theta} + u(t),$$

(1)

for k = 0, 1, 2, 3, ..., Q-1, where, Q is the number of antennas, $\lambda = c/f_c$ is the wavelength of the signal, y(t) is the signal envelope, β is the amplitude response and u(t) is the additive noise. The phase difference term $e^{j\frac{2\pi}{\lambda} dk \sin\theta}$ comes from different traveling distances to different antennas as shown below

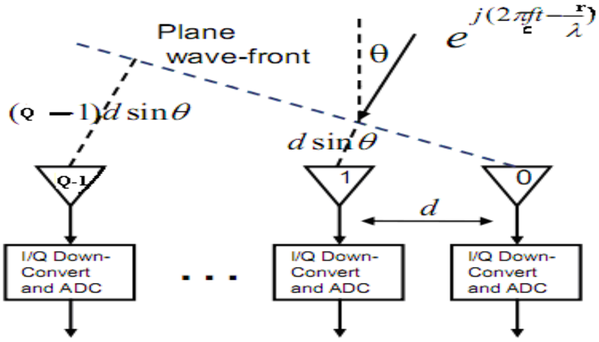

Fig.- 1: A uniform linear antenna array used for MIMO RADAR

To extract signal from θ, we can linearly combine the received signals [6] and obtain the following s(t)

$$s(t) = \sum_{k=0}^{Q-1} z_k b_k(t)$$
$$= \beta y(t) \sum_{k=0}^{Q-1} z_k e^{j\frac{2\pi}{\lambda} dk \sin\theta} + \sum_{k=0}^{Q-1} z_k u(t), \quad (2)$$

Where, z_k is the weighting coefficient corresponding to the k^{th} antenna. From the above equation, we see that the signal coming from different angle θ, has different gains also depending upon the value of θ. Again we can say that the summed signal can be controlled by the weighting coefficients z_k. Note that we have $\omega = \frac{2\pi}{\lambda} d \sin\theta$ in the above equation. If d>λ/2, there will be multiple values of θ mapping to the same ω. Thus aliasing effect arises. To get rid of this, we choose d ≤ λ/2. In practice, the spacing between antennas is about half of the wavelength. In this case,

$$-\pi \le \omega = \frac{2\pi}{\lambda} d \sin\theta = \pi \sin\theta \le \pi$$

(3)

and if so, there will be no aliasing in the incoming plane wave pattern to the RADAR Receiver.

Each antenna in a MIMO RADAR System, transmits orthogonal (or incoherent) waveforms. A set of Matched Filters is used at the RADAR Receiver to extract the waveforms returning back from the Target. At the time of propagation, the individual waveform faces individual path effect. So, the extracted components at the receiver side, contains the information of an individual path. Two different kinds of approaches are taken for further using this information.

First, the spatial diversity can be increased. In this scenario, the transmitting antenna elements are widely separated such that each views a different aspect of the target. Consequently the target radar cross sections (RCS) are independent random variables for different transmitting paths.

Second, a better spatial resolution can be obtained. In this scenario, the transmitting antennas are colocated such that the RCS observed by each transmitting path are identical. The components extracted by the matched filters in each receiving antenna contain the information of a transmitting path from one of the transmitting antenna elements to one of the receiving antenna elements. By using the information about all of the transmitting paths, a better spatial resolution can be obtained [7].

Let us consider the following Fig.-2, where P=3 antenna elements at the Transmitting side and Q=4 arbitrary antenna elements at the Receiving side.

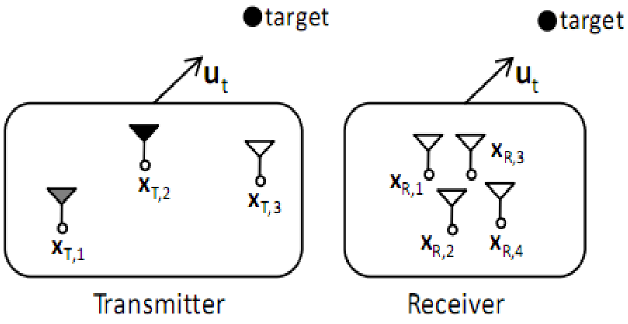

Fig.-2 : Tx side: P=3 & Rx side Q=4 Antennas of a MIMO RADAR System

Let us consider the coordinate of the mth transmitting antenna as $A_{B,j} \in R^3$. Similarly, the coordinate of the k^{th} receiving antenna is $A_{D,k} \in R^3$. If the transmitting waveform from the j^{th} transmitting antenna is represented by $\Phi_j(t)$, then the emitted waveforms are orthogonal and thus we can write

$$\int \phi_j(\Omega)\phi_q^*(\Omega)d\Omega = \delta_{jq}$$
(4)

So, at the receiver side, we need to extract these orthogonal signals and the number of Matched Filters required are P. Hence, the total number of signals extracted are Q.P if we consider a far-field point target. At the n^{th} receiving antenna, the mth Matched Filter [6] contains the Target information which can be mathematically expressed as

$$s_{k,j}^{(t)} = \sigma_t \exp(j\frac{2\pi}{\lambda} p_t^B (A_{B,j} + A_{D,k})) \quad ,(5)$$

where, $p_t \in R^3$ is the unit vector pointing towards the Target from the RADAR Transmitter, σ_t is the amplitude of the Target reflected signal. The Target Response $s_{k,j}^{(t)}$ of a MIMO RADAR as given by the equation (5) is same as the Response received by the array of an Q.P Antenna elements whose coordinate can be defined as $\{A_{Bj} + A_{D,k} \mid k = 0,1,2,\ldots\ldots, Q-1,\ j = 0,1,2,\ldots\ldots, P-1\}$. This Q.P number of antenna elements is called the "Virtual Array" of a P x Q MIMO RADAR System. This is depicted in Fig.-3 below.

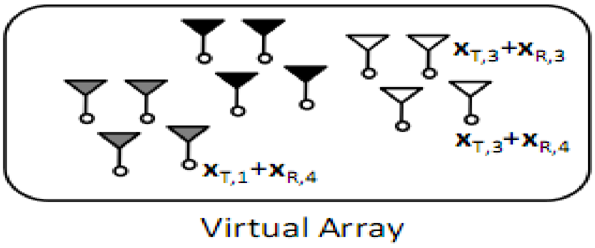

Fig.-3 : The Virtual Array of an P x Q MIMO RADAR System.

Let us define two functions to represent the Transmitting Array & Receiving Array respectively as below:

$$h_B(A) = \sum_{j=0}^{P-1} \delta(A - A_{B,j})$$
(6)

& $$h_D(A) = \sum_{k=0}^{Q-1} \delta(A - A_{D,k})$$
(7) So, the locations of the antenna elements of the Virtual Array [6] [7] in the MIMO RADAR System (as shown in Fig.-3 above) are represented as

$$h_G(A) = \sum_{j=0}^{P-1} \sum_{k=0}^{Q-1} \delta(A - (A_{B,j} + A_{D,k})) \quad (8)$$

or it can be said from equation (8) that $h_G(A)$ is achieved by performing convolution between the two antenna arrays as shown in Fig.-2. The mathematical expression in terms of convolution is given below

$$h_G(A) = (h_B * h_D)(A)$$
(9)

So, it is seen that the antenna array as shown in Fig.-3 is obtained by the convolution performed between the arrays as shown in Fig.-2.

2. SIMULATION

2.1 MIMO RADAR Modeling:

Let us model the MIMO RADAR System with Uniform Linear Array (ULA) which include the variables: (i) d_B is the spacing of the transmitting antennas, (ii) d_D is the spacing of the receiving antennas, (iii) P is the number of transmitting antennas, (iv) Q is the number of receiving antennas, (v) B is the RADAR Pulse Period, (vi) k indicates the index of RADAR Pulse (Slow Time) and (vii) Ω represents the time within the pulse (Fast Time). From this concept, the MISO RADAR Design has been explored

Let us assume that the transmitter and the receiver antennas are close enough so that they share same angle variable θ. Then the transmitted signal from the mth antenna element [8] is given by,

$$x_j(nB+\Omega)=\sqrt{E_P}\,\phi_j(\Omega)e^{j2\pi f_c(nB+\Omega)}$$

(10)

for j=0, 1, 2... P-1, where $\phi_j(\Omega)$ is the baseband pulse waveform, fc is the RF carrier frequency and E_P is the transmitted energy for the pulse.

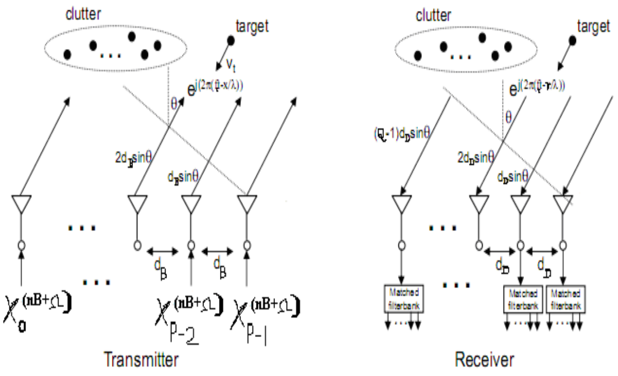

Fig.- 4: The MIMO RADAR Model

The demodulated received signal from the kth antenna is represented as below

$$s_k(nB+\Omega+\frac{2r}{c})\approx\sum_{j=0}^{P-1}\sigma_t\phi_j(\Omega)e^{j\frac{2\pi}{\lambda}(\sin\theta_t(d_Dk+d_Bj))}+\sum_{a=0}^{Q_c-1}\sum_{j=0}^{P-1}\sigma_a\phi_j(\Omega)e^{j\frac{2\pi}{\lambda}(\sin\theta_a(d_Dk+d_Bj))}+s_k^{(J)}(nB+\Omega+\frac{2r}{c})+s_k^{(W)}(nB+\Omega+\frac{2r}{c}),$$

where, r is the distance of range bin of interest, c is the speed of light, σ_t is the amplitude of the Target reflected signal, σ_a is the amplitude of the signal reflected by the ith clutter, θ_t & θ_a are the looking direction of the Target and the ath Clutter respectively, Q_c is the number of the clutter signals, $s_k^{(J)}$ & $s_k^{(W)}$ are the Jammer signal and the White Noise in the kth antenna output respectively.

2.2 System Design:

The WiMAX Baseband data Pattern is used (PN9 Code, Code Length=511) and the FEC, Interleaving, Alamouti Coding is done over it. Then the OFDM is carried out to get two independent streams of data which are Upconverted to IF and RF (at 2.5 GHz) individually and finally transmitted towards the Cluttered environment. The Correlation MIMO Channel is inserted before the Target model in the Simulation. At the RADAR Receiver, we have received the Target reflected signal through a 2x1 MISO Configuration to detect the Target

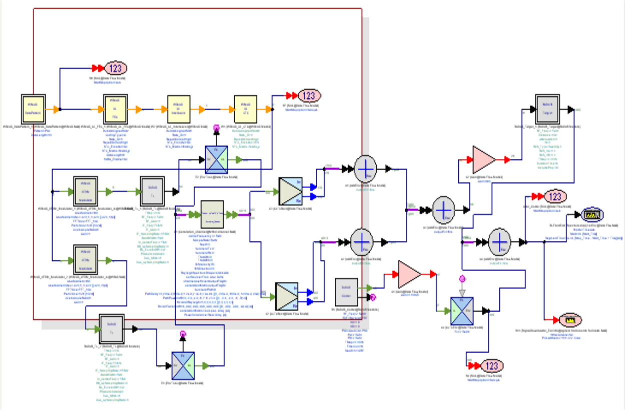

Fig.- 4: WiMAX MISO Transmitter for MISO RADAR is Downloadable to Arbitrary Waveform Generator Memory. (Simulation done using Agilent SystemVue)

The Cluttered Tx Signal propagating through two independent paths/streams are merged so that it can reach the Target and while reflecting back from the target, it is Downconverted and passed through the Cross-Correlation API provided by the SystemVue.

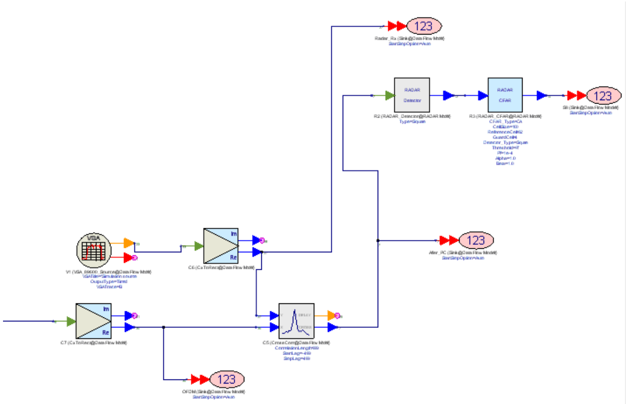

Fig.- 5: Post Processing Unit for WiMAX MISO RADAR is up loadable into Vector Signal Analyzer. (Simulation done using Agilent SystemVue)

The Tx End OFDM Frame has been taken as the Reference of the Correlator. The Correlated O/P is passed through the CFAR so as to achieve the Target Peaks. The 1st Peak achieved after the CFAR Technique [7] [8] represent the position of the Target. The peak value from the plot is taken in mV but the nearby clutter peaks are also considered which are also in mV. So, we convert the difference of these two peaks in dB so that output Signal-to-Clutter Ratio (SCR) is achieved in dB.

2.3 Results:

Case-1:

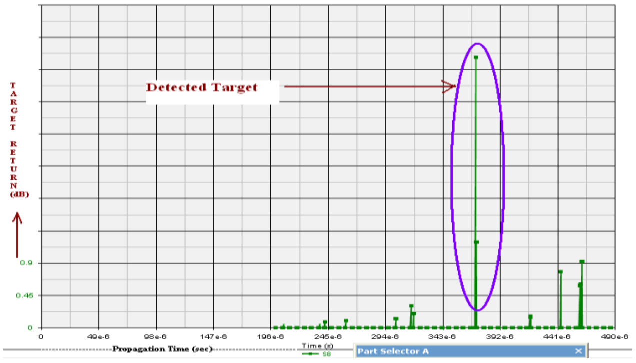

Fig.- 6: Target Detected at negative I/P SCR (= -3.383 dB) and Target Position is at 10Km.

The following figure shows the Input Signal-to-Clutter Ratio where the Clutter Level is greater than the Receiver Front End Signal Level.

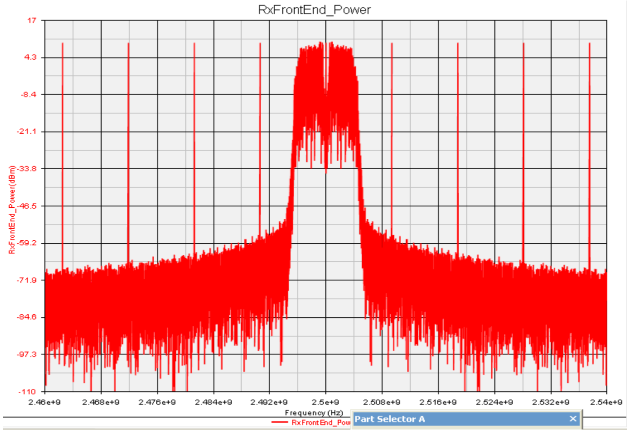

Fig.-7: Rx Front End: Signal Level = 6.0 dBm; Clutter Level = 9.383 dBm and I/P SCR (= -3.383 dB) and Target Position is at 10Km

As we see from the above Figures (Fig.-6 & 7), the WiMAX MISO RADAR is well working at negative SCR and detecting Target distinctly by reducing the Clutter Level to a satisfactory level. The next set of Simulation data is shown below.

Case-2:

In this case also, the Target is visible and detected at negative I/P SCR. So, still WiMAX MISO RADAR is giving reliable detectability at negative I/P SCR. The result is shown below in Fig.- 8 & 9.

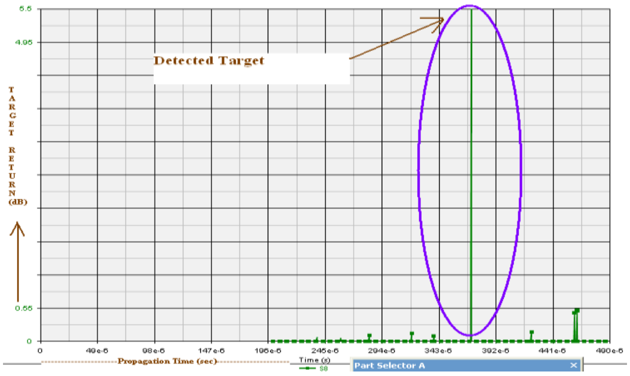

Fig.-8: CFAR O/P: Target Level = 9.199 dBm; Clutter Level = 0.511 dBm and O/P SCR (= 57.81 dB) and Target Position is at 10Km

The following figure shows the Clutter Peaks surrounding the original signal spectrum returning from the Target. Here the spectrum is measured at the RADAR Receiver Front End.

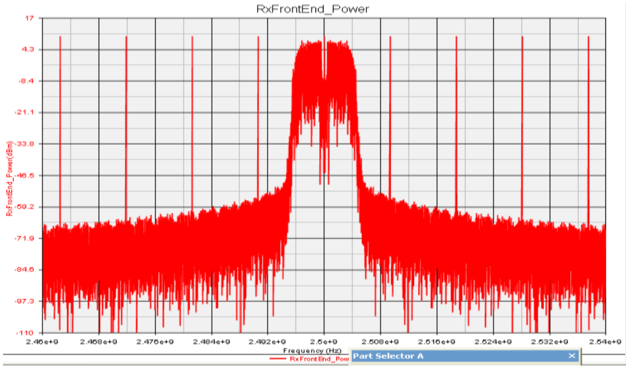

Fig.-9: Rx Front End: Signal Level = 6.0 dBm; Clutter Level = 9.666 dBm and I/P SCR (= -3.666 dB) and Target Position is at 10Km

Case-3:
Again, we see the target is visible (Fig.-10) at -3.944 dB negative I/P SCR as detected by the WiMAX MISO RADAR. Fig.-11 shows the Receiver Front End spectrum at RF level including Clutter also.

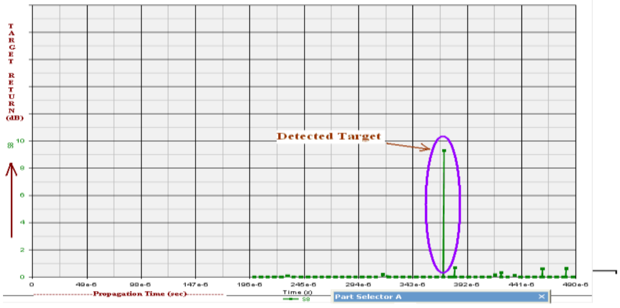

Fig.-10: CFAR O/P: Target Level = 9.287 dBm; Clutter Level = 0.682 dBm and O/P SCR (= 52.22 dB) and Target is at 10Km.

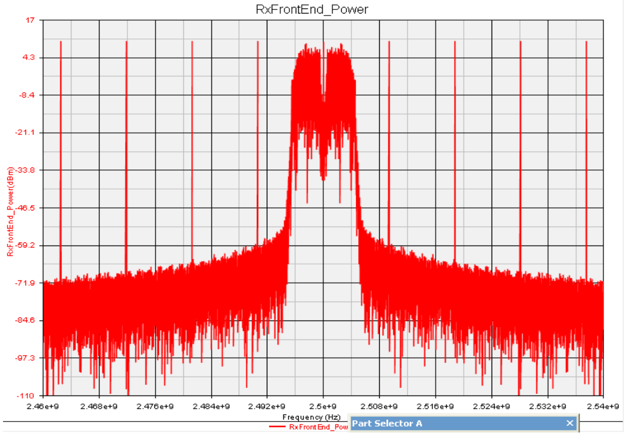

Fig.-11: Rx Front End: Signal Level = 6.0 dBm; Clutter Level = 9.944 dBm and I/P SCR (= -3.944 dB) and Target Position is at 10Km

Case-4:
Using the MISO RADAR, we are interested to test the Detection capacity of the RADAR if it operates under a severe Clutter condition. As we have considered only the Ground Clutter, the randomness in the signal content due to the clutter power is to be tackled in a way so that its effect is minimized to a desired limit. So, we have used the Cell Averaging Method which is Constant False Alarm Rate (CFAR) Technology to reduce the Clutter.

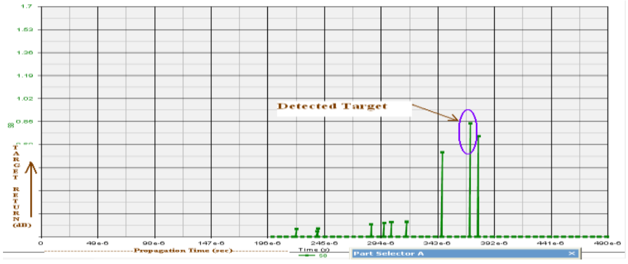

Fig.-12: CFAR O/P: Target Level = 0.837 dBm; Clutter Level = 0.743 dBm and O/P SCR (= 2.3826 dB)

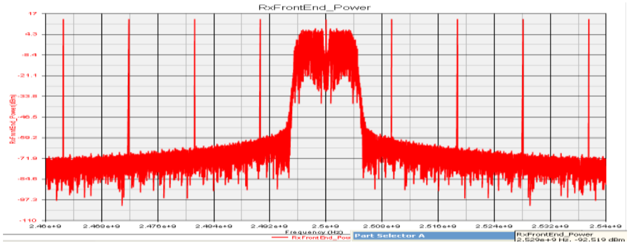

Fig.-13: Rx Front End: Signal Level = 6.0 dBm; Clutter Level = 13.664 dBm and I/P SCR (= -7.664 dB) and Target Position is at 10Km

So, from Fig.-12 & 13, we observe that at this level of negative I/P SCR, the detection capability is 0.837 dBm after CFAR while using WiMAX MISO RADAR. Hence, it is clearly observable from the above results, the WiMAX MISO RADAR is well performing at negative I/P SCR so far as the Target Detectability is concerned.

Detectability (in terms of I/P SCR versus O/P SCR) & the Comparative Plot for SISO and 2x1 WiMAX MISO RADARs:

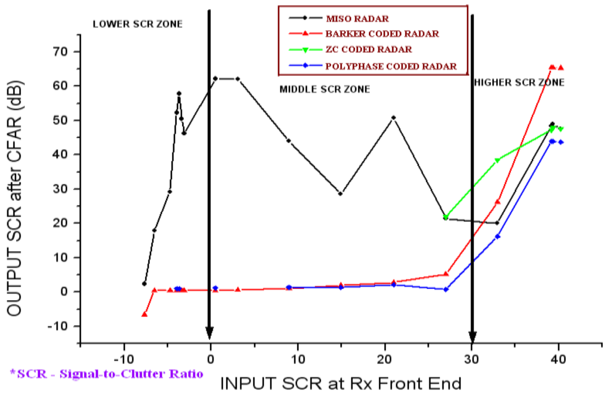

Fig.-14: Comparative Plots for SISO and 2x1MISO RADAR

The Detectability of a Target is nothing but the Output Signal-to-Clutter Ratio at which the Target is visible w.r.t the Clutter. If we increase this clutter level to a higher value, the 2x1 SISO RADAR can't detect the Target and giving ambiguous result from which the Target can't be segregated from the Clutter Peaks even if CFAR is adopted over the Correlated Output. But at the same time, the Multi Input Single Output (MISO) RADAR is well capable to have a significant Output SCR by which the Target can be made visible.

So, a Comparative Detection Performance Plot is given in Fig.-14 which justifies the relative Detectability among the SISO & 2x1 WiMAX MISO RADARs. The simulation of the later one is only given in this paper.

3. CONCLUSION

The Simulation, which has been done to test the performance of a Multi Input Single Output (MISO) RADAR, encourages the team to develop a Test Bed (i.e. an Embedded System for RADAR Testing also) which is very much useful to emulate the Environment with Clutter, and other hostilities. The Agilent SystemVue Software helps us to dump the RADAR Transmitter as well the Receiver Programme into Arbitrary Waveform Generator and a Vector Signal Analyzer to realize a complete MISO RADAR Test System that can be operated in a very low even at a negative SCR environment but leads to give high Detectability and thereby a reliable RCS estimation using MISO RADAR Technology. So, nowadays, RADAR Technology redefines its way of operation towards MISO RADAR to achieve an enhanced Target Detection Performance.

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