A New Approach for Target Detection Performance Enhancement Under Clutter Effect

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Abstract—**This paper discusses a new approach for target detection performance improvement in monostatic pulsed radar in presence of clutter based on Time Varying Gain Amplifier (TVGA). This new approach is used to compensate for power loss due to range in the received echo, which increases the input dynamic range and the sensitivity of the radar receiver. A constant threshold is selected for detection across the entire detectable range. The new approach is achieved by time controlling the received power, which enhances the detection performance in the presence of ground clutter and jamming effect, the simulation of a complete monostatic pulsed radar is considered with the environmental effect. The results shows thatafter applying the TVGA the signal can be detected effectively with a fixed threshold and gives more sensitivity and a wide dynamic range.**

Keywords-radar detection; time varying gain; automatic gain control; radar modelling; clutter

I. INTRODUCTION

The prime purpose of a surveillance radar system is to detect and locate the targets in the presence of noise andother interfering echoes, commonly referred to as clutter. It is possible to process the data obtained from surveillance radar to obtain parameters such as velocity, predicted position, and flight direction of the targets[1].

This work is focused on improving the probability of detection of a radar targets by taking advantage of prior knowledge of the radar-targets environment and devising appropriate detectors based upon the region where the target is located [2].For some circuits, thathave been designed to help radar receivers counteract the effects of external interference and to compensate the power losses. More common video enhancement featuresassociated with radar receivers such as Automatic Gain Control (AGC) [3] were adopted, where the gain control was necessary to adjust the receiver sensitivity for the best reception of signals of widely varying amplitudes. The simplest type of the AGC adjusts the Intermediate Frequency(IF) amplifier bias (and gain) according to the average level of the received signal.The AGC is not used as frequently as other types of gain control because of the widely varying amplitudes ofradarreturn signals. Another enhancement technique is the Instantaneous Automatic Gain Control (IAGC), which is used more frequently than the AGC because it adjusts receiver gain for each signal [4].The IAGC circuit is essentially a wide-band, DC amplifier. It instantaneously controls the gain of the IF amplifier as the radar return signal changes in amplitude. The range of IAGC is limited, however, by the number of IF stages in which gain

is controlled when only one IF stage is controlled, the range of IAGC is limitedto approximately 20 dB. In addition, the Sensitivity Time Control (STC)[5], [6] circuits applya bias voltage that varies with time to the IF amplifiers to control receiver gain, and the STC voltage affected on receiver gain is usually limited the distanceto approximately 50 miles. This is because close-in targets are most likely to saturate the receiver, beyond 50 miles, the STC has no effect on the receiver operates normally.

In this work in order to compensate the loss of the received power due to the range, the TVGA technique is introduced, whichdepends on the idea ofthe STC circuits , furthermore the TVGA is used for all ranges of the received echoes power, so it overcomes the drawback of the AGC and no dependent on the number of IF stages so also overcomes the drawback of using the IAGC and also it gives a good results at ranges over 50 miles.It is worthwhile to note that the TVGA are used in various applications such as biomedical devices in ultrasound scans [7], [8] for human body and the Ground Penetrating Radars (GPR). The TVGA is used to compensate the unequal attenuation and spreading of the received signals. The rest of this paper is organized as follows, the second section is to clarify the theoretical analysis of the TVG technique andthe modelling of the monostatic radar, the echo signal, and the clutter model, in the third section the simulation results are introduced, and finally the conclusions.

II. THEORETICAL ANALYSIS AND MODELLING

The TVG technique for a monostatic radar system having a predetermined gain versus time relationship is disclosed. The gain is substantially proportional to the square of the elapsed time measured from the last radar pulse initiating trigger signal. The amplifier in one embodiment employs a series connection of two amplifiers, each of which has a gain varies linearly with the elapsed time.

On the other hand, the received echoes in the later time will be increased with higher voltage gain so it is clear that the received echoes from the nearest targets (earlier time) will be little increased, however, the received echoes from the farther targets (later time) will be increased more so it will not suffer from the power loss due to long range.As in the ultrasound scan devices, the TVGA works at the same range of frequencies in the radar signal processor at the IF range. Therefore, the TVG technique can be appliedon the radar detection exactly in the receiver IF stages to compensate for the range dependent loss.The following flow chart shown in fig. 1 clarifies a part of a typical radar signal processor

containing the TVGA. The received pulses are first passed through a matched filter (MF) to improve the SNR before doing pulse integration [9], [10], threshold detection, etc.In our simulation, theAWGNand non-coherentdetection have been selected.The signal power threshold is given by [11],
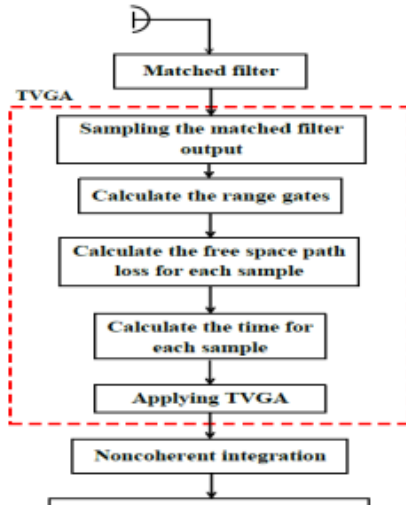

FIGURE 1: TYPICAL RADAR SIGNAL PROCESSOR.

$$T = -\beta^2 \ln P_{FA} \qquad (1)$$

Whereβ^2 is the total noise power, PFA is the Probability of false alarm.The TVGA is located after MF. The output signal of MF is firstly sampled, and then by calculating the range gates and the free space path loss for each sample, and calculating the time for each sample, we are then apply this signal to the input of the TVGA. In order to simulate complete model for monostatic pulse radar,the environment conditionssuch as ground clutter [12] (log normal distribution) and noise such as the AWGN areconsidered. Becausethe coherent detection requires phase informationand more computationally expensive,in our design of the pulsed radar system we will use a non-coherent detection scheme [13], [14].Table 1. is listed the design parameters used in the model.

TABLE I. DESIGN SPECIFICATIONS.

Radar parameter	Value	Radar parameter	Value
Probability of detection (P_D)	0.9	Range resolution R_{res} (m)	50
Probability of false alarm (P_{FA})	10^{-6}	Operating frequency (GHz)	10
Maximum range R_{max}(m)	5000	Rx and Tx antenna gain (dB)	20

We choose a linear frequency modulated (LFM) waveform in this model. Another important parameter of a pulse waveform is the pulse repetition frequency (PRF) [15]. The PRF is determined by the maximum unambiguous range. In order to model the transmitter we must calculate the peak transmitted power. The required peak power is related to many factors including the maximum unambiguous range, the required SNR at the receiver, and the pulse width of the waveform. For the non-coherent detection scheme, the calculation of the required SNR is, in theory, quite complex. Fortunately, there are good approximations available, such as

Albersheim's equation [16], in which the required SNR can be derived as:

$$SNR = -5\log_{10}N + \left[6.2 + \left(\frac{4.54}{\sqrt{N+0.44}}\right)\right]\log_{10}(A + 0.12AB + 1.7B) \quad (2)$$

Where$A = \ln\left(\frac{0.62}{P_{FA}}\right)$, $B = \ln\left(\frac{P_D}{1-P_D}\right)$, and N is the number of pulses.Once the required SNR has been obtained at the receiver, the peak power at the transmitter can be calculated using the radar equation given by the follow equation:

$$P_T = \left(\frac{R(4\pi)^3(SNR)kT_{\circ}BF_n L}{G_T G_R \lambda^2 \sigma}\right)^{1/4} \quad Watt \quad (3)$$

WhereP_T is the transmittedpeak power, GT, GR are the transmitter and the receiver gain, respectively.$\lambda$is the wavelengthandσ is the radar cross section (RCS), and$k$ is the Boltzmann's constant1.38×10-23 (Watt*sec/°Kelvin), and$T_{\circ}$is the temperature 290 K, and$B$ is the receiver bandwidth, and Fn is the receiver noise-figure, and$L$ is the loss factor.From eqn.3 the resulting power is about 1.7 KW, which is very reasonable. In comparison, the resulting peak power would be 3.5 KWif had not used the pulse integration technique, with all this information, we can configure the transmitter. In our approach assumed that there are three stationary, non-fluctuating targets in space. Their positions and RCSs are given in Table 2:

TABLE II. TARGET PARAMETERS.

Target number	RCS (m^2)	Position (m)
No.1	1	2215
No.2	1	3671
No.3	1	4005

III. SIMULATION AND RESULTS

After modeling the radar system and the echo signal we can do our simulation in order to test our system and get the results to validate the proposed algorithm. The threshold is increased by the MF processing gain, as shown in fig.2. This figure shows the first received pulse with the threshold before applying MF, and the same pulse after passing through the MF with the same RCS=1m2. Also fig. 3 shows two green dashed lines to see the difference in the power level of the 3 targets due to the range dependent.To ensure that the threshold is fair to all the targets within the detectable range, a time varying gain is applied to compensate for the range dependent loss in the received echo.The time varying gain operation results in a ramp in the noise floor as shown in fig. 3.
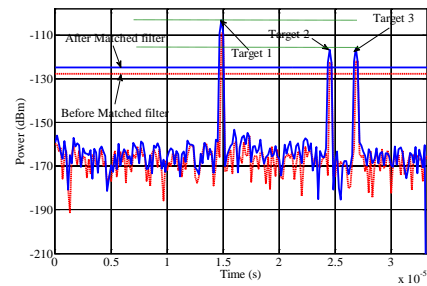

FIGURE II. THE FIRST RECEIVED PULSE BEFORE AND AFTER USING THE MF.
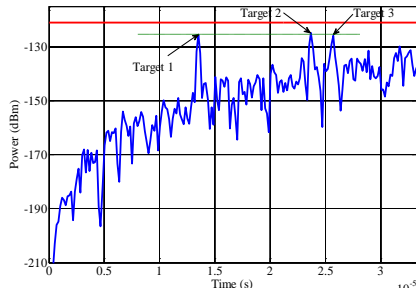
FIGURE III. THE FIRST PULSE AFTER APPLYING TVG.

However, the target return is now range independent. A constant threshold can now be used for detection across the entire detectable range.At this stage, the threshold is above the maximum power level contained in each pulse. Therefore, nothing can be detected at this stage yet, also we can see that there is no difference between the power levels of the three targets as the green dashed line indicate this is because the we applied TVGA to make the power loss compensation and now there is no loss of the power of targets (2, 3) due to range.We need to perform pulse integration to ensure the power of returned echoes from the targets can surpass the threshold while leaving the noise floor below the bar.

Figure 4.showsthat all three echoes from the targets are above the threshold, and therefore can be detected.We can further improve the SNR by noncoherently integrating the received pulses, after the noncoherent integration stage, the data is ready for the final detection stage. We can see that the required power has dropped to around 5dB. Further reduction of SNR can be achieved by integrating more pulses, but the number of pulses available for integration is normally limited due to the motion of the target or the heterogeneity of the environment. The 3D in Fig.5 shows the three targets peaks crossing the threshold level at different ranges and different directions.
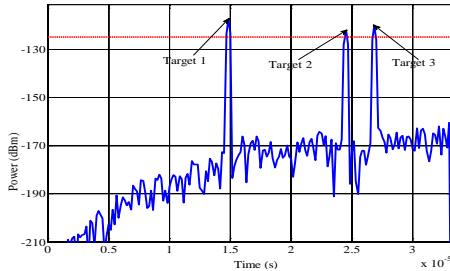

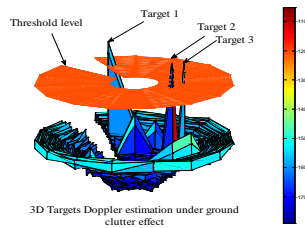FIGURE 4: THE FIRST PULSE AFTER TVG AND INTEGRATION OF 10 PULSES.

FIGURE V. THE THREE TARGETS CROSSING THE THRESHOLD LEVEL AFTER TVG.

By making the same simulation steps but without the clutter we can see that the three targets above the threshold level that means that they can be detected clearly at the absence of clutter using the same threshold, we do this simulation to show the difference between the detection of the three targets in different conditions and to give more validation to the proposed technique. From fig.6.it has been found that by using the new approach we can detect the targets in the absence of ground clutter at different ranges and the power consumption due to the range of the targets have no effect on the received power of the targets. To ensure that the TVGA is applicable for a wide dynamic range, we can make the simulation at different maximum ranges. Fig.7.shows the same results at maximum range of 250 km.
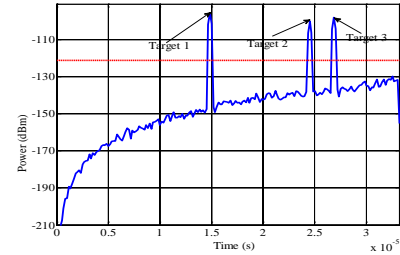

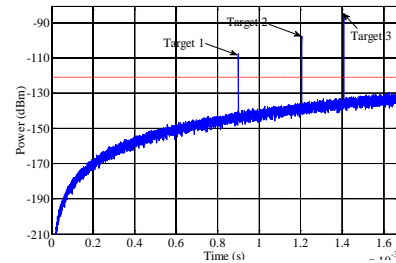FIGURE VI. THE FIRST PULSE AFTER TVG IN THE ABSENCE OF GROUND CLUTTER.

FIGURE VII. THE FIRST PULSE AFTER TVG AT MAXIMUM RANGE OF 250 KM.

The true ranges and the estimate ranges of the targets are shown in Table3:

TABLE III. RANGE RESULTS.

Target number	Estimate range (m)	True range (m)	Range error (m)
No.1	2225	2215	10
No.2	3675	3671	4
No.3	4025	4005	21

IV. CONCLUSION

In this paper, we have designed a radar system and studied the design parametersbased on a set of given performance goals. A new technique for improvement radar detection using TVGA to have a wide dynamic range by compensation of the power loss due to range dependent in the presence of ground clutter.Finally, the threshold detection is performed on the

integrated pulses. The detection scheme identifies the peaks and then translates their positions into the ranges of the targets.

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