



Smart Security Area (SSA) for Radar system technology

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Abstract

Our ability to align with the trend of innovations in science and technology will not only emancipate ignorance but also unfold our ability to evaluate, understand and predict possibilities in our society, environment, and the world at large. Radar system technology gives us the privilege to achieve the above-mentioned fact. The word Radar is an acronym for Radio Detection and Ranging. It is a mean of getting information about a distant target, by sending electromagnetic waves to them and analyzing the echoes from the target to generate relevant reports about the target. In this paper, we will focus on some metrics and the effect of changes in them on the performance of the radar system using the MATLAB Radar Designer.

Keywords: Smart Systems; Radar range; Environment losses; SNR; Probability of detection target.

1. Introduction

Radar is a technology that uses electromagnetic waves to detect and track objects [1]. It has become a critical tool in various fields, providing real-time information even in adverse weather conditions. Radar's importance lies in its ability to ensure safety and monitor the environment. In aviation, it is used for aircraft navigation and collision avoidance, while in meteorology it helps with weather forecasting [2]. In military defense, radars track and intercept ballistic missiles. The automotive industry utilizes radar for advanced driver-assistance systems in autonomous driving and obstacle detection. The continued advancement of radar technology will play a crucial role in shaping our future. The versatility of radar technology has led to its widespread use in a variety of applications. It is used in maritime navigation for detecting ships and avoiding collisions, in law enforcement for traffic monitoring, and in agriculture for soil moisture measurement. In addition, radars are also used in geology for oil and mineral exploration, as well as in space exploration for mapping celestial objects and monitoring space debris. The high accuracy and reliability of radar systems make it an indispensable tool in many industries.

The constant advancements in radar technology are expected to lead to even more innovative and sophisticated applications in the future. In conclusion, radar technology continues to be a vital area of research and development, with a wide range of applications and the potential to transform the way we live and work. The development of radar technology has been a continuous process since its inception, with the aim of making it more reliable, efficient, and cost-effective. One of the major areas of research in radar is in the development of more advanced waveforms, which can improve the accuracy and range of radar systems. Another area of focus is the development of more compact and lightweight radars, making it easier to integrate them into various applications, such as drones and unmanned aerial vehicles [3]. The use of artificial intelligence and machine learning in radar systems is also an area of growing interest, as it has the potential to improve the accuracy and efficiency of radar operations. In conclusion, the future of radar technology is promising, with the potential for even

more innovative and advanced applications, and a continued focus on improving its accuracy, reliability, and cost-effectiveness. With the rapid advancement of technology and the increasing demand for accurate and reliable information, radar technology is poised to play a significant role in shaping the future. The increasing use of autonomous systems in various industries and the growing need for real-time information has made radar technology even more important. With the advent of 5G and the Internet of Things (IoT), the use of radar technology is expected to become even more widespread and integrated into our daily lives. The use of radar technology in smart cities, for example, can help in traffic management, monitoring air quality, and providing early warning for natural disasters.

In conclusion, radar technology has come a long way since its inception, and its importance and impact on various industries and our daily lives is expected to only continue to grow in the future. The continued development of radar technology has the potential to revolutionize many industries and make our lives easier and safer. For example, the use of radar in autonomous systems such as self-driving cars and drones has the potential to significantly reduce accidents and improve the efficiency of transportation [4]. The use of radar in agriculture can help farmers make better decisions and improve crop yields. The use of radar in weather forecasting can help predict severe weather conditions and provide early warning, allowing people to take necessary precautions. In conclusion, the future of radar technology is bright and its impact on various industries and our daily lives is expected to be significant. The future of radar technology is also likely to see a greater emphasis on miniaturization, making it possible to integrate radar systems into smaller devices and platforms. This will open up new possibilities for its use in a variety of applications, from remote sensing to wearable devices. Additionally, the development of new materials and fabrication techniques is expected to lead to the creation of more efficient and versatile radar systems. With the increasing use of artificial intelligence and machine learning in various industries, it is likely that radar systems will also benefit from these advancements, leading to even greater improvements in accuracy, reliability, and efficiency. In conclusion, the future of radar technology is promising and full of possibilities, and its impact on various industries and our daily lives is expected to be significant.

The future of radar technology is also likely to be characterized by the integration of multiple sensors and technologies to provide a more comprehensive view of the environment. For example, the integration of radar with cameras and LIDAR (Light Detection and Ranging) systems will provide a more accurate picture of the environment and improve the efficiency of autonomous systems. The use of software-defined radar systems, which use software to configure and control the radar, is expected to become more widespread, leading to even greater flexibility and adaptability in various applications. The increasing use of cloud computing and big data analytics is also expected to play a role in the future of radar technology, enabling the processing and analysis of large amounts of data in real-time. In conclusion, the future of radar technology is full of possibilities and its impact on various industries and our daily lives is expected to be significant. The advancements in radar technology discussed above highlight the importance of radar simulation. Radar simulation is crucial in the development and testing of new radar systems and technologies [5]. It allows engineers and researchers to evaluate the performance of new radar systems and waveforms, and to optimize their design before actual implementation. This leads to cost savings and improved reliability and efficiency of the final product [6].

Radar simulation also provides a safe and controlled environment for testing and evaluating the capabilities of radar systems in various scenarios and applications. For example, the simulation of severe weather conditions and natural disasters allows researchers to evaluate the performance of radar systems under challenging conditions, which can improve the accuracy and reliability of the final product. In conclusion, the constant advancements and innovations in radar technology, and the growing demand for accurate and reliable information, underscore the importance of radar simulation. It plays a crucial role in the development and testing of new radar systems and provides a safe and controlled environment for evaluating their capabilities, leading to improved accuracy, reliability, and efficiency. But in this research paper, we will focus on the use of radar in defense, specifically in the identification of foreign objects and firing of missiles. By using radar simulation systems, we will examine the methods and technologies used to accurately detect, track, and respond to potential threats in real-world scenarios. Our goal is to provide a comprehensive overview of the current state of radar technology in the defense industry and to highlight the significance of using simulation systems to enhance the effectiveness and efficiency of radar-based defence systems. The block diagram of radar system is shown in figure 1.

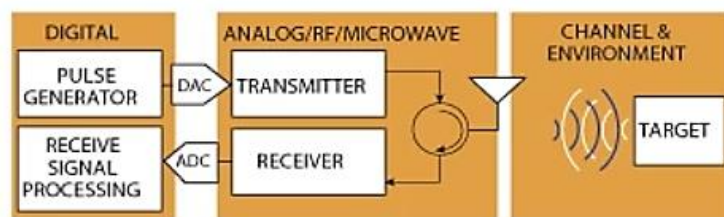


Figure 1: General radar block diagram

The remainder of this paper is organized as the following, section 2 discusses the related work on the paper topic. Then, the analysis and experimental results are covered in section 3. Section 4 concludes the paper.

2. Related Work

Author in [7] considered the coexistence and spectrum sharing between downlink multi-user multiple-input-multiple-output (MU-MIMO) communication and a MIMO radar. For a given performance requirement of the downlink communication system, designed the transmit beamforming such that the detection probability of the radar is maximized. While a review of the different approaches used for target decomposition theory in radar polarimetry discussed in [8]. Those based on the Mueller matrix and Stokes vector, those using an eigenvector analysis of the covariance or coherency matrix, and those employing coherent decomposition of the scattering matrix. Unified the formulation of these different approaches using transformation theory and an eigenvector analysis. Author in [9] presented The Oxford Radar Robot Car Dataset, a new dataset for researching scene understanding using Millimeter-Wave FMCW scanning radar data. The target application is autonomous vehicles where this modality is robust to environmental conditions. It encompasses a variety of weather, traffic, and lighting conditions.

Author in [10] presented low IF (*intermediate frequency*) techniques for noninvasive detection of vital signs from a mobile short-range Doppler radar platform. Stationary continuous-wave Doppler radar has been used for displacement measurement and vital signs detection an RF tag and a low IF radar architecture with an adaptive noise cancellation technique is employed to extract desired vital signs motion information even in the presence of large platform motion. Author in [11] introduced the Harmonic Path (HAPA) algorithm for estimation of heart rate (HR) and respiration rate (RR) with Impulse Radio Ultrawideband (IR-UWB) radar. A well-known result is that a periodic movement, such as the lung wall or heart wall movement, induces a fundamental frequency and its harmonics. IR-UWB enables capture of these spectral components and frequency domain processing enables a low-cost implementation. HAPA is the first reported algorithm to take advantage of the HR harmonics, where there is less interference, to achieve more reliable and robust estimation of the fundamental frequency.

Author in [12] introduced the process of automatic machine learning applied to radar emitter signal recognition. Through data simulation and experiment, the effect of traditional machine learning k-means algorithm and automatic machine learning AUTO-SKLEARN system in radar signal recognition is compared, which shows that automatic machine learning is feasible for radar signal recognition. The automatic machine learning AUTO-SKLEARN system can significantly improve the accuracy of the radar emitter signal recognition process, and the scheme is more reliable in signal recognition stability. Author in [13] introduced a new synthetic aperture radar (SAR) imaging modality which can provide a high-resolution map of the spatial distribution of targets and terrain using a significantly reduced number of needed transmitted and/or received electromagnetic waveforms. Author in [14] proposes an ambient radar sensor based a solution to recognize the activities that humans normally perform in indoor environments. designs a set of data preprocessing algorithms to convert the signal data into feature- rich spatial location changes. Author in [15] presented a new adaptive algorithm, called the Joint-Domain Localized Generalized Likelihood Ratio detection (JDL-GLR), which is data efficient i.e., with fast convergence to the joint-domain optimum,

as well as computationally efficient, together with such desirable features as the embedded constant false-alarm rate (CFAR) and robustness in non-Gaussian interference. Author in [16] presented a novel non-contact and privacy preserving approach on recovering physiological measurements like heart rate when multiple subjects are slowly walking in the scene using an ultra-wideband (UWB) multi-frequency radar system. employed joint probabilistic data association (JPDA) algorithm to separate detection from multiple moving objects. Author in [17] proposed the application of a modified variant, called MQEPS, of the quantum-inspired evolutionary algorithm based on P systems (QEPS) to the time–frequency atom decomposition for analyzing radar emitter signals. Extensive experiments conducted on satisfiability problems and radar emitter signals show the effectiveness and advantages of the presented algorithm. Author in [18] investigate the use of the Iterative Closest Point, ICP, algorithm together with an Extended Kalman filter, EKF, for localizing a vehicle equipped with automotive grade radars. Experiments using data acquired on public roads shows that this computationally simpler approach yields sufficiently accurate results on par with more complex methods.

3. Analysis and experimental results

The radar range equation is a powerful tool that ties together the main parameters of a radar system. It can give a radar engineer a good idea about performance of the system without resorting to complex analysis and simulations. The radar equation is especially useful in early stages of the design when specific information about various components (for example, transmitted waveform, size or shape of the antenna array, signal processing algorithms, and so on) might not yet be available.

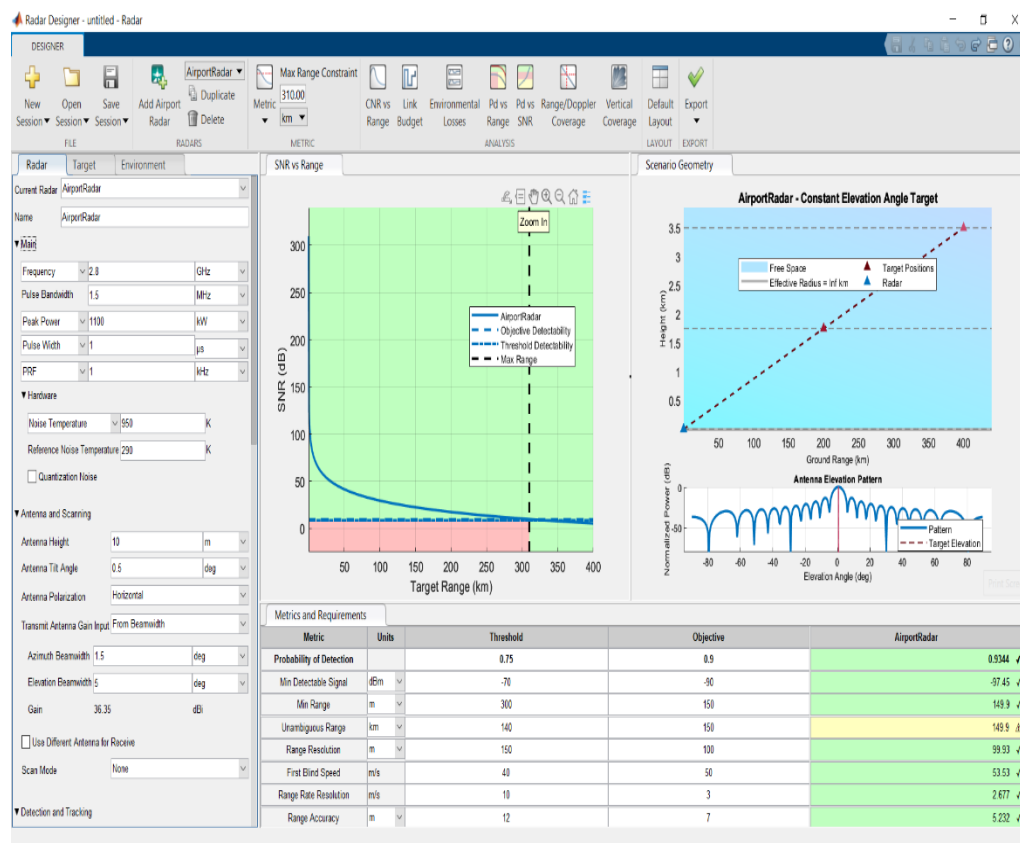


Figure 2: Radar design

Although the radar equation provides only approximate results, the fidelity of the analysis can be significantly improved by considering losses introduced by the components of the radar system and the signal propagation medium. The Radar Designer app is a tool for performing the radar equation analysis also known as the radar link budget analysis. It provides a user with many tunable parameters for the radar system, the target, and the environment, and offers a set of visualizations to aid with a

choice of these parameters as shown in figure 2. The Radar Designer app also allows to design a radar system based on a set of performance requirements.

A. Metrics and requirements

We have a specification detailing the performance of the final system. The computed metrics, which are shown in the Metrics and Requirements table, can be constrained by either the maximum range or the probability of detection. A choice of which variable to use as a constraint is made through the Metric button in the Metric section of the toolbar as shown in figure 3. The performance metrics and the corresponding requirements are housed in the Metrics and Requirements table. For each performance metric the app has two requirement values:

- Threshold — describes the minimum performance level for the metric.
- Objective — defines the value of the metric that will enable the new system to fully satisfy mission needs.

First, selecting maximum range as a constraint means that the performance metrics displayed in the Metrics and Requirements table are computed at the specified maximum range. Selecting the probability of detection as a constraint means that the displayed metrics are computed assuming the specified value of the probability of detection.



Figure 3: Max Range constraint

Then, we populate the Threshold and Objective values of the Metric and Requirements table with the numbers given in the specification. Since the specification does not provide requirements for all the metrics shown in figure 4, we leave the requirements for these metrics set to the default values. the system is considered to have an acceptable performance if the Threshold requirement is met.

Metric	Units	Threshold	Objective	AirportRadar
Probability of Detection		0.75	0.9	0.9344 ✓
Min Detectable Signal	dBm	-70	-90	-97.45 ✓
Min Range	m	300	150	149.9 ✓
Unambiguous Range	km	140	150	149.9 ⚠
Range Resolution	m	150	100	99.93 ✓
First Blind Speed	m/s	40	50	53.53 ✓
Range Rate Resolution	m/s	10	3	2.677 ✓
Range Accuracy	m	12	7	5.232 ✓
Azimuth Accuracy	deg	3	1	0.08061 ✓
Elevation Accuracy	deg	5	3	0.2687 ✓
Range Rate Accuracy	m/s	3	1	0.1401 ✓
Probability of True Track		0.95	0.99	0.9957 ✓
Probability of False Track		1e-08	1e-12	1.381e-14 ✓
Effective Isotropic Radiated Power	MW	1000	2500	4752 ✓
Power-Aperture Product	kW m ²	3500	4200	4335 ✓

Figure 4: Metrics & requirements

B. Environmental loss

The Environmental Losses plot gives a better idea about the contribution of the precipitation loss to the overall loss budget. It is accessed through the Environmental Losses button in the Analysis section

as shown in figure 5. [19]. This plot visualizes four types of range-dependent losses due to propagation and atmospheric attenuation. Assumed that it propagates in free space without any atmospheric attenuation. To make the analysis more accurate. Propagation losses and atmospheric attenuation can be included and parameters defined through the environment panel [20].

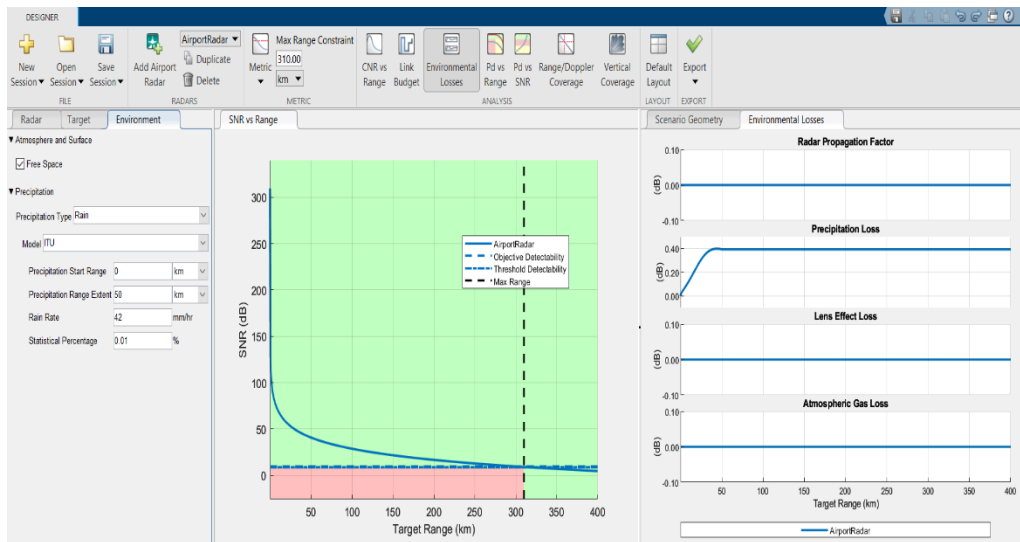


Figure 5: Environment losses due to rain

1) Losses under heavy rain

The specification states that the radar under design must maintain the required detection performance and measurement accuracy under heavy rain as shown in figure 6. It was mapped the precipitation type to rain in the precipitation section of the Environment panel in order to incorporate route loss caused by precipitation in the study. Next, we select the ITU model and specify the ranges for the precipitation. As a result, it can be seen in figure 7 [21].

Metrics and Requirements				
Metric	Units	Threshold	Objective	AirportRadar
Probability of Detection		0.75	0.9	0.8188 ▲
Min Detectable Signal	dBm	-70	-90	-97.42 ✓
Min Range	m	300	150	149.9 ✓
Unambiguous Range	km	140	150	149.9 ▲
Range Resolution	m	150	100	99.93 ✓
First Blind Speed	m/s	40	50	53.53 ✓
Range Rate Resolution	m/s	10	3	2.677 ✓
Range Accuracy	m	12	7	5.33 ✓
Azimuth Accuracy	deg	3	1	0.08292 ✓
Elevation Accuracy	deg	5	3	0.2764 ✓
Range Rate Accuracy	m/s	3	1	0.1428 ✓
Probability of True Track		0.95	0.99	0.9672 ▲
Probability of False Track		1e-08	1e-12	1.203e-13 ✓
Effective Isotropic Radiated Power	MW	1000	2500	4752 ✓
Power-Aperture Product	kW m ²	3500	4200	4335 ✓

Figure 6: Metrics & requirements due to rain

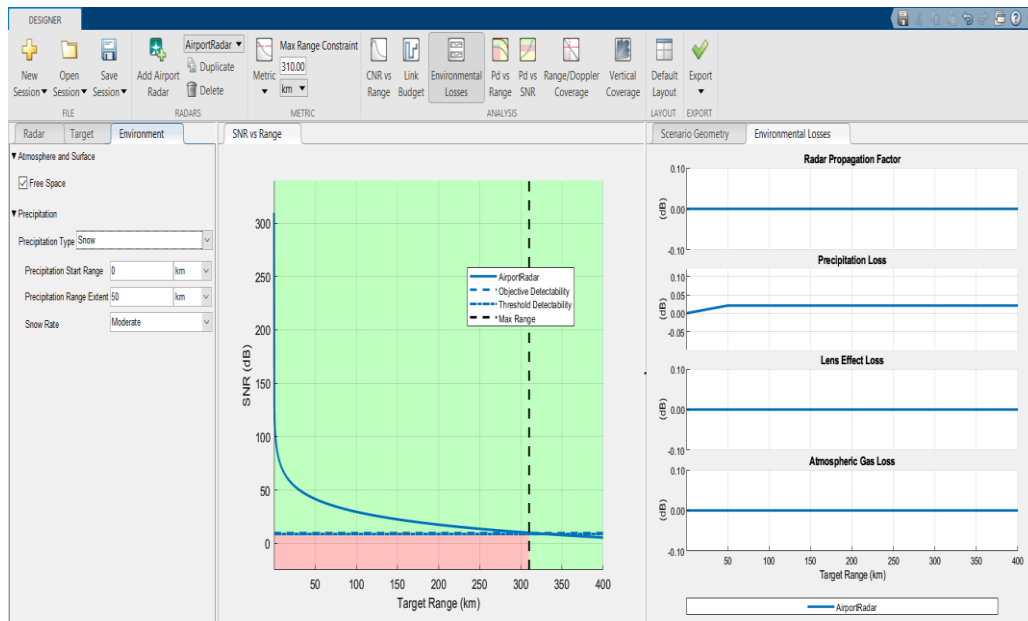


Figure 7: Environment losses due to snow

2) Losses and moderate snow

To include path loss due to snow in the analysis, select the precipitation type snow in the precipitation section of the Environment panel as shown in figure 8.

Metric	Units	Threshold	Objective	AirporRadar
Probability of Detection		0.75	0.9	0.9263 ✓
Min Detectable Signal	dBm	-70	-90	-97.42 ✓
Min Range	m	300	150	149.9 ✓
Unambiguous Range	km	140	150	149.9 ⚠
Range Resolution	m	150	100	99.93 ✓
First Blind Speed	m/s	40	50	53.53 ✓
Range Rate Resolution	m/s	10	3	2.677 ✓
Range Accuracy	m	12	7	5.236 ✓
Azimuth Accuracy	deg	3	1	0.08072 ✓
Elevation Accuracy	deg	5	3	0.2691 ✓
Range Rate Accuracy	m/s	3	1	0.1403 ✓
Probability of True Track		0.95	0.99	0.9946 ✓
Probability of False Track		1e-08	1e-12	1.757e-14 ✓
Effective Isotropic Radiated Power	MW	1000	2500	4752 ✓
Power-Aperture Product	kW m ²	3500	4200	4335 ✓

Figure 8: Metrics & requirements due to snow

C. Signal to noise ratio (SNR)

SNR defines the difference in level between the signal and the noise for a given signal level as illustrated in eqn. (1). The lower the noise generated by the receiver, the better the signal to noise ratio.

$$SNR = \frac{P_{signal}}{P_{noise}} \tag{1}$$

1) The relation between SNR and range with change in power

The higher the power, the higher the SNR value, which means a high ability to detect targets at long distances, as shown in the following:

- At 2000 Kw, shown in figure 9 the SNR at the maximum range is between (10-20 dB).
- At 1100 Kw shown in figure 10 the SNR at the maximum range is= (10 dB)
- At 200Kw, shown in figure 11 the snr at the maximum range is between (0-10dB) Which means that there is no signal or a very weak signal.

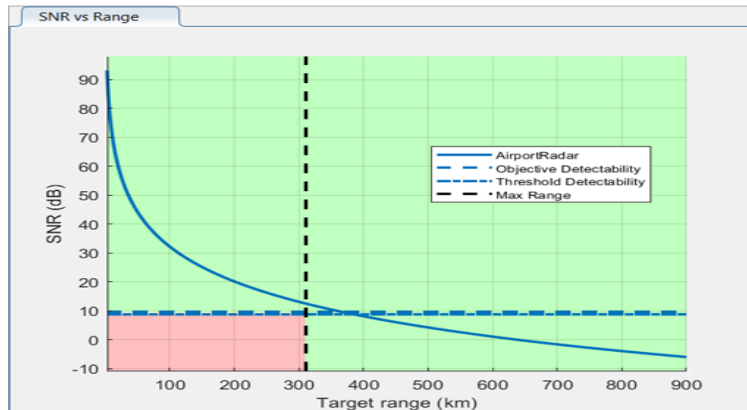


Figure 9: SNR at 200 KW

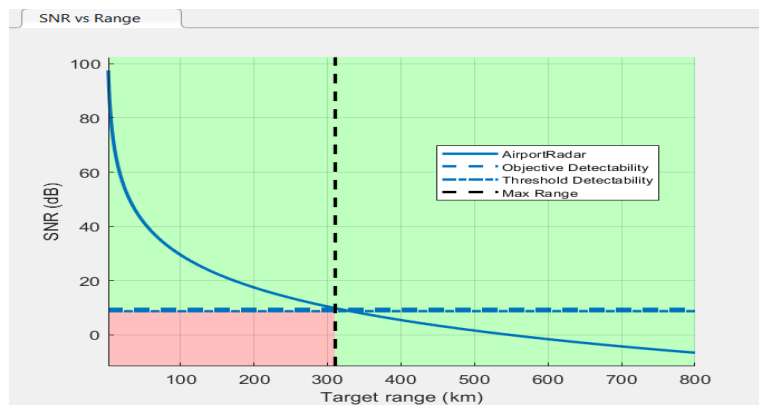


Figure 10: SNR at 1100 KW

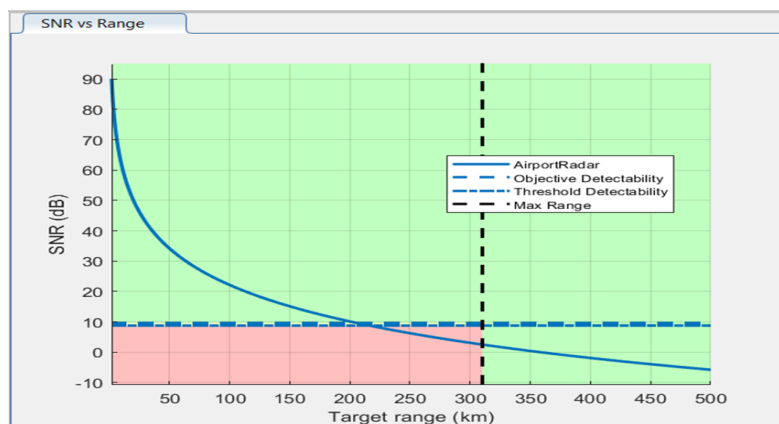


Figure 11: SNR at 200 KW

2) The relation between SNR and range with change in frequency

The relationship between SNR and frequency is an inverse relationship, that is, the lower the frequency value, the higher the SNR value, as shown in the following:

- At 4.8 GHz, shown in figure 12 the snr at the maximum range is between (0-10 dB) there is no signal or a very weak signal.
- At 2.8 GHz, shown in figure 13 the snr at the maximum range is = (10dB) Fairly acceptable value
- At 0.8 GHz shown in figure 14 the snr at the maximum range is =(20dB) Very good value

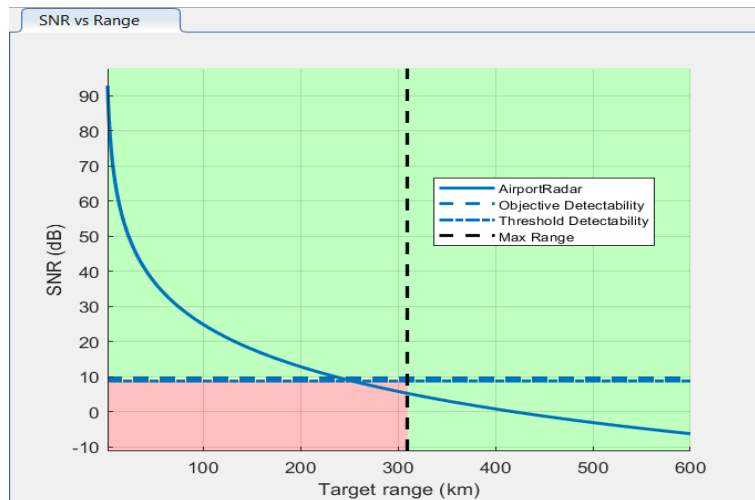


Figure 12: SNR at 4.8 GHz

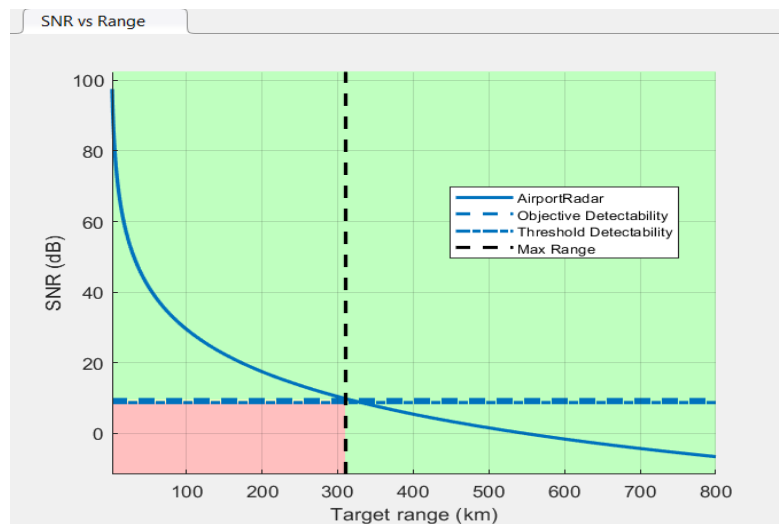


Figure 13: SNR at 2.8 GHz

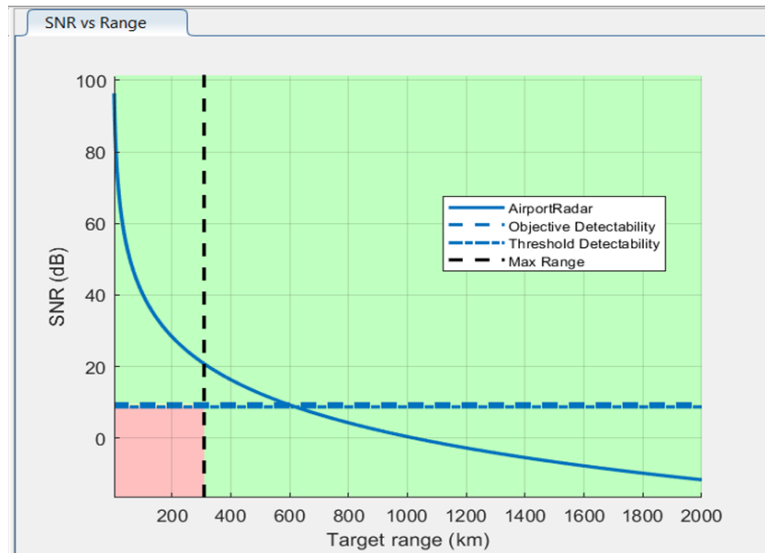


Figure 14: SNR at 2.8 GHz

D. Mathematical model

The power P_r returning to the receiving antenna is given by eqn. (2):

$$P_r = \frac{P_t G_t A_r \sigma F^2}{(4\pi)^2 R_t^2 R_r^2} \quad (2)$$

Where P_t is the transmitted power, G_t is the Gain, A_r is the effective aperture area which equals $\frac{G_r \lambda^2}{4\pi}$, λ is the transmitted wavelength, G_r is the gain of receiving antenna, σ is the radar cross section, F is the Pattern propagation factor, R_t is the distance from the transmitter to the target, and R_r is the distance from the target to the receiver. In the common case where the transmitter and the receiver are at the same location, $R_t = R_r$ and the term $R_t^2 R_r^2$ can be replaced by R^4 , where R is the range which gives eqn. (3)

$$P_r = \frac{P_t G_t A_r \sigma F^2}{(4\pi)^2 R^4} \quad (3)$$

4. Conclusion

Radar System Technology is a way of getting information about a distant target, by means of sending electromagnetic waves to them and analyzing the echoes from the target to generate relevant reports about the target. In this research, the importance and history of radar systems was discussed, and the focus was on obtaining accurate results on the effects of environmental changes on radar systems. The importance of SNR was also discussed. And the effect of changing the power and frequency on the value of the SNR. Accurate results were obtained using MATLAB Radar Design.

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