

# MILLIMETER WAVE RADAR DESIGN CONSIDERATIONS

**Osman YILDIRIM**

Hava Harp Okulu  
Elektronik Mühendisliği Bölüm Başkanlığı  
34807 Yeşilyurt/ISTANBUL

E-mail: [o.yildirim@hho.edu.tr](mailto:o.yildirim@hho.edu.tr)

## ***ABSTRACT***

*This study addresses the design considerations of an air to ground millimeter wave radar (seeker). Briefly, all major aspects such as seeker components, required mathematical formulation, system parameters, signal processing is included. Millimeter wave radars are currently being used in military applications as airborne millimeter wave radar and ground based radar to provide air-to-air, air-to-ground, ground-to-air, ground-to-ground operations. We all focused to reveal design parameter of active seekers that are called as a military weapon. After a detail analysis it was concluded that the transmission frequency of 35 GHz is most suitable for this application. The transmitted power is reduced to 25 Watts without reducing the performance of the system.*

**Keywords:** *Airborne Radar, Ground-Based Radar, Millimeter Waves, Design Parameters*

## **1. INTRODUCTION**

Historically, the principles of radar were first given by H. Hertz in the late nineteenth century. Great Britain implemented the first radar system in 1937. The progressed radar principles and the observation of weather phenomena were established in 1940's. Since then, radar technology progressed and became an integral facet of many technological and research fields. The millimeter waves (MMW) are defined from 30 GHz to 300 GHz. Millimeter wave radars (MMWR) have smaller components and greater bandwidths than microwave radars [1]. They have high speed and high resolution and less attenuation than microwave radars. Basic types of MMWR are continuous wave radar (CWR), frequency modulated continuous wave radar (FMCWR), and pulsed-wave radar (PWR).

Radar technology has many applications such as research radars, military radars. According to the purposes of using radars, radars can be designed as ground-based radar or airborne radar. For instance, the Navy has a need for a millimeter wave radar (seeker) for air-to-ground application. When a radar system is used to guide an armed missile to an enemy target, it is designed as a seeker.

To understand the role of clouds in the climate system, a ground-based millimeter wave radar can be used [2]. They have shown how millimeter wave radar can be used to show a detailed look at clouds and their three-dimensional structure. Weather radar can serve many purposes. Most meteorological radars are pulsed radars. Electromagnetic waves with fixed

*Received Date : 05.01.2003*

*Accepted Date: 06.06.2003*

frequency are transmitted from a directional antenna into atmosphere. The meteorological radars for atmospheric observation and climate regime investigation transmit electromagnetic pulses in the 3-10 GHz frequency range for detecting, mapping and measuring precipitation intensity. Higher frequencies (more than 35 GHz) are used to detect smaller hydrometeors effects on propagation.

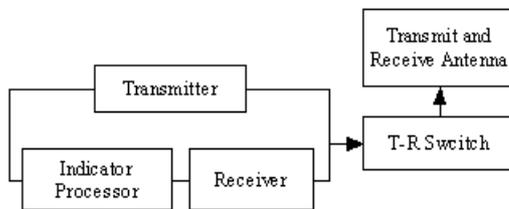
In this study, airborne radar application, namely seeker, is considered. We investigate the different design parameters of a millimeter wave seeker capable of locating different stationary targets like military vehicles.

## 2. SEEKER SYSTEM CONSIDERATIONS

A seeker should be designed to detect and lock on to ground targets such as military vehicles, artillery, military installations. It will be designed as an airborne millimeter wave radar and launched from military aircraft flying at approximately 15 000 feet over the ground.

### 2.1 System Block Diagram

A block diagram of the radar system is shown in Fig.1.



**Fig. 1** Radar system block Diagram

As shown in Fig.1, an active millimeter wave radar system transmits a beam of electromagnetic energy and receive backscattered echoes which can be correlated [3].

### 2.2 Antenna

The antenna size is limited by space on the airborne millimeter wave radar. A monopulse antenna can be chosen. Millitech provides a variety of series monopulse antennas for 18 to 220 GHz applications. The most standard

products use either a Cassegrain reflector antenna or a Gaussian optics lens arrangement. The Millitech MPA-KA10SLL type antenna features a bandwidth of 2 degrees, 35 dB gain, -17 dB side lobes, 1,5 VSWR, and 3 dB insertion loss. CMT-28-S-20S0, Millitech coupler, offers 0,3 dB maximum insertion loss with only 0,3 dB power split unbalance into collinear ports. A suitable circulator as an isolator, is the Millitech JFT-KA-RC3NP can be configured for operation at 35 GHz, typical performance parameters include 35 dB port isolation, 0,8 dB insertion loss. A 23,7 cm antenna operating 95 GHz will produce a 1 degree azimuth beamwidth with a side lobes down 27 dB.

### 2.3 Noise Level and Clutter

One another item to consider is the noise level and clutter. Experiments performed at a grazing angle of 30 degree showed that the nominal clutter reflectivity of desert was  $\sigma = -18dB/km$  [4]. It is very important whether the targets and clutter can be detected. The ground clutter RCS can be calculated from

$$(RCS)_{clutter} = \sigma \cdot (BW) \cdot R \cdot \Delta R \cdot S \quad (1)$$

where S=form factor ( $\pi/4 \cdot \sqrt{2}$  for ellipse)

$\sigma$  =Nominal clutter RCS

BW=Antenna bandwidth

R=Slant range

$\Delta R=c\tau/2$ =Range resolution

Noise power,  $P_n$ , of the receiver is given by [5],

$$P_n = k \cdot T \cdot B_0 \cdot F_n \quad (2)$$

where k=Boltzmann's constant

T=290 K

$B_0=1/\tau$

$F_n=5$  dB

Using these values, noise power,  $P_n = -129$  dBW. That is, the noise is 7 dB below the average signal level on a clear day for 10 m<sup>2</sup> target. Thus, clutter will be detected.

### 2.4 PRF Selection

We assume,  $R_{max}=3km$ ,  $c=3.108$  m/sec then  $PRF < 50$  kHz. The time on target  $t_t = 1,5 \cdot 10^{-3}$  sec, then total dwell time  $T_D > 4 \cdot t_t = 6 \cdot 10^{-3}$  sec, and  $PRF > 10/t_t = 6,66kHz$  (maximum 10 steps). Now, we can choose  $PRF=10$  kHz.

**2.5 Half-Power Beamwidth**

Half-power beamwidth is given by [6],

$$(BW)_{3dB} = 102/N$$

where N is the number of elements in the appropriate axis. If  $N_x = 45$ ,  $N_y = 40$ , then elevation and azimuthally angles,  $\theta_{AZ}$  ve ,  $\theta_{EL}$  will be,

$$\theta_{AZ} = 2,3^0 \tag{3}$$

$$\theta_{EL} = 2,5^0 \tag{4}$$

**2.6 Signal-to-Noise Ratio Considerations**

The signal –to-noise ratio for the system is given as [7,8],

$$S/N = \left( \frac{P_t \cdot G^2 \cdot \sigma \cdot \lambda^2 \cdot G_p}{(4\pi)^3 \cdot R^4 \cdot kT_s \cdot \beta \cdot L_T \cdot L_R \cdot L_p} \right) \tag{5}$$

Where  $P_T$  =Probability of achieving a valid track,  $k$ =Boltzmann’s constant

$G$ =Gain,  $G_p$  =processing gain,  
 $\lambda$ =wavelength,  $\beta$ =processing bandwidth  
 $\sigma$ =cross section,  $R$ =target range,  
 $L_T$ =transmitting loss,  $L_R$ =receiving loss,  
 $L_p$  =propagation loss

**2.7 Signal Processing**

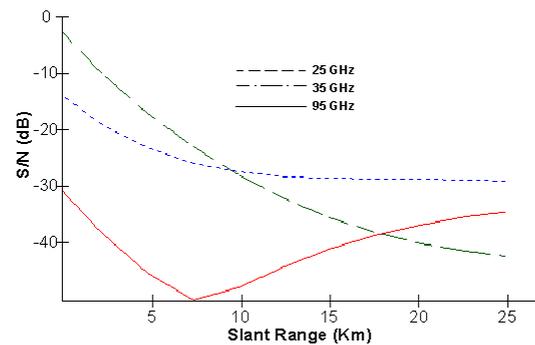
Many of signal processing techniques used in microwave radars are also applicable to MMWR. In the detection port, constant false alarm rate (CFAR) processor is used to separate potential targets from noise and clutters. In this work, we assume scalar discrimination techniques which use only scalar information such as amplitude frequency to achieve target-clutter discrimination. We are interested in stationary targets. That is why Doppler techniques are not useful for this case.

**3. FINAL SPECIFICATIONS FOR THE SEEKER SYSTEM**

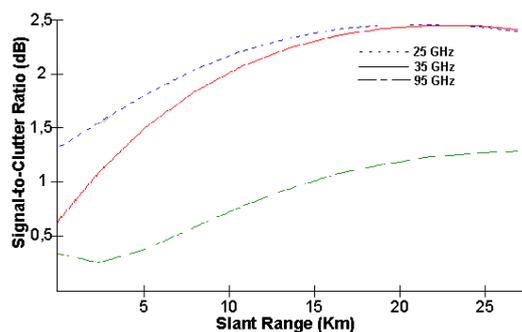
Final specifications of the mentioned radar system are summarized in Tablo 1.

**Table 1. Radar System Parameters**

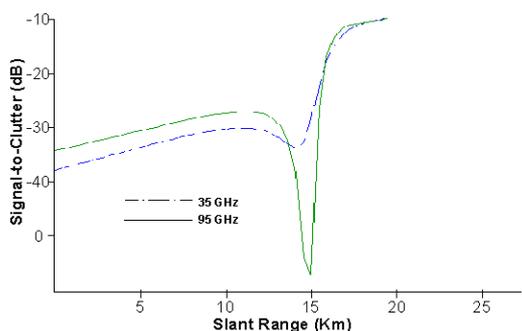
Factor	value
Pt	500 Watts
G <sub>t</sub>	36dB
Range	5 km
σ	40m <sup>2</sup>
L	8.42
ΔR	15 m
R <sup>4</sup>	Variable
kT <sub>s</sub>	1x10 <sup>-21</sup> W/Hz
Height	5000 feet
Noise Figure	5 dB
PRF	10 kHz
τ	Pulse length (50ns)
θ <sub>AZ</sub>	2,3 <sup>0</sup>
θ <sub>EL</sub>	2,5 <sup>0</sup>
Depression Angle	30 <sup>0</sup>
λ <sup>2</sup>	7.35x10 <sup>-5</sup> m <sup>2</sup>
DC Suply	28V at 15A
Launch height	15000 feet
Antenna Diameter	d <25 cm
Operation Frequency	35 –95 GHz
System Losses	9 dB
Pulse width	50 nsec
Seeker Velocity	500 m/sec
Environmental Temperature	-20 to 55



**Fig. 2 S/N versus Slant Range**



**Fig. 3** Signal-to-Clutter Ratio versus Slant Range



**Fig. 4** Signal-to-clutter versus Slant Range

#### 4. CONCLUDING REMARKS

This study has presented a successful implementation of a seeker required to detect stationary targets in the desert type clutter. After a detailed analysis it was concluded that the transmission frequency of 35GHz is most suitable for this application. In order to keep our receiver simple, non-coherent detection is suggested.

Some numerical results which show the variations of signal to noise ratio versus different ranges in Fig.2. At frequencies 25,35, and 95

GHz, signal to clutter variations versus slant range is given in Fig.3. Signal to clutter at 35GHz and 95GHz is depicted via slant range in Fig.4. The higher variations happen when the frequency increases.

#### REFERENCES

- [1] N. C. Currie and C. E. Brown, *Principles and Applications of Millimeter Wave Radar*, Artech House, Boston MA, 1988.
- [2] Clothiaux, E.E., Ackerman, T.P., Babb,D.M., *Ground Based Remote Sensing of Cloud Properties Using Millimeter Wave Radar*, Edited by Raschke,E., *Radiation and Water in Climate System*, Nato ASI Series, Springer-Verlag,1996.
- [3] Poloscia,S.,*Remote Sensing of Soil Moisture*, Edited by Raschke,E., *Radiation and Water in Climate System*, Nato ASI Series, Springer-Verlag,1996.
- [4] Nathanson,F.E., Reilly,J.P.,Cohen,M.N., *Radar Design Principles*, McGraw-Hill, NY, 1991.
- [5] N. C. Currie, R. D. Hayes, and R.N.Trebits, "Millimeter Wave RadarClutter", Artech House, Boston MA, 1992.
- [6] Ulaby, F. T., Dobson,M.C., *Handbook of Radar Scattering Statistics for Terrain*, Artech House, Boston MA, 1989.
- [7] Skolnik, M.I., *Introduction to Radar Systems and Radar Handbook*, McGraw-Hill, 1990.
- [8] Billetter,D.R., *Multifunction Array Radar*, Artech House, 1989.



**Osman Yildirim** was born in Kirsehir, Turkey, on July 03, 1956. He received the B.S. and M.Sc. degrees in Electrical and Electronic Engineering from Bogazici University in Istanbul in 1983 and 1986, respectively. In 1994, he completed his Ph.D. studies at Electrical Engineering Department of the Technical University of Istanbul. Since 1983, he has been with the Electronic Engineering Department of the Turkish Air Force Academy. In addition to giving lectures in that department he is directing the research and development center in the Air Force Academy. His research interests are in diffraction theory, high frequency techniques and antennas.