Simulation of Reflected Signal Spectrum of FMCW Radar for Different Terrain Conditions and Altitude

P.Preethi[1], Dr. G. Srivalli[2]

[1] Department of Electronics and Communication Engineering. G.Narayanamma institute of technology & science (for women). M.Tech student.

2 Department of Electronics and Communication, G.Narayanamma institute of technology & science (for women), Shaikpet, Hyderabad.

Mail id: srivalligundala@gmail.com & Mail id: preethi.p2494@gmail.com

Abstract:

FMCW Radar is the popular principle for measuring the range/altitude in military and civilian applications. FMCW radar principle is used as Radio altimeter application, where altimeter is used to measure the height above ground level. It provides the altitude information of the aircraft from the terrain over which it is flying. Radar altimeter operates in "C" band at 4.2GHz to 4.4GHz. The RAM transmits the FMCW signal and captures the reflected signal from the terrain. The altitude information is computed by analyzing the beat frequency spectrum using DSP signal processing techniques. Testing the Radio altimeter at different terrain condition such as water and grass at practical condition is not available on bench and hence needs to be tested on aircraft which involves high cost for every flight test. Hence in order to test the FMCW Radar for different terrain conditions "SYSTEMVUE" software provided by KEYSIGHT technologies is used. This software is used for developing the model to simulate the reflected signal pattern at different terrain conditions on bench, which reduces the flight cost and used to measure the altitude range for different delays. . .

Keywords

FMCW radar, Terrain conditions, Doppler Effect, Water Terrain, Grass Terrain..

1. Introduction

Radar is an electromagnetic system used for detection and location of the reflected objects such as aircrafts, ships, spacecraft, vehicles, people and normal environment. The term Radar is a contraction of the words radio detection and ranging. Radar is operated by transmitting electromagnetic energy and observing the backscattered echo signal. The returned echo signal not only indicates the presence of a target, but the location of the target can also be known by comparing the time elapses between received echo signal with that of the transmitted signal. It can operate in all environmental conditions like darkness, fog, rain, snow and haze.

FMCW Radar is special type of radar which continuously radiates the transmission power and has the advantage of changing the operating frequency during the measurement. This technique is used for Radio Altimeter application as it has many advantageous over the un-modulated continuous wave (CW) in measuring the distance and velocity of the target. The reflected signal will not be same as the transmitted signal it will be combination of both the transmitted signal and also the clutter signal. Clutter is a term used to describe any object that may generate unwanted radar return that may interfere with normal radar operations. Clutter signal is not always a noise signal and it is not always unwanted signal, it can also be wanted signal in few applications. Here clutter can be of any type like land clutter, sea clutter, water clutter, ice clutter, snow clutter, grass clutter, and mountain clutter etc.., Clutter signal produces loss in power of the reflected signal. Clutter echoes are always random and have thermal noise characteristics because the clutter components have random phase and amplitudes. In many cases the clutter signal is much higher than the receiver noise signal. The radar ability to detect target signal from the clutter signal depends on signal to clutter ratio (SCR) rather than signal to noise ratio (SNR).

2. Literature review

In reference to Mohandas Amarnathan [4], based on the modulating frequency the Radio Altimeter can be categorized into Pulse Based Radio Altimeter and FMCW type Radio Altimeter. A pulse based Radio Altimeter transmits a pulse shaped carrier and determines the time taken to receive the pulse. A Pulse Based Radio Altimeter is mostly used for military applications. A FMCW Radio Altimeter has a transmitter that transmits a radio signal towards the ground surface. The radiation from the transmitter is a continuous wave signal that is swept in frequency linearly. The frequency modulation can be a dual slope up-down ramp. The Difference Frequency Signal is at baseband frequency and it is processed by filters to improve the signal to noise ratio, normalize the strength of the returns for all altitude and suppress high frequency components.

According to Indu Konuganti [5], at the time of reception apart from the target information radar also detects some unwanted returns/echoes from other objects. These unwanted returns are termed as clutter. Such echoes are typically returned from ground, sea, rain, animals/insects, chaff and atmospheric turbulences, and can cause serious performance issues with radar systems. So, clutter modeling has to be done to detect the target effectively. Radars are generally placed in isolated areas like seas, oceans, remote areas etc. So, when the radar is placed near the sea, sea clutter is encountered. Sea clutter on the other side is modeled based on the reflectivity which is dependent on sea state and polarization.

According to Chunlin Xian, Yan Chen, Ling Tong and Mingquan Jia [6], the complex Dielectric Constant of vegetation plays an important role between the electromagnetic properties of vegetation and its physical properties in microwave remote. Vegetation is a mixture of air and vegetation material. The dielectric constant before drying increases with the density at the same frequency, but when the frequency increases, the dielectric constant real part of the sample turns down. It can be seen that the dielectric constant of the grass is increased with the density when it is dried.

3. Formulation of problem

The Radio altimeter can be categorized into pulse based radio Altimeter and the continuous based Altimeter:

In pulse based Radio Altimeter, a pulse shaped carrier determines the time taken to receive the pulse. The transmitter transmits a series of pulses and shuts down after the pulse is transmitted then the receiver is turned on to listen to the transmitted echo signal. The pulse based Radio Altimeter is less complex but does have limitation in measuring lower altitudes as the system uses the channel in a semi duplex manner between transmission and reception. The pulse also suffers from temporal distortion as it travels through free space.

In Simple continuous Radio altimeter, the radar radiates the transmission power continuously but it cannot determine the range of target because it lacks the timing marks between transmit and the receive cycles which is used to calculate the range. So, the continuous radar cannot measure the distance of the stationary objects. To obtain the range information in CW radar a time mark is needed to separate the received signal from the transmitted signal to know the delay time between the two signals. But the range calculated is not accurate by this process.

So, the spectrum of CW transmission is to be broadened by the application of modulation either by frequency or phase or amplitude. The example for amplitude modulated signal is the pulse radar. The more narrow the pulse the more accurate the measurement of range and broader the transmitted spectrum. A widely used technique to broaden the transmitted spectrum is to frequency modulate the carrier signal rather than amplitude modulate.

4. Proposed methodology

In Radio Altimeter, the FMCW Radar is used for single targets only, it is necessary to employ the linear modulation waveform. This is certainly advantageous since sinusoidal or almost sinusoidal frequency modulation is easier to obtain with practical equipment that is linear modulated. As it is linear modulation, the beat frequency obtained with sinusoidal waveform is not constant over the modulation cycle. It changes with the change in frequency. This beat frequency measured over the modulation cycle is the current value of the target range.

The general block diagram for FMCW Radar is shown in figure1.

International Journal of Research
Available at
https://edupediapublications.org/journals
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 08
July 2017

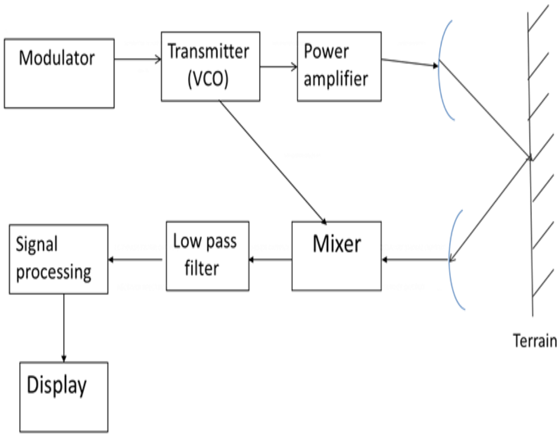

Fig 1: Block diagram for FMCW Radar

Oscillator is frequency modulated with a sawtooth input. The Frequency modulated output of oscillator is fed into power amplifier. Power amplifier amplifies the signal to an appropriate transmit level. The output of power amplifier is radiated out through the transmitter antenna. The frequency modulated carrier is reflected from the target at a range of 'R' meters. The reflected signal is delayed in time on its way to and from the target. The reflected signal is received by the receiver antenna and amplified by low noise amplifier. The output of low noise amplifier is fed into the RF port of mixer. Transmitter power is also coupled to the local oscillator port of mixer. The local oscillator input is multiplied with the radio frequencies in mixer and produces intermediate frequencies as its output. This intermediate frequency is proportional to range of target and is known as the beat frequency. The greater the beat frequency on the IF output port of mixer, the greater the range to target. If the target is moving, then the Doppler shift of the moving target is added onto the beat frequency. The output of mixer is low passed and passed through DSP processor to process the altitude information of target.

5. Theory of Operation

In the frequency modulated CW radar, the transmitted frequency is changed as a function of time in known manner. The transmitted frequency is assumed to increase linearly with time as shown in below figure. If there is reflecting object at distance R, an echo signal returns after a delay time $\tau = 2R/c$. If there is no Doppler frequency shift, the beat note is a measure of the targets range and $f_b = f_r$, where f_r is the beat frequency due to the target's range.

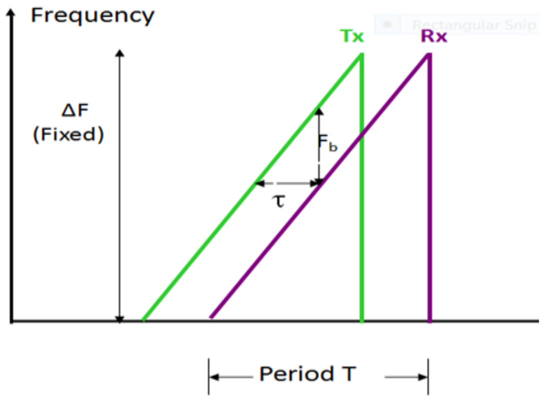

Fig 2: Frequency versus time characteristics of FMCW

In any practical CW radar, the frequency cannot be continuously changed in one direction only. Periodicity in the modulation is necessary. The modulation need not necessarily be sawtooth, it can be triangular, sinusoidal, or some other shape. The resulting beat frequency is a function of time for the sawtooth modulation. A sawtooth modulated FMCW radar signal is transmitted via an antenna on a target. The receiver receives the reflected signal after a delay time as shown in figure 2.

In the FMCW receiver input, the delay can be calculated by:

$$f_b(t) = f2\,(t) - f1(t-\tau) = \tau.\ dF/dT \quad \text{------ 1}$$

If the FMCW modulation is liner, then

$$\Delta F/T = dF/dT \quad \text{------- 2}$$

Where

ΔF --Total Frequency Deviation of the Transmitter

T --Modulation period

Now,

$$\tau = 2H/c \quad \text{-------- 3}$$

Where H --- Altitude above the terrain (m)

c---velocity of light

From eqns 1 & 2

$$f_b = \tau.\ \Delta F/T \quad \text{----- 4}$$

From eqns 3& 4

$$H = [c/2. (f_b / \Delta F).T] \text{ ----- } 5$$

From equation 5 it is observed that beat frequency is directly proportional to range of target. Thus the measurement of the beat frequency determines the range H.

6. Simulation Results and Discussions

Basic Simulation Steps:

The simulation steps listed below are considered in order to find the range information of aircraft over which it is flying using FMCW Radar for RAM application.

1. Generate an FMCW transmit waveform.
2. Introduce a delay to waveform. This is then the receiver waveform.
3. Multiply it with the transmit waveform. This is mixer output.
4. Low pass filter the waveform. This gives beat frequency signal.
5. Apply FFT and display.

A. Simulation Of FMCW Radar With Different Terrain Condition:

The Transmitter is an oscillator and power amplifier operates in the frequency range of 4.2 to 4.4 GHz producing variable output power up to 30 dbm (1W) maximum. Oscillator is modulated by a sawtooth signal to generate FMCW and is transmitted to the terrain through an antenna (Tx-antenna). The reflection from the terrain is collected by an identical but separate Rx-antenna.

The reflected RF signal, collected by the receiving antenna is fed to the receiver. Receiver consists of Low pass filter, LNAs, mixer and IF filter. The mixer also receives the transmitted signal from the LO input. Beating of these two signals, gives an IF signal consisting of different frequency components, corresponding to reflections from different point reflectors on the terrain, depending on the antenna beam width and on the instantaneous attitude of the aircraft. The nearest point on the terrain produces the least beat frequency and farther points produce higher beat frequencies. The signal from the nearest point is stronger than that from a farther point. This output is given out and to be coupled to an LF Amplifier.

The received signal is combination of transmitted signal and the clutter signal. The clutter signal is mainly dependent on the reflectivity of the terrain, its probability density function and power spectral density. The reflectivity of the terrain can be found from the dielectric constant of the terrain.

The input signal is shown in figure 3.

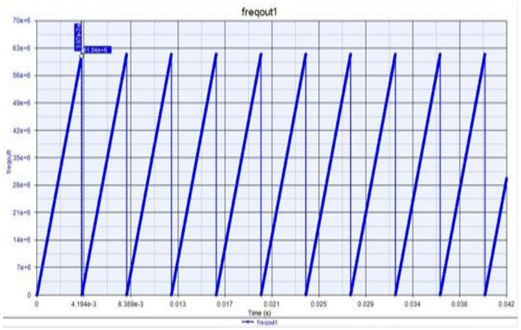

Fig 3: time vs frequency signal of FMCW Radar

The output spectrum of transmitter is deviated by 123MHz with centre frequency as 4.3GHz and is shown in figure 4.

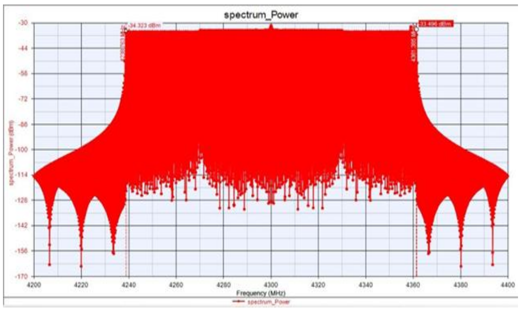

Fig 4: output spectrum of transmitter

The output spectrum at receiver for beat frequency at 1000m distance is 0.205MHz can be shown in figure 5.

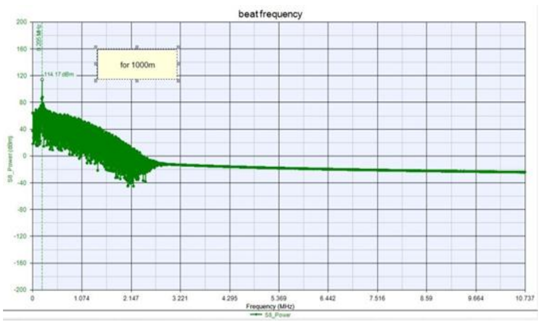

Fig 5: Beat frequency spectrum at receiver

B. *Results Of Comparison Of Beat Frequency At Receiver:*

S.NO	Distance (m) Different Altitudes	BEAT FREQUENCY f_b(MHz)	
		Theoretical	Simulated
1	100	0.0205	0.021
2	200	0.0405	0.041
3	500	0.1025	0.103
4	1000	0.205	0.205
5	2000	0.41	0.41
6	4000	0.82	0.82
7	6000	1.23	1.23
8	8000	1.64	1.64
9	10,000	2.05	2.05

C. *GRASS TERRAIN:*

Setting the temperature to 15°, before drying the grass the moisture content is 0.85 and the density is 0.9.Now for after drying the moisture content is 0.15 and the density is 0.2. The output spectrum for grass terrain with Rayleigh PDF, Gaussian PSD and reflectivity of grass terrain with -27.828db is shown in figure 6.

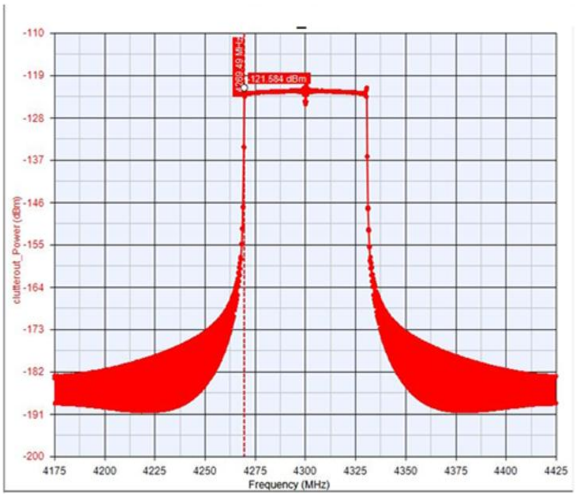

Fig 6: Output spectrum of Grass terrain reflectivity at 500m

The beat frequency signal for the corresponding altitude and grass terrain is shown in figure 7.

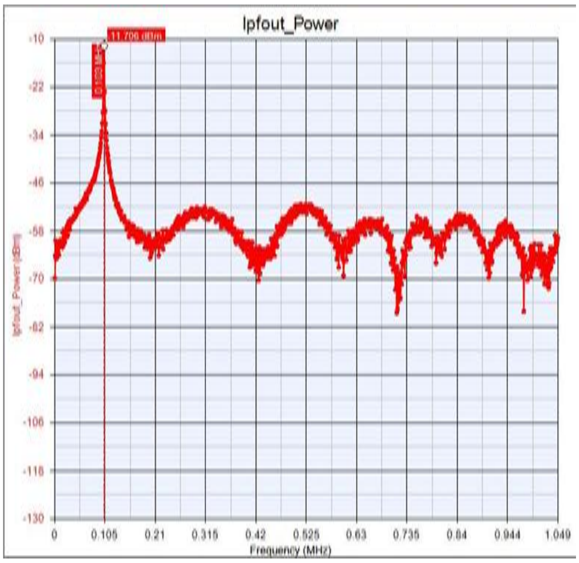

Fig 7: Receiver output spectrum of Grass terrain reflectivity at 500m

D. *WATER TERRAIN*

The dielectric constant for the pure water terrain is known as 81. The reflection coefficient of the water terrain is calculated as -1.938. The output spectrum of the received signal power that includes reflectivity of the terrain with Rayleigh PDF and Gaussian PSD is shown in figure 8.

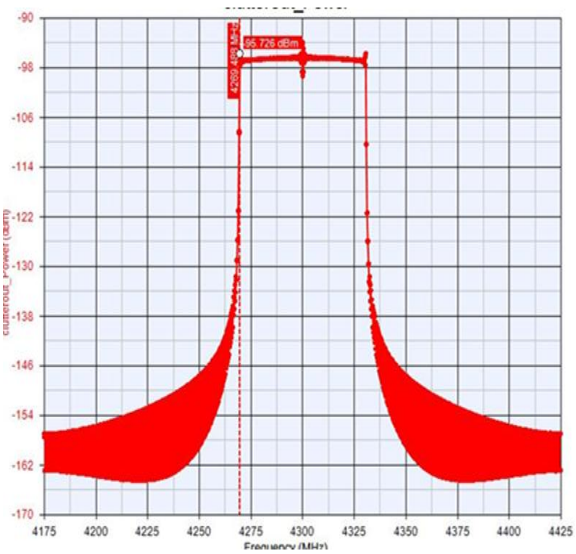

Fig 8: Output spectrum of Water clutter

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 08
July 2017

E. Results of Comparison of Received Power

S. No	Height (in m)	Water (dbm)	Grass (dbm)
1	100	-82.499	-108.415
2	200	-90.133	-115.966
3	400	-92.233	-118.122
4	500	-95.731	-121.59
5	1000	-100.309	-126.142
6	2000	-108.008	-133.92
7	3000	-110.79	-136.757
8	4000	-113.066	-138.979
9	5000	-115.648	-141.537
10	6000	-116.755	-142.711

F. Simulating Reflected Signal Pattern Of FMCW Radar With Doppler Conditions:

The received echo signal power is relatively smaller than the transmitted signal power and sometimes even less. Separate antenna for transmission and reception help to separate the weak echo from the strong signal, but the isolation is usually not sufficient. Feasible technique for separating the received signal from the transmitted signal when there is relative motion between radar and target is based on recognizing the change in the echo signal frequency caused by the Doppler Effect.

If the observer of the oscillation is in motion, an apparent shift in the frequency will result. This is the Doppler Effect and is the basis of continuous Radar. If ‘R’ is the distance between the Radar to target, the total number of wavelengths ‘λ’ contained in the two way path between the Radar and the target is $2R/\lambda$. The distance R and wavelength λ are measured in the same units. Since one wavelength corresponds to an angular excursion of 2π radians, the total angular excursion φ made by the electromagnetic way during its transit to and from the target is $4\pi R/\lambda$ radians.

If the target is in motion, R and the phase φ are continuously changing. A change in φ with respect to time is equal to the frequency.

G. Comparative Results of Altitude with Doppler Effect:

Range(m)	V_r(m/s)	f_d (Hz)	Ascent f_b(MHz)	Distance(m)	Descent f_b(MHz)	Distance(m)
100	10	286.667	0.020	97	0.021	102
	50	1433.333	0.019	90	0.022	110
	80	2293.333	0.018	87	0.023	112
	100	2866.667	0.017	82	0.023	112
500	10	286.667	0.102	497	0.102	497
	50	1433.333	0.101	492	0.104	507
	80	2293.333	0.1	487	0.105	512
	100	2866.667	0.099	482	0.106	517
1000	10	286.667	0.205	1000	0.205	1000
	50	1433.333	0.204	995	0.206	1004
	80	2293.333	0.203	990	0.207	1009
	100	2866.667	0.202	985	0.208	1014
6000	10	286.667	1.23	6000	1.23	6000
	50	1433.333	1.229	5995	1.231	6004
	80	2293.333	1.228	5990	1.232	6009
	100	2866.667	1.227	5985	1.233	6014

7. Conclusions and Future Scope

In this project, the Radio altimeter is modeled using SystemVue software to provide the altitude information of the aircraft from the terrain over which it is flying with variable delays. This provides to measure the altitude information of aircraft with and without Doppler conditions and also the reflected signal power for water and grass terrains on bench. We have measured the reflection coefficient of the terrain from the dielectric constant of the relative terrains and are programmed with the transmitted signal in order to provide the reflected signal power from the each respective terrain. From the practical results we can observe that the reflected power from the grass terrain is very worst when compared with that of water terrain conditions. The RAM is also modeled with the various radial velocities to verify and rectify the Doppler Effect in both the ascent and descent conditions.

In future work, the synchronization error due to SystemVue software has to be addressed by reducing delay time between the hardware and software. Pitch and roll simulation including beam pattern can be

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 08
July 2017

added in simulation so that real aircraft dynamic scenario can be simulated on bench.

8. References

[1] Skolnik, Merrill. I. "Introduction to Radar Systems". 2nd edition. 1997. Tata McGraw Hill, New Delhi.

[2] Skolnik, M.I. "Introduction to Radar Systems", 3rd edition, Tata McGraw-Hill, 2003.

[3] Volakis, J. L. "Antenna Engineering Handbook". 4th edition. 2007. New York, McGraw Hill.

[4] Mohandas Amarnathan, Venkata Lakshmi Siripurapu, Alok Kumar Chauhan. "Developing a Signal Processing Algorithm for A FMCW Radio Altimeter". IFAC-EGNCA. Honeywell Technology Solutions. 2012. Bangalore, India.

[5] Indu Konuganti, Manisha Chowdary, Valarmathi .J. "Sea Clutter Modelling and Target Detection". International Journal of Computer Applications (0975 – 8887), National Conference Electronics, Signals, Communication and Optimization (NCESCO). School of electronics engineering.2015.VIT University, Vellore.

[6] Chunlin Xian, Yan Chen, Ling Tong and Mingquan Jia. "Measurement on the Dielectric Constant of Grass with Rectangular Waveguide at C Band" Applied Mechanics and Materials, ISSN: 1662-7482, Vols. 130-134, pp 2138-2142, 2012, Trans Tech Publications, Switzer land.

[7] David. J. Daniels. "Ground penetrating Radar". 2nd edition. 2004. Institution of electrical engineers, London, United Kingdom.

[8] Yunhan Dong. "Models of Land Clutter vs. Grazing Angle, Spatial Distribution and Temporal Distribution - L-Band W Polarization Perspective" Electronics and Surveillance Research Laboratory, Department of Defense Science and Technology Organization. Approved for Public Release Distribution Unlimited, 2004.

[9] Sudarsan Krishnan. "Modelling and Simulation Analysis of FMCW Radar for Measuring Snow Thickness". A project report. B.E., Electronics and Communication engineering. 2000. University of Madras.

[10] Dr. N.Usha Rani, T. Pardhu. "Generation and Simulation of clutter for Radar testing using FPGA". A project Report. Masters of technology in embedded system. October 2013. School of Vignan's, Vadlamudi, Guntur.

[11] Donald E. Barrick "Radar clutter in an air defense system" Redstone scientific information centre, Redstone Arsenal, Alabama, Battelle Memorial Institute, 505 King Avenue Columbus, Ohio 43201. January 1968.

[12] Application Note of "Scenario Framework Simulation Technique for Advanced Radar Systems" by Key sight Technologies.

[13] [http://www.naic.edu/~phil/rfi/NAR_Radio_Altimeter.pdf] accessed on November 9th 2016.

[14] [https://en.wikipedia.org/wiki/Clutter_(radar)] accessed on January 20th 2017.

STUDENT

P.PREETHI

PROFESSOR

Dr. G. SRIVALLI