

WORLD METEOROLOGICAL ORGANIZATION

INSTRUMENTS AND OBSERVING METHODS

REPORT No. 88

TRAINING MATERIAL ON WEATHER RADAR SYSTEMS

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FOREWORD

The Thirteenth Session of the Commission for Instruments and Methods of Observation (CIMO) recognized the need for training and placed a greater emphasis on these issues as it planned its activities for its 13th Intersessional period. As next generation weather radars system are deployed the need for more in depth training in instrument and platform siting, operation, calibration, lightning safety and maintenance has been requested. Within this document the team of experts from Turkey, led by Mr Büyükbas, provided training materials that address the basic training needs requested by Commission Members. This excellent work will undoubtedly become a useful tool in training staff in many aspects of operating and maintaining weather radar systems.

I wish to express our sincere gratitude to Mr Büyükbas and his colleagues in preparing such a fine series of documents.



(Dr. R.P. Canterford)

Acting President
Commission for Instruments and
Methods of Observation

TRAINING MATERIAL ON WEATHER RADAR SYSTEMS

MODULES

- MODULE A: Introduction to Radars
- MODULE B: Radar Hardware
- MODULE C: Processing Basics in Doppler Weather Radars
- MODULE D: Radar Products and Operational Applications
- MODULE E: Radar Maintenance and Calibration Techniques
- MODULE F: Radar Infrastructure

TRAINING MATERIAL ON WEATHER RADAR SYSTEMS

COURSE SYLLABUS



TURKEY RADAR TRAINING 1.0 / ALANYA 2005



**TURKISH STATE METEOROLOGICAL SERVICE
(TSMS)**

**WORLD METEOROLOGICAL ORGANIZATION
(WMO)**

**COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATIONS
(CIMO)**

OPAG ON CAPACITY BUILDING (OPAG-CB)

EXPERT TEAM ON TRAINING ACTIVITIES AND TRAINING MATERIALS

TRAINING COURSE ON WEATHER RADAR SYSTEMS

MODULE A: INTRODUCTION TO RADAR

MODULE B: RADAR HARDWARE

MODULE C: PROCESSING BASICS IN DOPPLER WEATHER RADARS

MODULE D: RADAR PRODUCTS AND OPERATIONAL APPLICATIONS

MODULE E: RADAR MAINTENANCE AND CALIBRATION TECHNIQUES

MODULE F: RADAR INFRASTRUCTURE

TURKISH STATE METEOROLOGICAL SERVICE

12–16 SEPTEMBER 2005

WMO RMTC-TURKEY

ALANYA FACILITIES, ANTALYA, TURKEY

COURSE SYLLABUS
(TURKEY RADAR TRAINING 1.0 / ALANYA 2005)

1. OBJECTIVES OF THE COURSE

This course has been planned to be organized within the scope of the tasks of Expert team on training materials and training activities established by CIMO Management Group (OPAG on Capacity Building (OPAG-CB)/C.1. Expert Team on Training Activities and Training Materials) This course is expected to give a general view and information to the trainees about the basic features of Meteorological Weather Radars and why and how to operate a Radar and Radar network. It is believed that to organize such training courses will give an invaluable contribution to the capacity building activities and will be a great opportunity to be able to exchange the experiences and information between the meteorological services of different countries. On the other hand, as in that case, Regional Meteorological Training Centres will be used more efficiently. Turkish State Meteorological Service (TSMS) started modernization program of observation network and got many experience both on equipment itself and operating them. So TSMS's well trained staff will take the opportunity to transfer their knowledge and experiences to the representative of the other countries and get their experiences, comments and recommendations by means of that interactive training course.

Upon completion of the course;

Trainees will be able to;

- a) understand why we need more reliable, more accurate and continuous meteorological data and how these requirements can be met,
- b) learn basic principles and approach of an RADAR which has become a necessity for the meteorological observations,
- c) take benefits of experiences from users of an operational weather radar network,
- d) get the view how to maintain a single RADAR and an RADAR network.

Trainers will be able to;

- a) understand weak and strong parts of their knowledge and teaching method,
- b) learn how they can transfer their knowledge to the trainees,
- c) take the opportunity to check their system's features once more under questions of the trainees,
- d) get comments, experiences and recommendations of the representatives of the other countries.

COURSE CONTENT

Lecture Nr.	Lecture - Day / Hour	Lecture Module	Topic	Training Material	Training Method	Lecturer
	09:00 – 10:00		Opening Ceremony			
1	1 / 1 10:00 – 10:45		TURKEY WEATHER OBSERVING SYSTEMS AND RADAR NETWORK <ul style="list-style-type: none"> • Brief Explanation on Course • Observation Network of TSMS • Radar Network <ul style="list-style-type: none"> ○ Currently Operational ○ Planned for Future 	<ul style="list-style-type: none"> • Prepared text book and CD • Projector • Laptop PC 	<ul style="list-style-type: none"> • Explanation by Power point presentation 	Ercan BÜYÜKBAŞ
2	1 / 2 11:00 – 11:45	A	INTRODUCTION TO RADAR Radar Theory <ul style="list-style-type: none"> • The History of Radar • Basic Radar Terms • Radar Equation • Block Diagram of a Radar 	<ul style="list-style-type: none"> • Prepared text book and CD • Projector • Laptop PC 	<ul style="list-style-type: none"> • Explanation by Power point presentation 	Ercan BÜYÜKBAŞ
	12:00 – 13:15		Lunch break			
3	1 / 3 13:15 – 14:00	A	Propagation of EM waves <ul style="list-style-type: none"> • Electromagnetic Spectrum • Electromagnetic Waves • Refraction Radar Types <ul style="list-style-type: none"> • Pulse, Continuous, • Doppler Radar, • MTI, ASR, TDWR 	<ul style="list-style-type: none"> • Prepared text book and CD • Projector • Laptop PC 	<ul style="list-style-type: none"> • Theoretical explanation by Power point presentation • Drawings on the board 	Aytaç HAZER

4	1 / 4 14:15 – 15:00	B	RADAR HARDWARE Operation Principles of Weather Radar <ul style="list-style-type: none"> • General Overview • Typical Radar System Applications and Block Diagrams Receiver <ul style="list-style-type: none"> • General Overview • Oscillators 	<ul style="list-style-type: none"> • Prepared text book and CD • Projector • Laptop PC 	<ul style="list-style-type: none"> • Theoretical explanation by Power point presentation • Drawings on the board 	Oğuzhan ŞİRECI
5	1 / 5 15:15-16:00	B	Receiver <ul style="list-style-type: none"> • Low Noise Amplifier • Duplexer&TR Limiter • Basic Characteristics of Receiver Transmitter <ul style="list-style-type: none"> • General Overview • Transmitter Types • Modulator 			Oğuzhan ŞİRECI

Lecture Nr.	Lecture - Day / Hour	Lecture Module	Topic	Training Material	Training Method	Lecturer	
6	2 / 1 09:00 – 09:45	B	Antenna <ul style="list-style-type: none"> • General Overview • Antenna Types • Modulator • Basic Characteristics of Antenna • Main Parts of a Radar Antenna 	<ul style="list-style-type: none"> • Prepared text book and CD • Projector • Laptop PC 	<ul style="list-style-type: none"> • Theoretical explanation by Power point presentation • Drawings on the board 	İsmail TEMİR	
7	2 / 2 10:00 – 10:45	B	Radar Control Processor(RCP) and Radar Signal Processor(RSP) <ul style="list-style-type: none"> • General Overview • Control Processor • Signal Processor Radome <ul style="list-style-type: none"> • General Overview • Radome Types 	<ul style="list-style-type: none"> • Prepared text book and CD • Projector • Laptop PC 	<ul style="list-style-type: none"> • Theoretical explanation by Power point presentation • Drawings on the board 	Oğuzhan ŞİREÇİ	
8	2 / 3 11:00 – 11:45	B	Video Show <ul style="list-style-type: none"> • Video Images of Turkish Radars 			ALL	
	12:00 – 13:00		Lunch Break				
Lecture Nr.	Lecture - Day / Hour	Lecture Module	Topic	Training Material	Training Method	Lecturer	
			EXCURSION				

Lecture Nr.	Lecture - Day / Hour	Lecture Module	Topic	Training Material	Training Method	Lecturer
9	3 / 1 09:00 – 09:45	C	PROCESSING BASICS IN DOPPLER WEATHER RADAR SYSTEMS Signal Processing <ul style="list-style-type: none"> I/Q Demodulation Analogue receiver Channels Doppler Signal Processing Techniques Pulse Pair Clutter Correction FFT Implementation Maximum Unambiguous Range	<ul style="list-style-type: none"> Prepared text book and CD Projector Laptop PC 	<ul style="list-style-type: none"> Theoretical explanation by Power point presentation Drawings on the board 	Oğuzhan ŞİRECI
10	3 / 2 10:00 – 10:45	C	Velocity Determination <ul style="list-style-type: none"> Doppler Shift Total Distance to Target in Radians Pulse Pair Method Maximum Unambiguous Velocity Doppler Dilemma	<ul style="list-style-type: none"> Prepared text book and CD Projector Laptop PC 	<ul style="list-style-type: none"> Theoretical explanation by Power point presentation Drawings on the board 	Oğuzhan ŞİRECI
11	3 / 3 11:00 – 11:45	C	Radar Range Folding <ul style="list-style-type: none"> Recognizing Range Aliased Echoes Elimination of Second Trip Echoes Velocity Folding <ul style="list-style-type: none"> Staggered PRF for Velocity Folding Recognizing Velocity Aliasing 	<ul style="list-style-type: none"> Prepared text book and CD Projector Laptop PC 	<ul style="list-style-type: none"> Theoretical explanation by Power point presentation Drawings on the board 	Oğuzhan ŞİRECI
Lunch Break						

Lecture Nr.	Lecture - Day / Hour	Lecture Module	Topic	Training Material	Training Method	Lecturer
12	3 / 4 13:15 – 14:00	D	RADAR PRODUCTS AND OPERATIONAL APPLICATIONS Radar Products <ul style="list-style-type: none"> • RPG(Radar Product Generation) • Radar Parameters • Product Descriptions 	<ul style="list-style-type: none"> • Prepared text book and CD • Projector • Laptop PC 	<ul style="list-style-type: none"> • Theoretical explanation by Power point presentation • Drawings on the board 	Cüneyt GEÇER
13	3 / 5 14:15 – 15:00	D	Scanning Strategies <ul style="list-style-type: none"> • Winter Task • Convective(Summer) Task 	<ul style="list-style-type: none"> • Prepared text book and CD • Projector • Laptop PC 	<ul style="list-style-type: none"> • Theoretical explanation by Power point presentation • Drawings on the board 	Cüneyt GEÇER
14	3 / 6 15:15 – 16:00	D	Radar Product Applications <ul style="list-style-type: none"> • Z-R Relation • Gauge Adjustment • Hydrometer Classification • Radar Data Quality Algorithms 	<ul style="list-style-type: none"> • Prepared text book and CD • Projector • Laptop PC 	<ul style="list-style-type: none"> • Theoretical explanation by Power point presentation • Drawings on the board 	Cüneyt GEÇER

Lecture Nr.	Lecture - Day / Hour	Lecture Module	Topic	Training Material	Training Method	Lecturer
15	4 / 1 09:00 – 09:45	E	RADAR MAINTENANCE AND CALIBRATION TECHNIQUES Maintenance Types and Procedures <ul style="list-style-type: none"> Preventive Maintenance Corrective Maintenance Common Tools Used for Radar Maintenance	<ul style="list-style-type: none"> Prepared text book and CD Laptop PC Projector Measurement equipments Video Player/TV 	<ul style="list-style-type: none"> Theoretical explanation by Power point presentation Drawings on the board Practical application 	Ercan BÜYÜKBAŞ
16	4 / 2 10:00 – 10:45	E	Measurements on Transmitter <ul style="list-style-type: none"> Transmitted Power and Stability PW, PRF, Duty Cycle/Factor Klystron Pulse, Klystron Current 	<ul style="list-style-type: none"> Prepared text book and CD Laptop PC Projector Video Player/TV 	<ul style="list-style-type: none"> Theoretical explanation by Power point presentation Drawings on the board Video Presentation 	Aytaç HAZER
17	4 / 3 11:00 – 11:45	E	Measurements on Transmitter <ul style="list-style-type: none"> Klystron RF Input Level Transmitted Frequency Occupied Band width Trigger Control 	<ul style="list-style-type: none"> Prepared text book and CD Laptop PC Projector Video Player/TV 	<ul style="list-style-type: none"> Theoretical explanation by Power point presentation Drawings on the board Video Presentation 	Aytaç HAZER
	12:00 – 13:00		Lunch Break			

Lecture Nr.	Lecture - Day / Hour	Lecture Module	Topic	Training Material	Training Method	Lecturer
18	4 / 4 13:15 – 14:00	E	Measurements on Receiver <ul style="list-style-type: none"> • Oscillator Outputs • RX Gain, • MDS & Dynamic Range • TX IF Out&Exciter • Intensity Measurement • Velocity Measurement • Noise Figure 	<ul style="list-style-type: none"> • Prepared text book and CD • Laptop PC • Projector • Video Player/TV 	<ul style="list-style-type: none"> • Theoretical explanation by Power point presentation • Drawings on the board • Video Presentation 	Aytaç HAZER
19	4 / 5 14:15 – 15:00	E	Antenna and Radome <ul style="list-style-type: none"> • Periodical Checks • Antenna Test • Lubrication • Slipping Cleaning and Checks • Position&Velocity Check • Radome Check and Control • Obstruction Light 	<ul style="list-style-type: none"> • Prepared text book and CD • Laptop PC • Projector • Video Player/TV 	<ul style="list-style-type: none"> • Theoretical explanation by Power point presentation • Drawings on the board • Video Presentation 	İsmail TEMİR

Lecture Nr.	Lecture - Day / Hour	Lecture Module	Topic	Training Material	Training Method	Lecturer	
20	5 / 1 09:00 – 09:45	E	BITE System, Maintenance Software <ul style="list-style-type: none"> Built in Test Equipment Maintenance Software 	<ul style="list-style-type: none"> Prepared text book and CD Laptop PC Projector 	<ul style="list-style-type: none"> Theoretical explanation by Power point presentation Drawings on the board 	Oğuzhan ŞİRECI	
21	5 / 2 10:00 – 10:45	E	Calibration <ul style="list-style-type: none"> Transmitted Peak and Average Power Check and Adjustment Receiver Calibration Antenna Calibration Comparison methods for Checking Reflectivity 	<ul style="list-style-type: none"> Prepared text book and CD Laptop PC Projector 	<ul style="list-style-type: none"> Theoretical explanation by Power point presentation Drawings on the board 	Oğuzhan ŞİRECI	
22	5 / 3 11:00 – 11:45	E	Corrective Maintenance Samples <ul style="list-style-type: none"> Klystron changing Finding faults Replacement of the faulty boards 	<ul style="list-style-type: none"> Prepared text book and CD Laptop PC Projector 	<ul style="list-style-type: none"> Theoretical explanation by Power point presentation Drawings on the board 	Oğuzhan ŞİRECI	
	12:00 – 13:00		Lunch Break				
23	5 / 4 11:00 – 11:45	F	RADAR INFRASTRUCTURE General Overview Radar Site Selection Criteria Radar Site Infrastructure Requirements	<ul style="list-style-type: none"> Prepared text book and CD Laptop PC Projector 	<ul style="list-style-type: none"> Theoretical explanation by Power point presentation Drawings on the board 	Ercan BÜYÜKBAŞ	

- **Lecture Module Definitions:**

TURKEY RADAR TRAINING 1.0 / ALANYA 2005

A: Introduction to RADAR

B: Radar Hardware

C: Processing Basics in Doppler Weather Radars

D: Radar Products and Operational Applications

E: Radar Maintenance and Calibration Techniques

F: Radar Infrastructure

- **Excursion:**

Visiting the natural, historical and cultural heritage of Alanya.

- **Lecturers:**

1. Ercan BÜYÜKBAŞ(*Electric-Electronics Engineer, Manager of Electronic Observing System Division*)
2. Oğuzhan ŞİREÇİ (*Electric-Electronics Engineer, Chief Engineer in Electronic Observing System Division*)
3. Aytaç HAZER (*Electric-Electronics Engineer, Chief Engineer in Electronic Observing System Division*)
4. Cüneyt GEÇER (*Meteorological Engineer, Deputy Manager of Remote Sensing Division*)
5. İsmail TEMİR(*Mechanical Engineer, Engineer in Electronic Observing System Division*)

TRAINING MATERIAL ON WEATHER RADAR SYSTEMS

MODULE A

INTRODUCTION TO RADARS

[original PDF with bookmarks \(1,25 MB\)](#)



TURKEY RADAR TRAINING 1.0 / ALANYA 2005

**TURKISH STATE METEOROLOGICAL SERVICE
(TSMS)**



**WORLD METEOROLOGICAL ORGANIZATION
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**COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATIONS
(CIMO)**

OPAG ON CAPACITY BUILDING (OPAG-CB)

EXPERT TEAM ON TRAINING ACTIVITIES AND TRAINING MATERIALS

TRAINING COURSE ON WEATHER RADAR SYSTEMS

MODULE A: INTRODUCTION TO RADAR

ERCAN BÜYÜKBAŞ-*Electronics Engineer*

OĞUZHAN ŞİRECI-*Electronics Engineer*

AYTAÇ HAZER-*Electronics Engineer*

İSMAİL TEMİR-*Mechanical Engineer*

**ELECTRONIC OBSERVING SYSTEMS DIVISION
TURKISH STATE METEOROLOGICAL SERVICE**

**12–16 SEPTEMBER 2005
WMO RMTC-TURKEY
ALANYA FACILITIES, ANTALYA, TURKEY**

MODULE A: INTRODUCTION TO RADAR

MODULE B: RADAR HARDWARE

MODULE C: PROCESSING BASICS IN DOPPLER WEATHER RADARS

MODULE D: RADAR PRODUCTS AND OPERATIONAL APPLICATIONS

MODULE E: RADAR MAINTENANCE AND CALIBRATION TECHNIQUES

MODULE F: RADAR INFRASTRUCTURE

INTRODUCTION TO RADAR

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ABBREVIATIONS:

2-D	: Two Dimensional
3-D	: Three Dimensional
EM	: Electromagnetic
FM-CW	: Frequency Modulated Continuous Wave
TDWR	: Terminal Weather Doppler Radar
MTI	: Moving Target Indication
TSMS	: Turkish State Meteorological Service
CIMO	: Commission for Instruments and Methods of Observations
OPAG	: Open Programme Area Groups
OPAG-CB/C1	: Open Programme Area Groups on Capacity Building
RADAR	: Radio Detecting and Ranging
RDF	: Radio Direction Finding
Hz	: Hertz
KHz	: Kilohertz
MHz	: Megahertz
GHz	: Gigahertz
BW	: Bandwidth
PRF	: Pulse Repetition Frequency
PRT	: Pulse Repetition Time
RF	: Radio Frequency
mW	: Milliwatt
KW	: Kilowatt
MW	: Megawatt
Sec.	: Second
µsec.	: Microsecond
cm	: Centimetre
P_t	: Peak Transmitted Power
P_{avg}	: Average Power
P_r	: Received Power
P_s	: Backscattered Power
F_s	: Backscattered Power Flux
G	: Gain
dB	: Decibel
dBm	: Decibel Milliwatt
dBZ	: Logarithmic Scale for Measuring Radar Reflectivity Factor
c	: Speed of light
f	: Frequency
λ	: Wavelength
Z	: Reflectivity Factor of the Precipitation
L	: Loss Factor of the Radar
K	: Dielectric Constant
H	: Pulse Length of the Radar
R	: Target Range of the Precipitation
A-Scope	: A Diagnostic and Control Utility to Test Radar and Signal Processor
PPI	: Plan Position Indicator
RHI	: Range Height Indicator
STALO	: Stable Oscillator
COHO	: Coherent Oscillator

IF	: Intermediate Frequency
HF	: High Frequency
UHF	: Ultra High Frequency
VHF	: Very High Frequency
ITU	: International Telecommunication Union
E	: Electric Field
H	: Magnetic Field
hPa	: Hectopascal
CW	: Continuous Wave
ASR	: Air Surveillance Radars
SAR	: Synthetic Aperture Radar
ISAR	: Inverse Synthetic Aperture Radar
RASS	: Radio Acoustic Sounding System

1. INTRODUCTION

1.1. A Few Words on that Course

Recently, Turkish State Meteorological Service (TSMS) started a modernization program of observing systems including weather radars. So a great knowledge have been transferred to the staff of TSMS by means of installation high technology weather radars, getting training courses from radar manufacturers and international experts both on operation/interpretation and maintenance/calibration of weather radars. As a result of those very important activities, TSMS has caught a very important level on weather radar applications and then as an active member of WMO on Regional Metrological Training Activities, TSMS has planned to organize regular training activities on weather observing systems in line with the tasks of Expert Team on Training Materials and Training Activities established by CIMO Management Group (**OPAG on Capacity Building (OPAG-CB)/C.1. Expert Team on Training Activities and Training Materials**).

The training course organized by Turkish State Meteorological Service on weather radar systems and training documents prepared for that training course are intended to give a general information on radar theory, weather radars and meteorological applications, to highlight the important topics, to summarize the critical aspects by reviewing the information and comments from different sources and to provide some vital information why and how to install and operate a weather radar network. All these activities must be understood and accepted as just a key for opening a small door to the complex and great world of radars, particularly Doppler weather radars. Furthermore, we believe that such organizations will help the experts from different countries and community of meteorology will come closer. In addition, exchange of the experiences will support the capacity building activities extremely.

The training documents have been prepared by reviewing the popular radar books and the other documents available. On the other hand, a lot of useful information has been provided from the internet. TSMS has received very effective training courses from the radar manufacturers who supplied the existing radars operated by TSMS. Training documents prepared during those courses and notes from the lectures are the other important sources of those training materials. Radar manufacturers' demonstrations and power point presentations by experts have also been taken into consideration while preparing the documents.

Training materials have been prepared as a set of 6 (six) separate modules. In other words, modules are directly related to each other for completion of the topics covered by training course. Modules supplement each other.

It is very obvious that, as being our first training course and first training documents regarding radars in English, those training documents, most probably, will be in need of reviewing and modifying in some topics. Whoever makes any comment, recommendations and corrections will be highly appreciated. We think that those invaluable contributions will pave our way for further activities.

1.2. A Few Words on Weather Radars

To watch the atmosphere and the weather phenomena occurred is getting more and more important for the developing world. To be able to meet the meteorological requirements of the developing world, it is very obvious that there is a necessity for the provision of accurate and timely weather observations which will be the essential input of weather forecasts and numerical weather prediction models, research studies on climate and climate change, sustainable development, environment protection, renewable energy sources, etc. All outputs and products of any system are input dependant. So, accuracy, reliability and efficiency of the products of any meteorological study will depend on its input: **Observation**.

It is vital to observe the weather and to make weather prediction timely especially for severe weather conditions to be able to warn the public in due course. One of the most important and critical instruments developed and offered by the modern technology for observing weather and early warning systems are weather radars. It would not be a wrong comment to say that radar is the only and essential sensor which can provide real time and accurate information on hazardous weather phenomena such as strong wind, heavy precipitation and hail in large scale area.

Doppler and wind profiling radars are proving to be extremely valuable in providing data of high-resolution in both space and especially in the lower layers of the atmosphere. Doppler radars are used extensively as part of national and increasingly of regional networks, mainly for short range forecasting of severe weather phenomena. Particularly useful is the Doppler radar capability of making wind measurements and estimates of rainfall amounts. Wind

profiler radars are especially useful in making observations between balloon-borne soundings and have great potential as a part of integrated observing networks.

Hydrologist needs precipitation measurements. As simple as it looks, as difficult it is to obtain reliable data. We know that rain gauge measurements have errors owing to the type of the instrument and to the site. Wind, snowfall, drop-size influence the results. But the largest problem is the area representativeness. Measurements on a surface of 200 or 400 cm² are used to estimate the rainfall on areas in the order of magnitude of 100 km². Knowing the spatial variability of rainfall, especially during flood events, it is obvious that point measurements, even if the measurement itself would be correct, are heavily biased.

Some researchers say that the hope of hydrologists and meteorologists is concentrated on radar measurements. Radar provides images of instantaneous rainfall intensity distribution over large areas. However, when trying to obtain the desired quantitative results, one encounters a series of problems. Radar measures an echo, which is influenced by type, size and concentration of particles, all depending on the meteorological conditions, ground clutter, shadowing by mountain ridges, attenuation and parameters of the instrument itself. Calibration based directly on physical data is not possible, owing to the simple fact that no reliable data are available, since, as indicated above, rain gauge data are in error too. So one tries to obtain the best possible agreement with point measurements, being aware, that neither the gauge value nor the radar interpretation is necessarily correct. So, although it is asserted that radar is, and will be in future as well, a semi-quantitative measurement device, it seems that radar will keep its importance with very efficient capabilities and remain as an indispensable equipment for early warning systems and observation networks for monitoring the weather.

2. RADAR THEORY

2.1. The History of Radar

Radar term is the abbreviation of **RA**dio **D**etecting **A**nd **R**anging, i.e. finding and positioning a target and determining the distance between the target and the source by using radio frequency. This term was first used by the U.S. Navy in 1940 and adopted universally in 1943. It was originally called Radio Direction Finding (R.D.F.) in England.

We can say that, everything for radar started with the discovering of radio frequencies, and invention of some sub components, e.g. electronic devices, resulted invention and developing of radar systems. The history of radar includes the various practical and theoretical discoveries of the 18th, 19th and early 20th centuries that paved the way for the use of radio as means of communication. Although the development of radar as a stand-alone technology did not occur until World War II, the basic principle of radar detection is almost as old as the subject of electromagnetism itself. Some of the major milestones of radar history are as follows:

- **1842** It was described by Christian Andreas Doppler that the sound waves from a source coming closer to a standing person have a higher frequency while the sound waves from a source going away from a standing person have a lower frequency. That approach is valid for radio waves, too. In other words, observed frequency of light and sound waves was affected by the relative motion of the source and the detector. This phenomenon became known as the Doppler Effect.
- **1860** Electric and magnetic fields were discovered by Michael Faraday.
- **1864** Mathematical equations of electromagnetism were determined by James Clark Maxwell. Maxwell set forth the theory of light must be accepted as an electromagnetic wave. Electromagnetic field and wave were put forth consideration by Maxwell.

- **1886** Theories of Maxwell were experimentally tested and similarity between radio and light waves was demonstrated by Heinrich Hertz.
- **1888** Electromagnetic waves set forth by Maxwell were discovered by Heinrich Hertz. He showed that radio waves could be reflected by metallic and dielectric bodies.
- **1900** Radar concept was documented by Nicola Tesla as “Exactly as the sound, so an electrical wave is reflected ... we may determine the relative position or course of a moving object such as a vessel... or its speed.”
- **1904** The first patent of the detection of objects by radio was issued to Christian Hülsmeyer (**Figure 1**).
- **1922** Detection of ships by radio waves and radio communication between continents was demonstrated by Guglielmo Marconi.
- **1922** A wooden ship was detected by using CW radar by Albert Hoyt Taylor and Leo C. Young.
- **1925** The first application of the pulse technique was used to measure distance by G. Breit and M. Truve.
- **1940** Microwaves were started to be used for long-range detection.
- **1947** The first weather radar was installed in Washington D.C. on February 14.
- **1950** Radars were put into operation for the detection and tracking of weather phenomena such as thunderstorms and cyclones.
- **1990’s** A dramatic upgrade to radars came in with the Doppler radar.



Figure 1: First Radar Patent.

2.2. Basic Radar Terms

It seems beneficial to give at least the definition of some basic radar terms to be able to understand the theory and operation of radars. The common definitions of basic terms which will be talked about frequently during that training course are given below:

a) Frequency (f)

Frequency refers to the number of completed wave cycles per second. Radar frequency is expressed in units of Hertz (Hz).

b) Phase (δ)

Phase of an electromagnetic wave is essentially the fraction of a full wavelength a particular point is from some reference point measured in radians or degrees.

c) Bandwidth (BW)

Bandwidth is the frequency difference between the upper and lower frequencies of electromagnetic radiation. It is expressed in units of Hertz (Hz).

d) Wavelength (λ)

This is distance from wavecrest to wavecrest (or trough to trough) along an electromagnetic wave's direction of travel is called wavelength. Unit of wavelength is generally centimetre.

e) Pulse width (τ)

Pulse width is the time interval between the leading edge and trailing edge of a pulse at a point where the amplitude is 50% of the peak value. It is expressed in units of microseconds.

f) PRF and PRT

Pulse repetition frequency is the number of peak power pulses transmitted per second. Pulse repetition time is the time interval between two peak pulses.

g) Duty Factor/Duty Cycle

Duty cycle is the amount of time radar transmits compare to its listening to receiving time. The ratio is sometimes expressed in per cent. It can be determined by multiplying PRF and Pulse width or, by dividing the Pulse width with PRT. It has not any units

h) Beam width (θ)

It is defined as the angle between the half-power (3 dB) points of the main lobe, when referenced to the peak effective radiated power of the main lobe. Unit is degree.

Name	Symbol	Units	Typical values
Transmitted frequency	f_t	MHz, GHz	1000-12500 MHz
wavelength	λ	cm	3-10 cm
Pulse duration	T	μ sec	1 μ sec
Pulse length	H	m	150-300 m ($h=c.\tau$)
Pulse repetition frequency	PRF	sec^{-1}	1000 sec^{-1}
interpulse period	T	millisecond	1 millisecond
peak transmitted power	P_t	MW	1 MW
average power	P_{avg}	kW	1 kW ($P_{\text{avg}} = P_t \tau \text{ PRF}$)
received power	P_r	mW	10^{-6} mW

Table 1: Some Nomenclature.

2.3. Operation Principle of Radar

Operation principle of radar is very simple in theory and very similar to the way which bats use naturally to find their path during their flight (**Figure 2**). Bats use a type of radar system by emitting ultrasonic sounds in a certain frequency (120 KHz) and hearing the echoes of these sounds. These echoes make them enable to locate and avoid the objects in their path.

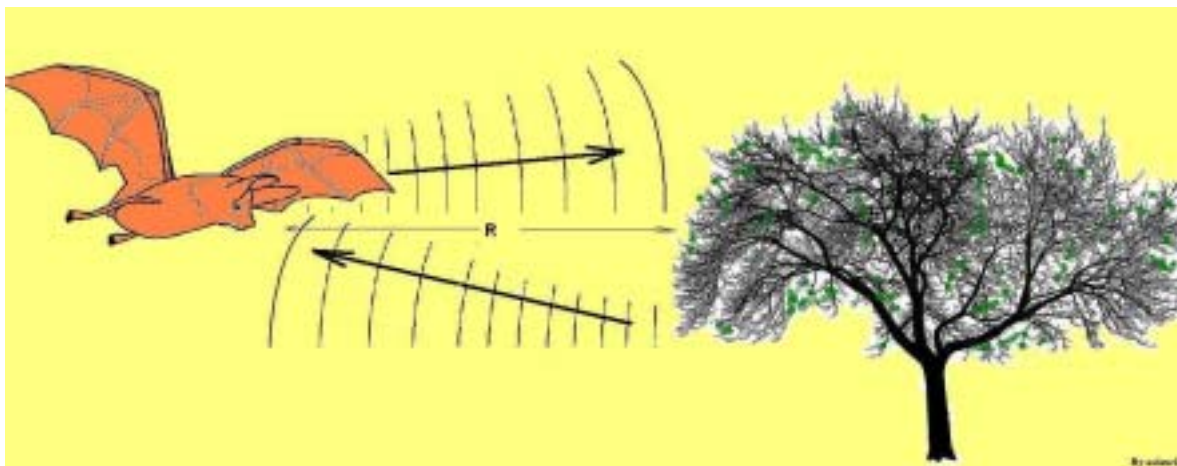


Figure 2: Natural Radar.

In the radar systems, an electromagnetic wave generated by the transmitter unit is transmitted by means of an antenna and the reflected wave from the objects (echo) is received by the same antenna and after processing of the returned signal, a visual indication is displayed on indicators. After a radio signal is generated and emitted by a combination of a transmitter and an antenna, the radio waves travel out in a certain direction in a manner similar to light or sound waves. If the signals strike an object, the waves are reflected and the reflected waves travel in all directions depending of the surface of the reflector. The term reflectivity refers to the amount of energy returned from an object and is dependent on the size, shape and composition of the object. A small portion of the reflected waves return to the location of the transmitter originating them where they are picked up by the receiver antenna. This signal is amplified and displayed on the screen of the indicators, e.g. PPI (Plan Position Indicator). This simple approach can be achieved by means of many complex process including hardware and software components.

2.4. Radar Equation

The fundamental relation between the characteristics of the radar, the target and the received signal is called the radar equation and the theory of radar is developed based on that equation.

$$P_r = \frac{P_t G^2 \theta^2 H \Pi^3 K^2 L}{1024 (\ln 2) \lambda^2} \times \frac{Z}{R^2}$$

This equation involves variables that are either known or are directly measured. There is only one value, **P_r**, that is missing but it can be solved for mathematically. Below is the list of variables, what they are and how they are measured.

P_r: Average power returned to the radar from a target. The radar sends pulses and then measures the average power that is received in those returns. The radar uses multiple pulses since the power returned by a meteorological target varies from pulse to pulse. This is an unknown value of the radar but it is one that is directly calculated.

P_t: Peak power transmitted by the radar. This is a known value of the radar. It is important to know because the average power returned is directly related to the transmitted power.

G: Antenna gain of the radar. This is a known value of the radar. This is a measure of the antenna's ability to focus outgoing energy into the beam. The power received from a given target is directly related to the square of the antenna gain.

θ: Angular beam width of radar. This is a known value of the radar. Through the Robert-Jones equation it can be learned that the return power is directly related to the square of the angular beam width. The problem becomes that the assumption of the equation is that precipitation fills the beam for radars with beams wider than two degrees. It is also an invalid assumption for any weather radar at long distances. The lower resolution at great distances is called the aspect ratio problem.

H: Pulse Length of the radar. This is a known value of the radar. The power received from a meteorological target is directly related to the pulse length.

K: This is a physical constant. This is a known value of the radar. This constant relies on the dielectric constant of water. This is an assumption that has to be made but also can cause some problems. The dielectric constant of water is near one, meaning it has a good reflectivity. The problem occurs when you have meteorological targets that do not share that reflectivity. Some examples of this are snow and dry hail since their constants are around 0.2.

L: This is the loss factor of the radar. This is a value that is calculated to compensate for attenuation by precipitation, atmospheric gases and receiver detection limitations. The attenuation by precipitation is a function of precipitation intensity and wavelength. For atmospheric gases, it is a function of elevation angle, range and wavelength. Since all of these accounts for a 2dB loss, all signals are strengthened by 2 dB.

λ : This is the wavelength of the transmitted energy. This is a known value of the radar. The amount of power returned from a precipitation target is inversely since the short wavelengths are subject to significant attenuation. The longer the wavelength, the less attenuation caused by precipitation.

Z: This is the reflectivity factor of the precipitate. This is the value that is solved for mathematically by the radar. The number of drops and the size of the drops affect this value. This value can cause problems because the radar cannot determine the size of the precipitate. The size is important since the reflectivity factor of a precipitation target is determined by raising each drop diameter in the sample volume to the sixth power and then summing all those values together. A 1/4" drop reflects the same amount of energy as 64 1/8" drops even though there is 729 times more liquid in the 1/8" drops.

R: This is the target range of the precipitate. This value can be calculated by measuring the time it takes the signal to return. The range is important since the average power return from a target is inversely related to the square of its range from the radar. The radar has to normalize the power returned to compensate for the range attenuation.

Using a relationship between Z and R , an estimate of rainfall can be achieved. A base equation that can be used to do this is $Z=200*R^{1.6}$. This equation can be modified at the user's request to a better fitting equation for the day or the area.

2.4.1. How to derive radar equation?

It may be interesting for somebody so, a general derivation steps of radar equation is given below. Our starting point will be flux calculations.

Flux Calculations - Isotropic Transmit Antenna

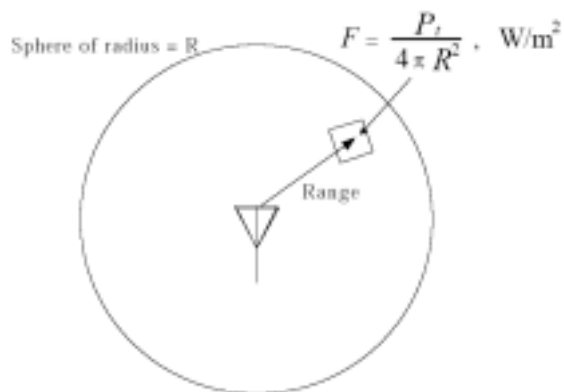


Figure 3: Flux at Distance R.

Flux Calculations - Transmit Antenna with Gain

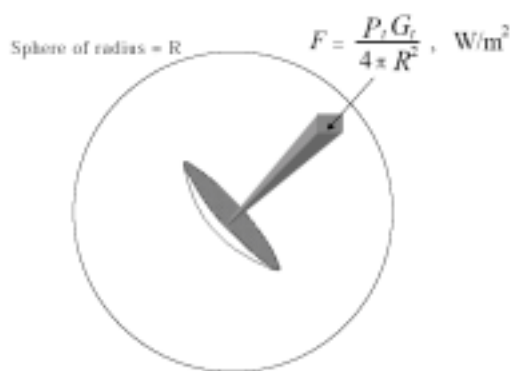


Figure 4: Flux at Distance R with Gain.

Radar Signal at Target, Incident power flux density from a Directive Source

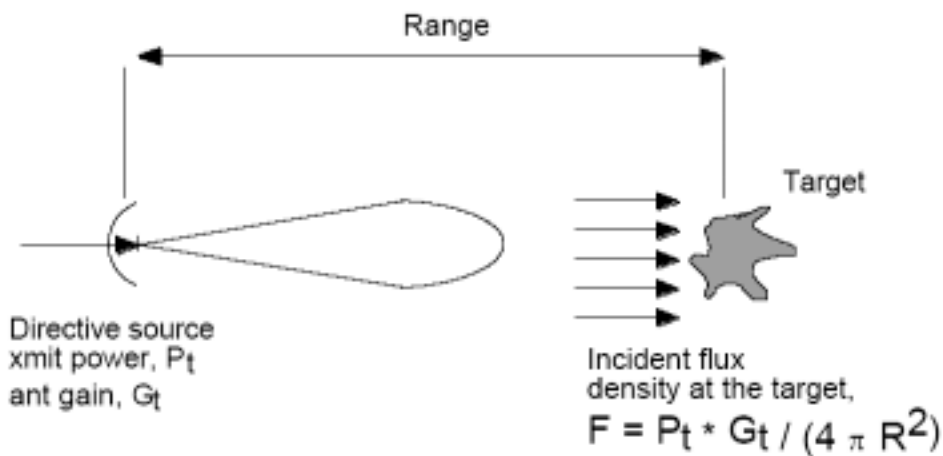


Figure 5: Incident Power Flux Density from a Directive Source.

Echo Signal at Target, Backscattered power from the target

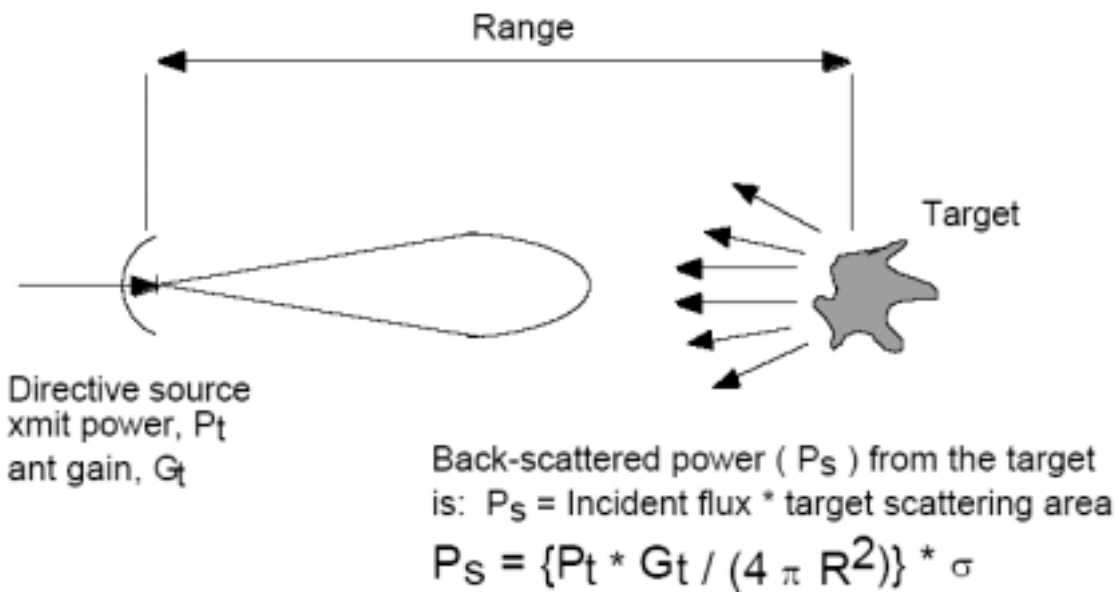


Figure 6: Power Back Scattered from Target with Cross Section.

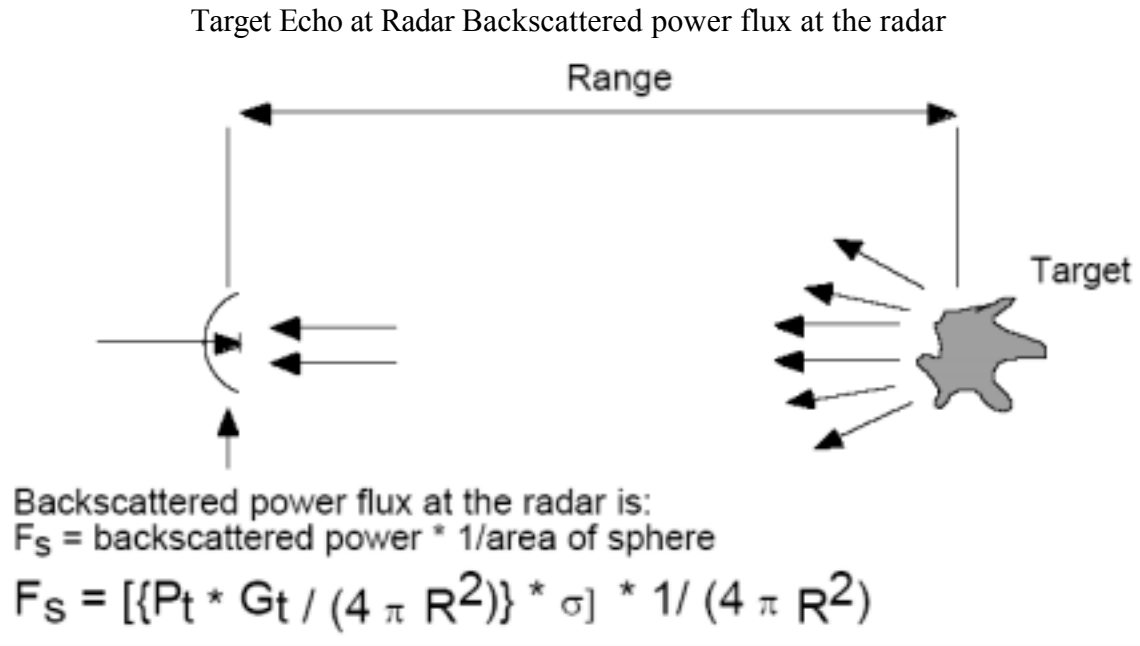


Figure 7: Flux Back Scattered from Target at Radar.

Radar Cross Section

The radar cross section (σ) of a target is the “equivalent area” of a flat-plate mirror:

- ◆ That is aligned perpendicular to the propagation direction (i.e., reflects the signal directly back to the transmitter) and
- ◆ That results in the same backscattered power as produced by the target

Radar cross section is extremely difficult to predict and is usually measured using scaled models of targets.

Target Echo Signal at Radar Received (echo) power at the radar

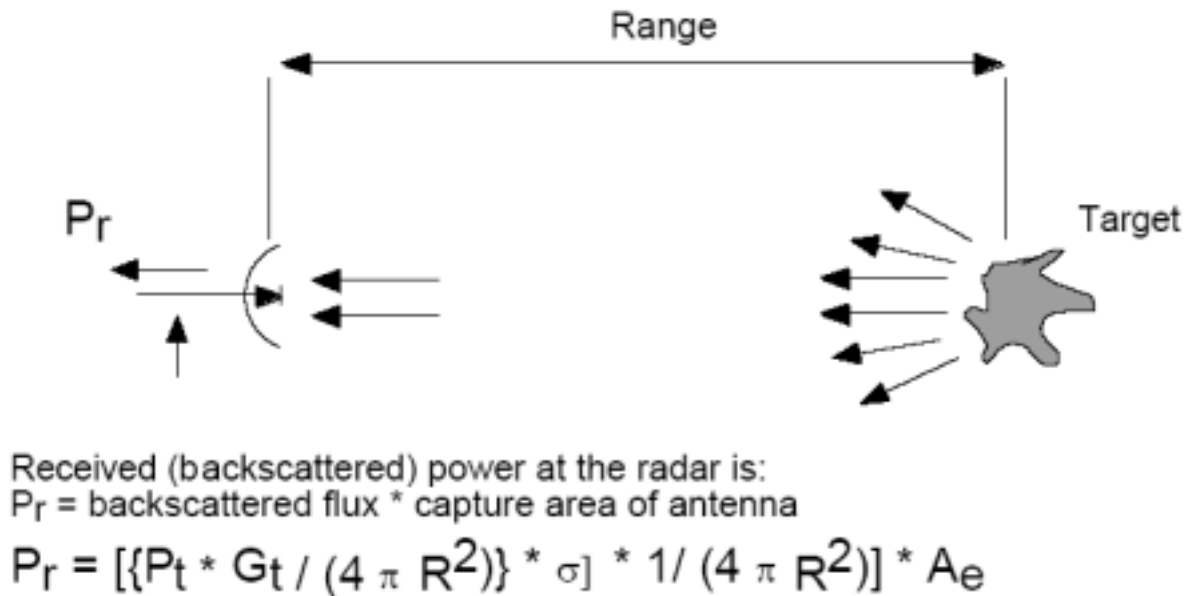


Figure 8: Received Power at Radar.

Relationship between Antenna Aperture and Gain

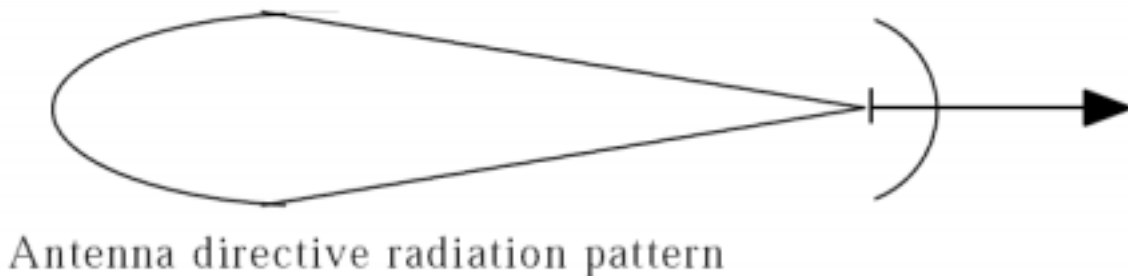


Figure 9: Antenna Aperture and Gain.

$$G_r = \frac{4 \pi A_e}{\lambda^2}, \text{ power ratio}$$

$$A_e = \rho_a * A, \text{ meters}^2$$

Where A= the physical aperture area of the antenna

ρ_a = the aperture collection efficiency

λ = wave length electromagnetic = c/freq

Idealized Radar Equation - no system losses

$$P_r = P_t * G_t * G_r \left[\frac{\lambda^2}{(4\pi)^3 R^4} \right] * \sigma , \text{ watts}$$

Since the antenna gain is the same for transmit and receive, this becomes:

$$P_r = P_t * G^2 \left[\frac{\lambda^2}{(4\pi)^3 R^4} \right] * \sigma , \text{ watts}$$

Practical Radar Equation - with system losses for point targets

$$P_r = P_t * G^2 \left[\frac{\lambda^2}{(4\pi)^3 R^4} \right] * \sigma * L_{sys} , \text{ watts}$$

Where:

- L_{sys} is the system losses expressed as a power ratio,
- P_r is the average received power,
- P_t is the transmitted power,
- G is the gain for the radar,
- λ is the radar's wavelength,
- σ is the targets scattering cross section,
- R is the range from the radar to the target.

The radar equation for a point target is simply given below:

$$\bar{P}_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$$

Radar Equation for Distributed Targets

Thus far, we've derived the radar equation for a point target. This is enough if you are interested in point targets such as airplanes. However, in a thunderstorm or some area of precipitation, we do not have just one target (e.g., raindrop), we have many. Thus we need to derive the radar equation for distributed targets. So let's review the Radar Pulse Volume.

Radar Pulse Volume

First, let's simplify the real beam according to the **Figure 10**:

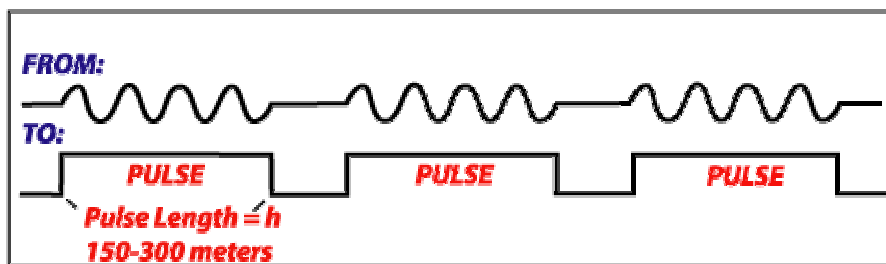


Figure 10: Radar Pulses.

What does a "three-dimensional" segment of the radar beam look like?

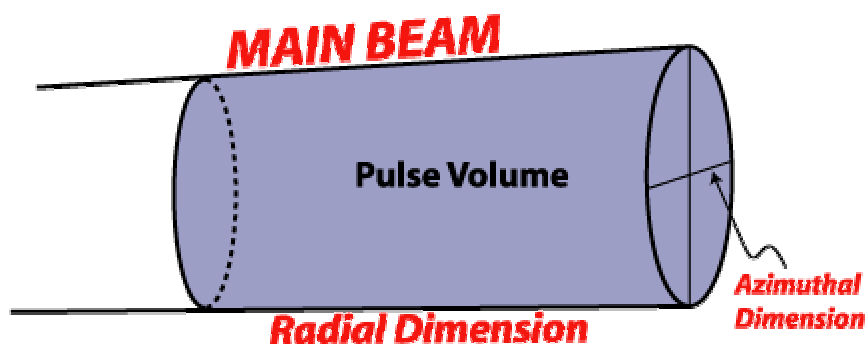


Figure 11: Radar Main Beam and Pulse Volume.

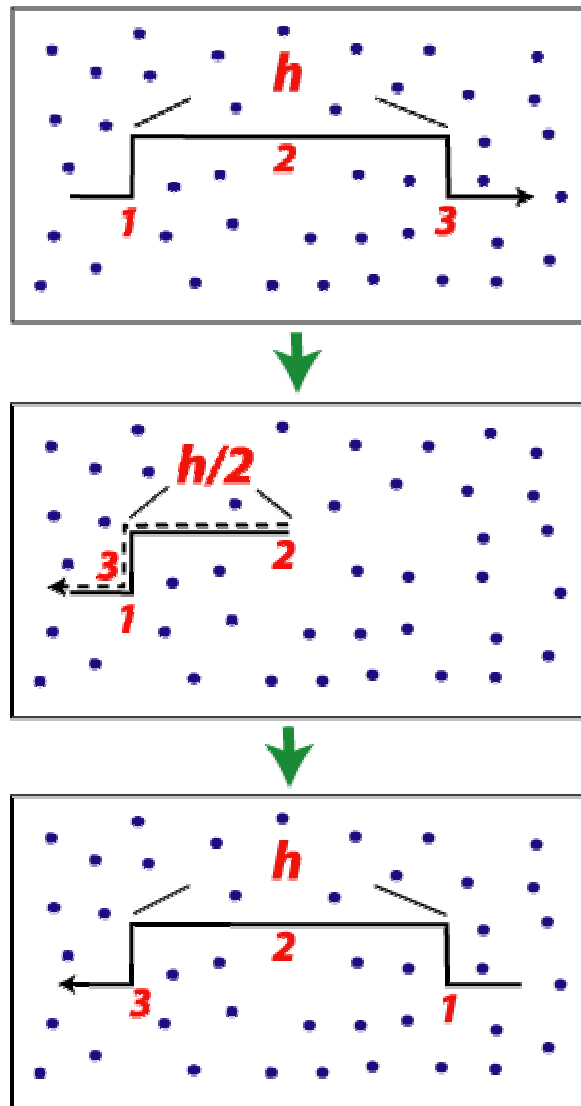


Figure 12: Form of Transmit and Received Signal.

So, the “volume” of the pulse volume is:

$$\pi \frac{R\theta}{2} \frac{R\phi}{2} \frac{h}{2}$$

For a circular beam, then $\theta=\Phi$, the pulse volume becomes:

$$\pi \frac{R^2\theta^2 h}{8}$$

Before we derive the radar equation for the distributed targets situation, we need to make some assumptions:

- 1) The beam is filled with targets.
- 2) Multiple scattering is ignored
- 3) Total average power is equal to sum of powers scattered by individual particles.

Recall the radar equation for a single target:

$$\bar{P}_r = \frac{P_i G^2 \lambda^2 \sigma}{(4\pi)^3 R^4} \quad (1)$$

For multiple targets, radar equation (1) can be written as:

$$\bar{P}_r = \frac{P_i G^2 \lambda^2}{(4\pi)^3} \sum_i \frac{\sigma_i}{R_i^4} \quad (2)$$

where the sum is over all targets within the pulse volume.

If we assume that $h/2 \ll r_i$,



Figure 13: Pulse Volume.

Then (2) can be written as:

$$\bar{P}_r = \frac{P_i G^2 \lambda^2}{(4\pi)^3 R_i^4} \sum_i \sigma_i \quad (3)$$

It is advantageous to sum the backscattering cross sections over a unit volume of the total pulse volume.

Hence the sum in (3) can be written as:

$$\sum_i \sigma_i = \left(\sum_i \frac{\sigma_i}{\text{unit volume}} \right) \text{total volume} \quad (4)$$

where the total volume is the volume of the pulse.

Thus, (5) can be written as:

$$\sum_i \sigma_i = \left(\sum_i \frac{\sigma_i}{\text{unit volume}} \right) \pi \frac{R^2 \theta^2 h}{8} \quad (5)$$

Substituting (5) into (3) gives:

$$\bar{P}_r = \left(\frac{P_i G^2 \lambda^2 \theta^2 h}{512 \pi^2 R^2} \right) \sum_i \sigma_i \quad (6)$$

Note that:

P_r is proportional to R^{-2} for distributed targets.

P_r is proportional to R^{-4} for point targets.

Radar Reflectivity

The sum of all backscattering cross sections (per unit volume) is referred to as the radar reflectivity (η). In other words,

$$\sum_i \sigma_i = \eta \quad (7)$$

In terms of the radar reflectivity, the radar equation for distributed targets (21) can be written as:

$$\bar{P}_r = \left(\frac{P_i G^2 \lambda^2 \theta^2 h}{512 \pi^2 R^2} \right) \eta \quad (8)$$

All variables in (8), except η are either known or measured.

Now, we need to add a fudge factor due to the fact that the beam shape is Gaussian.

Hence, (8) becomes;

$$\bar{P}_r = \frac{1}{2 \ln 2} \left(\frac{P_i G^2 \lambda^2 \theta^2 h}{512 \pi^2 R^2} \right) \eta \quad (9)$$

Complex Dielectric Factor

The backscattering cross section (σ_i) can be written as:

$$\sigma = \frac{\pi^5 |K|^2 D^6}{\lambda^4} \quad (10)$$

Where:

- D is the diameter of the target,
- λ is the wavelength of the radar,
- K is the complex dielectric factor,
 - σ is some indication of how good a material is at backscattering radiation

For water $|K|^2 = 0.93$

For ice $|K|^2 = 0.197$

Notice that the value for water is much larger than for ice. All other factors the same; this creates a 5dB difference in returned power.

So, let's incorporate this information into the radar equation.

Recall from (7) that. $\sum_i \sigma_i = \eta$ Using (11) can be written

$$\text{As: } \eta = \sum_i \sigma_i = \sum_i \frac{\pi^5 |K|^2 D_i^6}{\lambda^4} \quad (12)$$

Taking the constants out of the sum;

$$\eta = \frac{\pi^5 |K|^2}{\lambda^4} \sum_i D_i^6 \quad (13)$$

Remember that the sum is for a unit volume. Substituting (12) into (9) gives:

$$\bar{P}_r = \frac{1}{2 \ln 2} \left(\frac{P_t G^2 \lambda^2 \theta^2 h}{512 \pi^2 R^2} \right) \frac{\pi^5 |K|^2}{\lambda^4} \sum_i D_i^6 \quad (14)$$

Simplifying terms gives:

$$\bar{P}_r = \frac{P_t G^2 \theta^2 \pi^3 h |K|^2}{1024 \ln 2 R^2 \lambda^2} \sum_i D_i^6 \quad (15)$$

Note the D_i^6 dependence on the average received power.

Radar Reflectivity Factor

In Equation (15), all variables except the summation term, are either known or measured.

We will now define the radar reflectivity factor, Z as:

$$Z = \sum_i \frac{D_i^6}{\text{unit volume}} \quad (16)$$

Substituting (30) into (29) gives the radar equation for distributed targets:

$$\bar{P}_r = \frac{P_t G^2 \theta^2 \pi^3 h |K|^2 Z}{1024 \ln 2 \lambda^2 R^2} \quad (17)$$

- Note the relationship between the received power, range and radar wavelength
- Everything in Equation (17) is measured or known except Z, the radar reflectivity factor.
- Since the strength of the received power can span many orders of magnitude, then so do Z.
- Hence, we take the log on Z according to:

$$dBZ = 10 \log \left(\frac{Z \text{ mm}^6}{1 \text{ m}^3} \right) \quad (18)$$

- The dBZ value calculated above is what you see displayed on the radar screen or on imagery accessed from the web.

As a result, formulas can be written as follows:

- ♦ **Point target radar equation:**

$$P_r = \frac{P_t g^2 \lambda^2 A_\sigma}{64\pi^3 r^4}$$

- ♦ **Meteorological target radar equation**

$$P_r = \frac{\pi^5 P_t g^2 \theta \phi c \tau |K|^2 z l}{1024 \ln(2) \lambda^2 r^2}$$

2.5. Block Diagram of Radar

Radar systems, like other complex electronics systems, are composed of several major subsystems and many individual circuits. Although modern radar systems are quite complicated, you can easily understand their operation by using a basic radar block diagram.

Figure 14 below shows us the basic radar block diagram.

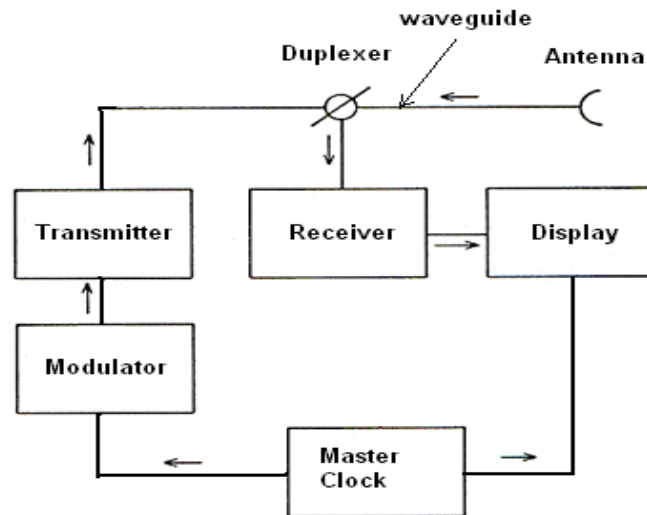


Figure 14: Basic Radar Diagram.

The parts of this block diagram in **Figure 14** are described below:

Master Clock/Computer: In older radars, this device was called the master clock. It would generate all of the appropriate signals and send them to the appropriate components of the radar. In modern radars, the function of the master clock has been taken over by the ubiquitous computer. Computers now control radars just as they control many other parts of modern technology.

Transmitter: The source of the EM radiation emitted by radar is the transmitter. It generates the high frequency signal which leaves the radar's antenna and goes out into the atmosphere. The transmitter generates powerful pulses of electromagnetic energy at precise intervals. The required power is obtained by using a high-power microwave oscillator (such as a magnetron) or a microwave amplifier (such as a klystron) that is supplied by a low- power RF source.

Modulator: The purpose of modulator is to switch the transmitter **ON** and **OFF** and to provide the correct waveform for the transmitted pulse. That is, the modulator tells the transmitter when to transmit and for what duration.

Waveguide: **Figure 14** shows that the connecting the transmitter and the antenna is waveguide. This is usually a hollow, rectangular, metal conductor whose interior dimensions depend upon the wavelength of the signals being carried. Waveguide is put together much like the copper plumbing in a house. Long piece of waveguide are connected together by special joints to connect the transmitter/receiver and the antenna.

Antenna: The antennas are the device which sends the radar's signal into atmosphere. Most antennas used with radars are directional; that is, they focus the energy into a particular direction and not other directions. An antenna that sends radiation equally in all directions is called **isotropic antenna**.

Receiver: The receiver is designed to detect and amplify the very weak signals received by antenna. Radar receivers must be of very high quality because the signals that are detected are often very weak.

Display: There are many ways to display radar data. The earliest and easiest display for radar data was to put it onto a simple oscilloscope. After that A-scope was found. PPI and RHI are new techniques for displaying the radar data.

Duplexer: Duplexer, somebody called Transmit/Receive switch, is a special switch added to the radar system to protect the receiver from high power of the transmitter.

Of course this is a briefly explanation about components of a radar. Later on this course and in the other modules of this training document, besides these parts, all components will be explained in detail. **Figure 15** shows us some important components of radar.

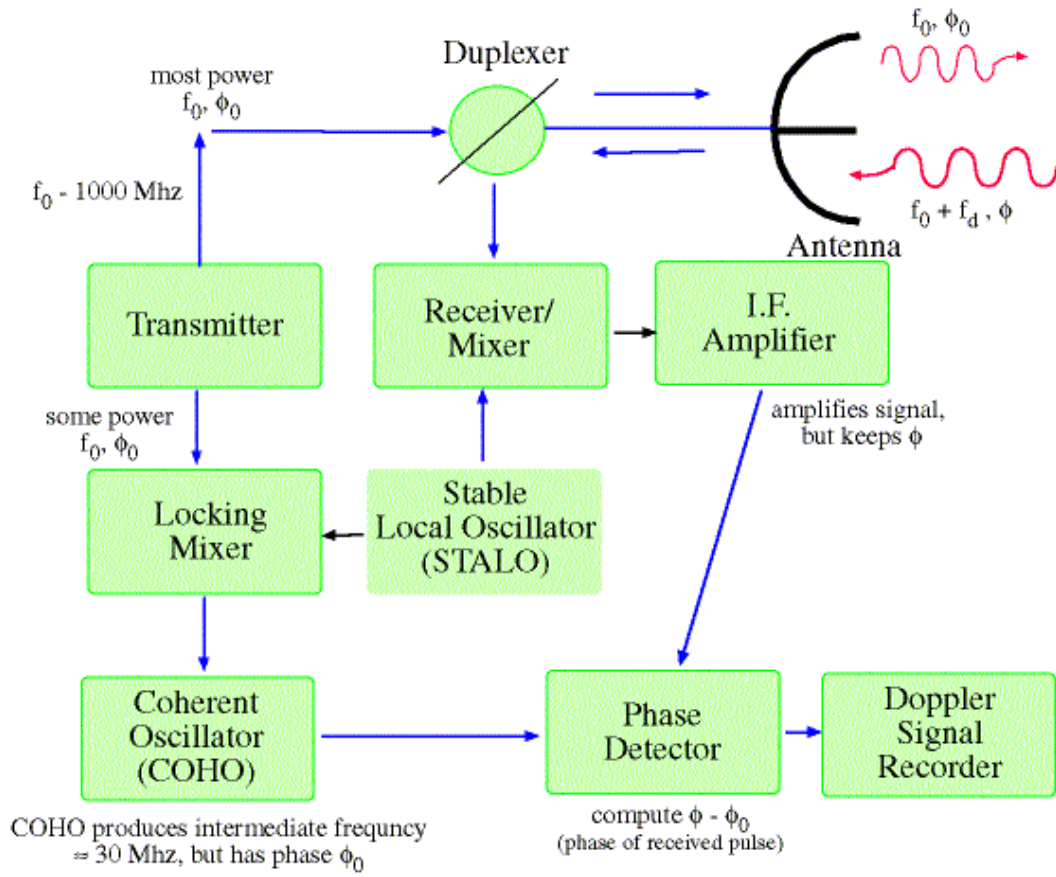


Figure 15: Block Diagram of Radar.

3. PROPAGATION OF EM WAVES

Radar signals are emitted in some frequencies within the electromagnetic spectrum located in a range from a few MHz to 600 GHz. First let us review the electromagnetic spectrum.

3.1. Electromagnetic Spectrum

All things (which have temperature above absolute zero) emit radiation. Radiation is energy that travels in the form of waves. Since radiation waves have electrical and magnetic properties, they are called as “electromagnetic waves”.

Most of the electromagnetic energy on the earth originates from the sun. The sun actually radiates electromagnetic energy at several different wavelengths and frequencies, ranging from gamma rays to radio waves. Collectively, these wavelengths and frequencies make up the electromagnetic spectrum.

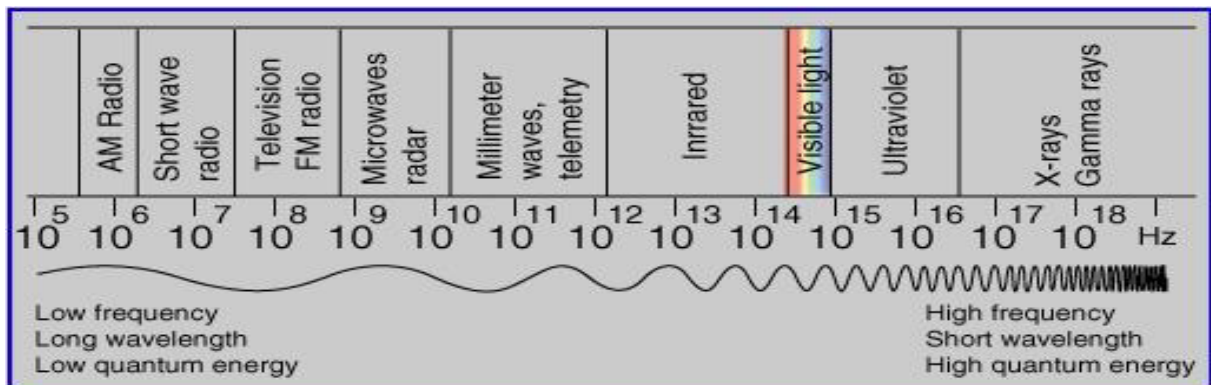


Figure 16: Electromagnetic Spectrum.

Frequency and wavelength of electromagnetic waves change with inverse of other. According to the famous formula about light, then f can be calculated as follows:

$$\lambda = c/f \rightarrow f = c/\lambda \rightarrow T = 1 / f \text{ [s]} \rightarrow \lambda = c/f = 299,792,458 / f \text{ [m]} \text{ (f in Hz [s}^{-1}\text{])}$$

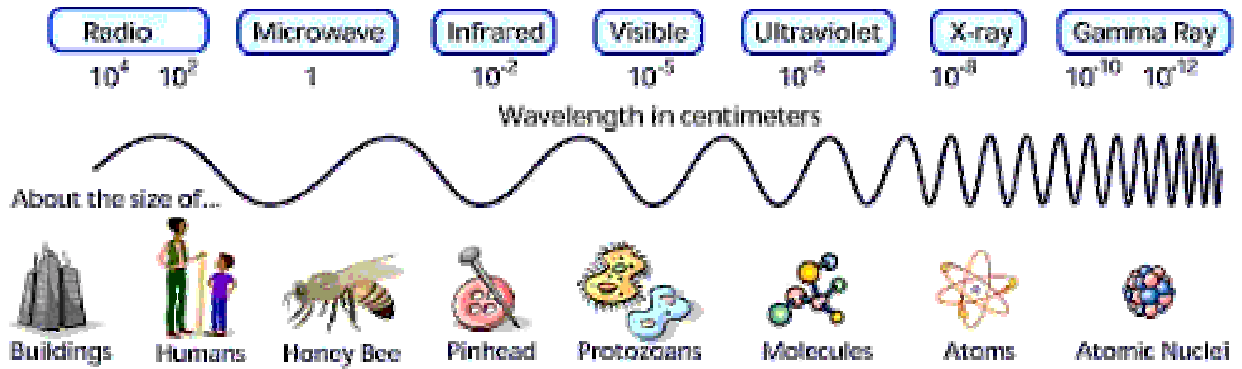


Figure 17: The Relationship between Frequency and Wavelength.

Radar operates in microwave region of EM spectrum and it emits the energy in the form of EM wave into the atmosphere through an antenna. While only a fragment of the energy returns, it provides a great deal of information. The entire process of energy propagating through space, striking objects and returning occurs at the speed of light. Targets are struck by electromagnetic energy and the return signals from these targets are called radar echoes.

The Figure 18 shows the electromagnetic spectrum and the location of radar frequencies in that spectrum.

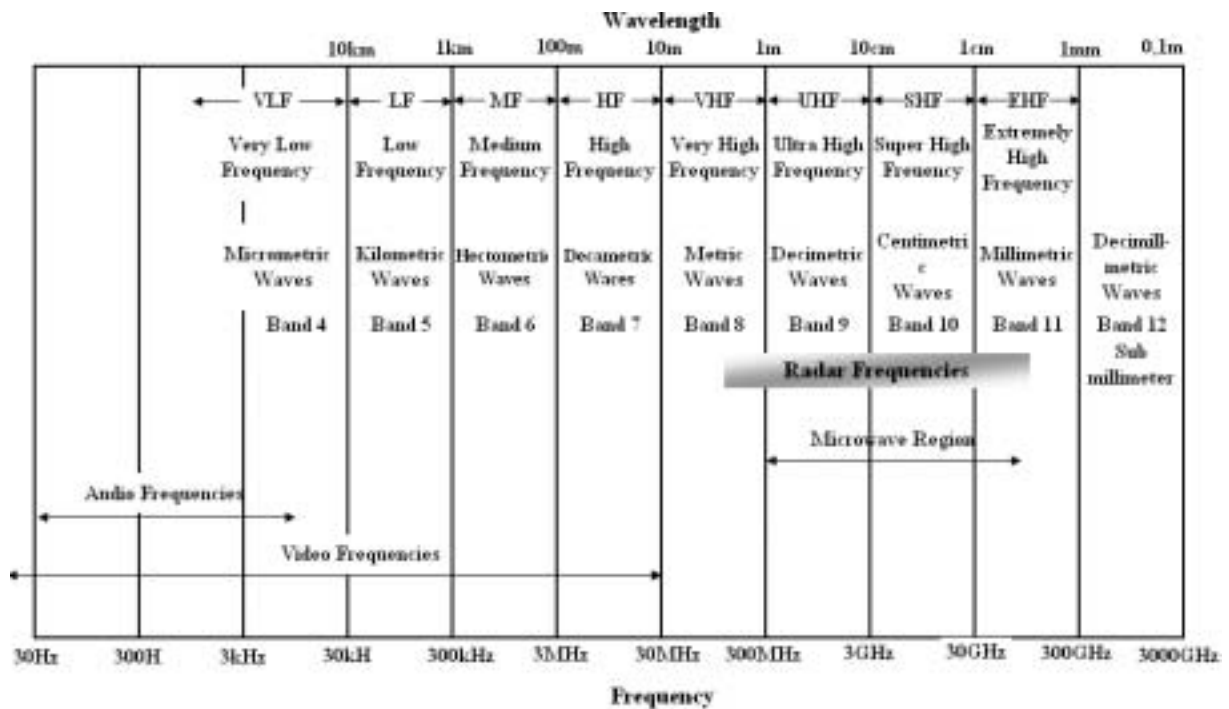


Figure 18: Electromagnetic Spectrum and Band Names.

The radar bands located in the spectrum have been designated by certain letters as follows:

<u>Band Designation</u>	<u>Nominal Frequency</u>	<u>Nominal Wavelength</u>
HF	3-30 MHz	100-10 m
VHF	30-300 MHz	10-1 m
UHF	300-1000 MHz	1-0.3 m
L	1-2 GHz	30-15 cm
S	2-4 GHz	15-8 cm
C	4-8 GHz	8-4 cm
X	8-12 GHz	4-2.5 cm
Ku	12-18 GHz	2.5-1.7 cm
K	18-27 GHz	1.7-1.2 cm
Ka	27-40 GHz	1.2-0.75 cm
V	40-75 GHz	0.75-0.40 cm
W	75-110 GHz	0.40-0.27 cm
mm	110-300 GHz	0.27-0.1 cm

Table 2: Band Designation, Nominal Frequency and Wavelengths.

Specific frequencies within above ranges have been assigned for radars by International Telecommunication Union (ITU). The radio frequency bands used by weather radars are located around 2.8 GHz (S-Band), 5.6 GHz (C-Band), 9.4 GHz (X-Band) and 35.6 GHz (Ka-Band).

3. 2. Electromagnetic Waves

Electromagnetic or radio waves consist of electric (E) and magnetic (H) force fields, which are perpendicular to each other and to the direction of propagation of the wave front, propagate through space at the speed of light and interact with matter along their paths. These waves have sinusoidal spatial and temporal variations. The distance or time between successive wave peaks (or other reference points) of the electric (magnetic) force defines the wavelength λ or wave period **T**. These two important electromagnetic field parameters are related to the speed of light **c**. The wave period **T** is the reciprocal of the frequency **f**.

Frequency refers to the number of completed wave cycles per second. Radar frequency is expressed in units of Hertz (Hz). Higher frequency transmitters produce shorter wavelengths and vice versa. Wave amplitude is simply the wave's height (from the midline position) and represents the amount of energy contained within the wave.

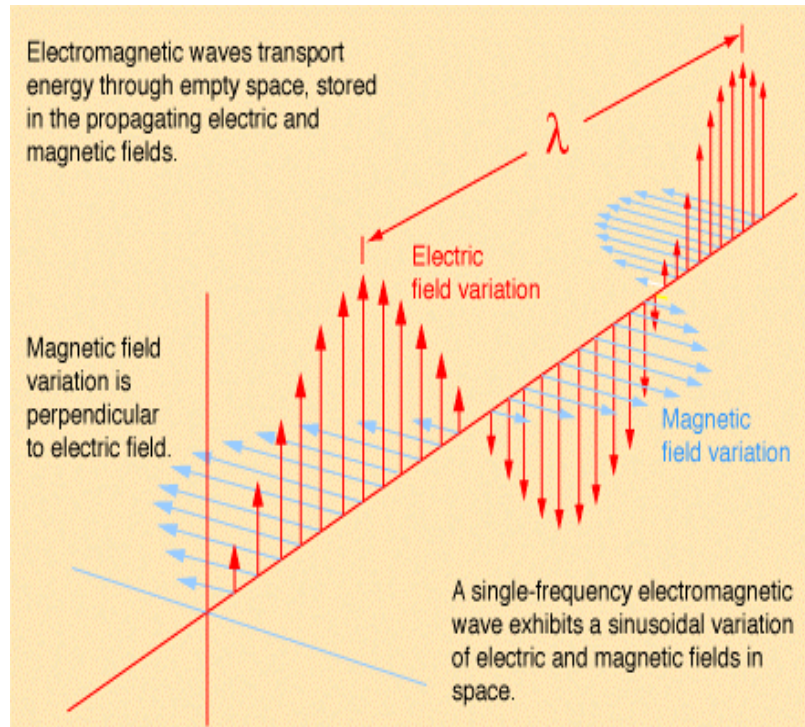


Figure 19: Electromagnetic Wave Propagation.

3.2.1. Polarization

As mentioned previously, electromagnetic radiation consists of electric and magnetic fields which oscillate with the frequency of radiation. These fields are always perpendicular to each other. So, it is possible to specify the orientation of the electromagnetic radiation by specifying the orientation of one of those fields. The orientation of the electric field is defined as the orientation of electromagnetic field and this is called as “**polarization**”. In other words, polarization refers to the orientation of the electrical field component of an electromagnetic wave.

The plane of polarisation contains both the electric vector and the direction of propagation. Simply because the plane is two-dimensional, the electric vector in the plane at a point in space can be decomposed into two orthogonal components. Call these the **x** and **y** components (following the conventions of analytic geometry). For a simple harmonic wave, where the amplitude of the electric vector varies in a sinusoidal manner, the two components have exactly the same frequency. However, these components have two other defining

characteristics that can differ. First, the two components may not have the same amplitude. Second, the two components may not have the same phase, so they may not reach their maxima and minima at the same time in the fixed plane we are talking about. By considering the shape traced out in a fixed plane by the electric vector as such a plane wave passes over it, we obtain a description of the **polarization state**. By considering that issue, three types of polarization of electromagnetic waves can be defined. These are Linear, Circular and Elliptical Polarizations.

a) **Linear polarization**

If the electrical vector remains in one plane, then the wave is linearly polarised. By convention, if the electric vector (or field) is parallel to the earth's surface, the wave is said to be horizontally polarized, if the electric vector (or field) is perpendicular to the earth's surface, the wave is said to be vertically polarized.

Linear polarization is shown in **Figure 20**. Here, two orthogonal components (**Ex-red and Ey-green**) of the electric field vector (**E-blue**) are in phase and they form a path (**purple**) in the plane while propagating. In linear polarization case, the strength of the two components are always equal or related by a constant ratio, so the direction of the electric vector (the vector sum of these two components) will always fall on a single line in the plane. We call this special case **linear polarization**. The direction of this line will depend on the relative amplitude of the two components. This direction can be in any angle in the plane but the direction never varies.

Linear polarisation is most often used in conventional radar antennas since it is the easiest to achieve. The choice between horizontal and vertical polarisation is often left to the discretion of the antenna designer, although the radar system engineer might sometimes want to specify one or the other, depending upon the importance of ground reflections.

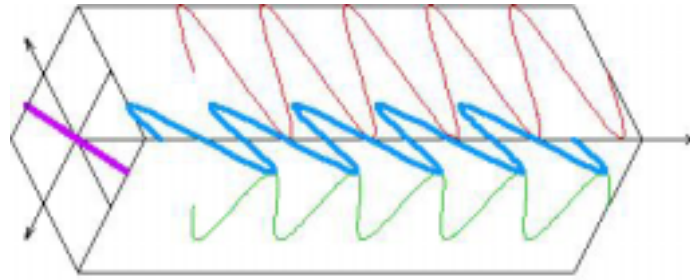


Figure 20: Linear Polarization.

b) Circular polarization

In case of circular polarization as shown in **Figure 21**, the two orthogonal components (**E_x -red and E_y -green**) of the electric field vector (**E -blue**) have exactly the same amplitude and are exactly ninety degrees out of phase. They form a path (**purple**) in the plane while propagating. In this case, one component is zero when the other component is at maximum or minimum amplitude. Notice that there are two possible phase relationships that satisfy this requirement. The x component can be ninety degrees ahead of the y component or it can be ninety degrees behind the y component. In this special case the electrical vector will be rotating in a circle while the wave propagates. The direction of rotation will depend on which of the two phase relationships exists. One rotation is finished after one wavelength. The rotation may be left or right handed. In another word, image of the electric field vector (E) will be circular and electromagnetic wave will be circularly polarized. Circular polarisation is often desirable to attenuate the reflections of rain with respect to aircraft.

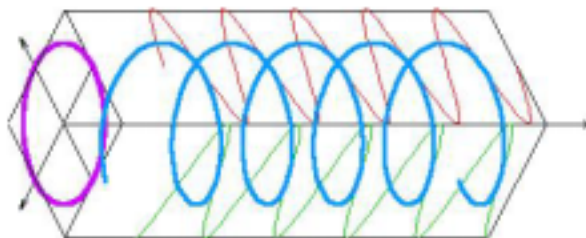


Figure 21: Circular Polarization.

c) Elliptical polarization

As shown in **Figure 22**, two components (**E_x -red and E_y -green**) of the electric field vector (**E -blue**) are not in phase and do not have the same amplitude and/or are not ninety degrees out of phase either. So the path (**purple**) formed in the plane while propagating will trace out an ellipse and this is called as **elliptical polarization**. In other words, image of electric field vector E will be elliptical and electromagnetic wave will be elliptically polarized. In fact linear and circular polarizations are special cases of the elliptical polarization.

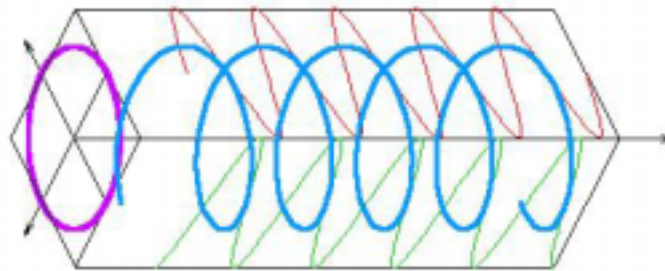


Figure 22: Elliptical Polarization.

3.3. Refraction

Electromagnetic waves propagating within the earth's atmosphere do not travel in straight lines but are generally refracted. The density differences in the atmosphere affect the speed and direction of electromagnetic waves. In some regions, a wave may speed up, while in other regions it may slow down. This situation is known as refraction. One effect of refraction is to extend the distance to the horizon thus increasing the radar coverage. Another effect is the introduction of errors in the measurement of the elevation angle. Refraction of the radar waves in the atmosphere is caused by the variation with altitude of the velocity of propagation or the index of refraction defined as the velocity of propagation in free space to that in the medium in question. Now, let us remind some basic parameters regarding refraction.

Refraction Models

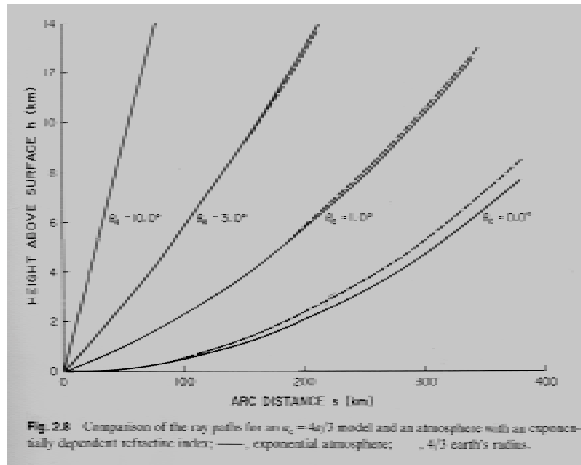


Fig. 2.8 Comparison of the ray paths for an $n_e = 4/3$ model and an atmosphere with an exponentially dependent refractive index; —, exponential atmosphere; - - - $4/3$ earth's radius.

Non-standard refraction models

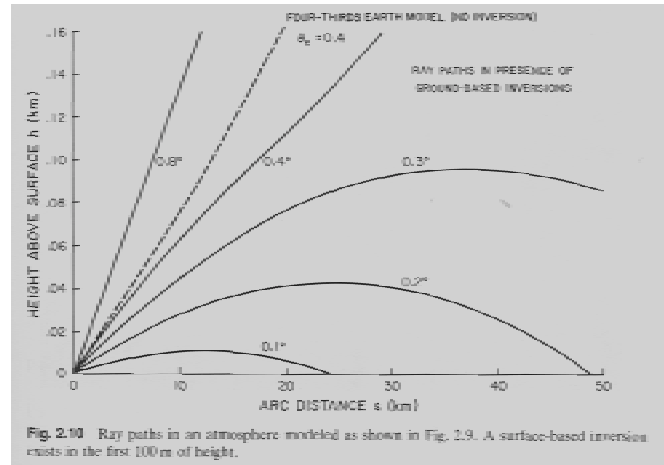


Fig. 2.10 Ray paths in an atmosphere modeled as shown in Fig. 2.9. A surface-based inversion exists in the first 100m of height.

Doviak and Zrnice 2002

Figure 23: Refraction Models and Non-refraction Models.

3.3.1. Refractive Index

The speed of electromagnetic radiation depends upon the material through which it is travelling. In a vacuum such as the nearly empty space between the sun and earth, for example, light travels at a speed of $299\,792\,458 \pm 6$ m/s, according to the National Bureau of Standards (Cohen and Taylor, 1987)

When electromagnetic radiation travels through air or other materials, it travels slightly slower than in a vacuum. The ratio of the speed of light in a vacuum to the speed of light in a medium is called the refractive index of the medium and is defined mathematically as:

$$n=c/u$$

Where c is the speed of light in a vacuum, u is the speed of the light in the medium and n is the refractive index.

The refractive index of the atmosphere depends upon atmospheric pressure, temperature and vapour pressure. Although the number of free electrons present also affects the refractivity of the atmosphere, this can be ignored in troposphere due to insufficient free electrons. At microwave frequencies, the index of refraction n for air which contains water vapour is:

$$(n-1)10^6 = N = \frac{77.6p}{T} + \frac{3.73e10^5}{T^2}$$

Where p = barometric pressure in hPa, e = partial pressure of water vapour in hPa and T= absolute temperature in K. The parameter N is called refractivity. N is defined as follows:

$$N = (n-1) 10^6$$

If n=1.0003 then N will be 300.

These values may be gathered by radiosondes. The index of refraction normally decreases with increasing altitude and is typically 1.000313 near the surface of the earth, i.e. N = 313. This means that electromagnetic radiation travels approximately 0.0313 % slower there than in a vacuum.

3.3.2. Curvature

Curvature is defined as “the rate of change in the deviation of a given arc from any tangent to it.” Stated another way, it is the angular rate of change necessary to follow a curved path. Another definition of curvature is the reciprocal of the radius and expressed as follows:

$$C = \delta\theta / \delta S$$

Where $\delta\theta$ is the change in angle experienced over a distance δS . When we think about a circle with a radius of R, expression becomes;

$$C = \delta\theta / \delta S = 2\pi / 2\pi R = 1/R$$

For a radar ray travelling relative to the earth when there is a non-uniform atmosphere present, the ray will bend more or less relative to the earth, depending upon how much the refractive index changes with height. Then;

$$C = \delta\theta / \delta S = 1/R + \delta n / \delta H$$

It is sometimes convenient to think of the radar rays travelling in straight lines instead of the actual curved paths they do follow. We can accomplish this by creating a fictitious earth radius is different from the true earth's radius. This effective earth's radius R' is given by

$$1/R' = 1/R + \delta n / \delta H$$

There are various relationships between curvature, earth's radius, effective earth's radius and refractive index gradient. So it is possible to calculate the actual path a radar ray will follow in real atmospheric conditions.

4. RADAR TYPES

Radars may be classified in several ways due to the criteria of the classification, e.g. receiving and transmitting type, purpose of the use, operating frequency band, signal emitting type (pulse-CW), polarization type. It is also possible to make sub classifications under the main classification of radars. So major types of radars have been denominated as monostatic, bistatic, pulse, continuous (CW), Doppler, non-Doppler, weather radar, air surveillance radar, mobile radar, stationary radar, X-Band, L-Band, C-Band, S-Band, K-Band, single polarization radars, polarimetric radars, etc. Although our main concern is Doppler weather radars which will be studied in detail, some brief explanation of major types of the radars are also given below:

4.1. Monostatic Radars

Monostatic radars use a common or adjacent antennas for transmission and reception, where the radars receiving antenna is in relationship to its transmitting antenna. Most radar system are use a single antenna for both transmitting and receiving; the received signal must come back to the same place it left in order to be received. This kind of radar is monostatic radar. Doppler weather radars are monostatic radars.

4.2. Bistatic Radars

Bistatic radars have two antennas. Sometimes these are side by side but sometimes the transmitter and its antenna at one location and the receiver and its antenna at another. In this kind of radar the transmitting radar system aims at a particular place in the sky where a cloud or other target is located. The signal from this point is scattered or reradiated in many directions, much of being in a generally forward direction. Such receiving systems may also be called passive radar systems.

4.3. Air Surveillance Radars (ASR)



Figure 24: Air Surveillance Radars.

The ASR system consists of two subsystems: primary surveillance radar and secondary surveillance radar. The primary surveillance radar uses a continually rotating antenna mounted on a tower to transmit electromagnetic waves, which reflect from the surface of aircraft up to 60 nautical miles from the radar. The radar system measures the time required for the radar echo to return and the direction of the signal. From this data, the system can measure the distance of the aircraft from the radar antenna and the azimuth or direction of the aircraft from the antenna. The primary radar also provides data on six levels of rainfall intensity. The primary radar operates in the range of 2700 to 2900 MHz.

The secondary radar, also called as the beacon radar, uses a second radar antenna attached to the top of the primary radar antenna to transmit and receive aircraft data such as barometric altitude, identification code and emergency conditions. Military and commercial aircraft have transponders that automatically respond to a signal from the secondary radar with an identification code and altitude.

4.4. 3D Radars

Three-dimensional radars have capability of producing three-dimensional position data on a multiplicity of targets (range, azimuth, and height). There are several ways to achieve 3D data. A 2D radar just provides azimuth and range information.

4.5. Synthetic Aperture Radars (SAR)

SAR is being used in air and space-borne systems for remote sensing. The inherent high resolution of this radar type is achieved by a very small beam width which in turn is generated by an effective long antenna, namely by signal-processing means rather by the actual use of a long physical antenna. This is done by moving a single radiating line of elements mounted e.g. in an aircraft and storing the received signals to form the target picture afterwards by signal processing. The resulting radar images look like photos because of the high resolution. Instead of moving radar relatively to a stationary target, it is possible to generate an image by moving the object relative to stationary radar. This method is called Inverse SAR (ISAR) or range Doppler imaging.

4.6. Continuous Wave (CW) Radars

The CW transmitter generates continuously unmodulated RF waves of constant frequency which pass the antenna and travel through the space until they are reflected by an object. The isolator shall prevent any direct leakage of the transmitter energy into the receiver and thus avoid the saturation or desensitisation of the receiver which must amplify the small signals received by the antenna. The CW radar can only detect the presence of a reflected object and its direction but it cannot extract range for there are no convenient time marks in which to measure the time interval. Therefore this radar is used mainly to extract the speed of moving objects. The principle used is the Doppler Effect. The Doppler principle will be explained in detail in following chapters.

4.7. FM-CW Radars

The inability of simple CW radar to measure range is related to the relatively narrow spectrum (bandwidth) of its transmitted waveform. Some sort of timing mark must be applied to the CW carrier if range is to be measured. The timing mark permits the time of transmission and the time of return to be recognised. The sharper or more distinct the mark, the more accurate is

the measurement of the transit time. But the more distinct the timing mark, the broader will be the transmitted spectrum. Therefore a certain spectrum width must be transmitted if transit time or range is to be measured.

The spectrum of a CW transmission can be broadened by the application of modulation, either by modulating the amplitude, the frequency or the phase. An example of the amplitude modulation is the pulse radar.

4.8. Moving Target Indication (MTI) Radars

The purpose of MTI radar is to reject signals from fixed unwanted signals, sky and/or ground clutter and to retain for detection the signals from moving targets such as aircraft or rain. There are two basic types of MTI namely coherent and non-coherent MTI. The former utilises the Doppler shift imparted on the reflected signal by a moving target to distinguish moving targets from fixed targets and the latter detects moving targets by the relative motion between the target and an extended clutter background and consequently by the corresponding amplitude changes from pulse to pulse or from one antenna scan to the next. By coherent it is meant that the phase of the transmitted wave must be preserved for use by the receiver if the Doppler shift in frequency is to be detected, whereas in non-coherent systems it is not necessary.

4.9. Pulse Radars

Pulse radar is primary radar which transmits a high-frequency impulsive signal of high power. After this a longer break in which the echoes can be received follows before a new transmitted signal is sent out. Direction, distance and sometimes if necessary the altitude of the target can be determined from the measured antenna position and propagation time of the pulse-signal. Weather radars are pulse radars.

4.10. Doppler Radars

Conventional radars use MTI in order to remove clutter as explained above. This processing system is used almost entirely to eliminate unwanted clutter from the background, selecting as targets only those objects which move with some minimum velocity relative to the radar or to the fixed background. A more advanced type of system is the pulse Doppler radar, defined as

a pulsed radar system which utilises the Doppler Effect for obtaining information about the target, such as the target's velocity and amplitude and not to use it for clutter rejection purposes only.

In practice most pulsed Doppler radars have evolved into forms which are quite distinct from the conventional pulse radars. Much higher PRF rates are used in order to eliminate or reduce the number of blind speeds. A blind speed exists when the PRF of the radar equals the Doppler shift frequency, therefore, the higher the PRF, the higher the first blind speed.

A Pulse Doppler Radar is characterised by one or more of the following:

- A relative high PRF which results in ambiguous range and blind range problems. Unambiguous Doppler can be extracted up to the PRF; otherwise the Doppler frequencies are ambiguous.
- A driven transmitter using a klystron or travelling wave tube as a RF power amplifier is used rather than a magnetron oscillator in order to obtain better frequency stability and hence phase stability. However, with the improvement of modern high-frequency magnetrons some pulse Doppler radars are using magnetrons with suitable lock pulse arrangements.
- A series of range gates or a movable range gate and a bank of clutter rejection filters (Doppler filter bank to cover the Doppler spectrum) are used rather than a simple MTI system described above, in order to cancel clutter and to extract the Doppler frequency and amplitude components of the received signal.

By extracting the Doppler characteristics of signals, it is possible to achieve much better clutter cancellation than in conventional radars and the target's radial velocity component can be calculated once the Doppler frequency is measured in addition it is possible by range gating to measure the Doppler and the amplitude of the returned signal in each radar cell. The location of the radar cell by measuring the return time, the position of the antenna (azimuth and elevation) at the time the signal in the radar cell was received. All this processing is done digitally. A simple block shows the essential components of the Pulse Doppler Radar that is used for weather observation.

4.11. Weather Radars

Although these names refer to the application of radar, there is a significant difference in the type of radar that is used which is worth to be illustrated. In general radars measure the location of a target that is range, azimuth and height. The major distinction between meteorological radar and other kinds of radars lies in the nature of the targets. Meteorological targets are distributed in space and occupy a large fraction of the spatial resolution cells observed by the radar. Weather radars are pulsed radars with Doppler capability. So we can call them as Pulsed Doppler Weather Radars. Weather radars can operate in different frequency bands. So a classification can be made based on the frequency band as follows:

L band radars:

Those radars operate on a wavelength of 15-30 cm and a frequency of 1-2 GHz. L band radars are mostly used for clear air turbulence studies.

S band radars:

Those radars operate on a wavelength of 8-15 cm and a frequency of 2-4 GHz. Because of the wavelength and frequency, S band radars are not easily attenuated. This makes them useful for near and far range weather observation. It requires a large antenna dish and a large motor to power it. It is not uncommon for an S band dish to exceed 25 feet in size.

C band radars:

Those radars operate on a wavelength of 4-8 cm and a frequency of 4-8 GHz. Because of the wavelength and frequency, the dish size does not need to be very large. This makes C band radars affordable for TV stations. The signal is more easily attenuated, so this type of radar is best used for short range weather observation. Also, due to the small size of the radar, it can therefore be portable. The frequency allows C band radars to create a smaller beam width using a smaller dish. C band radars also do not require as much power as S band radar.

X band radars:

Those radars operate on a wavelength of 2.5-4 cm and a frequency of 8-12 GHz. Because of the smaller wavelength, the X band radar is more sensitive and can detect smaller particles. These radars are used for studies on cloud development because they can detect the tiny water particles and also used to detect light precipitation such as snow. X band radars also attenuate

very easily, so they are used for only very short range weather observation. Most major airplanes are equipped with X band radar to pick up turbulence and other weather phenomenon. This band is also shared with some police speed radars and some space radars.

K band radars:

Those radars operate on a wavelength of 0.75-1.2 cm or 1.7-2.5 cm and a corresponding frequency of 27-40 GHz and 12-18 GHz. This band is split down the middle due to a strong absorption line in water vapour. This band is similar to the X band but is just more sensitive. This band also shares space with police radars.

4.12. Polarimetric Radars

Polarimetric Radars are Doppler weather radars with additional transmitting and processing functionality to allow furthering computing additional information on the directionality of the reflected electromagnetic energy received.

Most weather radars transmit and receive radio waves with a single, horizontal polarization. That is, the direction of the electric field wavecrest is aligned along the horizontal axis. Polarimetric radars, on the other hand, transmit and receive both horizontal and vertical polarizations. Although there are many different ways to mix the horizontal and vertical pulses together into a transmission scheme, the most common method is to alternate between horizontal and vertical polarizations with each successive pulse. That is, first horizontal, then vertical, then horizontal, then vertical, etc. And, of course, after each transmitted pulse there is a short listening period during which the radar receives and interprets reflected signals from the cloud.

Since polarimetric radars transmit and receive two polarizations of radio waves, they are sometimes referred to as **dual-polarization** radars.

4.13. Terminal Doppler Weather Radars (TDWR)

Terminal Doppler Weather Radars a member of weather radars family used generally at the airports for supporting the aviation safety. TDWRs have the capability of detecting wind parameters indicating connective microbursts, gust fronts and wind shifts. It provides a new capability for the dissemination of radar derived, real-time, and warnings and advisories. The characteristics of the TDWR make it well suited for additional applications. Its narrow beam and aggressive ground clutter suppression algorithms provide excellent data on boundary layer reflectivity and winds – in particular the locations of thunderstorm outflow boundaries. Similarly, its narrow beam (0.5 deg) could be useful for detection of severe weather signatures (e.g., tornado vortices) with small azimuth extent.

4.14. Wind Profilers

Wind profilers are specifically designed to measure vertical profiles of horizontal wind speed and direction from near the surface to above the troposphere.

Obtaining wind profiles consistently to the troposphere in nearly all weather conditions requires the use of relatively long wavelength radar. 404 MHz Wind profilers are relatively low-power, highly sensitive clear-air radars, operating at a wavelength of 74 centimetres. The radars detect fluctuations in the atmospheric density, caused by turbulent mixing of volumes of air with slightly different temperature and moisture content. The resulting fluctuations of the index of refraction are used as a tracer of the mean wind in the clear air. Although referred to as clear-air radars, wind profilers are capable of operating in the presence of clouds and moderate precipitation.





Figure 25: Some Wind Profilers.

At present, meteorological organizations use balloon borne systems to measure profiles of wind, temperature and humidity from the ground to high up in the atmosphere. While current wind profiler radars do not operationally measure all these parameters, they do have several advantages in comparison to the balloon based systems:

- they can measure winds up to many kilometres from the ground (remote sensing),
- they sample winds nearly continuously,
- the winds are measured almost directly above the site,
- not only the horizontal but also the vertical air velocity can be measured,
- they have a high temporal and spatial resolution,
- the cost per observation is low,
- they operate unattended in nearly all weather conditions.

Since wind profiler radars can be adapted to measure temperature profiles up to about 5 km when they are used in conjunction with a **Radio-Acoustic Sounding System (RASS)**, the possibility to obtain temperatures profiles much more frequently than when using balloon tracking. No other measurement technique will present comparable advantages within the foreseeable future, including satellite borne sensors.

4.15. Mobile Radars



Figure 26: Mobile Radars.

3-D mobile radar employs monopulse technique for height estimation and using electronic scanning for getting the desired radar coverage by managing the RF transmission energy in elevation plane as per the operational requirements. The Radar is configured in three transport vehicles, viz., Antenna, Transmitter cabin, Receiver and Processor Cabin. The radar has an autonomous display for stand-alone operation.

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TRAINING MATERIAL ON WEATHER RADAR SYSTEMS

MODULE B

RADAR HARDWARE

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TRAINING COURSE ON WEATHER RADAR SYSTEMS

MODULE B: RADAR HARDWARE

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**12-16 SEPTEMBER 2005
WMO RMTC-TURKEY
ALANYA FACILITIES, ANTALYA, TURKEY**

MODULE A: INTRODUCTION TO RADAR

MODULE B: RADAR HARDWARE

MODULE C: PROCESSING BASICS IN DOPPLER
WEATHER RADARS

MODULE D: RADAR PRODUCTS AND
OPERATIONAL APPLICATIONS

MODULE E: RADAR MAINTENANCE AND
CALIBRATION TECHNIQUES

MODULE F: RADAR INFRASTRUCTURE

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ABBREVIATIONS:

STALO	: Stable Oscillator
COHO	: Coherent Oscillator
RF	: radio Frequency
I	: In-phase
Q	: Quadrature
AC	: Alternating Current
DC	: Direct Current
LNA	: Low Noise Amplifier
TR(T/R)	: Transmit-Receive
S_{min}	: Minimum Sensitivity
MDS	: Minimum Detectable Signal
RX	: Receiver
TX	: Transmitter
dB	: Decibel
dBm	: Decibel Milliwatt
dBZ	: Logarithmic Scale for Measuring Radar Reflectivity Factor
LOG	: Logarithmic
LIN	: Linear
TWT	: Travelling Wave Tube
RCP	: Radar Control Processor
RSP	: Radar Signal Processor
AZ	: Azimuth
EL	: Elevation
HV-REG	: High Voltage Regulator
PLC	: Programmable Logic Control
IAGC	: Instantaneous Automatic Gain Control
AFC	: Automatic Frequency Control
BITE	: Built In Test Equipment
ACU	: Antenna Control Unit
IF	: Intermediate Frequency
P_{in}	: Input Power
P_{out}	: Output Power
Hz	: Hertz
KHz	: Kilohertz
MHz	: Megahertz
GHz	: Gigahertz
mW	: Milliwatt
KW	: Kilowatt
MW	: Megawatt
Sec.	: Second
μsec.	: Microsecond
SSPA	: Solid State Power Amplifier
CCPS	: Capacitor Charging Power Supply
SMPS	: Switch Mode Power Supply
PRF	: Pulse Repetition Frequency
PRT	: Pulse Repetition Time
G	: Gain
BW	: Bandwidth
D	: Diameter of Antenna
VSWR	: Voltage Standing Wave Ratio

Radome : **Radar Dome**
DSP : **Digital Signal Processor**
PPI : **Plan Position Indicator**
RHI : **Range Height Indicator**
CAPPI : **Constant Altitude Plan Position Indicator**
AR Scope : **Amplitude Range Scope**

1. OPERATION PRINCIPLE OF WEATHER RADAR

1.1. General Overview

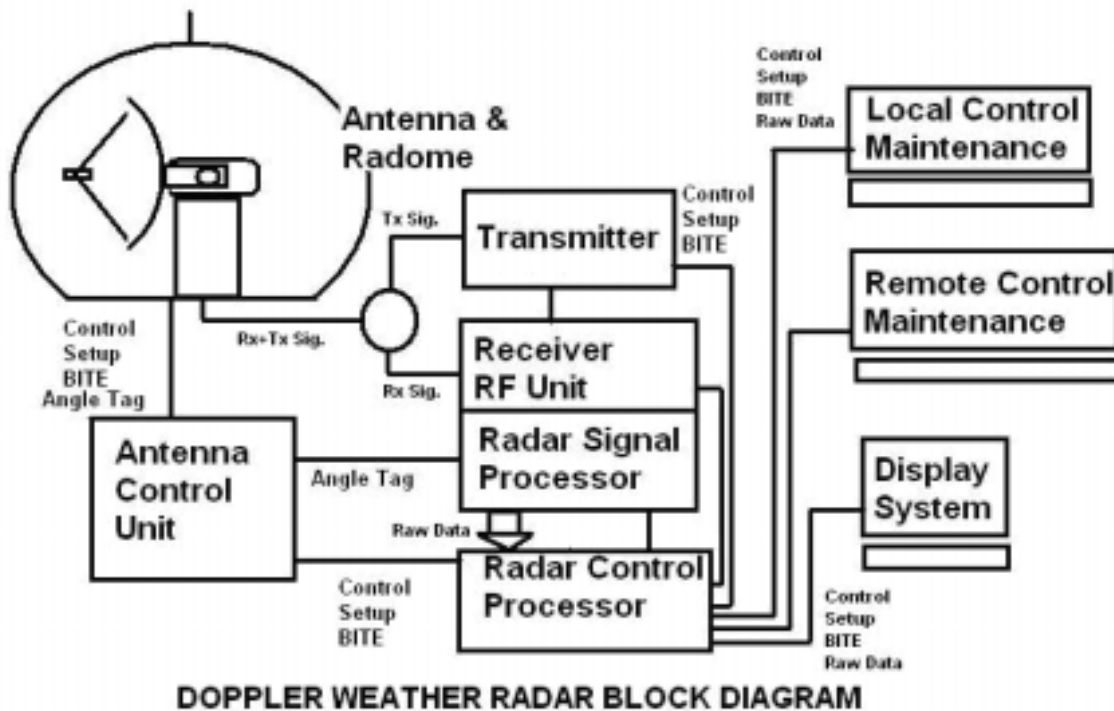


Figure 1: General Block Diagram of Doppler Weather Radar.

Primarily, the radar consists of a **transmitter** to generate microwave signal, an **antenna** to send the signal out to space and to receive energy scattered (echoes) by targets around, a **receiver** to detect and process the received signals by means of **processors** and a **display** to graphically present the signal in usable form.

In figure 1 of radar with klystron transmitter, an RF carrier signal is generated in the receiver and fed to the klystron amplifier. The transmitter generates a microwave pulse by means of pulse-modulated amplification of the carrier signal by the klystron. The microwave pulse is routed through the duplexer and radiated by the antenna. During this transmit phase the receiver is blocked by the T/R limiter of the duplexer which prevents leakage from the circulator of the duplexer to the highly sensitive receiver input stages.

The antenna emits the transmitter pulse in a symmetrical pencil beam. The atmosphere around the radar is scanned by moving the antenna in azimuth and elevation following meteorological scanning strategies.

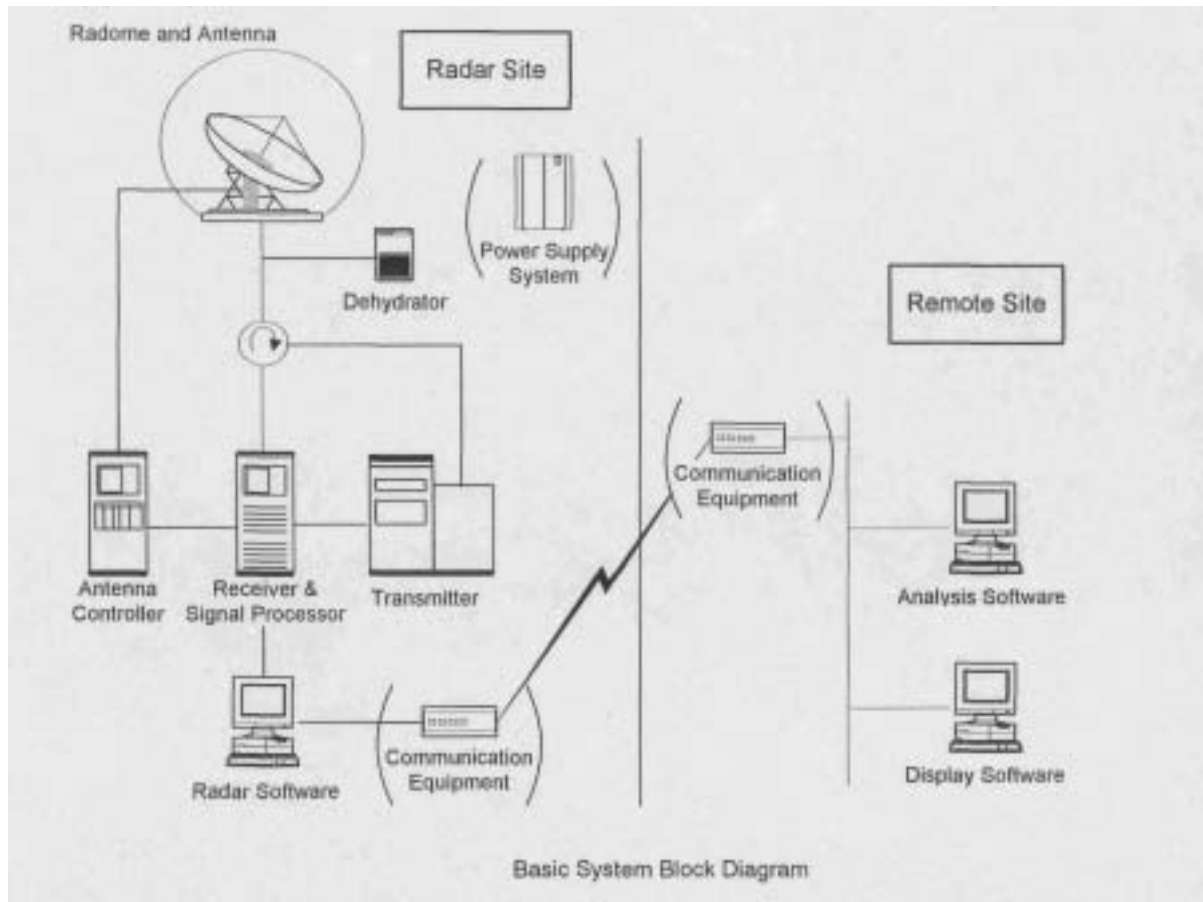


Figure 2: General Radar Block Diagram.

After the transmit pulse is terminated, the T/R limiter extinguishes and thus connects the receiver via the circulator to the antenna. The receive phase starts and the receiver is acquiring the signals scattered by the targets. This phase lasts until the next pulse is transmitted.

Due to its high sensitivity and its large dynamic range, receiver is capable of the detection of far clear-air echoes as well as strong signals from close thunderstorms.

After receipt of the echoes, **processing units** performs the tasks to convert those signals to required products to display on **indicators/displays**.

Main units of a meteorological radar system with their basic functions are shown in the radar block diagram below. The units compose the radar system and their functions will be explained in following chapters.

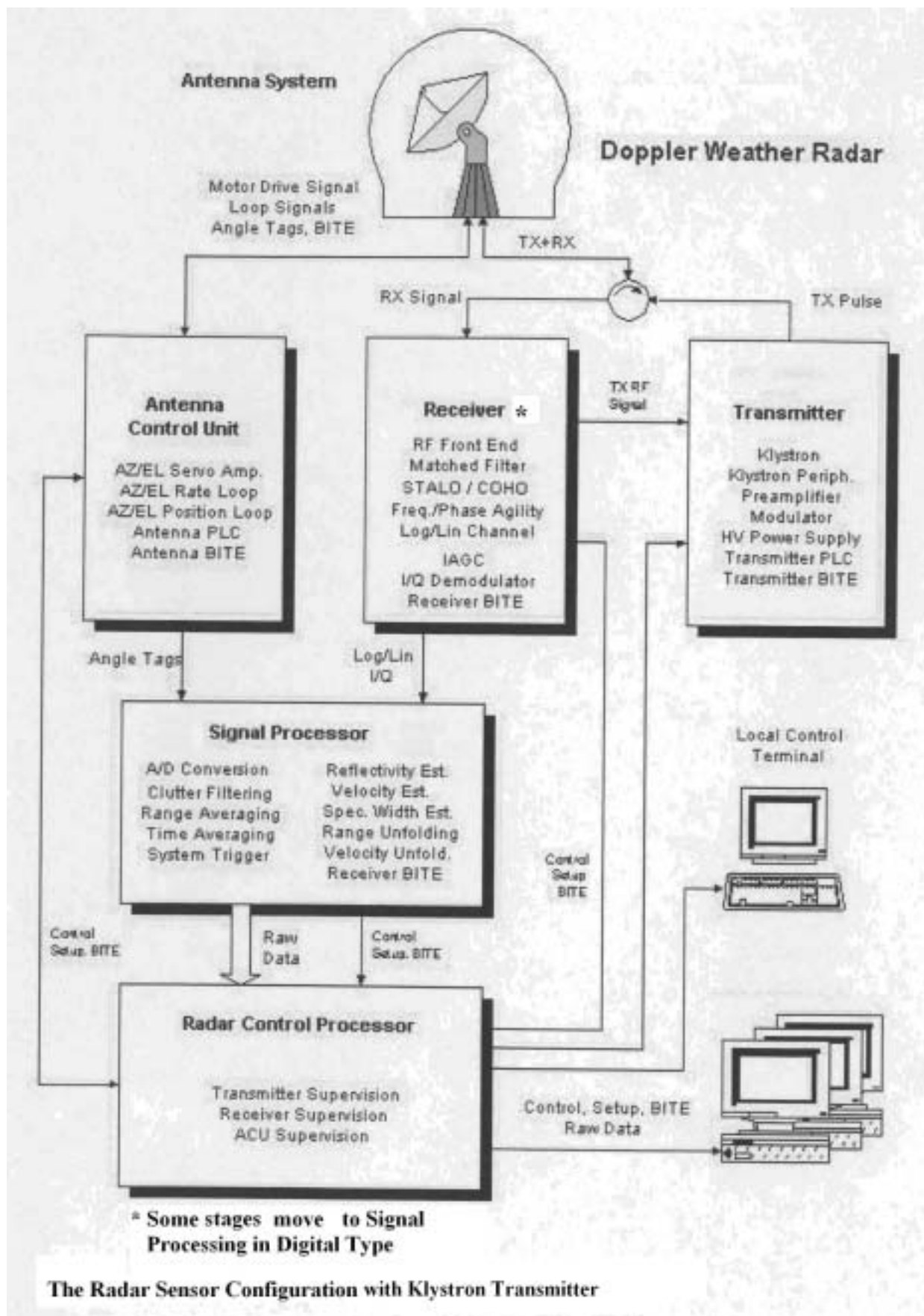


Figure 3: Another Block Diagram of Doppler Weather Radar.

1.2. Typical Radar System Applications and Block Diagrams

1.2.1 Single Magnetron Radar System

Block diagram of the RX for single Magnetron radar system is shown in Figure 4. Transmitted Burst RF is fed into the RX, so that digital phase detection can be made with Burst IF (down converted in frequency) in the Signal Processor.

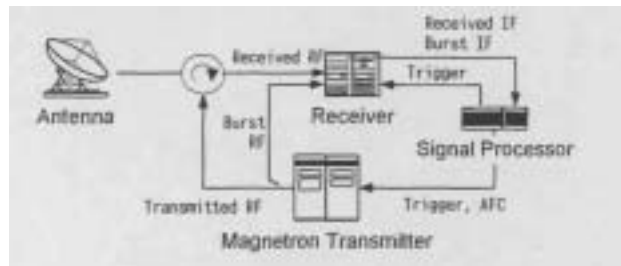


Figure 4: Single Magnetron Radar System.

1.2.2. Single Klystron Radar System

Block diagram of the RX for single Klystron radar system is shown in Figure 5. Exciter TX RF is generated in the RX and fed to Transmitter to be amplified by Klystron. Reference COHO (having same phase as TX RF) is output for digital phase detection processed in the Signal Processor.

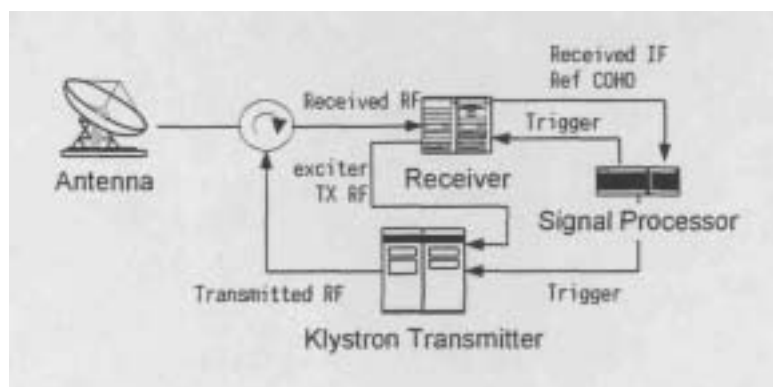


Figure 5: Single Klystron Radar System.

1.2.3. Dual Magnetron Radar System

Two identical RXs for Magnetron radar are used. Interswitching is performed through Waveguide Switch controlled by radar software.

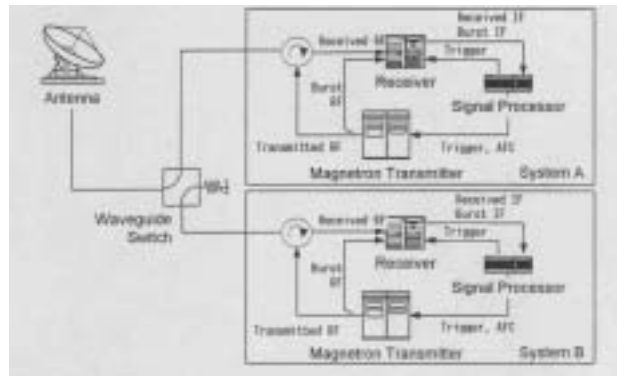


Figure 6: Dual Magnetron Radar System.

1.2.4. Dual Klystron Radar System

Two identical RXs for Klystron radar are used. Interswitching is performed through Waveguide Switch controlled by radar software.

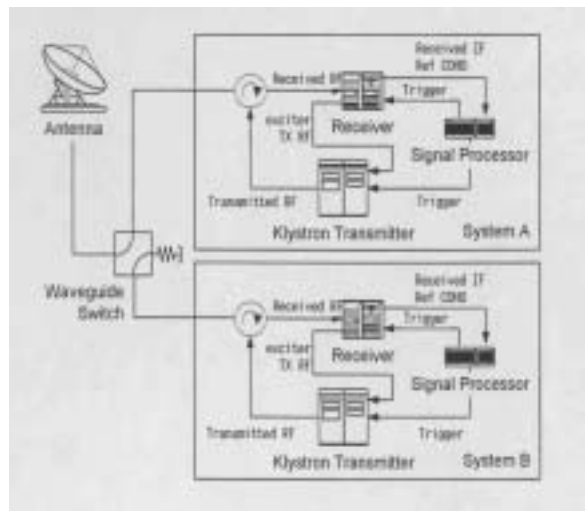


Figure 7: Dual Klystron Radar System.

1.2.5. Dual-Polarization Magnetron Radar System

Since observation is performed in both horizontal and vertical polarization simultaneously, two reception circuits are composed in the RX.

Higher phase stability is required for the RX used in Dual-Polarization system since it should be capable to process Differential Phase between horizontal and vertical channel for successful targets. Thus, two STALOs (for each horizontal/vertical channel) are synchronized to the reference COHO. COHO is also fed to IF Digitizer so that the digitizing clock is made synchronization.

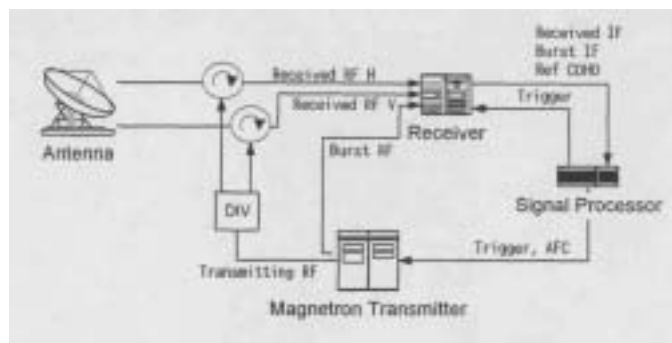


Figure 8: Dual-Polarization Magnetron Radar System.

1.2.6. Dual-Polarization Klystron Radar System

The system configuration is same as of Dual-Polarization magnetron radar system except a Klystron transmitter is used instead

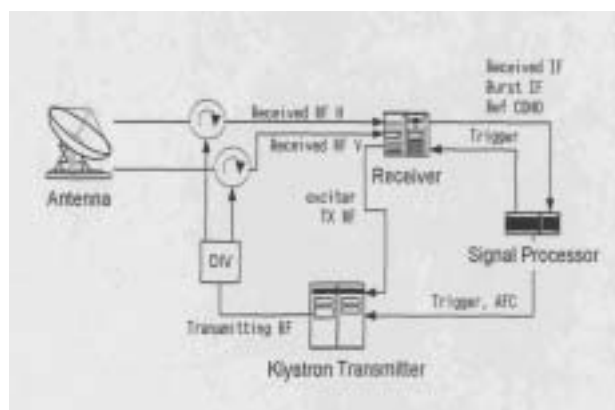


Figure 9: Dual-Polarization Klystron Radar System.

2. RECEIVER

2.1. General Overview

Pulsed radar sends out a high-power signal for a brief duration (typically a few microseconds) and then waits for the echoes of the signal from the targets around the radar to reach the antenna. After waiting for sufficient time (typically a few milliseconds), the next pulse is sent out. As the signal pulse travels at the speed of light, it does not take more than a few milliseconds for the signal to cover several hundred kilometres and get back to the radar with a wealth of information. Modern radar receivers are mostly solid-state super-heterodyne type, in which the received energy is mixed with a reference signal of different frequency for scaling it down in frequency for ease of processing. After down conversion, the information contained therein is filtered out and sent for further processing and display. Echoes of meteorological relevance span a wide range of the power spectrum say, from -110 dBm to about 0 dBm. A single receiver with such high dynamic range (the difference between the weakest and strongest power that it can handle) was difficult to design. Till recently, two receivers, one with logarithmic output to handle higher power and another with linear output to handle weaker power were used. However, radars with single linear receiver and dynamic range higher than 100 dB have now become available in Digital Receivers.



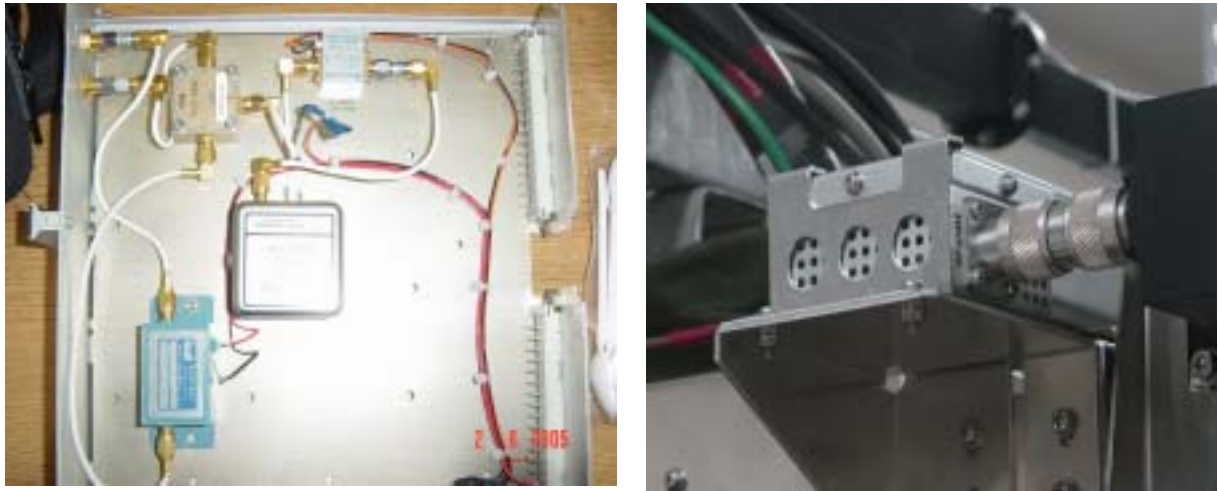


Figure 10: Some Pictures of Sub-Components of Receivers

The receiver includes the RF front end, the down conversion and up conversion chains, the STALO and COHO sections as well as the IF section with LOG channel and coherent LIN channel in Analogue Receivers.

The RF front end is directly connected to the duplexer. It preamplifies the received scattered signals by means of a low-noise amplifier and down converts them by mixing them with the Stable Local Oscillator (STALO) to the intermediate frequency (IF).

The generation of transmission frequency occurs through multiplications, conversion and filtering of quartz oscillators signals in order to obtain very low phase noise figure and hence high Doppler performances.

The phase coherent COHO output signal serves as reference for the I/O phase demodulator which generates the coherent I and Q video signals which are fed to the signal processor.

In the IF section of an Analogue Receiver the signal is matched filtered and splitted into the LOG and LIN channel. The LOG channel comprises a successive detection logarithmic video amplifier which compresses the signal and feeds it to the signal processor.

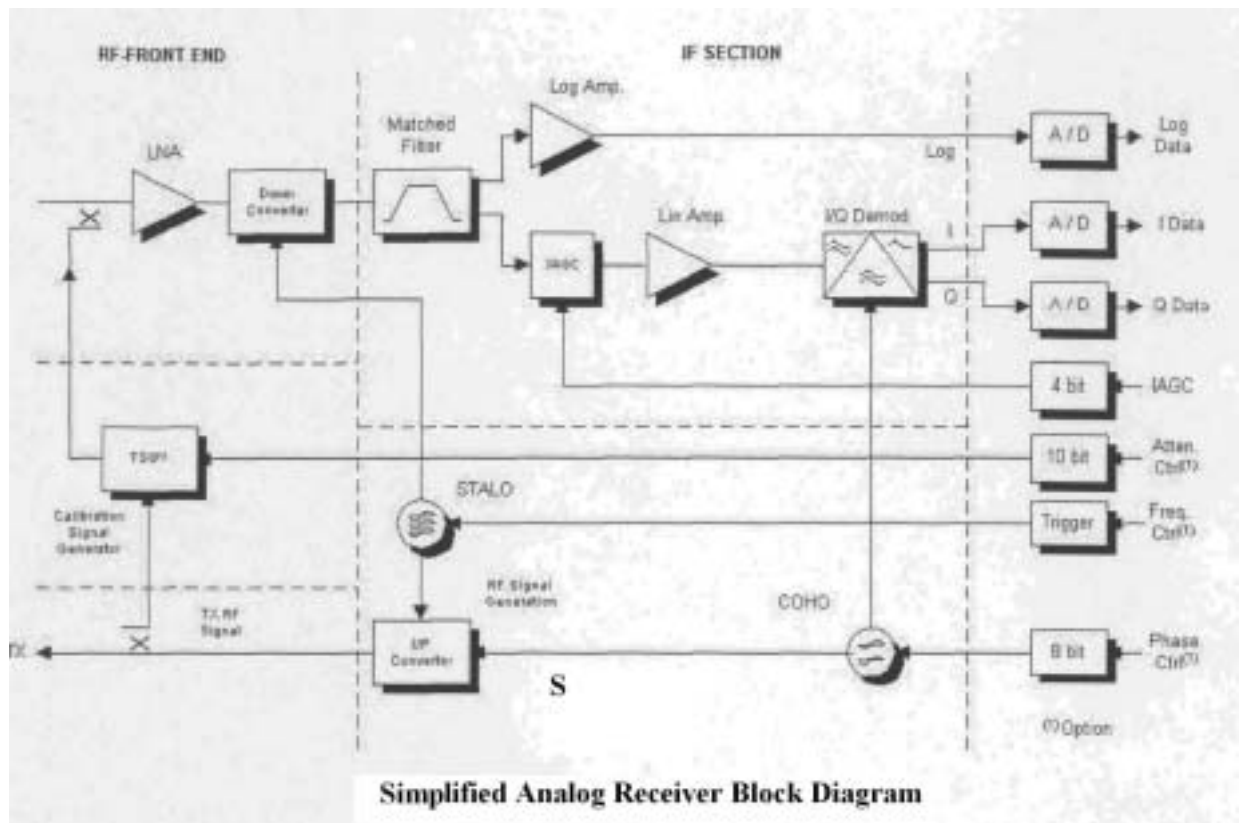


Figure 11: Analog Receiver Block Diagram.

Digital receiver provides better performance (wide dynamic range, improved phase stability, etc) and higher system availability. The digital approach replaces virtually all of the traditional IF receiver components with flexible software-controlled modules that can be easily optimized to the operational requirements.

The function of the RX in a Digital Receiver is to amplify the detected RF signal by Low Noise Amplifier (LNA), to convert to IF signal with a Stable Local Oscillator (STALO), and to send it to the IF Digitizer for Digital Phase Detection.

For the RX used in a Klystron system, there is an another function that to send the exciter TX RF signal to the Transmitter (TX), so that the TX transmits coherent RF which the phase is always identical. The Exciter TX RF is generated from the COHO, and is Pulse/Phase modulated and frequency up-converted with the STALO.

For a Magnetron system, the RX has the function to down-convert the Burst RF (transmitted pulse) frequency, so that the radar signal processor can perform the burst pulse analysis to obtain the amplitude, frequency and phase of the transmitted pulse.

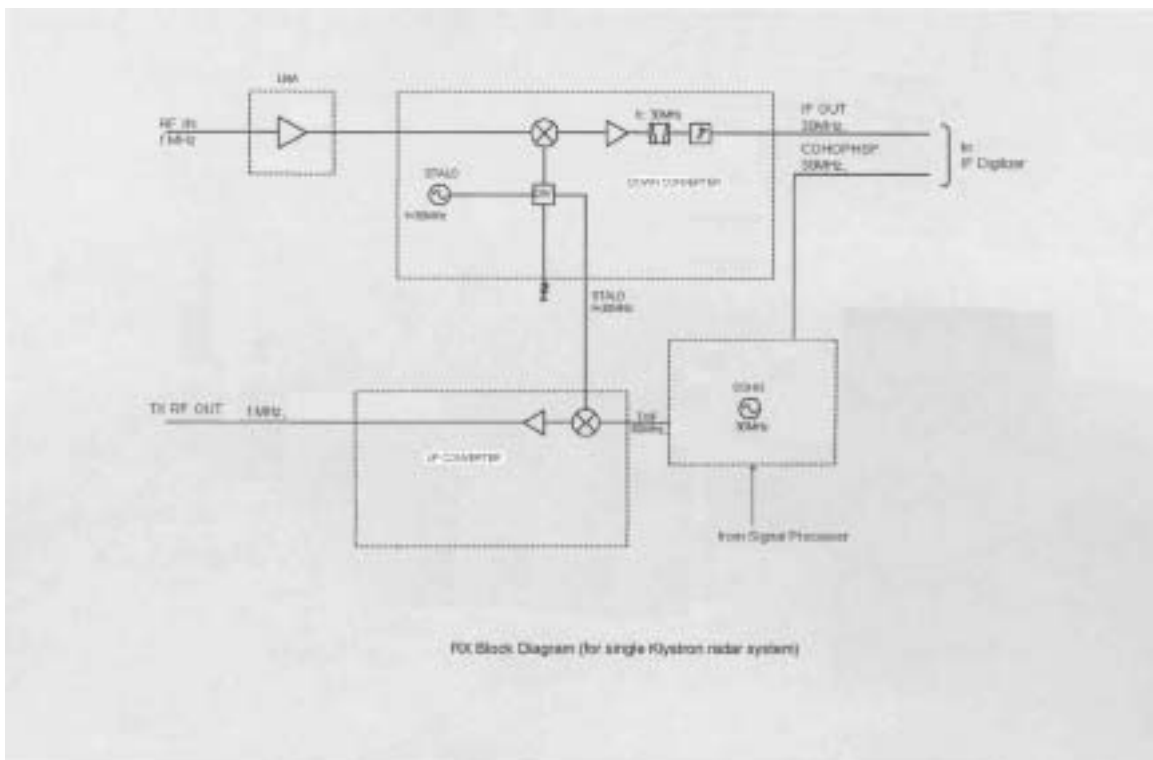


Figure 12: A Basic Block Diagram of a Receiver for a Klystron Radar System.

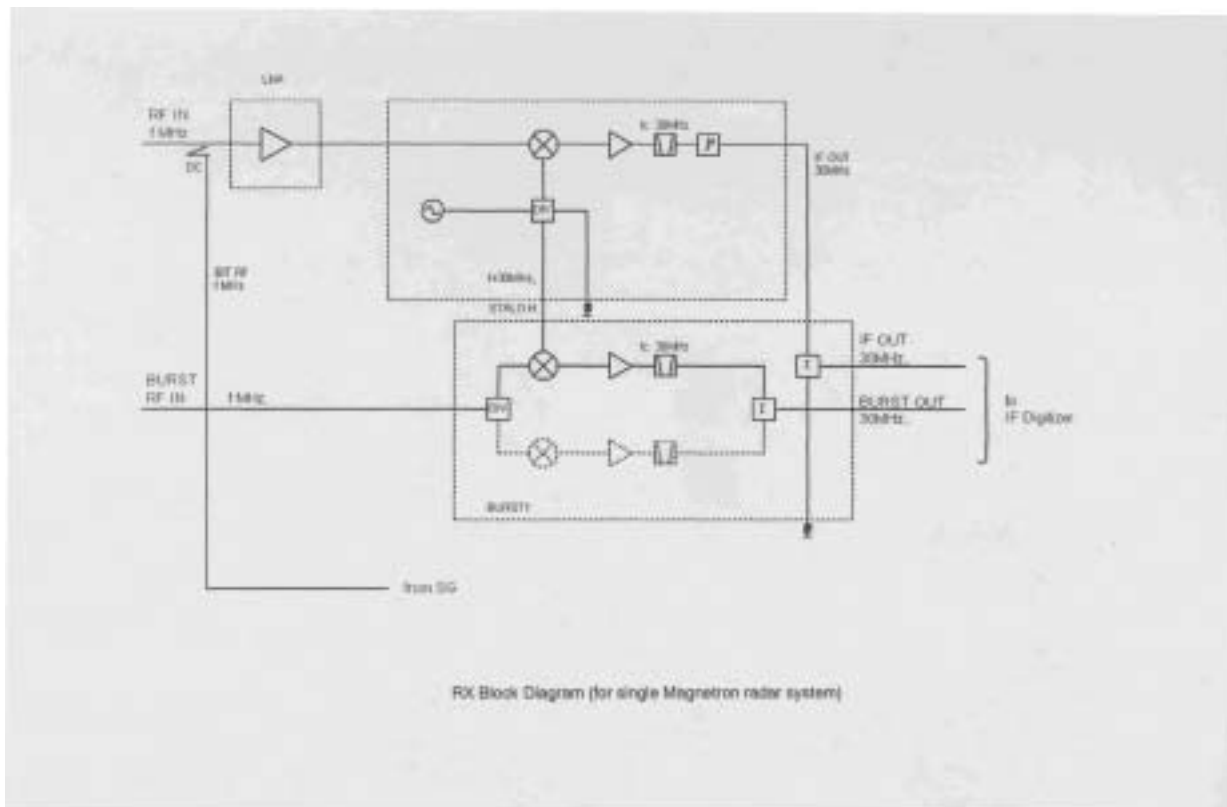


Figure 13: A Basic Block Diagram of a Receiver for a Magnetron Radar System.



Figure 14: Inside of Receiver Hardware (IF and RF Sections)

Second trip echoes can be a serious problem for applications that require operation at a high PRF. Second trip echoes can appear separately or can be overlaid on first trip echoes. In the Doppler mode out-of-trip echo dealiasing and recovery is achieved by a pulse-to-pulse phase shifting of the TX signal. The COHO is optionally interpulse **phase-shift** keyed to provide a means for the radar signal processor to distinguish between different transmit pulses for **second-trip** signal recovery purposes.

2.2. Oscillators

It is very important that the TX/ RX IF difference frequency and phase relationship be maintained within such systems. Where that is achieved the system is referred to as being **Coherent**. Coherent systems employ a coherent oscillator (COHO) and a series of stages that relate TX and LO frequencies. A stable local oscillator (STALO) is also used that determines the IF frequencies and, therefore, helps to maintain coherence.

Lets look at coherent on receive. To be coherent on receive one must have a **COHerent Oscillator (COHO)**. The COHO contains a stable phase and frequency relative to the magnetron's output. The COHO signal is used to detect the I and Q elements of the received targets for both weather and clutter relative to Transmitted Frequency.

So, a permanent, clean RF carrier signal is generated by means of stabilized quartz oscillators, which are up converted by mixing and multiplication processes to form the signal amplified by the transmitter and to serve as local oscillators for the receiver down-conversion chain.

2.3. Low Noise Amplifier (LNA)

LNA is a module to amplify weak signal received and sent from Antenna system with Low Noise Amplifier device (LNA). The LNA is a sensitive device which needs a protective circuit to prevent excess RF input which may leak from Transmitter. A TR-Limiter is normally used for the protection. The RF Input terminal shall be connected to the TR-Limiter output, directly.

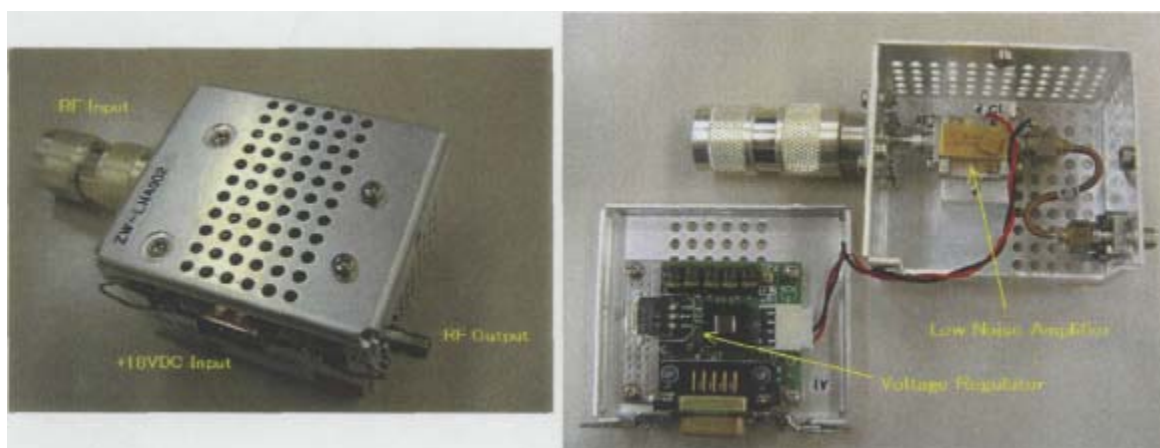


Figure 15: Low Noise Amplifier.

2.4. Duplexer and TR Limiter

A **duplexer**, sometimes called as Transmit/receive switch, is a device that isolates the receiver from the transmitter while permitting them to share a common antenna. The duplexer is the device that allows a single antenna to serve both the transmitter and the receiver. On transmission it must protect the receiver from burnout or damage, and on reception it must channel the echo signal to the receiver. Duplexers, especially for high-power applications, sometimes employ a form of gas-discharge device, i.e. TR tube. Solid-state devices are also utilized.

A duplexer must be designed for operation in the frequency band used by the receiver and transmitter, and must be capable of handling the output power of the transmitter. Furthermore, a duplexer must provide adequate rejection of transmitter noise occurring at the receive frequency, and must be designed to operate at, or less than, the frequency separation between the transmitter and receiver.

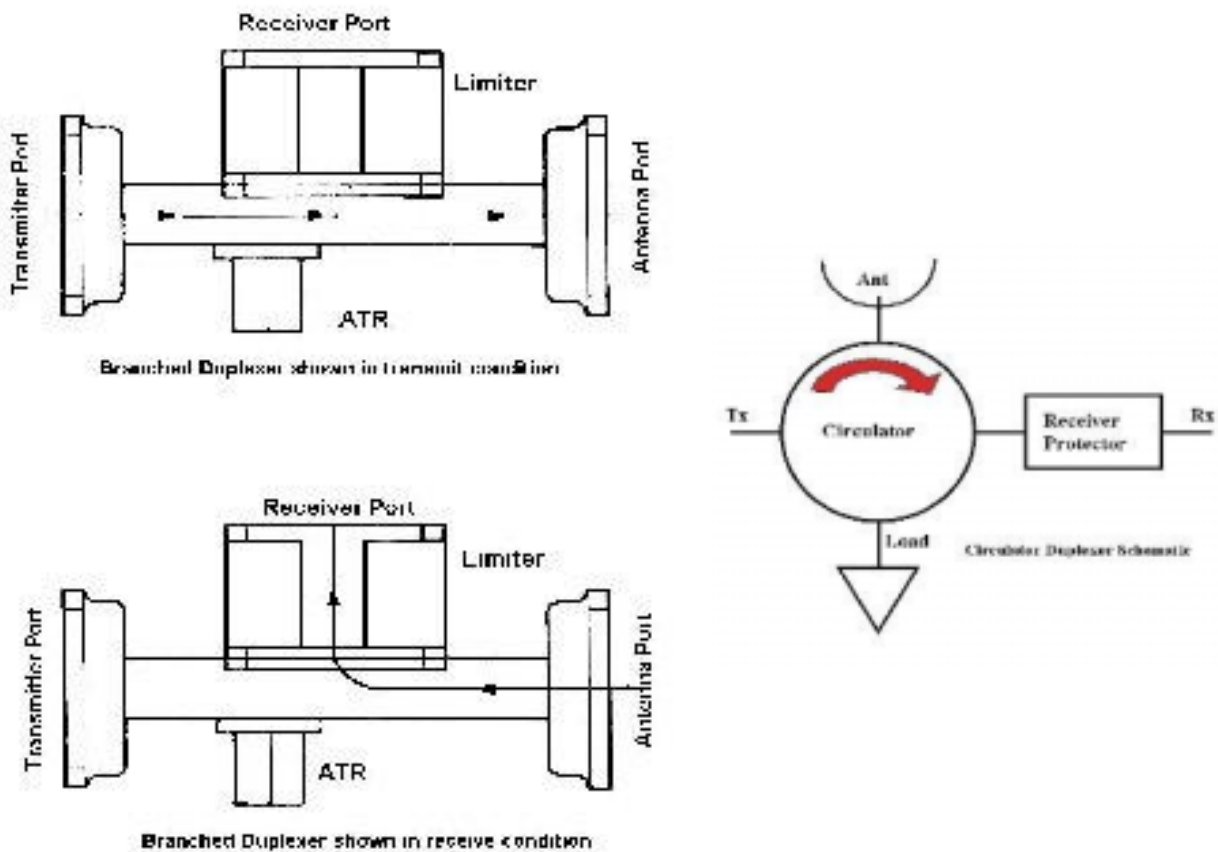


Figure 16: TR Limiter

TR Limiters (Transmit-Receive Limiters) are used in antenna between the high power transmitter and the receiver. The TR tube, as a gas-discharge device designed to break down and ionize quickly at the onset of high RF power, and to deionise quickly once the power is removed, is the most common receiver protector technology in use today. The construction of the TR tube includes one or more resonant filter sections in a piece of waveguide which is sealed at both ends with waveguide windows. Each filter section is a relatively high Q parallel L-C circuit. Truncated cones form the capacitive element and irises or post the inductive element. One common construction of a TR consists of a section of waveguide containing one or more resonant filters two glass-to-metal windows to seal in the gas at low pressure. A noble gas like argon in the TR tube has a low breakdown voltage, and offers good receiver protection and relatively long life. Pure-argon-filled tubes, however, have relatively long deionization times and are not suitable for short-range applications. The deionization process can be speeded up by the addition of water vapour or a halogen. The life of TR tubes filled with a mixture of a noble gas (argon) and a gas with high electron affinity (water vapour) is less than the life of tubes filled with a noble gas only.

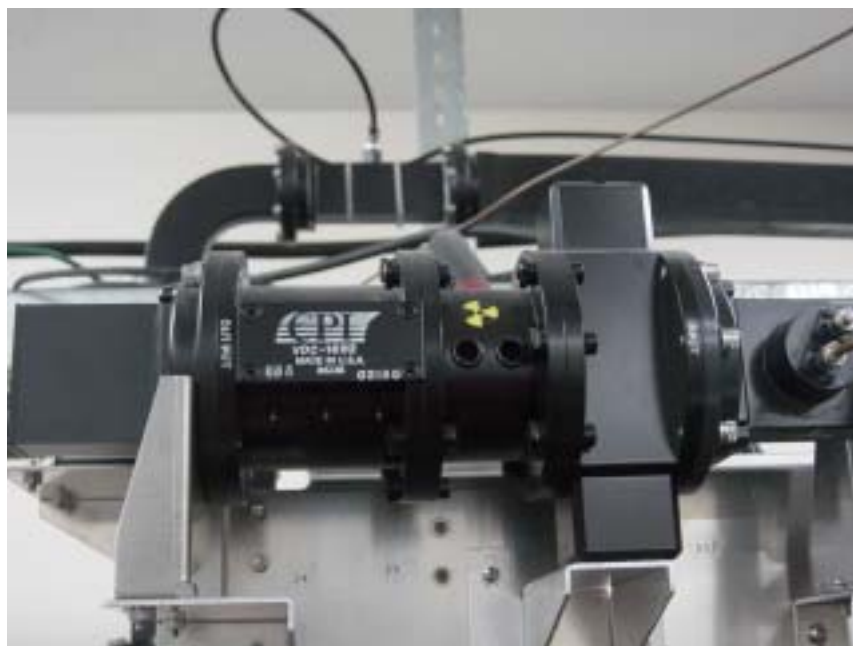


Figure 17: TR-Limiter.

2.5. Basic Characteristics of a Receiver

The quality and the performance of receivers depend on the some basic characteristics. Those receiver characteristics are explained briefly below:

2.5.1. Minimum Detectable Signal (MDS)

Due to the noise generated by the receiver itself, weak signals can not be identified. There is thus a bottom threshold on the ability to detect echoes. This is called the minimum detectable signal (MDS) or Sensitivity (S_{min}). In other words in a receiver, it is the smallest input signal that will produce a detectable signal at the output. In radar terms, it is the minimal amount of back scattered energy that is required to produce a target on the radar screen. In other words, MDS is a measure of the radar's sensitivity. If this is about 15 dBZ for a signal at 100 km, this means that a storm weaker than 15 dBZ at 100 km will not be detected by the radar.

2.5.2. Dynamic Range

The range, from the minimum, which is at a level 3 dB above the amplifier's internally generated floor, to a maximum input signal level that a component can accept and amplify without distortion.

$$\text{Dynamic Range} = P_{1dB} - P_{MDS}$$

Where the P_{MDS} = Minimum detectable signal 3 dB above the noise floor.

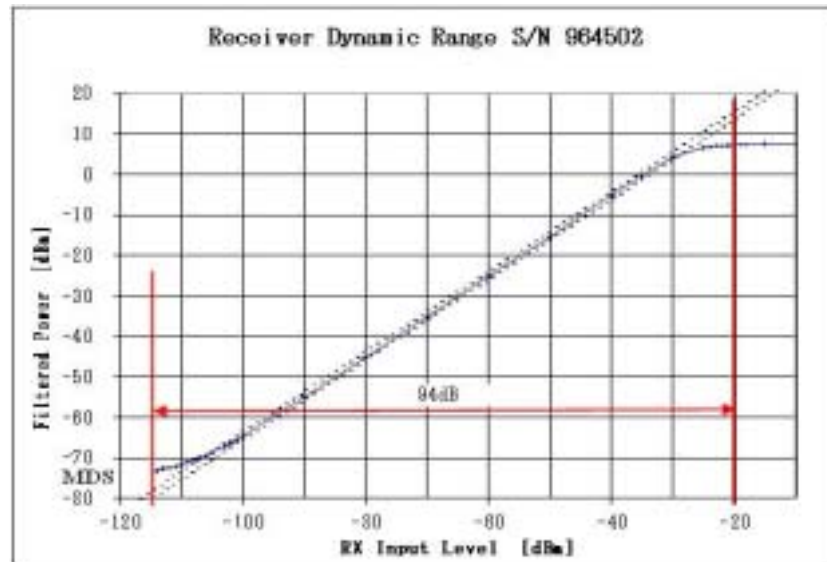


Figure 18: Typical Dynamic Range Curve a Receiver.

2.5.3. Receiver (RX) Gain

We can determine the RX gain by using the linear part of the dynamic range curve.

RX gain can be calculated by getting the difference between output and input value at any point of that linear part of the curve.

At the figure-2.9 of dynamic range;

Our output is -45 dBm while our input is -80 dBm.

So our RX gain= -45 dBm-(-80dBm)= 35 dB

2.5.4. One dB (1 dB) Compression Point

The 1 dB compression point is the point on a P_{out} vs. P_{in} graph, where an increase power input causes the measured gain to decrease from the linear gain by one dB. Typically, if not explicitly stated, the 1 dB compression point refers to the output power (P_{out}) at that point.

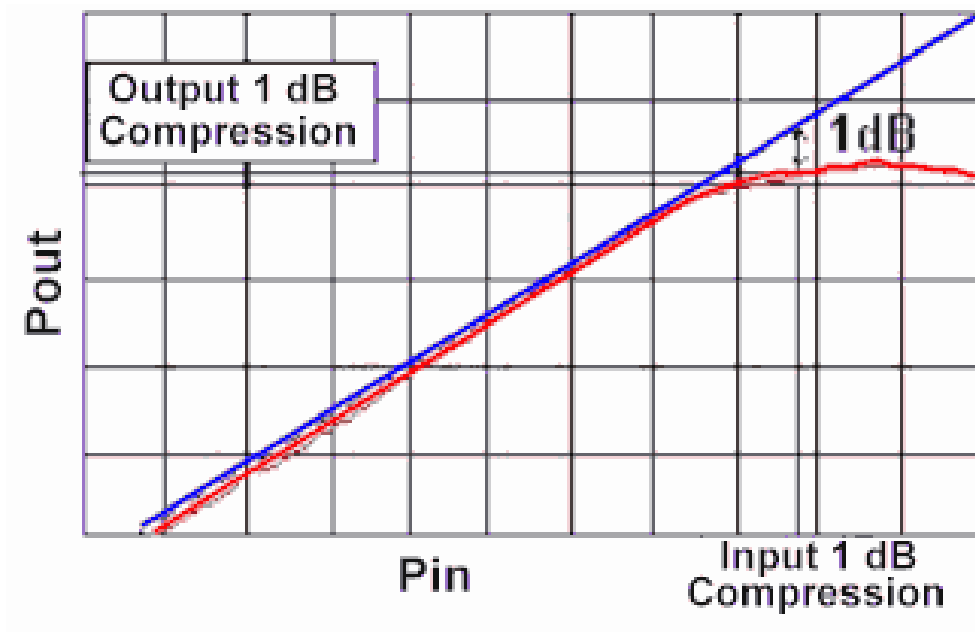


Figure 19: 1 dB Compression Point.

3. TRANSMITTER

3.1. General Overview

Transmitter is one of the essential components of the radar system with a function of generating high power RF signal which will travel through the atmosphere and echoes of that signal will be received by the antenna after reflected by targets.

Transmitter unit of radar systems consists of microwave tubes (or solid state devices), high voltage power supplies and transformers, voltage regulators, filters, processors and control circuits, blowers, modulators and RF circuits. Following figure 20 shows the general block diagram of a transmitter with klystron tube.

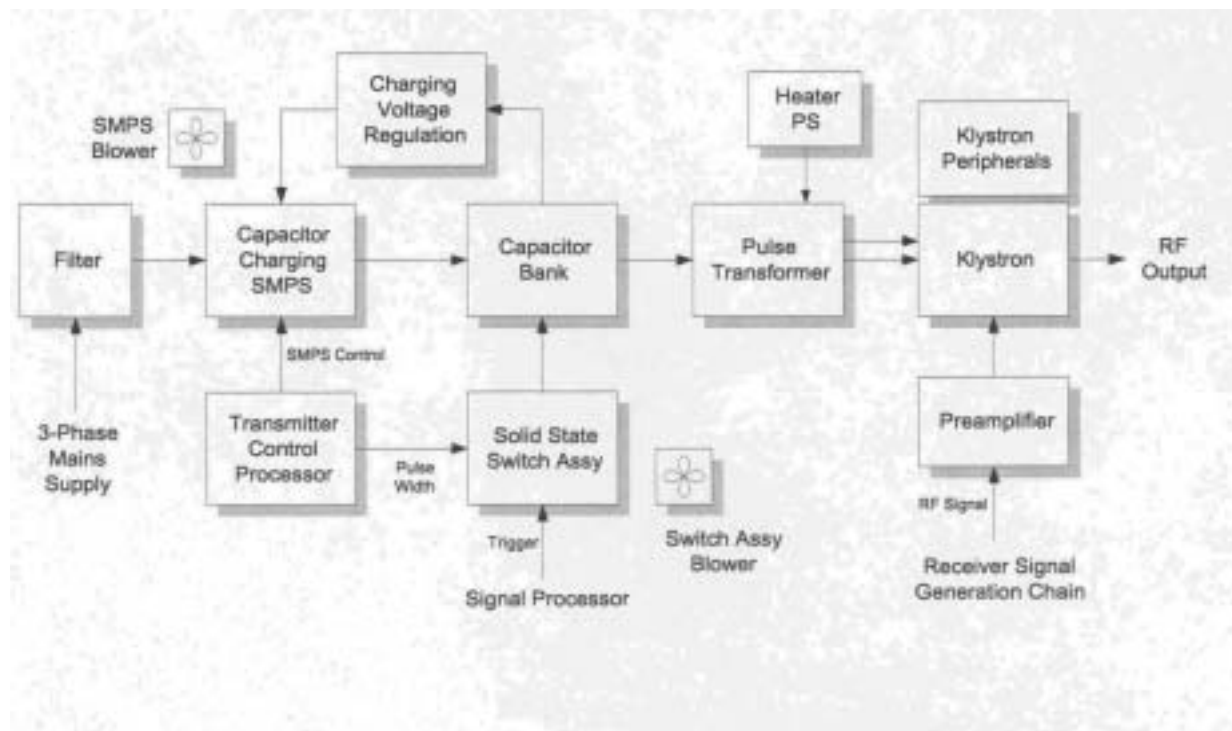


Figure 20: Simplified Transmitter Block Diagram.

A lot of types of transmitters are available for radars depending on type of the radars and the applications. Within the frequency range of interest, two technologies (vacuum and solid-state electronics) are used to generate and amplify microwaves. Each offers advantages for specific applications within the performance domain of radio frequency (RF) systems (see Figure 21). Microwave power tubes (the principal product derived from RF vacuum electronics) are preferred for applications requiring both higher frequency and higher power. Electron transport in a vacuum conveys as advantages to microwave power tubes such

features as wide band performance, efficiency, thermal robustness, and radiation hardness. Alternatively, solid-state power amplifiers combine the power from many transistors. The advantages of charge transport in a solid-state media yield compact devices with superior reliability, and competitive efficiency and bandwidth at lower frequency and power. Solid-state power amplifiers transmit/receive (T/R) modules, and active arrays use a variety of power combining techniques to provide competitive total power.

Conventional high-power-pulse radar transmitters (rated from 0.25 to 10 MW peak power) are the largest, heaviest, and most costly portions of a radar system. They require a lot of prime power and need a lot of cooling. The design of a transmitter is strongly affected by the type of RF transmitting source selected; this in turn is governed by what frequency needs to be transmitted or whether the transmitter is to operate on a single spot frequency or be completely frequency agile. That is, the frequency for each transmitted pulse deviates from the mean carrier frequency.

Magnetrons, klystrons and travelling wave tubes still continue to be the main powerhouse of most radars. They are used in radar transmitters to produce microwave energy of required wavelength and intensity. Though solid-state transmitters have become available, they have not overtaken the age-old vacuum tube technology so far due to their limited power. Gyrotrons are newly emerging microwave power tubes, currently with limited applications. Classification and characteristics of microwave tubes are shown below:

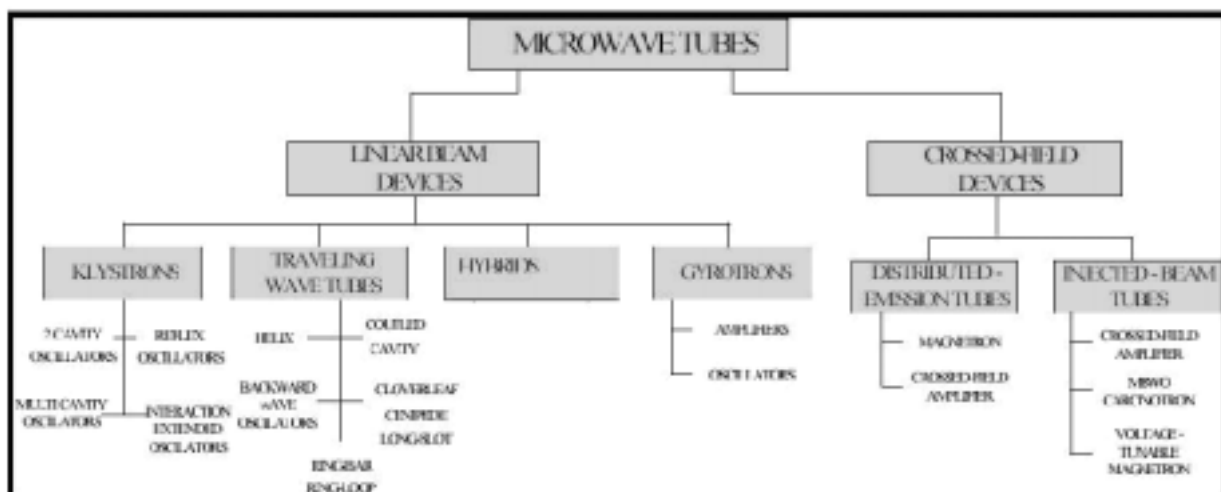


Figure 21: Microwave Tube Family.

Figure 21 summarizes the various types of microwave power tubes in use today.

Tube Type	Frequency ----- Bandwidth	Power Out (Typical)	Attributes ----- Drawbacks	Applications
Klystron	0.1 - 300 GHz ----- 5 - 10%	10 Kw CW** 10 Mw Pulse	High Power 40-60% Efficient Low Noise ----- Narrow Bandwidth	Radar Television Industrial Heating Satellite Uplinks Medical Therapy Science
Traveling Wave Tube (Helix)	1- 90 GHz ----- Wide bandwidth 2-3 octaves*	20w CW and 20 Kw CW	Broad Bandwidth ----- Power Handling Limitations Efficiency	Electronic Warfare Communications Comm'l Broadcasting Industrial Applications
Coupled Cavity TWT	1 - 200 GHz ----- 10 - 20%	300w CW 250 Kw Pulse	Average Power Capability ----- Complex & Expensive Slow Wave Structure	Airborne Radar Satellite Communications AEGIS FC Illuminator
Magnetron	1-90 GHz ----- N/A	100w CW 10 Mw Pulse	Simple - Inexpensive Rugged ----- Noisy	Radar / Medical Industrial Heating
Crossed Field Amplifier	1 - 30 GHz ----- 10-20%	1000w CW 5 Mw Pulse	Compact Size 30-40% Efficient ----- Complex & Expensive Slow Wave Structure	Transportable Radars Shipboard Radar Seeker Radars Industrial Heating
Gyrotron	30 - 200 GHz ----- 10% max	0.2 - 3 Mw Pulse	High Power @ High Frequencies ----- High Voltage Req'd	High Frequency Radar Fusion Accelerators Industrial Heating

Figure 22: Typical Microwave Tube Characteristics and Applications.

Figure 22 summarizes microwave power tube operating characteristics and applications.

3.2. Transmitter Types

3.2.1. Magnetron Tubes

The magnetron tube for generating microwaves was invented by John Randall and Henry Boot in November 1939 (Buderi, 1996). Randall and Boot were working on the development of radar for the British. Magnetrons proved to be one of the most important developments of radar for World War II. Their small size and high power output made them ideal for airborne use. Magnetron transmitters are now used at a variety of radar frequencies and can generate transmitted signals in excess of 500 kW.

Magnetrons are oscillators and usually operate in a pulsed mode. They are used extensively in commercial airliner weather and collision avoidance radar, in almost all military and commercial navigation and weather radar systems, in some of the less-expensive medical therapy equipment, and in various industrial heating applications, including the ubiquitous microwave ovens. Magnetrons can generate a lot of power in a small volume and are very efficient. They also are relatively inexpensive.

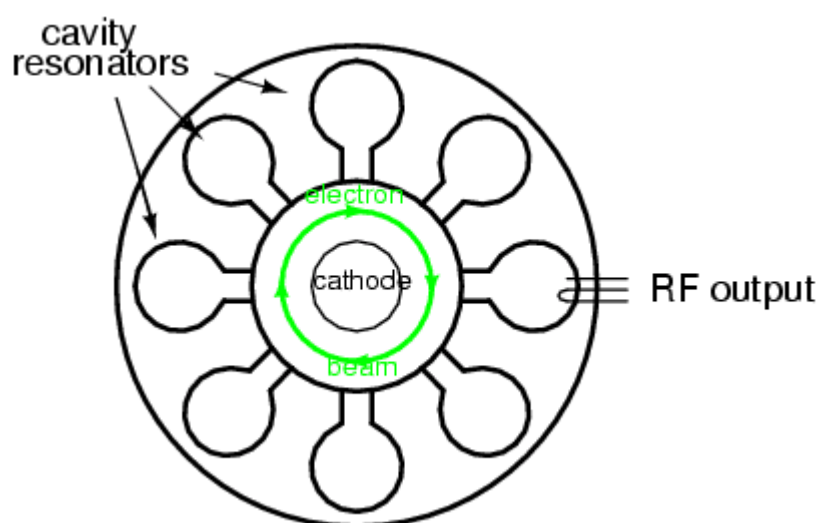


Figure 23: Magnetron Tube.

Magnetron tubes are representative of an entirely different kind of tube than the klystron. Whereas the latter tubes use a linear electron beam, the magnetron directs its electron beam in a circular pattern by means of a strong magnetic field:

In operation, as the electrons are released from the cathode, they are directed toward the anode. However, since the electrons are influenced by the magnets in the resonant cavities, they flow

circularly through the resonant chambers and set up an oscillation based upon their speed through the chambers. These resonating chambers comprise the anode of the magnetron. One or more chambers contain collecting antennas that let the generated RF signal flow outside the tube.

3.2.2. Klystron Tubes

The klystron tube, as a high power amplifier, was invented at Stanford University in 1937 and originally used as the oscillator in radar receivers during World War II by two of the researchers instrumental, a pair of brothers named Sigurd and Russell Varian.

The klystron generally is referred to as a “linear beam” device because it utilizes **a magnetic field in line with its electric field**. The energy distribution of the beam is altered as it travels through a resonant cavity. The resonant cavity is excited by an input signal such that the beam is “velocity modulated” (some electrons are slowed, some accelerated). Farther down the tube, the electrons “bunch” as the faster electrons overtake the slower electrons. As the bunched electrons pass through another resonant cavity, that cavity is excited at the same frequency as the input cavity, but at a much higher power level. This amplifies the signal. Klystrons range in length from less than a foot to over 20 feet and operate with voltages ranging from a few hundred to several thousand. Output power can range from 10 kilowatts (continuous) to 10 megawatts (pulsed).

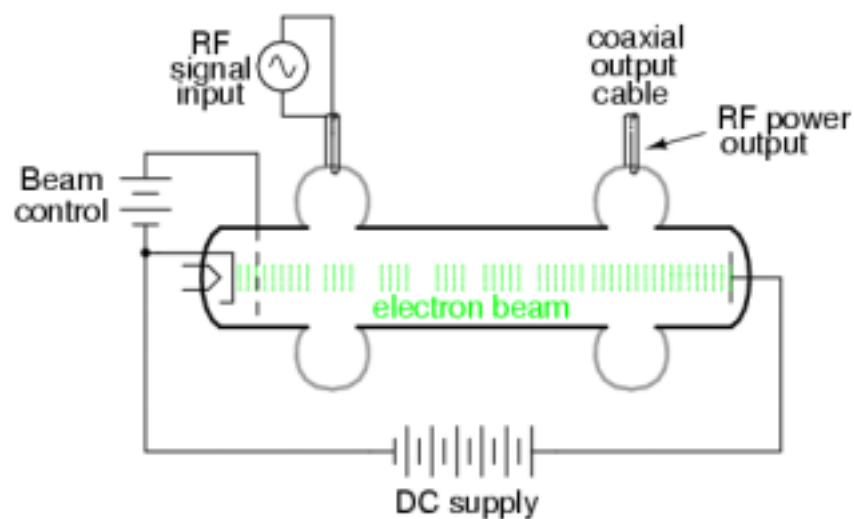


Figure 24: Klystron Tube.

Amplification klystrons continue to find use in high-power (**Radar**), high-frequency radio transmitters and in scientific research applications.

Civilian agencies continue to use klystrons in many of their radar systems. For example, the Federal Aviation Administration's Terminal Doppler Weather Radar uses a klystron amplifier because solid-state devices cannot generate the waveforms needed to detect severe weather and wind-shear conditions.

Transmitter- Performance of the full-coherent Klystron transmitter is extremely stable compared to a Magnetron transmitter, therefore, the system capability for "Precise Weather Measurement" is absolutely superior to systems using any other type of transmitters. The transmitter is designed solid-state based including the high-voltage modulator. The radiation sound is kept ultra low level so that maintenance can be performed easily and friendly.

3.2.3. Travelling Wave Tubes (TWTs)

The TWT is an important member of the linear beam family of microwave power tubes. It is similar to the klystron in that a pencil beam of electrons is generated in an electron gun and kinetic energy is converted into RF energy as the beam interacts with an RF circuit. Unlike the klystron, the interaction occurs continuously as an increasing travelling wave instead of discrete steps in cavities. The most common form of RF circuit used is a simple helix. The TWT's advantage is "bandwidth". It can instantaneously amplify signals over a range of frequencies – several octaves. A wide bandwidth is necessary in applications where good range-resolution is required or where it is desired to avoid deliberate jamming or mutual interference with nearby radars. Although low power TWTs are capable of octave bandwidths, bandwidths of the order of 10 to 20 percent are more typical at the power levels required for long-range radar applications. The gain, efficiency, and power levels of TWTs are like those of the klystron; but, in general, their values are usually slightly less than can be obtained with a klystron of comparable design.

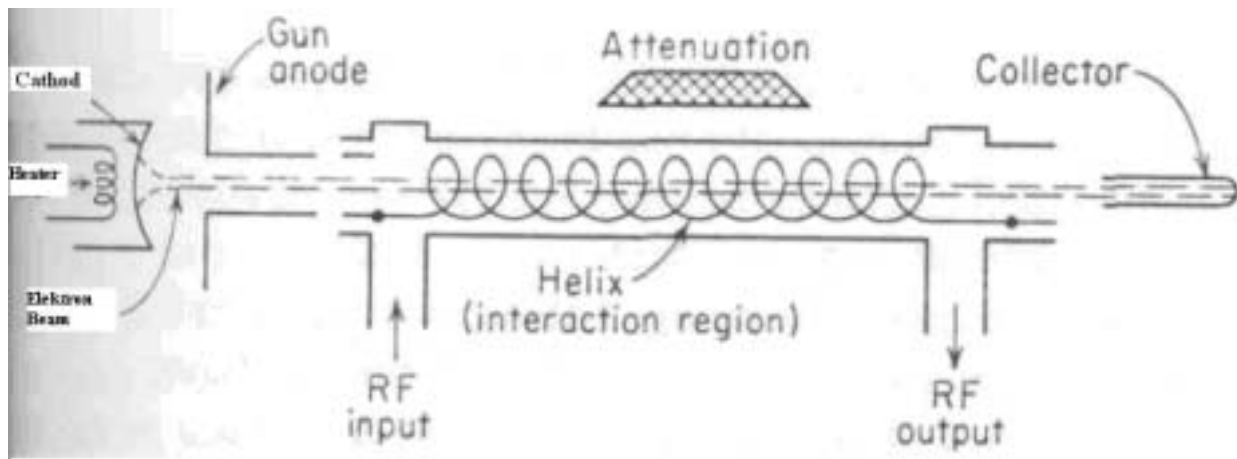


Figure 25: Diagrammatic Representation of Travelling Wave Tube.

3.2.4. Gyrotrons

A gyrotron, a more recent development, looks like a linear beam device but performs like a combined linear beam and crossed-field device. It is large, heavy, expensive, and employs very high voltages and high magnetic fields generated by superconducting solenoids. It can do what no other microwave power tube can do -- generate very high- power levels at millimetre wavelengths. The gyrotron promises important advances in fusion and because of the high resolution possible with its millimetre wavelengths, great improvements in radar imaging.

3.2.5. Solid-State Power Amplifiers

Solid-state power amplifiers (SSPAs) use transistors, not vacuum electronic devices, to amplify microwaves. Performance depends upon the characteristics of the transistors used and the efficiency of the combining technique. At lower frequencies and power, SSPAs are less expensive, more reliable, and inherently quieter than microwave power tubes. SSPAs for microwave applications are composed of many individual transistors connected in parallel, their output “summed” in a combining network to achieve power levels useful for radar or telecommunications. Each type of transistor has specific limitations due to its material properties (defect densities, carrier mobility, thermal conductivity, etc.) which determine its useful operating frequency and power output. In transistors of a given material, the output power generally varies inversely with the square of the operating frequency.

The assessments by some experts on that issue state that SSPAs soon will replace microwave power tubes in some applications. This prediction appears to be overstated. Microwave power

tubes continue to provide significantly higher power output and efficiencies than SSPAs, for mid- and higher-frequency applications.

Some researchers evaluated the current state of the technology and projected evolutionary improvements in the power output of well known microwave SSPAs. It is concluded that: (1) microwave solid-state amplifier capability would increase by a few decibels (dB) in the next decade, (2) the main solid-state progress would be in improved efficiency and lower cost, and (3) the new solid-state devices being developed are not expected to improve power performance in the mid- and higher- frequencies, where microwave power tube devices are dominant. Therefore, the applications being served today by microwave tubes will likely continue without significant change, particularly for mid- and higher-frequency applications.

3.3. Modulator

No matter what kind of transmitter is used in the radar, it is usually controlled by another electronic device called the modulator. The purpose of the modulator is to switch the transmitter on and off and to provide the correct waveform for the transmitted pulse. That is, the modulator tells the transmitter when to transmit and for what duration.

The modulator also serves another function. It stores up energy between transmitter pulses so when it is time for the transmitter to fire, it will have a storehouse of energy available for its use.

The Modulator generates high voltage pulse by switching high DC voltage from the HV REG. The switching devices are solid state. The solid state modulator represents the latest state-of-the-art in high power solid state electronics. The modulator applies a high voltage pulse through the pulse transformer to the klystron cathode. It is designed to support the inherent high stability of a coherent radar.

The solid-state modulator comprises a capacitor charging power supply (CCPS), charging voltage stabilization, a solid-state switch assembly, a capacitor bank and a pulse transformer. The CCPS is basically a switch-mode power supply. It charges a capacitor bank. The voltage on the capacitor bank is controlled by means of a sensitive topping electronics resulting in a very high stability. This is mandatory for Doppler operation.

The high-power solid state switch assembly comprises the solid state switches as well as their trigger and protection circuitry. As switches fast, high power semiconductors are employed. The selected switch modules provide sufficient margin in their critical parameters to guarantee trouble-free operation over the whole life time of the radar system.

The solid state switch assembly is directly triggered from the radar signal processor. The pulse width control is provided by the transmitter control processor. The pulse duration is set by a pulse termination trigger. Two different pulse durations are pre-programmed.

Similar to the capacitor charging SMPS the solid state switch assembly is current limited. Therefore if an arc occurs anywhere in the high voltage circuitry, an inherent protection is provided for the solid state switches.



Figure 26: Front Panel of a TX Cabinet.



Figure 27: Some Klystron Indicators.



Figure 28: High Voltage Section of a TX.



Figure 29: Monitoring Points from TX.



Figure 30: Klystron Tank.



Figure 31: A Klystron Tube.



Figure 32: Modulator of a Transmitter.



Figure 33: Inside of an Air Isolated Tank.



Figure 34: A Klystron Tube.



Figure 35: Modulator of a Transmitter.

4. ANTENNA

4.1. General Overview

A radar antenna (the British call it aerial) may be thought of as a coupling device between free space propagation and the waveguide from the transmitter. During transmission, energy from the transmitter is switched to the antenna by the duplexer, and the antenna causes the energy to radiate into free space. On reception, a signal in free space impinges on the antenna and is coupled to the transmission line that is connected to the duplexer, where it is delivered to the receiver. By reciprocity, the coupling to free space during transmission is identical with the coupling to the transmission line during reception. These two roles were expressed by the transmitting gain and the effective receiving aperture alias receiving gain. The main function of the antenna is to shape the transmitted beam so that the radiated energy is concentrated in the desired direction in space. The antenna is - so to speak - the 'eye' of the radar.

The antenna collimates the microwave energy into a narrow beam while sending it out. The larger the size of the antenna, the better the angular resolution. The antenna generally rotates about a vertical axis scanning the atmosphere in azimuth. It is also capable of changing its elevation by rotating about a horizontal axis so that probing of the hemispherical volume of the atmosphere with radar as the centre is possible, according to the scanning strategy decided by the user.

The antenna performance determines the update rate of radar images. In order to support the most advanced scan strategies, the antenna features the highest acceleration rates and the best step response times available on the market.

A radar receiver detects and often analyzes the faint echoes produced when radar waves bounce off of distant objects and return to the radar system. The antenna gathers the weak returning radar signals and converts them into an electric current. Because a radar antenna may both transmit and receive signals, the duplexer determines whether the antenna is connected to the receiver or the transmitter. The receiver determines whether the signal should be reported and often does further analysis before sending the results to the display. The display conveys the results to the human operator through a visual display or an audible signal.

In general, it is expected radar antennas to have the following properties:

- High forward gain or directive gain
- Narrow beamwidth
- Low sidelobe level
- Broad-banding - so that the antenna can transmit and receive a radar pulse without distortion and pass all operating frequencies within the allocated frequency band
- The beam must be scanned

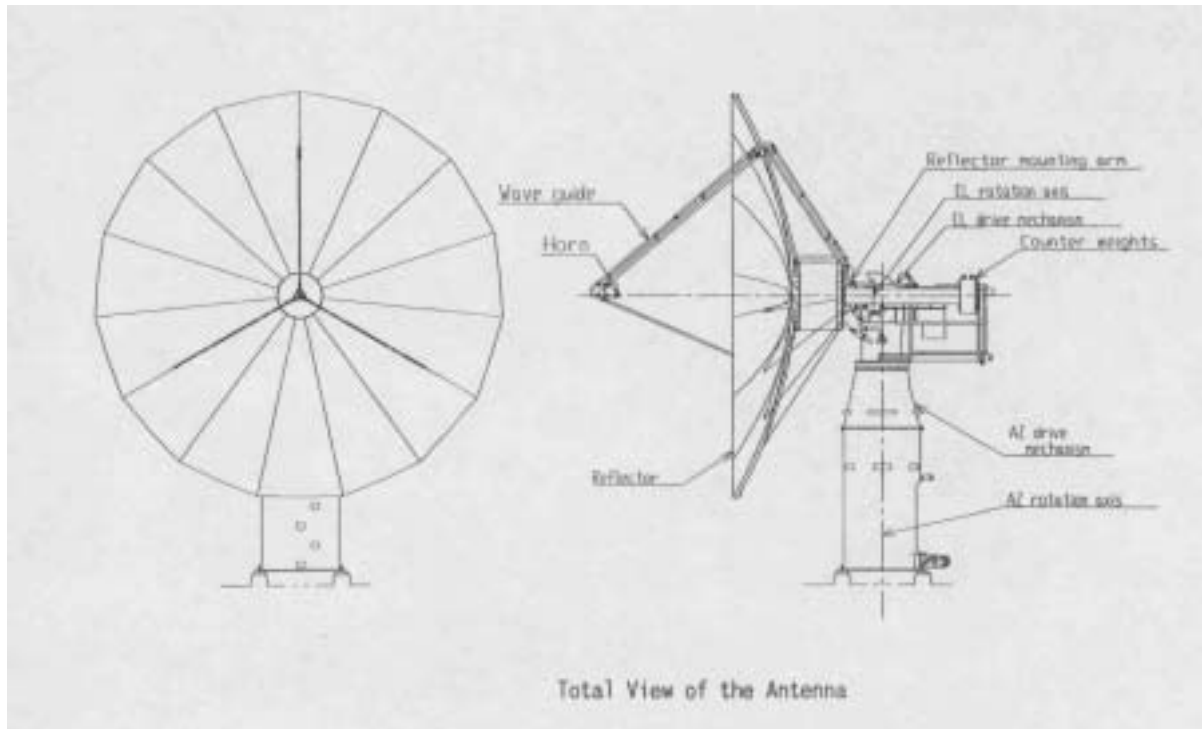


Figure 36: Pedestal and Antenna.

4.2. Antenna Types

There are three major types of antenna used in radar applications. These are phased array antennas, parabolic reflector antennas and offset feed antennas. Those types of antennas will be explained briefly.

4.2.1. Phased Array Antenna

Early radar systems used antenna arrays formed by the combination of individual radiators. Such antennas date back to the turn of this century. Today, after a long pause, the technology is advanced. Better components and not least the advent of computers led to designing well matched apertures.

The phased array antenna has usually a planar aperture that is assembled from a great many similar radiating elements, such as slots or dipoles, each element being individually controlled in phase and amplitude. Accurately predictable radiation patterns and beam pointing directions can be achieved. Phased arrays allow scanning the beam electronically to a certain degree which makes the mechanical movement of antennas unnecessary.

4.2.2. Parabolic reflectors

Parabolic reflectors emit all radiation at focus emerges in a beam parallel to the axis. These types of antennas give a narrow beam which increases performance of weather radars significantly. Parabolic reflectors are suitable mainly at microwave frequencies because it must be large compared with the wavelength. Most of the antennas used in weather radar applications are parabolic reflectors.

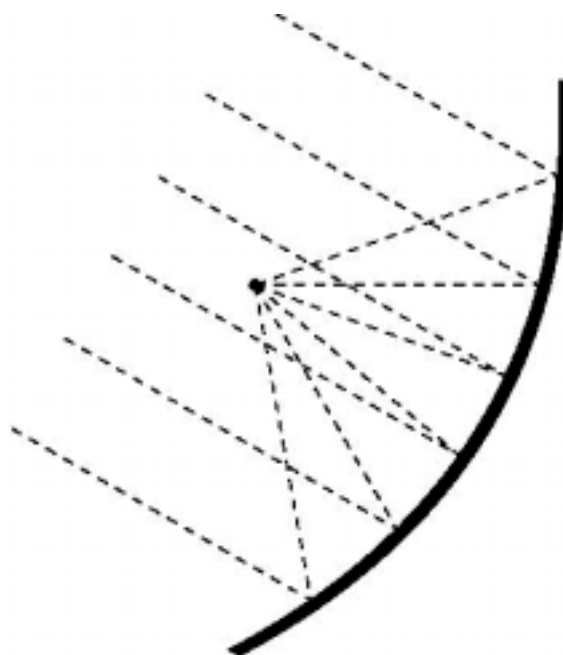


Figure 37: Parabolic Dish Antenna.

4.2.3. Offset Feed Reflectors

An offset-feed dish antenna has a reflector which is a section of a normal parabolic reflector as shown in Figure 37 and 38. If the section does not include the centre of the dish, then none of the radiated beam is blocked by the feed antenna and support structure. Otherwise, only a small bit at the edge of the beam is blocked. For small dishes, feed blockage in an axial-feed dish causes a significant loss in efficiency. Thus, we might expect an offset-feed dish to have higher efficiency than a conventional dish of the same aperture.

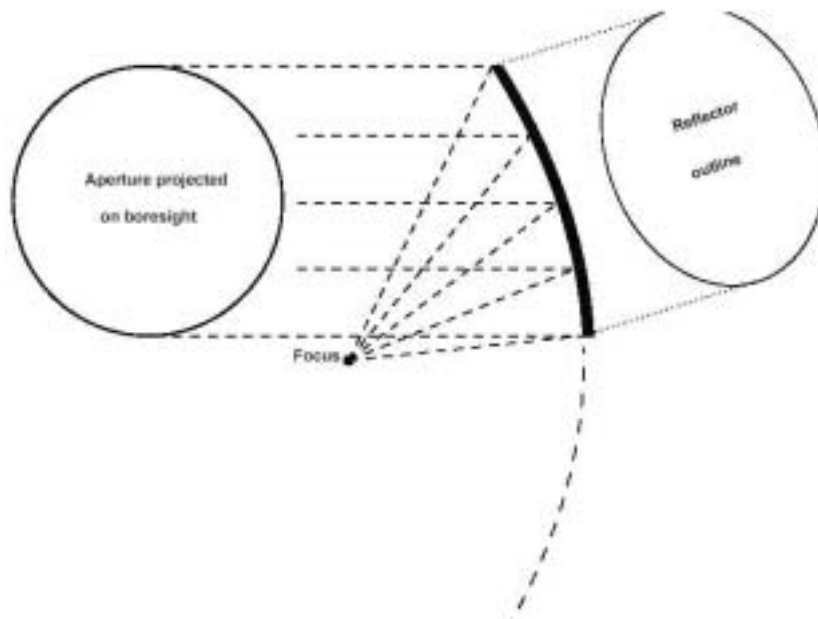


Figure 38: Geometry of Offset Parabolic Dish Antenna.



Figure 39: An Offset Feed Antenna.

4.3. Basic Characteristics of Antenna

4.3.1. Antenna Gain

An antenna which equally radiates in all directions is called an isotropic radiator or source, sometimes called a spherical radiator. There is no such antenna, because every antenna exhibits some directive properties. However, the isotropic antenna is a convenient reference point, and thus the gain or directivity of a given antenna is expressed as the increase in power radiated in a given

direction compared to the power radiated by the fictitious isotropic antenna, assuming the same total power in both cases accepted by the antenna. Thus

$$G = \text{Power gain} = \frac{\text{Maximum field strength radiated from given antenna}}{\text{Field strength radiated from reference antenna}}$$

The gain is a ratio, i.e. a number that is usually converted into dB. Thus a transmitting antenna with a gain of 30 dB would radiate a signal in the direction in which the signal is maximum 30 dB greater than a signal from an isotropic or reference source which is fed with the same transmitter.

Direct measurements of the antenna gain can seldom be made and a gain figure is usually obtained by knowing the effective receiving aperture of the antenna or effective area A_e . It may be regarded as a measure of the effective area presented by the antenna to the incident wave.

$$G = \frac{4\pi A_g}{\lambda^2}$$

All points on the antenna do not couple uniformly to the transmission line, so that the amount of energy reaching the receiver is reduced. The effective area of the antenna is therefore the area of cross section which, when uniformly coupled to the transmission line, delivers the same energy as the actual antenna. The ratio of the two is called the efficiency of illumination, and is expressed as $K = A_e/A$, where A is the physical area.

The relationship between the gain and the beamwidth of an antenna depends on the distribution of current across the aperture. For a reflector antenna the following expression is sometimes used:

$$G = \frac{20000}{\theta_B \phi_B}$$

Where θ and ϕ are the half-power beam widths, in degrees, measured in the two principal planes. This is a rough rule of thumb that can be used when no other information is available,

but should not be a substitute for more exact expressions that account for the actual aperture illumination

4.3.2. Antenna Pattern

Larger diameter antenna provides more antenna gain which directly affects to the system sensitivity. Another benefit of the bigger antenna is narrower beam width which is quite important performance especially for such as the system used in airports. Radiated power is focused into the pencil beam, so that the echoes have more precise information to be detected. Since accurate weather information should be correctly delivered to the various users responsible for weather alert management, this "Precise Weather Measurement" is one of the most important functions required to the modern Doppler Weather Radar.

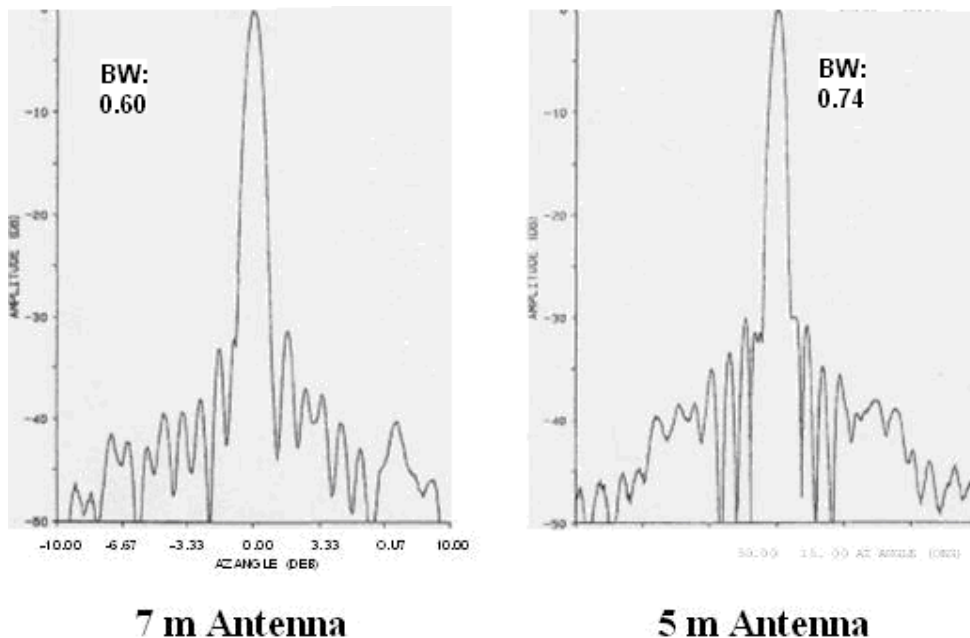


Figure 40: Antenna Size and Pattern (AZ Angle).

Beam width of parabolic reflector at half power point is simply given by

$$\theta = \frac{70\lambda}{D}$$

Where θ is the beam width, λ is the wave length and D is the diameter of the antenna.

In addition to the main beam, antennas produce rays of energy called side lobes, which surround the main beam (primary lobe) like haloes Side lobes extend outward only a short distance from the radar and contain very low power densities.

Side lobes are a direct result of diffraction occurring near the edges of a radar antenna.

However, even though they are weak, side lobes can detect strong non-meteorological targets near the radar and are also disturbed by nearby ground reflections. This leads to confusion in interpreting close targets because side lobe targets are displayed along with the main beam targets.

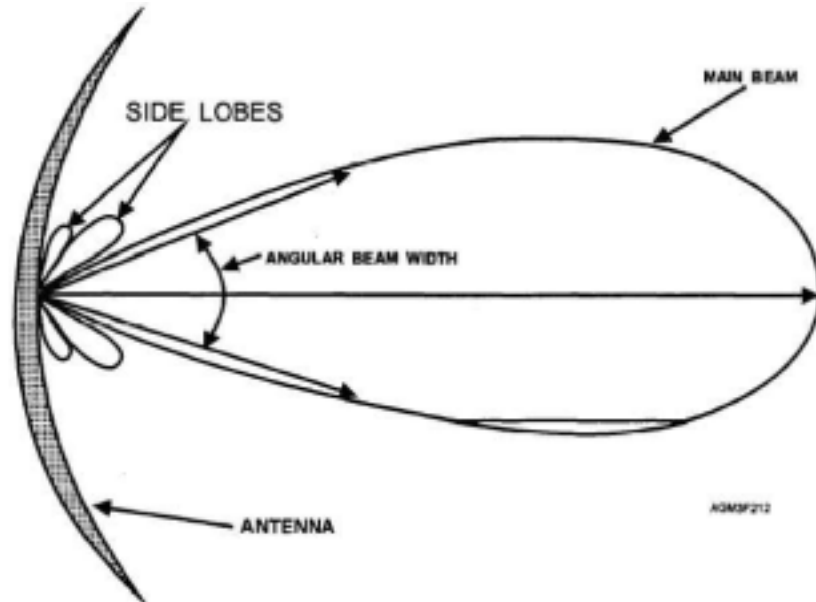


Figure 41: Main Beam and Sidelobes.

4.4. Main Parts of a Radar Antenna

Antenna consists of microwave circuit, electric circuit and mechanical system. The microwave circuit is composed of a parabolic reflector and a feed horn which feeds the electromagnetic wave to the parabolic reflector.

The function of the microwave circuit is to radiate electromagnetic pulse wave from the Transmitter, to concentrate the energy of radio frequency signals scattered due to rainfall particles etc. and to transfer them to the Receiver via drive mechanisms. The Antenna also includes rotary joints, which enable to transfer the radio frequency energy both ways between fixed waveguides and rotating Antenna.

The electric circuit is comprised of drive motors, resolvers and slip ring etc. Drive motor rotates the Antenna on both azimuth (AZ) and elevation (EL). Resolvers detect rotation angle on AZ and EL as an angle detector. Slip ring supplies power for AZ and EL axis motor between rotation part and fixed part.

It also transfers angle data from servo loop system. Resolver forms servo loop system together with other components for accurate control of rotation speed and positioning of the Antenna. Electric circuit controls rotation and positioning of the Antenna in azimuth and elevation. Mechanical system is structured by driving power transmission system to rotate the Antenna.

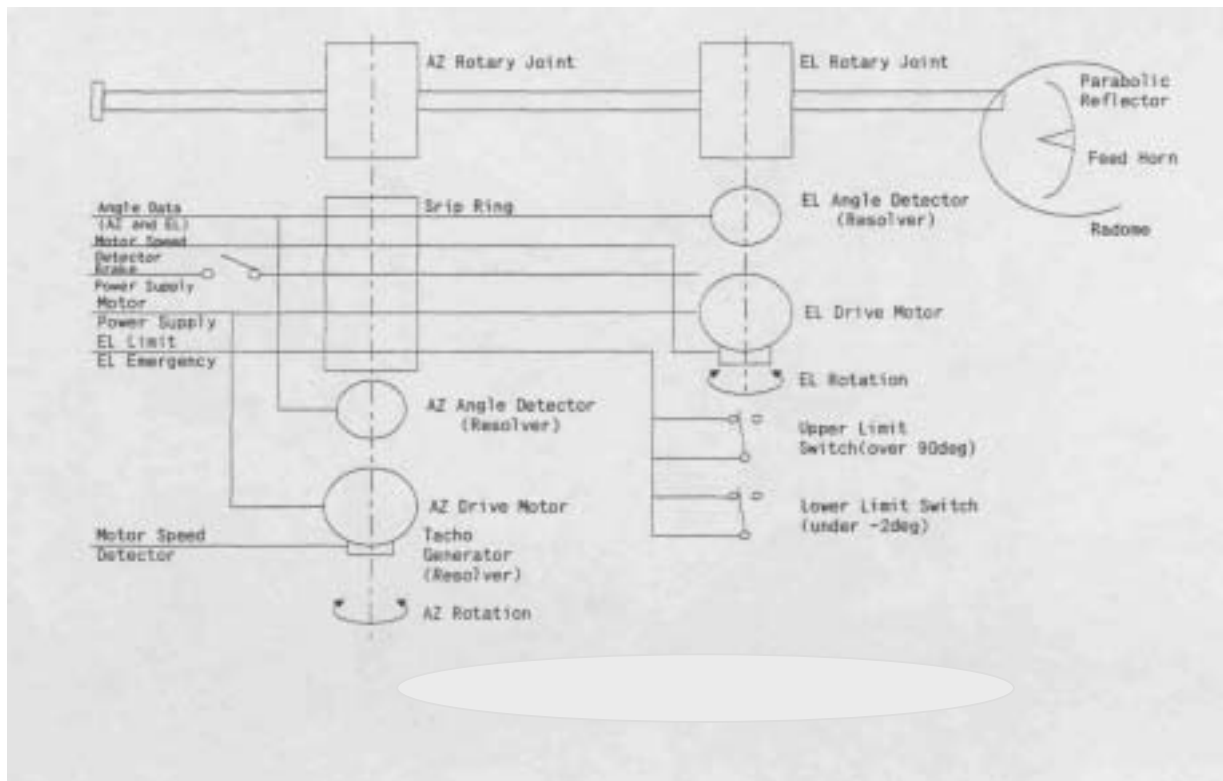


Figure 42: Diagram of the Antenna.

4.4.1. Pedestal and Reflector

The reflector generally consists of a partitioned solid surface dish with a stiffening back structure.

The **pedestal** carries the reflector and other equipment, which form the antenna, with a capability of continuous rotation in azimuth and elevation scanning continuously during whole operation period.



Figure 43: Pedestal and Reflector

4.4.2. Rotary Joint

Two rotary joints (one each for AZ and EL) are located in the waveguide near the Antenna. Rotary joint performs the role to relay between fixed waveguide and the Antenna which rotates and turns both on AZ and EL. As illustrated in Fig .1-2(a), coaxial line (upper part) on the output side and the one (lower part) on the input side are electrically joined by means of a choke coupling. Therefore, the upper part can rotate while the lower part is fixed.



Figure 44: Rotary Joint.

4.4.3. Slipring

The Slip ring sends power and signals to the EL drive mechanism when a ring part on AZ rotation side and a brush installed in a brush holder on the fixed side slide. Both the ring part and the brush are divided for signal and for electric power, and the appearances are different. The brushes are installed double in order to prevent the generation of electric arc.



Figure 45: Some Sliprings.

4.4.4. Waveguide and Feed Horn

Waveguide is a transmission device that controls the propagation of an electromagnetic wave so that the wave is forced to follow a path defined by the physical structure of the guide. Waveguides, which are useful chiefly at microwave frequencies in such applications as connecting the output amplifier of radar set to its antenna, typically take the form of rectangular hollow metal tubes but have also been built into integrated circuits. A waveguide of a given dimension will not propagate electromagnetic waves lower than a certain frequency (the cut-off frequency). Generally speaking, the electric and magnetic fields of an electromagnetic wave have a number of possible arrangements when the wave is travelling through a waveguide. Each of these arrangements is known as a mode of propagation. Waveguides also have some use at optical frequencies. The pyramidal horn is adopted to feed the parabolic reflector with electromagnetic wave. Since TE_{10} mode, which is the main mode of a rectangular waveguide, is applied to the pyramidal horn and also because of optimization of the aperture, symmetrical cross section beam width is realized. Electromagnetic waves are radiated from Feed horn. They are sprayed to the parabolic reflector, where they are formed into pencil beam usually less than 1 degree beam width and radiated into free space. The interface between feed horn and waveguide is shielded with a pressure window in order to prevent leakage of pressurized air within waveguide.

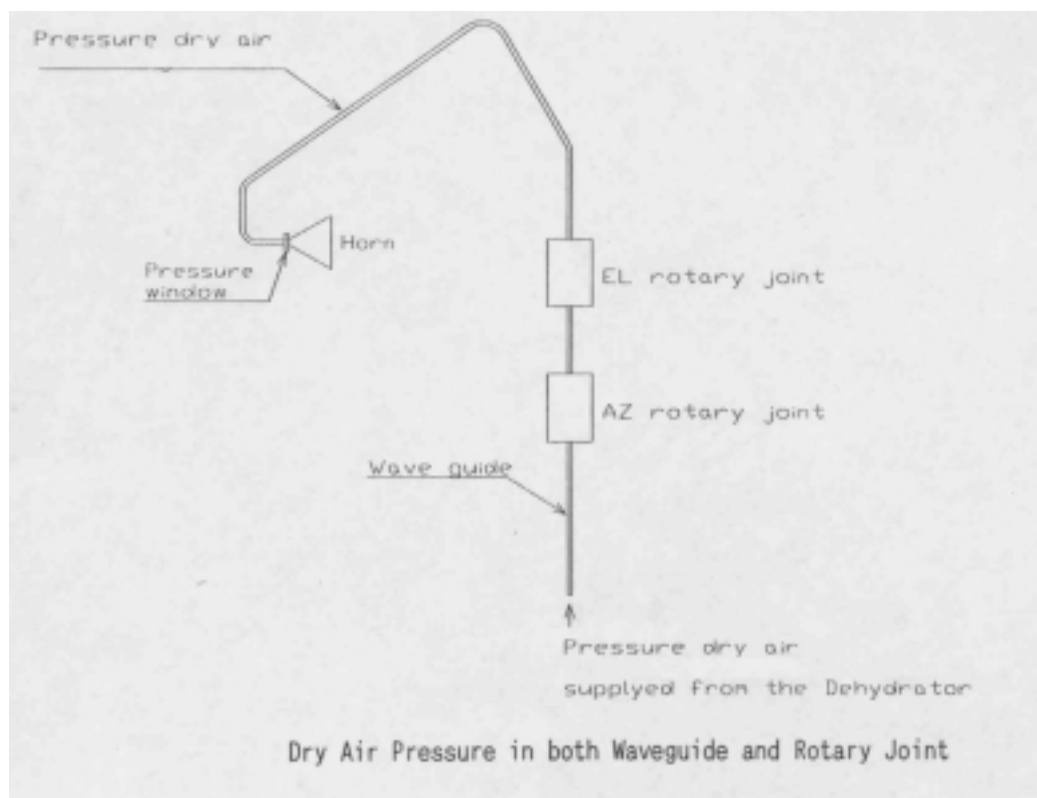


Figure 46: Rotary Joint and Waveguide.

4.4.5. Dual Polarization Units (in Polarimetric Radars)

Recently, some Doppler weather radars have been developed as Polarimetric System with a capability of detecting the Differential Reflectivity ZDR. In some cases, a dual polarization switch unit is used to make switching between the waveguides for vertically and horizontally polarized waves.

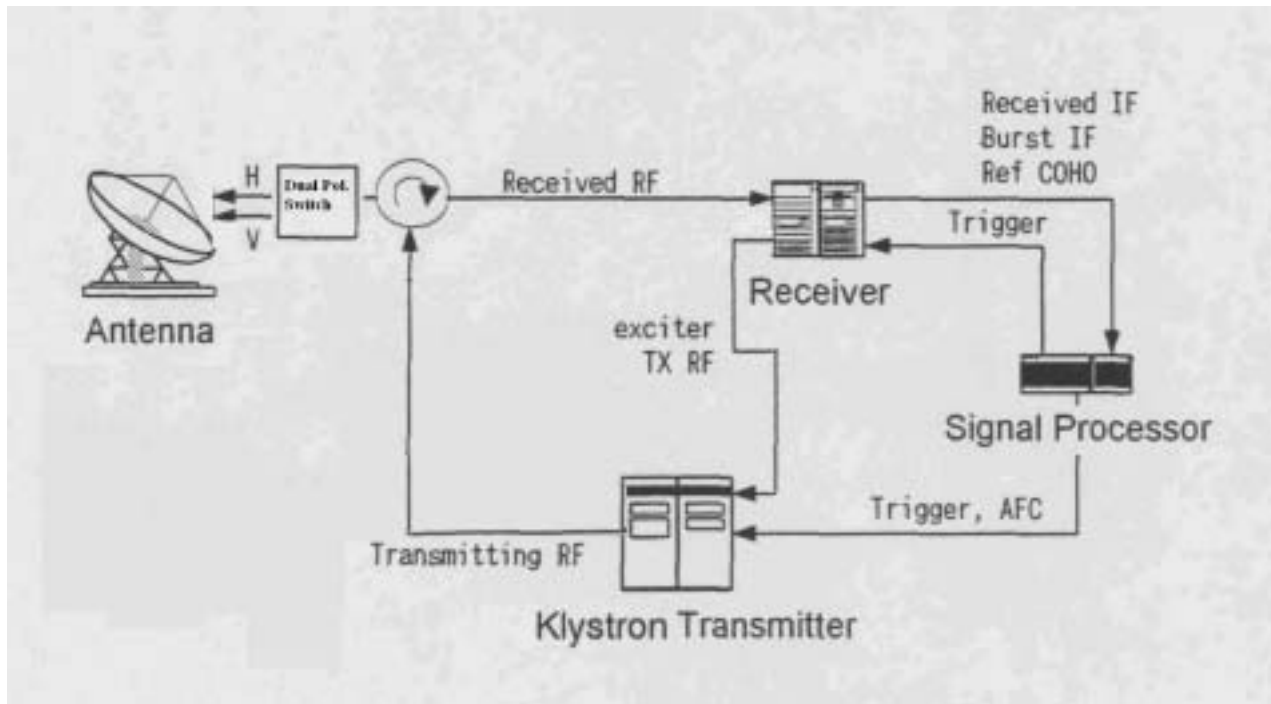


Figure 47: General Block Diagram of Dual Polarization System with Dual Polarization Switch.

The dual polarization switch is a special kind of waveguide component. It is used together with a single receiver/transmitter to connect an antenna with horizontal and vertical waveguide feed. This component is a very fast switching magnetic type. That makes it possible to switch between two normal pulses with a PRF up to 1200Hz. Mechanical switches are much slower than this magnetic type, so that the transmitter must not generate any pulses during the switching time of a mechanical switch.

The technical principle of this magnetic switch is similar to the circulator, which separates the transmitted and received pulses. Also the dual polarization switch works as a four port circulator. This is very important for the understanding of the operation of the whole system.

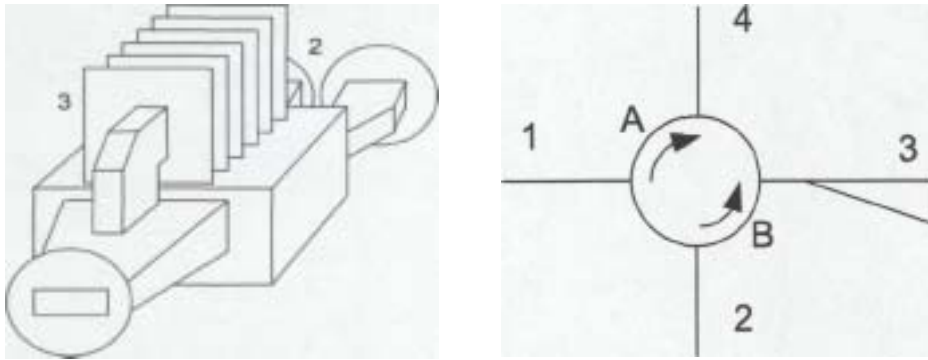


Figure 48: Dual Polarization Switch.

This kind of circulator has the opportunity to change the direction of the circulation by electrical driven magnets.

To change the direction of the circulation does not mean to switch like a normal mechanical switch

If direction A was chosen, the electromagnetic waves travel from port 1 to port 2, from port 2 to port 3, from port 3 to port 4 and from port 4 to port 1.

If direction B was chosen, the waves travel in the other way : from port 1 to port 4, from port 4 to port 3, from port 3 to port 2 and from port 2 to port 1.

Port 3 is terminated with a dummy load due to the reason that normally not all ports are needed.

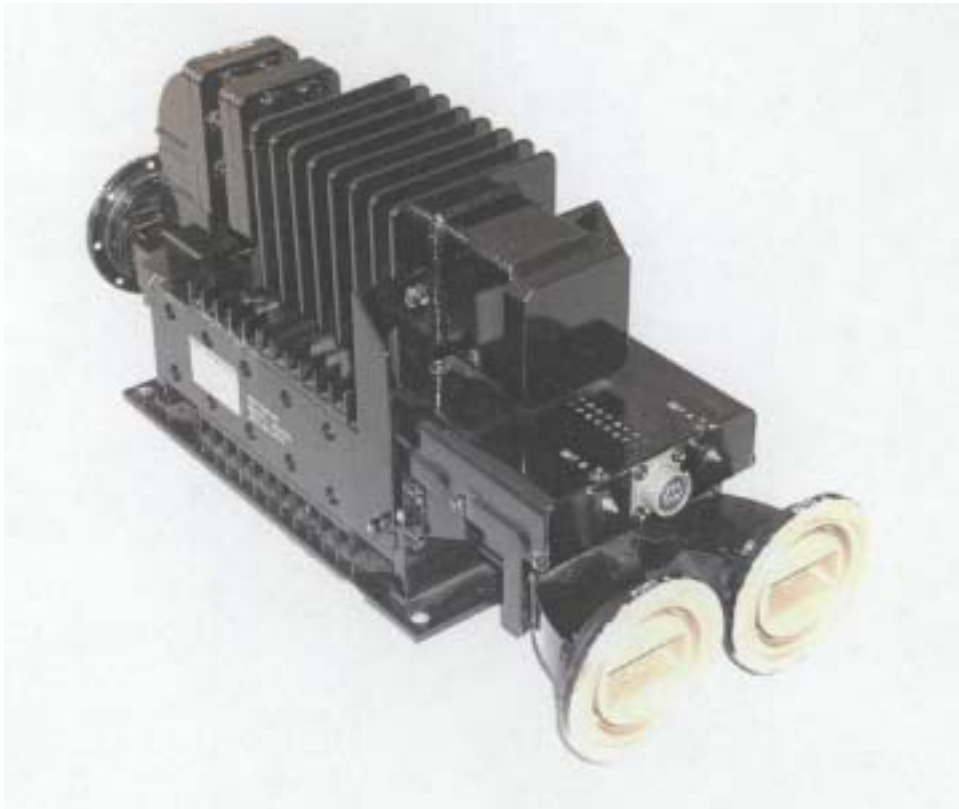


Figure 49: Dual Polarization Switch.

However, the most preferred method in Polarimetric Radar Systems is to divide transmitted power and send to antenna via two separate circulator and collecting received signal by two identical receivers. Signals sent are half powered for each channel here, but radiated **simultaneously** in contrast to Dual Polarization Switched Type. This allows user to get different Polarimetric Radar Products.

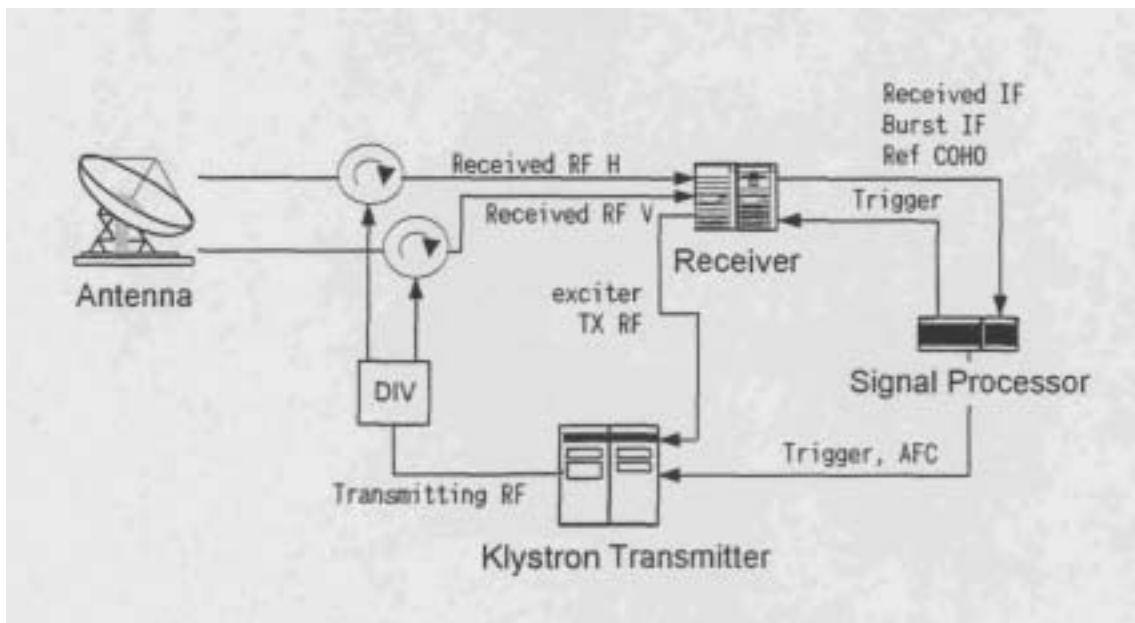


Figure 50: General Block Diagram of Dual Polarization System without Polarization Switch.

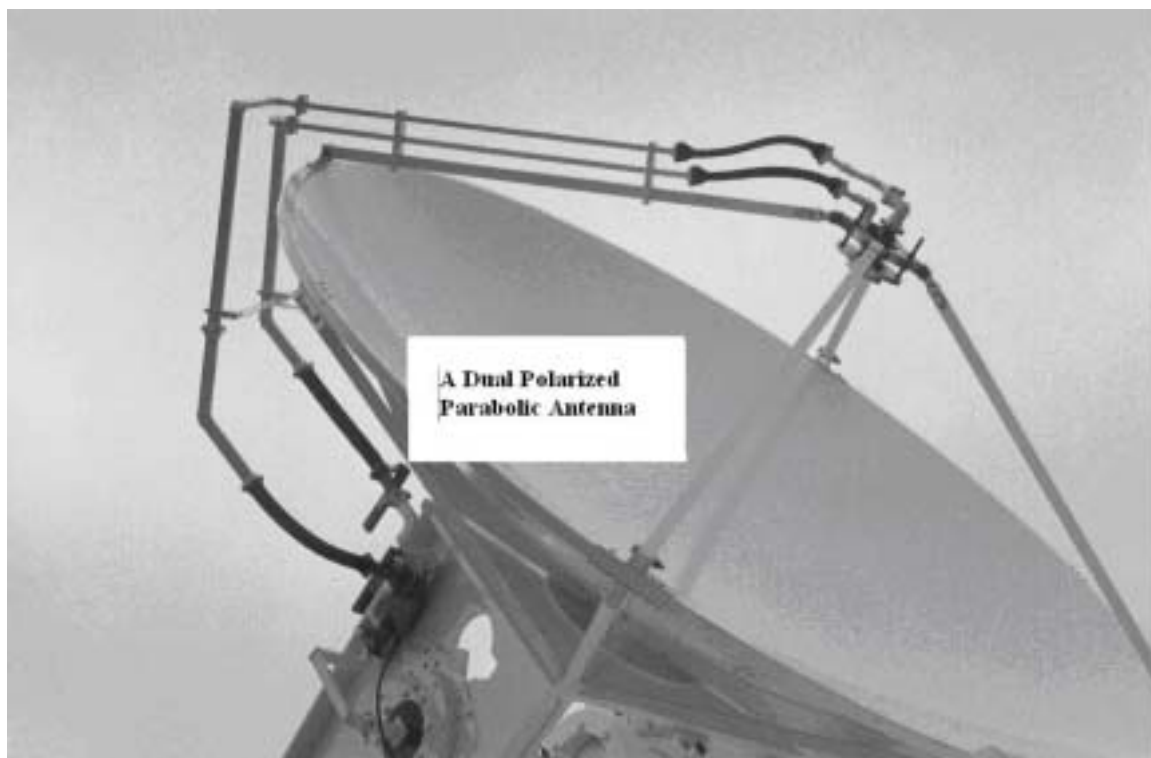


Figure 51: Dual Polarized Parabolic Antenna.

4.4.6. Antenna Control Unit, Servo Motors and Angle Detector

Antenna Control Unit

Antenna control unit (ACU) performs all functions regarding positioning, scanning, checking and safety control of antenna. It also generates BITE information and send to the radar control processor. ACU reports the actual angle of the antenna dynamically to external devices. Resolver system, as an angle detector, is being used for AZ and EL axis, independently. ACU has another function for safety control that, for example, the servo power commanded from external Servo Processor is cut when any interlock system is activated. This safety control is made with the status signals of ACU itself and those reported from ANT.

Servo Motors

It is generally required for an antenna used in a Weather Radar System to be capable of scanning its narrow pencil beam in any direction, and reporting accurate position to where the Antenna is facing. So, Servo Motor-Driver system is preferred in both Azimuth and Elevation scanning control.

Servomechanism is an automatic device for the control of a large power output by means of small power input or for maintaining correct operating conditions in a mechanism. It is a type of feedback control system. The constant speed control system of a Servo Motor is a mechanism that monitors any variations in the motor's speed so that it can quickly and automatically return the speed to its correct value.

Angle Detector

Angle detector, resolver system, detects rotation angle on AZ and EL. Angle detector forms servo loop system together with other components for accurate control of rotation speed and positioning of the Antenna.

Angle detector forms servo loop system together with other components for accurate control of rotation speed and positioning of the Antenna.

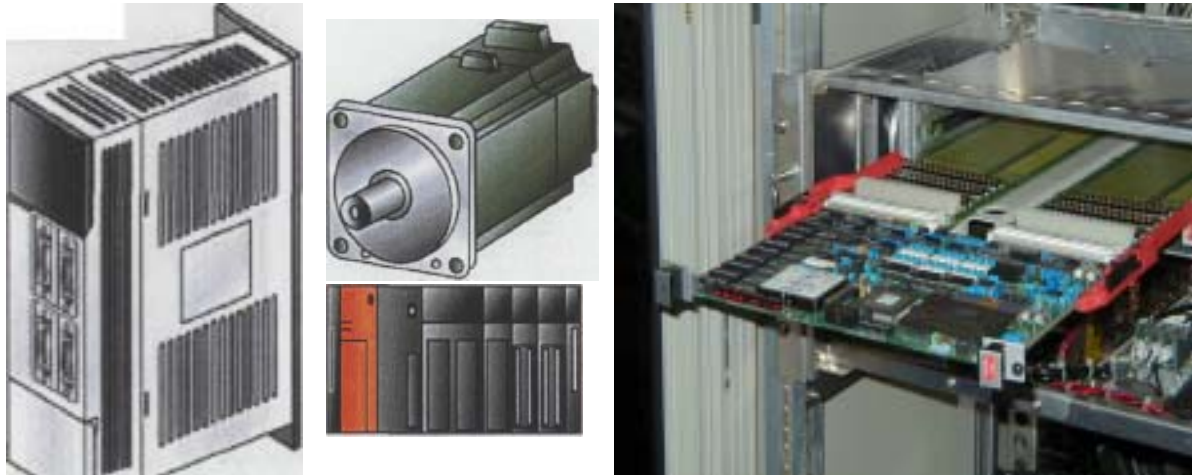




Figure 52: Some Pictures on Dehydrator, TX Cabinet, Cable, Waveguide and its Tray, 7m Parabolic Antenna, Antenna Pedestal, Obstruction Lights, Position Resolver of Antenna, Antenna Control Unit and Servo Amp., Antenna Control PCBs, Servo Amp., Angle Detector, Controller, Servo Motor.

5. RADOME

5.1. General Overview

Antennas of ground based radars are often subject to severe weather. So some enclosure is needed for antennas to survive and to perform under adverse weather conditions. These enclosures are called as RADOME.

A **radome** (radar dome) is a weatherproof enclosure used to protect an antenna. It is used mainly to prevent ice (especially freezing rain) from accumulating directly onto the metal surface of the antenna. In the case of a spinning radar dish antenna, the radome also protects from debris and rotational irregularities due to wind.

For stationary antennas, excessive amounts of ice can de-tune the antenna to the point where its impedance at the input frequency rises drastically, causing VSWR (Voltage Standing Wave Ratio) to rise as well. This reflected power goes back to the transmitter, where it can cause overheating. A fold back circuit activates to prevent this; however, it causes the station's output power to drop dramatically, reducing its range.

A radome prevents this by covering the antenna's exposed parts with a sturdy, weatherproof material, typically fibreglass, which keeps the ice far enough away from the antenna to prevent any serious issues. A radome does however add to the wind load and the ice load, in addition to its own weight, and so must be planned for when considering overall structural load.

For this reason, and the fact that radomes may be unsightly if near the ground, heaters are often used instead. Usually running on DC, the heaters do not interfere physically or electrically with the AC of the radio transmission.

Radomes must be mechanically strong if they are to provide the necessary protection and they must not more interfere with the normal operation of the antenna as absolutely necessary.

A properly designed radome should distort the antenna pattern as little as possible. The presence of a radome can affect the gain, the beam width, side lobe level, the polarisation, and the direction of the bore sight, as well as change the VSWR (voltage-standing-wave ratio) and the antenna noise temperature. In order to keep the affects as low as possible, the following radome characteristics are specified:

- One way transmission loss for the dry and wet state
- Increase of side lobe level
- Reflected power
- Cross polarisation degradation
- Bore sight error
- Beam width increase.

These parameters have a close relation to the antenna that is covered, thus the radome performance can only be estimated on the basis of the antenna characteristics.

There are several radome types available as far as the supporting structure and the wall material is concerned. There are foam radomes and space-frame radomes. The latter ones use different types of sandwich panels. Their properties may be adjusted to the antenna and local environment.

5.2. Radome Types

Due to its size the radome has to be subdivided into panels for production and transportation reasons. Out of an infinite number of possible solutions most of them can be assigned to one the following types:

Igloo : The radome is subdivided into small regular pieces with either vertical or horizontal joints.

Orange Peel: The radome is subdivided into relatively large vertical pieces with mostly vertical joints.

Quasi-Random: The radome is subdivided into a number of irregular pieces without preferred joint direction.

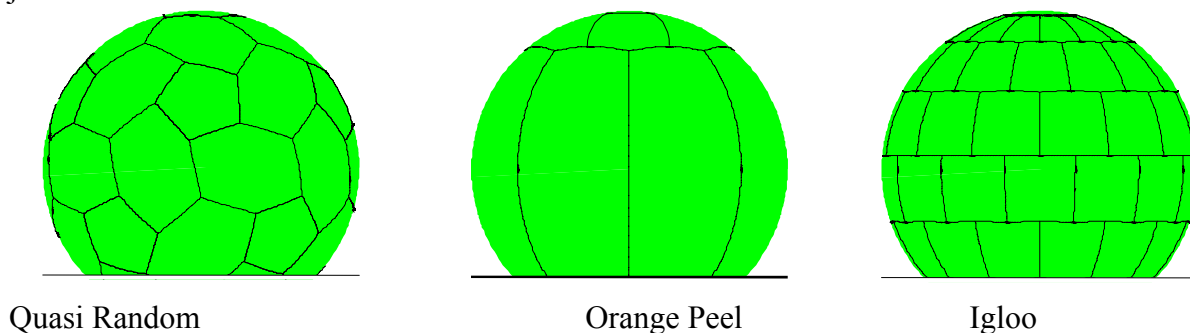


Figure 53: Different Types of Radome.

6. RADAR CONTROL AND SIGNAL PROCESSORS

6.1. General Overview

In modern radars, control of the function of each sub-unit and signal processing are done by dedicated computers incorporated within the system. They are generally known as control and signal processors.

6.2. Control Processors

The radar control processor is responsible for the control and supervision of the radar system. In particular the Built-in Test Equipment (**BITE**) is controlled by this processor. The states of a large number of subsystem parameters are monitored and if a fault is detected the control processor acts according to the severity. Additionally the control processor interfaces the radar system to the data processing system.

The signal processor computes the reflectivity (with and without corrections for clutter, second trip echo, attenuation and partial beam filling), mean velocity and spectrum width. Many commercially available off-the-shelf digital signal processors (DSPs) may be linked together to meet the computational requirement. The signal processor unit performs analogue to digital conversion, quality assurance and applying various corrections to the dataset in addition to performing complex statistical signal-processing jobs. Radar displays are of different types. Plan position indicator (PPI), range height indicator (RHI) amplitude range scope (AR scope), constant altitude PPI (CAPPI), described later in the article, are a few to mention. Earlier radars used dedicated cathode ray tubes to display the echoes. Modern radars use computer displays for displaying their products.

6.3. Signal Processor

The **signal processor is a critical unit of radar system with important functions.** It performs three main tasks:

- (1) Triggering of the radar system, especially of the transmitter,
- (2) Phase and frequency modulation of the carrier signal and
- (3) Digitizing, polar coordinate tagging and pre-processing of the received signals.

Signal processor accepts analogue linear channel I and Q as well as a LOG receiver input. The LOG receiver input is only used for an intensity estimation which is used to drive an attenuator which prevents a saturation of the linear channels.

Since the signal to be processed by signal processor is a complex linear signal, intensity estimation consists simply of integrating the power in the linear channel ($\text{power} = I^2 + Q^2$) over range and azimuth, as specified by the user. The resulting power estimate is corrected for system noise (by subtracting the average system noise level), for target range (using an R-squared relationship), for atmospheric attenuation (using an attenuation factor supplied by the user), and optionally for transmitter power.

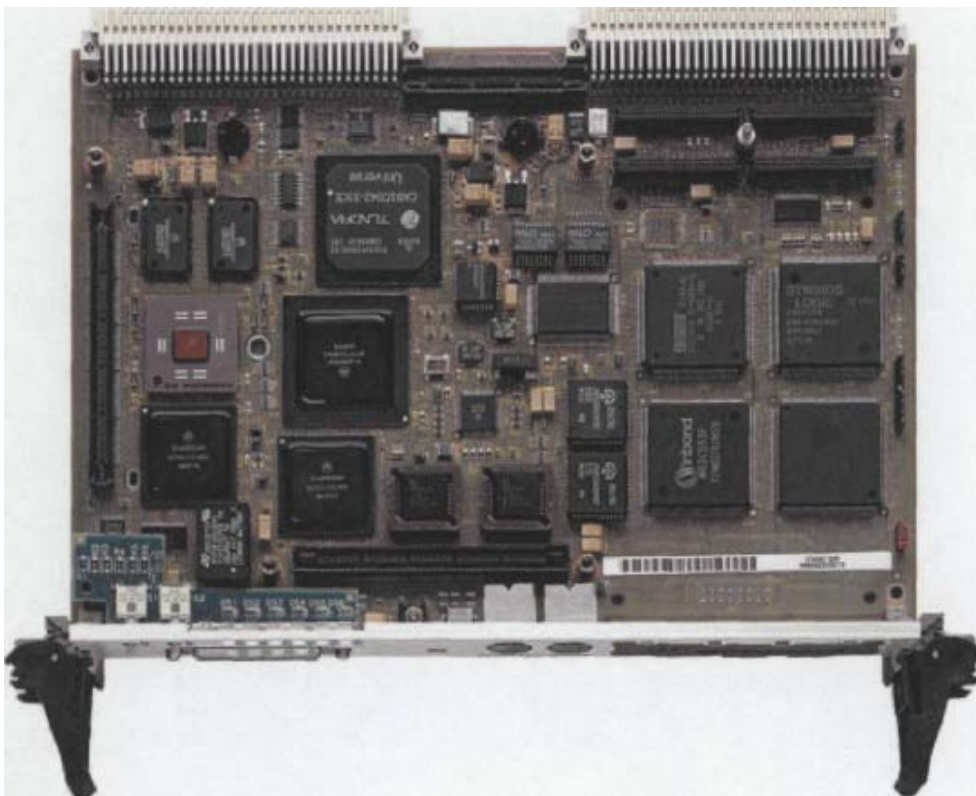


Figure 54: Signal Processor Card.

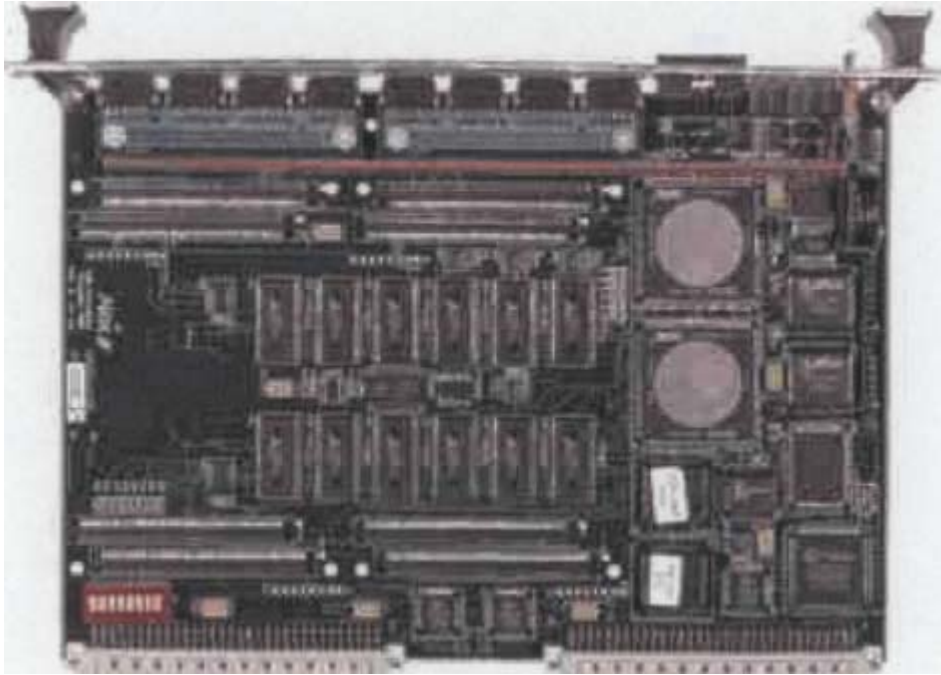


Figure 55: Signal Processor Card.



Figure 56: Digitizer.



Figure 57: A Radar Control Processor.

Some View of Radar Systems:



Figure 58: Balıkesir Radar Site-Turkey.



Figure 59: Hardware of Zonguldak Radar/Turkey.



Figure 60: Scenic View of Ankara Radar/Turkey.



Figure 61: General View of Radar Hardware.

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TRAINING MATERIAL ON WEATHER RADAR SYSTEMS

MODULE C

PROCESSING BASICS IN
DOPPLER WEATHER RADARS

[original PDF with bookmarks \(2 MB\)](#)



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EXPERT TEAM ON TRAINING ACTIVITIES AND TRAINING MATERIALS

TRAINING COURSE ON WEATHER RADAR SYSTEMS

MODULE C: PROCESSING BASICS IN DOPPLER WEATHER RADARS

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WMO RMTTC-TURKEY

ALANYA FACILITIES, ANTALYA, TURKEY

MODULE A: INTRODUCTION TO RADAR

MODULE B: RADAR HARDWARE

**MODULE C: PROCESSING BASICS IN DOPPLER
WEATHER RADARS**

MODULE D: RADAR PRODUCTS AND
OPERATIONAL APPLICATIONS

MODULE E: RADAR MAINTENANCE AND
CALIBRATION TECHNIQUES

MODULE F: RADAR INFRASTRUCTURE

PROCESSING BASICS IN DOPPLER WEATHER RADARS

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ABBREVIATIONS:

PRF	: Pulse Repetition Frequency
PRT	: Pulse Repetition Time
IF	: Intermediate Frequency
RF	: radio Frequency
I	: In-phase
Q	: Quadrature
FT	: Fast Transform
FFT	: Fast Fourier Transform
DSP	: Digital Signal Processor
V	: Velocity
Z	: Reflectivity
W	: Spectral Width
IFD	: Intermediate Frequency Digitizer
RX	: Receiver
TX	: Transmitter
W/G	: Waveguide
LNA	: Low Noise Amplifier
D	: Diameter of Particle
dB	: Decibel
dBm	: Decibel Milliwatt
dBZ	: Logarithmic Scale for Measuring Radar Reflectivity Factor
V	: Antenna Speed
Hz	: Hertz
KHz	: Kilohertz
MHz	: Megahertz
GHz	: Gigahertz
LOG	: Logarithmic
LIN	: Linear
IIR	: Infinite Impulse Response
PE	: Photo-Electron
CPU	: Central Processing Unit
AC	: Alternating Current
DC	: Direct Current
R_{max}	: Maximum Unambiguous Range
V_r	: Radial Velocity
STALO	: Stable Oscillator
COHO	: Coherent Oscillator

1. GENERAL OVERVIEW

Doppler Meteorological Radars are used to detect, to process, to distribute and display meteorological data in a large scale area. Doppler technology opened a new window in the field of the radar meteorology and increased the performance of weather radars significantly. Doppler weather radars are capable of acquiring particle velocity data in addition to range, direction, and reflectivity data. Software processing is used to control the radar operating characteristics to produce the optimum radar volume coverage patterns and to optimize the radar returns. The resulting base weather data is then processed through the application of meteorological algorithms to generate base and derived weather products. These products are further processed using graphics algorithms to produce readily interpretable weather data displays on colour monitors.

After receipt of the reflected echo from target, the signal passes some processing stages for product generation. These stages include many complex process and algorithms. These processes and algorithms including basic products will be explained in this module.

2. SIGNAL PROCESSING

Weather Radars employ high dynamic-range linear receiver and DSPs (digital signal processors) to extract information from the received echo power. Linear receiver output in intermediate frequency (IF) and analogue form is converted to digital form in the analogue-to-digital converter and fed to digital filters to split the power into in-phase (I) and quadrature (Q) components. DSPs process the raw I/Q data and perform phase and amplitude correction, clutter filtering, covariance computation and produce normalized results. These normalized results are tagged with angle information, headers and given out as a data set. Covariance computation is based on pulse pair processing. Intensity estimation consists simply of integrating the power in the linear channel ($I^2 + Q^2$) over range and azimuth. The resulting power estimate is corrected for system noise, atmospheric attenuation and transmitter power variations. The signal processing of the linear channel ends with the estimation of reflectivity, mean radial velocity and velocity spectrum width.

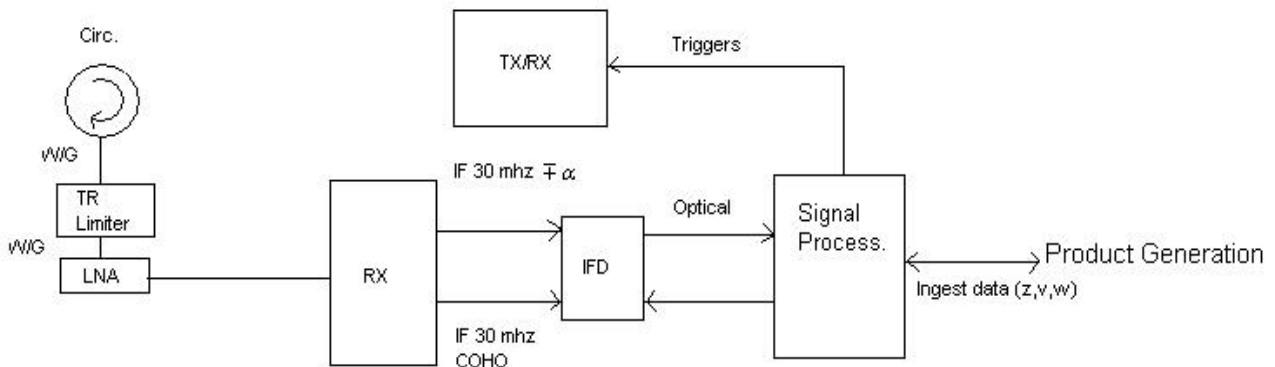


Figure 1: General Signal Flow Chart of Radar System.

Doppler velocity (V):

Doppler velocity is reflectivity-weighted average velocity of targets in the pulse volume and determined by phase measurements from a large number of successive pulses. This is also called radial velocity and gives only the radial component of the velocity vector. It is generally assumed that raindrops and other particles are advected with the wind and have no own motion except their falling velocity.

Reflectivity factor (Z):

This is the integral over the backscatter cross-section of the particles in a pulse volume. For particles small compared to the wavelength the scatter cross-section is D^6 , where D is the diameter of the particle. Radars are calibrated in the way to give directly (assuming the dielectric constant of water) the reflectivity factor from the received backscattered energy. Units for the reflectivity factor are $\text{mm}^6 \text{m}^{-3}$ or the logarithmic value of this in dBZ.

Spectral width (W):

Spectral measure is a measure of the dispersion of velocities within the pulse volume and standard deviation of the velocity spectrum. Spectral width depends among others from the turbulence within the pulse volume.

Sampling:

Sampling Rate is defined by the velocity of scan, PRF (Pulse Repetition Frequency) and Resolution.

$$V = \frac{\text{Resolution} * f(\text{PRF})}{\text{sampling}} \qquad \text{sampling} = \frac{\text{Resolution} * f(\text{PRF})}{V}$$

Resolution= 0.7°

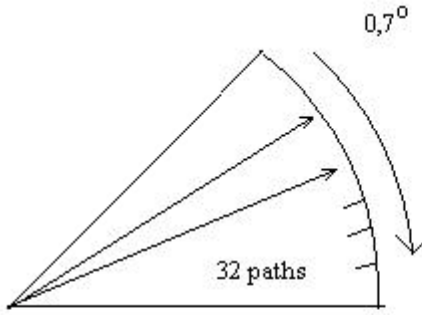
Min speed= 6 deg/sec

Sample=?

PRF= 1500 Hz

$$\text{Sampling} = \frac{0.7}{6} * 1500 = 175$$

$$\text{Beam spacing (Resolution)} = \frac{N_{\text{samp}}}{\text{PRF}} * \text{Ant. speed}$$



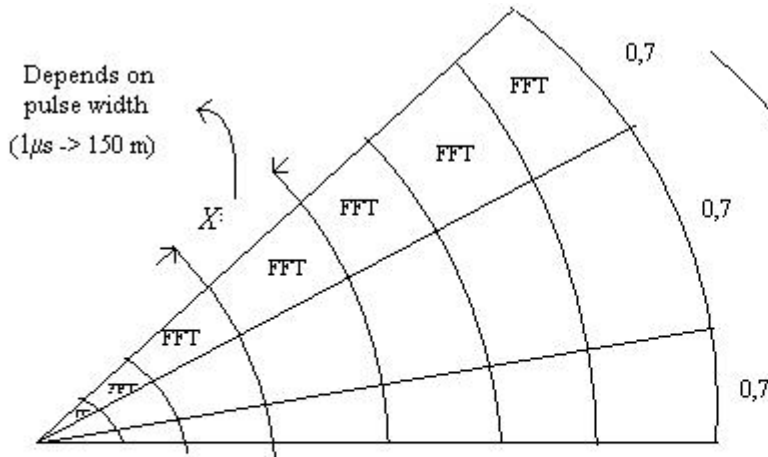
Sampling

Resolution: 0,7
 Sampling : 32
 Speed : 24 deg/sec
 PRF : ?

$$PRF = \frac{32 * 24}{0,7} = 1097$$

Number of Sampling: 2ⁿ is preferable because of FFT
 n: 1,2,3... sampling → 2,4,8,16,32...

Example:



360/0,7=514 > number of portion (514 dilim)

$$X = \frac{3.10^8 * 1.10^{-6}}{2} = \frac{300}{2} = 150 \text{ m}$$

120 km > our range(doppler)

$$\frac{120000}{150\text{m}} = 800 \text{ part (her dilimin içindeki sayı)}$$

of FFT = 411200 and

$$514 * 800 = 411200 > \# \text{ of FFT calculations for } 360^\circ (1\mu\text{sec})$$

Each FFT depends on Sampling Rate

2.1. I/Q Demodulation

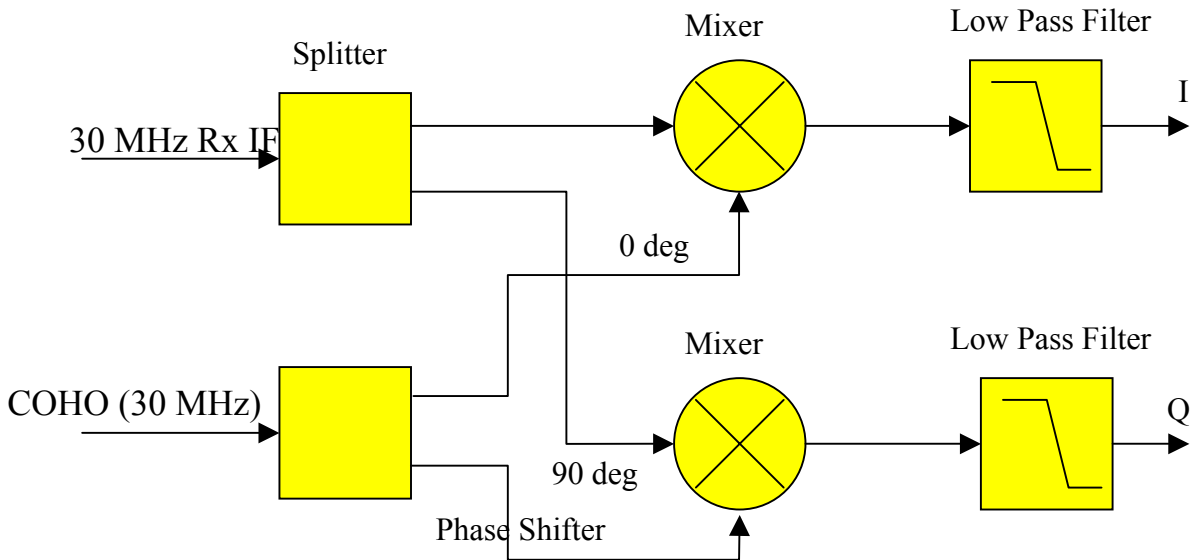


Figure 2: I/Q Demodulation.

2.2. Analogue Doppler Radar Channels

Reflectivity is calculated using the digitised LOG channel. Velocity is calculated using the linear channel's I/Q signals. An estimate of a PE's power contribution can be calculated using the digitised linear channel (I/Q data) and then applied to correct the LOG channel power estimate.

2.3. Doppler Signal Processing Techniques

- Pulse Pair
- Spectral Processing using Fourier Transform

2.4. Pulse Pair

Target velocity can be estimated by use of the “Pulse-Pair” technique. Pulse-Pairing provides an estimate of a target’s velocity by determining the average phase shift of a target that has occurred from PRF to PRF, averaged over several PRF.

As many PRF as can be obtained between 1 deg azimuth angle Boundaries are used. More PRF equates to less noise, giving more accurate estimates. The Pulse-Pair algorithm was traditionally used as the CPU horsepower required is not excessive.

I&Q data samples are considered to describe a complex vector that will rotate at a speed directly related to the target’s velocity i.e. $\text{sample}[i] = I + jQ$. An Auto-Correlation algorithm is applied to each individual range bin, across several PRF, and is defined as below:

$$\text{Lag}[n] = \sum_{i=0}^{\text{NumPRFsamples}-1} \text{conjugate}(\text{sample}[i]) \cdot \text{sample}[i+n] \quad \text{for } n = 0 \ \& \ 1$$

The conjugate of a complex value is simply flipping the sign of the imaginary component, in this case the Q value i.e. $\text{Conjugate}(\text{sample}[i]) = I - jQ$

The Auto-Correlation algorithm conveniently provides two valuable answers:

- ⇒ The **real component** of lag [0] provides Intensity information.
- ⇒ The **phase** of lag [1] provides Velocity information.

Pulse Pair: Algorithm – Lag Zero

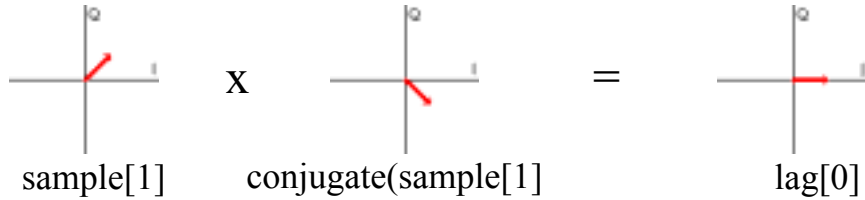
Lag Zero = Signal Power

Assume a Unit Vector - i.e. a vector length of 1 @ 45 deg, i.e. $0.707 + j0.707$

$$\begin{aligned} \text{Lag [0]} &= (I + jQ) \times \text{conj}(I + jQ) \\ &= (I + jQ) \times (I - jQ) \\ &= (0.707 + j0.707) \times (0.707 - j0.707) \\ &= 0.707 \times 0.707 - j(0.707 \times 0.707) + j(0.707 \times 0.707) - j^2(0.707 \times 0.707) \end{aligned}$$

$$\begin{aligned}
 &= 0.5 - j0.5 + j0.5 - j^2(0.5) \\
 &= 0.5 + j0 + 0.5 \\
 &= 1 + j0
 \end{aligned}$$

The real component provides the magnitude; the phase will always be zero.



Pulse Pair: Algorithm First Lag = Velocity

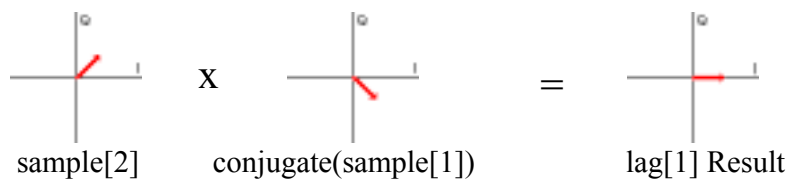
Stationary target:

I&Q samples for PRF₂ will ideally have exactly the same phase and magnitude as I&Q samples taken at PRF₁. eg. PRF₁ = 0.707 + j0.707 & PRF₂ = 0.707 + j0.707

Calculating the auto-correlation of the first lag will provide the phase difference between PRF₁ and PRF₂.

The phase of the resultant vector provides the phase difference between PRF₁ & PRF₂.

$$\begin{aligned}
 \text{Lag [1]} &= (I_2 + jQ_2) \times \text{conj}(I_1 + jQ_1) \\
 &= (I_2 + jQ_2) \times (I_1 - jQ_1) \\
 &= (0.707 + j0.707) \times (0.707 - j0.707) \\
 &= 0.707 \times 0.707 - j(0.707 \times 0.707) + j(0.707 \times 0.707) - j^2(0.707 \times 0.707) \\
 &= 0.5 + j0 - j^2(0.5) \\
 &= 0.5 + j0 + 0.5 \\
 &= 1 + j0 \quad \Rightarrow \text{Phase difference} = 0 \text{ deg}
 \end{aligned}$$



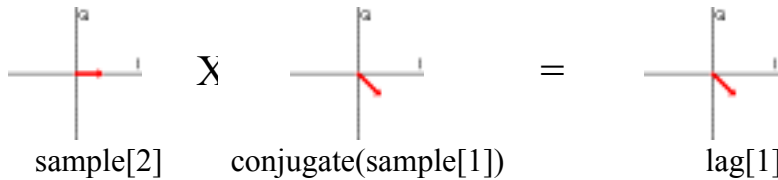
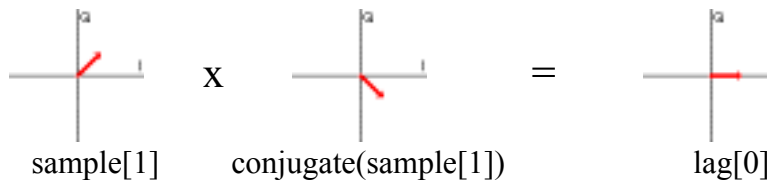
Pulse Pair: Algorithm First Lag = Velocity

Moving target: $PRF_1 = 0.707 + j0.707$

$$PRF_2 = 1 + j0$$

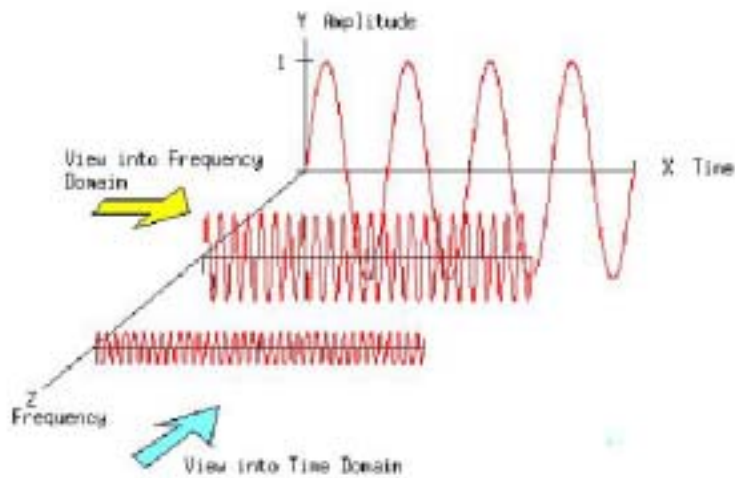
$$\begin{aligned} \text{Lag [1]} &= (I_2 + jQ_2) \times \text{conj} (I_1 + jQ_1) \\ &= (I_2 + jQ_2) \times (I_1 - jQ_1) \\ &= (1 + j0) \times (0.707 - j0.707) \\ &= (1 \times 0.707) - j(1 \times 0.707) + j(0 \times 0.707) - j^2(0 \times 0.707) \\ &= 0.707 - j0.707 + j0 - j^2(0) \\ &= 0.707 - j0.707 \end{aligned}$$

Phase = -45deg. or $-\pi/4$



2.5. Clutter Correction

The major difference between FFT and pulse pair processing is the way in which clutter filtering is performed. The pulse pair processing uses a time domain IIR filter while the FFT mode uses a frequency domain filter. Advantage of the FFT approach is that it is less destructive to overlapped weather than the IIR filter since the clutter filter algorithm attempts to interpolate over the weather. This results in more accurate estimates of velocity, width and clutter correction. Because the clutter correction is more accurate, the resulting reflectivity estimates are more accurate.



Looking at signals from two different points of view
Frequency Domain. Another name for it is the **Signal Spectrum.**

Figure 3: Frequency, Time and Amplitude Axis.

Pulse Pair: Clutter Correction

Clutter Correction is achieved by passing the incoming I & Q samples through a Time Domain high pass IIR filter. The high pass filter removes any signal power in the 0Hz region i.e. that of apparently non moving targets e.g. clutter. Various cut off frequencies can be chosen to determine how selective we are about removing signals near 0Hz.

- 1) The unfiltered I&Q samples are auto-correlated and the lag [0] result is known as Uncorrected Reflectivity.
- 2) The filtered I & Q samples are also auto-correlated but the lag [0] result will now contain the signal power devoid of signals near 0Hz (DC).

The difference between the lag [0] results of the filtered and unfiltered data provides an estimate of signal power contributed by any clutter.

This estimated value is then subtracted away from the averaged LOG channel data to give **Corrected Reflectivity** i.e. Reflectivity corrected for power contributed by a permanent echo.

Pulse Pair: Disadvantages

Pulse Pair clutter filtering is highly invasive to any signal near 0Hz. Recall that the radar can only measure **radial** velocity. Tangential rain targets will appear as non-moving targets (minimal radial component). Targets with a radial velocity that has folded back into an apparent 0 ms⁻¹ situation will also be filtered by the IIR filter.

Rain rates will be underestimated in either situation.

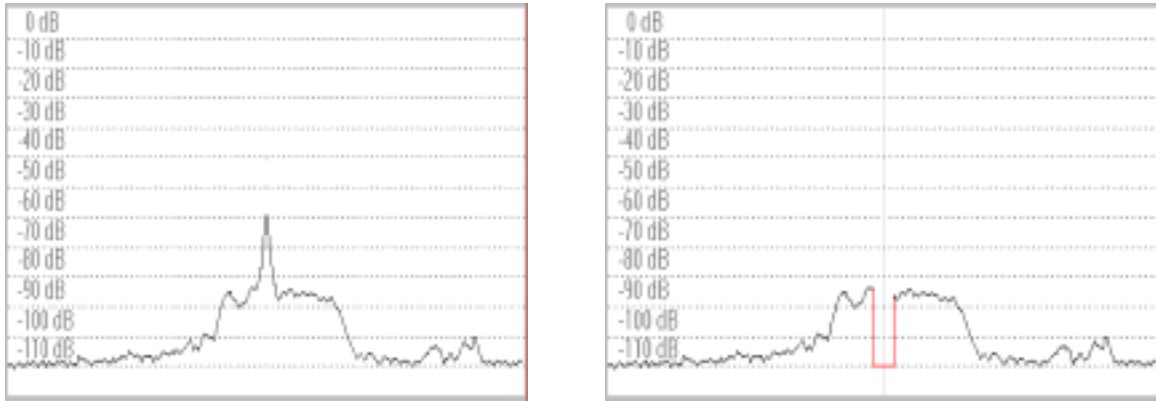


Figure 4: Rain Over PE Spectra and IIR Clutter Notch (Idealised).

Spectral Clutter Processing

I&Q data is transformed from the Time Domain to the Frequency Domain using Fourier Transform methods. Clutter rejection is performed by interpolating across the 0Hz region of the resultant Power Spectra. The reflectivity estimate is not as severely compromised as occurs when using a Time Domain IIR filter.

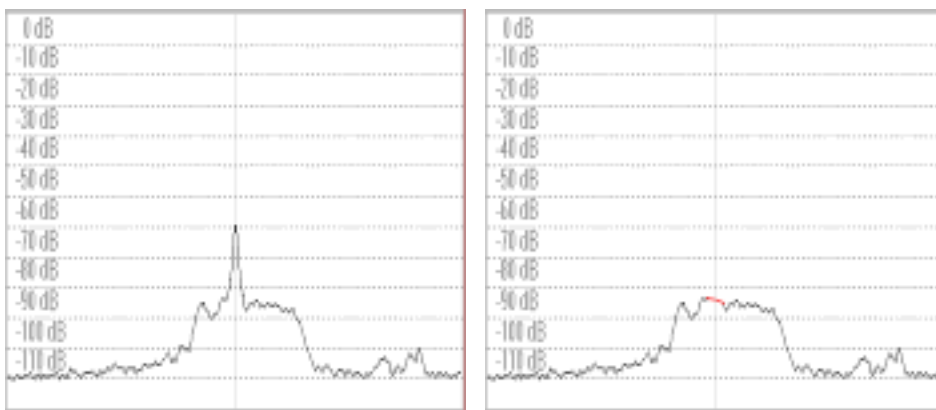


Figure 5: Rain over PE Spectra and Interpolated Spectra.

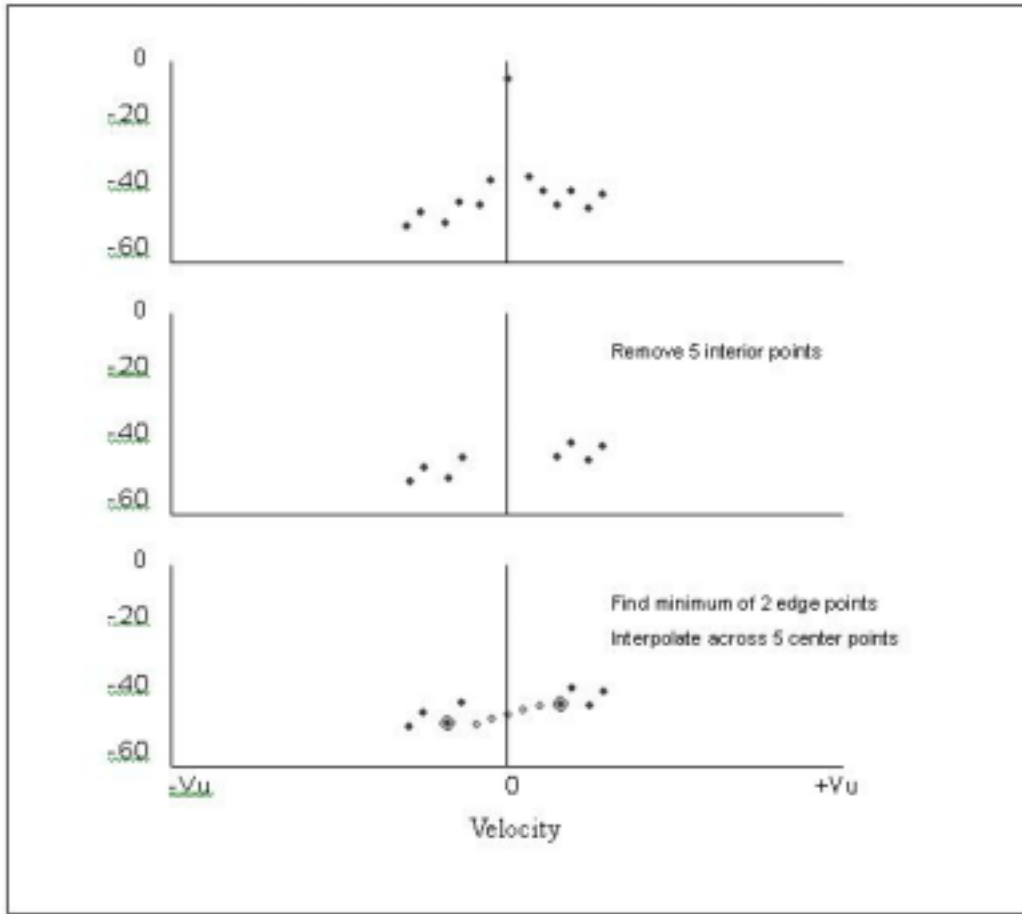


Figure 6: Example of Frequency Domain Clutter Filter

2.6. FFT Implementation

If we decide to use only 16 of the collected samples, $F_s/N = 1$, this means that each frequency varies by 1Hz. We see seven points. The values at frequencies 1, 3 and 5 are correct but in between this is a terrible looking representation of the real FT. All spectrums shown are one-sided and were done in SPW.

Case 1: Here we used 16 samples. Now we have a resolution of $f_s/N = 16/16 = 1$. Now we get 7 points, each 1 Hz away.

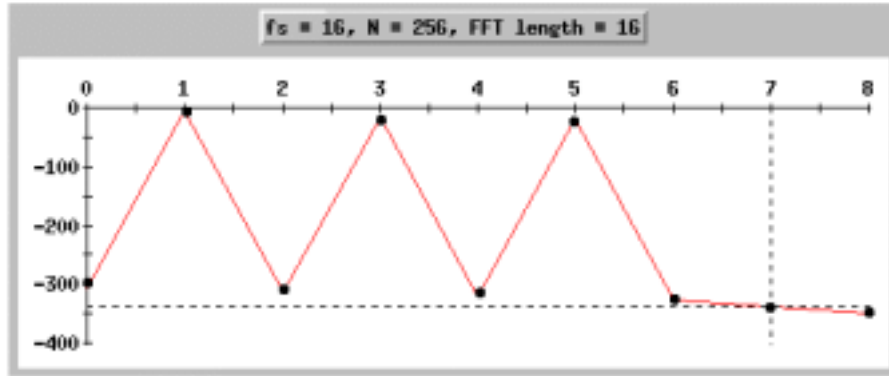


Figure 7: FFT of a Three-Frequency Signal with N = 16.

Case 2: Here we used 32 samples instead of 16. Now we have increased the resolution to $f_s/N = 16/32 = .5$. Now we get 14 points, each .5 Hz away.

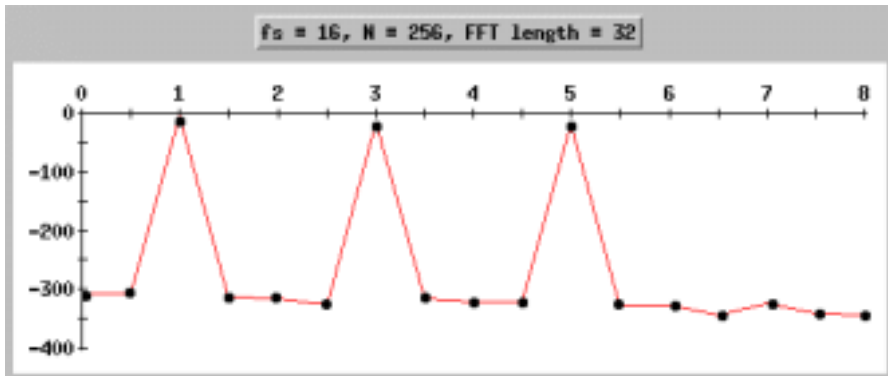


Figure 8: FFT of a Three-Frequency Signal with N = 32.

Case 3: N = 64 samples. Now $f_s/N = 16/64 = .25$. This Fourier Transform is looking much better.

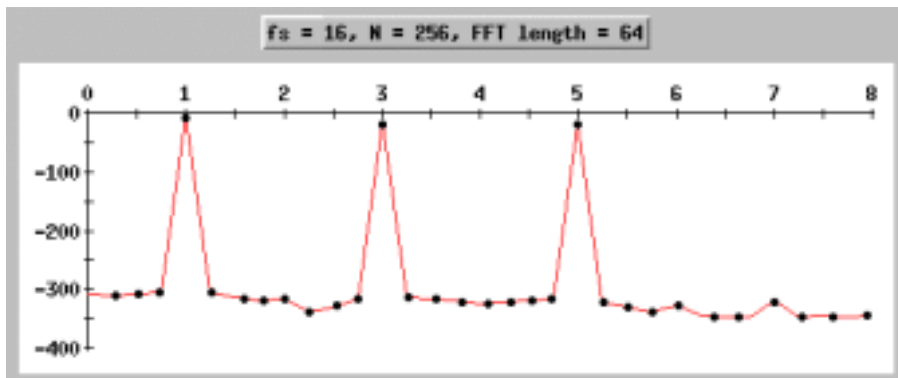


Figure 9: FFT of a Three-Frequency Signal with N = 64.

Case 4: $N = 128$, The FFT looks nearly like the theory.

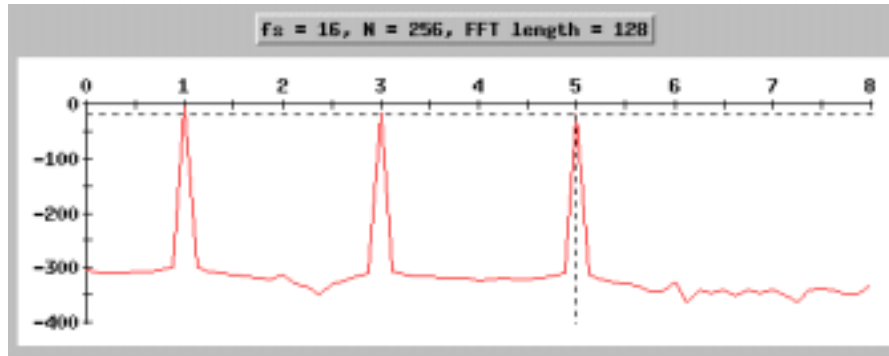


Figure 10: FFT of a Three-Frequency Signal with $N = 128$

Case 5: $N = 256$, This FFT looks quite satisfactory.

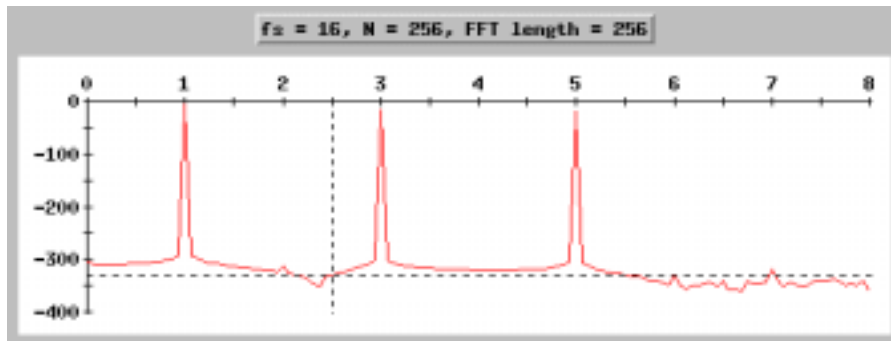


Figure 11: FFT of a Three-Frequency Signal with $N = 256$.

What conclusion can we draw from these? It is clear that the factor f_s/N has the largest impact. So we can always improve the FFT by increasing the size of the FFT.

3. MAXIMUM UNAMBIGUOUS RANGE

The **maximum unambiguous range (Rmax)** is the longest range to which a transmitted pulse can travel and return to the radar before the next pulse is transmitted. In other words, **Rmax** is the maximum distance radar energy can travel round trip between pulses and still produce reliable information. The relationship between the PRF and Rmax determines the unambiguous range of the radar. The greater the PRF (pulses per second), the shorter the maximum unambiguous range (Rmax) of the radar.

The maximum unambiguous range of any pulse radar can be computed with the formula:

Rmax = c/(2xPRF), where *c* equals the speed of light. (3x10⁸m/s)

Radar transmits many pulses each second. The rate is given by the *PRF*. The time *T* between pulses is thus

$$T = 1/PRF$$

The range to a target may be determined by the round-trip “time of flight” for the echo to return to the radar receiver. The “2” accounts for the distance out and back from the target. We know that electromagnetic radiation travels at the speed of light.

$$t = 2r/c$$

Where $c=3 \times 10^8$ m/s t =round trip time (sec)

Now, given *T*, we can determine the maximum range a radar signal can travel and return before the next pulse is sent out. This is simply:

$$r_{max} = CT/2$$

$$r_{max} = C/(2PRF)$$

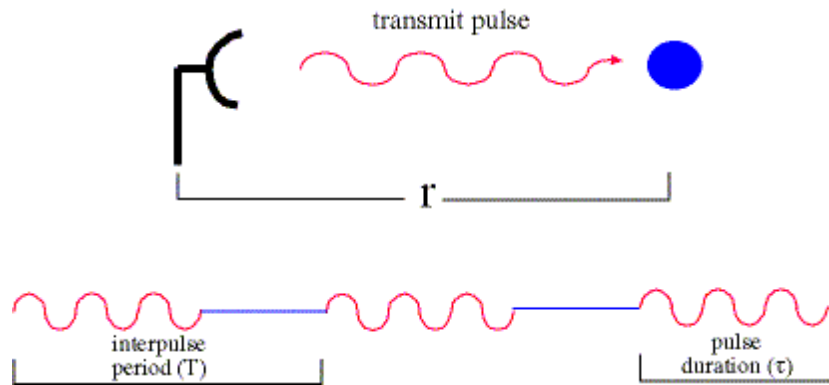


Figure 12: Finding the r_{max} .

Pulse repetition frequency (PRF) largely determines the maximum range of the radar set. If the period between successive pulses is too short, an echo from a distant target may return after the transmitter has emitted another pulse. This would make it impossible to tell whether the observed pulse is the echo of the pulse just transmitted or the echo of the preceding pulse. This produces a situation referred to as **range ambiguity**. The radar is unable to distinguish between pulses, and derives range information that is ambiguous (unreliable). In theory, it is best to strike a target with as many pulses of energy as possible during a given scan. Thus, the higher the PRF the better. A high PRF improves resolution and range accuracy by sampling the position of the target more often. Since PRF can limit maximum range, a compromise is reached by selectively increasing the PRF at shorter ranges to obtain the desired accuracy of measurements.

In the example above, where we had a pulse repetition time of 1 millisecond (1/1000th of a second), we may calculate how far the beam can travel in that time by multiplying 1 millisecond (0.001



seconds) by the speed of light (300,000km/second) for a result of 300km. However, keep in mind that the beam has to be able to reach its target and **reflect back** in that time which means the total **round trip** distance is 300km. That means, with a 1 millisecond pulse repetition time, the total range is **half** that: 150km.

Determining range of a target

In the graphic example to the left, the radar's beam bounces off a raindrop within the cloud and is detected by the radar 425 microseconds (0.000425 seconds) after it was sent. By multiplying the measured time by the speed of light we know that the beam covered 127.5km and we know that half of that distance was the distance *to* the cloud and the other half was the distance **back**. So we know the raindrop we detected is 63.8km away.



4. VELOCITY DETERMINATION

Doppler technology makes the radars enable to determine the velocity of the targets based on their movement from or towards radar. This is very useful information for meteorologists to be able to predict the direction and future location of the air mass and meteorological systems such as cyclones, tornados, etc. Velocity determination can be managed as described in following part of the document.

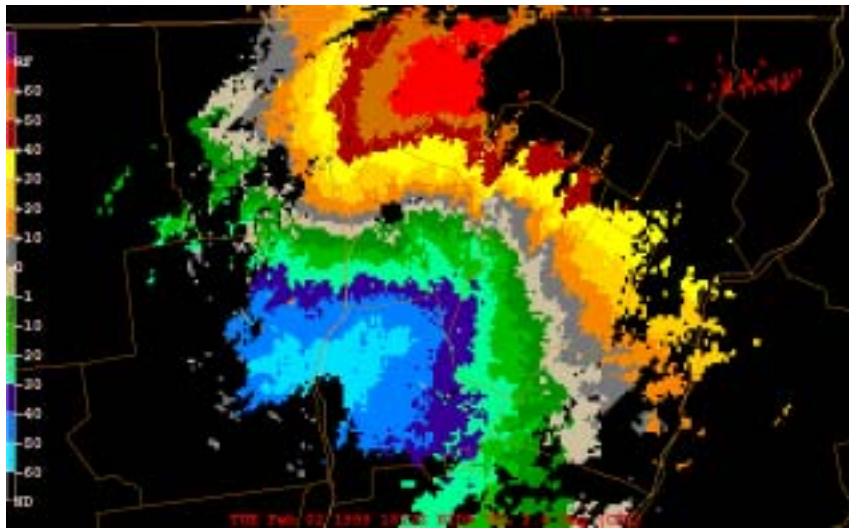


Figure 13: Velocity Example.

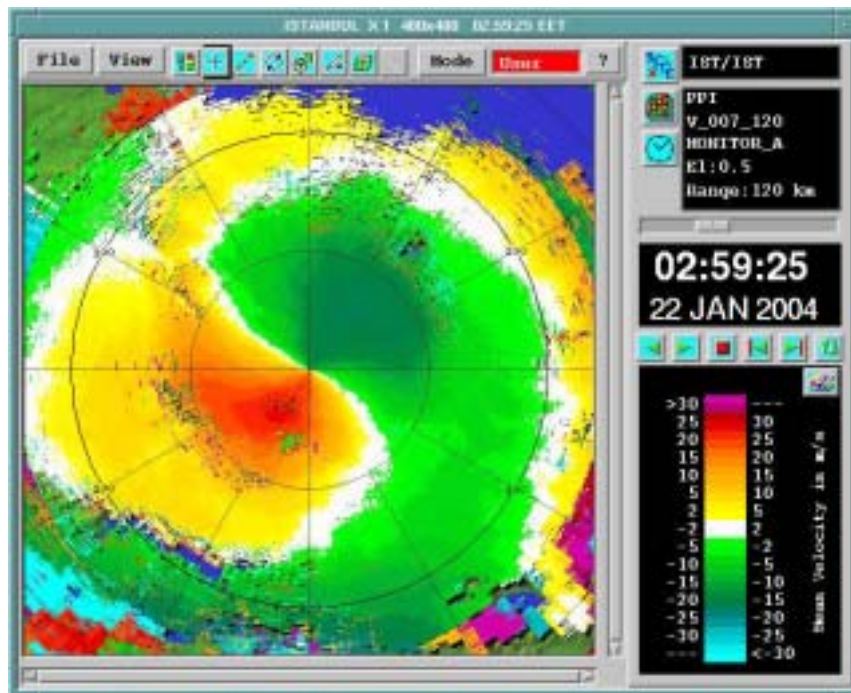


Figure 14: PPI Velocity.

- A Doppler radar can only measure the component of the winds in a direction parallel to the radar beam
- Measured wind speed is called the **radial velocity (V_r)**.

Radial velocity is defined simply as the component of target motion parallel to the radar radial (azimuth). It is that component of a target's motion that is either toward or away from the radar site along the radial.

Some important principles to remember about Doppler radial velocity are:

1. Radial velocities will always be less than or equal to actual target velocities.
2. Actual velocity is measured by radar only where target motion is directly toward or away from the radar.
3. Zero velocity is measured where target motion is perpendicular to a radial or where the target is stationary.

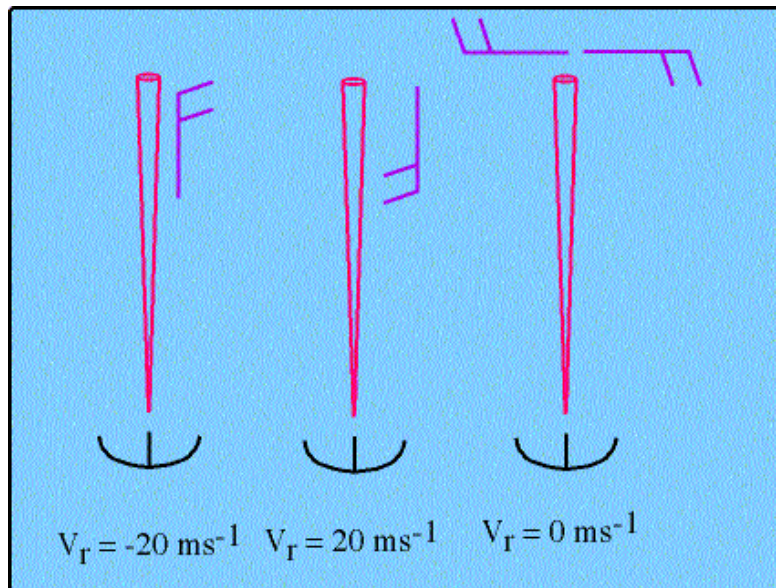


Figure 15: Radial Velocity.

4.1. Doppler Shift

Austrian physicist Christian Doppler discovered that a moving object will shift the frequency of sound and light in proportion to the speed of movement in 1842.

He then developed mathematical formulas to describe this effect called the **Doppler Shift**.

While not given much thought, you experience Doppler shifts many times each day. The change in pitch of a passing train whistle and a speeding automobile horn demonstrate its effects. When you hear a train or automobile, you can determine its approximate location and movement or you hear the high pitch of the siren of the approaching ambulance, and notice that its pitch drops suddenly as the ambulance passes you. That is called the Doppler Effect.

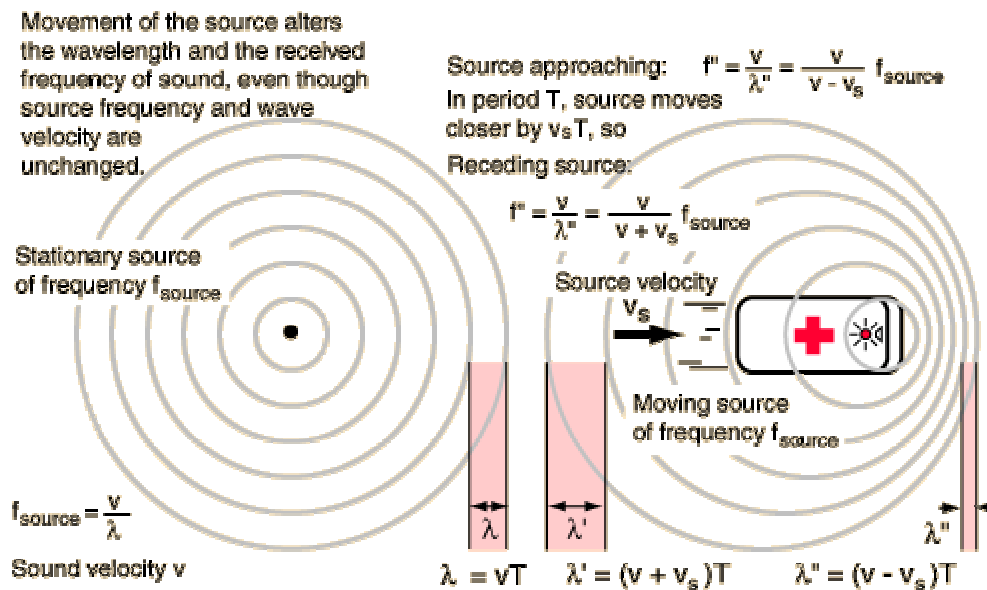


Figure 16: Frequency Stationary and Moving Target.

Exactly the same thing happens with electromagnetic radiation as happens with sound. Doppler radar accomplishes much the same thing, but to a higher degree of accuracy. As a target moves toward the radar, frequency is increased; if the target is moving away from the radar, the frequency is reduced. In the case of radar, the usual situation is to have stationary radar observing moving targets.

The radar then compares the received signal with the frequency of the transmitted signal and measures the frequency shift, giving the motion and speed of the target. While frequency of electromagnetic energy is modified by moving targets, the change is usually too slight to measure precisely. Therefore, Doppler radar focuses on the phase of electromagnetic energy. Using phase shifts instead of frequency changes can be compared to viewing an insect under a magnifying glass.

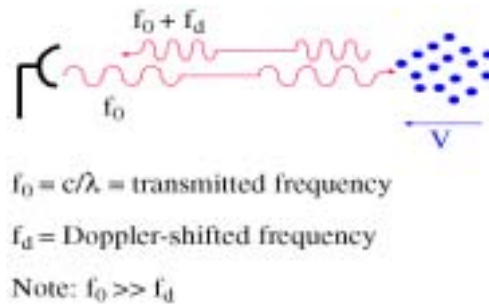


Figure 17: The Effect of Moving Target on Frequency.

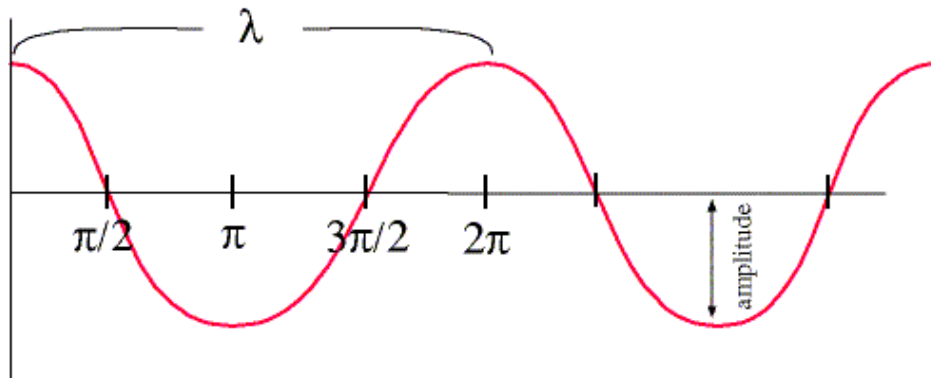


Figure 18: Wavelength and Amplitude of a Wave.

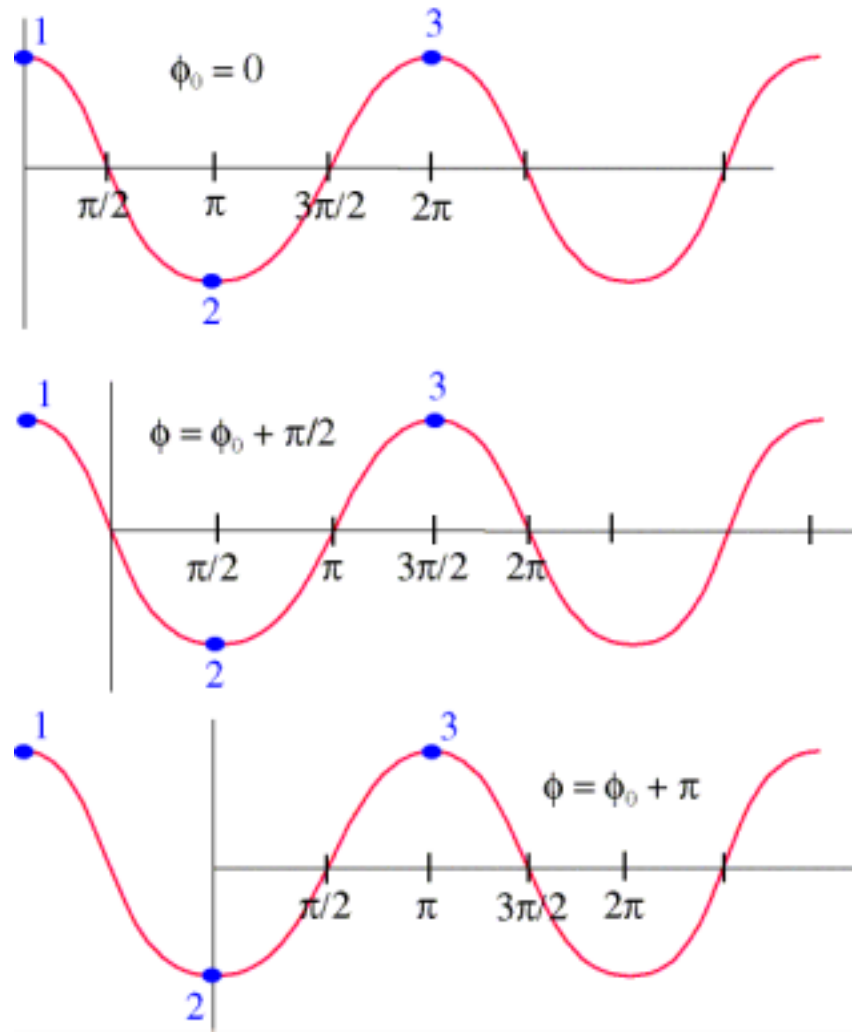


Figure 19: Phase of a Wave.

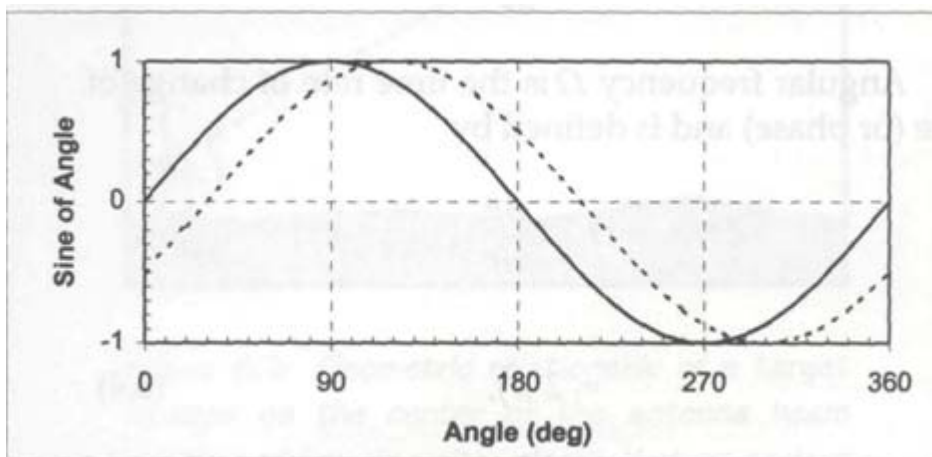


Figure 20: Sine Wave (Solid Curve) and a Second Signal 30° Out of Phase with the First Wave (Dashed Curve).

A pulse Doppler radar, in its simplest form, provides a reference signal by which changes in the frequency phase of successively received pulses may be recognized. The known phase of the transmitted signal allows measurement of the phase of the received signal. The Doppler shift associated with the echo from which the return originated is calculated from the time rate of change of phase. The phase of a wave, measured in degrees, where 360 degrees equals one wavelength, indicates the current position of the wave relative to a reference position. For example, look at figure below. At time T1 (fig., view A), the position of the wave along the vertical line was as shown, while at time T2 (fig., view B), the position of the wave along the vertical line was as shown. Notice that the wavelength did not change from T1 to T2. However, the wave's position relative to the vertical line changed 1/4 wavelength, or 90 degrees. This change is the phase shift.

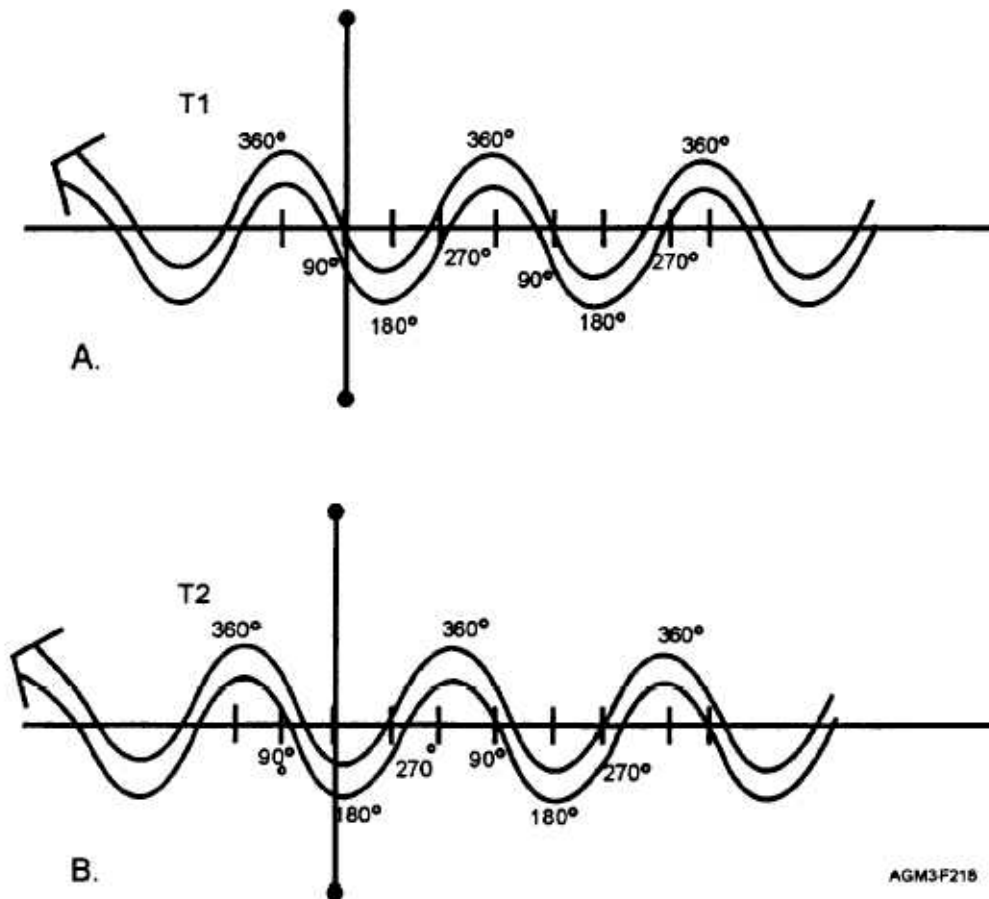


Figure 21: Wavelengths and Phase Shifts. (A) T-1 is Wave Reference Position. (B) T-2 Wave's Position has Changed 90° from Reference Position (T-1).

If the radar observes these changes (phase shifts) it will realize that motion has occurred and can then convert this information into target velocity. Keep in mind that the ability of a Doppler

radar to detect phase shifts and compute velocity depends upon the system maintaining a consistent transmitter frequency and phase relationship from one pulse to the next.

4.2. Total Distance to Target in Radians

Consider a single target at distance r from radar. The total distance a radar pulse will have to travel to detect this target is $2r$ since the wave has to go out to the target and back to the radar. Physical change in target distance is r metres, but the RF path length changes by $2r$ as signal travels both to and from the radar.

Knowing the radar's wavelength, $2r$ (full RF cycle) can be expressed as an observed phase change of target:

The total distance (D) travelled by the wave: $2r$

This distance can also be measured in terms of the number of wavelengths from the radar to the target: $2r/\lambda$

We can also measure this distance in radians by using the fact that

1 wavelength = 2π radians.

So, D in terms of radians:

$$\text{Distance in radians} = (2r/\lambda)/2\pi$$

If a radar signal is transmitted with an initial phase of $\langle f \rangle_0$, then the phase of the returned signal will be

f_0 = phase of pulse sent out by radar

f = phase of returning signal then,

$$\Phi = \Phi_0 + 4\pi r/\lambda$$

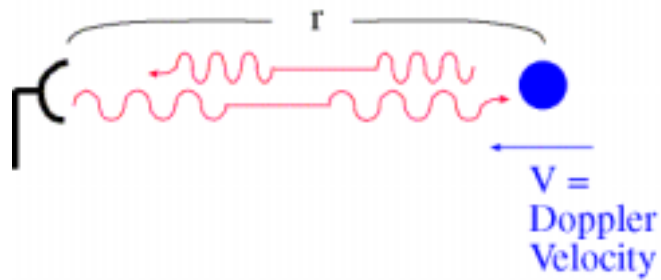


Figure 22: Doppler Velocity.

How does the radar then measure f_d ?

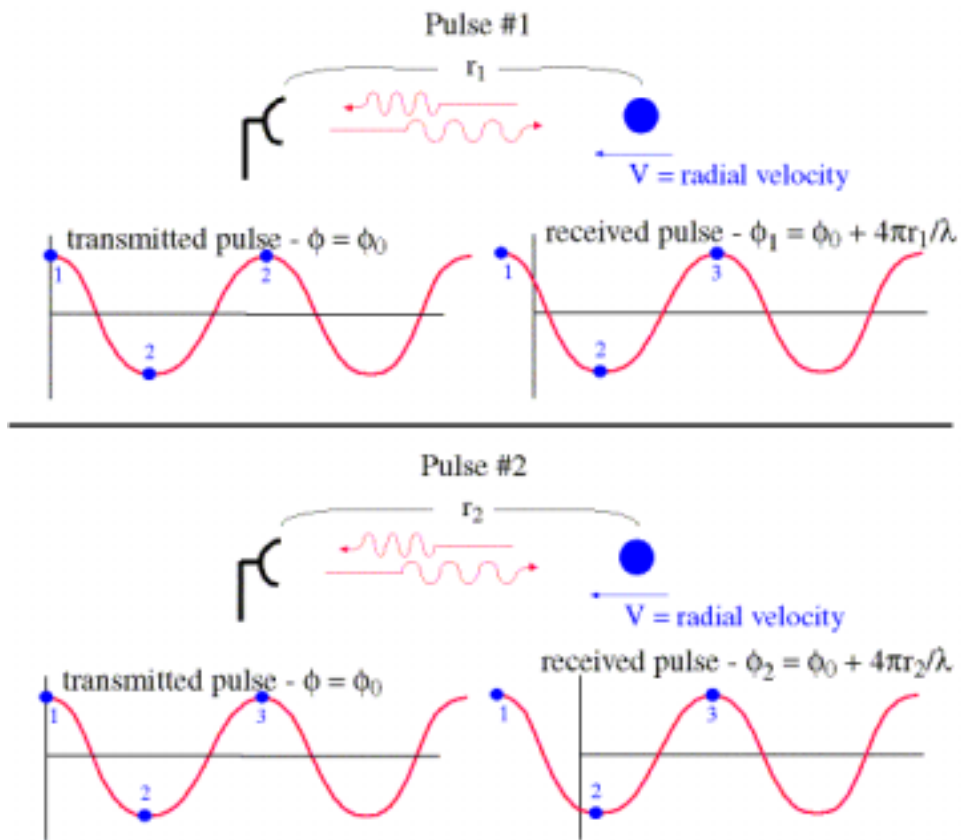


Figure 23: Phases at Different Ranges.

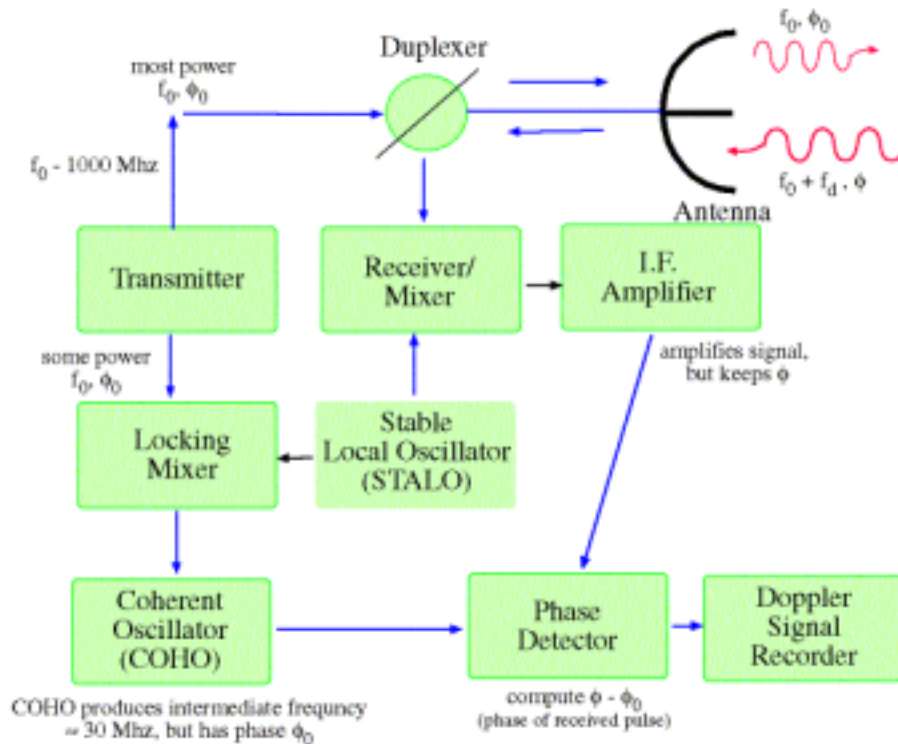


Figure 24: Basic Block Diagram of Radar.

4.3. Pulse-Pair Method

- 1) The transmitter produces a pulse with frequency f_0 and duration of t .
- 2) Some power with frequency f_0 is mixed with a signal from STALO and is passed to COHO
- 3) COHO maintains f_0 of transmitted wave
- 4) Receiver/mixer mixes signal from STALO and received signal
- 5) Mixed signal is then amplified
- 6) Phases of original and received signals are differenced, i.e., compute $f_1 = f_0 - f$. This is the phase of pulse #1.
- 7) Repeat 1-6 above for successive pulses. This gives you df/dt .

The change of phase with time from one pulse to the next is given by

$$d\Phi/dt = (4\pi/\lambda)(dr/dt)$$

Where dr/dt is the time derivative or time rate of change of the parameter. The radial velocity of an object is given by

$$v = dr/dt$$

Angular frequency Ω is the time rate of change of angular velocity (or phase) and is defined by:

$$\begin{aligned}\Omega &= d\Phi/dt \\ &= 2\pi f\end{aligned}$$

Where f is the frequency shift in cycles per second (Hertz).

Thus, by combining Equations, we get the frequency shift caused by a moving target;

$$f = 2v/\lambda$$

So a given phase shift in a given interval of time becomes a frequency shift which the radar can measure.

4.4. Maximum Unambiguous Velocity

What is the maximum Doppler-shifted frequency that can be unambiguously measured?

There are limitations in the **velocities** and **ranges** that radar can resolve unambiguously. Let us consider **velocity ambiguities** first. When a target is not moving toward or away from radar, it will have zero **radial** velocity. This does not necessarily mean that the target is stationary. It simply means that the target is remaining at a constant distance from the radar. It could be moving quite rapidly, in fact, but any movement it has must be perpendicular to the radar's beam. Since the only velocity a Doppler radar can detect using phase-shift principles is the radial velocity, we usually omit the qualifier "radial" and simply talk about the "velocity". While this is convenient, be careful to recognize that a Doppler radar detects only radial velocities (the velocity with which a target moves toward or away from the radar)

The maximum velocity a Doppler radar can detect correctly or unambiguously is given by the velocity which produces a phase shift of π radians. This is also called the Nyquist frequency or Nyquist velocity⁷, depending upon whether we are referring to the maximum unambiguous frequency or velocity, respectively. Mathematically, we can express this as:

$$f = 2v/\lambda, v_{max} = f_{max} \cdot \lambda/2$$

Where the maximum frequency f_{max} is given by:

$$f_{max} = PRF/2$$

(Nyquist Theorem)

And **PRF** is the pulse repetition frequency of the radar. Thus, the maximum unambiguous velocity detectable by a Doppler radar is:

$$v = PRF \cdot \lambda / 4$$

Example:

If PRF = 1000 Hz and $\lambda = 10$ cm, then $V_{max} = 25 \text{ ms}^{-1}$

This is an important result. It says that if we want to be able to detect high velocities, we must use long wavelengths, large PRFs or both.

What is Nyquist theorem?

The Nyquist theorem states that a signal must be sampled at a rate greater than twice the highest frequency component of the signal to accurately reconstruct the waveform

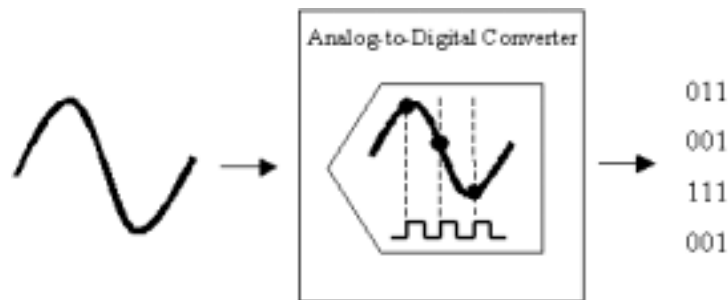


Figure 25: Analogue to Digital Converter (ADC).

- Suppose we are sampling a sine wave (How often do we need to sample it to figure out its frequency?)

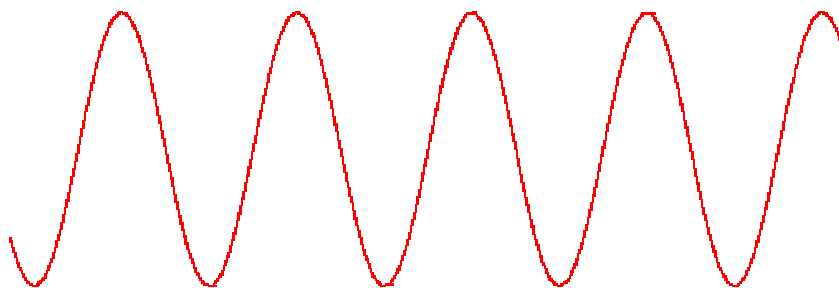


Figure 26: A Sine Wave.

- If we sample at 1 time per cycle, we can think it's a constant

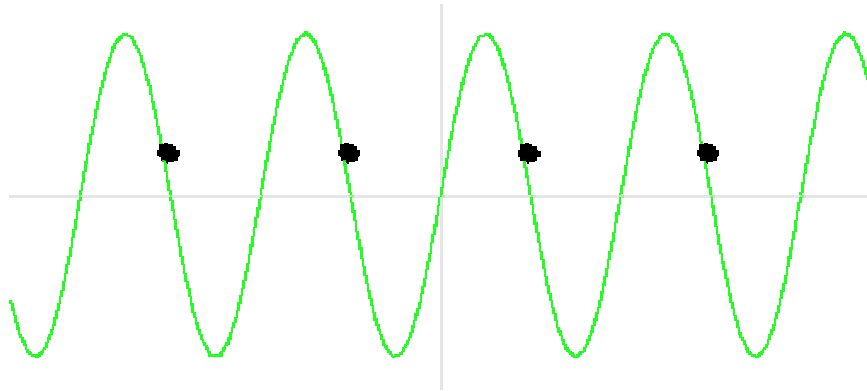


Figure 27: Sampling at 1 Time per Cycle

- If we sample at 1.5 times per cycle, we can think it's a lower frequency sine wave

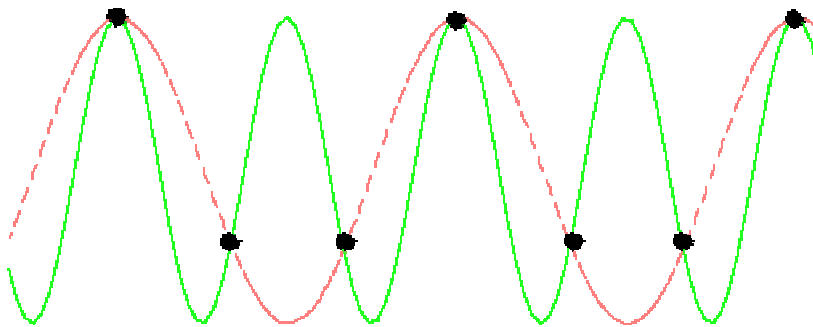


Figure 28: Sampling at 1.5 Times per Cycle

- **Nyquist rate** For lossless digitization, the sampling rate should be **at least twice** the maximum frequency responses.

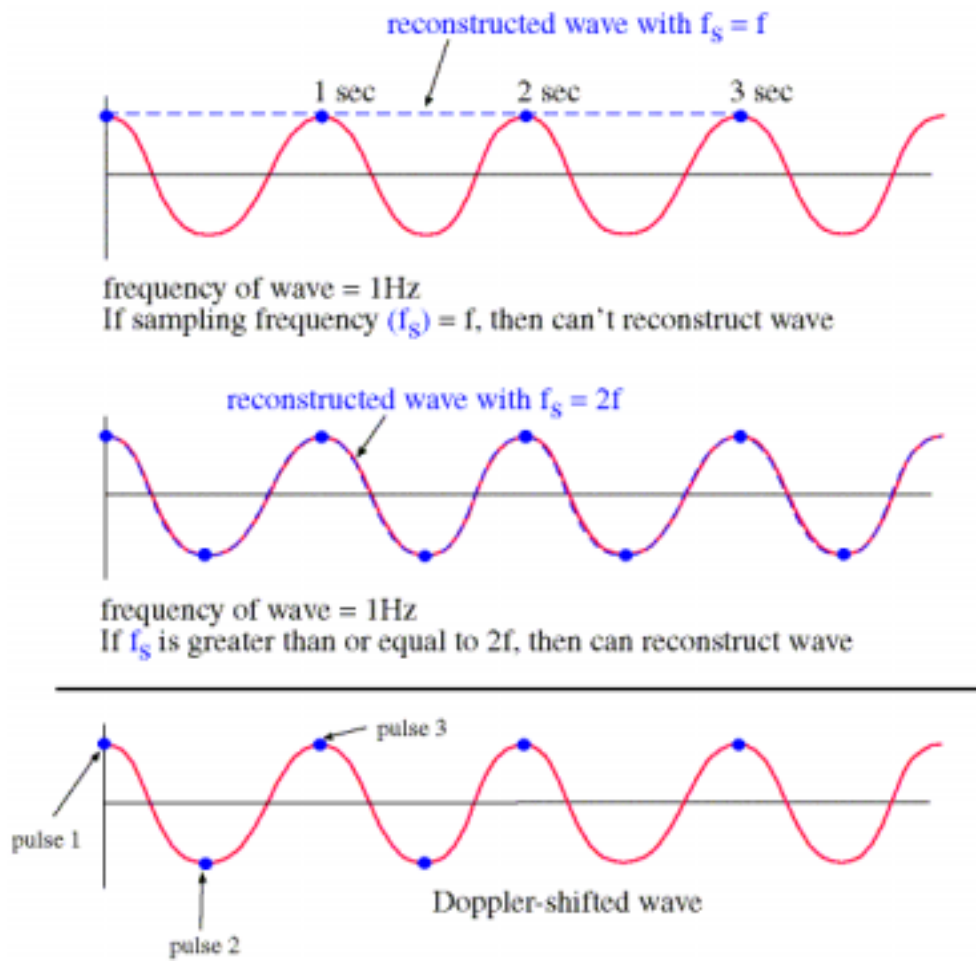


Figure 29: Nyquist Frequency.

5. THE DOPPLER DILEMMA

$$v_{max} = PRF \cdot \lambda / 4$$

$$r_{max} = C \cdot T / 2$$

$$r_{max} = C / (2PRF)$$

According to equations above, longer wavelength radars can measure larger radial velocity unambiguously for the given PRF. Larger the PRF, larger the radial velocity measurable unambiguously from a given radar. Unfortunately, the larger the PRF shorter the unambiguously measurable range [$R_{max} = C / (2 \cdot PRF)$]. On the other hand Reducing the pulse repetition frequency (PRF) and allowing for a longer listening time will alleviate the problem of range folding. However, as just discussed, low PRFs may then lead to the problem of velocity aliasing.

Thus there is an inverse relationship between the unambiguous range and the unambiguous velocity, the product of which is a constant ($v_{max} \cdot r_{max} = C\lambda/8$), where C is the velocity of light. This is widely known as Doppler Dilemma.

When PRF is low----unambiguous range is high---but that results in a low velocity range.

When PRF is high----unambiguous range is low---but that results in a high velocity range.

The combination of maximum unambiguous velocity and maximum unambiguous range form two constraints which must be considered in choosing the PRF for use with a Doppler radar. Notice that non-Doppler radars are only constrained by the maximum unambiguous range; since they cannot measure velocity, the velocity constraint does not apply.

If we want to have a large V_{rmx} we must have a small r_{max} since the right side of the equation is a constant for given radar. Conversely, if we want to detect echoes at long ranges, we can only detect small velocities.

$$V_{max} \cdot r_{max} = C \cdot \lambda / 8$$

For example, in order for a radar (for wavelength=5cm) to detect radial velocities of **12.5m/s**(45km/h) without aliasing, the PRF would have to be increased to about 1,000 pulses per second. ($V=PRF \cdot \lambda / 4$) However, this would reduce the maximum unambiguous range of the radar to about **150km**($r=c/2PRF$).

To have an unambiguous range of **300km**, the PRF would have to be 500Hz. If PRF is 500Hz then $V=6, 25m/s$

Another Example: Suppose a radar can sense up to 250 miles from the location of the radar (unambiguous range) and can detect velocities of up to 30 m/s before velocity folding occurs (a.k.a. velocity aliasing). If the PRF was increased, the unambiguous range will drop to say 200 miles but the unambiguous velocity will increase to say 35 m/s.

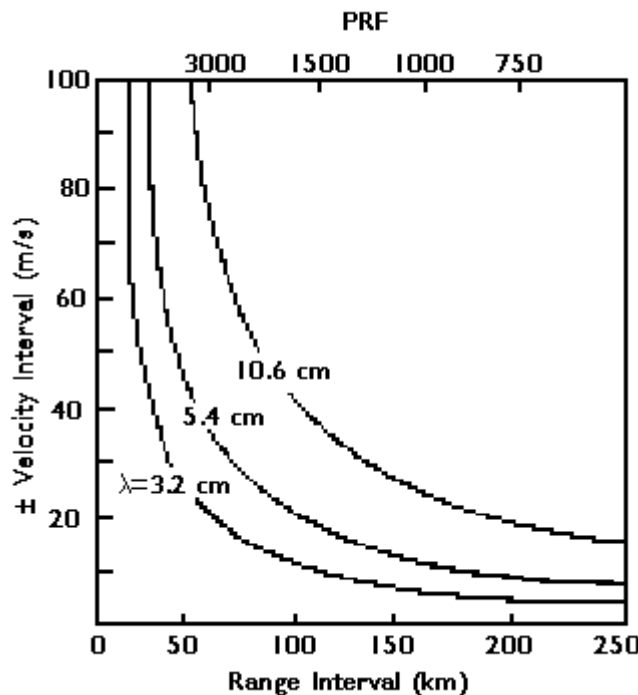


Figure 30: Velocity Interval versus Range Interval and PRF at Different Wavelength.

Figure (based on Gossard and Strauch, 1983) shows the Doppler dilemma graphically. Note that the ordinate (Y-axis) on this figure gives the maximum velocity interval corresponding to the Nyquist frequency. Normally we divide this interval in half with the maximum unambiguous velocity being divided into plus and minus half of the V_{mM} interval. For example, from the figure

we can see that for S-band radar, if the PRF is 1000 Hz, the maximum unambiguous range is 150 km while V_{mm} is ± 25 m/s. For X band radar using the same PRF, r_{max} is still 150 km, but V_{max} is now only ± 8 m/s. For meteorological situations, we may want to measure velocities as large as ± 50 m/s out to ranges beyond 200 km, so neither of the limits calculated above is completely adequate. The S-band system comes much closer to being useful than the X-band system, however. And C-band will be intermediate to these two.

One partial solution to the **Doppler Dilemma** is in our choice of wavelength. We can increase both V_{max} and r_{max} by using longer wavelength radar. Unfortunately, longer wavelength radars are more expensive and bigger, and they don't detect weather targets as well as shorter wavelength radars, so using a longer wavelength is not necessarily a solution to the problem. The result is that most Doppler weather radars usually suffer significant range or velocity ambiguities or both.

Even if there were not limitations on range because of PRF or velocity, in the real world, we do not wait very long before sending out a second pulse. There are a number of reasons for this. One is that we cannot detect targets at extremely long ranges or we are not interested in them. Meteorological targets typically exist only 10 to 15 km above the earth's surface. Even though the radar waves bend downward somewhat in their travel through the atmosphere, the earth's surface curves away even faster, so the radar beam usually gets so high above the earth's surface that storms are not detectable beyond 400 to 500 km from a ground-based radar.

Another reason we are not interested in distant targets is that the inverse square law decreases the power received from a meteorological target according to $1/r^2$. If a target is too far away, the power received from it will be so weak that the radar will be unable to detect it. For these and other reasons, radars are designed to send out subsequent pulses of energy at fairly frequent intervals.

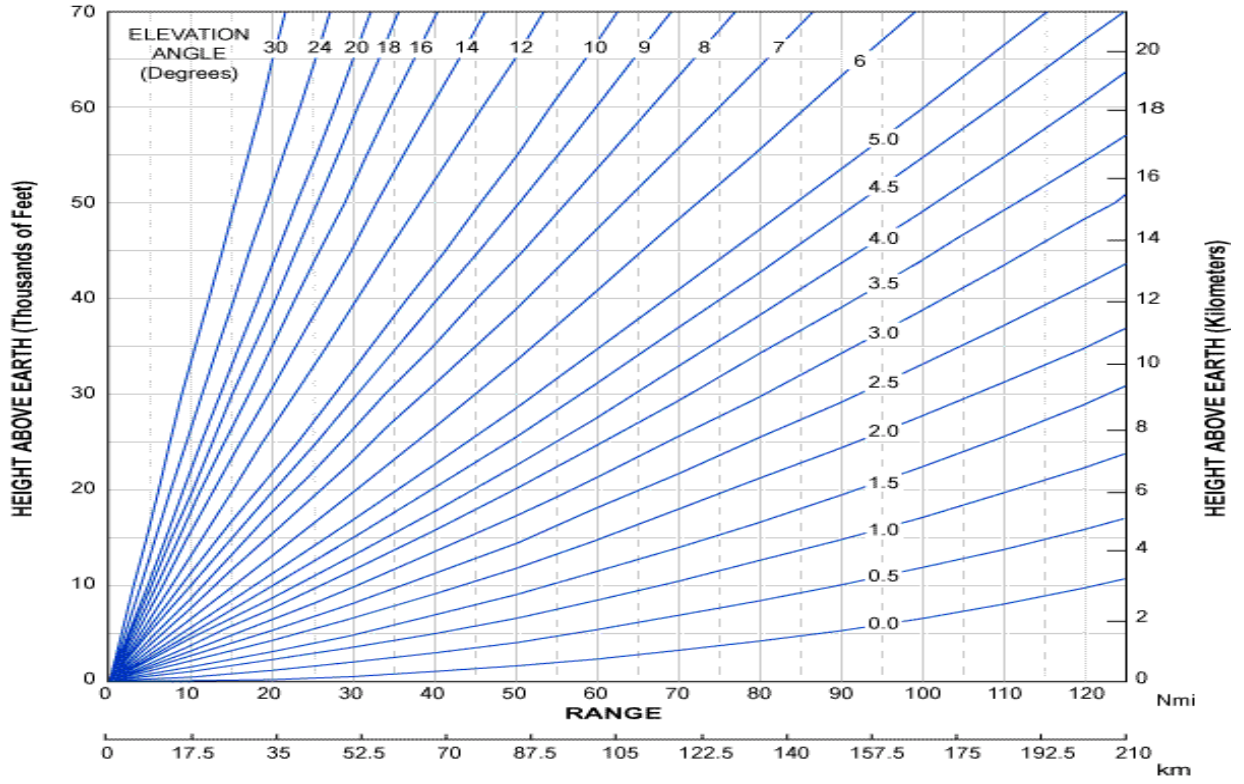


Figure 31: Range-Height Diagram.

6. RADAR RANGE FOLDING

While it's true that only targets within radar's normal range are detected, there are exceptions. Since range ambiguities (also called aliasing or folding) are so common with modern Doppler radars, let us examine the causes of this in a little more detail. Range aliasing occurs because we don't wait long enough between transmitted pulses. This happens when the first pulse of energy goes beyond maximum unambiguous range r_{max} and sometimes gets returned by a weather at a distance say r . The first pulse returns while the radar is expecting the second pulse (during the listening time of the second pulse). In other words, we transmit pulses close together (mostly to make the Doppler side of the radar work better), not giving one pulse enough time to cover the distance between the radar and some storms before the radar sends out the next pulse of energy. In this case echoes are displayed in the wrong range interval. If the PRF is high enough and distant echoes tall enough and strong enough, sometimes third or even fourth trip echoes can be detected. The radar displays it at a distance $(r-r_{max})$ superposed on the normal display. These are also known as multi-trip or second-trip echoes in Pulsed radars. Range folding may cause operators to base crucial decisions on false echoes. The data received from this stray pulse could be misanalyzed and echoes may be plotted where nothing exists. The data may look reliable and the radar may appear to be functioning properly, adding to the deception of normal operation.

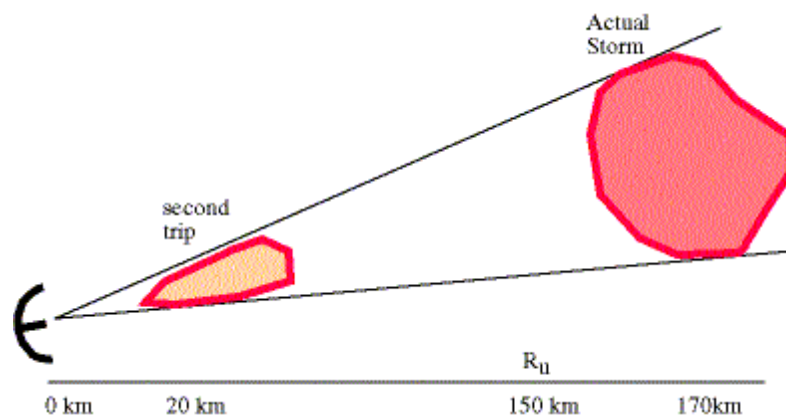


Figure 32: Second Trip Echo Example.

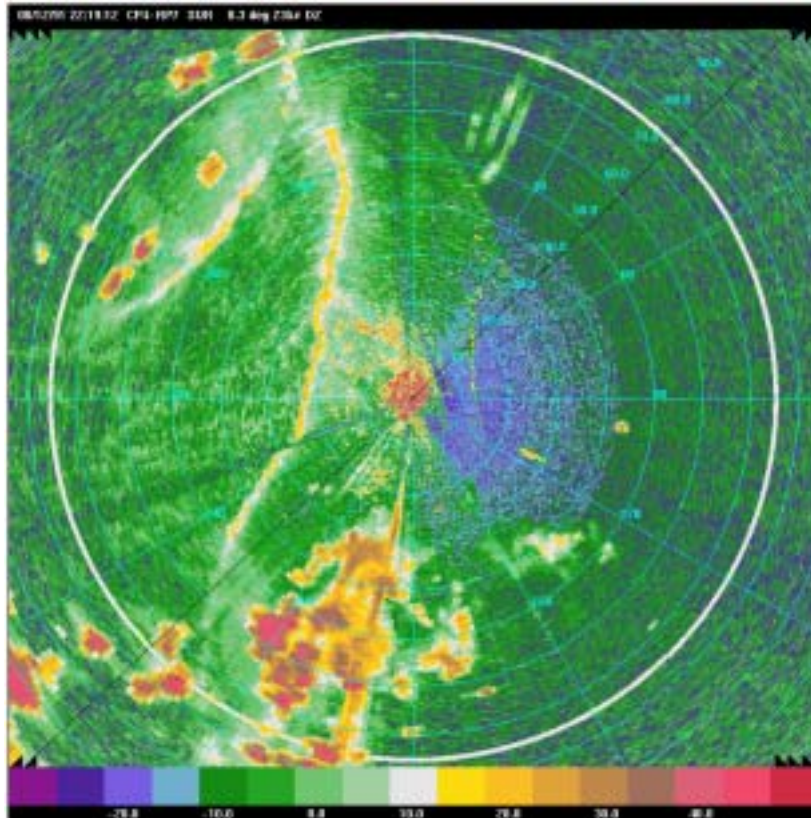


Figure 33: Second Trip Echo Example.

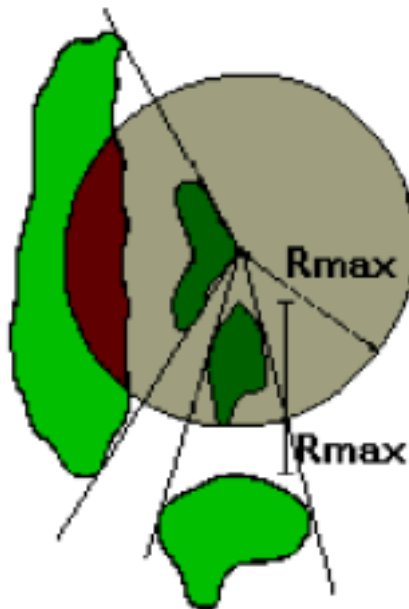


Figure 34: R_{max} and Second Trip Echo Relationship.

Figure 34 shows 2nd trip echoes.

6.1. Recognizing Range-Aliased Echoes

How are second trip echoes recognized on radar? There are a number of ways multitrip echoes can be recognized. One of the easiest is to simply look outside and see what is going on in the real world. If the radar shows a nearby storm in a particular direction but there is nothing outside, it is probably a multitrip echo.

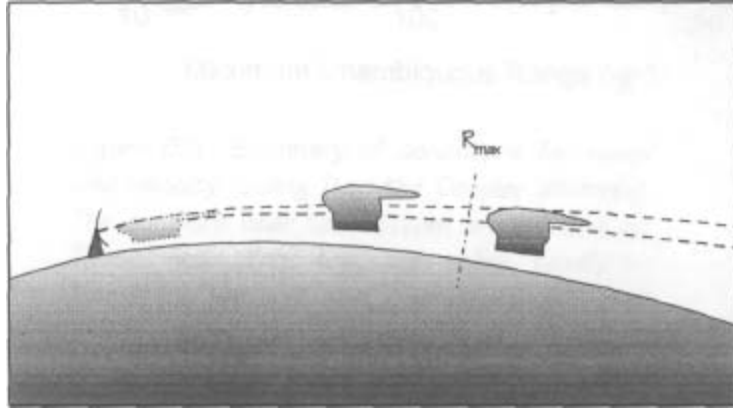


Figure 35: Second Trip Echo.

Figure Illustration of how a storm beyond r_{\max} can be displayed at the wrong range. Two real echoes exist. The first is less than r_{\max} away and is displayed at the correct range. The second is beyond r_{\max} ; it is displayed at a range of $(r - r_{\max})$. The faint, dashed storm near the radar is where the radar would display the distant storm.

A second way to recognize multitrip echoes is by their shapes (see Figure 32 and 33). Real storms are usually somewhat circular, elliptical, or irregular. Storms certainly should not know where the radar is located. Anytime a narrow, wedge-like echo is detected which points toward the radar, second-trip echoes should be suspected.

Another clue to the existence of multitrip echoes is height (see Figure 32). Real echoes, especially from convective storms, usually extend up into the atmosphere several kilometres.

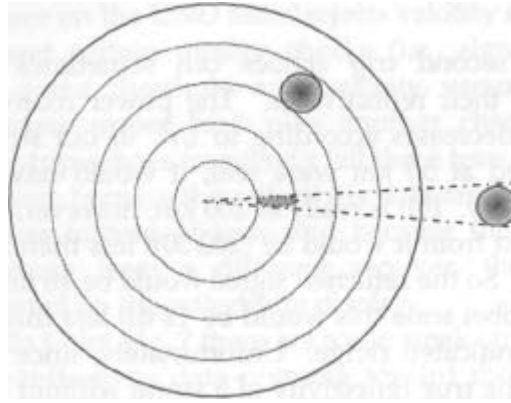


Figure 36: Real and Second Trip Echo.

Display showing a real echo located to the northeast. To the east is an echo beyond r_{\max} . It is displayed at a distance of $r - r_{\max}$ from the radar. It also has a very narrow shape. In the real and the aliased positions, but its aliased azimuthal distance is much narrower. Also, its reflectivity will be weaker because of the $1/r^2$ dependence on received power in the radar equation.

Thunderstorms are frequently 8 to 15 km in height. If a convective-like echo appears on the radar display but it has an indicated height which is much less than normal, it may be a second trip echo. For example, a real thunderstorm which is 10 km tall at a range of 200 km would be detectable at an elevation angle of about 2.2° (see Figure 36). If it is a second trip on radar with a PRF of 1000 Hz, it would show up at $200 \text{ km} - 150 \text{ km} = 50 \text{ km}$. If the echo from this storm disappears at 2.2° , its indicated height would only be 2 km. This is a ridiculously small height for a strong storm, so you should expect range aliasing.

Finally, second trip echoes can sometimes be recognized by their reflectivities. The power received from a storm decreases according to $1/r^2$. If our storm being displayed at 50 km were real, it would have a certain reflectivity. If it is really at 200 km, however, the power returned from it would be $(200/50)^2$ less than if it were at 50 km. So the returned signal would be 16 times less. On a decibel scale this would be 12 dB less than if it were at its indicated range. Unfortunately, since we do not know the true reflectivity of a storm without the radar giving it to us, we cannot be sure that a weak echo is simply a weak storm and not a second-trip storm. Nevertheless, low reflectivity combined with shape and height information can help differentiate real from multitrip echoes.

There is one guaranteed-or-double-your-money-back way to unambiguously determine if echoes are range aliased or not: **Change the PRF!** If we change the PRF and watch the positions of echoes, all correct echoes will not change their range whereas range-aliased echoes will shift in or out in range, depending upon whether the PRF is increased or decreased.

Alternatively, we can avoid range aliased echoes by using a **PRF** so low that r_{max} is so large that range aliasing cannot take place.

6.2. Elimination of Second Trip Echoes (Range Unfolding)

- 1) Phase-coding (random phase) of the transmitted signal is employed to filter out range-overlaid echoes. This phase-coding helps in identifying the second-trip echoes from the first-trip echoes for effectively filtering and displaying them in their appropriate range.
- 2) Change the PRF
- 3) Use a different PRF every 2-3 pulses, if echo moves, get rid of it!

7. VELOCITY UNFOLDING

If a particle's radial velocity is outside the range of the nyquist interval, then the radial velocity will be **aliased or folded**. This is called **velocity folding/aliasing**.

Example: if nyquist velocity is 25 m/s and the particle's radial velocity is -30 m/s, then it will fold over and the radar will interpret it as +20 m/s

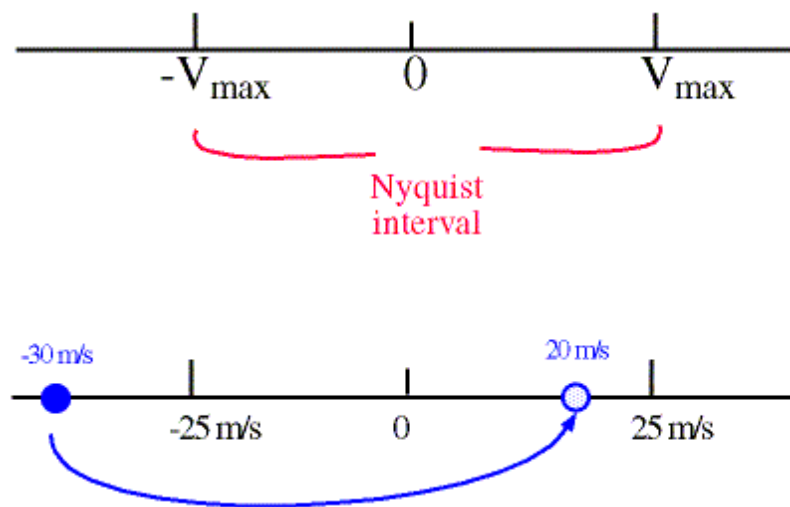


Figure 37: Velocity Folding or Aliasing.

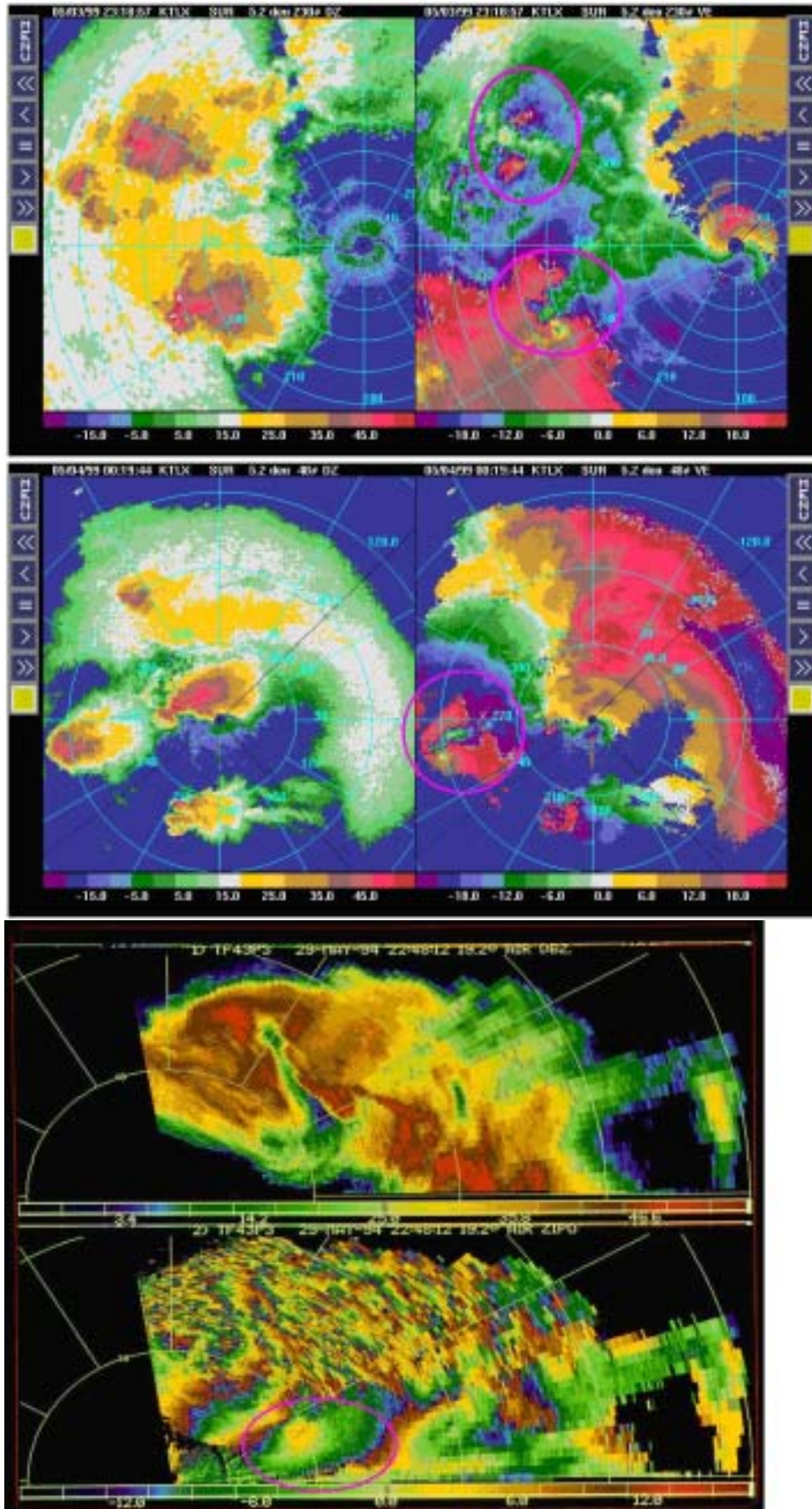


Figure 38: Folded Velocity Examples.

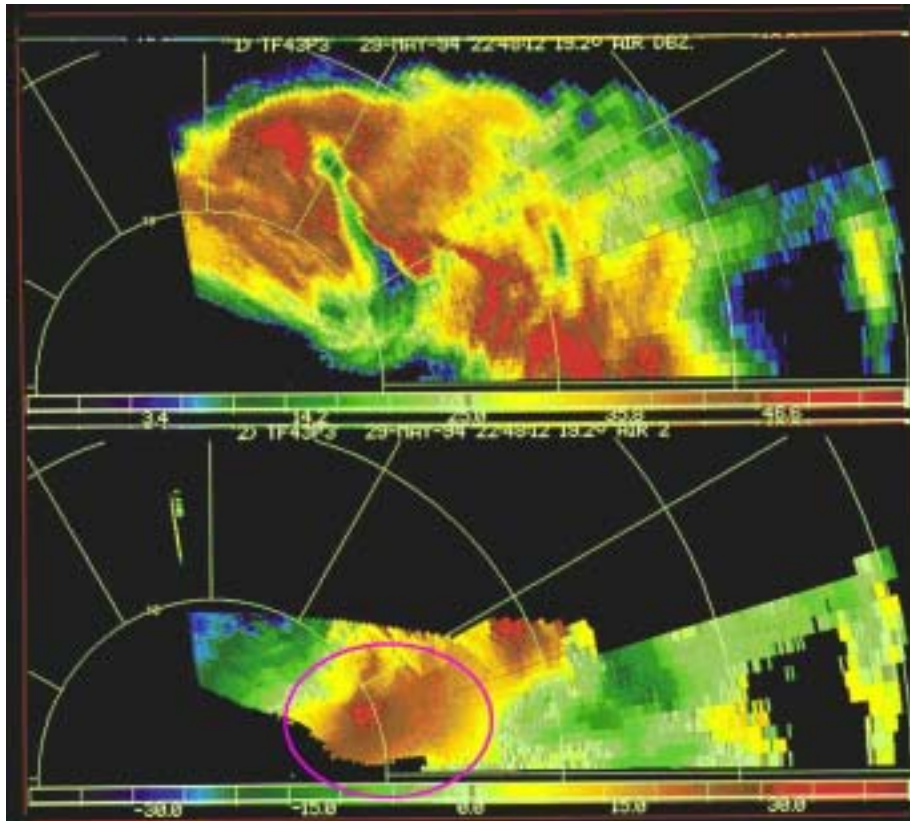


Figure 39: Unfolded Velocities for This Storm.

7.1. Staggered PRF for Velocity Unfolding

The maximum radar range is related to the PRF in inverse proportion, while the maximum velocity is related to PRF in direct proportion. Thus for a given range, there is an upper limit for maximum velocity measurable unambiguously. But there are techniques to double or triple the maximum unambiguous velocity by staggering the PRF or using dual PRF. Pulse-transmission rate is toggled from a high value to a low value and vice versa, for every set of fixed number of pulses. The velocity estimates from both sets can be combined suitably to increase the composite unambiguous velocity. Velocity aliasing can cause the two velocity estimates to vary significantly, and these differences can be used to resolve the true velocity. A velocity that has actually exceeded the nyquist velocity can be ‘unfolded’ to its true velocity. This is achieved by using **staggered PRF**.

Two different, but related, PRF are used for alternating output rays of data i.e. each 1 deg of azimuth.

A 2:3 PRF ratio provides a x2 increase of the apparent nyquist velocity.

A 3:4 PRF ratio provides a x3 increase.

A 4:5 PRF ratio provides a x4 increase.

The technique works by searching for a correlation of the phase shift of the target for the each PRF in use, taking into account that each PRF will produce a **different phase shift** for the same source velocity.

The technique is not without its drawbacks; firstly it relies upon a uniform transition in velocities from ray to ray to allow the correct unfolding estimates to occur. It also introduces several more images of the clutter filter notch previously described, which may result in the elimination of valid rainfall data and produce “spoking”.

Velocity without unfolding method

$$f_{dmax} = \frac{PRF}{2} = \frac{2V_{max}}{\lambda} \rightarrow v_{max} = \frac{PRF * \lambda}{4}$$

For PRF = 1200 \rightarrow $f_{dmax} = 600$ Hz \rightarrow $v_{max} = 300 * \lambda = 16$ m/s

800Hz which corresponds to **21,33m/s** in real, but Radar sees this echo as

200Hz which corresponds to 5,33m/s for **PRF: 1200Hz** ($v_{max} = 16$ m/s) and

350Hz which corresponds to 9,33m/s for **PRF: 900Hz** ($v_{max} = 12$ m/s)

Velocity with Dual PRF Technique:

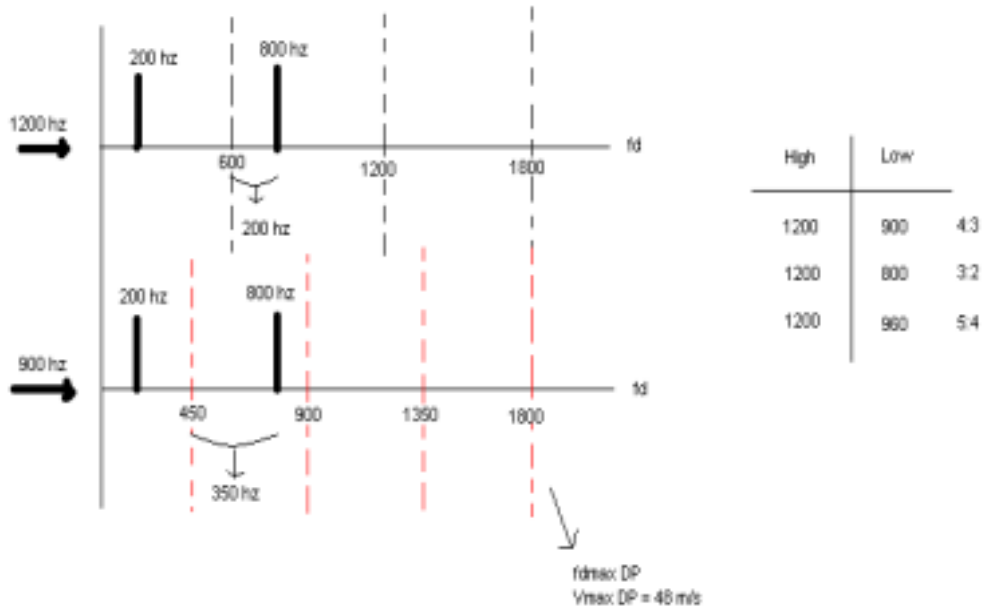


Figure 40: Dual PRF Technique.

If 3:4 PRF Ratio applied, folding intersection of $F_{d \max}$ for these two PRF will be 1800Hz
 In this case new $F_{d \max}$ will be 1800Hz. This means that, radar can detect up to 48m/s), Velocity can be calculated by using two incorrect velocity(5,33m/s and 9,33m/s) with dual-PRF algorithm as 21.33m/s.

PRF Ratio	$F_{d \max}$	V_{\max}	
2:3	1200Hz	32m/s	(if PRF ₁ :1200Hz and PRF ₂ :800Hz)
3:4	1800Hz	48m/s	(if PRF ₁ :1200Hz and PRF ₂ :900Hz)
4:5	2400Hz	64m/s	(if PRF ₁ :1200Hz and PRF ₂ :960Hz)

7.2. Recognizing Velocity Aliasing

How do velocity-aliased echoes appear on a radar display? The answer to this depends upon where the aliasing takes place. If a large region of echo is being detected by a Doppler radar and a region within it exceeds V_{\max} , then there will be an abrupt change in velocities surrounding the aliased region. For example, if the storm is moving away and part of it is moving away faster than V_{\max} then strong receding velocities would surround a region with apparently strong approaching velocities. Such a discontinuity is usually quite visible, and it is obvious that velocity folding is taking place.

If the storm causing range folding is completely isolated such that there is no surrounding echo, the velocities from the storm may appear entirely correct even though they have been folded into the wrong velocities. This would make recognizing velocity-folded data much more difficult. Fortunately, such isolated situations are not very common, so this is usually not a major problem. There are almost always several echoes on a display at the same time (perhaps even more so when velocities are so strong as to be folded), so velocities of nearby echoes are often useful to indicate whether folding is taking place or not.

A more difficult situation, however, occurs when C- or X-band radars are measuring storm velocities. For these radars V_{\max} can be moderately small. Thus, it is possible to have velocities which are not just folded once but are folded twice or more. This can make it extremely difficult to tell what the true velocities are from a quick visual inspection of the radar display.

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TRAINING MATERIAL ON WEATHER RADAR SYSTEMS

MODULE D

RADAR PRODUCTS AND
OPERATIONAL APPLICATIONS

[original PDF with bookmarks \(10 MB\)](#)



TURKEY RADAR TRAINING 1.0 / ALANYA 2005

**TURKISH STATE METEOROLOGICAL SERVICE
(TSMS)**



**WORLD METEOROLOGICAL ORGANIZATION
(WMO)**

**COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATIONS
(CIMO)**

**OPAG ON CAPACITY BUILDING (OPAG-CB)
EXPERT TEAM ON TRAINING ACTIVITIES AND TRAINING MATERIALS**

TRAINING COURSE ON WEATHER RADAR SYSTEMS

MODULE D: RADAR PRODUCTS AND OPERATIONAL APPLICATIONS

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**REMOTE SENSING DIVISION
TURKISH STATE METEOROLOGICAL SERVICE**

**12–16 SEPTEMBER 2005
WMO RMTTC-TURKEY
ALANYA FACILITIES, ANTALYA, TURKEY**

MODULE A: INTRODUCTION TO RADAR

MODULE B: RADAR HARDWARE

MODULE C: PROCESSING BASICS IN DOPPLER
WEATHER RADARS

**MODULE D: RADAR PRODUCTS AND
OPERATIONAL APPLICATIONS**

MODULE E: RADAR MAINTENANCE AND
CALIBRATION TECHNIQUES

MODULE F: RADAR INFRASTRUCTURE

RADAR PRODUCTS AND OPERATIONAL APPLICATIONS

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ABBREVIATIONS:

AWOS	: Automated Weather Observing System
SL	: Squall Line
Cb	: Cumulonimbus Cloud
TSMS	: Turkish State Meteorological Service
PPI	: Plan Position Indicator
CAPPI	: Constant Altitude Plan Position Indicator
RHI	: Range Height Indicator
MAX	: Maximum Display
VVP	: Velocity Volume Processing
VAD	: Velocity Azimuth Display
SRI	: Surface Rainfall Intensity
VIL	: Vertically Integrated Liquid
RDA	: Radar Data Acquisition
RPG	: Radar Product Generation
AP	: Anomalous Propagation
PRF	: Pulse Repetition Frequency
V_{max}	: Maximum Unambiguous Velocity
R_{max}	: Maximum Unambiguous Range

INTRODUCTION

Uses

The operational use of weather radars in many fields calls for automated forecast tools. Potential users are all who are interested in short-term forecasts of precipitation (rain, snow, hail) for a specific location or a specific region, e.g:

- Weather services,
- Media (Radio, TV, ...),
- Air services,
- Road services, Police,
- Agriculture,
- Construction companies (buildings, roads, ...),
- Water management services (municipalities, sewers, electricity ...),
- Sports and
- Private users.

Weather Detection by Radars:

- Precipitation measurements
- Severe storm detection and tracking
- Snow detection
- Cloud detection
- Weather modification programs
- Wind measurements

Nowcasting

Nowcasting methods based on satellite and radar data are a topic since more than 25 years. Radar measures rainfall and radial component of the wind over large areas in real-time. Furthermore, because it sees echo movement, it is also very useful for short term precipitation prediction.

Short-term Public Weather Forecasts: One of the primary applications of radar data is short-term (0-4 hr) weather forecasting, also known as **nowcasting**. Data collected at TSMS is sent in real-time to the Analysis and Forecasting Center. Since the range of the radar is limited to a few hundred kilometers and since weather generally moves at speeds averaging

50 km/hr (faster in winter, slower in summer), radar can only see precipitation a few hours ahead at most. It has hence limited applications for the usual longer term weather forecasts, but proves extremely useful to issue warnings when severe weather develops rapidly in the vicinity. In fact, if a severe thunderstorm warning is issued in your area, it is generally because it has been detected and tracked by radar.

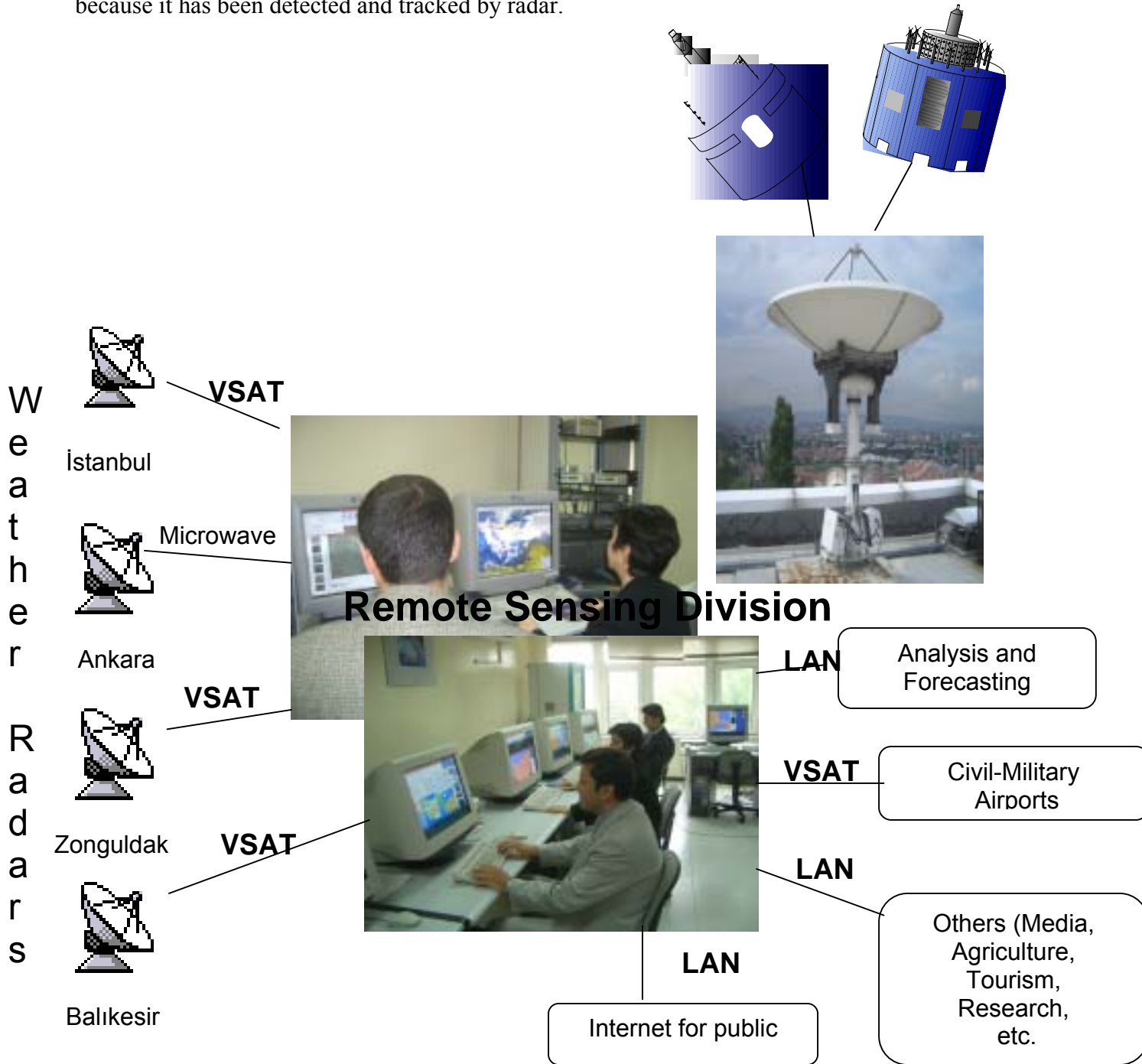


Figure 1: TSMS Radar and Satellite Data Acquisition.

Why is Radar Used in Meteorology?

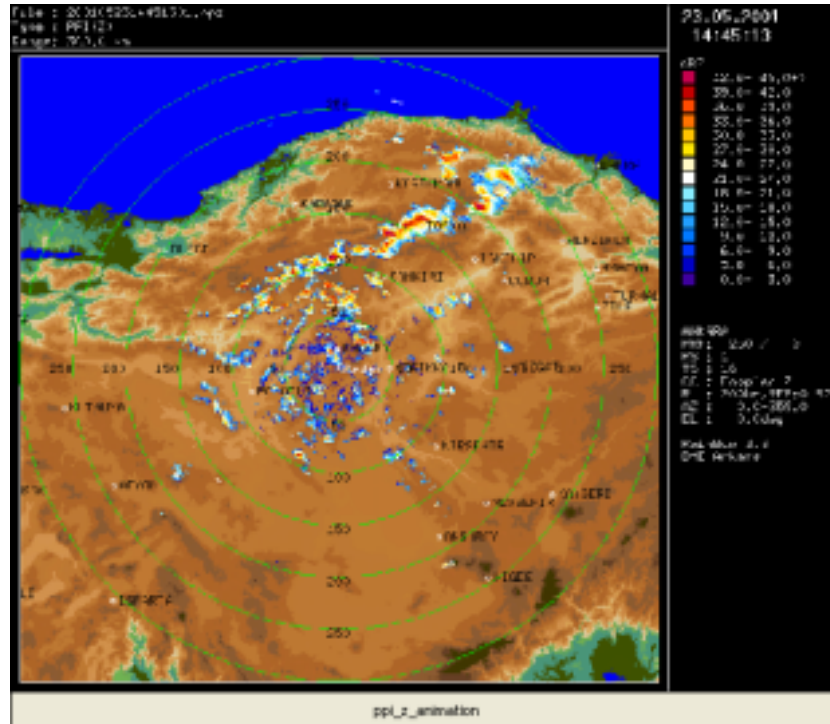


Figure 2: Radar Image of a Squall Line.

This radar image shows a squall line (a line or narrow band of active thunderstorms). It affected a certain area during its movement. SL caused to heavy rain and also some hail over the many places that can be seen by using radar easily. When records of the 9 meteorological observing stations at the area were studied, heavy rain and thunderstorms were observed by all stations, but hail could be observed by only one station (Osmancık) at the time from 15:10 to 15:13.

Conclusion:

- In fact, SL caused thunderstorms with hail over the many places through its movement.
- Weather radars allow a wide point of view to the meteorologists.
- While satellite data gives a forecaster a sense of the “big picture”, radar provides more detail on at smaller scales of weather.

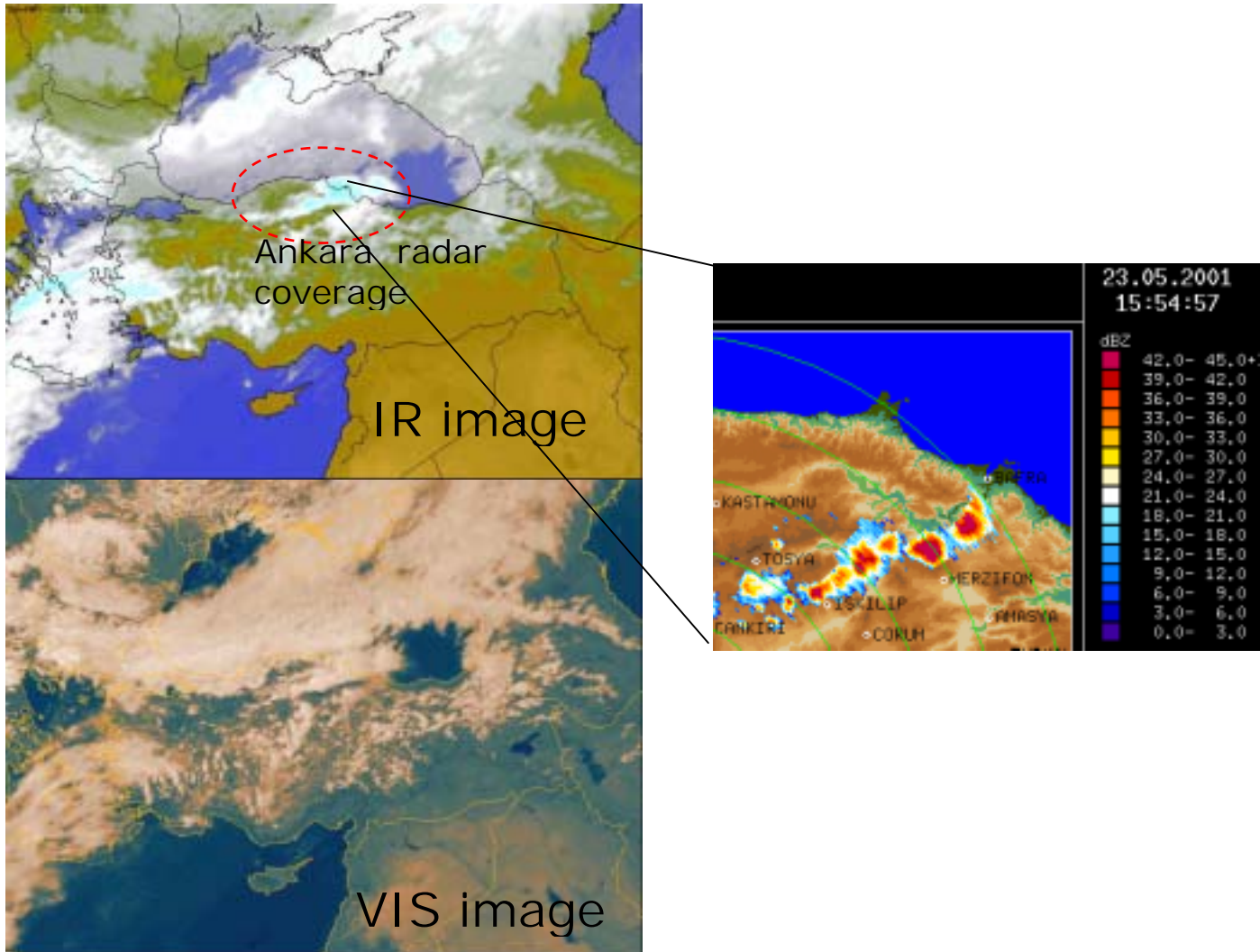


Figure 3: Satellite Images of the Squall Line.

Weather forecasters use radar to help determine:

- The movement and trend of thunderstorms
- Variability and concentration of precipitation

There are two important aspects of radar that we're concerned with:

- Amount of energy scattered back from a target to the radar

Estimate the intensity of storms and the amount of precipitation

- Velocity of a target relative to the radar

Estimate air motions and circulations within clouds

1. RADAR PRODUCTS

1.1. RPG (Radar Product Generation)

1.1.1. Signal Processing and Radar Product Generation

The processing of radar data generally involves two distinct steps. The first step, called **signal processing**, is the extraction of raw radar parameters like echo strength (reflectivity) or Doppler velocity from the radar signals coming out of the receiver. The second step, called **data processing** or **product generation**, is the further processing of raw radar parameters in order to obtain information that is useful for meteorological or hydrological purposes. In general, these two steps are done by different computers, signal processing being done at the radar site, while product generation can be done everywhere the data are sent to.

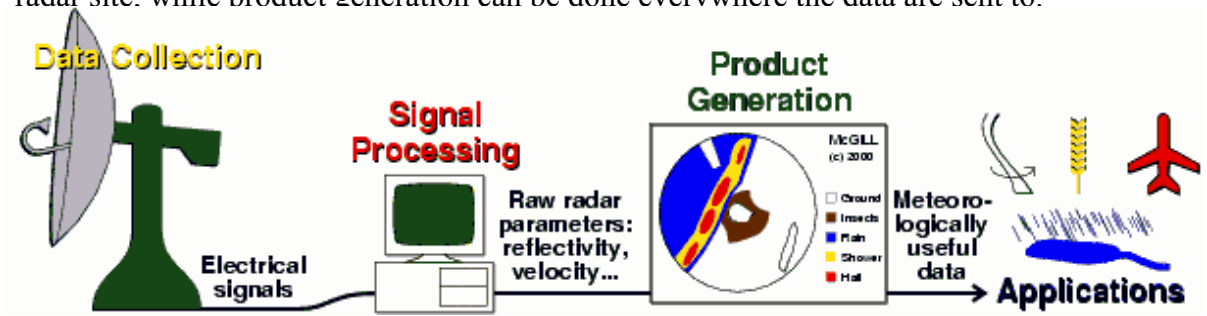
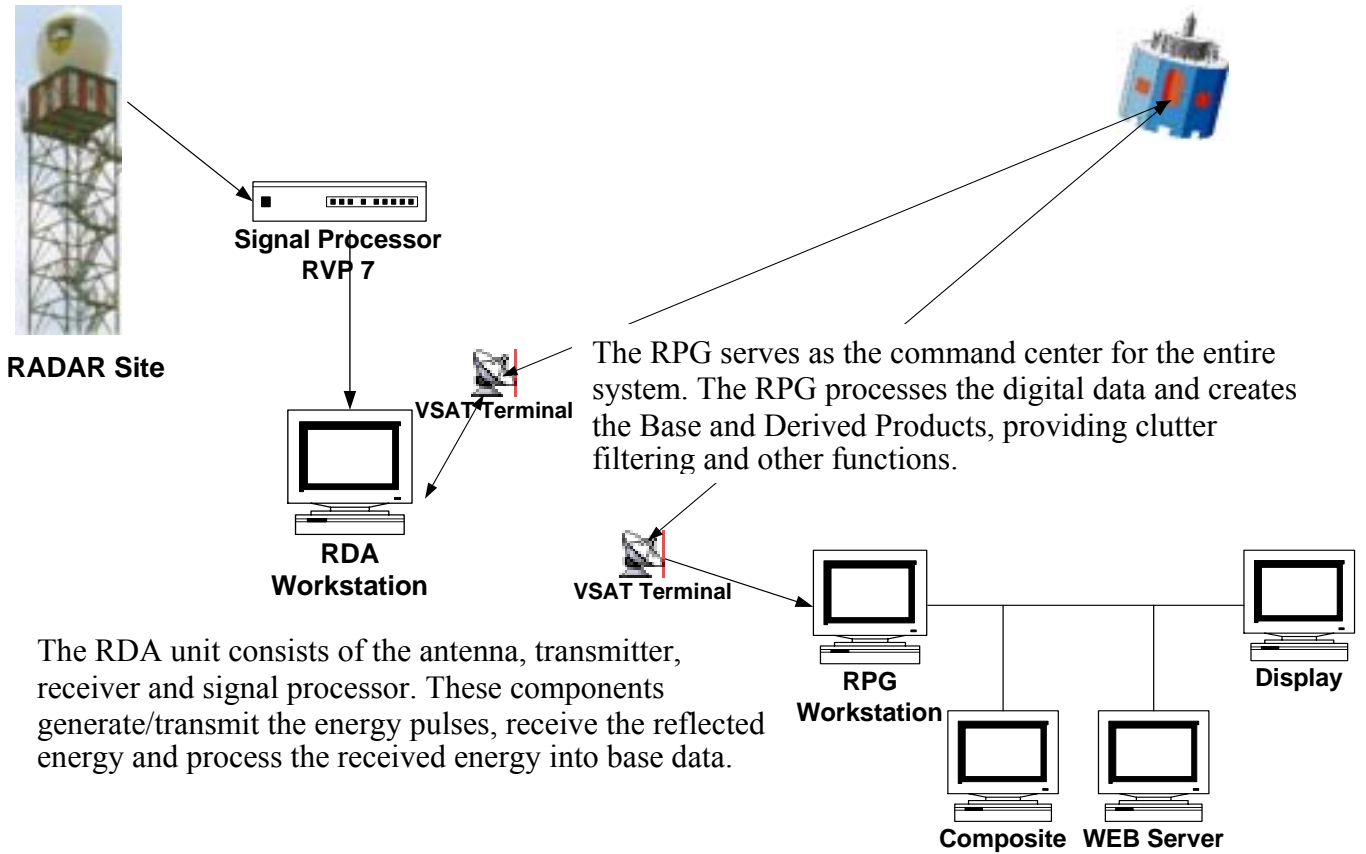


Figure 4: Signal Processing and Radar Product Generation.



The RDA unit consists of the antenna, transmitter, receiver and signal processor. These components generate/transmit the energy pulses, receive the reflected energy and process the received energy into base data.

Figure 5: Radar Data Flow Infrastructure.

Every product is associated with a TASK, defines a radar TASK such as a volume scan, single PPI sweep or sector scan. Up to three TASKS can be linked together to form a hybrid TASK for complex scan strategies. There is no limit to the number of TASKS that can be defined.

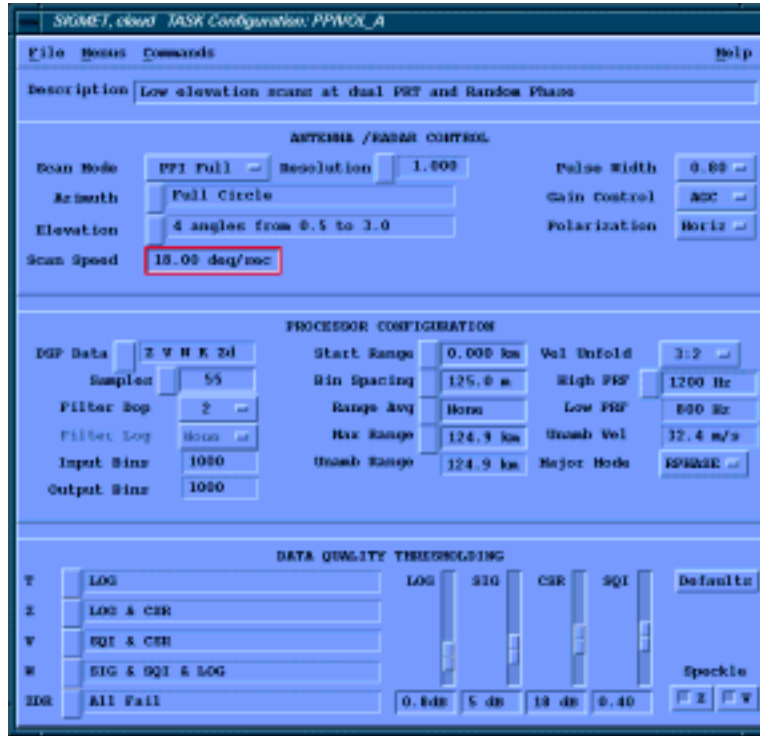


Figure 6: Task Configuration Tool.

To configure the details of the product generation for each product type such as the range and resolution of the product as well as product-specific information such as the CAPPI heights.

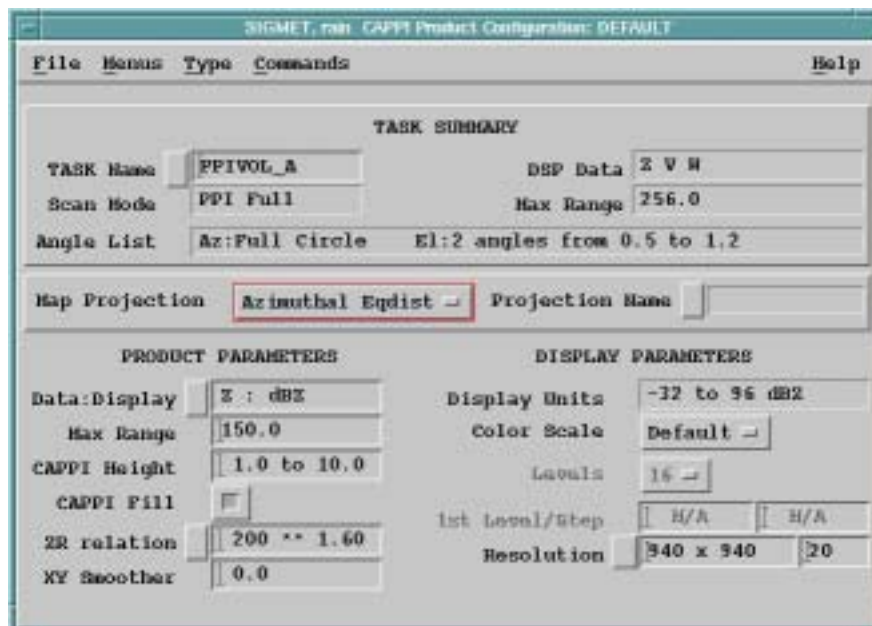


Figure.7: Product Configuration Tool.

1.2. Radar Parameters

The basic radar parameters are:

1. Reflectivity [Z]
2. Rainfall Rate [R]
3. Velocity [V]
4. Spectrum Width [W]
5. Differential Reflectivity [ZDR]

1.2.1. Reflectivity

Some degree of transmitted energy (power) is likely to be returned to the radar antenna (receiver) as a result of backscattering. Reflectivity is simply a measure of how much power was scattered back to the radar from any targets. Stronger targets have higher levels of reflectivity and return more energy. Thus, stronger targets have higher reflectivity values; that is, higher dBZ levels.

dBZ is also related to the number of drops per unit volume and the sixth power of their diameter (and also it can be related to rainfall rate through an empirical relationship called the “Z-R relationship”).

$z = \sum D_i^6$ (mm⁶/m³) → Linear Radar Reflectivity Factor

dBZ = 10log₁₀z → Logarithmic Radar Reflectivity Factor

Linear Value z(mm⁶/m³)	Logarithm log₁₀z	Decibels dBZ
1000	3	30
100	2	20
10	1	10
1	0	0
0.1	-1	-10
0.01	-2	-20
0.001	-3	-30

} No Precipitation

Table.1: The Range of Radar Reflectivity Factor.

Radar reflectivity factor can take on a tremendous range of values: 0.001(fog)–40,000,000 mm⁶/m³ (large hail) (-30 ~ +76 dBZ). Radar reflectivity factor of the clouds which do not produce rainfall or produce little rainfall is generally low. So, most of the meteorologists are not interested in very light precipitation.

Corresponding “dBZ” values of fog and hail:

$$z=0.001 \text{ mm}^6/\text{m}^3 \text{ (fog)}$$

$$\text{dBZ}=10\log_{10}z$$

$$=10\log_{10}(0.001)$$

$$=10 \times (-3)$$

$$\text{dBZ}=-30$$

Definition of this fog:

Assume that there is a cloud in a radar scope which has 1,000,000,000 drops and average diameter of the drops is 0,01 mm in 1 m³;

For each drops $\rightarrow D_i^6=0,01^6 \text{ mm}^6=10^{-12} \text{ mm}^6$

$$z=1,000,000,000 \text{ m}^{-3} \times 10^{-12} \text{ mm}^6 \rightarrow z=0.001 \text{ mm}^6/\text{m}^3$$

$$z=156,250 \text{ mm}^6/\text{m}^3 \text{ (heavy rain with some hail possible)}$$

$$\text{dBZ}=10\log_{10}z$$

$$=10\log_{10}(156,250)$$

$$=10 \times (5.19)$$

$$\text{dBZ}=51,9$$

Definition of this hail:

Assume that there is a cloud in a radar scope which has

10 drops and average diameter of the drops is 5 mm in 1 m³;

For each drops $\rightarrow D_i^6=5^6 \text{ mm}^6=15625 \text{ mm}^6$

$$z=10 \text{ m}^{-3} \times 15625 \text{ mm}^6 \rightarrow z=156,250 \text{ mm}^6/\text{m}^3$$

Energy backscattered from a target as seen on the radar display, i.e. echo intensities are displayed as on color figure below:

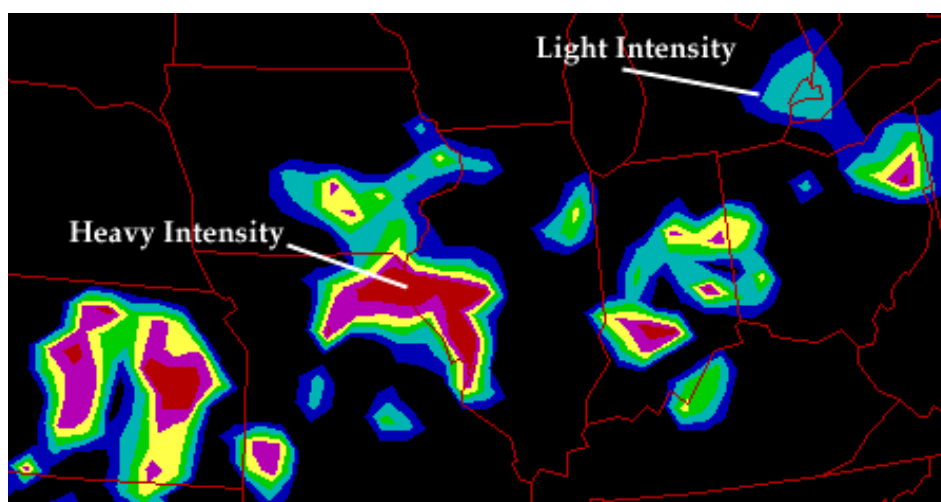


Figure 8: Echo Intensity.

Two different scales are generally utilized. A legend on the right side of the radar images show the relationship between the colours and the amount of reflected energy. Clear Air mode is more sensitive than Precipitation mode.

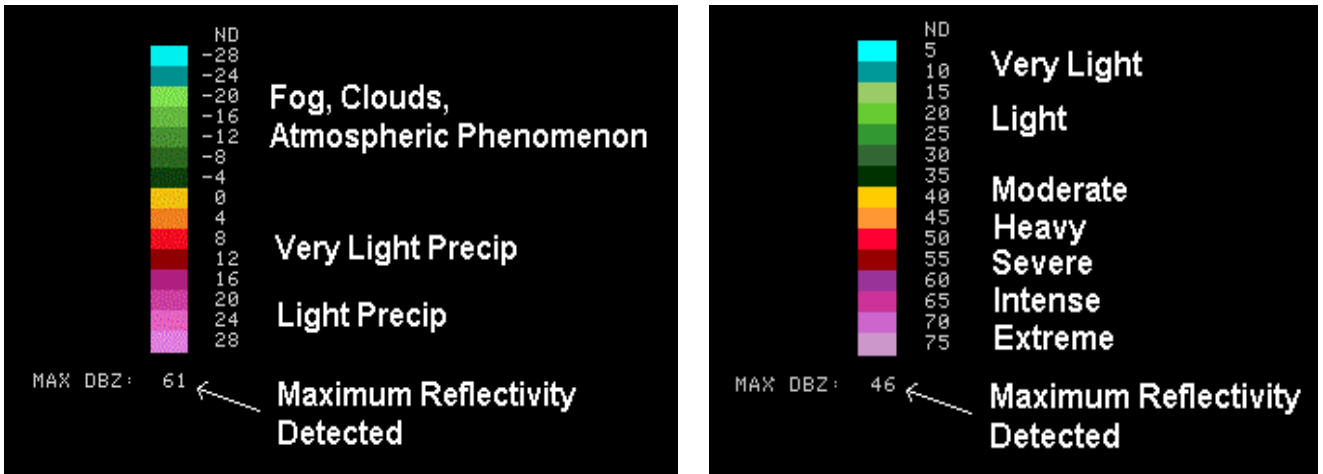


Figure 9: Echo Intensity Scales for Clear Air (on the Left) And Precipitation Mode (on the Right).

dBZ values are what you typically see on radar displays (e.g., on T.V.). In the table below a guideline on the interpretation of dBZ factors are given:

dBZ	Rain Rate	Comments
10	~0.2	Significant but mostly non-precipitating clouds
20	~1	Drizzle, very light rain
30	~3	Light rain
40	~10	Moderate rain, showers
50	~50	Heavy rain, thundershowers, some hail possible
60	~200	Extremely heavy rain, severe thunderstorm, hail likely

Table 2: The Interpretation of dBZ Factors.

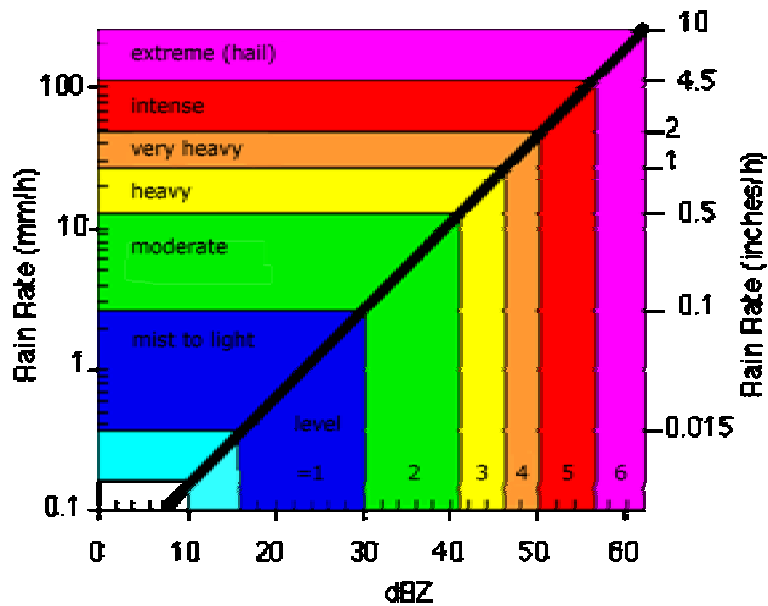


Figure 10: The Interpretation of dBZ Factors on Color Figure.

1.2.2. Rainfall Rate

One of the earliest quantitative uses of meteorological radar data was for the measurement of rainfall. Radar’s ability to scan rain showers and thunderstorms over large areas very quickly made it obvious to the early users that much could be learned about rainfall through the use of radar.

Weather radars are not able to measure precipitation directly. We saw earlier that the reflectivity factor (z) is related to the size of precipitation particles in the radar echo. If we assume that our radar echo has known distribution of precipitation particles (i.e., number of drops of different size categories), we can relate the reflectivity factor (z) to the rainfall rate (R - mm/hr) in our echo feature:

$$z = AR^b \text{ (A and b are constants determined by the assumed drop size distribution)}$$

This kind of equation between reflectivity factor and rain rate is called “Z-R relation”.

Precipitation measurement is done automatically by radar’s softwares.

Since the value of A and b will be specific to each radar site configuration, many researchers have produced a large variety of values A and b. A and b depend on the distribution and character of precipitation. Most common Z-R relation is:

$$z = 200R^{1.6} \text{ by Marshall and Palmer (in 1948). This is used for stratiform rain.}$$

Some other Z-R relations are:

- $z=31R^{1.71}$ for orographic rain (Blanchard, 1953)
 - $z=500R^{1.5}$ for thunderstorm (Joss, 1970)
 - $z=350R^{1.4}$ for convective rain
 - $z=2000R^2$ for snow (Marshall and Gunn, 1958)
- Scores more...

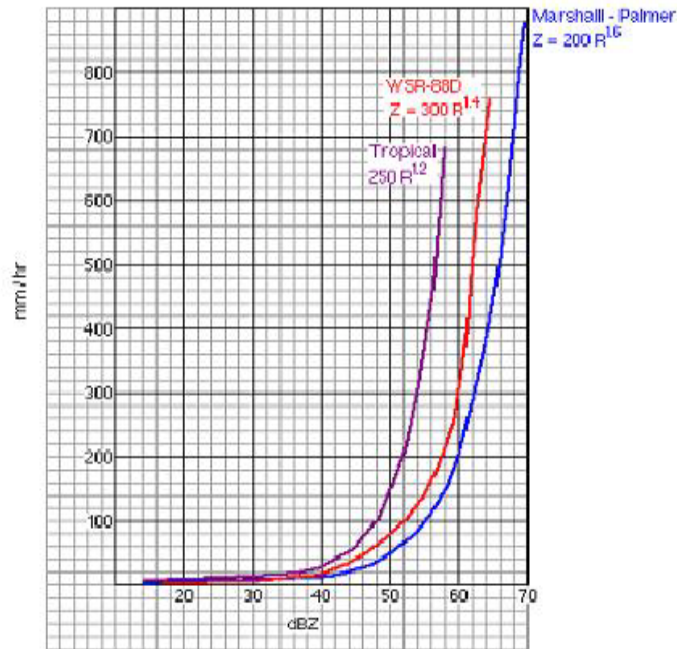


Figure 11: Some Z-R Relations as Graphically.

1.2.3. Velocity

Until now, we have only considered **power** measurements with radar. Most modern radars now easily measure **velocities** of targets. These are **Doppler radars**. Doppler is a means to measure motion. Doppler radars not only detect and measure the power received from a target, they also measure the motion of the target toward or away from the radar. This is called the “**Radial Velocity**”. Radial velocity is determined from **Doppler frequency shift** of the target. Doppler frequency shift caused by a moving target. Moving targets change the frequency of the returned signal. This frequency shift is then used to determine wind speed. Doppler radars routinely measure velocities and used to detect wind speeds, tornadoes, mesocyclones.

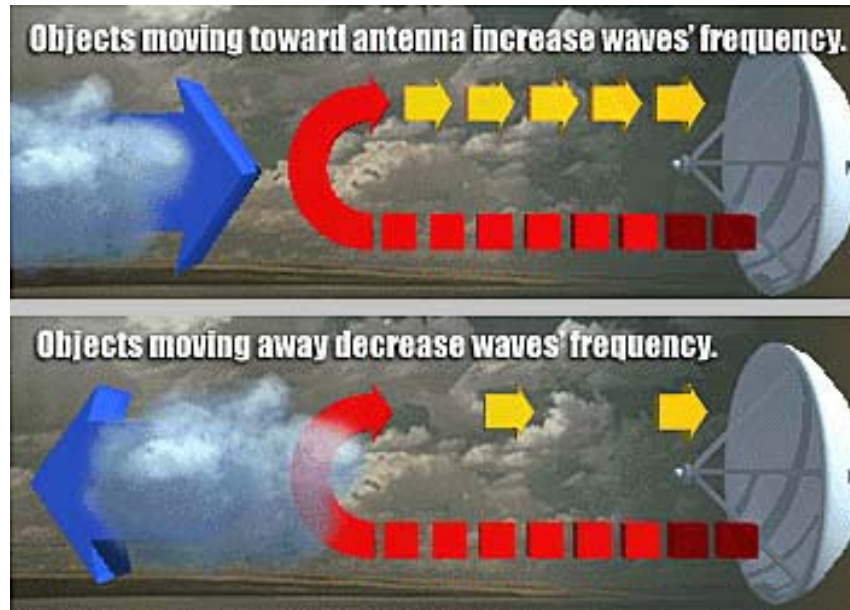


Figure 12: Doppler Frequency Shift by Moving Targets.

Motion towards a Doppler radar is expressed in negative values and green (cool) colours on a display screen. Motion away from a Doppler radar is expressed in positive values and red (warm) colours.

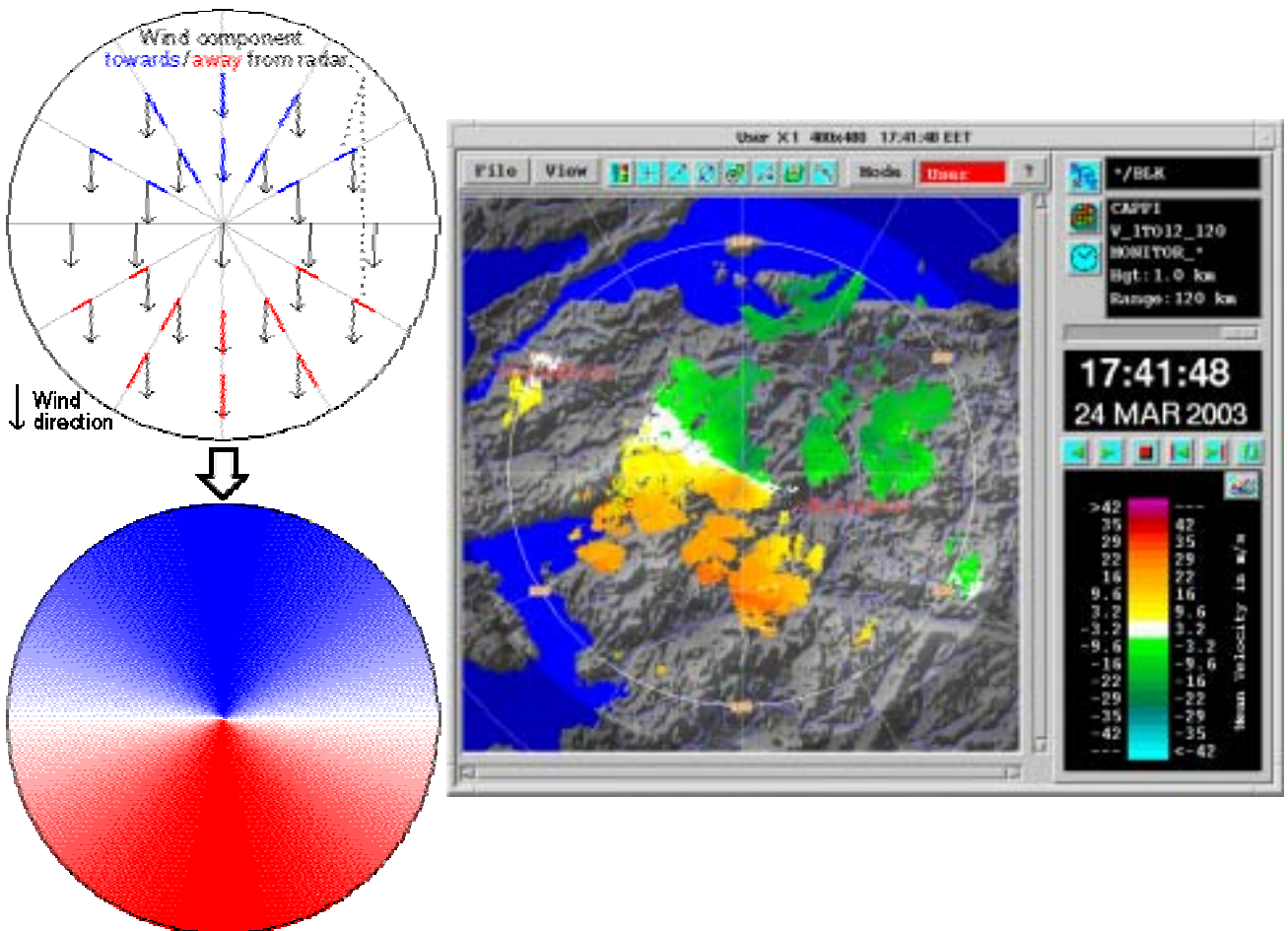


Figure 13: Doppler Radial Velocities and an Example Image.

If the target is moving sideways so that its distance relative to the radar does not change, the radar will record zero radial velocity for that target.

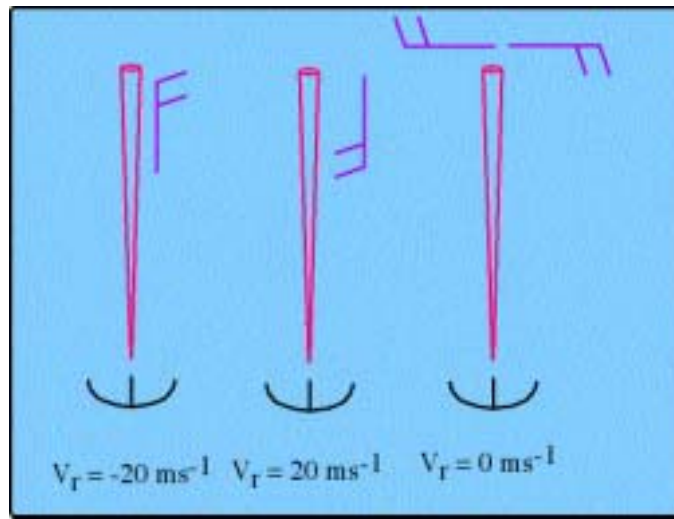


Figure 14: Another Schema of Doppler Radial Velocities.

1.2.4. Spectrum Width

Spectrum Width data is a measure of dispersion of velocities within the radar sample volume. In other words, it is the distribution of velocities within a single radar pixel. One pixel on radar represents a volume within which there can be literally millions of individual hydrometeors. Each individual hydrometeor will have its own speed and direction of movement.

The radar averages the individual radial velocities with a volume sample to produce a single average radial velocity that is displayed for that pixel. In a situation, where shear and turbulence is **small** within a pixel, the spectrum width will be **small**. In a situation, where shear and radial velocity is **large** within a pixel, the spectrum width will be **large**. A technical way of defining spectrum width is the **standard deviation** of the velocity distribution within a single pixel.

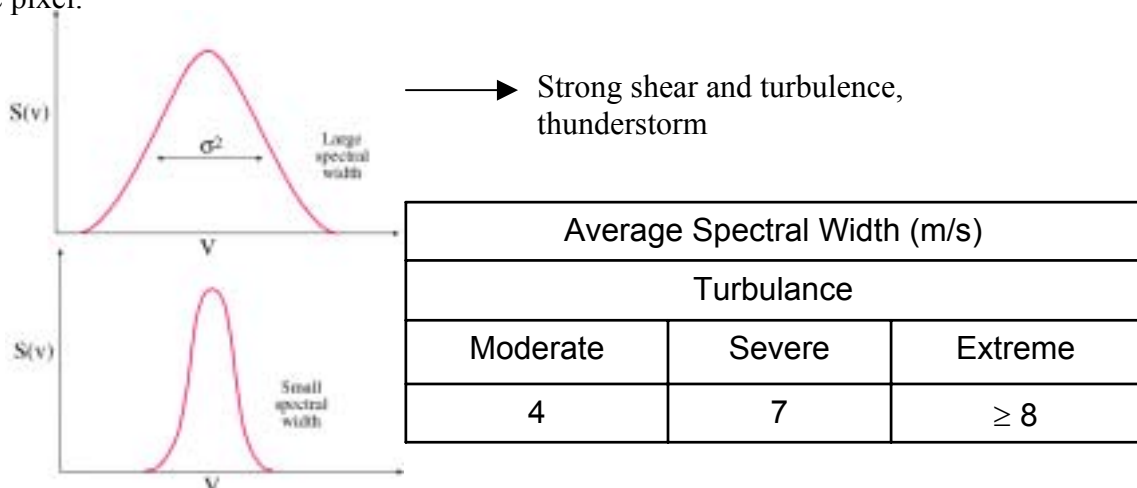


Figure 15: Spectrum Width and Its Averages.

1.2.5. Differential Reflectivity

Differential reflectivity parameter is a kind of data produced by polarimetric radars. In general, weather radars send and receive microwaves at one polarization, usually horizontal, because raindrops are usually oblate. By transmitting and/or receiving radar waves at more than one polarization, additional information can be obtained on the nature of the targets. Differential Reflectivity is a ratio of the reflected horizontal and vertical power returns. Amongst other things, it is a good indicator of drop shape. In turn, the shape is a good estimate of average drop size.

The signals that are received from each polarization channel are averaged separately, and radar reflectivity factors are determined from each, giving z_H and z_V . The reflectivity depolarization ratio is defined as:

$$Z_{DR} = 10 \log_{10}(z_H/z_V)$$

where z_H and z_V are the linear radar reflectivity factors at horizontal and vertical polarization, respectively. Z_{DR} is measured in decibels.

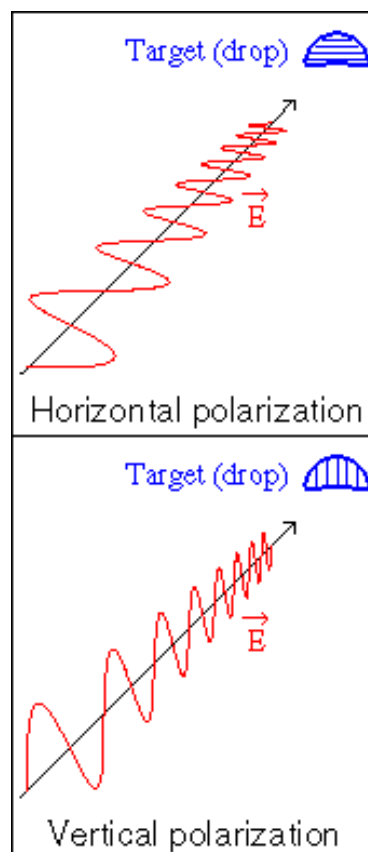


Figure 16: Dual Polarisation.

1.3. Product Descriptions

Radar data is displayed on three forms generally:

- **PPI** (*Plan Position Indicator*)
- **CAPPI** (*Constant Altitude Plan Position Indicator*)
- **RHI** (*Range Height Indicator*)

Radar scans for producing these basic products were explained in the Section of Scanning Strategies.

1.3.1. PPI (Plan Position Indicator)

PPI is the most common (classic) display of radar data and it is produced in much shorter time than volume scan. It shows the distribution of the selected data parameter (Z, R, V, W or ZDR) on a constant elevation angle surface (near to 0°).

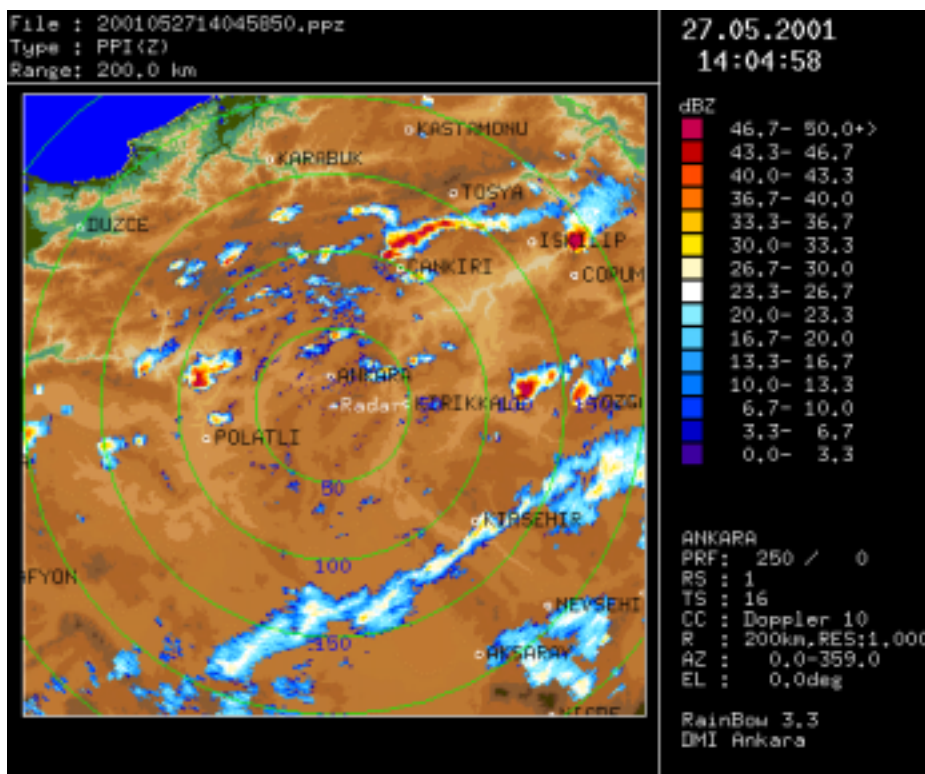


Figure 17: A PPI Reflectivity Product from Ankara Radar.

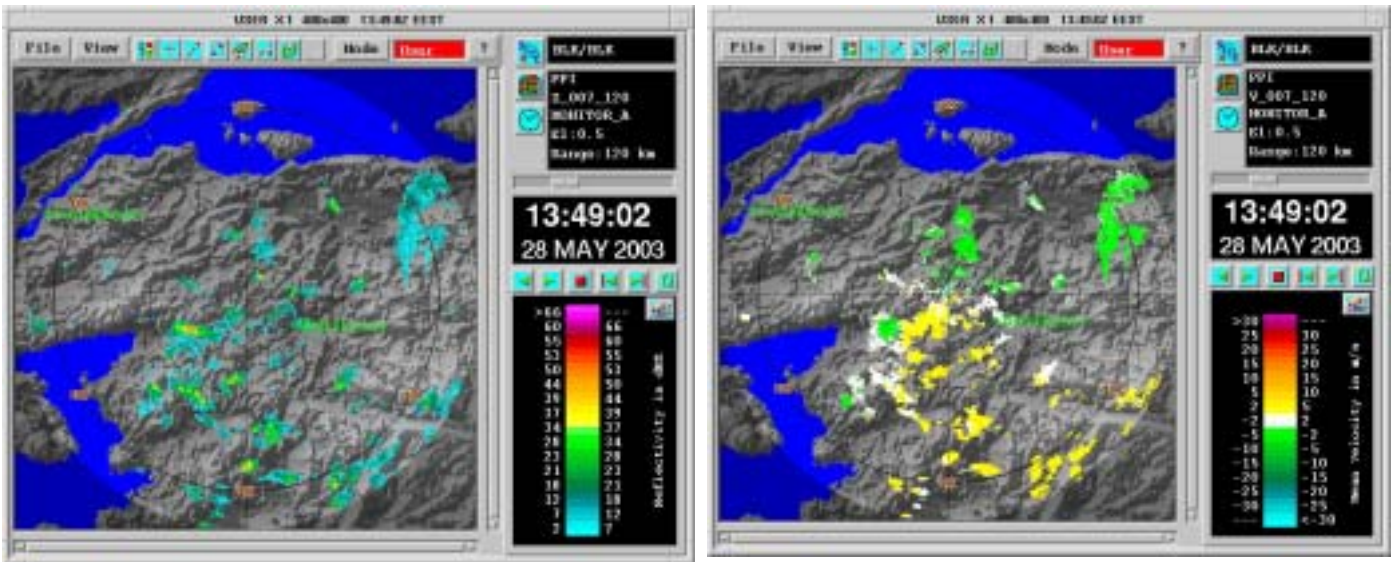


Figure 18: PPI Reflectivity and Velocity Products at the Same Time from Balikesir Radar.

1.3.2. CAPPI (Constant Altitude Plan Position Indicator)

CAPPI product is a horizontal cut through the atmosphere, therefore, it requires a PPI volume scan at multiple elevation angles. The number of angles and their spacing depends on the range and height of the CAPPI you want to produce.

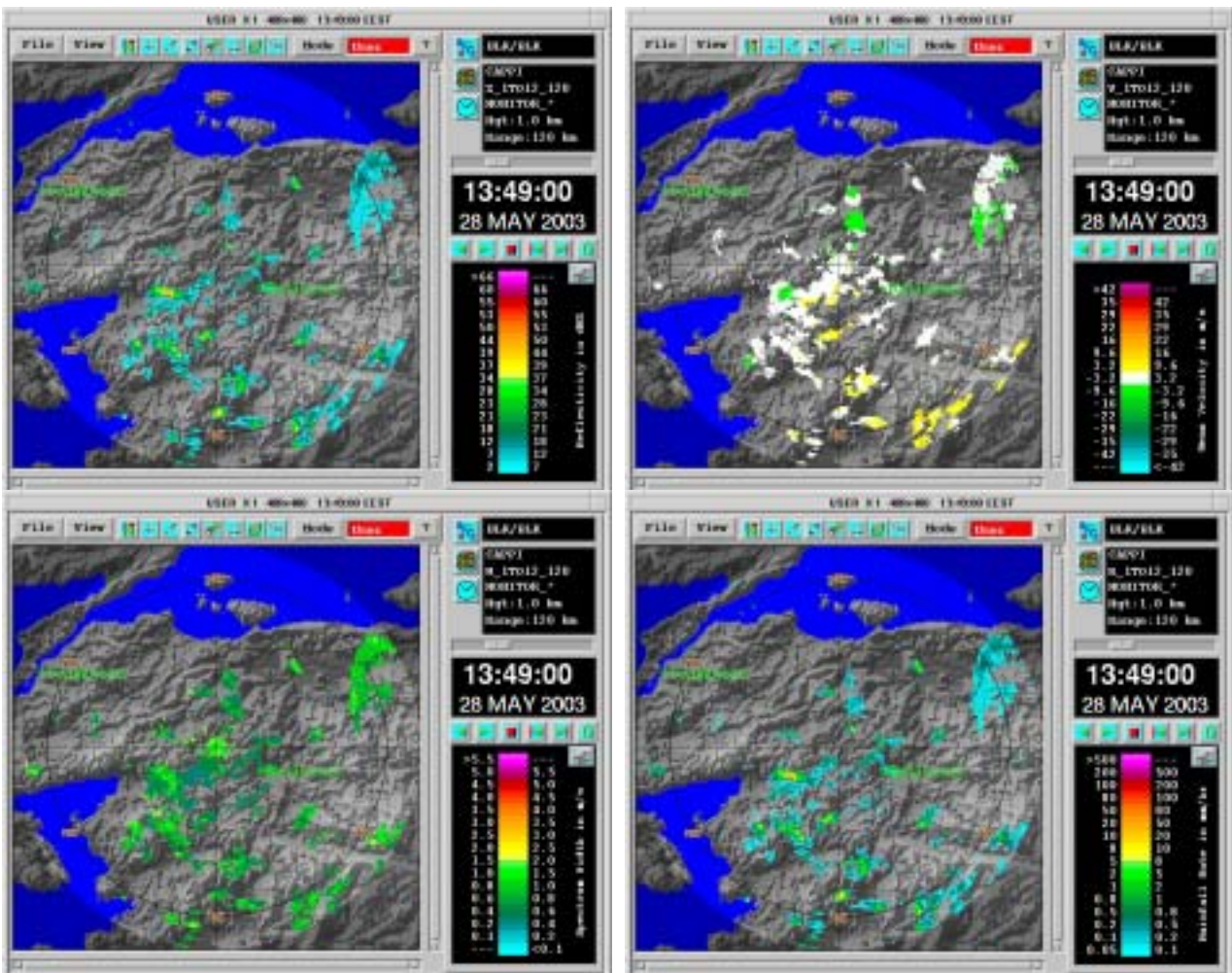


Figure 19: CAPPI Reflectivity, Velocity, Spectrum Width and Rainfall Rate Products at the Same Time from Balikesir Radar

1.3.3. RHI (Range Height Indicator)

RHI product is excellent for viewing the detailed vertical structure of a storm. In general, you should schedule a RHI TASK through a region of interest. During RHI scanning, the antenna azimuth is fixed and the elevation is swept, typically from near 0° to 90° to create a vertical cross-section effect.

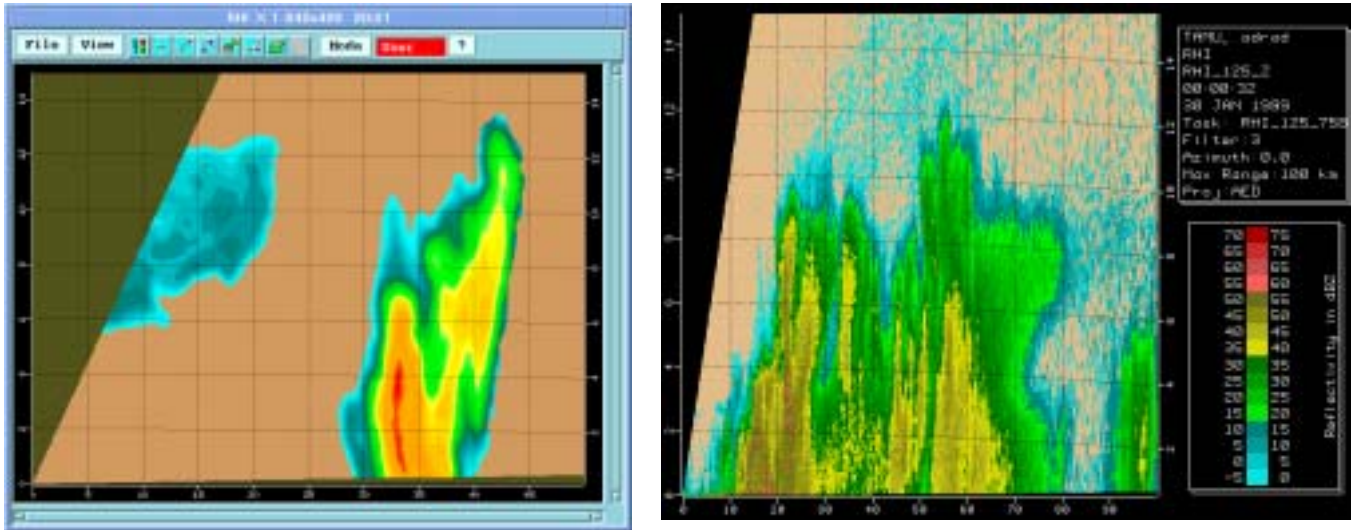


Figure 20: RHI Reflectivity Products.

1.3.4. Other Products

Some other important radar products are given below:

- MAX (Maximum Display)
- Echo Tops
- Wind Products
 - Horizontal Wind Vectors
 - VVP (*Velocity Volume Processing*) or VAD (*Velocity Azimuth Display*)
 - Wind Shear
- Rainfall Products
 - SRI (*Surface Rainfall Intensity*)
 - Hourly and N-Hours Rainfall Accumulation
 - VIL (*Vertically Integrated Liquid*)
 - Rainfall Subcatchments
- Warning Products

1.3.4.1. MAX (Maximum Display)

MAX product shows the maximum echoes on each pixels between user selected heights (in this case 0 km and 15 km, below).

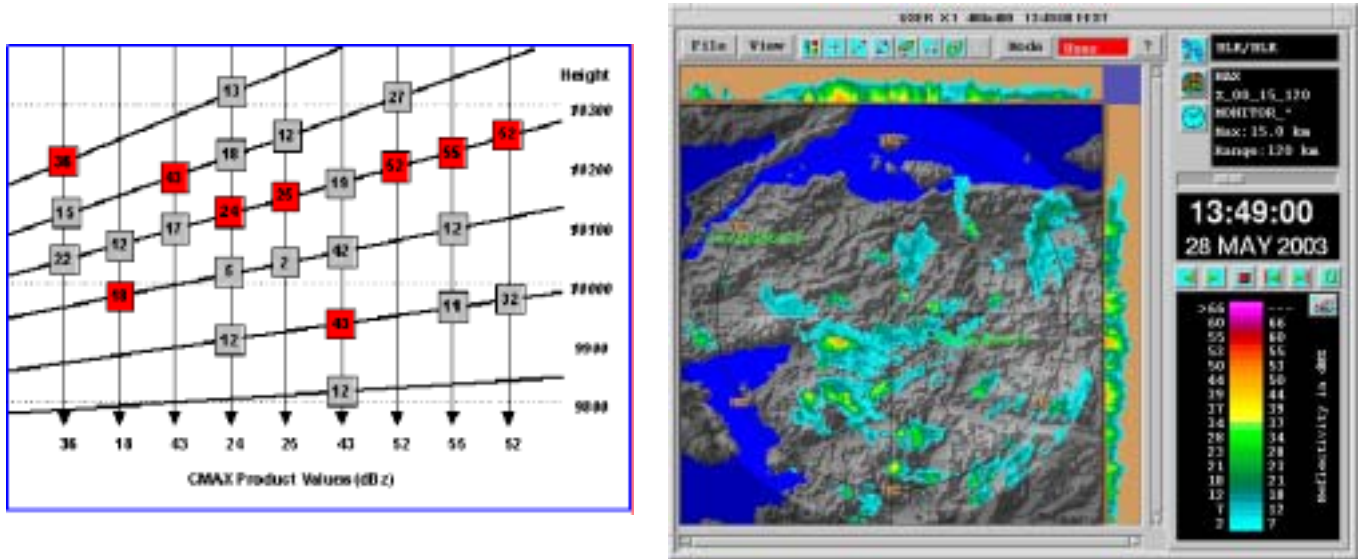


Figure 21: Schema of the MAX Product and a MAX Image from Balikesir Radar.

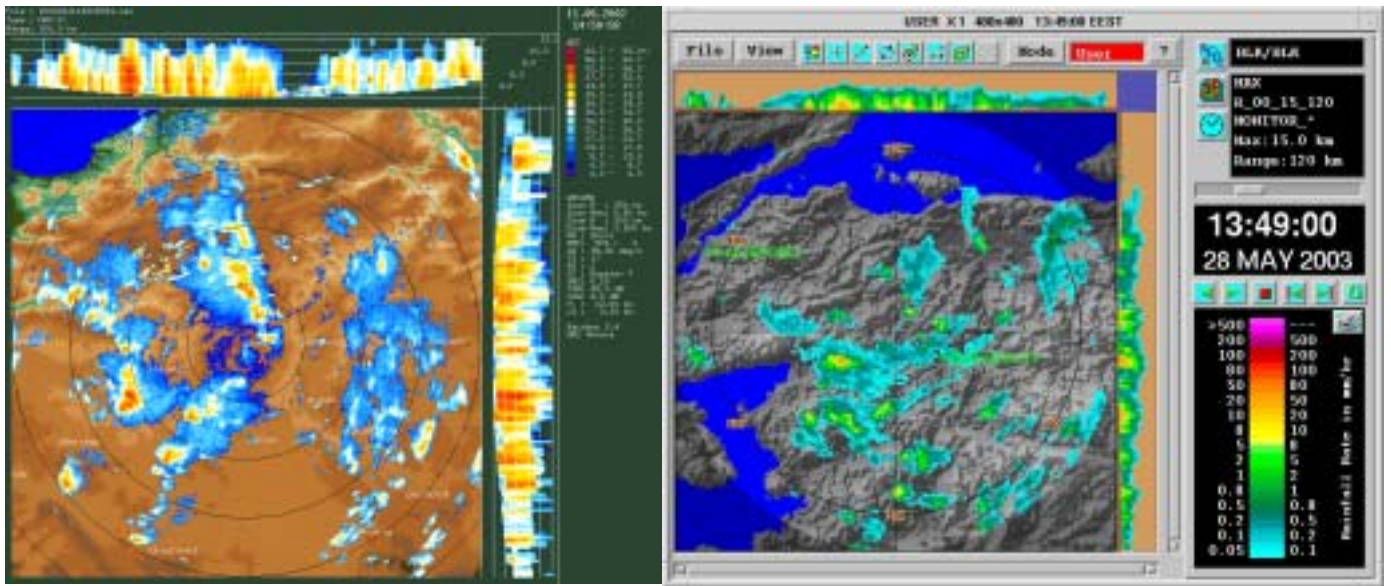


Figure 22: Other Some MAX Products (Reflectivity from Ankara, Rainfall Rate from Balikesir Radar).

1.3.4.2. Echo Tops

Echo Tops product shows tops heights (in kilometers) at the user selected thresholded (in this case at 30 dBZ, below). It is an excellent indicator severe weather and hail.



Figure 23: An Echo Tops Product.

1.3.4.3. Wind Products

1.3.4.3.1. Horizontal Wind Vectors

Horizontal wind vectors are displayed as wind speed and direction with either wind barbs or wind strings.

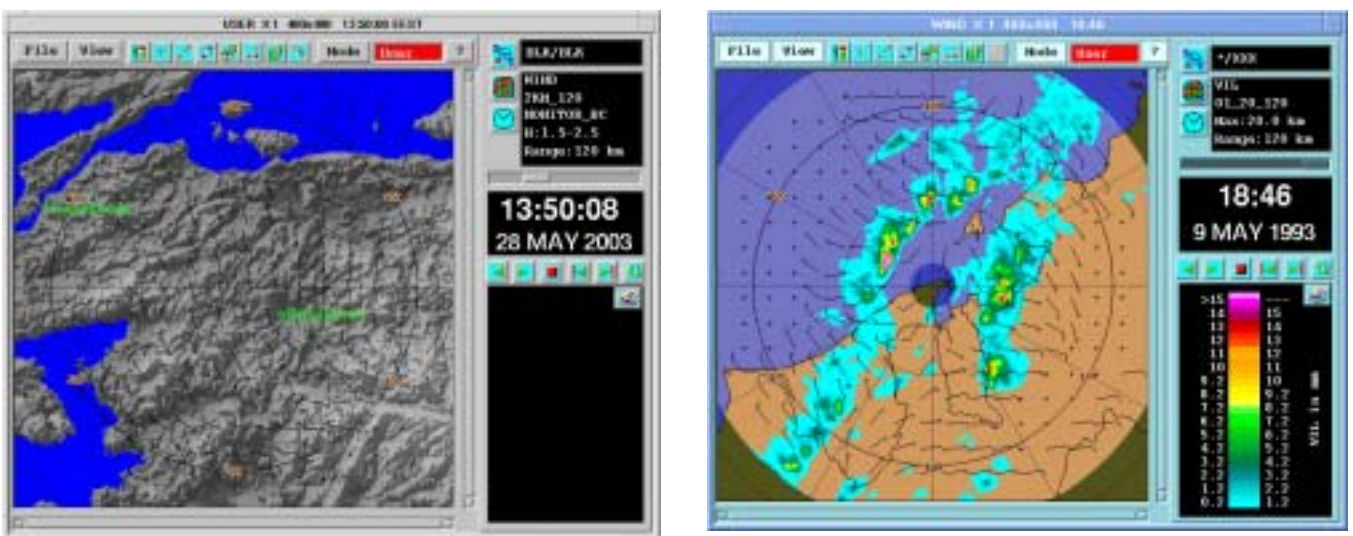


Figure 24: Horizontal Wind Vectors.

1.3.4.3.2. VVP (Velocity Volume Processing) or VAD (Velocity Azimuth Display)

In the VVP product, wind speed and direction (windbarbs) is plotted as a function of height an time. Also, the background is color coded with reflectivity levels.

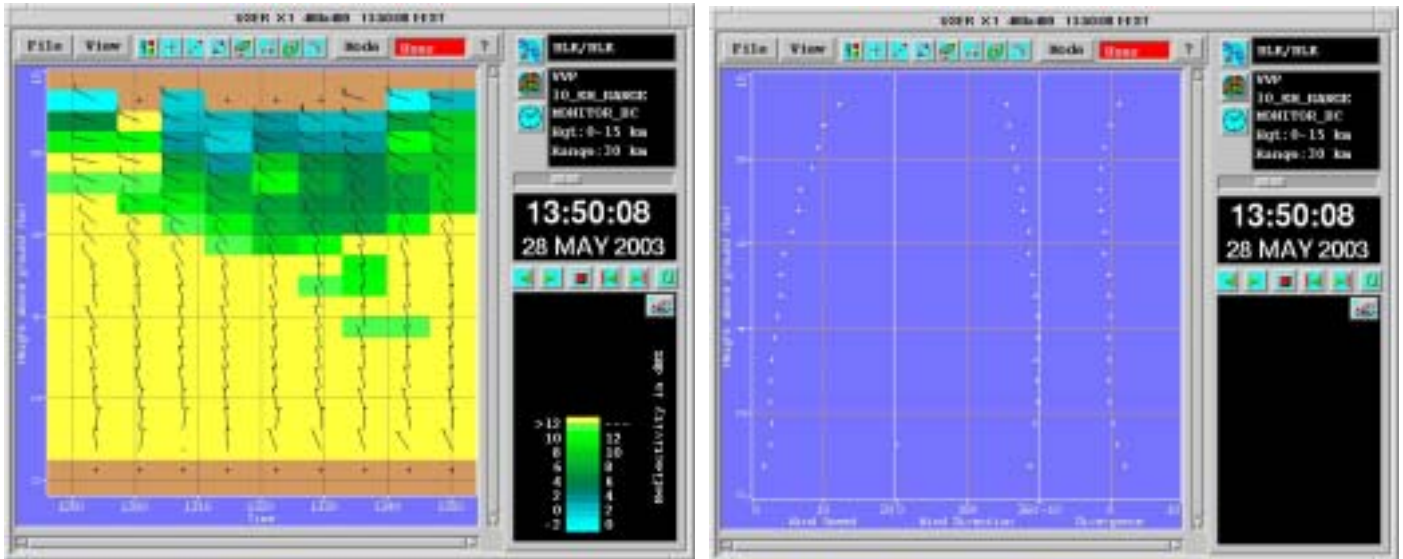


Figure 25: Some Types of VVP Product.

1.3.4.3.3. Wind Shear

Wind shear in the atmosphere can be detected by Doppler radars. Wind shear product is used for microburst and gust front detection. An important point that mountain radars are not able to observe to sufficiently low altitudes immediately above the airports to reliably detect microburst.

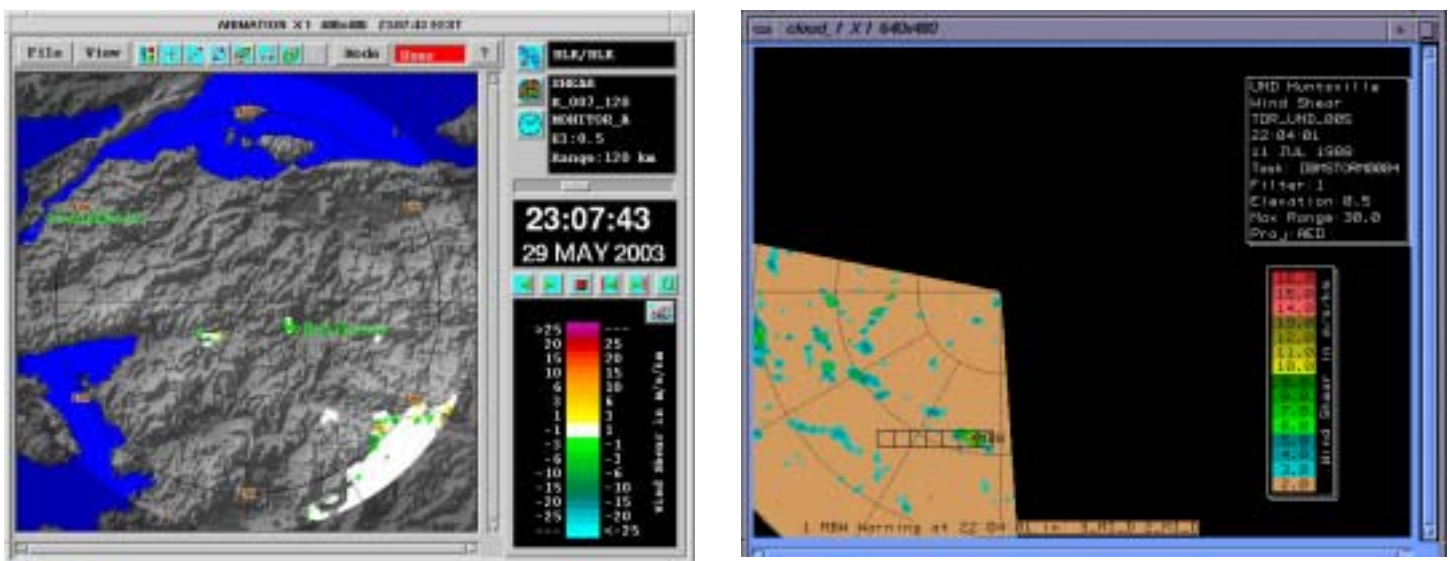


Figure 26: Some Wind Shear Products and Microburst Warning on the Right.

1.3.4.4. Rainfall Products

1.3.4.4.1. SRI (Surface Rainfall Intensity)

The SRI product shows the rainfall intensities based on Z-R relation.

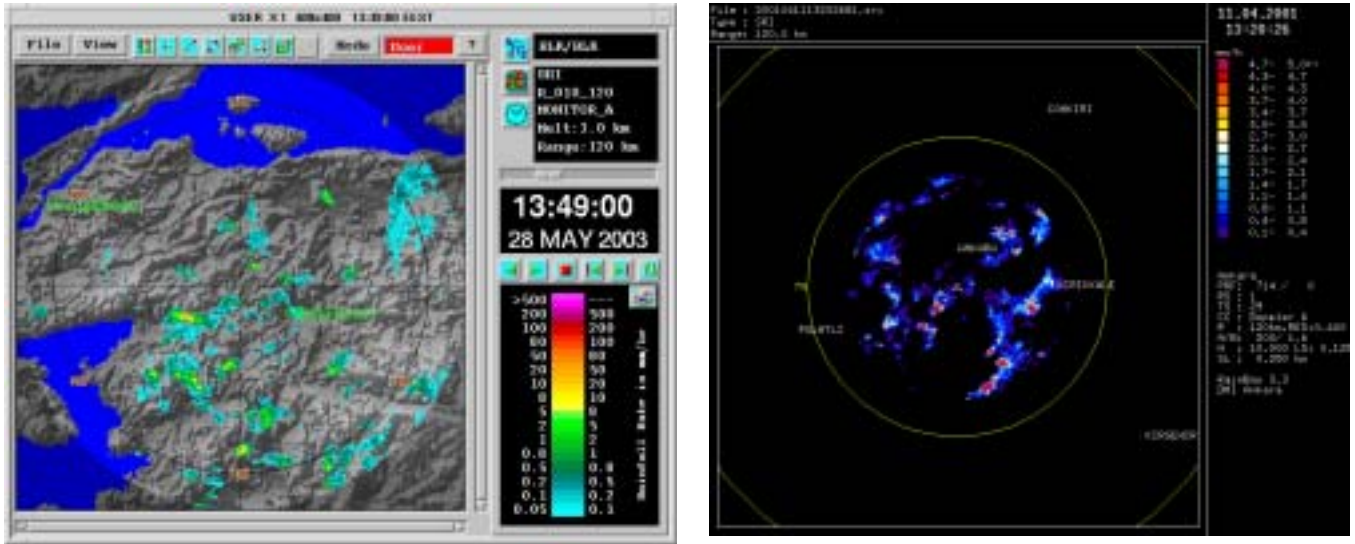


Figure 27: Some SRI Products.

1.3.4.4.2. Hourly and N-Hours Rainfall Accumulation

Hourly and last 6-Hours rainfall accumulation example products are below.

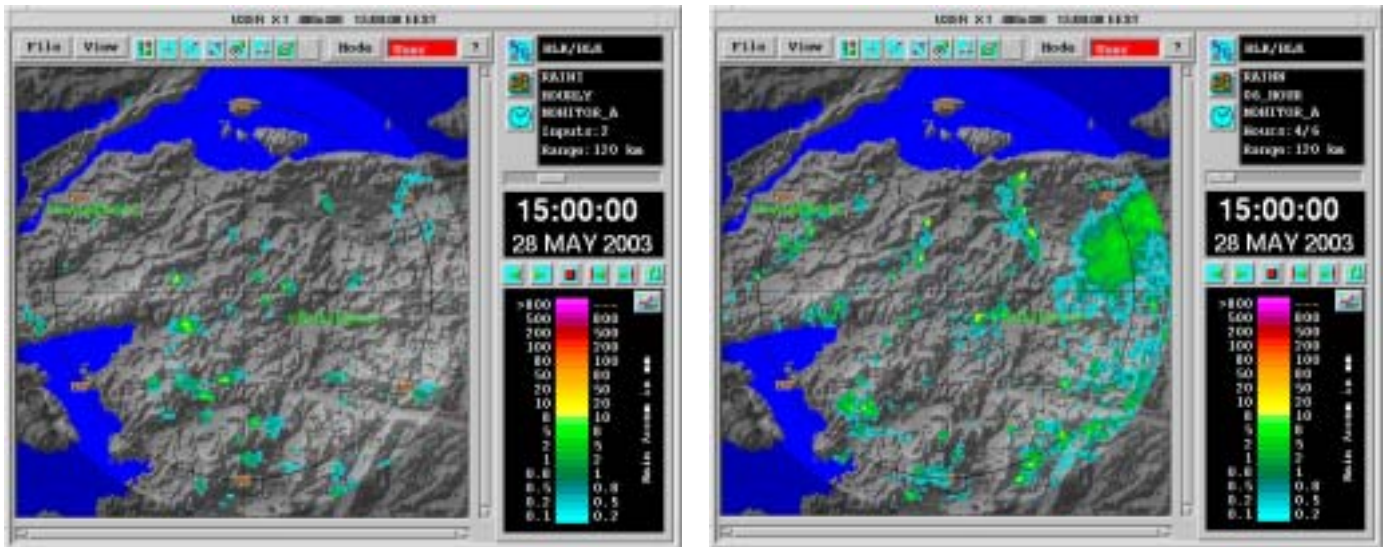


Figure 28: Hourly and 6-Hours Rainfall Accumulation Products.

1.3.4.4.3. VIL (Vertically Integrated Liquid)

VIL product is an excellent indicator of severe storm activity, especially with regard to the rainfall potential of a storm. The output shows the estimated precipitation (in millimeters)

contained within a user-defined layer. If the layer height is above the freezing level, high VIL values are an excellent indicator of severe storm and hail. If the layer height extends from the surface up to 3 km, then the VIL values serve as a forecasting guide as to how much precipitation is likely to fall during the next few minutes.

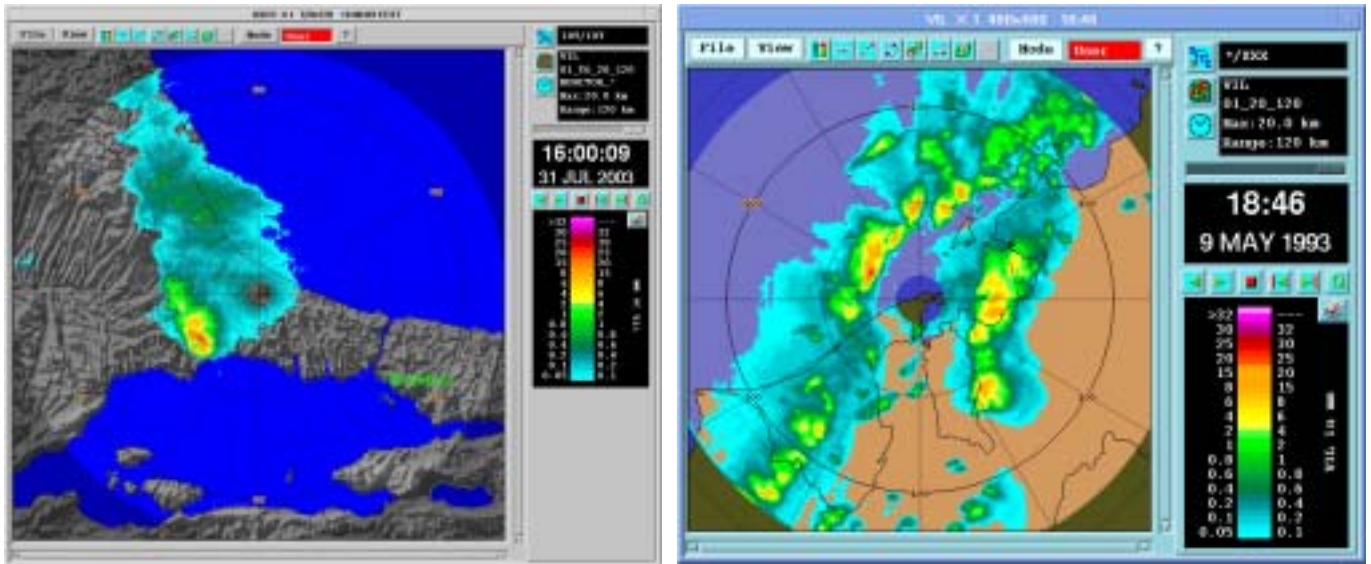


Figure 29: Some VIL Products.

1.3.4.4.4. Rainfall Subcatchments

The precipitation accumulation in subcatchment regions such as watershed areas can be calculated by radars. It is used for hydrometeorological applications such as estimating the total rainfall in a river basin for the purpose of flood forecasting. This product can also issue warnings if the precipitation in a subcatchment region exceeds a threshold value.

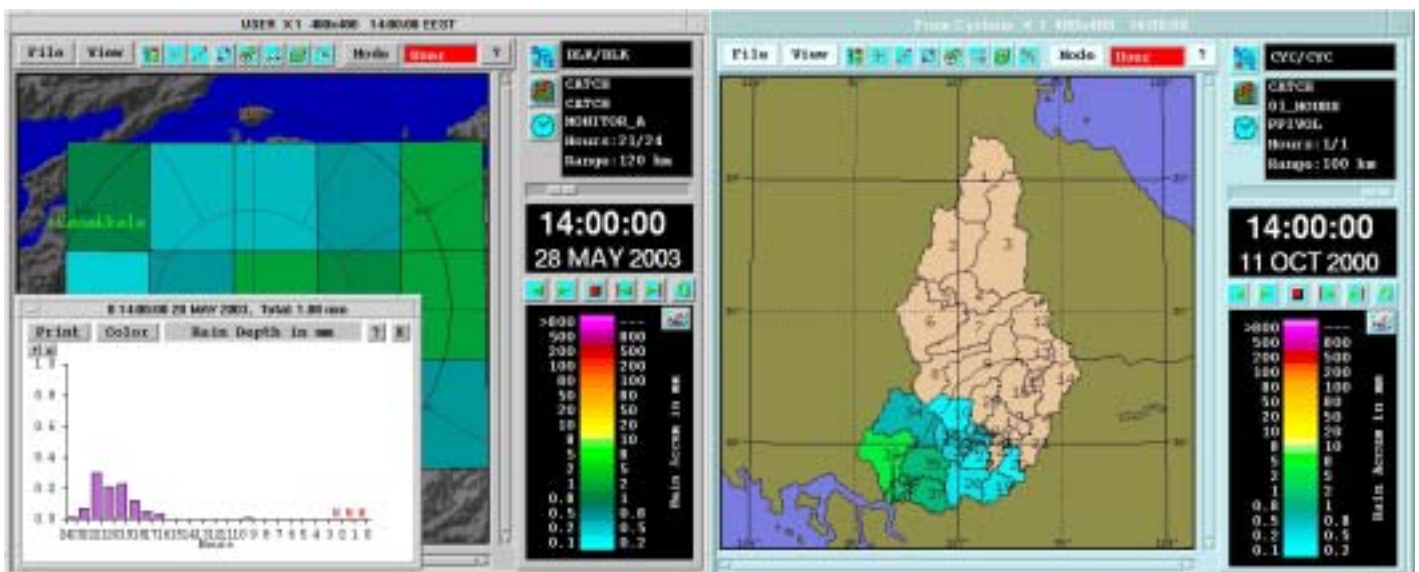


Figure 30: Some Rainfall Subcatchments Products.

1.3.4.5. Warning Products

Warning products are used for detecting significant weather. For example, the occurrence of 45 dBZ at 1.5 km above the freezing level is a good indicator of hail in many mid-latitude locations. Suppose the freezing level is at 4 km, and you run an Echo Tops product for the 45 dBZ contour. If the Echo Tops product shows 45 dBZ tops at heights greater than 5.5 km, there is a high probability of hail. Because of this general approach, the automatic warning feature can provide alerts for a wide variety of weather phenomena.

Some examples of warning criteria are summarized below:

Hail Detection: [45 dBZ Echo Tops > 1.5 km above freezing level] over an area of 10 km²

Wind Shear Detection: [Wind Shear > 10 m/s/km at 0.5° EL] .AND. [... at 0.7° EL] over an area of 3 km²

Storm Turbulence Detection: [Spectrum Width > 6 m/s] .AND. [Reflectivity > 20 dBZ] over an area of 10 km²

Precipitation Surveillance Detection: [1.5 to 14 km VIL > 1mm] over an area of 10 km²

Severe Storm Detection or Lightning Hazard: [1.5 to 15 km VIL > 10 mm] .AND. [10 dBZ TOPS > 8 km] over an area of 10 km²

Flash Flood Warning: [Hourly Rainfall or N-Hour Rainfall > 5 mm] over an area of 25 km²

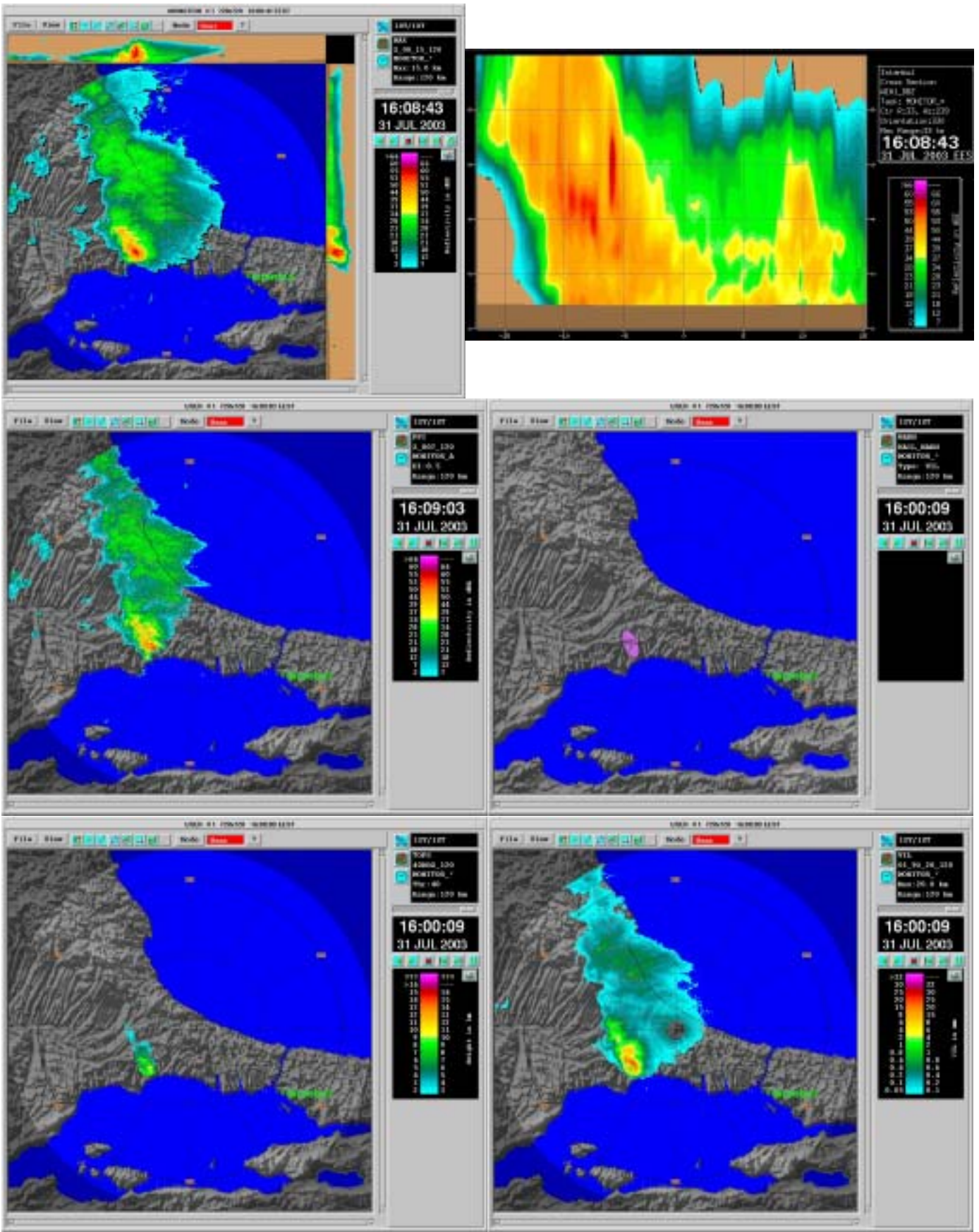


Figure 31: Hail Warning And Related Other Products.

The images below show a fairly typical microburst signature on the radar display. The left image (a) shows the radar reflectivity (dBZ) and the right image (b) shows the corresponding radial velocity (m/s) relative to the CSU-CHILL radar. In a microburst, the spreading out of the air near the ground surface is similar to turning a garden hose on and aiming the end toward the pavement.

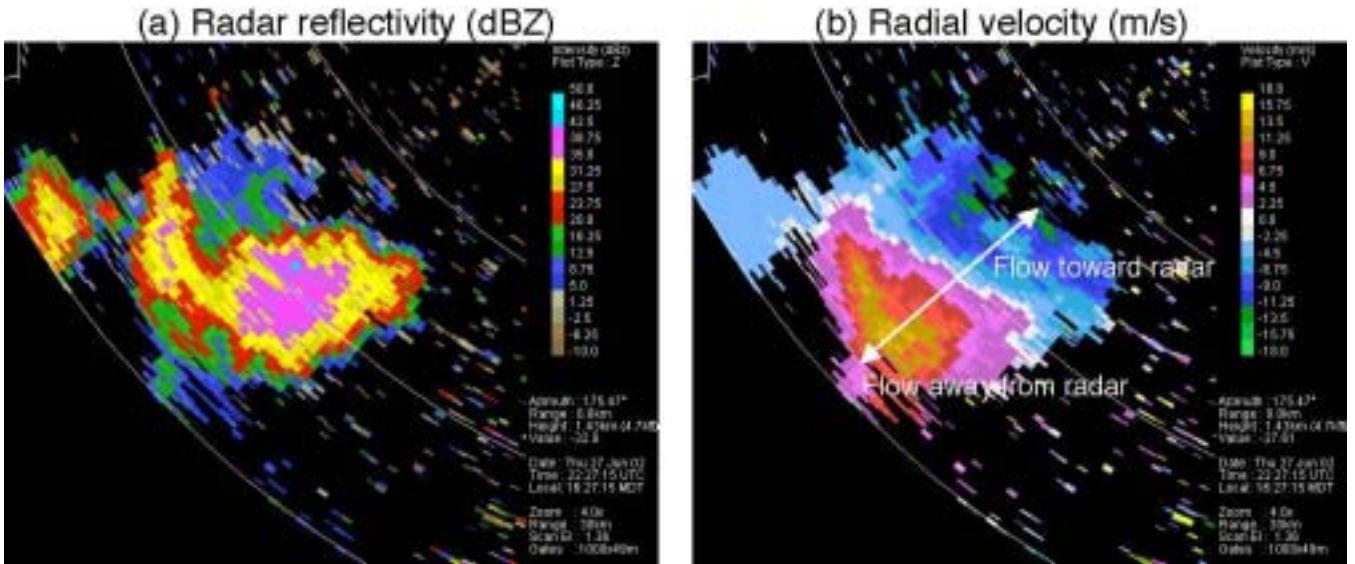


Figure 32: Detection and Warning Microburst on Radar Images.

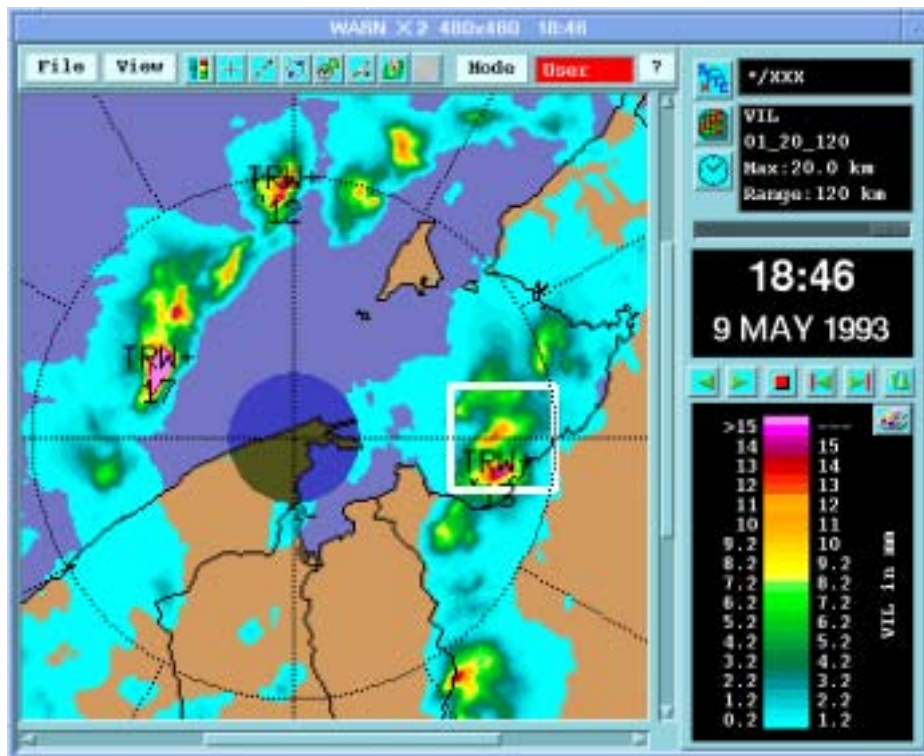


Figure 33: A Thunderstorm Warning Product

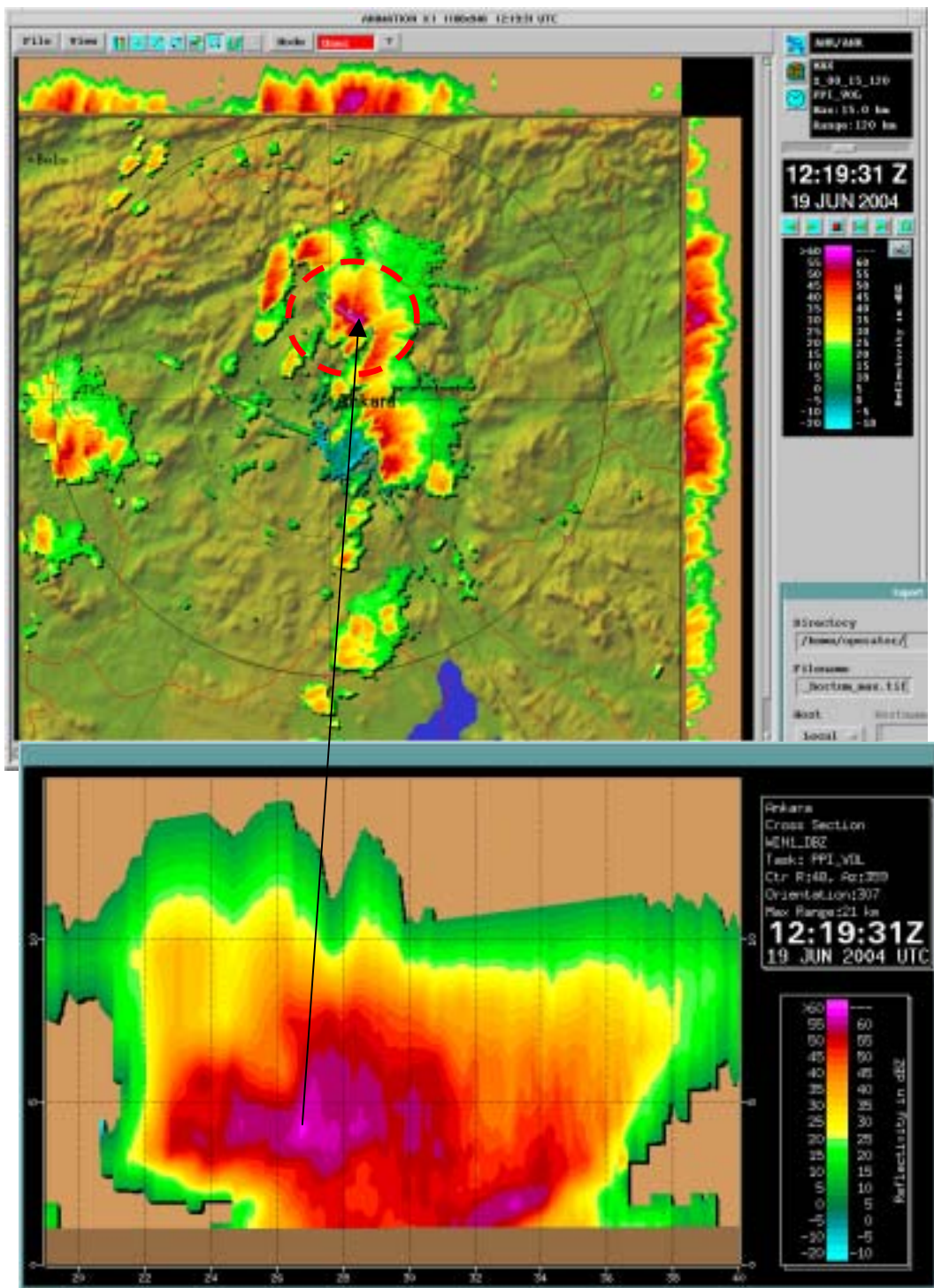


Figure 34: MAX Reflectivity and its Cross Section Indicate a Tornado in a Small Area

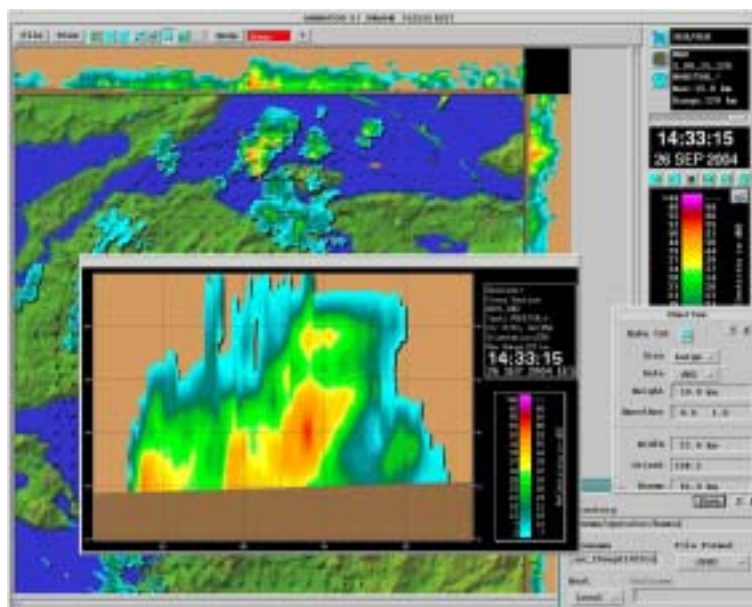
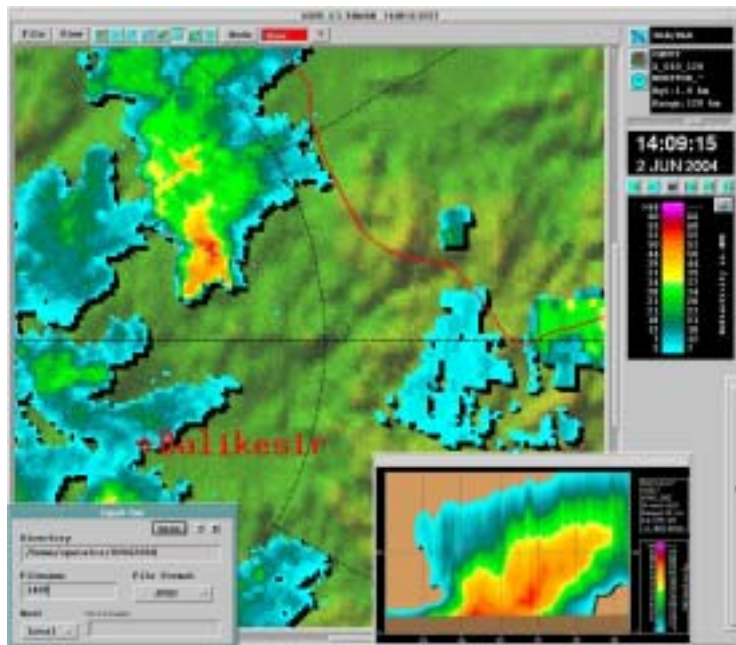
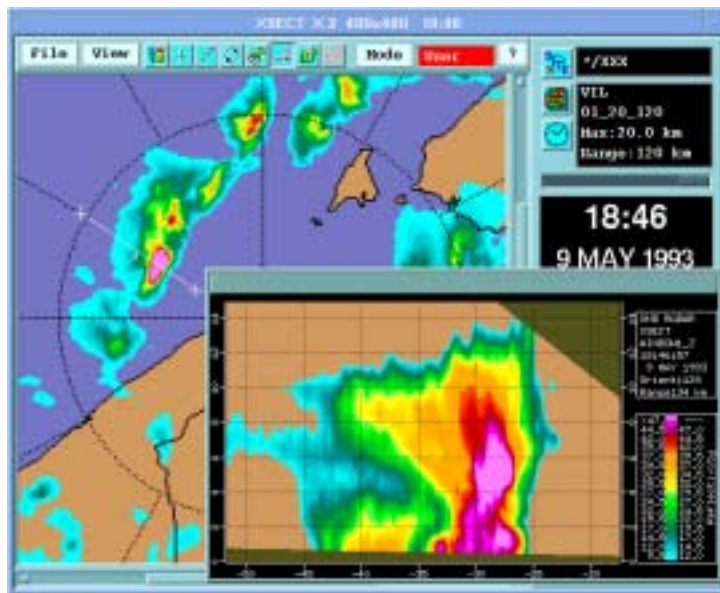


Figure 35: Some Cross Section Images From Supercells.

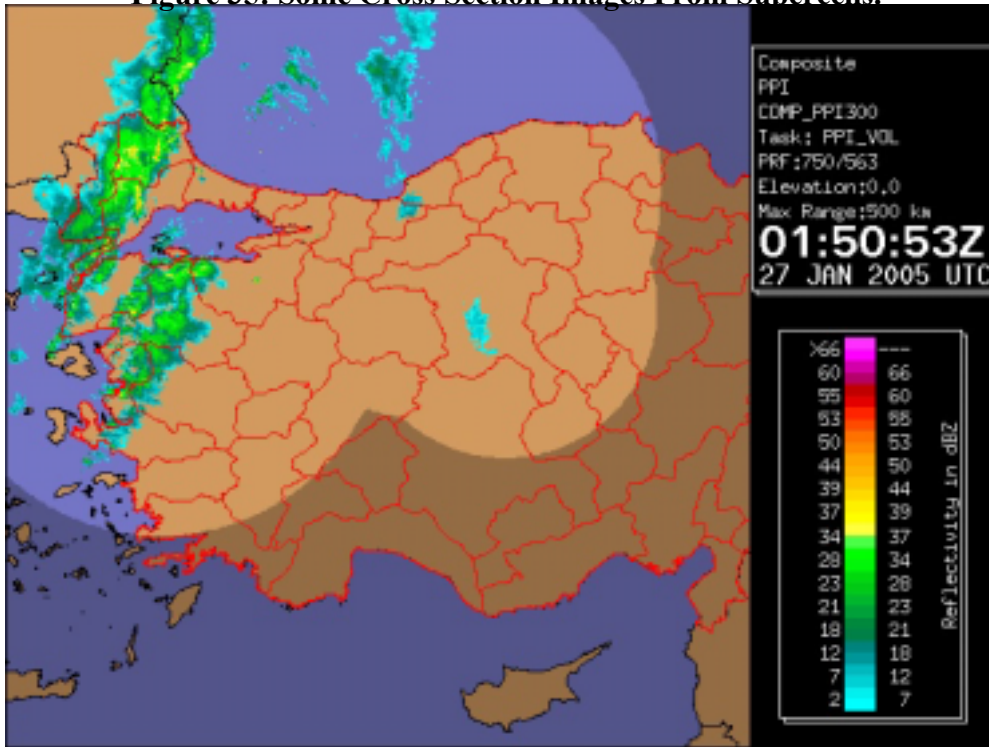
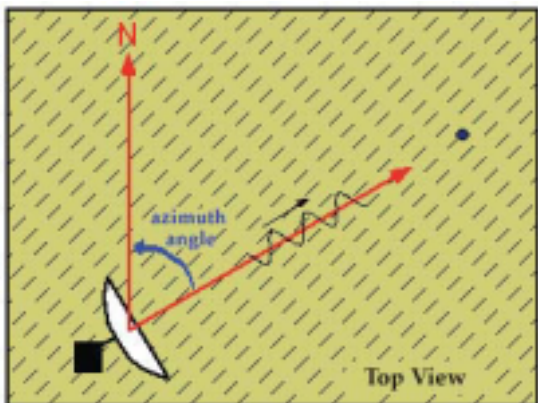


Figure 36: A PPI Reflectivity Mosaic Image Of Turkey Radar Network.

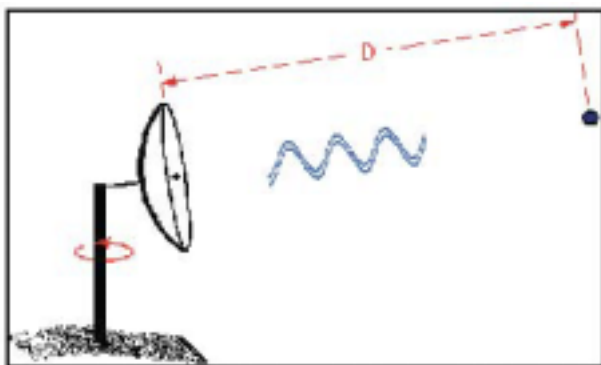
2. SCANNING STRATEGIES

For radar to find a target of interest (e.g., a cloud), three pieces of information are needed:



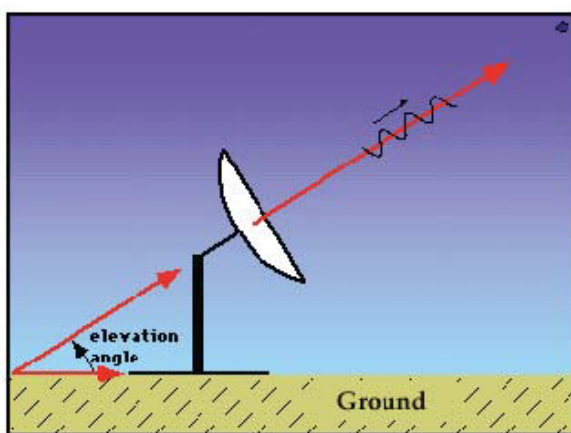
1. Azimuth angle (direction relative to north)

Figure 37: Azimuth Angle



2. Distance to the target of interest

Figure 38: Distance to the Target.



3. Elevation angle (angle above the ground)

Figure 39: Elevation Angle.

Scan Mode	PPI Full	PPI Sector	RHI
Azimuth	Full Circle: antenna scans 0° to 359° in azimuth continuously	Antenna scans between two azimuthal angles	Antenna is fixed in an azimuthal angle
Elevation	Single angle in elevation or different elevation angles from -2° to 90° in elevation can be chosen for volume scan	Single angle in elevation or different elevation angles from -2° to 90° in elevation can be chosen for volume scan	Antenna scans between two elevation angle

Table 3: PPI and RHI Scanning Types.

In meteorology, radars usually employ one of two scanning techniques:



Plan Position Indicator (PPI): The radar holds its elevation angle constant but varies its azimuth angle. If the radar rotates through 360 degrees, the scan is called a "*surveillance scan*". If the radar rotates through less than 360 degrees, the scan is called a "*sector scan*". It's good surveillance scan and good in operational setting.



Range Height Indicator (RHI): The radar holds its azimuth angle constant but varies its elevation angle. The elevation angle normally is rotated from near the horizon to near the zenith (the point in the sky directly overhead). It's good for determining the vertical structure of the storm.

Figure 40: PPI and RHI Scanning.

We are most concerned with the PPI scan. The TSMS radars operate by collecting a series of surveillance scans at increasing elevation angles. It takes a radar ~ 8 minutes to collect the data, depending on how many elevation angles are used. The radar then repeats the cycle.

2.1. Winter Task

Precipitation Mode is the standard mode of operation whenever precipitation is first detected. When rain is occurring, the radar does not need to be as sensitive as in clear air mode as rain provides plenty of returning signals. When the weather conditions turn severe, the Precipitation Mode can be activated. The Precipitation Mode provides a **faster scan rate** to monitor a larger volume of space in a shorter time. This permits the tracking of rapidly moving meteorological phenomena found in convective weather patterns. This mode is characterized by the use of a **short pulse width** at both **high and low PRFs**. It consists of the

Surveillance Task with Monitor Task. In addition, a RHI task can be scheduled for observing storm structure in detail, especially for storms close to the radar (max range 120 km). In precipitation mode, the radar products update every 6 minutes.

Elevation Angles (°)	0.5-45.0 (16 angles)
Resolution (°)	1.0
Pulse Width (usec)	1.00
Scan Speed (°/sec)	12.00, 24.00, 24.00
Data	T, Z, V, W
Samples	64, 32, 32
Number of Bins	1200
Bin Spacing (m)	250.0
Max Range (km)	120.0
PRF (Hz)	1200-900
Unambiguous Velocity (m/s)	48 (4:3)
Processing	RPHASE
Data Quality Thresholding	T: LOG, Z: LOG&CSR, V:SQI&CSR, W: SIG&SQI&LOG
LOG (dB)	0.8
SIG (dB)	10
CSR (dB)	18
SQI	0.4
Speckle	Z on, V on

Table 4: Precipitation Task Configuration.

2.2. Convective (Summer) Task

2.2.1. Clear Air Mode

Clear Air Mode task is preferred when significant precipitation is not estimated in the radar coverage. In this mode, the radar is in its most sensitive operation. This mode has the slowest antenna rotation rate which permits the radar to sample a given volume of the atmosphere longer. This increased sampling increases the radar's sensitivity and ability to detect smaller objects in the atmosphere than in precipitation mode. This mode allow to meteorologists, detecting clear air phenomena, such as dry lines, dry microbursts, and wind shift lines. In clear air mode, the radar products update every 10 minutes. It uses **a long pulse** and the radar is operated at a relatively **slow scan** rate that allows the sampling of **five** contiguous elevation angles (0.5° to 4.5°) in a period of 10 minutes. When a radar system detects precipitation of a specified intensity and extent (30 dBZ), it automatically switches from Clear Air to the Precipitation Mode by using Automatic Mode Switch Menu for two plans.

Elevation Angles (°)	0.5, 1.5, 2.5, 3.5, 4.5
Resolution (°)	1.0
Pulse Width (usec)	2.00
Scan Speed (°/sec)	12.00
Data	T. Z. V. W
Samples	55
Number of Bins	1200
Bin Spacing (m)	250.0
Max Range (km)	300.0
PRF (Hz)	500-375
Unambiguous Velocity (m/s)	20 (4:3)
Processing	PPP
Data Quality Thresholding	T: LOG, Z: LOG&CSR, V: SQI&CSR, W: SIG&SQI&LOG
LOG (dB)	0.8
SIG (dB)	10
CSR (dB)	18
SOI	0.4
Speckle	Z on, V on

Table 5: Clear Air Task Configuration.

2.2.2. Surveillance Task

Surveillance Task Configuration is used to generate PPI at a single elevation close to zero for **long range** weather monitoring (Elevation Angle:0.5°, Max Range:300 km, Pulse Width:2). It can be used for winter and summer conditions.

PPI is the fastest of all radar products and therefore suitable for studying the fast-developing mesoscale storms.

2.3. Negative Scanning and Cone of Silence

Mountainous terrain provides particularly challenging circumstances for weather radars. Radar scans are severely blocked at valley bottom locations and commonly overshoot important low-elevation phenomena (especially precipitation) for mountaintop locations. For mountaintop radars in Turkey the operational scanning strategy includes a Doppler scan taken at negative elevation angles. The lowest elevation angle Doppler scan of -0.5° corresponds to

the lowest observable local application angle. Doppler scans are taken at the first elevation angle of -0.5° during an 8 minutes cycle with a maximum range of 120 km.

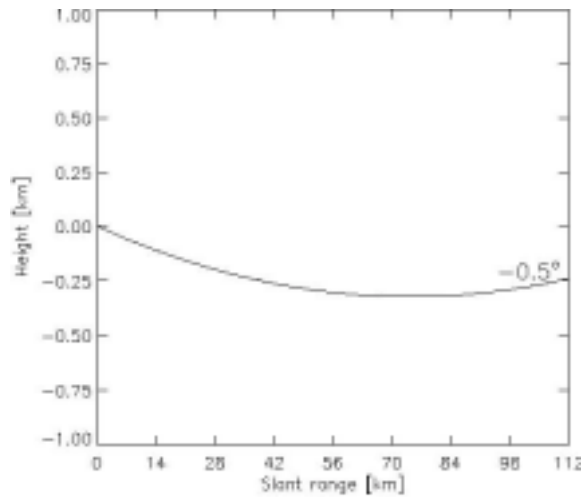


Figure 41 Slant Range-Height Diagram for an Elevation Angle of -0.5° .

Close to the radar, data are not available due to the radar's maximum tilt elevation. This area is commonly referred to as the radar's "**Cone of Silence**".

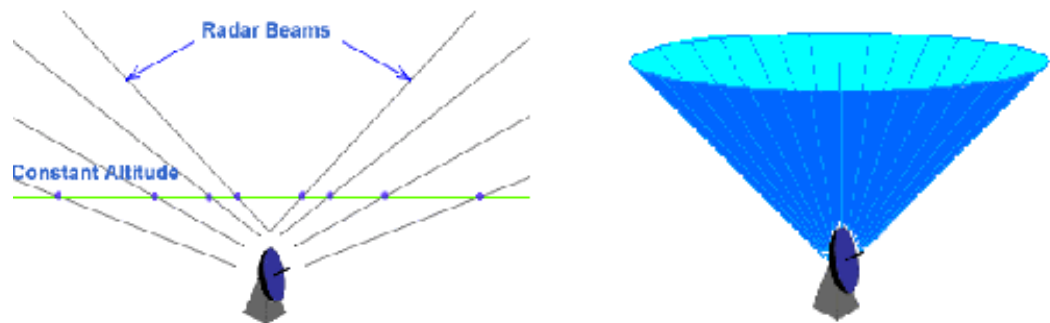
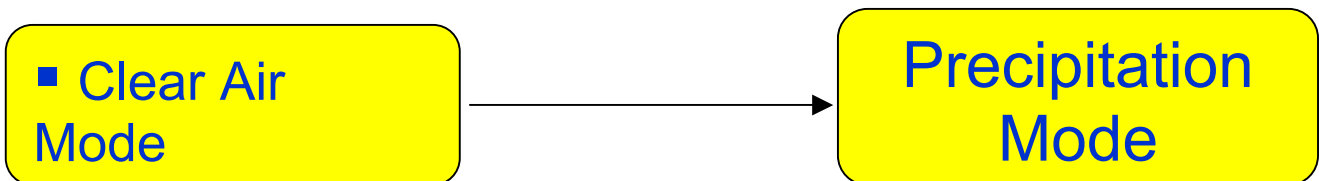


Figure 42: Cone of Silence.

2.4. Scanning Strategy Plan

Recall, when a radar system detects precipitation of a specified intensity and extent (30 dBZ), it automatically switches from Clear Air to the Precipitation Mode by using Automatic Mode Switch Menu for two plans. This is shown in figure below:

Turn severe weather



Activate the Precipitation Mode by Automatic Switching

Figure 43: A Scanning Strategy Plan.**3. RADAR PRODUCT APPLICATIONS****3.1. Z-R Relation, Gauge Adjustment**

Z-R relation was explained in Section 1.2.2. In practice, real-time adjustments to the Z-R conversion are sometimes made using readings from a number of raingauges or distrometers in radar's coverage automatically. As you have probably noticed, the precipitation estimates from radar data don't always agree with rain gauges! Meteorologists have been working on this problem for over 50 years now.

Question:**Why is it so difficult to compare rain gauge and radar measurements?**

Besides assumptions in the Z-R relation, there are a number of other complications:

- The radar samples precipitation in the cloud some distance above the ground. Particles may evaporate or otherwise be modified before they hit the surface.
- Clouds and precipitation frequently consist of a variety of particle types (e.g., ice and rain). Each particle interacts with the radar's energy in its own unique way.
- Rain that is further away from the radar returns a weaker signal than rain close by.

Other factors complicating the comparison of radar and rain gauge estimates of precipitation:

- The region sampled by the radar increases with distance. The wider the beam, the greater the likelihood of sampling a mixture of precipitation types, or the greater the likelihood of sampled both inside and outside of a cloud.

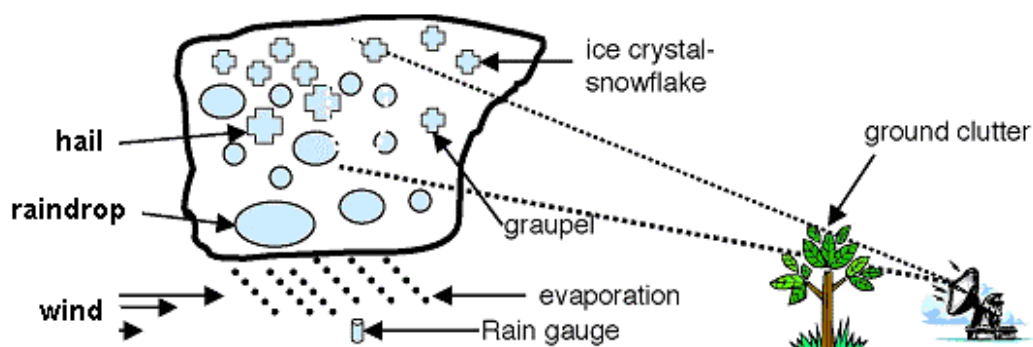
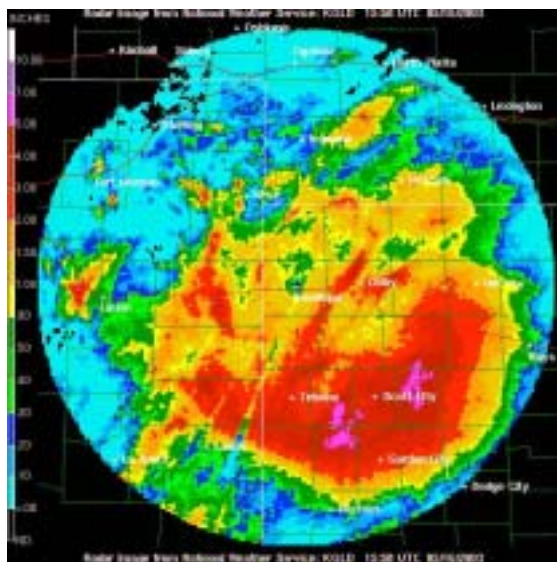


Figure 44: Radar and Rain Gauge Precipitation Estimating.

- Obstacles frequently block a portion of the radar beam, resulting in an artificially high power return.

Given all the issues, why use radar to measure precipitation?



- Radar is the only way to map the spatial distribution of precipitation over large areas
- Topography or other logistics may prevent locating gauges in many areas
- Radar can be used as a forecasting tool for flash flooding and severe thunderstorms

Figure 45: NWS NEXRAD (KGLD) Storm Total Precipitation 16 May 2003 15:58 UTC.

A Gauge Adjustment Method:

Recall, real-time adjustments to the Z-R conversion are sometimes made using readings from a number of raingauges or distrometers in radar’s coverage automatically. The rainfall data of automated weather observation stations can be used for reproduced Z-R relation. A method called **Bulk Adjustment** is explained below:

The new constant of a:

$$a=A(\sum R/\sum G)^b$$

a=radar estimate of rainfall (R) / raingauge total (G)

An example:

For a raingauae station, raingauge’s rainfall rate is 23.6 mm. Radar estimate of rainfall is 27.5 mm (A=200 and b=1.6).

$$a=200(27.5/23.6)^{1.6}=255.4$$

Error rate of radar estimate of rainfall is 3.9 mm.

$$z=aR^b$$

$$40,175.6=255.4*R^{1.6}$$

$\ln(40,175.6)=\ln(255.4)+1.6*\ln R \rightarrow R=23.6 \text{ mm}$ (The rainfall rate of the raingauge is obtained)

What is the dBZ value?

$$z=AR^b$$

$$\ln z=\ln A+b*\ln R=\ln 200+1.6*\ln(27.5)=10,601$$

$$z=40,175.6 \text{ mm}^6/\text{m}^3$$

$$\text{dBZ}=10\log_{10}z=10\log_{10}(40,175.6) \rightarrow \text{dBZ}=46$$

The new Z-R relation is determined as $z=255R^{1.6}$

3.2. Hydrometeor Classification

Perhaps a more significant result of polarisation measurements is the ability to perform hydrometeor identification, to differentiate liquid water from ice using their different dielectric properties and to identify various form of ice (snow, hail, crystals).

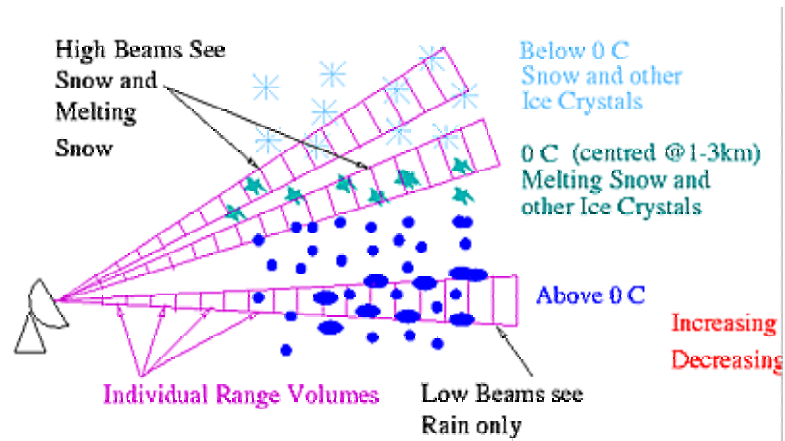


Figure 46: Hydrometeors in the Atmosphere.

The shape of raindrops falling in the atmosphere varies from nearly perfect spheres for small droplets up to a couple of millimeters in diameter to more flattened drops up to 5 or 6 mm across. These flattened drops give stronger returns at horizontal polarization than at vertical. Thus, Z_{DR} varies from near zero for spherical droplets to values as large as +5 dB for echoes from large water drops. This added information is useful for refining rainfall measurements made by radar.

Target	Z_{DR} (dB)
Drizzle	0
Rain	0.5 - 4
Snow, Graupel	(-1) – (+1)
Hail	~0

Table 6: Z_{DR} Values of Hydrometeors.

Z_{DR} is also useful for indicating the presence of hail. When hail is present, Z_{DR} often goes to near zero.

In moderate to heavy rain, the rain drops are large and as they fall they flatten to become oblate spheroids, giving a stronger echo for horizontal polarisation. Raindrop diagram:

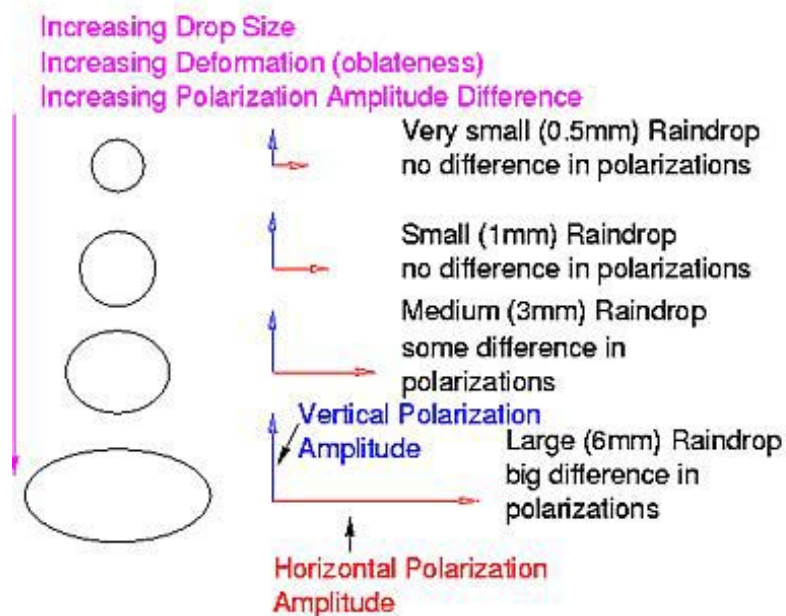


Figure 47: Raindrop Diagram.

3.3. Radar Data Quality Algorithms

- Radar reflectivity data is subject to many contaminants. Not all reflectivity corresponds to "true" weather.
- Radar reflectivity data must be corrected to account for anomalous propagation (AP), ground clutter and returns from non-weather echoes.
- Doppler clutter filter for clutter cancellation needs to remove clutter without destroying rain data.
- Quality control softwares can be produced.
- Real time quality control of reflectivity data using satellite infrared channel and surface observations.

These limitations are explained below:

3.3.1. Limitations of Doppler Radar

There are limitations in the velocities and ranges that a radar can resolve unambiguously. PRF is the pulse repetition frequency (PRF) of the radar. Maximum unambiguous velocity detectable by a doppler radar is:

$$V_{max} = PRF \lambda / 4$$

This is an important result. It says that if we want to be able to detect high velocities, we must use long wavelengths, large PRF's or both.

The maximum unambiguous range is:

$$R_{max} = c / 2PRF$$

c=speed of light

Unfortunately, the PRF appears in both expressions, but in the denominator of one and the numerator of the other. This forms what has been called the “Doppler Dilemma”.

$$V_{max}R_{max} = c\lambda / 8$$

If we want to have a large V_{max} , we must have a small r_{max} since the right side of the equation is a constant for a given radar. Conversely, if we want to detect echoes at long ranges, we can only detect small velocities.

An example:

If we use large PRF=1200

$$R_{max} = c / 2PRF = 300.000 \text{ km/s} / 2 \times 1200 \text{ s}^{-1} = 125 \text{ km}$$

If our radar's wavelength is $\lambda=5.35 \text{ cm}$;

$$V_{max} = PRF \lambda / 4 = 1200 \text{ s}^{-1} \times 0.0535 \text{ m} / 4 = 16.05 \text{ m/s}$$

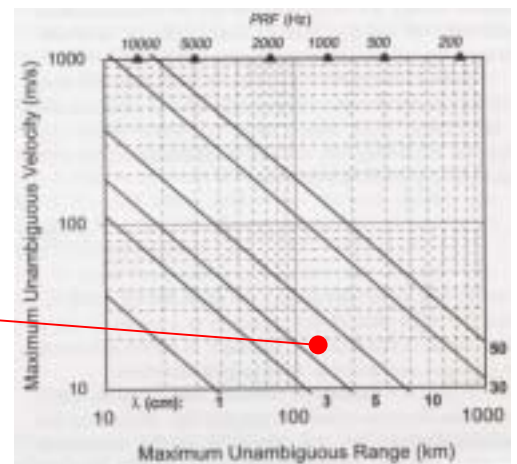


Figure 48: Doppler Dilemma Diagram.

PRF (Hz)	R _{max} (km)
1200	125
1000	150
750	200
500	300
300	500

Table 7: Values Of PRF-R_{max} Relation.

- One partial solution to the Doppler dilemma is in our choice of wavelength. We can increase both Vmax and rmax by using a longer wavelength radar. Unfortunately,

longer wavelength radars are more expensive and bigger, and they don't detect weather targets as well as shorter wavelength radars, so using a longer wavelength is not necessarily a solution to the problem.

- The result is that most Doppler weather radars usually suffer significant range or velocity ambiguities or both.
- **for defeating doppler dilemma**, the volume coverage pattern are organized in a way of the lowest elevation scans are sampled twice in low and high PRF, the middle scans are performed in alternating low and high PRF and the upper elevation in high PRF

3.3.2. Spurious Echoes

Not all echoes on weather radar are due to rain or snow. Non-meteorological returns may be caused by:

- The Earth's surface and stationary objects on it
- Transient objects (ships, aircraft, birds, insects)
- Technical problems with the radar equipment
- Interference from other sources, such as nearby radars

The most common of the non-meteorological echoes are ground echoes or "**clutter**". These occur when a radar beam intersects any surface feature, such as high ground, buildings and trees. The echoes mainly occur close to the radar site.

3.3.2.1. Beam Blockage

Beam blockage occurs due to ground clutters especially regions close to the radar. Data can not be obtained from these regions. Screening or occultation of precipitation by hills results in a reduction of the rainfall that is estimated by a radar at places beyond the high ground.

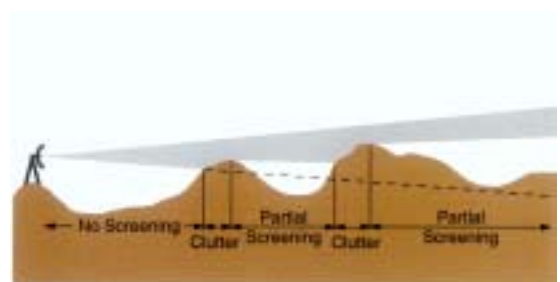
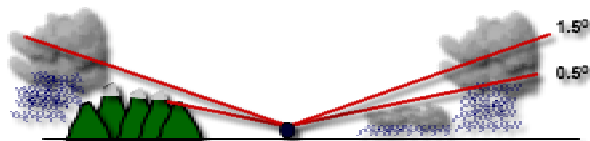


Figure 49: Beam Blockage.

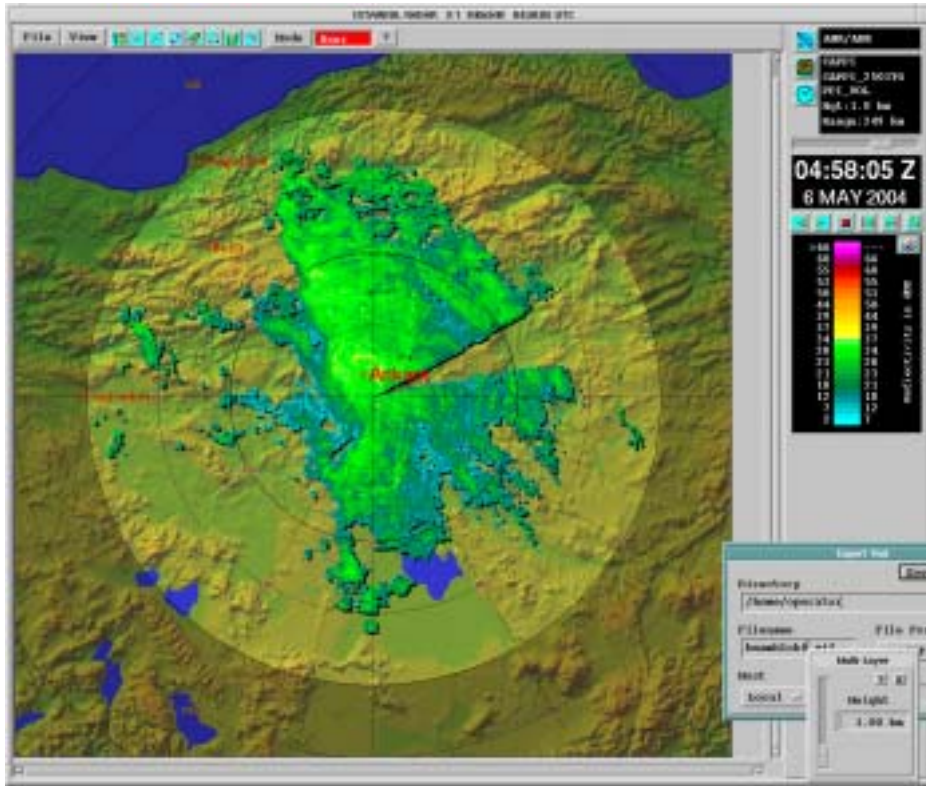


Figure 50: Beam Blockage Image.

3.3.2.2. Side Lobe

Radars transmit energy along a main beam having a typical beam-width of 1°. There are also secondary power transmissions along side lobes located a few degrees from the main beam centre. Normally the side lobe returns are too weak to be significant. An exception may occur with very highly reflective targets, such as columns of heavy rain or hail within a Cb cloud.

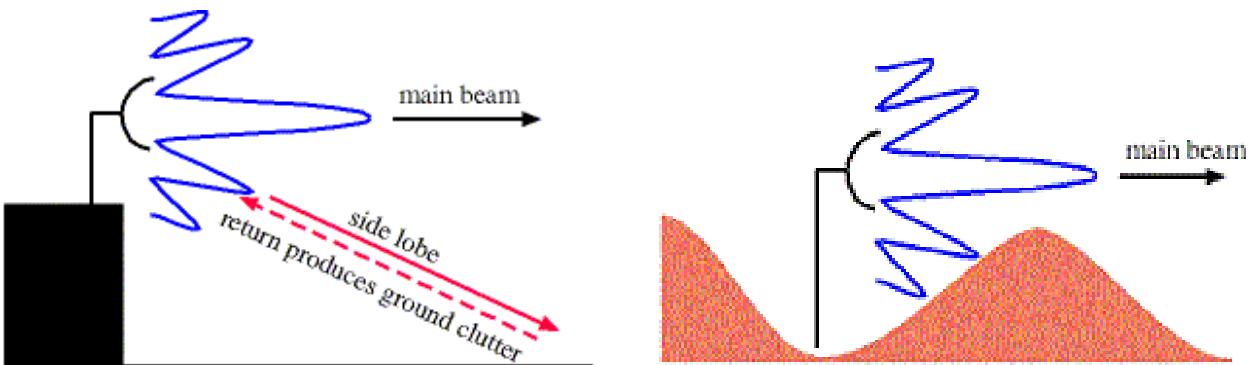


Figure 51: Side Lobe.

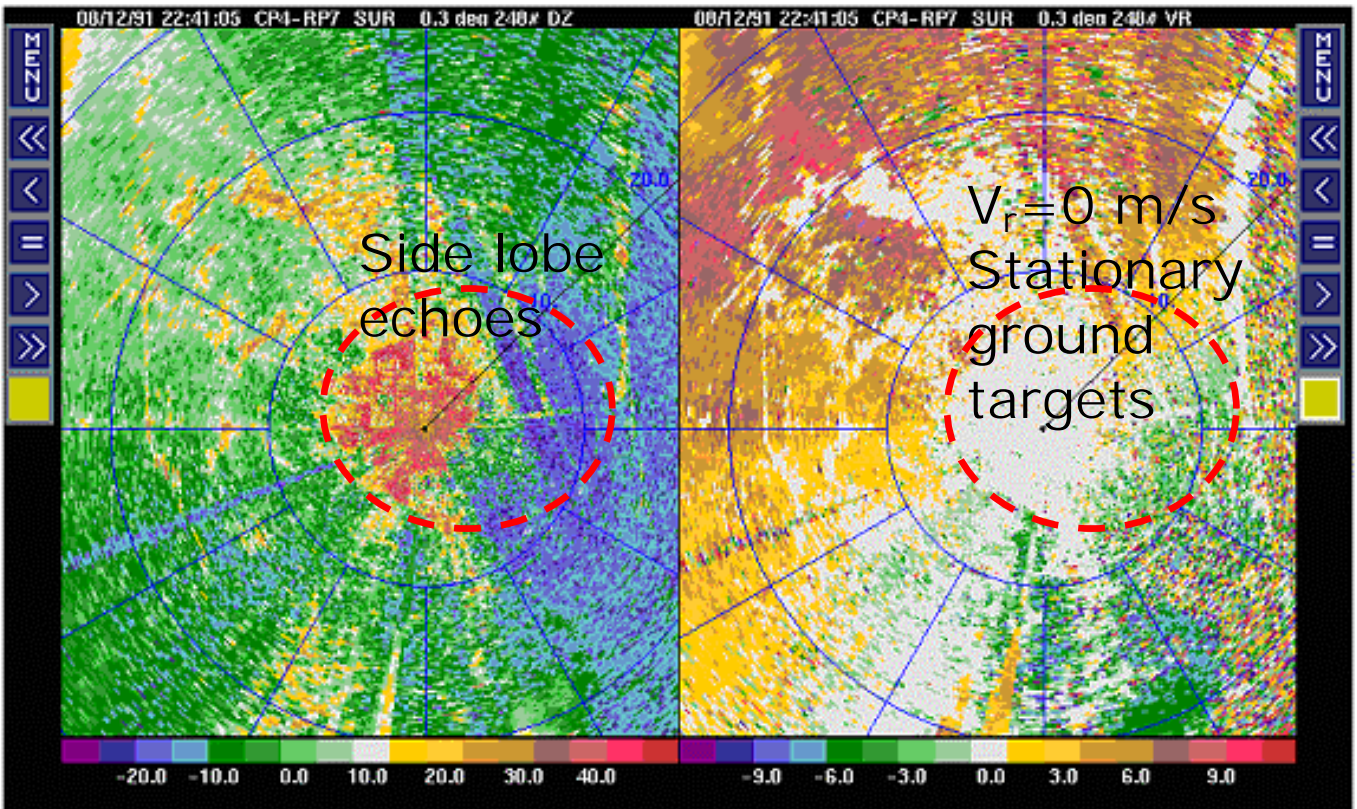


Figure 52: Side Lobe Images (Reflectivity Image on the Left and Velocity Image on the Right).

3.3.2.3. Attenuation

Attenuation is the weakening of a radar beam as it moves downstream due to some of the energy being lost to scattering and absorption. At short wavelengths, especially X- and C-band, the radar signal is attenuated by the precipitation along its path. So, attenuation is a severe problem at C-band.

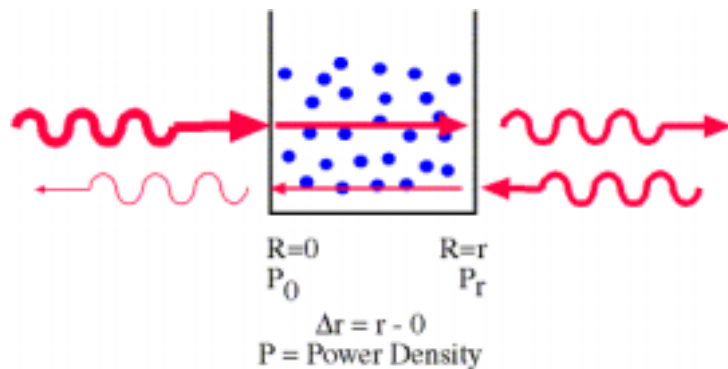


Figure 53: Attenuation.

- Attenuation is produced by clouds, rain, snow, hail, water vapor and other gases in the atmosphere.
- Attenuation at C-band radars can be serious especially during the heavy precipitation, so it can affect estimating precipitation.
- Attenuation by rain is even stronger than it is from clouds, in addition to this, attenuation by hail is strongest.
- Modern radar systems have capability to recognize and correction algorithms for attenuation.

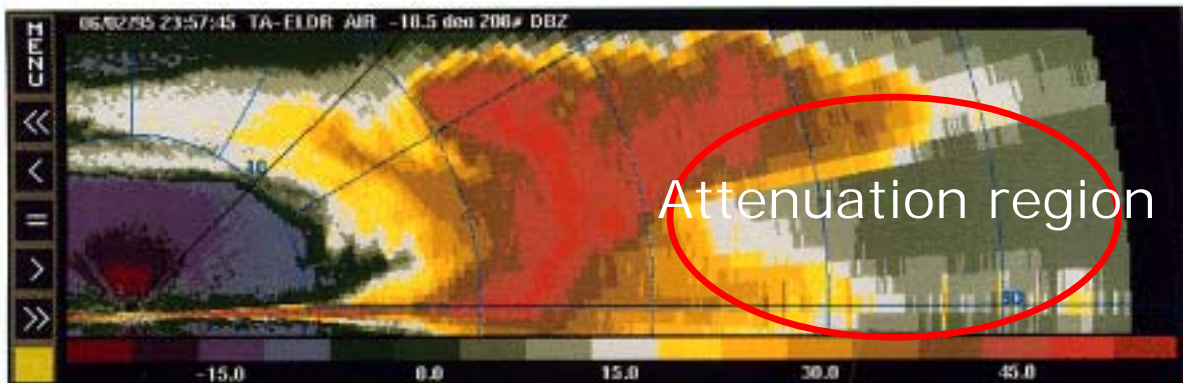


Figure 54: Attenuation Image.

3.3.2.4. Clear-Air Echo

Meteorological information can come from nonmeteorological as well as meteorological targets. We usually think that the radar is detecting echoes from weather. Some important wind phenomena are detectable largely because of clear-air echo.

Two general categories of radar echo in the clear air:

1. Insects, dust, chaff and other particulates in the atmosphere that are large enough to return some power to the radar.
2. Refractive-index gradients. When it changes significantly (lower atmosphere is unstable), the wind increases rapidly with height just above the ground. This indicates the mechanical turbulence.

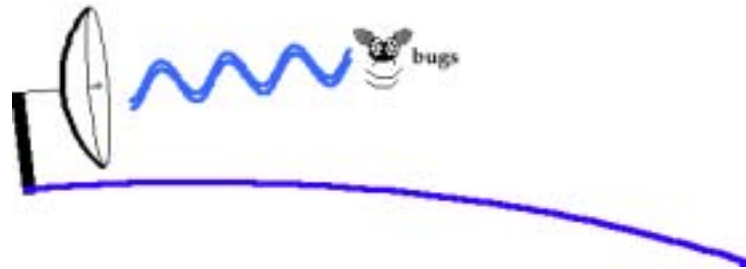


Figure 55: Clear-Air Targets.

- Clear-air returns are most common closer to the radar.
- They are always present during the warmer seasons

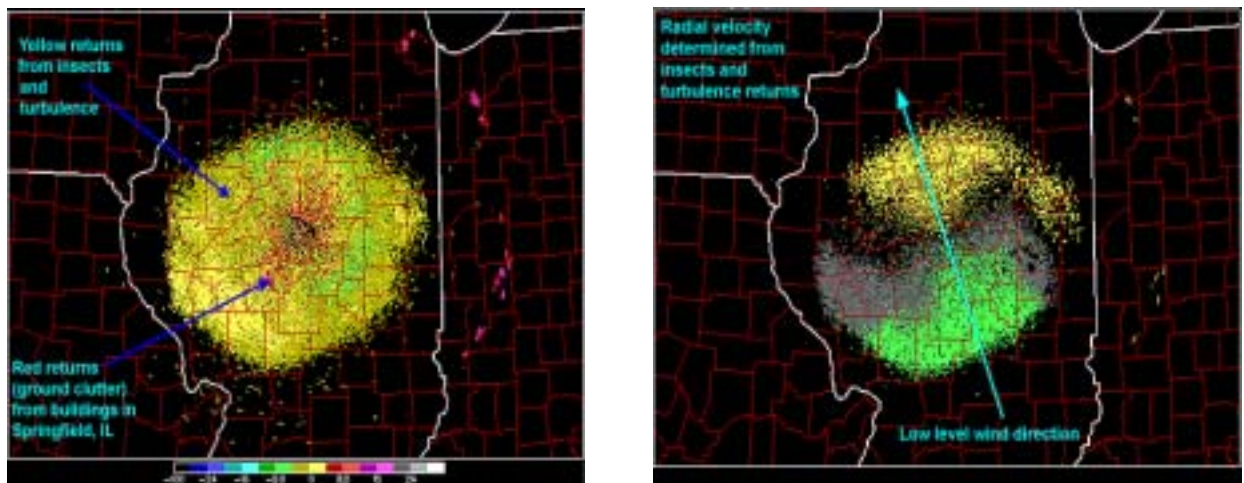


Figure 56: Clear-Air Echoes.

3.3.2.5. Bright Band

Occasionally a band of very high reflectivities will appear on the radar. This is called "**bright banding**" and is related to an area in the clouds where snow is melting into rain. The melting/wet snow has a much higher reflectivity than snow and a higher reflectivity than rain. It occurs at the altitude where the temperature is around 0 °C, i.e. temperature in the upper reaches of the cloud is below freezing and temperature of the cloud closer to ground is above freezing. The weather forecaster must be aware of this process so as not to confuse the bright band with an intense area of precipitation.

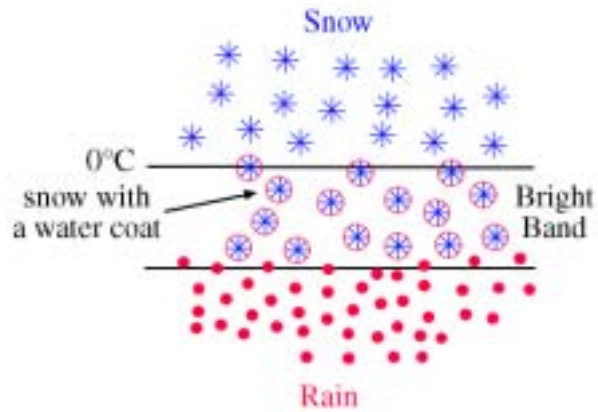


Figure 57: Bright Band.

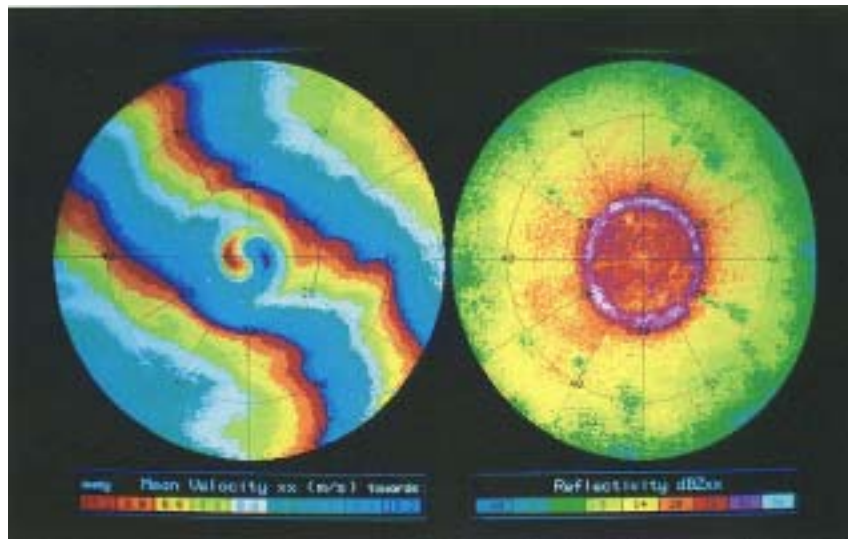


Figure 58: Bright Band Echoes.

3.3.3. Effects of the Earth's Curvature and Atmospheric Refraction

3.3.3.1. Effects of the Earth's Curvature

Earth is spherical. Microwaves do not follow the surface. In the picture on the next slide is shown the height of some radar beams as function of distance from radar at different elevations.

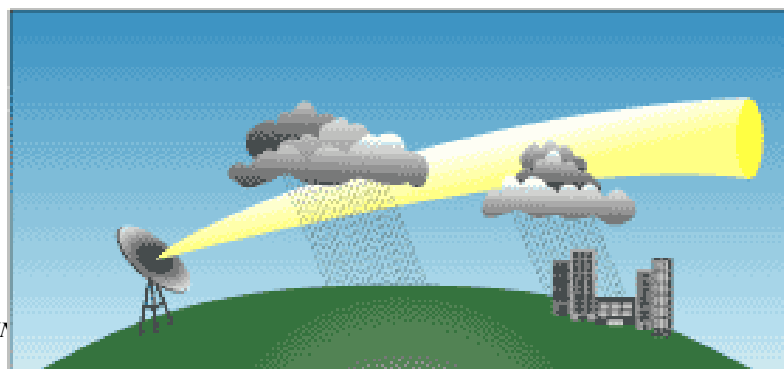
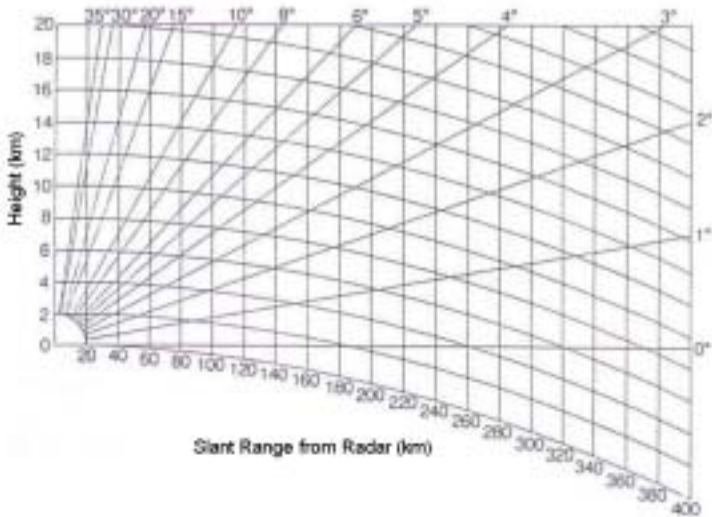


Figure 59: Earth's Curvature.

For standard refraction conditions, when a radar sends a signal into the atmosphere, signal will spread out of the above ground at the far away from radar. Therefore radar echoes can not be seen at long range.



If for a 0.8° elevation angle of signal is sent into the atmosphere, height of the radar beam will be at the distance of:

- 50 km → 0.8 km,
- 100 km → 2.0 km,
- 150 km → 3.4 km,
- 200 km → 5.1 km,
- 250 km → 7.1 km.

Figure 60: Radar Range-Height Diagram.

3.3.3.2. Atmospheric Refraction

Radar assumes the beam is undergoing standard refraction. The beam height will be misrepresented under super/subrefractive conditions.

Bending of light, or refraction, is a result of a density gradient in our atmosphere. The density gradient will depend on the temperature, pressure and humidity profile of the atmosphere.

Snells Law: Electromagnetic waves may be refracted in the atmosphere due to density variations. The bending of light as it passes from one medium to another is called **refraction**.

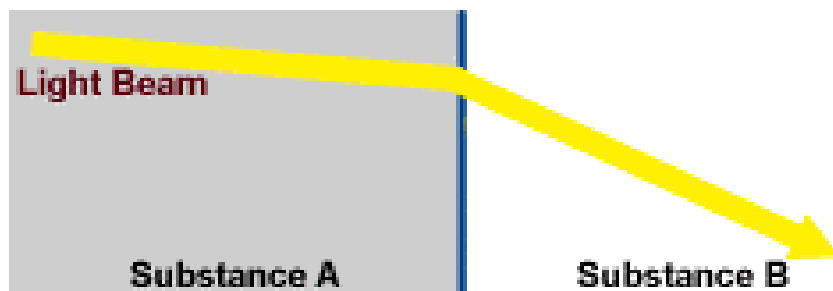
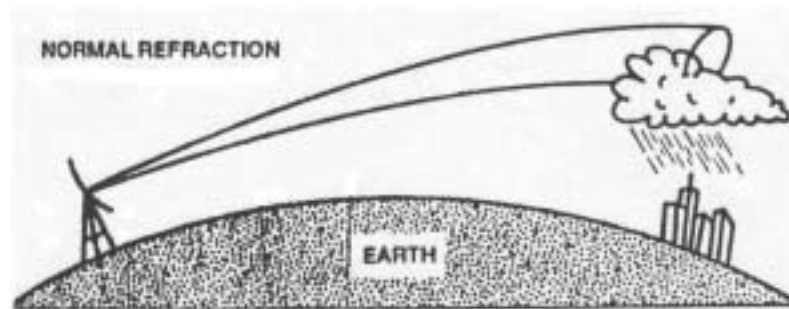


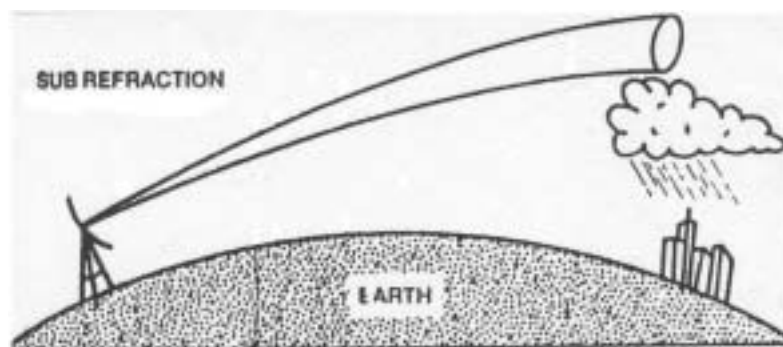
Figure 61: Refraction.**3.3.3.2.1. Standard Refraction**

This figure gives height as a function of range and elevation angle for standard refraction conditions and is a useful way to determine the height of a radar beam. Note that, if the radar located above sea level, its height must be added to the height determined from the graph to give heights above mean sea level (See Figure 59).

**Figure 62: Standard Refraction.****3.3.3.2.2. Subrefraction**

The beam refracts less than standard. The beam height is higher than the radar indicates. Beam can overshoot developing storms. This occurs when the beam propagates through a layer where:

- Temperature lapse rate is ~ dry-adiabatic (The dry adiabatic rate is 1.0°C/100 meters)
- Unstable atmosphere
- Moisture content increases with height
 - ✓ Will help eliminate ground clutter

**Figure 63: Subrefraction.**

3.3.3.2.3. Superrefraction and Ducting

The beam refracts more than standard. The beam height is lower than the radar indicates.

This occurs when the beam propagates through a layer where:

- Temperature increases with height (inversion)
- Stable atmosphere
- Moisture decreases sharply with height
 - ✓ Will likely produce ground clutter

If the refraction of the radiation is strong enough, the radar waves can be trapped in a layer of the atmosphere (Ducting).

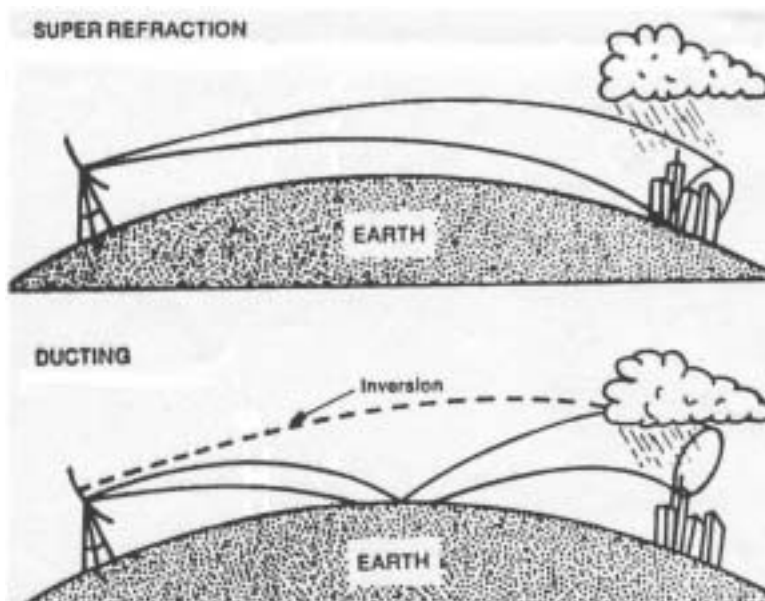


Figure 64: Superrefraction and Ducting.

The condition of extended range of detection of ground targets is called **anomalous propagation or anaprop (AP)**.

3.3.4. Reducing Ground Clutter

- The main way to reduce substantially ground clutter is generating a ground clutter map from the echoes received on a cloudless day. Echoes from the clutter regions on subsequent rainy days can then be ignored, and interpolated data from surrounding areas can be used.
- A higher beam elevation at close range.
- Used to Doppler radar for distinguish stationary clutter from moving rain.

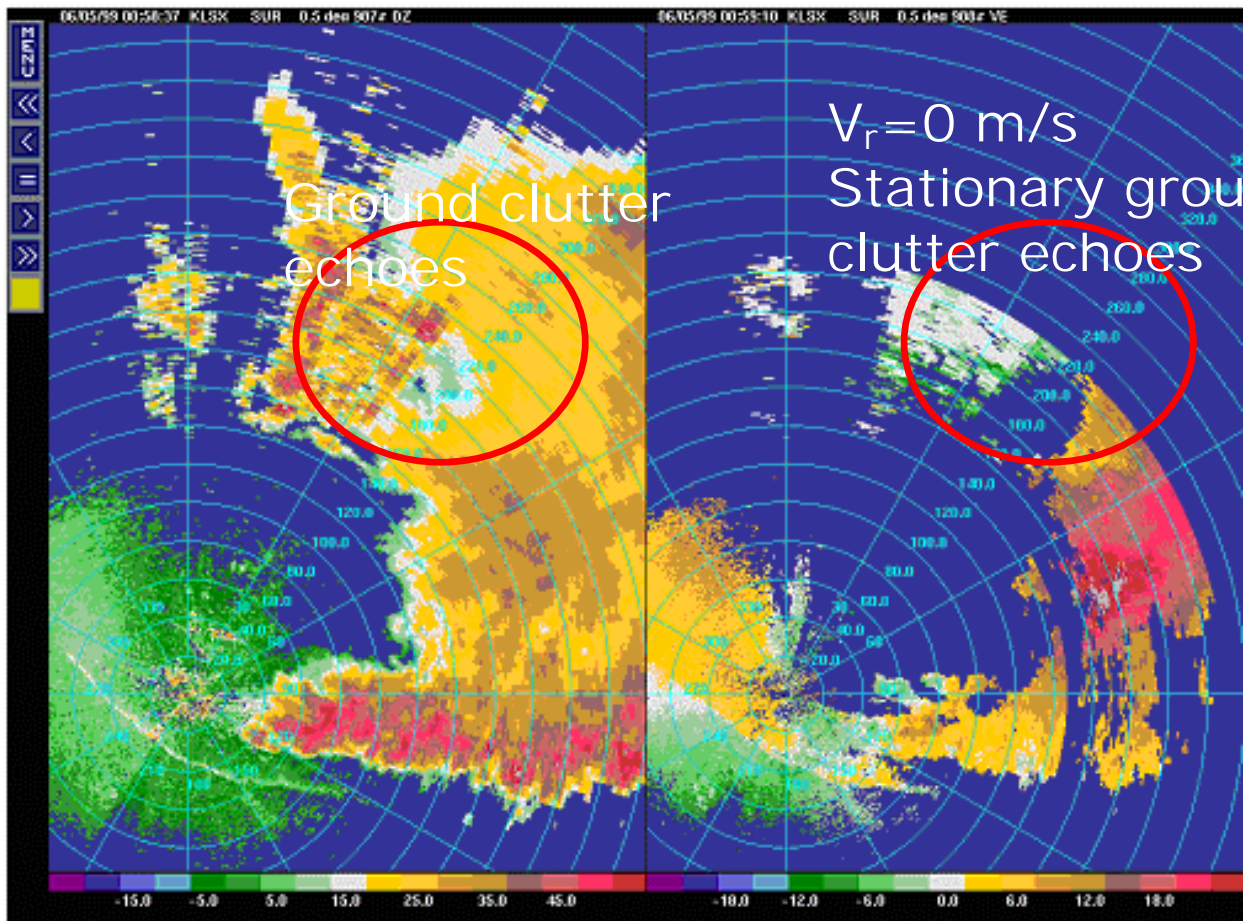


Figure 65: Ground Clutter Echoes.

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TRAINING MATERIAL ON WEATHER RADAR SYSTEMS

MODULE E

RADAR MAINTENANCE AND CALIBRATION TECHNIQUES

[original PDF with bookmarks \(27 MB\)](#)



TURKEY RADAR TRAINING 1.0 / ALANYA 2005

**TURKISH STATE METEOROLOGICAL SERVICE
(TSMS)**



**WORLD METEOROLOGICAL ORGANIZATION
(WMO)**

**COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATIONS
(CIMO)**

OPAG ON CAPACITY BUILDING (OPAG-CB)

EXPERT TEAM ON TRAINING ACTIVITIES AND TRAINING MATERIALS

TRAINING COURSE ON WEATHER RADAR SYSTEMS

MODULE E: RADAR MAINTENANCE AND CALIBRATION TECHNIQUES

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TURKISH STATE METEOROLOGICAL SERVICE**

**12–16 SEPTEMBER 2005
WMO RMTC-TURKEY
ALANYA FACILITIES, ANTALYA, TURKEY**

MODULE A: INTRODUCTION TO RADAR

MODULE B: RADAR HARDWARE

MODULE C: PROCESSING BASICS IN DOPPLER
WEATHER RADARS

MODULE D: RADAR PRODUCTS AND
OPERATIONAL APPLICATIONS

**MODULE E: RADAR MAINTENANCE AND
CALIBRATION TECHNIQUES**

MODULE F: RADAR INFRASTRUCTURE

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ABBREVIATIONS:

BITE	: Built In Test Equipment
PW	: Pulse Width
PRF	: Pulse Repetition Frequency
BW	: Bandwidth
RF	: Radio Frequency
STALO	: Stable Oscillator
COHO	: Coherent Oscillator
TX	: Transmitter
RX	: Receiver
MDS	: Minimum Detectable Signal
IF	: Intermediate Frequency
HV	: High Voltage
ZAUTO	: Receiver Calibration
FILPS	: Filament Power Supply
KLYLOWP	: Klystron Low Power
BCPS	: Bias Current Power Supply
SPM	: Switch Power Module
BNC	: Bayonet Neill Concelman
SMA	: SubMiniature version A
VSWR	: Voltage Standing Wave Ratio
AC	: Alternating Current
DC	: Direct Current
SSA	: Solid State Amplifier
PS	: Power Supply
Hz	: Hertz
KHz	: Kilohertz
MHz	: Megahertz
GHz	: Gigahertz
mW	: Milliwatt
KW	: Kilowatt
MW	: Megawatt
Sec.	: Second
µsec.	: Microsecond
dB	: Decibel
dBm	: Decibel Milliwatt
dBZ	: Logarithmic Scale for Measuring Radar Reflectivity Factor
HVPS	: High Voltage Power Supply
LED	: Light Emitted Diode
G	: Gain
AZ	: Azimuth
EL	: Elevation
ASC	: Antenna Servo Controller
L_{TS}	: Loss for Test Signal
A-Scope	: A Diagnostic and Control Utility to Test Radar and Signal Processor
RSP	: Radar Signal Processor
RADOME	: Radar Dome
LNA	: Low Noise Amplifier
SG	: Signal Generator
RVP7	: Radar Signal Processor Version 7

1. INTRODUCTION TO THE MAINTENANCE AND CALIBRATION

1.1. General Overview

Regular maintenance and calibration of radar systems is one of the critical aspects of operating a radar network properly and efficiently and to maintain the availability of data of high quality. How to make maintenance and calibration have to be considered very carefully at the design stage of radar network and must be implemented during the operation.

There may be two options for the realization of the maintenance and calibration tasks:

1) Maintenance and calibration can be done by the institution/organization (National Meteorological Service) which is owner of the radars.

In this case, expenses incurred in the running a maintenance program will be recurrent and would usually be funded through organisational running costs. To ensure the success of the maintenance program, staffing levels of suitable trained personnel would need to be maintained. These staff would be responsible for undertaking repairs, calibrations, maintenance, as well as analysis of status and diagnostics information on the operational network.

This option allows the organisation to be fully in control of all aspects of its operations. The inherent flexibility of this option allows the organisation to rebalance its resources to respond to any changing situations. The organisation also gains because its knowledge base is expanded by the number of staff trained in the various disciplines required. The increased knowledge then allows the organisation to either easily modify its methods of operating the radar network or even modify the radars to satisfy any new emerging requirements. In short this approach ensures the maximum flexibility for the organisation.

If the organization intends to perform that tasks by itself, then some critical issues should be taken into consideration such as staff resources, staff training, staff management, maintenance and calibration tools, equipment spares, equipment repair facilities, houses and transport arrangements.

2) Maintenance and calibration can be done by private contractors under the scope of a maintenance contract.

In this case, a contractor will take all responsibility of required maintenance and calibration tasks. If the service given is not satisfactory then the contractor is financially penalised for any deficient performance. To obtain a cost effective solution for contract maintenance, all requirements should be reviewed and the service required should be defined very carefully.

One of the advantages of that approach is all the administration tasks, as well as all the tasks involved in organising the spares support, technical training and logistic arrangements for visiting radar sites will under responsibility of the contractor. Providing the contract is appropriately structured this arrangement can provide an excellent result.

Another benefit with this approach is that any staff involved in the maintenance is not the responsibility of the organization and they are directly employed by the contractor. Consequently the contractor has all the responsibilities with respect to staffing matters, such as staff numbers, leave relief, workers compensation, etc. Overall the key to the success of this approach is the effective structuring of the contract to reflect the precise requirements of the organization.

Although it would appear to be a relatively simple task, in practice there are many areas that will require very skilled expertise. Perhaps the main area is the need to develop a comprehensive specification to carefully spell out the requirements. The person writing this specification needs to be fully familiar not only with radar operations but also needs to have a detailed appreciation of the difficulties a contractor may face in executing his required tasks. If this detailed knowledge is not resident in organization, then the contractor has the ability to use his superior technical knowledge of the equipment and the local conditions to seek extra funds or implement decreased performance targets.

Anyway, maintenance and calibration requirements of weather radars and basic procedures will be tried to be explained in this module of training course.

1.2. Maintenance Types and Procedures

In general, maintenance activities can be classified in two groups:

- (1) Preventive maintenance,
- (2) Corrective maintenance.

We are aware that maintenance requirements and procedures of radars from different manufacturers may vary in some points but most of them are similar to each other in general. Although a general view and procedures are tried to be given, the maintenance requirements and procedures for the radars currently operated by Turkish State Meteorological Service have also been used for the preparation of training document. **It is very important and vital to follow all safety regulations carefully during the any stage of maintenance actions.** Furthermore, flow charts and special algorithms should be prepared for the different applications to follow the procedures and to perform the tasks efficiently. It is important to accumulate a regular record of each device, as suggested in the maintenance instructions, in order that any change in each device is readily identified. If any indication will significantly differ from the typical value, the cause should be investigated.

1.2.1. Preventive Maintenance

Some regular maintenance tasks should be performed regularly to keep the system in operation properly and to avoid some failures may be occurred due the lack of maintenance care. Preventive maintenance actions carried out on a scheduled basis to keep the apparatus at optimum efficiency levels. These measures are aimed at preventing fault conditions caused by oxidation, excessive variations compared to the specification, due to wandering of parameters over time, or damage to moving mechanical parts. These measures, furthermore, at times enable the maintenance personnel to discover possible faults before they actually occur. The scheduled periodic check and maintenance will help to ensure optimum system performance and may serve to detect certain potential minor malfunctions prior to them developing into a major fault.

Month	Works to be done	1	2	3	4	5	6	7	8	9	10	11	12	
System	Daily Check •Radar Status •Remote Maintenance Software													
	Calibration •Antenna Position (Sun-Tracking) •Intensity, Velocity						0						0	
Subsystem	Antenna & Servo													
	Monthly Check •Visual Check •Sound Check	0	0	0	0	0	0	0	0	0	0	0	0	
	3-monthly Check •Lubricant Check •Slipring Cleaning			0			0			0			0	
	6-monthly Check •Lubricant Quantity, Leakage Check						0						0	
	Yearly Check •Grease Supply •Lubricant Change •Friction Torque Check •Slipring, Brushes Check •Limit Switch Function Check •Servo Voltage, Frequency Check													0
	Transmitter													

Monthly Check •Visual Check •Meter Reading	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	6-monthly Check •Klystron Replacement •Performance Check											
	Yearly Check •Air Filter Cleaning •HV Circuit Cleaning •Interlock Function Check											
Receiver												
Monthly Check •Visual Check	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	6-monthly Check •ZAUTO Calibration											
	Yearly Check •Gain Check •STALO, COHO Level Check											
Signal Processor												
Monthly Check •Visual Check	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

6-monthly Check • Internal Status Check								O						O
	Software •Upgrading (When up-version released)													

Table 1: A Sample Schedule for System Maintenance.

1.2.1.1. General Cleaning and Checks

The power supply should be disconnected before carrying out any of these cleaning operations. All cleaning operations must be carried out on properly conditioned premises even if the apparatus is already installed. The accumulation of dust on components can over time lead to the formation of layers which could not able to reduce the efficiency of the conditioning system. This would cause a general increase in the cabinets' internal temperatures which could in turn lead to malfunctions or faults in certain components. In order to prevent this happening, the equipment must be kept clean at all times.

1.2.1.2. Cabinet Cleaning

Even though the cabinets are fitted with air filter, regular cleaning of the internal parts is required to stop dust accumulation. This can be done using a vacuum cleaner, a clean dry cloth or a small brush.

Every trace of dust must be carefully removed both inside and on the external parts of the cabinet. It would be good working practice to carry out this cleaning operation at least once a year.

1.2.1.3. Air Filters

The air filter situated on the cabinet's front panel must be disassembled and cleaned to remove the layer of dust that has formed on it. The cleaning schedule will depend on the length of time the fans work and the quantity of dust removed. This, naturally, depends on environmental dust levels. It would, however, be good working practice to carry out this cleaning operation at least once a year. The filter is affixed to its container by four screws. If the accumulated dust has not hardened it can be removed using a high pressure water pump (circa 2 atmospheres). Once it has been cleaned, the filter is to be dried using compressed air.

1.2.1.4. Indicator lights and lamps

Make sure the lamps are inserted firmly into their holders. Remove all traces of oxidation, corrosion or dirt in general from the contacts. Replace the lamp when the bulb becomes blackened due to partial sublimation of the filament.

1.2.1.5. Fuses

Fuse terminals are liable to oxidation and so the fuses must be taken out of their housings to check for any oxidation. In fact, this and dust increase the circuit's resistance. Normally, the ends of the fuses should be cleaned with a cloth moistened with a trichloroethylene-type solvent. The fuses should be taken out one at a time to ensure that they are put back in their correct housings. The value stamped on the fuse must be the same as that stamped on the fuse housing.

1.2.1.6. Linking Cables

The cables should be inspected regularly to make sure there are no breakages in external insulation, which could cause short-circuits in the near future. Any parts of the cables showing signs of deterioration in the outer insulation should immediately be re-insulated carefully. The coaxial cables should be inspected with particular care since they can be damaged easily by dents or curves that are too tight. Inspect the connectors and make sure that they are correctly fixed. Any corrosion the metallic contacts must be carefully removed. Cables showing signs of damage should be correctly protected or replaced if necessary.

1.2.1.7. Transformers and Inductors

Carefully inspect the transformer and inductor terminals and remove all traces of dirt or moisture. Make sure they have been fixed correctly and if necessary, tighten the screws on mounting bases. Proof transformers in oil should be carefully inspected to make sure there is no loss. The external casings, terminals and ceramic insulators must be kept scrupulously clean. Use clean cloths and if need be, moistened in a trichloroethylene-type solvent. If any corrosion is visible on the connections, mark the associated conductor, disconnect it and clean the contacts with fine glass paper and then with a clean cloth before reconnecting the conductor.

1.2.2. Corrective Maintenance

This type of maintenance procedure comes into operation when a fault condition has appeared in the apparatus while it is working. There is no practical way of detecting a system impending fault or malfunction associated with each device except the Antenna. Most faults don't emerge as gradual performance degradation but will suddenly happen. On the other hand, a mechanical trouble in the Antenna has usually sent a message or sign in the form of unusual sound.

A fault condition can be ascertained in three ways:

- 1) During preventive maintenance works
- 2) From the **BITE (Built In Test Equipment)** mechanisms
- 3) By the operator who notices an anomalous operating state.

The BITE mechanisms constantly control the apparatus' most important functions and if a fault arises send the necessary information to the System's Remote Control Panel via the Receiver apparatus associated with the Transmitter. The fault signalled to the operator via the Remote Control panel is analysed by the Transmitter's Klystron Control Panel. Some faults can be seen through directly looking at the indicators located on the Klystron Control Panel's front panel, making up the Transmitter apparatus.



Figure 1: Some Corrective Maintenance.

1.2.2.1. Initializing Maintenance

This provides a step-by-step procedure concerning all the information necessary to energise the apparatus starting from the apparatus OFF condition. This procedure allows the maintenance staff to check which of the apparatus' functions is faulty.

1.2.2.2. General Fault Finding Method

A flow chart to be prepared by considering the system units and functionalities (generally prepared by the manufacturers) can help to find out the fault easily.

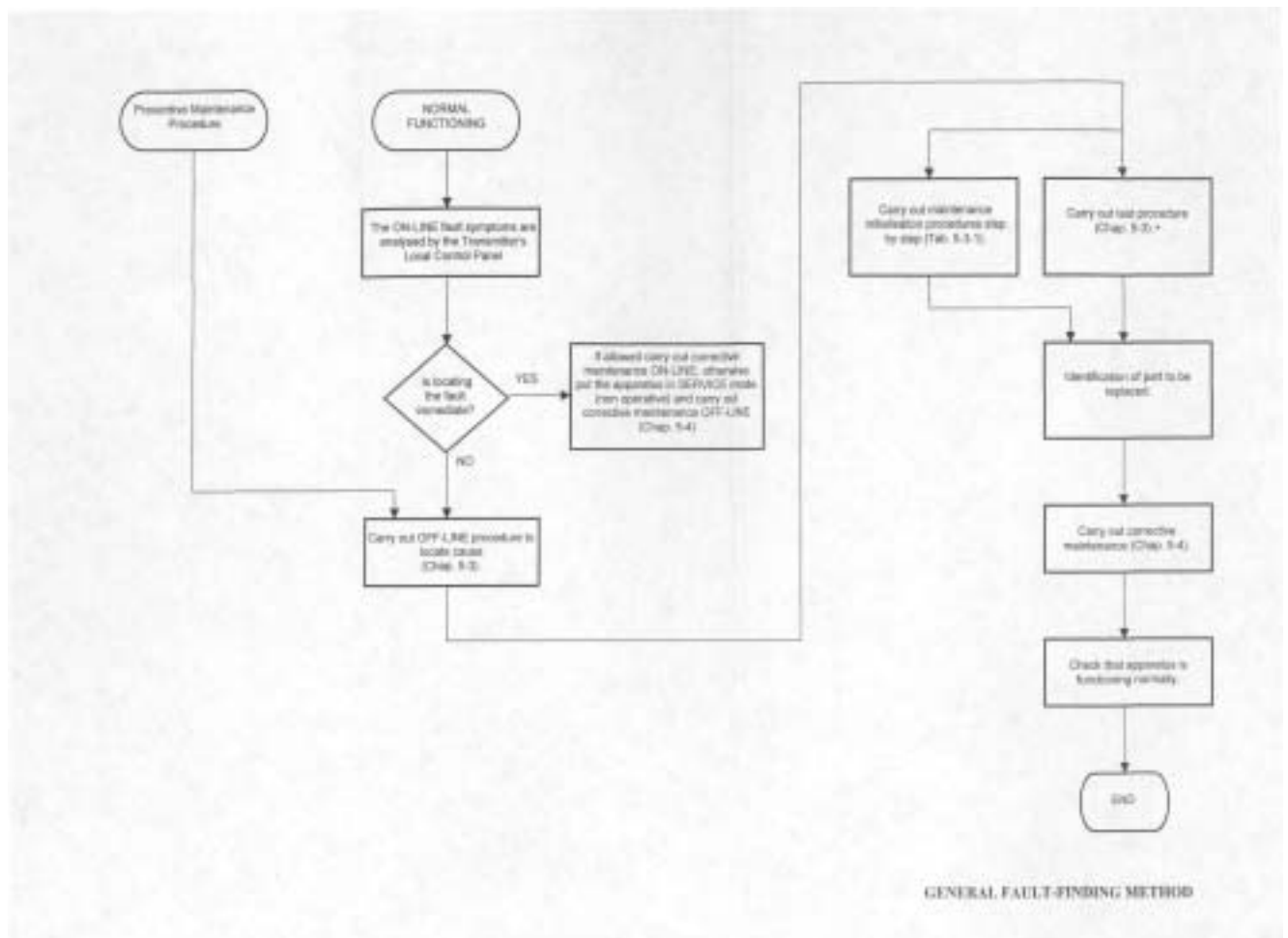


Figure 2: General Fault Finding Method Flow Diagram.

1.2.2.3. Analysis of BITE Results

Status report and log files from BITE system can show the bits exchanged with the sub-components of radar system such as Receiver, Transmitter, Antenna, Control and Processing Circuits and their corresponding acronyms and their meanings. Each bit has a signal on the Control Panel/Display which signals a fault to the operator.

1.2.2.4. Fault-Finding Diagrams

Finding the causes of faults is carried out using flow charts which suggest the actions to be taken in the various cases to locate the fault. The flow charts use symbols and instructions to describe the actions to carry out or decisions to take to locate the faulty module.

The flow charts aim to suggest to the maintenance staff once they have seen a fault message, the most probable route to follow and the actions to take to locate the area involved and the board/module/part to be replaced to eliminate the fault. Each fault symptom is associated to a main flow chart which may be divided into further flow charts.

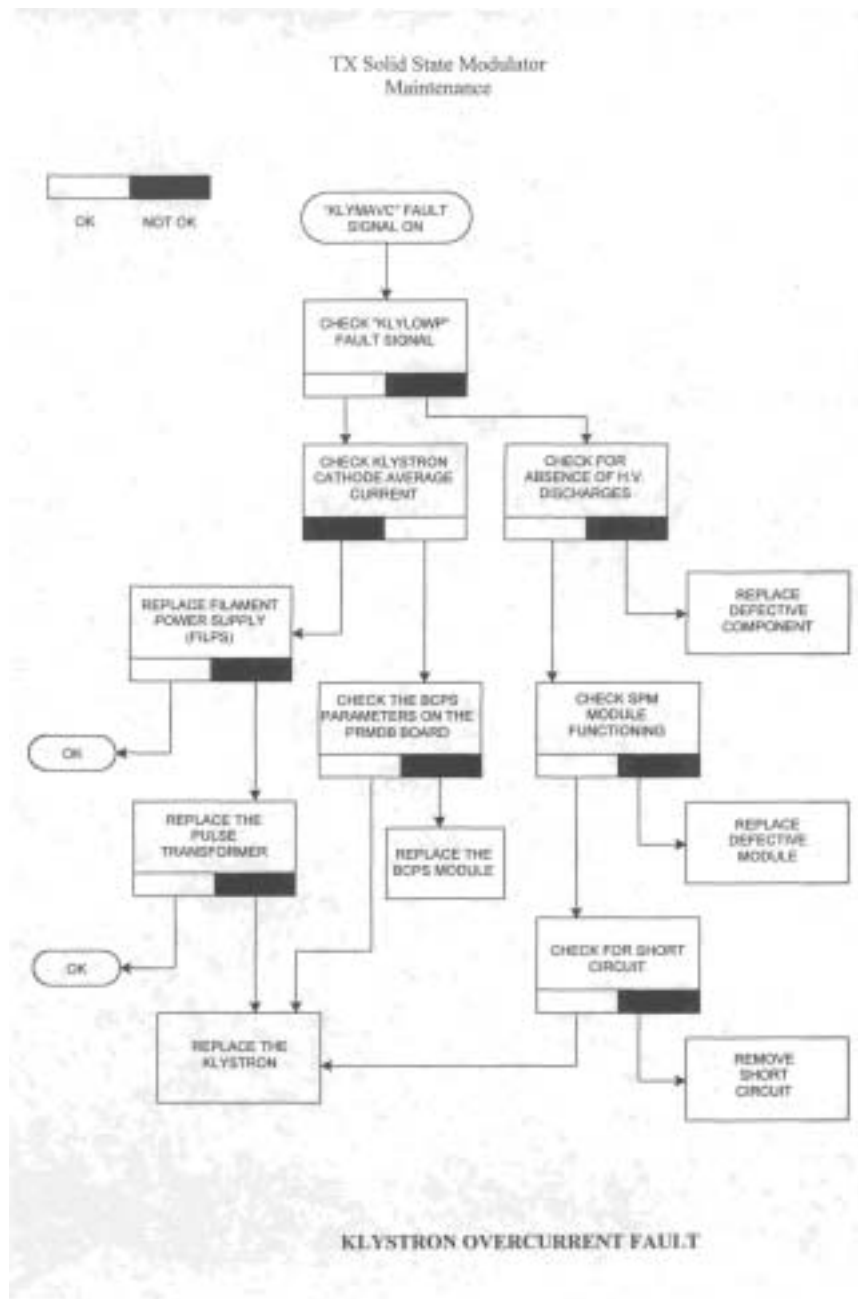


Figure 3: Finding the Reason for Klystron over Current Fault.

1.2.2.5. Replacement

In radars, also in all electronic equipment, if some component is failure, not working or component's life-time is finished, it needs to be changed. Here you can see the most important replacement pictures in Figure below.



Figure 4: Some Pictures on Klystron Replacement.

2. COMMON TOOLS USED FOR RADAR MAINTENANCE

Some test and measuring equipment are needed for maintenance tasks. These are briefly explained below. Sample measurement and test results also provided together with their pictures.

2.1. Multimeter

Multimeter is very common test equipment for measuring electricity (volts, amperes, ohms) that is widely used and available in numerous shapes and sizes.



Figure 5: Multimeter.

2.2. Spectrum Analyzer

Spectrum analyzer measures and displays the frequency domain of a waveform plotting amplitude against frequency.



Figure 6: Spectrum Analyser and a Measurement with it.

2.3. Oscilloscope

Oscilloscope displays electronic signals (waves and pulses) on a screen. It creates its own time base against which signals can be measured and displayed frames can be frozen for visual inspection.



Figure 7: 2 Channel Single Colour and 4 Channel Coloured Oscilloscope.

2.4. Powermeter

Power meter is used to measure the RF power. In radar systems both average power and peak power at the transmitter output can be measured by powermeters. It is adjusted according to the frequency used.



Figure 8: Power Sensor and Powermeter.

2.5. Frequency Counter

Frequency counter is test equipment for measuring frequency. Since frequency is defined as the number of events of a particular sort occurring in a set period of time, it is generally a straightforward thing to measure it.



Figure 9: Frequency Counter.

2.6. Signal Generator

Signal generator is a test tool that generates repeating electronic signals. Signal generator is used to simulate signals for desired frequency and power. So it is a very useful tool for calibration and maintenance tasks but noise generated by the signal generator should be low enough for radar measurements.



Figure 10: Some Measurement with Signal Generator.

2.7. Crystal Detector

Detector is used together with oscilloscope for displaying shape of pulse width and PRF by eliminating RF signals.



Figure 11: Crystal Detector.

2.8. Attenuators

Attenuator is a device that reduces the amplitude of a signal without appreciably distorting its waveform. Attenuators are usually passive devices. The degree of attenuation may be fixed, continuously adjustable or incrementally adjustable. Those devices are generally used together with other test equipments to reduce the power of the measuring parameters to a reasonable level.



Figure 12: Step Attenuator and Attenuator Set.

2.9. Other accessories

Cables, connectors (BNC, SMA, N-Type, etc.), adapters, high voltage probes, dummy loads for terminations, extension boards, transition parts, mechanical tools, e.g. screw drivers, torque wrenches are also auxiliary tools for maintenance tasks.





Figure 13: Measurement Tools in Radar.

3. MEASUREMENTS ON TRANSMITTER

The source of the electromagnetic radiation emitted by radar is the transmitter. It generates the high frequency signal which leaves the radar's antenna and goes out into the atmosphere. Following parameters of the transmitter can be measured and tested:

- Measurement of Transmitted Power and Stability
- PW, PRF, Duty Cycle/ Factor
- Klystron Pulse, Klystron Current
- Klystron RF Input Level
- Transmitted frequency
- Occupied BW
- Voltage Standing Wave Ratio (VSWR)

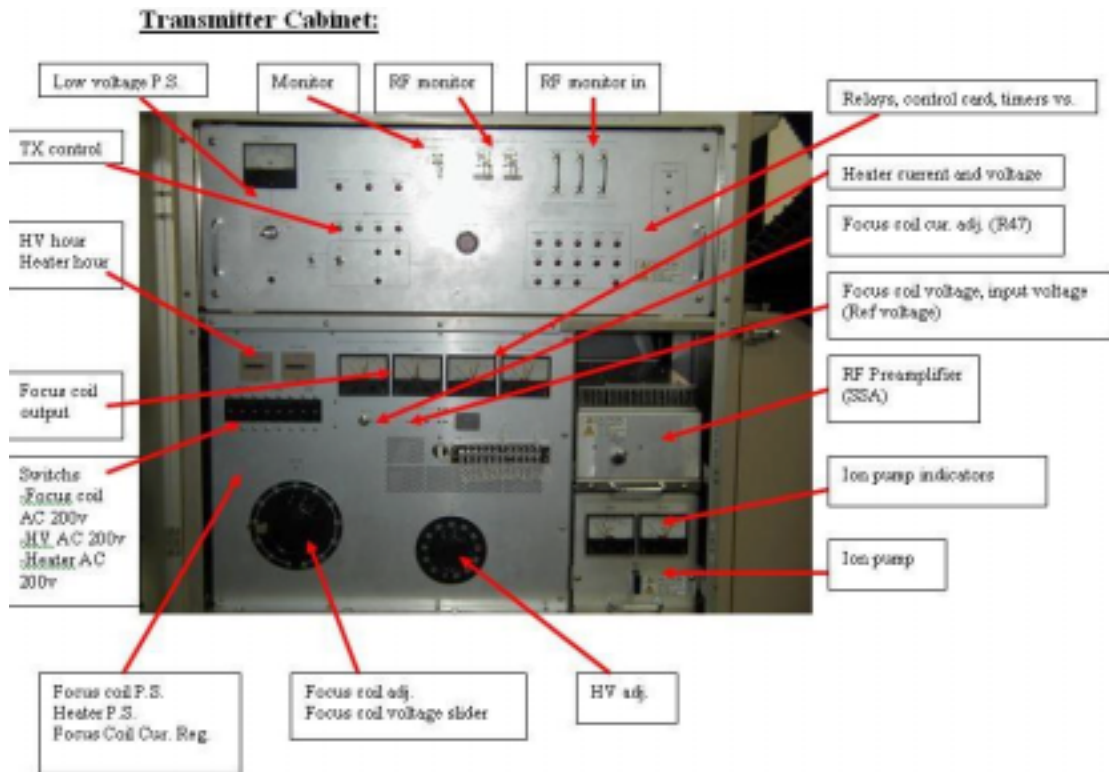


Figure 14: Front View of a Transmitter.

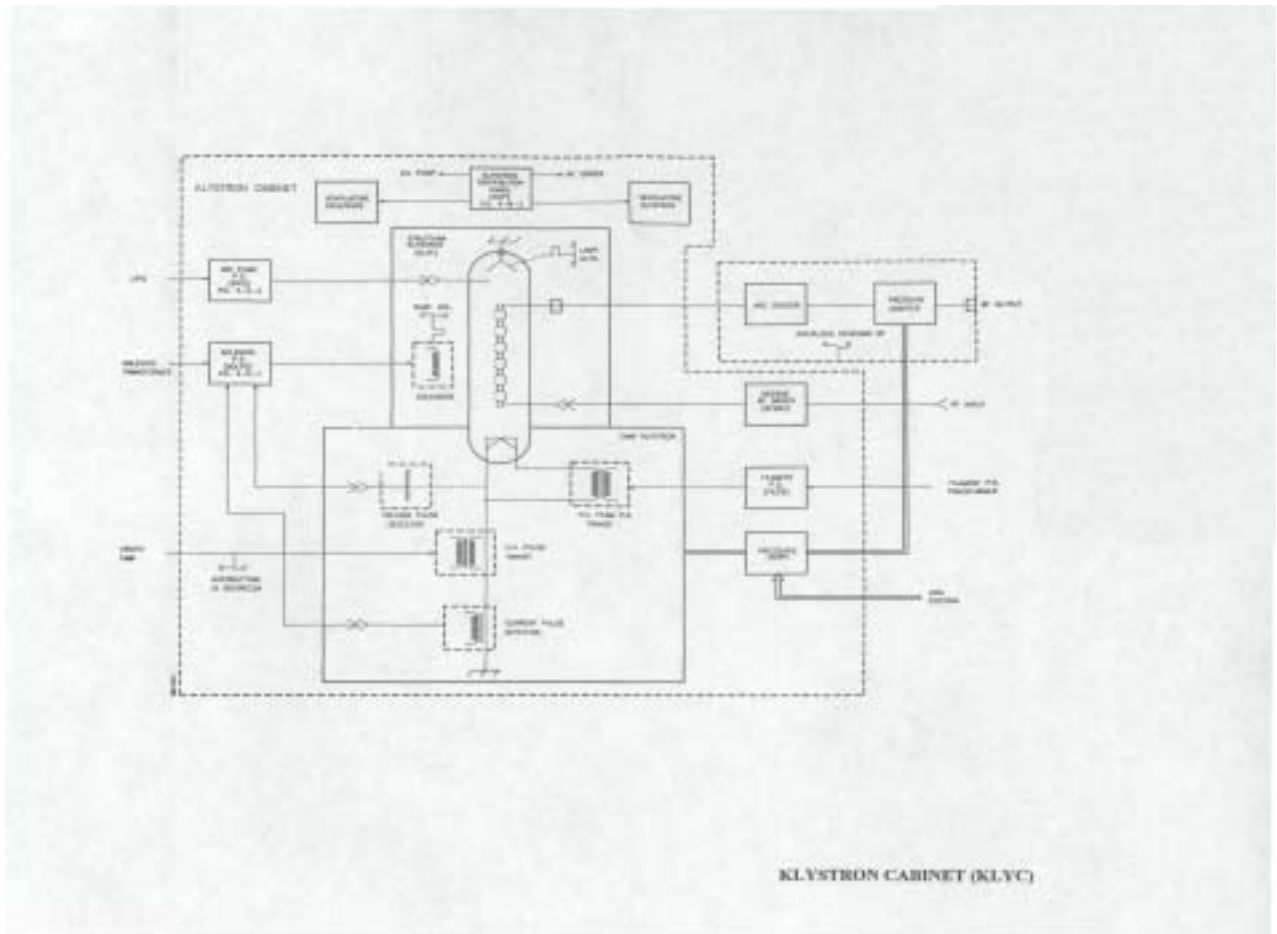


Figure 15: Block Diagram of Klystron Cabinet.

No.	Check Item	Check method	Standard value
1	Heater current	Read the meter after 30 min* preheating.	Within ± 0.1 A of the klystron data sheet.
2	Heater voltage	Ditto	Within ± 0.1 V of the klystron data sheet
3	DC power supply voltage	Read each DC Power Supply voltage switching by rotary switch	-15 ± 0.5 V, $+5\pm 0.5$ V $+12\pm 0.5$ V + 15 ± 0.5 V + 24 ± 1 V
4	Focus Coil Current	Read the meter after 30 min. preheating.	Within ± 0.5 A of the klystron data sheet
5	Focus coil Voltage	Ditto	Approx. 55 V ± 5 V
6	Ion Pump Voltage	Read the meter	3.5 ± 0.25 kV
7	Ion Pump Current	Ditto	Maximum 10 μ A Normal 0 μ A
8	HVPS Voltage	Read the meter during normal operation where Klystron Output is more than 250	Typical : 5 ± 0.5 kV
9	HV Regulator Voltage	Ditto	1000 ± 10 V @ PW = 1 μ s, PRF= 1200 Hz
10	Preheating Time	Measure the time period from POWER ON to the READY LED is on.	29 to 30 minutes
11	HOUR Meter	Write down the radiation time	

Table 2: Measurements to be Done on Transmitter.

3.1. Measurement of Transmitted Power and Stability

The transmitted power is measured by the power meter. This value is affected by loss of cable and duty cycle/factor.

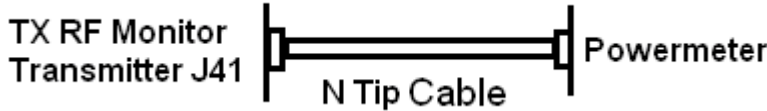


Figure 16: Transmitted Average Power Measurement.

Transmitter Measurement (50Hz)			Transmitter S/N : 964501 Klystron S/N : 0201						
Title	Specification	Measurement data							
Frequency	5625 MHz +/- 8MHz	5624.67MHz(bySPECTRUN ANALYZER)							
			0.5usec, 250Hz	0.5usec, 1500Hz	1use, 250Hz	1use, 1200Hz	2usec, 250Hz	2usec, 600Hz	3usec, 250Hz
PRF	+/- 1%	(Hz)	250,00290	1500,03820	250,00290	1200,02060	250,00290	600,00030	250,00290
Pulse Width	+/- 1.0 %	(usec)	0,500	0,520	1,000	1,000	2,000	2,000	3,000
Transmit Power		Ave. Pwr. (dBm)	-17,68	-10,11	-14,77	-8,17	-11,87	-8,14	-10,23
		Duty Factor (dB)	39,03	31,08	36,02	29,21	33,01	29,21	31,25
		Loss A (dB)	63,48						
Peak Power	More than 250kW	(dBm)	84,83	84,45	84,73	84,52	84,62	84,55	84,50
		(kW)	304,1	278,5	297,2	283,0	289,8	285,0	281,8
Occupied Band Width	5625 MHz +/- 8MHz	(MHz)	5620.30 5631.40	5620.10 5632.00	5619.90 5631.90	5619.90 5632.30	5621.90 5629.50	5622.00 5629.40	5622.60 5628.60
Peak Power(dBm) = Average Power(dBm)+Duty Factor(dB) + Loss A(dB) Peak Power(kW) = $10^{(Peak\ Power(dBm) / 10) / 10^6}$ Duty Factor : $10 * \log(Pulse\ Width(sec) * PRF(Hz))$ Loss A : the loss between output flange of the Klystron and "RF MONITOR TRANSMITTER" connector									

Table 3: Some Transmitter Measurement Values.

Peak Power Calculation:

$$\text{Peak Power (dBm)} = \text{Average Power (dBm)} - \text{Duty Factor (dB)} + \text{Loss A (dB)}$$

$$\text{Duty Factor (dB)} = 10 * \log (\text{Pulse Width (sec)} * \text{PRF (Hz)})$$

$$\text{Loss A (dB)} = \text{RF Monitor (inside transmitter) Loss}$$

$$\text{Peak Power (kW)} = \text{Inv. log (Peak Power (dBm)/ 10)}$$

Sample:

$$\text{PW} = 0,520 \mu\text{sec. PRF} = 250,00 \text{ Hz. (Measured), P(Average)} = -16,77 \text{ dBm.}$$

$$\text{TX- RF Monitor- Transmitter Loss} = 62,4 \text{ dB.}$$

$$\text{Peak Power (dBm)} = \text{Average Power (dBm)} - \text{Duty Factor (dB)} + \text{Loss A (dB)}$$

$$\text{Peak Power (dBm)} = -16,77 \text{ dBm} - 10 * \log(0,520 * E-6 * 250,0) + 62,4 \text{ dB.}$$

$$\text{Peak Power (dBm)} = -16,77 \text{ dBm.} - (- 38,86) + 62,4 \text{ dB.} = -16,77 + 38,86 + 62,4$$

$$\text{Peak Power (dBm)} = 84,49 \text{ dBm.}$$

$$\text{Peak Power (kW)} = \text{Inv. log (Peak Power (dBm)/ 10)}$$

$$\text{Peak Power (kW)} = \text{Inv. log (84,49 dBm/ 10)} = \text{Inv. log (8,449 dBm.)}$$

$$\text{Peak Power (kW)} = 281,2 \text{ kW.}$$

Power stability measurement:

At PW: 1µsec and PRF: 250Hz. power output goes from -14.95dBm to -15.05dBm half an hour later. Acceptable level: +/-0.5 dB Difference: 14.95 - (-15.05) = 0.1 dB ok

3.2. PW, PRF, Duty Cycle/Factor

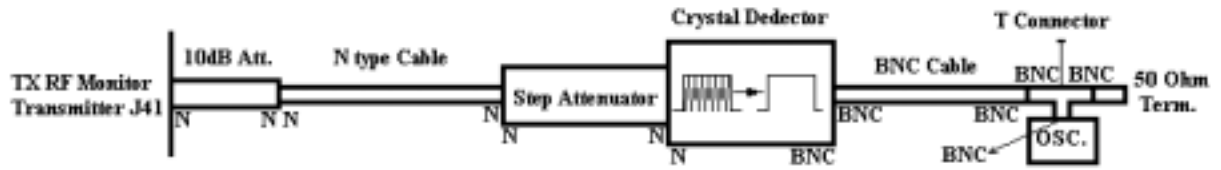


Figure 17: Preparation for Measuring PW and PRF.

This measurement is done by oscilloscope. Due to the limited capability of the oscilloscope for measuring the high frequency, a step attenuator and crystal detector must be used to measure the high frequency.

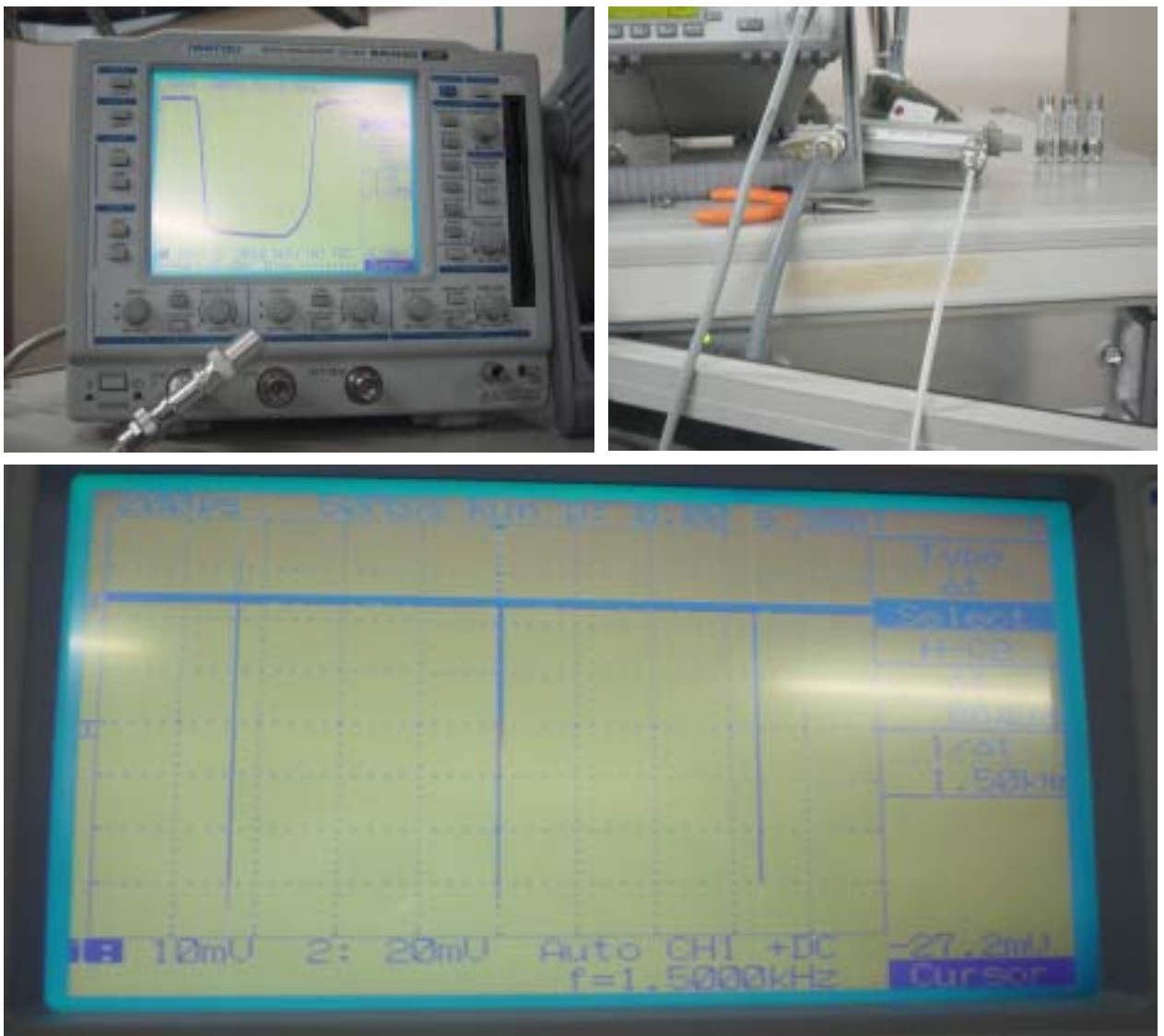


Figure 18: Measuring PW and PRF.

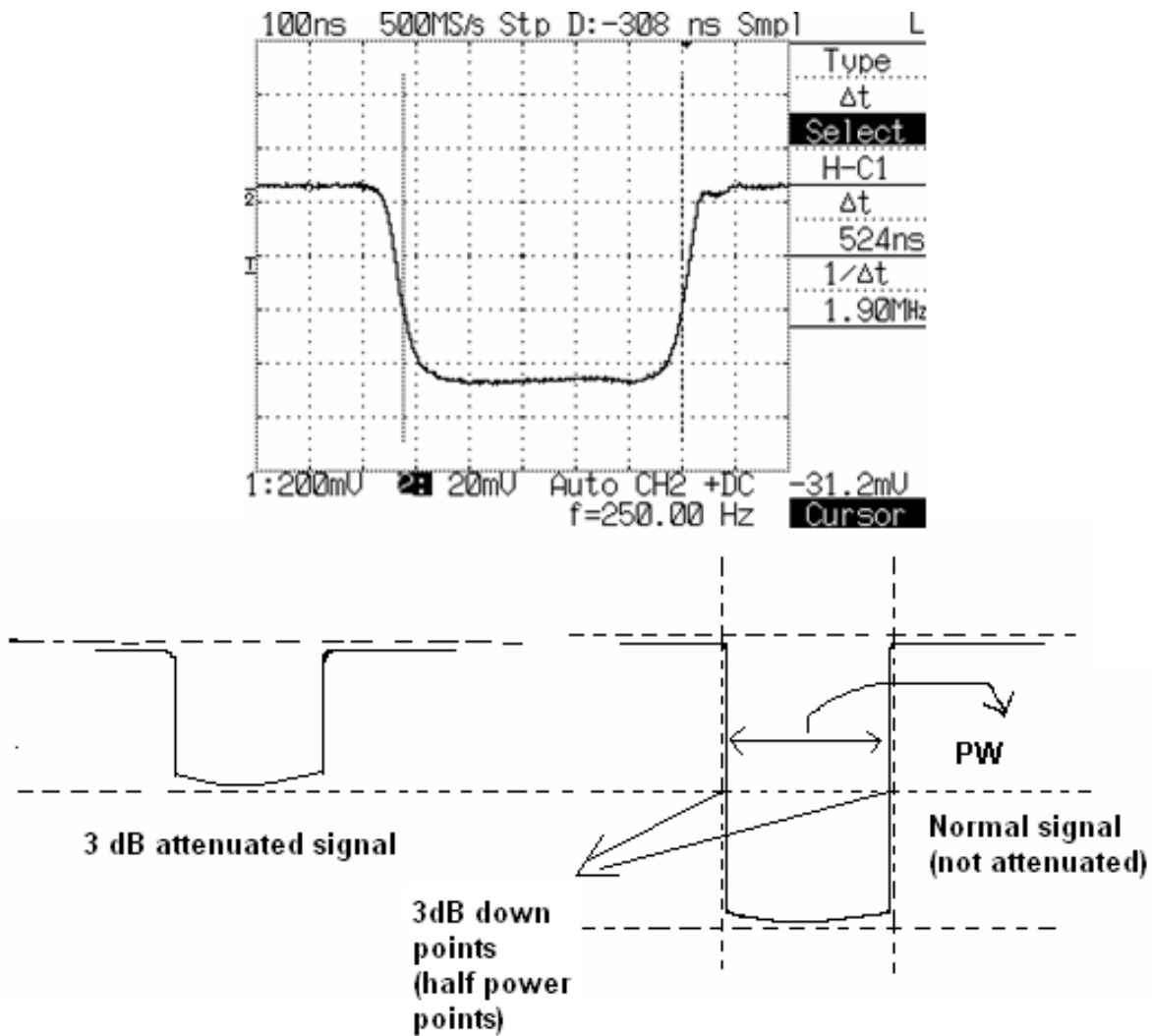


Figure 19: Usage of Half-power on Measurements.

Because signals must be measured from half-power point, we need 3dB attenuation to measure PW. 3dB attenuated signal's amplitude will be our measurement points on our normal (not attenuated) signal.

3.3. Klystron Pulse, Klystron Current

Waveform of transmitting Klystron pulse is measured by using oscilloscope from the klystron pulse output at the transmitter front panel.

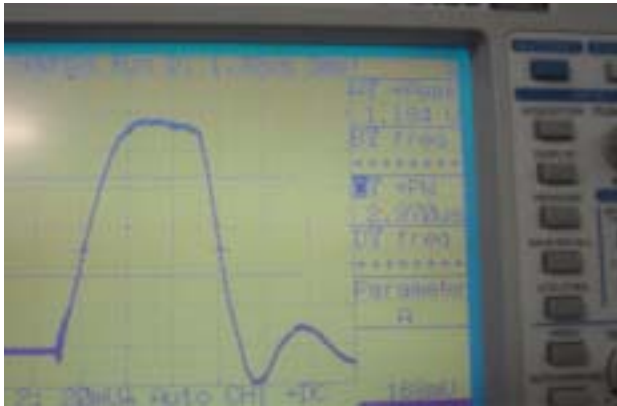


Figure 20: TX Klystron Pulse and Current from Test Point at TX Front Panel.

The purpose of measuring is to see the pulse width (PW) and peak point of the signal. We can calculate the Klystron Current by multiplying the value on oscilloscope with 10.

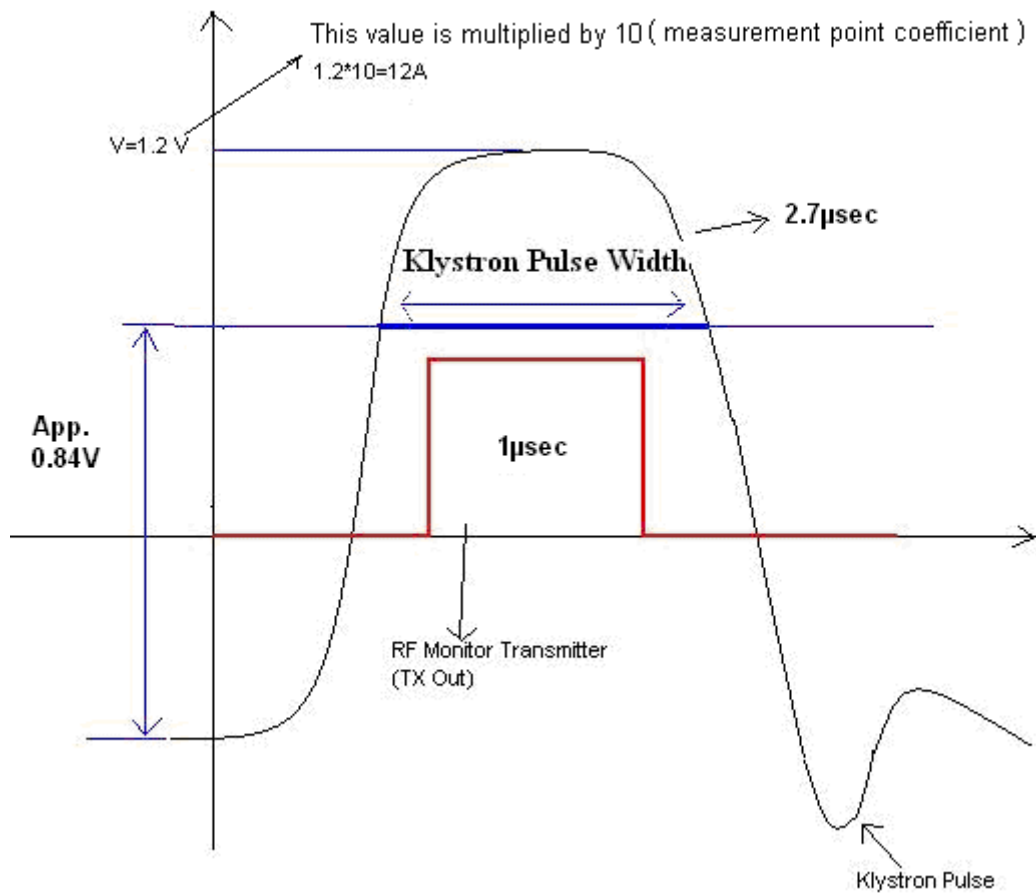


Figure 21: Measurement and Calculation for Klystron Pulse Width and Current.

3.4. Klystron RF Input Level

In this measurement, RF Drive Power Level and frequency to Klystron are checked whether they are in normal ranges or not.



Figure 22: Klystron RF Drive Power and Frequency Level Measurement.

3.5. Transmitted Frequency

The aim of the transmitted frequency measurement is to determine RF signal is to be 5625 MHz or not. This measurement is doing by the spectrum analyser or frequency counter.

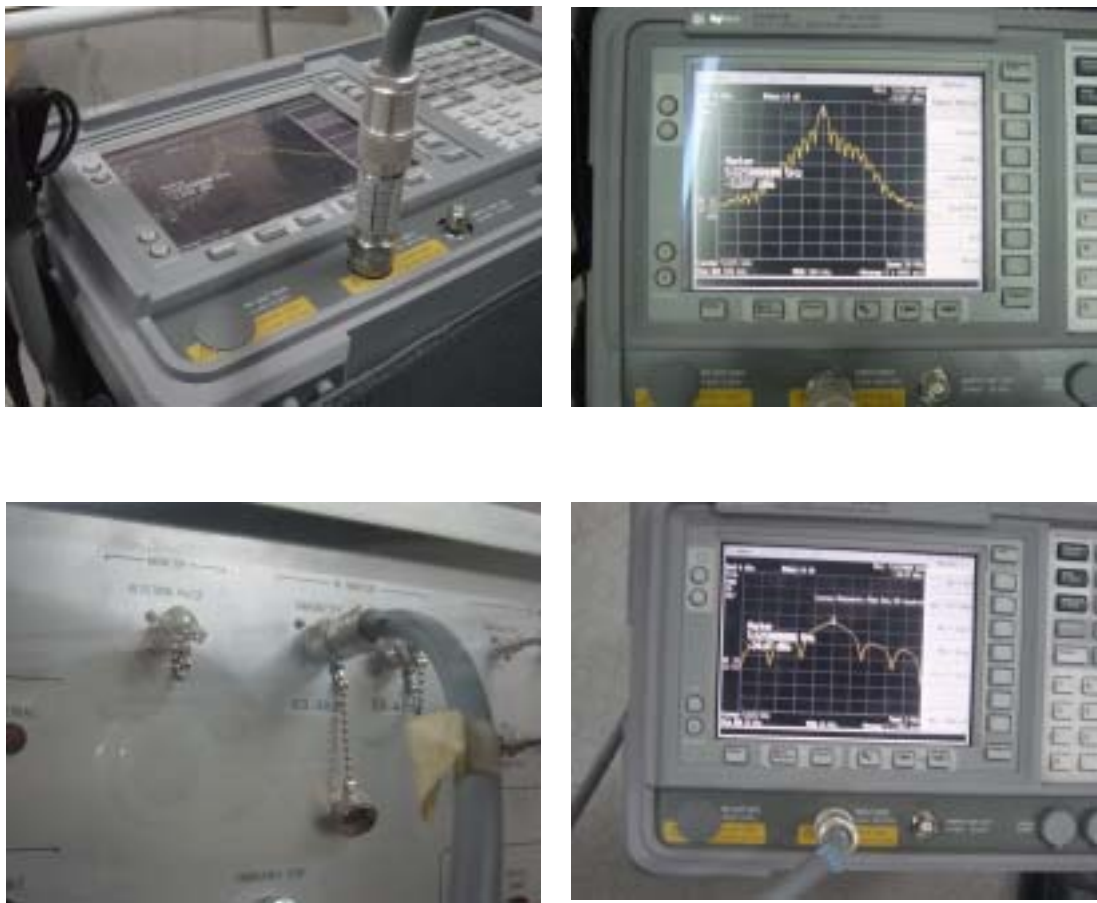
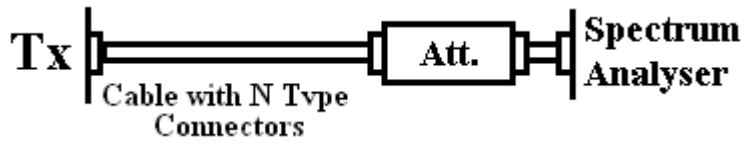


Figure 23: Transmitted Frequency Measurement.

3.6. Occupied Bandwidth (BW)

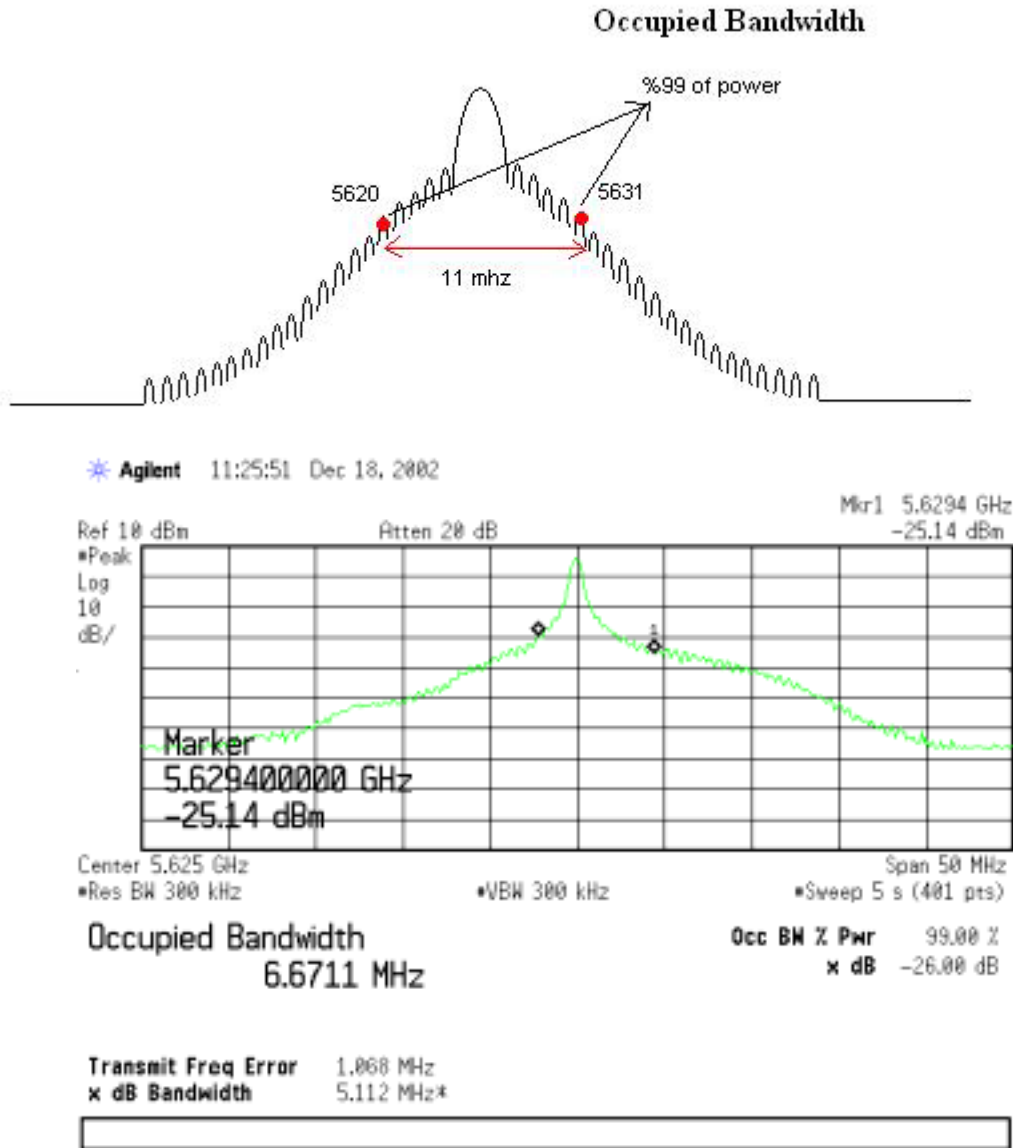


Figure 24: Occupied Bandwidth Measurement.

Occupied Bandwidth is the width of the frequency band used such that, below the lower and above the upper frequency limits, the mean powers emitted are each equal to a specified percentage(99%) of the total mean power.

3.7. Voltage Standing Wave Ratio (VSWR) Measurement

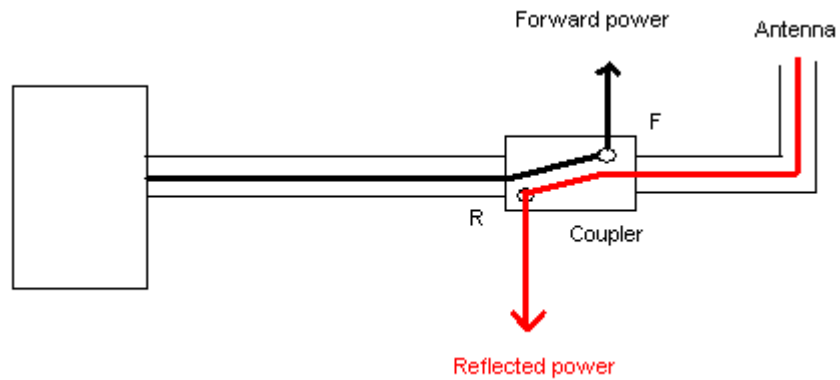


Figure 25: Voltage Standing Wave Ratio (VSWR) Measurement.

VSWR (Good) = R_{loss} big
 VSWR (Bad) = R_{loss} small

R_{loss} = forward power – reflected power,

If the return loss is big, return power will be small and it is preferred that VSWR must be closer to one (1) as much as possible.

$$VSWR = \frac{1 + 10^{\frac{RL}{20}}}{1 - 10^{\frac{RL}{20}}}$$

4. MEASUREMENTS ON RECEIVER

Receiver is designed to detect and amplify the very weak signals received by the antenna. Radar receivers must be of very high quality because the signals that are detected are often very weak. Most weather radar receivers are of the super-heterodyne type in which references signal at some frequency which is different from the transmitted frequency. Some Parameters can be measured regarding sensitivity and performance.

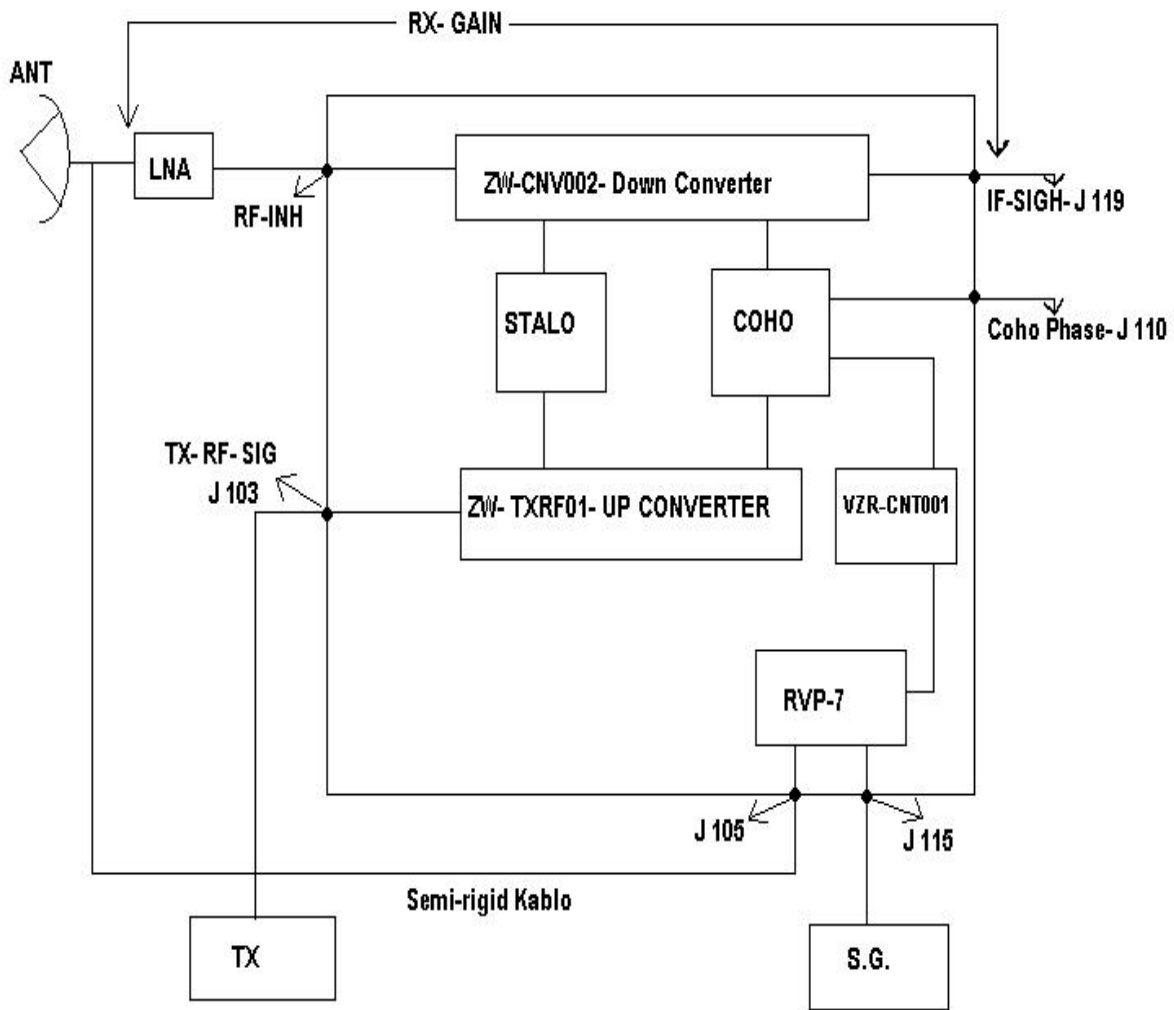


Figure 26: General Block Diagram of System and Some Important Measurement Points.

4.1. Oscillator Outputs

4.1.1. STALO Level Measurement

STALO (Stable Oscillator) must be very stable. Radar systems can have different STALO frequencies and power levels.

The purpose of this measurement is to determine the power of the receiver to get the very weak signal coming from it.

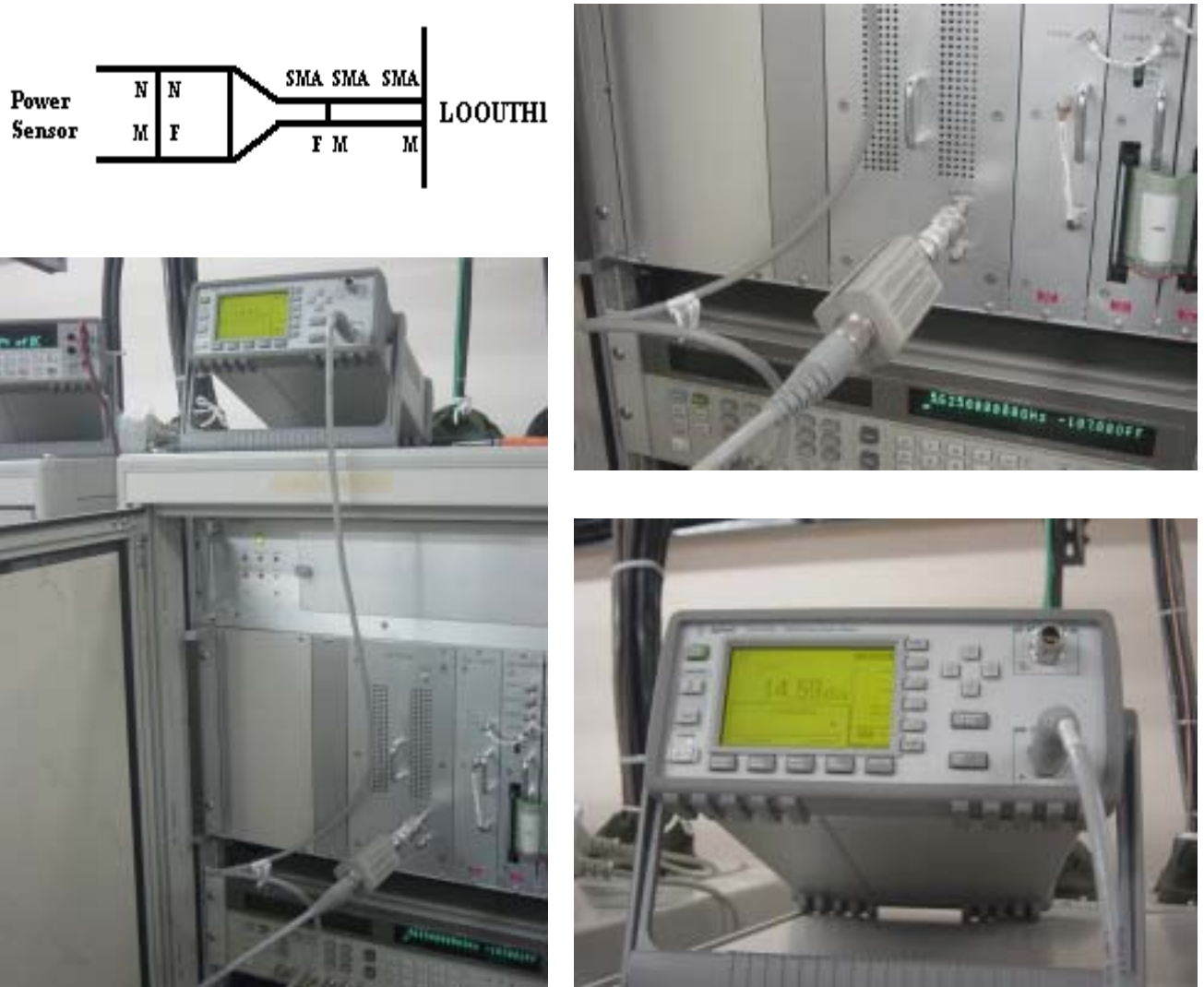


Figure 27: STALO Level Measurement.

4.1.2. COHO Level Measurement

COHO is abbreviated from **CO**Herent **O**scillator words. COHO frequency is generally 30MHz.

If the system produced appropriate to dual polarization so there will be four measurements point. We measure the power of the COHO output.

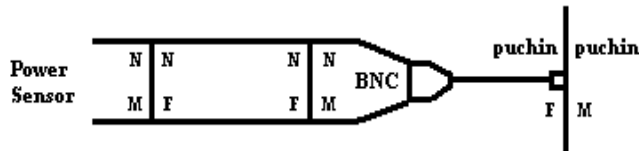


Figure 28: COHO Level Measurement.

4.2. RX Gain

To perform a receiver calibration, a signal generator is connected to the directional coupler and turned on and allow to warm up. It may be better to do the receiver calibration with the transmitter off. The frequency of the signal generator must be matched to that of the radar receiver.

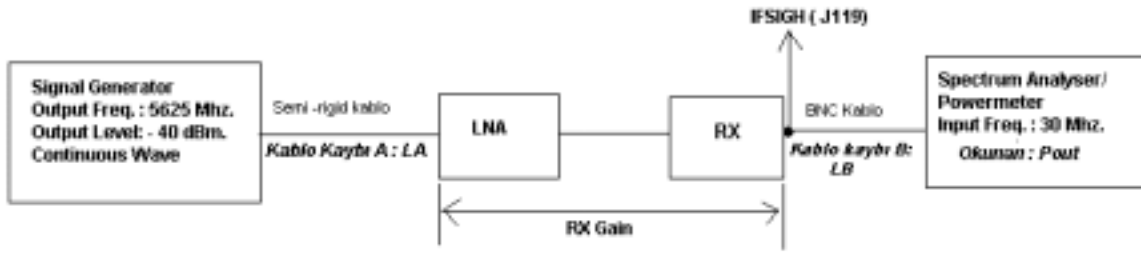
If the input power is so weak, Receiver can not this signal and the minimum signal that receiver can sense is **MDS (Minimum Detectable Signal)**. If the input power is increased above some level, the receiver cannot put out any more power and the receiver is said to be **saturated**.



Figure 29: Receiver Gain Measurement.

$$G_{RX} = \text{output}_{dBm} (\text{IF SIGH}) - \text{input}_{dBm} (\text{LNA}) = \text{output}_{dBm} (\text{IF SIGH}) - 40dBm$$

$$S.G. \text{ output} = -40dBm + L_{TS}$$



$$RX \text{ Gain (dB)} = P_{out} + L_A + L_B - (-40)$$

Figure 30: Measurement procedure for RX Gain.

$$RX \text{ Gain (dB)} = P_{out} + L_{TS} - (-40 \text{ dBm}) = P_{out} + L_A + L_B - (-40 \text{ dBm})$$

4.3. MDS (Minimum Detectable Signal) & Dynamic Range

<u>SG (dBm.)</u>	<u>RX Input (dBm)</u>	<u>RX Output</u>
-114	-116.3(-2.3 dB loss)	-73.2
-113	-115.3	-73.0
-112	-114.3	-72.8
-111	-113.3	-72.4
-110	-112.3	-72.0
-109	-111.3	-71.1
-108	-110.3	-70.8
-107	-109.3	-70.4
-106	-108.3	-70.0
-105	-107.3	-68.7
-104	-106.3	-68.4
-103	-105.3	-67.7
-102	-104.3	-66.7
-101	-103.3	-65.8
-100	-102.3	-64.8
-90	-92.3	-55.1
-80	-82.3	-45.0
-70	-72.3	-37.0
-60	-62.3	-25.0
-50	-52.3	-15.0
-40	-42.3	-5.1
-30	-32.3	4.6
-25	-27.3	7.8
-24	-26.3	8.0
-23	-25.3	8.3
-22	-24.3	8.4
-21	-23.3	8.6
-20	-22.3	8.6
-19	-21.3	8.7
-18	-20.3	8.8
-15	-19.3	8.9
-10	-12.3	8.9

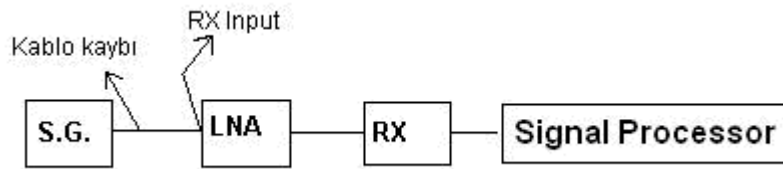


Figure 31: Simple Block Diagram for Measuring MDS and Dynamic Range.

From Dynamic Range Curve, RX-Gain can be detected also. If values from middle part of (linear) the curve used,

$$\text{RX-GAIN} = \text{LNA input} - \text{Sign. Processor Input}$$

$$\text{RX-GAIN} = -37.0 - (-72.3) = 35.3 \text{ dB.}$$

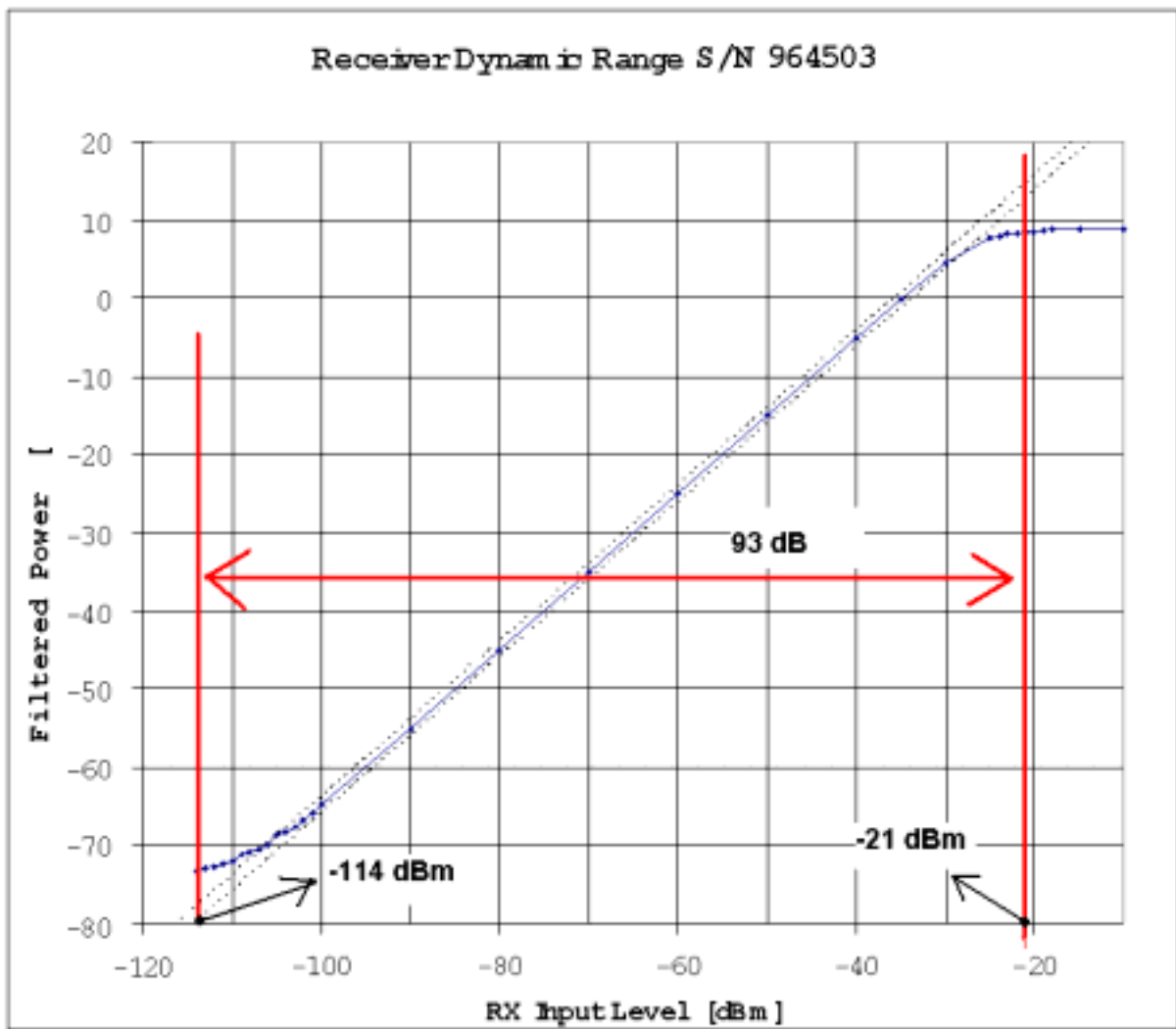


Figure 32: Receiver Dynamic Range Curve.

4.4. TX IF Out and Exciter RF

TX If out signal is Pulse Modulated COHO output to be up converted to RF level and **Exciter RF signals** is sent to Klystron. The purpose of this measurement to investigate the signal is normal or not going to Up Converter part and RF circuit in TX.

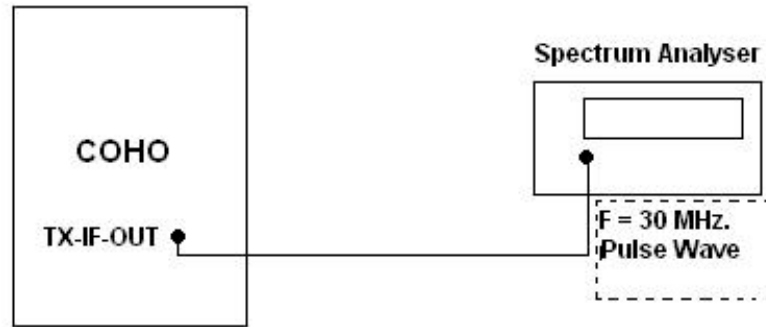
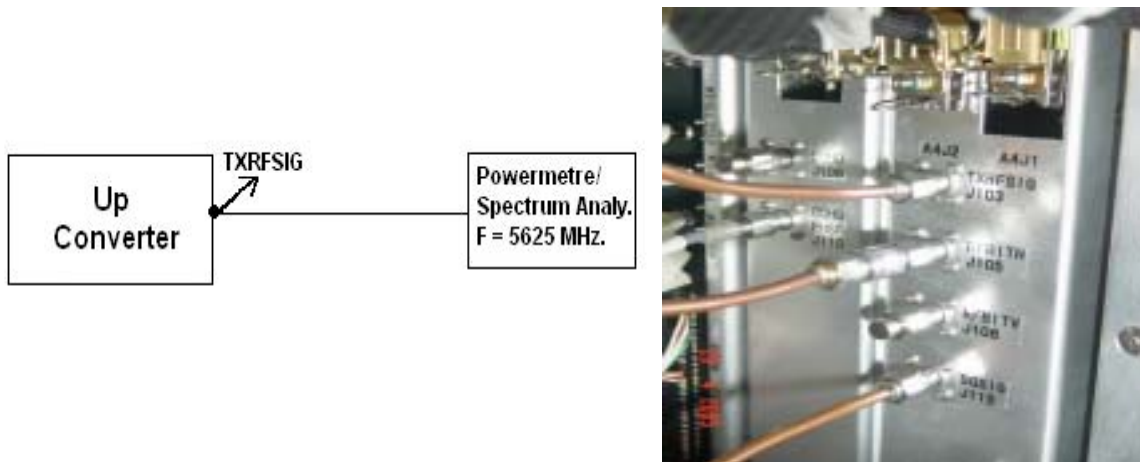


Figure 33: TX IF Out Measurement.



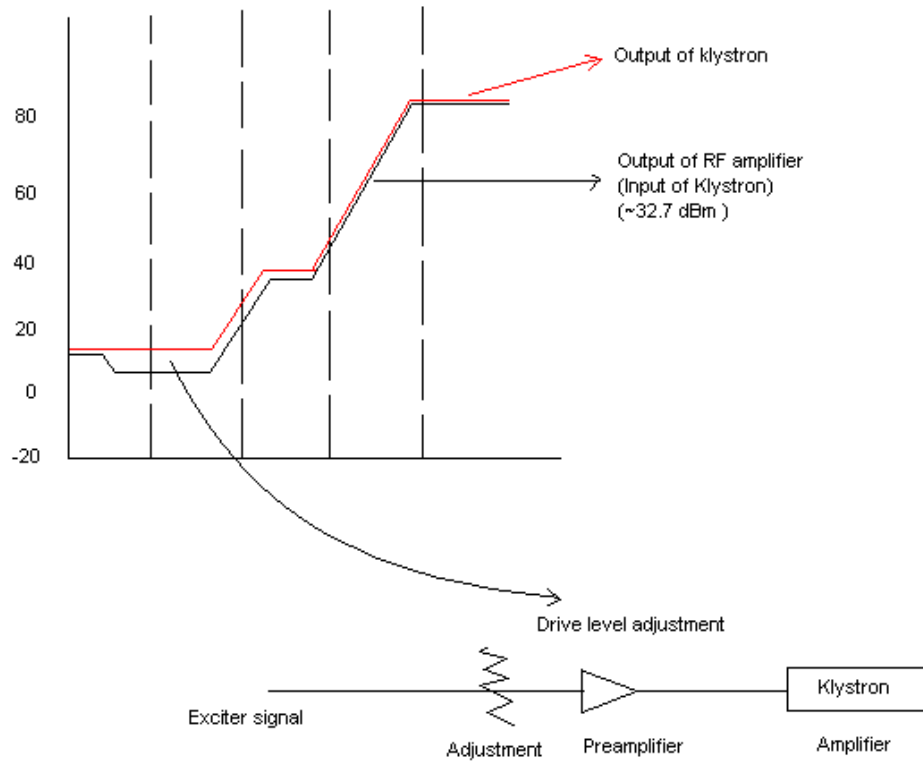


Figure 34: TX RF Signal Measurement.

4.5. Intensity Check

Intensity check measurement is done to see how well the system performs the processing of the reflected signal after coming into LNA through Signal Processor.

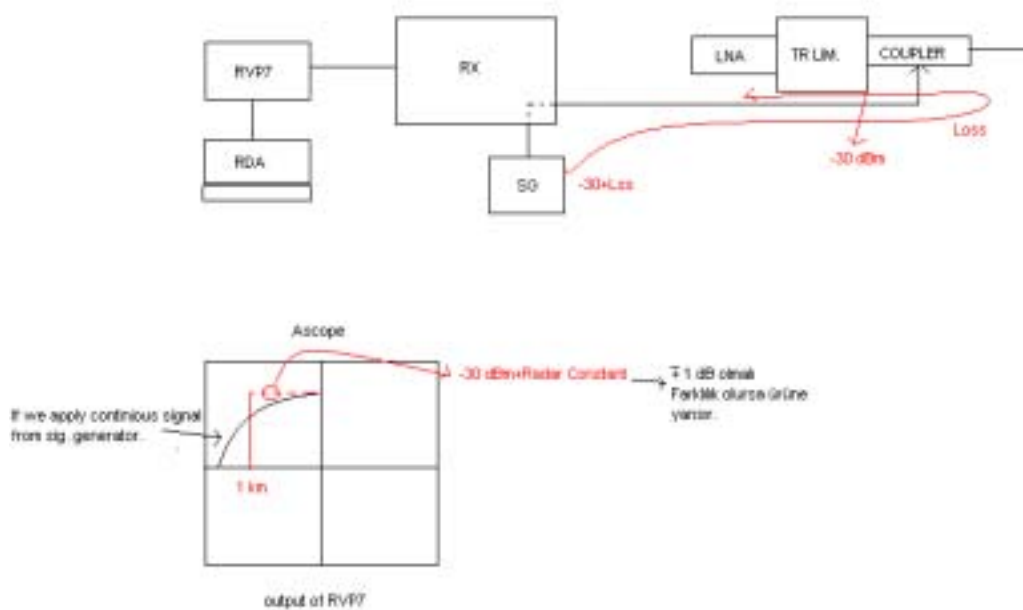


Figure 35: Intensity Check Measurement.

$$P_{RX} = C \frac{\beta R^B}{r^2} \quad C: \text{Radar Constant}$$

$$\beta R^B = \frac{r^2 P_{RX}}{C} \text{ (dBm)} \quad \beta R^B = C' r^2 P_{RX} \quad (C' = \frac{1}{C})$$

For applied PW: 2 μsec, PRF: 250Hz -----> Radar Constant: 60.94dB

LNA input from Signal Gen. =S.G. - 6,6 dBm =- 6,6dBm (S.G. out) - 33,4dB (loss) = - 40 dBm

The Measured Value for 1 km range from A-scope (in RSP) =21,0 dBZ

dBZ =Radar Constant (dB) + Prcalculated (dBm)

Pr (dBm) calculated =dBZ - Radar Constant (dB)

Pr (dBm) calculated =21,0 - 60, 94= - 39,94dBm

Expected value by calculation = -40dBm (which is applied by S.G)

Measured Value= -39.94dBm

Difference= 0.06dBm (which should within the range: -/+1 dBZ)

4.6. Velocity Accuracy

Velocity accuracy check measurement is done to see how well the system calculates the velocity of an echo.

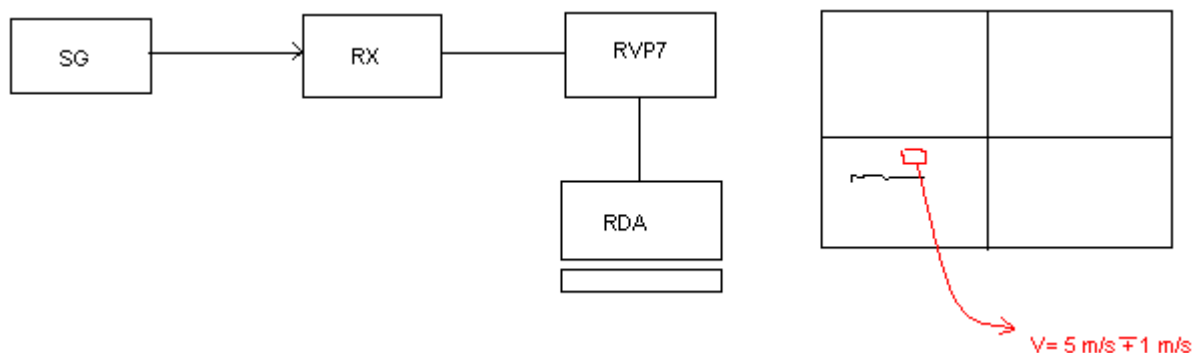


Figure 36: Velocity Check Measurement.

$$F_{dmax} = \frac{PRF}{2} = \frac{2V_{max}}{\lambda} \rightarrow V_{max} = \frac{PRF * \lambda}{4}$$

$$F_d = \frac{2v}{\lambda} \quad v: \text{Doppler velocity, } \lambda: \text{Wavelength: 0.0533 m. @ 5625 MHz}$$

Firstly, we should check output frequency of the Receiver at that moment.

$f_{rx}=5624999604$ Hz which corresponds to **Reference Signal**

For 10 ± 1 m/sec
$$F_d = \frac{2v}{\lambda} = -375 \text{ Hz}$$

From Signal Generator $5624999604\text{Hz} - 375 \text{ Hz} = 5624999196\text{Hz}$ applied as **Received Signal**.

We observed 10.7 m/sec from a-scope.

This means that 375 Hz frequency shift (which correspond to 10m/sec) observed is the system as 10.7 m/sec

The result should be within the range= +/-1 m/s. This can be improved by more stable Oscillators in Receiver System.

4.7. Trigger Control



Figure 37: Trigger Control.

Trigger Control Unit is a kind of switching unit between radar control processor and other units for performing pulse generation and transmission task. The trigger signals should be checked by using test tools, e.g. oscilloscope periodically to ensure that system performs its functions properly.

5. ANTENNA AND RADOME

A radar antenna (the British call it aerial) may be thought of as a coupling device between free space propagation and the waveguide from the transmitter. Some maintenance actions regarding antenna are listed below:

- Periodical Checks
- Antenna Test
- Lubrication
- Slipping Cleaning and Check
- Position and Velocity Check
- Radome Check and Control
- Obstruction Light Check

5.1. Periodical Checks

A Typical Periodic Maintenance Check Program for Antenna is below.

Check of every month:

No.	Check/	Location	Check Method, etc.
1	External Appearance	Entire Antenna System	Make sure that there is nothing unusual in appearance. Make sure that there is no deformation in reflector, feed horn and waveguide, etc.
2	Slip ring and Brush	Slip ring	Clean particles of abraded brush (powder) with vacuum cleaner. Wipe stains with dry cloth. Make sure that brush works smoothly without unusual friction.

Table 4: Monthly Antenna Check.

Check of every 3 months

No.	Check/ Maintenance	Location	Check Method, etc.
1	Operating Part	All Operating Parts	Make sure that there is no unusual sound during regular operation. The following parts should be checked. <ul style="list-style-type: none"> • AZ gear box • AZ drive motor • Rotation bearing • EL gear box • EL drive motor
2	Internal Gear and Pinion	Rotation bearing	Make sure that there is no unusual abrasion and scratches on internal gear and pinion. Check lubrication of gears.
3	Slip ring and Brush	Slip ring	Clean particles of abraded brush (powder) with vacuum cleaner and wipe stains with dry cloth. Make sure that brush works smoothly without unusual friction.
4	Oil in AZ gear box	AZ gear box	Check the amount of oil and oil leakage. When it is not sufficient, replenish AZ gear box with oil.
5	Oil in EL gearbox	EL gear box	Check the amount of oil and oil leakage. When it is not sufficient, replenish EL gear box with oil.

Table 5: Antenna Check Every 3 Months.

Check of every 6 months

No.	Check/ Maintenance	Location	Check Method, etc.
1	Grease for AZ Rotation Bearing	Rotation Bearing	Supply grease from grease nipple.
2	Lubricating oil for AZ gear box	AZ gear box	Exchange the lubricating oil.
3	Grease for AZ gear box.	AZ gear box	Supply grease from grease nipple.

Table 6: Antenna Check Every 6 Months.

Annual check

No.	Check/ Maintenance	Location	Check Method, etc.
1	Limit Switch Function	EL Drive Unit	Check the function.
2	Slip ring and Brush	Slip ring	Clean particles of abraded brush (powder) with vacuum cleaner and wipe stains with dry cloth.
3	Oil for EL gear box	EL gear box	Supply Oil.
4	Friction torque of AZ Drive Unit	AZ Drive Unit	Supply Grease.
5	Friction torque of EL Drive Unit	EL Drive Unit	Supply Grease.

Table 7: Yearly Antenna Check.

Five-year-check

No.	Check/ Maintenance	Location	Check Method, etc.
1	EL gear box and EL drive mechanism	EL gear box	Make sure that there is no unusual sound or noise. Make sure that there is no oil leakage from shaft bearing.
2	Rotation Bearing and AZ drive mechanism	Rotation Bearing	Make sure that there is no unusual sound or noise.

Table 8: Antenna Check Every 5 Years.

ASC Monthly check

No.	Check Item	Procedure	Standard
1	Output of DC Power Supply	Check the voltage at each jack (Test) Check dc power supply outputs	Tolerance
2	Blower Function	Check the Blower on each unit is correctly functioning.	All the Blowers is functioning.
3	LED Test		All the LEDs turn on.
4	Alarm	Confirm there is no alarm on the SERVO	No alarms indicated.

Table 9: Monthly ASC Check.ASC 6 Monthly check

No.	Items	Procedure	Standard
1	SERVO AMP	1. Check for dust and rubbish inside, and remove. 2. Check for loosening of the terminals and tighten it up. 3. Check parts. (For change of colour, damage or disconnection.	1. No unusual sounds 2. No unusual

Table 10: ASC Check Every 6 Months.

5.2. Antenna Test

Antenna test can be proceed by following checks

	MEASUREMENT	FUNCTION / VALUES
AZ movement 0° - 360°	Use ACU or Maint. Software	o.k. / not o.k.
AZ velocity (as specified in tech. req.) e.g. 0 – 36 °/s	Use ACU or Maint. Software	o.k. / not o.k.
AZ positioning (as specified in tech. req.) ± 0.1°	Use ACU or Maint. Software	o.k. / not o.k.
EL movement (as specified in tech. req.) e.g. -3° - +180°	Use ACU or Maint. Software	o.k. / not o.k.
EL velocity (as specified in tech. req.) 0 – 36 °/s	Use ACU or Maint. Software	o.k. / not o.k.
EL positioning (as specified in tech. req.) ± 0.1°	Use ACU or Maint. Software	o.k. / not o.k.
Lower limit switch	Use handle	o.k. / not o.k.
Lower main limit switch	Use handle	o.k. / not o.k.
Upper limit switch	Use handle	o.k. / not o.k.
Upper main limit switch	Use handle	o.k. / not o.k.
AZ SAFTY switch	Turn AZ safety switch	o.k. / not o.k.
EL SAFTY switch	Turn EL safety switch	o.k. / not o.k.
RAD OFF switch	Turn RAD OFF switch	o.k. / not o.k.
Door interlock	Open / close Door switch	o.k. / not o.k.
Levelling	Via SUNPOS program or water levelling	o.k. / not o.k.
Alignment into the north	Via SUNPOS program or fixed target	o.k. / not o.k.

Table 11: Antenna Tests.

5.3. Lubrication

Klystron Tank and Gear Oil Changing:

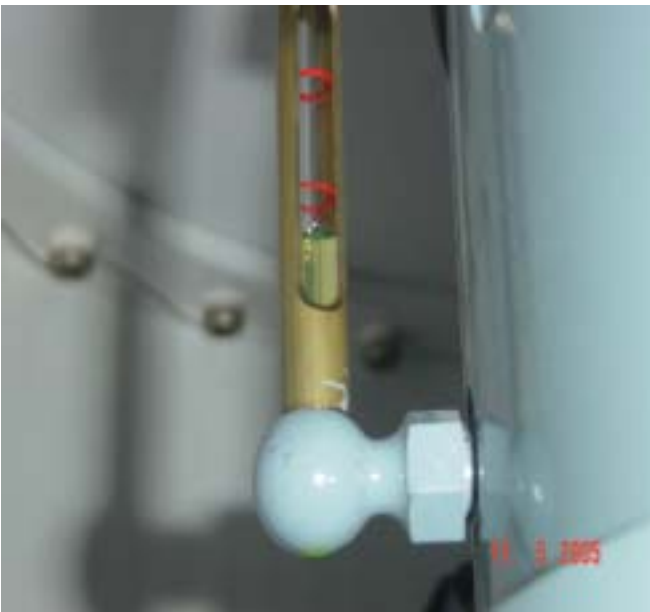
Oil is important for antenna to works properly. It is important to changing oil at a certain time in a year. We can also understand the changing the oil time to see colour of the oil inside the oil tank. If the colour of the oil is getting dark, it means that it is time to change oil. The purpose of the changing oil inside the AZ/EL is to extend the life of the both AZ/EL Gear box and also decrease the friction and to prevent corrosion between gears. We can see the oil level in the oil indicator.



Changing Klystron Tank Oil



Changing Gear Oil



Oil level indicator



Specified oil by the manufacturer should be used

Figure 38: Some Pictures on Changing Oil.

Greasing

Supply grease is also important for rotating parts and the pinion to prevent friction and the corrosion between rotating parts. If the colour of the grease is getting dark or periodically we should supply new grease by using grease gun.



Figure 39: Greasing, Grease Nipple and Some Types of Grease.

While greasing AZ/EL pinions, gear the antenna should be turned slowly by crank handle and also ASC motor should be in off position.

5.4. Slipring Cleaning and Check

A slip ring is an electrical connector designed to carry current or signals from a stationary wire into a rotating device.

Typically, it is comprised of a stationary graphite or metal contact (brush) which rubs on the outside diameter of a rotating metal ring. As the metal ring turns, the electrical current or signal is conducted through the stationary brush to the metal ring making the connection. Additional ring/brush assemblies are stacked along the rotating axis if more than one electrical circuit is needed.



After Cleaning of the Slipring, The Length of Brushes Must Be Checked.



Cleaning of Slipring by Using Hard Sponge.



Some Kinds Should Be Cleaned by Brush.



**Some Sliprings Use Springs Instead of Brushes.
These Sliprings Should Be Checked Periodically.**

Figure 40: Some Pictures on Sliprings, its Types, Cleaning and Controls.

5.5. Position and Velocity Check

If the antenna has some degree of failure after sun tracking then the antenna positioning accuracy should be done by manually. Defined velocity can be checked by getting some reference position of the antenna by using a chronometer.



Figure 41: Position Check of Antenna.

5.6. Radome Check and Maintenance

The bolts of the radome should be checked every three years particularly in larger diameter radome applications. Because of the strong winds the bolts might be loosened. The bolts loosened must be tightened by using a torque wrench by professional experts. Also, silicon isolation should be checked and renewed.



Figure 42: Obstruction Light and Lightning Rod Connections on Radome, Applying Silicon to the Leakage and Changing Obstruction Light.

5.7. Obstruction Light Check

Obstruction light should be checked periodically and replaced if necessary for safety reasons.



Figure 43: Obstruction Light.

6. BITE SYSTEM, MAINTENANCE SOFTWARES

- Built in Test Equipment (BITE)
- Maintenance Software

6.1. Built In Test Equipment (BITE)

Built In Test Equipment (BITE) monitors status of the radar's sub-units such as transmitter, receiver, antenna and signal processing system. System status and certain parameters of each sub units can be monitored by BITE system. It is also used for the automatic calibration of the receiver.

BITE system includes the facility of using solar measurements to calibrate the receiver and antenna positioning sub system.

6.2. Maintenance Software

The purpose of the maintenance software is to check and monitor of the system status and maintain the system remotely or locally. Maintenance software can be developed in accordance with the customer requirements and system capabilities. One of the features of such software is its capability of system calibration. But it must be remembered that maintenance software is one of the essential tools for the system visualisation and maintenance.

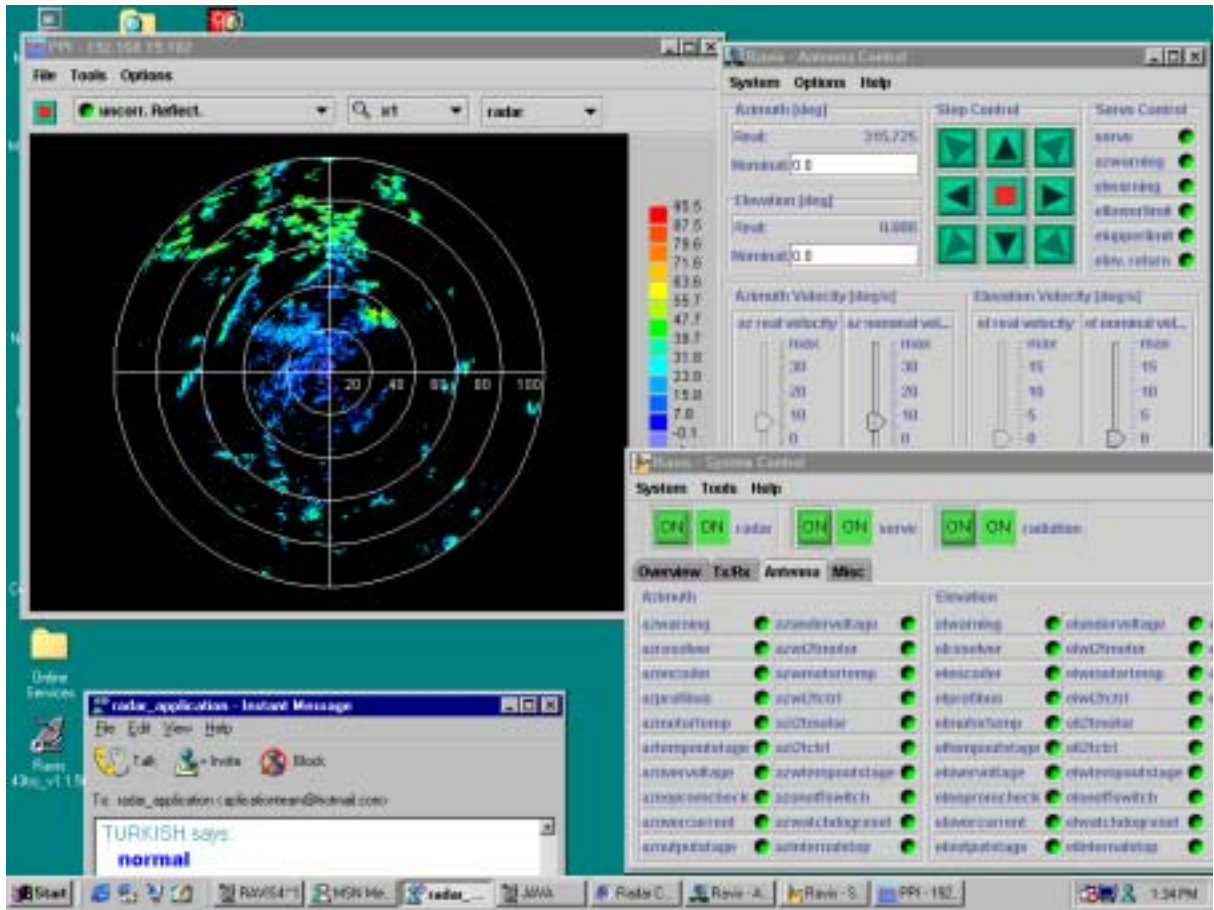




Figure 44: Some Pictures about BITE and A-Scope.

7. CALIBRATION

7.1. Transmitted Peak and Average Power Check and Adjustment

It is explained how to measure the transmitted power in section 3. After measuring transmitted power, if there is any abnormalities it is tried to be adjusted by means of some hardware set-up based on the design of the transmitter.

If the adjustments can not be done satisfactorily by using the above method, the output power determined during the test measurements should be set into radar signal processor to define new radar constant values for the calculation of reflectivity.

7.2. Receiver Calibration

7.2.1. Receiver Response Curve Calibration and Intensity Check

Receiver response curve for each radar defines that which value of signal processor input corresponds to which value of RX input. After this curve is set by calibration, assumptions are done by the help of the curve. In time, receiver response to a coming signal can change. So the new curve has to be introduced to the system, otherwise the calculations would be faulty.

By the help of an internal or external Signal Generator, Receiver response to a wide range of incoming signal should be defined. Then the new curve which represents the receiver response is recognized to the system.

Intensity calculation of the system depends on accuracy of the receiver response curve. After a new curve set, intensity check is done as defined in 4.5.

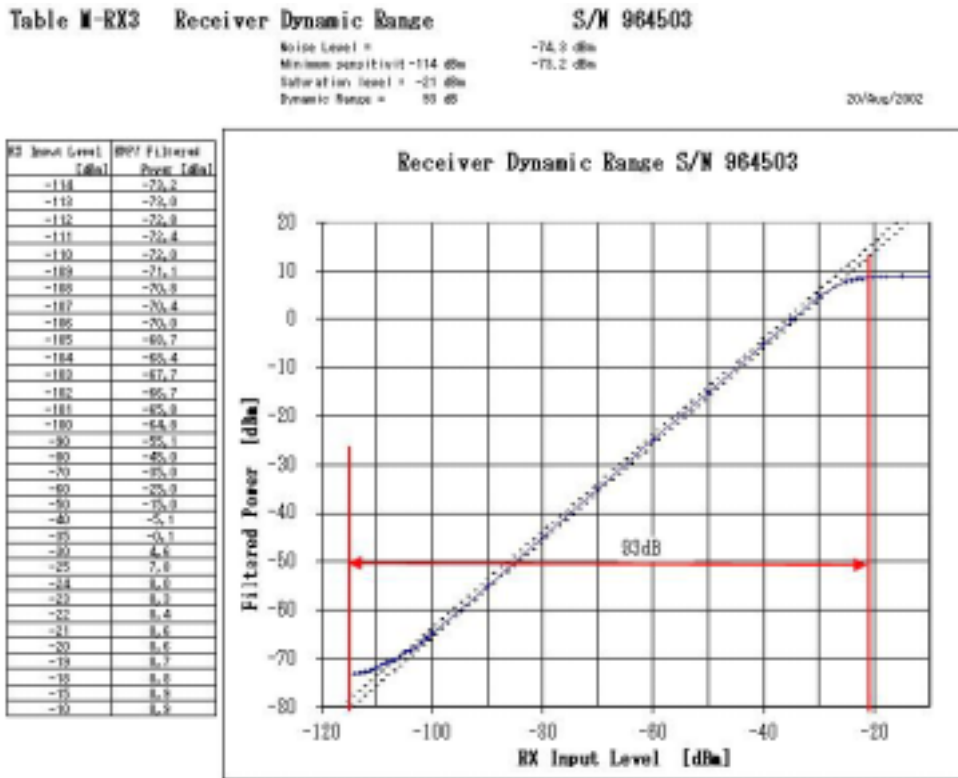


Figure 45: Receiver Dynamic Range Curve.

7.2.2. RX Noise Level and MDS Check

Receiver noise level check is done by the system to define the noise level of the receiver. Then a threshold can be set to this level and faulty signal is not displayed depend on that noise level. This noise level adjustment should be done frequently by the system automatically.

7.2.3. RX Gain Calibration

RX Gain should be checked by the system automatically and in case of out of the limits, it should be calibrated by maintenance staff.

7.3. Antenna Calibration

7.3.1. Sun Position Calibration

The sun radiates not only visible light but also electromagnetic energy at all frequencies. The amount of energy emitted by the sun at radar frequencies is sufficient to be detectable by most modern radar receivers. It is simply a matter of aiming the antenna at the sun and measuring the power received. Note that we do not use the transmitter for this. We are not bouncing an echo off the sun; we are using the sun as a ‘calibrated’ signal generator at a known position. If we get correct time and correct position of the sun then we do sun tracking.

If any error of the antenna position we do some adjustment. First we do electrically, the other is mechanically.



Electrically adjustment by using dip switch



Mechanic adjustment by using antenna

Figure 46: Electrically and Mechanically Adjustments.

7.3.2. Solar Gain Measurements

There are a number of solar observatories located around the world which measure the solar flux density at a number of different frequencies each day.

- The sun can be used as a “standard target”
- By knowing (from the measurements of others) how much power the sun is emitting, we can get the gain of a radar antenna

Solar Gain

$$g_0 = 4\pi s^* / [Fl^* l^2]$$

Where g_0 is the gain of the radar, s^* is the corrected radar-observed solar spectral power, Fl^* is the observatory-published flux value at the wavelength l of the radar.

Solar Flux Measurements

- Solar flux density is measured at several locations around the world: Australia, Canada, Italy, Massachusetts, Hawaii
- Measurements are made at various frequencies (MHz): 245, 410, 610, 1415, 2695, 2800, 4995, 8800, 15400
- Measurements are corrected for
 - atmospheric attenuation (0.1 dB)
 - distance of 1 astronomical unit

Relationship between s^* and F^*

Whiton *et al.* show that the corrected observatory solar flux density F^* is

$$F^* = s^*/A_e$$

Where A_e is the effective area of the radar antenna.

Antenna theory shows gain is given by

$$g = 4\pi A_e / l^2$$

- Combining all the terms correctly, should give antenna gain.

7.4. Comparison Methods for Checking Reflectivity

Time to time reflectivity of ground clutters or specified targets should be compared by the reflectivity of calibrated one. Following pictures are given as an example of that process.

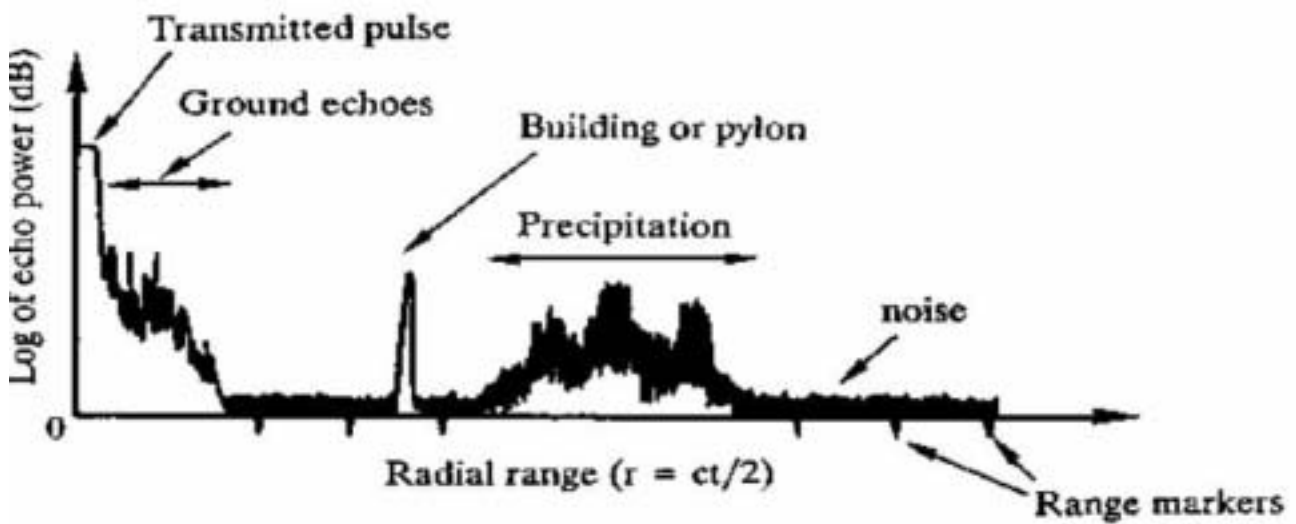
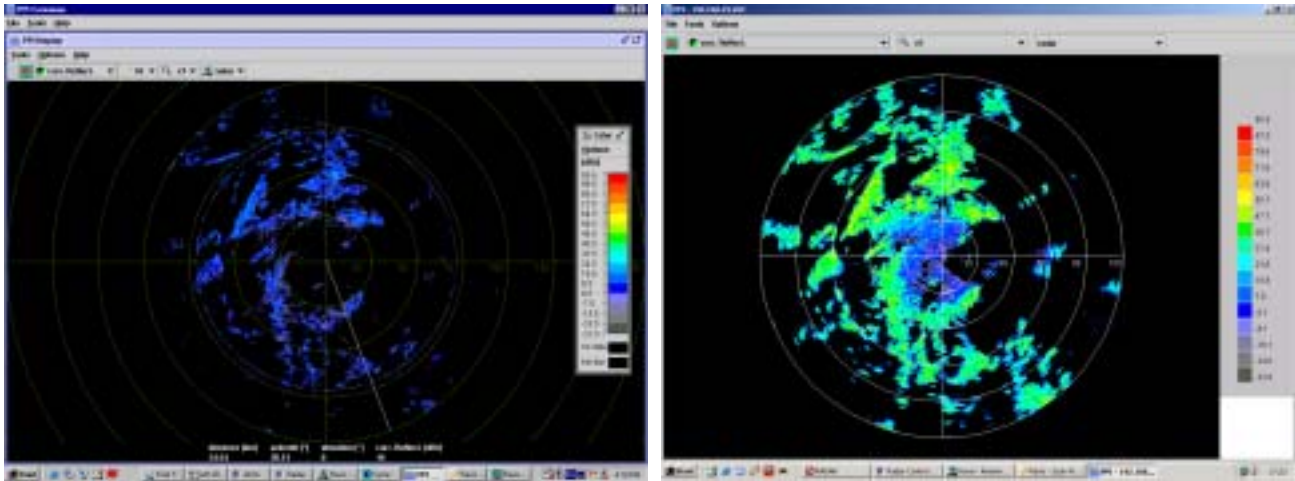


Figure 47: View from A-Scope and Reflectivity Differences between PPIs.

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TRAINING MATERIAL ON WEATHER RADAR SYSTEMS

MODULE F

RADAR INFRASTRUCTURE

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TURKEY RADAR TRAINING 1.0 / ALANYA 2005

**TURKISH STATE METEOROLOGICAL SERVICE
(TSMS)**



**WORLD METEOROLOGICAL ORGANIZATION
(WMO)**

**COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATIONS
(CIMO)**

OPAG ON CAPACITY BUILDING (OPAG-CB)

EXPERT TEAM ON TRAINING ACTIVITIES AND TRAINING MATERIALS

TRAINING COURSE ON WEATHER RADAR SYSTEMS

MODULE F: RADAR INFRASTRUCTURE

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**ELECTRONIC OBSERVING SYSTEMS DIVISION
TURKISH STATE METEOROLOGICAL SERVICE**

12–16 SEPTEMBER 2005

WMO RMTC-TURKEY

ALANYA FACILITIES, ANTALYA, TURKEY

MODULE A: INTRODUCTION TO RADAR

MODULE B: RADAR HARDWARE

MODULE C: PROCESSING BASICS IN DOPPLER
WEATHER RADARS

MODULE D: RADAR PRODUCTS AND
OPERATIONAL APPLICATIONS

MODULE E: RADAR MAINTENANCE AND
CALIBRATION TECHNIQUES

MODULE F: RADAR INFRASTRUCTURE

RADAR INFRASTRUCTURE

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ABBREVIATIONS:

EMC	: Electromagnetic Compatibility
3-D	: Three Dimensional
TUBITAK	: The Scientific and Technological Research Council of TURKEY
TSMS	: Turkish State Meteorological Service
RF	: Radio Frequency
WAN	: Wide Area Network
LAN	: Local Area Network
ISDN	: Integrated Services Digital Network
ATM	: Asynchronous Transfer Mode
SONET	: Synchronous Optical Network
VSAT	: Very Small Aperture Terminal

1. GENERAL OVERVIEW

The first step of the each activity is always very important. So, the site selection and determination of the infrastructure requirements at the design stage of the radar network is very critical and affect the overall success of the network operation seriously. All issues regarding the operation of the radar network should be evaluated by considering the data and services expected from radar network. Meteorological evaluation, e.g. rainfall and flash flood, radar coverage, big settlements areas, existing infrastructure and the requirements, communication options for data transmission, etc. should be done by the experts.

A complete review and design of a weather radar network must begin with an analysis of the rainfall and flood producing weather systems and the applications for which the radar network is being installed. For example, hail, tornadoes, thunderstorms, and orographically enhanced rainfall would become all present different problems and may require different hardware configurations. While it is relatively easy to measure thunderstorms with weather radar, winter rainfall in a mountainous region represents the worst case scenario due to difficulties with ground clutter, the shallow nature of the rainfall, occultation of the radar beam, and possible orographic enhancement at low levels.

The terrain covered by the radars is generally very rough, and this forces the use of high, relatively isolated, hills as radar sites. This, together with the need to scan at low elevation angles due to bright band and orographic rainfall considerations, means that ground-clutter may be a major issue for the network. There are several strategies that can be used to minimise the effect of ground clutter including the use of a narrow beam, rejecting the pixels that have clutter on fine days and using the statistical characteristics of the individual pulses.

2. RADAR SITE SELECTION CRITERIA

As stated above, there are some critical issues to evaluate while determining the site for installation radar. These are described briefly as follows:

Radar coverage can be defined simply as the area in which radar beams can travel to detect the targets without any blockage. Radars are used for the large scale monitoring of the weather phenomena. So the radar beam should scan a large area as much as possible and the site selection must be done by considering the radar network concept. A part of the area which can not be covered by one of the radars in the network can be covered by another radar of the network. So all required area would be under coverage of entire network.

The meteorological phenomena to be monitored by radar network should be also evaluated very carefully within the radar coverage area. The general approach to the design of an appropriate radar network was therefore to understand the applications for which the data are being collected, to assess the suitability of the proposed network in light of the meteorology of the area and to assess the level of experience in radar measurements prior to starting a detailed specification of the radar hardware.

On the other hand, **electromagnetic compatibility (EMC)** analysis should be performed to determine the suitability of the site on the basis of interference between the radar and other types of radio/radar services, and human exposure to the transmitted radar beam. Such analysis should identify the operating frequency and the power of the radar. Furthermore, the location, frequency and power of other radio services that are either potential sources of interference for the radar, or that the radar has the potential to interfere with should be identified. Human exposure to the radar beam is rarely a problem, but it should still be considered.

There is **special software** available to make radar coverage analysis by means of digital terrain elevation data of high resolution. Some examples of radar coverage analysis are given below.

The software developed by The Scientific and Technological Research Council of Turkey (TUBITAK) is used by TSMS for radar coverage analysis.

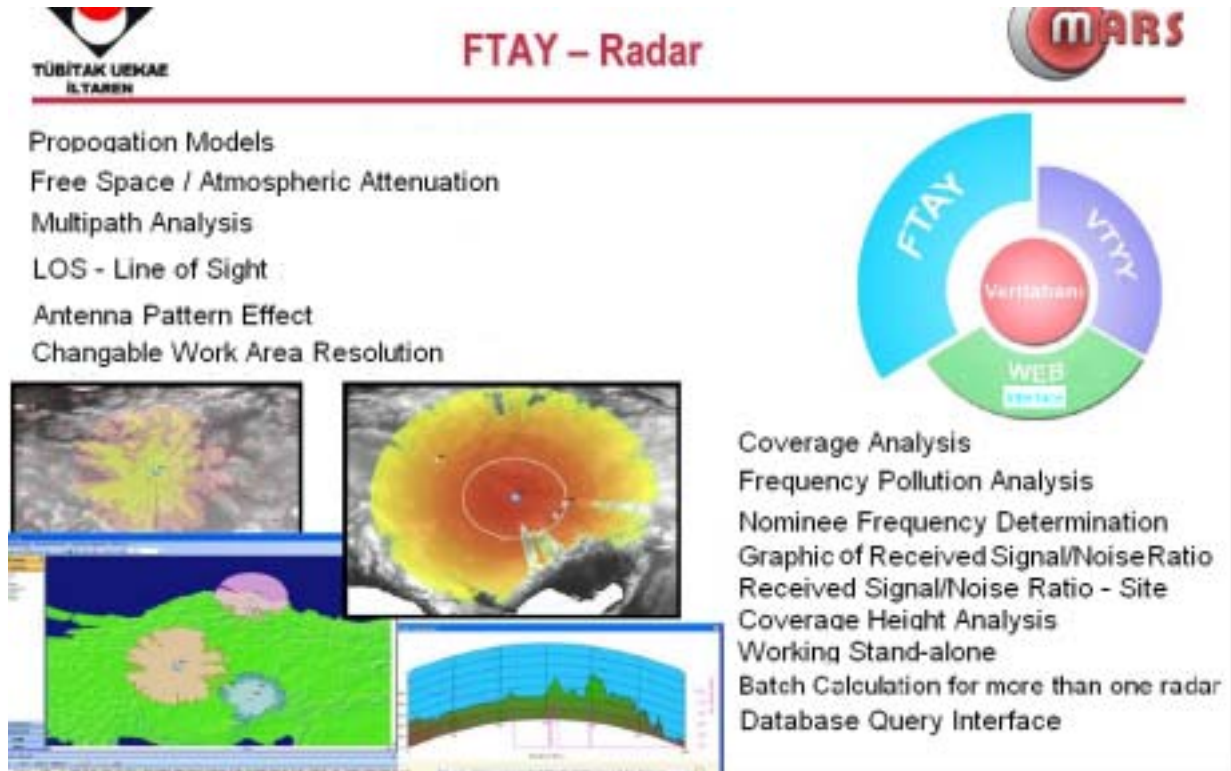


Figure 1: Radar Coverage Analysis by TUBITAK’s MARS Software.

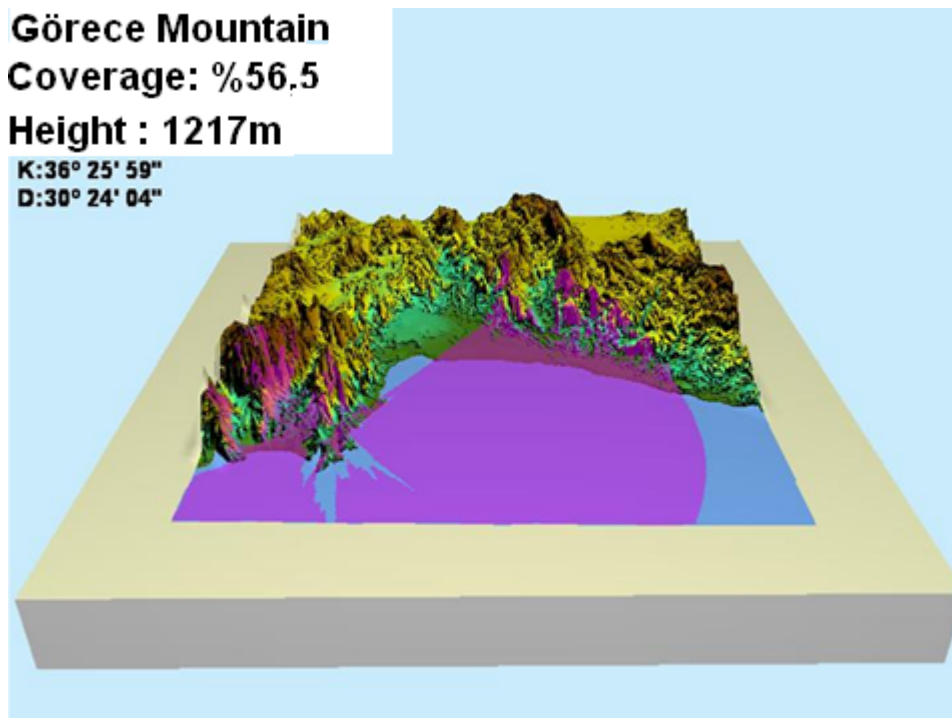


Figure 2: A 3-D Radar Coverage Image.

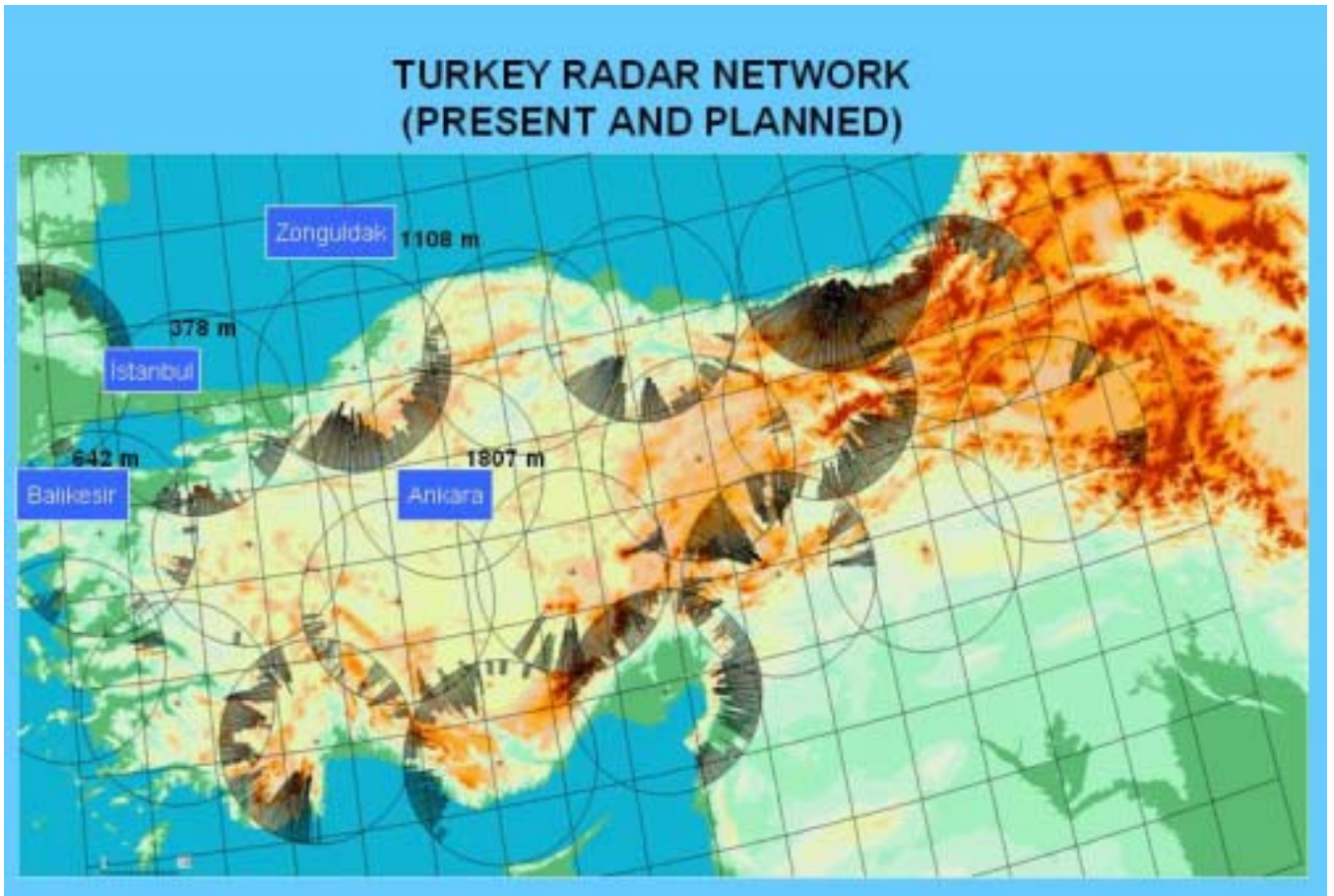


Figure 3: TURKEY Weather Radar Network.

3. RADAR SITE INFRASTRUCTURE REQUIREMENTS



Figure 4: Balıkesir Radar.

- Tower
- Power
- Lightning protection and grounding
- Communication
- Others

3.1. Tower

In some cases, a tower of certain height is required to install the antenna and radome on the top of it. There several types of the tower can be designed in accordance with the site condition and requirements. The tower must be designed strong enough against the heavy storms and severe weather conditions. Some types of the towers are as follows:







Figure 5: Some Tower Pictures.

3.2. Power Supplies

The proximity of the radar site to the **main power lines** should be considered. It should be noted that, radar site has to be powered by **oil generators** if radar site is chosen very far from the power line. In case of not availability of power at the radar sites, power line from main line to the radar site can be installed by laying down the cables from underground or via electrical poles (aerial line). It must be remembered that, electrical poles may be exposure severe weather conditions and so they must be strong enough against such conditions.

In general, the power supply to radar sites is expected to be very uncertain with frequent brown-outs and power cuts of short duration, as well as occasional cuts over extended periods during and after severe weather. The successful deployment of the radar network therefore depends on the careful design of a robust power conditioning and backup system suited to the conditions found at each radar site.

Power supply, transformer, voltage regulator, uninterruptured power supply, generator backup, oil tank, lightning protection, protection circuits, cabling, by following international standards should be included in overall design of the radar site.

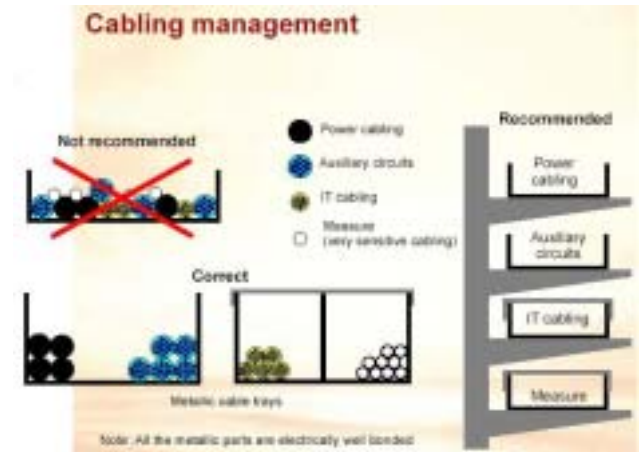
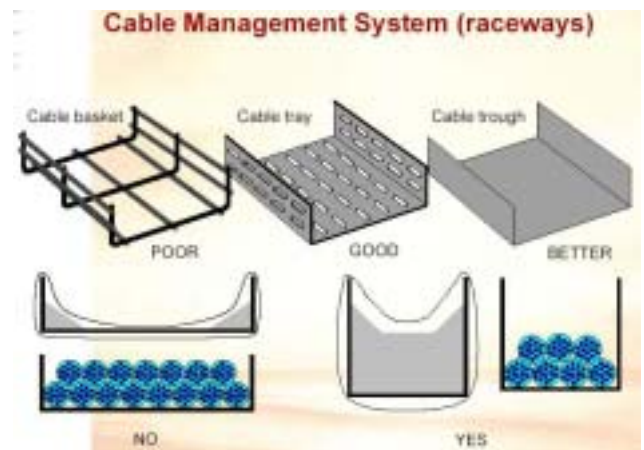






Figure 6: Some Cabling, Main and Back-up Power Supply and Electric Poles Destroyed from Severe Weather.



3.3. Lightning Protection and Grounding

Lightning is the most dangerous and hazardous event for radar sites. An effective lightning protection and grounding system should be designed and installed based on a very detailed analysis of the site conditions. These protection systems should include surge protectors/absorbers. When a surge is input, the absorbers work to arrest the surge not to input to radar unit.

The primary purpose of the grounding is to provide a low impedance RF ground path for the radar system, and to provide a ground point for lightning protection. The grounding system will typically consist of an underground grid or radials or rods, typically copper, which provide a **ground resistance of not more than one ohm**. The grounding system shall have a connection point at the base of the tower, and shall include a suitable ground wire to the top of the tower.



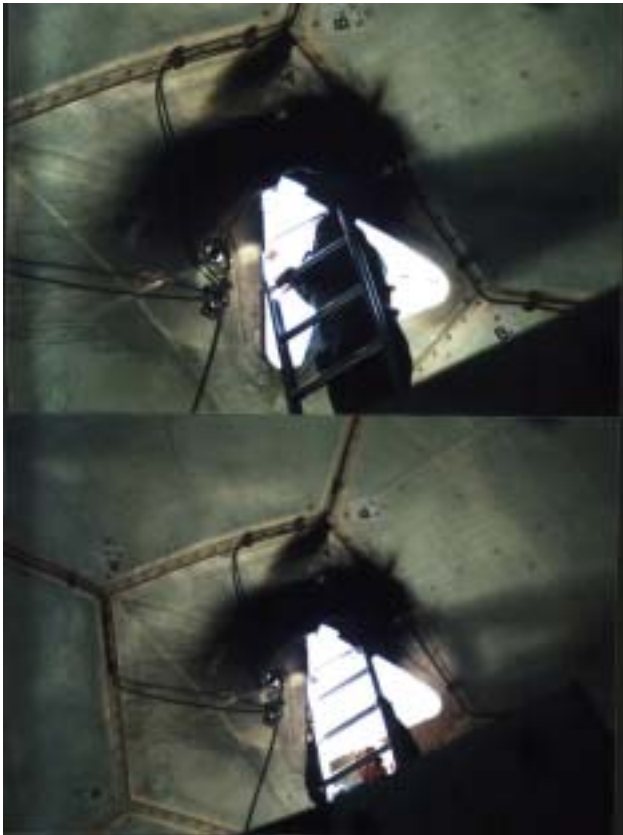
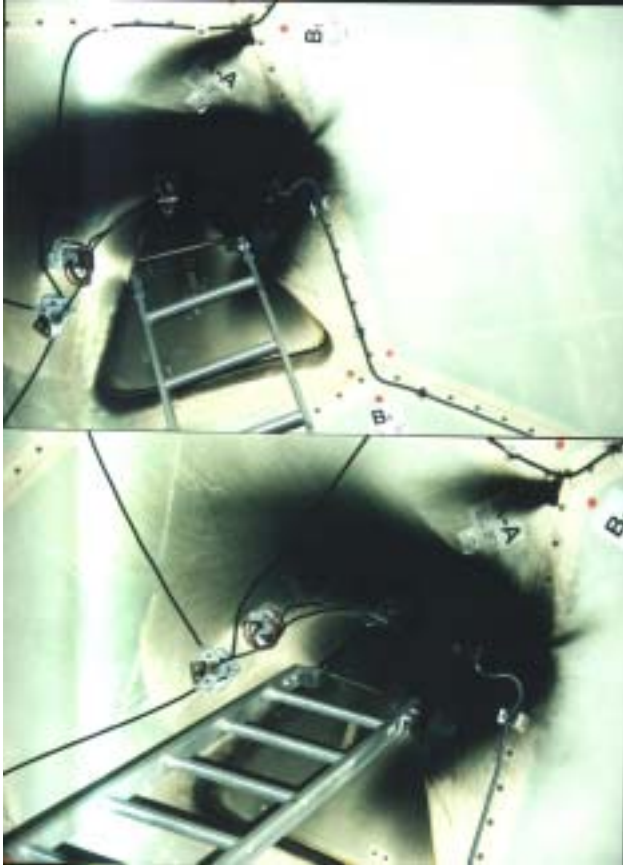




Figure 7: Some Lightning and High Voltage Protection Pictures.



Figure 8: Lightning at Radar Site.

3.4. Communication and Network

There must be a permanent communication system between radar site and operation centre. This can be managed several ways. Terrestrial line, fibre optic cables, satellite and microwave data link can be optional communication methods. Telephone service is required if telephone circuits are to be used for radar data and/or control. If other communications circuits (microwave, satellite, etc.) are used for radar data/control, a voice grade telephone circuit is highly desirable for maintenance technicians at the radar site.

If a microwave data link is required between the radar site and the central site, the EMC aspects of this must also be surveyed. The microwave link will require a clear, unobstructed "line of sight" path from the radar site to the central site. That means the microwave antenna at the radar site must be visible from the microwave antenna at the receiving site, with no buildings, trees, hills, etc. blocking or interfering with the path. If the microwave antennas are more than a few miles apart, a small telescope may be required to verify the line of sight path.





Figure 9: Communication Equipment Pictures.

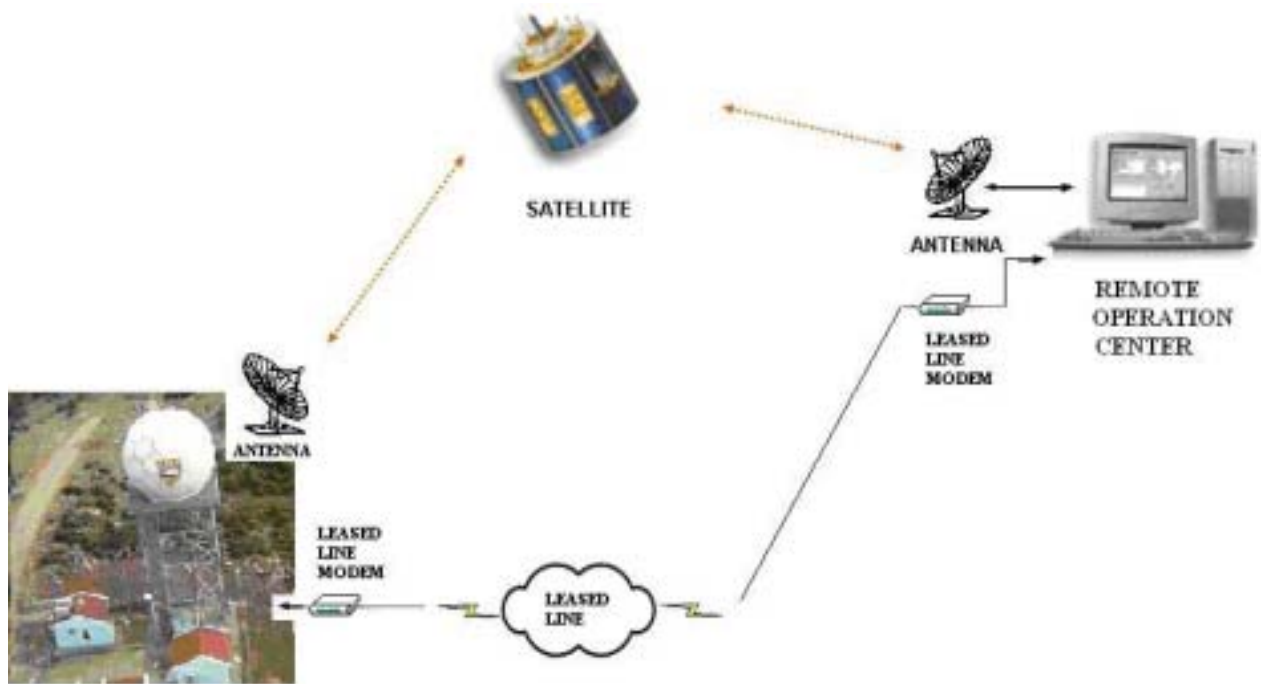


Figure 10: Communication with Centre via VSAT.

To establish a wide area network (WAN) will be needed for operation and communication of radar network. WAN is interconnected LANs to access to computers or file servers in other locations. As a result of being networked or connected computers, printers, and other devices on a WAN could communicate with each other to share information and resources, as well as to access the Internet.

Some common WAN technologies are:

- Modems,
- ISDN (Integrated Services Digital Network),
- DSL (Digital Subscriber Line),
- Frame Relay,
- ATM (Asynchronous Transfer Mode),
- The T (US) and E (Europe) Carrier Series: T1, E1, T3, E3, etc.,
- SONET (Synchronous Optical Network).

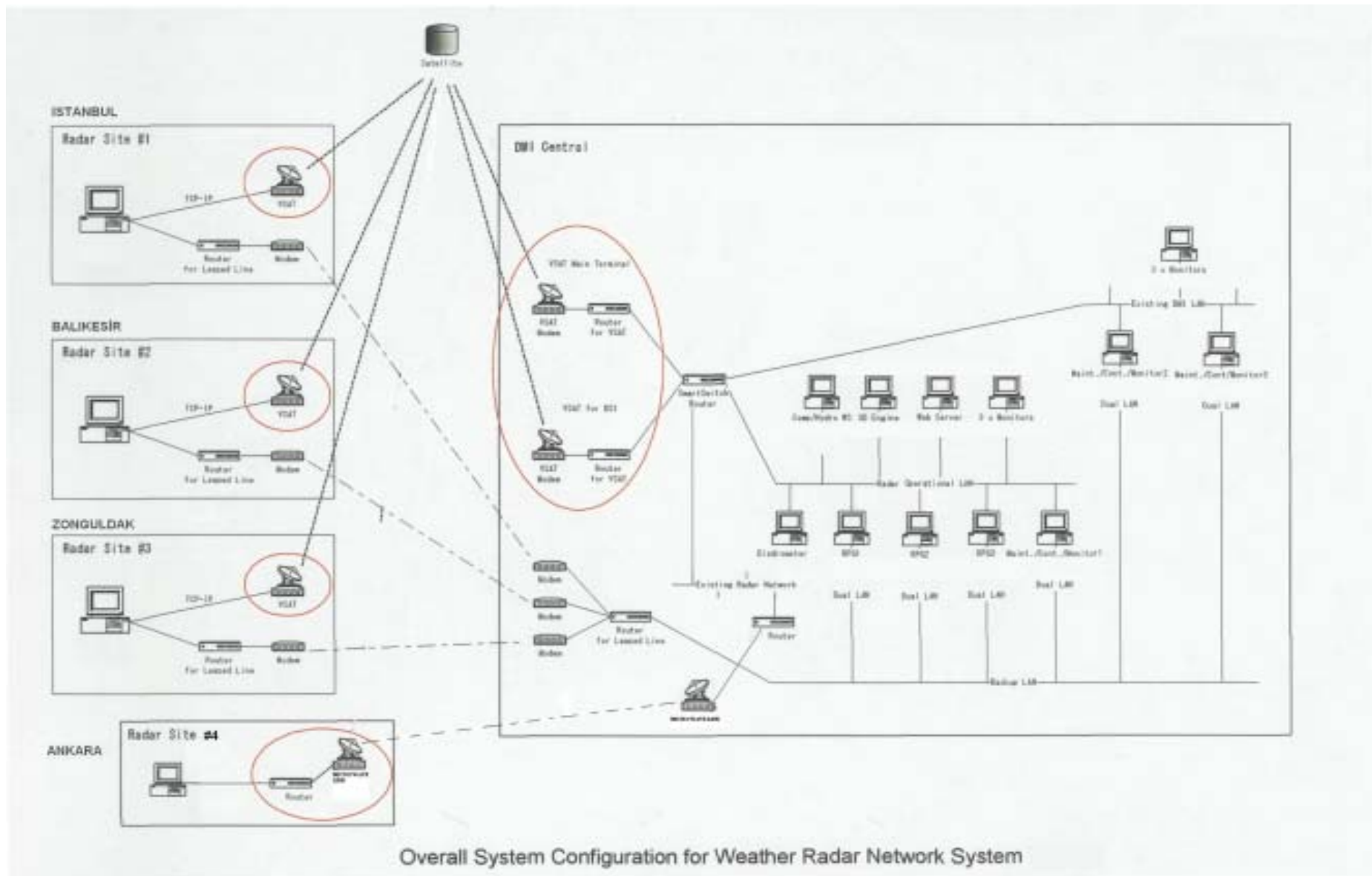


Figure 11: TURKEY Weather Radar Network General View.

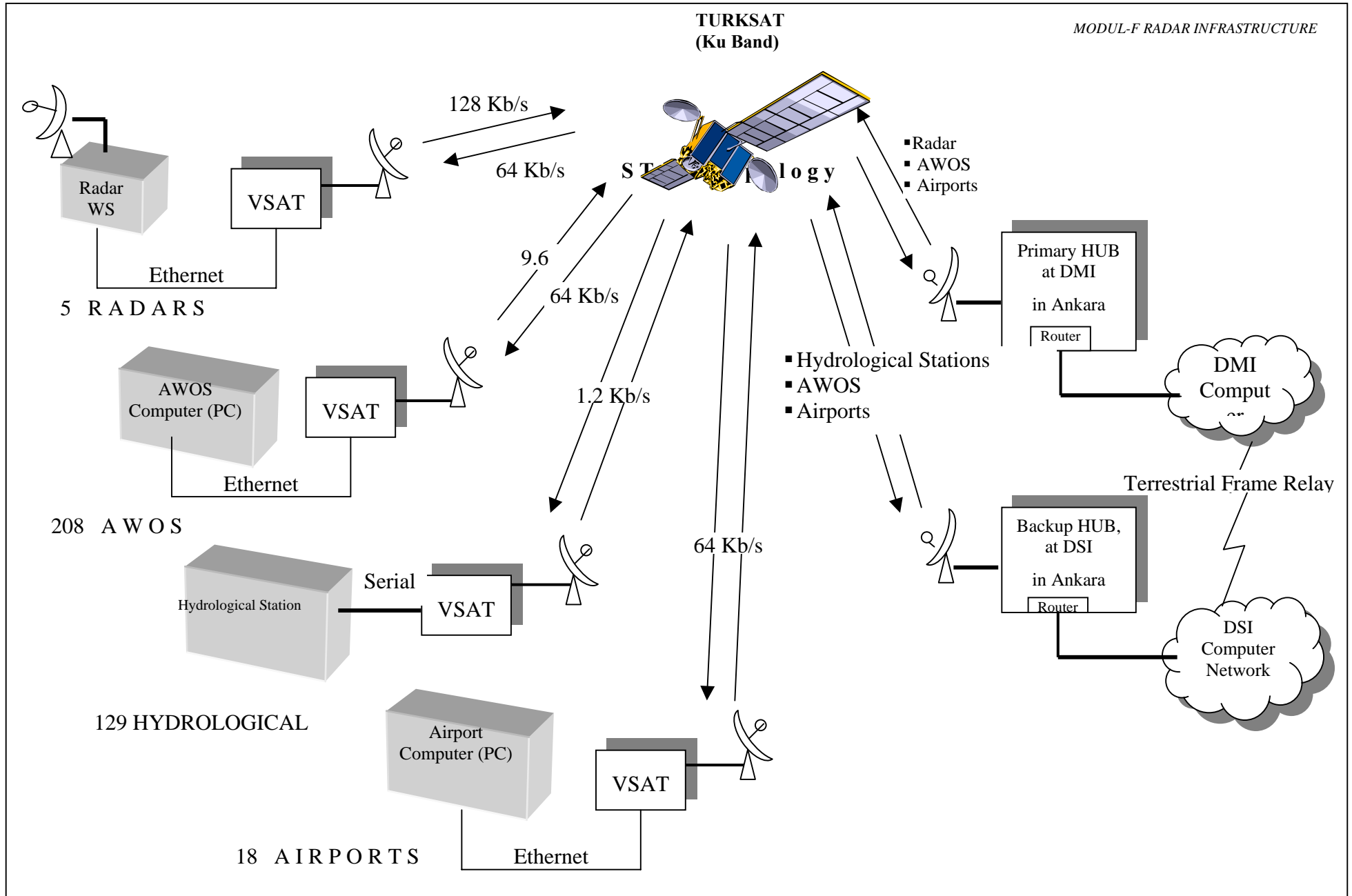


Figure 12: VSAT Communication System Overview.

3.5. Others

A **land survey** should be performed to accurately determine the boundaries of the radar site land area, the location of the entrance road to the site, and the location of any required easements for access to the radar site property. The survey should also determine water runoff and drainage of the radar site area.

Soil tests should be performed to determine the load bearing capacity of the soil for the foundations for both the radar building and for the radar antenna tower. These soil tests should serve as the basis for the design of the building and tower foundations.

Access road is also very critical issue for the operation of radars. Access roads should be available or constructed/ improved by considering the need of the access to the radar sites in any weather conditions with heavy trucks.



Figure 13: Severe Weather Conditions and Transportation with Snow Mobiles.

Fire Alarm System should be installed with a capability of remote indication via the radar communications system. This alarm system should be located in the equipment room and also at the personnel building. Automatic fire extinguishers should be available in the equipment room.



Figure 14: Fire Extinguishing Systems.

Heating and air conditioning system is needed for keeping the stability of the temperature at the equipment room. It is also necessary for the personnel accommodation.



Figure 15: Heating and Air Conditioning Systems.

The **security** requirement should also be taken into consideration against possible risks.

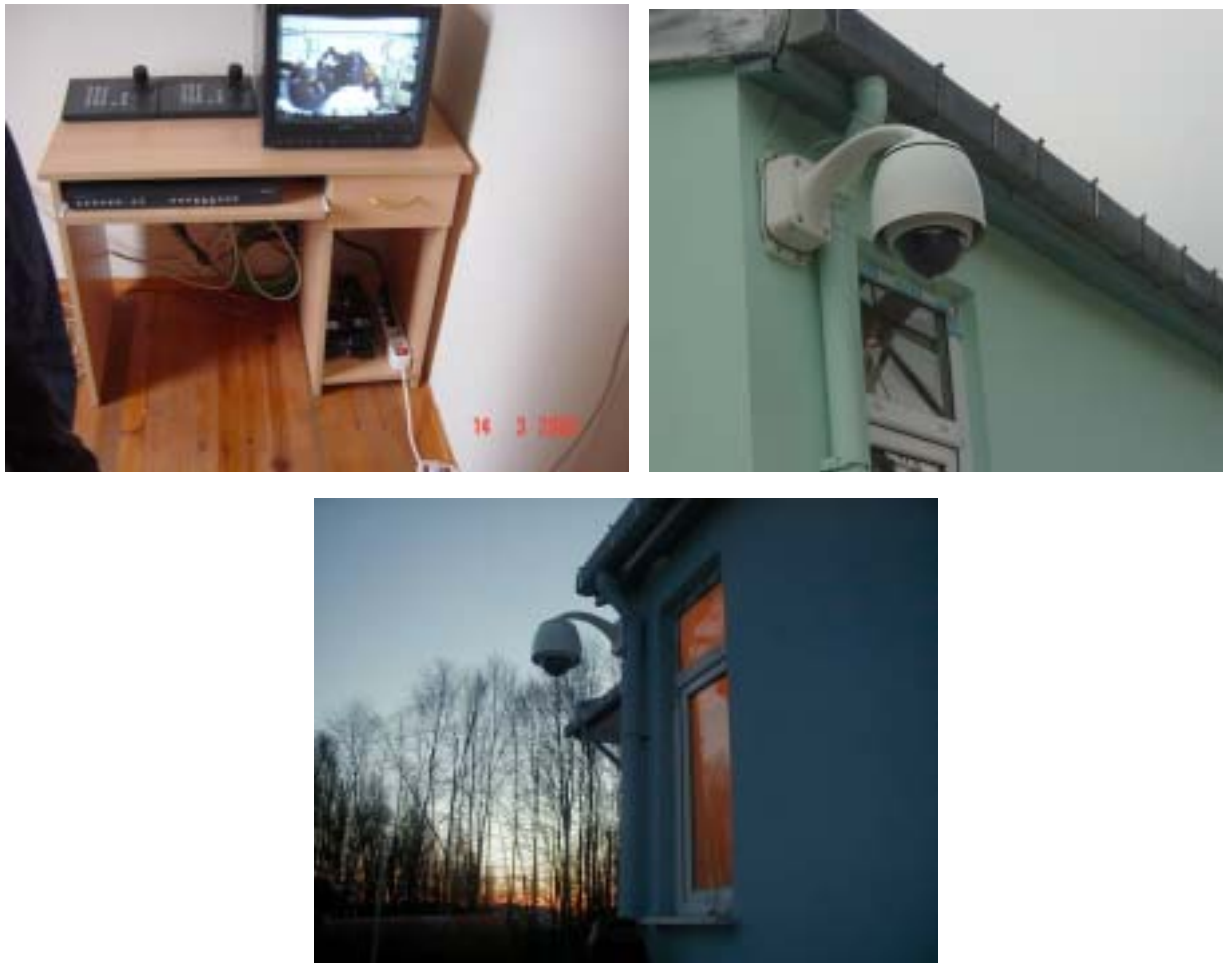


Figure 16: Monitoring with CCD Cameras.

TRAINING MATERIAL ON WEATHER RADAR SYSTEMS

END