SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

Prof. Radhakanta Koner

Department of Mining Engineering

Indian Institute of Technology (Indian School of Mines) Dhanbad

Module 04:
Advanced system in Mining Industry

Lecture 09 A:
Sensing System: Radar Technology

CONCEPTS COVERED

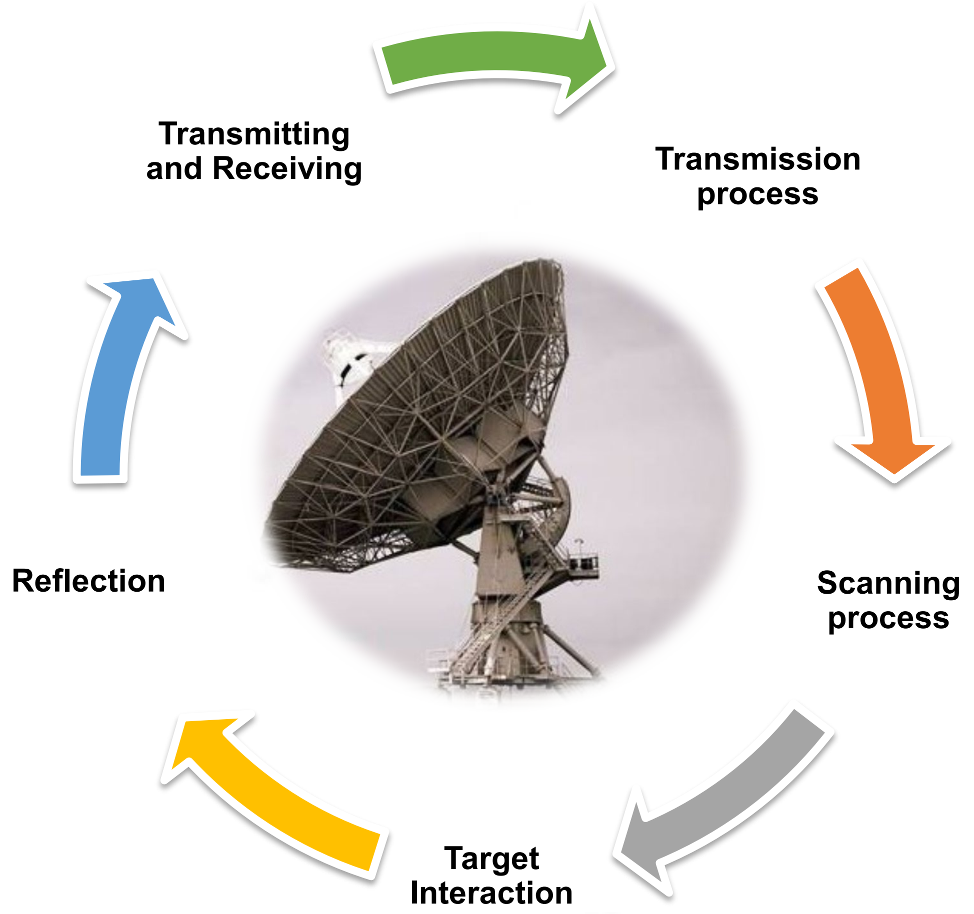
- Introduction to Radar
- Fundamental of Radar
- Types of Radar
- Basics of Radar Technology
- Principle of measurement
- Introduction to slope stability radar(SSR)
- Risk management with SSR
- Case study on radar

Introduction to Radar

It is an electromagnetic sensor used for detecting, locating, tracking, and recognizing objects of various kinds at considerable distances. It operates by transmitting electromagnetic energy toward objects, commonly referred to as targets, and observing the echoes returned from them.

Radar =

Fundamentals of radar



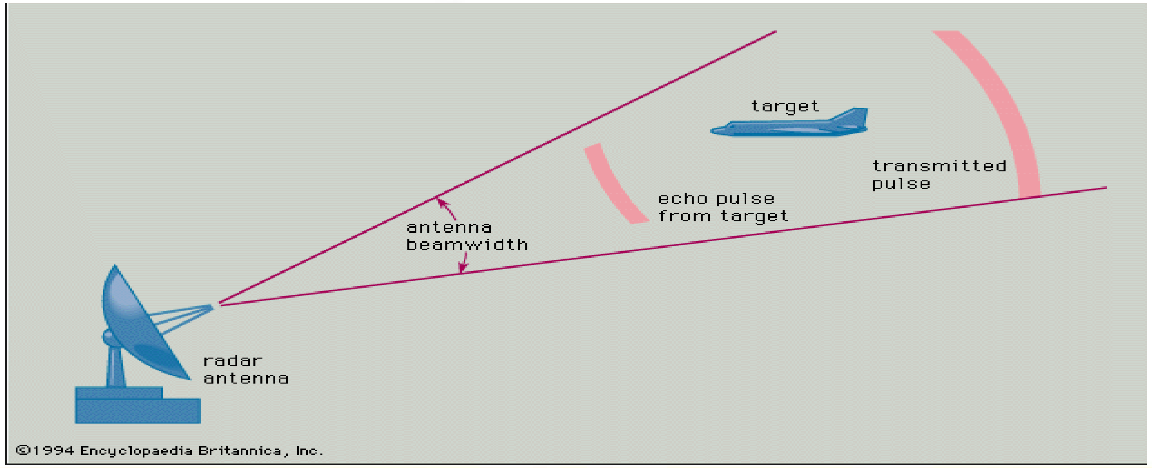
Fundamentals of radar

Transmission process

- Radar involves the transmission of a narrow beam of electromagnetic energy into space. The energy is emitted from an antenna.

Scanning process

- The narrow antenna beam scans a specific region where potential targets are anticipated.



Fundamentals of radar

Target Interaction

- When a target is within the scanned region, it intercepts a portion of the radiated energy.

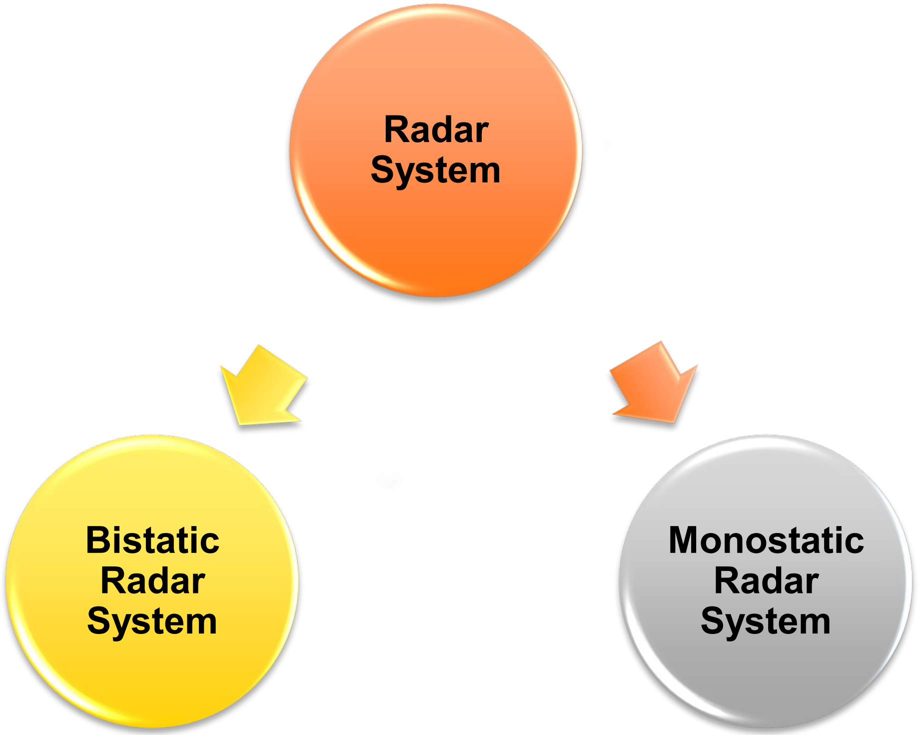
Reflection

- The target reflects a part of the intercepted energy back towards the radar system.

Transmitting and Receiving

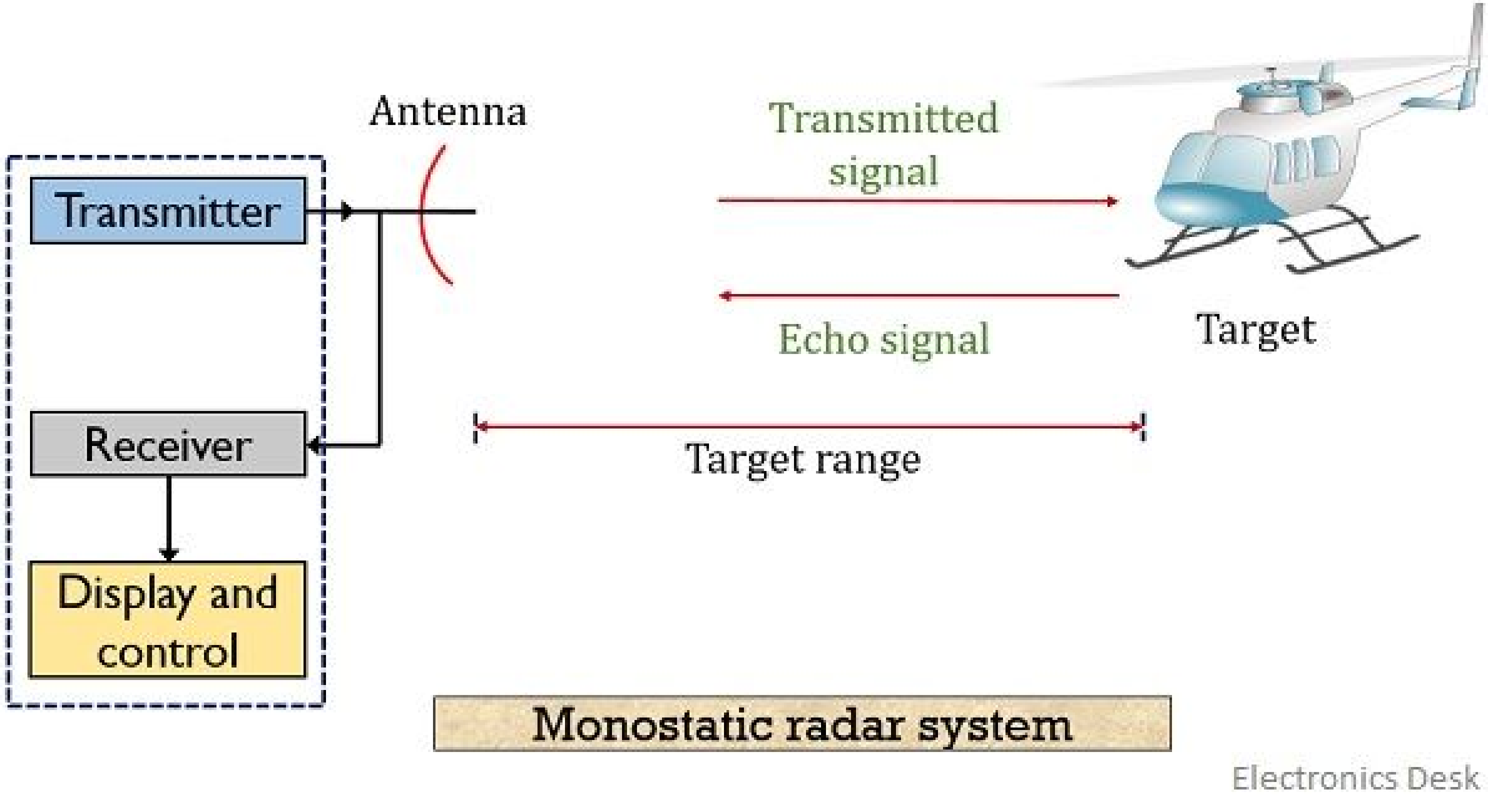
- Most radar systems do not transmit and receive simultaneously. A single antenna is commonly used on a time-shared basis for both transmitting and receiving.

Types of Radar System



Monostatic Radar System

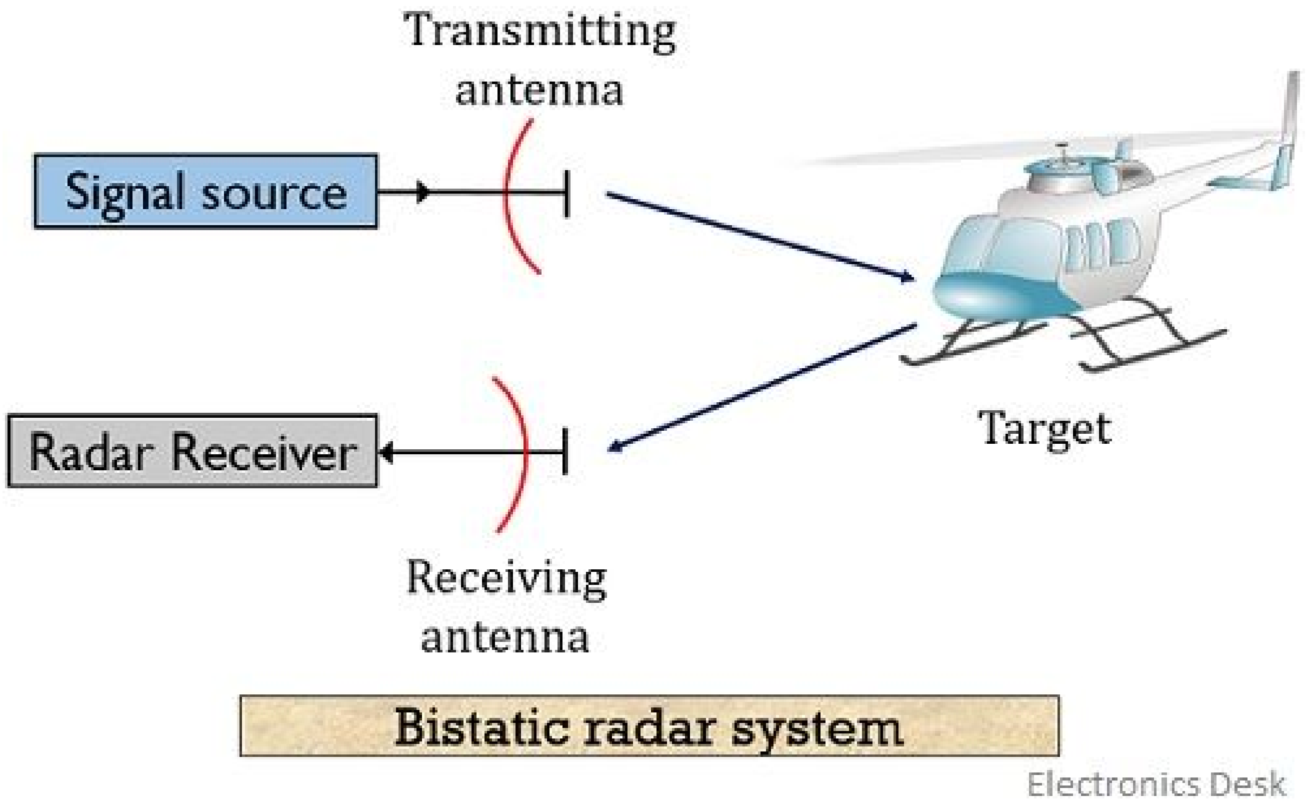
A monostatic radar system uses a single antenna for transmission as well as reception purposes.



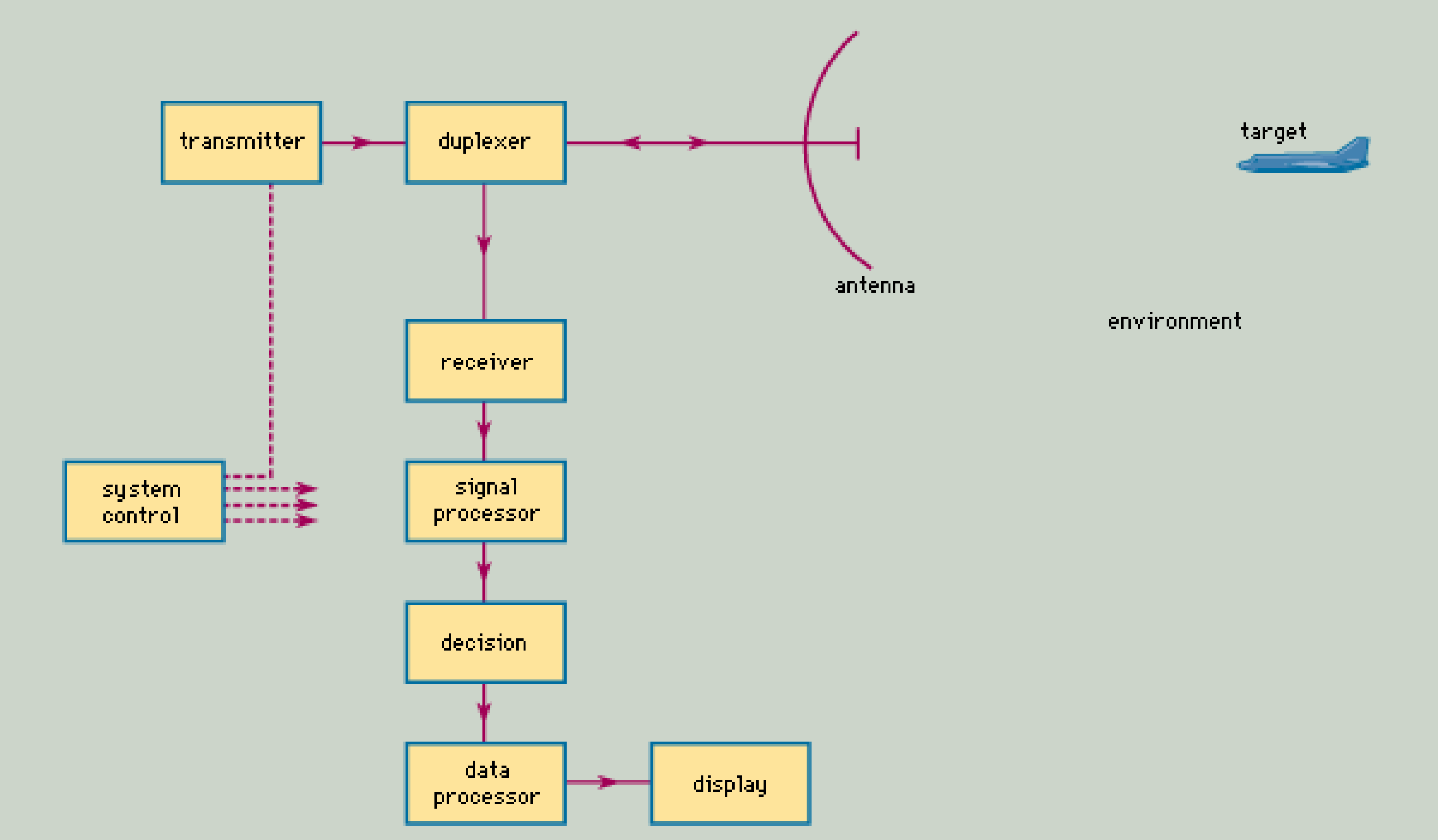
Monostatic radar system

Bistatic Radar System

A bistatic radar system utilizes independent antennas for the transmission and reception of the signal.



Basics of Radar Technology

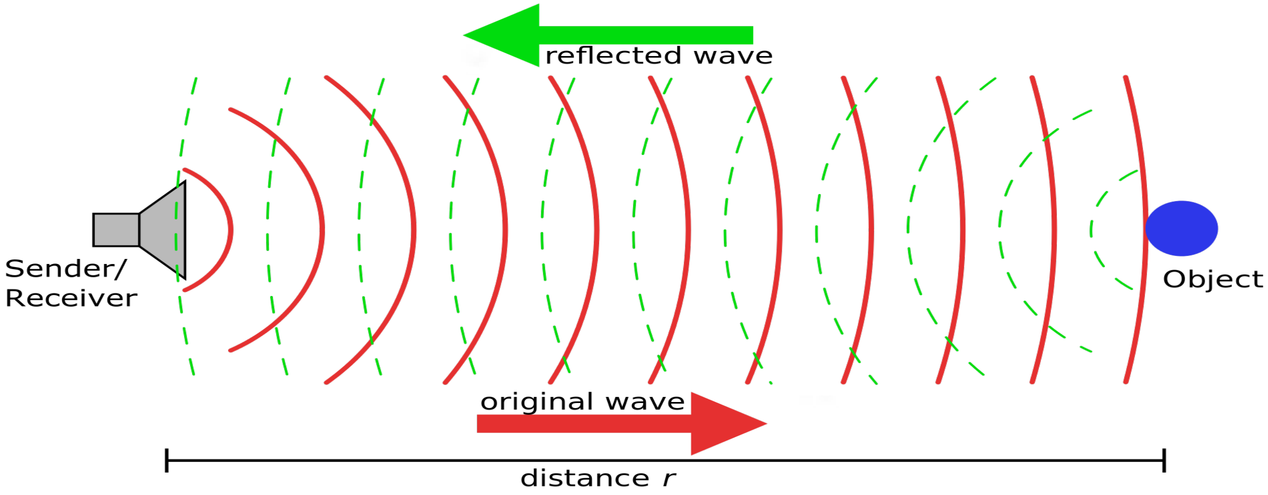


Radar Antenna

- An antenna is a structure that serves as a transition between wave propagating in free space, and the fluctuating voltages in the circuit to which it is connected.
- An antenna receives energy from an electromagnetic field or radiates electromagnetic waves from a high-frequency generator.

Radar Transmitter

- The transmitter of a radar system must be efficient, reliable, not too large in size and weight, and easily maintained, as well as have the wide bandwidth and high power that are characteristic of radar applications.
- In general, the transmitter must generate low-noise, stable transmissions so that extraneous (unwanted) signals from the transmitter do not interfere with the detection of the small Doppler frequency shift produced by weak-moving targets.



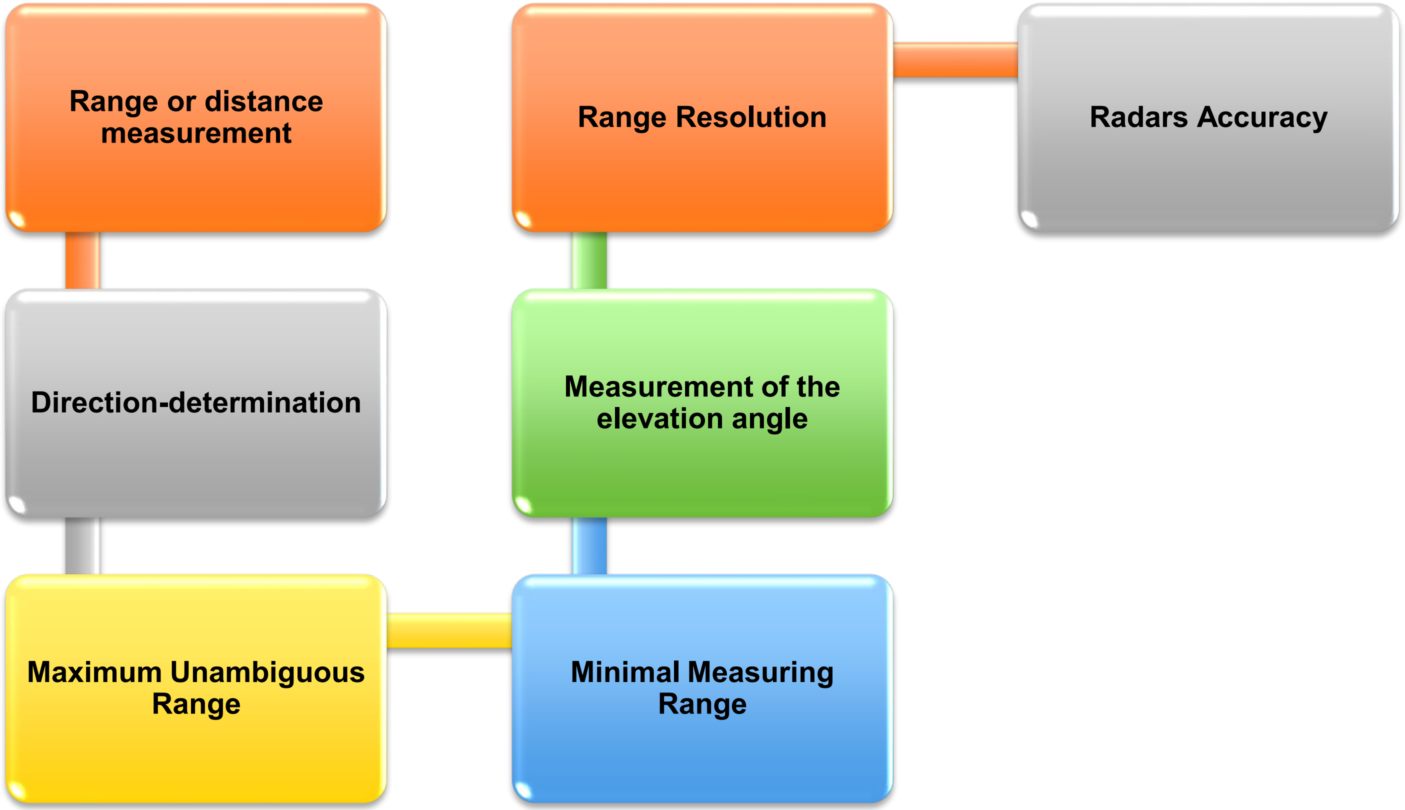
Radar Receiver

- The function of the receiver is to take the weak echoes from the antenna system, amplify them sufficiently, detect the pulse envelope, amplify the pulses, and feed them to the indicator.
- The receivers used in radars can accept weak echoes and increase their amplitudes by a factor of 20 or 30 million. Since radar frequencies are not easily amplified, a superheterodyne receiver changes the radio frequency to an intermediate frequency for amplification.

Radar Signal Processor

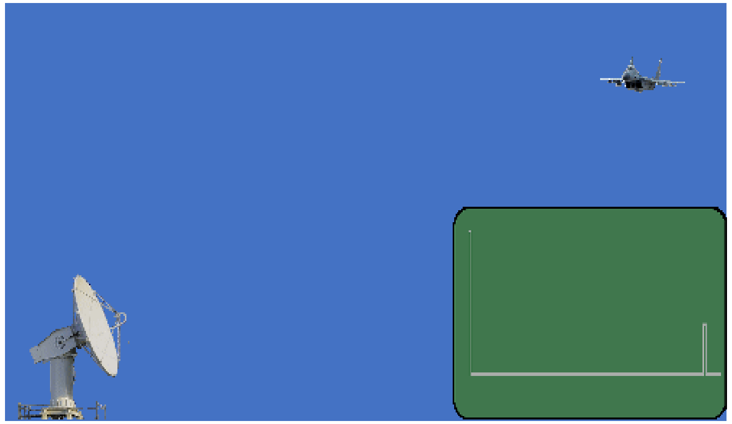
- **The signal processor is the part of the receiver that extracts the desired target signal from unwanted clutter. It is not unusual for these undesired reflections to be much larger than desired target echoes, in some cases more than one million times larger.**
- **Large clutter echoes from stationary objects can be separated from small moving target echoes by noting the Doppler frequency shift produced by the moving targets.**
- **Most signal processing is performed digitally with computer technology. Digital processing has significant capabilities in signal processing not previously available with analog methods**

Principle of Measurement



Range or distance measurement

- Radar calculates the distance to a reflected object by measuring the time between pulses.
- Electromagnetic energy travels in a straight line, allowing calculation of azimuth and elevation.
- Radar sends a signal, and receives a reflected signal (echo) in time T0.
- Based on the constant speed of light, the radar determines the distance (R) to the object.



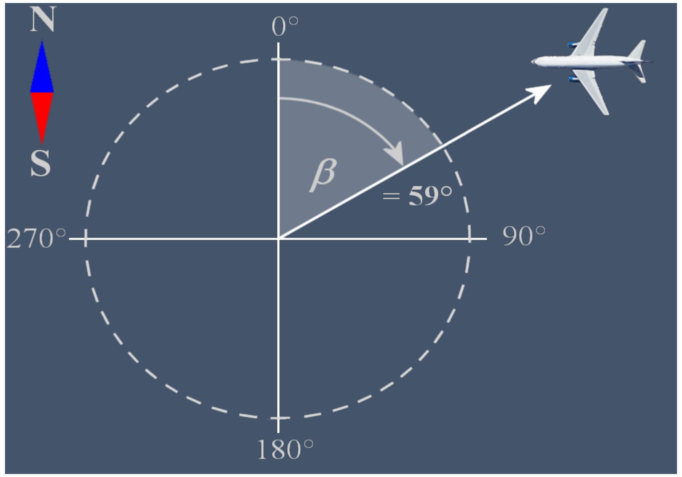
Runtime measurement by radar

$$R_0 = \frac{c * T_0}{2}$$

(c = 300,000 km/s).

Direction-determination

- Angular determination of the target relies on the directivity of the antenna.
- Directivity, also known as directive gain, concentrates transmitted energy in a specific direction.
- An antenna with high directivity is termed a directive antenna.
- By measuring the antenna's direction when receiving the echo, azimuth and elevation angles to the object are determined.
- The accuracy of angular measurement depends on the directivity, linked to the antenna's size.



Direction-determination (bearing

Maximum Unambiguous Range

The maximum unambiguous range *(R_{max})* is the longest range to which a transmitted pulse can travel out to and back again between consecutive transmitted pulses. In other words, R_{max} is the maximum distance radar energy can travel round trip between pulses and still produce reliable information.

Therefore maximum unambiguous range Rmax is the maximum range for which t < T.

$$R_{max} = \frac{c_0 \cdot (T - \tau)}{2}$$

R_{max} = unambiguous Range in [m]

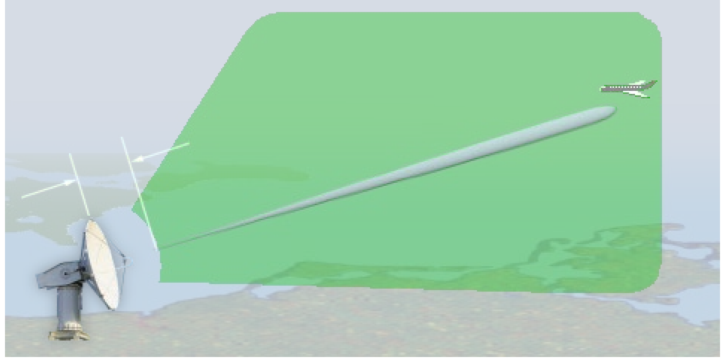
c_0 = speed of light [$3 \cdot 10^8$ m/s]

T = Pulse Repetition Time (PRT) [s]

τ = length of the transmitted pulse [s]

Minimal Measuring Range

Monostatic pulse radar sets use the same antenna for transmitting and receiving. During the transmitting time the radar cannot receive: the radar receiver is switched off using an electronic switch, called duplexer. The minimal measuring range R_{min} ("*blind range*") is the minimum distance which the target must have to be detect. Therein, it is necessary that the transmitting pulse leaves the antenna completely and the radar unit must switch on the receiver. The transmitting time τ and the recovery time $t_{recovery}$ should are as short as possible, if targets shall be detected in the local area.

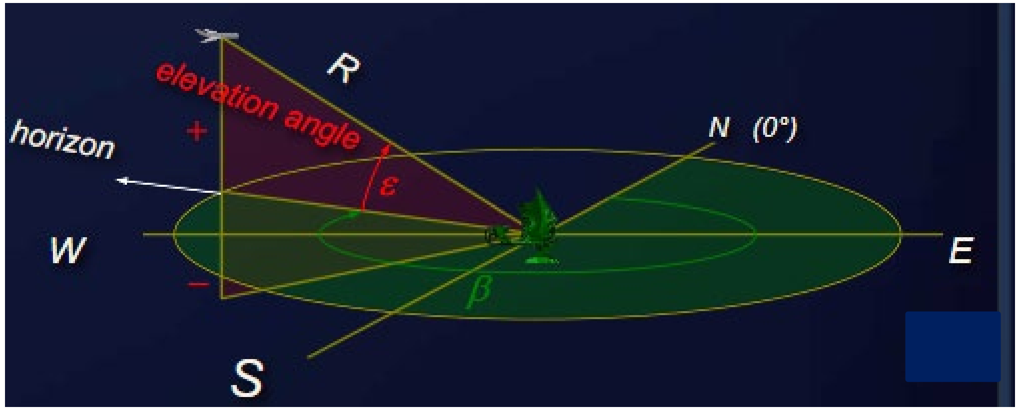


The Radars "blind range"

$$R_{\min} = \frac{c_0 \cdot \left(\tau + t_{recovery}\right)}{2}$$

Measurement of the elevation angle

Elevation angle is the angle between the horizontal plane and the line of sight, measured in the vertical plane. The reference direction (i.e. an elevation angle of zero degrees) is a horizontal line in the direction to the horizon, starting from the antenna. The elevation angle is denoted by the Greek letter *ε* (epsilon) mostly. It is positive above the horizon but negative below the horizon.



Definition of elevation angle ε

Measurement of the elevation angle

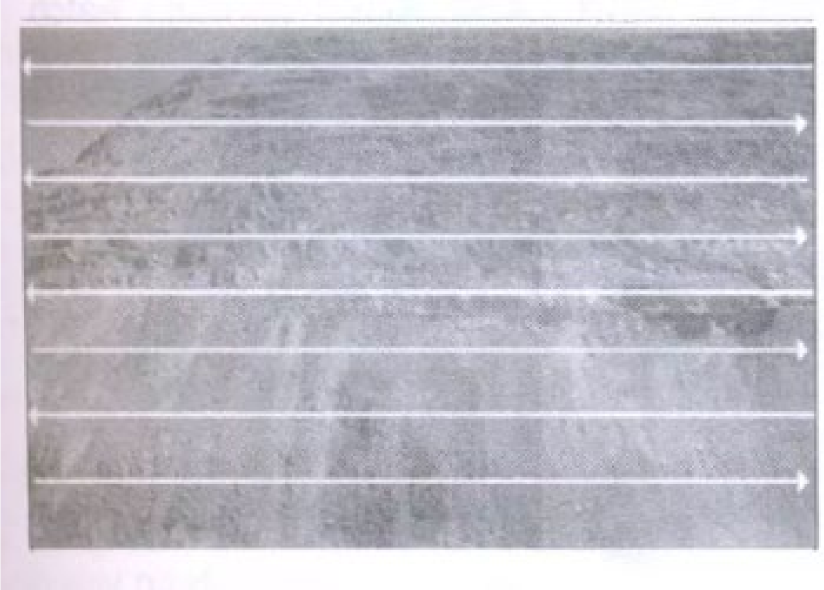
- **Altitude- or height-finding radars use a very narrow fan beam in the vertical plane. Height-finding radar systems that also determine bearing must have a narrow beam in the horizontal plane in addition to the one in the vertical plane. The beam is mechanically or electronically scanned in elevation to pinpoint targets. If an echo signal is detected in the receiver, then the current elevation angle is equal to the direction of the antenna pattern.**

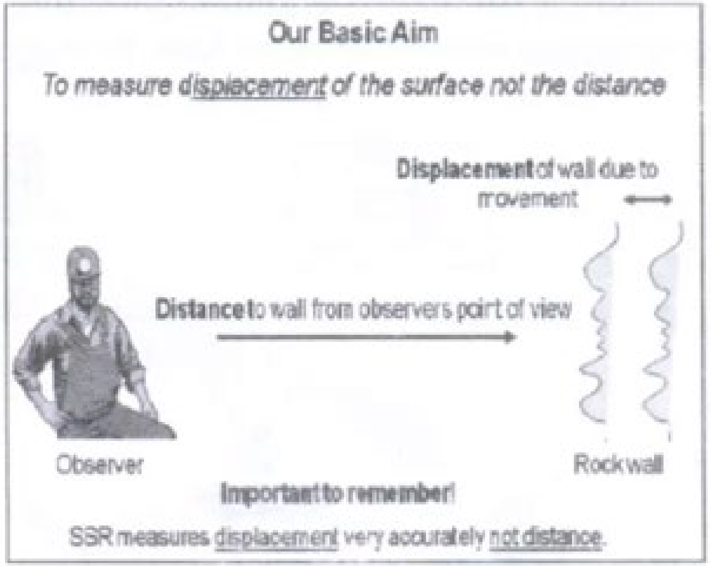
Introduction to Slope Stability Radar (SSR) Technology

- Ground-based radar is a remote sensing technology that uses phase-change interferometry to measure the surface deformation of a slope over time.
- Ground-based SSR systems remotely measure the surface deformation of a slope from a stationary platform without a need for reflectors or prisms.
- A system scans a region of a slope and divides an area into pixels. An amount of movement is measured for each pixel and compared with an amount of movement from the previous scan.
- Using ground-based radar allows for active monitoring of a slope with deformation alerts of a sub-millimeter precision, making the data available for interpretation usually within minutes.

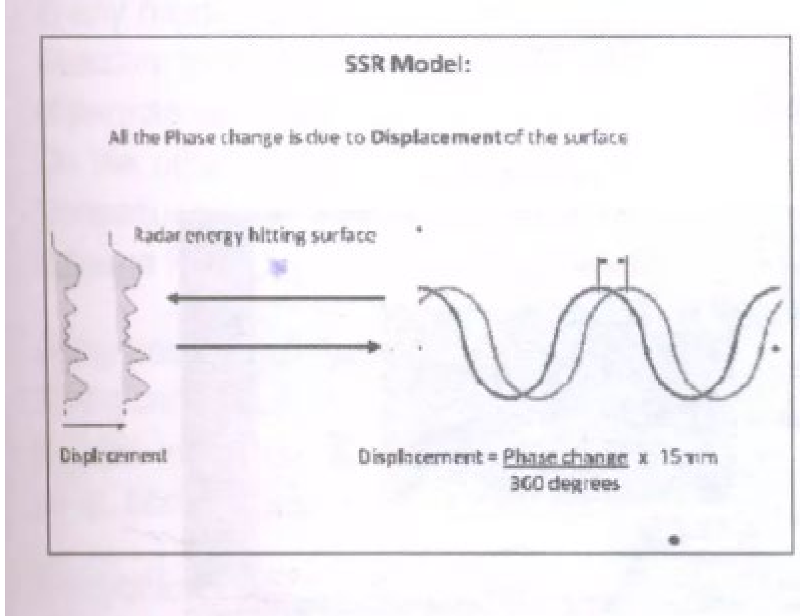
Slope Stability Radar – Operation

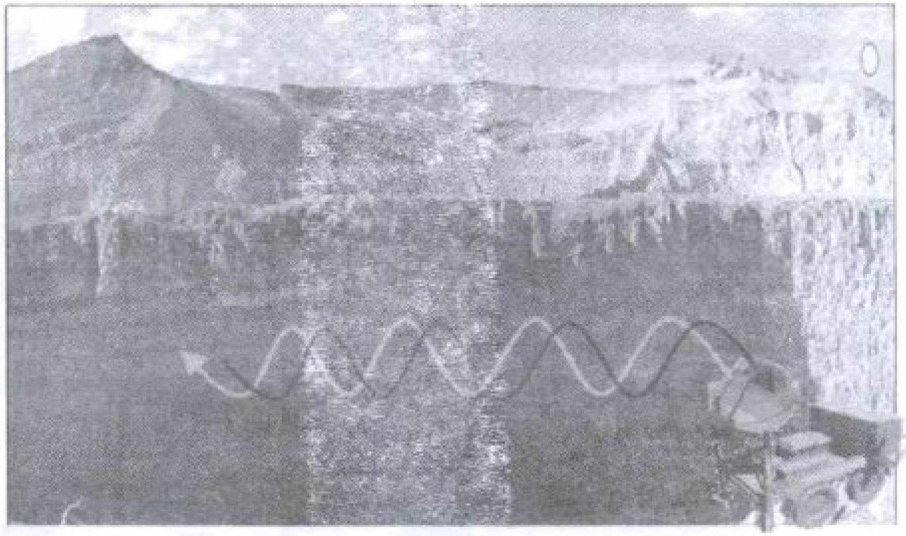
- **Basic aim of this real time monitoring system is measuring the displacement of Pit slope rock. It sent some wave and after hitting on the surface of the front side wall the wave came back on SSR and thus it measured the displacement.**





SSR radar to measure displacement

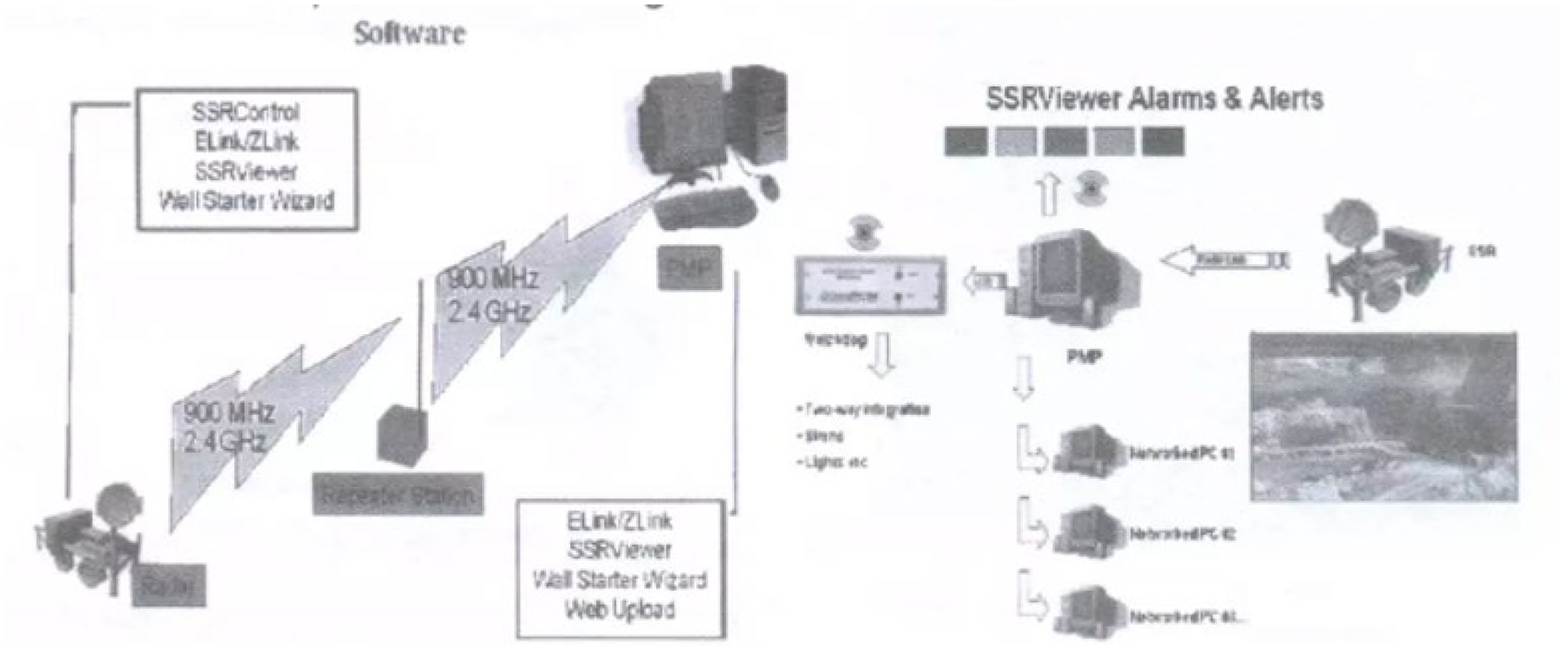




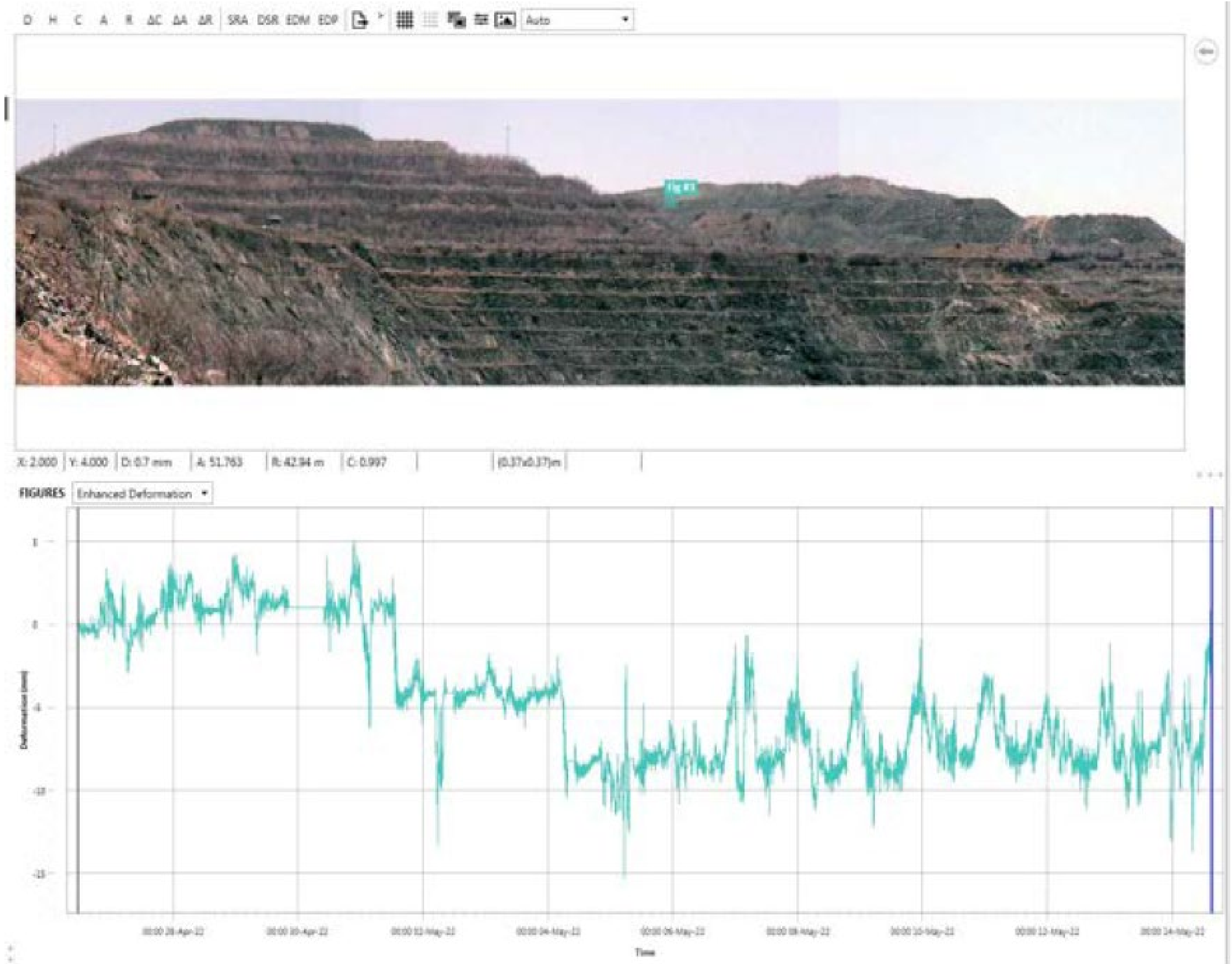
SSR to slope monitoring

Software

- **SSR data can be viewed at SSR computer, at primary monitoring point (PMP) computer and Office by using SSR viewer suit software developed by ground probe. Radar data is transmitted through E-link software to PMP. From PMP, it is connected to the Office network. SSR send Alarm and alert through E-mail.**



Software to displacement analysis



The rock slope with displacement data screen.

- **SSR is one of the best advanced monitoring systems to monitor pit slope stability and can be easily used for monitoring open-pit slopes.**

- **SSR enables mine managers and geotechnical engineers to make informed decisions, to relate evacuate people and equipment before slope failure.**

Risk Management with SSR

The slope stability radar can be used as an early warning system. In general, an early warning system has a few main aims such as monitoring, which consists of data collection and it transmission, as well as maintenance of the equipment a prediction and an analysis.

An evacuation alarm is one of the alarm types. The mines mostly are using four alarms:

- **Green Alarm**

A small system failure, during which the SSR is close down and the SSR program has to be restarted according to procedures.

- ## Yellow Alarm

A radar system failure, which causes that a pit superintendent to receive an information about the unavailability of a radar, and a geotechnical department is informed to determine a problem with the help of an equipment producer.

- ## Orange Alarm

In other words, “a Geotech alarm”, is an announcement of a ground movement development, which should make a geological department conscious of possible dangers.

- ## Red Alarm

Serious situation in which a pit superintendent must evacuate an area of concern or a whole pit.

Case study-1 at Leveäniemi Open-Pit mines

The SSR unit employed at Leveäniemi Open-Pit mines from the Italian company IDS Georadar. Here's an overview of its features

Detection Capabilities:

- **Remarkable capacity for detecting small movements.**
- **High spatial resolution: 0.5 m x 4.4 m per cell at a 1 km distance.**

Monitoring Area:

- **Covers an expansive area of up to 5 km^2.**

Case study-1 at Leveäniemi Open-Pit mines

Data Acquisition

- Quick acquisition time: Approximately 2 minutes for a single data acquisition at a 1 km range.

Power Options

- Versatile power sources: Wi-Fi, solar panels, or a diesel generator for battery charging.

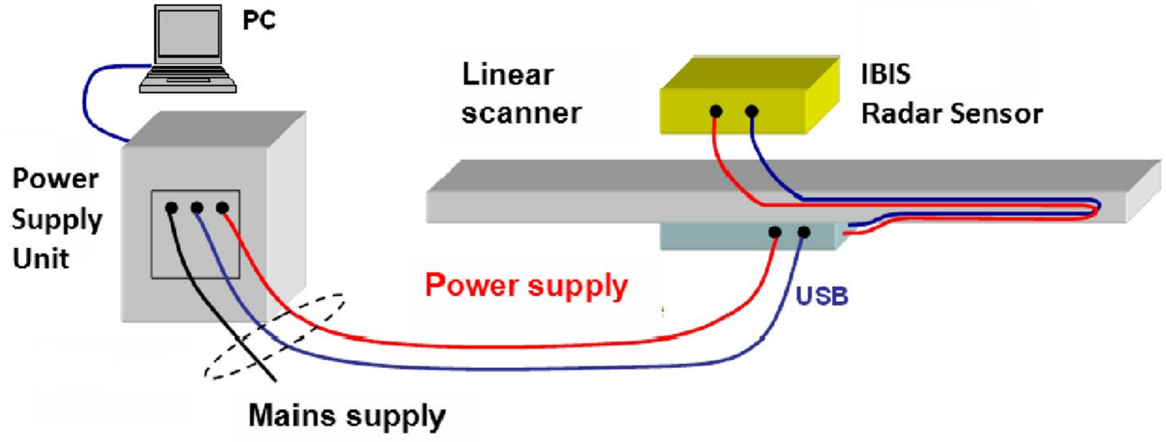
Resilience to Weather Conditions

- Operates in diverse weather conditions.
- Temperature range: -25 °C to +50 °C (-50 °C if placed indoors).

Case study-1 at Leveäniemi Open-Pit mines

Hardware

- **The basic hardware (Figure) consists of Radar Sensor (RS), Linear Scanner (LS), Power Supply Unit (PSU) and Field Laptop (FL).**
- **Additionally, the system can be equipped with: an eagle-vision camera, a weather station, a power generator, solar panels, a Wi-Fi radio or a watchdog.**

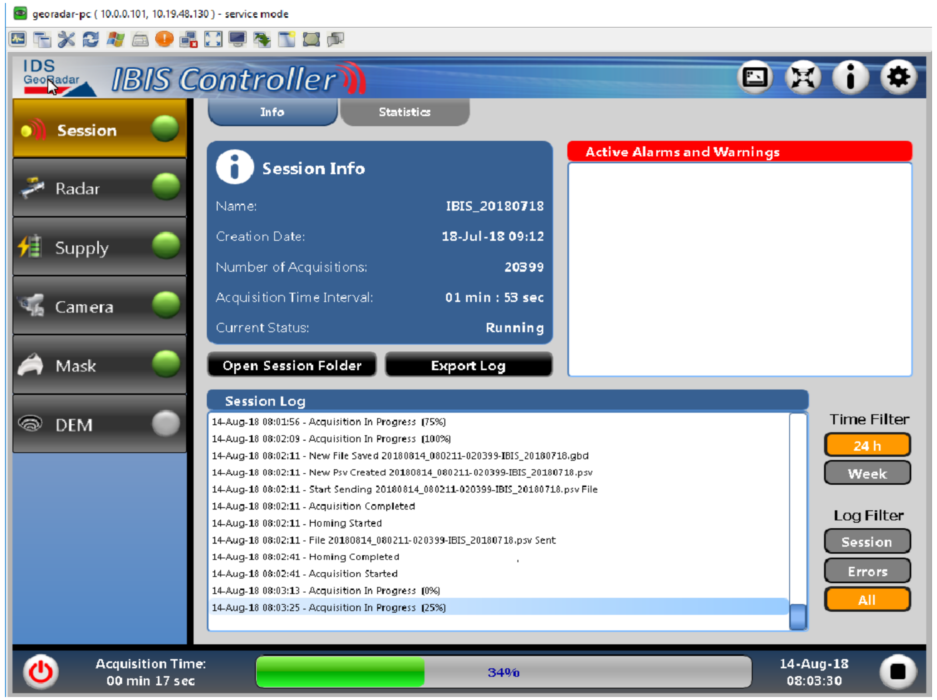


Hardware connection

Case study-1 at Leveäniemi Open-Pit mines

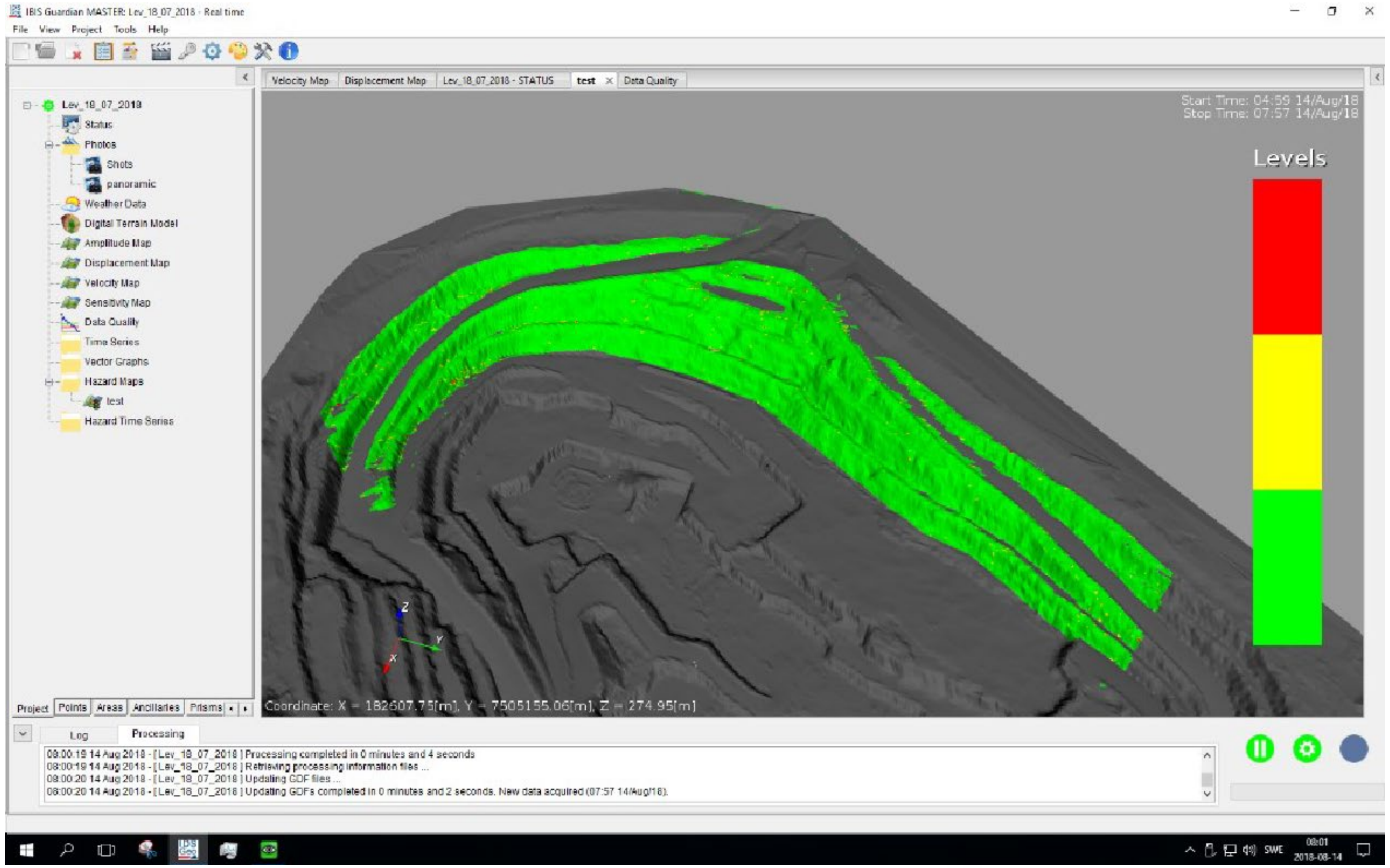
Software

A software of the radar system consisting of two connected between each other programs: IBIS Controller and Guardian.



IBIS Controller

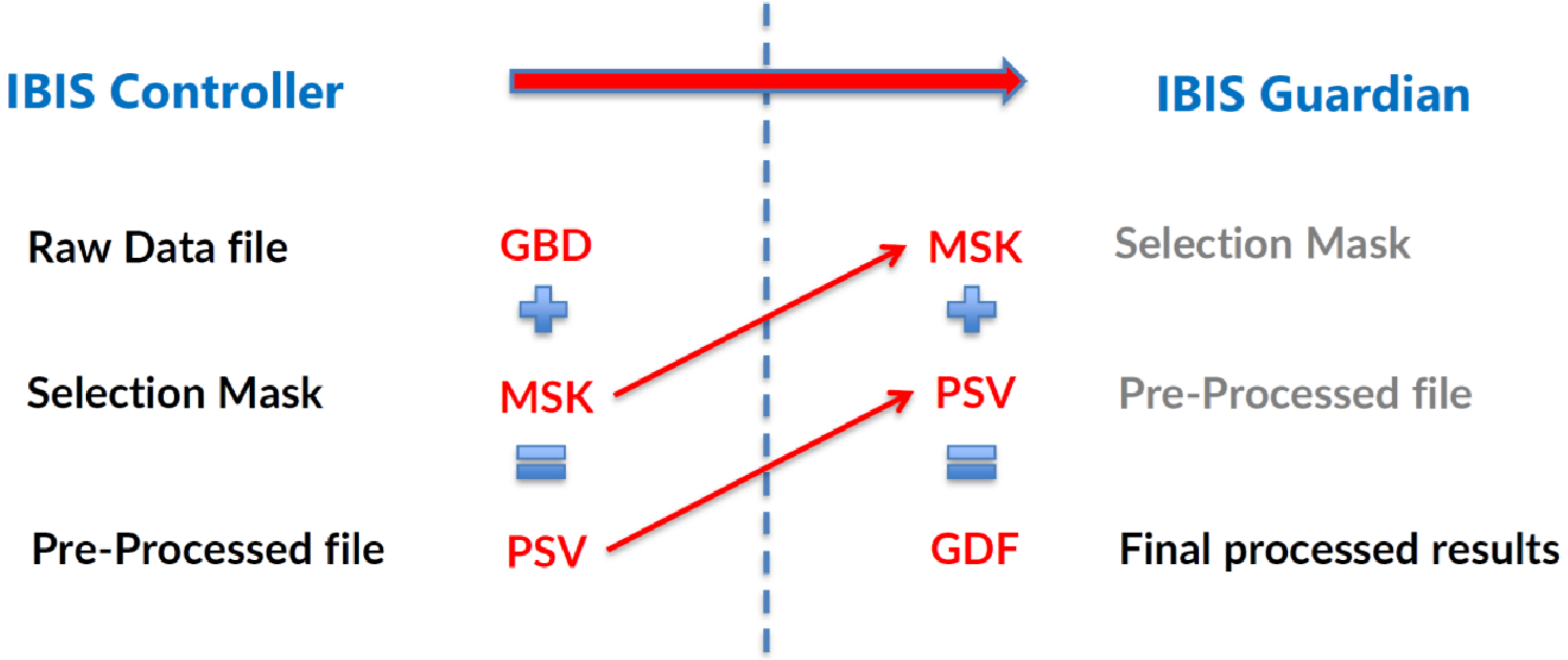
Case study-1 at Leveäniemi Open-Pit mines



The Guardian

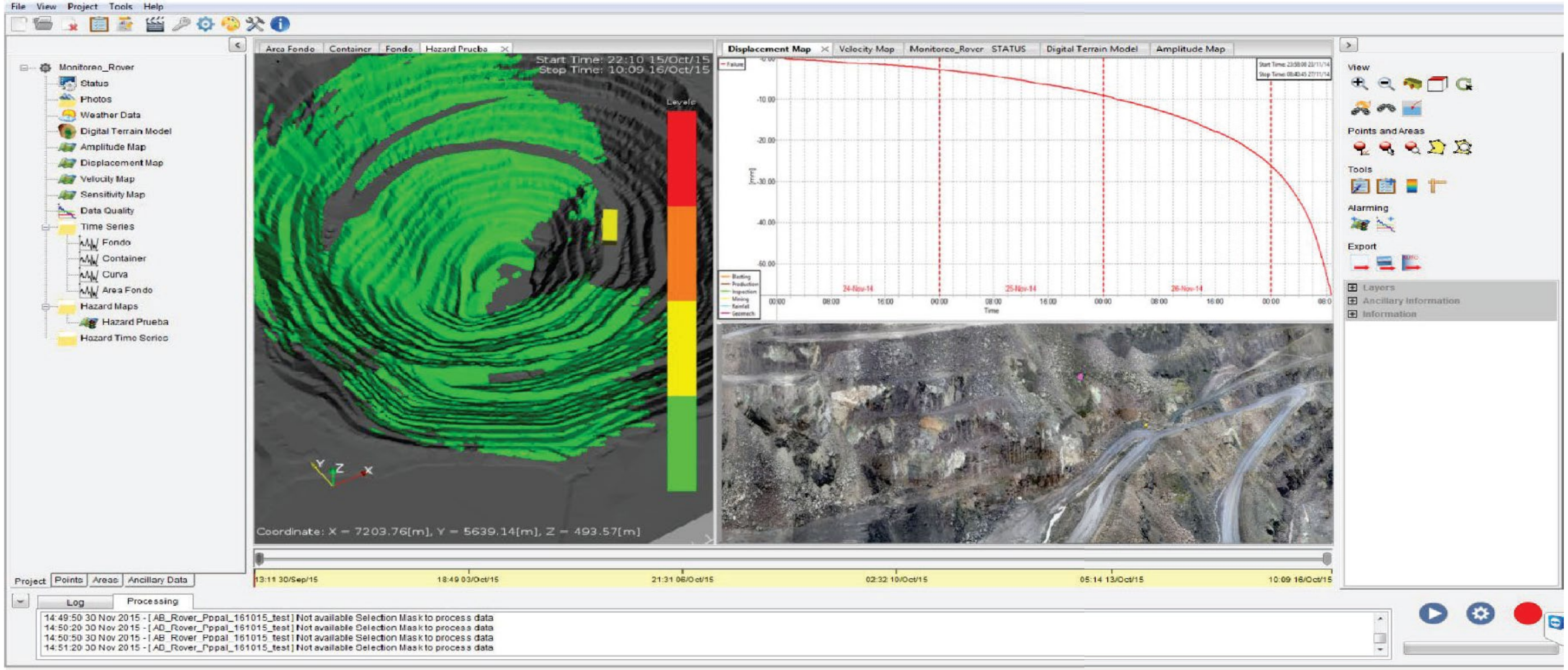
Case study-1 at Leveäniemi Open-Pit mines

The IBIS Controller creates 3 types of files, during each scan: GBD (raw data), MSK (selection mask), and PSV (pre-processed).



Data flow between programs

Case study-1 at Leveäniemi Open-Pit mines



Typical schematic data acquired by SSR in the surface mines and its representation in the slope geometry.

REFERENCES

- Niekrasz, J. (2018). Review of radar system performance and estimation of slope deformation threshold values for the Leveäniemi open pit., https://aaltodoc.aalto.fi/server/api/core/bitstreams/fcfd7da5-21c5-4c62-9069-ee94ba45b89d/content

- Niekrasz, J. (2018). Review of radar system performance and estimation of slope deformation threshold values for the Leveäniemi open pit., https://aaltodoc.aalto.fi/items/5635ed35-0dee-4642-8397-d6abbc4101b3

- https://www.aviationfile.com/cone-of-silence-a-crucial-aspect-in-aviation/
- https://www.aviationfile.com/the-evolution-of-radars-in-aviation/
- https://www.britannica.com/technology/radar/Transmitters

CONCLUSION

- Provided an initial overview of Radar technology.
- Explored the foundational principles underlying Radar systems.
- Examined the various categories and applications of Radar technology.
- Introduced the fundamental concepts and working principles of Radar systems.
- Discussed the methodologies involved in the measurement processes of Radar technology.
- Introduced the specific application of SSR within Radar technology.
- Explored how SSR contributes to risk management, particularly in slope stability scenarios.
- Examined a real-world case study illustrating the application and outcomes of Radar technology in a specific context.


THANK YOU