Applications of Microwaves in Remote Sensing

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ABSTRACT
The electromagnetic spectrum extends from Hertz to terahertz. In this large range of EM spectrum there are window defining the smaller ranges and one of the important windows which covers frequency range from 3GHz to 30GHz is known as Microwaves. These Microwaves have various applications in communication Industrial, Medical and Remote Sensing. The Microwaves have unique Properties that include day and night capability all weather capability, Soil Moisture determination and penetration through vegetation and Soil.
Because of these unique properties Microwave Remote Sensing gives information about targets which otherwise will not be available by optical and infrared remote Sensing. The Sensors used for Microwave Remote Sensing are Broadly Classified in two types they are (i)Passive Sensors and (ii) Active Sensors. These Sensors could be Non imaging and Imaging type. The Microwave radiometers are passive Sensors whereas Real Aperture and Synthetic Aperture Radars are imaging type Active Sensors and Altimeter, Scatterometer are non imaging type Active Sensors.
These sensors at different frequencies can be used for various applications. Major areas of application are for Land, Ocean, and Atmospheric. In land the Microwave Sensors can be used for study of Crops, Forest cover, SNOW and ice, Soil Moisture and Soil types. For ocean application the active as well as passive sensor can be used for determination of salinity Sea Surface Temperature, Microwave Temperature Significant Wave Heights, and the detection of TSUNAMI and in Atmospheric applications the study of minor constituents could be studied. The Microwave remote Sensing can be used for Planetary Exploration, the planets like MARS and VENUS and Satellites like MOON and Titan have been explored using Microwaves and in future Microwaves will provide unique opportunity to detect presence of frozen water on MOON and presence of buried channels under sand dunes on MARS.

Thus one can say that in present as well as in FUTURE Microwave part of EM spectrum will play major role in remote Sensing of Earth, Natural Satellite and Planets. In this paper details of Microwave application in Remote Sensing will be presented.

General Terms
Remote Sensing, Microwave application et. al.

Keywords
Remote Sensing, microwave sensor, Image radar

1. INTRODUCTION

Obtaining information about an object through analysis of data acquired by a sensor that is not in direct contact with the object is known as remote sensor. These remote sensors are operated in Microwave Frequencies.
It has evolved into an important tool for monitoring the atmosphere and surfaces of planetary objects. It has diverse applications and is very efficient technique to help the growth of economy and solve some of its problems.
Unique capabilities of microwave remote sensing are:
Microwave sensors give complementary information in some applications and supplementary information in others, to the optical and infrared sensing. The Combination of microwaves, visible and infrared radiation allows a study of the geometric, bulk-dielectric and molecular resonance properties of a surface.
For some Remote Sensing Applications Microwave Remote Sensing is UNIQUE and has Stand Alone applications.
Microwaves have capability to penetrate clouds. The Microwave sensors can penetrate clouds and so they can operate in all weather conditions. The frequencies above 15 GHz have effect of water clouds and frequencies above 10 GHz are attenuated by heavy rains.
Microwaves are Independent of sun as SOURCE and so Microwave Sensors can detect objects in Day as well as in Night. Because for microwave sensor receive signature which are generated due to self emission in case of the target which is self emitting. Similarly in case of scattering coefficient, the physical properties of target give different coefficient for different angles of incidence, polarization. Thus it does not require sun's illumination and so the target properties can be studied during day as well as in night.
Microwaves are capable of penetrating more deeply into vegetation as compared to optical waves. In case of microwaves the longer wavelengths penetrate deeper through vegetation as well as soil. The depth of penetration is more for dry vegetation and dry soil. The penetration reduces for smaller wavelengths .The penetration decreases with increase in the moisture content in vegetation and soil
Microwaves are sensitive to the moisture content. Microwaves are capable of penetrating into the ground itself. The depth of penetration is function of moisture content in the soil. The microwaves are sensitive to the presence of moisture in the soil as well as in vegetation or any material which absorbs moisture. This is due to the variability of dielectric constant of the dry material and that of water. The dielectric constant of dry soil varies between 2-3 depending upon the texture whereas the dielectric constant of pure water is around 80 at room temperature and at around 1 GHz. Thus the dielectric constant will vary between dielectric constants of dry soil and of the saturated soil which is around 30.Thus one can measure the moisture content in soil by measuring the dielectric constant of the soil. Fig 1 shows the variation of dielectric constant of soil with frequency and different moisture content. Electrical parameters are useful for Microwave Remote Sensing.

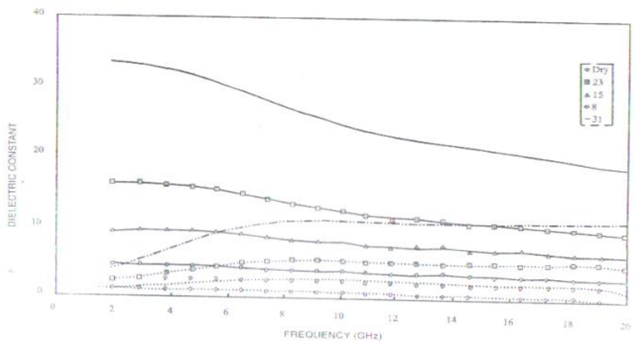


Fig 1: Variation of Dielectric Constant of Soil with Frequency and Different moisture Content

1.1 Areas of Application for Microwave Remote Sensing-

The broad applications of Microwave Remote Sensing are for land, ocean and atmosphere.

1.2 Application for Land

The spatial and temporal variation of soil moisture is of great importance for crop yield models, dry land farming, status of crop health, irrigation scheduling, etc. Microwave sensing is unique for soil moisture because of its penetration capability and because of the sensitivity of microwave energy to moisture.

The microwave remote sensing can be used for study of the different target properties on earth. This technique has been successfully used for study of natural material like soil, water and snow on the earth. Different land based applications that can be studied are

- Soil moisture estimation
- Crop identification
- Flood mapping
- Snow studies
- Geology
- Forestry
- Urban land-use
- hydrocarbons

1.2.1 Oceanographic Applications

Due to the focus on the utilisation of Exclusive Economic Zone (EEZ) in the future, applications like sea-state, ocean circulation, and shallow-water topography are of high priority. Apart from this, applications like oil pollution monitoring, retrieval of geophysical parameters of the ocean and the study of the ocean geoid are also important. The latter two are considered to be an input for meteorological prediction

Parameters that could be studied using microwave remote sensing are

- Sea-state measurement
- Measurement of sea surface salinity
- Topography in shallow sea
- Wind speed over sea surface
- Ocean circulation
- Significant wave height
- Oil pollution
- Sea surface temperature
- Geophysical parameter retrievals
- Ocean geoids studies

1.3 Atmospheric Applications

This application area is accorded a high priority under atmospheric application. Other applications of interest include profiling the moisture and temperature in the atmosphere which is essential for delineating mesoscale climatic systems. The application for studying the minor constituents in the atmosphere is considered important for stratospheric research. These applications have a potential for using microwave data.

The Parameters that will be studied will be useful for

- Indian monsoon studies
- Monsoon temperature profile
- Atmospheric minor constituents

Microwave Sensors for Remote Sensing Microwave Remote Sensing uses two types of sensors. They are:

- Active Sensors
- Passive Sensors

These Sensors measures

- Scattering Coefficient
- Brightness Temperature/Emissivity

The Brightness Temperature/Emissivity and Scattering coefficient are function of Dielectric Constant of the Target Material. Dielectric Constant is a very important electrical parameter of a natural material. The natural materials include soil, water and snow.

1.4 Passive microwave Sensors

(i) Non imaging Sensor
- Microwave Radiometer

(ii) Imaging Sensor
- Scanning Microwave Radiometer

Active microwave Sensors

(i) Non Imaging Radar
- Scatterometer
- Altimeter

(ii) Imaging Radar
- Real Aperture Radar
- Synthetic Aperture Radar

For microwave applications in remote sensing two types of sensors will use they are passive and active, further classified as non imaging and imaging. Radiometers are passive sensors (non imaging) and Scatterometer and altimeter are active sensors (non imaging) and real aperture radar (RAR) Side Looking Airborne Radar (SLAR) Synthetic Aperture Radar (SAR) from airborne and space borne platforms are active sensors (imaging).

The radiometers are non-scanning and scanning type. The scanning type radiometers will have mechanical scanning of the antenna with larger swath. The radiometers have two types of resolutions one is temperature resolution or sensitivity and other is spatial resolution.

1.5 Radiometer

A Passive Microwave Sensor used for measuring the brightness temperature of the target. The Functional block diagram of dicke radiometer is given in figure 2 –

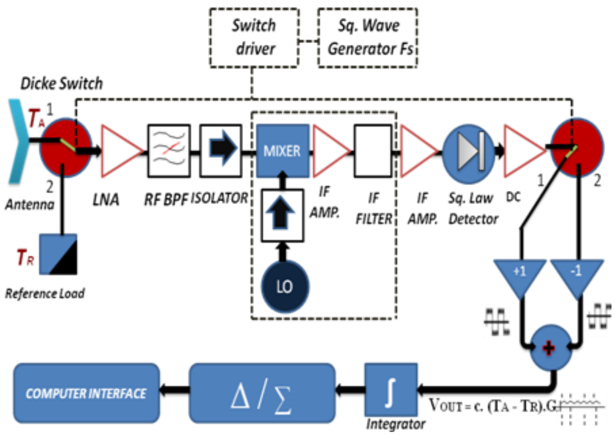


Fig 2: Block Diagram of Radiometer

1.6 Scatterometer

The Scatterometer measures scattering coefficient. It is non imaging radar. The block diagram is given in figure 3.

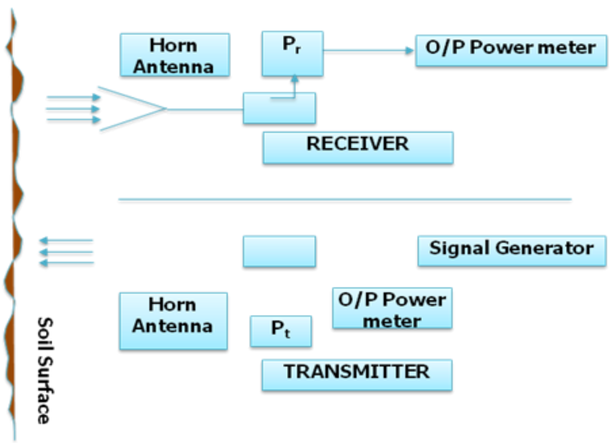


Fig 3: Block diagram of Radar Scatterometer

1.7 Altimeter

It is a nadir looking radar and it is used for measuring height. It is a monostatic radar altimeter.

The Scattering Coefficient σ° which is measured by active sensors is given by equation (1)

$$\sigma^0 = \frac{(4\pi)^3 R^4 P_r}{P_t \lambda^2 G_t G_r A} \quad \text{.......... (1)}$$

Where

R is the distance, Pr is the received power, Pt is the transmitted power, Gt is the gain of transmitting Antenna, Gr is the Gain of receiving Antenna, A is the physical area of the target, λ is the wavelength of the operating system.

1.7.1 Imaging Radar

The radars can be used for imaging the targets and they are categorized as.

1. Real aperture radar
2. Synthetic aperture radar

These radars are basically scatterometers and they provide along with the values of scattering coefficient the range information thus they can be used for imaging purpose.

1.7.2 Real Aperture Radar

The real aperture radar will provide image of the scene and has two resolutions like along the track resolution and across the track resolution. These resolutions depend on the beam width of the antenna and the pulse width of the radar. The along track resolution will depend upon the height of the platform on which the radar is mounted. The block diagram of Real aperture radar is shown in fig 4 and the along track and across track resolution geometry is shown in fig 5.

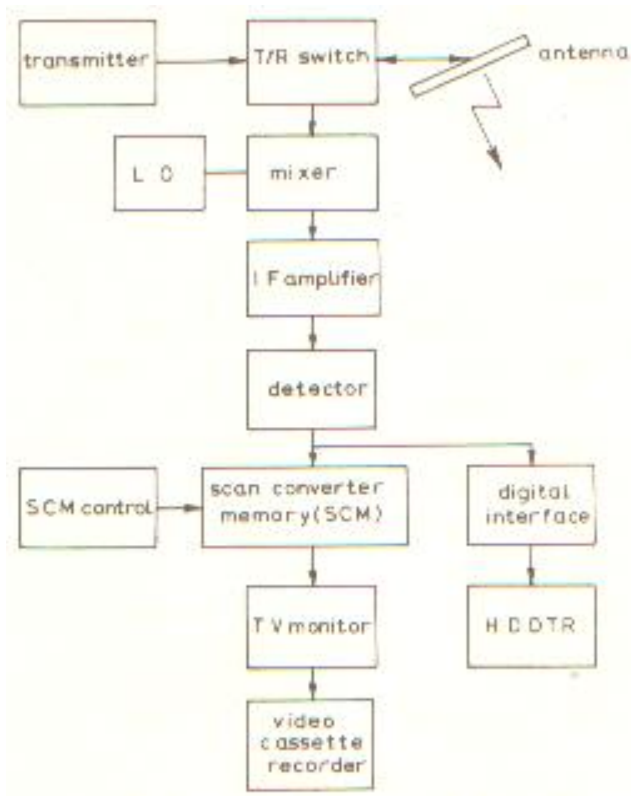


Fig 4: Block Diagram of Real Aperture Radar (RAR)

1.8 Synthetic Aperture Radar

The synthetic aperture radar also works on similar principle of radar but the information that the radar gathers include the amplitude of the return signal as well as the phase of the signal. This also takes the Doppler history as the radar is placed on the moving platform .the antenna is synthesized and so the along track resolution improves. Thus both the resolutions in case of synthetic aperture radar are better than that of real aperture radar.

These Sensors in Microwave Remote sensing are used for remote sensing of the Earth that includes, Land, oceanography, SNOW as well as Atmosphere which have been explained earlier.

2. The Indian Space Remote Sensing program using microwaves:

2.1 Satellites carrying Passive Sensors-

Figure 6a shows BHASKAR I & II Satellites the First Experimental Remote Sensing Satellite built in India, which carried SAMIR Payload (Microwave Radiometers operating at 19, 22 and 31 GHz).

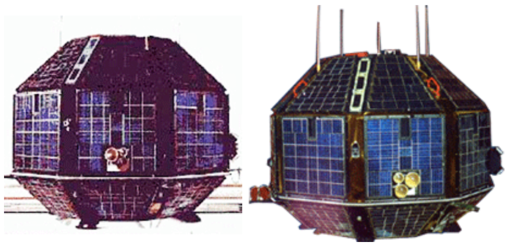


Fig 6a show the satellite BHASKARA-I and BHASKARA-II

Figure 6b and 7 shows the IRS-P4 (OCEANSAT I) and OCM (Ocean Color Monitor) and MSMR (Multi-frequency Scanning Microwave Radiometer) sensor package, one of the method of calibration which can be used for space borne Microwave Radiometer of MSMR is shown in figure 7.

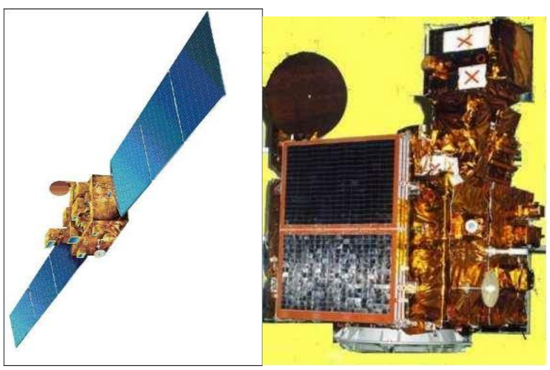


Fig 6b shows IRS-P4 (OCEANSAT I) and OCM and MSMR sensor package.

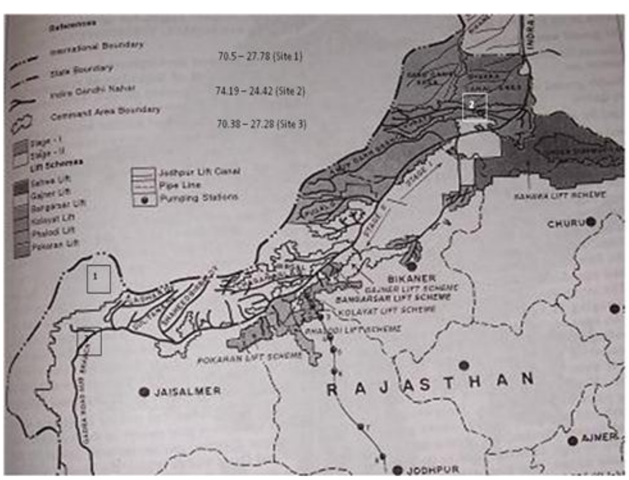


Fig 7. Showing sites for calibration of MSMR

As shown in figure 7, here three sites are chosen to be used for calibration of MSMR. Out of these three sites first site can be used for calibration because the microwave temperature measured by MSMR is steady as compared to other two sites.

2.2 Satellites carrying Active Sensors

The first Indian active sensor onboard Oceansat-2 was the Ku band Scatterometer. The figure 8 shows the Oceansat -2 Satellite.

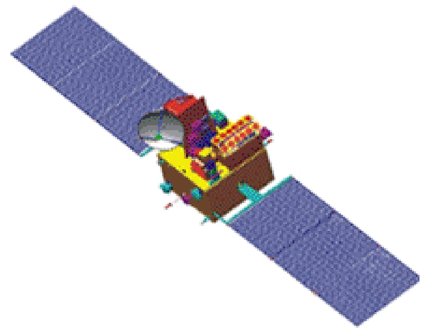


Fig. 8 shows Oceansat-2 satellite

Another satellite RISAT 2, radar imaging satellite was built by ISRO which carried a SAR (Synthetic Aperture Radar) manufactured by Israel Aerospace Industries. Figure 9 show the computer generated conceptual RISAT-2.

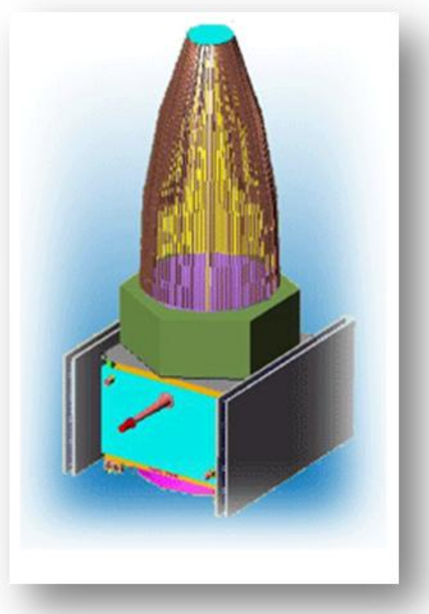


Fig 9: RISAT-2, Radar Imaging Satellite

The RISAT I which will carry Indian Imaging Radar is undergoing testing and is in queue for launch by the PSLV.

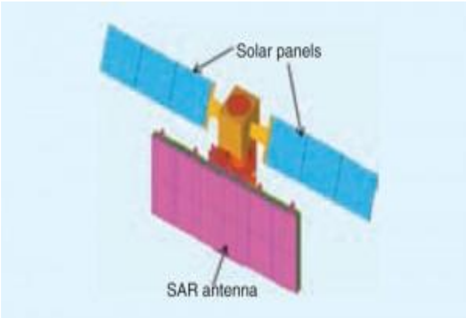


Fig 10 shows Computer generated RISAT –I

3. Planetary Exploration using Microwave Remote Sensing

The planets have been explored using Microwave Remote sensing. The planets like Mars and Venus as well as Satellites like Titan and Moon have also been explored using Microwave sensors.

3.1 Exploration of Mars

The Mars have been explored by different countries using Microwave Sensors. The figure 11 shows optical image of Martian surface. In this one can see that the Martian summer in the northern hemisphere results in a large south polar ice cap. Two seasonal dust storms can be seen, one at top centre and one over the Hellas impact basin at lower right.

Fig.11. An optical Image of Mars

The Soviet Union has sent unsuccessful mission to Mars in 1969- Mars 1960A &B but they failed. The American efforts were successful and they had sent different missions like Vikings 1& 2 which was Successful. In 2005 Mars Reconnaissance Orbiter , 2001 Mars Odyssey and in 2003 ESA Mars Express was sent.

The Indian Space Research Organization is planning for Mars mission and this is under planning phase.

3.2 Exploration of Venus

Venus is a planet which is always covered by clouds. The figure 12 shows Venus in real color. Many countries have tried to explore Venus.

Fig 12. Venus in real color

Early efforts were done by Soviet Union by making robotic space probe which were unsuccessful. At the same time United States of America also tried to explore Venus by sending different Satellites like Mariner 1 &2. Mariner 2 was the first one to get success. Venus is also explored by Japan. The Akatsuki probe will image the surface in ultraviolet, infrared, microwaves, and radio, and look for evidence of lightning and volcanism on the planet.

3.3 Exploration of Satellites of the Planets-

The planets have satellites like Titan is Satellite of Saturn and Moon is a satellite of Earth. These Satellite have also been explored by sending Satellites to these planetary bodies.
Exploration of Titan.

Titan is the moon of Saturn also known as Saturn VI. It was discovered by Christiaan Huygens On March 25, 1655. Figure 13 shows the Optical photo of Titan.

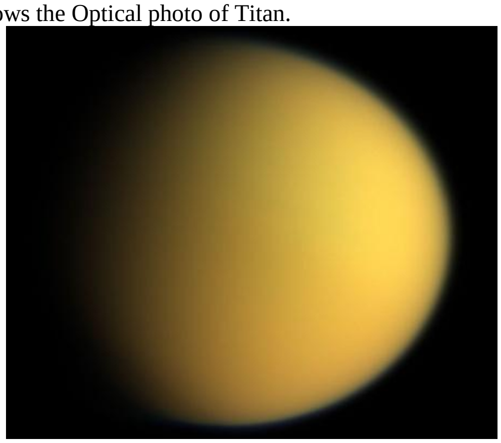


Fig 13: shows optical photo of Titan

The Titan has also been explored by different countries. The USA had sent different missions to Titan. They include 1979- Pioneer 11 ,1980 and 1981- Voyager 1 and 2 .
the European Space Agency (ESA) has also sent space mission to Titan in collaboration with NASA in July 1, 2004 the Cassini–Huygens spacecraft. Cassini began the process of mapping Titan's surface by radar. Figure 14 shows the Radar image of surface of Titan.

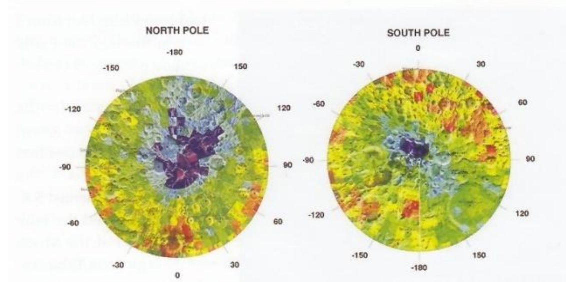
Fig 14.shows Radar image of surface of Titan

3.4 Exploration of Moon

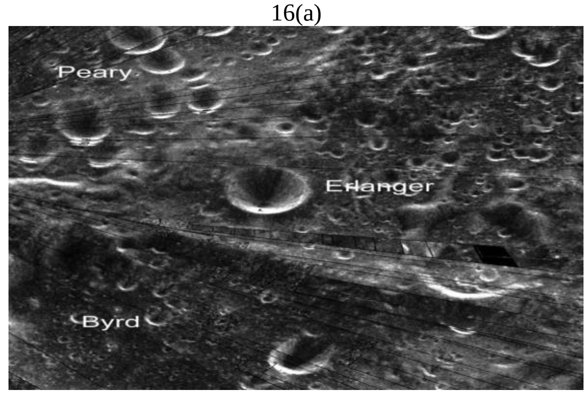
The Moon is earth's natural satellite and our closest neighbor and we are familiar to it. Figure 15 a shows the optical image of Moon and figure 15 b shows assembled Chandrayaan I. Chandrayaan I carried MINISAR for Lunar Exploration by ISRO.

Fig 15a. Image of moon

Fig 15b. Chandrayaan I



16(a)



16(b)

Fig 16a & b shows image of North and South poles of Moon and image showing craters on North polar area of moon(Mini-SAR radar image, Chandrayaan-1 mission)

Figure 16 shows Hydrogen-bearing compounds, presumably water-ice distribution around north and south poles of Moon based on Lunar Prospector data. Deep purple colour represents areas of high concentration of hydrogen and Mosaic of Mini-SAR image strips of the north polar area, showing the crater Erlanger, just south of the crater Peary. North Pole is in the direction of left top, out of frame.

4. Lunar Missions from different countries-

4.1 India

After successful launching and operationalization of CHANDRAYAAN – I (October 22, 2008) Mission, ISRO is Planning to launch Chandrayaan 2 in near future. Chandrayaan - 2 will have ORBITER AND ROVER.

4.2 Exploration of Moon by Japan

1990 – Hiten was the first Japanese lunar mission; spacecraft released the Hagoromo probe into lunar orbit, but the transmitter failed. Later in 2007 they launched the SELENE spacecraft, with the objectives "to obtain scientific data of the lunar origin and evolution and to develop the technology for the future lunar exploration". This carried a low frequency Radar.

4.3 Exploration of Moon by US

Clementine mission was sent in 1997 by NASA with objective to test sensors and spacecraft components under extended exposure to the space environment and to make scientific observations of the Moon and the near-Earth asteroid 1620 Geographos. Later in 1998 Lunar Prospector was sent which was designed for a low polar orbit investigation of the Moon, including mapping of surface composition and possible polar ice deposits, as well as the measurements of magnetic and gravity fields, and study of lunar outgassing events was done. The mission ended in July 31, 1999, when the orbiter was deliberately crashed into a crater near the lunar South Pole in an unsuccessful attempt to detect the presence of water. Recently LUNAR RECONASIANCE ORBITOR (LRO) of NASA also carried MINISAR operating at S AND X –bands.

4.4 Exploration of Moon by Europe Space Agency

In 2003, SMART 1was sent to Moon whose goal was to take three-dimensional X-ray and infrared imagery of the lunar surface. it was intentionally crashed into the lunar surface in order to study the impact plume. ESA is also planning more missions to Moon.

4.5 Exploration of Moon by China

Chang'e program for exploring the Moon and investigating the prospect of lunar mining is specifically looking for the isotope helium-3 for use as an energy source on Earth. China launched Chang’e 1on October 24, 2007 and Chang'e 2 on October 1, 2010. Chang’e 1 had carried Microwave Radiometr for Lunar exploration.

4.6 Study of Terrestrial Analog of Lunar Soil-

At ICRS the electrical properties of Terrestrial Analog of Lunar Soil have been measured at microwave frequencies.

Fig 17 shows JSC 1A Lunar Simulant

Figure 17 shows JSC-1A Lunar regolith simulant used for measurement of complex dielectric constant.

The following table shows Values of dielectric constant of terrestrial analogues of Lunar soil for temperatures from -196° C to +200°C at 1.7GHz & having density 1.8 gm/cm3.Measurements were made at ICRS.

The Graph below shows that dielectric constant of terrestrial analogues of lunar soil ε' & loss factor ε'' increases with increasing temperature from -196□ C to +200□ C at 1.7GHz frequency.

S no.	Temp (°C)	ε'	ε''	tanε=ε''/ ε'
1	-196	3.66	0.15	.041
2	-50	4.07	0.25	.061
3	0	4.17	0.28	.067
4	30	4.22	0.29	.069
5	50	4.29	0.31	.072
6	100	4.38	0.36	.082
7	150	4.47	0.4	.089
8	200	4.59	0.43	.094

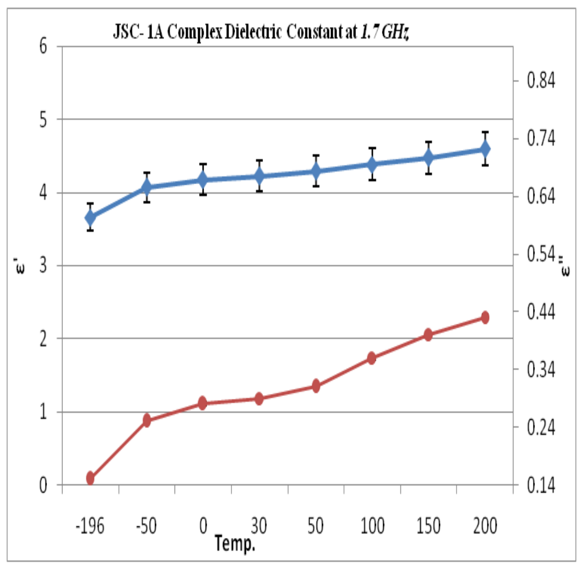


Fig 18 shows the graph between the Dielectric constant and Temperature

5. Conclusion

The Microwaves have unique applications in remote sensing. Also along with optical and infrared they provide complimentary and supplementary information about the targets. The Remote Sensing of PLANETS also is possible using microwave sensors. As can be seen the hitherto unknown areas in PLANETS can be explored by microwaves. Thus the microwave remote sensing will play a major role in exploration of EARTH as well as PLANETS.

6. ACKNOWLEDGEMENT:
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