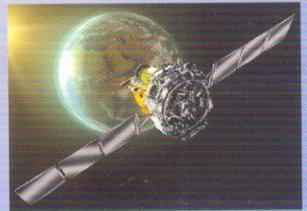
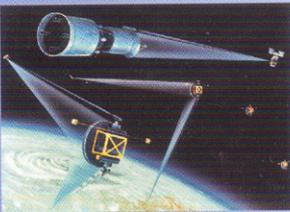
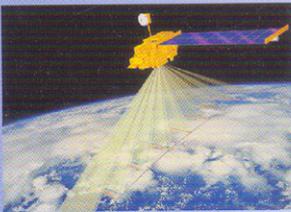




# MICROWAVE REMOTE SENSING

OPN Calla



**Defence Research & Development Organisation**  
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# MICROWAVE REMOTE SENSING

## OPN Calla

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## **PREFACE**

The radio frequency spectrum is divided into different regions known as High Frequency, Very High Frequency, Ultra High Frequency, SHF and also in microwave, millimeter waves, sub-millimeter waves, etc. The frequency range from 3 GHz to 30 GHz is known as microwaves and millimeter waves range from 30 GHz to 300 GHz. This part of radio spectrum has different applications. These are in (a) communication, (b) remote sensing (c) medical, and (d) industries. The choice of the frequency depends upon the type of application. In this monograph, the remote sensing applications of the microwaves have been dealt with.

The unique capabilities of microwaves like all weather, day and night, sensitivity to soil moisture and ability to penetrate soil and vegetation etc., make the microwave remote sensing capable of having stand-alone application in some areas of oceanography, land and atmospheric applications. For other applications, microwave remote sensing complements as well as supplements other techniques of remote sensing.

The fundamental parameter for microwave remote sensing is the dielectric constant of the material on which other electrical parameters like emissivity and scattering coefficient depend. The information about dielectric constant, emissivity, and scattering coefficient is obtained by measurement of these parameters as well as by estimation using the theoretical models. For microwave remote sensing, the knowledge about these three electrical parameters of the target material is extremely important.

The designing of sensors for microwave remote sensing depends on the emissivity for passive sensors, and scattering coefficient for active sensors. The passive sensors include radiometers, both imaging and non-imaging types. The active sensors are imaging radar, altimeter, and scatterometer. The knowledge of sensors, platform, data products, and applications of microwave remote sensing will provide great inputs for national development. This monograph will serve to those who will be interested in microwave remote sensing.

February 2009

OPN Calla  
Director, International Centre for Radio Science



## **ACKNOWLEDGEMENTS**

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# Chapter 1

## Introduction to Microwave Remote Sensing

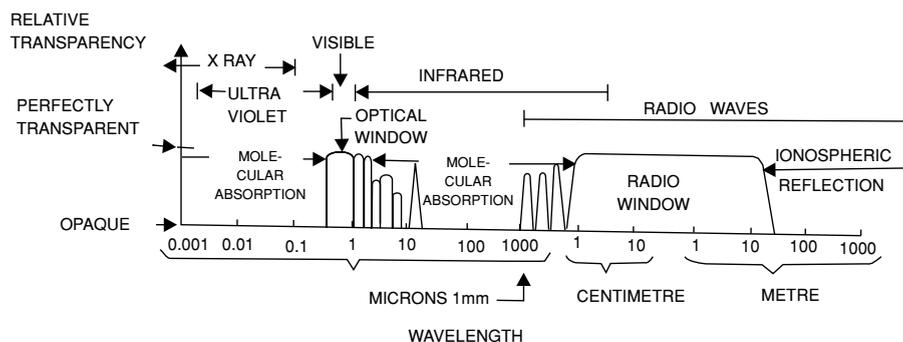
### 1.1 INTRODUCTION

Remote sensing has diverse applications and it has been identified as a technique with good potential to help the nation's economic growth and solve some of its problems. These include better management of natural resources through wasteland mapping, identifying flood-prone areas, water in catchments areas, assessment of situation of reservoirs, estimating forest area, and prediction of crop yield and scarcity of resources etc. The electromagnetic spectrum with different wavelength bands has applications in diverse areas. With increase in demand for natural resources, non-availability causes scarcity and one has to identify the factors behind these. For this, the conventional methods are not adequate, remote sensing can play an important role in solving these problems.

Remote sensing can be applied in areas like prediction of climatic conditions, rainfall, cloud cover, etc., and to help identify the areas covered by clouds, and other physical parameters. In cloud covered areas, i.e., during *kharif* season when crops get affected and yield prediction of wheat is difficult, and on crops like groundnuts, coffee, tea etc., which require high rainfall remote sensing can play a vital role. During rainy season, another area of concern is flood. Flood wreck havoc for many years. Movement of clouds could not be predicted as the clouds restrict the observation by conventional methods. Observation is not possible during night so one needs sensors which can work in night as well as in cloud covered areas.

### 1.2 ELECTROMAGNETIC SPECTRUM

The applications of remote sensing depend on the choice of frequency. The Radio Regulations of International Telecommunication Union limit the term radiowaves to electromagnetic waves of frequencies arbitrarily lower than 3000 GHz. For both active and passive microwave remote sensing, different parts of radio spectrum is used. Figure 1.1 gives the electromagnetic spectrum.



**Figure 1.1. Electromagnetic spectrum showing relative transparency of the earth's atmosphere and ionosphere<sup>1</sup>.**

The Table 1.1 gives the radio spectrum starting from Extremely Low Frequency (ELF) to Extremely High Frequency (EHF) and from myriametric waves to sub-millimeter waves. This spectrum extends from 30 GHz to 3000 GHz. Different portions of radio spectrum have different applications.

The microwave spectrum is from 0.3 GHz to 30 GHz and millimeter wave spectrum ranges from 30 GHz to 300 GHz, the sub-millimeter wave spectrum is from 300 GHz to 3000 GHz. For utilisation of these spectra for various applications, it is split into different bands.

The nomenclature of the bands with frequencies is given in Table 1.2 and the nomenclature for bands adopted by US Military in 1970 is given in Table 1.3.

**Table 1.1. Part of the electromagnetic spectrum**

Frequency bands	Wavelength	Descriptive designation
30–300 Hz	1000–10000 km	ELF
3–30 kHz	10–100 km	Myriametric waves–VLF
30–300 kHz	1–10 km	Kilometric waves–LF
300–3000 kHz	100–1000 m	Hectometric waves–MF
3–30 MHz	10–100 m	Decametric waves–HF
30–300 MHz	1–10 m	Metric waves–VHF
300–3000 MHz	10–100 cm	Decimetric waves–UHF
3–30 GHz	1–10 cm	Centimetric waves–SHF
30–300 GHz	1–10 mm	Millimetric waves–EHF
300–3000 GHz	0.1–1 mm	Sub-millimetric waves

**Table 1.2. Microwave band designations**

<b>Band*</b>	<b>Frequency region (GHz)</b>
P	0.3–1.12
L	1.12–1.70
LS	1.7–2.60
S	2.6–3.95
C	3.95–5.85
XC	5.85–8.20
X	8.2–12.40
KU	12.4–18.0
K	18.0–26.5
KA	26.5–40
Q	33–50
U	40–60
M	50–75
E	60–90
F	90–140
G	140–220
R	220–325

\* Microwave frequency spectrum extends through UHF, SHF and EHF (300 MHz–325 GHz)

**Table 1.3. Military microwave band designations**

<b>Band*</b>	<b>Frequency region (GHz)</b>
A	0.1–0.25
B	0.25–0.5
C	0.5–1.00
D	1–2
E	2–3
F	3–4
G	4–6
H	6–8
I	8–10
J	10–20
K	20–40
L	40–60
M	60–100

\* US new military microwave band, the US Department of Defense had adopted another band designation for microwave frequencies in 1970.

Table 1.4 gives characteristics of microwave frequencies from 3 GHz to 30 GHz and Table 1.5 gives characteristics of millimeter wave. The characteristics of the sub-millimeter waves are given in Table 1.6.

The frequency bands are allocated for passive microwave remote sensing and radio astronomy. Table 1.7 gives different frequencies which can be used for radiometers. Table 1.8 gives the frequencies allocated for radars.

**Table 1.4. SHF centimetric waves (3–30 GHz)**

<b>Parameter</b>	<b>Characteristics</b>
Atmospheric influences	Rain, hail, snow, etc.,- variable attenuation with frequency refraction and ducting, refractive index fluctuation, scintillation
Terrain influences	Diffraction around buildings, screening by hills, scatter and reflection off elements of buildings and terrain, sea reflection depends on wave height
System considerations	High-gain parabolic dishes and horn waveguides large numbers of channels on each carrier
Typical services	Fixed (terrestrial point-to-point carrying multiple voice channels and several television channels), fixed satellite, radar, mobile services, future satellite mobile, remote sensing from satellite
Comments	Not yet fully utilised; about 15 GHz (where atmospheric effects are the worst)*

\* Super High Frequency (SHF) offers large numbers of wideband channels on each carrier, with opportunities for versatility in use of channels for multi-path voice, TV or high-speed data. Extensive terrestrial line-of-sight networks have developed as well as earth-space routes, sometimes with frequency sharing between services. Site-shielding from interference signals may employ hills or even groups of building (according to frequency). Absorption by rain, fog, and cloud, as well as atmospheric gases, rapidly becomes a severe constraint at higher frequencies for system reliability, both on terrestrial and earth-space paths. Ducting on trans-horizon paths may be a serious cause of interference, and multi-path effects may cause severe fading on near-horizontal paths.

**Table 1.5. EHF millimetric waves (30–300 GHz)**

<b>Parameter</b>	<b>Characteristics</b>
Atmospheric influences	Rain, hail, snow, etc. – very severe attenuation and scatter cloud mist-variable attenuation with frequency effect
Refractive index gradient-scintillation	Absorption by atmospheric oxygen and water vapours
Terrain influences	Screening by objects larger than a few decameter (e.g., buildings)
System considerations	Paraboloid dish antenna becomes small
Typical services	Short line-of sight communications - both fixed and mobile some satellite applications. Remote sensing from satellite
Comments	Frequency band likely to develop rapidly as equipment elements become available, planning around atmospheric effects. Allocations for terrestrial and satellite up to 58 GHz*

\* Extremely High Frequency (EHF) region of the spectrum is now being developed, though the process has been delayed due to system technique. Improvements introduced to give increased efficiency in use of lower frequencies. Precipitation, clouds and fog, and atmospheric gases become a severe problem though some windows remain. Equipment are becoming available for research and development and for communication systems. Private user fixed link systems are appropriate in metropolitan areas to link customer buildings with the nearest network node. Mobile systems may operate within public places (for e.g., shopping areas and travel terminals), domestic, and office buildings (cordless telephones) and public transport. Satellite uses may include satellite services and inter-satellite direct broadcasting (probably HDTV) and mobile as well as extension of fixed satellite-to-launch-vehicle links. Applications of remote sensing of the surface and the atmosphere are also major uses of this part of the spectrum, both for research and operations.

**Table 1.6. Sub-millimetric waves (300–3000 GHz)**

Parameters	Characteristics
Atmospheric influences	Rain, hail, snow, etc., – very severe Cloud, mist - very severe, dust, smoke – very severe Localised refractive index gradient (mirage) refractive index fluctuations - scintillation, absorption by atmospheric gases
Terrain influences	Scareeing by objects larger than a few metre (e.g., large trees)
System considerations	Mirror or lens antennas
Typical services	Possibly short line-of-sight communications
Comments	Propagation restraints to communication are almost total, except for very short paths, equipment is mostly lacking, since requirement is very limited, remote sensing uses this part of the spectrum

**Table 1.7. Passive sensor frequency allocations (GHz)**

0.404–0.406a	10.60–10.68p	36–37p	150–151p
1.370–1.400s	10.68–10.70a	50.2–50.4p	164–168a
1.400–1.427a	15.20–15.35s	51.4–54.25 a	174.5–176.5p
1.6605–1.6684p	15.35–15.40a	54.25–58.2p	182–185a
2.640–2.600s	18.6–18.8s	58.2–59.0a	200–202p
2.690–2.700a	21.2–21.4p	64–65 a	217–231a
4.2–4.4s	22.21–22.5s	89–92 a	235–238p
4.80–4.99s	23.6–24.0a	100–102 p	250–252a
6.425–7.250s	31.3–31.5a	105–116 a	
10.60–10.68p	31.5–31.8p	116–126 p	

*a* Protected for radio astronomy - no transmitters allowed.

*p* Shared primary use is for services having transmitters.

*s* Shared secondary use is for services having transmitters.

**Table 1.8. Radar frequency allocations for remote sensing (GHz) (all are shared with other services)**

Equipment	Frequency (GHz)
Radar altimeter	4.2–4.4
Doppler navigator	8.8, 13.25–13.40
Meteorological radar	5.6–5.65, 9.3–9.5
Coastal radar	5.35–5.65, 9.0–9.2, 10.0–10.55
Ship radar	5.46–5.47, 9.3–9.5, 14–14.3, 24.25–25.25, 31.8–33.4

### 1.3 UNIQUE CAPABILITIES

Sensors operating in the microwave region of the electromagnetic spectrum are used for remote sensing of regions covered by clouds and for

24 h data collection. Microwave sensors have advantages and unique capabilities over the optical sensors. These are:

- (a) All weather penetration capability through clouds
- (b) Day and night capability (independent of intensity and angle of sun illumination)
- (c) Penetration through vegetation and soil to a certain extent
- (d) Sensitivity to moisture (in liquid or vapour forms).

### **1.3.1 All Weather Penetration Capability**

The performance of sensors operating at microwave frequencies is likely to get affected by ice clouds, water clouds, and rain. These three natural phenomena affect the radio waves differently at different frequencies. The ice clouds are completely transparent to all microwave frequencies whereas these are opaque at optical wavelength. Water clouds strongly affect the frequencies above 30 GHz whereas below 15 GHz, the effect is negligible. Ulaby<sup>1</sup> *et al.* showed the effect of clouds on radio transmission from space to ground. The effect of rain is more pronounced above 10 GHz in case of intense rain.

The imaging radars operate mostly independent of weather and are not affected by cloud cover or haze. Water clouds significantly affect the radars operating above 15 GHz frequencies and the effect of rain is not important at frequencies below 10 GHz. Ulaby<sup>1</sup> *et al.* gives the effect of rain on radio transmission from space to ground.

The effect of the weather is more important for microwave radiometers and the selection of operating frequency depends on the windows in the electromagnetic spectrum. It has been found that radiometers operating at frequencies of 10.0 GHz or 7.5 GHz are blocked for very short period. In 1974, it was reported that sensors operating at 19.35 GHz and 37.00 GHz on NIMBUS 5 and NIMBUS 6 have produced maps of the areas of Greenland and Antarctica without any effect of clouds.

From the above discussion, it is clear that in such weather conditions, it is impossible to get results using optical remote sensing techniques and only sensors operating at microwave frequencies produce good results.

### **1.3.2 Day and Night Capability**

At microwave frequencies, the sensors receive the target signals which are wholly dependent on their dielectric properties and physical properties like surface roughness and texture of the target. Thus, the signal received by the sensor does not depend upon the illumination of sun and its angle or its intensity. Thus, at microwave frequencies, one gets information about the target object even during night. This is not possible using optical sensors

because they need the illumination to image the target. Similarly, infrared also require illumination of sun to some extent.

### **1.3.3 Penetration through Vegetation and Soil**

The microwaves can penetrate through vegetation and soil to a limited extent. The longer wavelengths penetrate deeper as compared to shorter wavelengths. Thus, using higher frequencies, one can get information about canopies, and using lower frequencies, one can get information about the soil and also subsoil information. The moisture content and density of vegetation also plays an important role in this phenomenon. The skin depth variation with moisture content and frequency show that for dry soil, deep penetration is obtained at low frequencies. Ulaby<sup>1</sup> *et al.* gives the penetration of radar signals through vegetation.

### **1.3.4 Sensitivity to Moisture**

The microwaves are sensitive to the presence of moisture in the soil. The dry soil and moist soil behave differently at different microwave frequencies. This is due to the electrical parameter, i.e., dielectric constant of the soil, which has different values for dry soil or dry natural material and the materials with water either in liquid form or in vapour form. Calla<sup>2</sup> *et al.* studied soils with moisture content at frequency range from 2 GHz to 20 GHz for the soil from oven-dried state to saturated moist state<sup>2</sup>. The variability of dielectric constant provides the sensitivity to moisture at microwave frequencies. Figure 1.2 gives the variation of dielectric constant of soil with different moisture values at different frequencies.

As it is seen, the information available at microwave frequencies is largely due to the geometric and bulk dielectric constant of soil, whereas in visible and infrared frequencies it is due to the molecular resonance in the surface layer of the vegetation or soil. From this, one can conclude that when all the three – microwaves, visible, and infrared, are used together, it is possible to get information about geometric, bulk dielectric constant, and molecular resonance properties of the surface. Thus, for remote sensing, all the three are complementary, and to get best results, these should be used in combination to delineate all the properties of the surface.

## **1.4 MICROWAVE REMOTE SENSING**

The microwave remote sensing (MRS) has tremendous potential because of its unique capabilities. It offers certain specific advantages in applications like geological survey for petroleum and mineral prospecting, crop and vegetation monitoring, soil moisture detection, water resources management, agriculture, oceanography, and atmospheric sciences. The remote sensing at microwave frequencies is carried out using both passive microwave sensors, and active microwave sensors.

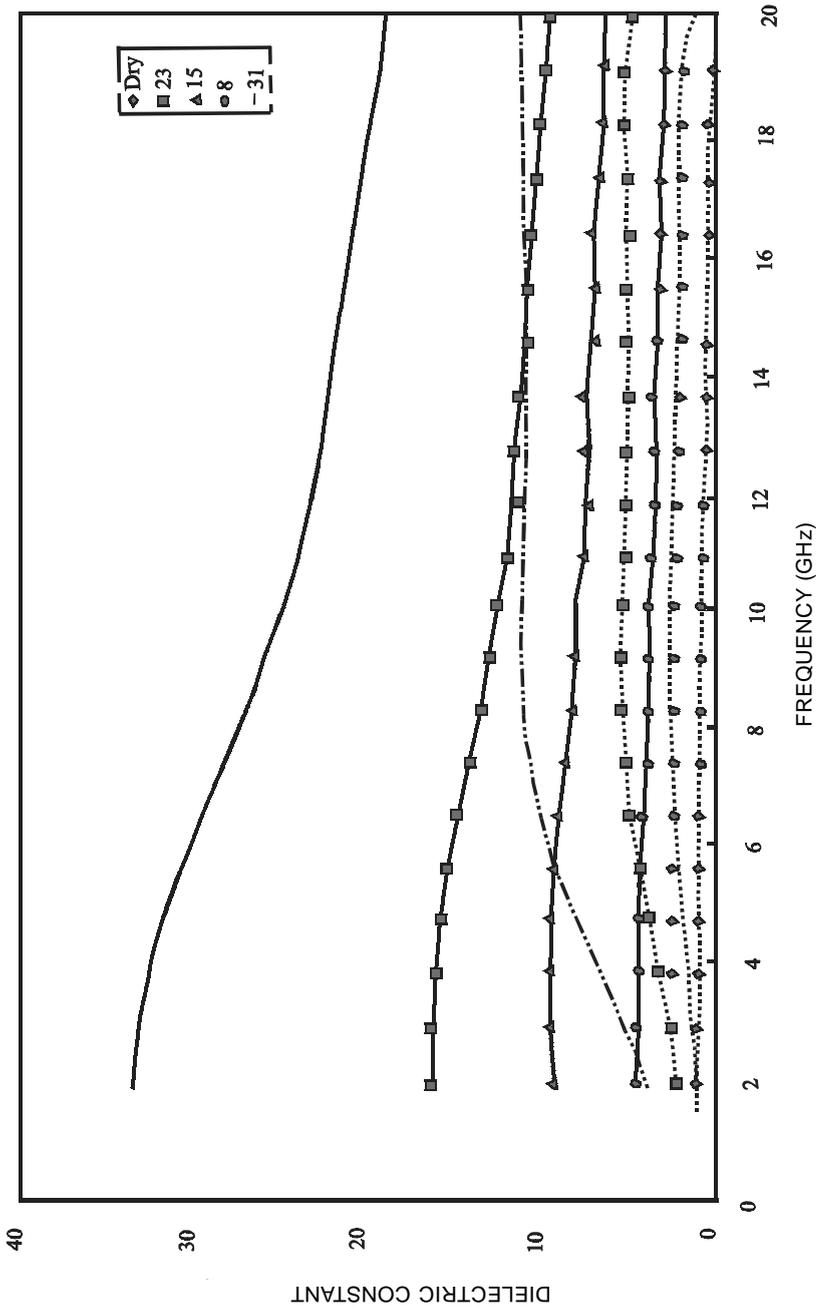


Figure 1.2. Variation of dielectric constant of soil with various frequencies for different moisture content (solid curves for  $\epsilon'$  and dotted curves for  $\epsilon''$ ).

### **1.4.1 Passive Microwave Remote Sensing**

The passive MRS is carried out using microwave radiometers. It is possible to use this technique because all natural materials emit electromagnetic radiation, which is a complex function of physical properties of the emitting surface. In the recent past, apart from optical sensors, sensors operating at microwave frequencies have been used on a limited scale for a variety of applications. The passive sensors, earlier called radiometers, detect the radiated energy in the microwave spectrum.

The basic principle governing the process of detection by the radiometers is the Rayleigh Jeans approximation of Planck's law. The behaviour is guided by the electromagnetic emission from a blackbody at a given temperature  $T$  °K as governed by Planck's law.

The Planck's law when it is approximate for  $f/T \lll 2 \times 10^{10}$ , is known as Rayleigh Jeans approximation for blackbody, which is given by

$$B(\lambda, T) = \frac{2KT}{\lambda^2} \quad (1.1)$$

In natural situations, the ability to absorb or emit is related by Kirchoff's law which is given as

$$B(\lambda, T) = \varepsilon(\lambda) \left[ 2KT/\lambda^2 \right] \quad (1.2)$$

where emissivity  $\varepsilon(\lambda)$  is the ratio of the emission between the object and the blackbody maintained at the same thermodynamic temperature. The emissivity depends upon a number of parameters such as temperature, polarisation, frequency, angle of incidence, and the physical properties of the surface.

### **1.4.2 Active Microwave Remote Sensing**

The active MRS uses the scattering properties of the terrains and targets for analysis of the data obtained and differentiating one target from the other. The scattering properties are manifested in the scattering coefficient of the target. The scattering coefficient is a function of the angle of incidence, the frequency of operation, and polarisation. The scattering coefficient also depends on the electrical properties of target like dielectric constant and conductivity as well as on the physical properties like texture, surface type, etc. In active MRS, the two important parameters of radar, i.e., capability to produce very high resolution imagery and to measure the distance/altitude with high accuracy are also exploited.

The fundamental radar equation on which the active MRS depends, is given by

$$P_r = \frac{P_t G^2 \lambda^2 \sigma^\circ}{(4\pi)^3 R^4} \quad (1.3)$$

where  $P_r$  is received power at receiver,  $P_t$  is transmitted power,  $\lambda$  is wavelength,  $R$  is range or distance of target,  $\sigma^\circ$  is Radar scattering cross-section.

From Eqn. 1.3, one can derive  $\sigma^\circ$  as

$$\sigma^\circ = \frac{(4\pi^3) R^4 P_r}{P_t G^2 \lambda^2} \quad (1.4)$$

and  $\sigma^\circ$  can also be written as

$$\sigma^\circ = A_{rs} (1 - f_a) G_{ts} \quad (1.5)$$

where  $f_a$  is fraction of the incident power absorbed by the target,  $G_{ts}$  is Gain of the scatterer in the direction of receiver,  $A_{rs}$  is Area of the incident beam from which all power would be removed if one assumed that the power going through the rest of the beam is continued uninterrupted.

The radar cross-section of the target depends upon the dielectric constant and conductivity, shape, type, and texture of the material in addition to the sensor parameters like illuminating frequency, angle of illumination, and polarisation.

The electromagnetic power gets scattered, as it is incident on a target. This depends on the type of surface of the target. If the surface is smooth, there will be a specular reflection and the maximum power will scatter in the direction of the specular reflection. If the surface is rough, the power will scatter in all the directions. The scattering phenomenon takes place when the surface roughness has relation to wavelength of the sensor. As the electromagnetic waves can penetrate the surface, the scattering coefficient also depends on the subsurfaces properties of the target. It is believed that the scattering, which takes place both at surface and subsurfaces levels, is a volume scattering phenomenon. But in the case of sea surface, the backscatter is only from the sea surface.

The natural earth materials are water, soil, snow, and ice. The MRS using passive and active microwave sensors measures parameters like emissivity ( $\epsilon$ ) for passive sensors, and scattering coefficient ( $\sigma^\circ$ ) for active sensors. These two parameters,  $\epsilon$  and  $\sigma^\circ$  are the functions of physical and electrical properties of these materials. The electrical parameters in case of natural earth material are permeability ( $\mu_0$ ), permittivity ( $\epsilon_0$ ), and conductivity ( $\rho$ ). In case of microwave remote sensing, all of these parameters are interrelated.

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