Remote Sensing: Principles and Applications
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Lecture-41
Passive Microwave Remote Sensing-Part 2

Hello everyone, welcome to the next lecture in the course remote sensing principles and applications. We have started discussing the concepts of passive microwave radiometry and today let us continue with it. In the last lecture, we got introduced to passive microwave radiometry, the fundamental Planck's law behind it and we have also converted the Planck's law from wavelength to frequency form and then we got to know what is known as a Rayleigh Jean approximation, which will help us to calculate the radiance coming out of an object in microwave wavelengths in a more simpler way. So, Rayleigh Jean approximation is kind of a more relatively very simple equation to calculate the radiance coming out, provided you know the temperature of an object and emissivity of an object.

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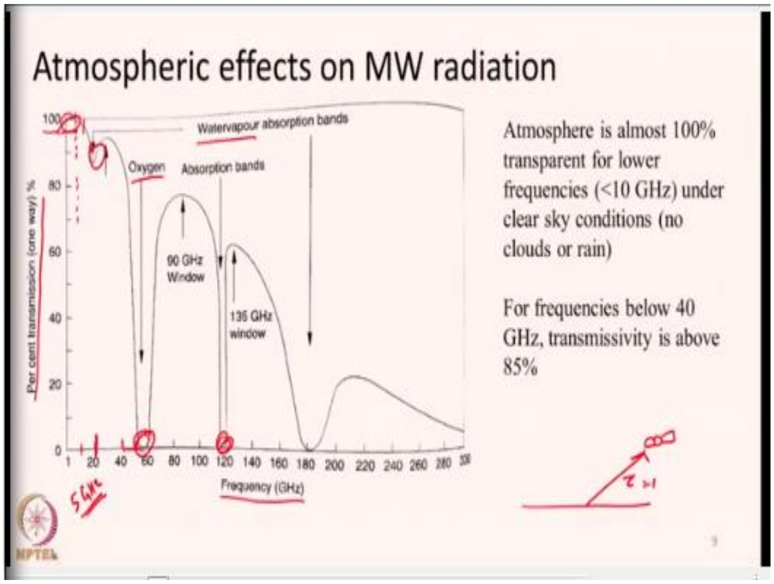

Today, we will look into the concept of effect of atmosphere in microwave radiation. We have discussed in detail about the effect of atmosphere in optical wavelengths and thermal infrared wavelengths. Basically in 3 ways the atmosphere will interfere with the radiation going out from the surface, what are they?

First thing is through atmospheric transmissivity, whatever the radiation that is emitted by that surface, while it is going toward the sensor, a fraction of it will be absorbed and scattered. So, if the atmospheric transmissivity is say 0.8 and if 100 units of energy radiates from earth surface then only 80 units of energy will reach the sensor, remaining 20% will be absorbed or scattered, so that is transmissivity. Second way is atmosphere will add a path radiation component, a path radiance due to the atmosphere's own temperature. Atmosphere will also emit some radiation especially in thermal wavelengths and in passive microwave wave lengths. So, that emitted radiation by atmosphere will reach the sensor. And third component is this emission by the atmosphere will come towards the earth surface and get reflected by the earth surface and will reach the sensor. So, 3 different paths we have seen, when we discussed thermal infrared wavelengths.

And also earlier, the radiance reaching the sensor, a topic which we discussed in detail has this same 3 components, path radiance, transmissivity and surface reflected downwelling atmospheric emission. However, in microwave the effects of atmosphere are reduced in comparison with TIR wavelength.

Let us look at this particular slide. Here if you see, in x axis we have the frequency, here we have the transmissivity for one way, that is if this is earth surface and this is like the radiation going towards the sensor. If you look at this, for frequencies less than 5 gigahertz, the atmosphere is extremely transparent, the transmissivity is almost equal to 100% or 1 and within this 20 gigahertz frequency the transmissivity is more than 95%. And only after 40 gigahertz frequency, the transmissivity decreases drastically. In microwave region also we have specific atmospheric absorption bands like due to oxygen, due to water vapour and all.

But if you look at the lower frequencies less than 10 gigahertz or even less than 5 gigahertz, the atmosphere is fairly transparent. So, most of the frequencies we use for earth observation, say typically C band around 5 gigahertz, L band 1.4 gigahertz and all, these frequencies are fairly less prone to atmospheric absorption and scattering, so the transmissivity is almost equal to 1.

When we move towards higher frequencies, say x band and higher k band, ka band and all, there the atmospheric transmissivity comes down but even still the transmissivity is relatively higher than TIR wavelengths. So, this is one of the main reason why we can use microwave in all weather conditions, even during cloudy conditions we can observe using passive microwave radiometers.

Even during light rainy conditions, low frequency microwave will be able to penetrate through the clouds and less rainfall and get the signals from the earth surface. So, this microwave radiometry provides us all weather capability, because atmosphere is fairly transparent. The attenuation of microwave radiation in the atmosphere is very low especially at lower frequencies, when we compare this with thermal infrared wavelengths.

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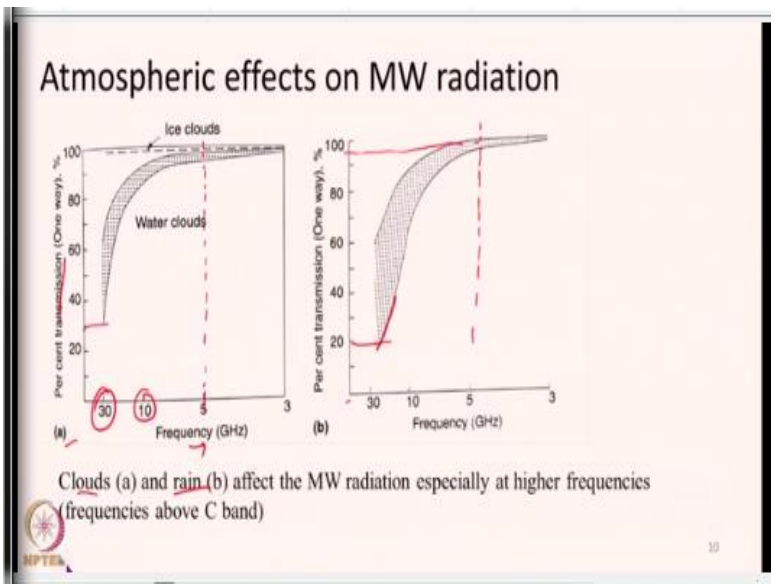
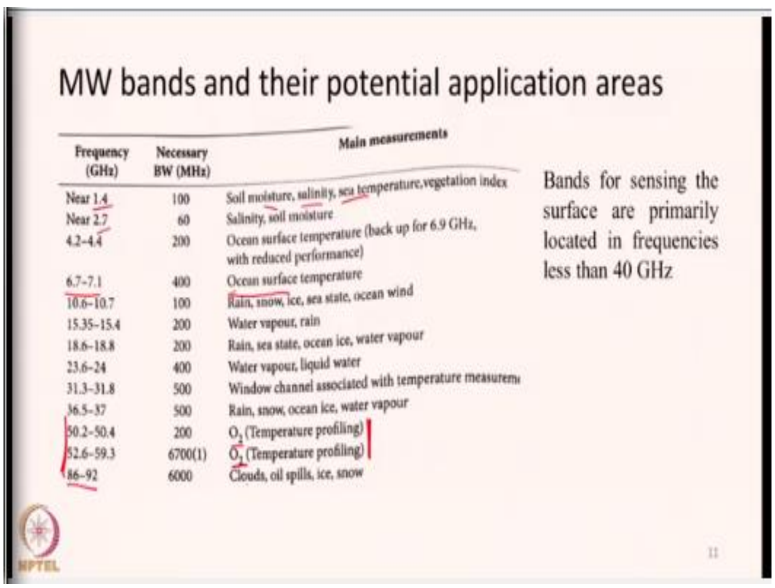


As I said clouds and rain will have some effect on atmospheric transmissivity, we will see how those things vary typically. Say this is the curve with frequency in the x axis and transmissivity in the y axis, again we look at frequencies less than 5 gigahertz, so we have C band and L band. Here if you observe, even in presence of water bearing clouds or ice clouds, the transmissivity is fairly high more than 95%. This plot a is for cloudy condition and plot b is for rainy conditions. So, again if you look at this 5 gigahertz threshold, the transmissivity is fairly high more than 95%, only when we come to high frequencies, around 30 gigahertz or even past 10 gigahertz the transmissivity comes down significantly especially if you move towards higher frequencies such as k band or ka band and all.

The atmospheric transmissivity drops drastically in presence of clouds and also in presence of rain. But remember one thing, if we have even a thin layer of cloud, we will not be able to get any signal from earth surface when we are doing optical remote sensing or thermal infrared remote sensing. But in microwave, we see there is still some amount of transmission even though it may be low 40%, 50% still some amount of transmission is there. So, the data will be cloud contaminated, but still some information will be provided. So, the penetration capacity of microwave is fairly high when we compare with other wavelengths we have discussed till now, the optical and thermal infrared wavelengths. So, microwave can be used for observing the earth surface even during cloudy conditions or light rain conditions. So, this is one of the primary advantages of microwave remote sensing in both active and passive modes. So, there are specific bands which are often used for various applications. Let us see which bands are being used for which applications typically.


MW bands and their potential application areas

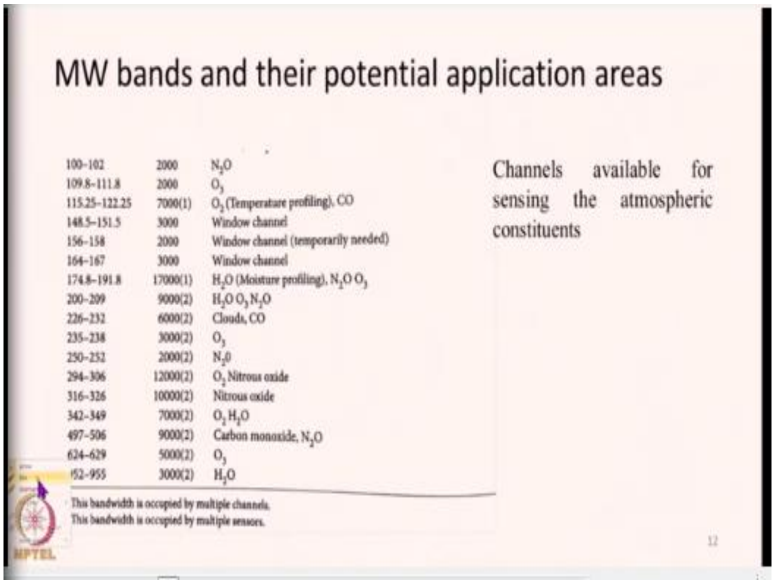
Frequency (GHz)	Necessary BW (MHz)	Main measurements
Near 1.4	100	Soil moisture, salinity, sea temperature, vegetation index
Near 2.7	60	Salinity, soil moisture
4.2-4.4	200	Ocean surface temperature (back up for 6.9 GHz, with reduced performance)
6.7-7.1	400	Ocean surface temperature
10.6-10.7	100	Rain, snow, ice, sea state, ocean wind
15.35-15.4	200	Water vapour, rain
18.6-18.8	200	Rain, sea state, ocean ice, water vapour
23.6-24	400	Water vapour, liquid water
31.3-31.8	500	Window channel associated with temperature measurem
36.5-37	500	Rain, snow, ocean ice, water vapour
50.2-50.4	200	O_2 (Temperature profiling)
52.6-59.3	6700(1)	O_2 (Temperature profiling)
86-92	6000	Clouds, oil spills, ice, snow

Bands for sensing the surface are primarily located in frequencies less than 40 GHz

Say the frequencies near 1.4 gigahertz or 2.7 gigahertz, normal used for measuring soil moisture, ocean salinity, sea surface temperature and all. And similarly the frequency around the 6 gigahertz is for measuring ocean surface temperature. The bands which are close to this atmospheric absorption band, around 50 gigahertz and around 100 gigahertz are basically used for calculating or observing the atmospheric components like oxygen or water vapour and all.

You can see, here the specific wavelength around this 50 gigahertz which has an oxygen absorption band is actually helpful for understanding or knowing the oxygen constituent in the atmosphere

O_2, the temperature profiling. So, something around this 90 gigahertz is for understanding clouds and so on.



So, typically the frequencies less than 40 gigahertz are used for applications related to land, say observing soil moisture. Observing land means in earth surface, be it land or ocean, the frequencies less than 40 gigahertz is primarily used for soil moisture, ocean salinity, sea surface temperature and all. When we move to atmospheric components for measuring water vapour, for measuring winds and all, normally higher frequencies are used. So, there are large range of frequencies in microwave which are potentially used for several applications.

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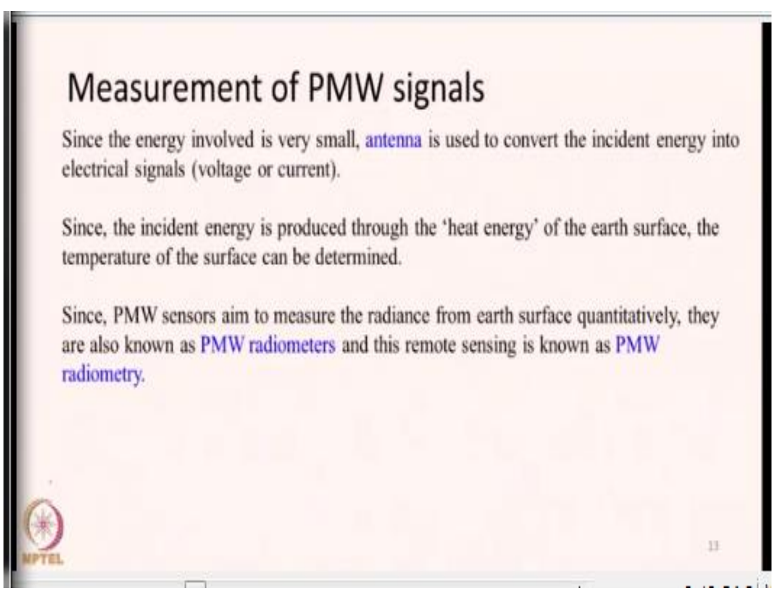

So, how do we measure this passive microwave signals? When we talked about optical remote sensing like visible, NIR and TIR remote sensing, we got to know about this Whisk broom sensors, push broom sensors, 2D array kind of sensors, all those things. So, there will be detectors, they will be looking at one particular area collect all the energy within it, and store within it as digital numbers, we have seen it. So, similarly how it is being done in microwave domain. In microwave domain, the detector we use for collecting information about earth surface is an antenna. It is not like a simple detector that we use in optical remote sensing, but it is like an antenna. So, antenna we might have seen normally for communication purposes and all. Similar concept is used, and the purpose of antenna is to convert the energy falling on it into an electrical signal.

Say the antenna is looking something like this, radiation from the earth surface will be coming towards the antenna. So, this particular antenna will collect the energy and in the other end within the satellite system, the antenna will convert this incoming energy to electrical signals. So essentially, what the antenna is sensing? The antenna is sensing some radiance that is because of the thermal emission from the earth surface. So, this will cause an electrical signal to generate inside the system and this energy that is reaching the antenna can used to calculate the temperature of antenna itself. So, essentially what we will be observing is what is known as an antenna temperature.

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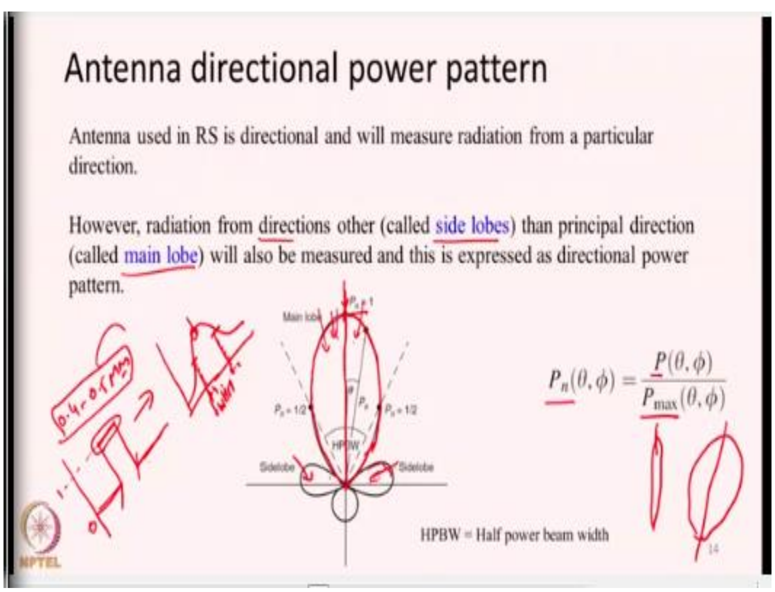

So if this is the radiation going from the earth surface and reaching the antenna, then we will be calculating what is known as an apparent antenna temperature. From which we can remove antenna sensor properties to calculate the actual brightness temperature or the effect of radiance that came in from the earth surface. So, essentially antenna converts the radiance emitted from the earth surface due to the thermal property into electrical signals. And this electrical signal is again use to calculate the temperature of objects, or emissivity whatever we need.

So, antenna is highly directional. So, direction means each antenna will be actually focusing in a particular direction. If the antenna is looking something like this, then it will be expected to collect radiation from only one direction what is coming straight towards it. So, antenna are essentially directional detectors, but most of the antennas will not be perfect, 100% perfect.

So, even though there is one primary direction of energy collection, there will be what is called side lobes, that is even in different directions, a small amount of energy can leak in and enter the antenna. For example see, this is the primary direction in which the antenna should collect the energy with its maximum capacity.

So, P_n is nothing but the power collected to the power max, so this is 1 here, this is the primary direction. This will have a lobe like pattern, lobe means this will slowly decrease as we move away from this particular direction. And this is maybe the center point from where the antenna is seeing. So, whatever power coming within this direction will be collected by the antenna.

So, the power coming in exactly from this direction will be collected as it is, but in other directions there will be some amount of deviation and the power may not be collected as it is. Each antenna may have its own lobe pattern, some antenna may be extremely directional, some antenna may not be as directional as we need and so on. So, it depends on the directionality of the antenna.

If the antenna is highly directional, then it may collect all the power coming in from only one particular direction avoiding all other directions. These are the side lobes, so that is even some energy coming in through these directions may enter the antenna in other directions apart from this specified one.

The main direction in which the antenna supposed to collect energy we call it as main lobe. And the other directions from which energy can leak through in or the radiation can leak through in, we call it as the side lobe. So, based on the antenna pattern, the energy that is being collected will vary.

Say if antenna is highly directional, let us say a hypothetical antenna which is collecting exactly in one direction. So, it will be collecting energy only from direction and other directions will be completely omitted. But let us say the antenna has a lobe like pattern, so one primary direction of energy collection will be there, but energy from some other features on the side will also be coming in and joining in.

So, this antenna pattern will play a role in sensing the radiance collected by the sensor. So, just think it in analogy with the spectral response function of optical sensors. When we discussed optical sensors I told you spectral response function though each sensor has one specific bandwidth say 0.4 to 0.5 micrometres and if the sensor is supposed to work within this bandwidth, we may expect the sensor to work something like this. All the energy less than 0.4 is not sensed, all the energy greater than 0.5 is not sensed, all the energy between this 0.4 to 0.5 sensed completely. So, this is like the relative response function, here it is 1, here it is 0, this is what we will normally think. But essentially what will happen, the sensor may not have a uniform data collection or response pattern within this 0.4 to 0.5.

That is why we define full width at half maximum concept, so this will define 0.4 to 0.5. So, there will be a peak wavelength at which peak response will be there. Then the response will go off and the point at which we have half response, full width at half maximum, we choose those endpoints and define it as bandwidth for that particular sensor.

Same concept here. So, at one particular direction the antenna will collect all the energy and in other directions also it will collect, but it will be lesser fraction, and all these things combined together will define how much energy is being collected by the antenna. So, the effect of this antenna pattern has to be removed, if we want to really get the signals only from the earth surface**.**

There are some equations to derive, relating this temperature emitted by ground surface, temperature reaching the antenna and all. For the sake of simplicity we will not derive those equations.

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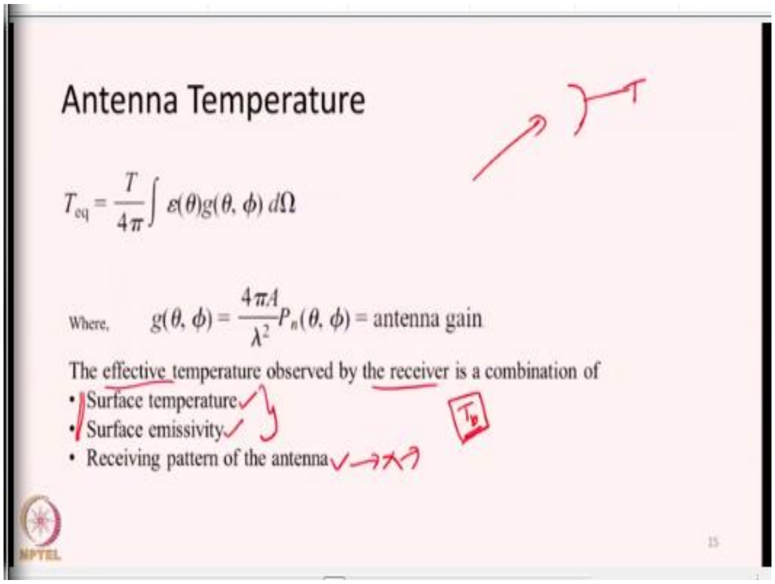

So, if there is antenna emission going from the ground, whatever is the temperature as detected by the antenna is actually due to the combined effect of the surface temperature itself, surface emissivity and then the receiving pattern of antenna. So, essentially if we want to get only the surface information we should remove this and have only these 2.

So, normally whenever satellite providers provide us the brightness temperature information, they will remove this antenna effect. They will do calibration to remove this antenna effect and they will provide us only the brightness temperature information containing signals about the earth surface. So, the temperature reaching the sensor or the temperature sensed by the antenna will have the effects due to surface, temperature and emissivity of surface plus the antenna receiving pattern plus some noise produced within the antenna.

Like thermal noise, antenna will also be having its own temperature and there will be some sort of thermal signals produced within the systems. All those things has to be removed off completely.

And the remaining signal is what we call, the brightness temperature which contains information about surface temperature and surface emissivity.

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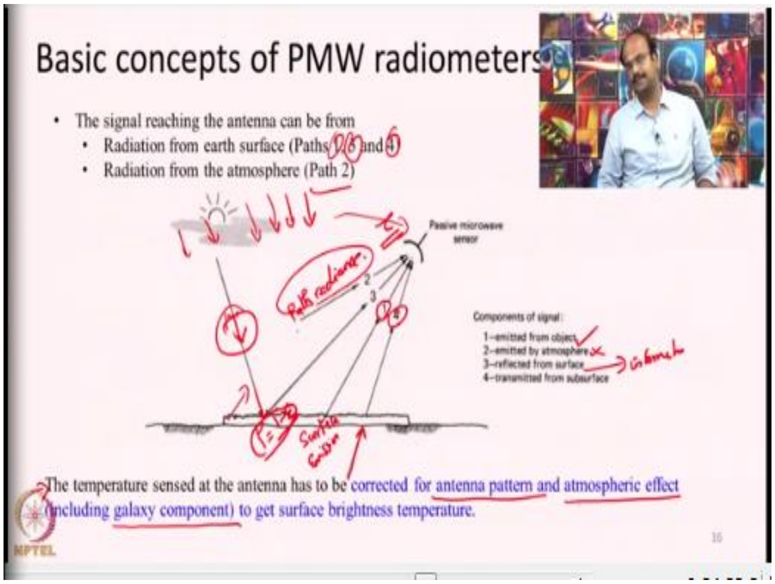

Next, what we are going to see is the different components of the signal that is reaching the antenna. See, this is the antenna or a passive microwave sensor. The radiation that is going towards the antenna can come from any one of the four path. Path 1 is the direct one which we need, that is due to surface emission. So, the surface is at a given temperature T with a given emissivity ε.

Due to those effects, the surface will emit some radiation; it will reach the sensor, direct emitted by the object, so this is of our primary interest. The second component here is the path radiance. So, the path radiance is essentially the emission from the atmosphere that is directly reaching the sensor without coming towards the earth surface, we do not actually need this, this is kind of unwanted thing.

Third thing is the emission from the atmosphere that is travelling towards the ground and getting reflected by the ground surface. So, path 3 also carries information about the surface, but here the major source of energy is not the surface emission, but the emission from the atmosphere. So, here we are providing the surface with some energy as an input in whatever frequencies we are observing.

And that incoming energy is irradiating the ground, getting reflected by the surface and moving towards it. So, reflectance = 1 - emissivity. So, at that particular wavelength or at that particular frequency, the reflectance will be 1- emissivity and that will be going towards the sensor. And the fourth component, especially this is present in microwave wavelength, that is emission from the subsurface features.

So, this is one of the major difference between TIR remote sensing and microwave remote sensing. In microwave remote sensing the emission emitted by features slightly below the surface will also reach the sensor because of the penetration capacity of microwave. Microwave can penetrate through various objects to a large extent, when compared with visible or NIR or TIR wavelengths. And hence the signal switching the sensor will have to have some information about what is being emitted by the subsurface. The depth may vary, sometimes it may be just 1 centimeter depth, sometimes it may be 5 centimeters depth, under extreme dry conditions it may be like few tens of centimeters and so on. But some information about the subsurface may be there in passive microwave signals.

So, if we look all these things, then essentially paths 1 and 4 contain the signal that is purely because of emission by the earth surface, the path 3 will contain signals both from atmosphere and also from the reflectance of the object, that is the emissivity of an object, and path 2 is the atmospheric path radiation components which normally we do not want. So, in total, the temperature sensed at the antenna has to be corrected for, first thing the antenna pattern, which we have already seen.

And the atmospheric effects in order to get surface brightness temperature. Atmospheric effect means this path radiance term and these atmospheric emission terms, if we correct for these 2 and sometimes transmissivity, especially at higher frequencies. So, we have to correct all these effects in order to calculate the surface brightness temperatures. Also in addition to atmospheric effects, there can be a galaxy component. Galaxy component means say the sensor is there in outer space, outer Space also will be continuously emitting radiation because that is also not in an absolute zero temperature. Some temperature is there, even though it will be extremely cold, it is still not at absolute zero, due to which it will emit radiation. That emitted radiation can enter the earth's atmosphere gets reflected by the surface or that cosmic radiation can directly reach the sensor.

All these kinds of outer space emission has to be taken care of. Because at the temperature of outer space, the primary emission from outer space will occur in microwave, most likely to occur in microwave wavelengths. So, that will also add up to what is being sensed by the sensor especially at low frequencies around this 1 gigahertz frequencies. It is essential for us to correct for this emission by outer space. Sometimes we call it as galaxy emission or sometimes we call it as cosmic emissions and so on. So, the microwave wavelengths emitted by the outer space because of its own temperature also can reach the sensor sometimes and we also have to correct for it before we get information about the land surface.

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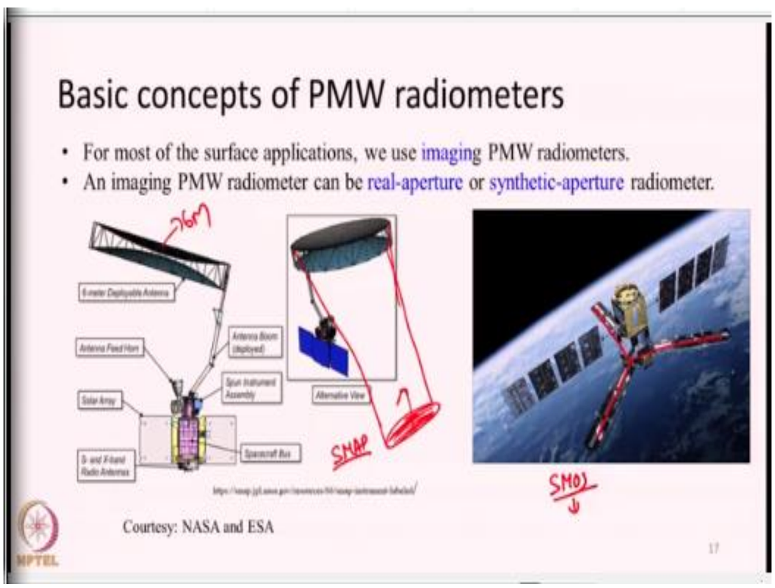

So, this is some basic information about the signals reaching the sensor about the antenna and all**.** So, now we know that antenna is going to collect radiation and what are the different components that will reach the sensor. How this will be collected anyway in general, say whether they will be like Whisk broom scanner or whether there will be like a push broom scanner, how this will be? In passive microwave radiometry, the instrument that collects the radiation from the earth surface, is called as a radiometer. Because, we are interested in collecting the actual radiation reaching the sensor, so we call them as radiometers. So, the passive microwave radiometers can be a real aperture radiometer or a synthetic aperture radiometer.

So, even before going towards it, the radiometers can be classified as imaging or non imaging, whether they acquire a 2D image or whether they acquire non image data. For our course, we will look at imaging radiometers that is radiometers which will provide us a 2-dimensional picture of earth's brightness temperature**,** say satellites like SMAP or SMOS.

So, such imaging radiometers, they can work in both real aperture way or synthetic aperture way, what are these 2? A real aperture radiometer is nothing but antenna will be there in space, so based on the antenna's diameter and other properties, it will have what is known as the antenna beam width. So, it will observed like a small area on the ground, very similar to our optical sensors. Our optical sensors will have some detector size. Based on the detector size it will have a GIFOV on the ground**,** same concept. Because of antenna size, it will have a footprint on the ground. So, whatever the energy coming within that particular footprint will be collected by this particular antenna. Now when the satellite is moving like this, the antenna will be now looking at certain area along this particular footprint.

So, whatever energy is emitted by this earth surface will be collected, but if the antenna is stationary, then nothing will happen, energy will be collected only within the straight line and when satellite is moving antenna will also be moving like this, that is all. So, antenna is looking somewhere here at an angle away from the nadir. Normally in microwave radiometers they will have some sort of incidence angle, not exactly at nadir. But it will look somewhat away from the nadir, so it will be tilted when seeing the ground surface. So, as the satellite moves it will cover one track of the energy, the antenna can be rotated mechanically or electrically to cover an area. So, let us consider mechanical rotation. Now the antenna is here, if it rotates continuously what will happen?

As a satellite is moving the antenna will collect energy in terms of overlapping circles. For example SMAP satellite which is launched by NASA, is actually a real aperture radiometer. So, it has a 6 meter deployable antenna, and it looks at some portion on the ground. Say this is the antenna footprint on the ground. So, whatever energy is emitted by the earth surface will be collected by this particular antenna element. So, now this antenna will not be stationary, this antenna will rotate about its axis. So, what will happen? If the antenna is here, slowly it will start rotating, so it will collect energy in the footprint in form of like a circle, now the satellite will move. Now the next circle will be collected, now the satellite will move, the next circle will be collected. So, slowly it will build kind of a swath around it, so just because of its rotation, it will collect energy in one particular swath, and it will be keep on collecting. But there will be repeated collections, say at some time it will be looking the object here, and when the satellite shifts, it will be collecting the energy over the same region by looking backwards.

So, energy will be collected redundantly, one by looking forward and for the same surface when it is rotating back. But anyway, at every rotation of the antenna it collects energy from new portion on the ground and it will be keep on adding up which will build a swath width. So, this is one very simple example of how energy is being collected by passive microwave radiometers. This is an example for real aperture radiometer, which is being employed by satellite called SMAP. There is another way, synthetic aperture radiometer where there will not be physical movement and all. One very good example of synthetic aperture radiometer is SMOS, another satellite that is there in space to observe soil moisture and ocean salinity.

So, here the satellite has 3 arms having lot of tiny, tiny antenna elements arranged in terms of arms of Y**.** So, this is like a Y English alphabet. There will be lot of antenna elements, so nothing will rotate here, but the same ground point will be seen by several antenna elements. And electronically they will be processed and combined together to create one full image. So, there are no physical motion involved, it is due to the complex data processing that the land surface observed by different, different antenna elements are stitched together to form one footprint or one full area. So, that is visualizing a passive microwave radiometer is not very easy. That is why I explained about like a real aperture radiometer to give a feel for how the data will be collected.

So, as a summary in this particular lecture, we have seen the atmospheric effects in the microwave radiation. We have seen also the basic concepts about how microwave signals are being collected in passive microwave sensors. With this we end this lecture.

Thank you very much.