Remote Sensing: Principles and Applications
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Lecture-04
Properties of EMR-Part 1

Hello everyone, welcome to the next lecture in the course Remote sensing principles and applications. In this lecture, we are going to see few properties concerning electromagnetic radiation. In the last class, we have seen the basic laws which help us to calculate the amount of radiation emitted by natural objects. So, we know how electromagnetic radiation is produced in nature, the basic principles of it.

So, now we are going to study what are the basic properties of this EMR and how these properties will be helpful for us in remote sensing purposes.

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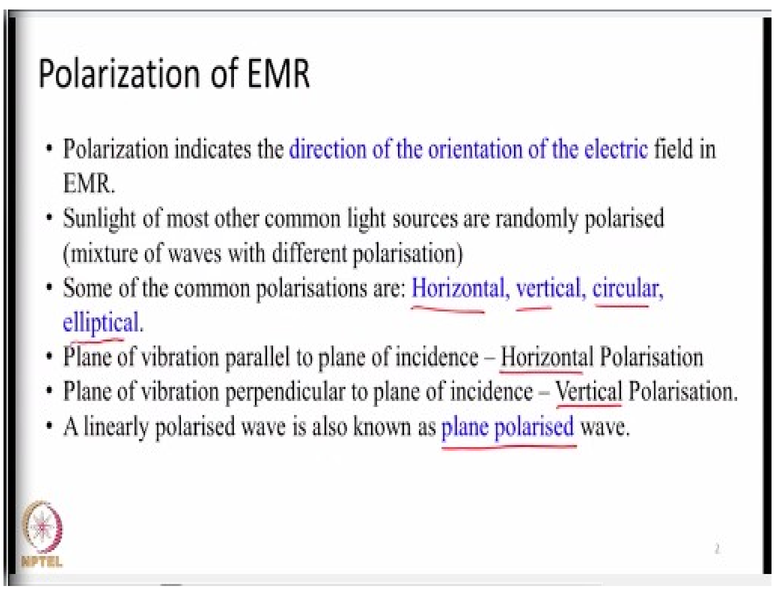

The first property of EMR that we are going to study is known as the polarization. When I introduced you to electromagnetic radiation, we came to know that EMR consists of 2 components, electric field and magnetic field. We also studied these 2 fields will be perpendicular to each other and also to the direction of motion. But even if we consider these 2 components are perpendicular to each other in a three dimensional space, they can take any orientation.

They can be vertical, can be horizontal or can be continuously changing its orientation and so on. So, polarization indicates the orientation of the electric field in electromagnetic radiation. So, in which direction electric field is oriented in relation to magnetic field and also in relation to the direction of motion, so this is polarization. So, the sunlight which is a primary source of energy for remote sensing purposes, consist of waves, at different wavelengths and with different polarizations.

That is, it is a mixture of waves which consist of different, different wavelengths and different, different polarizations. So, we naturally call the sunlight as randomly polarized or some literature call it as unpolarized that is it contains waves with variation in polarization. So, some of the common polarization we have are horizontal, vertical, circular and so on. So, first we see what a polarization is by 2 examples, then we will see more about few intricate details about polarization.

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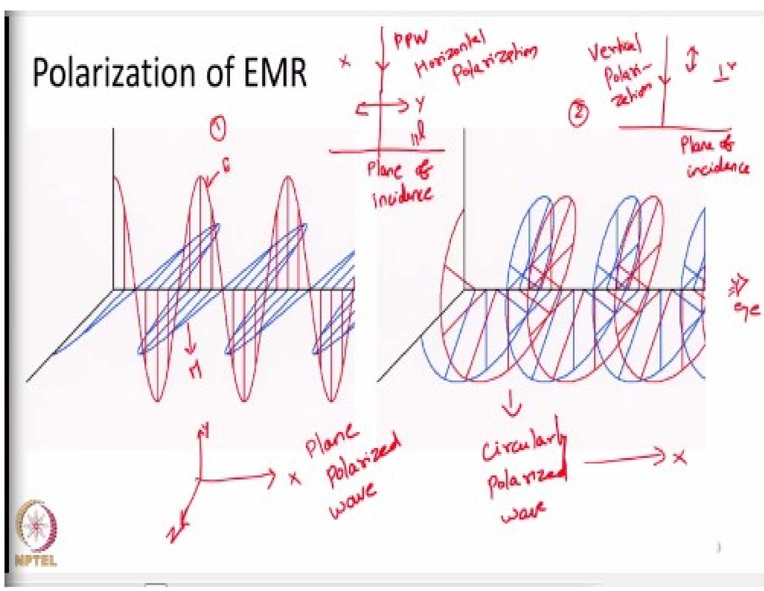

So, in these 2 figures we have examples for 2 kinds of polarization. In the figure 1, the red line is the electric field, blue line is the magnetic field. If you observe the wave is progressing from left to right in the screen, and the electric field is vibrating in a plane perpendicular to the direction of motion. And if we look at it, we can see that the electric field is vibrating in a vertical plane.

That is say if we take this direction as X, this direction as Y and this direction as Z. Then the wave is progressing along the X direction, electric field is vibrating along the Y direction and magnetic field is vibrating along the Z direction. This remains constant throughout the wave progression. Look at figure 2, using the same coordinate axis system, the wave is still progressing in the X direction.

Here electric field and magnetic field are vibrating in the Y, Z plane that is perpendicular to the X direction. But the orientation within the Y, Z plane keeps on varying, it is not a constant. As the wave progresses, the orientation of electric and magnetic fields keep on varying. That is if an observer is standing here and viewing, say if this is the eye of an observer looking at the wave coming towards him/her.

He or she can sense that the wave is now rotating, like the orientation is continuously rotating when it is coming towards the observer. So, the electric and magnetic fields are vibrating in Y, Z plane only. But the orientation is not constant it is keep on changing while coming towards observer. And the observer can sense it as almost like a circle, like it is rotating in form of a circle.

So, in figure 1, the polarization in which electric field is vibrating in only one particular plane, we call it as plane polarized wave. That is the wave is vibrating or the electric field is oriented in only one particular plane, we call it as plane polarized wave whereas in figure 2 we call this as a circularly polarized wave or circular polarization.

So, essentially if the orientation remains in only one plane we call it as plane polarized. If the orientation keeps on changing as the wave progresses, either if it is a circle we call it as circularly polarized, if it is elliptical we call elliptical polarized, there are different names. So, how to relate this polarization with respect to the plane of incidence? That is let us assume there is a plane or surface here, electromagnetic radiation is coming towards it and going to fall on it.

Let us assume this is a plane polarized wave, if this particular incoming wave has its electric field oriented along this direction. That is it is vibrating, see if you take this as X, if this is Y, if the electric field is continuously orienting itself only in the Y plane, then this is like a plane polarized wave. And this direction of orientation of electric field is parallel to the plane of incidence.

The plane of incidence is horizontal and the electric field is also vibrating parallel to it. Such orientation, in which the orientation of electric field is vibrating in a plane parallel to the plane of incidence, we call it horizontal polarization. On the other hand if the surface is like this, this is the incoming wave, in the incoming wave the electric field is vibrating in this particular direction that is perpendicular to the plane of incidence, then we call that particular polarization as vertical polarization. So, if the plane of vibration is parallel to plane of incidence that is horizontal polarization. If the plane of vibration is perpendicular to the plane of incidence, that is vertical polarization. And these 2 kind of polarization in which the electric field will be vibrating in only in one particular wave, such waves we call it as a plane polarized waves.

So, some of the common polarizations we use are horizontal, vertical, circular, elliptical and so on. So, this is the basic orientation of electric field which defines with which polarization electromagnetic radiation is coming in. What is the need for studying polarization? Why we should care about in which direction the electric field is oriented? Isn't it necessary if you just look at the total amount of radiation coming in. Actually the total amount of energy coming in or reflecting out of an object will vary with polarization also, that is I will give you like an example.

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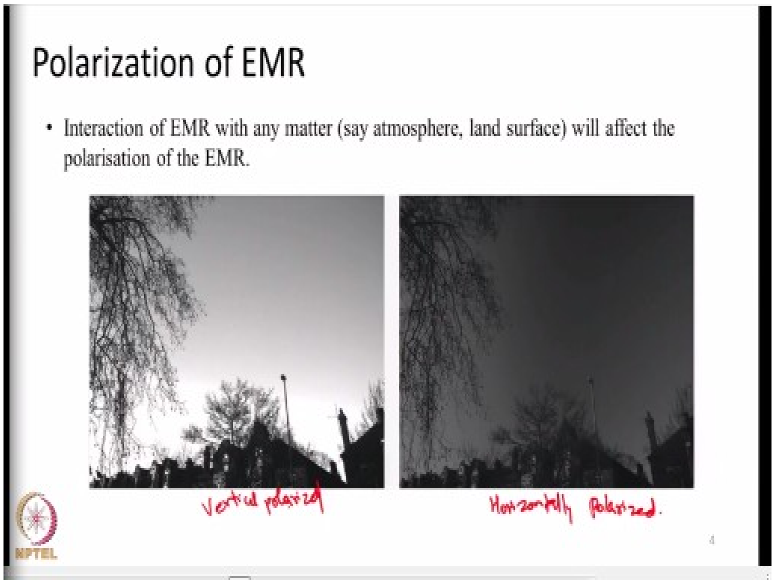

In this particular figure, same area is photographed at the same time but with 2 cameras one attached with a horizontally polarized filter and one attached with a vertically polarized filter. So, one on the left is photograph taken with the filter allows only vertically polarized light and on the right the filter will allow only horizontally polarized light. So, you can see the picture is for the same region taken in the same time but these 2 pictures appear completely different.

Because as we have studied that the incoming energy or the reflected energy whatever maybe will have spectral variation, that is the energy will vary with wavelength. And also within a given wavelength the amount of energy will vary with polarization also. That is say whatever energy coming in from the sun, a certain fraction of energy will be having certain polarizations.

Some maybe horizontal, some maybe vertical, some maybe like circularly polarized and so on. Similarly when electromagnetic radiation is incident on an object and interacts with the object, naturally the polarization will change. Like some objects will reflect more of vertically polarized light, some objects will reflect more of horizontally polarized light and so on. So, essentially the amount of energy that is incident on an object and reflected by an object will vary with respect to polarization also. So, the sensor which we use should be able to capture this polarization effect. That is by looking at the polarization we will be able to understand more details about the object. This object is reflecting more of horizontally polarized light, this object is reflecting more of vertically polarized light. So, such polarization information will help us to know more about the object.

And limiting one particular polarization will actually limit the total amount of energy coming in. That is like in this photograph itself shown in the slide, the one on the left actually removed all the horizontally polarized light. So, from the total amount of radiation coming in towards the camera a certain amount of energy is removed, only vertically polarized light is allowed in. Whereas on the right side only horizontally polarized light is allowed, vertically polarized light is totally removed. So, if you look at these photographs and infer the one with vertically polarized light appears much brighter, the one with horizontally polarized light appears much darker. So, what it means? In this particular scenario, if we look at the total amount of energy coming in, the energy had relatively a larger component of light that is vertically polarized rather than horizontally polarized light.

So, by limiting the waves in certain polarization, we will be limiting the total amount of energy reaching an object that is a major implication. And also as the objects interact with EMR, the orientation of electric field that is the polarization tends to change which gives us an indication about the nature of the object. Normally like when we go out in bright sunny days we used to wear polarizing sunglasses. If we wear such polarizing sunglasses the outer surfaces will not appear so bright, we will feel comfortable. Why? because the polarizing sunglasses naturally filters out certain polarization, like some of the polarization will be removed. That means you are limiting the total amount of energy reaching our eyes. That is why our eyes appear comfortable when we wear a polarizing sunglass.

So, having certain polarization filters will help us to limit the total amount of energy coming into a sensor. And this is really important when we do microwave remote sensing. In microwave remote sensing, the sensors will be capable of observing microwave signals in different, different polarizations, like horizontally polarized, vertically polarized, cross polarized and so on. And each object will behave differently under different polarized signals. So, polarization is really critical in order to understand about the nature of objects.

The next property we are going to see about electromagnetic radiation is known as coherency.

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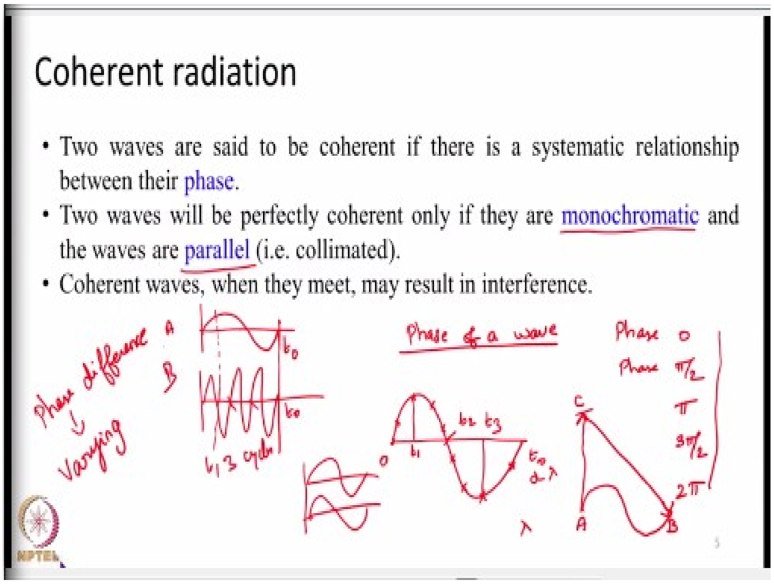

Before looking at what coherence is, let us quickly go back to our school physics days and recall what is known as a phase of a wave. So, we will see what is the phase of a wave? So, this is like one full cycle of a wave. Let us say a time is taken between like 0 and at a certain interval time t and at a certain distance d, that is λ, it completes one full cycle. So, for this one full cycle of wave, at each stage we should be able to tell at which stage the wave is.

That is if the total time taken by one full wave is t_0, then what is the stage of the wave at time t_1, what is the stage of the wave at time t_2, what is the stage of the wave at time t_3? If I want to tell at a given time interval at which stage of wave is progressing we have assigned certain angular values to it, say for example, if the wave is just going to start from 0th state, we call it as phase 0.

Let us say after a time period of t_1 the wave has come to its peak in its positive side, we call it as phase π/2. Then after crossing the peak in positive side it comes towards the 0 again, we call it as phase π. Then it goes in the negative direction reaches a negative maxima, we call it as phase 3π/2. Then again it comes back to 0, we call it as phase 2π, then we say the wave has completed one full cycle. So, the phase tells us at a given time or at a given point in phase, what is the stage at which the wave has progressed? This is like a simple explanation for phase, we generally correspond angular values to it and also commonly we call it as phase angle or phase and so on.

So, 2 waves are said to be coherent, when they have a systematic phase relationship between them, what is meant by a systematic phase relationship? Say 2 waves A and B are travelling together. If these 2 waves have same phase at a given time t or at a given space X, Y whatever, phase can be calculated at both temporal scale and spatial scales. So, if the phase is constant, if they both have the same phase or if they have a same phase difference, then those 2 waves are said to be coherent.

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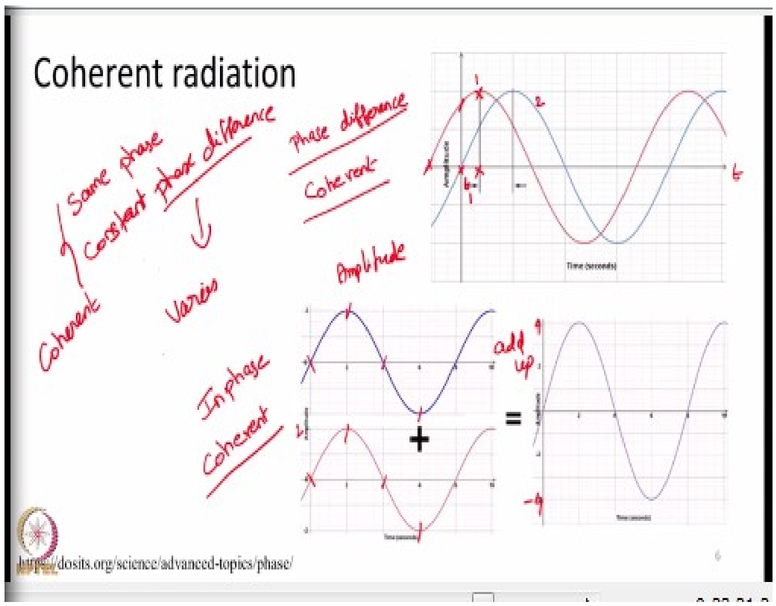

So, we will see this with few examples, there are 2 waves given here, one marked with blue color, one marked with the red color. So, here what is happening? With a given time axis, these 2 waves starting at a same time interval t_1, the wave marked in blue is just starting here whereas the wave marked in red has started from a 0 value and is moving towards this peak.

So, when wave 2 in red color reaches its peak, wave 1 is still not reached its peak value. So, this denotes wave 1 and wave 2 has a phase difference among them. These 2 waves do not have the same phase they have phase difference among them. So, if they have a common phase difference, if the phase difference remains constant throughout whenever it is along in the time axis, then we call this wave as coherent. That is the phase difference is there but still the phase difference is constant throughout. We look at the example given in the bottom figure, 2 waves are there same blue wave and red wave. But here in this case, both the waves are exactly in the same phase at the same time interval.

That is when it is time 0 both the waves are starting, when the time is 2 seconds, say like 2 units both the waves are reached its peak in its positive side, when time is 4 both the waves are reached 0 again. So, essentially it means both the waves are exactly inphase, then also we call these 2 particular waves as coherent. So, as long as 2 waves have same phase or constant phase difference, we call those waves as coherent waves.

On the other hand if the phase difference varies either with respect to time or with respect to space then those 2 waves will not be coherent. So, those 2 waves should definitely maintain a systematic phase relationship. They should either be in same phase or have a constant phase difference, then only we called those 2 waves as coherent waves. So, we go back to the previous slide, 2 waves will be perfectly coherent only if they are monochromatic and they are parallel to each other.

So, what exactly monochromatic is? Let us see example of 2 waves A and B, so wave A is like this slightly longer wavelength, wave B is like this, ok. So, this is sometime t_0, in time t_0 wave A completes only one cycle whereas in the same time t_0, wave B completes three cycles which essentially means, at any given time interval say t_1, t_2 and all, if you calculate the phase between these 2 waves, the phase will not match, there will be a phase difference.

And this phase difference will not be constant the phase difference will be keep on varying as the time progresses. Because of this difference in wavelength or frequency of these 2 waves, the phase difference also will be keep varying. So, unless these waves are monochromatic that is they travel with same wavelength or frequency they cannot be perfectly coherent, this is one thing.

And second thing is the wavelength should be collimated, so what exactly collimated is. They should travel parallel to each other or they should be having same path length. Let us say this is point A, this is point B, 2 waves are actually starting from point A with a wavelength λ and one wave is travelling directly to point B. Another wave is travelling in a different direction there is a mirror kept here at point C.

Another wave first travels towards C gets reflected at C and then reaches B. So even though the net displacement of the wave is from A to B because of the difference in length travelled and the difference in the time taken to reach A to B. These 2 waves even if they were coherent at the initial starting point, due to the variation in the path length and the time interval t, they would have definitely became out of phase. Their phase difference or the phase relationship between them would have changed.

So, 2 waves will be perfectly coherent only if they are parallel that is they are travelling parallel to each other and only if they are monochromatic. So, what is the implication of waves being coherent or not? So, another example is given here. In this particular slide we have seen these 2 waves are in phase, they are coherent. So, at a given time interval, they are having certain phase certain amplitude, like this peak or this trough we call it as amplitude, how much it is varying from the central 0 axis 0 plane of vibration. So, when 2 waves are exactly in phase, the amplitudes will add up and will produce a net resultant wave with an increased amplitude. Like these 2 amplitudes will add up, say if this is 2 unit when they add up they become four unit.

Similarly on the negative side also this is - 2, this is - 2 this becomes - 4. So, when 2 coherent waves meet up they produce what is known as interference. That is the amplitude changes because of the mixing of or the interference of these 2 waves. So, if 2 waves are in phase with each other, the amplitudes will add up and it will produce the net resultant wave with a much larger amplitude variation.

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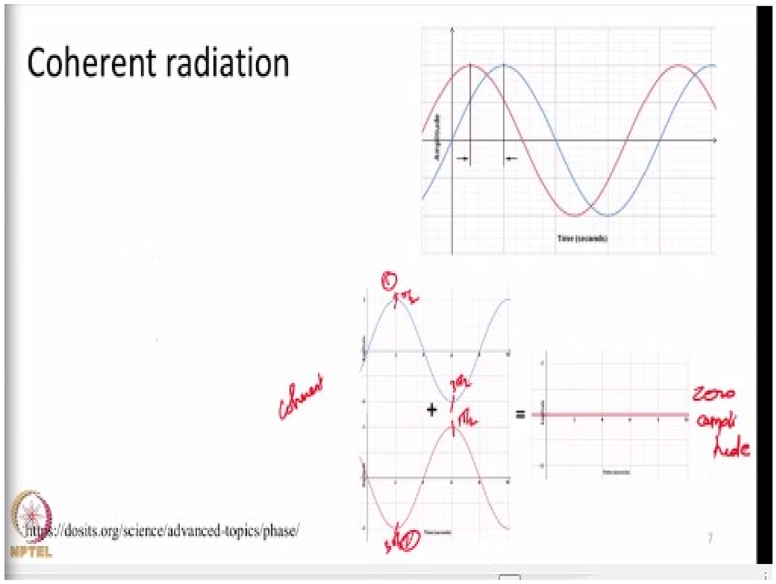

On the other hand if 2 waves are coherent but they are not in phase. Like here wave 1 and wave 2, they are coherent actually they have a constant phase difference between them. Like it is the phase difference here it is π/2 on the positive side, here it is 3π/2 phase. So, the phase difference is more or less constant, here when it reaches 3π/2, here it is π/2, so the phase difference is constant, so these 2 waves are coherent.

But when they mix together with each other because of the exact opposite sign in amplitude, they get nullified and produce the wave with zero amplitude. That is when 2 coherent waves meet, they either increase the amplitude of the net resultant wave or they decrease the amplitude of the net resultant wave, this is what we call it as interference. So, coherence, sometimes it will be like positive to us, sometimes it will be negative.

Like if you look remote sensing images due to coherence there can be some bright patches all along the image which will like obscure our signals, essentially it will occur more in microwave remote sensing, the coherence is quite a lot. So, coherence or interference will kind of act as a minor disturbance for us in remote sensing images. So, this is one of the important property about EMR that we should keep in mind.

Coherent radiation produce interference, the interference can be positive interference that is the amplitudes can add up if 2 waves are in phase or the interference can be negative that is those 2 waves can cancel out each other if they are out of phase. But non coherent waves cannot produce interference, like if the waves are not coherent, interference problem will not be there, ok.

So, just to summarize what we have learnt in today's class. We have studied 2 important properties of EMR, one is polarization another thing is coherence. So, polarization will help us to know how much of energy is coming in with different polarization and also how the objects interact. And second, we have seen what coherence is and how coherent radiation will either increase the amplitude of the net resultant wave or decrease the amplitude of net resultant wave. So, with this we stop this particular lecture, thank you very much.