Slide 1 – Title Slide

Hello and welcome to Week 3, Part 1 of EGM703: Principles of Microwave Remote Sensing. In this lesson, we'll learn about a portion of the electromagnetic spectrum that we haven't really worked with before, the microwave spectrum.

Slide 2 – Week 3 Outline

Through the rest of this week, we'll cover microwave interaction with the atmosphere and Earth's surface, and start talking about active remote sensing in the form of radar. There's also a supplemental lesson on complex numbers – it's there as an introduction in case you haven't worked with complex numbers before, as they are quite useful when working with microwave remote sensing generally, and synthetic aperture radar in particular.

Slide 3 – The microwave spectrum

Up until now, we've focused our attention on visible and infrared wavelengths, between roughly 400 nm and 35000 nm or so. For microwave remote sensing, we're going to be looking at the portion of the electromagnetic spectrum with wavelengths ranging from about 1 mm to 1 m. In the literature especially, you may see frequency discussed more often than wavelength – microwaves have a frequency ranging from about 300 GHz at the high end, up to about 300 MHz at the low end. Remember that 1 Hz is just 1 cycle per second, so even the "slower" frequencies are quite high – 1 MHz is 1 million cycles per second. Finally, similar to what we've seen for the visible and infrared portions of the electromagnetic spectrum, the microwave spectrum can also be divided up into different bands or regions corresponding to "similar enough" properties – we'll see this a bit more next week when we talk about applications of radar remote sensing.

Slide 4 – Recap: The Wave Model

We've seen this slide already when we discussed thermal remote sensing, but I wanted to show it again to highlight the phase, or partial wavelength. For the different forms of passive remote sensing that we've covered up until now, we've mostly ignored this aspect of electromagnetic radiation. When we discuss active microwave remote sensing such as radar and synthetic aperture radar, however, this is going to become rather important, because it contains information about how far away the target, or object that we're observing, is from the sensor.

Slide 5 – Polarization

Light is a transverse wave – that is, the electric and magnetic components of the wave oscillate perpendicular to the direction of motion. We can therefore define, or specify, an orientation for this oscillation, called the polarization of the wave. By convention, we normally define the polarization using the electric component of the wave.

In this top example, the wave is vertically polarized – the electric field is oriented along the x-axis, in the xz-plane. In the second example, the electric field is still propagating along the x-axis, but it is oscillating in the xy-plane – we would say that this is horizontally polarized. Light can be polarized at any arbitrary angle – it can even have a circular or elliptical polarization, where the plane is rotating around the direction of motion. Just as a side note, the fact that electromagnetic waves have a polarization is used frequently in microwave or radar remote sensing.

Because of this, we can actually construct filters that will only allow through light at a specified polarization. This is especially useful for radar remote sensing, where the polarization of the radar signal partly determines what we actually "see" with the signal. We can also use this to create glare-reducing polarized sunglasses, for example.

Slide 6 – Superposition of waves

Waves can also combine, or add together. You might also see this combination referred to as "superposition" or "interference" – if you've ever thrown multiple stones or pebbles into water, you've actually seen this in action. Mathematically, we write this as a simple addition: the combined wave, psi, is just the addition of ψ_1 and ψ_2 shown here. What this actually looks like, however, may be difficult to visualize, since the amplitudes, frequencies, and phase shifts (φ_0) are often different. In general, though, we can talk about two main types of interference, based on the phase shift between the two waves. If the phase shift is not an odd multiple of π, then we have something called "constructive" interference – the waves add together in a way that increases the overall amplitude of the wave. The example here, with a phase shift of 0 between the wave on the top and the wave on the bottom, shows how this works. The peaks and troughs of these two waves align (because there is no shift in phase between them), and the result is that the total amplitude of the combined wave is the sum of the amplitudes of the component waves. If, however, the phase shift is an odd multiple of π, we have what is called "destructive" interference. The example here shows what this looks like for a phase shift of π – the troughs of the first wave align with the peaks of the second wave, with the result being that the two waves cancel each other out – the combined wave has an amplitude of 0.

Slide 7 – Superposition

Of course, most of our examples won't be quite so simple, which is where complex numbers can be very useful. Because we can express electromagnetic waves as a complex number, and because we can express complex numbers as vectors, the combination of waves is just vector addition, which is usually quite a bit easier to visualize than trying to add together sines and cosines. So, let's say we have a wave, ψ_1, which we can describe as a vector with a real part and an imaginary part. As a side note, if this is all Greek to you, I encourage you to watch the supplemental lesson on complex numbers, which will hopefully clear things up. And, let's say we have a second wave, ψ_2, which is also a vector with a real and an imaginary part. The sum of these two waves, which we called ψ on the previous slide, is just the sum of the vector representations of the two component waves – again, this way of thinking about waves, as complex vectors, is mostly a technique to make the math, and the visualization, less complicated.

Slide 8 – Coherence

The last topic that we'll cover in this first lesson is coherence. If the phase differences between two vectors, or two waves, are constant over time, then we say that those waves (or vectors) are coherent. Because we can treat time-varying signals as a vector that rotates in time (again, see the supplemental lesson for a bit more detail there), this means that the angular frequencies of these two vectors (or the frequencies of the waves) are the same. This also means that we can treat them as stationary vectors – because the differences aren't changing in time, we can add them together without worrying about time. For example, if we have a number of different vectors, we can add them together like we showed on the previous slide. Starting with this first one here, we can add a second vector, and a third, and a fourth, and a fifth, and a sixth, and that's probably enough for now. The resulting vector, or wave, is still just the sum of these different vectors – we'll see this more when we talk about synthetic aperture radar later this week. Another way to think about coherence is that it's like a measure of predictability – if we have high coherence, that means that the phase difference is constant, and we can predict the result of interference by adding the two vectors. If, on the other hand, we have low coherence, that means we have a changing phase difference, and it's less predictable (because it depends on time). One way to measure coherence is by using cross-correlation, usually over a small window around a pixel. For radar applications in particular, high coherence between images acquired at different times tells us that the surface is not changing very much – this also helps us apply a number of techniques that we'll cover next week.

Slide 9 – Summary

In this lesson, we've re-capped how electromagnetic radiation is a self-propagating wave – we'll explain what we mean by this a bit more in the next lesson. We saw how we can combine, or interfere, different waves, and how this can be easier to visualize if we think about waves as complex vectors. Finally, we covered how life is much easier when the phase difference between waves is constant over time, a property known as coherence.

Slide 10 – Additional resources

You can read more about the topics we've discussed here in the textbooks – Lillesand, Kiefer & Chipman, Chapter 6.6. I've included a link to a video that provides a great (non-mathy!) explanation of Maxwell's equations, which are the fundamental equations that underpin the theory of electromagnetism, which is what has allowed for the development of electronics, remote sensing, and a whole host of other things. I've also included a link to a good video that talks about the polarization of light – it provides a bit more detail than we'll go into here, but it helps explain why things like polarized sunglasses or 3D movies work they way they do. There's also a link to the course material for GEOS657 at the University of Alaska Fairbanks, put together by Dr Franz Meyer – the material is far more detailed than we'll be able to get through in 2 weeks, but if this is a topic that interests you I very much recommend it, and it's a great resource to have online. Finally, I've included a link to a short article titled "Grand Challenges in Microwave Remote Sensing," which provides an overview of both the state of the field of microwave remote sensing, as well as some of the challenges that we still face.

That’s all for this lesson – I hope you found it interesting, and you have any questions, please don’t hesitate to e-mail me or post in the discussion forum on blackboard. Bye!