# Optical Engineering
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## Lecture – 40
## Holography

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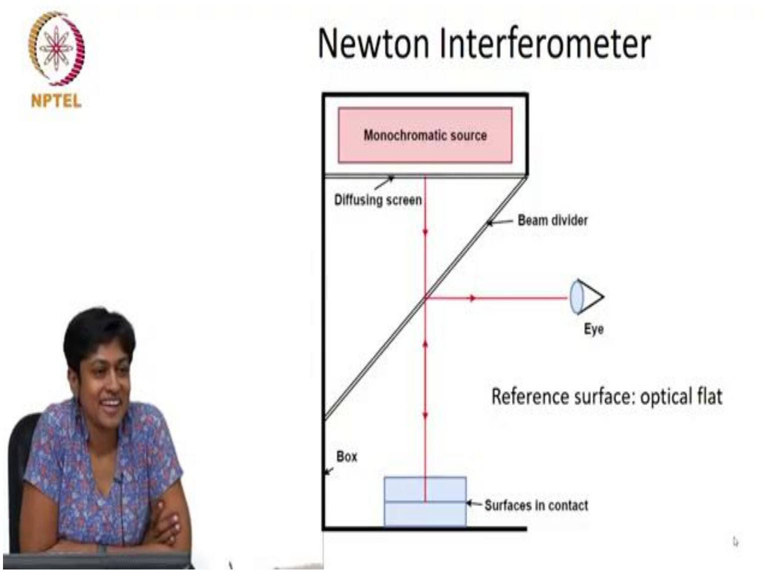


Good morning. So, we were looking at applications of interference last week. And in particular we were looking at using it to test surfaces, right. So, just to refresh your memory I have the Newton interferometer here. And as the name interferometer suggests it will create two beams.

The two beams that we are creating are, one is the reflection of the top surface of the device that is being tested, and one from the lower surface over here. And we saw some of these images, so, if you had a convex surface for example, resting on the reference flat you would get fringes like this.

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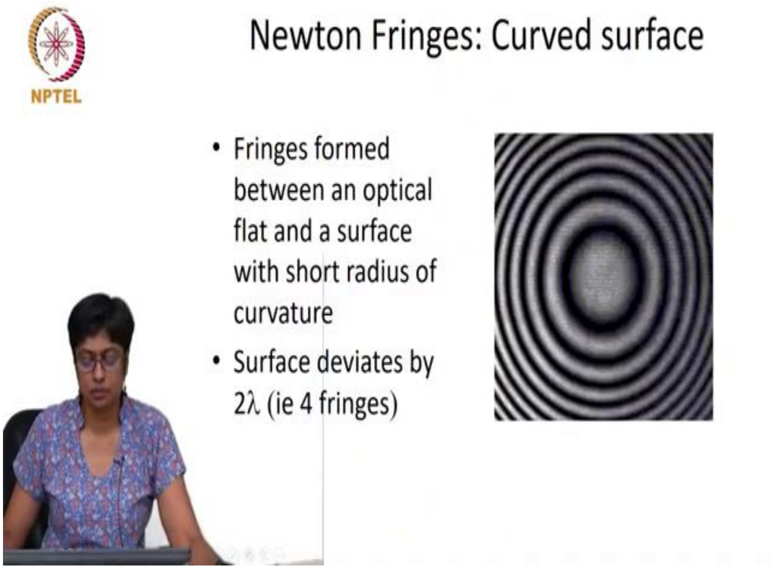


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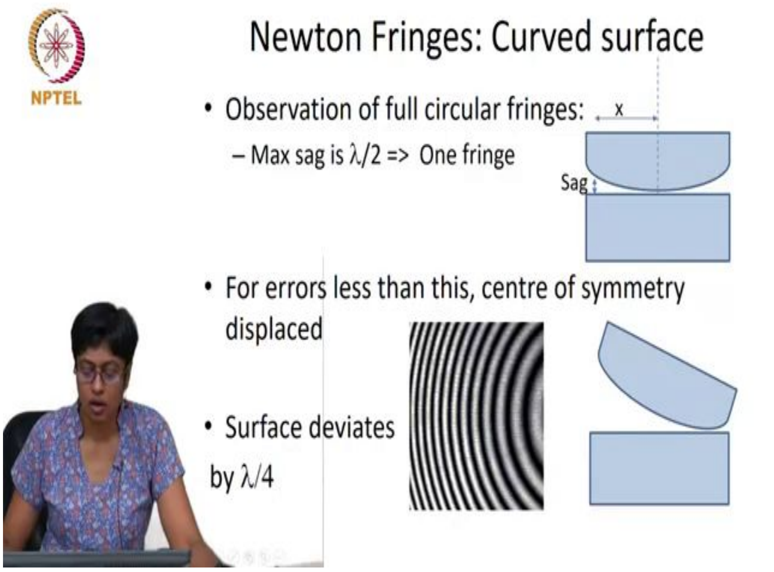


And you could not only check, what is nature? What is the shape of that surface? But you could also get a quantifier you could also quantify, how much is the curvature by counting the number of fringes. And if you had a very low curvature, so that you did not have a full fringe you could tilt the device. So, that you create more fringes and use that to help you quantify the curvature.

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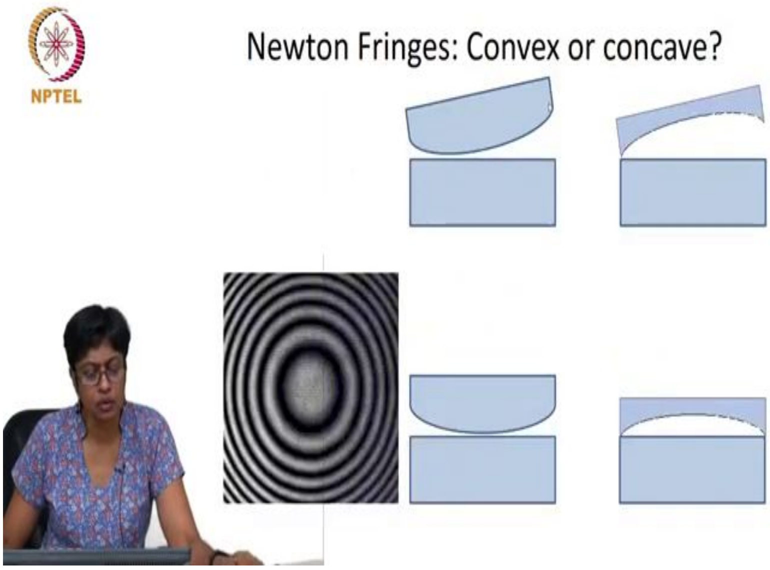


Then we also looked at how do you tell the difference between a convex and a concave structure and that would be based on how the fringes move depending on how you apply pressure to the device under test ok. So, the main point you should have got from yesterday, last week's lectures, is that interference very quickly gives you a visual on the shape or it could be the shape or the refractive index right.

So, it gives you a visual on the optical path length difference, between some test object and a reference object. And the main idea is that you are always introducing a reference whose sole purpose is to allow the interference to happen.

So, the idea is you have a reference that is known, it doesn't matter if it's a plane wave that is tilted, if it's a spherical wave it's a diverging wave it really does not matter if you know everything about that wave. And you are interfering with the wave you do not know anything about, but from the fringe pattern you can extract information about the unknown, that is the idea.

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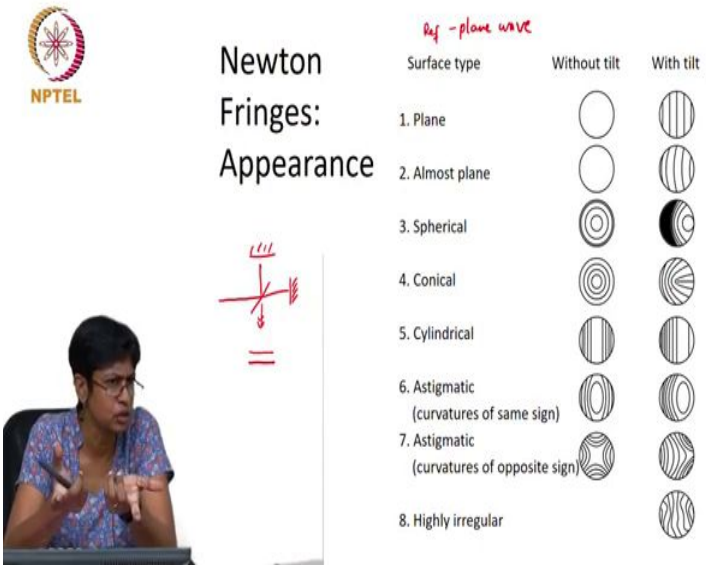


So, today I want to move on; before I move on just to show you typical fringes you get with the Newton interferometer, for different types of surfaces.

So, if you think back to our very early geometric optics days we had waves you could think of the wave traveling through your system, we looked at rays and we looked at ray pictures or intercept curves to tell what are the kind of aberrations we had in our imaging system.

But you could also look at a fringe pattern, and the fringe pattern between a plane reference wave and the wave of interest that the fringes would tell you about the wave front, the shape of the wave front. And if there is an aberration in that wave front it's going to be obvious in the fringe pattern ok.

So, if we look at the list of surface types here it could mean this is my surface and I am the wave that is now reflected off this surface. So, the wave now carries this information of the surface, I could also just think of it as a wave front has this shape and I am interfering it with another wave front and therefore, I am getting certain fringes.

Now, if the two beams that are interfering, the reference and the beam from the surface of interest. There is no angular tilt between them, they are perfectly in line, in the case of the plane wave we know that you are not going to see any fringes at all, we discussed this case with Michelson.

So, we said in Michelson you have a beam coming from source, you have a beam splitter, you have a mirror, you have another mirror and if these two mirrors are perfectly perpendicular to each other, the wave fronts coming from them are going to have an equal spacing between them. And since the spacing is everywhere equal between them, you are not going to see fringes because there is no difference in path length. You see constructive or destructive interference because of the change in the path length. If the path length is the same everywhere, I am not going to see that.

So, if I do not have any tilt and the reference here assumed to be a plane, it's a plane wave. So, if two plane waves have no tilt between them, I am not going to see the fringes. So, it's only useful to me if somehow, I introduce a tilt and I see these fringes. If it's almost plane, it means the fringes are going to deviate slightly from those linear cases as is shown here and of course, if it's spherical as we saw you will get the rings and for different shapes you can start seeing how the fringe pattern varies.

So, this is a visual way of quickly seeing how aberrated your wave front is or if not aberrated, what is the shape of the wave front ok. So very quick interfering interferometric technique to do that. And because you are looking at the reflection from the surfaces from the top and the bottom of this element under test, the path length is very small. So, you do not have to worry about coherence length, the source that they are using its coherence length will be larger than this.

And there is no alignment that you need. Have you done an interference experiment? Even the tech lab will have Newton’s Rings. You will have Newton’s Rings, right? Do you put it in and you see the fringes immediately, you have to look carefully and do something? Newton’s rings should be fairly straightforward, have you done a Michelson interferometer experiment? Did you get fringes immediately? No.

Student: No, (Refer Time: 07:06).

Right. So, when you have these different path lengths, then you have to match the path length quite carefully. Even for a source with the good coherence length right. So, whenever your setup is such that the paths are the same, the interferometer is a common path interferometer it will it's much easier because you put it in and there is no alignment right.

So, the Newton interferometer is a very powerful interferometer because it very quickly gives you information and there is no alignment needed. So, earlier in a workshop, in an optical workshop it would be definitely a tool that everyone would be using ok.

So, with that we end the one part of using interference for testing, but the applications or the possibilities that exist using interference are huge, there are so many things you can do with interference, you could; I could run an entire course on interference. I am, since you only have a few classes where I want to take you to one another idea that is used in a lot of different applications, but I am going to show you the idea and then we look at a couple of applications of that idea.

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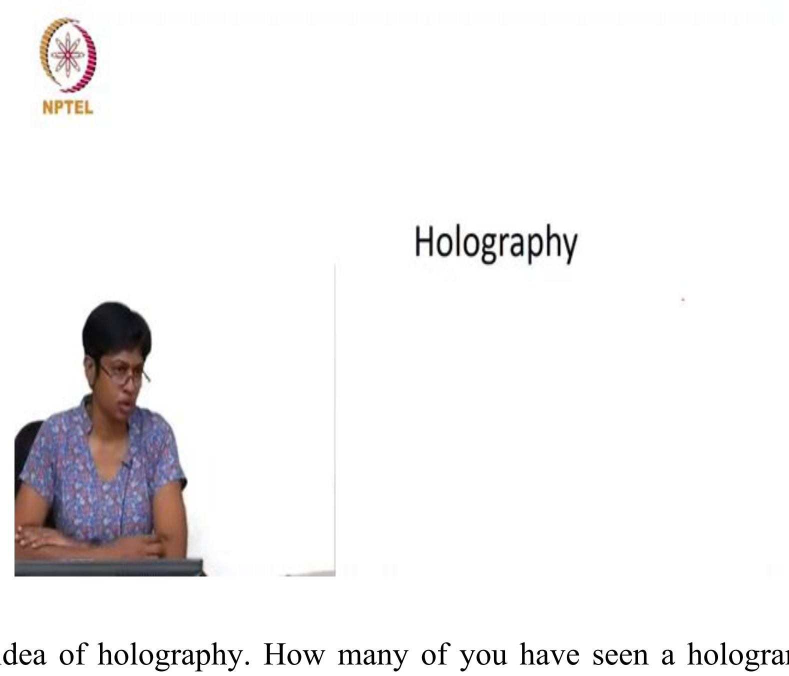


So, this is the idea of holography. How many of you have seen a hologram? You have all seen a hologram ok. The answer to that question is you have all seen a hologram, where have you seen a hologram?

Student: We have (Refer Time: 08:52) certificates.

Certificates ok, that is the first thing you think of every day you see a certificate. What else?

Student: (Refer Time: 09:01).

Lot of products nowadays will have a hologram stuck on it, why? Because, you want to show that it is a Genuine product and if you just put a sticker that says this is a Genuine product, you might find that it's pretty easy to print such a sticker ok. Whereas, a hologram is not easy to make.

So, the belief is that it's harder to make a hologram and therefore, that is a good thing to use on a security device, say a lot of currency notes in the world which have holograms on them and they are used in a variety of places as security devices. That they are used because, you can see now you have to you holography uses interference so you it's not a simple matter of taking a photograph or just taking a picture of something, you have to set up and create this interference pattern and somehow create the hologram out of that.

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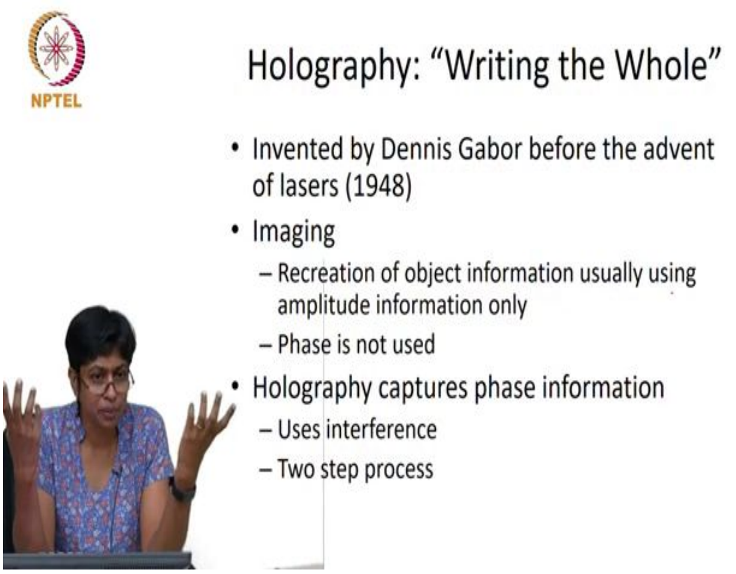


Now, what is holography? For all of this course we have been looking at designing systems or looking at the optics of systems and many of my examples talked about imaging systems.

So, in an imaging system, you took some optical system and created an image. What we may not have explicitly said or at least not every time I said we took an image, what we were really doing is looking at the intensity variation? Right. That is what a standard camera will do, we will look at the intensity or the colour variation, it tells you nothing about the phase.

But as you should now know, phase carries a wealth of information, and in fact, if I want to get true depth information, intensity is not going to give me that. If I see a picture which has only an intensity variation across, it's a lot of processing that happens in my brain based on prior experience that feeds me the depth information.

So, I know what the depth information would have been, but that is not giving me something I can quantify. And in a case where I do not know what to expect, I am looking at the images of some cells, I do not know what I am supposed to see. Then, I cannot look at a pure intensity image and really be able to tell anything about what I am looking at.

So, holography, it was invented well before the laser and it was thought this is interesting, but so what ok. Because, it was not very useful at that stage. It does not only recreate the intensity; it also recreates phase in other words it means you get the depth information ok, very very crucial.

It's a two-step process, unlike the use of a camera which well you might have thought earlier camera was also two step because you have to take on multi step. Because you took a photograph, you had a film, you had to process and so on. But nowadays with the digital camera, you take a photograph and you have an image, but in holography it's still a two-step process, because you take an image and that image you take is not a direct image, but it's an interference pattern.

So, you have to somehow record that pattern and then creating the image is the second step which is called reconstruction. When you see holographic stickers on you know used as security or as to show something is Genuine. What you are doing is the second part, you are using white light ambient light for the reconstruction process. Somebody else is carrying out that initial recording process and somehow stores that information in that sticker that you are looking at ok.

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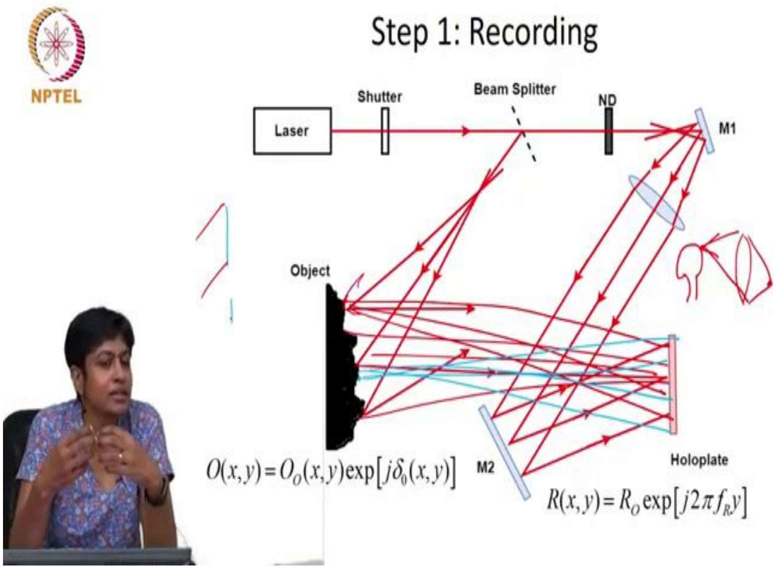


So, the first part, the recording part, since it's an interference based technique you will have a source with a good coherence link. So, like a laser, I will talk about why you have a shorter one later. So, you have a beam splitter, which will redirect some part of the beam to an object, I am not showing you all the optics in this, so if you need it the directions are shown by these lines, but if you needed the if the object was large of course, you will use appropriate optics. So, that the light illuminates the object. Just as with the camera if you have not illuminated it you are not getting back that information.

So, one beam goes to the object and scatters off this object, the scattered light now carries the information of the object, that is the information you want to somehow store and then later extract through the reconstruction process. The other beam goes to another mirror, I will come back to this element later and that mirror just you have a set of optics a set of mirrors and lenses that gets it to the correct size, as well as redirects it through a plate which is sensitive to light, which is called the hollow plate here ok.

So, these are the two beams now. There is one beam that acts as a reference that carries no information. All it does is travel a certain optical path length and arrive at this plane and the second beam goes to the object it reflects off the object, it carries the information I am interested in and that scattered light arrives at the same plane.

So, what happens on this plane is an interference if you have set up your system correctly. The hollow plate is a substrate, which has a material on it which is sensitive to light. So, when light is incident, a chemical reaction is happening and that reaction varies also depending on the intensity that is on.

So, it's not only sensitive to light, it's also sensitive to the amount of light ok. So, that is why you have a shutter over here because you need to block and protect the haloplate and until you want to expose it. This ND is actually a neutral density filter, it just cuts the intensity of light, why do we have this here?

Student: (Refer Time: 16:03).

To help with the visibility. You want the fringes that are recorded to have good visibility; that means, a scene well, the modulation depth is high. In order to do that the intensity of both these beams must be as close as possible one is scattering of an object, you would not be surprised if you said that is the weaker beam reaching the hollow plate and therefore, you have usually will have a filter here that just uniformly cuts the intensity, it's usually a variable filter you can change how much you cut, depending on how much gets reflected of your object or the type of object you are looking at.

And therefore, you are cutting, you are losing light in this arm. So, that the intensities in both arms are closer in value ok. And that interference pattern now gets recorded here.

Now, I have written out expressions here, this is the expression for the object wave, it has a certain amplitude that varies laterally. It has a certain phase therein lies the information, I do not know what that is, so I have just represented it as delta naught or again it varies laterally, so its a function of x and y. The reference wave on the other hand of course, also has an amplitude that is not a phase, but here I can be more specific about the phase because this is a known beam.

So, this expression $2\pi fR_y$ means, I have now got a plane wave that is tilted and it's tilted in one direction, which is why I do not worry about the x axis, here I worry only about the y axis. And that fR is related to the tilt and the length and the wavelength of light.

So, though I have similar expressions for both beams, object and reference, with the reference I can write out a specific expression because that is the known beam ok. So, that is the first step. So, what happens at that haloplate? Some I have to capture the interference of these two beams.

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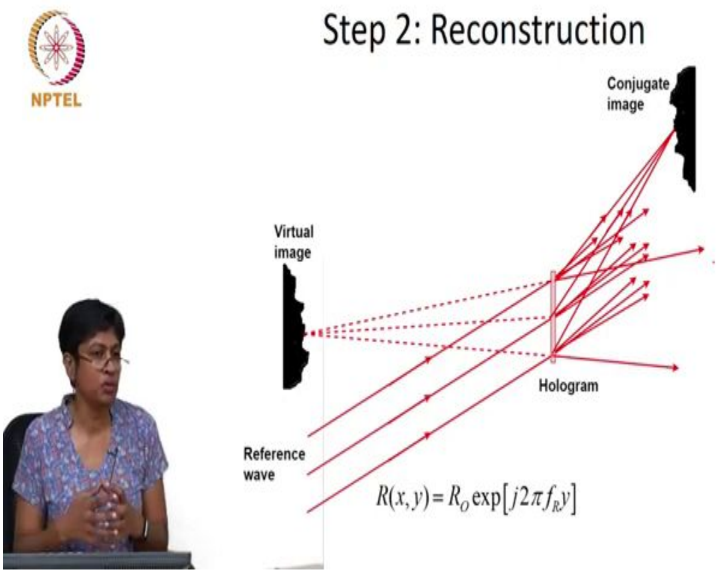


Student: Madam, why is that the convex lens is not converging previous one?

Why should a lens is; so, his question is why does not this converge. Why should it converge? Does a lens always converge?

Student: It's a by convex lens (Refer Time: 18:44).

Only if it has parallel beams on it. First of all this optics is put into this system, so the mirrors and optics are put into the system only to indicate you may need optics here to change the size of the beam. Do not go by the scale or position, but a lens converges to focus if you have a parallel beam of light incident otherwise, it is not right. But do not worry too much about what is happening over here. Anyway.

Now, if somehow this interference pattern is stored on the hologram, the way there is construction happens is that you will now, you remove all the rest of the optics, so all this optics that was here is gone. The object is also gone. What do you do? You have the hologram and you illuminate it with the same reference wave ok.

Now, when I say the same reference wave, I might be recording a hologram somewhere and doing the reconstruction somewhere else. So, I cannot have exactly the same wave. What we mean by the same wave here is it's the same wavelength, it coming in at the same angle of incidence. So, I can write out, I can describe the wave in the same mathematical sense that is what we mean by the same wave.

So, we have removed the entire setup that was used for recording and we now illuminate this hologram with this reference wave. And what happens in the reconstruction process is you will end up getting an image of the object ok. And it's a three-dimensional image of the object because it contains the depth information.

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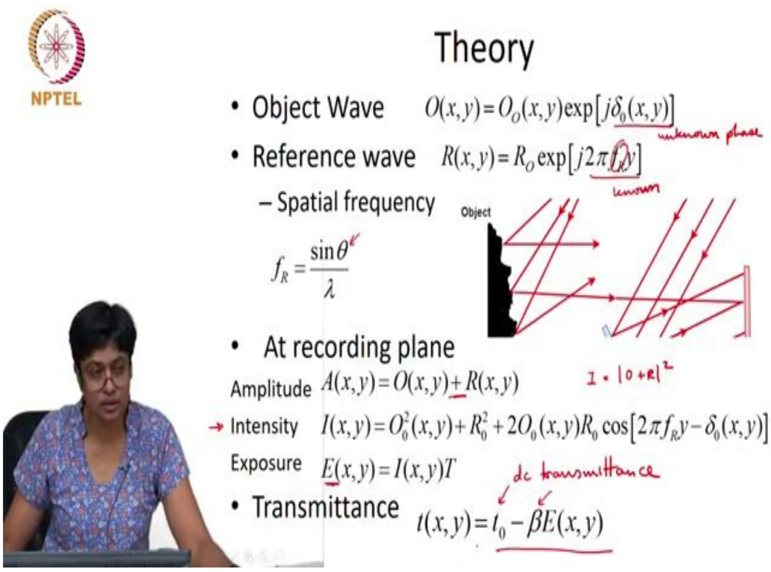


So, let us see how that happens. This was our object wave right, this was the unknown phase that contains the object information right. In a hologram, it's not necessarily that I want to get a value for $\delta_0(x,y)$ right. It may not be that I need to quantify that right. But I want that stored somehow, so that I reconstruct the object, that is the idea. This is a reference wave that is known right. And in fact, as I said this $f_R$, is a function of the angle of incidence and the wavelength of the light.

So, these two beams overlap and the amplitude of course, is going to be nothing, but the sum of them, the intensity is going to be this squared ok. So, the next term gives you the result of that squaring, I take this squared. So, I have the intensity of the object beam, this squared I have the intensity of the reference beam.

This is exactly your two-beam interference equation, it was I a 1 and a 2 now, and you had $I_1$ and $I_2$, that is what you see here. The next one would be the sum of the two terms that are $O*$ R, the phase difference between them O $R*$ the phase difference between them and if I combine those terms I will get this cosine term here, that is; this is exactly your two beam intensity, interference equation ok.

So, this is the intensity that is falling on the plate which has this material sensitive to light. And you can see the intensity varies across the plate, what is it a function of, it is of course, a function of the original intensities, but it is also a function of the phase difference everywhere ok. You now let this light be incident on the plate for a certain period of time T. So, that is the exposure.

So, the exposure this intensity I into the time T and we looked at what happens when you have a optical element with a certain transmittance right. We said if an element every optical element has a certain transmittance; that means, you have a certain beam of light incident on the element and then based on the transmittance it's going to have a certain behavior after the element. By exposing this holographic plate, you are changing the transmittance of that element, and you are changing it in accordance to the intensity that is falling on it.

That is how you are storing that phase information because the intensity that is falling on it is a function of the phase right. So, you are creating a transmittance, how are you creating that transmittance, you are creating a transmittance based on the phase difference between these beams. So, the transmittance ends up being something like this, where you can consider it naught like a dc transmittance. Maybe, the plate throughout will cut out ten percent. So, it's not, it should have been perfectly 100 percent transmitive, but it's not.

So, everywhere some amount of light is lost. So, that is this DC bias everywhere, irrespective of the location it cuts out some of the light. And then the transmittance varies location to location as a function of this exposure, and this is to do with some of the properties of the film, that is on the holographic plate.

So, there is some film which has these chemicals and so that beta is a function of one of that ok. As well as the development you have to actually this plate has to be very similar to the old film technology. So, it responds to light. that is the exposure part when you actually have to put it into a chemical and develop it. So, those regions where the light fell you fix that and you remove other regions and then you are left with this pattern all the things.

There is a whole process you go through. But finally, what you are left with is a plate with a certain transmittance that varies laterally and that is a function of the intensity pattern that fell on it, which in turn is a function of the phase difference between these two beams ok. Is it clear till this point?.

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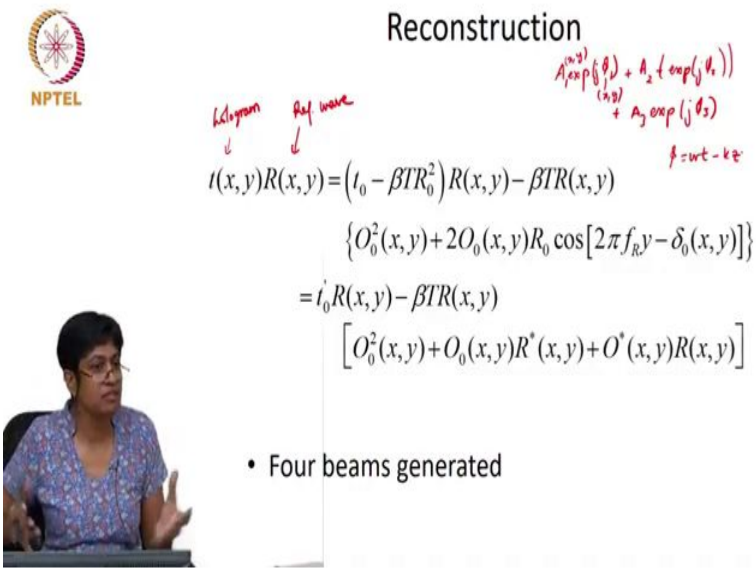


So, how do we do the reconstruction? Well we know if you have an optical element with a certain transmittance, multiply it by the incident beam to find out what happens after the element. So, that is what we will do here. We and what is the incident beam? What does it have to be, for a hologram? It has to be the reference wave. So, we take this as our hologram or the transmittance of our hologram. This is the reference wave, multiply them and remember this is the expression that we had.

So, substituting this multiplied by the reference wave is going to give me these different expressions ok. Let us take a moment and look at them right. It's just taking the transmittance and multiplying it by the reference wave and since the transmittance has every term of the interference pattern in it, the resulting transmittance has a number of different terms in it, it's not a single term.

It turns out. In fact, there are four terms. Now, if I take you know I write something like this. That summation means, that I am looking at the combination or; sorry this is not a summation this is ok. The summation between each of these terms means that I could consider each of these to be a unique beam, it has a certain amplitude.

In fact, that amplitude may be a function of x and y, the phase may be a function of x and y right. Each of these I could consider as a beam, when I say take this beam plus this beam plus this beam, it means all three beams exist simultaneously. Buried in that phase information would be information on which direction this beam is traveling, I have just put it as $\phi$ but $\phi$ remember is $\omega t - kz$. It tells me the direction of travel right.

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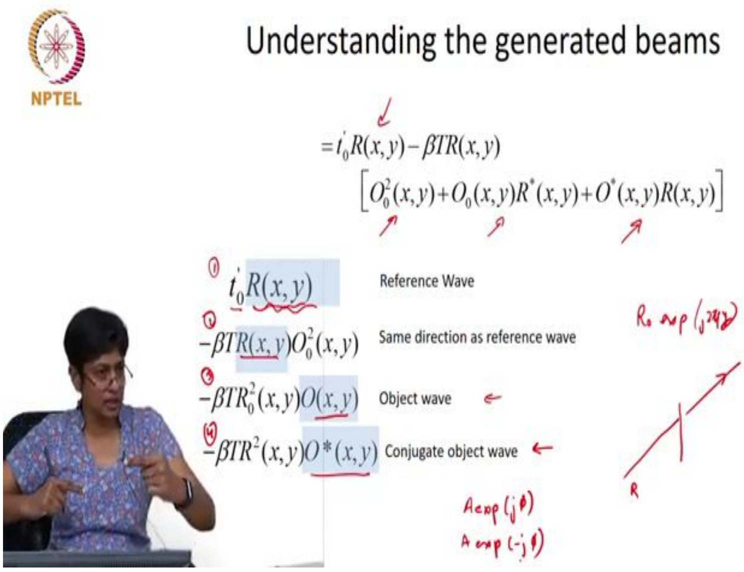


We might assume that these beams all have the same wavelength. Let us say I make no changes in wavelength. So, these beams are incident on something they are reflected and now

I am looking at these different beams and let us say the wavelength does not change, but the direction can change in each case right.

So, buried in this information about the direction, I can clearly see there is an amplitude variation, when I say this plus, this plus, this I am then looking at a space in which these three beams exist though they may be traveling in different directions. So, I am looking at that combination.

So, what happened when I multiplied the hologram with the reference beam, since its transmittance was the sum of several terms the multiplication also resulted in the sum of several terms, optically what does that mean?

It means multiplying or having the reference beam incident on the hologram, generates a number of beams right. And there are 4 terms. So, I can quite confidently say it generates four beams ok. What do those four beams mean? So this is our expression right. You have this you have this and you have this ok and of course, this ok.

So, if I look at them separately, I have; so, these are the 4 beams. I have one beam and how do I, how do I make out what each beam is from this multiplication of so many parameters? Right. Which one of these gives me amplitude information, which one gives me phase information?

How can I tell; which of these, what part of each of these will give me phase information? You all agree the multiplication results in these four beams right. So, if these are beams, then I must be able to say this is the amplitude of this beam, this is the phase of this beam. And if I can say this is the phase of this beam, then I can say this is the direction this beam is traveling right.

So, in each of these, which term will tell me what is a phase? Or has the phase within it? Can I tell or can I not tell?

Student: The last term (Refer Time: 31:47).

You say the last terms.

Student: Last two terms.

Last two terms, meaning.

Student: (Refer Time: 31:53) conjugate.

Each one of these is a beam.

Student: Hm.

So, this is beam number 1, this is beam number 2, this is 3, this is 4; that means, each one of these has an amplitude and each one has a phase. So, what is the phase in each one of these. The phase has to have that exponential something term right. And where does that exist, it does not exist here. It will exist in this I have written this is capital $R_x(y)$, but you know that is $R_0$ that whole term right, $j2\pi fR_y$ right. That is what we had put $2\pi fR_y$

So, the phase lies in this. In the second term, where does the phase lie? It will again lie here. Because, the O naught squared the phase has been multiplied out of that, that is a pure amplitude term. And in the next one the R naught squared, the phase is no longer there, so the phase lies in this. And in this case the phase lies here ok.

So, the rest of the terms contribute to the amplitude of the beam in each case. So, you are generating 4 beams, but you are not generating identical beams, you are not even generating 4 beams with identical amplitude, you are generating 4 beams, with each one having a different amplitude each one having a different phase, traveling in a different direction ok. So, of interest in terms of phase is the highlighted ones in each case ok. For the first beam, what is the direction it's traveling.

Student: First one (Refer Time: 33:50) same direction.

It is the same direction as the reference beam. So, you can imagine that you have this holographic plate, you have the reference beam incident and then you have a beam that continues in that same direction right. Unsurprisingly its amplitude is not the same as the incident because it interacted with this plate with this varying transmittance of all of the light. That incident is not going in the same direction.

If all of the light incident was going in the same direction, there would be no light or energy less to go in any other direction. I should not strictly speak of any other beams here. Then, I would just say I have a beam of light from that incident and this plate does nothing to it. It's as if it does not exist and the beam continues on the path.

The whole point of that hologram is that somehow it imposes information on the beams. And we can see, beam number one is not giving us any information. So, it arises from the nature of the setup, but otherwise is useless to us.

So, which beams or which beam carries the information that is useful to me well, it must be the beam that has the object phase in it. And you can see there are two beams, there is one which has this and one which has this ok. What do you think is a conjugate object? How would; so, the object wave carries the object information, the object phase? If I take the conjugate of that how would that look like? Or how would I perceive it differently?

Student: Phase is negative.

Phase is negative. You have mathematically told me, what happens. So, I have a beam of power. So, exponential j phi and then I take the conjugate and I say that is exponential minus j phi. And you look at these two. How will our eyes perceive this was different?

Student: (Refer Time: 36:01).

Will we see that difference? Finally, what is our response to? Intensity or phase.

Student: Intensity.

So, we cannot tell the difference. Right, but what the difference could be actually is whether something is here or something is here, could be some difference like that we might not be able to tell.

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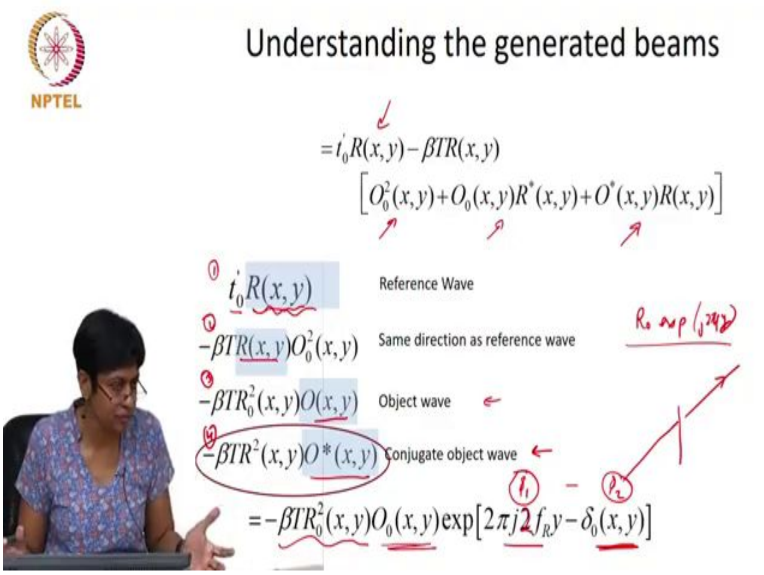


So, the beam of interest then to us I can look at as this beam number 3, it seems to be the beam of interest the object wave and if I write it out explicitly you can see it contains the phase of the object.

So, that is the phase we are interested in. But the phase term does not have only the phase of the object it has this phase. Because, its R naught squared there is an extra 2 here. So, how has this changed the phase of the object, the phase I am interested in is this. And yet in the exponential I have this $\phi_1$ and $\phi_2$ . I want $\phi_2$ , but I have $\phi_1 - \phi_2$ ,. What is that going to do? How is this beam now different from what I want? What is adding a $\phi_1$ do, what will it do to a beam.

Let us say I took this beam and I somehow remove this phase from this beam. What would I be doing to the beam? I do not affect the amplitude, but I remove this phase and what would I be doing to beam? What is adding a phase that does? In fact, when we wrote out the expression for the reference beam this, I said this f is a function of.

Student: Incidence.

The angle of incidence and wavelength. So, we are keeping everything simple, we are saying everything has the same wavelength. So, wavelength is not affected. So, what could this phase by removing $\phi_1$ or adding phi 1 or introducing $\phi_1$. How am I changing this object beam?

Student: Direction.

You are just changing the direction of the beam, right. If it has the original angle then you say that the beam travels in the same direction, I expect to see it in that same path, in that same axis. But by adding this phase, I have just changed the direction of where the object is.

So, what was our entire goal or starting goal with holography? We wanted to capture the phase of an object, so that we could reconstruct that object and get the full three-dimensional view. What this expression is telling us, that yes. I can do that, I generate a beam that has the object information in it. This tells me there is some scaling factor that is multiplied, right.

So, the object beam amplitudes are this, but I multiplied throughout by some scaling factor. So, that does not matter, this is going to have a certain scaling factor. And in addition that object beam is traveling now in some direction which is different from the original object beam, but that does not matter. My goal is to get the object beam.

I live with the fact, it's in a different direction what controls the direction, if the original reference beam angle will control that direction. So, I have some clay there, I can change that angle a little bit, but there are some reasons why I would not change that angle too much. But I could in this recording set it up to have a certain angle. So, that I control where the object beam happens ok.

So, what were the steps to get there? We did recording where we took the light scattered of the object and interfered it with a plane reference wave, that intensity got transferred to a plate sensitive to light and modified the transmittance of that plate, that plate is now what we call the hologram we illuminate the hologram with a reference wave with the same angle. And we see we generate a number of beams.

One beam clearly not useful to us it's the reference wave. And in fact, if you look at the second beam this is also a reference wave right. Both of these travel in the same direction their amplitudes are slightly different right. So, these 2 are of no use to us. The second 2 seem to have the information we want, the difference between these 2 is the directions they travel.

So, they are separated which is good right. So, it may at first glance appear like you have created 2 objects. And in a sense, you have, but it turns out one is a real object and one is a virtual object.

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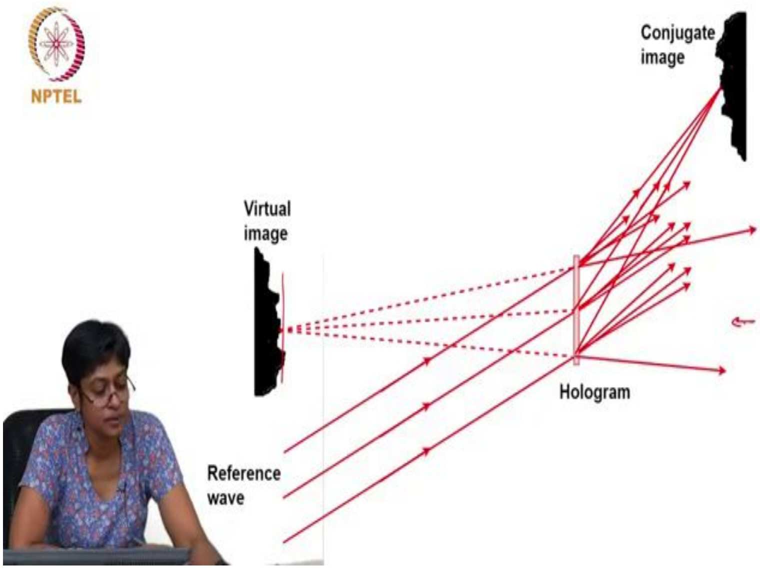


So, when you illuminate you will have light that converges forming this is the conjugate beam. So, it's not in the same position as the original object, but the image is actually formed by light focusing and coming to that point. So, if you put a camera there or screen there you would actually see the image. The second image is a virtual image, so that is light going off in some direction, but if you were to trace back it would look as if it were coming from the original object position right.

So, if I actually put a screen here, I would not see anything. Because, there is no light actually focusing to that point. But if I looked from this direction, my eye lens would look at that light and it would reconstruct as if the light were coming at that point and so I would see the virtual image ok. So, 4 beams are generators, two are following the direction of the reference beam, one converges to an image that I could then photograph and make a two-dimensional image out of, and the other one gives me a virtual image ok.

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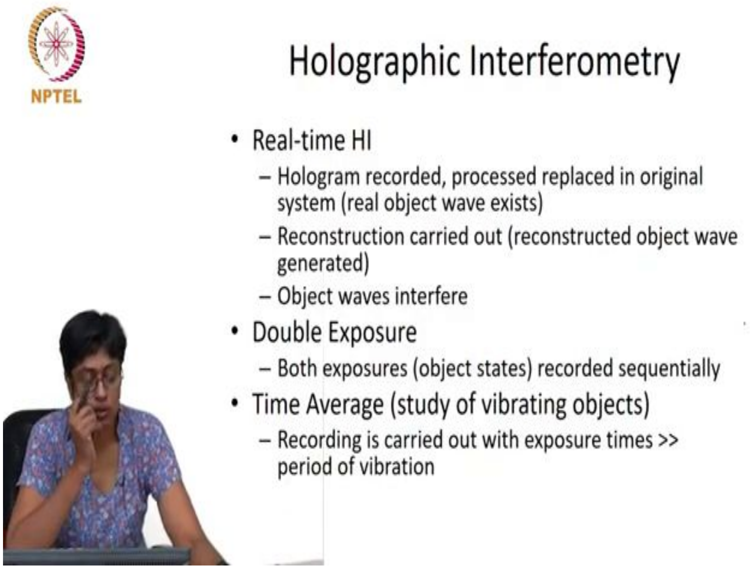


So, the 4 beams correspond to these 4 different directions ok. So, in a nutshell , holography came out ok. By using interference by adding this reference beam, you are capturing and storing the phase.

And then for reconstruction you are able to get out, so with the so the thing is we say conjugate image here, how do you think this image is different from image you see in a magazine or on your TV screen or on your phone, how is this image different from an image taken by a camera? I mean we have said it, but what could you do with this image different from what you do with your phone, when you look at something on your phone.

Student: With the incident perceive depth.

You can actually perceive depth, you could walk around this image and you would get perspective, you would see something from this side that you do not see from this side right. You would walk around depending on how that hologram was recorded, if lights were scattered from all around and there are many different ways of recording the hologram right.

So, in tomorrow’s demo which you will see in the physics department, they will show you Holograms and you will be able to walk around and see how it's very different ok. There is another big difference between an image taken with a regular camera and the image taken with Holography.

So, if we look at where my; this recording process is, if I have not drawn all the rays here, if I drew all the rays it would be just too messy right. Can you tell one big difference between this recording process and a recording of a regular of an image taken with a regular camera? What, there is one very big difference. In fact, we spent the first six weeks doing geometric optics and saying some one sentence I went on saying we use a lens to ensure that dash dash dash dash.

What is the big difference, from the light coming from the object in this case compared to how we capture light from an object, when we are going to take an image with a regular camera? First of all, there is something missing here, which I could not, I mean I cannot take an image in a regular camera without that right. I need a lens, my regular camera always has a lens right. What role did that lens; when did we say we had an aberration? Geometric optics, remember that topic that we briefly brushed against.

Student: Off axis focusing (Refer Time: 46:39) because of lens.

These are 3 useless answers ok.

Off axis big lens because of lens and mathu, I did not even hear your answer. Give me hope, what was your answer?

Student: There is no focused image (Refer Time: 46:56).

So, you said not focused. There is no lens here. There is no question of focus here right. So, how is it that I am getting the information that I want, that is not even the question I wanted to ask you, I want to ask you something else, but we need to answer this first too.

Student: Mam you did not actually describe the optics used in this case.

There is this. I am saying the only optics I may have left out is optics to make it large enough to illuminate the object ok. The light that scatters off the object is what hits the holographic plate.

Student: If we use more chromatic lights there is (Refer Time: 47:49).

That might get rid of chromatic aberration, but that is about it. That is, that does not. So, all in the in a conventional imaging I used to keep doing this, I would say; let us say I am imaging a tree, then all the light from one point on this tree or one point on this object, this optical system has to capture all of this light and if it's a good system or well-designed system all of this will go from one.

Student: Point.

Point image. I am not doing that here. I am saying the light scattered of the object, all of the light scattered of the object reaches this right and; that means, light scattered from this point some of it will reach this, some of it will reach this, some of it will reach this. In my conventional image in system all of the light from one point had to go from one point on the image plane, that is how we defined aberration. If it did not form one point, we said it's a aberrated.

Here I removed that constraint completely right. Because I am not capturing the image directly, I am capturing the interference pattern ok. So, that is not an issue here, but there is a big advantage in seeing light from one point. So, let us say this point hits this part of the plate, it hits this part of the plate, it hits this part of the plate, it hits this part of the plate. What is the advantage in having that light hit every single part of the Hologram? What does that mean? Do not get confused, you might say we spent half the semester learning about why I need a lens to do imaging and now you say I do not.

Holography is one thing I find a bit easier to understand when I do the maths. Because, with the maths I showed that the intensity is a function of these two beams and one of these beams is the scattered beam, that is going everywhere right that transforms the Holographic plate and when I illuminate it you saw you got 4 beams of which some beams carry object information.

So, go back and understand, be convinced of the maths the physics of it will follow right, but what is the advantage of the fact that light from one point exists all over my hologram, what is the advantage in that?

Student: Same point looks in different (Refer Time: 50:41).

It looks different from different angles, that is part of the holographic process yes, but what is the other, what would what would. So, you will see this tomorrow, he will show you a Holographic plate. So, if I give you a Holographic plate and I give you a photograph with the photograph you look at, you immediately know what you are looking at, right. When you look at the hologram you do not have a clue, what you are looking at you will see a fringe pattern or some weird noisy if kind of fringe pattern.

So, you do not directly see you need that reconstruction process to see ok. If I take my photograph and cut it in half, have I lost information? Cut it in half and throw away half the photograph, I have lost information right. If I take my hologram and break it in half and throw away half, have I lost information?

I have not, because every point on the hologram contains information about every point of the object right. That is one big advantage. Of course, when I reconstruct, I am reconstructing with half a hologram so if I could send so much light onto the system, I can only send half that light.

So, the intensity may go down, the brightness may go down. Because less light is taking part in the process, but the information about every point on the object is stored everywhere on the hologram, that is a big difference. No, it is not a free lens, that is what I said it's not a free lens because, if I had a hologram and I send this much light all of this plays a role in forming an image.

Now, if I break the hologram, that is always true. What you capture is what has scattered and reached your holographic plate. If the scattered light does not reach the holographic plate, you are not capturing that information. That is true, whatever the size of your hologram right. But I have shown you a very simple setup of holography. In reality, in practical systems they have systems where they will record and move 360 degrees around, so that they capture all of the scatter there are many different means of recording.

So, that you capture depends on I will not get the information I said you would walk around the hologram and you can see everything around that only happens if you are recorded scattered light from all around. You are not going to see the back of a statue if you never recorded the scattered light from the back of the statue. So, it of course, rests on what scattered light you captured

But for the scattered light captured, assuming that for some a cone of light all of the scattered light covers all of the holographic plate, if I break it into half or why half I take one tenth of the size or one hundredth of the size I will still reconstruct my object. But I can only shine so much light on that smaller area. So, I have less bright reconstruction. Whereas, of course with the photograph if I cut it into small and smaller bits, I am losing more and more information.