Applied Optics
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Lecture 56
Basic Concepts of Holography - II

Hello, everyone. Welcome back to the class. In the last class, we were talking about holography, and there in we will learn about inline hologram. And there we found that there is some limitations which inline hologram exhibits. Now, to rectify those limitations, a new type of hologram has been proposed.

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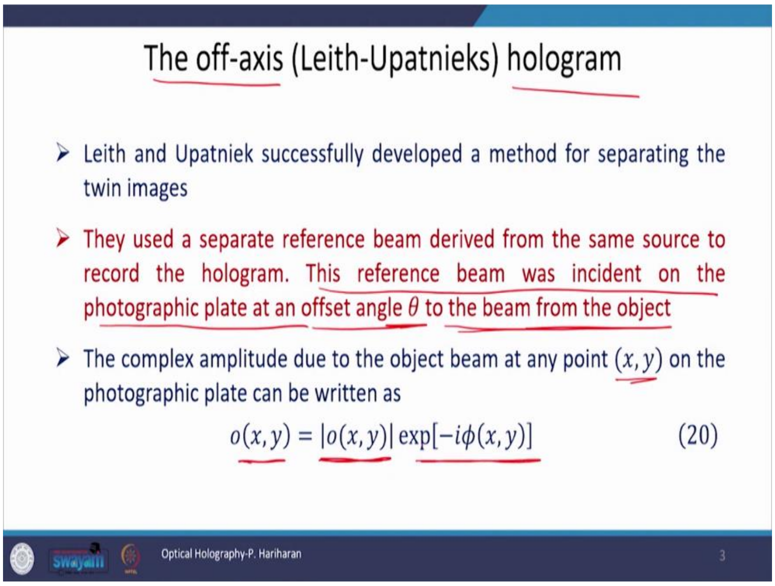

And this is called off axis hologram. And Leith and Upatniek successfully developed this method. And they were successful in separating these twin images, twin images means the one virtual image and the real image which we found that they were overlapping in on axis hologram. Leith and Upatniek, they use the separate reference beam derived from the same source to regard the hologram.

While in the ON axis hologram, we found that there was one source which was illuminating the semi-transparent object and the part of the light which was transmitting this semi-transparent object was working as a reference beam, but here a separate reference beam was used and a separate beam which goes to the object and then get scattered these two beams combine at the photographic plate, but both of these beam originate from the same source.

Now, the new reference beam was incident on the photographic plate at an offset angle θ to the beam from the object. And the complex amplitude due to the object beam at any point x y on the photographic plate this can be written in this form, $o(x, y) = |o(x, y)|exp(-i\varphi(x, y))$ and its phase part here in this exponential part.

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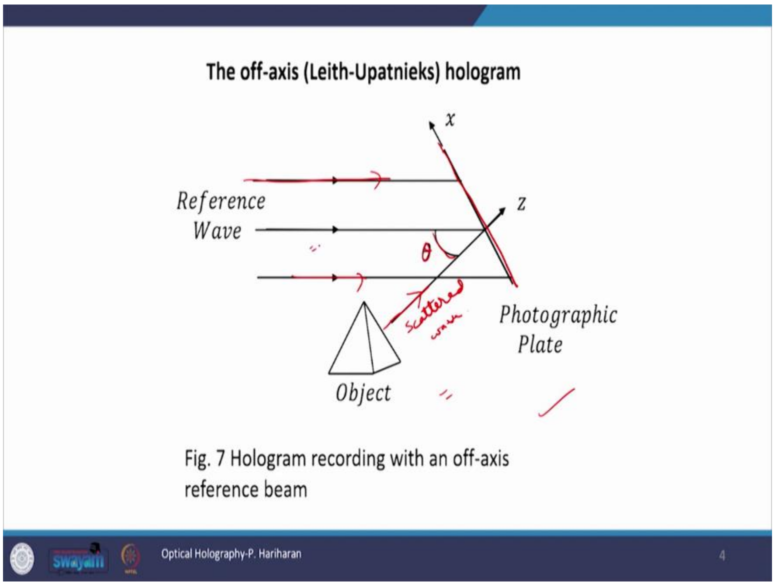

Now, the schematic representation of this off axis hologram is shown here in figure number 7, where you see that we have a source, from source the reference beam is directed to the photographic plate and from object we are the photographic plate is also receiving the scattered waves here, from object we see scattered wave, the object is also illuminated from the same source.

And the reference beam is also being generated from the same source and then these one beam goes to the object get scattered and then again falls on the photographic plate while the reference beam directly falls on the photographic plates and there they combine and they generate a hologram. Now, this process is called recording of off axis hologram, you see that the scattered beam is inclined at angle θ with respect to the reference beam.

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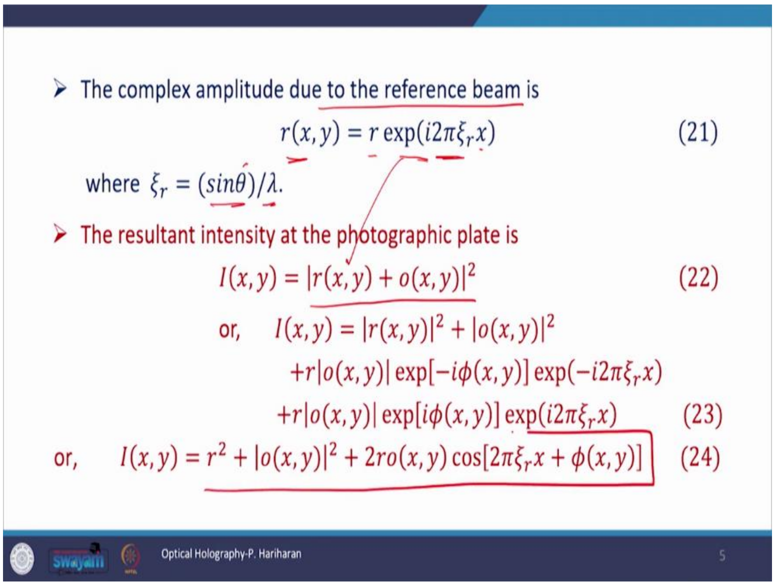

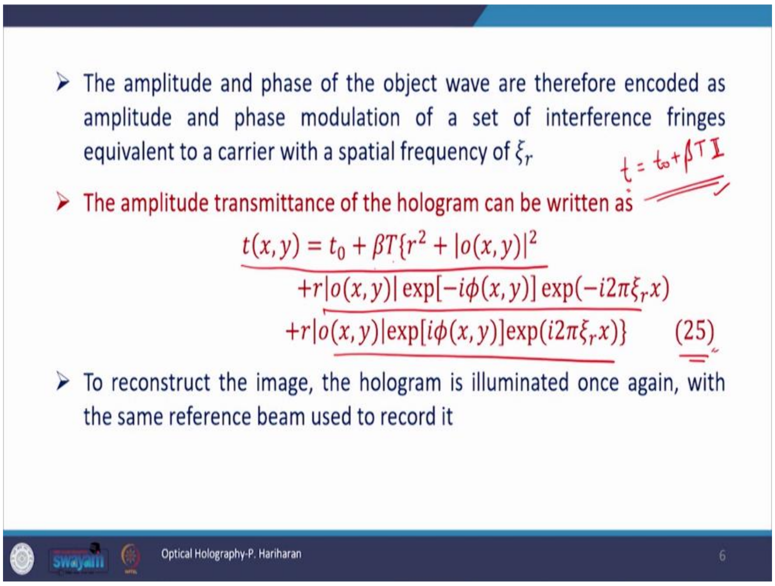

Now, the complex amplitude due to the reference beam is represented by r, which is the same representation we used in the on axis hologram. And here r is represented by $r(x,y) = rexp(i2\pi\xi_r x)$ where $\xi_r = (sin\theta)/\lambda$, θ is a same angle which we saw here in this figure, this is the θ now, the resultant intensity at the photographic plate would be $|r(x,y) + o(x,y)|^2$ here we are using the superposition principle.

Now, we will substitute the values of r and o from equation number 20 and 21 respectively. And after substitution, we finally get equation number 24 which is the resultant intensity at the photographic plate due to both reference beam and the scattered beam or beam from the object. Now, the amplitude and the phase of the object wave are therefore, encoded as amplitude and phase modulation of a set of interference fringes that is equivalent to carrier with a spatial frequency of ξ_r which is very much obvious from equation number 24.

Now, following the similar analysis what we did in case of inline hologram the amplitude transmission in this hologram is also expressed by this expression where $t = t_0 + \beta TI$. Now, if you substitute for I from equation number 24, then you get this detail expression of 25, I just want to represent transmitters t is equal to t_0, t_0 is the background transmittance and then βTI this is the same expression which we used in case of inline hologram.

The same is being used here, but now the intensity I is replaced by equation number 24 in the stage. And now, this is the transmittance which we receive from the hologram. Now, to reconstruct the image, the hologram is illuminated once again with the same reference beam used to record it. Now, once you illuminate the hologram, we will see some transmission beam and there we expect the hologram to be formed.

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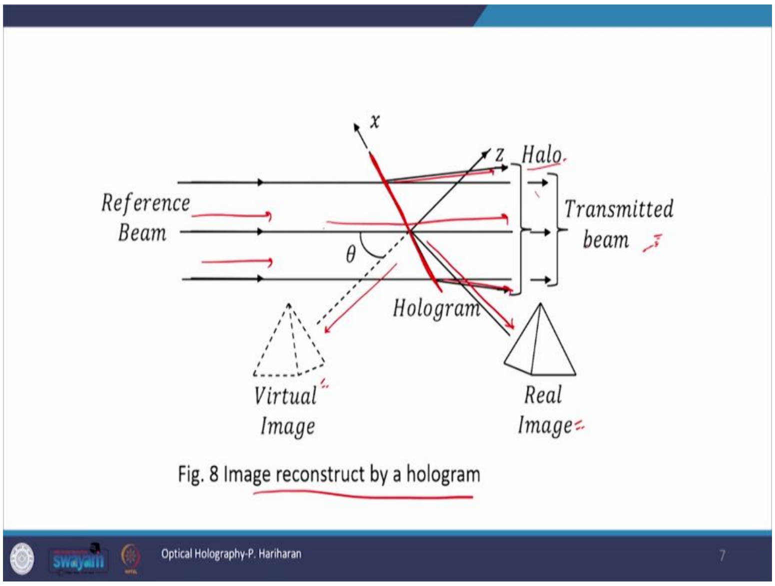

Fig. 8 Image reconstruct by a hologram

Now, this is how the reconstruction is done in off axis hologram, this is the holographic plate or the recorded hologram, which is illuminated with a reference beam, the same reference beam which we use to record the hologram. And from here what we see is that a part of the beam goes in this direction which gives us a real image. And here we get virtual image that part of the light get directly transmitted which is seen here and apart from this directly transmitted light we see some halo in a bit off axis position, we will talk about these in coming slides.

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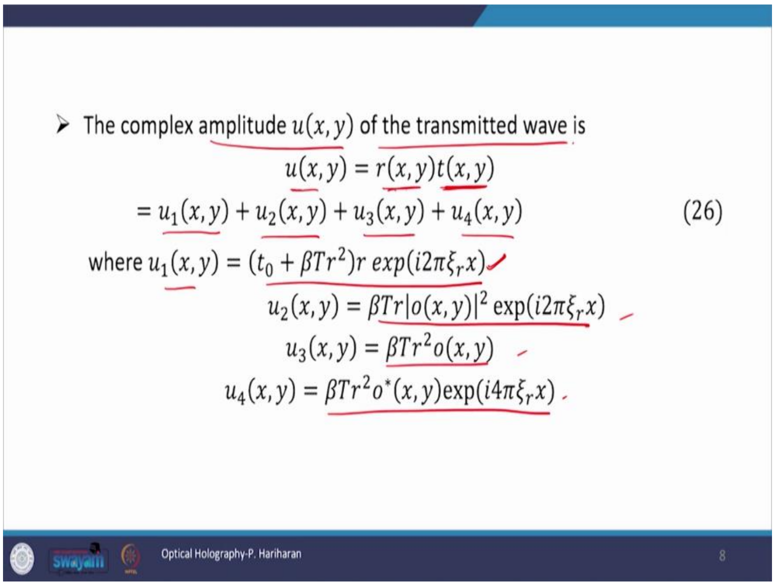

Now, the complex amplitude of the transmitted wave is given by the transmission function which we derived in the last slide multiplied by r, r is the complex amplitude of the reference beam. Now, if you multiply r with t then we will get a big expression and there would be four term in that big expression, let us represent those four terms as u_1 and u_2, u_3 and u_4 where u_1 is given by this expression, u_2 by this, u_3 by this and u_4 by this.

Now, in u_1 you see that it is independent of o, it does not have any information of the object therefore, it is not of our interest, while all other three terms they have o, and therefore, they can form the image.

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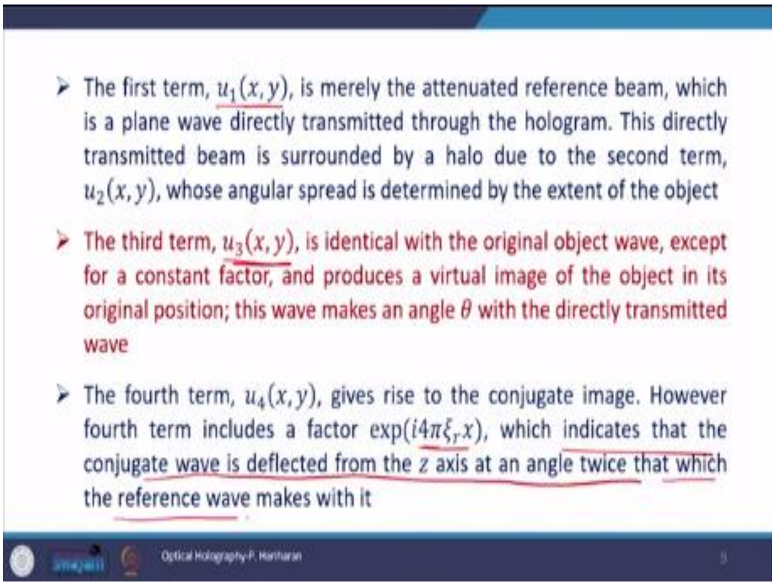

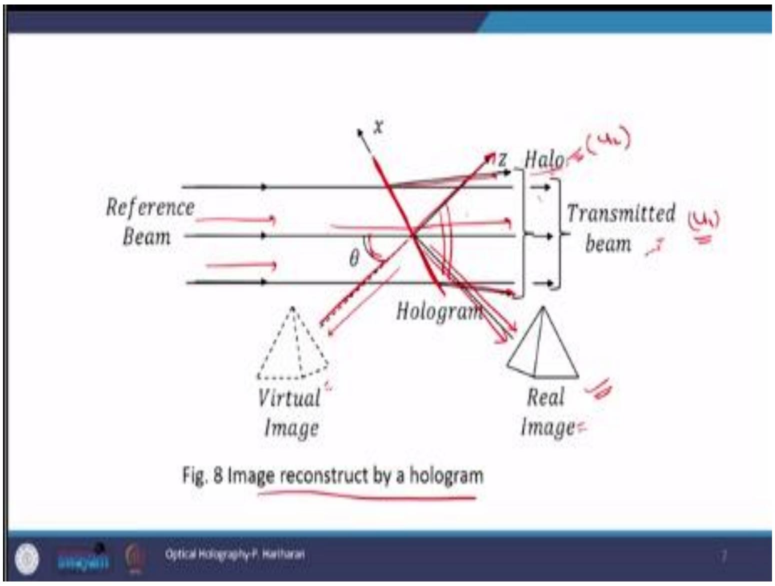

Now, the first term now, let us talk about the first term which is $u_1(x, y)$, it is merely the attenuated reference beam, which is a plane wave directly transmitted through the hologram, this directly transmitted beam is surrounded by a halo due to the second term $u_2(x, y)$ whose angular spread is determined by the extent of the object.

Now, you see here that $u_2(x, y)$ has $|o|^2$ which is a small term. Now, this is the term which is responsible for this halo which we see here in the transmitted beam. Now, transmitted beam is surrounded by this halo which have their origin in u_2 term and u_1 is the directory transmitted beam which does not have any information about the object.

Now, the terms of our interests are u_3 and u_4 now, if you see the u_3 term it is $\beta T r^2 o$, if you remove one r from here, then this is identical with the original object wave, and this term produces a virtual image of the object, u_3 term produces the virtual image of the object. Now virtual images produced in its original position and this wave makes an angle θ with the directly transmitted wave as shown here in this figure.

Now, you see that this wave which is forming the virtual image, it is inclined at angle θ with the reference wave. Similarly, the fourth term which is u_4 it gives rise to the conjugate image. However, fourth term includes a factor $e^{i4\pi\xi_r x}$, instead of 2π here, we see that it is 4π, which indicates that the conjugate wave is deflected from the z axis at an angle twice that of which the reference wave makes with it. It is deflected by a larger angle and this is why here in this figure, you see that the real image is formed here.

And this angle is larger, this is why it is said that this exponential term where we have $e^{i4\pi\xi_r x}$, it indicates that the conjugate wave is deflected from the z axis at an angle twice that which the reference wave makes with it. And this is our z direction. And deflection is larger here.

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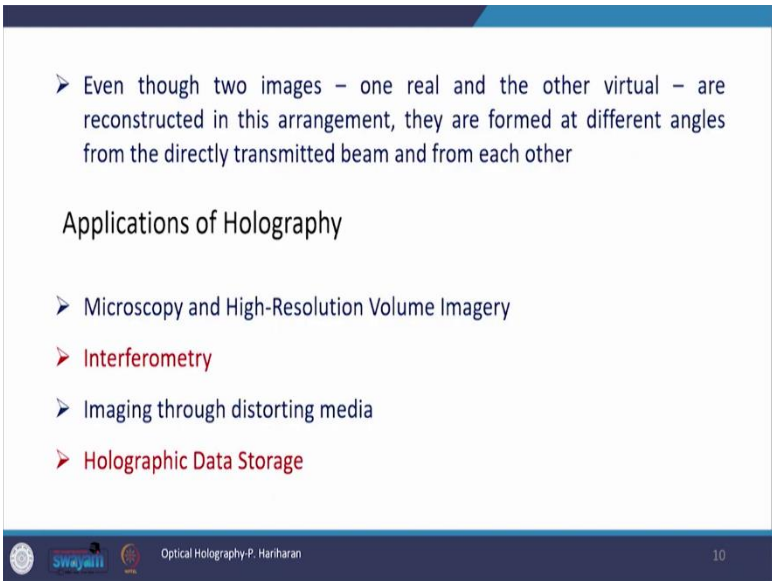

Now here you see that the two images, virtual and real, they are not collinear, even though two images, one real and the other virtual are reconstructed in this arrangement they are formed at different angles, different angles from the directly transmitted beam and from each other. And therefore, if you view them, they will not fall in the same line of view, you can see them separately, since they are at a different angle you can clearly distinguish them they are not overlapping on top of each other.

Now, therefore, this off axis holographic method, it does not have the limitations which we saw in case of inline hologram. Now, the holographic holds a lot of applications and a few of them are listed here. The first one is in microscopy and high resolution volume imagery. The second is in interferometry in imaging through distorting media. And then holography is also used in data storage. This is all about holography and I end my lecture here and see you in the next class. Thank you for joining me.