Modern Optics
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Lecture – 56
Acousto-optic Modulators and Devices (Contd.)

We were discussing Acoust-optic modulators. In this connection, we have discussed Ramanath modulators and now today we will be discussing Bragg type modulator.

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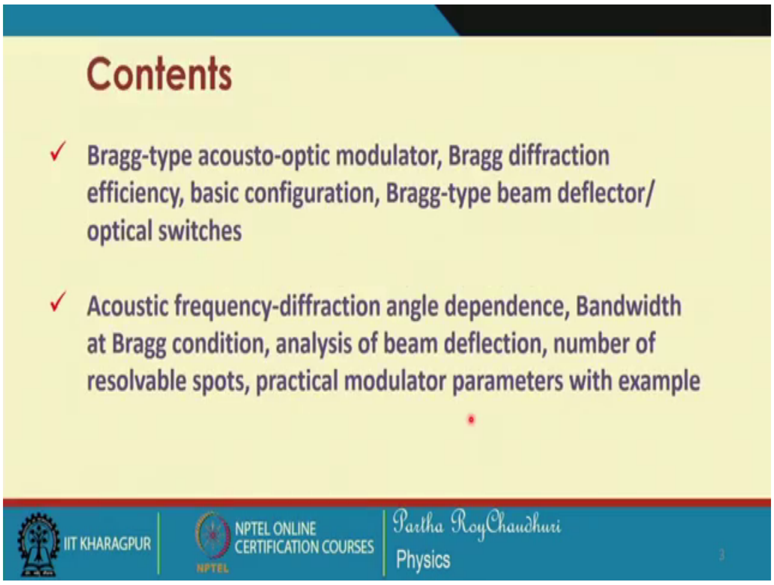

And in this context we will be discussing this Bragg type acousta optic modulators basic design diffraction efficiency and the configuration of the device. Bragg type deflection as a modulator as a deflector and it can also be used as an optical switch we will see that, the acoustic frequency and diffraction angle dependence this analysis will also bring out. Then the bandwidth of Bragg condition and as a deflector we will analyze the performance of a modulator. In this connection, an important parameter is the number of resolvable spots and the parameters which are involved in the designing of a practical modulator with an example.

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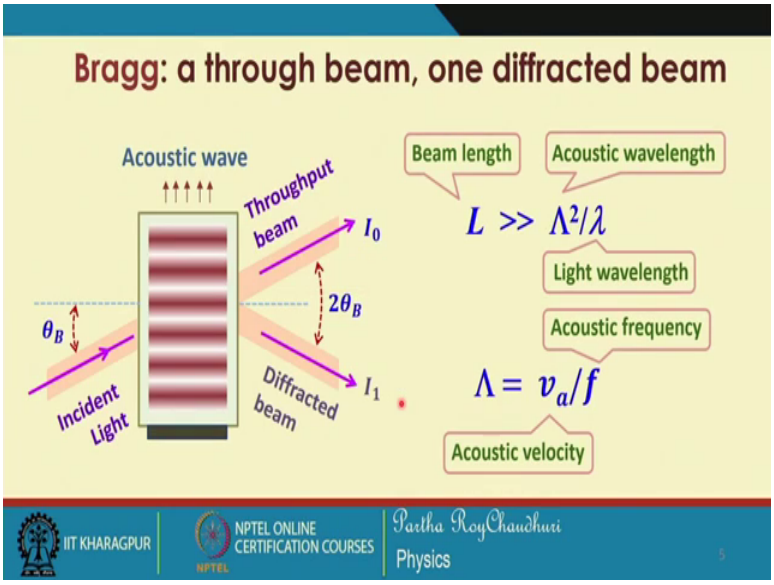

So, Bragg type, a modulator as we know that you have an incident optical beam and there is an acoustic wave. And in absence of the acoustic wave the beam will be passing through and that is what we called the through beam and in presence of the acoustic beam under acoustic wave under the Bragg condition the beam will be deflected as the first order diffracted beam. So, as a consequence we can see that if it satisfies the Bragg angle theta B, then the deflection of the beam under the Bragg condition will be by an angle twice theta B. And for this Bragg type modulator to work these are the basic conditions the beam length L of the acoustic wave will be related to this acoustic wavelength in this form, which is this lambda square by lambda and lambda is the light wavelength.

So, this condition has to be satisfied throughout and for the acoustic wave this acoustic wavelength is related to the acoustic wave velocity and the frequency in this form that is all we know, but we will have to make use of these parameters these conditions in understanding the Bragg type modulator.

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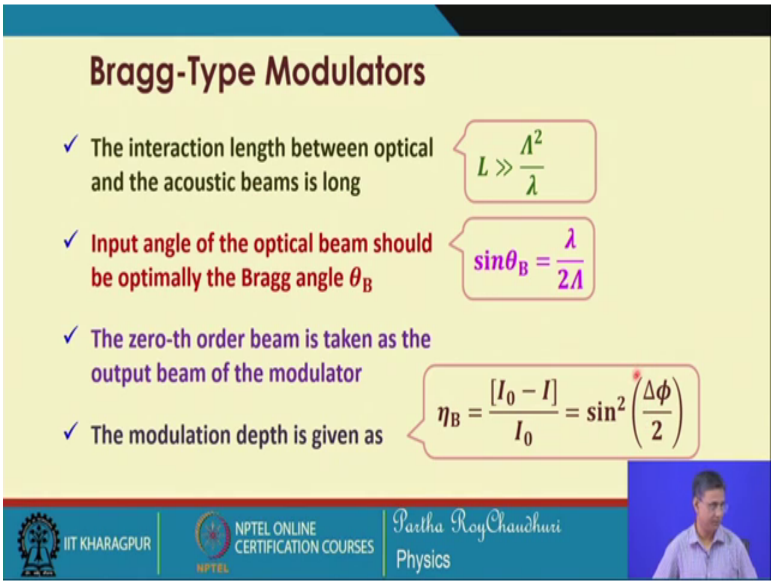

The interaction length between the optical and the acoustic beam will be long. So, that it does see a volume grating instead of a thin grating thin phase grating which was the case of the (Refer Time: 03:15) type diffra diffraction. And the input angle of the optical beam must satisfy the Bragg condition optimally that is sin theta B will be equal to lambda by twice capital lambda which is the period of the acoustic wave. The zeroth order beam is taken as the modulator output, that is when the maximum of its modulation then the zero'th order beam will be 0 and the first order beam will contain the maximum output. The modulation depth therefore, it comes out to be eta B is equal to this quantity where this del phi is the phase that is this is equal to kappa into l the length of the acoustic wave and kappa is the is the coupling coefficient of the zero'th order beam to the first order beam.

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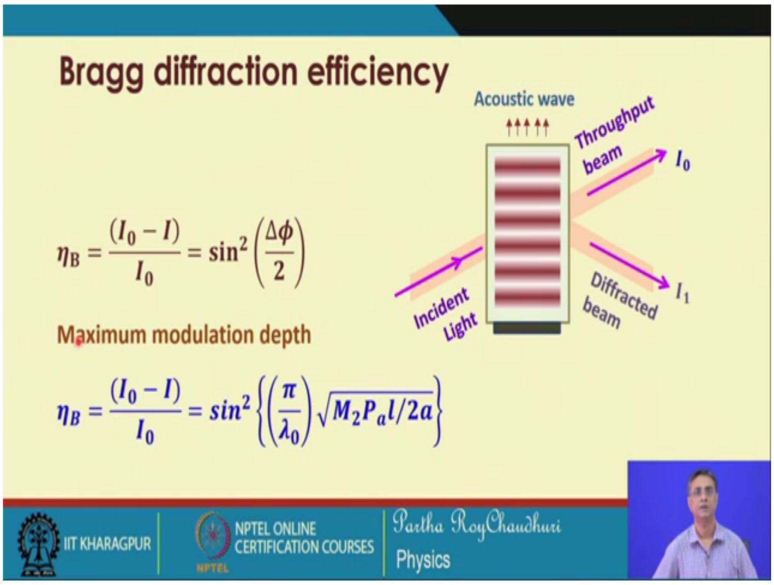

Therefore, the maximum modulation depth will be given by this, this also we have seen will be equal to this quantity, that is in terms of the figure of merit M 2 and the acoustic power length etcetera.

So, basically we are looking for the diffract deflection of an optical beam by this modulator and the reflected beam and the incident beam they are we will first look at the relationship.

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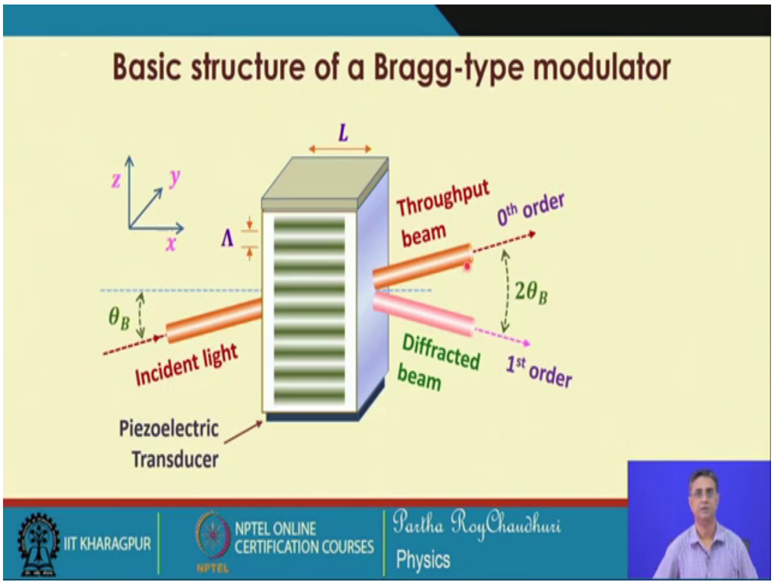

As I have mentioned that if the incident angle is the Bragg angle under the Bragg condition, that is your theta B then the reflected beam the beam in absence of the acoustic wave would have traveled along this line undeviated and undisturbed, but in presence of the acoustic wave the beam will be deflected in this direction.

So, the net deflection is twice of theta B, which is the theta B is the Bragg angle.

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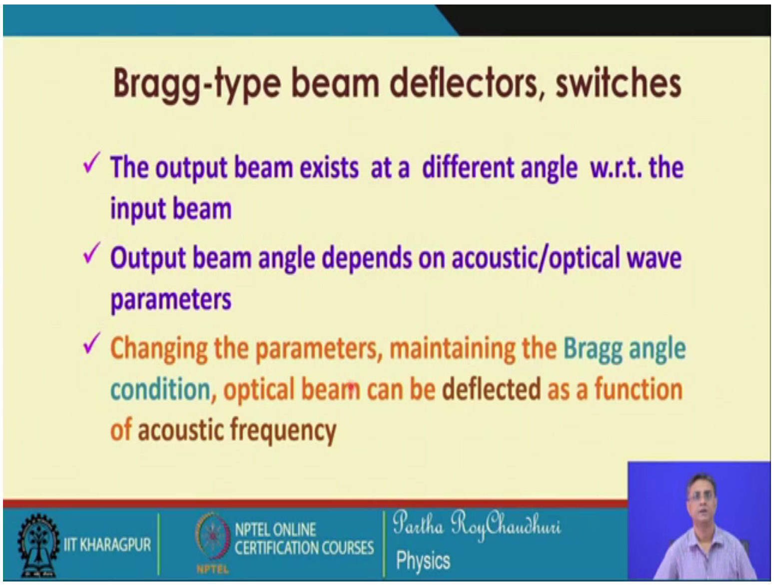

Therefore, therefore, the Brag type output beam exists at different angles with respect to the input beam condition. Output beam angle depends only the acoustic and optical wave parameters. So, therefore, changing the parameters and maintaining the Bragg angle condition optical beam can be reflected as a function of acoustic frequency.

So, let us look at this if we if we maintain this the condition the same, but for different angles of input beam incidence angle, then there will be different deflected direction of the first order beam if we change just the condition of the acoustic frequency. We will see that this acoustic frequency and the beam deflection they are just linearly proportional under a small angle, small Bragg angle condition; we will first look at this consequence and then we will.

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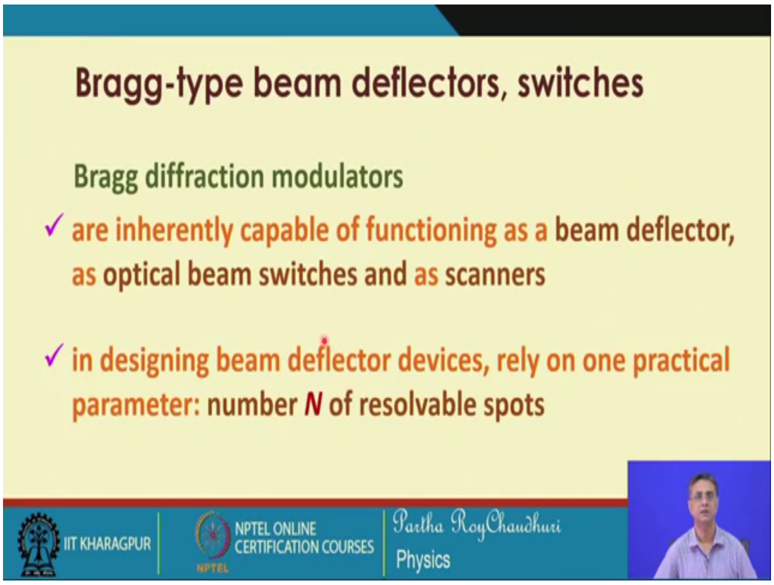

So, Bragg diffraction modulators are inherently capable of functioning as a beam deflector as an optical beam switch or as a scanner. Because by changing the acoustic frequency the deflected beam can scan over different positions along a line. So, it can be used as a scanner, and Bragg deflection modulators in designing beam deflector devices mainly rely on one very important and very practical parameter that is the number N of the resolving spots.

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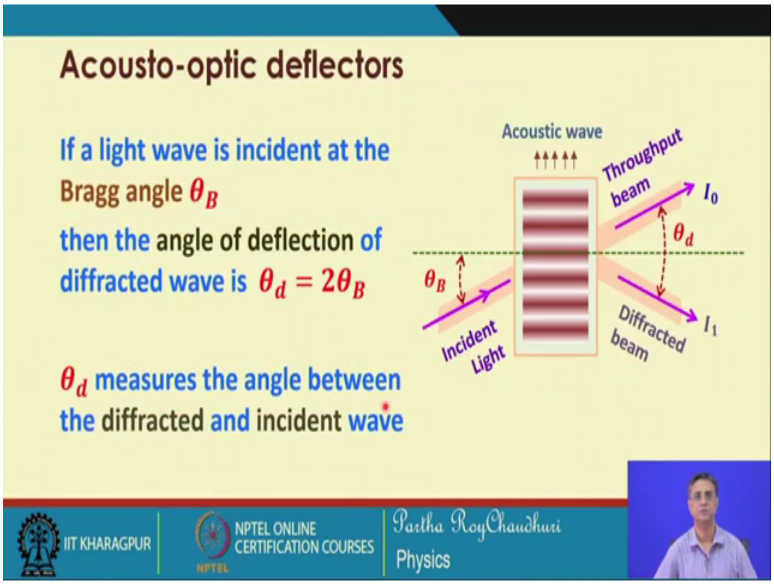

So, which is the key point of discussion that how we can increase the number of we can maximize optimize the number of spots resolvable spots under this Bragg deflection condition.

If a light wave is incident at the Bragg angle, then the angle of deflection will be theta d we call this is theta d which is equal to twice of the Bragg angle do this we have seen repeatedly and therefore, these delta theta measures the angle between the diffracted and the incident wave, which is very clear if you have an incident angle that is theta B Bragg angle, then the deflected angle will be theta d which is just twice the Bragg angle.

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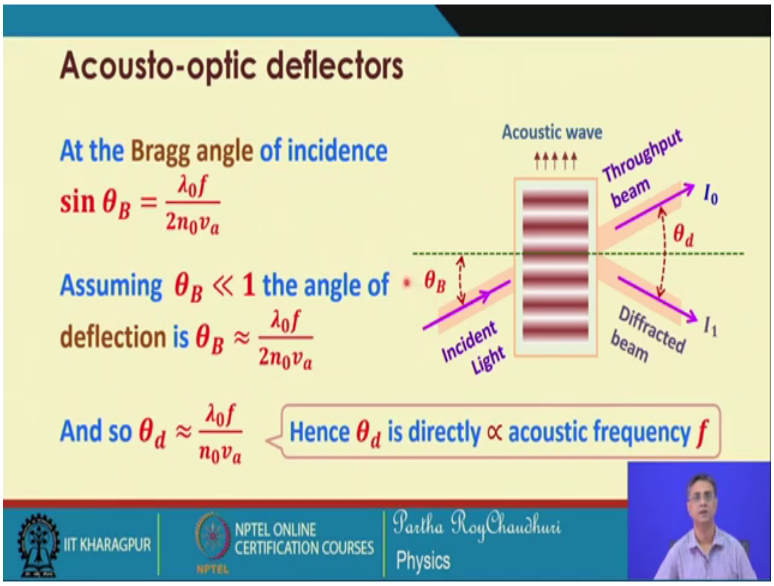

So, now let us look at the Bragg condition that sin theta B will be equal to lambda 0 the optical wavelength, optical beam wavelength and f is the acoustic frequency n 0 is the refractive index of the of the modulator cell medium and v a is the acoustic wave length acoustic velocity wave velocity. So, assuming small Bragg angle diffraction that is theta B is very small as compared to data is very small as compared to this deflection, then the deflection is theta B and so, delta theta d is directly proportional to the acoustic frequency. Ok

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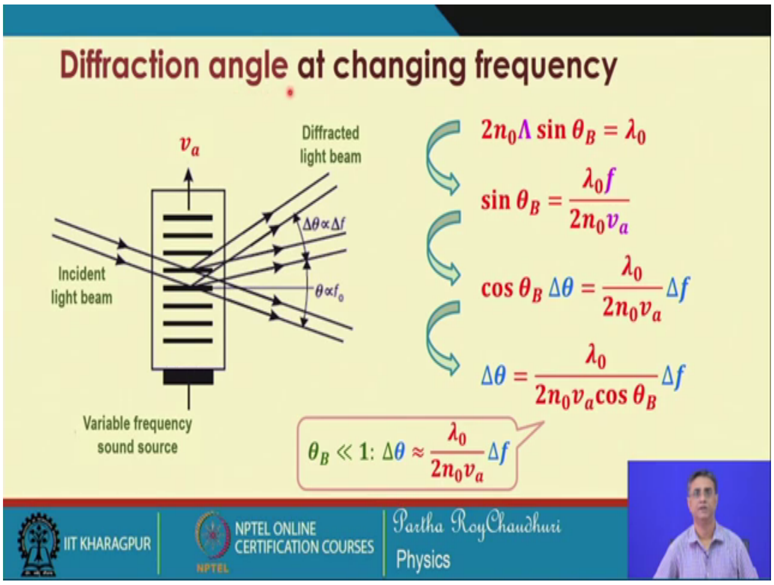

Diffraction angle at changing frequency this relationship; if I change the acoustic frequency then keeping the incidence angle the same how this deflection angle will change that relationship will actually decide the modulator as a Bragg deflector. So, from the from the starting point that this is the Bragg condition twice n 0 lambda sine theta be equal to lambda 0 n equal to 1.

So, this is just the equivalence of 2 d sine theta equal to n lambda because for this Bragg diffraction n equal to 1. So, this is the basic equation and from here we can write that sine theta B is equal to just taking these quantities on the right hand side and replacing this lambda capital lambda by v a by f we can write this equation. Now if you take the differential of this equation on either side then we can write cosine theta be delta theta which is equal to this quantity into delta f.

So, this tells you that delta theta is proportional to delta f that is the acoustic frequency. So, the deflection angle is directly proportional to the acoustic frequency provided that for small Bragg angle condition that is delta theta B theta B is less than 1 then we can write this equation rewrite this equation that delta theta is proportional to delta f. So, this is the basic guideline of a modulated deflector, we will if we change the frequency then the reflected beam will undergo a change in the position and that is how by just changing the frequency here or changing the frequency of the acoustic wave, the beam can be can be deflected from here to here.

So, you can see that this beam is this is the undeviated beam and it undergoes a change in the position because of this frequency f naught and you can see that the, this f this delta f delta theta is proportional to delta f. So, that is very clear.

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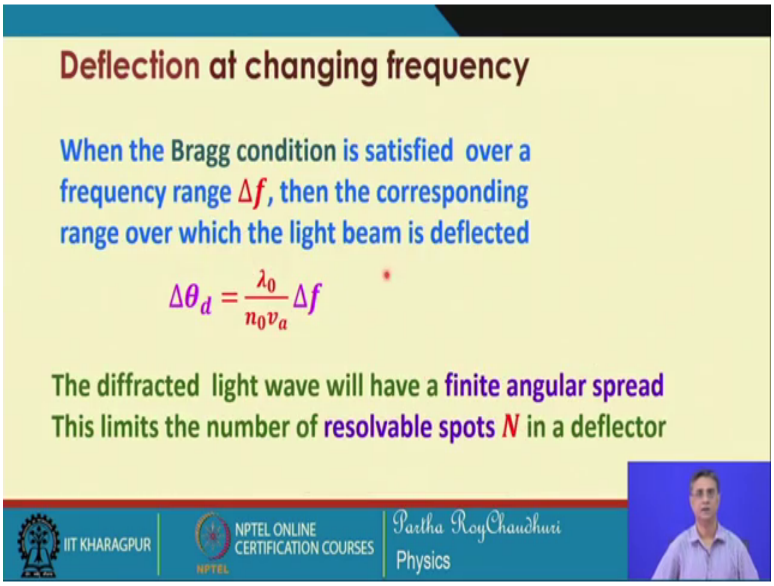

So, this tells you that when the Bragg condition is satisfied over a range of frequencies that is delta f of the acoustic wave, then the corresponding range over which the light beam is deflected is given by this. So, delta theta the reflected beam angle range will be proportional to the delta f. The diffracted light wave will have a finite angular spread and this limits the number of resolvable spots.

Because the wave the optical beam which will be siffracted through the acousta acousta optic modulator that will have a finite angular spread.

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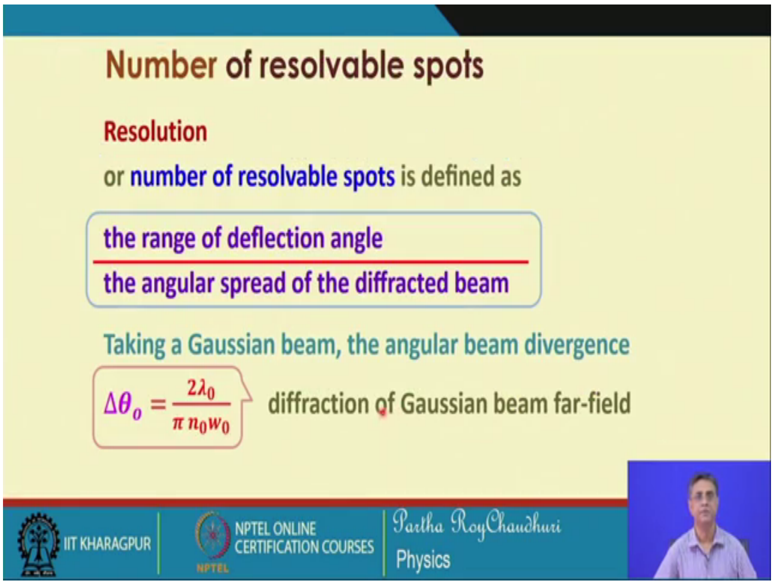

And the spread comes from the fundamental divergence of the, of a beam optical beam and also the diffraction of an optical beams through a grating a type of device. So, this resolution is that is the number of resolvable spots is defined as the range of deflect deflection angle and divided by the angular spread of the, deflect diffracted beam. So, taking as an example a Gaussian beam, the angular beam divergence is given by of the optical beam is given by this, this is the this is from the theory of the divergence angular divergence of a Gaussian beam. So, diffraction of a Gaussian beam at far field is given by this equation.

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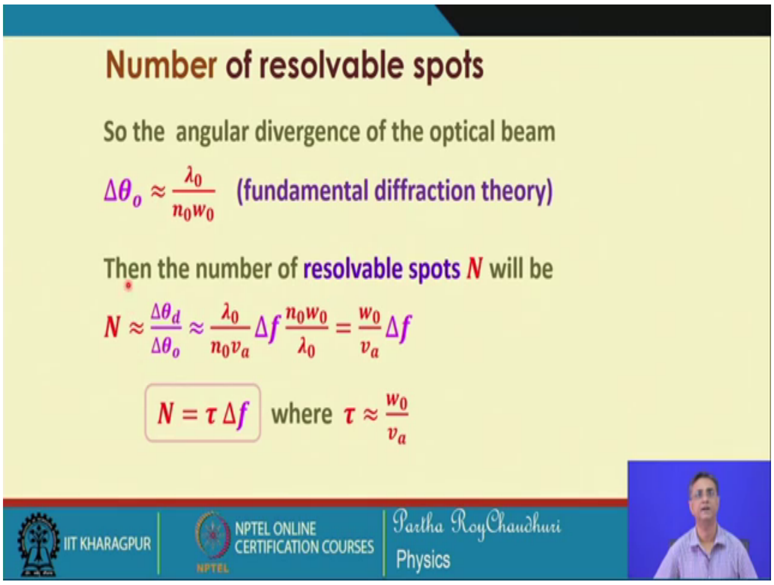

We can approximately write this delta theta 0 that is the angular divergence of the optical beam as by this that is the optical beam wavelength, the refractive index of the medium and the beam size that is w 0 the spot size of the of the beam.

So, this comes from the fundamental diffraction theory, then the number of resolvable spots N will be given by the give given by the deflection angle the range of the deflection angle divided by the angular divergence of the total beam. So, therefore, this will be this will be given by this equation, we can just replace this delta theta by this quantity and delta theta d is already this lambda 0 by n 0 into acoustic velocity. So, this n turns out to be w 0 by va into wf.

So, the number of reservable spots on the output of the deflector is directly proportional to the range of the acoustic frequency. So, more the acoustic frequency more will be the number of resolvable spots. And from here because w 0 by v a is the transit time over which the acoustic beam interacts with the optical beam which is equal to tau. So, we can write n equal to tau into delta f and this tau w 0 by va is the access is also called the access time.

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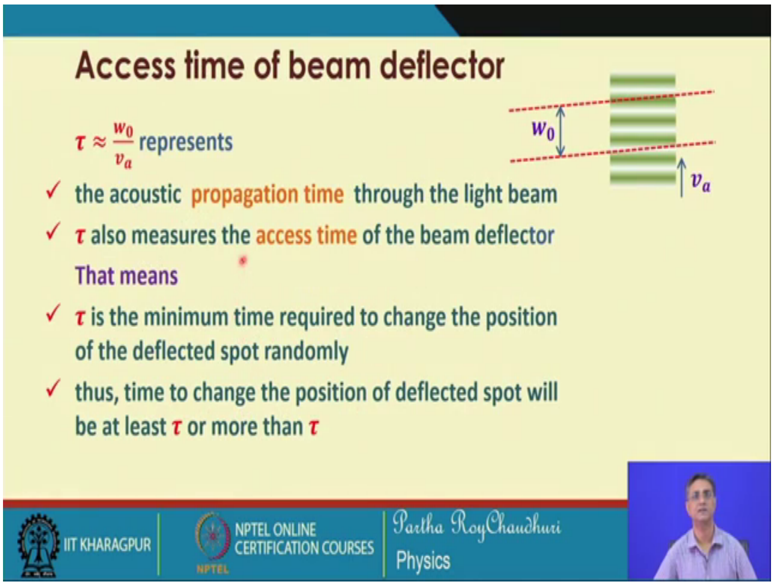

That is what we want to explain again tau is w 0 by va. So, this is the width of the acoustic beam with optical wave optical beam, this is the width of the optical beam and this is the acoustic wave so, this acoustic wave velocity v a. So, there is an interaction time between this acoustic wave and the optical beam, which is given by this because over the time tau they only interact. So, the acoustic propagation times to the light beam and tau also measure the access time of the of the beam deflector. So, the beam deflector is active only over this time this access time um.

So, tau is the minimum time required to change the position of the deflected spot randomly. So, if you change the frequency the spot will also change, but this happens only over the minimum time required to happen this is tau. Thus the time to change the position of the deflected spot will be at least tau or it could be more than tau. So, this is the minimum requirement of the access time for the deflection to be visible or measurable.

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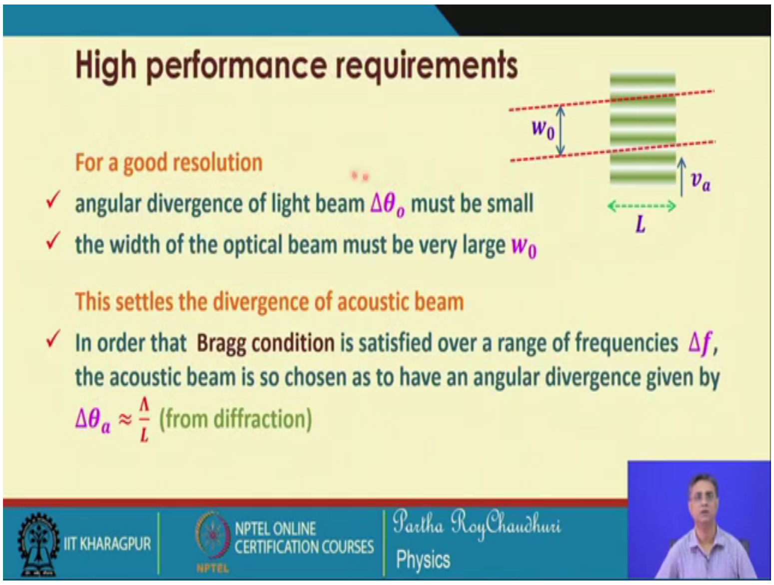

For a good resolution of the for a good resolution of the of the acousta optic Bragg type modulator, these are the requirements the as g as you can see from here from this equation from this equation that your delta theta must be small because it appears in the denominator if it is small, then you will get more number of resolvable spots that is what is intended and delta theta d should be large.

So, delta theta 0 that is the angular divergence of the optical beam should be as small as possible, the width of the optical beam must be very large. This condition comes from here you can see that this up because the number of resolvable spots anyway the acoustic velocity wave velocity is limited it is fixed for a medium by which with which this acoustic modulator is made up of. But this acoustic beam width of optical beam width can be can be tailored can be controlled. So, if this is more, than more number of resolvable spots will be available; therefore, if it is very large, but this then settles the divergence of the acoustic beam. In order that the Bragg condition is satisfied over a range of frequencies delta f, the acoustic beam is so, chosen to have an angular divergence that is given by this.

This is also we have seen that is the condition and either the beam divergences will come from this the ratio of the acoustic wave length divided by the width of the acoustic beam. So, this again from the fundamental diffraction theory; so, this condition has to be accommodated.

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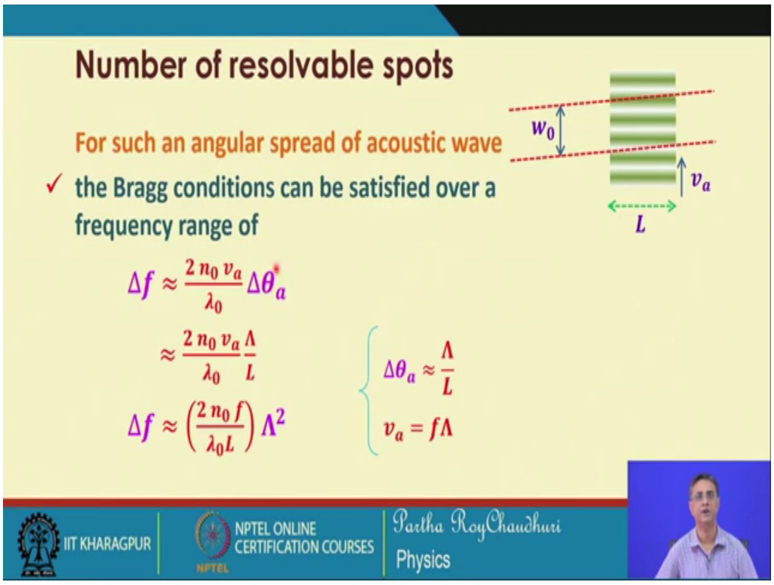

So, for such an angular spread you know this is the L the width of the acoustic wave, is the width of the optical beam and this is the direction of. So, this is over this length the interaction takes place and the Bragg condition can be satisfied over a range of frequencies, and that the range of acoustic frequency delta f is as we have seen is given by this equation.

Now, delta theta a if we replace by capital lambda by capital L, then it turns out that this delta f is proportional to lambda square the wavelength of the acoustic wave square of the wavelength of the acoustic wave. We will see an example how practical deflector can be designed using the realistic numbers. So, here we have used this x this relation va equal to f into lambda and delta theta a equal to capital lambda by L which has come into this expression.

So, this is the most useful expression for the designer for an acoustic acousta optic deflector Bragg type deflector.

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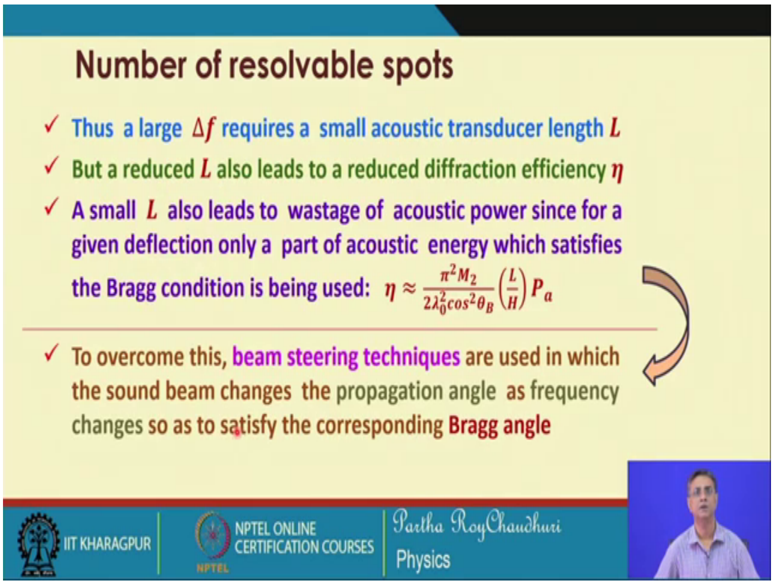

Now, thus the large number the large delta f requires a small acoustic transducer length look at this equation, this L should be small if you want to get a good range of acoustic frequencies over which the deflection should take place.

So, for a wide range of acoustic frequency as a as a deflector this L should be small, and then this L, but this reduced L also leads to a reduced diffraction efficiency. You have seen at the beginning we have discussed that this diffraction efficiency is also limited by the width of the acoustic beam that is L. A small L also leads to wastage of acoustic power.

Because if you make a small L then most of the power will not be utilized by the optical beam and the deflection only a part of the acoustic energy which satisfies the Bragg condition this condition. So, therefore, there will be an wastage of acoustic power if we if we restrict the length of the acoustic the width of the acoustic beam. So, to get to get a wide range of acoustic frequencies for the deflection.

Now to overcome this there are various techniques, one very useful practical technique used by the designers are this beam steering techniques, which are used as sound beam changes with the propagation angle as the frequency changes. So, the technique is that the beam propagation angle changes as you as you as you change the frequency of the acoustic wave. So, for different frequencies in a continuous way for different frequencies, you have different acoustic beam propagation angle, which can be electronically can we designed. So, this is what is called the beam steering technique.

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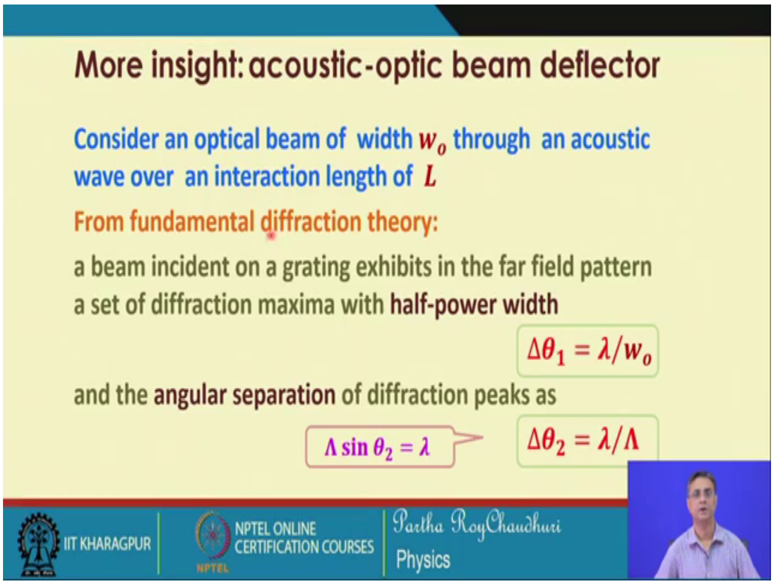

So, in order to understand with more insight this beam deflection beam deflection by an acoustic modulator, let us consider an optical beam width w 0 which is passing through an acoustic wave and the interaction length of the optical beam with the acoustic wave is the width of the of the acrostic wave that is L. From the fundamental diffraction theory there are two equations there are two relations which are useful to understand this, one is that that the just diffraction by a grating that exhibits the.

You see this has come from d sin theta equal to n lambda this width therefore,. So, this delta theta 1 is equal to lambda by w 0, which is the optical beam width. So, optical beam width and the optical beam wavelength ratio in this form it gives you the half power width of the diffraction maximum. And for various orders design theta equal to n lambda sort of relation this gives you that delta theta 2 that is the spacing between the two diffraction peaks separation of different diffraction peaks one is along theta 1, waves this the separation between the two peaks it comes in this form lambda by delta lambda.

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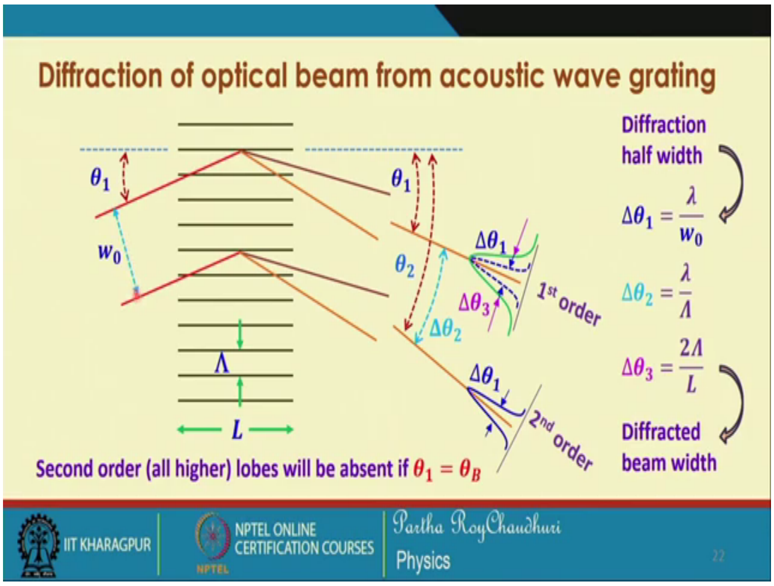

So, if you look at this general form of the optical beam diffraction, you have this width w 0 and which gets reflected you know you have one order here you have second order here, but in this case it is only the first order, but this is a very general form to understand this reflection. Now you can see that delta theta one which is equal to lambda by w 0 is the half width of this reflected beam and delta theta this is anyway not useful in this case because we are not considering the second order diffraction. So, this does not come into the picture, but this delta theta three that is twice lambda by l this comes because this is the overall beam size of the diffracted wave.

So, how many of these small half widths are accommodated within this delta theta 3 is the number of resolvable spots. The number of this small delta theta 1 within this delta theta 3 is the number of result of spots. So, that is what we want to understand

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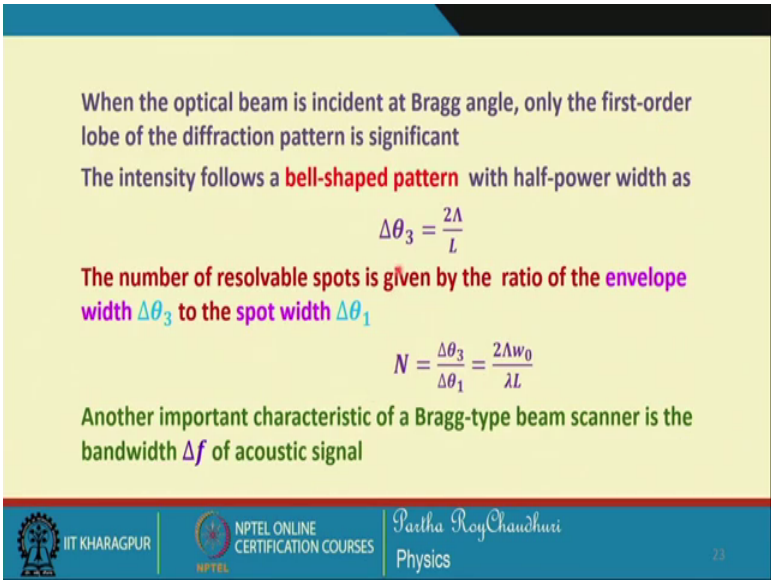

So, we write this the intensity follows a bell shaped pattern after the diffraction from the acoustic wave, this the overall beam will look like a bell shaped pattern twice lambda by L and therefore, the number of resolvable spot is given by the ratio of the envelope with delta theta three to the spot size spot of the width delta theta 1 this is we just explained that delta theta 3 by delta theta 1 will give you the number of resolvable spots.

So, this comes out to be this and which is the same. So, it can also be used as a beam scanner, which is in which this delta theta of the acoustic signal is very important.

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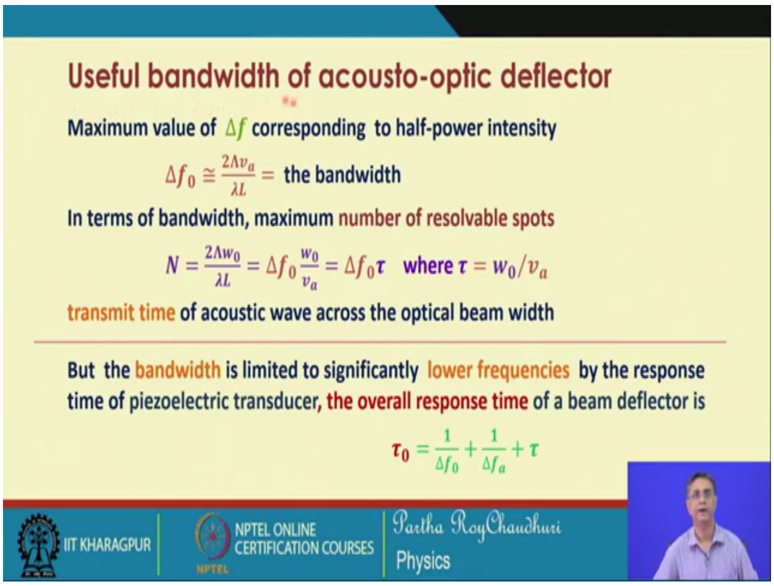

So, useful bandwidth for this because we have seen that delta theta can take up a value within the as long as this Bragg diffraction condition is satisfied keeping the incident angle the same. So, under this condition the useful bandwidth of the acoustic deflector it comes in this form. So, in terms of the bandwidth we can we can write this equation that delta f 0 this is the useful, this is the maximum value of delta f corresponding to half intensity, if I call this is equal to delta f 0.

Then you have a relation because it includes the response time of the interaction of the acoustic beam. That is the time of the piezoelectric transducer. The moment to feed the signal it is not instantly appearing, but there is a there is a response time. So, because of this tau 0 the overall beam deflection response time is related to this is the acoustic frequency range and this is the maximum useful bandwidth and tau is the beam access time. So, that is again very for maximum speed of operation we can optimize this in this form.

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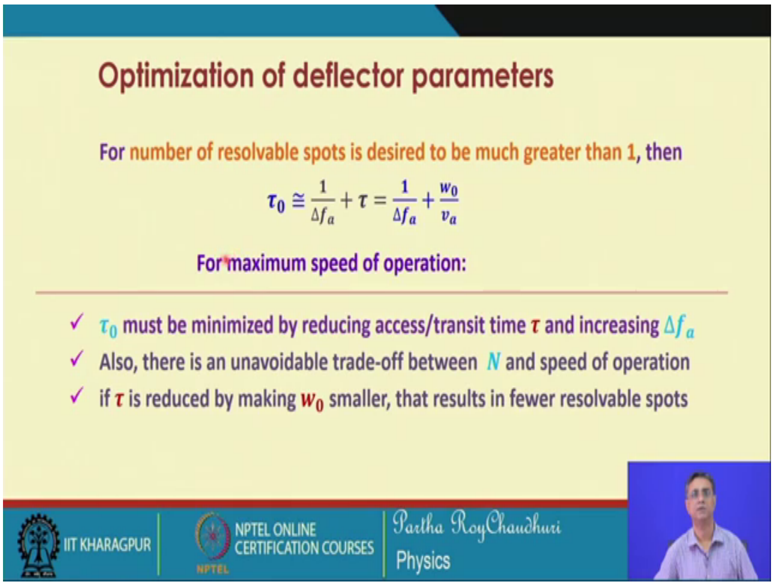

So, tau t must be minimized by reducing the access time or the transit time tau, increasing this delta f you have to increase this equation also there is an unavoidable tradeoff between the number of resolving points and the speed of operation. Because if you want to increase the speed of operation, then the number of resolving resolvable points will become automatically less. So, that is why one has to make an optimization of this if tau is reduced by making w 0 that is the optical beam with smaller that result in fewer resolvable spots

So, these are the limitations which the designer has to work on to maximize to get the best high performance of the modulator.

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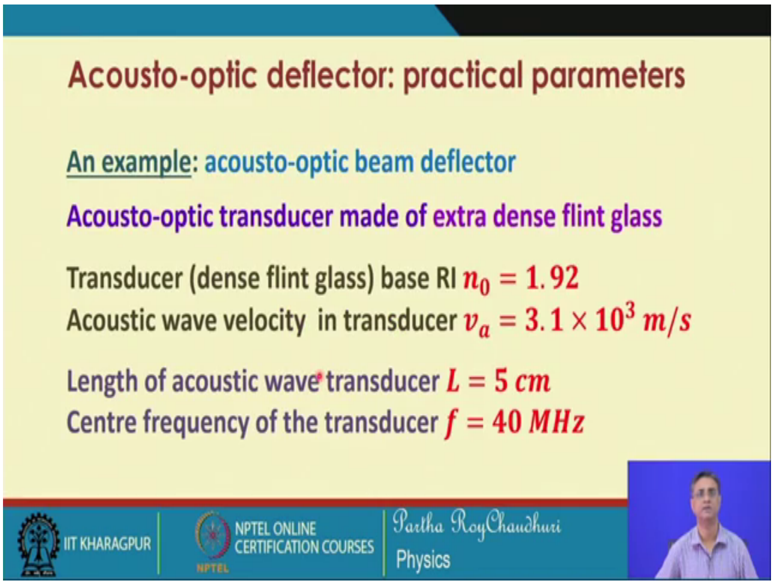

Now let us take a quickly glance at some example, that an acoustic beam deflector which is which consists of dense flint glass whose refractive index is given by this 1.92, acoustic velocity in this medium is 3.1 10 power 3 meter per second and let us consider the length of the acoustic transducer as L equal to 5 centimeter and the frequency of the transducer is 40 megahertz.

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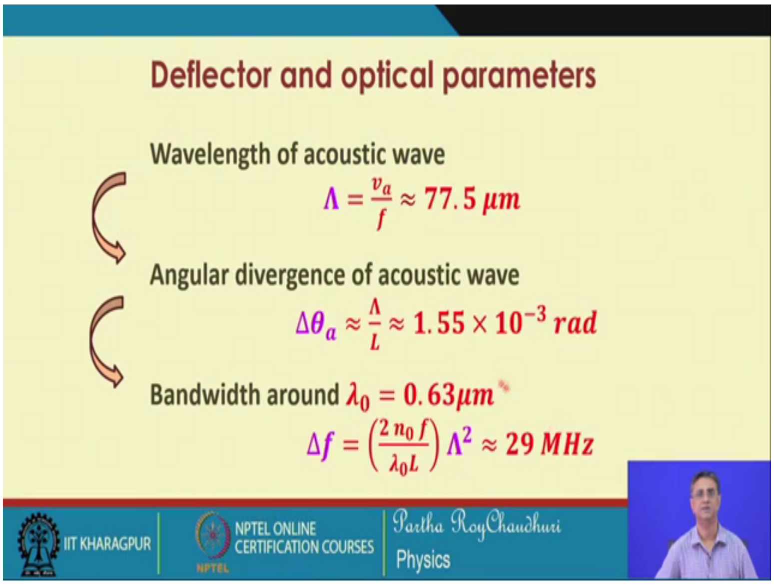

Therefore, the wavelength of the acoustic wave knowing this frequency, now the (Refer Time: 27:13) and the acoustic velocity you know acrostic velocity and the acoustic frequency, we have seen this relation it turns out to be 77.5 micrometer. This is the acoustic wavelength now the angular divergence which comes from this lambda and l because you have chosen L equal to 5 centimeter and lambda equal to this. So, you get a very small angular divergence delta theta a of the acoustic beam. So, this is the divergence of the acoustic beam therefore, bandwidth around lambda 0 equal to 0.3 h is the helium neon laser wavelength 0.63 approximately and delta f will be equal to this.

So, this gives you a bandwidth useful bandwidth for this acousta optic deflector to operate which is equal to approximately equal to 29 megahertz. So, you have a frequency of 40 megahertz acoustic frequency and the range of frequencies acoustic frequencies which can be used for the deflection of the of the optical beam is over this frequency 29 megahertz

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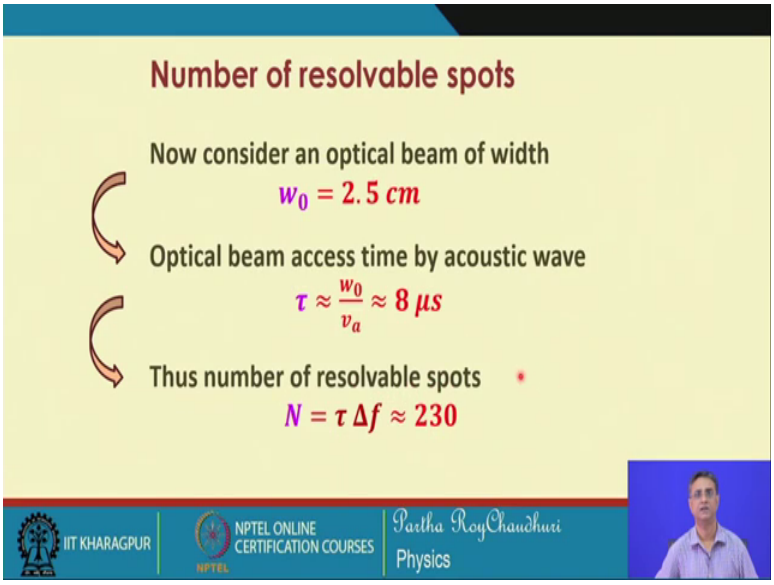

So, so if we now consider that optical beam width is 2.5 we consider, the acoustic beam width was five centimeter and the optical beam is 2.5 centimeter, therefore, optical beam access time by the acoustic wave is this we have seen is equal to 8 micro second which is very instant and thus the number of resolvable spots in this case will be 230. This is a very beautiful example to understand with the with the realistic practical numbers to understand how you get a number of resolvable spot, which is more than 200 for a frequency range of 29 close to 30 megahertz within 30 megahertz you will get we will get these many spots by using this acousta optic and optical beam parameters.

.So, this gives a very clear understanding about how this deflector can be used with the practical numbers and for the deflected beam the angular width of the refracted light will be this.

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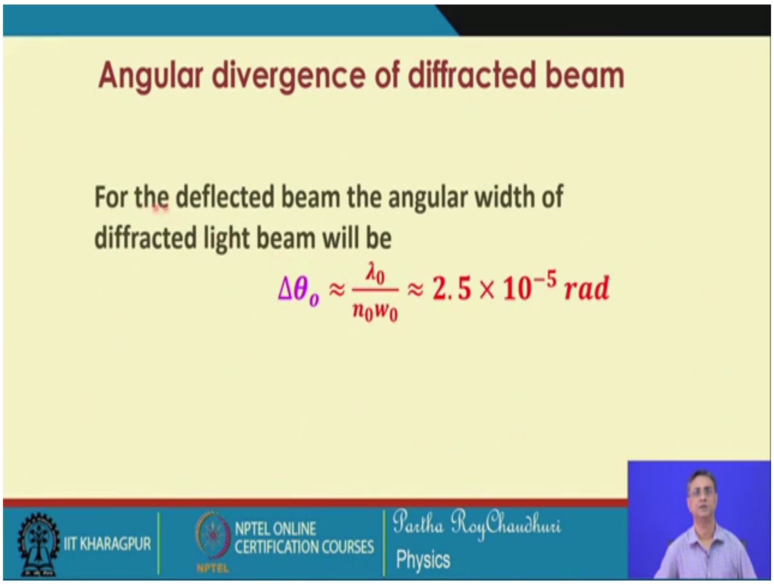

So, this is the number that one has to keep in mind that, this is again a very small optical beam divergence and that is why you get double number. So, in summary that we have discussed this acousta optic Bragg type modulator, the very interesting application as acousta optic beam deflector which is used for scanning for optical switches and many other applications in photonic devices in integrated optics.

We have analyzed this frequency dependence of the diffraction angle, bandwidth of the Bragg condition and analysis of the beam deflection. We also took up one example with practical parameters that what will be the numbers attached to a practical modulator for this deflection type of application.

Thank you.