Transmission lines and electromagnetic waves
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Lecture - 33
Cavity Resonator and Real Life Applications of Waveguides and Cavity

All right, we will get started the prior lectures, we had seen about rectangular waveguides and their modes and the field distribution and expression extra. In this class I will just demonstrate to you how simply, you can extend that analysis to a Rectangular Cavity Resonator ok.

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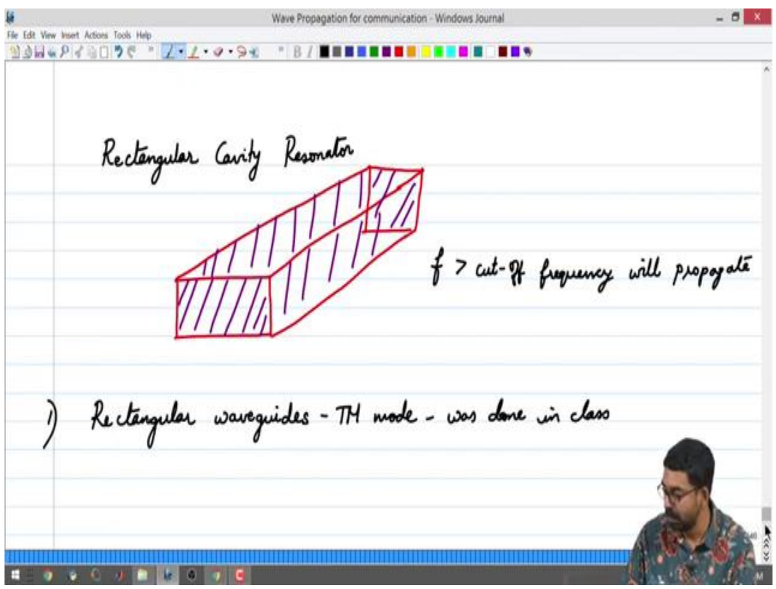

So, I will begin with rectangular cavity resonator. So, the idea is simply this in the past, we had seen about a properties of the waves travelling within a single medium. We also saw about properties of waves at an interface all right. So, we also discussed about what happens between a dielectric and a metal interface? After that we talked about two dielectric metal interfaces in the form of a parallel plate waveguide. And then we proceeded even further to have 4 rectangular walls forming a rectangular waveguide and we saw the description of the fields in such a structure in the past.

Just to brush up what we had seen earlier, the structure looked like rectangle in cross section and it was assumed to be infinitely long all right. And the assumption is, you have the top bottom and the 4 sides do we made up of metal and the region inside over here could be a dielectric. It could be vacuum or it could be any other dielectric right. So, we had seen this particular case and to summarize what we had seen without going into too many details, we saw that there is a frequency known as the cut off frequency and those are the frequencies that will propagate ok.

And the description for the cut off frequency, we have already seen that a we can arrive at the cut off frequency for different kinds of modes and we also discuss what the modes would look like right. How many sinusoids or how many half cycles of the sinusoids you will have in each direction extra. This discussion has been done for parallel plate and rectangular waveguide in the past.

Now in this lecture what we are going to do is, we are going to make some small modifications to this structure. Previously, we had seen that the electromagnetic wave would be launched in this port like this and it would travel through the waveguide forming some standing wave patterns in the cross section and it would arrive on the other side of the waveguide, but we saw that the waveguide is infinitely long or is the impedance matched. So, you do not get any reflection back ok.

In this particular lecture, we are just going to change this detail all right. Let us go ahead and make the facets all right also to be of metal right. Let us also go ahead and remove this condition where it is semi-infinite right or where it is infinite right. And let us say that you have a facet on the backside which is also going to be made up of a metal. So, in other words you have a cuboidal box and all the walls of the box are made up of metal.

So, there are 6 a phases each one of them is being made up of a metal and you have a dielectric region inside. If there is a chance of an exciting all right, this structure with an electromagnetic wave from inside all right. Suppose, we connect a source from the inside what would be the field description inside this volume is what we are going to talk about.

So, this lecture will have two parts, the first is the analytical part. Then I will go over some of the pictures of the waveguides that are used as you know conventionally in practice. So, that you get a feeling for what they look like and then the last part we will have a simple demonstration which you can relate to very well because, I will be making use of a conventional appliance to show what the cavity modes would look like in practice ok.

So, here if there is a source and if we were to excite the structure with the source what would be the description of the electromagnetic wave right. Now in order to proceed with this analysis, let me just recap what we had seen for a rectangular waveguide all right for the TM mode ok.

So, the rectangular waveguide I am not going to write all the components and I am just going to write the electric field a z component ok. So, I have a rectangular waveguide and a TM mode was already done in class.

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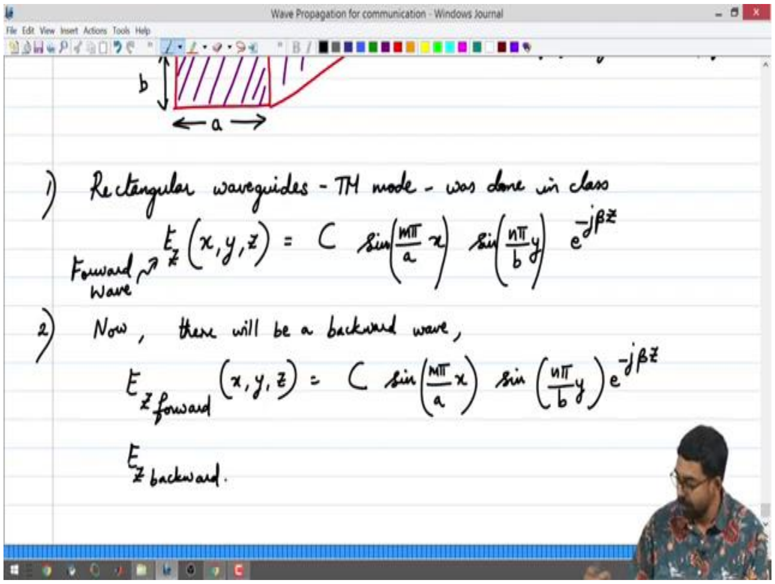

And from the prior lecture, I just had the description for Ez as a position of I mean depending upon the position x y and z coordinates all right was looking like

$$E_z(x,y,z) = (C_2 Sin Ax)(C_4 Sin By)(C_5 e^{-j\beta z})$$

and if, we are talking about the forward and the forward wave only we had a description which said that we will form a plane wave all right kind of it will form a propagating wave all right. Along the length of the waveguide or the longitudinal direction of the waveguide. So, this is what we had and a now, I will mark a few quantities to make this a little bit clearer right ok

So, in the earlier class what we had done was, we had marked the cross section with a and b. So, we will do the same thing over here. So, this part could be and the height in the cross section could be b right. And we can now start with this description and add the two facets and bring in the excess analysis that is needed for analyzing this structure with 6 walls right.

So, this is the forward wave. Now, because we have introduced a metal wall at a finite distance we will have a reflection and there will be a backward wave right ok. Now there will be a backward wave and just for the sake of completeness, I will write both the forward and backward wave once again. So, the forward wave is going to look like the description that I already have. So, I am just going to rewrite that here.

So, I am just going to say Ez, but I am going to make a note that it is forward still depends on x y and z positions. It is looking like

$$E_z(x, y, z) = C\left[Sin\left(\frac{m\pi}{a}\right)x\right]\left[Sin\left(\frac{n\pi}{b}\right)y\right][e^{-j\beta z}]$$

m and n are the mode numbers all right.

So, a we also saw the details about what m and n could be all right. For the mode to exist m or n should not be equal to 0 right. So, the fundamental TM mode will be 1 1 right. This we had already seen. So, I am just extending this, if I had to write down the backward wave just by looking at this expression I can mark new term right.

Ez backward will also depend on the position x, y and z and I can say that this could be some constant with respect to the cross section the standing wave patterns are going to look identical. So, I do not have to change the first two expressions or the first two part which have the sinusoids because this fixed for the forward and the backward wave. The only thing that is going to change is just like in transmission lines and just like in plane waves, we just denote the backward travelling wave with $e^{-j\beta z}$ ok. So, with respect to the cross section the patterns will be same, but with respect to the direction of propagation we definitely have a change. The forward wave is going in the positive z direction the backward wave is travelling in the negative z direction right.

Now, one of the things that we can talk about when we have a forward and backward wave is the total electric field ok.

$$E_{z_{forward}}(x, y, z) = C\left[Sin\left(\frac{m\pi}{a}\right)x\right]\left[Sin\left(\frac{n\pi}{b}\right)y\right][e^{-j\beta z}]$$

$$E_{z_{backward}}(x, y, z) = D\left[Sin\left(\frac{m\pi}{a}\right)x\right]\left[Sin\left(\frac{n\pi}{b}\right)y\right][e^{j\beta z}]$$

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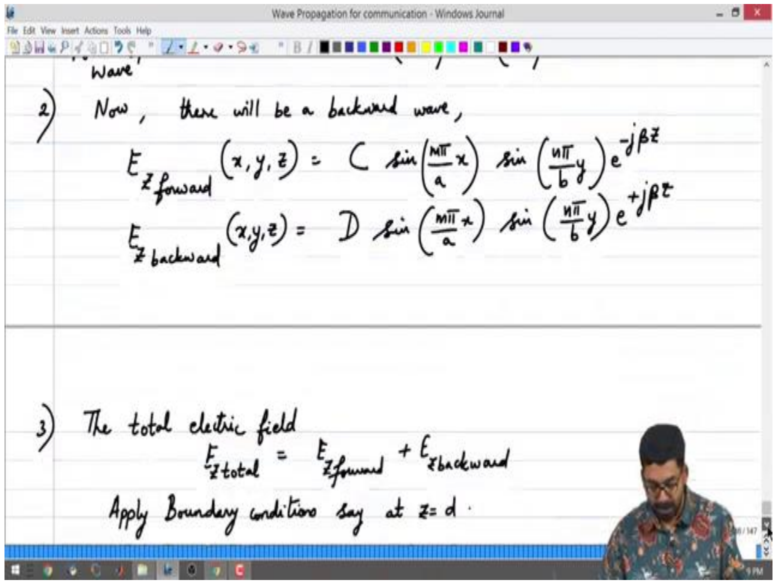

Now, that we have the expression for a forward travelling wave and the backward travelling wave in this structure, we can always look at the total electric field all right. We can write down the total electric field to be a super position of the forward and the backward electric fields all right. So, we can write this as E_{ztotal} is going to be

$$E_{z_{total}} = E_{z_{forward}} + E_{z_{backward}}$$

equal to the superposition of the forward wave and the backward wave for which I have the analytical description. So, I have the fields and I know how they will look like all right, just by a glance from the waveguides expression I am just going ahead and a writing down for forward and backward waves.

Now, one of the things that we can do is a once you know that you are going to be talking about a summation of these two in these structures since the longitudinal direction is also finite, we can talk about reflections that will be happening at these boundaries or at these extremities. So, one of the things that we can do is apply boundary conditions say at z equal to distance d right. Now in the diagram z equal to 0 corresponds to the place where its one extremum all right, z equal to d is the other extremum you can apply the boundary condition either here or here does not matter it will be identical all right.

So, I am just taking one place and we can say that at that place all right, the boundary condition is going to be that Ez forward is going to be Ez backward because it is the normal component and that is completely reflected back.

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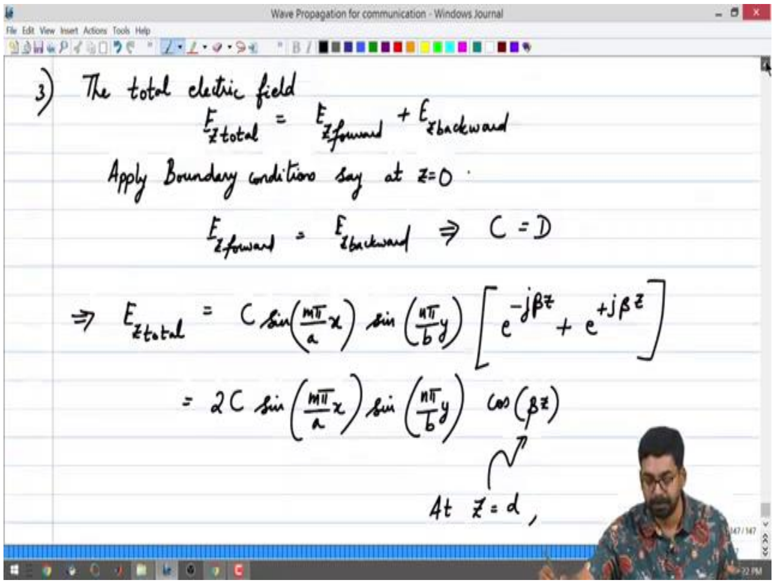

So, I can simply write this as

$$E_{z_{forward}} = E_{z_{backward}}$$

all right. So, if you were to take it at d all right, you will substitute z equal to d in $e^{-j\beta}$ thing and $e^{-j\beta z}$. If it makes it any simpler, you can always take z equal to 0 because in that way you will get rid of these term fully. So, you will have E to the minus 0 and then E to the plus j 0. So, you can get rid of it and then you will notice that the constant C and D are actually identical all right.

So, this is another way you can apply the boundary conditions anywhere. z equal to 0 is very simple because you eliminate some two terms. So, Ez forward becomes equal to Ez backward and the implication is that the constant C has to be equal to constant D. So, we applied the boundary condition just to figure out the proportional relationship between C and D in the expressions for the electric fields.

This now, means that the total electric field right is going to be a summation of these two quantities that is going to be

$$E_{z_{forward}}(x, y, z) = C\left[Sin\left(\frac{m\pi}{a}\right)x\right]\left[Sin\left(\frac{n\pi}{b}\right)y\right][e^{-j\beta z} + e^{j\beta z}]$$

So, you have some summation of two complex exponentials coming into the picture for the total electric field expression.

So, once again you can apply some trigonometric rules for a reducing the a complex exponentials on the right side. So, this means that I will end up having

$$E_{z_{forward}}(x, y, z) = 2C\left[Sin\left(\frac{m\pi}{a}\right)x\right]\left[Sin\left(\frac{n\pi}{b}\right)y\right]Cos(\beta z)$$

So, on the right side now I have two times a constant that will determine the amplitude of this electric field all right.

Then I have $Sin\left(\frac{m\pi}{a}\right)x$ which will determine the a pattern or the standing wave pattern about the x direction and in our diagram it is the horizontal direction of the cross section. $Sin\left(\frac{n\pi}{b}\right)y$ it will determine the number of half a cycles that you will have in the vertical direction and $Cos(\beta z)$ tells you what kind of pattern you will be having in the longitudinal direction.

Now, if you want it to be more specific about a this $Cos(\beta z)$ all right, you can once again apply boundary condition previously, we had applied it at z equal to 0. Now in order to get a better description of what this βz could be all right. We can always do the same things that we had done for the rectangular waveguides to arrive at $\left(\frac{m\pi}{a}\right)x$, $\left(\frac{n\pi}{b}\right)y$ and which is simply using boundary conditions. So, I know that in the position z equal to d ok at the position z equal to d according to this diagram I am having an interface once again between the dielectric and the metal wall.

So, the wave that is travelling forward hits the wall gets reflected back and it has to be reflected back fully and since the forward and the reflected wave are having similar description all right. So, the waves will have to add up and the maximum will be present at the place where the interface is present. So, the maximum will be at the interface all right.

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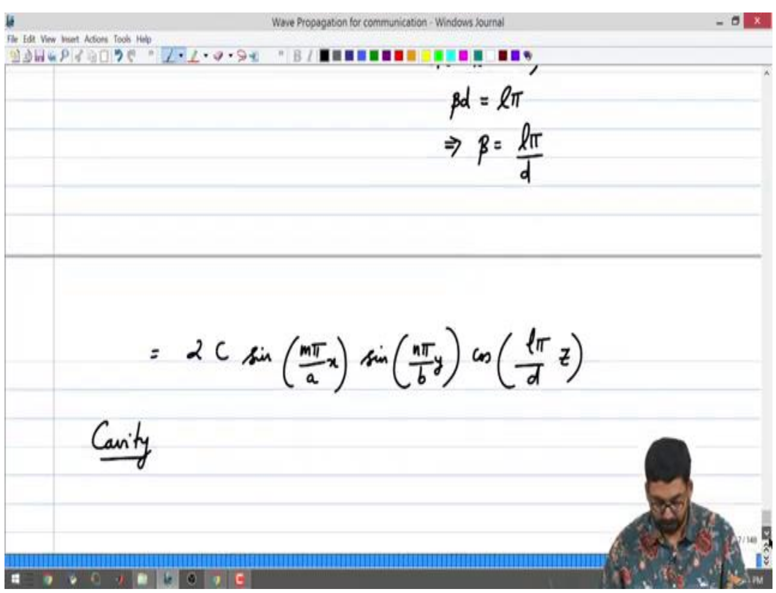

So, here that gives us some idea the cosine will reach its maximum all right. At z equal to d you will write this as βd all right, the argument of the cosine will look like βd and for the cosine to be maximum its value has to be equal to 1 and this means that a we will be having

$$\beta d = l\pi$$

So, here we are not worried about the sin so much ok. So, $\beta d = l\pi$ all right which means that I can write down

$$\beta = \frac{l\pi}{d}$$

So, this means that I can take the prior expression and rewrite this as

$$E_{z_{total}}(x, y, z) = 2C\left[Sin\left(\frac{m\pi}{a}\right)x\right]\left[Sin\left(\frac{n\pi}{b}\right)y\right]Cos(\frac{l\pi}{d}z)$$

I could have used o, but o usually gets confused with a 0 again, I could have used to C for the denominator, but z is what we are using for the velocity of light in this course. So, I had to choose some slightly different variables which gives me cos $\frac{l\pi}{d}$ into z.

So, here the thing that we notice is that this is the total electric field that is present in the volume of this cavity, if I wanted to find out what the electric field would be at a location x comma y comma z inside this cavity, I would simply substitute the value of x comma y comma z in this formula all right. And if I have some knowledge of C then I will be able to exactly figure out what the electric field would be at different place for the z component right. And once I know that I can calculate say different components based on the Maxwell's curl equations, some of this we have already done in the past. So, you can refer to the past lectures ok.

So, this expression corresponds to what is known as a cavity and there is a reason why right. Now in the case of rectangular waveguides that we had seen in the prior lectures ok.

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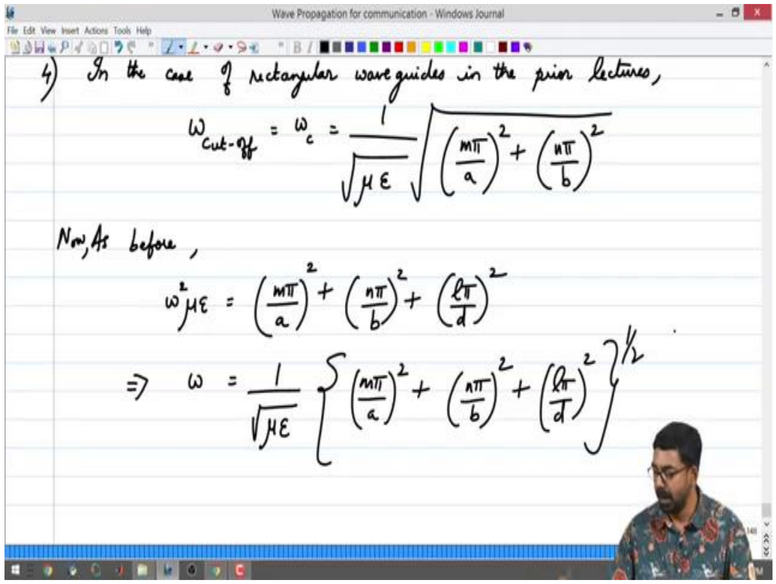

In the case of rectangular waveguides, we wrote down a relationship while analyzing the modes all right. And a we saw that the cut off frequency, we used ω_c all right it looked like

$$\omega_c = \frac{1}{\sqrt{\mu\epsilon}}$$

So, this is the expression that we have from the prior lectures right. Now as before we can extend the same analysis here, we can say in this particular case just look at the third dimension all right and wherever you had beta. So, if you look at the prior lectures, wherever you had β for the a waveguide ok.

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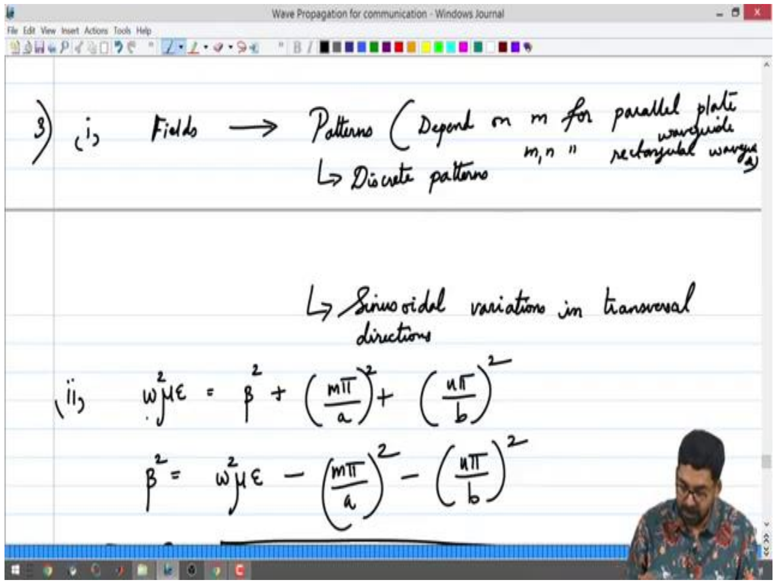

So, we had an expression which states that

$$\omega^2\mu\epsilon = \beta^2 + \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2$$

Now instead of β we just have to substitute $\frac{l\pi}{d}$. So, the same old expression we can use just that we have to make a substitution for β to be $\frac{l\pi}{d}$ in accordance to the boundary condition for the structures that we are talking about now all right.

So, here all we need to do is we have to rewrite that expression

$$\beta^2 = \omega^2\mu\epsilon - \left(\frac{m\pi}{a}\right)^2 - \left(\frac{n\pi}{b}\right)^2$$

Where μ and ϵ ϵ are the permeability and permittivity of the material that is covering the volume all right. I mean that is forming the volume covered by metal plates all right. So, this is going to be

$$\omega^2\mu\epsilon = \left(\frac{l\pi}{d}\right)^2 + \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2$$

This means that I could write down an expression for the frequency which is going to be

$$\omega = \frac{1}{\sqrt{\mu\epsilon}}\left\{\left(\frac{l\pi}{d}\right)^2 + \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2\right\}^{\frac{1}{2}}$$

1 by square root μ ϵ, once again μ and ϵ are the dielectric parameters. So, it is the dielectric constant and the permeability of the material inside the volume right. This is what the expression for the frequency looks like.

$$\omega = \frac{1}{\sqrt{\mu\epsilon}}\left\{\left(\frac{l\pi}{d}\right)^2 + \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2\right\}^{\frac{1}{2}}$$

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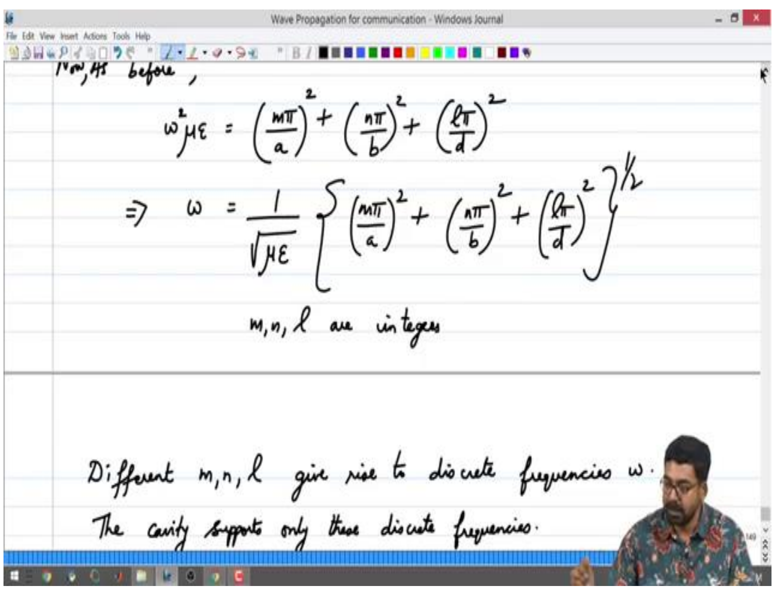

And just like before we can also make a few statements m n l are integers m n l are integers. So, different values of m n and l can be substituted in this expression for a given cavity geometry which has the sides of a centimeters by b centimeters by c by d centimeters extra.

So, if we are talking about a particular mode in a cavity which is having particular dimensions filled with a particular material with permittivity and permeability given, then we can always find out the frequency that is supported by such a cavity, but what is the key difference between this structure and the waveguides that we have analyzed in the past. Well there is one key difference and the key difference is, different m n l give rise to discrete frequencies omega all right.

Previously, we had an inequality that is we had something like the input frequency has to be higher than the cut off frequency all right, but in this particular case what we are noticing is the different m n l values will give rise to specific frequencies that are supported by these structures and a we have to make a note that, the structure which is the cavity all right supports only these discrete frequencies. Its supports discrete frequencies ok, which can form the standing wave patterns according to the boundary conditions in all the sides and these kinds of discrete frequencies all right are known as cavity resonance frequencies ok.

So, for a given geometry, depending upon the values of a b and d depending upon m n l you will have only one frequency which satisfies the boundary conditions and that will be your cavity resonance frequency for that particular mode ok. So, the key difference here is your cavity resonance frequencies will be discrete, you do not have an inequality saying that frequency is above this cavity resonance frequency.

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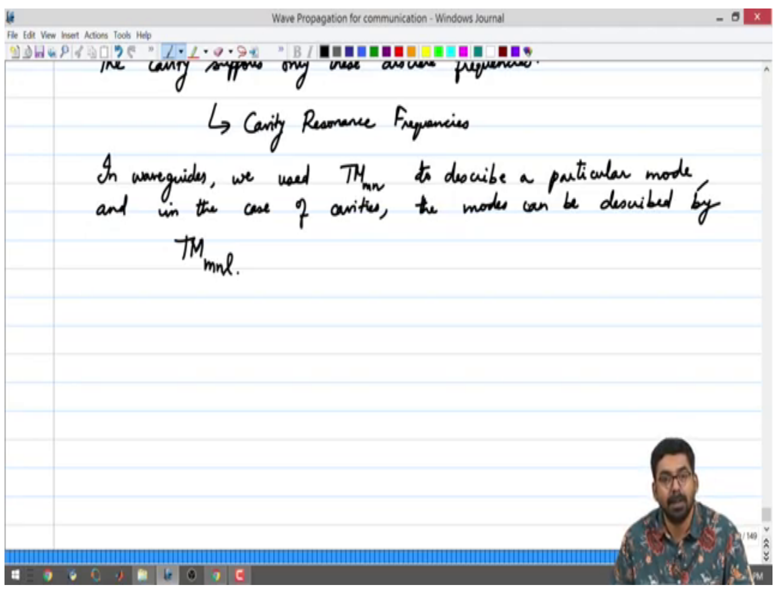

Just like in the waveguides we used in waveguides we used TM say mn to describe a particular mode, whose cut off frequency can be calculated by using the field descriptions that we had before.

And in this case the case of cavity the modes can be described by TM_{mn} and l you just need three subscripts to describe what standing wave patterns you are talking about. m will tell you the number of standing wave half cycles that you have along the horizontal direction, n will tell you the number of half cycles along the vertical direction, l will talk about the number of half cycles you will be having in the longitudinal direction. So, this kind of concludes the analysis for cavities.

So, if you were to take the t e structure transverse electric structure you will have very similar approach and the end result will be same because they are degenerate, you will have the same expression for the cut off frequencies for these cavities. You could do this as an exercise by using appropriate boundary conditions and with that now you know how to analyze a single interface 2 interfaces 4 interfaces and all 6 interfaces. If you know how to do one and if you a have a fair understanding of the boundary conditions, you will be able to pick up from your last point and then elevate the analysis to higher levels ok.

Now, what we will do is we will have a look at a few a pictures and talk about a few practical aspects of the waveguides that are used in practice all right.

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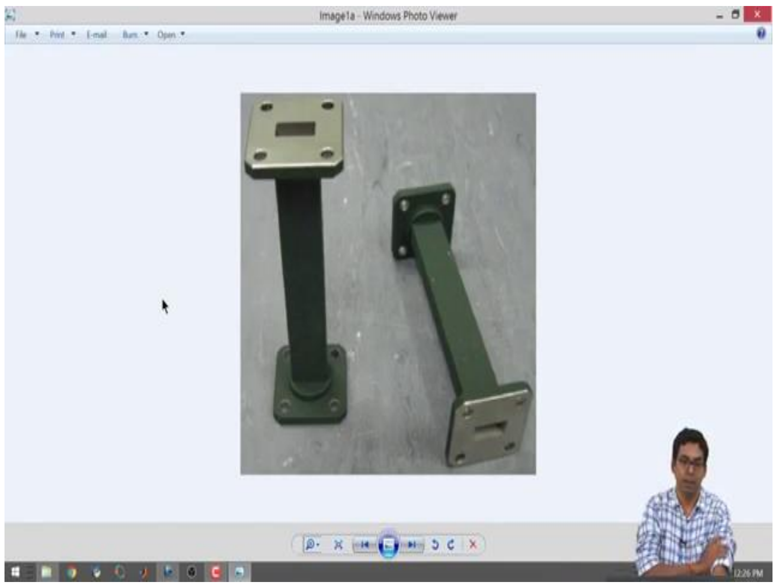

So, I am having a picture over here, this is what a rectangular waveguide looks like all right these are for you know hundreds of megahertz or gigas frequency I do not know the exact dimension looks like it is a few centimeters a wide and few centimeters tall extra, but this is what it looks like ok. So, you can launch the electromagnetic power on one side, you should expect a particular mode to be excited depending upon the dimensions and depending upon the frequency you are using and on the other side you will be able to detect them. The pictures that are shown here are straight waveguides all right are straight waveguides, it is not necessary that you need to have only straight waveguides all right you could bend right.

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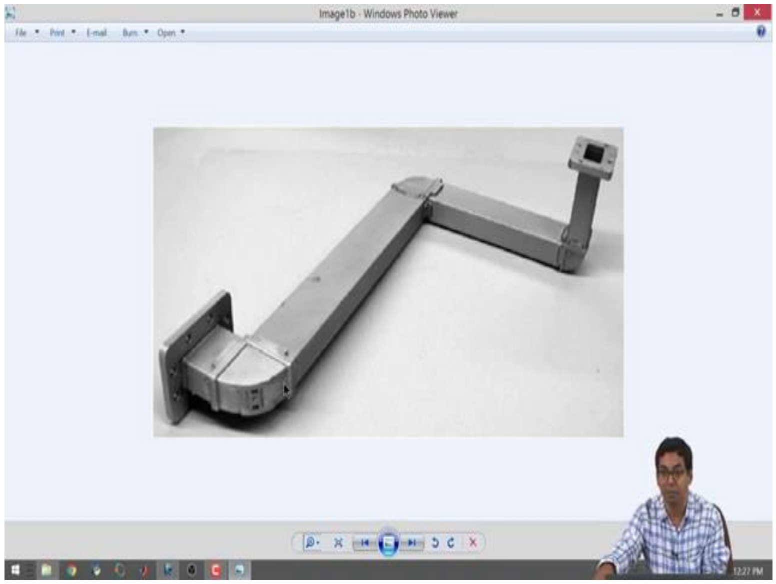

In this particular case, it is a very nice a waveguide construction because you are launching here. First you are bending it along the horizontal direction all right. Now, you will notice that the bend is very slow in the previous class, when we tried to do a computer experiment, we saw that if you had an abrupt bend there is a mode conversion that is happening all right. In this case they have bent it very slowly rather than being abruptly. So, maybe there is no more conversion, I do not know the details of this, but it looks like it is a slow bend that is happening ok. So, there is a horizontal bend goes to the other side another horizontal bend on the other side these are all 90-degree bends and then to make the problem even a better know to give complete understanding the bend is going in the vertical direction.

So, you could have 3 dimensional control on the way your electromagnetic wave is going to travel from one point or another. It is not necessary to be having a planner configuration, you could have control over and entire volume ok. So, whichever position you want you can direct. So, this is how it is constructed.

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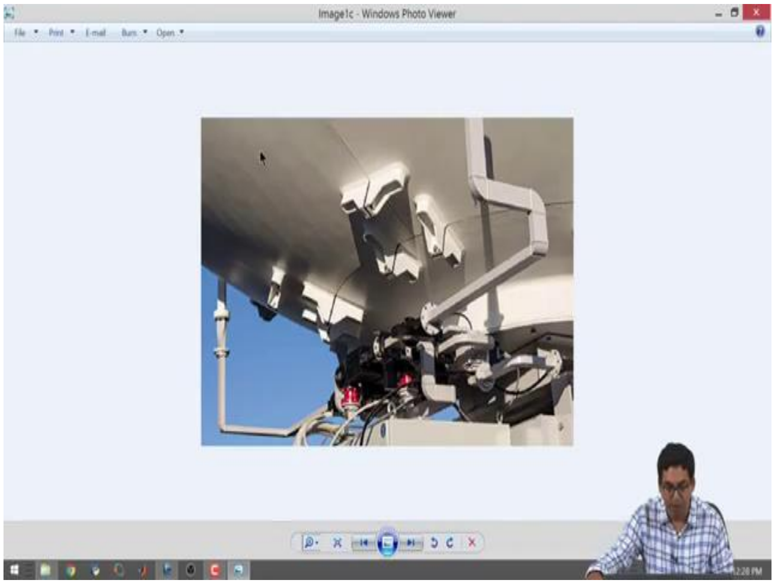

So, this is in practice. So, on top you are seeing the antenna all right there is a giant dish antenna over here and from the antenna all right, there is a waveguide that is coming into the picture it is being bent being bent again and it is being sent to some units which are going to detect and do some processing this is from a radar ok.

So, this is what in reality it looks like. Now, if you see these kinds of structures should you should immediately strike your mind that maybe it has this shape because it is a rectangular waveguide right. So, this is what it looks like on top of that if you look at the bottom there are multiple constructions here all of these are rectangular waveguides, you also have something happening here that is also a rectangular waveguide. So, this is what it looks like ok practice.

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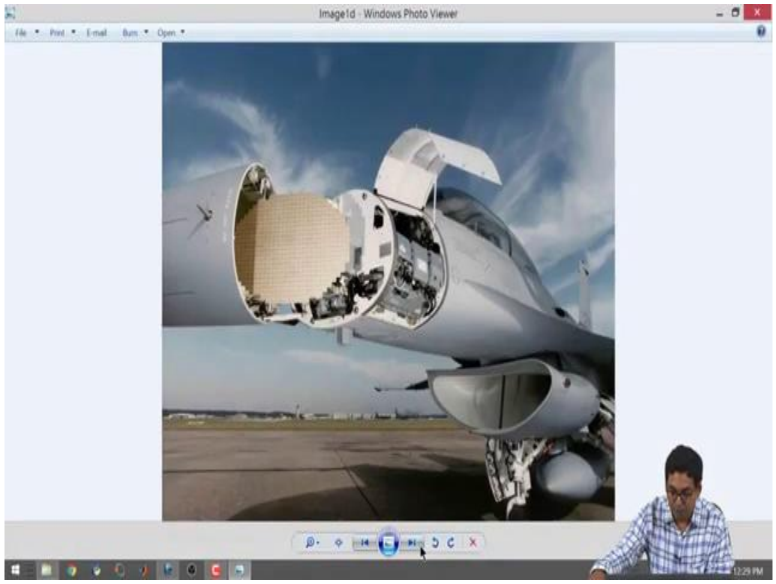

Where is it used all right? So, if you have a look at this, this is a fighter plane all right. Now the front of the fighter plane usually has an antenna array all right. This antenna array is used for detection and ranging all right. So, what happens is you can turn on the antenna, you can turn on a source of electromagnetic wave ok.

Then what happens is it will direct electromagnetic wave from the front of the aircraft all right and it also has detectors right. So, these are arrays of detectors which are placed over here. So, it will we all remember time domain reflectometry from our transmission line and we also remember that time domain reflectometry can also be done with electromagnetic waves its time of flight base things.

So, it will send a wave it is going to get some reflected wave back based on the amount of time it will it will judge at what distance an obstacle is there could also do more complicated things like the shape of the object extra all right, but here in the simplest sense you can gauge at what distance a conductor of some sort is there. Now, how the waves are transferred to a system that will do the analysis if you notice carefully there as a large number of slots present here, each of them is connected to a waveguide and the rectangular waveguide carries this information to a central processing place where it is converted into some other form and an electronic analysis you know is done. In order to show you how it how that part looks like right.

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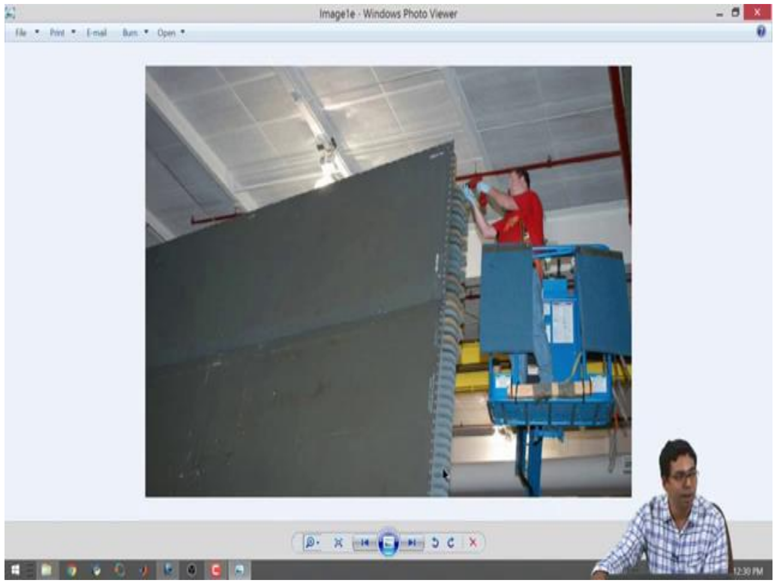

So, you can have a look over here all right. This is how an array of antennas will be connected to array of detectors using some waveguides. So, you have large number of 90 degree bents going on all right. It means some kind of an array detector and the energy is going to some place where it is going to get converted into say electric signal and then you are going to make an analysis.

So, this is what it would look like ok so, obviously, these are going to be heavy right and these are going to be a you know a large depending upon the frequencies of operation they could also be tinier, but this is conventionally you know the range of sizes that people use in the megahertz and gigahertz will change right.

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So, here this is another a just a simple you know demonstration to show you that even this is a I think this is taken from inside the a you know inside a section from the aircraft itself right. So, it is not only on the outside it is information also goes along the body of the aircraft to different places. Maybe they need to do a variety of a you know calculations with they need to do a variety of a you know processing extra. It is just showing that you know, you can have them inside you can have them outside it is it is fine right.

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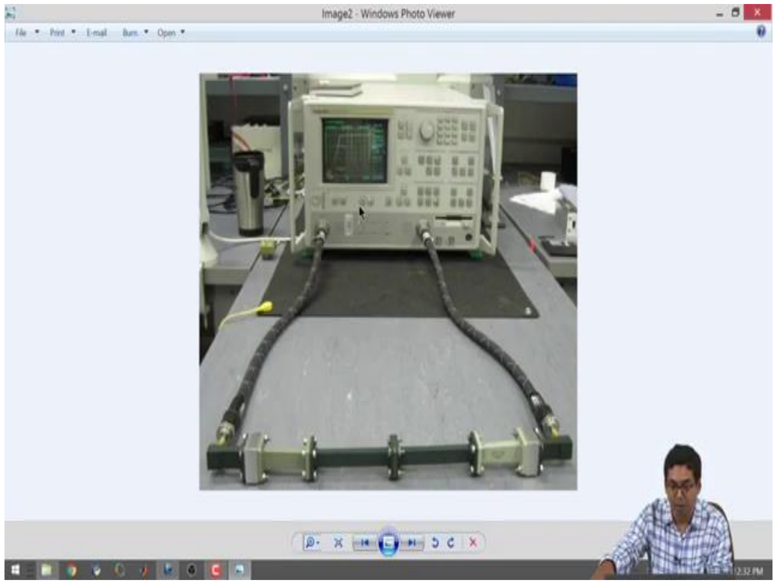

So, in the lab what would an experiment look like, we have all already seen a demo for vector network analyzer ok we have also talked about a transmission line cables extra right. So, in the lab you would have a vector network analyzer, you will have a transmitter or a Tx port you will connect this using some special cables all right to your rectangular waveguides all right. And you will connect the receiver port back to this. You could also have more configuration, you could keep an antenna over here all right. You can excite it with something and you can have a receiving antenna which will receive and you can process it to a signal and all that, but in a typical lab, when you are doing an experiment with waveguides this is what it looks like.

So, it is clear that you are taking different sections putting together nuts and bolts and actually joining them together all right is a very simple construction. So, you get them in pieces of finite a you know sizes and depending upon your application you will put them together tighten it and then you will you can start using it right. This is what it looks like in a regular lab. Now a these are all for waveguides. Now in this class, we saw about waveguides that are covered with a metal on one side and the other side which means, it is a box of metal and the box of metal the example that we have is a microwave ok.

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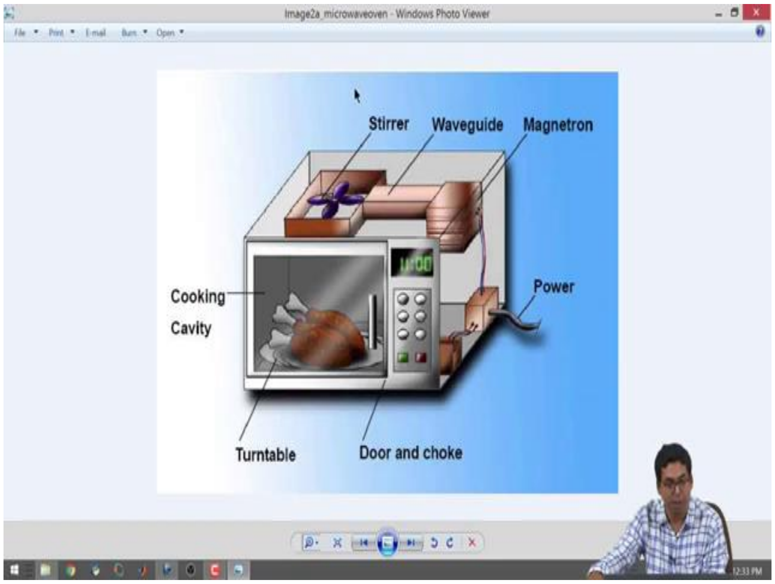

It has metal on the right side metal on the left side, metal at the bottom, metal at the top, metal at the back and you also have a glass door in the front, but if you noticed all your microwave ovens they would not give you plain glass doors ok. There will be having some pattern and there is also a bulb inside of the microwave there is a pattern and that pattern is made up of metal ok if you look it will be like a millimeter sized dots where you have openings for the visible light to pass through ok.

So, the front is also actually acting like a conductor all right, but it has got holes for you to see the visible, visible wavelength is like 400 to 700 nanometers it is very small all right. So, it has place to pass through, but a microwave typically operates in gigahertz the wavelengths are in centimeters.

So, it does not pass through these a thin I mean these small regions ok. So, in practice you can say that this is a cavity, but since you want to see what is happening you have made some slight imperfections. Now, how does a this work you have a source of power that is connected to your mains ok and then you have a device which is known as a magnetron.

I do not think we have a you know bandwidth and this goes to cover what is a magnetron extra. We have not had advance course called antennas circuits and waveguides all right. So, there I think you will spend some time discussing about what is a magnetron typically it is a solid state device which will convert your electrical energy into gigahertz power ok.

Once it is done the electromagnetic wave is carried through a waveguide all right and then it is used to excite your cavity and the cavity naturally produces standing waves all right. Now this is known as the cooking cavity and this is a standing wave and there are some questions that come to our mind all right. Sometimes, we notice that when we put the plate of food inside the microwave some portions are very hot some portions are very cold. Let us suppose you put. This means that some portions are getting heated more some portions are not getting heated more this is something that one would observe.

So, in order to avoid that what people do is, they put what is known as a turntable at the bottom. So, you have food rotating. So, that not the same portion is getting heated all the time. So, you have rotation on top of that to make it even more efficient some heat is being created inside. So, the mechanism of cooking is because the water molecules present in your food will actually absorb this microwave. So, they will oscillate and then due to the friction you are having heating up ok.

So, that is the mechanism and a you are having some heat being produced in this cavity and some models could provide us stirrer which is nothing, but a fan all right a fan that will rotate. So, that the heat is actually you know circulated inside to get more even cooking of some kind right.

So, this is a cavity so, it has a source it has a waveguide and it has a cavity right and this is what happens right.

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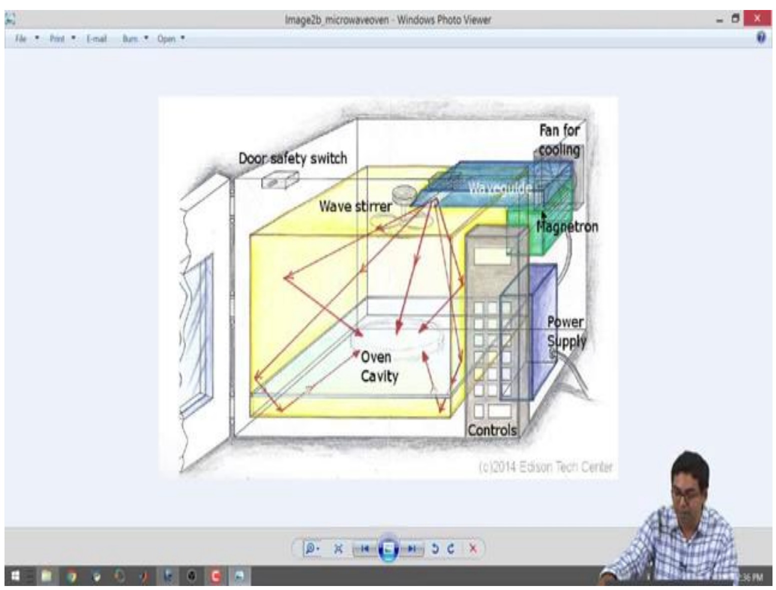

So, another picture would be like this which just shows a little bit more detail on how this cavity is functioning. So, I am having a power supply magnetron, I am having a waveguide and I am having a wave stirrer the waveguide takes the power from the magnetron actually launches it into the cavity. Now the cavity is a you know though it is present it needs to have specific dimensions because, we know that it has to produce standing waves which match the boundary conditions at all these interfaces which means that there is some standard for the size of the you know the box that you can have that also means, that for a given box you can have only specific source with specific frequency all right, that means, to be present extra.

But you can see the wave can directly hit the food, it can have one bounce and hit the food it could have for example, two bounces and then hit the food it could have many bounces hit the food extra, but it is not an ideal cavity in any case because once you place the food, you have disturbed something inside the cavity all right. So, small shifts are supposed to happen all right. So, a so, the you know the way of cooking for one type of food is different than another type of food. So, one big jug of milk is different from one small cup of milk everything should happen. So, it is not a very ideal scenario, but it does work ok.

So, now what we are going to do is, we are going to do this with a microwave all right.

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I think I have a microwave all right. So, what I am going to do is first going to I am I am going to open it right and I am going to take of a few things. First of all, I am going to remove this glass plate over here, it is going to be the turntable. Secondly, I have a motor that twist this around. So, I do not want this I am going to get rid of it all right and I also know that all the portions are made up of reflecting surfaces and this particular part if you notice it has some perforated a metallic cover all right. So, I know that it is going to be a cavity and I know that the field values near these on the surface is going to be 0 corresponding to the boundary condition all right.

So, now what I am going to do is, I am going to position a cup ok and I am going to keep this plate on top of this cup ok like this all right and then I am going to put something inside of it and I am going to cook and I am going to see whether I am getting standing waves all right. So, this is an experiment that is done in multiple ways in multiple Youtube channels. So, I thought there should be some Indian touch to it. So, we will be cooking papad ok. So, I will put this all right. So, I have loaded them in some form covering the entire plate all right and I am going to close it, I do not really care what mode I choose let us say soup why not ok.

So, now, I have it at about 15 seconds I can see that things are started to puff all right, but I am going to remove this now all right.

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And this is what I have I could of course, do it for longer, but this is good enough for me to make the analysis. Now one of the thing that I noticed is, some portions have puffed up some portions have not puffed up all right. So, I am going to place it as such and I am going to use our idea of standing wave, I am going to take a ruler and I am going to measure the distance between two of the puffed regions all right.

So, I am going to go ahead make a measurement like this all right. So, if I were to look here all right between the adjacent ones having about 6.3 centimeters I will confirm this with this side 6.3 I will just say another place has gone in. So, I will just make a measurement there also that is about 6.3 6.4 centimeters all right

So, 6.4 centimeters, let us a think about this I will take my mobile phone and make a quick calculation. So, I have 6.4 centimeters all I want to do is I want to calculate the frequency all right. So, it is 3 times 10 to the power 8 all right divided by a 6.3 all right let us, but now I have to apply some other thought. I know that, I am creating standing waves all right and I know that I am going to be measuring these would be two antinodes all right at the nodes you are having nothing.

So, there is a distance between two antinodes is actually 6.3 centimeters. I also know from my past simulations extra that the spacing between the antinodes and the spacing between the nodes in the case of a standing wave is half the wavelength and not the full wavelength. So, I have to accommodate for that I am having between 6.3 and 6.4. So, I am going to take 6.35 and I am going to say that 6.35 multiplied by 2 all right. So, that is about 12.7 ok.

So, I am going to make a calculation for 12.7 all right. So, I am having three divided by 12.7 to give me the estimate. So, I am getting 2.36 gigahertz to be the frequency of the signal that is excited inside. Incidentally, this microwave has a writing on the back that says it is 2450 megahertz that is 2.45 gigahertz. I think my estimate with this simple experiment is actually very close ok.

So, now I think you should be able to use a microwave and simply estimate what is the frequency that you are exciting. Now this could change a little bit with the kind of food you are cooking also right. We already know that there are some imperfections are happening in the cavity, but it should be around this region. Now, you can also do this experiment, you could take this put it in the bottom and you will notice that there is a different pattern in the way the you know the Papads are blooming all right, it means that in the volume all right as you go from bottom to top as you go from left to right everywhere, there are there is a standing wave pattern and depending upon the way you position the food different things can get cooked at a different rate.

That is why you have a turntable and that is why you have a stirrer also. That is a simple demonstration of a cavity and how to estimate the frequency of operation from the cavity. I think we are done all right.