Transmission Lines and E.M. Waves
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Lecture-8

Welcome, in the last lecture we developed a graphical tool called a smith chart by transforming the impedances on to the complex Γ-plane. So we see here the smith chart which is superposition or constant resistance and constant reactance circles. before we go into the use of the smith chart for the Transmission Line calculations let us develop one more set of circles called the constant VSWR circles which are to be superimposed on the smith chart for doing Transmission Line calculations.

We know that the reflection coefficient at any point on the Transmission Line Γ at a distance l is equal to the load reflection coefficient $\Gamma_L\ e^{-j2\beta l}$ where l is the distance from the load point, Γ_L is the reflection coefficient at the load and β is the phase constant on Transmission Line.

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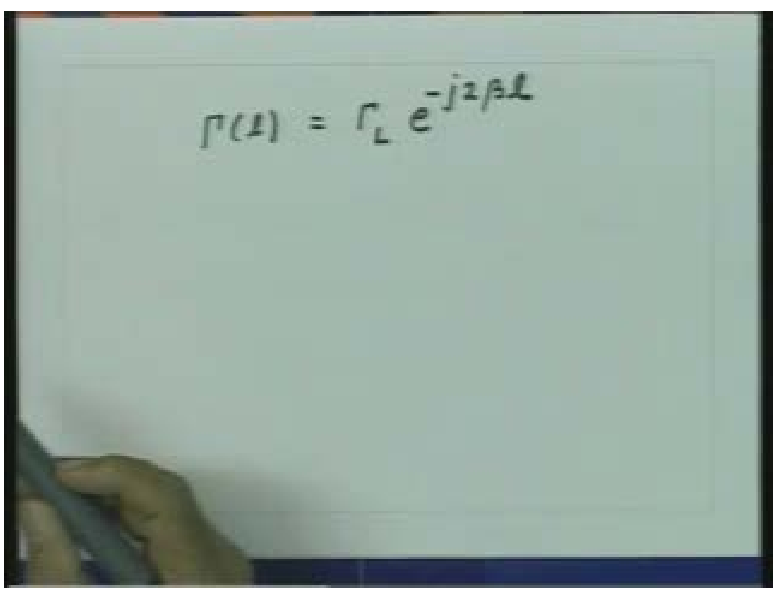

Let me remind you we are still discussing the Transmission Line which are Loss-Less Transmission Line and therefore the attenuation constant of the Transmission Line is zero. If you write this reflection coefficient at the load explicitly as the modulus of the reflection coefficient and the phase angle we can write this as the $|\Gamma_L|\ e^{j\theta_L}\ e^{-j2\beta l}$ where θ_L is the phase angle of the reflection coefficient at the load. So the total phase of the reflection coefficient at a distance l from the load will be $|\Gamma_L|\ e^{j(\theta_L\ -2\beta\ l)}$.

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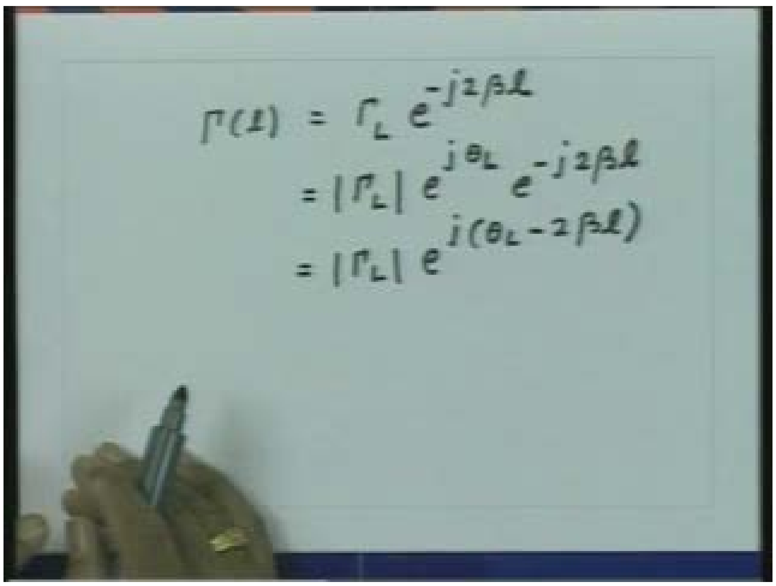

So, on the complex gamma plane if I get the reflection coefficient it has a magnitude whose value remains constant but the phase changes as we move on the Transmission Line and l is positive if we move towards the generator. So as we move towards the generator the phase becomes more and more negative the distance of the point from the center which is the magnitude of the reflection coefficient remains constant so essentially this represents a circle on the complex gamma plane with a center which is same as the origin of the complex gamma plane.

So I can plot this on the complex gamma plane this is u, this is jv I get a circle on the complex gamma plane whose radius is $|\Gamma_L|$ and the angle is $(\theta_L\ -2\beta\ l)$.

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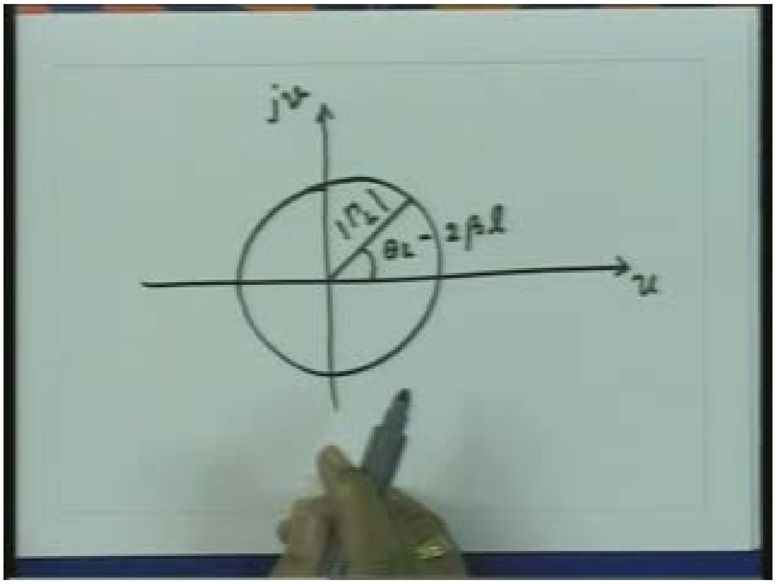

So l is positive as we move towards the generator so this quantity becomes more and more negative so the point essentially moves on this circle in the clockwise direction. So the movement of on Transmission Line by a distance l is equal to a rotation on this circle in the clockwise direction.

Now for this circle the magnitude of reflection coefficient is same no matter what point you take on this. So the phase angle changes for different points on Transmission Line but the magnitude of reflection coefficient remains same. And we know that the VSWR on Transmission Line is $\frac{1+|\Gamma_L|}{1-|\Gamma_L|}$ as we saw last time. So for this circle any point on this circle this quantity VSWR is same because $|\Gamma_L|$ is same for all the points on this circle and that is the reason the VSWR is same for all points on this circle. So you take any impedance which lies on this circle it magnitude of reflection coefficient will be same and that is the reason the VSWR will be same.

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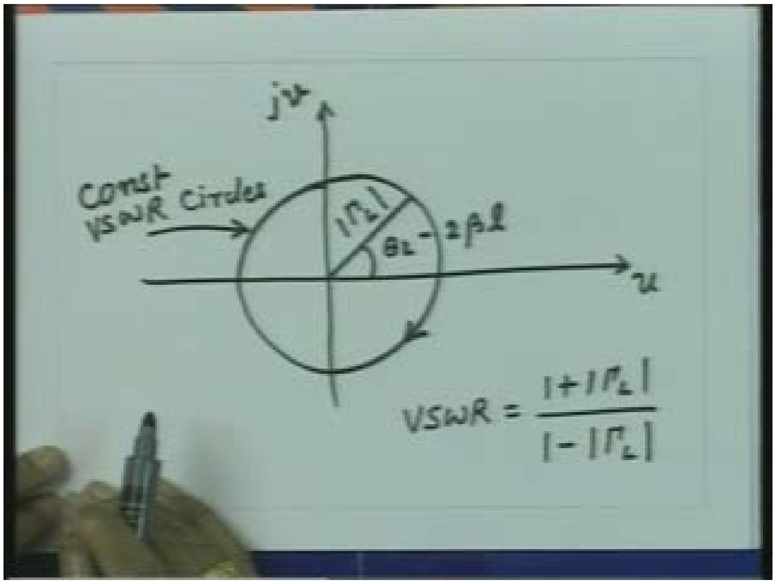

Consequently we call these circles as the constant VSWR circles. You have to draw these circles whenever we solve the Transmission Line problems using smith chart. So smith chart readily gives you the set of circles which are constant resistance and constant reactance circles and while solving the problem we have to draw the circles called the constant VSWR circles on the smith chart and then do the transmission line calculations.

As we can see there are special properties for the constant VSWR circles, firstly the center of all constant VSWR circle is same as the origin of the complex gamma plane, secondly for all passive loads the magnitude of reflection coefficient is always less than or equal to one so these circles are concentric circles with origin as the center of the circles and the maximum radius for this circle is one. Larger the radius gives you more reflection coefficient that means worse is the impedance match so what that tells you now is if you take a point which is closer to the origin of the reflection coefficient plane it denotes smaller magnitude of reflection coefficient which means smaller reflection which again means better magnitude.

So visually whenever we have impedance marked on the smith chart or on the complex gamma plane visually if the point is closer towards the center of the smith chart better is the match because that is representing smaller value of the magnitude of the reflection coefficient. With this understanding and superposing the constant VSWR circle on the smith chart then we can solve the Transmission Line problems.

However as I mentioned last time you may require many times the connections of Transmission Lines which could be in the form of parallel connections and we know from electrical circuit analysis that whenever we have parallel connections it is easier to deal with the admittances rather than impedances. Till now, we have been talking about the load impedances or any impedance on Transmission Line however now if you want to make parallel connections we have to represent this loads and other characteristic in terms of admittances.

So what we first do before we go into analysis of Transmission Line using smith chart let us find out how the smith chart would look like if I do all the calculations in terms of the admittances. Since the smith chart deals with the normalized impedances as we have seen the same thing we can do for the admittances. So we can first define the normalized admittances on Transmission Line and for that we will require the characteristic admittance of Transmission Line.

So what you do first is we define a quantity called the characteristic admittance which is denoted by Y_0 and that is nothing but one upon the characteristic impedance Z_0.

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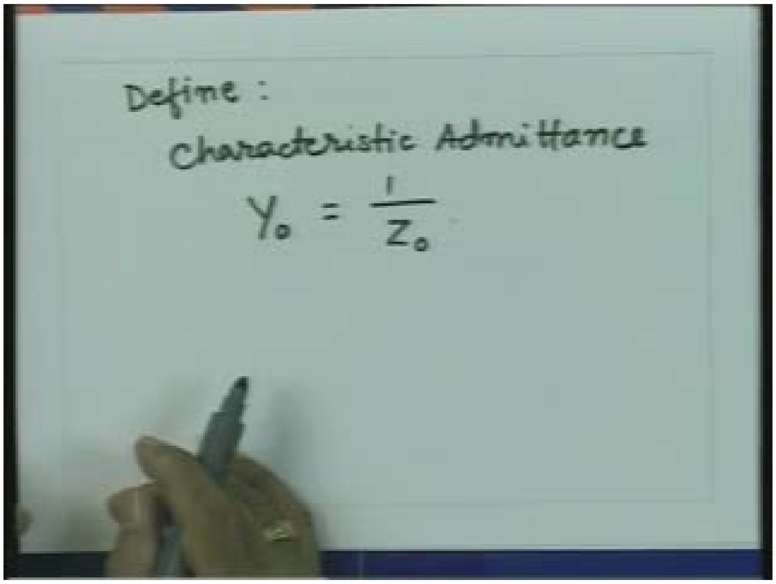

Then every admittance which we see on Transmission Line is normalized with respect to the characteristic admittance of the Transmission Line. So following the same notation as we did for the impedances normalize the admittance which is denoted by y bar that will be equal to the actual admittance divided by characteristic admittance on the Transmission Line. Similarly the load admittance normalized will be equal to the actual load admittance divided by the characteristic admittance of the Transmission Line.

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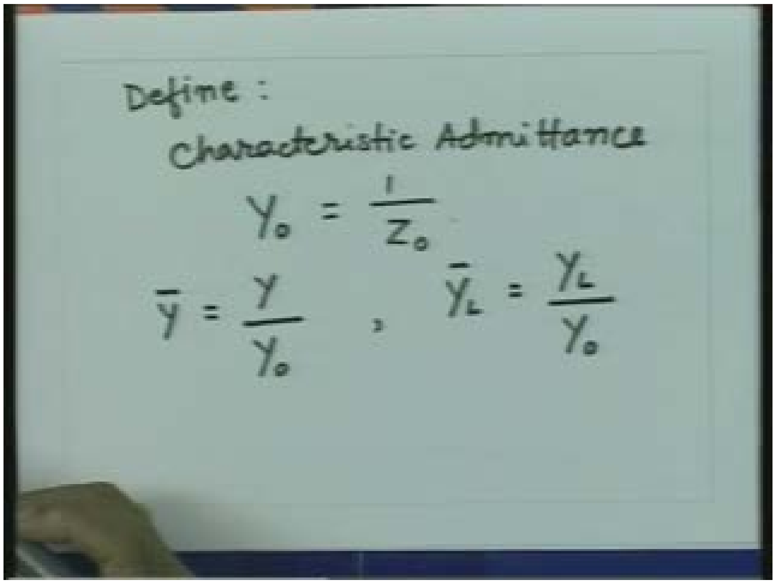

Once we make this definition for the characteristic admittance and the admittances on the Transmission Line then one can ask how do I write down the reflection coefficient in terms of the admittances. Going from the definition of the reflection coefficient which we have derived in terms of the impedance the Γ at any location is $\frac{Z - Z_0}{Z + Z_0}$.

The admittance will be $\frac{1}{Z}$ the characteristic admittance will be $\frac{1}{Z_0}$ so you can write this as $\frac{1/Y - 1/Y_0}{1/Y + 1/Y_0}$ which will be equal to $\frac{Y_0 - Y}{Y_0 + Y}$.

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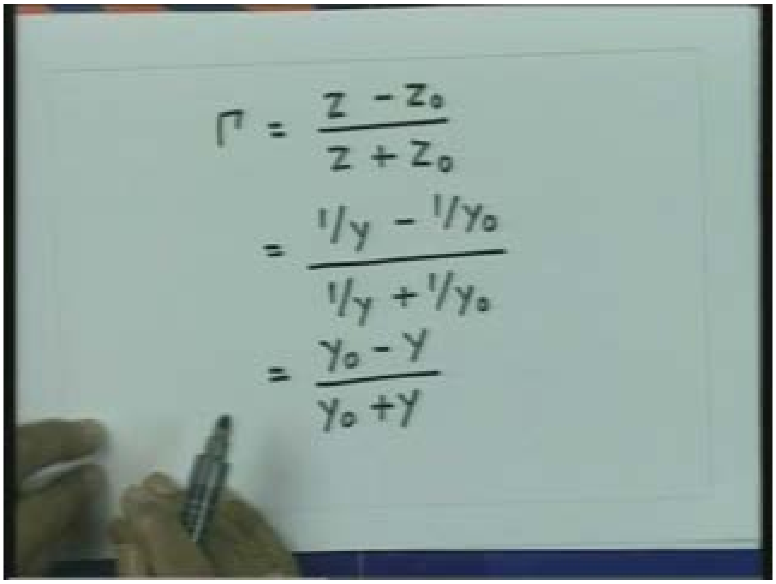

If I want to write in terms of normalized admittances I can take Y_0 common so that will be equal to $\frac{1-\bar{Y}}{1+\bar{Y}}$.

If I take negative sign common this will be $\frac{-(\bar{Y}-1)}{\bar{Y}+1}$ so we can write this as $\frac{\bar{Y}-1}{\bar{Y}+1}$ and the minus sign is nothing but the phase change of 180˚. So this is same as $e^{j\pi}$.

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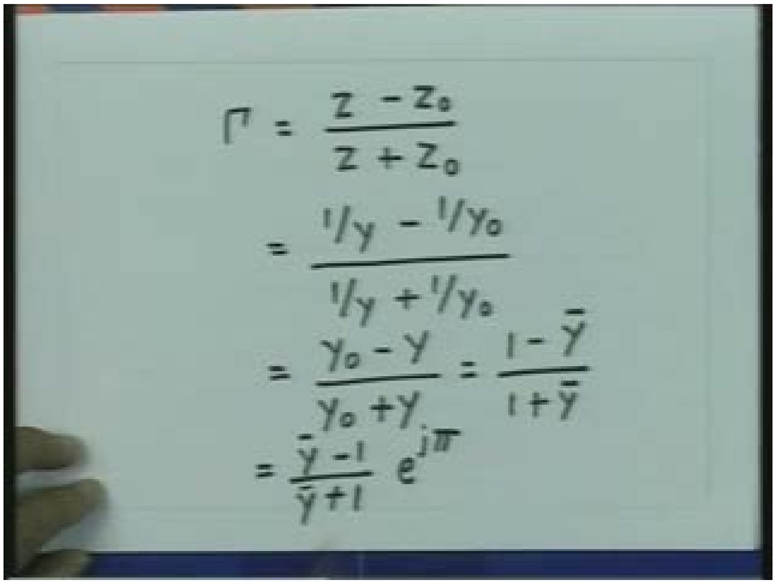

So a reflection coefficient if I write it in terms of normalized admittances it is same as if I got the reflection coefficient by using normalized impedance except there is going to be a phase change of π.

What that means is if I take the same normalized value of impedance and admittance and calculate what that reflection coefficient would be the magnitude of the reflection coefficient would be same but the phase difference between the reflection coefficients will be 180˚ or in other words on complex gamma plane the 180˚ phase change would correspond to a rotation by an angle 180˚. So essentially the normalized admittances and normalized impedances can be dealt in a same way except whenever we are doing calculation for the normalized impedance there is a rotation of 180˚ on the complex gamma plane otherwise all other things remain same. So what essentially we are saying is if I take the gamma plane as we did it earlier here and I take certain value of the normalized impedance I get the reflection coefficient here if I take the same normalized value for the admittance the point has to rotate by 180˚ so if I take a diagonally opposite point on this circle that is the point which will correspond to the complex reflection coefficient for the normalized admittance.

So essentially as far as the set of circles are concerned called the smith chart if I rotate every point on the smith chart by one eighty degrees I get the set of circles for the normalized admittances.

Let us say the normalized admittance is denoted by g + jb so $\bar{y}$ is the normalized admittance and let us denote that by the conductance g plus the susceptance jb which is same as the actual conductance plus the actual susceptance divided by the characteristic admittance y_0.

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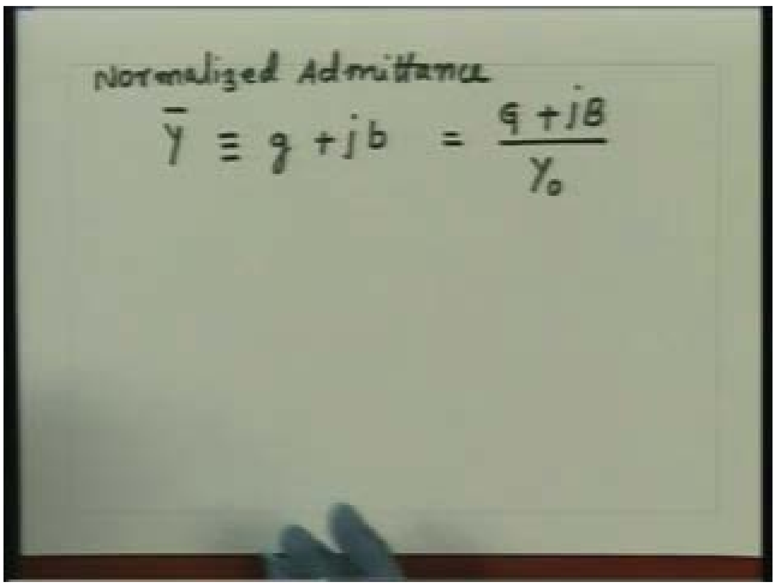

So if I have a admittance on line which is given by the conductance g plus susceptance b and normalized characteristic admittance y_0 I can calculate the normalized admittance on the transmission line which is g + jb.

So if I interchange r with g and x with b I will get set of circle which will be constant g circle for constant conductance circles and constant susceptance circles and these circles will be rotated version on the complex gamma plane by 180˚. What that means is if I have initially a chart there is rotation of every point on this around the center of the smith chart which is origin of the complex gamma plane by 180˚.

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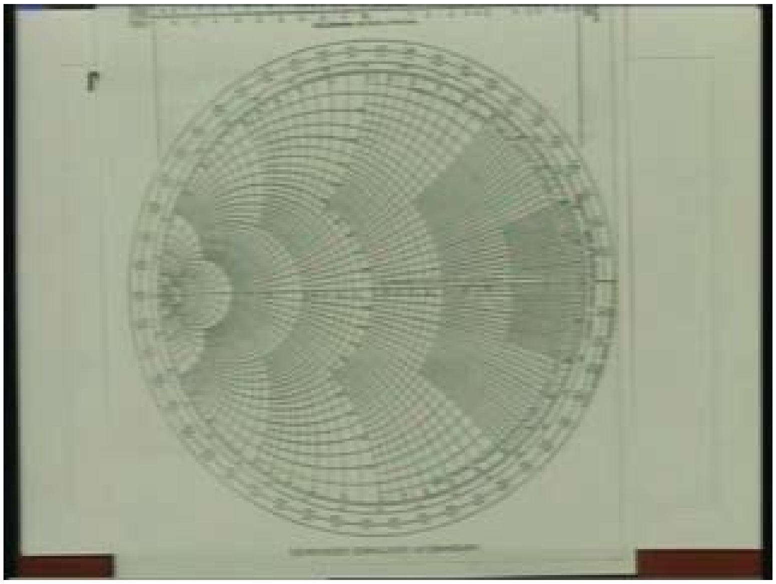

So if I keep gamma plane fixed that this is the real axis of the gamma plane, this is the imaginary axis of the gamma plane then every point on this will rotate and the constant conductance and the constant susceptance will look like that. Now in this case these circles which were earlier constant resistance circles are now the constant conductance circles these circles which were constant reactance circles are now constant susceptance circles so nothing is changed as far as the smith chart is concerned except the first smith chart is rotated by 180˚.

Now there are two things if I keep the axis for the complex reflection coefficient same then the smith chart will be rotated by 180˚ alternatively I can keep smith chart same and rotate the complex gamma plane axis by 180˚ whenever I do the calculation for the admittances. So if I develop an understanding that I will not rotate the smith chart I will use always in this form which means the most clustered portion of the smith chart is on my right then if I do the impedance calculations the positive real axis is towards right and the positive imaginary axis is upwards, however if I do the calculation by using this chart for admittances then the real axis will be on my left and the imaginary axis will be downwards. Normally whenever we do the smith chart calculations we do not rotate the smith chart. We follow this convention that the smith chart is fixed but for the impedance the gamma axis is like that where as when i go to admittances i get the gamma axis which will be like this.

So depending upon whether we are doing any calculation for the impedances or the admittances and if I require the phase measurement phase angle measurement in the complex gamma plane then appropriately the axis has to be rotated by 180˚ depending upon whether I am using the impedance or I am using the admittance.

But if I do not want to find out the phase of the reflection coefficient then the axis of gamma plane does not come into picture it is just the impedances and admittances which we want to use on the smith chart. So we can use the smith chart for the admittance as well as for the impedance calculations without worrying of the complex gamma plane axis. That is the reason why if you look at the smith chart carefully you will see that the upper half of the smith chart is denoted by (+x, +b), lower is denoted by (–x, -b), the circles are denoted by either r or g. So any normalized value of r which is equal to the same normalized value g will represent the same circle.

So as long as we are dealing with the normalized quantities the impedance and admittance can be treated exactly same way on the smith chart. However the normalized values of g and r or b and x have different meaning physically, they do not represent same physical conditions. For example suppose I consider r = 0, x =0 which corresponds to the short circuit conditions the impedances is zero at that point but if I take a normalized value g = 0, b = 0 which represents the admittance equal to zero is not short circuit that is the open circuit condition on the line.

So the normalized values of impedances admittances can be treated exactly same way but when we go for the physical conditions the physical conditions are not same for the same normalized value of the impedance and admittance. So as we looked at the point last time which was some special points on the smith chart, now let us look at these points for the admittance smith chart.

If I take the smith chart and say suppose these values are not impedances but they are admittances that means if I replace r by g and x by b this point represent g = 0, b = 0 which is open circuit, this points represents g = ∞, b = ∞ which is short circuit, the upper half which is the positive value of susceptance represent capacitive loads and the negative value of susceptance represent the inductive load.

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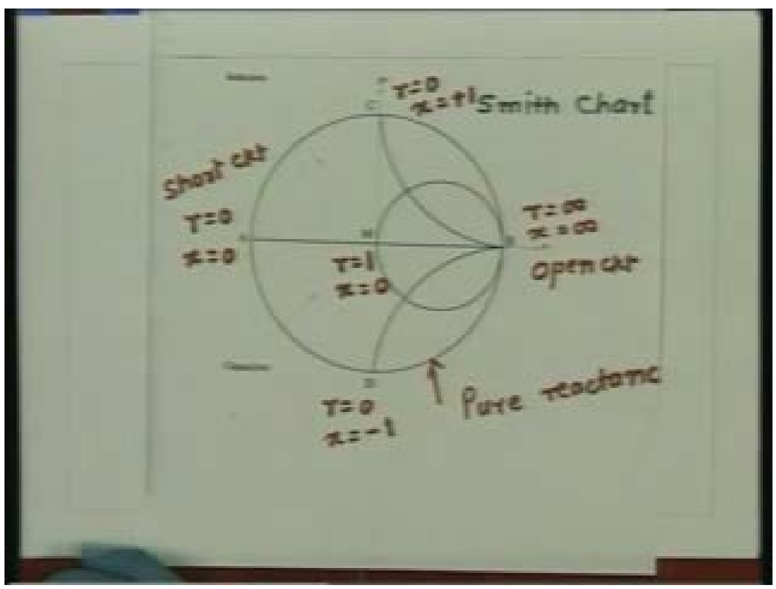

So if I keep the smith chart fixed then while doing calculation with the admittances the upper half of the smith chart represents the capacitive load, the lower half represent the inductive load this is open circuit point and this is short circuit point. Since the resistance circles are symmetric there is no difference so replacing r by g essentially tells you the g value is increasing from zero to infinity as we move on this side but the point is going from the open circuit to the short circuit. Then keeping these things in mind the use of smith chart for impedance and admittance calculation is very straight forward.

So what we will do with this understanding is now we will try to make use of the smith chart for solving the Transmission Line problems.

The simplest problem one can think of for a Transmission Line is, find the reflection coefficient at the load point for a given load?

Now we discuss the use of smith chart for Transmission Line calculations.

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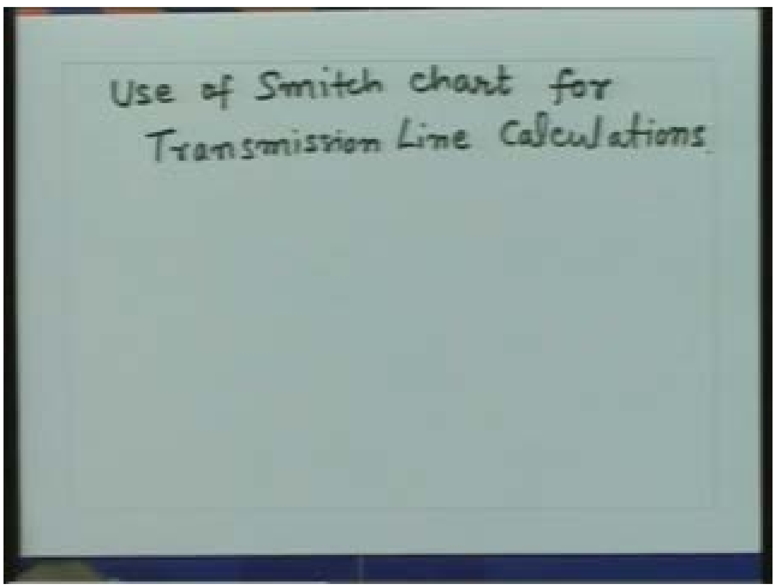

The simplest problem one can solve by using smith chart is if somebody gives you the load impedance and ask you what is the reflection coefficient, analytically I can use the formula $\frac{Z_L - Z_0}{Z_L + Z_0}$ but by using smith chart we will see the problem is much simpler remember the impedances and admittances which we have on the smith chart are all normalized quantities.

So the first step in any calculation using smith chart is normalize all the impedances with respect to the characteristic impedances or normalize all the admittances with respect to the characteristic admittances. So let us say my impedance was Z_L so first step which I do is normalize it get $\frac{Z_L}{Z_0}$ which is $\overline{Z}$.

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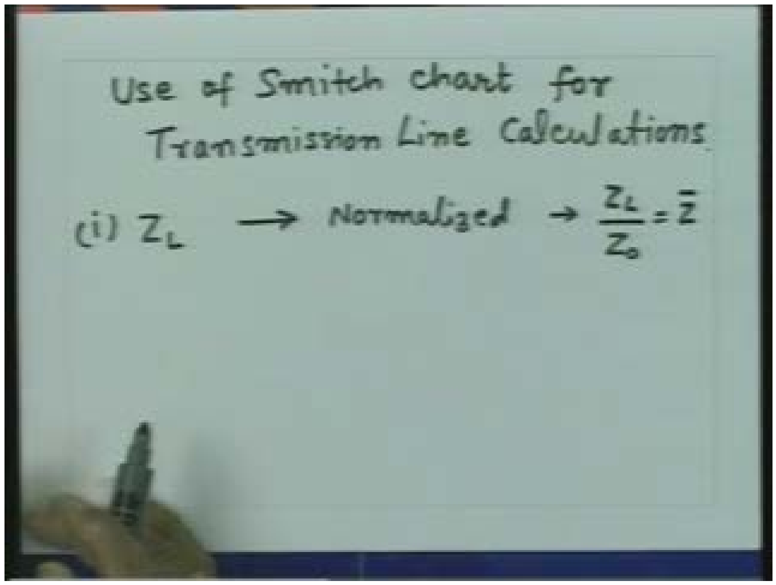

Now read on the smith chart this point, recall the smith chart as set of circles, this is the constant resistance circles which are going like that or constant reactance circle which go like that. Let us say this is given by some r + jx like that. First identify a constant resistance circle which is having this value r, let us say that circle is this side for which the resistance value is this value r. Then identify a circle for which the reactance value is this x which is will be this value the intersection of these two circles the constant resistant circle which is having value r and a constant reactance circle which is having value x. Now this point represents this normalized impedance $\overline{Z}$ so this point here is $\overline{Z}$.

Once this point is marked on the smith chart then calculation of reflection coefficient is very straight forward because now the point has been marked on the complex gamma plane so if I read of this value on complex gamma plane that directly gives you the complex reflection coefficient so if I measure the distance from the smith chart this is my origin and let me draw now the complex gamma axis which is not drawn on the smith chart so this is my u axis this is my jv axis and this is the origin. If I measure the distance of this point that gives me the magnitude of the reflection coefficient Γ_L and the angle that means generally we measure the angle on the complex plane from the real axis this angle is the angle of the complex reflection coefficient at the load end. So this angle is nothing but θ_L and this distance is $|\Gamma_L|$.

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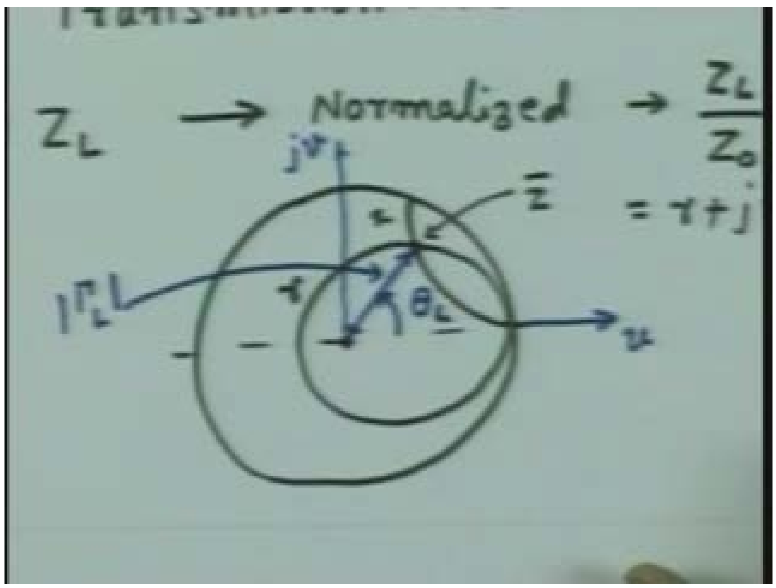

So first thing on standard smith chart you find out the radius of this by using any scale then measure this distance the maximum distance of the smith chart is unity so any distance which you get on the smith chart normalized with respect to the maximum distance that quantity directly will give you the magnitude of the reflection coefficient and the angle which this radius vector makes with the right hand horizontal axis is the real gamma axis that is the angle of the reflection coefficient at the load end.

So without doing any calculations just by measuring this distance and this angle I can get the reflection coefficient from the complex impedance. Exactly same thing I can do for calculating the reflection coefficient from complex admittance also. So instead of impedance if I had admittance for calculation then normalize value of admittance is g + jb.

Now in this case as you mention earlier we keep the smith chart same so let us say this circle which we have here corresponding to this is the value which is this g value and a circle which passes through this and say this value is the b value so this is the g value this is the value which is the susceptance value. So this is the point which is $\bar{y}$.

However now if I want to find out the complex reflection coefficient remember the real u axis or the real reflection coefficient axis is not on the right because we have kept the smith chart fixed and the coordinate axis has been rotated by 180˚ for admittances. So for admittances the real u axis is this axis and the imaginary gamma axis is jv axis. So for this point here which is the admittance point I have to measure the angle from this axis so this distance from center to this point gives you complex reflection coefficient magnitude so this is $|\Gamma_L|$ and the angle of reflection coefficient is measured from this axis so this angle is θ_L.

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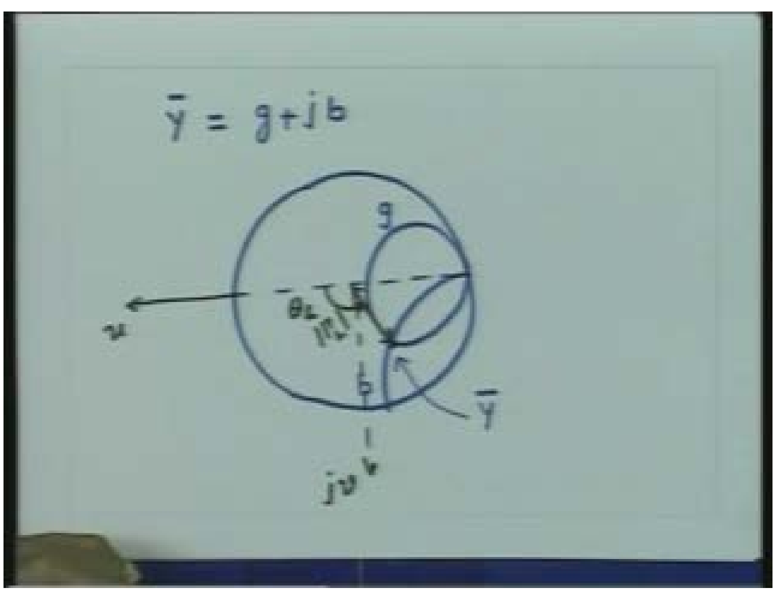

So keeping in mid whether we are using normalized impedances or normalized admittances appropriate rotation of the coordinate axis has to be made on the smith chart. But once you do that then the calculation of the complex reflection coefficient is very straight forward mark the normalized point on the smith chart, find out the radial distance from the center of the smith chart to that marked point which gives you the magnitude of the reflection coefficient, measure the angle from the real axis of the reflection coefficient for the radius vector and that gives you the angle of the complex reflection coefficient.

One can have exactly opposite problems many times somebody might give you a reflection coefficient then you have to find out what is the corresponding load. So the problem is very straight forward, mark the point on the complex reflection coefficient the magnitude is given to you, the angle is given so you can draw this point. Once you get this point read out the circles which are passing through these points so essentially you read out the coordinates on this constant resistance and constant reactance circle and that give you the corresponding value of the impedance. So without doing any analytic calculation just by graphical measurements of angle and distance you can find out the reflection coefficient from the impedance or admittance and vice versa.

Now, one can go to the next stage that if the load impedance is given to you then you would like to find out the reflection coefficient or impedance at some other location on the Transmission Line. So the problem is given, say Z_L is normalized or yl and you want to find out "Find z at a distance l from the load"

Go to the smith chart generally we draw only these three circles where r equal to one circle, r equal to zero circle then the reactance circles which are two circles like that so this corresponds to $x = +1$, $x = -1$, $r = 1$, $r = 0$ and $x = 0$ so normally just for clarity we just draw only this few circles to represent a smith chart.

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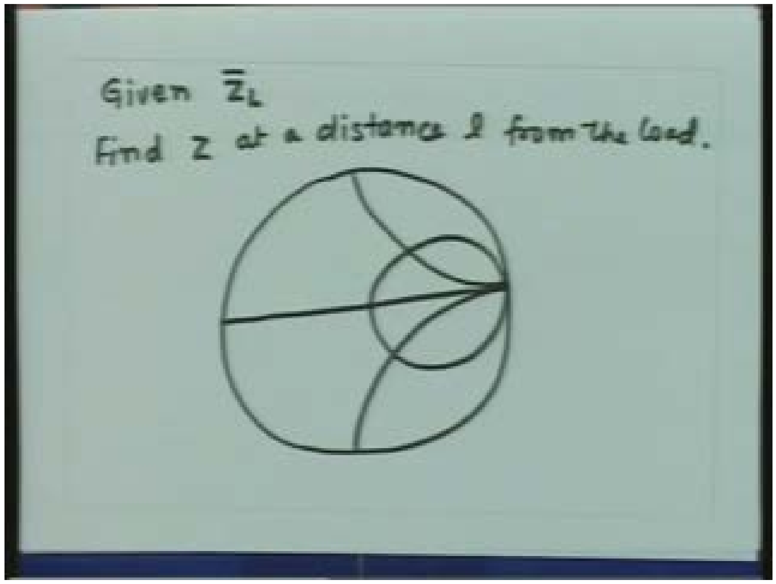

Now the first step involves that you have given the normalized impedance if the impedance was not normalized we normalize first, mark this impedance on the smith chart as we did it in the previous case. So, find out the constant resistance and constant reactance circles corresponding to this load the intersection point of these two circles will represent the load which is Z'_L so this point is Z'_L. So that corresponds to the circle passing through this a reactance circle passing through that so this is my load point.

Now as we have seen earlier when we move on the Transmission Line the magnitude of reflection coefficient remains same and the point moves on a circle keeping that magnitude constant. That means as we move on Transmission Line the point moves on the constant VSWR circle passing through this load. So now what we do is once this point is marked we take compass and draw a circle passing through this point which is a constant VSWR circle.

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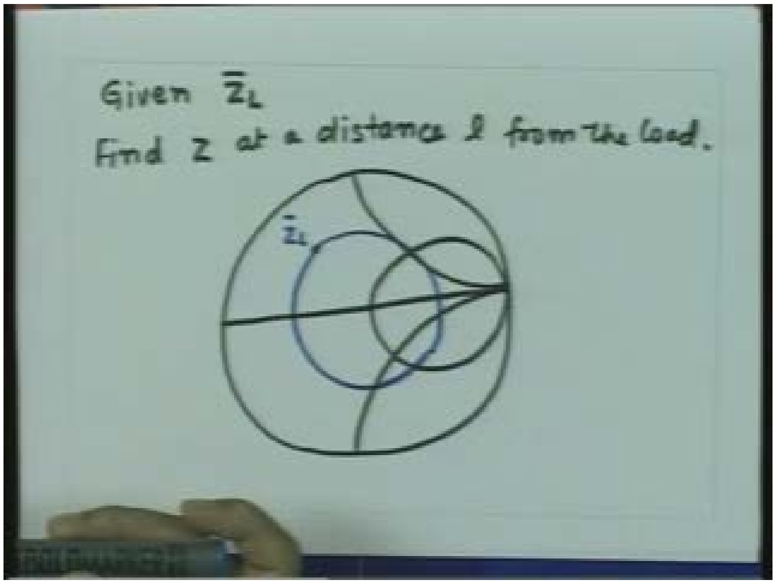

Now as we move on Transmission Line the angle changes by 2βl in the clockwise direction, normally for the standard smith chart the distance is directly marked on the periphery of the smith chart instead of marking the angles on the periphery. how do we do is a distance of 2βl if I take one rotation on the smith chart the angle change will be equal to 2π, if I move on the smith chart by 2π that is equal to 2βl $2.\frac{2\pi}{\lambda}.l$

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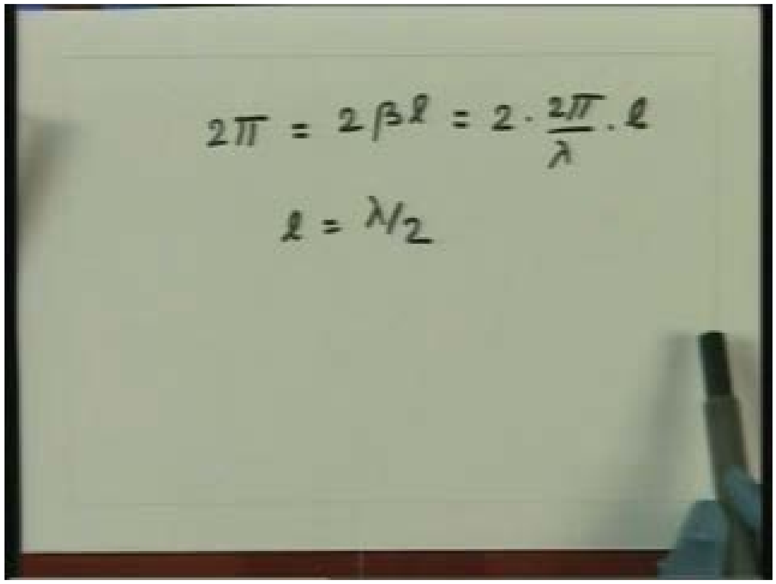

So l will be equal to $\frac{\lambda}{2}$. That means one full rotation on the smith chart or the constant VSWR circle corresponds to a distance of $\frac{\lambda}{2}$ that means if I move by a distance of $\frac{\lambda}{2}$ on the constant VSWR circle I reach to the same point.

And that makes sense because if you recall the characteristic of Transmission Line we had seen that the impedance characteristic of Transmission Line repeat itself for every distance of $\frac{\lambda}{2}$. That is what essentially we are reaffirming saying that by taking one rotation on the constant VSWR circle we reach to the same point and beyond that again the characteristics are repeated. So the angles here which are the load angle minus 2βl now can be calibrated directly in terms of the wavelength. So generally we have the outer circle of the smith chart marked with the wavelength and with the calibration that the full one rotation on the smith chart is equal to $\frac{\lambda}{2}$. So the distance from this point to this point is $\frac{\lambda}{4}$ from, this point to this point is $\frac{\lambda}{4}$. Once we get that then I want to find the impedance at a distance l which is this impedance.

So now you move from the load impedance by a distance l or rotate this point in the clockwise direction by an angle which is equal to 2βl. Let us say this was the initial angle which was there, I rotate now my point on the constant VSWR circle by an angle which is 2βl.

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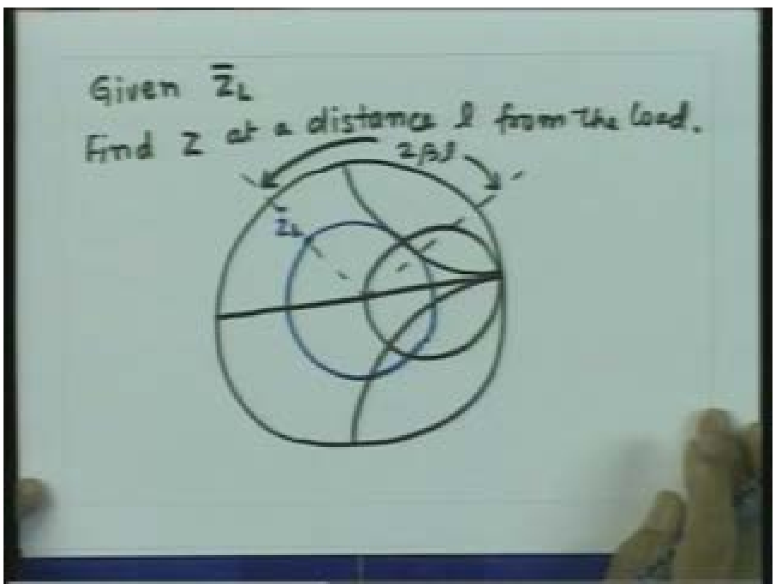

Keep in mind we are rotating in the clockwise direction because we are moving from the load towards the generator and distances measured towards the generator are positive distances that means the l is positive. Therefore the angle becomes more negative so the point moves in a clockwise direction. This sense of rotation is very important in doing all Transmission Line calculations.

So if I move in the clockwise direction by a distance of 2βl I would reach to a location l on the Transmission Line. Then this point would correspond to the reflection coefficient at a distance l from the load. The magnitude of reflection coefficient remains same which is same as this so this angle was theta l, this angle will be the angle of the reflection coefficient at location l I can read this angle the magnitude is same is what I had got from here. So I got the complex reflection coefficient at location l. So this is my Transmission Line, this is my load impedance Z_L the reflection coefficient here was Γ_L if I move a distance l over here the reflection coefficient at this then Γ is represented by this point.

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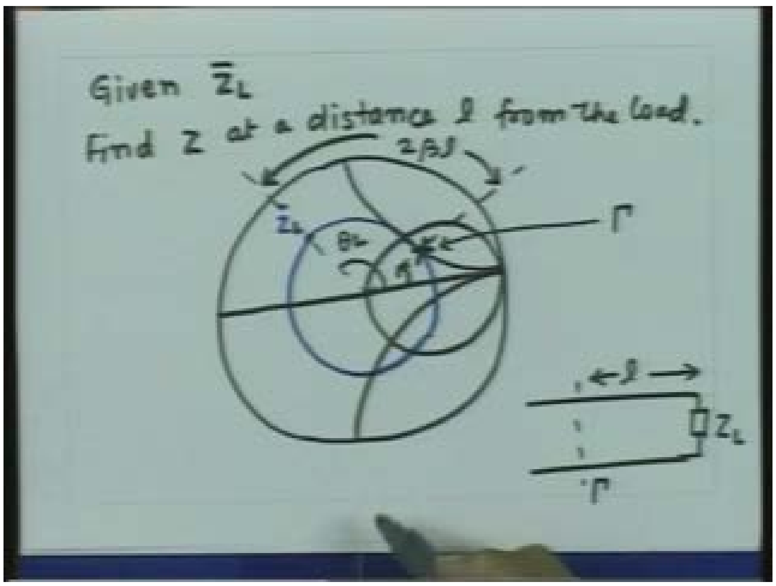

Once I get the reflection coefficient like this I can just find out what are the constant resistance and constant reactance circle are passing through this point and I can read of that value. So I can get the impedance corresponding to this point which is nothing but the transform impedance at a distance l from the load. This point represents Γ at a distance l and if I read of the value at the impedance that will be the impedance at that point at a distance l so here this is the impedance z which is at this point.

Analytically if you remember the impedance transformation requires calculation of the cosine sine functions and the expression is rather complicated. With the help of smith chart the impedance transformation is very simple you simply draw this VSWR circle passing through the load point move by an angle which is equal to 2βl read of the value of this new point which you have got here that gives you the transform impedance at a distance l.

So the calculation of impedance and reflection coefficient at any other location on the Transmission Line is extremely simple and straight forward by using the smith chart.

Now in this case we were transforming the impedance which was load impedance to a location l towards the generator. One may have a general situation that a impedance is given at any arbitrary location on Transmission Line and you would like to find the transformed impedance at some other location on the line. How does the procedure changes? The procedure is exactly same wherever you know the impedance first mark the impedance, draw the constant VSWR circle passing through this point move by an angle 2βl either clock wise direction or anti clock wise direction depending upon whether I am moving towards generator or away from the generator find the new point read out the value that will give you the transformed impedance at the new location.

So in general case either I might move in the clockwise direction or I might move in the anti clockwise direction and that will depend upon whether I am moving towards the generator or away from the generator. So let me again mention that the sense of rotation in impedance transformation calculation is extremely important because that tells you whether you are moving towards the generator or away from the generator. So in all Transmission Line calculations you should always remember that which direction the generator is because that will decide the movement on the Transmission Line and that will decide which way you should rotate on the constant VSWR circle on the smith chart.

Now if I replace the impedances by the admittances if I am not interested in the calculations of the reflection coefficient as I am interested only in the transformed admittances then the axis for reflection coefficient do not come into picture. So the procedure for transforming the impedance and the admittance are exactly identical. What you do is just simply take this point as a normalized admittance point, mark the normalized admittance Z draw this circle which is constant VSWR circle, rotate it by an angle which is equal to $2\beta l$ read this point so that this point will correspond to the admittance at that location and that value can be straight away read out from this smith chart.

So the transformation of impedance or admittance is exactly identical on the smith chart. As we saw earlier if I have to find out the phase of the reflection coefficient then only marking of reflection coefficient axis comes into picture and then you have to remember that the real axis is rightwards for the impedances where as the real axis is leftwards for the admittances. But otherwise for impedance transformation calculation once the impedance and admittance is normalized the procedure for the transformation is exactly identical.

Next thing then one can ask is that I have the load impedance which is connected to the line the parameter which is of interest is one is magnitude of reflection coefficient which gave you the reflection but we have define a another quantity which is the measure of reflection and that is the VSWR so one way of finding VSWR is you get the measurement of reflection coefficient, magnitude of reflection coefficient from the constant VSWR circle then use the formula $\frac{1+|\Gamma_L|}{1-|\Gamma_L|}$ and you will get the reflection coefficient.

However once you have smith chart with you then you do not have to do even this calculation you can just read of the value on the smith chart. So let us say this is my smith chart and let us say I have some impedance which is marked here this is my some load impedance Z_L.

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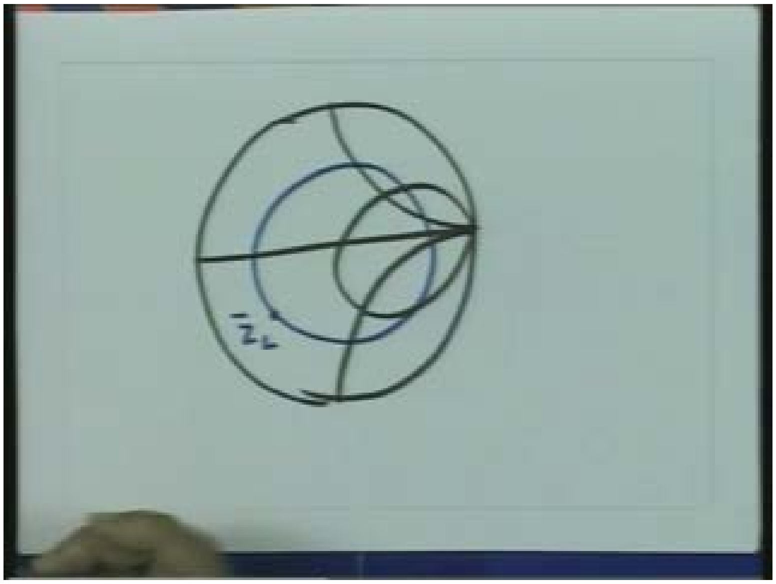

As routine we draw the constant VSWR circle passing through this so we get a circle which is this as I move on the Transmission Line I move on this circle. Now recall the VSWR is nothing but ratio of the maximum impedance seen on the line divide by the characteristic impedance we have derived it earlier so we have R_{max} which we see on the line which is equal to Z_0 into the VSWR or in terms of normalized quantity if I take R_{max} normalize that is R_{max} divide by Z_0 that is nothing but is equal to ρ. So, the maximum value of the resistance in terms of normalized quantity is nothing but the VSWR. Now as we move on this circle here the highest value of resistance will be seen when this circle intersect this line.

The right most point on this circle corresponds to an impedance which is R_{max} normalized and the reactance for that is zero so this point here the right most point on this axis that corresponds to normalized R_{max} and normalized R_{max} is nothing but ρ. So if I read out the value of this point from the smith chart they straight away gives you the VSWR so this quantity straight away gives me the value of ρ.

Similarly as we know the minimum value which we see on Transmission Line is $\frac{Z_0}{\rho}$ so we have seen earlier $R_{min} = \frac{Z_0}{\rho}$.

So again normalized R_{min} will be $\frac{1}{\rho}$ so on this circle the minimum resistance which I see is corresponds to this point so if I read of this value will directly give me $\frac{1}{\rho}$.

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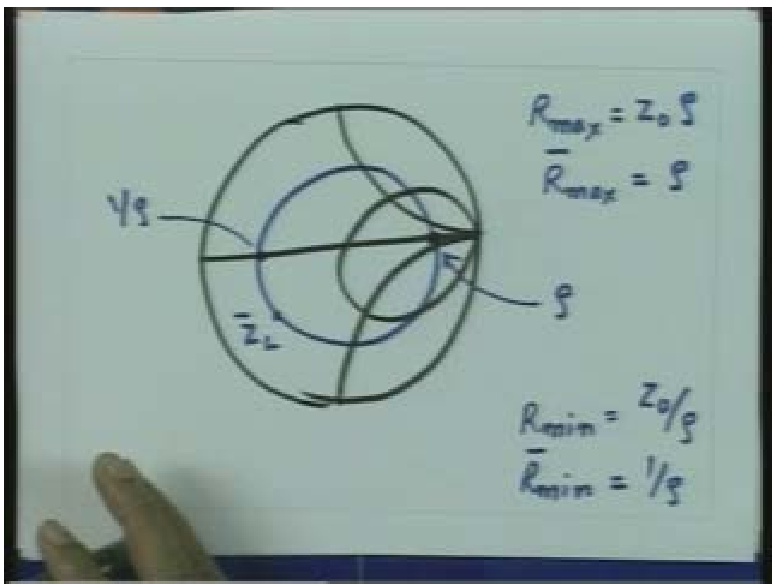

So again once the load impedance or any impedance is marked on the smith chart and this circle which is called the constant VSWR circle is drawn on the smith chart. Then calculation of VSWR reflection coefficient transformation impedance all is very straight forward problem it is just a matter of reading of the values from different locations on the smith chart. So this is the way you can calculate VSWR using smith chart.

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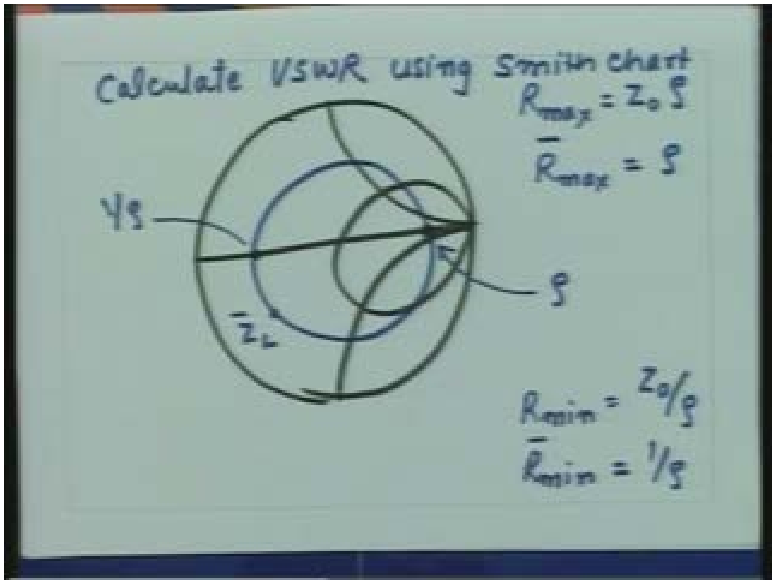

Next thing one can do is find out the location of the voltage or the current maximum or minimum on the Transmission Line and then one can use the information to find out that just looking at the standing wave pattern on Transmission Line what kind of load that Transmission Line is terminated line.

So taking a simple case let us say some load impedance marked the load impedance at the smith chart then you want to find out what is the distance of the voltage maximum or current maximum or voltage minimum or current minimum from the load end of the Transmission Line.

What we want to do now as we did earlier is we want to find out find distance of voltage or current maximum on the line. Let us do the same thing we take the smith chart mark the load impedance on the line lets say the load impedance is here this is nothing but your Z_L normalize. Again as a first step draw the constant VSWR circle passing through this point I get this point.

Now if you go back to your basic understanding of Transmission Line we know that at the voltage maximum as the current is minimum so at that location the impedance seen is the maximum impedance which is nothing but R_{max} and wherever you have voltage minimum at that location current is maximum and impedance seen will be R_{min}. That means the extreme point which is this point corresponds to an impedance which is R_{max} that means this corresponds to a location on Transmission Line where voltage is maximum or current is minimum. So this point here now corresponds to the voltage maximum or current minimum location. Similarly this point here which represents the current minimum resistance on the line corresponds to voltage minimum or current maximum location.

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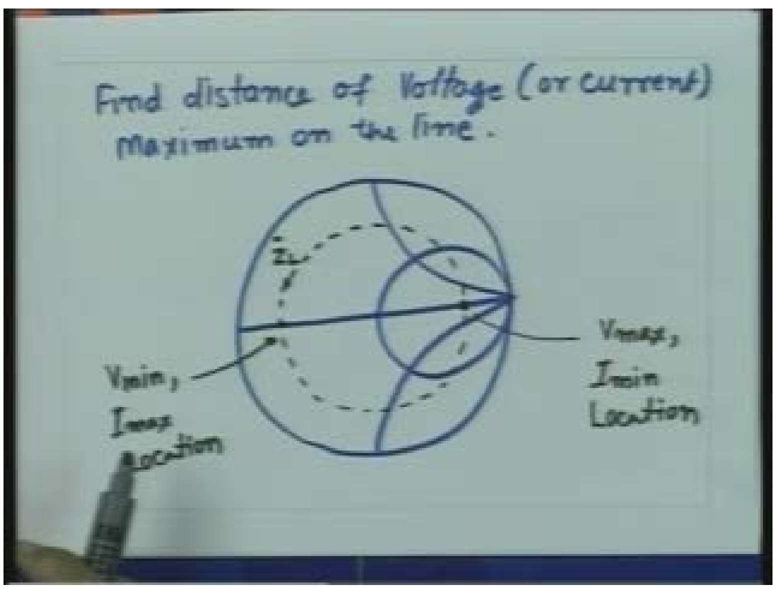

We want to find out this location from the load. The job is very simple you draw a radius vector passing through the load its here, if I move towards the generator up to this point on the constant VSWR circle I will reach to the location where the resistance is maximum or the voltage is maximum. So essentially we can find out what is this angle this arc here is. Whatever angle I get I divide it by 2β then I will get a distance of the voltage maximum from the load point. I can use our understanding that the voltage minima and voltage maxima are separated by distance of $\frac{\lambda}{4}$ so I can add a distance of $\frac{\lambda}{4}$ to find out the location of voltage minimum once I know this distance or I can measure this angle all the way up to this divide by 2β to find out the location of the voltage maximum.

So if this angle was θ_{max} then the location of voltage maximum l_{max} will be equal to the $\frac{\theta_{max}}{2\beta}$. So finding the location of voltage maximum or current minimum is extremely straight forward.

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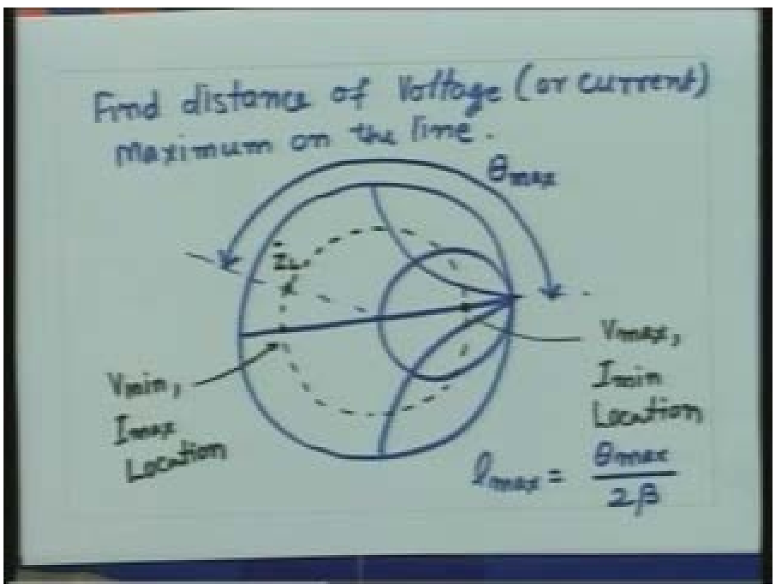

Once you mark the impedance on this draw the constant VSWR circle just find out the angle from this radius vector up to this horizontal line on right hand side and you would get this angle which if you divide by 2β you will get a distance of voltage maximum.

We will continue with this and then in next lecture we will view this information to find out what is the impedance just by looking at the standing wave patterns on the Transmission Line. Thank you.