Antennas

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Module – 03
Lecture – 13
Loop Antennas

Hello and welcome. Today we are going to discuss about Loop Antennas followed by Slot Antennas. Now in the last lecture we had talked about dipole antenna and monopole antenna, so let just look into this here.

Suppose, if this is a dipole antenna which is carrying a current we are feeding in the center here, now for this particular case we saw that H field is like this here and E field is in this particular fashion which is making a figure of eight like this here. Now a loop antenna is nothing but a complementary of this; in a sense if we take a small loop then small loop will be let us say something like this here we can actually look into small loop is like this. Now this small loop if we assume that the current is uniform over here. So, this can be thought about that if there is a magnetic dipole like this then a magnetic dipole; see for example if it is electric dipole we will have a magnetic field, if it is now a magnetic dipole then this will be electric field or a current is flowing like this.

In fact, a small dipole antenna is nothing but we can correlate that with a magnetic dipole antenna. So, whatever the derivations whatever the calculations we did for the dipole antenna they are valid for the loop antenna; in a sense that E field will become H field and H field will become E field, open circuit over here will be close circuit over here. So, let us see about Loop Antenna today.

So, today as I mentioned we will talk about loop and slot antennas we will first cover loop antenna and in the next one we will talk about slot antenna.

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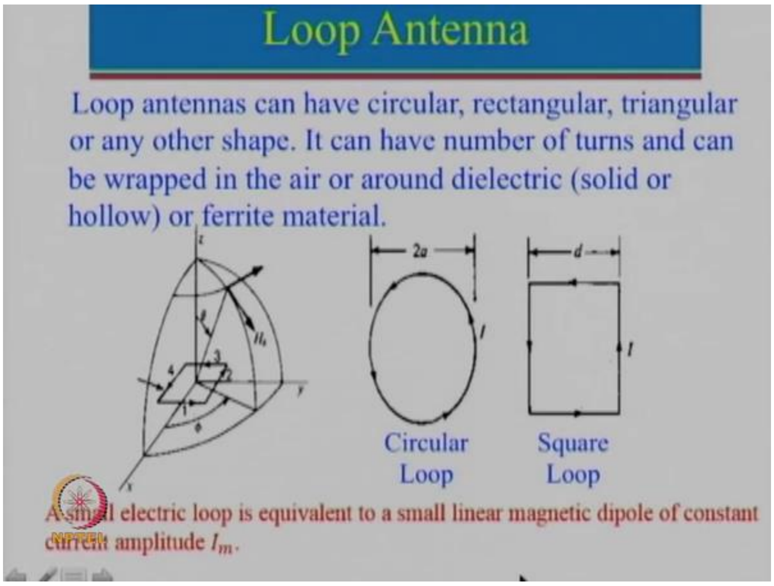

So, we will actually think about a very small loop, let us say this small loop is put around the origin. So, this is the origin here x axis, y axis z axis and as before we are going to measure phi angle from x axis, theta is measured from the z axis and these are the components which are the field component at any faraway distance r. Now we can actually start with the let us say circular loop or a square loop. In the beginning we will just look at the small circular or square loop; small means whose circumference is much less than wavelength.

Now in this particular case as I mentioned if we assume that there is a uniform current then this can be approximated as a magnetic dipole over here and along with that there will be electric current. So, all we need to do it is we use the same concept of the dipole antenna except that we change E field to H field and H field to E field. So for this particular case when the loop dimensions are small; now by the way this can be a single turn loop, it can be multiple turn loop, the loop can be wound in the air itself or it can be wrapped around a dielectric which can be solid or hollow or it can be even a ferrite material also. So we will see one by one; what are the different scenarios.

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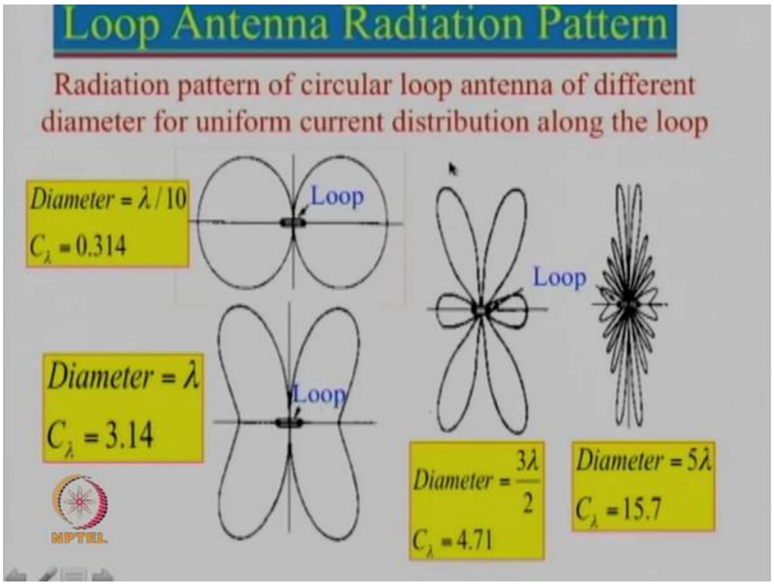

So, let us first look at the radiation pattern of the loop antenna. Here we have taken a diameter which is lambda by 10 so circumference will be equal to pi times d. So, C lambda is nothing but C divided by lambda so that will be 0.314 which is nothing but pi divided by 10 that is the value here. And here the loop is placed in this particular fashion over here. So, the loop is placed over here and we are saying that this particular loop will be equivalent to a magnetic dipole which will be something like this here. So for a dipole we know that there will be no radiation in this direction, so here also for the same in the same way for loop antenna there is no radiation over here.

So, please remember loop is placed like this here and then the pattern in this particular plane is nothing but making a eight figure of eight shape. And if you look at the pattern in this plane here that will be circular just like a dipole antenna, but now this is actually a instead of electric field earlier now this is a magnetic field, and the field which will be uniform along this direction now will be electric field. Now, we will look into different patterns. So, let us say for diameter equal to lambda C lambda will be this, so now this pattern changes it is not maxima in this particular direction. Again this is somewhat similar to a dipole antenna; for larger length dipole antenna radiation is not maximum here, but radiation is maximum in this direction.

Now, these are now further larger ones instead of lambda it is 3 lambda by 2 5 lambda. But I just want to tell you that this is not really a real scenario, in a real scenario current will be never be uniform along the loop. So, that is why theoretically it is we can assume anything, practically this is not going to be feasible. So, in general very rarely these kind of a antennas are used, the most popular antennas are only this one here where loop antennas are taken smaller in diameter or circumference and for that we know that this is the radiation pattern.

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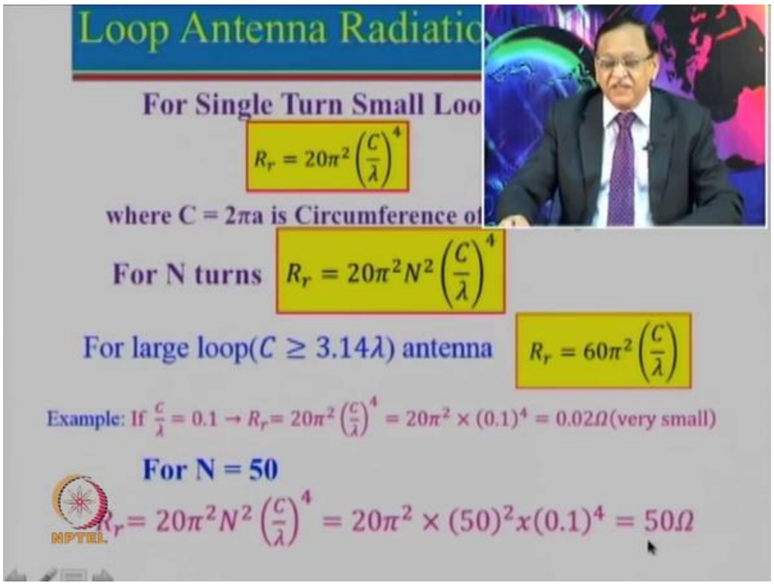

So, for this then for single turn loop we can actually find out what is the radiation resistance. In a very similar way for dipole antenna what we had done we found e and then from e we also knew H field and then power was calculated by integrating e and h and then power was equated to half I square R r. So, the same way we have to do the same thing, so we get a radiation resistance which is given by this formula here. Now please recall for a small dipole antenna radiation resistance was 20 pi square l by lambda square. Here the differences it is to the power 4, but this is for small loop antenna; where C is circumference, circumference is nothing but 2 pi a which is also equal to pi d.

Now most of the time we do not use a single loop antenna, we use multiple turn loop antenna. This will be obvious when we take this design example here. So, if we take N turns, for N turn R r increases by a factor of N square. So, radiation resistance can be increased significantly by increasing number of turns then R r increases by N square. Now for large loop antenna the value is given by this particular expression.

I want to tell again most of the time we do not do use large loop antenna, but never the less let just see here. So, this expression is valid for C by lambda much less than 1. This expression is valid for C by lambda much greater than 1. Let us see what happens if C by lambda is 1. If C by lambda is 1 this expression will give me roughly 200, because pi square is approximately 10. And this one here for C by lambda equal to 1 will give roughly 600. So, we know that for C by lambda equal to 1 neither of these two formulas are correct it will be between say 200 to 600 ohm.

So let just take an example; here the example we have taken is C by lambda is 0.1. So, if we now substitute this value over here what we get is 0.02 ohm. Now you know that this is a very very small impedance if we try to feed this 50 ohm coaxial feed it will result into a large mismatches and most of the power will reflected back very little power will be transmitted. But here now if we take N equal to 50, so N equal to 50 this has to be multiplied by 50 and 50. So, 50 multiplied by 0.02 will be 1, another 50 will give us 50 ohm.

So, you can actually see that if I take a C by lambda equal to 0.1 use 50 turn we can get a good matching with the 50 ohm coaxial feed. So, that is a very simple way to design an antenna.

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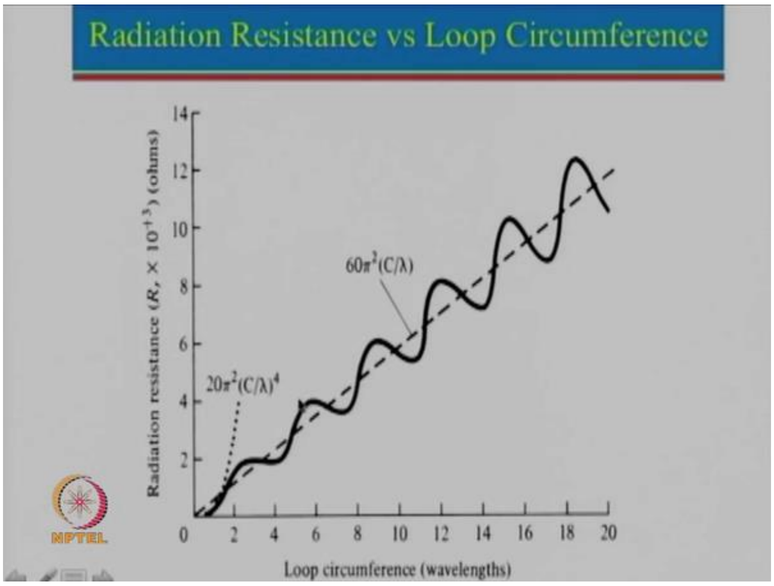

Now, these are the relations for radiation resistance versus loop circumference. So, actual value calculated is something like this here which is varying sinusoidally, but increasing along this line here. So, this particular variation has been approximated by 2 equation; one is this equation that is valid for very small loop antenna and one can see that for the real value here this approximated formula is matching fairly well, but for larger loop antenna this is the expression given by the 60 pi square C by lambda.

And again I want to repeat that most of the time you do not use a large loop antenna, generally use a small loop antenna. So, this expression is relatively and this is what you need to use majority of the time.

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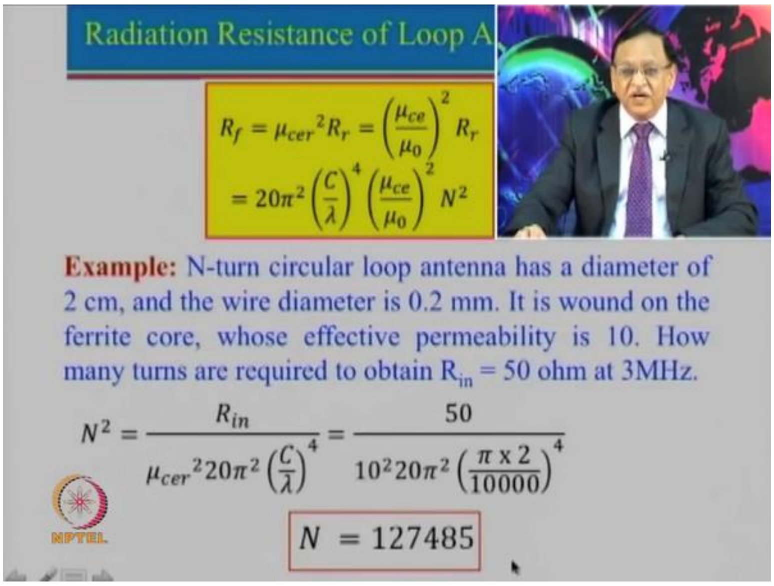

So, now many a times this loop antenna is actually put on a ferrite core and I will tell you the reason also where it is done also. And the practical example is; AM radio receiver generally uses loop antenna which is wrapped around a ferrite core. So, if it is wrapped around a ferrite core then the actual radiation resistance will increase by a factor of mu square and here it is used as effective mu, because some air might come into picture in between when you put a loop antenna around a ferrite core. So, this is the expression to be used. And let us just look at one example.

So, let us say we have N turn circular loop antenna whose diameter is say 2 centimeter and the wire diameter is thin which is a 0.2 mm. Now this is put on a ferrite core whose effective permeability is 10. And what we need to know is how many turns are required to obtain 50 ohm impedance at 3 mega hertz. Now at 3 mega hertz what is the wavelength? Wavelength is going to be 100 meter. So, that is the wavelength lambda 100 meter we have converted into centimeter so that becomes 10000 centimeter.

Desired R input is 50 ohm which comes over here, mu is 10 so 10 square 20 pi square comes here, and C is nothing but pi times d, and d is equal to 2 centimeter. And if we use this here one can now see calculate this and find out the square root of N square which comes to this. You can see that it requires about 127485 turns.

Now you just imagine if it was not a ferrite core if it was air then this number will change by a factor of 10. So, if it was wrapped around just air then this number would actually increase by 10 times. So, that is the advantage of using a ferrite core that you can reduce the number of turns.

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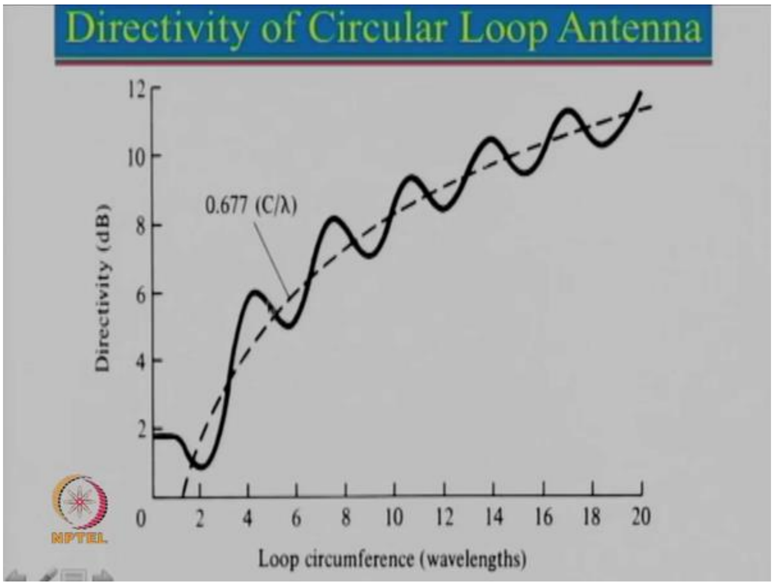

So, here is the expression for the directivity. So, here we have a loop circumference normalized with respect to wavelength and this is the directivity in dB. Now for a very small loop which is actually here. So, very small loop you can see that the directivity is slightly less than 2 dB, which is somewhat similar to for a dipole antenna which is a small length dipole antenna we saw that the directivity is of the order of 1.74 dB. So, it is very similar to that.

Now, one can see that the directivity increases with the loop wavelength. However, if you just look at it corresponding to wavelength of 10 here which is a normalized thing loop circumference. So, 10 times wavelength if you corresponding here, if you see here you are only getting 8 dB or so. However, if we use different types of antennas or if we use arrays of antennas we can get much larger directivity. Hence, this one I strongly recommend never ever to use it.

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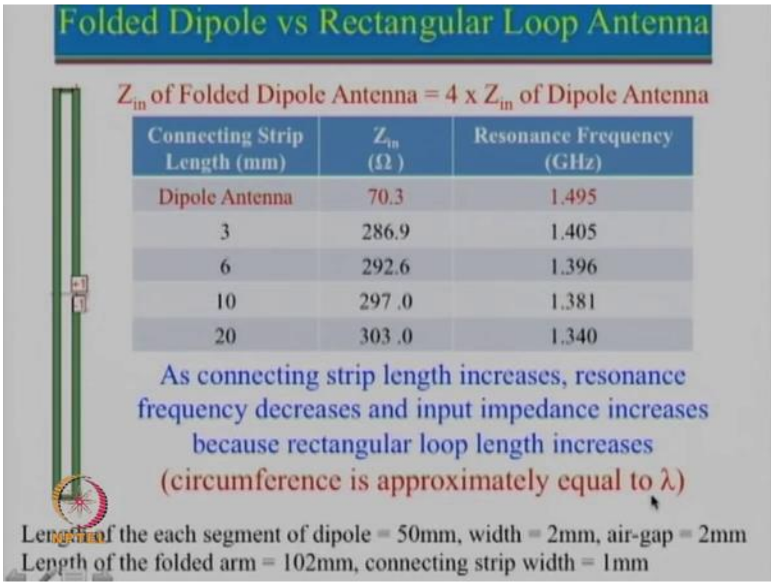

So, now in the last lecture if you recall I did mention we talked about a folded dipole antenna and I did tell you that folded dipole antenna can also be thought of as a rectangular loop antenna. So, just have a quick thing here: suppose if it was just a dipole antenna for a dipole antenna fed with plus minus 1. This is the dipole antenna; we have done the simulation for these dimensions. So, we have the length of each segment of dipole which is 50 mm here, 50 mm here, the width is actually taken as 2 mm and the air gap is taken 2 mm here. So, just for this particular dipole antenna the impedance is about 70 ohm and resonance frequency is close to 1.5 gigahertz.

And that can be very quickly looked into it. So, if I just say approximately this is 50 and 50, so that will be 100 mm that is approximately equal to 10 centimeter corresponding to 10 centimeter, wavelength will be that is the wavelength if we take 10 centimeter as lambda by 2 then wavelength will equal to 20 centimeter which corresponds to frequency of 1.5 gigahertz. So, you can see that it is very close to that.

Now for a folded dipole antenna we have seen that for a folded dipole antenna impedance is 4 times Z input of dipole antenna. Now by the way these are all simulated results we have simulated using i e 3 D software. Now when we looked into this folded dipole antenna that particular equation does not say anything about what is the length of this connecting strip here. So what we have done here, we have used variable as a connecting strip length here. So, we have taken this over here as 3, 6, 10 20 and the width of the connecting strip has been taken as 1 mm.

Now if we just notice here. So, as we increase this width here, so the resonance frequency keeps on decreasing. And impedance is roughly 4 times you can say that 70.3 multiplied by 4 will be about 281 ohm, so we are getting about 286 which is close, but as this strip length increases it is this expression or the impedance is increasing slightly. Now this phenomenon cannot be explained only by this over here. Also if we notice as we keep on increasing the strip length 3, 6, 10, what is happening? We can see that the resonance frequency is decreasing.

Again that phenomena cannot be explained by just this particular expression here. However, this phenomena can be very easily explained if we assume that this whole thing is now acting as a loop antenna. Then when this connecting strip length is increasing what will happen? The total loop circumference will increase. And if the circumference increases and we can actually just notice here that circumference approximately equal to lambda. So, if we just add up all that dimension and calculate the resonance frequency you will see that with increase in the strip length here the total length will increase. So, resonance frequency should decrease.

So, a folded dipole antenna can be very easily explained by rectangular loop antenna. And also please recall I did mention when circumference is equal to lambda the limit can be between 20 pi square which is 200 to maximum 60 pi square which is 600. So, between 200 and 600 ohm this is what we are getting it for the lambda equal to C.

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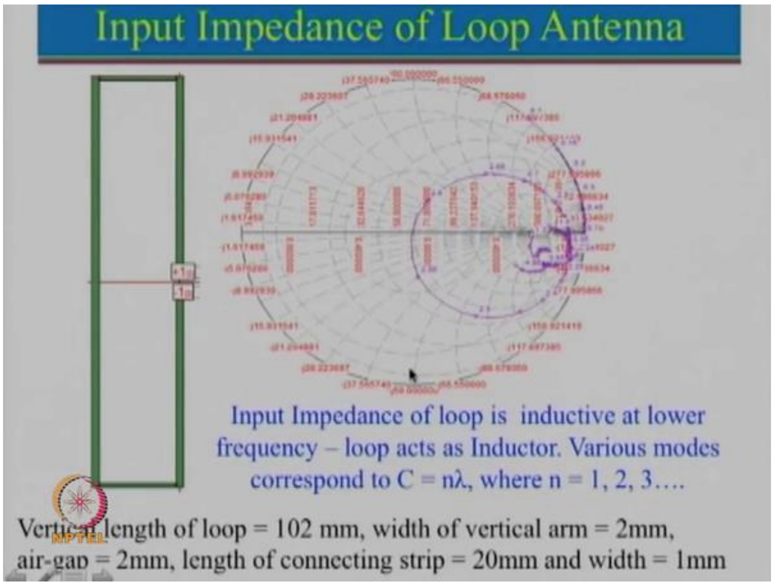

So, here are some of the plots here. So, what we have done we have taken a little larger loop here. So, connecting strip is taken as a 20 mm long over here and this whole thing is total is 100 2 mm this is 50 and 50 with a gap of 2. So, for this we can see actually the input impedance plot, and I want to show that we started with a very low frequency simulation. So, at low frequency one can see all these things are inductive. Now recall for a dipole antenna, for a dipole antenna it was all capacitive. Now this is a reverse of that so this is now all inductive here.

You also know that for a closed this thing it acts as a inductor or a multi turn loop also will also act as an inductor, and that is why impedance is inductive. And one can actually see that there is a resonance first coming over here. So, this is the fundamental resonance which we had seen in the previous case for which impedance is close to 300 ohm we can just check that. So, corresponding to this here impedance was roughly 300 ohm. So, in the smith chart we know that this is about 50 ohm here that is close to 300 ohm. And then this one here is actually corresponding to the second order mode and the second order mode can be determined whenever circumference is equal to N lambda.

So, for N equal to 1 it will be the fundamental mode and then N equal to 2-3. So, this result is actually for the second order mode.

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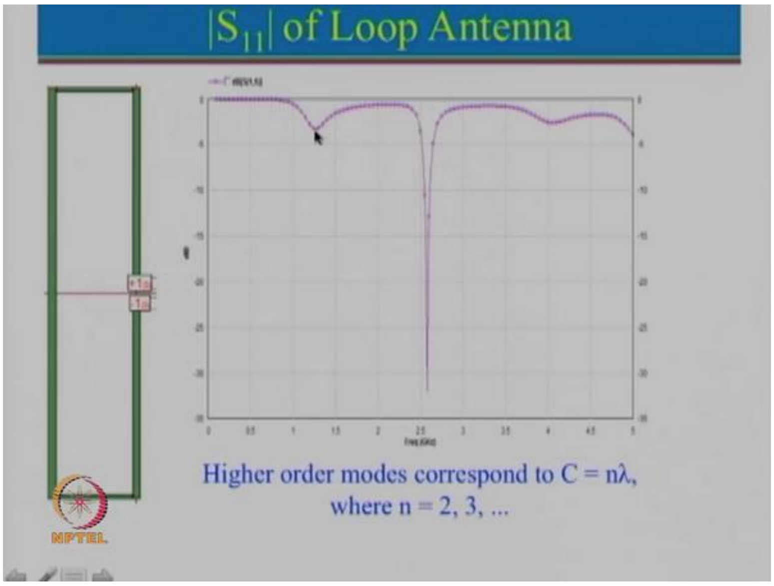

And one can see the reflection coefficient plot. So, this is the value corresponding to the fundamental mode and this is the value corresponding to the second order mode. This is the value corresponding to the third order mode. And one can actually see that from here this is approximately double of that value. So, we see that it is not matched with the 50 ohm because input impedance is close to 300 ohm it will not be matched with 50 ohm.

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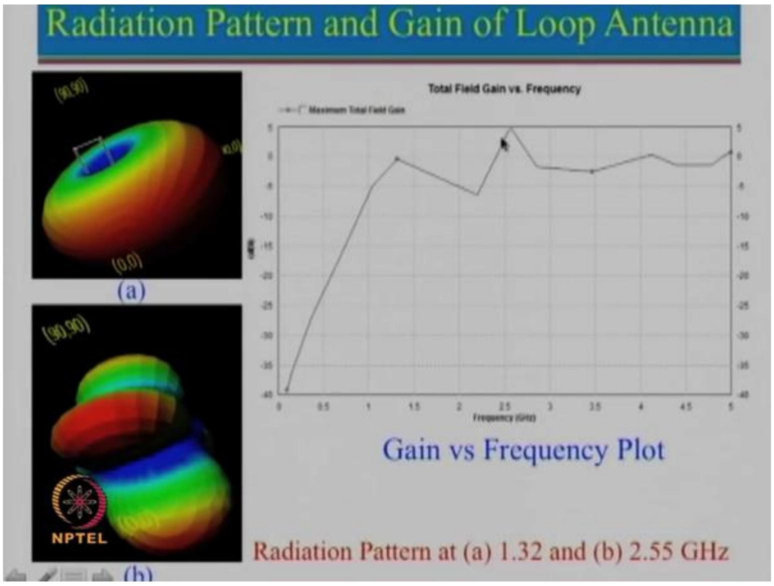

Now let us see; what is the radiation pattern. Even though the case which we are looking; so radiation pattern at 1.32 gigahertz at which this whole circumference was equal to lambda even for that the radiation pattern is very similar to that of a dipole antenna except that E field has become H field H field has become E field. So, we can see that the maximum radiation is not in this direction, but it is in this direction which is perpendicular to the loop axis. And perpendicular to the loop there is a no radiation which is given by dark blue. So, we know that dark blue is the least radiation and green and yellow and orange, red shows maximum radiation.

Now I have shown the radiation pattern at the second order mode; you can see that the radiation is maximum in this direction in that direction as well as in this direction here. So, majority of the time this is not really used, so we generally use the fundamental mode only. Or in fact, majority of the time we use small loop antenna which could be a multi-turn loop antenna. And you can see that here gain is actually close to 0 dB that is not the directivity, directivity may be close to 1.52 dB gain is less because matching is not very good at this particular point here.

One can see that at this point because of the good matching gain is also higher; you can see the higher value of the gain which is approximately 5 dB.

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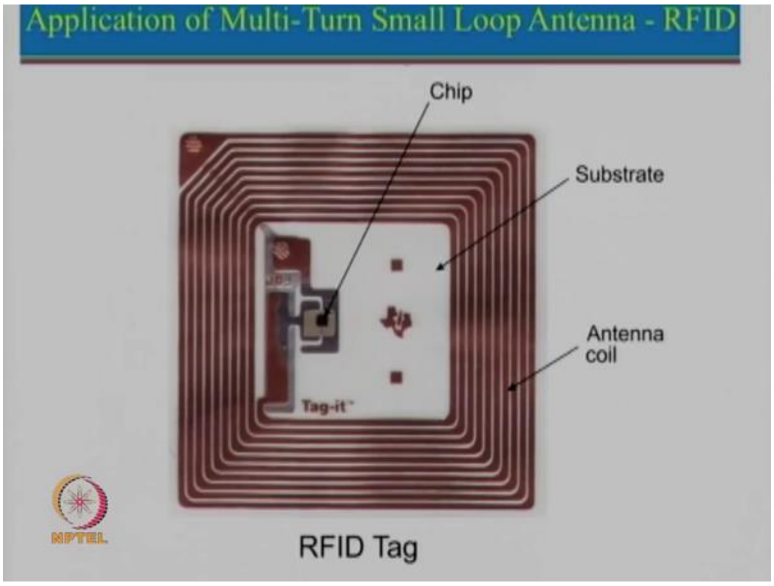

So, let us just look at one of the typical application of a loop antenna. So, we did look at one of the application where the loop antenna was wound around the ferrite core there, but now let us just look at another application. In fact, loop antennas are finding lot of application these days in RFID tag what is RFID tag radio frequency identification. So, let us see what we have here. So, one can actually see that there is a one; this is the chip which is put over here and that is the padding where the connection is done. So, one turn of the loop, so let us just follow here; so the loop is going over here it is going around this is printed on a flexible PCB or you can call it a substrate and it is actually going from here going all the way. So, the loop antenna almost looks like a you know spiral antenna also, but it is still a loop antenna.

And then the last turn over here you can see that a plated through hole is made over here and through the other side then from the backside of the substrate it is actually connected over here. So, one can see that this is a multi turn loop antenna which is actually going to the RFID chip. So, this is one of the applications, in fact of the majority of RFID tags are either using something like this here or in the last lecture I even showed an application where RFID had used the dipole antenna. So, here application of loop antenna is there.

In fact, some of these things for example this particular RFID tag which I showed you that application is for 13.56 mega hertz. Now 13.56 mega hertz if one tries to use a dipole antenna the length will be very very long. However, a multi-turn loop antenna can be used which will actually still be in a very small area, so the area is important because many of these RFID tags their size is almost fit on to a visiting card of about the size here. So, we need the compact antenna which should fit in that particular size.

Many a times I just also want to tell that capacitance is also put in parallel so that we can create a resonance also. In fact, I would like to emphasize for AM radio now AM radio frequency range is from 530 to 620 kilo hertz. So, if I take a in between frequency which is 1 mega hertz. Now at 1 mega hertz wavelength is about 300 meter. Now you cannot have a antenna of 300 meter for a receiver.

Now just to mention for AM transmitter they generally use lambda by 4 monopole antenna. Now lambda by four 4 300 meter will be 75 meter. So, 75 meter is almost if I take a building height as 10 feet which is equal to 3 meter. So, 75 meter tall will be about 25 storey building. Now we also need a radio receiver which is going to be this small. So, for radio receiver working at let us say around 1 mega hertz, so what need we use actually a loop antenna and it is actually wrapped around a ferrite core and then the two ends of the loop antenna are actually terminated with a variable capacitor. And that variable capacitor, so when you change or tune the radio station all you do it is you actually change the value of the capacitance. So, resonance frequency is given by omega 0 is equal to 1 by square root LC.

So, this loop antenna does two things; one is it is acting as an antenna, another thing is it is acting as an inductor and you put a capacitor in parallel to that and change the capacitor value and that is how you tune the radio station. So, loop antenna are used in some of these applications and RFID has been used; I mean they are using loop antenna in so many different applications. In fact, many a times these loop antenna are also used for sensing the magnetic field at a given place. So, it is a good antenna to be used, but most of the time it is the small loop antenna which is used not really the large antenna with respect to the wavelength.

So, just to summarize we talked about a loop antenna and we recommend strongly only to use small loop antenna; it can be multi turn so that you can do the impedance matching properly. And typically total circumference length should be approximately lambda so that the resonance condition is obtained. And then we also saw that if you use number of turns then R r increase by N square.

Of course, I want to again emphasize it is not just radiation resistance it also has a associated inductance. So, at lower frequency inductance is there and that is why sometimes we put capacitance to tune it out or you can use a larger number of loop turns and then we saw that you can get a just a real number also and which can be fed directly with the coaxial feed to do the matching. And then we looked at some of the application.

In the next lecture we will talk about slot antenna. Again just to tell you slot antenna is nothing but a complement of a dipole antenna, so whatever is good for the dipole antenna it is again good for the slot antenna; except for the difference. In the case of dipole antenna whatever is E field it will become H field and H field will become E field. So, in the next lecture we will see how to design a slot antenna.

Thank you.