Analysis and Design Principles of Microwave Antennas
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Lecture – 39
Ultra Wideband Antennas

Welcome to this NPTEL lecture on Ultra Wideband Antennas. While discussing broadband antennas we said that there are locked periodic antennas, spiral antenna etcetera their broadband, but they are dispersive in nature. So a pure pulse of very short duration typically of nanosecond or picosecond duration on time that cannot be passed through and that type of antenna it will have severe distortion.

But today we will see both various types of ultra wideband antennas that can pass that type of pulses. And we would not go into the details, because these are quite advanced topics, but to have a glimpse of the applications of these antennas, and requirements why these antennas are being developed for that. Today, we will have this lecture.

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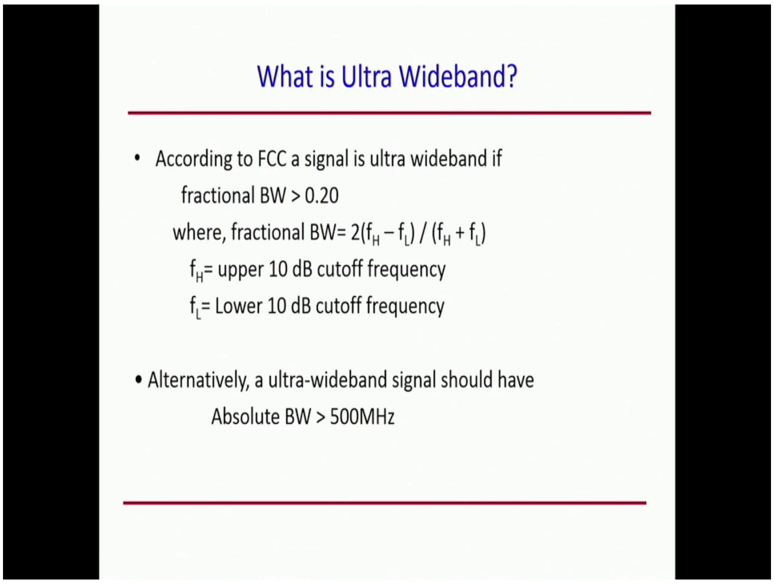

So, the first we start with the first slide that what is the definition of ultra wideband? Actually there is a lot of debate over these and IEEE is still now does not come up with the proper definition of a ultra wideband, but FCC - Federal Communication Commission they have already came up with a correct definition scientific definition of ultra wideband.

So, we will see that. According to that a signal is called ultra wideband, if the fractional bandwidth is greater than 20 percent. What is meant by fractional bandwidth actually this is the new thing that fractional bandwidth is basically, because for ultra wideband signals, there is no question of center frequency. So, there is a low frequency of operation, there is a high frequency of operation. So, they are a defined as typically 10 dB from the maximum.

So, f H is a highest frequency at which 10 dB from the maximum of the signal is there signal f L. So, it is f H minus f L by f H plus f L by 2, so that gives it the bonded definition. And alternatively also a ultra wideband signal should have at least the absolute bandwidth should be greater than 500 Megahertz.

And if we again look at this bandwidth definition please note that, we can easily find out that what is the maximum bandwidth that is possible. So, theoretically the maximum will come to be from this one, because f H and f L both should be positive frequencies or actually f L should be positive frequency, so that shows that 200 percent is the maximum that an any signal can have maximum bandwidth. So, an ultra-wideband signal it is maximum bandwidth is 200 percent.

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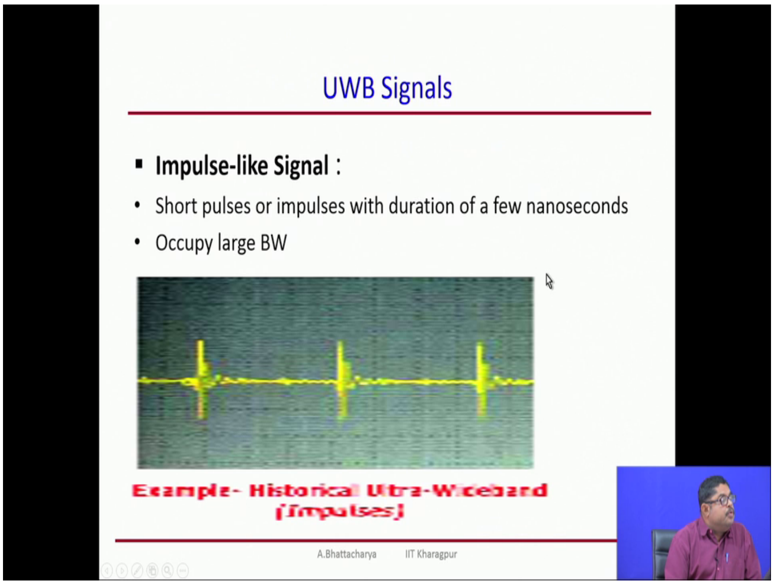

Now, we see that these are typically impulse like signals, but actually they are short pulses of duration few nanoseconds. So, obviously they are so short in time they occupy large bandwidth.

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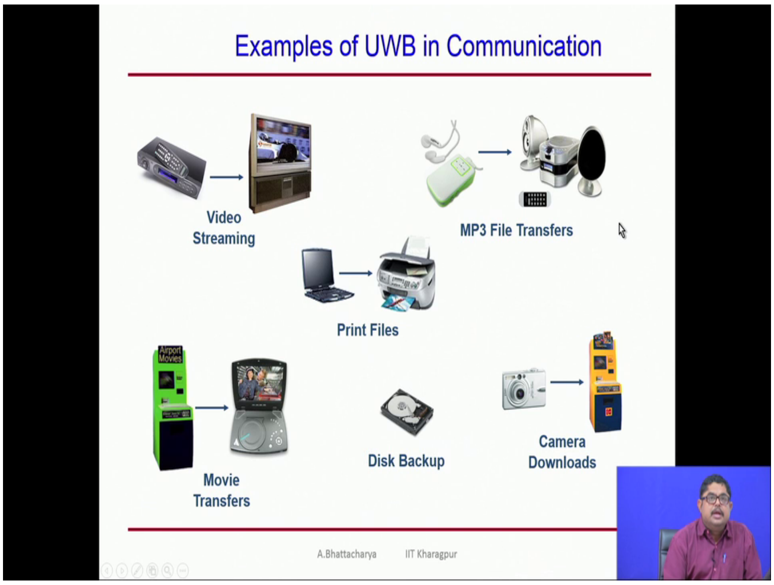

Then these are in communication this UWB you can see that these various applications, where these are required. So, this is UWB communication, obviously these type of short pulses they do not go much distances their range is limited. So, initially their range was only some few meters that is why you see all these applications are very close distance things the range is not much.

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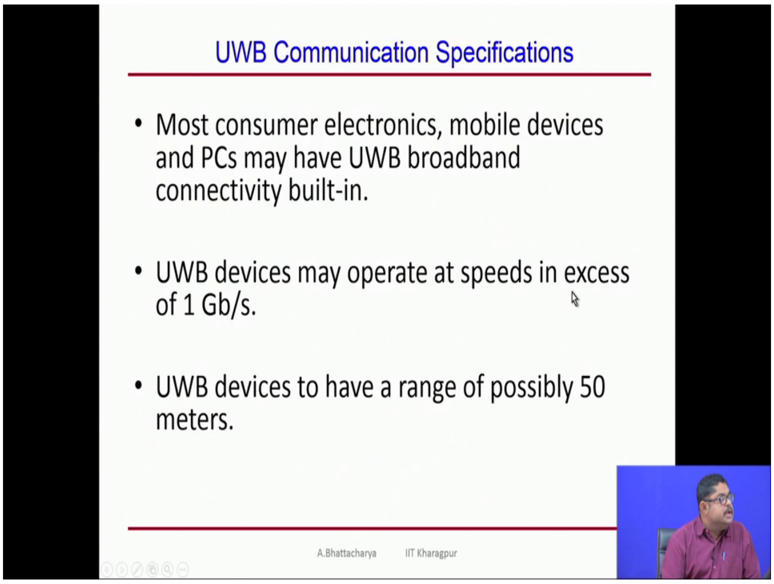

But, nowadays in consumer electronics mobile device devices and PCs all have U UWB broadband connectivity built-in. Typically, UWB devices may operate not typically, but excess of 1 Gbps is quite natural nowadays. And their range is possibly 50 meters. So, from few meters up to 50 meters people are using it, but their unmodulated signals directly the pulse is getting transmitted. Obviously, there are lot of attenuation that is why the range is limited.

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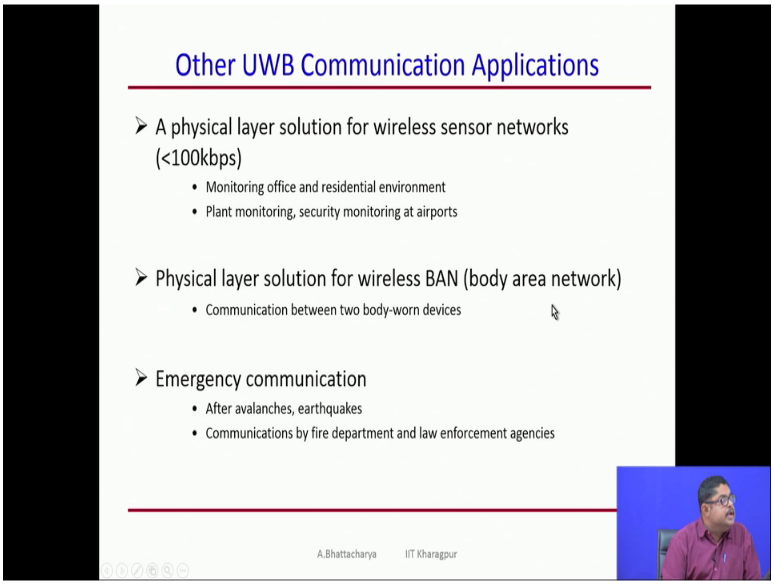

But, other UWB communication applications are for wireless sensor networks typically 100 kbps less than that speed, so monitoring office and residential environment. Then plant monitoring, security monitoring at airport etcetera. Then wireless BAN body area network communication between two body-worn devices they are also people are using it. Then for some emerging emergency purposes like after avalanche earthquake, if no communication is there to establish communication this is used. Then communication by fire department and law enforcement agencies etcetera.

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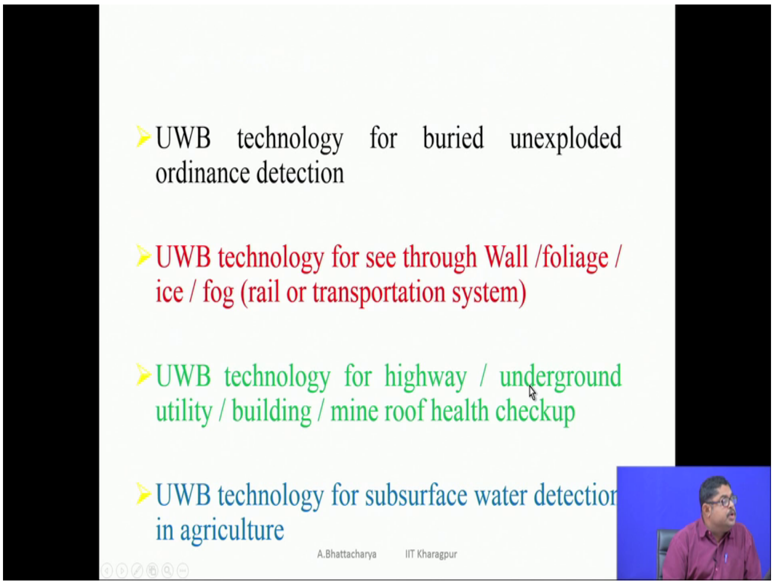

But, more than communication actually this technology has so many other applications. So, UWB technology particularly in the form of radars which are a different kind of radars than the conventional radars. So, UWB technology can be utilized for seeing whether there is any buried unexploded ordinance. Actually, in an what tone country there are many mindset sector are kept. Also sometimes many arms ammunitions some ieds etcetera they are kept.

And later when the war is over that possess problem to civilian people, so detection of that is a UNOS job, so this is required for that. Then UWB technology is also used for seeing whether anyone is there behind wall, though wall imaging it is called anyone behind foliage whether something it buried inside ice in various mountain war fares these are required.

Then in case of you know in our country in winter season whole North India the railway movement gets disturbed, because of fog etcetera. So, due within fog during fog can the rail to system or transportation system go on in me unimpeded. UWB technology also is used for highway health checkup, highway inspection, underground utility like water pipes etcetera what is their health whether they are linking. Then building whether that is will fall down or not in mines where the mining industry, mine roof health whether it is or it will fall.

UWE technology also is used for subsurface water detection for agriculture. It predicts how much the growth of any crop will be there. So, various lot also lot of industrial uses to find out the crane movement, exact position of the molten stuff. So, lot of lot of things UWB technology is used.

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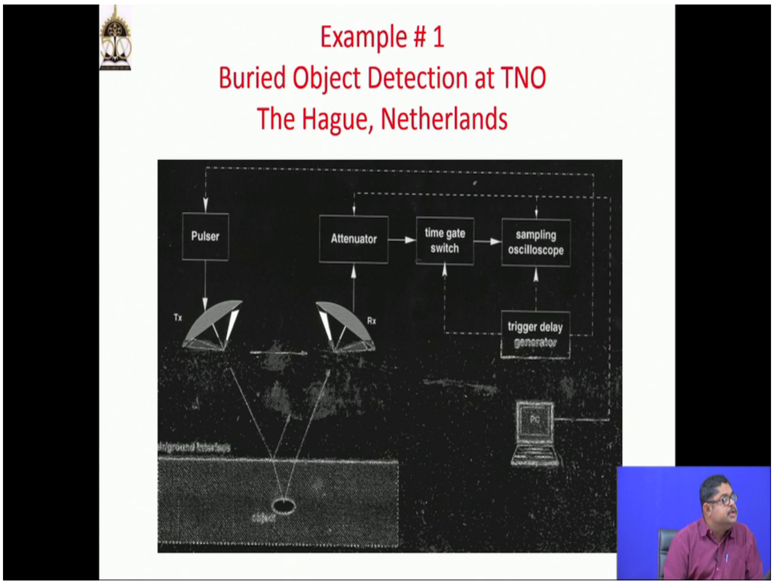

Some of the examples I will have it through this is buried object detection.

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Then what I say that these type of mines are there. So, can we detect it by this UWB technology.

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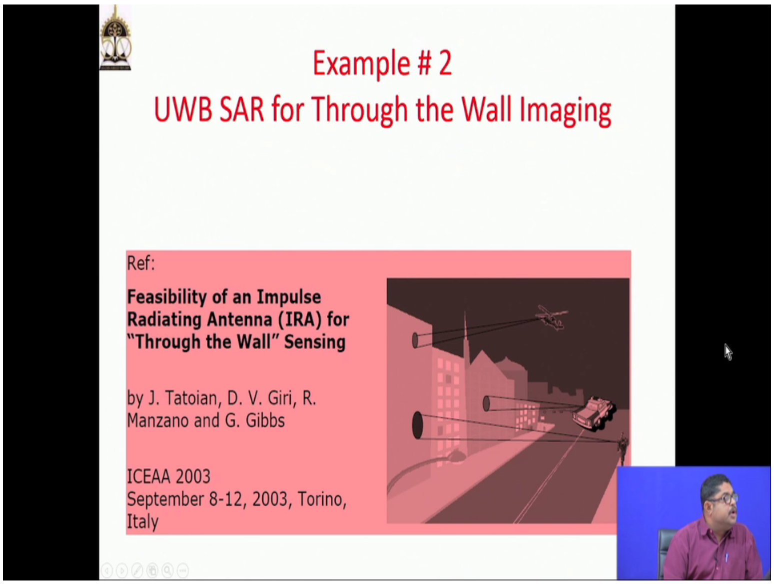

Then through wall imaging, whether someone has taken some hostages. So, people want to see police department want to see from outside who is there inside.

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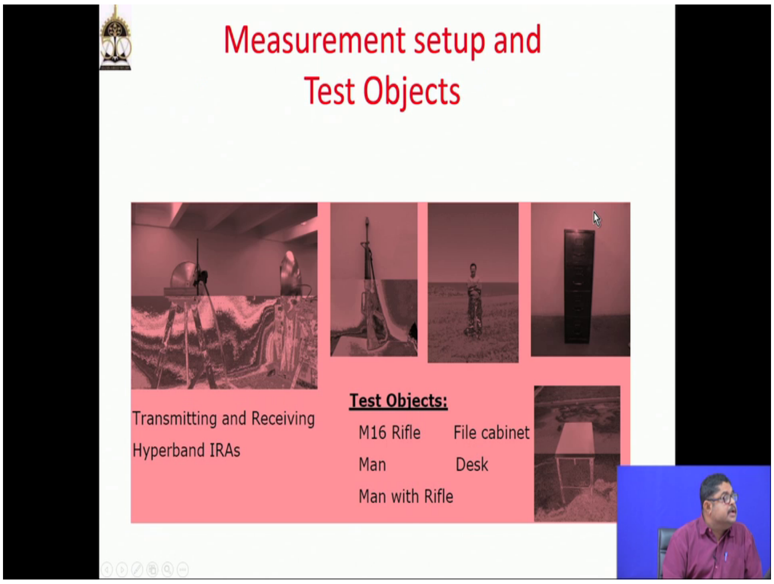

Then suppose whether behind any wall someone escape some rifles or whether some person is thereby so.

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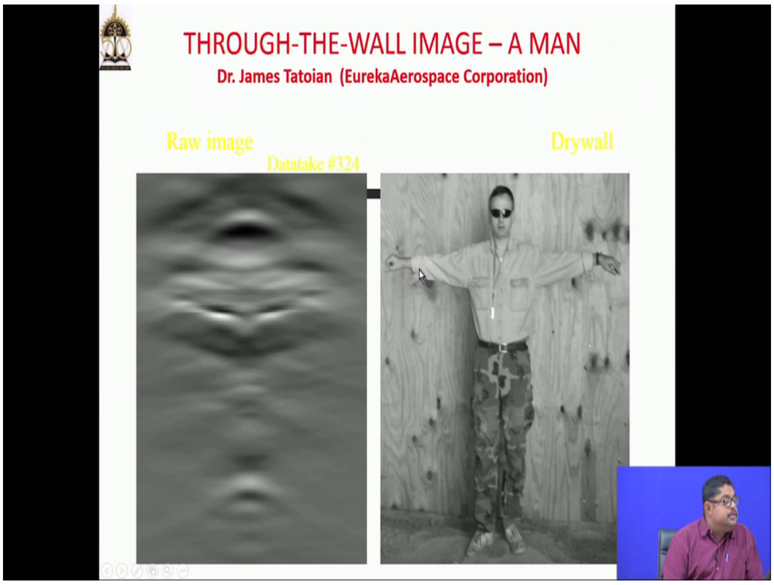

Suppose, this person is behind this wall from the other side of the wall, this image shows that there is a person.

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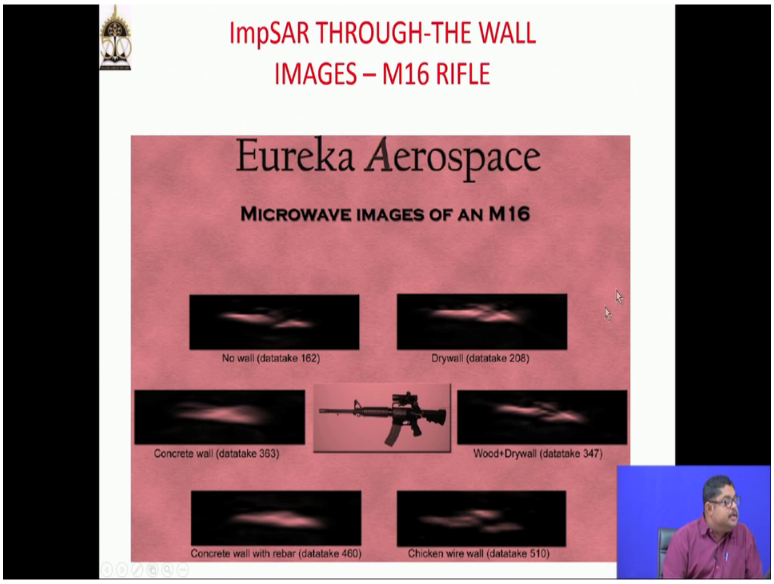

Then these are all various this rifled. So, it is various pictures.

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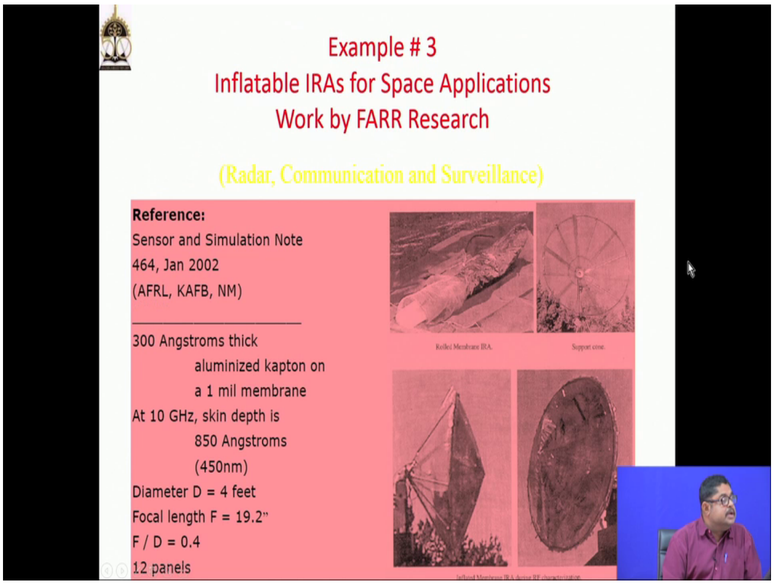

Then there are also that suppose in the space you want to have an inflatable antenna. Nowadays, people are using that that after going to space antenna will be flown.

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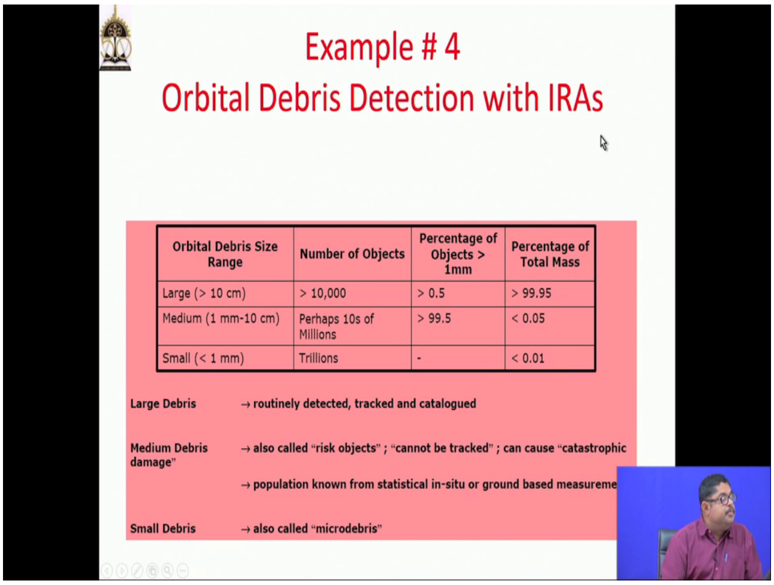

So, can it have that UWB technology? Then orbital debris lot of orbital debris are flowing so can anyone harm us so for that there is a need for detection of that.

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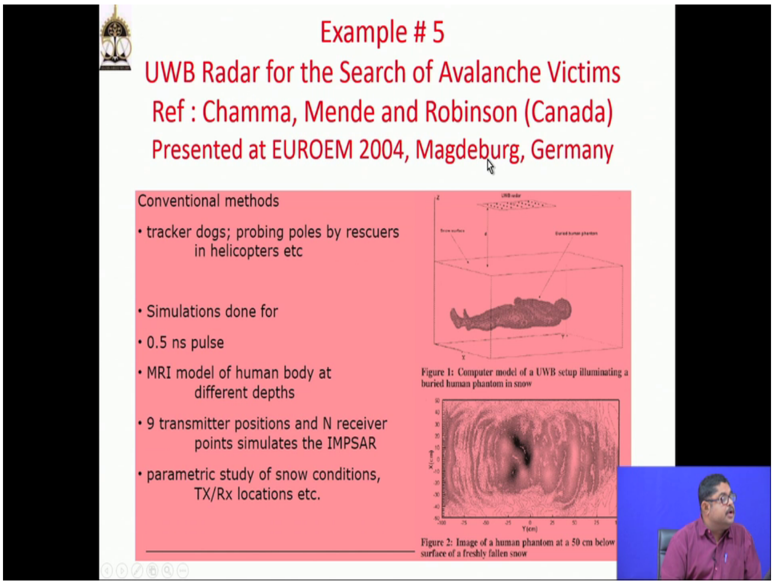

Then suppose someone is trapped under some avalanche. So, can we detect that whether is where the some person is strapped or under debris of some building collapse, also whether the person is live or not that is an active area of research

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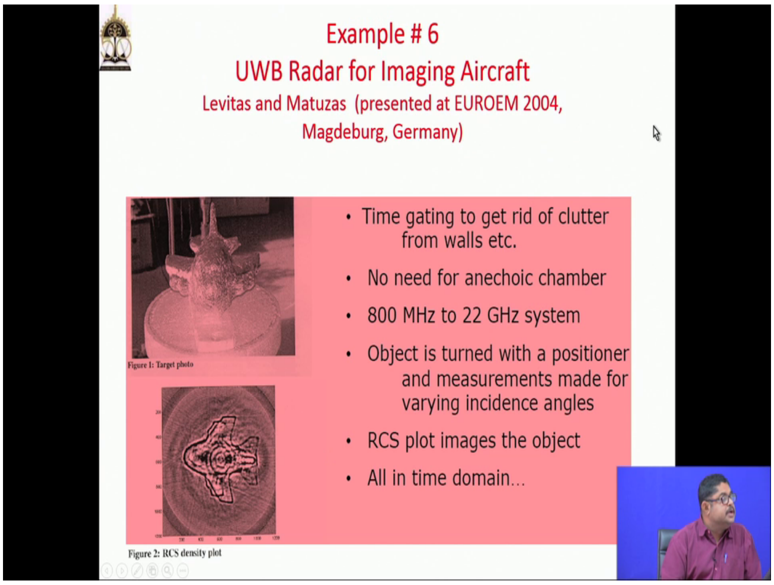

Then an aircraft can we fully take an image of that aircraft as we take from optical cameras, so for that this is required.

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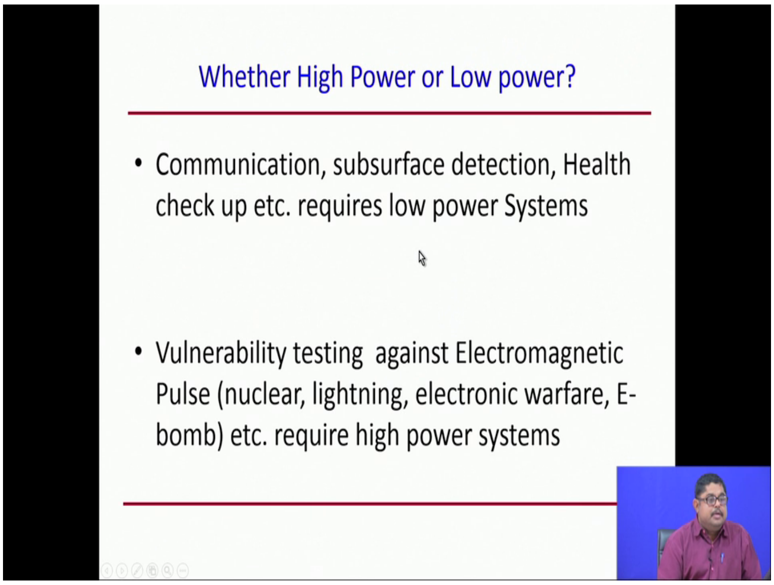

Now, so if we see various applications, there are basically two types of application. One is high power or low power like communication, subsurface detection, health check up for various utilities that requires low power systems. Whereas there is a thing called nuclear electromagnetic pulse or lightning, electronic warfare, E-bomb etcetera requires that whether your electronic system is susceptible to that or not, so that is called vulnerability testing against electromagnetic pulse that require high power systems.

Actually basically the second thing high power systems that was a cold war time thing so that time while trying to answer these questions or trying to develop these systems people came out with the high power developed these systems. And on developing that system actually came the high power UWB antennas. But, low power is a more you see civilian type of need or internal security type of need. And it is now those applications are coming up and people have also come up low power UWB things.

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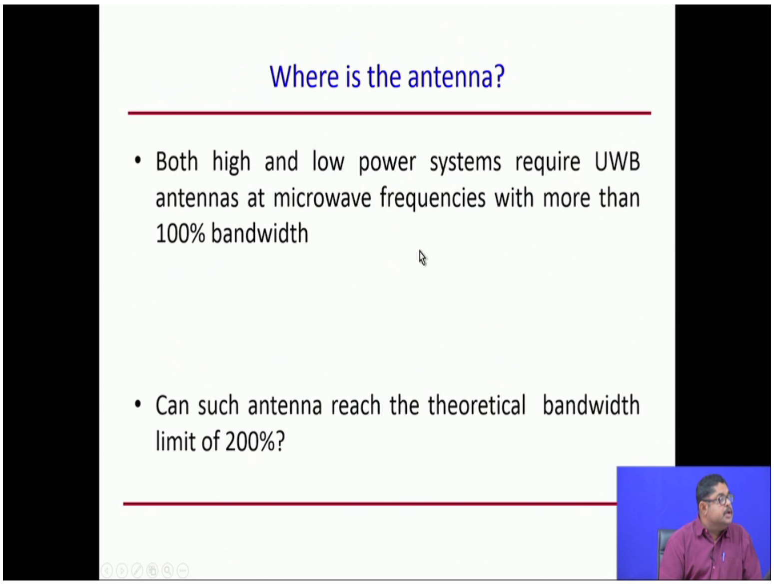

So, question is that to have this cater to this technology we need antennas. Now, both high and low power systems require UWB antennas at microwave frequency with more than 100 percent bandwidth that means if microwave frequency typically you can say 10 Gigahertz, so that means I will require a bandwidth of 10 Gigahertz. So any 10 Gigahertz frequency of operation. If I require 10 Gigahertz or can it have 20 Gigahertz type of bandwidth that means 200 percent bandwidth, the answer is fortunately yes people have come up with such type of things. May not be 200 percent, but very close to 200 percent that we will show today.

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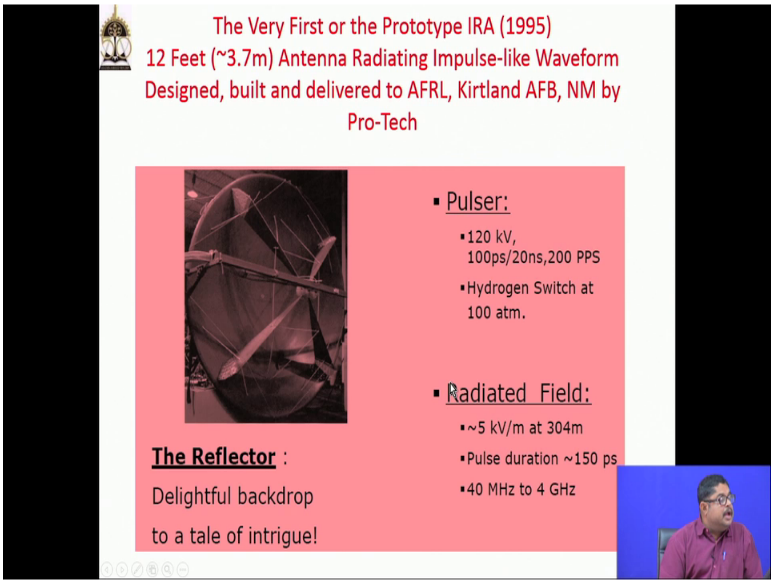

Now, first we will see the high power UWB antennas. The first one was developed in 1995. It was developed by three scientists Carl Bom D.V Giri and Everett far. Actually it was developed at air force research laboratory Kirtland AFB New Mexico. And pro tech is a farm which supplied that, but that whole design etcetera whole research was carried out for almost 20 years.

And then that culminated in this, so that is why in these three persons they got the John crews award for antenna this antenna development. Actually this is the first time they have shown that a nanosecond type of pulse non dispersively can be sense. And this is the picture of the first develop this thing this is called impulse radiating antenna.

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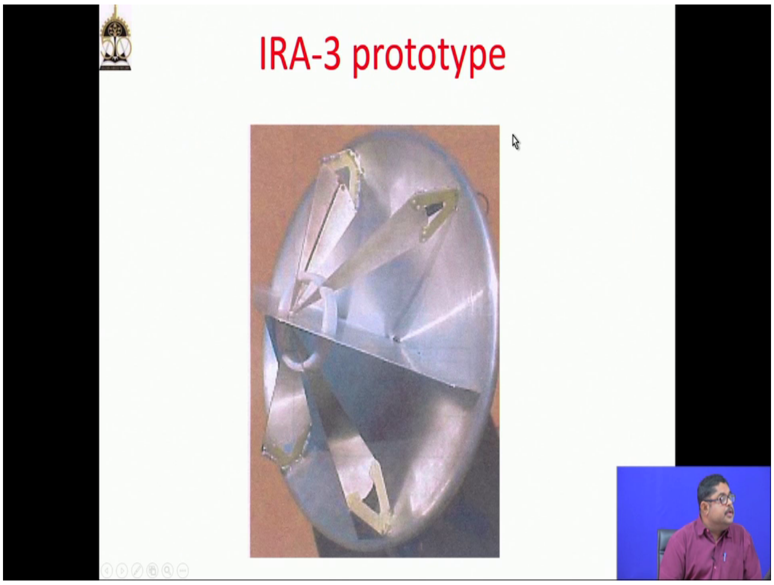

Now, this is the more clearer view of this. So, you see there is a parabola reflector. Actually there is a, this is called some launcher web launcher.

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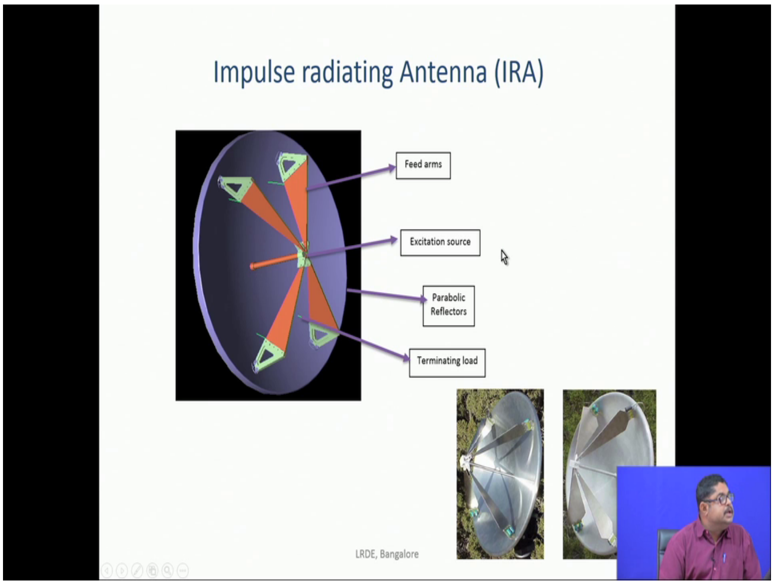

And so, we will see this thing scientifically. So, there is an excitation source. It is a very high power excitation source. It is a pulse excitation. Then there are these feed arms they actually take that wave. And they are actually should carry TEM wave. They do not allow the way to the T or TEM mode to come, because if they come TEM mode have a cut off, so they cannot have a wideband characteristic.

So, this and then the on parabolic reflector they fall that thing. And after that becomes a plane wave. Also there are some terminating loads at the ends these are for cutting, if any by chance high frequency components the undesired component comes to cut that.

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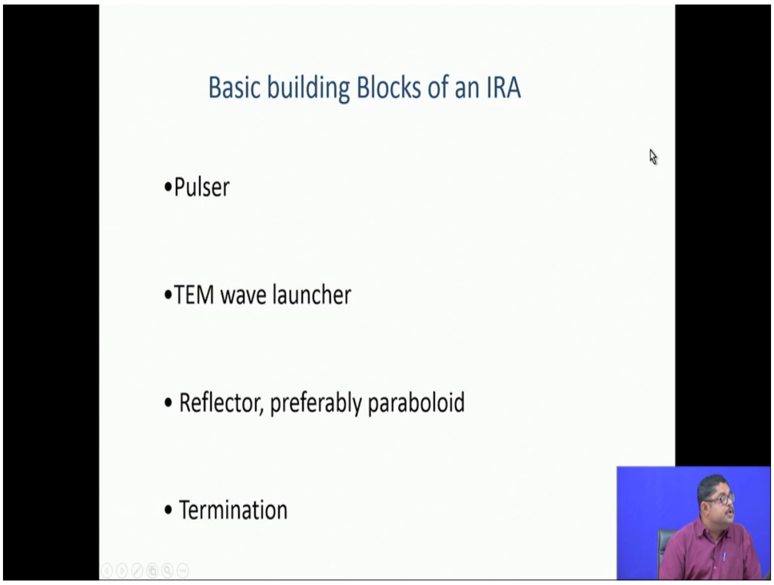

So, basic building blocks of an IRA, one is a pulser that they call that pulse source it is a high power pulse. So, then there is a TEM wave launcher. Then there is a reflector you can have any type of reflector, but preferably paraboloids are used and then some terminations.

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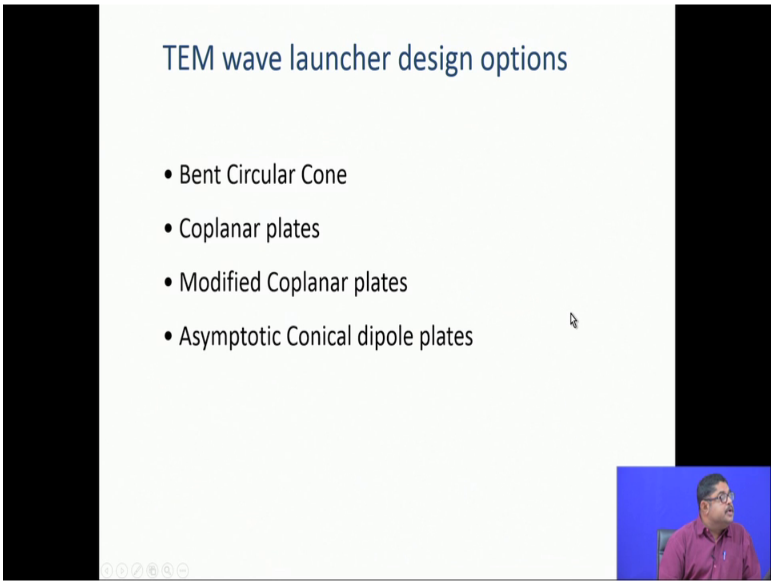

Now, TEM wave launcher design options it can be a bent circular cone. It can be coplanar plates, modified coplanar plates or asymptotic conical dipole plates. This is a very modern thing.

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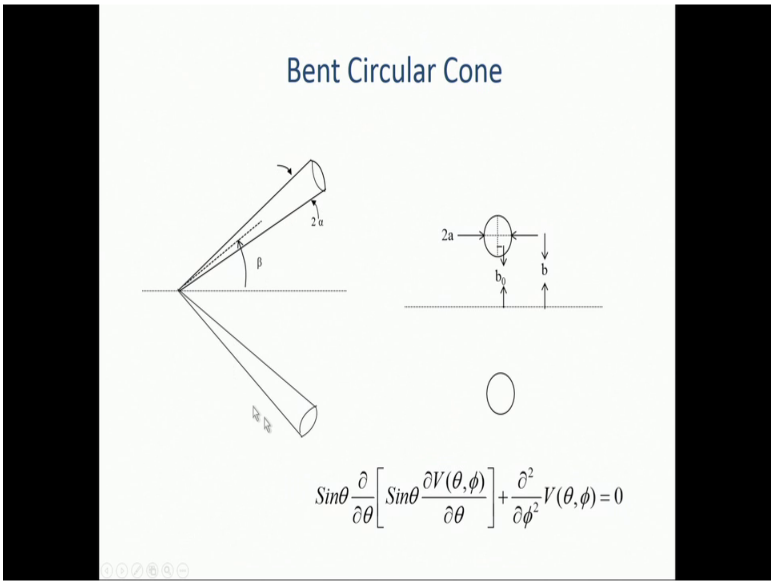

So, we will see that bent circular cone. So, this also this can launch TEM waves

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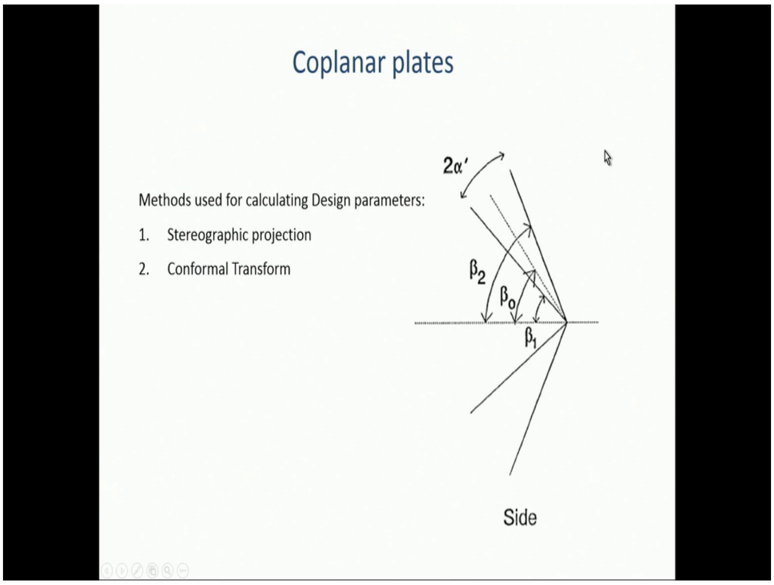

Or this is coplanar plates, planar plates, but coplanar.

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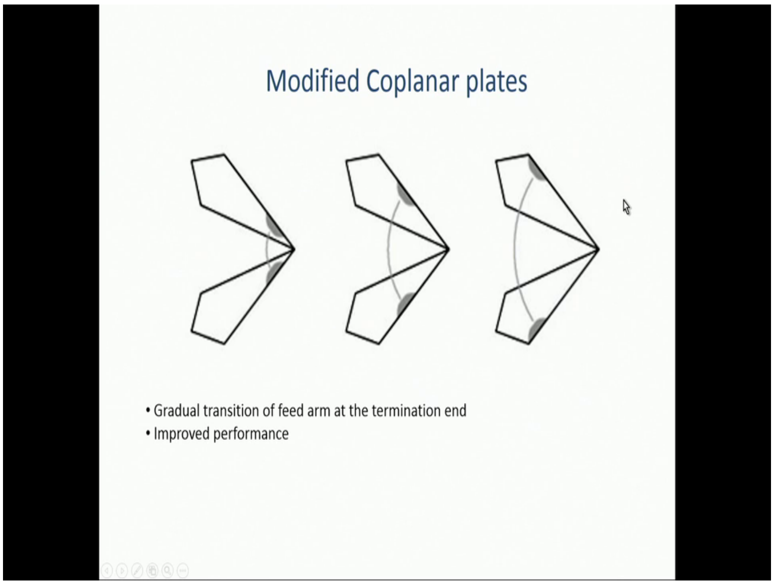

Now, this is modified coplanar plate.

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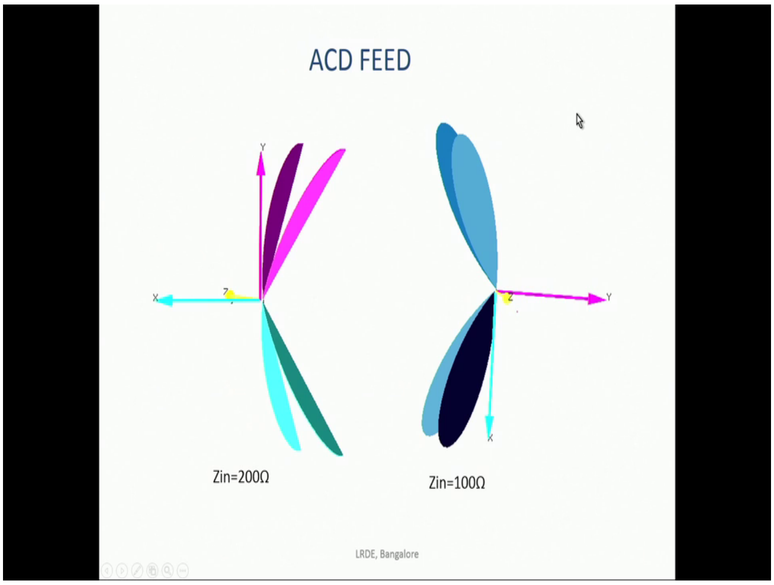

And finally, ACD Asymptotic Conical Dipole feed this is the thing.

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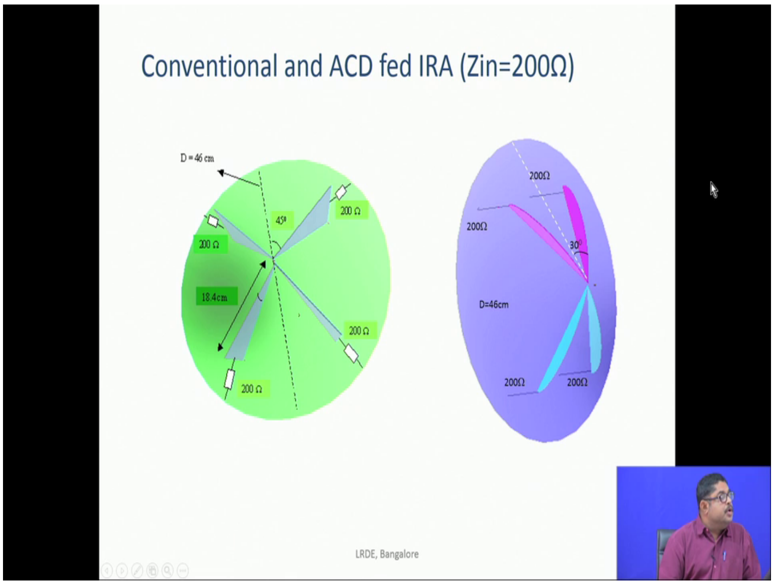

So, actually conventional IRA was designed from coplanar plates, but it was found out that it has an input impedance of 200 Ohm. So, ACD also can give you that, but the beauty of asymptotic conical dipole is that it can be amenable. So, you can make IRA with any input impedance. So, here it is showing that 200 Ohm.

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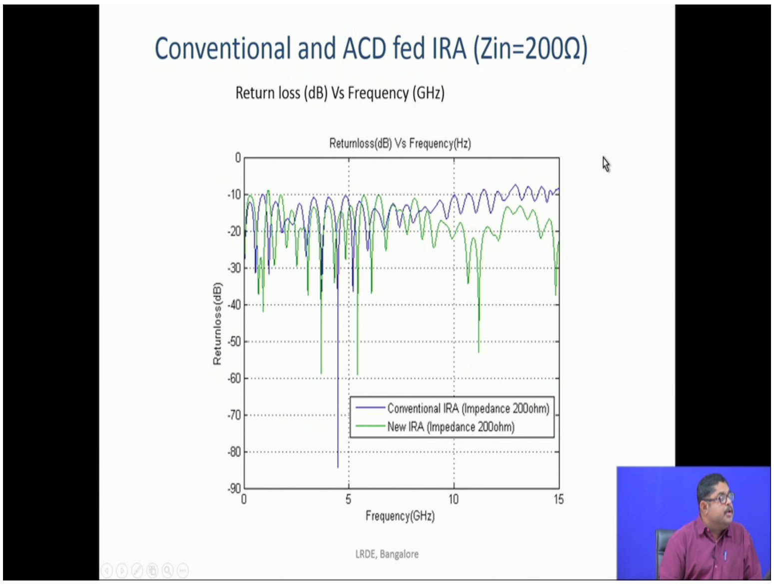

But, this is the comparison. And it can be proved that these ACD feed things that gives a better gain also. This is a return loss you see typically 10 dB is the impedance bandwidth.

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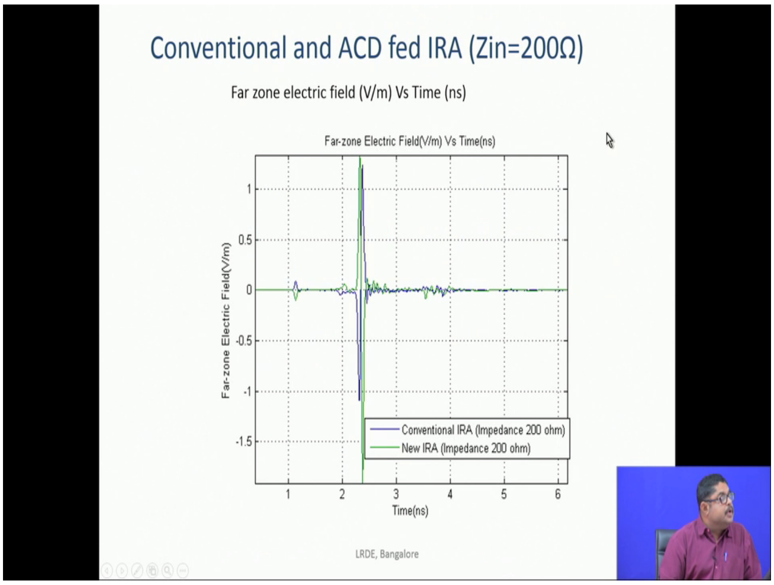

And this is the electric field how it looks like for a given very nanosecond type of a thing. Then this is the gain. So, the ACD feed that is better compared to a slightly better.

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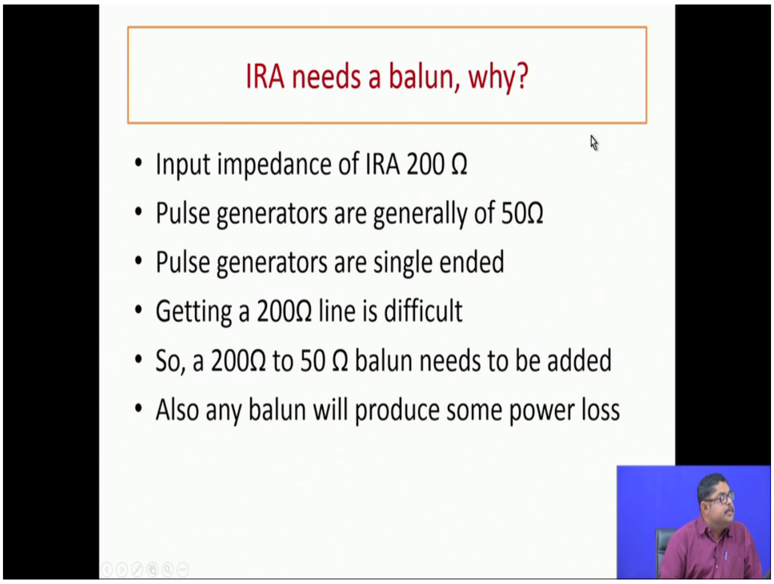

Now, IRA basically needs a balun typically, because the conventional IRA that was designed that has an impedance of 200 Ohm. Now, pulse generators generally you know electronics industry produces generators with 50 Ohm. So, also pulse generators are single ended. So, getting a 200 ohm line is difficult. So, a 200 ohm to 50 Ohm balun needs to be added. And also any balun will produce some power loss which is undesired. So, the question was that people have modified the IRA, so that the balun is not required.

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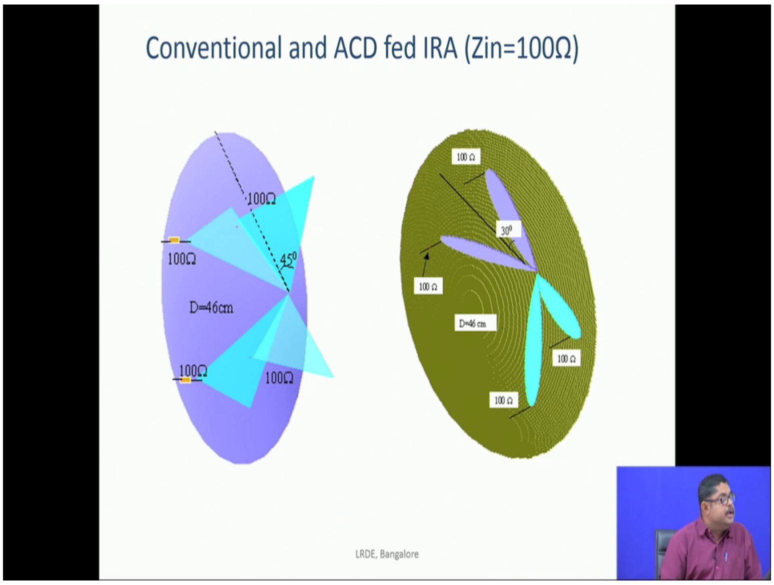

So, you see that with ACD you can design a 100 Ohm impedance also

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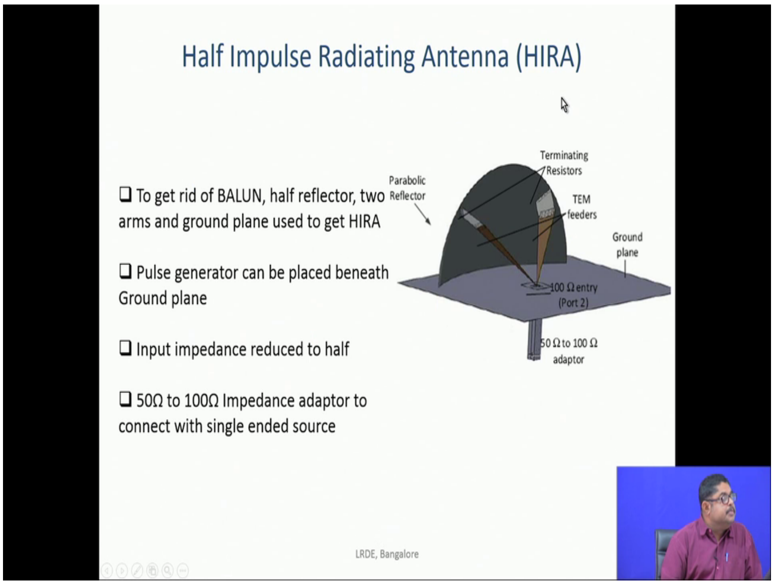

Similarly now if you have a ground plane, and if you have half of the IRA that is called HIRA Half Impulse Radiating Antenna then to get rid of balun you can use this. So, 50 Ohm to 100 Ohm impedance can be achieved from this.

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This is a the half HIRA. This is it is input impedance. So, you see 100 to 50 Ohm it is varying. Certain times it is going even below 50 Ohm, but this is good with the thing. And this is the excitation. If you give an excitation of this, this is the measured voltage at a distance. So, you see that faithful it is reproducing this. There is no dispersion here. And this is the impulse response of the HIRA.

So, this is all IRA etcetera requires this. So, very load (Refer Time: 17:33) and you see that successfully. It is giving a good impulse response that means if you give an impulse, it gives. Now, you can say that impulse is one sided, but why there are 2. Actually that will always come, because actually in the far field the wild up web is getting launched that there is a direct return that gives you this one negative side, but with that these positive side is enough to say that there is an impulse present. Now, these are the various terminations you can have metal film resistors or you can have carbon composition resistors etcetera so that was about high power T.

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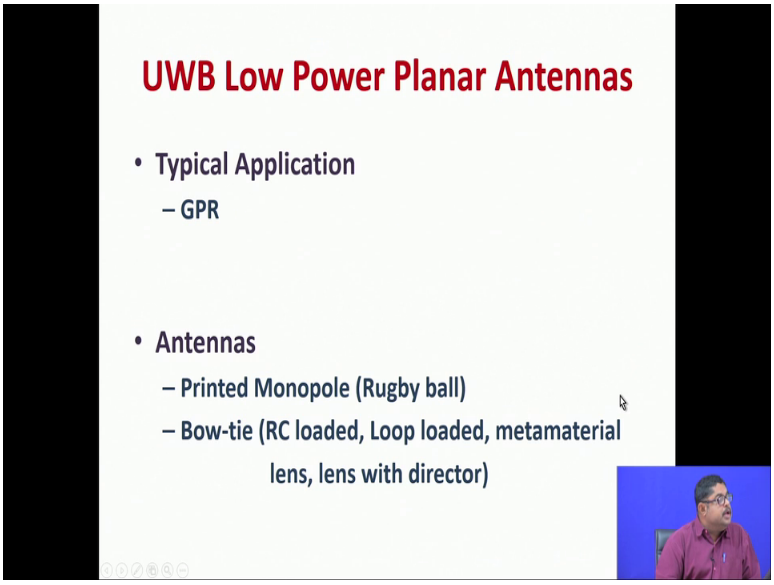

Now low power. UWB you see one typical application of low power things are making ground penetrating radar which all the applications I have said about this except communication. They can be done. So, various options are there are printed monopoles rugby ball antenna, then there were Vivaldi antennas, there were bow-tie antennas etcetera.

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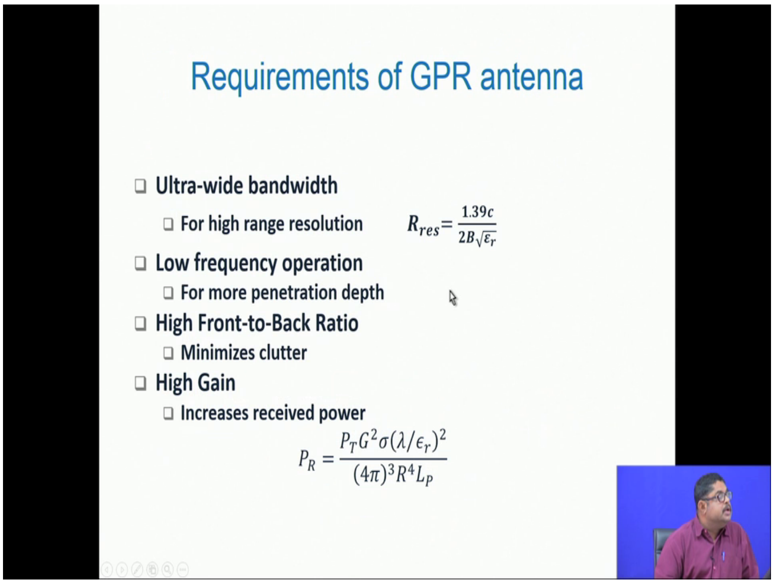

So, we will see them. So, what is the requirement of a GPR antenna? Actually it requires ultra wide bandwidth because any range resolution is a inversely proportional to the bandwidth. So, greater you get the bandwidth you get the resolution. So, get very fine resolution we want UWB type of bandwidth at and 10 Gigahertz etcetera type of thing.

Then also GPR wants low frequency operation, because it needs to penetrate the ground. Ground or any material wall etcetera so for that it also should have a low frequency were up to the f L that should be quite low typically in the order of Megahertz 300, 400 Megahertz like that.

Then also it should have high front to back ratio that means backlog should be reduced, because GPR always see below the ground so, why unnecessarily power should be there in the thing. And also if any gain is, obviously better gain means power requirement will be less or more range in the ground. So, these are the four requirements of any low power GPR type of antenna.

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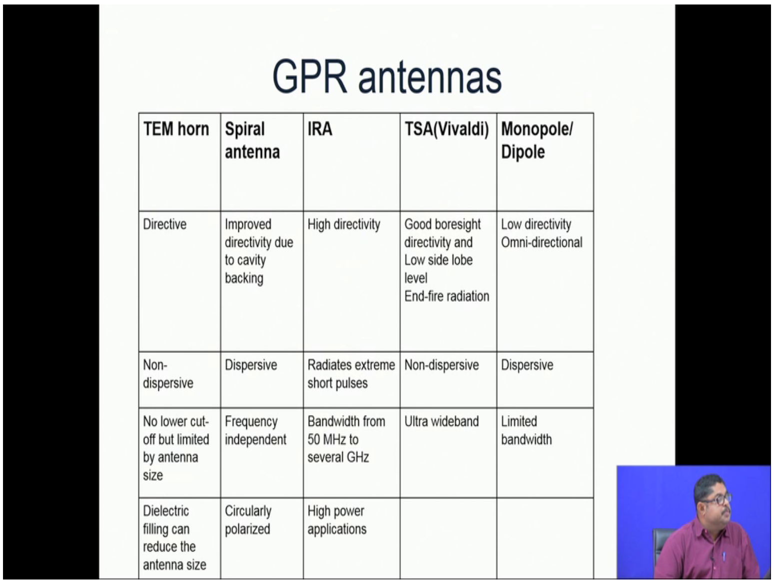

TEM horn	Spiral antenna	IRA	TSA(Vivaldi)	Monopole/ Dipole
Directive	Improved directivity due to cavity backing	High directivity	Good boresight directivity and Low side lobe level End-fire radiation	Low directivity Omni-directional
Non-dispersive	Dispersive	Radiates extreme short pulses	Non-dispersive	Dispersive
No lower cut-off but limited by antenna size	Frequency independent	Bandwidth from 50 MHz to several GHz	Ultra wideband	Limited bandwidth
Dielectric filling can reduce the antenna size	Circularly polarized	High power applications		

So, there are comparison of GPR antennas one is TEM horn. It is a simple horn for point is it is also gives a non dispersive thing. It has a good directivity but problem is it is size is very big. Spiral antenna we have already discussed about this, it is dispersive that is why it creates problem. Impulse radiating antenna also sometimes for this low type applications may be used, but again the problem is that it size is quite big.

Then there are tapered slot antenna which is commonly called Vivaldi antenna it has good boresight directivity and low side lobe level, but its problem is its radiation is end-fire that means, maximum radiation takes place in the end fire direction. So, in some applications it creates problem, because then the size of the thing becomes quite large, also it is also non dispersive it is ultra wideband. Then there are various types of planar monopoles, and dipoles, but sometimes they becomes dispersive etcetera.

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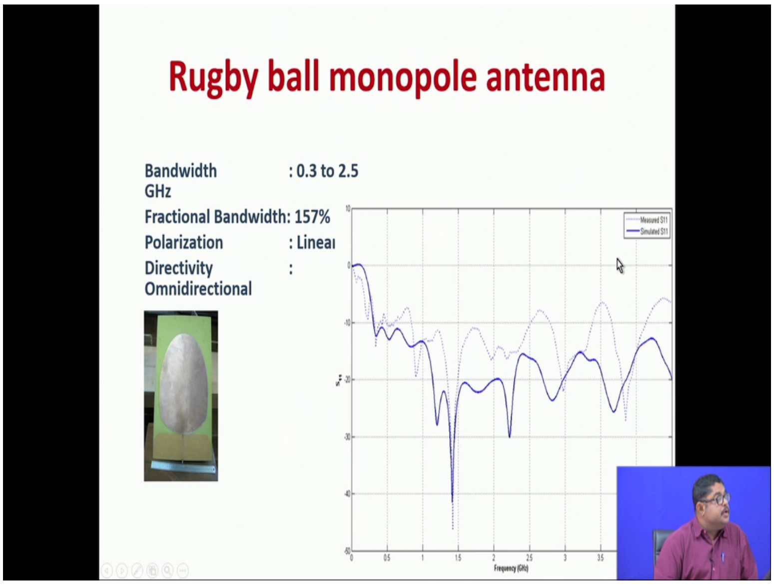

Now, let us say one of the antenna rugby ball monopole antenna. Its bandwidth you see 0.3 Gigahertz to 2.5 Gigahertz. And fractional bandwidth from that definition, if we calculate it gives 157 percent bandwidth. Its polarization is linear, directivity is omnidirectional. This is the impedance bandwidth you see from 0.3 to 0.25 it is working.

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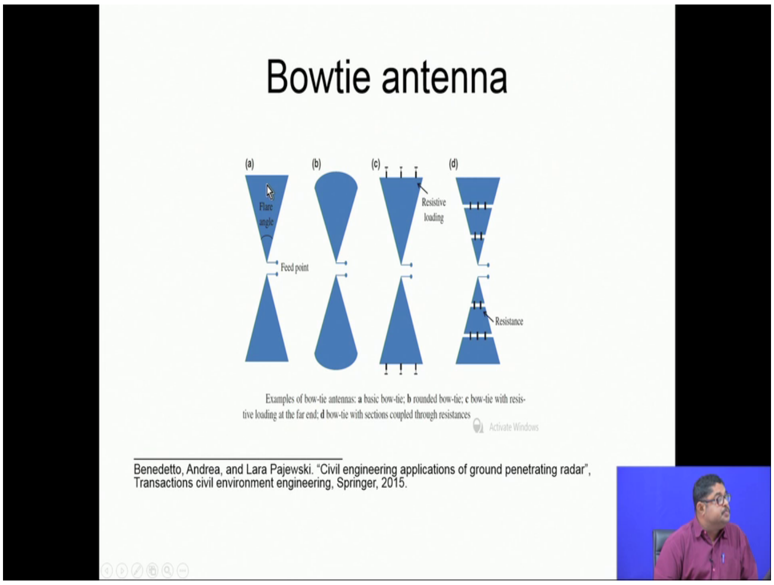

Another option is bowtie antenna. Actually this type of this is a dipole from that actually people have modified this. And then put some resistive loading to cut off various high frequency undesired things. Then there are instead of loading at the lamp once people have also loaded here. So, this is one in civil engineering various applications like health checkup or various buildings infrastructure health this antenna is used.

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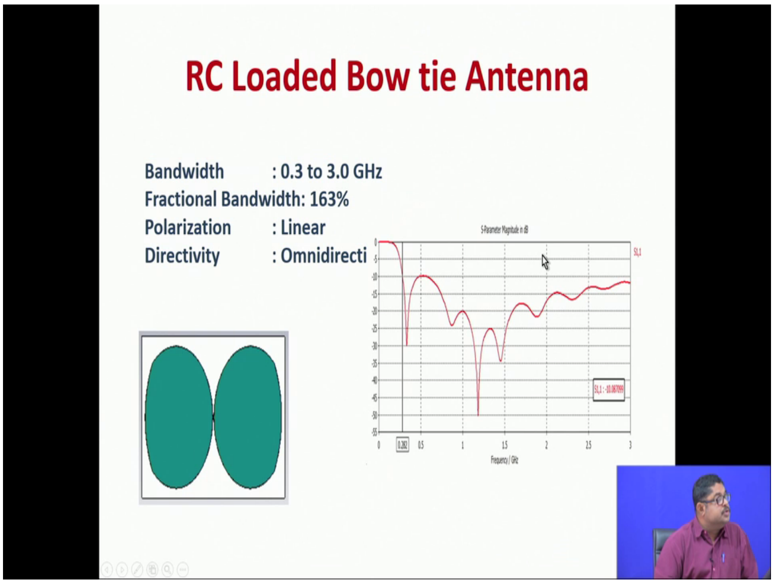

Now, there is also one R C loaded bow tie antenna. So, in the in this one this is a planar one the RC loading is kept inside the antennas conducting plane itself. Its bandwidth it is 0.3 to 3 Gigahertz. Fractional bandwidth compared to the previous one 163 percent.

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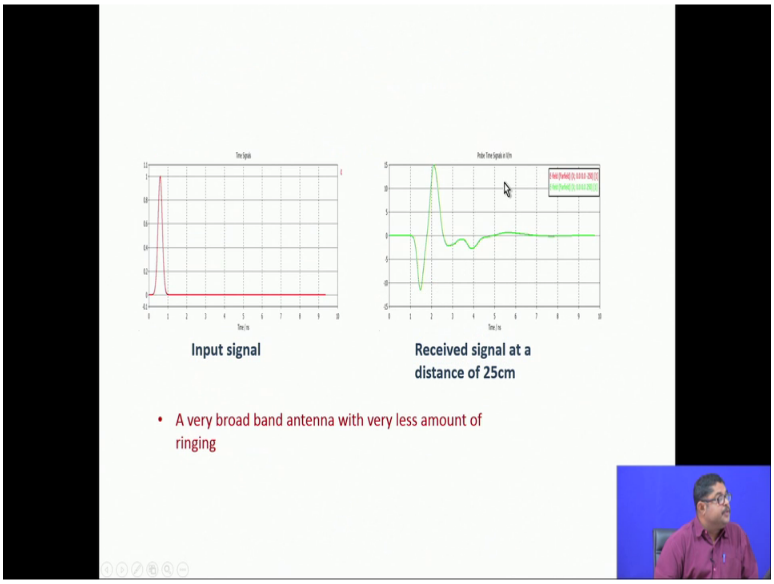

You can see this is the graph. Also if you give a input signal like this, this one gives you signal like this. As I said always you see if you give an impulse, it will have this double sided thing that is typical of any antenna, because antenna in the far field actually puts derivative. So, there are one signal is going up another signal is going down. So, if you take that derivative, you will always get this positive peak and negative peak.

Now, this is a fabricated RC bowtie antenna looks like. And this is the simulated results for it is S11. This is the realized gain that things. Finally, also you can put some lenses to better the backlog radiations. So, this lens design is again from the surface equivalence principle that we have seen.

And so this is a people are nowadays using metamaterial lens. Metamaterial as a property actually metamaterial means which does not exist. Actually for meta materials out of mu or epsilon; that means, the permittivity and permeability one of them is negative that gives us various properties which are not found in existing material. So, it is a planar array of some cells. It is a periodic structure one cell looks like this. And then if you have so you see this back sorry this back one this there are this is the antenna plane, and there is a lens in a different plane. So, this is the model.

So, RC bowtie with metamaterial lens this together makes an antenna it gives various input properties. And so you see that with return loss is measured return loss you can see that within 10 dB starting from here to here up to 3 Gigahertz that means impedance bandwidth is 0.3 to 3 Gigahertz, quite good.

Then front to back ratio you see with lens and without lens is shown here. So, front to back ratio maximum is 15.39 dB that means, it is cutting the back radiation by 15.39 dB at 1.46 Gigahertz and better than that up without lengths at all frequencies. So, putting the lens helps that front to back ratio is input.

And bore sight gain you see gain maximum with lens is 11.52 dB. This is quite significant for a GPR antenna. And gain max without lens is 6.45 dB so at least 5 dB improvement in the gain at frequencies above on two point gigahertz was given by the lens.

Then people came up with another thing that instead of RC loading, if you load with a loop. So, this is a loop bowtie equal. So, evaluation of loop that these were loadings this is suppose the actual antenna. And you are loading like this. So, if you consider that these two if you join, it becomes something like this. So, this is a bowtie antenna loaded with a loop.

So, this is the fabricated antenna, these are some results. And the radiation pattern, now one of the thing is all this UWE antennas they had one problem before all these modern antennas came that. At lower frequencies they are always having boresight maximum radiation.

But, after certain frequency they start tilting, the main beam starts tilting, but this one you see that there is no tilting in the throughout the whole band there is no tilting. Now, that makes actually whatever impedance bandwidth was giving the whole bandwidth was not usable floor UWB antennas; that is why there is a term called useful bandwidth. So, it turned out that all the planner antennas UWB planar antennas was suffering from these.

Now, this one seems that it can it has make that and also you can put some directors you see instead of one there are more loops so that gives a director sort of thing. So, this is a fabricated antenna loop loaded bowtie. These are the various design parameters. And this is the width directors, this is the radiation pattern.

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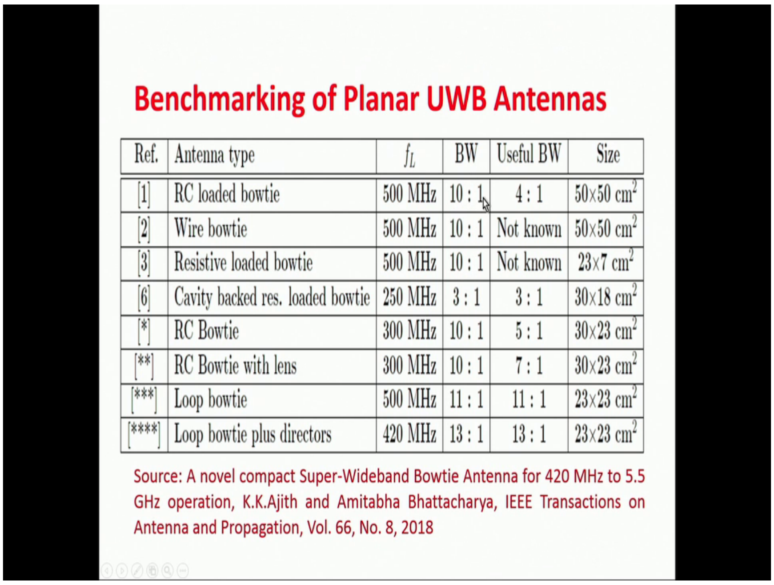

Benchmarking of Planar UWB Antennas

Ref.	Antenna type	f_L	BW	Useful BW	Size
[1]	RC loaded bowtie	500 MHz	10 : 1	4 : 1	50×50 cm²
[2]	Wire bowtie	500 MHz	10 : 1	Not known	50×50 cm²
[3]	Resistive loaded bowtie	500 MHz	10 : 1	Not known	23×7 cm²
[6]	Cavity backed res. loaded bowtie	250 MHz	3 : 1	3 : 1	30×18 cm²
[*]	RC Bowtie	300 MHz	10 : 1	5 : 1	30×23 cm²
[**]	RC Bowtie with lens	300 MHz	10 : 1	7 : 1	30×23 cm²
[***]	Loop bowtie	500 MHz	11 : 1	11 : 1	23×23 cm²
[****]	Loop bowtie plus directors	420 MHz	13 : 1	13 : 1	23×23 cm²

Source: A novel compact Super-Wideband Bowtie Antenna for 420 MHz to 5.5 GHz operation, K.K.Ajith and Amitabha Bhattacharya, IEEE Transactions on Antenna and Propagation, Vol. 66, No. 8, 2018

You see the radiation pattern is changing at various frequencies, but the maximum radiation is always at the bore sight so that makes it that that is why you see here it is listed that various contender for this bowtie antenna. The bandwidth you see that 10 is to 1 is typical, 10 is to 1 means if you have a 500 Megahertz, then your would lope f L is 500 and the your f H is 10 times that that means 5 gigahertz so that but unfortunately that R C loaded bowtie that has a useful bandwidth 4 is to 1, because up that means after 2 Gigahertz the beam will start tilting

Now, you see other things also people have come up various these are various references, so where people have come up people have gone to 250 Megahertz, but you see 3 is to1 was the bandwidth. And also size is a factor because for these systems the smaller size is good. So, R C bowtie can give you 10 is to 1 that has been input to 5 is to 1. But, then if you put the lens then that becomes 5 is to 1 become 7 is to 1. You see other things are more or less same, but loop bowtie you see 500 Megahertz is 10 is to 1 has been changed to 11 is to 1 that means, the bandwidth is increasing.

And loop bowtie plus directors you see it is going glower and also 13 is to 1 this is the best till now achieved. And also the usable bandwidth is full this impedance bandwidth so, that is a remarkable improvement. And this is a very good GPR antenna. So, hopefully this will have a lot of applications in feature.

So, with this we have seen that various UWB antennas, there are various characteristic how to make that. And this is an active area of research hopefully people will come up with better and better antennas after this. So, with this UWB antennas we have shown that you can have by giving the picture that you are giving a pulse excitation very narrow pulse is or picosecond duration, but you are also getting the radiated signal is also like that. So, there is no dispersion there.

So, these are promising things, hopefully your people also will have better search antenna design, but basics whatever we have seen that absolute designed these type of antennas. So, we conclude this lecture here. In the next lecture, we will see what is the how to measure various antennas characteristics, so antenna measurements we will concentrate there.

Thank you.