Basic Tools of Microwave Engineering
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Lecture – 01
Challenges of Microwave Design

Welcome to the first lecture; Challenges of Microwave Design.

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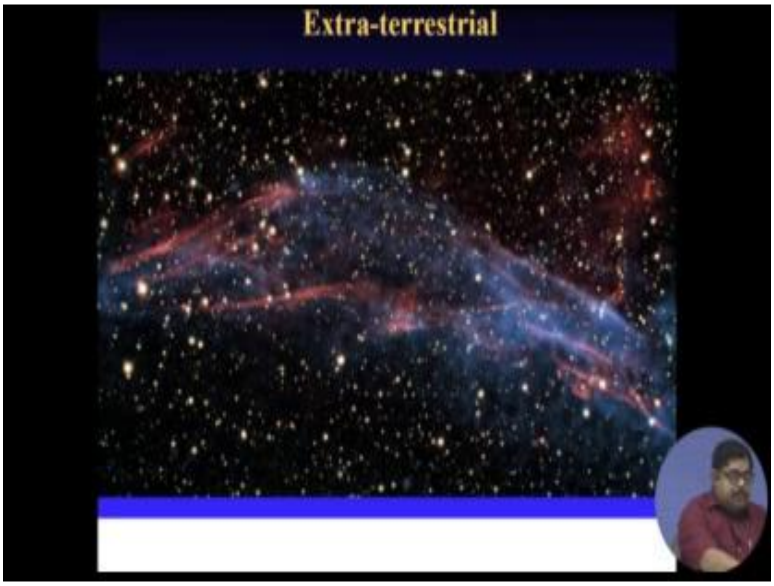

If you look at the universe there are lot of stars, some of them are radio stars which emit radio frequency signals, lot of microwave radiation they emit and by properly listening to them we can get many information from this radio sources. Microwave technology is required to listen to these types of extra terrestrial sources.

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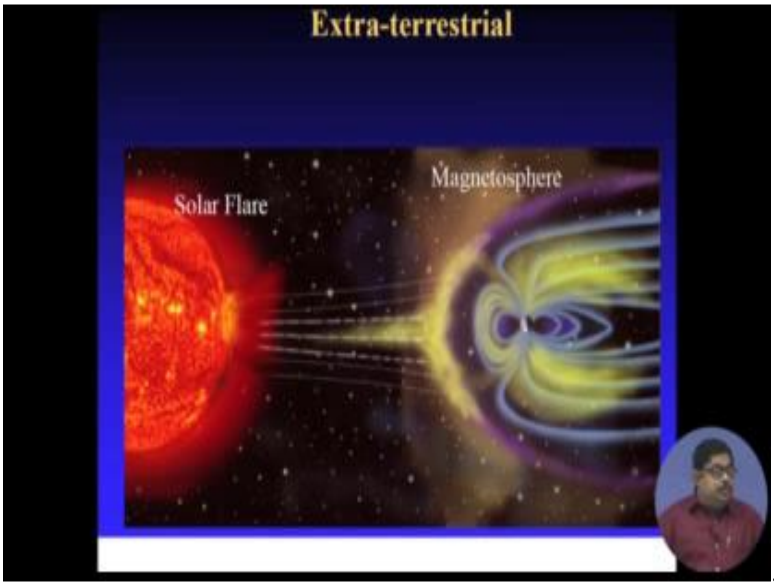

You see sun emits solar flare which affects, which falls on our atmosphere which can disturb our communication. So, there also you need to understand microwave technology that in such cases, what to do? How to shield our communication systems? Our various application systems insulated from those solar flares, you see this is a very common thing; we see lightning.

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Now, we have various systems man has made, which need protection against this lightning, so to understand that you need to understand microwave technology.

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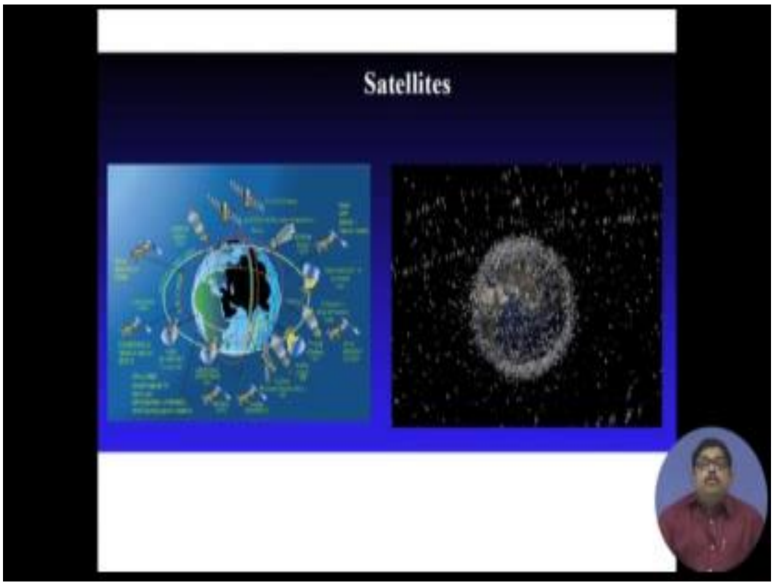

All of you know that our mother earth is surrounded by so many satellites. Now, most of them are artificial satellites which man has launched, so that to extend our vision into space, to communicate with them, to gather data from them you need to understand the technology of microwave.

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You see today's world, all of us are surrounded by Wi-Fi, satellites, mobile towers, you have TV, pagers, you have cell phones, you have various communication antennas installed on ground, you have your computer, everyone radiates and this seems electromagnetic signal to understand that you need to know the technology behind them, which is microwave technology.

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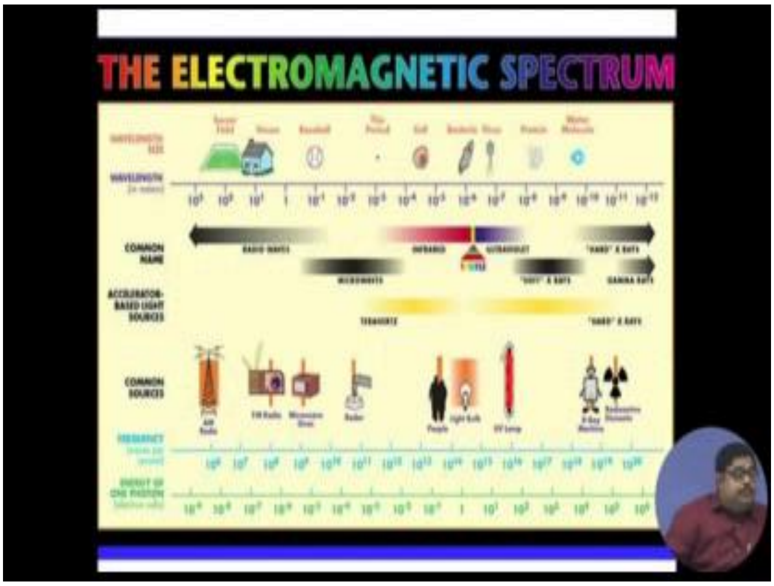

You see the electromagnetic spectrum; you see starting from very large wave lengths or the order of a large soccer field, a large stadium to very small wave lengths like a water molecule, an electron, a sub atomic particle all these are composed of electromagnetic waves. So, the electromagnetic spectrum covers from very small frequency to very high frequency, typically 100 hertz to you can go up to 10 to the power 20 hertz. So, all these are part of electromagnetic spectrum, but as you can see from the slide that there is a broad division of radio waves and micro waves, which roughly we can say from kilohertz sort of frequencies to gigahertz sort of frequencies. We roughly call radio waves and a part of that particularly you can say 100 hertz, 100 gigahertz to roughly 100 megahertz that is called microwaves. So, basically these frequency range we have certain techniques to handle these applications, etcetera.

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Now, you see there are some inventions which happened in the twentieth century. There were radios; radio communication was invented just at the start of the twentieth century by transactional communication. Then we have seen TV communication, etcetera. Now, due to invention of radio, this radio communication, TV communication; these became possible. Also at the same time in the dawn of the twentieth century there was aircraft was invented which gave rise to the field of avionics, the aircraft electronics which also gave rise to microwave, high to mankind that is called radar by which you can detect aircrafts or any other thing that is coming to you.

Also in the middle of the century last century there was invention of transistor and that gave rise to IC; integrated circuits varies in a very small volume or area large number of those transistors and other circuitries, electronic circuitries are packed and now we are seeing the very large scale integration. So, there also this microwave technology is useful because when two transmission lines are nearby there is lot of coupling issues, etcetera was stopped and all those are analysed by these technology of microwave.

Then you know that in the seventies or eighties of the last century there were invention of micro processor and that gave rise to digital control of everything and finally, microprocessor evolved to computers which are peripherated today's our households and in all them also, when today we are having the clock speed going to almost gigahertz. So, there are lot of electromagnetic waves that come out from them and you require microwave technology to understand them like, for example, we see an application here.

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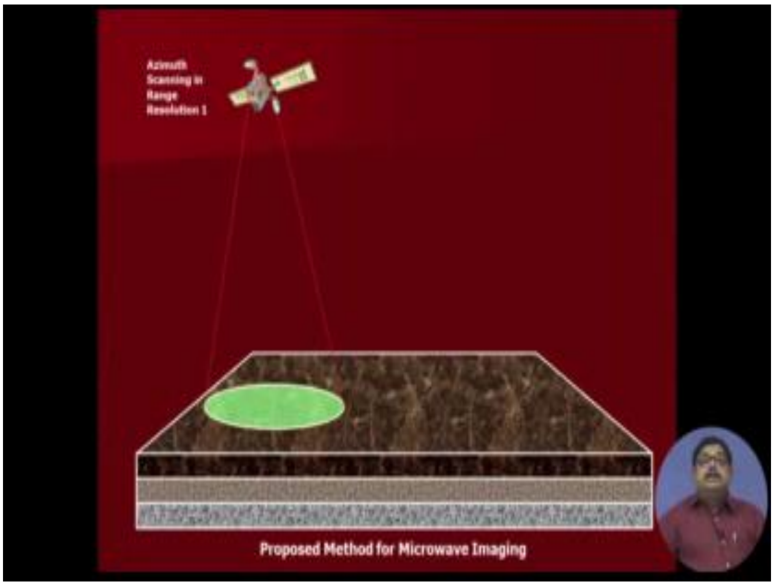

Suppose all the countries are nowadays sending the planetary explorating various satellites, various robots, various advitors. Now, if you want to find out what is there in a new planet, you see that you flow the satellite like the slide is doing that it is focussing on various parts of the planet and then it is gathering the reflected data and from that you see that there is a slice that one layer information.

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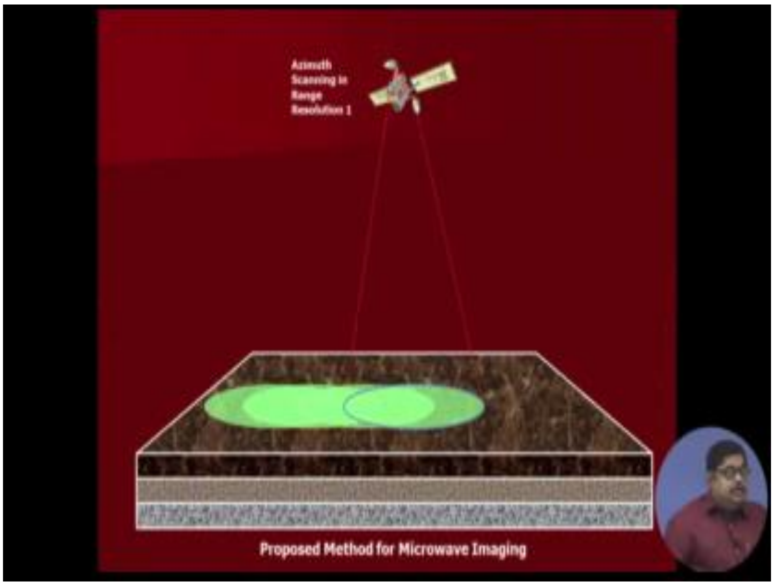

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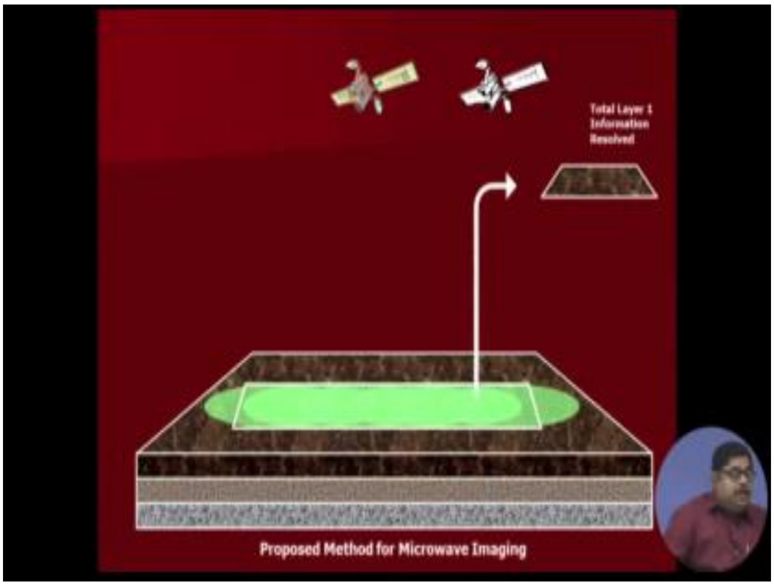

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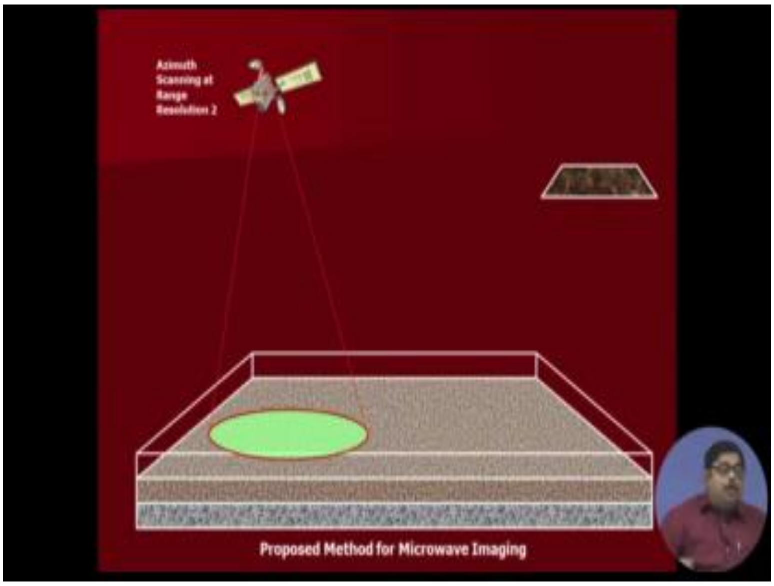

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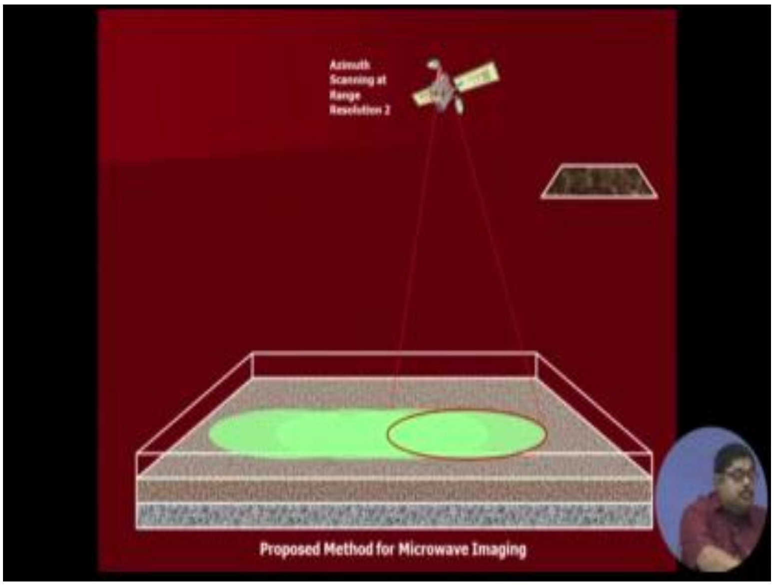

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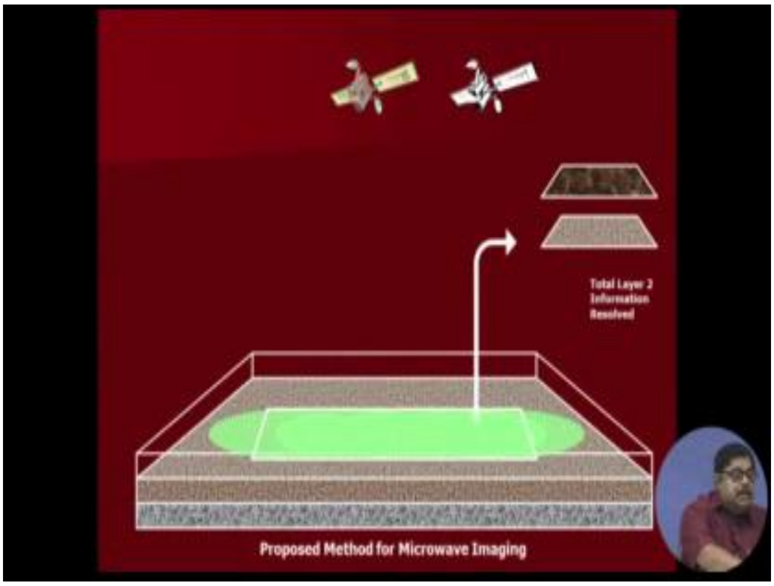

You can pick out, you go on doing this for various layer after layer under the soil of the planet and you get various layers of information by which scientists can predict, space scientists predict what are the various layers composed of; whether there are various minerals? Whether there are various valuable minerals which are not available in earth or which are scarce in earth they also can be extracted and taken.

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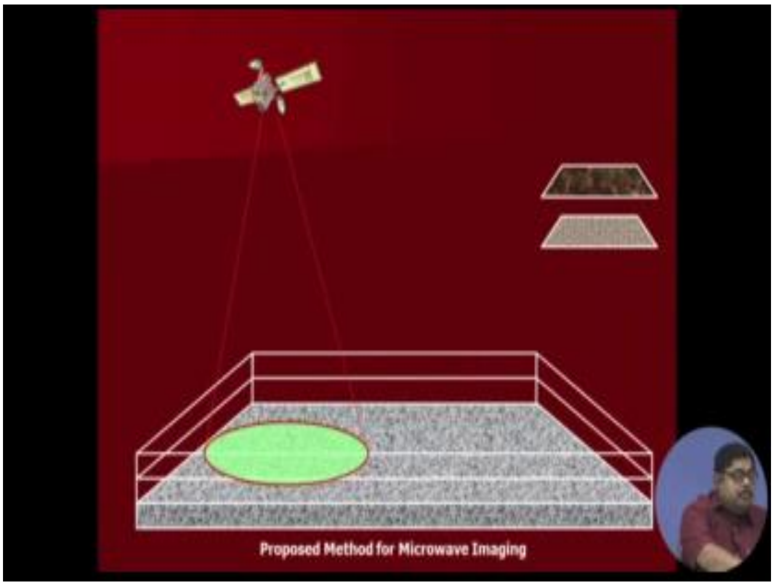

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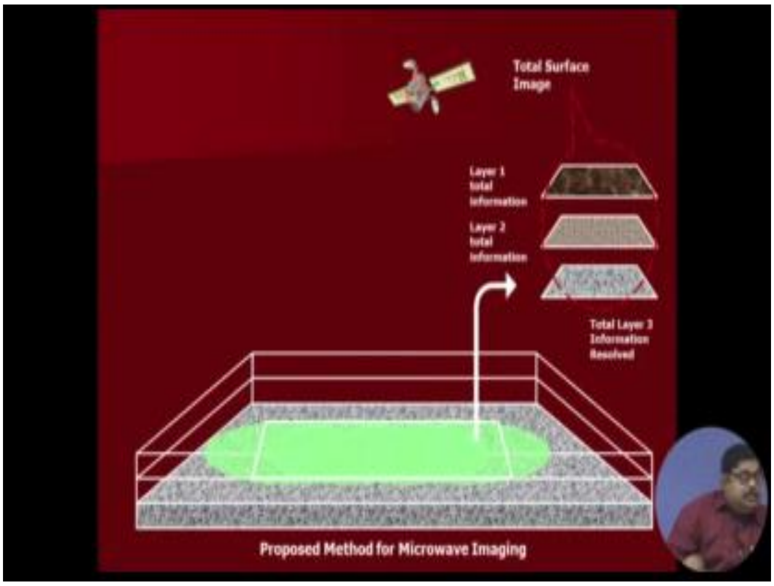

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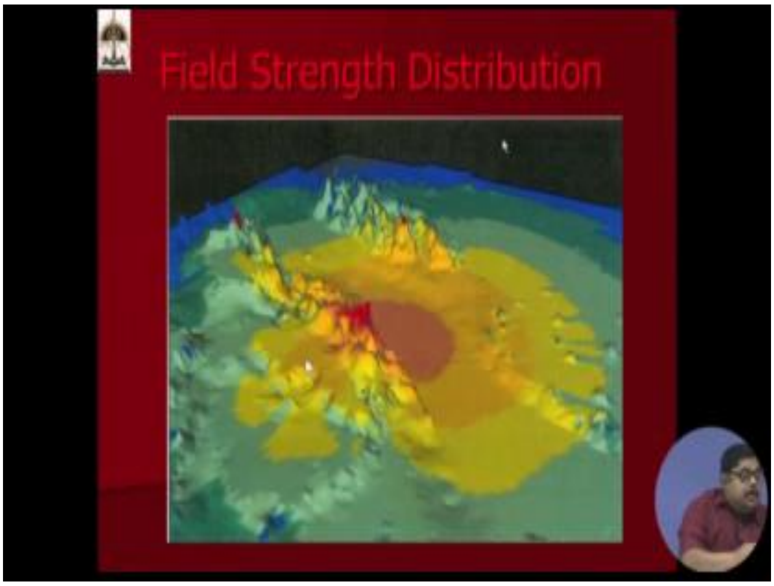

Similarly, you see that suppose you have a new area and there you want to start your various communications, your radars etcetera you want to deploy. So, you want to first understand, what is the ambient that is present there? What that you need to find out how the electric field look like in this slide? You can see that how the electric field is looking place in a particular terrain. So, to do this you require those tools of microwaves which we will discuss in this lecture.

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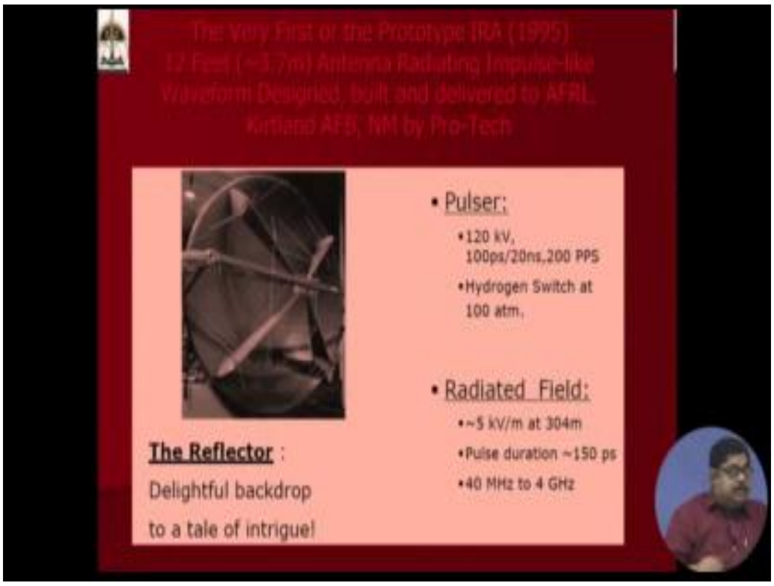

Then this was a fairly recent development that nowadays we want to send very short pulse of the duration of; let us say 50 picoseconds, now, when a nuclear explosion takes place these type of pulse come to earth. So, we need to know that what happens if our systems get exposed to that, but generally mankind did not have any means by which we can either detect or we can radiate this type of signals, but in 1995, this antenna called impulse radiating antenna was developed purely from this microwave technology stand point, so that now you can create a feel of 5 kilo volt per meter at 300 meters that means, quite 300 meters away. If you can create a kilo volt per meter order of the feel with the pulse duration of 150 picoseconds, so that you can produce by one pulse a huge band of frequencies 40 megahertz to 4 gigahertz.

Now, this is purely when the microwave technology was applied this antenna came out it was not known throughout almost the last century, but fortunately in the last decade of the century 1995, we got this antenna which has got tremendous application today and it has changed the whole ball game of microwave technology.

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This is a better view of that antenna and you can see it is a dish antenna, but there are serve on the back of it, there are transmission lines properly designed. So, that a pure pulse almost an impulse sort of thing you can radiate to them.

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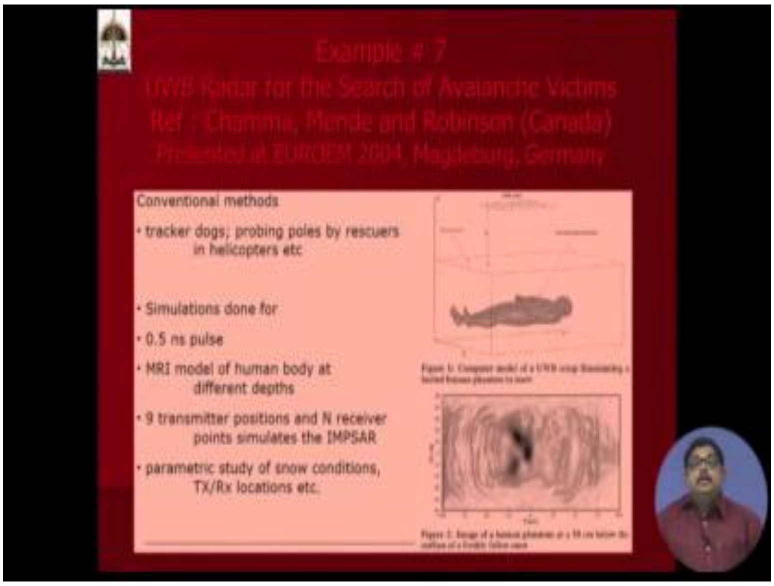

Now, application you see when a person, suppose there is an earthquake or an avalanche and then a person is buried under that earthquake, debris or due to the snow of the avalanche. Now, you want to first detect whether there is any person. Now, there were no probes before tracker dog, etcetera or helicopter could not see whether, what is there in the sub surface, but with the technology that impulse radiating antenna? Now, people can find out whether there is any person or any object which is hidden behind say 1 to 2 meters of snow or 1 to 2 meters of those debris and then technology is coming up by which you can detect whether he is dead or alive. So, that whether less co operations are needed?

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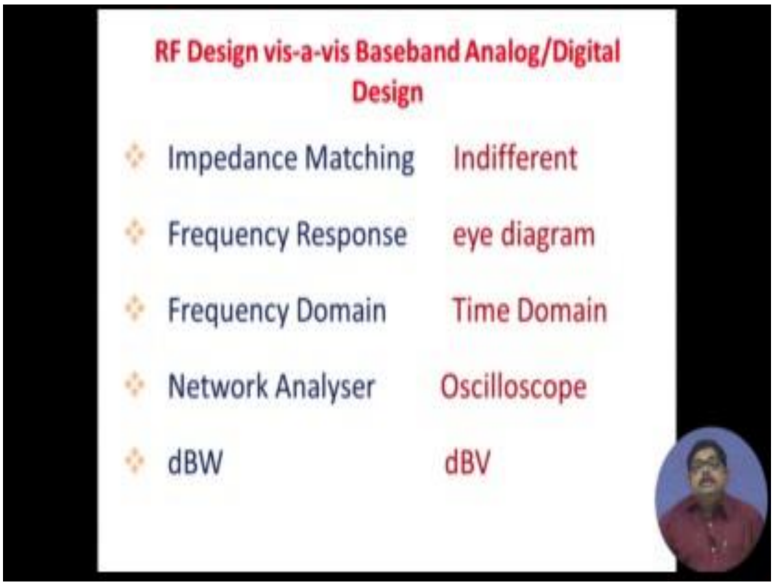

Now, we see that there are lot of applications where these RF design or microwave design, we say is needed. Now, generally in our undergraduate classes at the initial stages, we are taught various analogue and design procedures like you are taught, how to design a C amplifiers? How to design a fate amplifier? How to design a filter etcetera, but RF design is a bit different from that because it evolves from primarily from electromagnetic field theory, then as a technology it evolved from microwave technology.

Now, what are the salient points, where this RF design differs from microwave design? RF design differs from the base band analogue or digital design. So, the first thing is you see impedance matching, actually from maximum power transfer theorem that if there is a source of energy, source of power electronic power, AC power that you want to deliver to a load then load and source should be matched there should be a conjugate relationship between them.

So, that maximum power can be transferred, but unfortunately or fortunately, in analogue or digital base band design this is not always applied because there are in base band that means, where your basic source either it is a audio source or a video source those things which are at lower frequencies, typically some kilohertz or megahertz frequencies small amount of megahertz frequencies are there, then you have plenty of those source and their energy. So, power is not a problem that is why they try to maximize those voltage etcetera from those designs.

But when we go higher up in frequency, when producing power is very costly, it is a costly resource that is why the RF design people they take very special care about, how to maximize the transfer of power from one network to another network. That is why they are very sparse, they take a lot of care for this impedance matching whereas, we can say that the analogue or digital designs are indifferent to that.

One example, I will say that when we design AC amplifier, we try to say that our design goal is will have maximize the input impedance and minimize the output impedance, but from the power maximum power transfer theorem, we are not at liberty because what is the source we will have to match to that both in the input side and output side, but we can take that liberty in the case of the low frequency design or base band design. We call a typical analogue digital design that we see there because they have plenty of power.

So, even if it is not optimum in the power sense, the design of AC amplifier which is a classic, very good amplifier voltage amplifier sort of thing here we do not pay heat to the maximum power transfer theorem, whereas, in an RF frequency or microwave frequency you are bound to pay this attention that is why impedance matching is an important concept for RF design and we will have special lectures for tackling how to do those impedance matching.

Then you see that generally in lower frequency thing, we thought about eye diagram that if you have a digital signal then generally how much the interference is causing you disturbance we see through eye diagram, but in the microwave region generally the more important frequency response of an any block an amplifier block or a escalator block or mixer block etcetera we always see because we know that if you change frequency and when you are at higher frequency end then the basic building blocks at different frequency they behave differently like a capacitor at certain frequency.

It can be behaving as a capacitor, but if you change the frequency it may also become a resistor or an inductor, the same thing for an inductor becoming resist capacitor other frequency. So, frequency response is an important thing and always you should be aware that if you change the frequency a new whole new circuit from the same components you can get. So, that is why frequency response is a very useful thing for RF design.

Then generally it is seen that digital circuits, etcetera they talk of time domain whereas, it is apparent that more concentration is given in RF design for frequency domain. One of the reasons also is that as you have seen that those very short pulse, type pulse of signals like impulse signals, etcetera. Previously, RF circuits were not able to pass that, but now what is this distinction is coming down also in time domain. There are lot of microwave technology coming up, but whatever is existing in wave frequency domain is useful thing for RF design.

Then you see that, you see any device like since you know that in low frequency thing, we will look at oscilloscope to look at an wave form, but at higher frequency we need to see by changing frequencies how the behaviour is taking place and also we need to have a wave sort of picture that means, whether there is a wave going in forward direction or getting reflected and coming into backward direction. So, that is not available from oscilloscope that is why the basic instrument that is used at RF frequency is network analyser that is why we will see network analyser also at the end of this series of lectures or this course.

Then the basic unit in which the analogue or digital baseband designs, they generally talk of voltage; if that voltage range is quite high, then instead of an absolute scale it is generally expressed in dB scale. So, dB volt is the one that they talk of, but in RF designs we talk of power not only voltage, but the cross product of that voltage and current that gives us the power. So, the unit of power of the dB scale is dB watt. So, we talk of dB watt, I think all of you know that if there is an absolute scale of.

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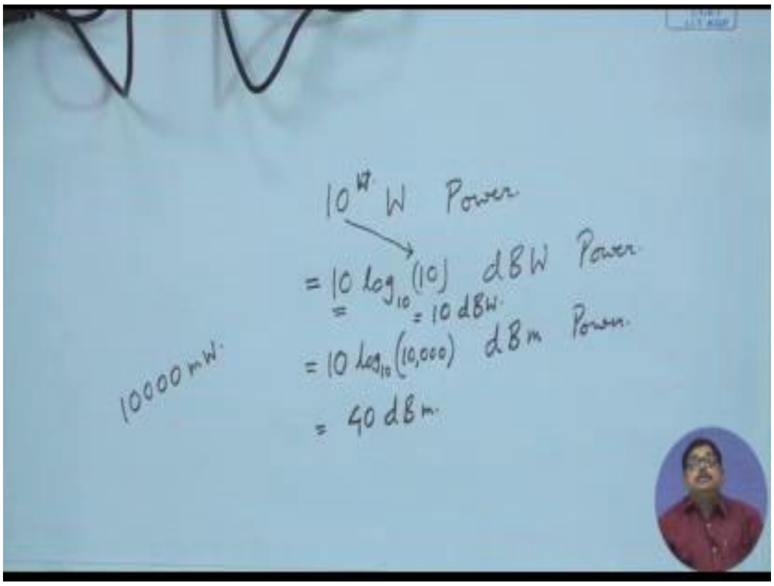

Suppose, I have 10 watts of power, 10 watts of power then equivalently, this I can also convert to dB watt of power dB w of power, how since it is a power quantity I will have to take 10 log to the base 10, this quantity 10. So, this multiplier is for power quantity, it is log 10 dB w. So, by this you can calculate any of the power to dB w watt also there is another watt which we will another unit of power which we will be using in this theme that is called dB m power powers another unit is dB m.

Because, generally in RF frequency in particularly now our applications we or in laboratories we deal with smaller amount of power. So, dB m means that you convert this watt to milli watt. So, the same 10 watt of power will be in milli watt. If, I put it will be how much that it will be multiplied by 1000, 100 milli watt. So, if I to get dB m of power the same power will have to be written as since it is power again the multiplier is 10, but log 10100. So, that will be that it will be 4. So, I will have 40 dB m of power whereas, here I had that 10 dB watt of power. So, this is the power units that in RF frequency we generally use.

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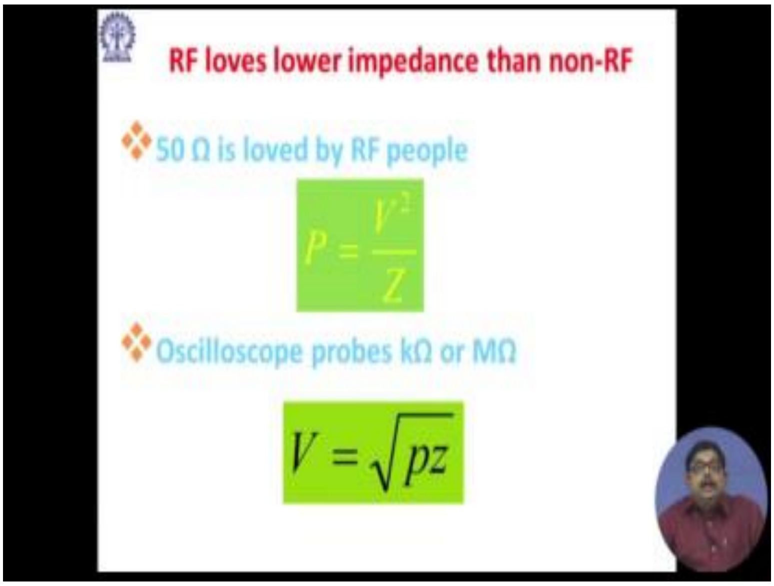

Now, another thing is you see, generally since the same reason that we are scarce of power. So, RF at RF people they the instruments, etcetera that is designed generally for 50 ohm of power 50 ohm of 50 ohm impedance. So, it is a small impedance whereas, oscilloscope probes they are kilo ohm or mega ohms sort of impedance you have seen that in your oscilloscopes the probes that are coming there you can change it to 1 ohm or 10 ohm probes etcetera.

So, you see the reason of this difference is if you consider power is given by as the slide shows that power is given by V square by z. So, for a same voltage, if you give smaller z smaller impedance you get more power that is why the RF people uses 50 ohm whereas, oscilloscope people they are interested in baseband, people are interested about the voltage. So, voltage is given by root over p z. So, more impedance means you will get more voltage when the same power is given that is why the non RF people, they love higher impedance, RF people loves lower impedance.

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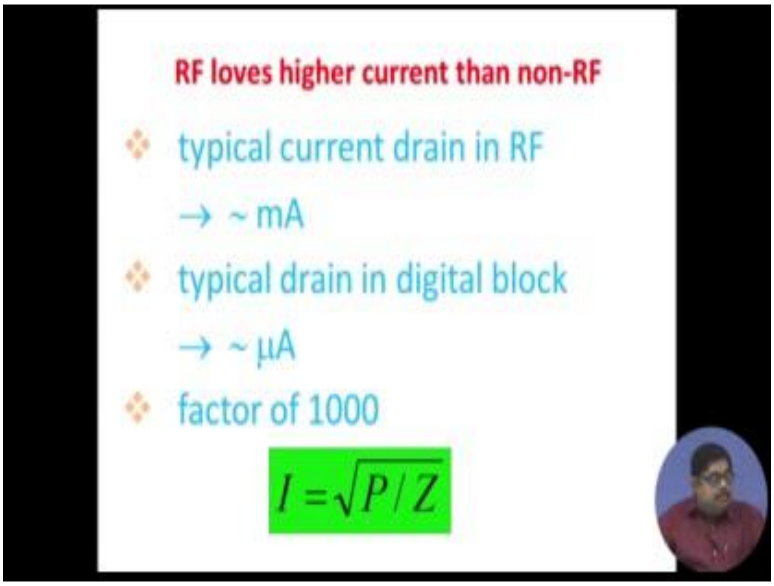

Then also typically the RF has higher current drain, typically of the order of milli ampere whereas, in a typical digital block particularly with semi-conductor technology you have of the order of micro ampere or even smaller. So, current wise RF people they have more power compared to that again due to the same reason that the impedance is small. For RF people, that is why the current for the same power the current will be higher in case of RF designers.

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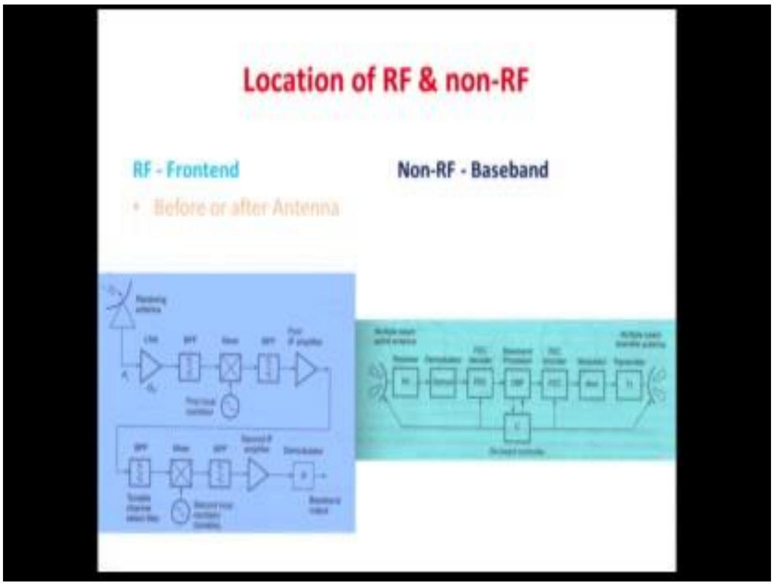

When you see that where the RF things are placed, this shows typically the left side is showing, you see this left side diagram is a satellite system. So, you see that there is an electromagnetic wave coming from the satellite falling on the receiving antenna, then there is some amplifier, etcetera, then there is some band pass filter mixer again a band pass filter fast IF amplifier. So, this is part of your RF that means, these are all at typically gigahertz or several 200, 300 megahertz sort of thing. So, that is why we call it RF frontend.

Generally, before or after the antenna the system those are called RF frontend. So, there you need to apply these principles that will be learning in course some of the principles. So, that you will have to be apply into your design whereas, if you see the right side thing that typically in a non RF system like from this antenna finally, this after this IF amplifier it comes to finally, a demodulator sort of thing. So, after demodulator you have there is a forward error correcting decoder then there is a base band processor then on mode controller forward error correcting controller modulator.

So, all these you have learnt in your other courses. So, these are basically typically a base band processing blocks like demodulators error control coding error decoding base band processing then your various modulation things those are generally the non RF things or analogue or baseband things. So, they are a bit away from the antenna. So, basement wise also there is a clear cut demarcation in the in any system if you look in any radar system in any communication system the RF's, they are at the forefront when they are pumping the power to the free space or outside world and the backend that is generally the RF and non RF things.

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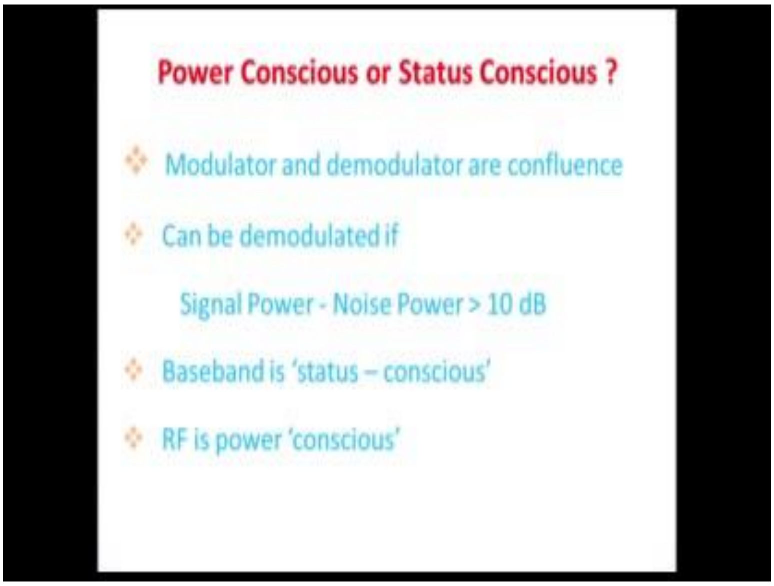

Now, that is why as I am saying that this RF people. They are power conscious whereas, status means the voltage because most of the decisions in the baseband things, they are taken by whether a certain thing is above a particular voltage threshold or below 5 volt or it is more than 5 volt or less than 5 volt more than 2.5 volt TTL logic or not. So, there it is a status conscious thing whether in RF it is how much power, etcetera and generally modulators are the confluence of this base band and the RF blocks. So, this similarly in a receiver demodulator is the confluence of these two blocks and generally base band we call status conscious RF power conscious.

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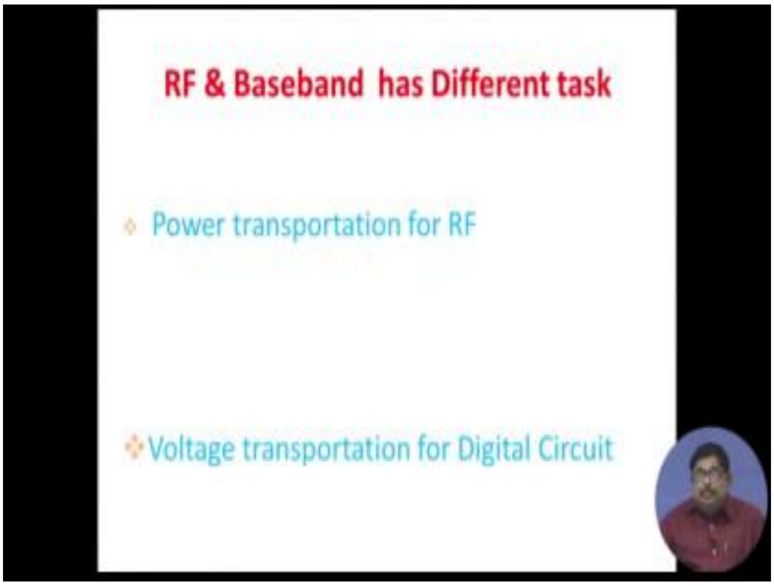

And also they have different tasks by now, I can summarize that power transportation is the basic task for RF whereas; voltage transformation is the basic task for our base band systems.

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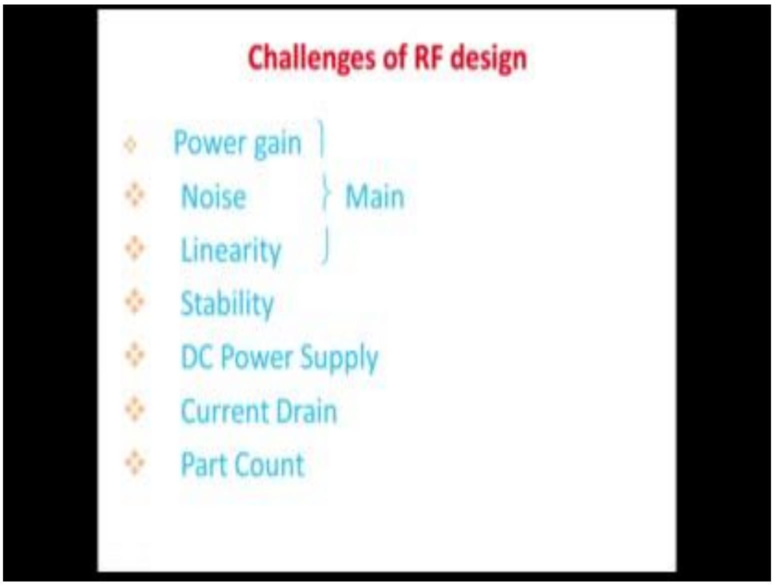

Now, what are the challenges of RF design briefly that we need to consider various parameters you see, one of the parameter is power gain not voltage gain. The next is how much noise because since you are opening up to the outside world, you are also giving or taking lot of outside noises, suppose a lightening takes place, suppose some star is radiating radio star all those your antenna is picking up. So, you are getting noise.

So, you need to find out what is the noise power you are getting that is why we talk of signal to noise ratios etcetera then whether you are maintaining linearity in your devices because if you do not maintain linearity a particular frequency in which you are working you will generate some other frequencies due to that non-linearity which will create trouble for you because we have seen that, if you change the frequency the whole ball game is changed in an RF circuit. So, these are the three very important parameters in RF design.

But there are also when you if you design an active circuit like an amplifier, etcetera. You need to consider stability of that you need to consider that to operate this RF signal. How much DC power supply, you have used you need to find out also what is the current drain you need to find out what is the part count of that?

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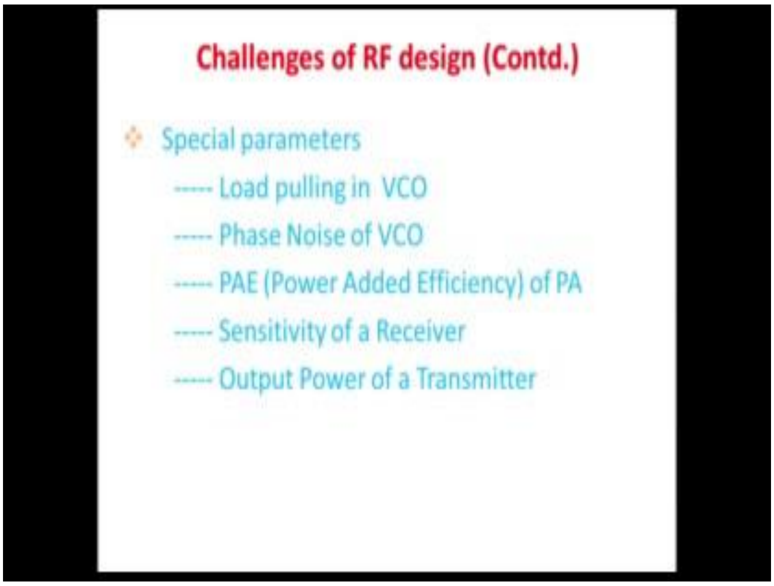

Then there are some special parameters which are not always applicable in RF, but in some critical blocks they are very important like if you have a voltage control oscillator there due to the change of load the frequency of the oscillator changes. So, load pulling in VCO is a very important parameter for oscillators, similarly in the VCO or oscillators there is a phase noise created that is also a very important parameter because if you do not characterize that properly lot of functional disability come for other parts of the network. Then how much is the power added efficiency for a power amplifier power amplifier is before the transmitter is radiating there is a power amplifier its efficiency is very important in communication.

Then sensitivity of a receiver, how small a signal you can sense when you are sensing a radio star sending from millions of kilometre away is signals you need a receiver very sensitive receiver for detect that. So, RF receivers they need to characterize what is the sensitivity of the receiver and obviously, when you are pumping power you are trying to communicate, you are trying to send the signal another transmit their characteristic for a transmitter or parameter for a transmitter is how much output power you are trying to generate. So, with this we come to the basic what are the challenges. So, definitely I think you have understood that there are lot of challenges in the RF design. So, will see some tools in our next lectures by which we can address this type of challenges.

Thank you.