Microwave Theory and Techniques
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Module – 01
Lecture – 01
Microwave Theory and Techniques Introduction – I

Hello everyone. I am Girish Kumar, professor at IIT, Bombay in the Electrical Engineering Department and I am going to conduct this course through NPTEL, the title of the course is Microwave Theory and Techniques. Just to tell little bit about myself, I have been here at IIT, Bombay since 1991 and I have been teaching mainly antennas and microwave circuits course. So, this microwave theory and technique related course; I have been teaching for last 25 years.

So, to help me in this course, there will be 3 teaching assistance. All 3 of them are PhD students at IIT, Bombay and their names are Rinkee, Rajbala and Vinay. They will be taking some of the lectures in this particular course. So, let us start with the formal outline of the course. So, the course outline is we will start with the introduction to a microwaves.

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And what is the history of the microwaves, how it really started and what are the different applications and when we are working on microwave radiation, we should also

know; what are the effects on the human body. So, any system we want to develop, we must also consider; what are the social effects of this particular technology. After that; we are going to talk about microwave transmission modes and we will talk about a waveguides and transmission lines.

So, transmission lines could be strip line or microstrip line, after that we will talk about Smith chart. Smith chart is used for plotting impedance admittance a reflection coefficient and VSWR. So, it is a graphical representation of all these quantities and then we will talk about a very important concept of impedance matching techniques. We all know that for maximum power transfer, the load impedance should be equal to source impedance, but that may not be always the case.

So, this impedance matching network should be lossless so that the maximum power transfer takes place to the load or it could be an antenna. After that we are going to talk about ABCD and S parameters; ABCD parameters are defined in terms of input voltages and currents and output voltages and currents. And S parameters are defined in terms of a weight parameters because at microwave, we are mostly concerned with the electromagnetic waves. So, this will be followed by power dividers. So, we will talk about 2 way, 3 way, 4 way power dividers equal and unequal power dividers and combiners.

Then we will talk about different types of couplers which will be followed by microwave filters. So, in filters, we will talk about low pass filter, high pass filter, band pass filter and band reject filter, then it will be followed by microwave diodes and attenuators. So, we will see; what are the different type of microwave diodes are there and how these diodes can be used for attenuation purpose, RF switches as well as phase shifters.

Now, all these things are required for developing a microwave system. So, this will be followed by microwave transistors and we will see that how these microwave transistors can be used for general purpose amplifier and LNA which stands for low noise amplifier. Now, in this particular course our emphasis will be on the design, design and design. Our prime minister has been saying make in India, but make in India will be only successful if we emphasize on the design.

So, my saying is; at this sentence should come before make in India which is design in India, then make in India. So, after this, it will be followed by power amplifiers which

will be will cover about solid state power amplifiers and followed by microwave tubes such as klystron magnetron and so on. Then we will discuss about microwave oscillators and mixers and this will be followed by different type of antennas. So, we will talk about fundamentals of antennas dipole antenna, monopole antenna, arrays, horn antenna, helical antenna, microstrip reflector, Yagi-Uda.

Now, in this course we will basically talk little bit about antennas if you really want to know more about antennas through NPTEL only, I have recorded 30 hours of lectures on antenna. So, you can see that also to enhance your knowledge about antennas. Now, till now, we have talked about various microwave components and now we will talk about systems also, but first we will cover RF MEMS which is a important emerging technology. Then we will talk about microwave measurements; how measurements can be done and then we will talk about several microwave systems and microwave imaging again that is also emerging as a new technology.

And the course will be concluded with software session as well as lab demonstration since this one has a very wide course coverage. So, no single book covers all these things. So, I would actually recommend several books on microwave circuits separately and antennas separately. So, you can see that for the microwave circuits there are 8 different books, we have mentioned.

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Reference Books on Microwave Circuits

1. D.M. Pozar, Microwave Engineering, John Wiley & Sons, 2012.
2. K.C. Gupta, et. al., CAD of Microwave Circuits, Artech House, 1981.
3. B. Bhat and S.K. Koul, Stripline Like Transmission Structures, John Wiley & Sons, 1989.
4. R.E. Collin, Foundation of Microwave Engineering, McGraw Hill, 2001.
5. S.Y. Liao, Microwave Circuit Analysis and Amplifier Design, Prentice Hall, 1987.
6. I. J. Bahl and P. Bhartia, Microwave Solid State Circuit Design, John Wiley & Sons, 2003
7. G. D. Vendelin, A. M. Pavio, and U. L. Rohde, Microwave Circuit Design using Linear and Nonlinear Techniques, John Wiley & Sons, 2005.
8. Stephen A. Maas, Microwave Mixers, Artech House, 1986

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So, these are you can D. M. Pozar, Microwave Engineering book K. C. Gupta and so on. So, you can look at thing and I strongly recommend that you please try to buy any one of these books and many of these books are also available as a PDF file for free from internet. So, you can download those and read it and for antennas, I have actually given only 3 books which cover basically most of the theoretical and practical concepts of the antennas.

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So, the first book is by Kraus which was actually used in many places undergraduate level, Balanis book is slightly more advanced which covers antenna theory analysis and design and the third book is actually written by me which is Broadband Microstrip Antenna. So, I am going to cover lot of microstrip antenna portion from this particular book. So, now, what is the electromagnetic spectrum; what are we really looking at.

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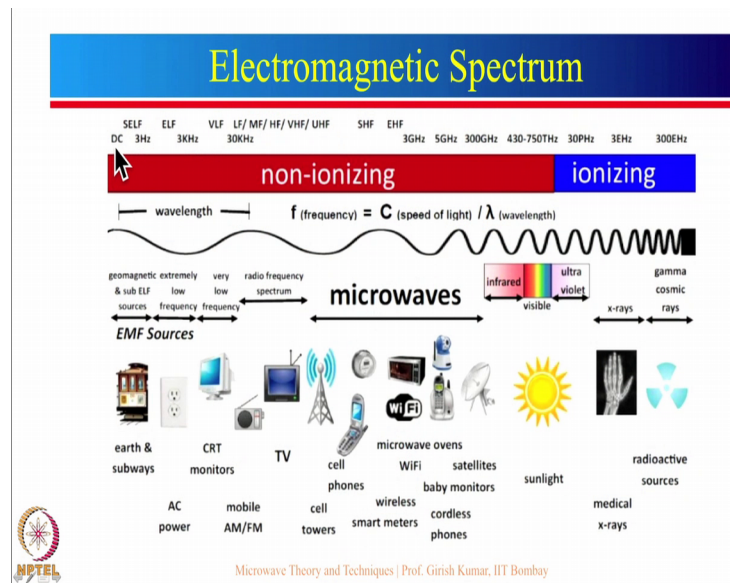
So, the electromagnetic spectrum; as you can see from here, it starts from DC 3 kilohertz all the way, it goes to several tera hertz also ok. So, now, let us just look at the application point of view. So, you can see that extremely low frequency, the sources are basically earth and subways. So, which are really transmitting extremely low frequency, then you are familiar with ac power which is 50 hertz in India and 60 hertz in USA.

Then you might have used CRT monitors and you can say that AM FM radio. So, AM FM radio; AM radio frequency is from 530 to 1620 kilo hertz and then FM radio which is basically from 88 megahertz to 108 megahertz, then we have TV transmission. This is a picture of a mobile phone tower and that is a cell phone. Now, there are several technologies are there in India and abroad which starts from 800 megahertz goes up to about 2.5 gigahertz.

Then you can see here a microwave oven and Wi-Fi just to tell you microwave oven works at 2.45 gigahertz and Wi-Fi works from 2.4 to 2.483 gigahertz. So, these are almost in the similar frequency range and then we have satellites which work at x band or even higher band and then we have all these other sources of electromagnetic radiation. So, electromagnetic radiations are defined in 2 zone; one is known as a nonionizing zone, another one is known as ionizing zone.
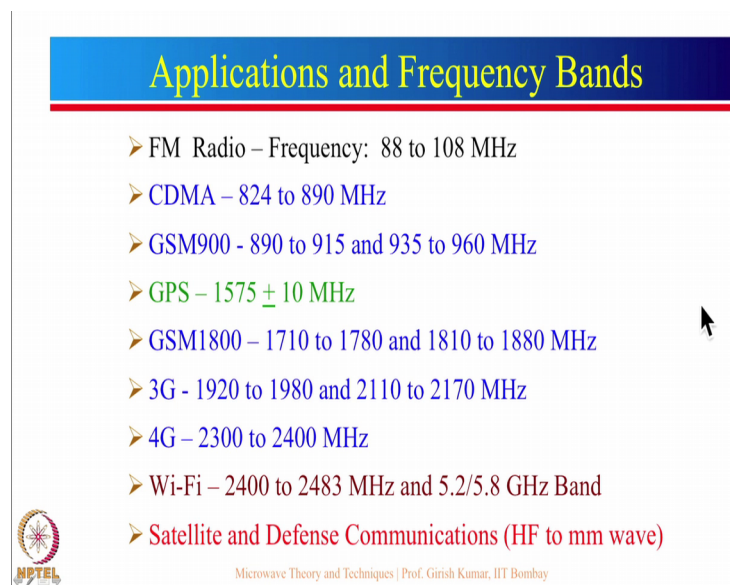
So, x-rays; nuclear rays gamma rays, other thing are in the ionizing radiation form and these are nonionizing, how do we differentiate between the 2 ionizing radiation has more

energy which is given by the formula E equal to Hf where f is frequency. So, higher the frequency, it will have a higher energy. So, it can break the molecular bond and hence, it is known as ionizing. Now microwave frequency in this region, basically has a lower frequency and hence, it has a lower energy.

So, E is equal to Hf; f is smaller; however, energy is not defined only by E equal to Hf energy is also equal to power multiplied by time. So, if power is more less time will be required and if the power is less larger time will be required to do the thing, just think about a heating in a microwave oven. So, when we do the heating in a microwave oven. So, you can see that if the power is high; let us say if you put on a full power a cup of water may boil in about 1 to 2 minutes.

However, if you put on the lower power mode, the water may get heated after several minutes. So, this is what I also want to mention here that; for example, cell phone cell phones transmit about 1 watt of power, but people use it for hours and hours and after almost close to a 5 to 10 years, people start developing various health problem. Similarly, people who live next to the cell tower and especially if in their main beam of the antenna, then they will get affected quickly; So, I am going to talk a lot about this effect of microwave radiation in the next few lectures.

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So, let us see first of all quickly application. So, you all are familiar with fm radio with the frequency band is 88 to 108 megahertz. Now, all these blue colors are various, you

can say a cellular phone bands. So, CDMA works from 824 to 890 GSM 900; 890 to 915 and 935 to 960, actually speaking; one part is used for transmit and another part is used for receive.

So, what is transmit for cellular tower? It becomes received frequency for mobile phone and what is the receive for cellular phone? It becomes transmit for the cell phone. So, these are the GSM 1800 band 3G and 4G. Now in between, we have a GPS band. Now most of the mobile phones have GPS and that works at 1575 megahertz and the bandwidth of that is plus minus 10 megahertz, I did mention about Wi-Fi which is from 2400 to 2483.

But Wi-Fi is also being used at 5.2 to 5.8 gigahertz band and then of course, there are many applications in satellite and defense and they use high frequency to all the wave millimeter wave frequencies also. So, there are a huge amount of applications.

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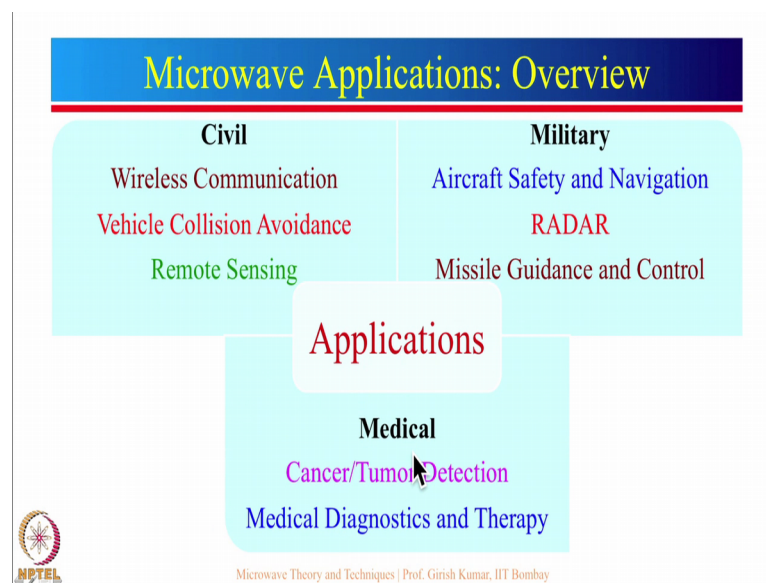
So, let us see; how these applications are divided into civil military as well as medical application. So, in civil application, we have a wireless communication mobile communication is part of this particular thing, here FM radio, AM radio, all the broadcasts are basically one way communication.

Now recently vehicle collision avoidance has also taken a significant step in the present vehicle things. In fact, you might have heard about that many companies have now

started actually developing these driverless cars. So, in that we have a vehicle collision avoidance, of course, remote sensing is again a very very important thing where they actually; it sense the weather or they can actually find out what is the soil current conditions or what are the other conditions for remote sensing.

Now, there are military applications. So, that could be aircraft safety and navigation of course, if aircraft navigation also comes and the civilian application also, there are various types of radar which is which are being used for military application, then missile guidance and control that is all part of microwave system, then of course, now there are applications in the medical domain also. So, microwave can be used for cancer or tumor detection. In fact, a controlled microwave radiation can also be used for cancer treatment also.

So, microwave radiation can cause cancer and microwave radiation can cure cancer also. It all depends upon if it is a controlled radiation, then microwave can be used for proper diagnosis as well as proper treatment, of course, it can also be used for medical diagnostic and therapy and along with that to all these areas microwave imaging is finding applications in all civil military and medical applications.

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So, let us just look at the history of electromagnetic waves first the reason for that is that before we start with the microwave, we must look at what is the history of electromagnetic waves and I would actually recommend that you please see this

particular website which is of course, Wikipedia excellent coverage is given on the history of electromagnetic waves. So, history of electromagnetic waves goes back to 200 years or more and before Maxwell's equations became famous a lot of work had been done by various people for example, Gauss law is there, Ampere's law is there, Faraday's law is there.

But electromagnetic wave equations were basically first proposed by Maxwell in the 1860s and I am sure this thing; you must have studied in the electromagnetic waves the 4 famous Maxwell's equation. So, I just quickly read for you divergence of D is equal to rho divergence of B is equal to 0 curl of E is minus del B divided by del T and curl of H is J plus del D by del T. Now this is of course, the differential form of Maxwell equation there is an integral form of Maxwell equation also.

So, then it was eighteen ninety one when hertz basically validated Maxwell's theory and this is the original apparatus used by hertz for this electromagnetic experiment and you know what is the unit of the frequency it is given by hertz. So, that is why it is a very important thing that the person who really develops all this thing and now he becomes almost immortal. So, whenever we talk about frequency we talk about 50 hertz or 1000 hertz or giga hertz and so on. So, now let us just look at the next part which is history of microwave engineering. So, again here we have divided into different parts.

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So, first we will talk about a radio communication what are the historical events and it was actually Jagadish Chandra Bose who did the first experiment demonstrated in Calcutta, India and that was in 1895. So, he first publicly demonstrated electromagnetic waves and he used that to ring a bell remotely as well as to explode some gunpowder. So, that people can really understand; what are the different applications around that time only Popov from Russia, he also wrote a paper, but it was actually Marconi in 1901 who really demonstrated a long distance thing.

So, first transatlantic radio communication over a distance of 2000 miles from Poldhu, UK to Newfoundland, Saint John's in December 1901. And this is what really speaking set the tone for radio communication you can also see the website for detailed information now transmission line.
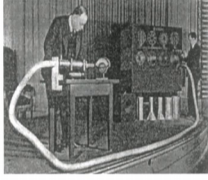
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Let us see; what are the developments took place, it was in 1897 when Lord Rayleigh actually speaking showed that the waves could propagate within a hollow conducting cylinder. Before that of course, coaxial lines were there, but coaxial line has a center conductor and outer conductor, whereas, inside a waveguide there is a low central conductor.

So, it is a hollow conducting cylinder and he first presented the concept of critical or cutoff frequencies in waveguide, you might have studied in electromagnetic waves that the cutoff frequency lambda C is equal to 2 a. However, in later in this course we will

briefly discuss about that part. And then it was in nineteen thirties when systematic development of waveguide theory was actually developed and this was developed parallely by 2 groups Bell labs as well as MIT lab, both are situated in USA and then it was 1950 when the concept of stripline was invented and stripline then later on the next concept was 1952 which was microstrip line.

So, for very long time stripline was stopped, you can say printed circuit version which was being used for lot of applications and development. But later on microstrip lines have been used for developing various microwave circuits and component. So, in this course we will talk more in more detail about these two things, but our main focus will be on microstrip lines.

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Then let us see how all these radars and other transistors were developed. So, it was in 1942, MIT radiation laboratory first demonstrated X-band radar, but; however, that X-band radar did not contain any solid state devices, it was in 1947 when bell labs actually invented the first transistor and it was in 1954 when bell labs actually develop the working silicon transistor.

And then later on microwave gallium arsenide MESFETs were developed in 1965 and in 1970, the first solid state radar was demonstrated at X-band. So, this is the general historical perspective how the microwave really started; but now let us look at the one basic block diagram which is used for microwave communication system.

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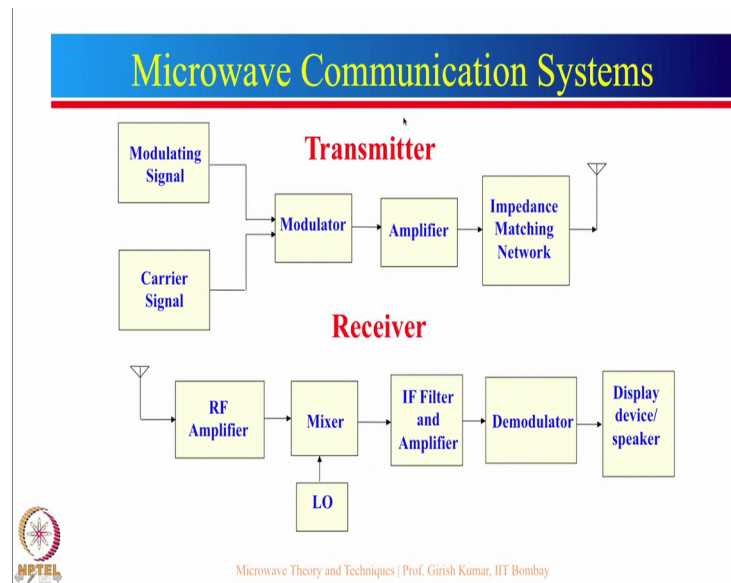
So, here is a block diagram for transmitter and this is the block diagram for receiver. So, let us see one by one; what these block diagrams are all about. So, this is the modulating signal. In fact, in some books they use that intelligent signal or you can say information signal. So, it is the information which you want to send to a faraway distant and that can be a voice signal, it can beat at a signal or video or audio signal and then this is the carrier signal carrier signal is basically, you can say in a different way that this carrier will carry this particular signal and that is how most of the time we define.

Let us say FM radio; the carrier frequency is between 88 to 108 megahertz or we can say that a mobile phone 900 megahertz. So, that becomes the carrier frequency or for a Wi-Fi 2.45 gigahertz becomes a carrier frequency, then these 2 signals are modulated. Now, there are several modulation schemes are there, for example, analog modulation and digital modulation and the all of this thing that modulated signal has to be amplified and basically the here, we will have a high power amplifier and that is connected to the antenna.

Now, many books do not include this impedance matching network, but I think it is a very very important thing between antennas and amplifier just to give you a little bit of an idea majority of their time antennas are designed for let us say 50 ohm impedance, but the amplifier output impedance may not be 50 ohm, this impedance can be very small or it can be very high depending upon the application, for example, if this amplifier is let us

say op amp amplifier or a simple low frequency transistor amplifier then the output impedance required here may be several hundreds of ohms to kilo ohm that cannot be connected with 50 ohm.

Just think about if this is 50 ohm and if this is 1 kilo ohm and this part is not there. So, what will be the voltage at this point? It will be 50 divided by 50 plus 1000. So, voltage here will be very small power delivered to the load also will be very small. Now for high power solid said amplifier, the output impedance may be of the order of few homes, it can be even 2 or 3 ohm. So, if you connect 2 ohm with the 50 ohm, again, 50 divided by you can say that 50 divided by 52, it will still give this one here.

But the problem with this is that the current going through here will be very small. So, the net power will not be very good and also the maximum power transfer theorem says that output impedance is 2 ohm, finally, what I should have here input impedance at this point should be 2 ohm. So, this 50 ohm has to be converted to either 2 ohm or kilo ohm depending upon the application. So, what we really need is a lossless impedance matching network. So, in this particular course we will actually talk about several techniques of impedance matching network and of course, the importance is that this technique has to be lossless impedance matching network.

Now, the signal which is being transmitted from this antenna through various medium it will come over here and this is where the power is received. Now, that received power goes through RF amplifier and this is the place here where we actually have to have a low noise amplifier because this signal is very weak and along with the travel from here to here it has picked up lot of noise. So, we do not want to add more noise by this amplifier.

Now, before this RF amplifier, many a times, we also put a band pass filter here. So, that it selects only the frequencies which are required now of course, sometimes antenna itself acts as a band pass filter. So, that is why it is not always hundred percent required you need to put a band pass filter, but most of the time you do require a band pass filter. So, that you really get only the desired signal.

So, then this signal actually speaking comes here. In fact, this RF amplifier consists of multiple stages, it has a low noise amplifier followed by the small signal amplifier and. So, on because this signal could be very weak, for example, for FM radio the signal input

may be of the order of a microwatt, but for mobile phone this signal could be as small as Pico watt also. So, the signal is very small here most of the time. In fact, for GPS it can be even a fraction of Pico watt and even the TV transmission signal which we receive through the satellite also may have a very low power at this particular input.

So, that is why we need to have an amplifier which may be amplifying the signal by forty to even 80 dB also which really comes out to be 10,000 to even million times signal to be amplified and then this signal goes to a mixer. Now this is a one block diagram of a heterodyned receiver not all the receivers use this particular concept, but nevertheless this is one of the most popular concept. So, this is a heterodyned receiver. So, where this signal which has been amplified comes to a mixer and there is a local oscillator. So, that local oscillator and the RF amplifier to frequencies mix up.

And the mixer has a property that it actually generates sum and difference of these 2 frequencies, now of course, in majority of their receivers it is only the difference of these 2 frequencies which is considered. In fact, many a times in the transmitter mixer may be used for up conversion also where the 2 frequencies may be added and get the sum of the 2 input frequencies, but over here majority of that time it is the difference of the 2 which is known as if intermediate frequency.

So, again what we need now if filter and then amplifier this whole thing goes to the demodulator this demodulator is opposite of modulator. So, if it has done analog modulation it should do analog demodulation, if it is digital modulation it should do the digital demodulation and that goes to the display device speaker. So, this is what a complete microwave communication system chain is there. So, in this particular course, we will talk about almost all the things except for the modulation and demodulation techniques which is generally covered in different courses.

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So, let us just look at what are the various components the various microwave components have been divided into two parts passive and active microwave component. So, in the passive we have a transmission line antennas power divider combiners couplers filters attenuator. Now, in active microwave components we have amplifiers oscillators mixers switches phase shifters and so on and then we have several microwave systems.

So, this is not the complete list of the microwave system, but just to tell you; you all are familiar with mobile phone. Now, mobile phone jammers are required where we do not want the nuisance of mobile phone, where signal is very weak we need repeaters or signal enhancer RFID stands for RF identification. In fact, you can see that these days there are lots of applications for RFID, then RF transceiver RF transceivers are nothing, but transmitter and receivers are now built into a single IC. So, that design becomes very very simple and convenient.

Even GPS and GSM modules are available separately as well as a single module is there which has both GPS and GSM of course, there are varieties of radars are there and now since there is a. So, much RF energy available in the atmosphere for example, there are cellular towers almost everywhere their Wi-Fi modems are there, there are TV transmitters are there fm transmitter. So, this is also becoming a very important topic today which is the RF energy harvesting.

So, you can harvest this RF energy which is available in the environment and that can be used to charge a battery or it can even use a low power electronic circuits then we will talk about microwave equipment which are very very important for testing or developing any microwave system. So, there are 3 main equipments are there these are microwave generator spectrum analyzer and network analyzer and then we will also talk about high power microwave systems and what are their applications.

So, just to conclude that we started with the course outline; so, we did mentioned about what are we going to cover in this particular course and we also looked into history of electromagnetic waves as well as history of microwave. So, how the microwaves really started and how the radio communication was established when the transmission lines were developed and when these transistors and radars were developed. So, we will conclude today's lecture at this particular point and then now onwards, we will start covering these components in detail and then we will talk about microwave system.

Thank you very much and we will see you next time.