**Microwave Theory and Techniques**
**Prof. Girish Kumar**
**Electrical Engineering Department**
**Indian Institute of Technology, Bombay**

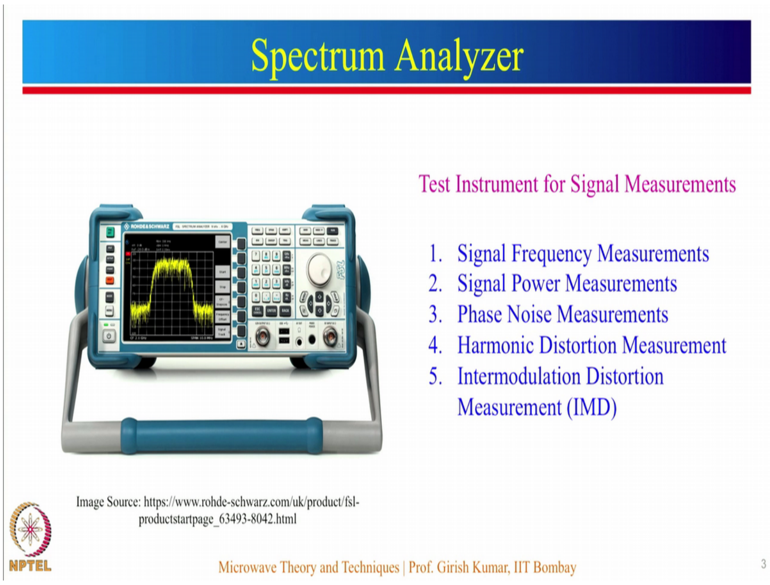
**Module - 11**
**Lecture - 53**
**Microwave Systems**

Hello. So, far in the course we have studied various Microwave Devices and Circuits, be it passive circuits like power dividers, couplers, filters or active circuits like; oscillators, amplifiers, mixers and so on. In this lecture, we are going to study how these different passive and active circuits are integrated with each other depending on a particular application to form an entire Microwave System. Let us begin.

(Refer Slide Time: 00:49)


So, we are going to discuss 4 different Microwave Systems. The first one is spectrum analyzer, the second is network analyzer, the third is mobile phone jammer or silencer and the fourth one is ground penetrating radar which is GPR.

(Refer Slide Time: 01:09)

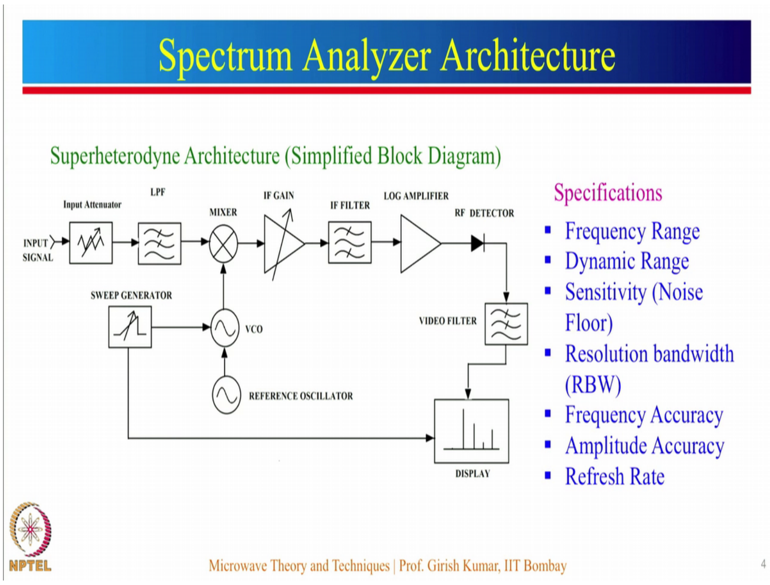



Let us start with the first one spectrum analyzer. Spectrum analyzer is a test instrument used for signal measurements, such as signal frequency measurements, power measurements, phase noise measurements; it is also used to measure different distortions such as harmonic distortions and inter modulation distortions or IMD. The spectrum analyzer typically looks like this.

So, you have a display embedded into the instrument and you have various controls to enter and analyze various parameters. The spectrum analyzer basically functions as follows. So, the spectrum analyzer has to display various frequency components present in the input signal which is given over here, along with their power levels which is displayed on the Y axis.

For the spectrum analyzer X axis consists of frequency whereas, the Y axis displays the power levels typically in DBM. Let us have a look inside of the spectrum analyzer.

(Refer Slide Time: 02:15)




So, there are various architectures available to implement spectrum analyzers. And, super heterodyne architecture is the most widely used architecture, this is the simplified block diagram. So, we know about the super heterodyne, down conversion principal. The input signal is down converted to an IF using a mixer and local oscillator input. The local oscillator is implemented using a VCO and a reference oscillator. The VCO is govern using a sweep generator, which mean that the local oscillator frequency sweeps from a lower value to a higher value in the operation.

The, IF signal which is available at the mixer output is processed using an IF amplifier and an IF filter. And, the power level of this IF signal, which corresponds to the input signal frequency components power level is detected using an RF detector and log amplifier. The signal is further processed using a video filter and given to the Y axis of the display. The X axis of the display which corresponds to the frequency is govern by the sweep generator output.

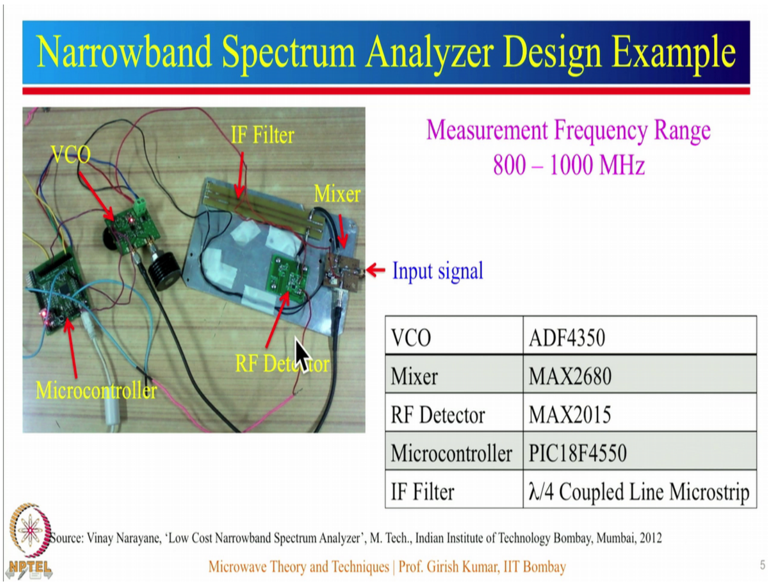
So, the sweep generator generates a sawtooth voltage waveforms, which sweep the yellow frequency at the input of the mixtures from a lower value to a higher value. And, from that range various frequency components correspondingly in the input signal are displayed on to the display.

The, input attenuator is important to prevent the damage of rest of the circuit components from a very high level input signal. This is typically implemented using a variable attenuator technique, which we have discussed in the course. These are some important specifications of a spectrum analyzer; we have frequency range, which is nothing, but the range of analysis through which the spectrum analyzer can work. Dynamic range is defined as the difference between the highest signal that can be displayed on to the spectrum analyzer display. And, the minimum signal that can be detected and displayed on to the spectrum analyzer display.

Sensitivity is the minimum detectable signal and is governed by the noise floor of the spectrum analyzer, which arises due to noise in the various components of a spectrum analyzer. Resolution bandwidth of a spectrum analyzer which is abbreviated as RBW, it tells the ability of the spectrum analyzer to differentiate between 2 closely spaced frequency components in the signal. And, there are accuracy specifications we have frequency accuracy and amplitude accuracy, which measure the accuracy of the entire system. Refresh rate is governed by the frequency of the sawtooth voltage waveform, which is generated by the sweep generator.

.

(Refer Slide Time: 05:28)

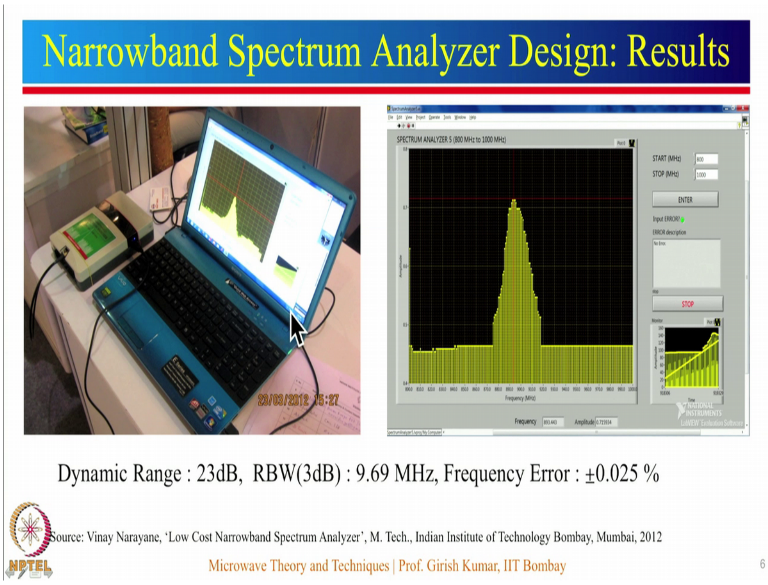



Let us have a look at a practical spectrum analyzer system which was implemented at IIT Bombay. So, this is a narrow band spectrum analyzer, which works from the frequency range of 800 to 1000 megahertz this is a system. So, the system consists of a microcontroller section the microcontroller used is PIC18F4550. The microcontroller section generates a voltage sawtooth waveform, which governs the VCO, the VCO or the PLL or the frequency synthesizer is implemented using ADF4350IC.

The VCO output is given at the yellow input of the mixer the mixture is implemented using a MAX2680 IC from maximum semiconductors. The input signal is down converted using this mixer and the yellow signal to an IF. We have an IF filter implemented using a coupled line microstrip filter. This IF amplitude or IF power level is detected using an RF detector, which is implemented using MAX2015IC. So, you can see all the different components in the circuit are designed based on the requirement using several market available ICs and micro strip techniques which we have studied in this course.

The RF detector output which is the voltage output is given back to the microcontroller unit. The microcontroller sends the sawtooth waveform information and the detected signal level to a PC or to a software which is running on a PC, where it is displayed along the X axis and Y axis. The frequency is displayed on the X axis and amplitude level is displayed on the Y axis. So, this system does not have it is own display, it uses the display of any available PC, which is personal computer and it requires a software to run on that computer.

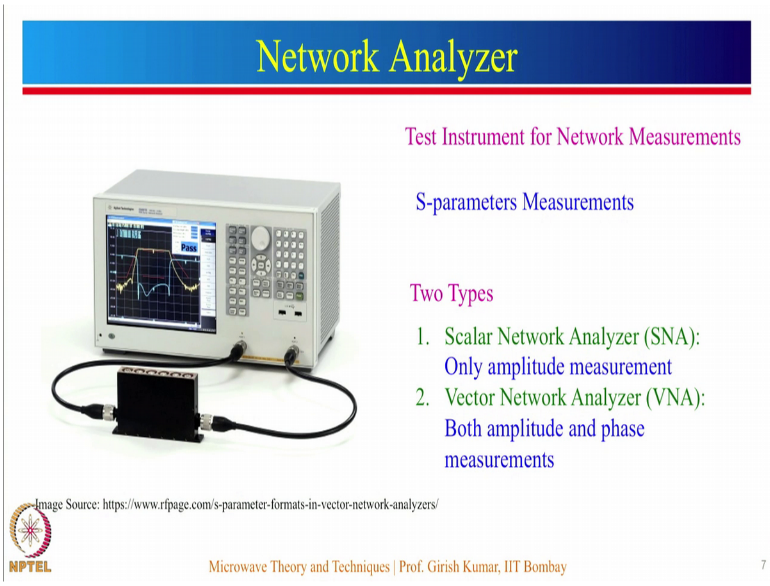
(Refer Slide Time: 07:34)




So, these are the results of this narrow band spectrum analyzer, as you can see we have used a laptop a software running on this laptop enables the display. So, the entire circuit is packed into a small box this is your spectrum analyzer, it gets powered by the USB of the computer. So, it is very compact and portable the output is given again through USB to the software running on this PC. The software backend processes the data and displays on to a GUI the GUI looks like this. So, you have different options to enter the start and end frequency; yeah some error console and you have a monitor as well.

And, this is the main graph where you have frequency on the X axis and power level on the Y axis. We also have marker functionality. So, the marker values are displayed over here. So, the as a result the dynamic range of the system comes to be around 23 dB, the resolution bandwidth is 9.69 megahertz, which is equal to the; if filter bandwidth. And, frequency error is quite low which is plus minus 0.025 percent. And, a very accurate system has been developed at least in the frequency domain to have a functional spectrum analyzer. Moving next we have a network analyzer system.

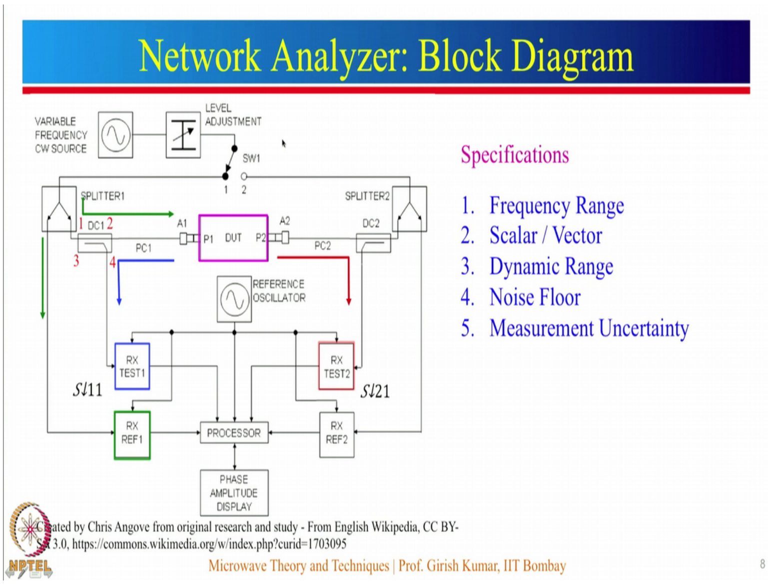
(Refer Slide Time: 09:05)




So, this is a test instrument used for network measurements, which are nothing, but S parameter measurements. There are 2 types of network analyzers; one is a scalar network analyzer which is SNA. Another one is a vector network analyzer which is VNA. SNA is capable of displaying only the magnitudes of the S parameters. So, only amplitude measurements are done in SNA whereas, VNA is capable of displaying both magnitude as well as phase information of the S parameters, which are being measured a typical network analyzer looks like this.

So, you have an embedded display, your various controls to enter and analyze different parameters. There are 2 ports, which can act as in an out ports and the DUT, which is device under test whose S parameters are to be measured is connected in between these 2 ports.

(Refer Slide Time: 10:09)



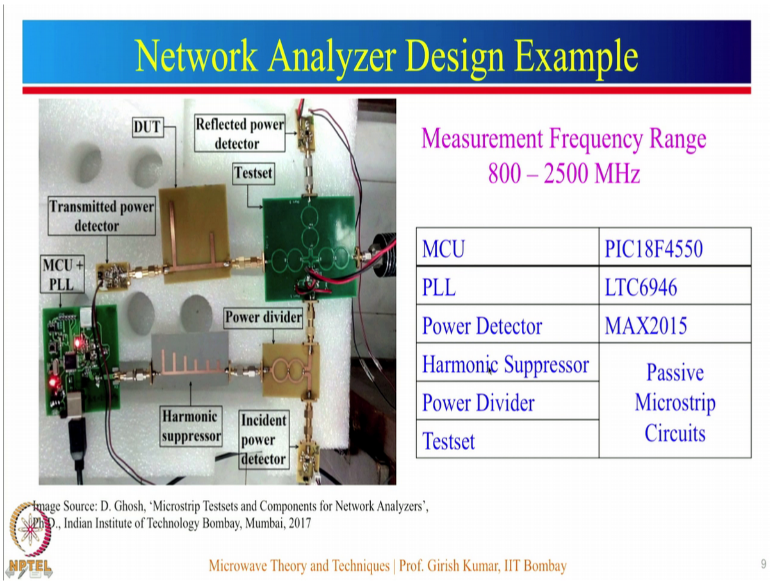

We will see what is inside a network analyzer next. So, this is very simplified architecture of a network analyzer, you have a variable frequency continuous wave source, which is given to the input of 2 power dividers or splitters through a level adjustment which is nothing, but a variable attenuator. Through a switch this power dividers one end is connected to what you see here is a power detector, again power detector. The other half of the power is given to a directional coupler, we have direction coupler here as well and in between these 2 sets the DUT, there are 2 more power detectors which are test 1 and test 2. We will discuss the operation of this network analyzer in a while.

So, as you can see there are various blocks which are VCO power divider, coupler, which we have studied in this course in detail. So, let us see the operation the signal that has been generated by the variable, frequency, continuous, wave source. Is split into 2 halves the 1 half that goes into this power detector actually corresponds to the incident power level. The second half that goes through the directional coupler to the DUT some part of that signal is transmitted by the DUT, and is measured using the test 2 power detector. So, the measurement of this power detector corresponds to transmitted power level.

Some of the signal might get reflect back depending on the characteristic of this DUT. So, the reflected signal through the coupler is incident on this power detector and the measurement of this power detector corresponds to the reflected power level. Now, the ratio of reflected power level and the incident power level enables the calculation of S11. Whereas the ratio of transmitted power level and incident power level enable the calculations of S 2 1, and these calculations are performed in the processor. And, these calculated values are given to the display unit, where on the Y axis this S parameter magnitudes or phases are displayed and on the X axis the frequency which is generated by the continuous wave source is displayed.

So, this is how a very simplified model of network analyzer works and these are some important specifications for a network analyzer system. So, first is the frequency range which specifies the range of frequency values, which can be displayed on to the network analyzer display. Second is the type of the network analyzer weather it is a SNA or a VNA. Third is the dynamic range, in this case the dynamic range is defined as the difference between the output power levels for open or short load which is close to 0 dB. And, that of a matched load, which is typically 50 ohm. Fourth one is the noise floor, which arises due to various components inside the network analyzer. And, fifth one is measurement uncertainty which is nothing, but errors in the measurements.

(Refer Slide Time: 13:48)

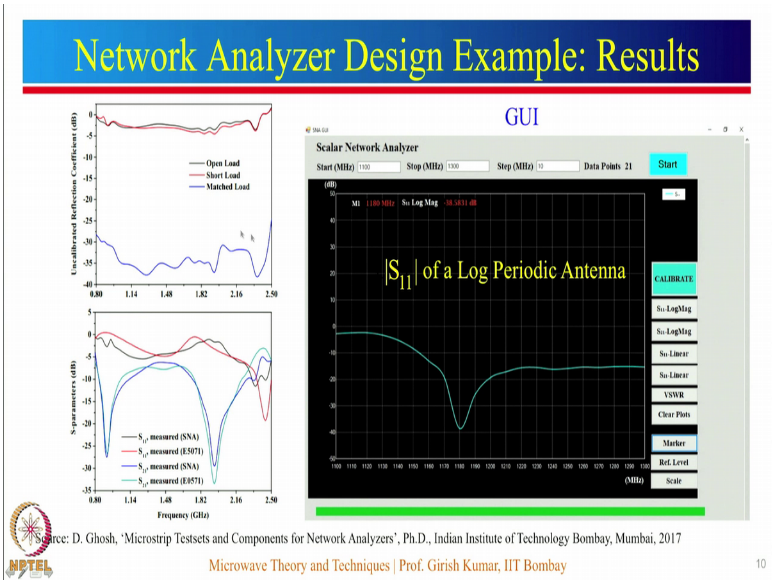



Let us have a look at a practical implementation of a network analyzer, scalar network analyzer in particular develop at IIT Bombay. The measurement frequency range is from 800 to 2500 megahertz, the system consists of an MCU which is microcontroller unit and PLL on a single board. The MCU is implemented using a PIC18F4 double 50 microcontroller. The PLL or the frequency synthesizer is implemented using LTC6946 IC from linear technology. The output of this PLL is given to the harmonic suppressor to suppress out various harmonics present in the PLL output.

And, we wish to process only the fundamental frequency. This fundamental frequency component is then divided into 2 parts, we can see incident power detector over here. And, the rest of the part is given to the DUT, through test set some of the power gets transmitted by the DUT, which is measured using transmitted power detector. And, the reflected power is separated from the incident signal using this test set and is measured at this particular point using reflected power detector.

So, these are various system components and you can see the power detectors are implemented using MAX2015 ICS, the harmonic suppressor power divider and test set are implemented using passive micro strip techniques.

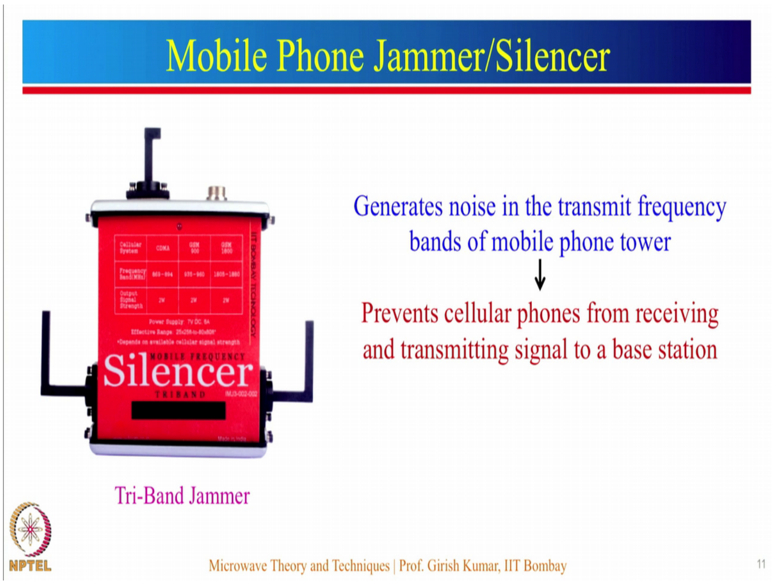
(Refer Slide Time: 15:31)




Let us have a look at the results of this system. So, on the left top you see the results for open shot and match, which is 50 ohm load and you can see that the for open and short the results are closed to 0 dB which is the ideal case. And for load case the results are well below minus 30 dB which is also good. So, the dynamic range that is achieved is around 30 dB and these are un calibrated results. If you connect the DUT which is dual band stop filter in this case and in this graph the SNA results are compared with a standard VNA, which is E 5071. And, you can see that the results of SNA are in close agreement with the actual major results using a market available VNA.

Of course, a calibration is required to make these results more accurate and on the right side you see that the GUI of the system, which is a result of a software running on any computer. So, the GUI consists of start stop step input for frequency and you have various options available here calibration display options and so on. You also have marker functionality. What you see currently on the graph is S11 of log periodic antenna. And this is of course, magnitude this being a scalar network analyzer; it will display only the magnitude part of the S parameters.

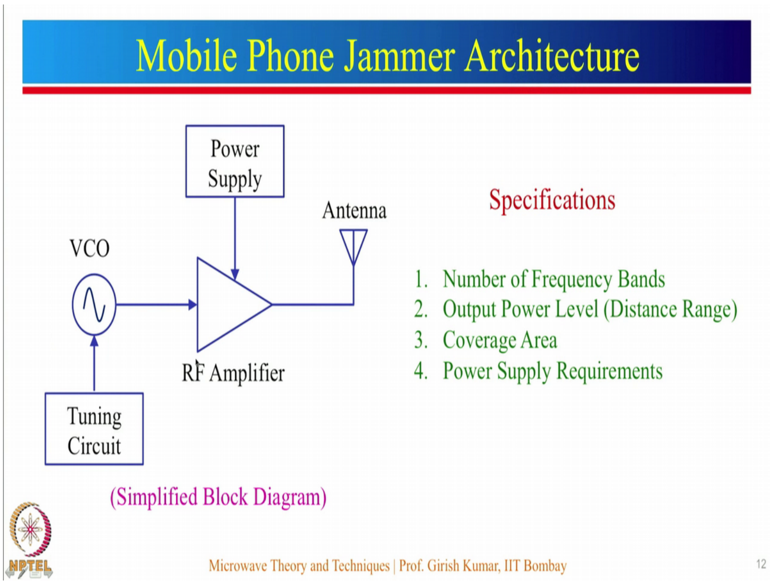
(Refer Slide Time: 17:11)




Next is a mobile phone jammer or silencer system. A mobile phone jammer generates noise in the transmit bands of a mobile phone tower which is nothing, but the downlink frequency bands, which prevents cellular phones from receiving and transferring signals to the base station.

So, the downlink frequency bands are jammed using this jammer which prevent the mobile phones from sending and receiving any data or voice. So, this is a typical image of a tri band jammer what you see protruding from this rectangle are the antennas, which are for 3 different bands which is CDMA GSM 900 and GSM1800. Let us have a look at the architecture of a mobile phone jammer.

(Refer Slide Time: 17:59)



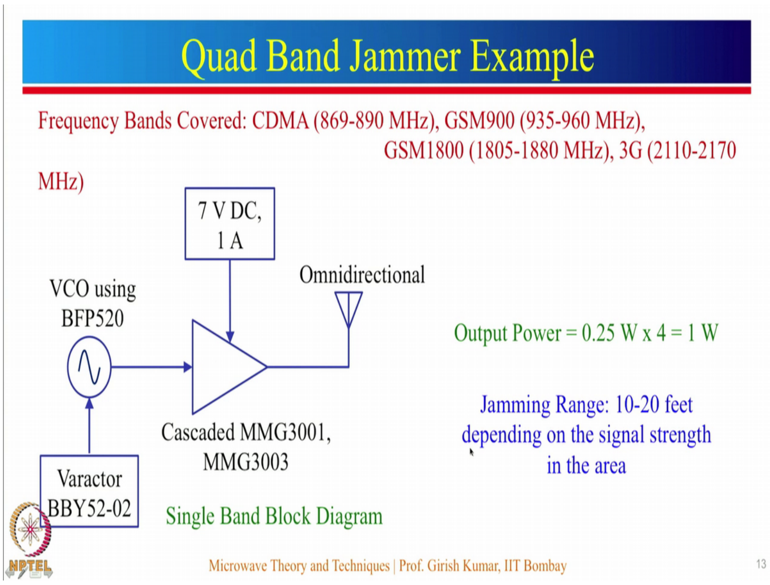

This is a very simplified architecture, but it explains the functionality of the jammer remember the objective of the jammer is to jam the signal that is received from the base station to the cell phone.

So, all the system needs to do is to create a noise signal and translate it in the same frequency band as used by the downlink band of the base station. So, the system consists of a VCO, which is voltage controlled oscillator. We generate the frequency of the desired frequency band. This VCO is controlled using a tuning circuit the output of the VCO is amplified by using an RF amplifier. So, that we have enough power transmitted by the antenna and entire system is powered using a power supply.

The specifications are number of frequency bands that can be jammed by a mobile phone jammer. The, output power level which specifies the distance range that can be covered by the jammer, coverage area which has the directional properties and specific to the antenna that is being used inside the jammer.

And we have power supply requirements. So, depending on the output power level and hence the distance range to be covered the power supply requirements will change.

(Refer Slide Time: 19:23)



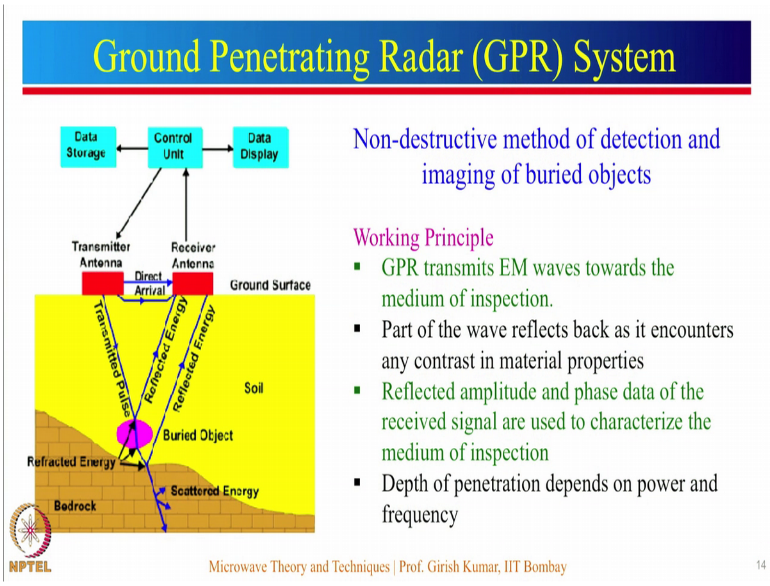

Let us have a look at a practical implemented system of mobile phone jammer, which is quad band jammer. This system can jam 4 bands, which is CDMA 869 to 890 Mega Hertz GSM900 which is 935 to 960 megahertz, GSM1800 which is 18O5 to 1880 Mega Hertz and 3G which is 2110 to 2170 megahertz. As you can observe, all these bands are downlink frequency bands and not uplink, this is an important factor to be remembered the system that is implemented looks like this.

So, the VCO is implemented using BFP520 transistors from Infineon technologies. We have studied the VCO implementation using BFP 520 in the oscillator class. This VCO is controlled using Varactor BBY52 to 02. The VCO output is given to the cascaded arrangement of amplifiers and these amplifiers are implemented using MMG3001 and, MMG3003. The power requirement which is quarter watt or 0.25 watt in this case for single band cannot be achieved using a single stage of the amplifier, and hence the cascaded arrangement.

The power at the output of the amplifier is transmitted in a using an omnidirectional antenna. And, entire system requires a voltage of 7 volt DC and maximum current that can be drawn from the source is one ampere. So, this system is only for a single band and for 4 bands, 4 such separate systems have to be implemented. As, a result the output power of this system is 0.25 watt per band, there are 4 such bands. So, one watt of power is actually outputted or transmitted in air, and the jamming range of this particular jammer is in 10 to 20 feet range depending on the signal strength in that area.

So, this is how a jammer can be implemented using the circuits that we have already study in the class. So, we have studied the VCO circuits, we have studied the MMG 001 circuit in the class, and simply you have to connect all the systems along with the antenna that we have also studied, and connected together properly to achieve the functionality of a jammer. Lastly, we will move to the ground penetrating radar or GPR system.

(Refer Slide Time: 22:03)

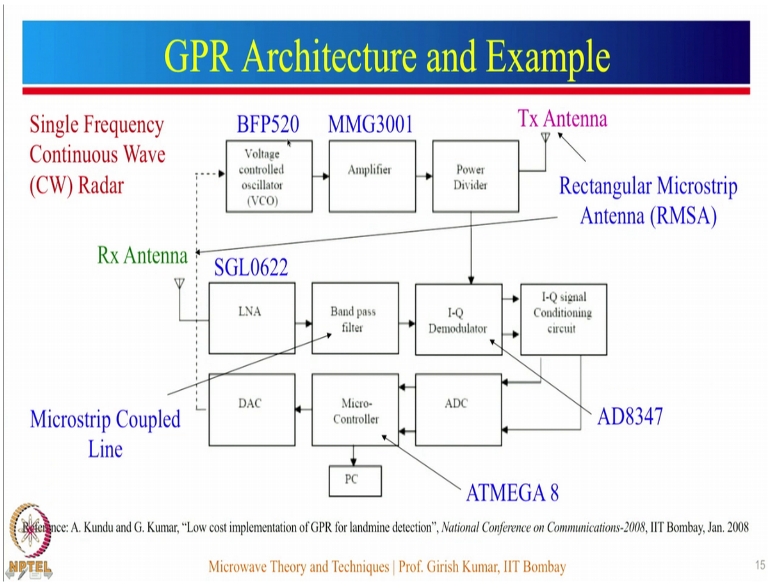



So, this is a non-destructive method of detection and imaging of buried objects. The system looks like this I will explain the working principle using this image.

So, there are 2 antennas; one is a transmitter antenna, second one is a receiver antenna. Both, these antennas are placed on the ground surface and the objects are actually buried inside the soil. Now, the transmitter antenna transmits a signal at a particular frequency at a particular power level. This signal penetrating the ground reaches the buried objects and because of this object, which has different dielectric properties compare to the soil. Some of the signal gets reflected back and that signal is received using the receiver antenna, this received signal is processed using a processing unit and finally, displayed on to the display.

So, the processing involves finding out the depth of this object primarily. The depth of penetration depends on the power level of the transmitter antenna, and the frequency of operation which is used by the transmitter and receiver antenna.

(Refer Slide Time: 23:19)




Let us have a look at a practical implementation system or an architecture of GPR, this is a continuous wave single frequency radar. In the transmit change you can see there is a VCO, which is voltage controlled oscillator followed by an amplifier a power divider and finally, the signal is given to the transmitting antenna.

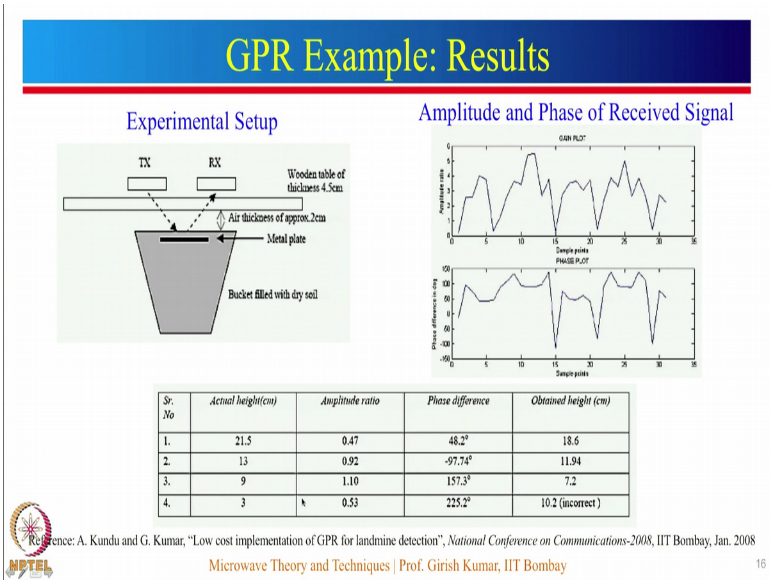
The signal that gets reflected from the object buried inside the soil is received by the receiving antenna, the signal is amplified using a LNA, then band pass filter then given to an I-Q Demodulator, which gives the phase and amplitude of the received signal. And, this phase and amplitude signal is further processed using a microcontroller unit after digitization, and then given to a software running on a PC for further processing and display. So, such a system has been implemented at IIT Bombay and these are the various practical ICS and circuits that were be used.

In transmit part the VCO is implemented using a BFP 520 transistor we have seen this circuit already. The amplifier is implemented using an MMG3001IC, the transmitting antenna is of rectangular micro strip type which is RMSA. So, is the receiving antenna again an RMSA, the received signal is amplified using an LNA, the LNA is implemented by SGL 0622 I C the band pass filter is implemented using microstrip coupled line. The

I-Q Demodulator which is the key part in the system is developed using ad 83 47IC and the controller has a inbuilt ADC, which is at mega 8.

The signal that has been received by the I-Q demodulator through the controller is given to software running on a PC for further processing and display.

(Refer Slide Time: 25:22)




Let us have a look at the results of this GPR system. So, this is a experimental setup. So, transmit and receive antennas are there, below that a wooden table is kept with the thickness of 4.5 centimeter. And below that after the air gap of around 2 centimeters there is a bucket filled with soil and inside that soil a metal object or metal plate is buried. Now, the transmitter antenna transmits the signal the signal travels through the wooden block air soil and reaches the metal plate where it gets reflected back.

And the reflected signal is received by the receiving antenna. The amplitude and phase information of the signal received by the receiving antenna is shown over here. So, this is the amplitude information and this is phase information and based on this information after further processing we can estimate the depth of this metal plate from the system. So, as you can see there are different depths at which this metal plate was kept. So, at 21.5 centimeter 13 9 and 3 and these are the amplitude ratio and phase differences of the received signals.

And, the estimated or calculated height or depth of the metal plate in each case is like this. So, for actual depth of 21.5 centimeter the estimated or calculated depth was 18.6 centimeter for 13 it is 11.9 4 for 9 it is 7.2.

However for 3 cm depth the estimated or calculated depth was 10.2, which was incorrect. So, for the calibration is required to make the results more accurate and the system performance can be further improved after calibration and finally, design the different circuit components.

So, just to review we have discussed 4 different an important microwave systems in this lecture be focused on spectrum analyzer system, which is widely used for signal measurements, then we focused on network analyzer system, which is again widely used for S parameter measurements. Then, we focused on a mobile phone jammer system, then we studied GPR, which ground penetrating radar system. And, in all the 4 systems we saw that all the building blocks are the blocks that we have studied in this course, we have studied how to design this blocks from scratch, using ICS or using components and you can build an entire microwave system, depending on the specifications using the material that has been taught in this course I hope this was beneficial to you.

Thank you.