

Microwave Theory and Techniques
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Module – 11
Lecture No - 52
RF MEMS and Microwave Imaging

Hello, in this lecture, we will talk about RF MEMS and Microwave Imaging. So, let us start the lecture with RF MEMS. MEMS stands for Micro Electro Mechanical Systems; MEMS are the tiny devices nearly invisible to human eyes. They are also known as micro machines or micro systems.

The MEMS element ranges in size from 1 to 100 micrometers. MEMS devices are categorized into 2 categories; sensors and actuators. Sensor, sense the data from the surrounding environment and converts it into electrical signals. Then actuator, process this data using the electrical signals and perform the action. So, it creates a force to manipulate itself or other devices or perform an action on the surrounding environment to do the useful task.

MEMS devices are fabricated using basic fabrication techniques and then multiple layers are deposited on the base, then the selective areas are etched out to form the 3 dimensional structure. Now, the recent development of communication devices has led towards the miniaturization of devices which is possible with the help of MEMS technology.

Therefore, RF MEMS is one of the emerging area in MEMS devices. In MEMS functional components are controlled by various method of actuations, they could be electrostatic forces, piezoelectric forces, electromagnetic forces, electro thermal forces. Now, the RF MEMS based components can be of various types. It could be variable capacitors, inductors, switches, phase shifters, filters, high quality resonators, antennas, microwave transmission lines.

Now these RF MEMS devices provides the components with reduced size and weight they provide very low losses, with low power consumption over a wide bandwidth.

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RF MEMS

- MEMS stands for micro electromechanical system. MEMS elements ranges in size from 1-100 μm .
- MEMS functional components are controlled under various methods of actuation (e.g. electrostatic, piezoelectric, electromagnetic, electrothermal)
- RF MEMS is one of emerging area of MEMS devices.

RF MEMS Components:

- Variable capacitors
- Inductors
- Switches
- Phase shifters
- Filters
- High Q Resonators
- Antennas
- Micromachined transmission lines

- RF MEMS provides components with reduced size and weight, very low loss, low power consumption, wide bandwidth, higher linearity, lower phase noise, better phase stability and high isolation.



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They provide high linearity with low phase noise and better phase stability with very high isolation.

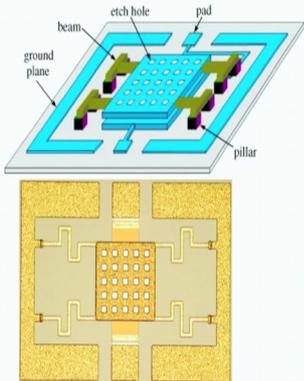
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RF MEMS Capacitors

- Most important characteristics of lumped capacitors are the tuning range and the quality factor (Q factor), which both should be as large as possible. RF MEMS capacitor is the solution.
- Tunable RF MEMS capacitors using
 - Electrostatic actuator
 - Electro-thermal actuator
 - Piezoelectric actuator

Application Areas

- VCO- “Voltage controlled oscillator”
- Tunable filters
- Tunable networks
- Impedance matching
- Phase shifters



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Now, I would like to talk about the various microwave components, which are made using the RF MEMS technology. So, the first component is the RF MEMS capacitor. For most of the wide band applications performance is given by the electrical parameters of capacitors, which is wide tuning range and (Refer Time: 03:18) phase noise and wide bandwidth. In case of capacitors, that is of semiconductor type, they do not provide the

white tuning range at higher frequencies. Additionally they provide the high insertion loss.

The RF MEMS type of capacitor provides a prominent solution and they provide the white tuning range at higher frequencies with relatively low losses. These capacitors are of parallel plate capacitor type, here the bottom plate is the fixed plate and the top plate is suspended at an air gap.

This top plate is suspended using the T shaped beams, which supports it for the suspension of the top plate. Here these metal plates are separated by air gap. And the capacitance of these plates can be changed by wearing the gap through various types of actuators. These could be electrostatic electro thermal or piezoelectric.

So, in this case firstly, the gap is changed by the electrostatic actuator by applying the bias voltage. This can be changed to one third of the gap between the plates, which corresponds to 50 percent increase in capacitance. The electrostatic actuator based capacitor provides low power consumption. They also provides high activation speed and large deflection capability.

But, the tuning range in these capacitors is relatively less. This tuning limit can be overcome by the electro thermal actuators, where the gap is reduced using the thermal mismatch. So, differential thermal temperatures are provided between the wide and the narrow strips of the parallel plate capacitors, in this case the narrow strips wide is more so, they bends down.

Therefore, it removes the limit of 50 percent increase in capacitance, but these Electro-thermal actuator based capacitors are relatively. So, the both of the capacitors, they suffers with the low power handling capability, because for high capacitance ratio the gap should be as close as possible.

But, it may results in RF breakdown. Next type of capacitor gap can be controlled by the piezoelectric actuator. They provide linear tuning of the capacitor and they provide low driving voltage. So, these are the advantages of piezoelectric actuator, when the bias voltage is applied between the controlling pads. The piezoelectric actuator moves down the dielectric of the top metal plate. It provides the area tuning instead of gap tuning, because there is no limit on the area tuning. One of the common structure of these type

of structure is the common structure, where the resonance frequency is controlled by changing the length of the common structure and the spring constant of these structures.

Now, these capacitors can be used in variety of application areas like, voltage control oscillator, tunable filters, tunable networks, impedance matching networks and phase shifters in.

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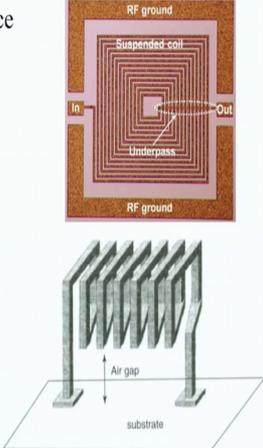
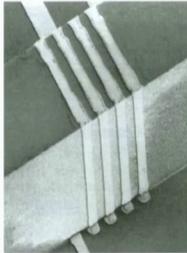
RF MEMS Inductors

Micromachined inductors offers better performance than present CMOS inductors

Planar inductors
Solenoids inductors

Applications

- Low noise oscillators
- Integrated LC-filters
- Amplifiers
- On-chip "matching" networks
- Impedance transformers
- Phase shifters



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Next type of component is the RF MEMS Inductors. The most important properties of the RF inductors are the inductance value the quality factor, and it is self-resonance. Among this quality factor is the most critical parameter.

So, in case of voltage control oscillator, if you remember the phase noise is the critical parameter and it should be low. The phase noise of the V C O is given by the inverse of E square of the quality factor. Now, in general the inductors are made in three dimensional geometry, but there are demands of the planar inductor the high quality inductors, in the RF design should provide high gain low insertion loss less phase noise and high selectivity.

The RF MEMS base inductors is the solution to that, these are of 2 types planar inductors and the solenoid inductors. The planar inductors could be of 2 types a spiral and the meandrical in shape. The spiral inductor inductance can be increased by increasing the

number of turns, but it increases the capacitance between the turns, which reduces the quality factor.

So, it should be optimized properly. So, the optimum value between the quality factor and the inductance value can be selected by narrowing down the inner strips and widening the outer strips. These inductors can be easily fabricated by the current fabrication technology.

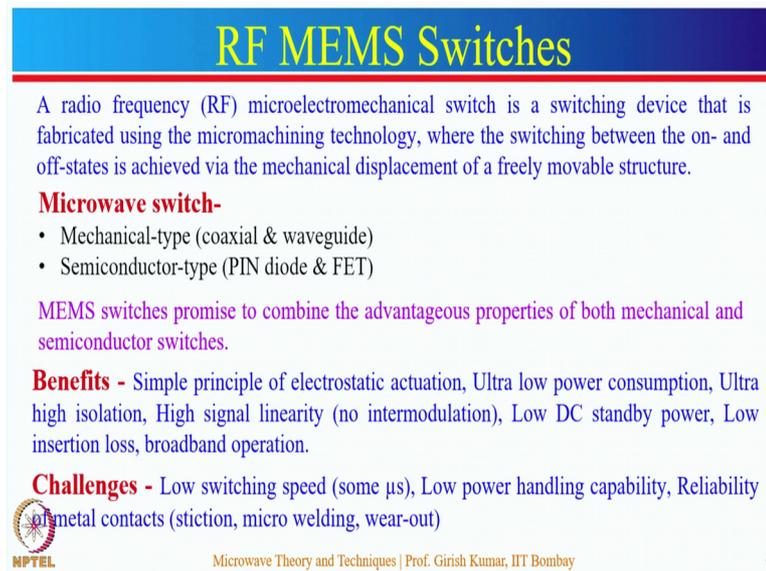
Now, in the case of the spiral inductor the size is relatively more, additionally these suffer from the direction of the flow of flux. And, in the case of meander type of structures they provide the low inductance value, and these problems can be overcome with the help of solenoidal inductors, but they are difficult to fabricate due to their 3D geometry. Here, they can be made using the metallic strips over the core, but as I mentioned the fabrication of these inductors is relatively difficult due to the limitation in the fabrication technique.

The losses will be there in these types of inductors due to the substrate that is used to make the core. These losses can be reduced by using an air core based inductor, which is shown over here. Here the air gap between the substrate and the metallic strips reduces the stray capacitance.

Now, the losses in the core occur because of the 2 reasons; one is the capacitive coupling which occurs due to the conduction current in the metallic strips, and the current between the metal and the substrate region. The other is due to the inductive coupling which is due to the current loops and the magnetic field which flows between the metal and the substrate. And, these provide the losses, and this reduces the quality factor of the inductor.

The quality of the inductor can be improved by narrowing the inner turns and by widening the outer turns. Now, these inductors can also be used in similar applications as we discussed for the capacitors. They can be used in low noise oscillators, integrated LC-filters in amplifiers on chip, matching networks. They can also be used in impedance transformers and phase shifters.

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RF MEMS Switches

A radio frequency (RF) microelectromechanical switch is a switching device that is fabricated using the micromachining technology, where the switching between the on- and off-states is achieved via the mechanical displacement of a freely movable structure.

Microwave switch-

- Mechanical-type (coaxial & waveguide)
- Semiconductor-type (PIN diode & FET)

MEMS switches promise to combine the advantageous properties of both mechanical and semiconductor switches.

Benefits - Simple principle of electrostatic actuation, Ultra low power consumption, Ultra high isolation, High signal linearity (no intermodulation), Low DC standby power, Low insertion loss, broadband operation.

Challenges - Low switching speed (some μ s), Low power handling capability, Reliability of metal contacts (stiction, micro welding, wear-out)

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The next we will talk about the other microwave component that is switch. So, a switch is a device to make the electrical connection or to break the electrical connection. The RF micro electro mechanical switch is a switching device that is fabricated using micro machining technology, where the switching between the on and the off states is achieved by the mechanical displacement of a freely movable structure.

Now, if you remember in case of switch there are various important features like, they should provide the low insertion loss, they should provide high isolation. The lifecycle should be more and they should have series resistance with low value; the transition time should also be less for the switches. These characteristics will be provided by RF MEMS switches.

Now, if you remember there are 2 type of microwave switches; mechanical and semiconductor type. The mechanical type of switches could of either coaxial type and waveguide type; they provide low insertion loss and the RF power handling capability of these switches is also high. Additionally they provide the high isolation in reverse case, when the switch in off state, but they are bulky in size the next type of switch is a semiconductor type switch, which are made using the pin diode or the FET.

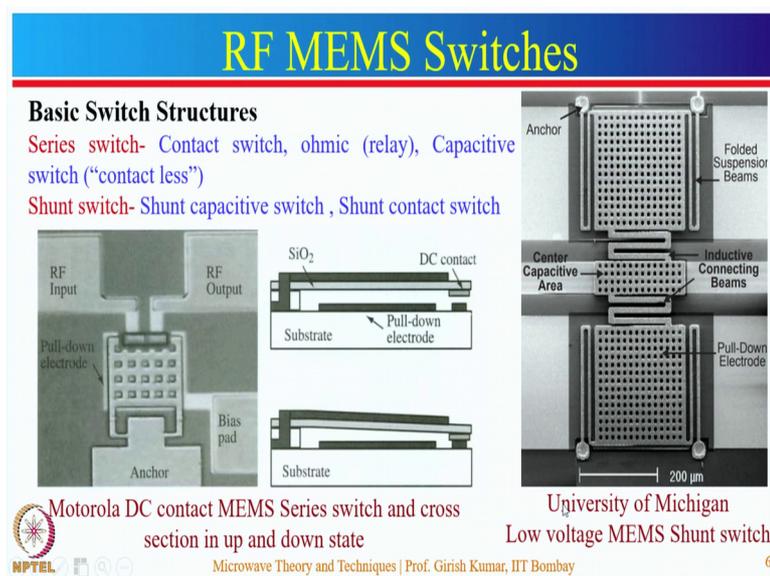
So, the size of the semiconductor type switch is relatively very less, but this suffers from the low insertion loss and low isolation at higher frequencies. So, RF MEMS switches,

combines the advantage of both mechanical and the semiconductor type of switches. So, they offer the advantage of both the switches.

The benefits of these switches are they are simple and they can operate in a simple way through electrostatic actuation, they provide the ultra-low power consumption. The isolation is also very high in these switches; they provide high signal linearity and Low DC standby power. The insertion loss is also less in these switches as compared to semiconductor type. And, they are more suitable for broadband operations.

However, they suffer from the challenges like they provide low switching speed, and low power handling capability as compared to the semiconductor type of switches. They are also limited in terms of reliability of the metal contacts.

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Now, these switches could be of 2 type series or the shunt. The series switch can be of various types the contact switch relay switch or the capacitive switch with contact less geometry.

The shunt switch could be of various type the shunt capacitive switch and the shunt contact switch. So, here is geometry of series switch which is made by Motorola and the 2 up and down state of this switch is shown here. This series switch is made using the cantilever, which is fixed at one end and the metal strip is made at the cantilever. It is connected in series with the micro strip line and a metal electrode is placed below the

cantilever which is suspended. This electrode is known as the pull down electrode, the operation of this switch is given by 2 mechanism here in the metal strip is connected to the anchor region it provides the supports to the wider region. And the second part is the wider region which is overlapping with the metal electrode. So, they form a parallel plate capacitor.

Now, when the actuation voltage or the electrostatic actuation is applied, they forms a closed path and it is in conducting state. Now, when the bias voltage is applied it tries to pull down the cantilever. And, it creates a tensile force which will try to pull it back, when the bias voltage is increased further, when it is greater than the threshold voltage then the tensile force will not be able to balance this electrostatic force which is created due to the bias voltage. So, it will fall down and it will fall to the pull down electrode. Now, if you see in this case in unactuated state there is no current pass. So, it provides a high impedance state. So, they will not be any D C current in this type of switches. So, in this case the D C biasing can be provided with the help of resistor.

However, if you member in case of solid state switches there is a large amount of D C current flow. So, the biasing cannot be provided with the help of resistor because they will result in voltage drop of high amount. So, the biasing is provided with the help of inductor in case of solid state switches, is the next is the example of low voltage MEMS shunt switch which was made by University of Michigan, it is a capacitively coupled switch.

In this case the pull in voltage is reduced by increasing the area or it can be reduced by decreasing the gap between the capacitor and the switch and by decreasing the spring constant value. So, if you see in this case the increase in area is not a feasible solution, because the MEMS devices are invented by the target of miniaturizing the devices only.

If you reduce the gap then in that case there maybe chances that the RF isolation of the switch may reduce. So, that is also not a feasible solution. So, the most feasible solution to decrease the pull in voltage is to reduce the spring constant value with low mass if possible.

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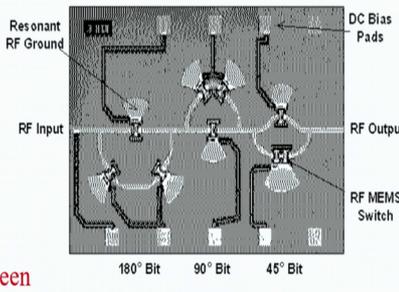
RF MEMS phase shifters

A. Analog Phase Shifters
Using distributed, capacitive shunt-switches

B. Digital Phase Shifters-
Based on MEMS switches

- Discrete phase change
- Phase shift set by switching between different phase paths

Low insertion loss, High isolation, Negligible actuation power and standby power consumption



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The next type of component is the RF MEMS phase shifter. In case of semiconductor phase shifter, if you remember they do not provide the desirable insertion loss at higher frequencies. Additionally, they do not provide the continuous phase variation. So, they are not suitable in the phase array antenna or in adaptive array antenna. Now, the if RF MEMS based phase shifter is a solution to this because they provide very low insertion loss at higher frequency in millimeter wave frequency range.

The phase change in these types of phase shifters can be controlled by varying the path length with reference to the least reference state. Now, these switches are divided into 2 categories analogue phase shifter, digital phase shifters. The analogue phase shifters can be designed using distributed and capacitive shunt switches. In case of digital phase shifter they are made using the discrete phase changes, here the phase shift is achieved by switching between the different phase paths. So, here is the example of a digital phase shifter, which is a switched line phase shifter, it is designed for curved end. In this case here the DC biasing is provided here. This is a wireless topology, here the resonant strips X is a RF ground.

In this case to turn off a particular section 2 quarter wave transformation technique is used between the resonant step and the T junction. So, one quarter wave transformer is from the quarter wave step to the centre of the switch, here it is open. So, it will act like a short at the centre of the switch. The, another quarter wave transformation line is this.

So, the centre of the switch is short. So, it will act like a open at the T junction. So, in this way, when the switch is in actuation state or if you want to have the phase change with respect to the reference state, then the signal which is passing through with this line will see an open circuit. So, it will move to the desired path to provide the additional phase change in the reference path by providing this additional length. So, this is geometry for one eighty degree phase shift.

Similarly, the line length can be adjusted for the 90 degree width and 45 degree width. Here with this geometry the phase change can be achieved from 0 to 315 degree with a step size of 45 degree. This geometry provides the insertion loss of 1.7 DBI at curve end. Now, these type of phase shifters provide the low insertion loss high isolation, negligible actuation power and lower standby power consumption. So, these are the advantages of RF MEMS base phase shifter.

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RF MEMS Filters

- The performance for RF MEMS filters is enhanced by using a series of resonator tanks connected together with coupling networks. The number of such tanks used is equal to the order of filter.
- Two resonator configurations are possible.
 - In first configuration the structure is driven on one of the comb structures and sensed at the other, for capacitance variations.
 - In second configuration, both comb structures are used to drive differentially, while sensing is achieved by monitoring shift in impedance at resonance.

The diagram illustrates the structure of RF MEMS filters. The top part shows a top view of a filter consisting of two resonators connected by a coupling spring. Each resonator has a comb shape transducer. The first resonator is driven by a signal sending port, and the second resonator is sensed by a signal sensing port. The filter is connected to a ground plane and a DC bias. The bottom part shows a cross-sectional view of a resonator electrode, which is a thin layer of material on a substrate. It is connected to an input electrode and an output electrode. The resonator electrode is driven by a voltage V_d and is connected to a ground plane. The resonator electrode is connected to an input electrode through a resistor R_{D1} and a capacitor C_{D1} . The resonator electrode is connected to an output electrode through a resistor R_{D2} and a capacitor C_{D2} . The resonator electrode is connected to a ground plane through a resistor R_{D3} and a capacitor C_{D3} . The resonator electrode is connected to an output electrode through a resistor R_{D4} and a capacitor C_{D4} . The resonator electrode is connected to a ground plane through a resistor R_{D5} and a capacitor C_{D5} . The resonator electrode is connected to an output electrode through a resistor R_{D6} and a capacitor C_{D6} . The resonator electrode is connected to a ground plane through a resistor R_{D7} and a capacitor C_{D7} . The resonator electrode is connected to an output electrode through a resistor R_{D8} and a capacitor C_{D8} . The resonator electrode is connected to a ground plane through a resistor R_{D9} and a capacitor C_{D9} . The resonator electrode is connected to an output electrode through a resistor R_{D10} and a capacitor C_{D10} . The resonator electrode is connected to a ground plane through a resistor R_{D11} and a capacitor C_{D11} . The resonator electrode is connected to an output electrode through a resistor R_{D12} and a capacitor C_{D12} . The resonator electrode is connected to a ground plane through a resistor R_{D13} and a capacitor C_{D13} . The resonator electrode is connected to an output electrode through a resistor R_{D14} and a capacitor C_{D14} . The resonator electrode is connected to a ground plane through a resistor R_{D15} and a capacitor C_{D15} . The resonator electrode is connected to an output electrode through a resistor R_{D16} and a capacitor C_{D16} . The resonator electrode is connected to a ground plane through a resistor R_{D17} and a capacitor C_{D17} . The resonator electrode is connected to an output electrode through a resistor R_{D18} and a capacitor C_{D18} . The resonator electrode is connected to a ground plane through a resistor R_{D19} and a capacitor C_{D19} . The resonator electrode is connected to an output electrode through a resistor R_{D20} and a capacitor C_{D20} .

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The next component which is based on the RF MEMS topology is the filter. Now, if you remember in case of filter it is desired to have the flat band pass response, high out of band rejection ratio and high roll off factor. Now, if you see in case of RF MEMS filter the performance of the RF MEMS filter is enhanced by using a series of resonator tanks connected together with the coupling network. Here, the number of resonated tanks decide the order of the filter more will be the number of resonated tanks more will the order of the filter and it will improve the selectivity of the filter.

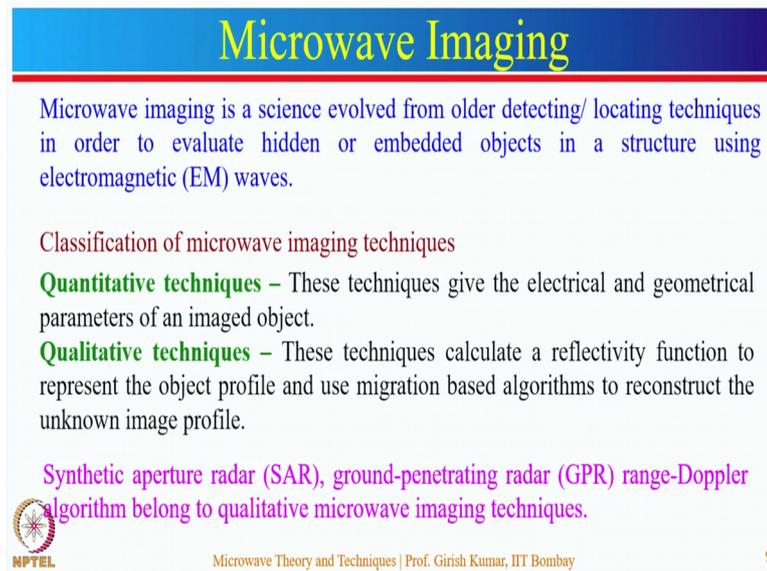
The one of the common configuration to make the filter is the parallel plate capacitor of the type comb structure. Now using combed structures 2 type of configurations are possible. In the first configuration structure, the structure is driven on one of the comb structure and it is sensed at the other comb structure, for the capacitive variation. In the second structure both the comb structures are used to drive differentially, while the sensing is achieved by monitoring, the shift in the impedance at the resonance frequency.

Now, there are 2 topologies of these filters series and parallel. In case of series filters, the resonant structures should be separated by the square tressed spring and the resonance frequency of this structure can be controlled by lowering the spring constant value of this square tressed spring.

In case of parallel structure, it can be measured by the input and output current they should add up in phase. To design the band stop filter, they should be added in reverse phase. One more thing I want to highlight here, in order to reduce the coupling or to reduce the excitation of higher order modes. The ground plane should be used over here, which is shown here. And, the number of resonators can also be increased here to increase the selectivity of the filters. These filters can also be used in the similar applications in various Tran's receiver or tools or wherever the band is to be selected from a wider band, these filters can be easily used.

So, far we have discussed about the RF MEMS components and the RF MEMS topology.

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Microwave Imaging

Microwave imaging is a science evolved from older detecting/ locating techniques in order to evaluate hidden or embedded objects in a structure using electromagnetic (EM) waves.

Classification of microwave imaging techniques

Quantitative techniques – These techniques give the electrical and geometrical parameters of an imaged object.

Qualitative techniques – These techniques calculate a reflectivity function to represent the object profile and use migration based algorithms to reconstruct the unknown image profile.

Synthetic aperture radar (SAR), ground-penetrating radar (GPR) range-Doppler algorithm belong to qualitative microwave imaging techniques.

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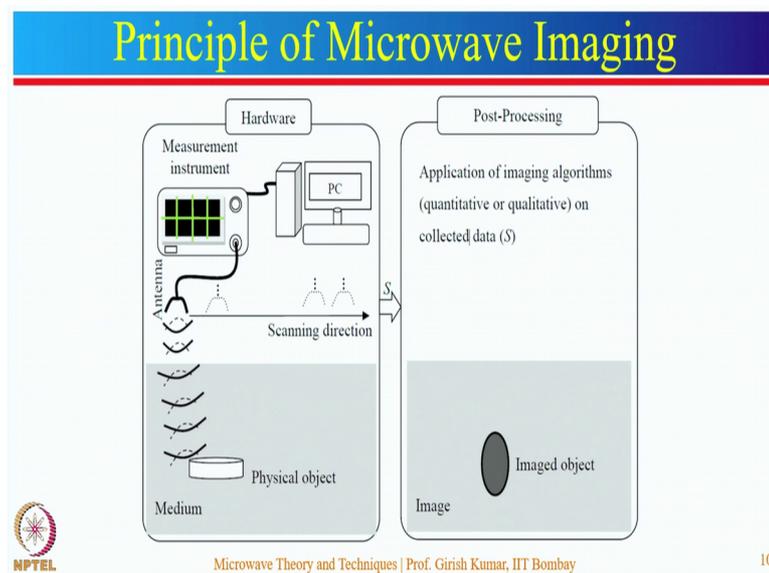
Now, we would like to discuss about the microwave imaging. So, microwave imaging is a science, which is evolved from the older detecting and locating techniques in order to evaluate the hidden or embedded objects in a structure using electromagnetic waves in the microwave region. Engineering and application oriented microwave imaging is known as the microwave testing. The microwave imaging is an area of research, where the idea is to make use of low power to detect the physical and the electrical properties of the device and a test. It is an efficient diagnostic procedure for non-invasive visualization of dielectric properties of non-metallic bodies.

The dielectric properties of the material cannot be measured through any insitu procedure yes any direct or insitu procedure are destructive in nature. The measurement of dielectric properties for a wide variety of material over the broad frequency range is the area of research and it is crucial in the microwave imaging and sensing. The microwave imaging can be classified into 2 ways to quantitative techniques and the qualitative techniques.

In case of quantitative techniques, they give the electrical and the geometrical parameters of the image object. The electrical parameter means that the electrical and the magnetic properties and here the geometrical parameter means the shape size and the location of the hidden object. And, the qualitative techniques calculate the refractivity function of the hidden object and then use this simplification approximation to simplify the imaging

problem. And, then use the back propagation algorithm to construct the unknown image profile. Synthetic aperture radar, ground penetrating radar, and the Doppler radar belongs to the qualitative technique.

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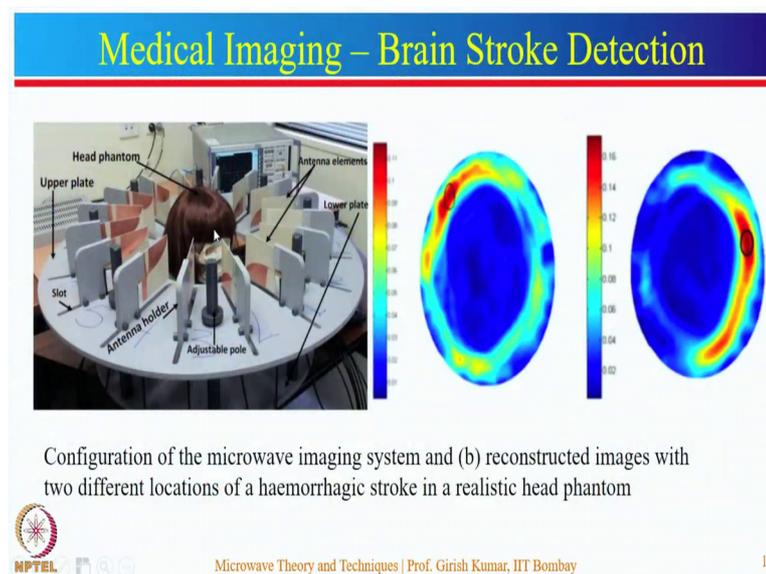
Now, this microwave imaging principle can be defined in the 2 ways; through hardware components and the software component.

The hardware component collects the data from the sample under tests. It sends the electromagnetic waves through the antenna to the sample under test. Now, if the sample is of homogeneous type and it is of infinite size, then they do not reflect any E M waves. Now, if there is any anomaly in this sample, then it will reflect the E M waves. So, more the anomaly is more will be the reflection. Now, this is a reflection can be captured by the same antenna in case of monostatic system and buy a different antenna in case of bio static configuration.

Now, the cross range resolution of these antennas can be improved by using the array of antennas, but these arrays should be separated by less than one wavelength, but in this case there could be coupling which may reduce the accuracy of the measurement. So, therefore, a single antenna should be used and it should scan the overall area and the mapped data can be collected in terms of coordinate system, which can be further post processed using the software and the various imaging algorithms to construct the unknown object image profile.

The microwave imaging has applications in various areas like, medical imaging; the next type of application is the non-destructive testing and evaluation through wall imaging, and his structure wall monitory, concealed weapon detection at security points. We will discuss these applications one by one in a while. So, the first application of the microwave imaging is the medical imaging. In case of head imaging the idea is to detect and locate the damaged brain tissue, which happens due to either any injury or due to haemorrhagic stroke in the head.

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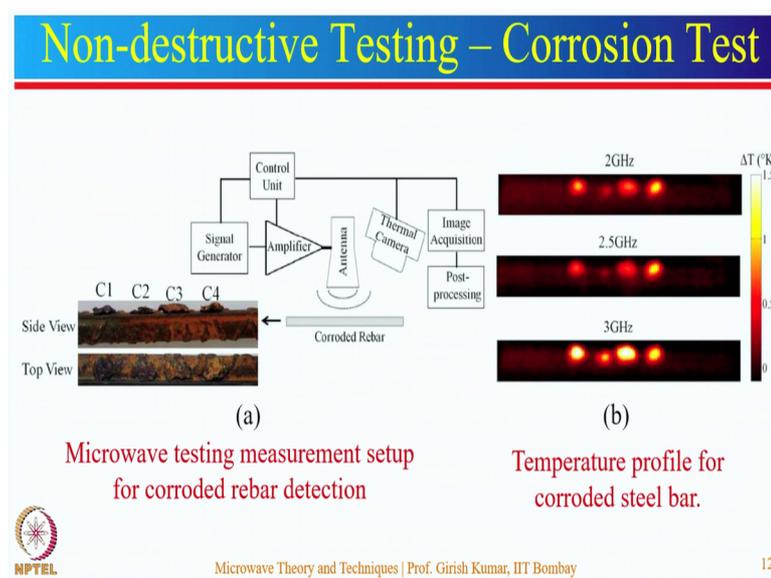
So, here is this system for head imaging. It contains the 16 antenna elements; it is a corrugated slot antenna operating in the frequency range 1 to 4 gigahertz it provides the directional radiation pattern. So, it is confined in the area of interest. This plate form contains 2 little plates; one plate is the adjustable one to accommodate the head phantom. And, in this case it is adjusted in such a way. So, that there is not any error in case of measurement the radius of this plate is 34 centimeter.

In the second plate the inner radius is 17 centimeter and the outer radius is 42 centimeter. It is selected to accommodate the various size of the head phantom, it contains the adjustable pole which can be varied any height. It also contains the horizontal slots to fix the antennas in these slots. They, contains the holders where the horizontal location can be varied, according to the head phantom. These antennas are connected to vector

network analyzer. And, they are selected using the 2 SP AT switches. The first switch select the antennas from 1 to 8 and the second switch select the antenna from 9 to 16.

Now, this plate form considers the normal human brain conditions, which contains the skull white metal, grey metal, and cerebral spinal fluid. Now for the measurement a hemorrhagic stroke affected brain head phantom is taken. And, the set of measurements are taken to collect the data. Head data is collected in terms of reflection coefficient in s parameters. And, then by using the post processing algorithms the N image is created. So, this is the image created after post processing it indicates the 2 location of brain stroke. So, in this way with the help of this plate form one can locate the brain stroke in a head phantom with the help of microwave imaging.

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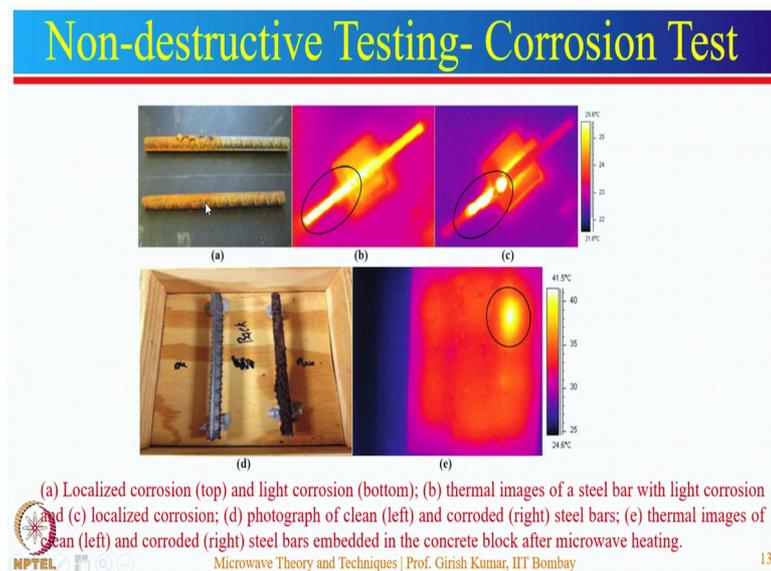


So, in next application of the microwave imaging is non-destructive testing, here it can be used to do the measurement of corrosion in the steel bar. So, this is a setup of non-destructive testing system. This is an antenna which is of horn type the size of this antenna is 14 cross 24 centimeter square. It is separated from the steel bar by a gap of 1 centimeter it is radiated by a 10 watt of power.

So, in this steel bar it is corroded by 4 types of corrosion and they are separated by 1 centimeter gap, when they are radiated you can see that with the help of a thermal camera and image profile is created at the frequency 2 gigahertz 2.5 gigahertz and 3 gigahertz. So, in case of uncorroded a steel bar they will be the maximum absorption.

However, in case of the corrosion the absorption will be less. So, it will show the highlighted spots to yes, you can see the highlighted spots which corresponds to the corroded areas. You can see here at higher frequencies the absorption is even less. So, it provides even brighter spots. Now, we will see what will be the effect of these steel bars when they are embedded in a concrete metal.

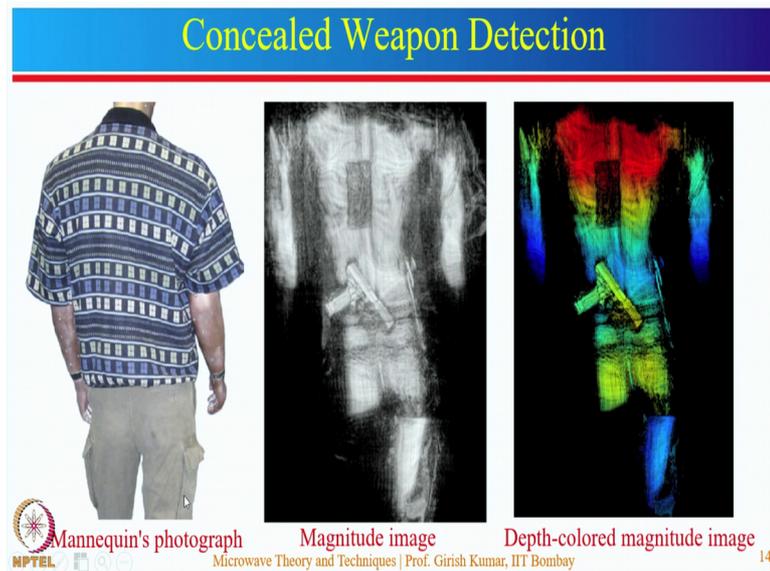
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So, here is the example; in this 2 steel bars are taken, in this half of the area is uniformly corroded in another steel bar, it is non uniformly corroded in some of the area and the corrosion is more in this area. When this is exposed by a microwave oven at 2.4 5 gigahertz for 10 seconds and the thermal image profile is taken by a thermal camera, then these types of images are created here the black circle shows the area of corrosion.

So, this is the thermal profile of this rod, it shows the brighter spots for the corroded area in the half length. In the second case corroded area is confined in this region, which can be seen from the thermal profile. From here you can see this shows the uncorroded steel bar. Now, when these steel bars are embedded in the concrete region then the absorption is more. So, you can see from the image profile, the corroded region can still be identified with the help of microwave testing. Here, the intensity of a spot is less, because of the loss tangent of the concrete metal. With the help of microwave imaging the non-destructive testing for the corrosion can also be done.

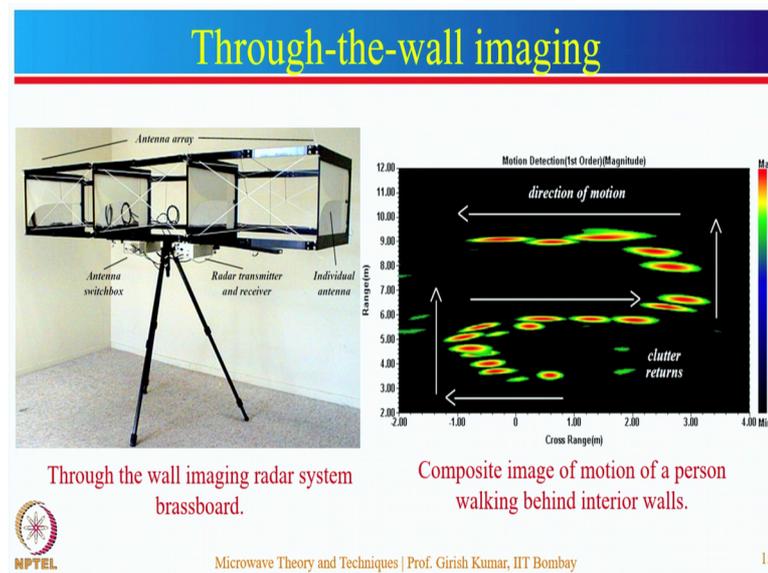
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In the next application is the concealed weapon detection at security. Here is the photograph of the mannequin; it contains the cloths along with the concealed weapons these concealed weapons could be of various types like scissors knife, pistol chip or any non-metallic body. When, it is exposed with microwave radiation it will show different reflectivity profile for the non-metallic objects or the metallic objects. So, it will be different from the human body the corresponding variations can be seen in the image profile when it is created after post processing. So, this is the image which is created after post processing. So, it shows the concealed weapon which is with the person.

The colored image can also be created here; in this case this red color shows the less distance with respect to the measurement system, and blue color represents the more distance with respect to the measurement system.

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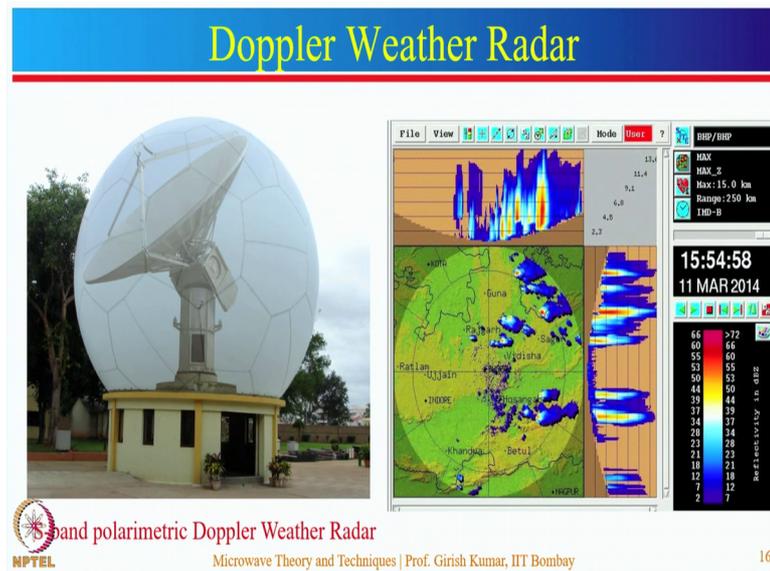


Now, similarly this microwave imaging can be used for the through wall imaging applications. So, this is the through wall imaging radar system the size of this radar is 2.4 meter in it is expanded form, it can locate the person inside a building at an offset from the building. It can also tell about the size of the building and the activities that are going in the building. So, it is very useful for the strategically operation of the security. So, here is the image shown for a person, when it is measured using this system.

In this case a person is moving first to the left side, then it is moving towards the wall, then it is move in right side, then it is moving towards the another wall and then it is taking the reverse motion. Now, in this case the walls are stationary. So, the reflection will be constant.

However, reflection will vary due to the movement of the person. So, the reflection due to walls can be suppressed and the motion of the person can be tracked easily with the help of this system. So, this is a very useful application from the security point of view.

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The next application is the Doppler weather radar, which is used for the measurement of weather conditions for the extreme weather changes, these weather changes could be like cyclone, extreme heavy rainfall, extremely high wind loading etcetera.

So, with the help of this Doppler weather radar one can easily intimate in well advance. So, that the proper measures can be taken to save lives and other things so, here is the S band Polarimetric Doppler weather radar which is made by the ISRO and BEL organization. It is install in the cherrapunji which is known for heavy rainfall, this radar can successfully provide the weather changes at 500 kilometer. So, with the help of this radar in well advanced one can be notified about the extreme weather changes. So, that they can save their life or they can take the proper measures to counter attack these extreme situation. So, these are the applications of microwave imaging.

Now, with this I would like to conclude we started with RF MEMS, we saw how the RF MEMS devices are made. Then we talked about various types of RF MEMS components we talked about RF MEMS capacitor, inductor, switches, phase shifters and filters and then we saw how they are different and superior over the semiconductor microwave devices.

After, that we talked about the microwave imaging we talked about the principle of operation of microwave imaging; then we saw the various application of microwave imaging in various areas like we saw, the application of microwave imaging in medical

field, for brain stroke detection. After that we talked about the application of microwave imaging for non-destructive testing. We saw the identification of corrosion in steel bars after that we talked about the application of microwave imaging in concealed weapon detection, then we talked about the application of microwave imaging in through wall imaging applications, then we talked about the application in the weather measurement using the Doppler weather radar with this I would like to conclude.

Thank you very much bye.