Millimeter Wave Technology
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Module 8
Lecture No 40
Millimeter Wave Systems (Contd)

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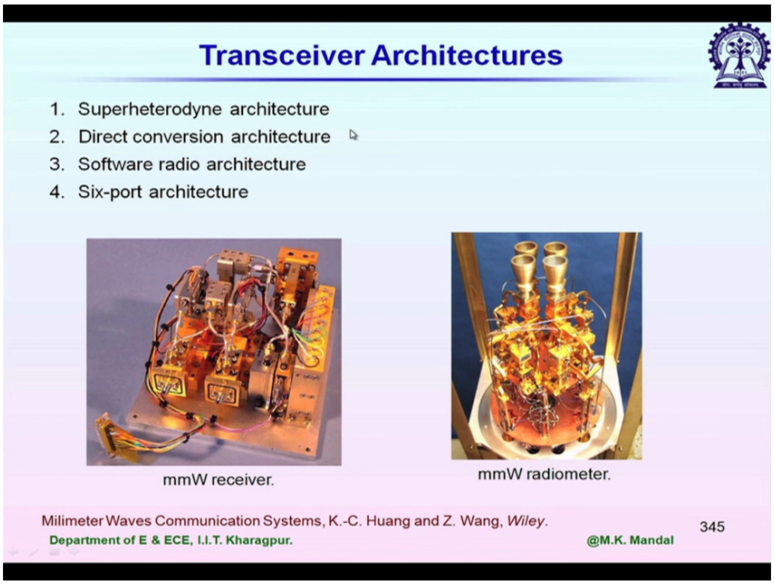

So next is transceiver architecture, there are different types of architectures already being used in different applications, they have their own advantages and disadvantages, some of them already known to you and I will introduce one new that is called 6 port receiver architecture. So we are going to discuss on the very popular one only, so these are Super heterodyne architecture, Direct conversion architecture, Software radio architecture and 6 port architecture, so all these 4 different architectures are popular even at millimetre wave frequency. So here I am showing 2 pictures, left one is a millimetre wave receiver, right one is millimetre wave radio meter.

So one thing you see, millimetre wave component itself is very small, but when we go for millimetre wave system it looks big this is due to the packaging problem. If you look carefully here, all this shiny part they are actually gold plated glass metal, they are used for packaging we call it split block technology. So packaging is much bigger and it is a real problem, people are working on it how we can minimise the packaging size, one it is done then it becomes very small component.

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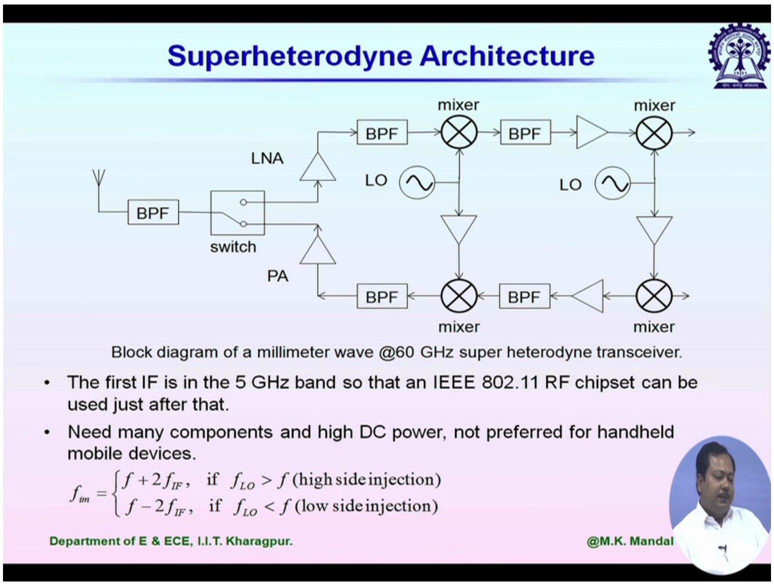

So that we start with the super heterodyne architecture, so as you know that here we use some sort of mixer to down convert the signal to lower frequency and here the intermediate frequency IF is fixed. So for this typical transceiver architecture whatever I am showing here, it starts with the antenna and followed by one band pass filter then we have a switch channel selector, we can select either the transmitting part on the receiving part by using this switch. So for the receiving part the first element is low noise amplifier, which should have very small noise figure that already we know why, and for the transmitter last component is power amplifier in this chain and then we have one band pass filter followed by Mixer.

So Mixer it multiply the local oscillator signal with the incoming RF signal and in frequency domain it generates incoming frequency f rf and the local oscillator frequency f lo, then f rf +- f lo component. Usually we take the smaller one difference and for this particular example working at 60 gigahertz, the first mixer it down converts the 60 gigahertz signal to 5 gigahertz band. And right-hand side mixer then it produces the baseband signal from that 5 gigahertz band, so why 5 gigahertz is chosen because 5 gigahertz already we have popular applications and IEEE 802.11 chipset already available for that 5 gigahertz application, so we can directly use we do not have to design any main chip for this particular thing.

So we have to be very careful about the image rejection, so for high side injection if I consider f lo is greater than f rf, in that case it is f + twice f if and for low side injection it is f - twice f if. So because otherwise this image frequency will be passed through the filter and it will interfere right-hand side, so we have to avoid them or you can use image rejecting filter or image rejecting mixer, where mixer itself will cancel the image. Okay, now I will skip this part okay so what are the advantages and disadvantages of super heterodyne receiver principle? So super heterodyne receiver so usually it is very accurate, high-performance architecture if you compare with other popular architecture, but it has a problem.

Problem is that it uses too many components particularly filters and design of band pass filters at millimetre wave frequency it is a it occupies very large volume, so components itself becomes very big and not only that, it consumes very high-power. So for measurement instruments super heterodyne principle is very popular, but for handheld devices like mobile phones it is not used.

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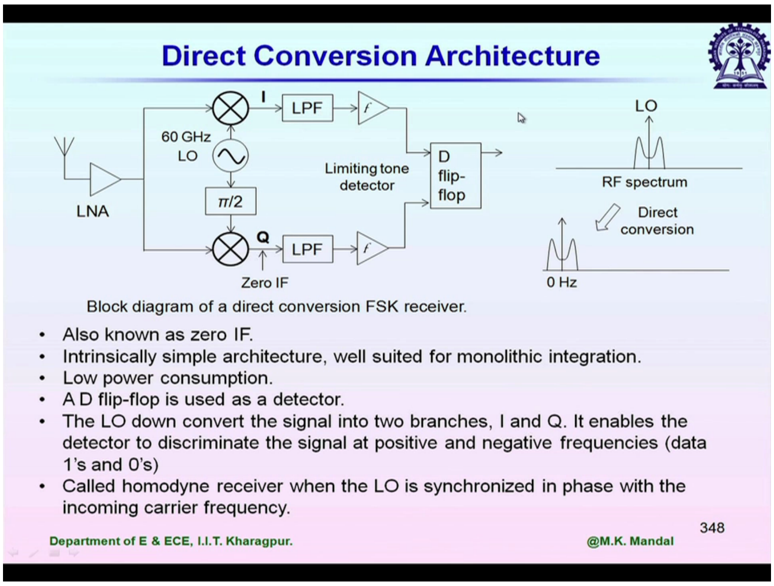

Next is Direct conversion architecture, sometimes it is called 0IF. So here f lo it it has the same frequency as f rf, so if yellow spectrum is given by this, then after multiplication it is directly converted to DC and the immediate IF band, so it has some DC components as well, it in some modulation scheme it is a problem. So look at the receiver architecture, after LNA we have 2 mixers for I and Q channel In-phase channel and Quadrature phase channel and one single LO is being used. So for the one if we multiply it by cosine the second one is being multiplied by sinusoidal and that is how we can recover the I channel and Q channel information, it is followed by low pass filter then IF amplifier and then simply we can use a D flip flop as detector or we can use some other detection technique.

So the LO down converts the signal into 2 branches I and Q and then it enables the director to discriminate the signal at positive and negative frequencies that corresponds to 1 and 0s. It is sometimes called Homodyne receiver when the LO is synchronised in phase with the incoming carrier frequency, since it is not using any BPS and number of components is very small, it is very popular in handheld device applications.

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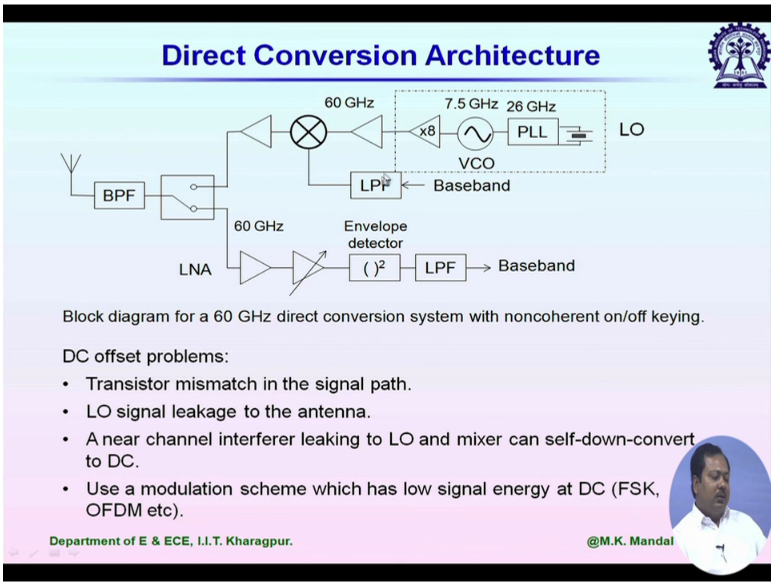

Here is one transceiver architecture, we have both transmitter and receiver in Homodyne principle, so you see at the transmitting side the main challenge is to generate that 60 gigahertz signal, so here one VCO is being used typically of the order of 7 to 8 gigahertz range, then it is being multiplied by 8 times to generate that 60 gigahertz signal. And at the input at the receiving side we have LNA then a variable gain LNA then the envelope detector followed by LPF, so after that we have baseband. So main problem for direct conversion architecture we face with the DC offset because if I look at this spectrum, you see we have some DC value, so there are many problems DC offset values because of transistor mismatch in the signal path.

LO signal leakage to antenna and why you see this LO signal whatever is coming to antenna, antenna is not perfectly matched so some of these incoming power can be reflected back towards source, and which will be received by the receiver side. And once it is received it will be mixed with LO again, so it will self down convert to DC component this leakage. Similarly, we may have near channel interference leaking and that can also self down convert to DC so we have a DC offset due to that. So how we can avoid this system, actually we cannot avoid this scenario but we can minimise the DC offset effect by choosing a suitable modulation scheme, which has low spectral density at DC frequency. For example, if I use simply Amplitude shift keying ASK it will have high DC spectral component compared to

FSK, so for conversion then FSK would be preferred over ASK. Here are some more examples, OFDM also this is popular, which has lower DC signal energy.

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Next third one software radio architecture, so if you look at the architecture it does not have any mixer and from that calculation radiometric calculation we have seen that mixer is the most lossy component in the chain. It simply has one band pass filter, LNA followed by one ADC at the receiving side and at the transmitting side we have a DAC and they directly connected to computers data processing units. So the number of millimetre wave components it can be minimised, but at the same time we need very high speed ADC and DAC, it is really very challenging. And till now whatever ADC/DAC available at high frequency is very expensive, so that is why it did not become popular at millimetre wave frequencies but it is being expected once that cheaper ADC/DAC available let us say at 60 gigahertz it would become very popular since it does not need many millimetre wave components.

So but one solution, sub-sampling receiver using high-speed switch can relax the AD conversion rate difficult by 4 times the base bandwidth, but we have to use BPF to avoid image frequencies. So next is the fourth one, 6-port architecture, it might be new to you. So originally this 6-port architecture was proposed as a reflectometer to measure reflection coefficient of any device under test that means simply S 11. When we deal with as parameter, you remember that it is a complex function it has both magnitude and phase and a 6 port reflectometer it can accurately measure the complex S 11 of any given device, and later it was used as a millimetre wave receiver with some additional modifications. Now) if you look at the date of invention or introduction, this millimetre wave 6 port receiver or as a whole this 6 port receiver it is the latest technology, it around 1993 to 1994 actually it was introduced as a receiver.

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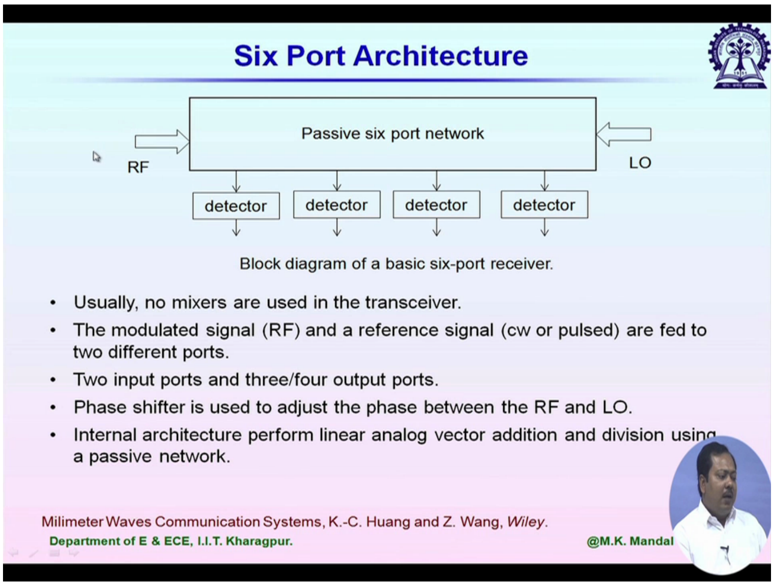

And if you compare the performances, it provides best accuracy typically if you want to measure phase of incoming signal it can provide accuracy of the order of less than 0.01 degree even at millimetre wave frequency as claimed by different publications. So let us see what are the different function of ports, so we have 6 ports is used for the incoming RF signal, second port is used for the local oscillator and remaining 4 ports they are connected to detector diodes. So in detector diodes we need actually millimetre wave diodes, which will give you simply DC voltage and reading this DC voltage we can determine the magnitude and phase of incoming RF with respect to the local oscillator signal. Now let me justify why we need these4-ports for this for detector diodes?

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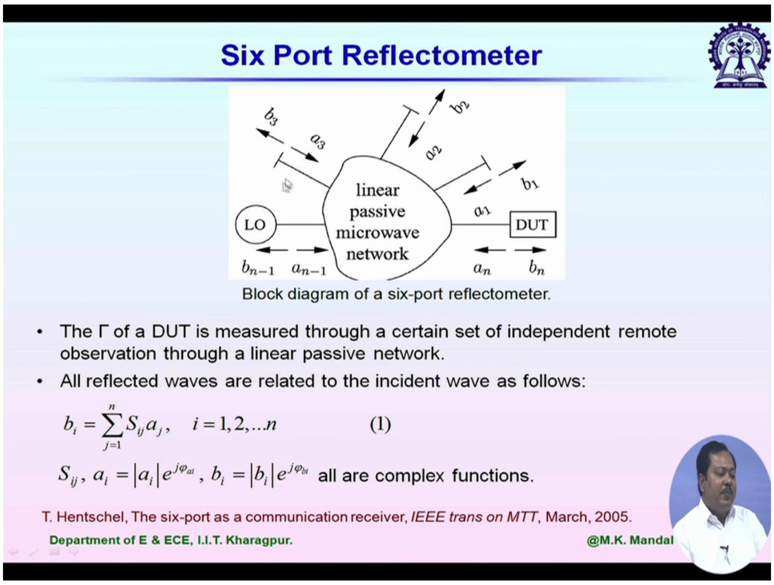

So before that let me first describe what is the working principle of a reflectometer, then we will use the reflectometer as a receiver with some modification. So look at the very basic N port reflect a meter in general, we have port from 1 to N. Nth we are using for device under test so main aim for measurement of S 11, the local oscillator it is connected to N - 1 port. Now whole 6 port network it consists of simply passive microwave networks so that is its main advantage. In addition if you look if you look at the previous architecture, the only millimetre wave active component is diode nothing else, we do not have any mixer so this is another example of mixer less receiver technology.

And here we do not use any multiplication in time domain, recall for super heterodyne we multiply the incoming signal by local oscillator signal, but here we will be using vector addition, we will be simply adding local oscillator signal to the incoming RF signal so port 1 to 3 or N - 2 you can say in general, they are connected to the observation points and all the incoming signals to with respect to this passive network they are represented by A and all the outgoing signals from this N port passive network, it is given by b i in general. Then using the definition of S parameter we can express b in terms of a, this is b i = submission j equal to 1 to n S a j, where i = 1 to N.

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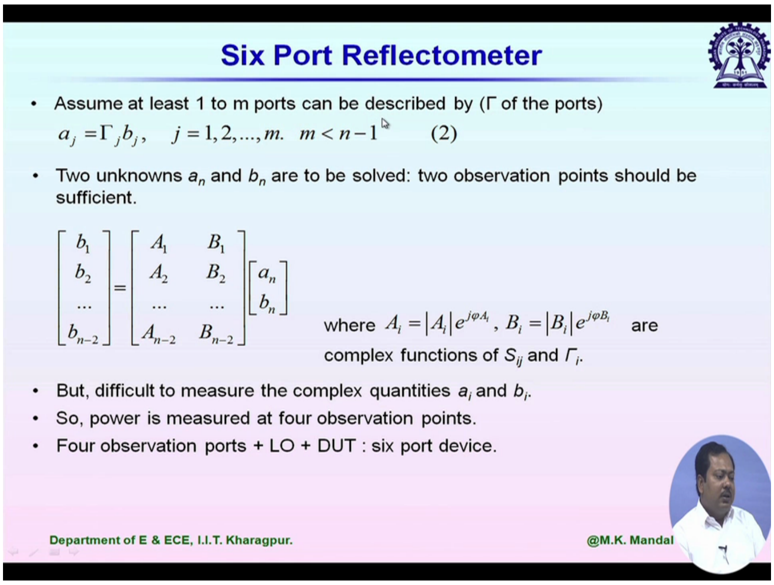

So you see here S parameter it is a complex function, not only that signal coming out from the input device or falling on the input device all are complex function, so we can represent then a i or b i buy its magnitude and phase. Now assume at least 1 to m ports can be described by drama, so that means at least we have N number of equations N number of solutions, from that we can form N number of equations. So a j that is equal to Gamma j into b j, where j = 1 to m, m is less than n - 1. Now, two unknowns we have a n and b n, they are to be solved you see we are using it as a reflectometer, so if we can determine the values of a n and b n then we can calculate what is the S 11 of this device under test, the reflection coefficient of this device, so a n, b n have to be solved.

So from this it seems that since we have 2 unknowns; 2 equations or 2 observation points should be sufficient, but it is not since they are complex quantities, they have magnitude and phase. So we can form n number of n - 2 equations from this known 1 to n values, so we are expressing them in terms of a n and b n these are the unknown quantity. So b 1 to b n - 2 that is equal to this matrix multiplied by a n b n, so we know the values S parameters if I go back here so this linear passive network you can simply measure its S parameter by using vector network analyser, right. So then from that then we can calculate what are the coefficient values starting from A 1 to A n - 2 and B 1 to B n - 2.

So obviously they are a function of these S parameters, so they are complex quantities we can represent them in magnitude and phase form, they are functions of both S parameters and Gamma i. Now A n B n again they are complex quantities and it is really difficult to measure these complex quantities directly phase and magnitude. So what we measure at millimetre wave frequency at millimetre wave frequency it is easier to measure the power level, so simply then A n square so if we want to measure power level in that case we need at least 4 observation points or 4 equations, so that is why actually 6 port, 4 observation points and 1 for local oscillator another one for the device under test of the same port we can use as the RF port for incoming signal.

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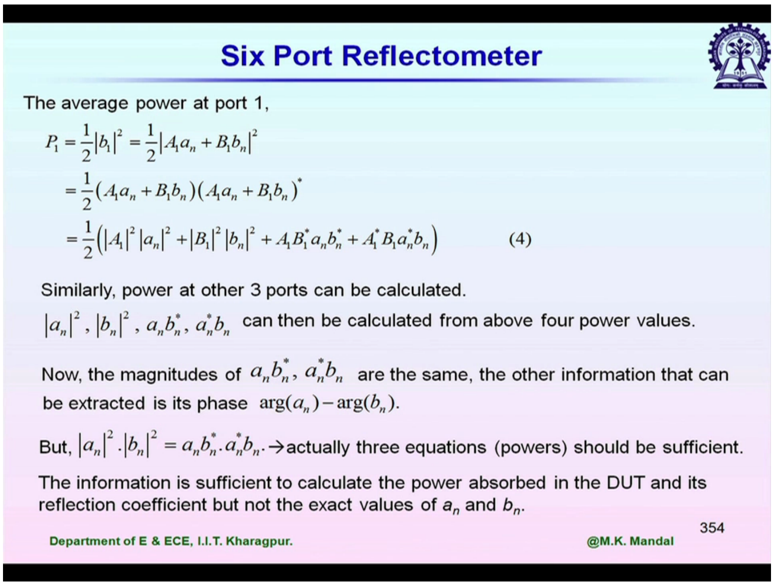

So let us see here, then the average power at Port P 1, we have 4 observation ports P 1 to P 4, we are calculating average power available at Port P 1, so if I go back it should be power coming out from Port P1 it can be represented in terms of b 1, so b 1 it represents the signal coming out from Port 1. So if I take time average, then we have a factor of half, so this is then half so this is then half b 1 square or from this matrix b 1 this is equal to capital A 1 multiplied by small a n + capital B 1 multiplied by small b n, so we can write down then half into A 1 a n + B 1 b n whole square. Or we can also express them like this, A 1 a n + B 1 b n multiplied by its complex conjugate or if we simplify this expression, we can also express half A 1 square a n square, so you see it is now having only the magnitude part, the second term also it is having only the magnitude part, but the third and fourth term for them we have both magnitude and phase.

So this is given for Port P 1 will early, we can calculate average power at Port P 2, P 3 and P 4. Now a n b n we have already this matrix, so once we have all these quantities so we can then calculate a n b n from these 4 power values. Now you see one interesting thing, the magnitude of a n b n star and a n star b n are the same in the equation 4. Then the other information that can be extracted is its phase, so but we know that a n square multiplied by b n square that is equal to a n b n star dot a n star b n, so it seems that if we use these relationships since already we have calculated a n square and b n square. So if we use this relationship it seems that 3 equations should be sufficient, but the thing is that from that other terms since we use that co-sinusoidal term and because of the nature of that co sinusoidal function, phase can lead phase can lag, but we cannot find out simply just solving these equations it is reading or writing.

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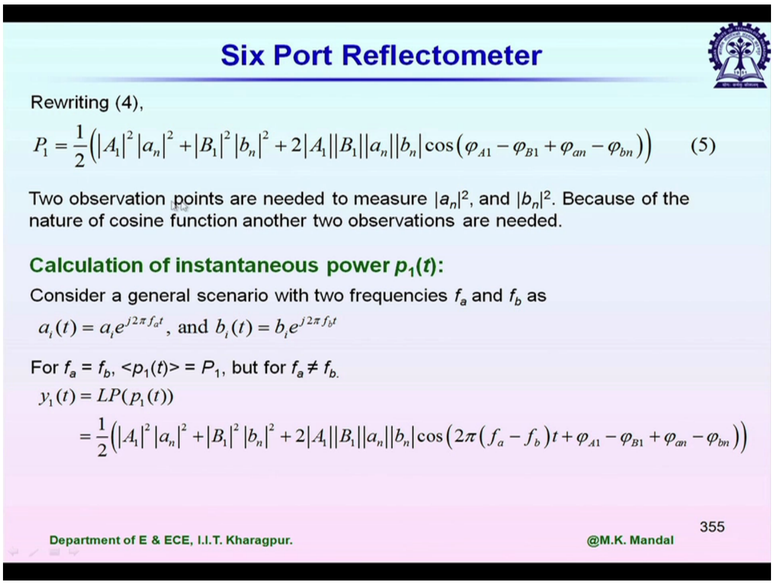

So we need at least another equation to solve that to obtain the sign of the phase that is why it is justified that at least we need 4 observation points, even though we have that relationship. So here you see it is explicitly written here using that co sinusoidal term, the same equation, equation 4 but these third and fourth terms we are expressing in terms of co sinusoidal terms. Now, let us say we are going to use this 6 port receiver and 6 port reflectometer by a communication receiver, so in that case what we will be doing if I go back to this reflector port or device under test port, we will be replacing by the RF input port.

So obviously RF input it may have a different frequency than the local oscillator frequency, so let us say let us consider a general scenario, we are dealing with 2 frequency components f a and f b and in that case a i it is represented by a I into e to the power j twice Pie f a t and b i = b i e to the power j twice f b t and f a = f b, in that case the average power is P 1, but if f a is not equal to f b in that case if we use equation 5 it becomes too long, we have to use both contribution due to f a and f b, so after low pass filtering you see that is the expression.

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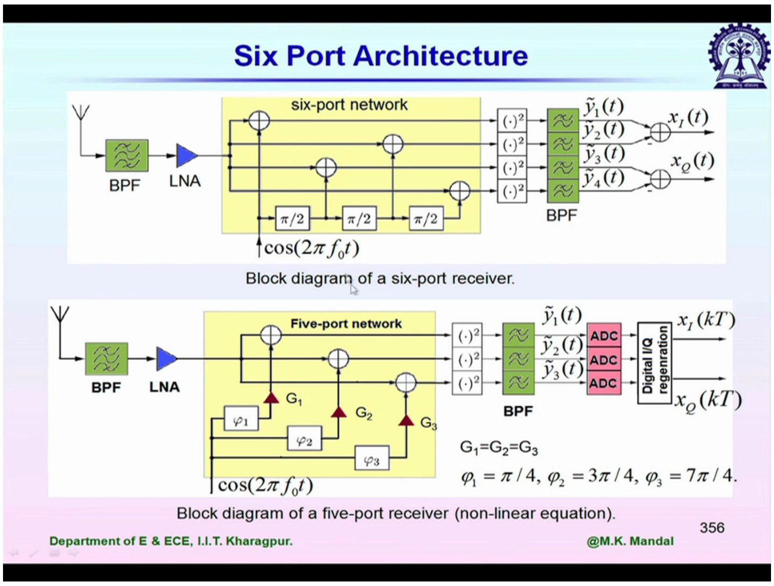

So this is practical realisation, the basic principle is that we have to form 4 equations. So in this first example for a 6 port receiver this is the incoming signal and you see cos twice Pie f 0 t it represents the local oscillator signal, so it is being added we can use one simple Wilkinson power divide, one port we will be using RF and at another port we will be using LO and at the output port we will be having vector addition of these 2 signals. And for the second, it is now being phase shifted by Pie by 2 and it is added for the third line, again it is shifted by pie by 2 it is being added in the second line. So similarly for the fourth line we have 270 degree phase shift, so that is how we have basically 4 equations and rom the first and second where we have 0 phase component and 180 degrees phase shift component, we have the I channel and from 90 and 270 we have the Q channel.

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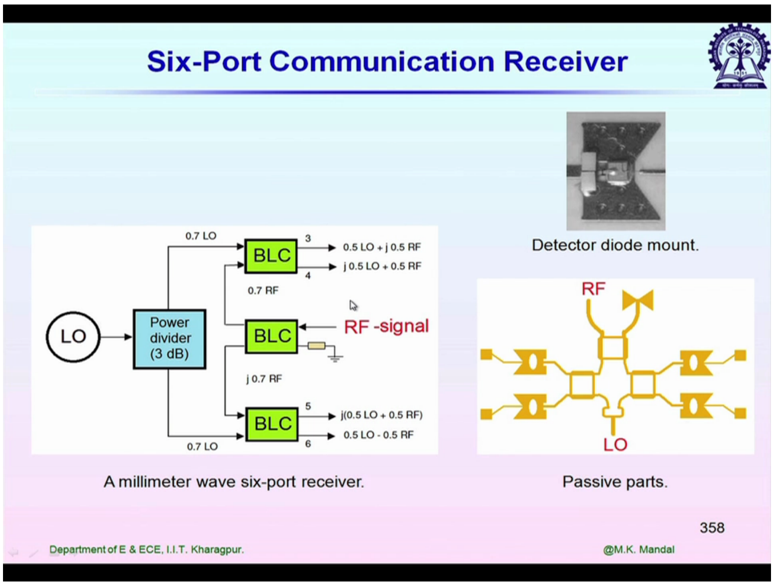

So obviously after this detector we need many signal processing, so let me show you a practical implementation scheme of a 6 port communication receiver, so local oscillator is fed to one 3 dB power divider then it will divide power into 2 components simply without any phase difference between them. It is being fed to 2 branch line couplers, so if you feed one signal to branch line coupler, it will divide it into 2 components for a conventional VLC with a phase difference of 90 dB. RF signal it is also being fed to another VLC and altogether it is so used that we have that condition, so this local oscillator is being phase shifted 3 times then it is being added with the RF and you can find out the values here.

Right-hand side it shows the implementation scheme layout, let us say we want to fabricate it in microstrip line technology, already we know how to design a Wilkinson power divider and branch line coupler in microstrip line technology, so if we fabricate it then the metallic layout PCB layout is shown here, this thicker part it shows the detector mount, so 4 diodes will be placed 1, 2, 3 and 4.

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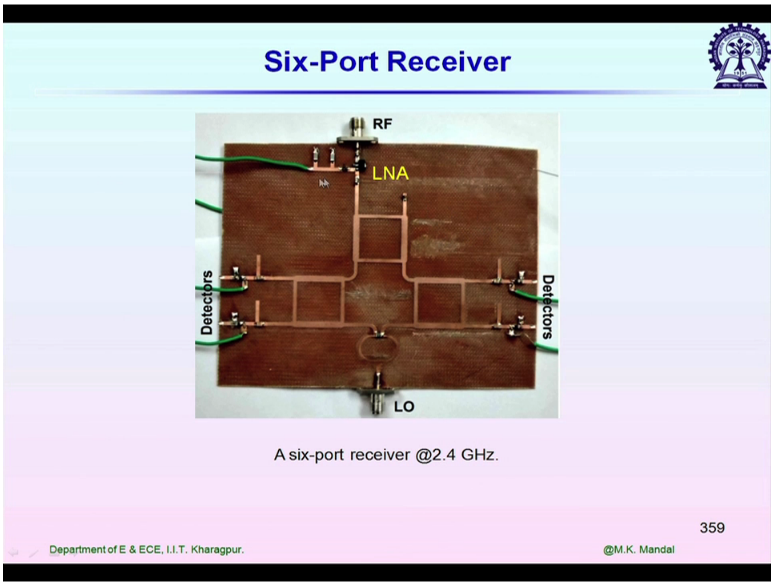

I am showing you one 6 port receiver, it is fabricated here in IIT Kharagpur but it is not at millimetre wave frequencies, it is at 2.4 gigahertz social can easily identify the branch line components 1, 2, 3 and here this is the Wilkinson power divider, so LO it is being fed to this Quadrature hybrid coupler and this is the RF port, just after RF port we have actually one LNA.

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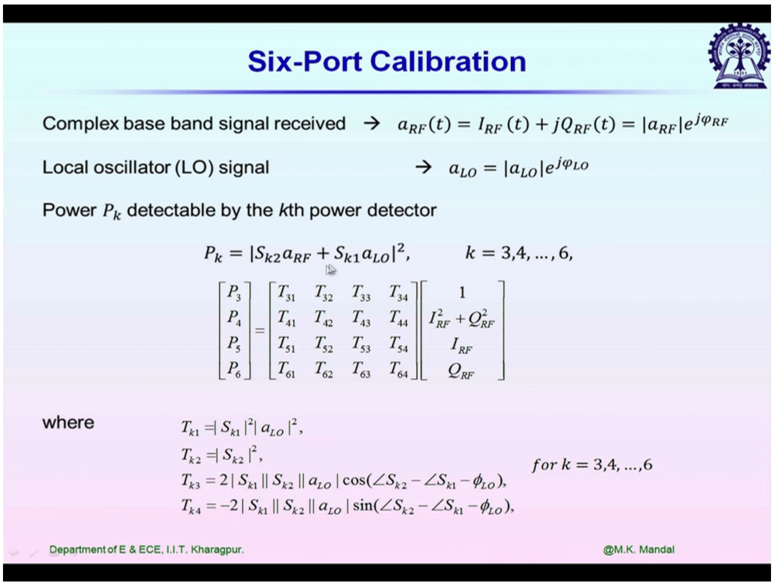

Next part is the calibration, calibration actually it is another it becomes very complicated because we are dealing with 6 ports. When we go for the layout design, obviously whatever ideal scenario we have considered that VLC is giving exactly 90 degrees phase difference, Wilkinson power divider is giving exactly 3 dB power ratio with 0 phase difference and in addition to that we have connecting sections, so in practical scenario these are not ideal, it will give you some error some phase shift, magnitude problem, so we have to calibrate the system. So the calibration scheme is shown here, this is the very simplified form, so what we have to do, we have to express this power available from at Port P 1 to Port 4, here it is shown P 3 to P 6 actually and we have to express them in terms of I and Q and from that we have to calculate this T matrix by measurement, so we are not going into details here.

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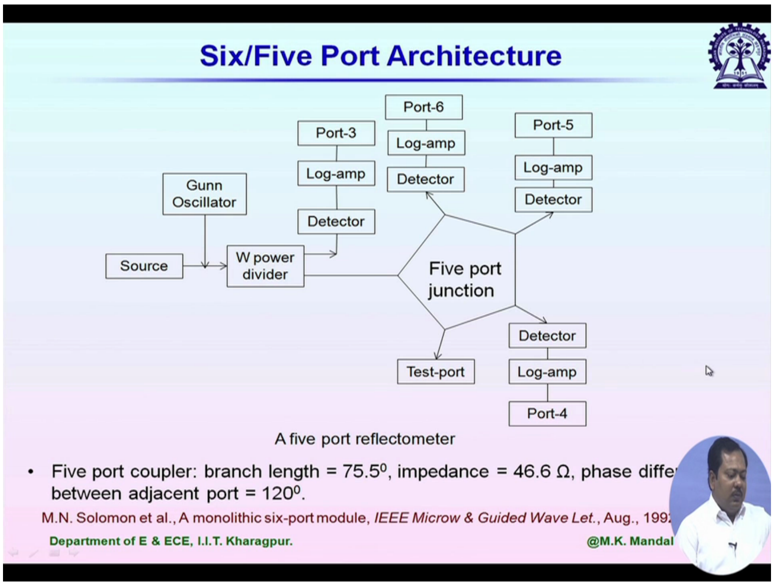

So there is also an alternative 5 port junction, but it is not very popular as 6 ports when we go for communication receiver applications. Okay, so till now what we learned some military systems, the effect of noise on millimetre wave system and also some popular transceiver architecture. So hope you enjoyed the course and if you have any questions, you can send me by email, so I will answer those, thank you very much.