Wireless Communications

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Lecture No. # 16

Mobile Radio Propagation - II (Continued)

Welcome to the next lecture on Mobile Radio propagation. The outline of today’s talk is as follows.

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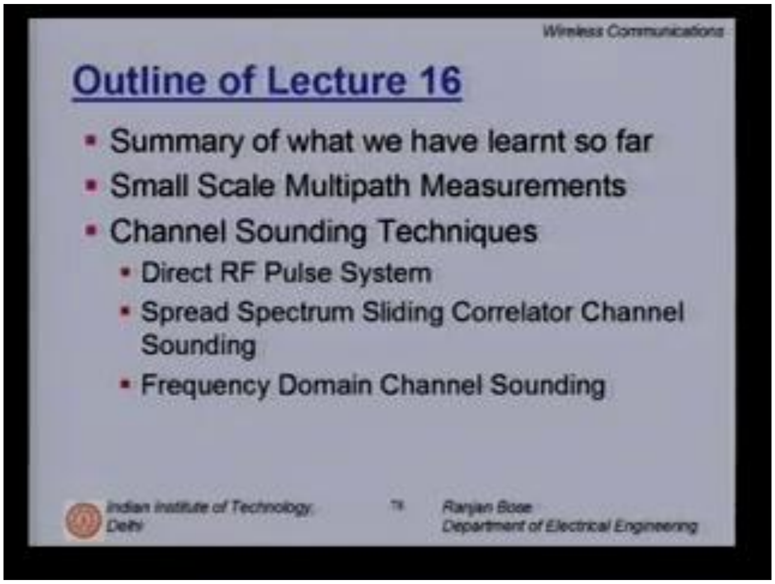

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Outline of Lecture 16

- Summary of what we have learnt so far
- Small Scale Multipath Measurements
- Channel Sounding Techniques
  - Direct RF Pulse System
  - Spread Spectrum Sliding Correlator Channel Sounding
  - Frequency Domain Channel Sounding

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We will start with the brief recap of what we have learned so far in the previous lectures. Then will talk about small scale multipath measurements. We will see that measurements are an important part to come up with a realistic channel model. So how do we take these measurements what are the pros and cons of various measurement techniques is what we will learn today. Then will talk about channel sounding techniques. There will be a discussion on direct or pulsed systems. We will talk about spread spectrum sliding correlator channel sounding technique. And then frequency domain channel sounding method. We will discuss these methods in detail. What is involved, what are the pluses and - points of these various techniques. First let us recap briefly what we learnt last time.

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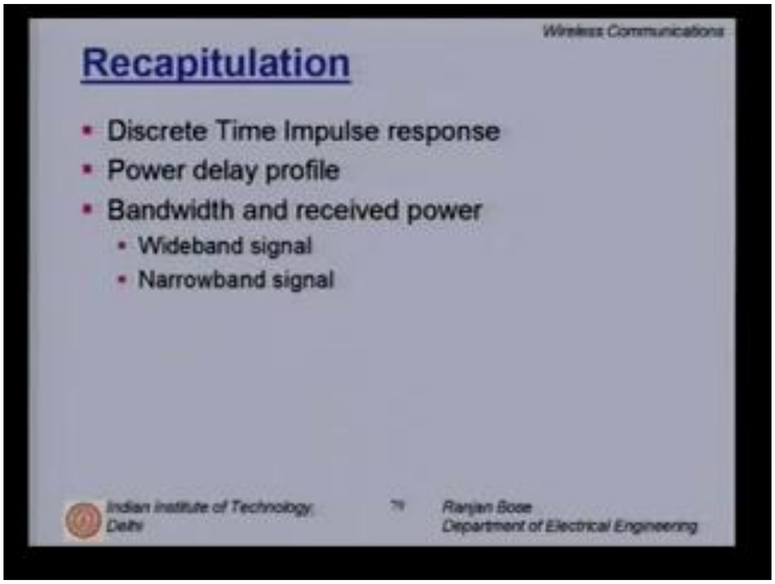

Recapitulation

- Discrete Time Impulse response
- Power delay profile
- Bandwidth and received power
  - Wideband signal
  - Narrowband signal

We started off with a description of the discrete time impulse response model of a mobile multipath fading channel. We then looked at the power delay profile. We realized that the wideband signals and the narrowband signals are treated differently by the same multipath channel. We looked at how wideband signals behave and how narrowband signals behaved.

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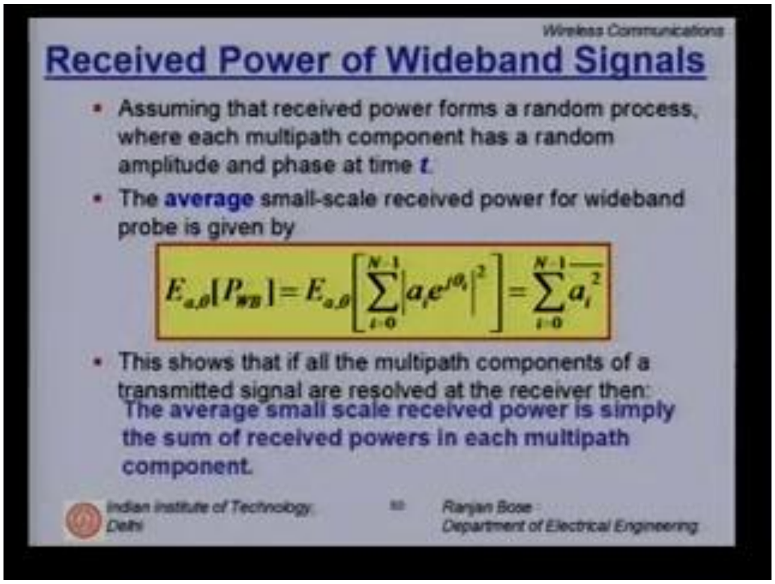

Received Power of Wideband Signals

- Assuming that received power forms a random process, where each multipath component has a random amplitude and phase at time *t*.
- The **average** small-scale received power for wideband probe is given by

$$E_{a,\theta}[P_{WB}] = E_{a,\theta}\left[\sum_{i=0}^{N-1}\left|a_i e^{j\theta_i}\right|^2\right] = \sum_{i=0}^{N-1}\overline{a_i^2}$$

- This shows that if all the multipath components of a transmitted signal are resolved at the receiver then:

The average small scale received power is simply the sum of received powers in each multipath component.

What we saw is that the received power of wideband signal depends on the multipath channel. if we assume that the received power forms a random process where each multipath component has a random amplitude and a phase at any time 't'then the average small scale received power for a wideband probe is given simply by E averaged over a and theta of the power of wideband is equal to summation i is equal to zero through N -1a_i squared average value where a_i represents the power received in the various multipath components from 0 through N –1. So we have consider N multipaths here. What we realized is that the different multipath components of a transmitted signals are resolved at the receiver, then the average small scale received power is simply the some of the received powers in each of the multipath components. We also saw that this is the reason why there are no rapid variations as we move in the small scale dimension. So we do not see much fluctuations as we move our receiver with respect to the transmitter when we are talking about wideband signals. The story was slightly different for narrowband signals.

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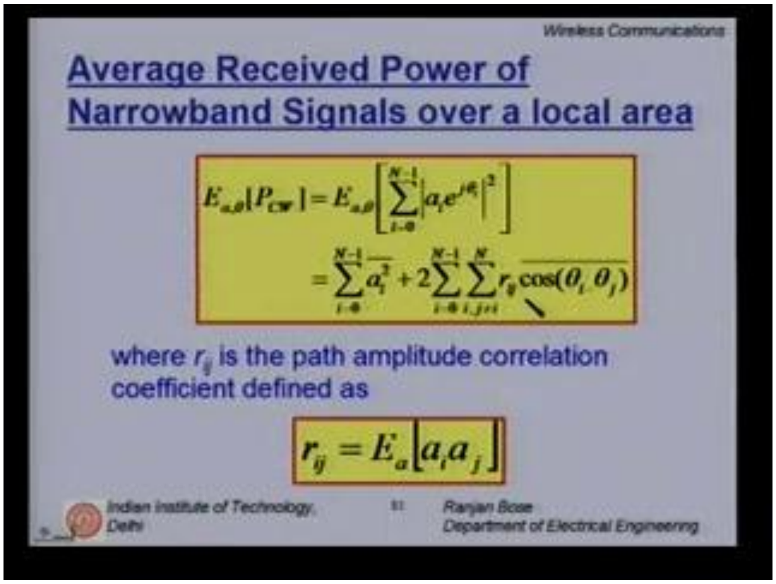

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Average Received Power of Narrowband Signals over a local area

$$E_{a,\theta}[P_{CW}] = E_{a,\theta}\left[\sum_{i=0}^{N-1} \left|a_i e^{j\theta_i}\right|^2\right] = \sum_{i=0}^{N-1} \overline{a_i^2} + 2\sum_{i=0}^{N-1}\sum_{i,j\neq i}^{N} r_{ij}\,\overline{\cos(\theta_i\ \theta_j)}$$

where r_{ij} is the path amplitude correlation coefficient defined as

$$r_{ij} = E_a\left[a_i a_j\right]$$

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So if we talk about the average received power of the narrowband signals over a local area and what do we mean by local area? A few lambdas or a few wavelengths. then the expected power of a continuous wave narrowband signal is given by summation i is equal to 0 through N-1ai squared average value which is the same as what we see in the wideband scenario plus another term which has two summations. There is an r_{ij} which is the path amplitude correlation coefficient defined as rij is equal to expected value over 'a' the amplitudes in the received components of multipath aiaj for the two different multipaths. So r_{ij} multiplied by an average value cosine theta i - theta j. so only in the case when either r_{ij}'s are zero or the average value of cosine theta i - theta j's are zero does the average received power of a narrowband signal become the same as that of a wideband signal. In all other cases, the second component here contributes to rapid fluctuations.so even a little movement of the receiver antenna with respect to the transmitter shows wide fluctuations. There is an inherent difference between wideband signals and narrowband signals.

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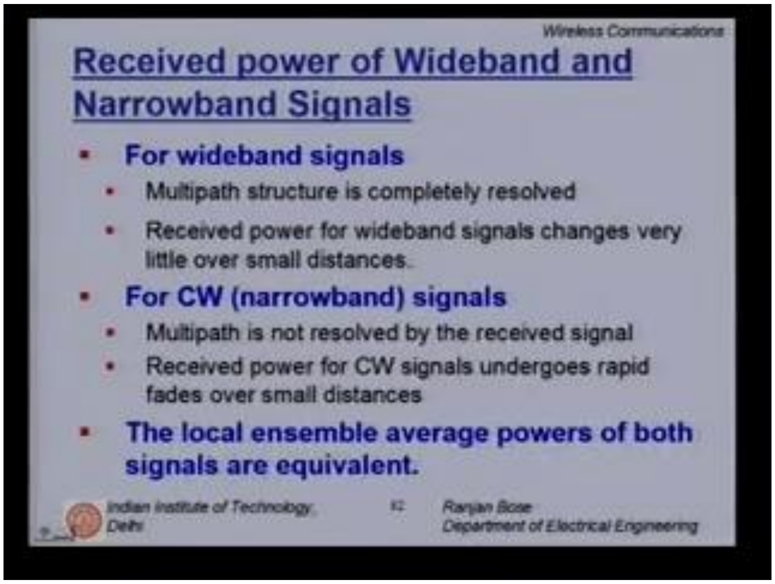

Received power of Wideband and Narrowband Signals

- **For wideband signals**
  - Multipath structure is completely resolved
  - Received power for wideband signals changes very little over small distances.
- **For CW (narrowband) signals**
  - Multipath is not resolved by the received signal
  - Received power for CW signals undergoes rapid fades over small distances
- **The local ensemble average powers of both signals are equivalent.**

So if you want to compare for the wideband signals, we learnt that multipath structure is completely resolved. The received power for wideband signal changes very little over small distances. Small as in, a few wavelengths. On the other hand for the CW say, narrowband signals multipath is clearly not resolved by the received signal. The received power for the CW signals undergoes rapid fades over small distances. What we will see in today’s lecture is that wideband signals can be used effectively to measure the channel impulse response. The measurement values help us come up with a good model for the channel. What is interesting is that the local ensemble average powers for both the signals, both narrowband and wideband are equivalent.

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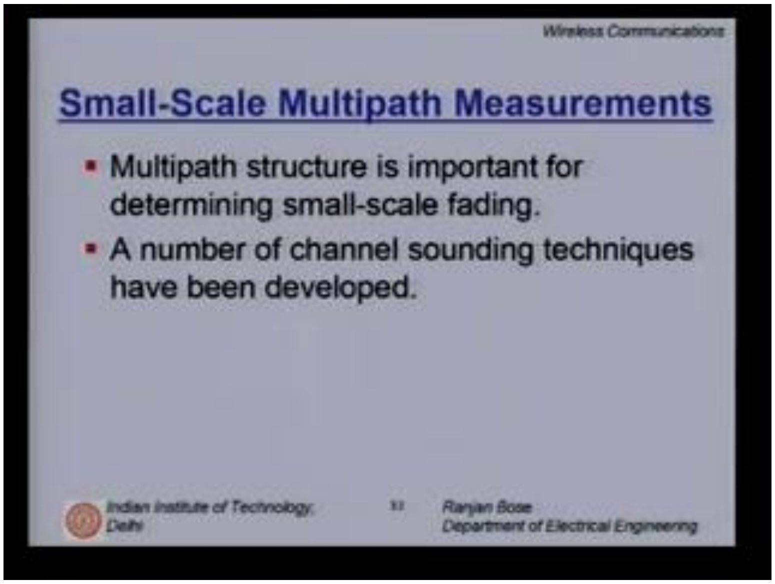

Small-Scale Multipath Measurements

- Multipath structure is important for determining small-scale fading.
- A number of channel sounding techniques have been developed.

Now let us come to today’s topic which deals with multipath measurements.how does the channel actually behave when we prove it with a certain kind of signal. Please note: multipath structure is important for determining the small scale fading. We are not concerned here for the long term fading. We are just talking about the small scale fading. A number of channels sounding techniques have been developed over the years to look at the channel impulse response. They can be broadly classified into time domain channel measurement techniques and frequency domain channel sounding techniques. Three specific techniques that we will talk about today are as follows.

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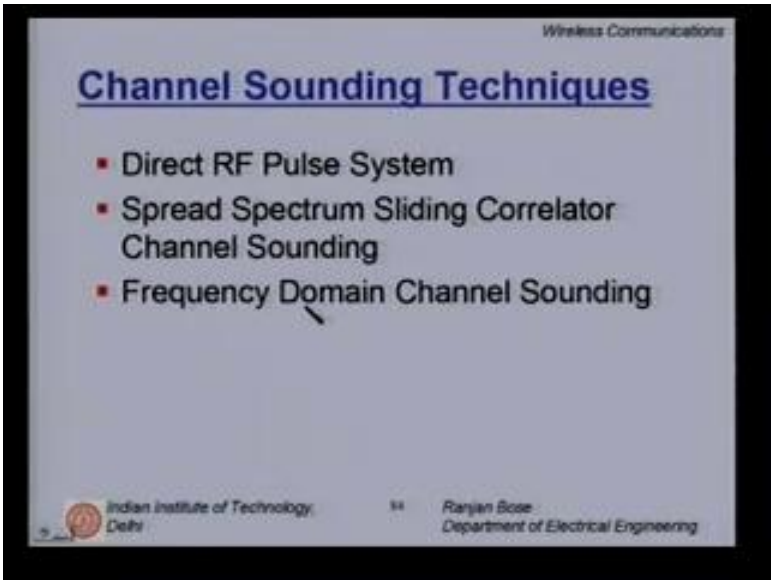

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Channel Sounding Techniques

- Direct RF Pulse System
- Spread Spectrum Sliding Correlator Channel Sounding
- Frequency Domain Channel Sounding

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The first one is direct RF pulse system. Here, we use a very narrow pulse to probe the channel and the impulse response is obtained directly. The other technique is Spread Spectrum Sliding Correlator Channel Sounding technique. Here, there are two terms that is of importance.one is the spread spectrum. We make use of a pseudo random noise sequence - a PN sequence to spread our signal. We use a very interesting concept of a sliding correlator at the receiver in order to obtain the channel characteristics. We will talk about it in detail. The third one is a frequency domain channel sounding technique. We can use this also to find out the channel impulse response because of the duality of frequency and time. So we can measure the channel either in time domain or frequency domain. We will talk about the frequency domain channel sounding technique also.

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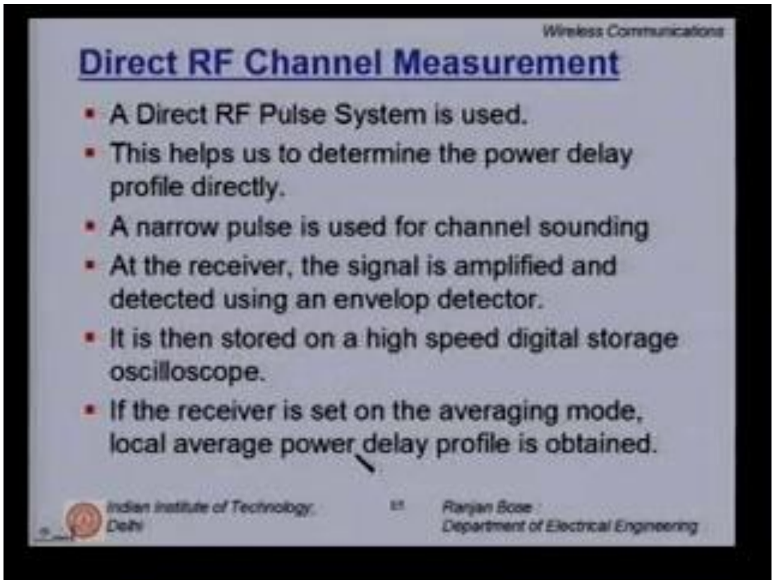

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Direct RF Channel Measurement

- A Direct RF Pulse System is used.
- This helps us to determine the power delay profile directly.
- A narrow pulse is used for channel sounding
- At the receiver, the signal is amplified and detected using an envelop detector.
- It is then stored on a high speed digital storage oscilloscope.
- If the receiver is set on the averaging mode, local average power delay profile is obtained.

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So let us first consider the direct RF radio frequency channel measurement technique.in this technique we simply use a direct RF pulse. So we will say a direct RF pulse system is used.this helps us to determine the power delay profile directly. Please remember our objective here is to find out the impulse response of the channel. Later on, if you have to use some kind of a deterministic modeling or do some kind of a ray tracing, then this kind of a channel model will be useful. What is used is a narrow pulse. Simulating almost an impulse.

A narrow pulse is used for channel sounding.at the receiver, the signal is amplified and detected using an envelope detector. Now please note the moment we bring into effect an envelope detector, we tend to lose out the phase information. Whereas, it is important for us to measure both the amplitude and phase. Once we detect the signal and amplify it, we then store it on a high speed digital storage oscilloscope. If the receiver which is your antenna followed by an envelope detector, then followed by an oscilloscope is set on an averaging mode, the local average power delay profile is then obtained.in most cases we are interested in the local average power delay profile.

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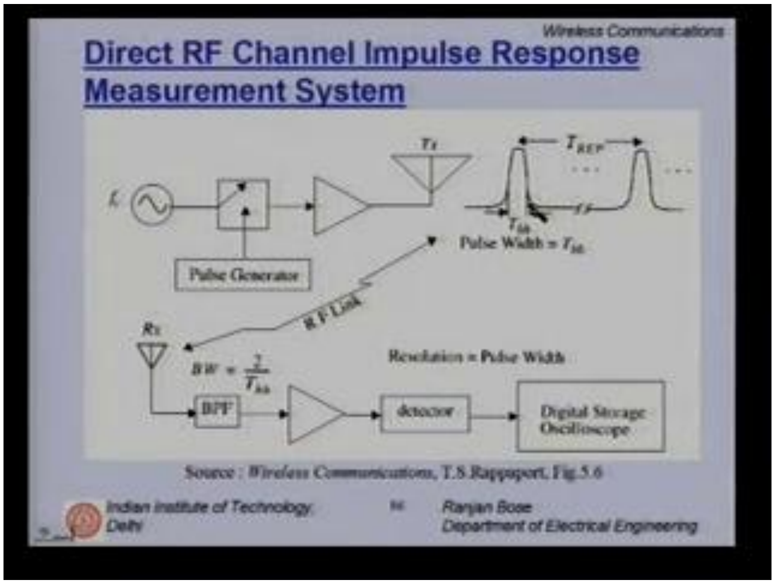

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Direct RF Channel Impulse Response Measurement System

Source : *Wireless Communications*, T.S.Rappaport, Fig.5.6

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Let us look at a measurement set up.so on the top; I have put the transmitter portion. There is a carrier wave which is being modulated with a pulse generator and then amplified and sent through a transmit antenna. So what I have are very narrow pulses. the pulse width is T_{bb} and clearly if I am doing a channel sounding within a room, they are a few nanoseconds wide. Then there is a pulse repetition frequency or the pulse repetition duration t_{rep} which deals with how soon the next pulse comes. This distance is kept keeping in mind the delay spread of the environment. In a room environment, ti can keep t_{rep} smaller whereas outdoors, I have to increase the t rep. on the other hand; I have a receiver where there is a receiver antenna. Then a band pass filter whose bandwidth is 2 over T_{bb} where T_{bb} is the pulse width. Then there is an amplifier followed by a detector. This is usually an envelope detector. But here we could also replace it by a coherent detector. It has its own problems. But let's put for the sake of simplicity, just an envelope detector here followed by the digital storage oscilloscope. So this set up is sufficient to directly measure the channel impulse response and the average power delay profile. we will talk about what the constraints on the pulse width, etc. are.

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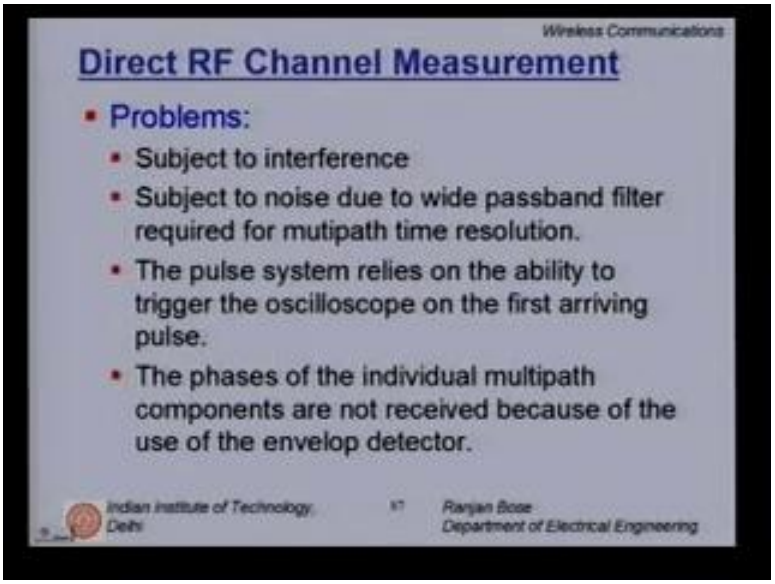

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Direct RF Channel Measurement

- Problems:
    - Subject to interference
    - Subject to noise due to wide passband filter required for mutipath time resolution.
    - The pulse system relies on the ability to trigger the oscilloscope on the first arriving pulse.
    - The phases of the individual multipath components are not received because of the use of the envelop detector.

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Let us talk about the general problems with this technique. First of all, this method is subject to interference. It is also subject to noise due to the wide passband filter required for multipath time resolution. Please note that this direct RF channel measurement technique essentially is using a wideband pulse. What is happening is you have to have a wideband receiver. Otherwise it doesn’t make sense. But the moment you have a wideband receiver, you bring in all the interference and all the noise. There is no way to eliminate that. We can really do the elimination in the second technique which we will study after this. So interference and noise will form a major impediment. Now the pulse system relies on the ability to trigger the oscilloscope on the first arriving pulse. If you fail to do so, then you are lost. Sometimes, the first arriving pulse may not be the strongest. The other problem is the phases of the individual multipath components are not received because of the use of an envelope detector. Of course you can make a system more complicated by employing a coherent detector. But these are generally the problems associated with direct RF channel measurement. Of course the flip side is that you directly get the channel impulse response. There is no requirement of post processing. What you see is the actual channel impulse response on the oscilloscope.

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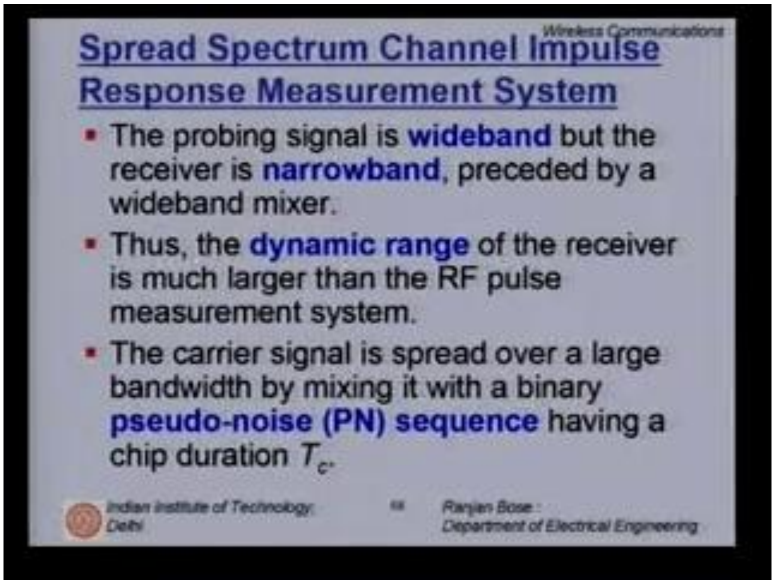

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Spread Spectrum Channel Impulse Response Measurement System

- The probing signal is **wideband** but the receiver is **narrowband**, preceded by a wideband mixer.
- Thus, the **dynamic range** of the receiver is much larger than the RF pulse measurement system.
- The carrier signal is spread over a large bandwidth by mixing it with a binary **pseudo-noise (PN) sequence** having a chip duration T_c.

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Now we move to the next technique which is called the spread spectrum channel impulse response measurement system. It promises to overcome some of the problems associated with the direct RF channel measurement technique although this technique also works in the time domain. Here, the probing signal is wideband. Please remember in the previous lectures we have seen that if we have a channel response model, we must use a wideband technique to do the measurements because that will take care of all the subsequent frequency bands. The channel impulse response measurement will be able to address all the narrowband scenarios as well. We probe the signal using a wideband pulse but the receiver is narrow band preceded by a wideband mixer. So the mixer at the receiver is wideband. However the receiver itself is a narrow band because we deploy a narrowband filter. What is the advantage? The dynamic range of the receiver is much larger than the RF pulse measurement system. There are ways and means already put in here to reject extra noise and interference.my receiver is in principle, narrowband. What is done is the carrier signal is spread over a large bandwidth by simply mixing it with a binary pseudo noise sequence- a PN sequence having a chip duration Tc. we will soon see what is the advantage of doing this kind of a mixing which actually spreads the signal.

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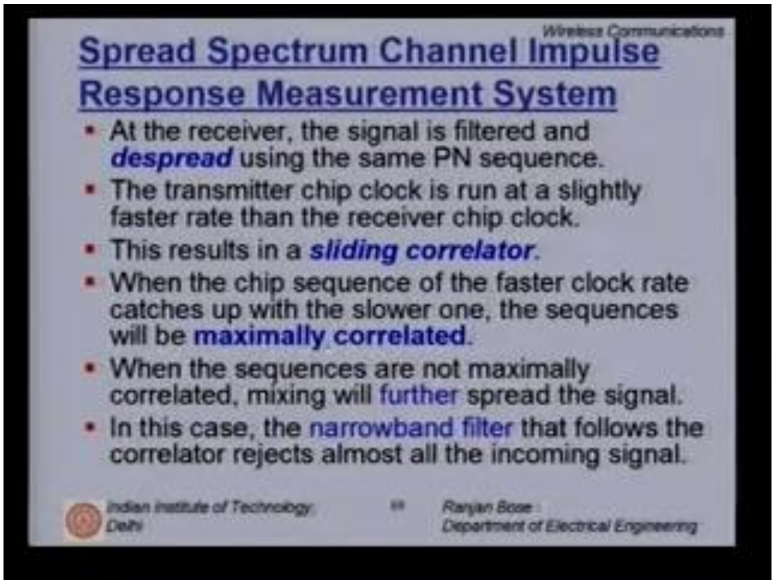

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Spread Spectrum Channel Impulse Response Measurement System

- At the receiver, the signal is filtered and ***despread*** using the same PN sequence.
- The transmitter chip clock is run at a slightly faster rate than the receiver chip clock.
- This results in a ***sliding correlator***.
- When the chip sequence of the faster clock rate catches up with the slower one, the sequences will be **maximally correlated**.
- When the sequences are not maximally correlated, mixing will further spread the signal.
- In this case, the narrowband filter that follows the correlator rejects almost all the incoming signal.

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At the receiver the signal is filtered and despread using the same PN sequence.so if you have a PN sequence that you multiply a signal with, its spreads the signal clearly. because the chip duration is very small which means it is a wideband signal that you are mixing with at the receiver if you use the same PN sequence perfectly synchronized then you recover back your original signal you despread it. On the other hand, if you are dispreading it with a wrong PN sequence then it spreads further. you cannot despread it. however please remember we have put a narrowband filter at the receiver which will only collect energy coming in the required band.so the transmitted chip clock is run at a slightly faster rate than the receiver chip clock. this is done to ensure that synchronization is not an issue. clearly the PN sequence at a transmitter and receiver must match and synchronize so that I can effectively despread my signal. but synchronization is clearly a problem. the simple way to overcome this problem is to ensure that the transmitted chip clock runs at a higher rate. so eventually the receiver signal will be caught up by the transmitter signal. this results in a sliding correlator. when the chip sequence of the faster clock rate catches up with the slower one, the sequence will be maximally correlated and at that time, we effectively despread a signal. in all other cases we do not and the pass band filter takes into account the signal which is supposed to be taken in. when the sequences are not maximally correlated, that is, we have not been able to synchronize properly and the transmitted clock is yet to catch up with the receiver clock, mixing will further spread the signal. in this case the narrowband filter that follows the correlator rejects all the incoming signal.so I am only in business when the maximal correlation takes place when the PN sequences are exactly synchronized. we do not have to worry about the synchronization issues. please remember in most channel sounding techniques we do not have the luxury to run a wire from the transmitter to the receiver to synchronize. they are spatially apart. only then we are measuring the channel. So if synchronization was of consequence, then the system would become very complicated.so this sliding correlated method makes you do the task without the need of synchronization. it’s a major plus point.

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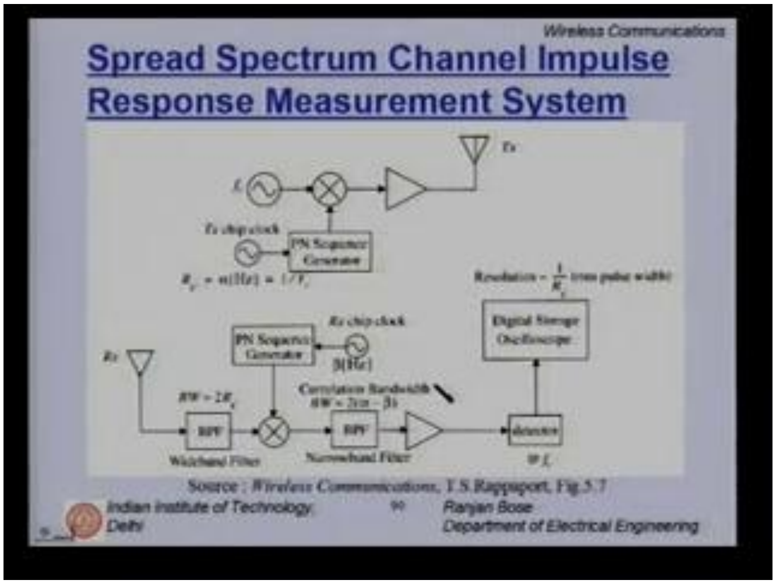

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Spread Spectrum Channel Impulse Response Measurement System

Source : *Wireless Communications*, T.S.Rappaport, Fig.5.7

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Let us now look at the block diagram of the spread spectrum channel impulse response measurement system. We have a PN sequence generator running at a certain clock rate. Let’s call it alpha. Then the signal is multiplied or mixed with the PN sequence generator so as to obtain a wideband spread sequence. It’s amplified and transmitted.at the receiver, we have a band pass filter whose bandwidth is 2 times Rc. what is Rc? It is nothing but one over Tc,Tc being the chip interval. Now this PN sequence generator at the receiver.it has a same PN sequence. It multiplies with the received signal and then goes to another band pass filter.

Now only when this PN sequence coincides exactly with the PN sequence being used here without any phase shift, does the despreading occur.in all other cases this band pass filter will reject the extraneous power. It is then amplified and passes through a detector. Then it is put into a storage oscilloscope. Please note that the chip clock rate here is beta which is different from alpha here. In general alpha is slightly larger than beta. Alpha and beta can be used together to calculate something called as a sliding rate which tells us how fast is a sliding correlator moving. If it is fast enough, there will be a time that you will catch up with this clock rate. Finally you will get a maximal correlation. This method overcomes the effect of a wideband receiver. It’s clearly not wideband. It is a narrowband and rejects all the extraneous interference and noise.so it’s a preferred way to do things. Clearly you need to do some processing.

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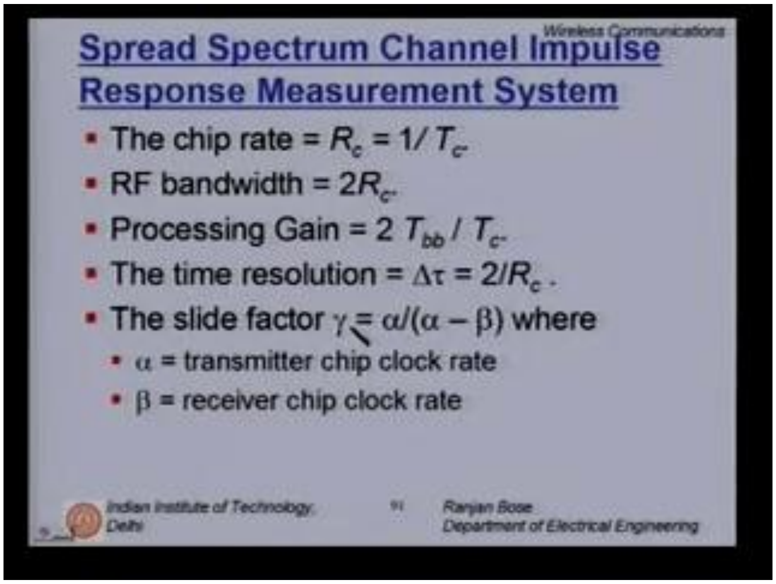

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Spread Spectrum Channel Impulse Response Measurement System

- The chip rate = $R_c = 1/T_c$.
- RF bandwidth = $2R_c$.
- Processing Gain = $2\ T_{bb}/T_c$.
- The time resolution = $\Delta\tau = 2/R_c$.
- The slide factor $\gamma = \alpha/(\alpha - \beta)$ where
  - α = transmitter chip clock rate
  - β = receiver chip clock rate

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So what are the parameters that we use for this spread spectrum channel impulse response measurement system? We have the chip rate Rc given by 1 over Tc. the RF bandwidth is two times Rc. the processing gain, the gain that you obtain because of the spreading and despreading is 2Tbb, Tbb is the width of the signal divided by Tc, the chip duration. The time resolution that you obtain delta tau is 2 over Rc.so it is clearly linked with the Tc. this time resolution is about the resolution in time that you do for a channel impulse response measurement. So better the resolution, more multipath components you can resolve.so this chip interval clearly has a bearing on the accuracy of your impulse response that you measure. the slide factor ‘gamma’ is given by alpha divided by alpha – beta, where alpha is a transmitter chip clock rate and beta is the receiver chip clock rate.as suggested before, alpha is slightly larger than beta and gamma is greater than 1.

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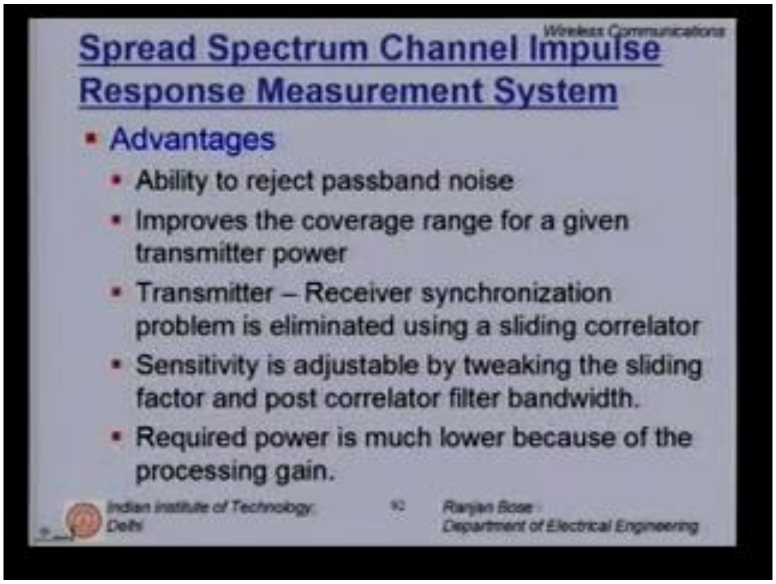

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Spread Spectrum Channel Impulse Response Measurement System

- Advantages
  - Ability to reject passband noise
  - Improves the coverage range for a given transmitter power
  - Transmitter – Receiver synchronization problem is eliminated using a sliding correlator
  - Sensitivity is adjustable by tweaking the sliding factor and post correlator filter bandwidth.
  - Required power is much lower because of the processing gain.

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What are the advantages of this spread spectrum channel impulse response measurement technique? First of all, the most important advantage is the ability to reject pass band noise because the receiver inherently is narrowband. It improves the coverage range for a given transmitter power. I am no longer limited by noise. I can increase the spacing of my transmitter and receiver. I can increase the coverage for the same transmitter power. It's a big advantage. Otherwise very soon the received signal tends to get cluttered by noise. The transmitter-receiver synchronization problem is eliminated using this sliding correlator.so we can really spatially separate the transmitter and receiver without worrying about the synchronization. It's an important advantage.

Then, the sensitivity of the measurements is adjustable by tweaking the sliding factor and the post correlator filter bandwidth. The required power is much lower because of the processing gain.so we have inherently a processing gain which is obtained by despreading the signal. That helps us and the required power is actually much lower in comparison to the RF direct measurement technique. So clearly this spread spectrum channel impulse response measurement system is better than the direct RF method although in the direct RF measurement technique we obtain the channel impulse response directly. There is no post processing required.

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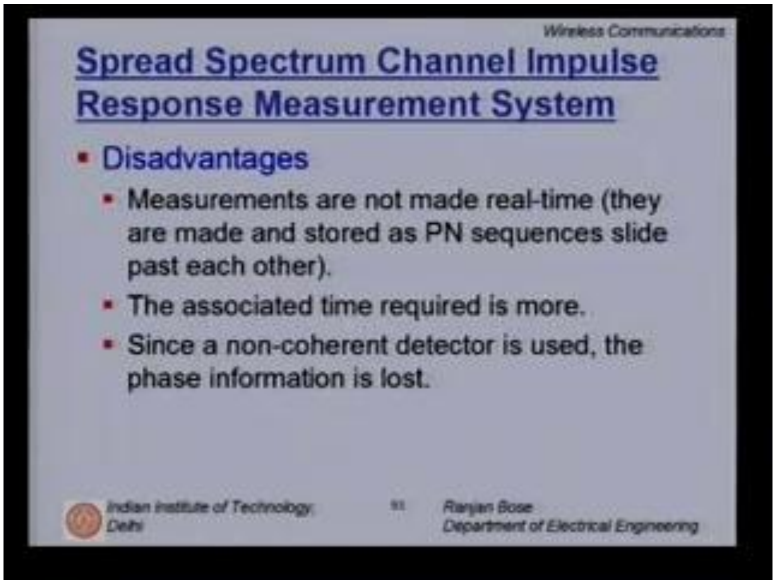

Spread Spectrum Channel Impulse Response Measurement System

- Disadvantages
  - Measurements are not made real-time (they are made and stored as PN sequences slide past each other).
  - The associated time required is more.
  - Since a non-coherent detector is used, the phase information is lost.

Let us look at the disadvantages of spread spectrum channel impulse response measurement system. The measurements are not made real time. They are made and stored we showed a storage digital oscilloscope. So the measurements are stored as the PN sequences slide past one another. Somewhere in the sliding process, the maximum correlation takes place. Only when the entire sliding process is over can we take out the data, process it and find out what is the channel impulse response. The associated time required is more. Clearly, if you have to take many measurements at many places, then this becomes a much slower process as compared to the direct RF pulse measurement technique. Since a non-coherent detector is used again, the phase information is lost. We have to do something about the space information. We are only getting part of the information.

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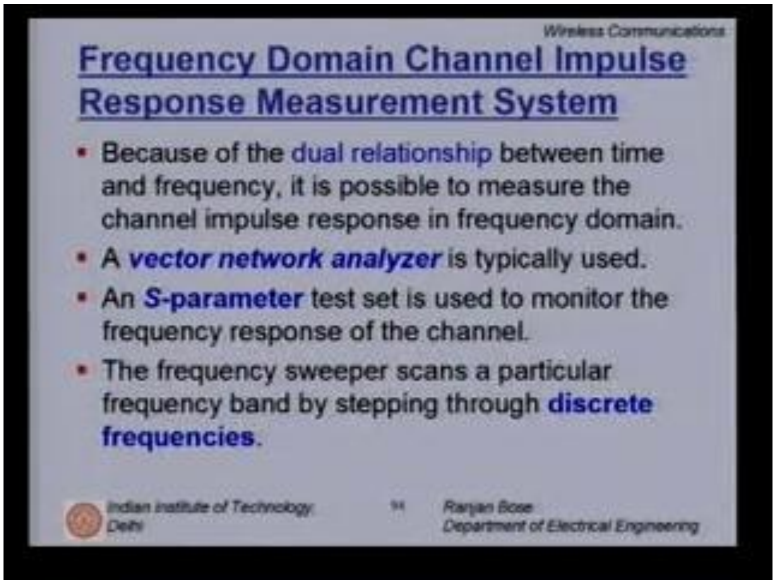

Frequency Domain Channel Impulse Response Measurement System

- Because of the dual relationship between time and frequency, it is possible to measure the channel impulse response in frequency domain.
- A ***vector network analyzer*** is typically used.
- An ***S*-parameter** test set is used to monitor the frequency response of the channel.
- The frequency sweeper scans a particular frequency band by stepping through **discrete frequencies**.

Now let us look at the third technique. This third technique works on the basic dual relationship between time and frequency. Lately this technique has become one of the very popular techniques for indoor wireless channel measurements. There are certain constraints we will see for this frequency domain channel impulse response measurement system which will force at not to separate the transmitter and a receiver too much. so because of the dual relationship between the time and frequency, it is possible to measure the channel impulse response in frequency domain and then simply take the inverse Fourier transform to obtain the time domain channel impulse response. Normally, a vector network analyzer is used. An S-parameter test set is used to monitor the frequency response of the channel.

The frequency sweeper scans a particular frequency band by stepping through discrete frequencies. Please note a couple of things. The entire measurement is being done in the frequency domain. So the vector network analyzer has a frequency sweeper for which you can set the start frequency and the stop frequency. That is your band of interest. Clearly this is different from a time domain measurement where you did not have to specify a desired band to measure. This is not a bad constraint because you carry out channel measurements for a certain application or a certain frequency band. So first you have to tell the frequencies sweeper what is the start and what is the stop point for the bandwidth over which you are going to sweep. Then the next question of importance is: what is your step size? It's not a continuous sweep. There are discrete steps. Now the step size will have a direct bearing on the accuracy of the measurement of a channel. We will talk about this. But what is important is to note that the frequency band is swept by stepping through discrete frequencies.

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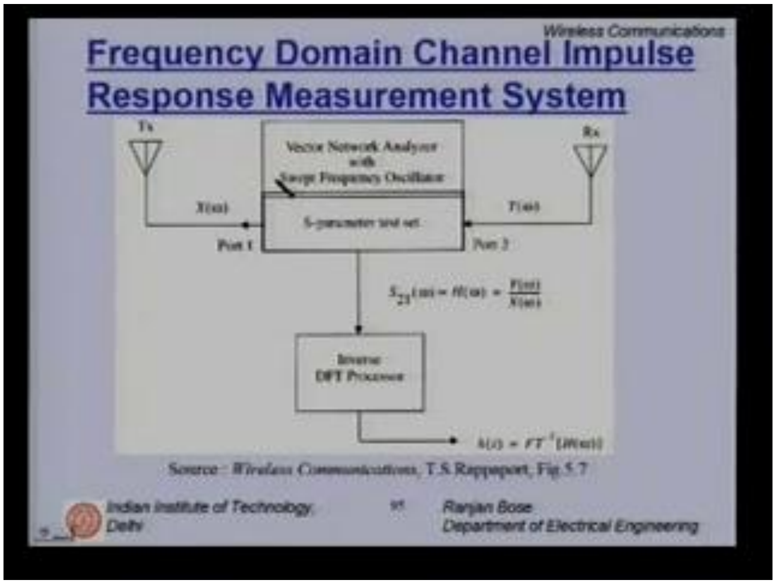

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Frequency Domain Channel Impulse Response Measurement System

Source : *Wireless Communications*, T.S Rappaport, Fig 5.7

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Let us look at the block diagram. Here, what is interesting is, in the centre we have the vector network analyzer with swept frequency oscillator. This is where you fix the start frequency and the end point. Then you have an S parameter test set. The transmitter and receiver are both connected to the vector network analyzer. So this will put the first constraint on the maximal separation that is possible between the transmitter and receiver. Both have to be connected to the vector network analyzer.

Only then we can carry out our S $_{21}$ measurement which is nothing but the transfer function. S21omega is the transfer function. H of omega is nothing but y omega divided by x omega. If we have this, this would be a complex measurement. Then the inverse Fourier transform here will be the channel impulse response. It is a smart technique. You avoid the time domain problems. You have to have a synchronized transmitter and receiver. You must have an S-parameter test set but other than that, it’s clearly mechanical. So, if you carry out this measurement, you fix the location of a transmitter and usually the vector network analyzer is kept much closer to the transmitter. You have to have a longer cable which connects the receiver.

The losses in the cable have to be accounted for because; if the distance between the transmitter and receiver has to be increased then the cable should be long enough. Usually some characterization of this system is done before you go ahead and take the final measurements. Clearly this system is not real time in terms of giving you the channel impulse response. You do a lot of measurements, then finally you take the inverse Fourier transform and obtain the channel impulse response. Also note that this method requires you to first take a lot of measurements. Suppose, I want to really find out the small scale fading characteristics of this room, then I will fix the transmitter at a certain location. Then the receiver will be moved around over a grid. So we first mark a grid on the floor, keep the receiver at grid location1, then carry the entire sweep for that one particular grid location.so maybe we will have say 1600 points being stepped from start of frequency to end of frequency. Now not only that, for every frequency point you would like to average the data because the channel itself might be changing.in fact that is a major issue here. What happens if during my stepping process, during my sweeping over the frequency the channel changes? Then my measurement is irrelevant. There are ways and means to overcome that and of course an associated cause. But in general, we do not take just one single measurement for a typical frequency. As we step along the frequency axis, for every step, we take hundreds of measurements and average them over. Once we do this entire stepping from frequency start band to frequency stop band, then we go to the next receiver location and repeat the entire exercise. So this is how frequency domain channel impulse response measurement is done.

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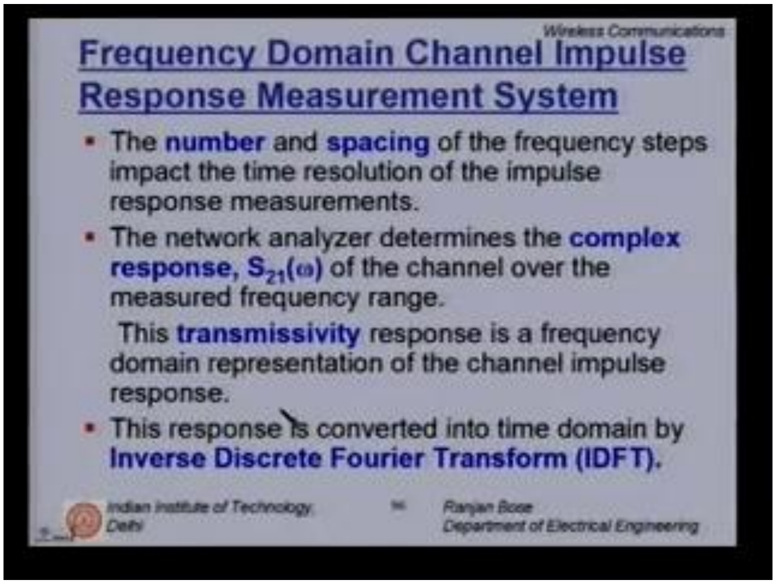

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Frequency Domain Channel Impulse Response Measurement System

- The **number** and **spacing** of the frequency steps impact the time resolution of the impulse response measurements.
- The network analyzer determines the **complex response, $S_{21}(\omega)$** of the channel over the measured frequency range.

  This **transmissivity** response is a frequency domain representation of the channel impulse response.
- This response is converted into time domain by **Inverse Discrete Fourier Transform (IDFT).**

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Now the number and spacing of the frequency steps impact the time resolution of the impulse response measurement. Remember the time resolution is related to your excess delay spread and how much of energy you are getting in different multipath components. The network analyzer determines the complex response S 21 of omega of the channel over the measured frequency range. This transmissivity response is a frequency domain representation of the channel impulse response. This response is converted into time domain simply by taking the inverse discrete Fourier transform- IDFT.

Now what is interesting is the moment you take IDFT, suppose you had 128 points frequency domain samples, you take IDFT and you get another 128 points time domain response. Now what will happen is all the points will have some values. Clearly when you take IDFT you will get some values however small in most of the time slots. However that doesn’t mean that all bins are getting some energy out. If you use a proper thresholding method you will be able to see what are the bins which get energy and what are the time bins which do not have any energy. So you have to be a little careful when you take the IDFT. There is some amount of post processing analysis required before you come to the correct channel impulse response. for the time being, this is a theoretical statement that this response is converted into time domain simply by taking the inverse discrete Fourier transform.

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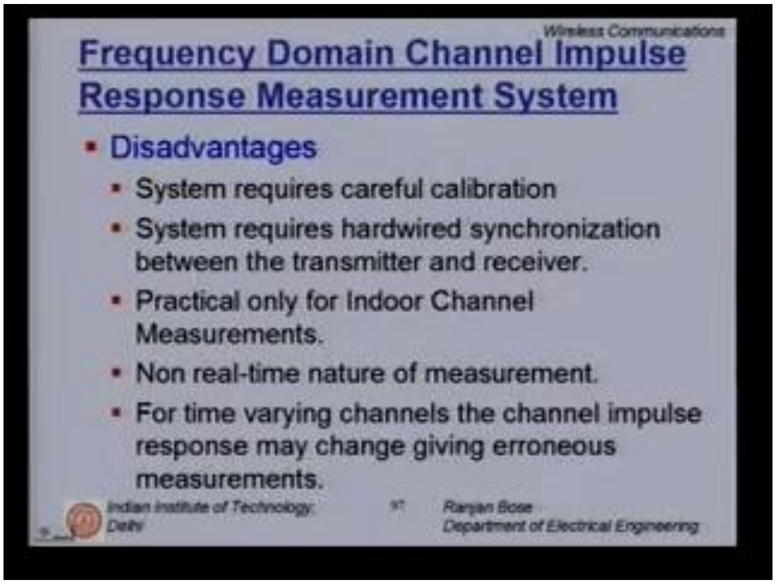

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Frequency Domain Channel Impulse Response Measurement System

- Disadvantages
  - System requires careful calibration
  - System requires hardwired synchronization between the transmitter and receiver.
  - Practical only for Indoor Channel Measurements.
  - Non real-time nature of measurement.
  - For time varying channels the channel impulse response may change giving erroneous measurements.

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What are the disadvantages? The system requires careful calibration. What do you mean by careful calibration? We have the transmitter antenna the receiver antenna and then their long cable associated with it. Then there are connectors so all the losses have to be taken into consideration before you start your actual measurements. Calibration is a problem. The system requires hardwired synchronization. As mentioned before the transmitter and the receiver both are connected to the vector network analyzer which means that the maximum distance between the transmitter and receiver is limited. I cannot use this technique to carry out a channel measurement outdoors when the separation of transmitter and receiver is 1 km. I cannot have such long cables.

So it is practical only for indoor channel measurements. In fact it is very preferred for indoor channel measurements. However, the other disadvantage is non-real-time nature of the measurement so we are carrying out these kinds of measurement in house and IIT for ultra-wideband channel measurements and what is done is first a lot of data is just taken. Suspense exists till we go download the data and then do the post processing and then find out the channel impulse response. If something is wrong, we go back and redo the measurements again. So this is the real disadvantage of this frequency domain channel impulse response measurement system. For time varying channels, the channel impulse response may change giving erroneous measurement. This is a big problem. If the channel is time varying and many indoor wireless channels are time varying, then the channel may change while you are taking the measurement. That’s unfair.

The measurement loses its credibility because when you started of your sweep the channel had a different H of t impulse response. By the time you finished the measurement the H of t has changed. Clearly this measurement will not be valid. So we have to speed up the process. But you cannot speed up the process faster than what your vector network analyzer allows you to do. So what you do? You cut corners. You increase the step size. How else will I reduce my sweep time I will take larger and larger steps over the frequency band so as to quickly complete my scan. If I take larger frequency steps, I pay in terms of time resolution. So somewhere we have to draw a line. Please remember channel sounding is an art which comes with practice. Once you carry out these practical measurements, you realize the practical difficulties associated with it. So what is the solution?

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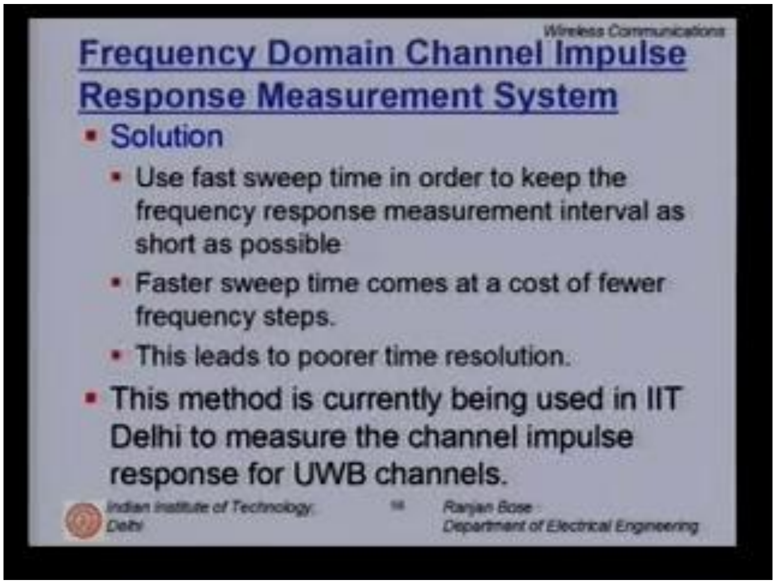

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Frequency Domain Channel Impulse Response Measurement System

- Solution
  - Use fast sweep time in order to keep the frequency response measurement interval as short as possible
  - Faster sweep time comes at a cost of fewer frequency steps.
  - This leads to poorer time resolution.
- This method is currently being used in IIT Delhi to measure the channel impulse response for UWB channels.

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The solution about the time varying channel is use fast sweep time in order to keep the frequency response measurement interval as short as possible. But faster sweep time comes at a cost. What is the cost? Fewer frequency steps, larger frequency steps and poorer frequency resolution. This leads to poorer time resolution. This frequency domain channel impulse response measurement is currently being used in IIT Delhi to measure the channel impulse response of ultra-wideband channels from 3.1 to 10.6 GHz. again practical systems have a lot of difficulties. For example your antenna must be wideband.

The antenna characteristic should be relatively flat and unchanging over the entire frequency band. Then how do you take the measurements will the deductionality of your antennas effect the system? Your answer will be different if you are half power beam width is small as opposed to an omnidirectional antenna. You will get many more multipath components if your half power beam width of your antenna is larger. Typically for UWB example you would like to have an omnidirectional antenna. Then you have to calibrate your system. So all these practical things have to be kept into consideration while taking these measurements. So this is a nice place to stop today. I'll summarize the various techniques that we have learnt.

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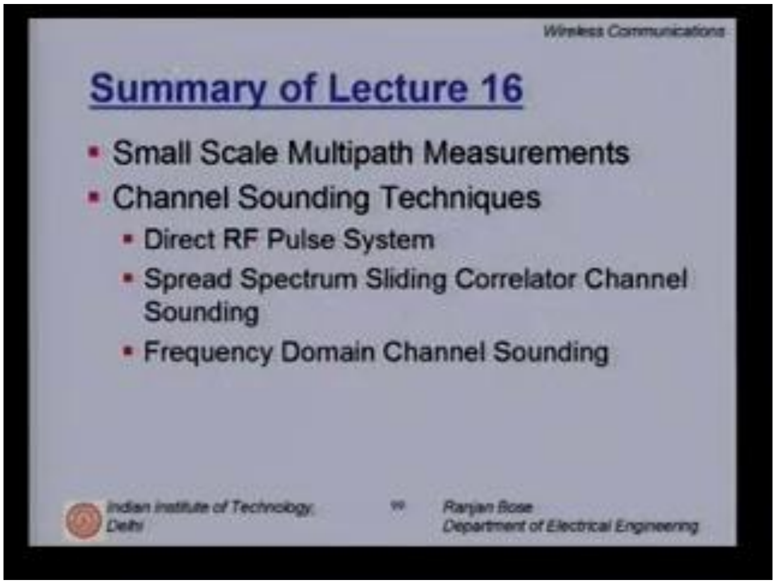

Wireless Communications

Summary of Lecture 16

- Small Scale Multipath Measurements
- Channel Sounding Techniques
  - Direct RF Pulse System
  - Spread Spectrum Sliding Correlator Channel Sounding
  - Frequency Domain Channel Sounding

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Today's lecture has focused on small scale multipath measurements. We looked at various channel sounding techniques. We started off with RF pulse system where we saw that RF narrow pulses could directly give you the channel impulse response of the system. It is a direct method. It doesn't take much time but it has a problem. The problem is it is a wide receiver band and it takes into the system all the noise and interference. So interference and noise is a problem. This forces the system to take measurements not of long channels, that is, you can have the transmitted receiver separation only up to a certain amount provided you do not increase the power of the transmitter. Some of these problems of the direct RF pulse system are addressed for in the case of spread spectrum sliding correlator channel sounding technique. Here we use a PN sequence. We first spread the signal. At the receiver we despread it, pass it through a narrowband filter and then process it.

The use of sliding correlator, we saw that it makes it redundant to have a synchronization between the transmitter and receiver. Also the spread spectrum technique removes the problem of extra noise and interference. The first two techniques we studied were the time domain. Then we looked at another technique, the frequency domain channel sounding technique. Here we have vector network analyzer. The problem is the transmitter and receiver must be synchronized. It should be hardwired to the vector network analyzer. This puts a constraint on the maximal separation allowable between the transmitter and the receiver. However this technique is popular for indoor channel measurements. So these are the three popular techniques.

The last one is being currently employed in IIT for ultra-wideband channel measurements. We will conclude here and may be in one of the subsequent lectures we can discuss the actual measurements being carried out for ultra-wideband channel measurements in IIT which gives us a practical perspective to these slides.