CMOS RF Integrated Circuits
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Module - 09
Mixers
Lecture - 27
Mixer Non – Idealities (Contd.) Oscillators Introduction

Today lecture 27 this is we are kind of in between modules nine and ten. So, the goal of this lecture is to wrap up the discussion on mixers and move on to oscillators now while we are transitioning from 1 module to another you will find out how these 2 connect with each other alright. So, in the last class we develop the superheterodyne architecture right and reason why we develop that was to accommodate for 1 of the important non idealities that arise out of this mixing operation it is a d c offset right.

So, any kind of local oscillator leakage into the R f port of the mixture will cause a d c offset and this d c offset has drastic it really creates a drastic performance variation as far as direct down conversion receivers are concerned right. So, because this particular local oscillator leakage is variable it varies with the process from process to process varies over temperature it varies with the parasitic right as a result this leakage is variable.

Now, if the leakage is variable the d c offset is also variable and it is something we cannot tolerate because under the direct down conversion you are actually translating the signal all the way to d c and if you have a d c offset on top of that and that is going to cause problems. So, that is why we went to super heterodyne architecture and why called it super heterodyne architecture because you can have multiple heterodyne stages you can have 1 IF stage you can have a second IF stage a third IF stage and. So, on and. So, forth sophisticated radials have I have seen up to 3 IF stages in sophisticated extremely sophisticated radials could have 3 intermediate frequencies. So, 3 heterodyne stages. So, all called super heterodyne right.

The reason why we have these multiple intermediate frequencies they are not just 1 is because of is because of the image frequency because every time you do a heterodyne stage there exists an image frequency which can also translate to a frequency which is the IF frequency. So, if there is a blocker at the image frequency then the blocker will go right on top of the desired frequency and will cause interference right. So, this is the reason why we need to put an image filter before we do the mixing operation.

Now, the image filter has certain limitations it cannot be a extremely high quality factor right we can afford to make a filter of a quality factor of 10 right which means that there is a certain restriction on where the image frequency can be in relation to the R f frequency I am sorry not image fre[quency]- yes where the image frequency can be in relation to desired frequency. Now, this means that there is a restriction on what the IF that is the intermediate frequency can be with respect to the R f and because of this we went for multiple heterodyne stages that is the super heterodyne right.

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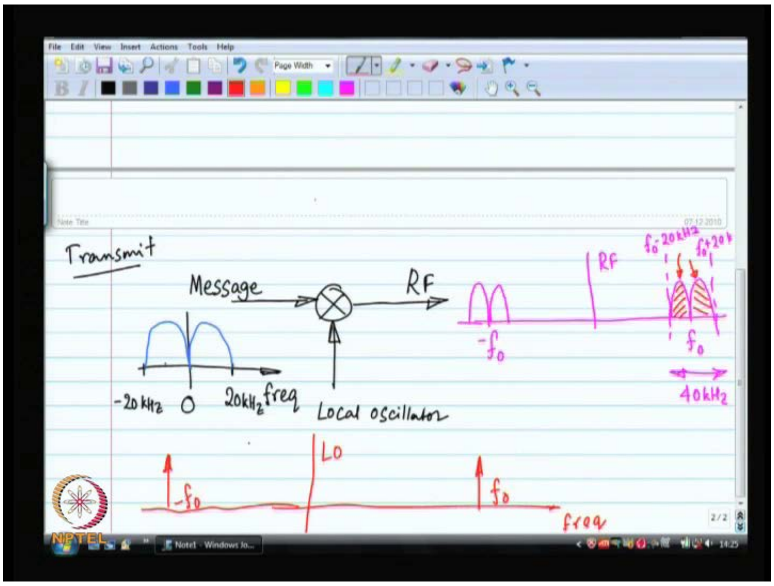

Now, with this background the next problem that we have not really a problem more like a suggestion think about this let us talk about the transmit path ok. So, in the transmit path this particular signal is not a R f here this is the message and over here we have got the local oscillator and this is the R f output alright. So, this is the scenario in the transmit path now this message that we are talking about suppose its voice yes crude assumption it is no longer a voice is no longer directly sent like that, but anyway let say its voice right it its voice then the spectrum of message is something like this.

So, x axis is frequency axis and if you look at how the signal is the signal will look something like this right this is typical for a voice signal it is going to be restricted to twenty kilohertz because humans speech or even a music does not content ah frequencies beyond twenty kilohertz and there is also a lower lower cutoff. Lower cutoff is around twenty hertz forty hertz something like that you normally do not hear frequencies below that below that whales can communicate at even lower frequencies human begins cannot and bats can communicate at frequencies higher than twenty kilohertz human beings cannot that is ultrasonic and subsonic right ultrasonic is bats can communicate beyond twenty kilohertz whales can communicate below twenty hertz also human beings cannot human beings speak within twenty hertz and twenty kilohertz something like that alright.

So, this is the characteristic of voice or music audio now when you translate this to R f let say that the local oscillator it is a cosine omega t right it has 2 impulses R plus minus f naught right this is the fourier transform of the local oscillator and when you do a mixing operation of this particular local oscillator with this particular message what you wish to get or what you are going to get you are going to convolve the spectrum of the local oscillator with the spectrum of the message and when you do the convolution operation this is what you are going to get you are going to get modulation of the message to the R f frequency to the local oscillator frequency.

So, around f naught you will get 2 side lobes now the suggestion this came is that term this is wasteful. So, why this is wasteful is because this is f naught minus twenty kilohertz and the other 1 is f naught plus twenty kilohertz which means that the net bandwidth that I am using is forth kilohertz right. So, that is why I am saying that is wasteful.

My information contents stuff from 0 to twenty kilohertz, but I am using up a band which is forty kilohertz wide double its wasteful in any case 1 side lobe is the mirror image of the other one. So, there is no new information in the second side lobe right there is nothing new in the other side lobe that is why its wasteful that is that is why I am saying it is no good.

So, the suggestion was that lets get rid of 1 of the 2 and lets transmit only 1 of the 2 side lobes. So, we do not want to transmit both of these spectrum is a valuable resource cost. So, lot of money and you are just wasting half of money over here and its very wasteful no good both the lobs content the same amount of the same information very same thing. So, let gets rid of one Now, it is easy to say let us get rid of 1 it is very difficult to actually get rid of 1 of the 2 how do you propose to get rid of the [-two] 1 of the two. So, lets think about it you know different way

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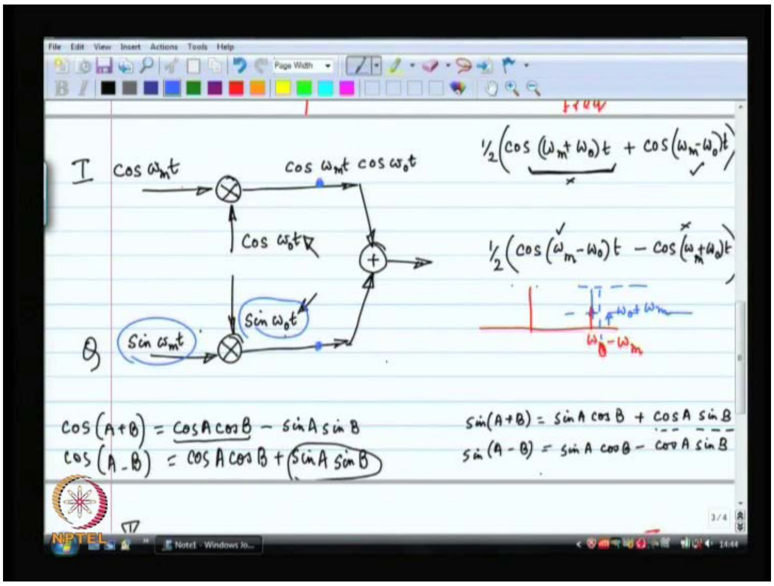

Let say that my message is cosine omega m t omega message t and let say that my local oscillator is cosine omega 0 t when I multiply the 2 I get cos omega m t times cos omega 0 t right and I presume you are the best with your trigonometry and you can split a product of 2 cosines into a sum of 2 cosines. Cos a times cos b is half of cosine a plus b plus cosine a minus b am I right t think I am right. So, this is what happen this is actually what happen when you did the convolution this is just talking about it from a trigonometry point of view as opposed to doing the fourier transform and doing convolution now is there a way to get rid of 1 of their components I like to keep this let say I like to keep this I do not want to keep this 1 there should be a way.

So, what do I need to generate I need to generate cosine omega m plus omega naught t minus cosine omega m minus omega naught t if I can generate this new term and I sum the 2 things then I have got rid of 1 and how do you generate this new term how do you generate this new thing cos a minus cos b is twice you forgotten you're in trigonometry right I will help you. What is this what is sin a times sin b sin a times sin b remember all you have to remember is this ridiculous I am teaching trigonometry in R f electronics class, but what can be done.

So, if you remember just there 2 things and you do not need to remember hundreds of different formulae these 2 are sufficient right you are interested in these particular terms sin a times sin b. So, sin a times sin b is clearly going to be half of cos a minus b plus I am sorry half of cos a minus b minus cos a plus b which is really this right and now if I do a subtractions or an additions of some sort then I get rid of the term that I do not want and I get to keep the term that I want if you do an addition then you do the other way I think I do also addition if you do the addition then this 1 will be cancel out the other 1 is stay that is what will happen if you do an addition of these 2 right

So, this is how you would generate a single sideband modulation system right 1 of these parts called a in phase the other part is called a quadrature phase. So, this is called a cosine is a called in phase the sin is called the quadrature field. So, this is do in transmit side and on the receive side you do something very very similar right you can reconstruct the message is there any problem over here there's a problem.

The problem is there are 2 problems 1 is if my message is cosine omega m how do I generate the sin part of it that is problem number 1 and problem number 2 is if my local oscillator is generating cosine omega naught t and how do I generate sin omega naught t right. So, these are problems 2 different problems well problem number 1 is not very difficult to solve you have to understand that these messages are no longer audio signals we are not talking about audio signals any more these are some form of digital signal its actually coming from a d 2 a convertor right

So, there are going to be a processor which is going to be create this message and if the processor can create the cosine part of the message it can equally create the sin part of the message. So, it is being degenerated by a by some sort of digital signal processor. So, as far as the message is concerned if cosine can be generated the sin can also be generated there's no problem. What about the oscillator the oscillator has to be design in a way that cosine and sin are generated hand in hand you you make your oscillator such that it generates both and in phase and quadrature phase at the same time.

So, in phase 0 degrees quadrature phase in ninety degrees shifted from in phase ninety degree offset from the in phase. So, it is possible to generate to make to design an oscillator which will generate inphase and quadrature phase at the same time right. This is something important when we studied oscillators which we shall start today hopefully we have to make sure that we understand how to generate in phase and quadrature phase together at the same time important do not let me get away without explaining these ideas alright

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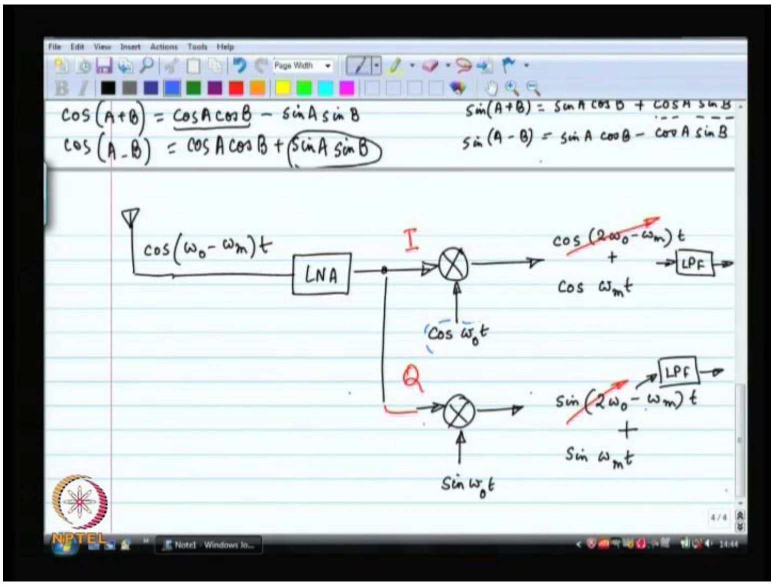

Now, as far as the receiver is concerned let us now think about the receiver the receiver is receiving something from the antenna this is what I am receiving from the antenna and then there is LNA low noise amplifier etcetera etcetera alright and now I want to figure out cosine omega m t that is my message cosine omega m t and sin omega m t as well maybe right that is my message how do you propose to do this I have to do exactly the same thing . So, if I multiply by cosine omega naught t then what am I going to get cosine times cosine.

Cosine times cosine looks like the sum of [two] 2 different cosines the sum of cosine a plus t plus right cosine of minus theta is the same as the cosine of theta what happens if I multiply with a sin cosine times sin what is cosine times sin. Cosine times sin is really looking like let say this particular term right. So, it looks like the difference of 2 sins sin of minus theta is equal to minus of sin theta alright and then if you low pass filter this I can get rid of the high frequency component it is a component of 2 near somewhere near twice omega naught all I need to do is put a low pass filter and I will get rid of that particular component.

So, this component can gotten rid of using a low pass filter. So, can this 1 and what you are going to left with R cosine omega m t and sin omega m t right this is straightforward only problem here is to once again generate cosine omega naught t and sin omega naught t at the same time once again when we design our oscillators we need to learn how to make quadrature oscillators. So, this particular thing is called as I path this is called a q path in phase and quadrature phase there are 2 paths over here right

So, this is the basic idea of in phase and quadrature phase now of course, no 1 really thinks the way I have described to you this is for your basic understanding normally people deal with complex signals they treat the signal like a complex signal and it is like the sin path the quadrature path is what you are doing to the imaginary part of the signal and real part of the signal is the in phase path and. So, on and. So, forth, but this is the more realistic treatment and I hope that if you keep this kind of treatment in mind then when sooner or later you come across a treatment which use a complex numbers for in phase and quadrature phase it with be clear to you right ok.

So, this is 1 particular suggestion the suggestion was why are we doing why are we wasting bandwidth we should be utilizing just about enough bandwidth as there is information the problem of course, the problem is that this cosine and sin generation is never perfect they have to be perfect they are to be exactly nine degrees away from the each other cosine and sin if they are not then you are going to get an image as far as your transmit path is concerned in your transmit path the desired output is over here impulse at omega 0 minus omega m right.

If you do a bad job as far as the quadrature path is concerned then you are going to get an image of this at omega naught plus omega m of course, the image will be smaller than the desired signal because you have done something over there, but because you’ve done a bad job it would not be much lower than the signal it needs to be 0 it would not be 0 because you’ve done a bad job and why have you done a bad job because you’ve done a bad job as far as generating sin omega naught t is concerned you’ve done a bad job over here.

So, maybe you’ve done a bad job at all of these message because you’ve done a bad job there’s going to be. So, many d b of rejection between the in phase path and the quadrature phase path the next thing is that both of these mixtures that you have made you have made 2 mixtures they have to be identical mixtures they have to have the same gain they have to have the same conversion loss right same characteristic otherwise the amplitude of these 2 signals over here are going to be different and if the amplitudes are different and they do not exactly cancel each other which means once again that you have resulted in a bad job as far as the image cancellation goals and you're going to get some image next to the desired signal and you are going to transmit this also right.

So, the the wireless standard that you are following will tell how much this image can be how large it can be how large it can possibly be for your device to be sold in the market right. So, you have to do a good job over there the same scenario is as far as the receiver is concerned its far as the receiver is concerned if there is a mismatch or rather if there is some alignment issue between cosine and sin omega naught t then you are going to receive something in addition what you wanted to receive in the first place.

So, if there is blocker where the image signal is then that blocker is going to come on top of your signal and its going to harm you right and as far as this is concerned it is no hard and fast rule about how large how good your ah quadrature phase has to be with respect to the in band phase yes the in phase, but there it has to perfectly nine degrees or eighty nine degrees is good enough to once goanna to tell you what they are going to tell you is the blockers size this much now do what do you want right the size of the blocker next to your signal desired signal is.

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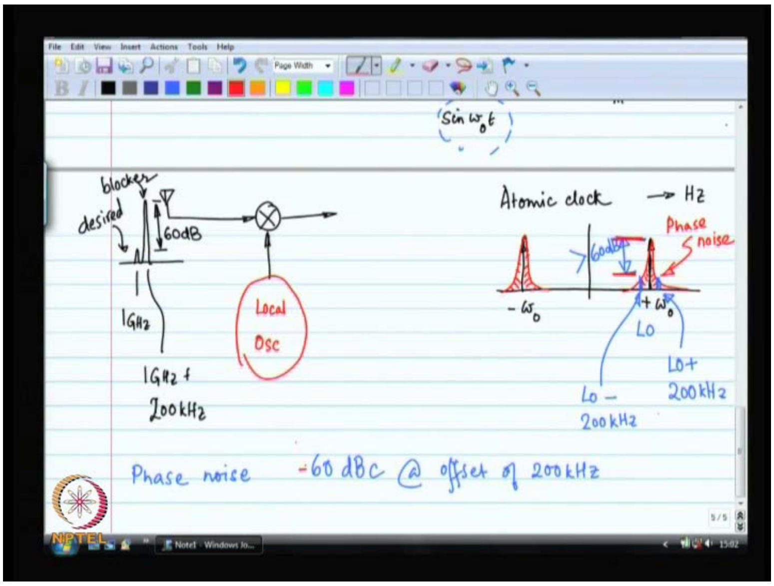

So, big now we will your receiver work if it works it works if it does not it would not sell in the market alright the next thing this particular oscillator that we are talking about the all important oscillator how good can an oscillator be So, the question is if I say I am the base station you are the cell phone base station that is me I am telling you to go to a frequency of 1.254 gigahertz now. Now, you are the handset you go to 1.254 gigahertz according to my wishes because I am going to send you some signal at 1.254 gigahertz; however, your definition of a second is different from my definition of a second because we are not on the same cheep right the transmitter the base station is somewhere and the receiver the handset is somewhere else far away from the base station.

So, the handset has no idea of what the base station means when the base station saying 1.254 gigahertz right the definition of second as far as the handset is concerned could be a little different from the definition of second for the base station which means that the definition of what 1.254 gigahertz means as far as the base station is concerned could be a little different from what the handset thinks which means that instead of going to 1.254 gigahertz maybe the handset goes to 1.254 5 gigahertz.

Is it good it is no good because you have tuned to a wrong frequency and if you have tuned to a wrong frequency then you are not getting all of the signal your entire receiver is gone astray. So, when I talk about 1 second you need to know what exactly that second is we need to have a common definition as far as 1 second is concerned what is the definition of a second you must have read in studied this in your class twelve or something like that class 10 those are definition of a kilogram a definition of a second definition of a meter right some standard or kept in some museum and these are the that is the definition of kilo right some object that is placed in a museum somewhere in london I do not [-know] you remember that and then the second as far as the second was concern it was. So, many oscillations of some krypton or cesium atom remember that cesium atom right.

So, there we go that is the definition of a second you pick your brain I do not remember the exact definition there’s a number of oscillations of a cesium atom or a krypton atom keeps changing from time to time. So, what was that mean. So, there is the cesium atom or krypton atom and its vibrating and it vibrates. So, many times 1 second has elapsed rather the krypton atom is vibrating at. So, many hertz a frequency of. So, many hertz.

So, many cycle per second right. So, this is your atomic clock you've heard of atomic clocks.

So, the atomic clock is a most precise definition of time and. So, many vibrations of the atomic clock gives you a second rather the atomic clock is vibrating at. So, many hertz. So, this is defining hertz for you right. So, if you look at the fourier spectrum of the output of an atomic clock the fourier spectrum of an atomic clock will look like 2 perfect impulses.

So, let say the vibration it sets it some cos omega naught t I do not know the exact number, but this is how the spectrum of [-an] the output of an atomic clock is going to look like any other clock not atomic any other clock the output is not going to look like that guess what the output of any other clock which is not an atomic clock is going to look like this alright and all of that garbage.

So, you hope that it will be 2 impulses it is never going to be 2 impulses only the atomic clock will have 2 impulses at plus and minus omega naught everything else will have some junk around the impulse. So, this junk is called phase noise that is called phase noise. So, the oscillator whatever it is it tries to oscillate at perfect frequency it cannot oscillate at a perfect frequency there is some noise around that frequency that is called phase noise right

Now, what are good oscillators available in the market the cheapest form of a good oscillator is a quartz crystal. So, available in the market if you are wearing a wrist watch most probably it is a quartz wrist watch just check if its running on a battery its likely it is a quartz crystal there's a quartz crystal inside and quartz crystals have extremely good phase noise characteristics still not perfect not perfect they are extremely good that is all I am saying right very low phase noise and to quantify the phase noise I am not really go to try to quantify the phase noise I am going to quantify the jitter in the clock.

So, the variation in the timing is about 10 parts per million if you buy a good quartz crystal in a market it is not very expensive fifty rupees hundred rupees you will get a good quartzs crystal and the jitter is of the order of 10 parts per million what; that means, is that the quartz crystal when you buy it it something will be written on it.

It will be written maybe 30.0001 megahertz so; that means, that particular crystal oscillates perfectly at thirty point 0 zero 0 1 megahertz each period of oscillation is 1 by 30.00001 million seconds with some jitter and the jitter in that period is 10 parts per million or something like that you'll get it from the datasheet for that particular quartz crystal its of the order of 10 parts per million usually right

So, coming back to the question the definition of the second of the base station has to be a same as the definition of second for the handset now the handset is not gonna be carrying an atomic clock right cheaply available is a quartz crystal all handsets will have a quartz crystal and that will give the handset a rough approximation as to what the definition of a second is and then and then there is going to be some handshaking between the base station and the the handset the base station is probably going to send a pilot tone somewhere which will be known to the handset to be at the certain frequency and the handset will definition its second based on that particular pilot tone. So, this is typically what is done.

How does the base station definition its second what is the definition of a second 2 base station they will have different definition of seconds and they have different definition of seconds communication in between them is going to a wire right. So, the base station what it does is it talks to a g p s satellite right and onboard g p s satellite there are atomic clocks and if if a base station talks to is able to talk to 4 g p s satellite at the same time that is the idea if I can talk to 4 g p s satellites at the same time then the x y z coordinates and the time coordinate can be fixed right.

So, we are really going out of bounds of this particular course over here this discussion is going to away, but that is basically the idea the base station talks to [-g p s] talks to 4 g p s satellites figure out what is the time is all the base stations talk to 4 satellites these satellites onboard carry atomic clocks. So, the base station definition of second is synchronized with the definition of second of the g p s satellites which are are defined by atomic clocks now each handset synchronizes its definition of a second with a pilot tone that is coming from a base station and as a result the second is defined everywhere this is basically the scheme of things.

Now, we go back to the oscillator. So, this particular oscillator has phase noise. So, presumably you are going to build some local oscillator and this local oscillator unfortunately will have phase noise now think about it in a different fashion let say at the antenna I am receiving my desired signal and right next to the desired signal I am receiving a blocker alright let say that the desired signal is at 1 gigahertz and the blocker is at 1 gigahertz plus hundred kilohertz it is a 2 hundred kilohertz and let say that the blocker is a 60 d b larger than the desired signal alright under worst case situation.

So, what does that mean as far as my oscillator is concerned how good does the phase noise of my local oscillator have to be let us take a look at that. So, this is the se [-cond] situation I have got a desired signal I have got a blocker which is 60 d b above the desired signal 2 hundred kilohertz away from the desired frequency right.

What does the spectrum of my local oscillator need to be. So, that I do not corrupt my signal it is easy to understand that 2 hundred kilohertz away from the desired signal from the desired L O lets say this is my desired L O 200 kilohertz away if I have got something then that something is going to modulate with my blocker. So, that is something going to multiply with my blocker signal right and the resulting product is going to come on top of my desired signal at the output.

So; that means, that this separation has to be 60 d b more than 60 d b this is the way we define phase noise. So, phase noise is defined in this fashion 60 d b with respect to the carrier at an offset of 2 hundred kilohertz right. So, the definition of. So, how you talk about phase noise is like this I need 60 d b with respect to the carrier my phase noise has to be 60 d b less than the carrier at an offset of 2 hundred kilohertz from the center frequency alright

So, this is the way I defined the phase noise of an oscillator and this is where the requirement comes from it is a very basic requirement it is a blocker next to the signal I cannot corrupt the signal. So, this is minus 60 d b see if I want 0 d b of signal to noise ratio signal to blocker ratio right if you want more d b then you're phase noise specification will go up alright.

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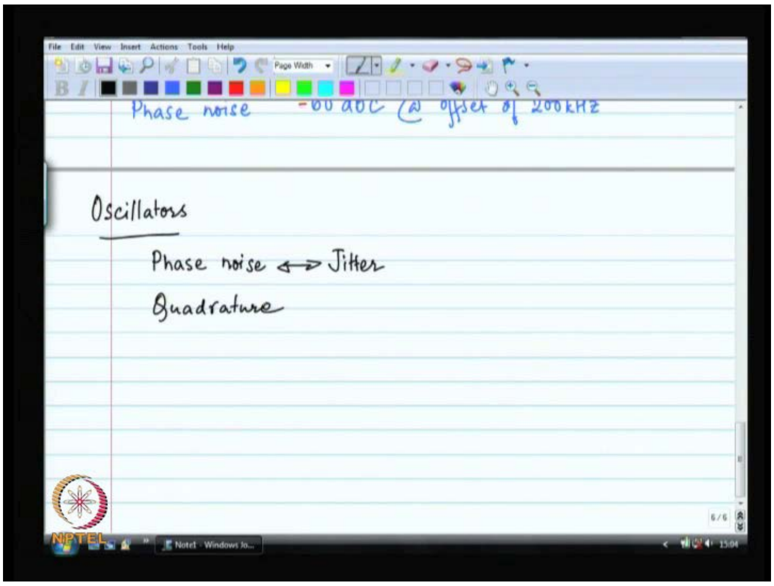

So, lets now move to oscillators. So, important as far as the oscillator is concerned and important specification is phase noise of the oscillator and it kind of understand that phase noise is related to jitter it is like there is an uncertainty what the period of the vibration is exactly right that is where its coming what are the other important parameters what are the other important thoughts that we have we need quadrature. So, I need to able to generate the sin and cosine at the same time anything else not at the moment ok. Now, what are popular methods what is the most basic oscillator that you can think of think of your high school class twelve alright

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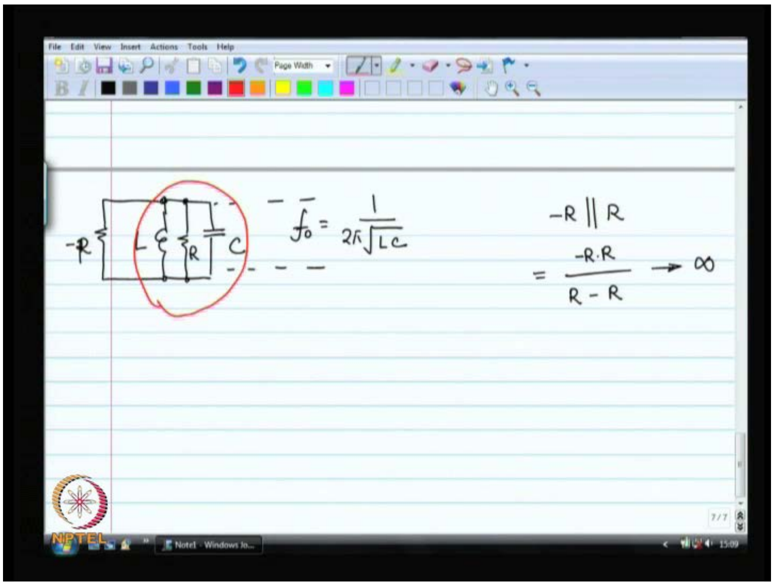

So, this is the most basic oscillator isn't a inductor or an capacitor and if you do an analysis you can show that energy will be stored in this oscillator and it will keep getting transferred from the capacitor to the inductor. So, on the capacitor it will be stored as the voltage as charge and in the inductor it will be stored as the magnetic flux a current right and it will keep shuttling back and forth between the inductor and the capacitor and if you observed the voltage across these 2 points you will see that the voltage is a sinusoid some sort of cosine at what frequency at the regimen frequency the regimen frequency is 1 by 2 pi square root of l c alright.

So, this is a most basic oscillator unfortunately this kind of an oscillator is not practical why why is this kind of an oscillator not practical because you can never make these perfect components the wire will have resistance the capacitance will have some leakage the inductor will have some series resistance. In fact, the inductor resistance is what is going to hurt you the most as a result this is not possible to make you'll always end up with this and as soon as end up with some series resistance oscillation in the circuits are never going to be sustain if at all this startup they are going to get damped and they are going to go down to 0 soon very soon right.

This is basically the problem you can modeled l in series with R as l enshont with R it is possible to modeled a series l and R to enshont l and some other R you know how to do this right even then the oscillations are not going to be sustained. So, what can you do over here. So, 1 thought is that let me invent a new component which is a negative R and a negative R enshont with a positive R is as if you got an infinitely large resistance enshont an infinity large resistance enshont is as if you have got nothing enshont and in that case the system is going to start oscillating and the oscillation will be sustained right.

So, this is the thought that maybe I can invent certain component which has an effective impedance of minus R I am going to put enshont with this tank this is called a tank the R is not intentional the R that is run inside the tank is not something that is intentionally there its something that has a reason out of imperfect components right you never you are never going to put a real resistance over there fine it is called a tank I do not know what reason it could be that because energy is stored in this particular tank circuit energy stored and it keep getting transferred from the inductor to the capacitor back and forth. So, that is probably why it is called a tank I am not sure anyway. So, this is the basic idea it is called a tank circuit right. So, this is 1 thought process another thought process which you might be familiar with are using ring oscillators. So, you could think of your digital circuits you could think of an inverter

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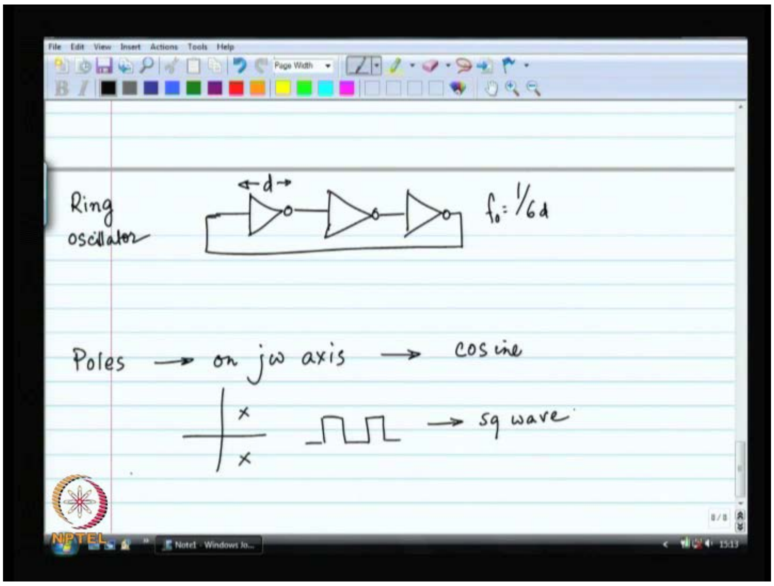

And let say I put 3 inverters in feedback make a ring if each inverter has a delay of d then this particular circuit is going to oscillate somehow it is going to oscillate at a frequency of 1 by six d right. So, this is a second line of thought a third line of thought is as follows that remember your amplifier design etcetera etcetera and you remember poles and zeros and. So, on what if I place some poles on the j omega axis if I am able to place poles on the j omega axis and my system is going to oscillate. So, this is a third line of thought this will generate perfect cosine if I manage to place the poles on the right half plane if manage to place poles on the right half plane some [-where] somewhat like this then the system will have a response which is the raising exponential times some cosine.

Now, of course, a system is never going to keep growing in terms of voltage that probably means that the output is going to get saturated at the power supply voltages which probably means that I will end up with this square wave. So, this is going to give me a square wave remember we like square waves. So, this is a third line of thought alright Now, we are going to try to stop here and in the next class we are going to see how all of these 3 lines of thoughts are actually 1 in the same right they all are actually exactly the same thing you are placing eventually you are placing poles on the j omega axis or outside the j omega axis on the right half plane etcetera. So, this is the basic idea and we are going to see this in the next class haven't we carry out the discussion further.

Thank you for your attention.