Basics of software-defined radios & practical applications
Dr. Meenakshi Rawat
Department of Electronics & Communication Engineering
Indian Institute of Technology, Roorkee

Lecture – 04
Software-defined radio architecture Part II

So, we are continuing our discussion on software defined radio architectures, we have seen that we have two types of architectures; homodyne, heterodyne and the others are there combinations. Now we will LO into the limitations of transmitter receiver contents, and for these different architecture how they why they implicate. So, first is LO leakage; as you know that in homodyne structure we have signal at RF and the LO frequency is equal to the RF frequency.

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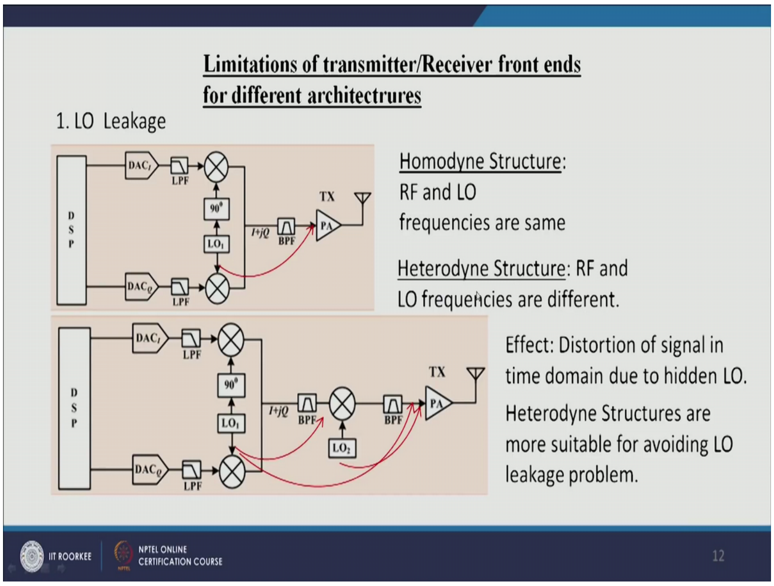

In heterodyne structure we can choose our RF frequency is separate from the RF frequency. So, what is LO leakage, basically when we are putting our signal in the contacts your phase by using a LO, then some of the LO might directly leak into the direct path.

So, what will happen in the case of homodyne? Our signal which is being modulated by this LO 1 is broadband signal it is it has some bandwidth.

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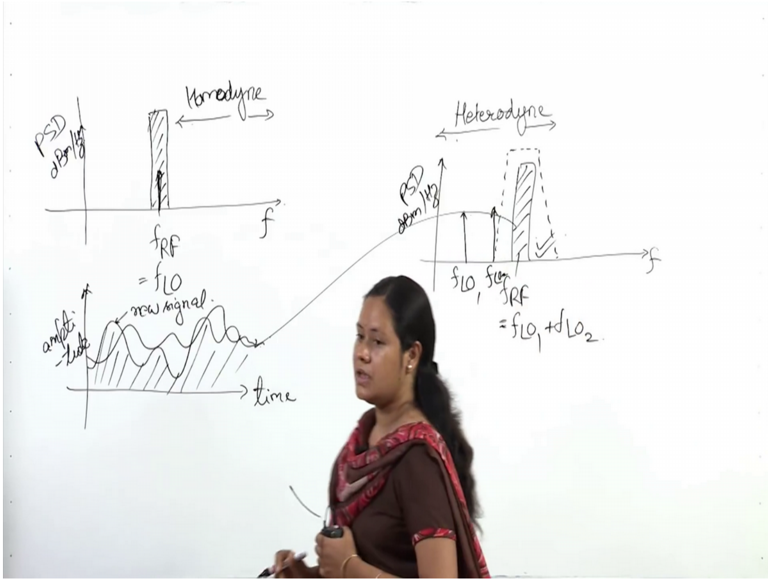

So, let us see in the frequency domain, this is our RF signal, which is a broadband signal based on our chosen signal, it can be any (Refer Time: 01:42) signal it can be w c d m a y max, l t any of the signals and it is a bad limited signal it is RF signal at the fRF, but our LO is basically a sinusoidal it is a oscillator. So, it will have the leakage from there which will be like this and it will be hiding under this f RF because f RF is equal to f LO. So, it will create a distortion basically it is frequency domain, and it was signal d B m per hertz basically PSD a power spectral density if I am showing it here.

In the time domain if I try to plot our signal, and suppose our signal was suppose to LO like this. Because now we have a hidden component here of this sinusoidal this signal will not be like this it will be something different depending on our new sin signal. So, of course, it has been distorted now. So, this distorted signal it is the amplitude, when received by receiver the LO component cannot be separated and it will be distorted signal. Now in the heterodyne case if you see here this LO is leaking here in the both paths because of both the LOs this is I f LO and it is the eventual LO which is breaking our signal to the RF frequency, and we have two frequency is here which has which are oscillator frequencies they will be single carriers and our original signal the RF signal which will have the frequency of f LO 1 plus f LO 2.

So, how that will look like homodyne architecture and it is heterodyne architecture. So, our signal which was the RF signal f RF it is f LO 1 plus f LO 2. Now f LO 1 is a signal which is here and f LO 2 is another signal oscillator single carrier signal, which is the f LO two, but they are at different frequency from the RF signal. So, basically in the receiver side the band pass filters will be able to take two separate it properly. So, in the heterodyne were able to keep our signal intact and we will have our original waveform ship in the time domain. So, let us write it completely PSD dBm per hertz. So, (Refer Time: 04:58) each is more prominent in the homodyne structure as compare to the heterodyne structure.

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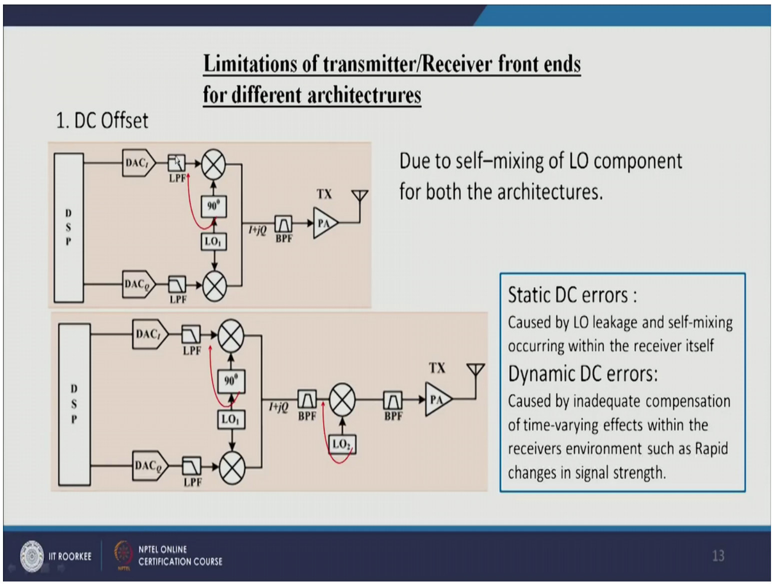

Now look at the DC Offset. Actually DC Offset is again after effect of having the LO leakage. Now LO is leaking from this part to the previous to the mixing path.

So, as you can see we had this mixtures here, which were allowing as to multiply our sin signal to this sorry our cosine signal to this in phase component and our sign signal to this auto phase component right. So, this was supposed to be our signal, but now because of LO is going before this mixing signal, what will happen? It is also an entering from there. So, we will have a DC offset because this mixer will do what.

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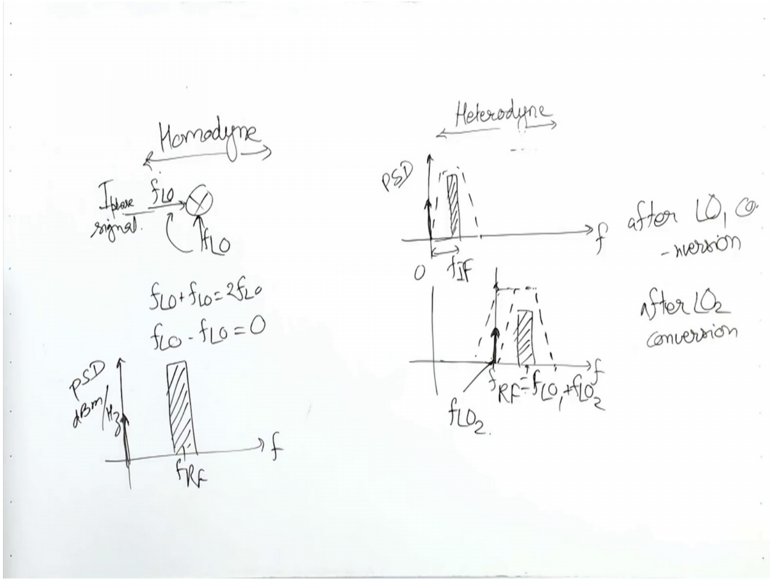

So, we are having mixing before our quadrature mixer. So, mixer is having LO, f LO and this f LO is leaking here. So, it is also having in f LO apart from other components which is I phase one I phase of the signal. So, this will have the component it is f LO plus f LO which is two f LO it does not matter because our band pass filter, which is here it will remove this component. But what about the f LO minus f LO component it will be a DC. So, it will be abrogate DC and it will not be taken out by our BPF and that is why its name is DC offset. So, how our frequency domain signal will look like perspective density d b m per hertz of you see we have a signal appearing here apart from RF, f RF signal which is the actual signal here right. So, this is what we call DC offset because of this component the amplitude level of all the signals goes high.

Now, what will happen in the heterodyne case? Again self mixing is there right. So, because that self mixing this DC component was there at this distance, because this band pass filter it was this is allowing the signal to go through, but the DC is also creeping which is bringing the amplitude of now because of the LO two because we have two stages here after LO 1 conversion right. So, after LO 1 we have f i f and then we were having this DC component there. After a LO 2 second conversion our signal is at f RF right and this f i f will appear here and this signal will be here at the RF frequency right because it was a 0 before now it is it is up converted to new signal.

So, this f RF will be what f LO 1 plus f LO 2 as we discussed earlier this one, and this will be f LO 2 which is this plus f LO 2 right. So, this component will be there. So, this DC error we cannot avoid once our signal will be taken down, we can filter it like that, but if our filter is not sure and it is we do not have components like capacitor to stop it then this will appear this. So, now, they are two types of DC errors one is caused by LO leakage self mixing as I have shown in this example, another one is dynamic DC errors. It happens when some in incoming signal is coming and suddenly its attitude changes, but our automatic gain controller in the receiver, it is not able to follow it properly and it stops suddenly . So, there is a jump in the amplitude and that also brings the DC error it is called dynamic DC error. So, what is the effect of this DC offset?

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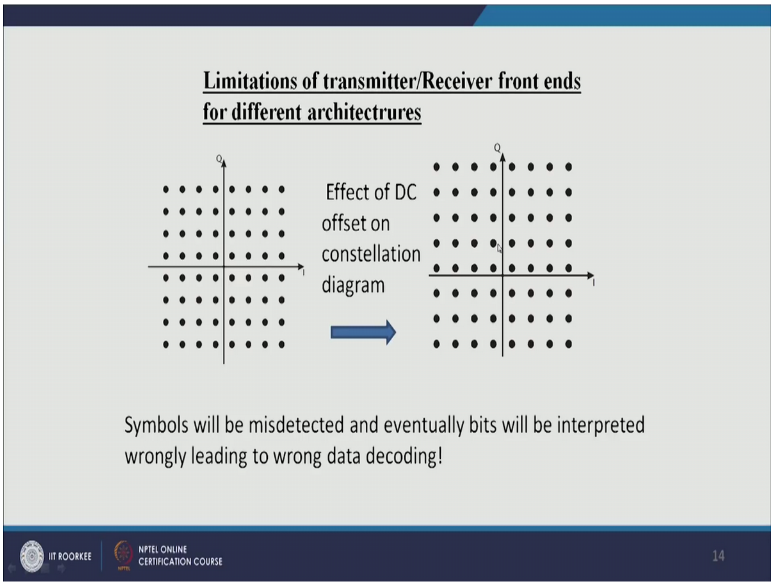

In the LO we can see the destruction was there, because of the DC offset in the constellation diagram we can see that the constellation shifts in one direction, and shifts in the direction where actually our amplitude is being added.

So, in this constellation diagram which I am showing for the 64 com, we can see that the bits are shifted towards Q, everything is we point has a addition of some amplitude in the Q direction. So, this is the DC offset was coming on the Q side then in this case. What will happen because of this the symbols will be missed detected because earlier what it wanted to when it wanted to read this symbol that symbol is now here. So, instead it will read this symbol and interpret that this symbol is basically this symbol which is wrong information. So, accordingly the bits will be converted back in a wrong sequence and your b r will be very high because of this. So, we have to remove this there can you methods such as capacitive methods. So, that the DC can blocked at the earliest stage there is some additional methods also which we will cover in later in this course.

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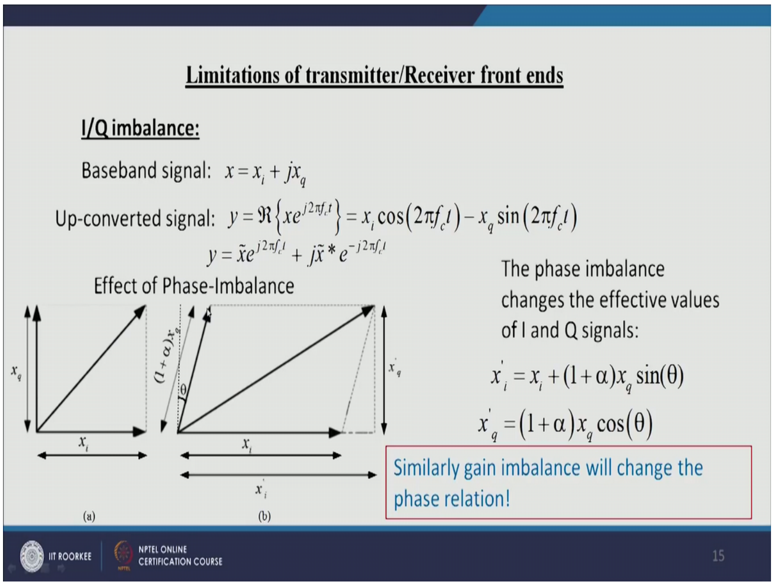

Now, another limitation is the I Q imbalance. Now let us have a look at the baseband signal basically when we have designed our signal it has I and Q component because of its a constellation diagram, after pulse shaping they are not like pulse basically they becomes continuous, but they still have I and Q components here. The symbol which is in the air it is actually the real part of the x into e q per j 2 pi f c t because it cannot have a complex, way from the complex representation is in the basement in the mathematics and real life it only contains the real proportion.

So, eventually in the air it is x i, cos component minus x x q sin comp onent if this is the form it is found in the air. Now this same formulation can be given as formula also means this x bar here is representing.

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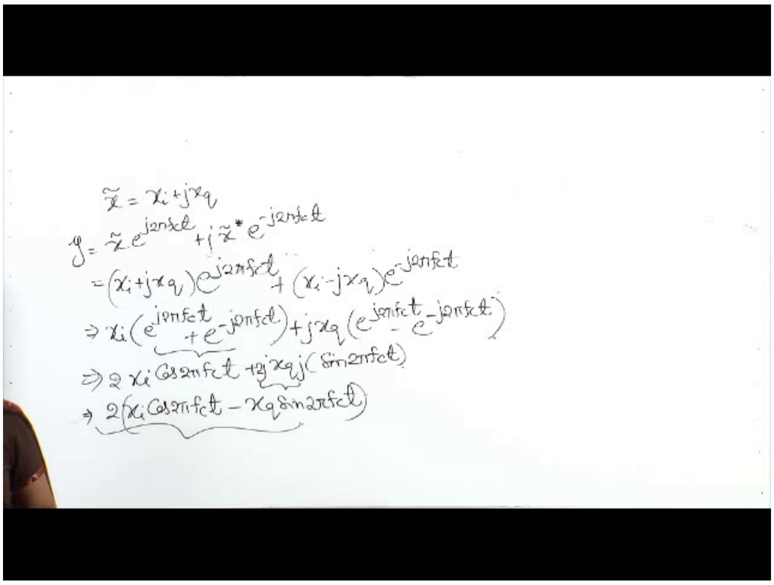

So, this x bar here is representing x i plus j x q. When you open this expression 2 pi f c t plus j eventually taking the f i component common, we can have similarly by taking our j x q component common. So, this together mix twice of cosine 2 pi f c t, this makes sin 2 pi f c t into j. So, this j is square will be actually minus 1. So, twice of this.

So, this is the expression we are getting and this is the same expression, which you are looking for our RF signal up one exception is of this twice factor which is just the amplitude which can be adjusted, but the information is intact in this formula. Now we have seen this in this formulation because we will see the effect of I Q imbalance, what is this affect? Basically we are supposing whenever we are sending a signal through our any of the architectures that they are at 90 degree this is suppose there right. And both the parts are supposed to have constant magnitude. So, that the information level does not change, but in real life it does not happen it is possible that 90 degree given by one of the oscillator the that phase is not exactly 90 degree, but this is a shift of theta from the 90 degree.

Similarly, it is possible that both of the path does not have exact equal amplitude let us say, let us x q is actually having extra alpha times of x q as a gain imbalance, what will happen because of that. If f s c we do not have this gain imbalance, even then this theta component when it will fall on the original y axis it will have x q cos theta component which is equivalent to new x q dash, and x q sin theta component will be added to the actual x i. So, in phase component is also changing. So, it will eventually change its gain similarly even if the phase is 90 degree and the gain imbalance is there it will change the phase, because the vector location will change. So, by assuming that we have both imbalances amplitude as well as phase, then we can see the what will be our new I and q signals which will be red which will be sent by our modulator condition modulator. So, x i dash which is the new x i dash is basically x i plus 1 plus x 1 plus alpha x q sin theta.

So, it is a new component in the in phase direction and qudrature is phase direction we have simply 1 plus alpha x q cos theta. Now this new x i dash x q dash are the components are the vectors which will be propagated into the RF domain. So, transmitter signals with the I Q imbalance is given by this formula basically what we have done we have introduced this formulas this notations in this formulation. So, let us do that.

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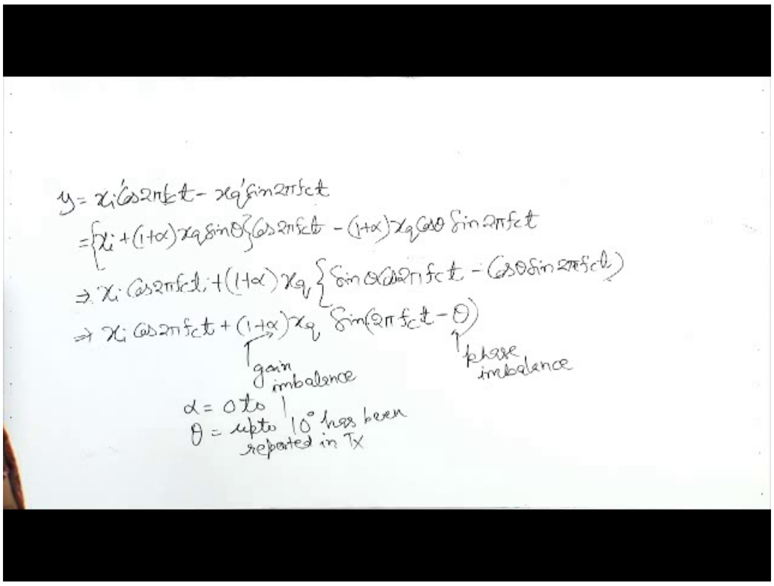

So, our y was x i cos 2 pi f c t minus x q sin 2 pi f c t, but now our x i and x q are not what we used to have, now they are actually their modified versions. So, let us put these values x i is, x i plus 1 plus alpha x q sin theta and it is it will be multiplied with cosine 2 pi f c t minus 1 plus alpha x q cos theta, which is this x q component (Refer Time: 18:40) x q component sin 2 pi f c t. So, let us try to simplify this x i component is simply multiplying with the this component, but x q component is little bit more complex and let us take this common the common components will be sin theta cos 2 pi f c t minus cos theta, sin 2 pi f 2 pi f c t.

So, it becomes x i cos 2 pi f c t plus 1 plus alpha x q sin a cos b minus cos a sin b. So, it will become. Now this theta is a phase imbalance and this alpha is representing gain imbalance. So, if you look at this formula and the this alpha value can go from 0 to 1 and theta will you can go from 0 to 180 degree, but in real life practical scenario it takes very small value and up to 10 degrees has been reported in the transmitter side. In receiver side because it goes from channel the it becomes very high the price rotation can be higher than that, but in the transmitter side normally our oscillators are not so, unstable that we will have any phase imbalance more than this.

So, these are the imbalances as you can see here if you put our theta is equal to 0 and alpha is equal to 0 we will be having our original expression back, and if you put alpha equal to 1 its will be have ties of that one which will be very very high component.

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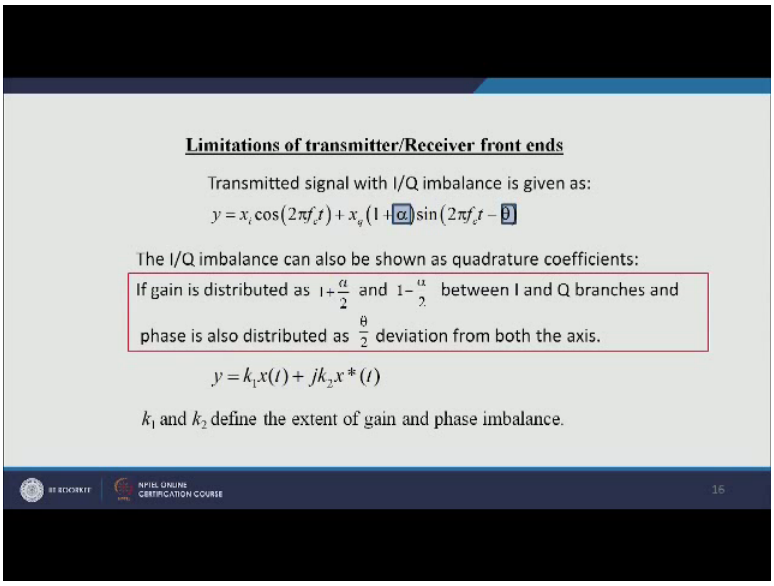

So, this was the its expression when we are talking in terms of phase and gain in the polar format, but if you want to talk in terms of the quadrature of coefficient, then normally when we want to do this analysis it is assume that gain is distributed as 1 plus alpha by 2 and 1 minus alpha by 2 between I and Q branches. So, basically it is not alpha we will say 1 plus alpha by 2 and it will be having 1 minus alpha by 2 in this way the gain imbalance is a still of total alpha.

Similarly theta will not be theta from here it will be theta by 2 from here and this vector will also be having theta by 2. By doing this derivation, we can actually see that the output in the time domain the y can actually be given as k 1 x t plus j k 2 x conjugate t. So, again if you see the expression this y which we were representing in terms of the signal complex signal and its conjugate, we are the doing the same thing, but we are saying that we can attach to cosine there so that we are able to compensate for this imbalances and we can tune this imbalances. So, what is the effect of this imbalances at the receiver side how do we get about data in the I and Q domain normally.

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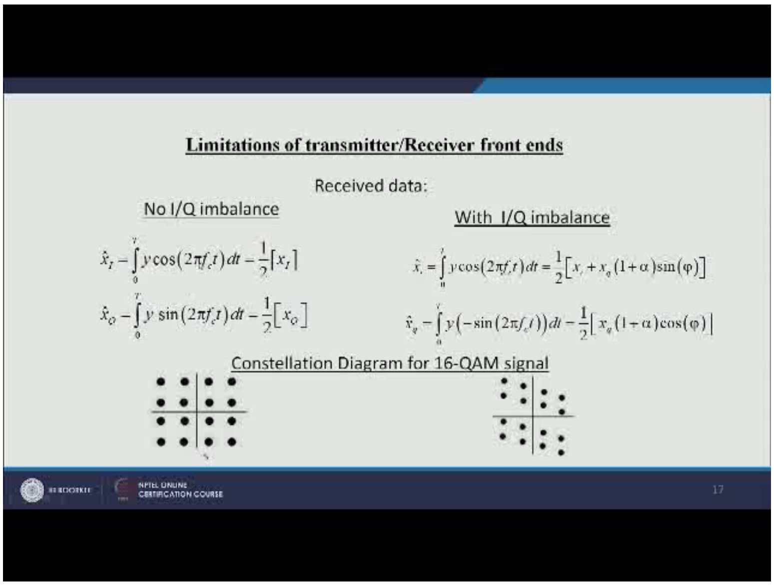

Whenever we get our signal output signal we multiplying the cosine factor and take its integration over 0 to t and do the low pass filtering.

If you do the integration here the high pass high frequency component means our y is given by this formulation when there is no imbalance. So, when it is multiplied with their sin and cosine factors, we will have the high frequency component which are basically block by your filter and low pass component is basically x i divided by 2, this two of factors again just the amplitude. So, original information x i and x Q is preserved. Now in the, with the I Q imbalance our I and Q come comes out to be what we had seen in our first slide showing the I Q imbalance. So, this is the, what we will see in the receive data. So, there is the, our information which we will receive will not be accurate.

Now, constellation diagram will look something like that with gain imbalance there is a gap between these two depending on from where the gain in which direction the gain is tilting to and then because of the phase imbalance there is this rotation. So, from here we can see this one is having a negative direction of phase which we can see from here so, that this five this theta will be negative here.

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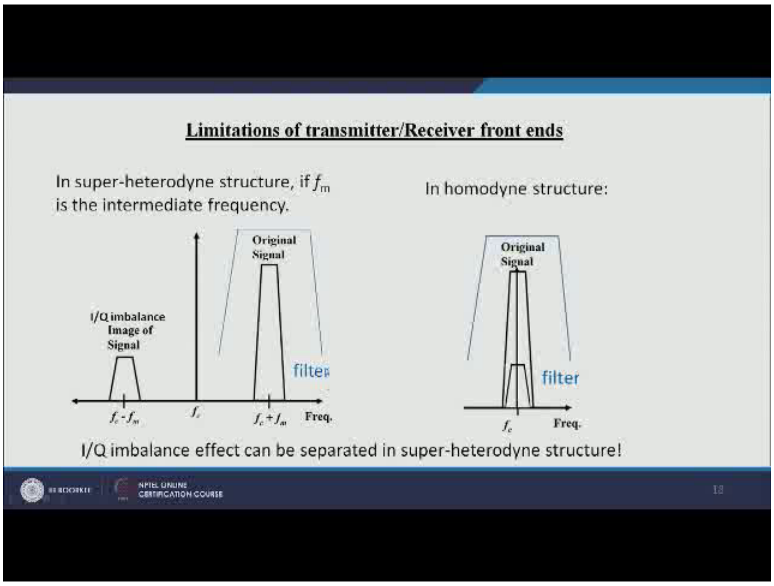

as I as told you that our signal can be shown as x t and x conjugate t there combination of these two in the frequency domain it appears like this in the heterodyne structure if f m is our intermediate frequency which is all over in heterodyne structure then f m plus f c will be having the original signal, but f c minus f m will be having the I q imbalance this is happening because of this component which is having the negative frequency conjugate component there in homodyne case because our I f f m is equal to zero. So, our image is actually falling on top of original signal.

So, in this case we cannot separate this image by using the filters. So, again heterodyne has this particular benefit in this case.

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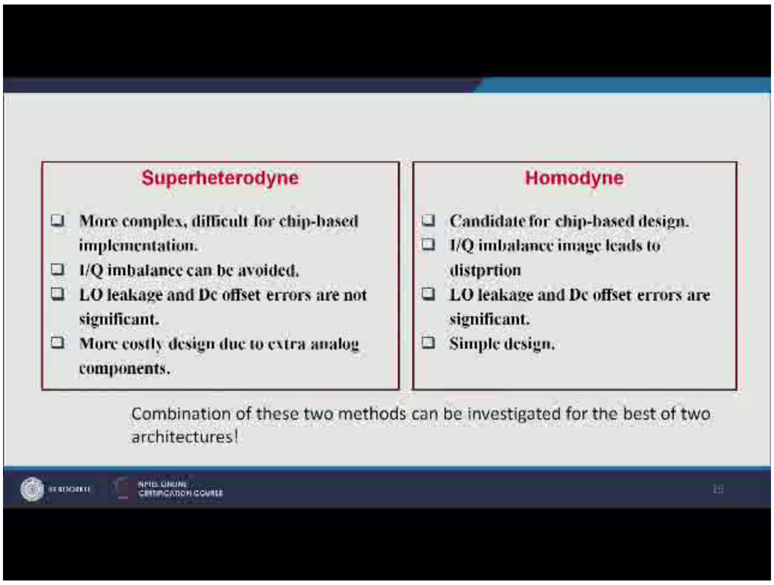

So, to summarize if you summarize the super heterodyne and homodyne structure based on whatever we have a cover till now superheterodyne is certainly more complex and difficult for chip based implementation it has why it is because it has many components and it at every stage it is using filters now depending on the frequency the filter has a particular size and if it has to be made tunable then size becomes increasingly large now for the homodyne case because there is only one step one filter will be there particularly for that frequency. So, it is a good credit for candidate for chip based design in super heterodyne we had seen that I q imbalance falls in a negative I f frequency.

So, by using filter we can remove this I q imbalance image component and we can have our original component back it can be avoided in homodyne the images falling on top of the signal we cannot avoid it by using simply add a filters LO leakage and DC offset errors are not that significant because we can do the two level I f conversion by and use the filter again LO leakage and DC offsets again LO and RF at the same frequency the follow and top of each other cannot be avoided it it becomes also costly, because we have extra component here for the superheterodyne and for homodyne this design is quite simple now we have seen the pros and cons of these two methods. So, by using the combinations of these two methods we can have more better architectures.

Thank you.