Basics of software-defined radios & practical applications
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Lecture – 03
Software-defined radio architecture Part I

Today in this part we will be describing the software defined radio architectures. So, before starting that let us look at the radio requirements and specification. Basically, we have 2 components transmitter and receiver and they are the main required equipment for wireless communication.

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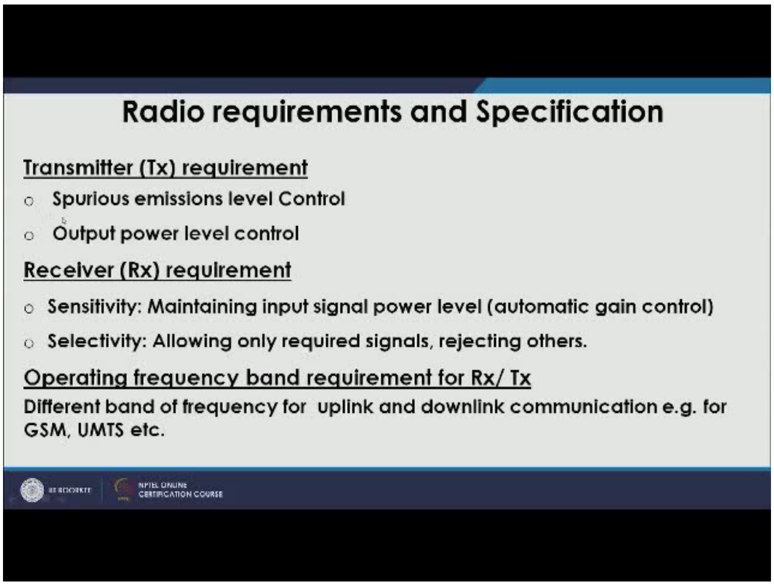

So, for the transmitter you require a Spurious emission level control; it means you have to keep the distorted signal extra component from the main area and you have to keep them from coming to the neighborhood areas in the frequency domain, and there are some regulatory bodies which keep a tab on this they try to control it. So, transmitter has to look into it.

Moreover, transmitter apart from modulation up conversion and transmission, it has to also control the power level because the signal has to travel to a distance so, it should be able to give the sufficient power. So, that should be part of transmitter. In the receiver side there are 2 main criteria’s, one is sensitivity another is selectivity. Sensitivity means maintaining input power level so that our a DC is able to detect the signal in log domain properly and it is able to convert it into digital domain.

Selectivity allows to capture the proper signal among so many signals in another frequencies, while it should be able to allow the signal which you want at a particular band it should be able to reject the others which we do not want. So, these 2 requirements for the receiver apart from these, transmitter and receiver they should be synchronized they should know what are the operating frequencies they are working on and based on that they will be choosing their filters and other component. Now before going into the details of architecture let us look at the hardware components which will be used in these architectures.

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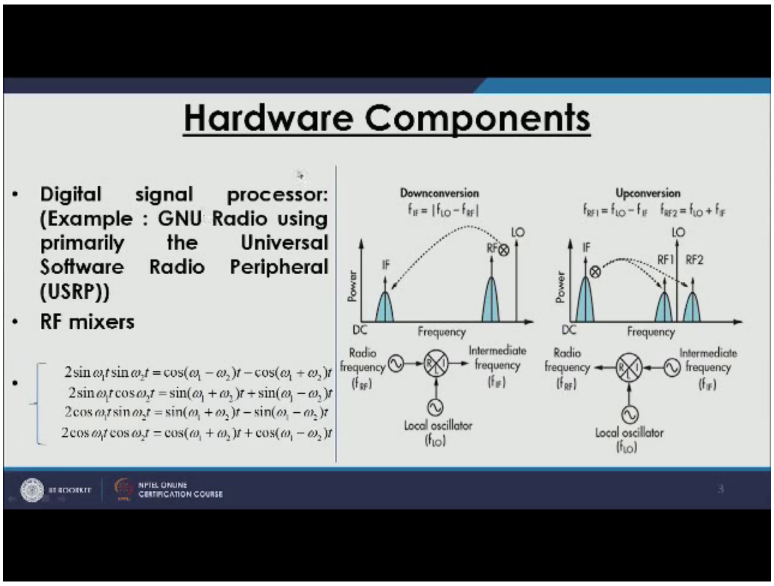

First of all, of course, it is software defined radio. So, digital signal processor is a part of the system. Digital signal processor is a system where after the down conversion and in distillation you have digital data you do the all the processing all the coding is happening in this domain.

So, some of the examples can be your personal computer, your laptop as PGAS are there are some leading companies for example, from analog devices there was a shark based DSP processor then you have a arm cortex 8, cortex 4 this series are for the DSPs. And recently GNU Radio is has been also very popular where actually the it is using the universal software radio peripheral by using a FPGA, but all the processing happening in this peripheral outside the FPGA. It is very fast it is allowed it is able to give you very high speeds.

Now apart from this the next component will be RF mixers. If you look at this diagram, it is showing the RF mixer here, RF mixer is basically a non-linear component, whenever it has 2 inputs which are sinusoidal in nature; their outputs have the frequencies which are either summation or subtraction of these 2 frequencies.

So how it happens actually, it allows the multiplication of these 2 sinusoidal. So, if you look at the word trigonometric formula here the multiplication of 2 sinusoidals they

Provide us the cosine component which is the difference of these 2 frequencies and the summation of these 2 frequencies. So, at the output we can either choose w1 minus w2 the frequency, difference or the summation of the frequency. Similarly, for other combination of sin and cosine we always have this kind of components. So, in case of up conversion in the transmitter which is shown in the right-hand side figure here, when you apply our LO signal and RF signal is applied also then, from the IF level it has the output which is LO plus IF frequency or LO minus IF frequency. Apart from that it will also have the frequency which are IF minus LO, but those frequency will be on the negative side.

So, they will not appear here also they will be part of the system. So, they will not appear in the system. So, if you look at this diagram this is the LO signal and RF 2 which is the summation it is appearing here and the subtraction is appearing in the left-hand side. Based on our requirement, both of them contain the same information. So, we can put particular filter and we can down convert it, we can select and then use it. Similarly, in the receiver side when we already have RF signal and we want to take it back to the basement level then we apply LO.

The outputs will be either summation or the subtraction. So, subtraction will bring it near to the basement levels. The addition will be on the right-hand side of this LO and it will be filtered out it will be at high frequency. So, in this way we are able to get our signal at a basement level. If our LO is equal to RF our frequencies are same for LO and RF, in that case this signal will come directly at the DC level which is the basement with 0 frequency 0 IF.

So, based on these choosing IF are not choosing IF gives us the homo dying or super heterodyne architecture which we will be discussing later. As we have seen earlier filters are very much the part of the system they can be low pass or band pass.

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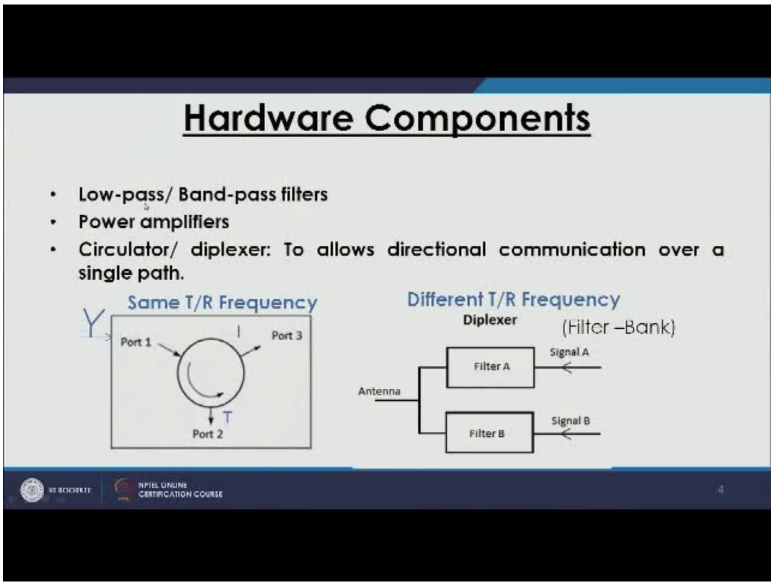

If we are looking at the system when it is very near to the DC which is basement mostly we use the low pass filters and in the RF domain mostly we are using the band pass filter designed for that particular application. Now filters can be digital in nature they can be resonators or they can be band pass filter in the RF domain. So, depending on the application and the domain they can be created in applied.

Power amplifiers are very important part of this system because they allow the signal to be amplified to a particular power level. So, in that case basically we have different classes of power amplifier some of them are very linear like class a, but it does not provide very good output power. Then very high output power basically on an efficiency also then we have class b, c, d, e, f which are d, e, f are basically switch put power amplifiers we will be discussing some of the these letters and we will be also discussing the limitation of this particular component.

But for the timing, let us go to the circulator or the diplexer. Now circulator or a diplexer it allows the directional communication over a single path. So, here we can see the circulator which is being used for the same frequency at the transmitter and receiver. So, we can see we have 3 ports here port 1, port 2, port 3.

These circulators are basically made of some ferrite elements and whenever you apply any signal at port1, it passes to the next port, but it does not pass through the next to next port. So, basically it will allow anything to pass through the next, but nothing will go here so the S2 1 will be low here and sorry S2 1 which is which is the which is allowing to pass the signal is high here and in this case the insulation very high so signal will not be going to here.

So, how can we use the circulator in a system of a transmitter and receiver?

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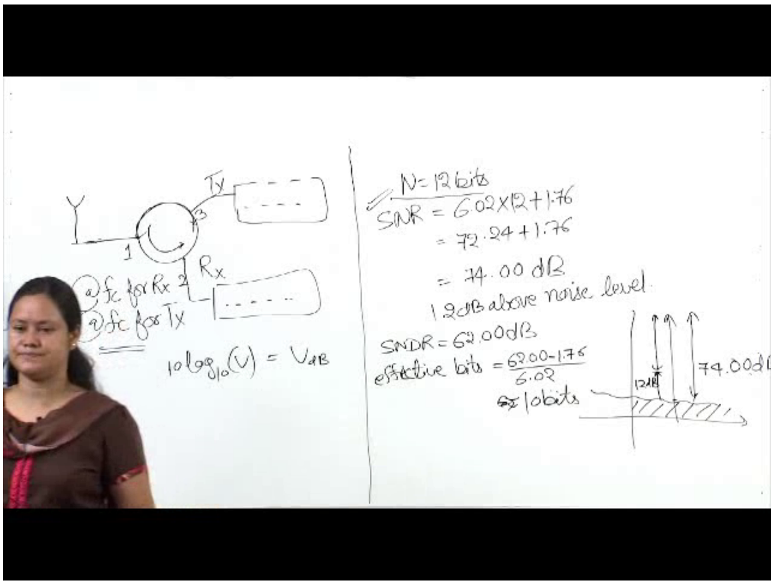

This is the circulator and this is the direction of circulation port1, port 2, port 3. So, let us say it is the Rx and it is the Tx port. So, all the Tx circuitry is connected here and all the Rx circuitry is connected here and here is the antenna. Now this antenna is working at the frequency of fc for Rx as well as frequency of fc for transmitter Tx. Whenever a signal is coming here it will allow that signal to go here.

So, it will pass to receiver, but the same signal cannot go here because it is not allowed by the circulator. So, it will allow signal to come here. Similarly, whenever any signal is being sent from the transmitter here, by this direction, it will allow it to go here, but it will not allow it to go here. So, the signal will be passed to the antenna and it is able to transmit. So, the same antenna can be used for the transmitter and receivers.

Now, it was the example when it was at the same frequency, suppose we have a signal which is that different frequencies. So, here if you look at the diagram the diplexer come into picture which is basically a filter bank. So, because of our transmitter and receiver they are at a different frequencies. So, whenever a transmitter is working it will allow the signal to go to antenna and whenever the signal is received being received by the receiver then the other filter will be acting because the first filter will be closing that signal will be blocking that signal. So, simple diplexers, simple filter bank will be useful there, but at the same frequency we may have to use circulator. Now digital to analog converters and analog to

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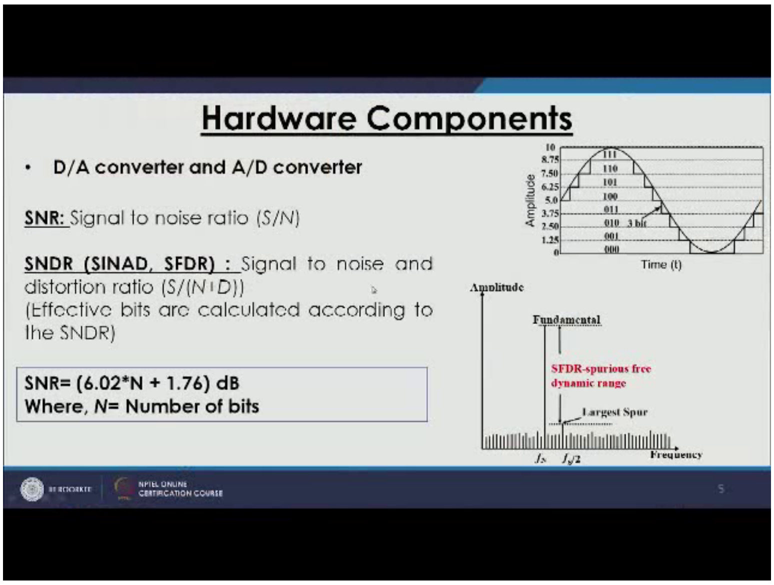

Digital converters they are very much required in a software defined radio and those are the parts which we cannot remove because they are the convergent threshold components basically.

So, if you look at this diagram D A and A D basically they are converting this bit information back into the amplitude for D A and this amplitude information back to bits for A D converter. So, in this case, we are taken the example of simple sinusoidal which looks as a single carrier at the frequency domain. If we want to quantize this with the 8 level then how many bits we should have 2 to the power 3, because we have 2 states 0 and 1.

So, if you apply your logic you should have 2 to the power 3 8 levels, for 16 levels you should have 2 to the power 4 means you will be using 4 bits to provide that quantization. Now, in this case when you see the system kind of function you can see that there is a discontinuity here and quantization noise is coming from this step here. So, lower bit means; you will have more high quantization noise, higher bits means; you will have finer quantization and lower quantization noise apart from the contention noise in the system we also have temperature and environmental noise

So, based on that we define the SNR which is signal to noise ratio. Now, signal to noise ratio is mostly defined for a single carrier signal, in the lower diagram you can see that we are showing a single fundamental signal here it is sinusoidal signal and this is the noise level which because of the temperature and the quantization noise etc. Then the ratio of these 2 power levels they are called the signal to noise ratio in the voltage.

So, this amplitude can be voltage this can also be dB if you are doing your converting it back into decibels so in dB what you will do 10 log 10 of that voltage will be basically V in dB. So, that you can represent there mostly it is represented in terms of power. So, it is 20 log 10 instead 20 log 10 of that voltage, apart from SNR the another parameter is SNDR, it is also called SNAD or SFDR it is signal to noise and distortion ratio. So, noise is one thing which is constantly there, but apart from there is sometimes there is per coming from sampling process or you know not perfect filters then it is the effective dynamic range.

It is also called SFDR which is a spurious free dynamic range. It is called signal to noise and distortion ratio also so all these are the name for the same thing. Now SNR for a system this is this is the thumb rule for calculating the number of bits which will give you SNR. So, 6.02 times number of bits plus 1.7 6 dB for example, if I say I have 12-bit A D and what is the SNR that SNR I can get from this.

So, if N is equal to 12 bits. So, SNR you can calculate in dB and it will be 6.02 into 12 and 1.76. So, what is what it will become 74 in dB? So, for 12 bit this is the system. Now this is the SNR sometimes it is asked that what will be SNDR or bases on the SNDR, what will be the effective bits here. So, effective bits can be given by the SNDR. So, for example, if I say there is a distortion component which is 12 dB above the noise level, then what will be the effective number of bits.

So, let us do calculation for that component is 12 dB above noise level. So, what does it mean that if you are signal it was your noise and this was 74 that is spurious component is 12 dB above the noise level; it means it is spurious free range will be 74 SNDR becomes 74 minus 12 it will be 62 dB. So, number of effective bits from here, again from this formula we can calculate it will be 62 minus 1.76 divided by 6.02. So, it will be approximately 10bits. So, we have 12-bit system, but it is effective as good as 10-bit system. Now, once we have looked at these components let us go to the architecture of the transmitter and receivers.

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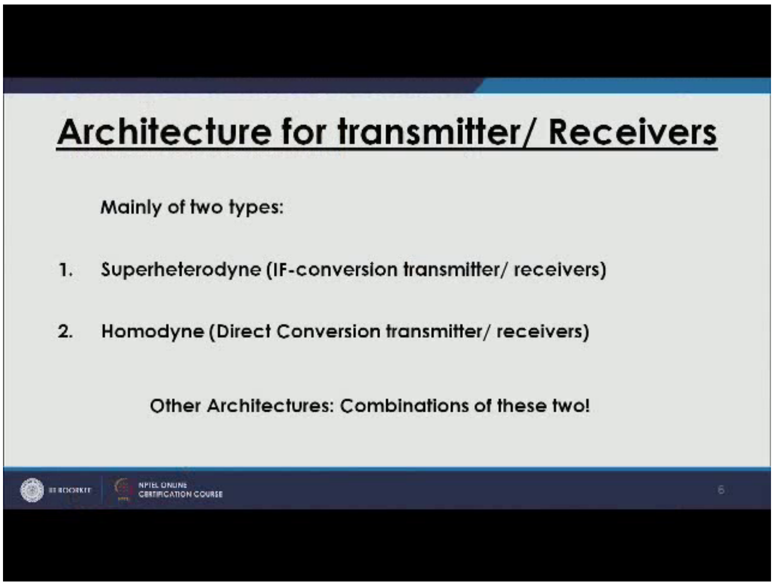

Mainly there are 2 type of architecture, one is called Superheterodyne which is also called IF convergent transmitter in the receiver also it is called IF convergent receivers.

In Homodyne we have names such as Direct Convergent transmitter and receivers. There are some other names such as synchrodyne and 0 IF transmitter which are used for the homodyne. Then there will be some architecture which can be combination of these 2 or motivated by these 2 architectures. So, let us have a look at these architectures

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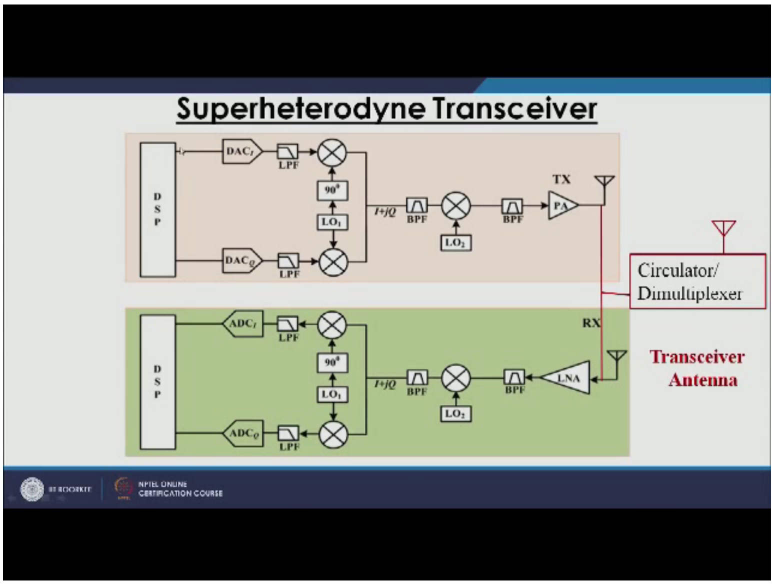

So, Superheterodyne architecture transceiver is shown in this figure in DSP you have your bits you have put them in symbols and then you have modulated them before that you encoded them, then you have done the digital to analog conversion for both eigen q branches and as we have discussed before that we have 2 we have a complex data I plus jQ which we have to modulate using a local oscillator in a system.

Now in superheterodyne a transceiver we have 2 stages of up conversion. First of all, LO1 with which are up converts this information to the frequency intermediate frequency. After that you have band pass filter which removes all the spurious and keeps only this information at that particular LO1 frequency and then you have second level of up conversion LO2. So, in this case what will be the RF frequency?

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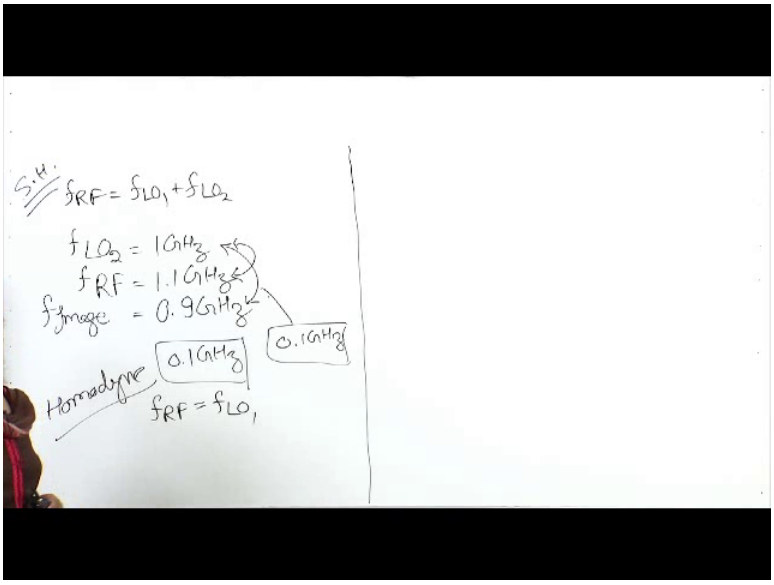

So, the RF frequency for superheterodyne case fRF will be basically FLO1 plus f LO2. So, we have dual conversion there once this data is transmitted by transmitter if this is a separate receiver somewhere it travels through the media and then we required our low noise amplifier. So, that we can have a good sensitivity at the receiver it have sufficient amplitude. This signal is again band passed why because there might be other signals coming from some other sources nearby this frequency.

Now, we have our signal which is that LO2 plus LO1. So, you use signal LO2 for the down conversion band pass it and then LO1 again you have 2 stages here. So, if you have single transmitter and receiver then basically you have single antenna which is shown by this red color diagram. In this case this circular turret is allowing both Tx and Rx to work simultaneously by selecting their paths the transmission remains the same.

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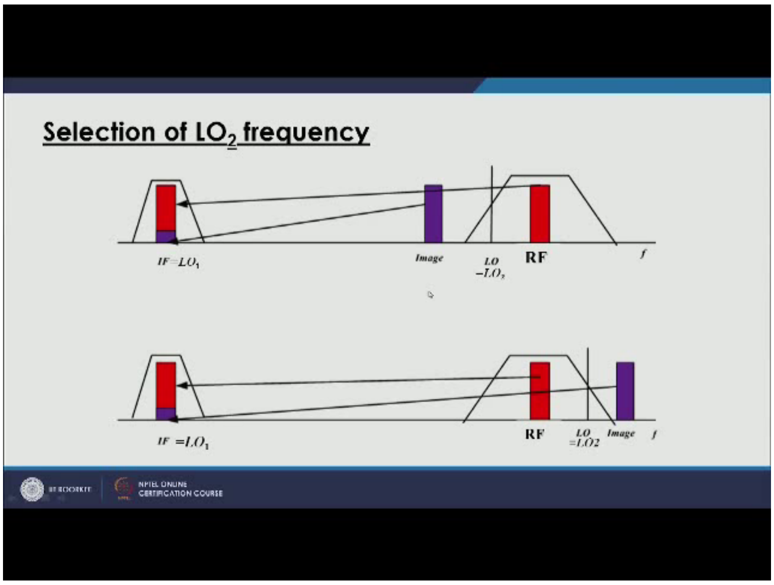

So, in this case here we are showing a case well this is the RF signal which we want to transmit and receive eventually at the receiver, but there is a signal which is appearing here, this signal which is appearing it is called Image signal. The definition of this image signal is the signal which is falling at a frequency which will eventually fall at the IF frequency when down converted. So, what is it what do we mean by this? Suppose we have a signal at RF let us say LO2 is 1 GHz and this RF is at one-point 1GHz.

The image signal is someone which will be at this frequency because when it will beat with this frequency it will give us 0.1 gigahertz which is the same frequency which we will achieve with our required signal, but beating this 2 we are also getting 0.1 gigahertz. And at IF level the both will fall on top of each other which we do not want.

Similarly, there is another case whenever RF is that minus f distance from the LO and the image is falling at the another in this case also your image and the signal will fall on top of each other, we want to avoid this. So, what can we do we can choose our LO properly. This case will be more clear once we have the idea of the homodyne receiver or 0 transceiver. So, in this case all the components are similar to the heterodyne case, but we can see that there is only 1 LO1. So, super heterodyne architecture f RF is f LO1 plus fLO2 and homodyne architecture will have fRF basically as FLO1 which is the single frequency available there. So, again if they are 2 separate transmitter receivers they have separate antenna. So, otherwise you can reduce single antenna with the circulator. Now what will happen in this case?

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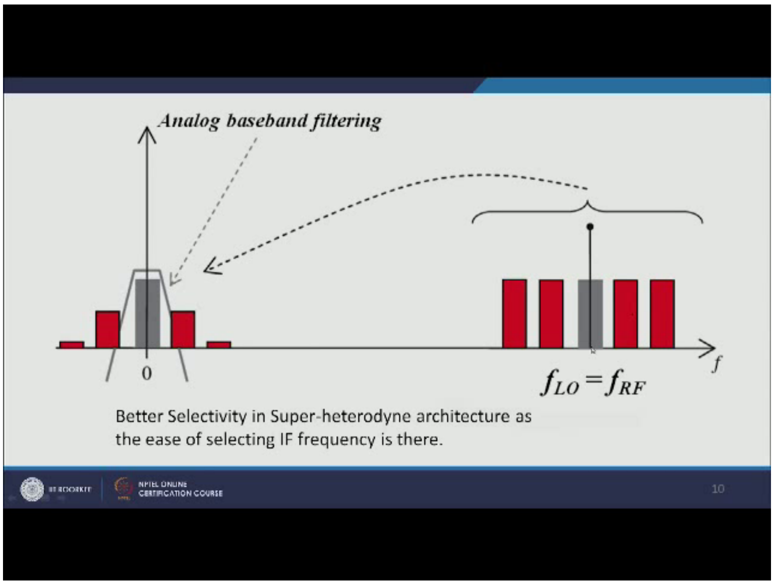

In this case, this gray signal is our required signal and this red color signals are representing the other signal distortion signal which we do not require which are not what we are looking for.

So, we put a band pass filter low pass is sufficient for the homodyne case and we are able to get our signal big back. So, what is the loophole here what are the good and bad points about these 2 architecture it can be understood by one example so let us say.

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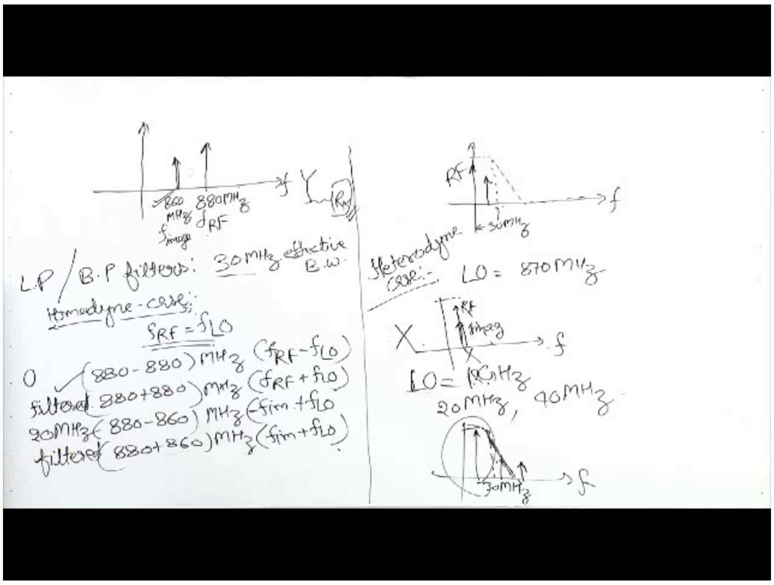

This is a our frequency range and our signal which we are receiving at our antenna. The signal we want to actually work with is that 880MHz, and there is a signal at 860MHz which is image signal or a signal which we do not want. Now, it is a RF signal and our filters they are practically not very sharp. So, let us say we have band pass filters with the range of 30MHz effective bandwidth. So, what will happen if it is a homodyne case? This fRf is the fLO in homodyne case.

So, the signal this will be down converted there. So, we will have components such as 880 minus 880MHz which is because of we will have component as 880 plus 880 which is because of fRF plus fLO, we will have signal as 880 minus 860 because now this components are also here which we can now not avoid because our filter is not stopping them. F image minus f image plus fLO, then we will have 880 which is again summation of fim plus fLO.

So, we can see from here it will fall at 0 frequency or DC it can be filtered because it is very high frequency and our signal band pass or we can say low pass, they it is 30MHz in the range it is very high for that. So, anyhow it will go away, this will be to 20 megahertz. So, it will be there and it will can again be filtered right. So, we have these 2 signals. So, in frequency domain basically after down conversion in this homodyne structure, the required RF signal will be falling here and our filter has a range of 30MHz. It will be this is the 30Mhz range and the other signal which we do not want it is falling here. So, our filters are not removing it. So, it will be a problem there. Now in the heterodyne case, we can choose our LO. So, how can we choose our LO? Let us say heterodyne case and we choose our LO to be equal to 870, right?

So, what competency will have from here if you do the summation and subtraction both of them are at 10MHz distance right. So, what will happen? We will have RF here and we will have our image signal also, here right? On top of each other and this will be our filter. So, not required this LO is not good at all. What we can do we can actually select a range for which it is it will not be good, if we select our LO in this direction let us say LO 1GHz.

Then it will have components such as 20MHz and from here it will be 40 megahertz. So, in the frequency domain it will be over filter which has 30MHz range and 20MHz signal will be here and then another will be at 40 which will be not used by which will be compressed which will be stopped by our band pass filter.

Moreover, if you make it more far let us say 1.2 it will be even further and our band pass filter low pass filter will completely stop it. So, by choosing our LO properly we will be able to get our signal back. So, this is the advantage of the heterodyne system based over the homodyne system it is more flexible by choosing LO properly we can select our signal and we can demodulate it properly.

Thank you.