Communication Engineering
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Lecture – 13
Superhet Receiver etc.

If we recollect, we were talking about frequency translation and mixing and in particular, we were looking at the effect in the situation where, the local oscillator is used to translate incoming carrier frequency from the value omega 1 to some value omega 2.And we said, we could do this by choosing a local oscillator a frequency omega 1 plus omega 2 or omega 1 minus omega 2. However, when we do that, we also found that there is a small problem which we have to keep in mind and the problem is that of the image frequency.

The image frequency will also get translated to the same output frequency, so if the input is omega 1, output is at omega 2, the local oscillator is omega 1 plus omega 2. If the input is omega 1 plus 2 omega 2 with the same local oscillator frequency, you again get an output frequency, which is omega 2. Therefore; omega 1 plus 2 omega 2 is the image frequency corresponding to omega 1. Similarly, omega 1 minus 2 omega 2 with image frequency, if the local oscillator has a frequency of omega 1 minus omega 2.

So, that is what basically what we have done, the concept of image frequency, so that is a brief review of what we did last time, today we will look at the application of this in designing, what is called as super heterodyne receiver.

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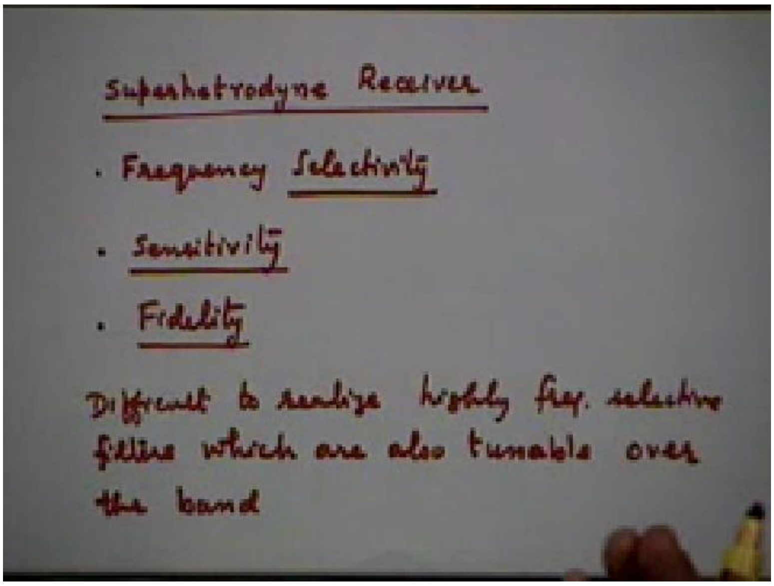

In short sometimes known as super heterodyne receiver, but basically, it is super heterodyne receiver, as to what heterodyne means we already know, why do we use prefix super is something that we will learn today, after finding out what this receiver is all about. Let us discuss, what we want a typical broadcast receiver, any other kind of receiver which has to tune itself, which has to receive signals, not necessarily at single carrier frequency, but form a range of a carrier frequencies in a certain band of operations.

That is going to be typically the case; the receiver is not going to be designed to operate at a single carrier frequency, we going to fix a certain band of frequencies, from which signals could be received. And multiple sources of information could be available and you may like to tune in to any one of the sources of information that is what we like to have. When you want to deal with a requirement like this, you need to design a receiver which can tune itself properly and give us some of the things we want.

Now what are the things that we want, let us from a good receiver, suppose we were to try to enumerate, a few important features that is should have. In this kind of situation, from common sense can we figure out 1 2 3 number of criteria, which we should, which this receiver should satisfy.

Can you make any suggestions; first thing is that it should be frequency selective that is basically what is meant by tuning. But more importantly what is meant by this term is that if we 2 radio stations and if the 2 transmitting stations at close by carrier frequencies, I should be able to reject one and accept the other, I should be able to except one without having interference from the closely spaced frequency. So, should be frequency selective enough, to reject a closely a close carrier frequency, so it should be frequency selective.

Selectivity therefore is one very important criterion in receiver design, the second is you would like, even the weak signals are captured nicely. So, even if signal is coming from transmitting station which is far off therefore, the signal strength at the receiver, antenna is small, you would like that it be captured nicely. And therefore, that property, we call sensitivity, they should be sensitive to weak signals, and they should have good sensitivity, even weak signals it should be possible to acquire.

And of course, the most important thing is in all the situations, the basic message signal should not get distorted. The output message signal in the receiver is finally, that you hear or that you see, depending on whether you are hearing something or seeing something should be as close a replica of the transmitted message as possible and that is referred to as fidelity. So, these are the 3 important properties that any good receiver will have, should be highly selective, it should be sensitive to weak signals and should have good fidelity.

So, for example, you talk about high fidelity systems, so receiver should be a high fidelity system, it should produce a very good replica of the actual message, without any distortions there should be very small amount of distortion if any. Now let us look at the issues, now how can you achieve all this, the important, let us discuss, let us the one this problem and see why, it is not easy to achieve this unless it s something clever.

Take for example, frequency selectivity, frequency selectivity and these 2 things, high frequency selectivity and these 2 other properties; it is very difficult to go together, if you for example, try to achieve all these selectivity, directly at the input to the receiver. So, I mean, the first reaction is that the receiver front end should be a filter a tunable filter, which you can tune to any frequency. That is the most obvious solution to having a receiver, which can tune in to a different whole band of frequencies.

So, obviously you should have a front, at the front end of the receiver you should have a filter, which will allow, the passage of only a single carrier frequency inside and around that. The message bandwidth let us say, suppose it is a music signal that we are looking at voice or music signal, the bandwidth is going to be about 15 kilohertz at more than that, so let us say you are operating at a frequency of one megahertz.

So, you want a selectivity such that the bandwidth is about 15 kilohertz with the center frequency of 1 megahertz not only that, see if it was a fixed center frequency a fixed bandwidth. This specification 15 kilohertz bandwidth at 1 megahertz makes the pretty high, the quality factor of a such a tube circuit is quite high, if you compute it, how much is it is 1000 by 15.It is of the order of how much about 60 or 70, so fairly high q, now difficulty arrive, this q is achievable with fairly complex circuitry.

But, this q when you want the circuit to also be tunable, when the carrier frequency can be has to adjustable is very difficult to achieve, when this carrier frequency let us say has to be adjustable across the whole AM band ((Refer Time: 09:39)).So, if we go for500 kilohertz to 5000 kilohertz, very difficult to achieve such a high q, such a high selectivity while having this tuning option, very difficult to have this, in terms of technical filters.

So, very difficult to realize highly frequency selective filters, which are also tunable over the band, as they say you cannot everything in your life is not, it same thing here, not only that, if you want sensitivity good sensitivity. What you want is it should not just do filtering operation, it should provide a large gain, so that a weak signal is strengthen, sensitivity means, how can you achieve sensitivity by having a large gain receiver. So, it should actually be a RF amplifier, which is tunable, highly frequency selective and provides a high gain.

Now, these are, if you have all these ingredients in the RF amplifier, they are bound to most probably generate an oscillator, when you try to realize it, rather the amplifier, because these are the prescriptions of a run stable amplifier. High gain associated with high frequency selectivity etcetera, etcetera will generate conditions, which will be very difficult to control ((Refer Time: 11:34)) and your various other elements in the circuit will make it highly unstable. It will be very difficult to realize such a tune filter, which provides all these things.

Of course, fidelity would simply require that bandwidth of the filter should be sufficient to pass the message without distortion. So, if it is a 15 kilohertz signal over the 15 kilohertz, you do not have a lot of variation in the frequency response of the filter, either in amplitude or in phase. Of course, phase distortion is not very important in voice applications, music applications, but is clearly important in TV applications, picture applications.

So,

Student: ((Refer Time: 12:23))

That is true the question is if the sensitivity is increased, it will also increase the response to the noise. True, but ultimately what matters is signal noise ratio, so for that we make we make sure that only, that portion of the spectrum is allowed to pass through, which carriers the message signal.

That is why we have to be selective, selectivity is also required not only to avoid interference from other sources, from other transmissions, but also to ensure that, too much noise does not come through, because noise is typically, you know is distributed equally at all frequencies. So, only want to leave that amount of noise, which is inescapable, so frequency selectivity takes care of that to some extent.

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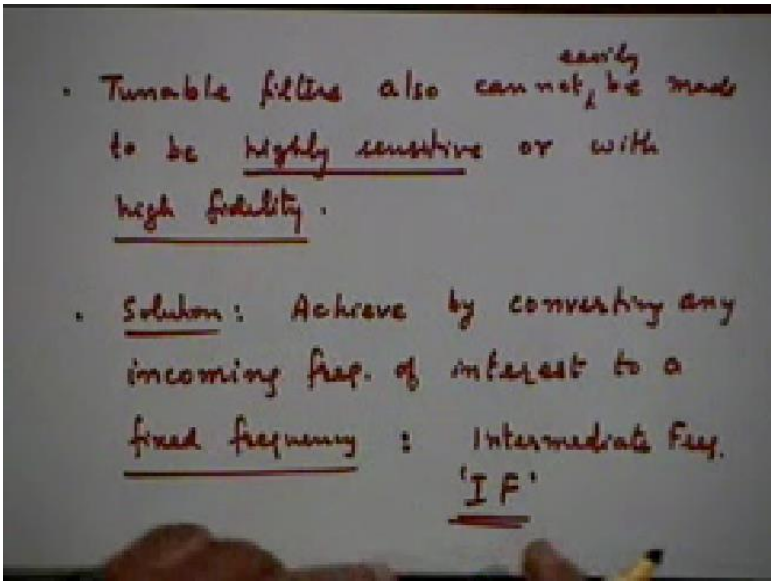

So, the other points therefore, I made are that tunable filters of this kind, also cannot be made, cannot easily be made. If you pay price you can always get anything, if you want, you should pay very high price. In that case cannot easily make to be highly sensitive or let us say high fidelity. So, these are the problems, this is not a key problem, but this is definitely a problem.

So, tunable filters cannot be made highly selective, they cannot be made highly sensitive and these are the requirements that, we would like to have in a receiver. So, how do you achieve these requirements then, what is the alternative, can you think of a clever solution. The hint is that the discussion that, we had last time, about frequency translation and mixing should provide us a solution, can the solution come from the ((Refer Time: 14:34)).What features should we remove, in this slightly bleak picture, so that this these disadvantages go away.

Student: Sir, we can have the amplifier design ((Refer Time: 14:51)) amplifier one particular frequency very well and then translate the signal, we want to be amplifier to that particular frequency.

Very good, that is basically the idea; you translate every single frequency that comes in, any carrier frequency in which you are interested after tuning in to that on to a single fixed frequency. And the features that you want selectivity, sensitivity and fidelity should be features of this fixed frequency tune filter, rather in variable frequency tune filter. So, that is the answer to our question, so the answer is the solution to this problem is achieve or try to achieve, these 3 properties by converting any incoming frequency of interest by frequency here I mean carrier frequency, it is implied.

There is a message along with this carrier frequency, incoming frequency of interest to a fixed frequency. This at this freq at the receiver carries out most of it is nice job it has to do at this fixed frequency and it is typically known by the name of Intermediate frequency or in short IF. Last time I put, IF for image frequency, but IF is more commonly used for intermediate frequency. And therefore, typical receiver picture.

Student :((Refer Time: 16:52))

I am giving the details now, let me go through the process then, I think if you have any questions after that will take care of that.

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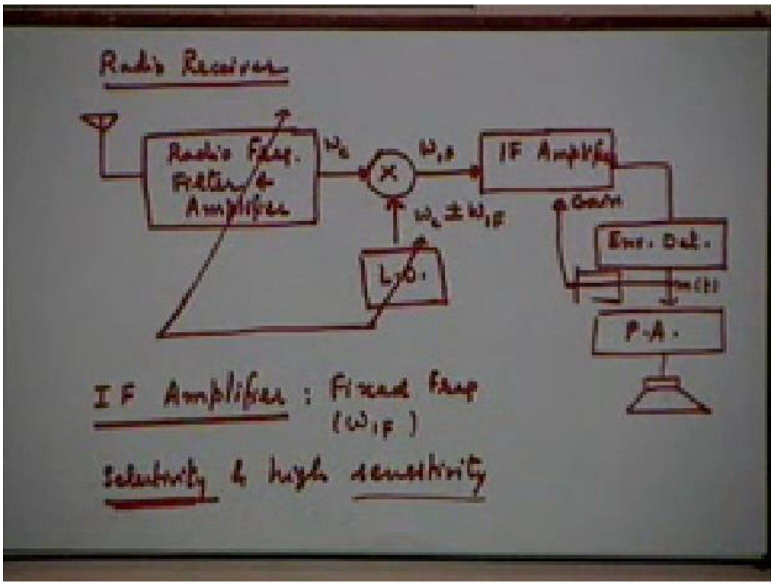

So, the super heterodyne receivers precisely does that, you have your signal coming in from the antenna, the first stage has to be, the radiofrequency stage, which carries out initial. This is the radio frequency filter and may be some amplification, remember filtering has to be done for 2 reasons, one to reject, other signals and the other the remove noise out of band noise.

Noise which does not lie in the message bandwidth, noise that lies in the message bandwidth, we cannot do really very much about it; it has to come along with the signal. This signal, now therefore, so you have circuit frequency, may not be very highly frequency selective at the movement, because we are saying that selectivity will put somewhere else, but we are roughly tuning to the frequency of interest. And what should we do, we should convert this signal of to an Intermediate frequency signal.

So, this is like the frequency translation we were discussing yesterday by using a mixer and mixer will have 2 inputs, one incoming signal here and a local oscillator. So, this mixer is again a multiplier, gets the other input from local oscillator, this frequency is suppose this is omega c, this will be omega c plus minus omega IF.

If it is omega, so that the converted frequency is omega IF and now no matter whatever the input signal here, this will always be omega IF, the output here will always be a omega IF, of course we will have to make sure that these 2things.The filter and the amplifier combination here and local oscillator here are tuned together. So, that the tune this to a different frequency, this also generates different frequency, if this goes from omega 1 to omega 2, this also this change from omega 1 plus omega IF to omega 2 to omega IF.

As this is tuned, this also should tune, so this tuning is typically ganged up, this happens together, so single ganged up set of capacitors or whatever. In fact, if you any of you is familiar with or who has ever opened the radio set, you will see a set of parallel plate capacitors, which are ganged up together. There are 2 sets of plates and when you do tuning; basically both the set of capacitors will move in and out.

So, that ganging up is done, to change both the local oscillator frequency, as well as the center frequency of the tune filter here, so that different between these 2 frequency is always omega IF, so, that has to be tuned. This is now past through in IF amplifier and it is this amplifier, which provides all the nice properties that you want from the receiver, you can make it frequency selective, it is bandwidth can be exactly 15 kilohertz no more no less.

Typically, if you are providing a bandwidth for 15 kilohertz in your radio receiver, the different transmitting stations will have a frequency separation of 20 kilohertz to 25 kilohertz. So, we make sure that an adjacent signal, which will be 25 kilohertz away, does not come out ((Refer Time: 21:34)) IF amplifier is detected, so that kind of selectivity can be provided by the IF amplifier. Similarly, the IF amplifier will can provide high gain, because this is not a fixed frequency, realizing such an amplifier with high gain is not a problem.

And of course, it can give you the fidelity that you want, of course, fidelity most of the fidelity problems arise not at this stage, but they arise at the power amplifier stage, which typically follows this, after we have detected the signal. So, at anyway then nature let me complete, the nature of the signal here and the signal that was coming in, they are identical all you have done is translate it the signal the modulated signal from omega c to omega IF.

So, you again get an amplitude modulated signal here, except that the carrier frequency is no longer omega c, but the carrier frequency is omega IF. So, after this we have to do demodulation, which you can use, for which you can use, whatever you like to use. Typically, in this kind of an application it is an envelope detector followed by a power amplifier, which is where most of the distortions are likely to arise.

Because, now you have the message signal here, which you want to power amplify, before you drive in to a speaker or display device you have, output device you have and this can go to let us say, if it is voice or music, this will go to a speaker. That is typically the block diagram of a radio receiver, so that is your typically radio receiver, yes I think there was a question there.

Student: ((Refer Time: 23:34))

IF amplifier, basically what we are saying is because the IF amplifier is at a fixed frequency, what is the fixed frequency, omega IF. No matter what the incoming signal frequency is the same signal is now available at omega IF, I can it is much easier to design, an amplifier of fixed frequency with the properties actually want selectivity high selectivity and high sensitivity. These are very easy to build in an amplifier of fixed frequency rather than the amplifier of variable center frequency.

So, if you can make it highly selective in the sense that2 signals, which are separated by suppose, this follow here are RF amplifier here does not do job well. Suppose signals, which are close by will come out, well it will not be just omega c, but a whole a couple of a few other frequencies, which are close to omega c will also come out here with some amplitude. So, they will also be present here, but their frequencies will be slightly different, because at they are exactly local oscillator IF.

So, this will also be present here, but this IF amplifier will be able reject it, because it is designed to only accept the 2 omega IF, any other close by frequencies, which are not of interest. It will be able to reject it, you can make frequency selective enough to reject all close by signals, which are not rejected by the RF filter, let us proceed to what I have said that is what is meant by selectivity, I can make it highly selective and highly sensitive by providing a large gain to it.

So this is roughly the block diagram of a radio receiver, there are few features that I have not mentioned, for example can you give me some idea of some problem, which has not been taken care of in this picture. Image frequency is something I am coming to that has to yes, I will come back to the image frequency that is an important issue yes, any other any other thing, which is not been taken care of, please speak a little louder I cannot.

No distortion, we said if the power amplifier designing is done properly, there will be no distortion any other thing, noise we already discussed. Let me tell you something, we saw that the signal, this has to be highly sensitive, which means you are saying that the this gain should be, the gain of the amplifier should be large can that be a problem, if the gain is large. Suppose the signal that is coming in already very strong and you have a very large gain sitting here, what can that do to the system.

The amplifier will go in to saturation, so we do not want that situation also, should the other things that you require in the receiver, for example, there should be some mechanism to automatically control the gain depending on whether the incoming signal is weak or whether it is strong. Typically, that is done by taking a feedback from here, we are looking at the message signal and see how strong it is and use that feedback to modify the gain of this amplifier.

So, there is gain control signal, which is generated from this to some processing, yes gain control is carried out and the IF amplifier gain is reduced or increased depending on whether you are working on a weak signal or a strong signal. So, there are other such nice features, that we like to include in the design of the filters actually the receiver is quite com complex, if you include all these things. The principle is very simple, but the details become more and more complex as we as we try to include more and more features in the receiver.

So, but broadly speaking this is for radio receiver has to do, a somebody mentioned a few minutes ago, the problem of image frequency, that will be a problem. So, let us look at that problem. So, to appreciate the problem, let very clearly, let me draw a picture here.

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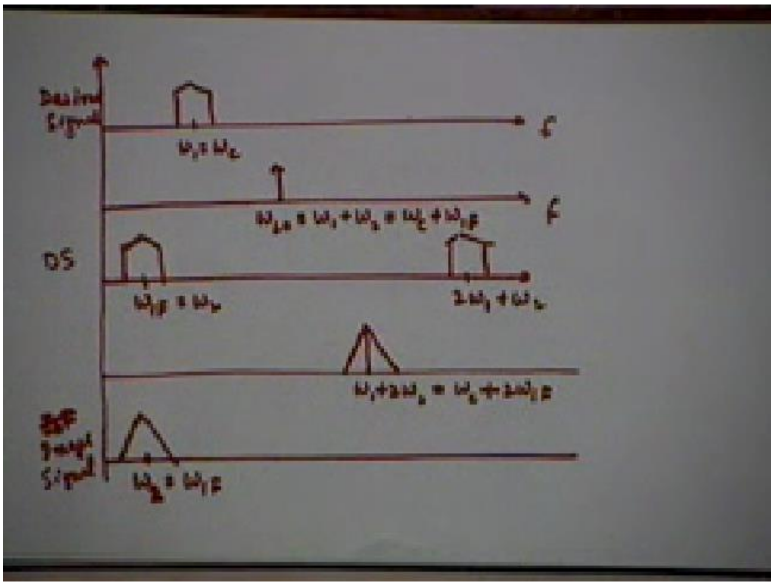

Let us say your desired signal is at frequency omega 1, which is a carrier frequency, I am talking about, this is I am plotting this in a frequency domain. So, this is the desired signal, it has this spectrum, I just arbitrarily plotted some spectrum, it is not really plotting the shape I arbitrarily draw. So, what will your local oscillator frequency chosen to be omega L o will be omega 1 plus omega 2, which is omega c plus omega IF. It could be minus also, omega c minus omega IF is also permissible, but we will see whether plus is better or minus is better in a few minutes.

And after the mixing of these 2, this signal will be translated to omega IF, which is typically a lower frequency, than incoming carrier frequency. So, this is this message signal is put back to omega IF, so this is omega 2, omega 2 is now equal to omega IF. Now, it is quite possible and this of course, there will component at omega 1 plus omega 2 plus omega 1, so there will also be component at 2 omega 1 plus omega 2, when you are mixing omega 1 with omega 1 plus omega 2, you will have a component at omega 2.

And another component at 2 omega 1 plus omega 2, however this is not of interest this by the filter following this, band-pass filter the IF filter. This is what you want, this is the desirable thing, and the undesirable thing is image frequency. What is the image frequency here, omega 1 plus 2 omega 2, so let us say somewhere here and let us, there is another message signal present here. The second signal, there is a radio station, whose center frequency is omega 1 plus 2 omega 2 that means omega c plus 2 omega IF, suppose there is second transmitting station, which is transmitting at this frequency.

When this mixes with this local oscillator, what will this produce, it will again produce an output with it is center at omega 2, so we will get this signal at omega 2, which is at omega IF. So, this was the desired signal and this is the image frequency signal, now I should not use IF image signal, these 2 things are coming together in to the IF amplifier. Because, the IF amplifier will see this spectrum as well as this spectrum in the input, both these signals will go in and now you will have the problem, there is no frequency.

Student: ((Refer Time: 32:33))

Sorry, why cannot we.

Student: ((Refer Time: 32:43))

So, you are absolutely right, basically the important point that you have made is the correct point, what we need to do is to make sure, while this filter may not be very selective. It should at least be selective enough to make sure, that while this passing omega c, it does not pass omega c plus 2 omega IF. So, therefore the selectivity requirement of the RF filter it is still there, but, it is very moderate selectivity requirement.

What we are saying is the 2 carrier frequencies, which are separated from each other by 2 omega IF, be separated at the are RF stage itself and that is your friend was proposing here, which is the right solution. So, the image frequency will be taken care of will not be a problem. It shows that the radio frequency filter that you have here, the radio frequency amplifier that you have at the input stage is at least slightly selective to make sure, when it is selecting omega c, it is rejecting omega c plus 2 omega IF.

And typically 2 omega IF is clearly well separated from omega c plus 2 omega IF is well separated from omega c. So, that separation should not be a major problem realizing a RF filter with that kind of selectivity’s should not be a major problem, right to see things more specifically let us some figures. For typically radios that we use the AM radios or whatever that you use.

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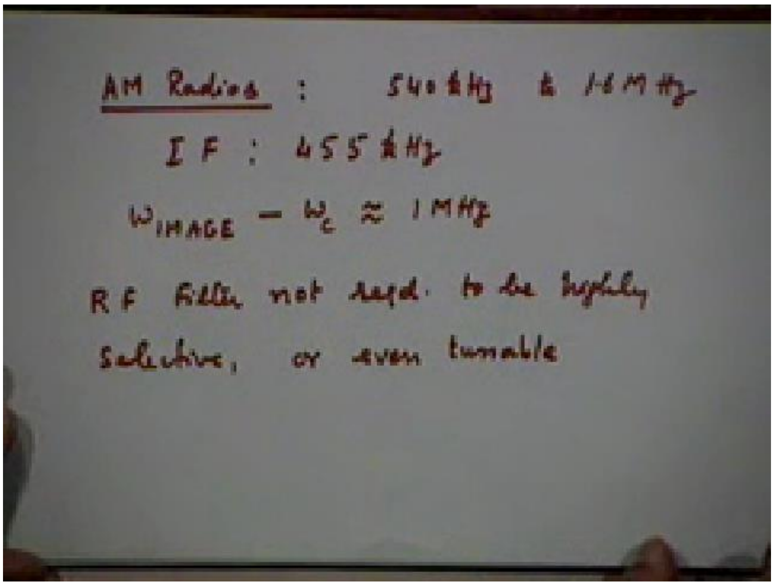

Let us talk about AM radios, the band frequency the typically AM band that, we work with is 540 kilohertz to 1.6 megahertz and a typical convenient IF frequency to use intermediate frequencies, frequency to use is 455 kilohertz. So, what is the separation between any incoming signal frequency and it is image frequency 455 into 2 omega image minus omega c is of the order of 1 megahertz; almost 1 megahertz 500 into 2 is 1 megahertz.

What does it mean? Your any way incoming signal frequency of in this Range 540 kilohertz to1.6 megahertz, which means, for this particular situation the RF filter need not be tuned at all. It does not require any frequency selectivity and still because, the bandwidth requirement, the image frequency separation is quite far in this case, image frequency will not typically cause a problem because most of your transmitting stations are lying in this Range.

So, even if the worst situation will arise, if omega c is 1.6 or let us sat omega c omega c is 540 and omega image will be 1.54, the separating if you all, if I very moderate selectivity, hardly any selectivity. When the 540 kilohertz signal is coming in the 1.54 signal should not be allowed to pass through the RF filter. It is hardly a, it can easily be done such a RF filter, which is tunable and providing this kind of selectivity is not an issue.

So,

Student: ((Refer Time: 36:52))

You making the job more difficult in that case, you do not want to go outside the band of interest; you must keep well below, because it is much easier to build amplifiers with high gain and cheap components al lower frequencies than at higher frequencies. You do not want typically intermediate frequencies will be much less than, the band of operation that will the answer to this.

So, in this case the RF filter, need not even be not required to be highly tunable, highly selective or for that matter even tunable at least in this case. How much the down tuning you can take care of? Any questions, one last issue in this connection.

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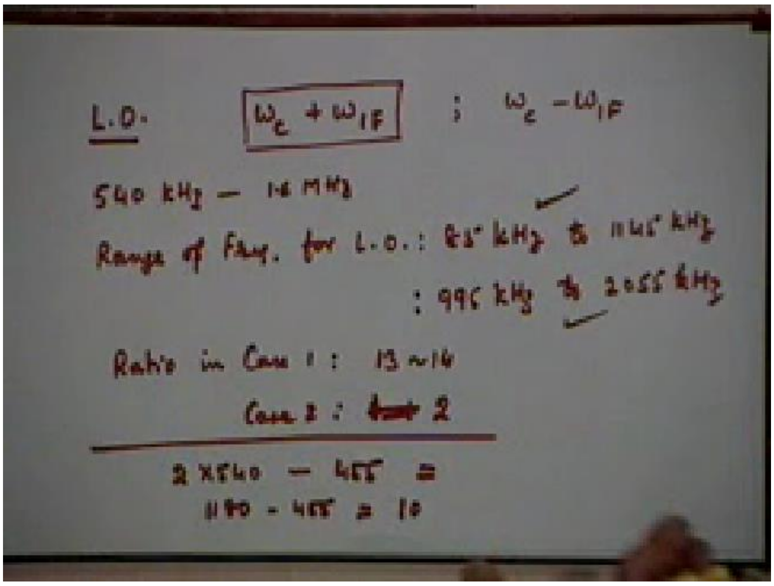

Let us look at the local oscillator requirement, the local oscillator, you could choose a frequency, which is omega c plus omega IF or you could choose a frequency, which is omega c minus omega IF. The question is there any preference for any of the 2, what would you like to say about it, which one will be better and why to understand that issue let us consider the same 540 kilohertz to 1.6 megahertz or 1600 kilohertz.

If you choose this, if you choose omega c minus omega IF, what is the Range of frequencies that the L.O is required to generate. It will 540 minus 455, which will be let us say about 85 kilohertz and 1600 minus455, which will be about 11 45 kilohertz, if on the other hand you choose omega c plus omega IF, then the Range of frequency will be

995 kilohertz to 600 plus 4455, which is 2055 kilohertz.

So, the issue of whether to choose this or choose this really boils down to whether, this is better to use or this is better to use or this is easier to build or this is easier to build, what is your gut feeling about it upper one or lower one, which oscillator you think is easier to design. Lower one why, the Range the ratio of the frequencies that you need to vary it over see you want a tunable oscillator here, variable frequency oscillator is what we are looking for and the ratio of frequencies is almost one is to 2 here, where here it is 1 is to 20 almost, I am not13 14.

So, the ratio in Case 1, for the 2 frequencies, this divided by this is in the order of 13 to 14, whereas in Case 2, it is almost1 to 2. Typically in the order of 2, it is much easier design oscillators where the tuning Range or the variable frequency Range has a smaller ratio than a much larger ratio. And that is why typically you go for the higher local oscillator frequency rather than the lower local oscillator frequency and that is in fact, the reason, why this is called as super heterodyne receiver.

Heterodyning you know, Heterodyning is mixing, but we are mixing with a local oscillator, which is at a higher frequency and the name super heterodyne; heterodyne comes from there. Besides if you wish, you may say that, it is super heterodyne because, it does a superb job, but that is not the reason, yes please.

Student: The lowest value of omega c and omega IF are comparable then 2 omega c minus omega IF ((Refer Time: 42:05))

But, again you can say that, if you do not require very large separation let us see 2 omega let us say 2 omega c would be 2 into 540 minus 455, because the separation is still for separation between these 2 is still of the order of 450 kilohertz. That will be taken care of by the IF filter

Student: But the omega is also 450 ((Refer Time: 42:41))

No omega IF is at 450.

Student: sir, one signal is omega IF and the other is 2 omega c minus IF.

Let us see the difference, the difference is still huge, this is what 1180minus 455, whatever it is quite large where as the IF filter, which is centered at 455 kilohertz, where as the desired signal lies as a bandwidth of 20 kilohertz and so, it is not an issue, think about it, if you still have a question will take care.

Student: ((Refer Time: 43:27))

Yes if you have a peculiar situation, then certainly you should guard against such a situation, but it is not going to arise in this application, you must choose a value of IF, which satisfies all these requirements. So, IF has to be carefully chosen and the value of 455 kilohertz is a standard value for most radio receivers, this is standard value, it is important to do such standardization, so that you can in a market and buy components.

You cannot if somebody decides to one intermediate frequency and some other person wants do design some other carrier intermediate frequency. It is going to be very chaotic, you cannot go to the market and buy components and make the receiver, if you want buy it. So, that is something, now we have enough time just to take up one small issue in some detail, another is you know the practical realization of the devices, which we have taken for granted in all these discussions. These devices are the mixers, the multiplier, the modulator, we call it by different names, precisely it is a multiplier, and we have had opportune to discuss these briefly elsewhere.

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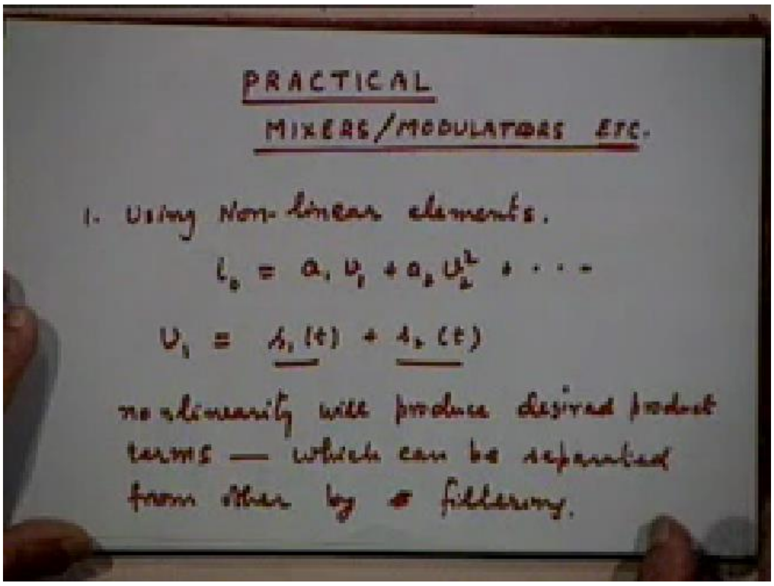

But, let us spend some time on you know, only a small discussion, we like to have on, how do we realize these things, because I wanted to give a brief idea about these things in this class. It is reason why, I put that etcetera in the title of lecture today that is super heterodyne receiver etcetera, so the etcetera was because, I wanted to spend some time on this.

Now, I will just have brief discussion here one is we can realize these kind of devices using nonlinear elements, for example the nonlinear elements that basically, what do we want to multiply 2 signals. It could be the message m t with the carrier, it could be the incoming carrier frequency signal with the local oscillator signal, these are the kind of things, and we want to do. How do we multiply, we know how to add signals, we know how to subtract signals, addition is multiplication is possible by nonlinear elements in the circuit with the linear elements it is impossible to do that.

For example, we can have nonlinear IV characteristics of some device, which we should exploit, for example, you can have a device whose current voltage characteristics are of this kind, in which case, if I choose my input voltage V1 to be sum of the 2 signals, I want to multiply. Then the cause of the nonlinearity, I will get some product terms, the only thing I have to assure is that there should along with the product terms, there will lot of other terms as well, what we have to ensure is that it is possible to separate out the desired product term from the rest of them.

So, nonlinearity will produce product terms, of the desired product terms, typically they can be separated out from the others by appropriate filtering, if you, if it is possible to do that you do that. So, this is one mechanism of realizing these multipliers or these modulators or mixers, typical devices, which will exhibit these characteristics, are PN junctions of diodes and transistors. So, most of the mod mixers and modulators can be realized using diodes and transistors, I will not have time to go in to, I like you to look it up yourself, I will give a reference for thisin the class next time.