Communication Engineering
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Lecture - 9
Amplitude Modulation (Contd.)

If you recollect we were talking about Amplitude Modulation, we have looked at the important properties of an amplitude modulated signal and, looked at the time domain waveform looked at the frequenciesat the main spectrum and we were now, discussing the demodulation ofamplitude modulation. And, what we discussed, sofar was that by the insertion of this carrier at the transmit transmitter, along with the modulated signal along with the DSB SC component.

If we make sure the envelope, that the envelope of the resulted signal follows the message waveform, the shape of the message waveform then we have an advantage. This could of course be done by making sure that we have sufficient carrier inserted into themessageinserted into the transmitted signal.In this case,we basically the modulation index should be less than 100 percent should be less than 1 if it becomes. If it becomes more than 1 essentially that the shape following property will not be there, and we will not be able to have the advantage of using a very simple demodulator and the demodulator structure was extremely simple.

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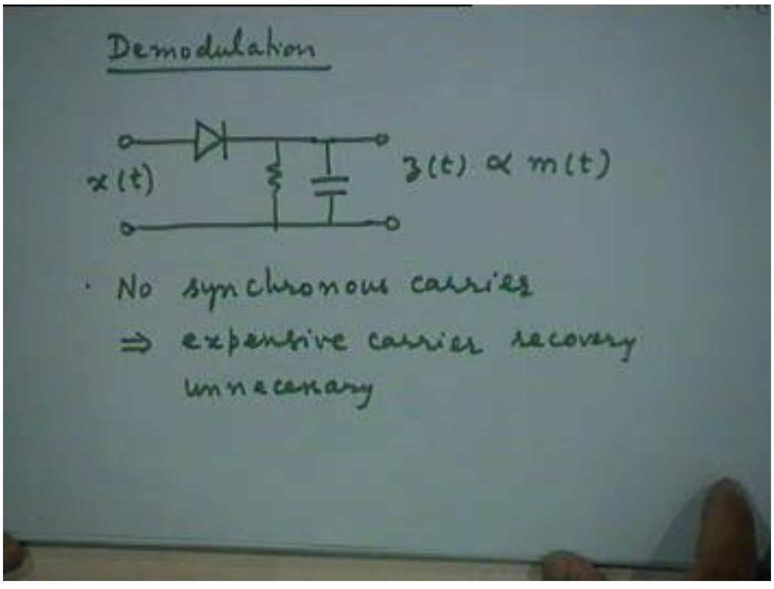

This was the circuit we discussed very briefly,we will discuss it in more detail now, where you have a simple diode followed by a resistor Rl in parallel with the capacitor c.And our premises that if at the input you apply a message signalthe modulated signal x of t, the amplitude modulated signal x of t, the output z of t will be proportional to the message signal or message waveform m of t.

And if this works as we in detail briefly, how it could the advantages of simple circuits are that we do not require any complex circuits for synchronization of local carrier to the incoming carrier. So, no synchronous carrier is required and there by the receiver becomes a much cheaperversion, nowthis was a very brief introduction to how the demodulator works, it is again a repetition of what we did that day.

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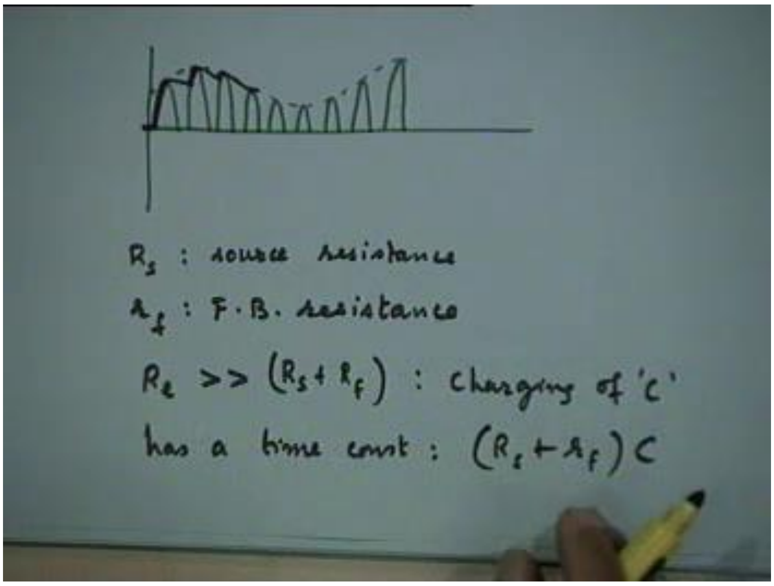

So, what we said was that the diode will conduct only in the positive half cycle of the carriereven there it does not always conduct, in the beginning when the diode is when this positive half cycle comes the diode conducts.And, if we assume that the charging circuit for the capacitor has very small time constant then, the capacitor voltage will more or less follow the carriersignal that is coming in during this half cycle.

So, we will keep on getting charged to the incoming voltage, till it reaches the peak value. Sowhen it reaches the peak value at this stage and when the input voltage now drops, this diode becomes reverse biased because, this point is at higher voltage than this point. So, there is no conduction of diode, the diode remains reversed biased during this falling portion of thecarrier half cycle.

And, during this period the capacitor discharges through this load resistance, through this R sub land let us say there is a certain discharging time constant which is not too fast, the discharging we do not want the discharging to be too fast.So, that it more or less stays at the constant value that it help chargetoo, except there it decays just a little bit and then, the next half cycle comes in at this point again the diode becomes forward biased, again the capacitor starts charging.

Charges to the new peak value and this cycle of operation repeats itself, to produce an output waveform which looks like this, which looks like the black profile I have shown here and thereby, you can see of course, this diagram is highly exaggerated in the sense, that the carrier cycles will be much more closely spaced thatI am shown in this diagram. So, actually what you see is not such a wavewavy envelope, but a fairly smooth envelope which can be smoothened still further by a suitable low pass filter, if required.

So, that is the basic principle, for this to work or there any conditions that you should satisfy obviously, yes let us look at the charging path, the charging path is solet us say some sources that we met you might associate with the input.After all the input is a voltage source, coming from somewhere may be from an antenna or from someprevious stage of thesome amplifier previous to the demodulator.

So, there would be a source resistance associate with the waveform x of the, let us say the source resistance is Rs. And let us say the forward bias, in the forward bias, they couldthe diode behaves like a simple resistor, would the resistors are small value of resistor is equal to r sub f.So, we can call it the forward bias resistance of the diodetypically, both the source resistance the source impedance and the forward biased resistances are small values.

And, what would be the charging path, the charging path will essentially this, this is the charging path that has kept charges like that, assuming that Rl is sufficiently large it will hardly affect the charging path.If you assume that, soif we assume that Rl is say let us say much greater than Rs plus r f, the charging path charging of c has a time constant, what is the time constant associated with it, given by Rs R sub s plus r sub f C.

And, what would you like this charging time constant to be large or small extremely small, can we quantify this how small it should be. It should be much smaller than let us say the half cycle duration, or thelet us say cycle duration of a carrier wave. So, that it follows thecarrier as it comes more or less.

Student: ((Refer Time: 08:29))

Yes, please

Student: ((Refer Time: 08:31))

Is not that obvious, the question is why would the diode stop conducting at this, in this interval. That is because, the output at this point the voltage here is now higher than the input voltage, when does the diode conduct if the, iflet us say suppose it is a pn junction diode, with the p side at a higher voltage than the n side then, only it conducts isnot it, it is a very elementary operation of the diode, is it clear.

Student: ((Refer Time: 09:10))

R l is the load resistance that I have talked about.

Student: ((Refer Time: 09:17))

I just explained because, if you assume that then this would not come to picture of the charging time constant.This is sohigh that the current will hardly flow, the charging current will hardly flow through this resistance those were the currents were immediately used to charge up, the capacitor and the charging time constant.Therefore, would be would not have to worry.

We do not have to worry about the value of R sub l in calculating the charging time constant, if you want to calculate the charging time constant more accurately what will it be, it will be the resistance involved would be Rs plus rf in parallel with Rl. So, all the thing is Rl is much larger than this, sothe thereforethe parallel communication behaves more or less like Rs plus r f itself, so that is the end of this theory.

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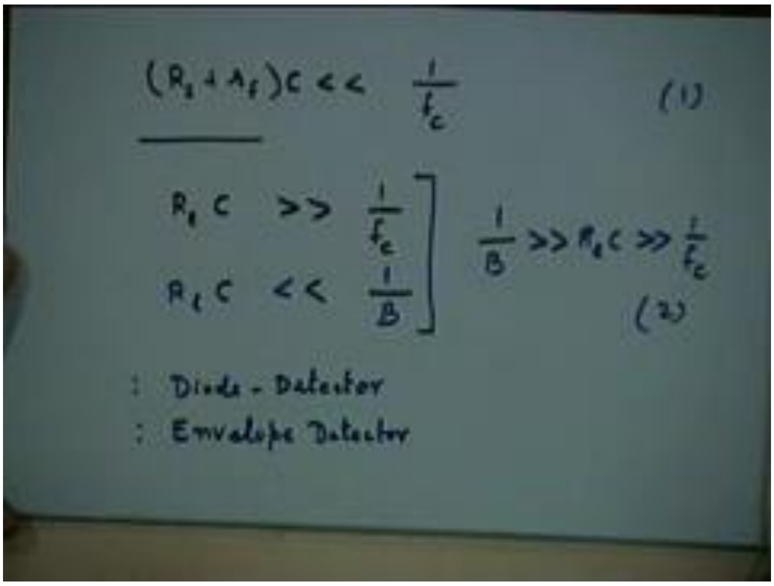

So, the point is that for the charging time constant the condition that you should have is, that this time constant is much less than the reciprocal of f sub c, which is the timeperiod of the carrier wave. It should be a much smaller than that, so that the capacitor immediately charges the moment the diode starts to conduct it follows the, it follows the cycle half cycle of the carrier wave as it comes.

During the positive half cycle, sothis is one condition that is required the second condition is regarding the discharge, what would you like to discharge in time constant, what is the discharge for just come back to this through Rl. So, what is the discharging time constant R l times C, sowhat would you like Rl times C to be should it be a large value or a small value.

Student: ((Refer Time: 11:13))

It should be large,it should discharge slowly, soRl C should be much greater than 1 by fc, but this is one aspect, this can lead to a situation which is not desirable we appreciate that, let us look atthis picture once again.Suppose your time constant discharge time constant is very slow, let me take a different color now it can happen that the discharging is very slow and let us say suppose it is very slow here. Suppose it is so slow that the next peak comes at a lower value, then the amount by which the amount which the previous peak has discharged,is that good or is that bad.

It is bad because, you are not following the envelope, sothis would lead to a kind of clipping, you would missed all these variations in between, sowhile this discharge time constant should be slow.It also should not be soslow that, it does not follow the fast fluctuation that might take place in the envelope itself, this envelope fluctuation here is much faster than the rate of discharge of the capacitor.

And therefore, there is a kind of distortion that will come up in the envelope which you call the clipping distortion and which you should avoid, if you want to get afaithful reproduction of the envelope. So, what should we what condition should be satisfied for that, while this time constant should be much larger than 1 by fc that is, that is perfectly fine,but it should be much smaller than the rate at which the highest rate at which the message signal itself can vary.

The modulated signal itself can vary and what would be the highest rate of message signal variation depend on the bandwidth of the message signal, the highest frequency present in the message signal. So, let us say the highest the bandwidth of the message signal is b therefore, the highest frequency present in it is b and therefore, thetime interval of interest is 1 by b, sowhat we would like to have.

Therefore, in addition is that Rl C should be much less than complete the sentence1 by b, these two conditions we can put together,we will say that the time constant Rl R sub l times C should be much less than 1 by b, but should be much greater than 1 by fc.So, if these two conditions are satisfied by enlarge, we have a system which works nicely, sothese are the two conditions that we need to satisfy any questions, any questions?

Student: ((Refer Time: 14:52))

It will depend on the amplitude basically, they have captured the relation the approximate relation that details are definitely a little more involved, the question was would this also depend on the amplitude variation of the envelope. Actually, amplitude most of it is kept most of the variations are captured by 1 by b. But there is some amplitude dependent which is not captured by this equation,we will discuss them separately let us say in some problem session.

You see, here

Student: ((Refer Time: 15:38))

No more, why fc plus b, you are trying to track the envelope, fc does not comes into the picture, you are trying to track the envelope is nothing to do with fc.The envelope is entirely a property of the message waveform m of t f sub c has nothing the carrier has nothing to do with it we just want to make sure, that this condition does not arise.We want to make sure that while the rate of the charge is slow, it is not soslow that you capture the fast fluctuations in the envelope itself. Soyou are comparing this rate of deviation with the rate of initial message waveform of envelope, is that clear?

So, there is thiscarrier frequency does not enter into the picture at this stage, sothat is what the envelope detector is all about, sothis is what we call the diode detector it has various names.We also call it the envelope detector, and as you can see thus with these three components the diode the resistance of this result into large value and the capacitance, we can build in very simple demodulator. And,that is what you most of your AM receivers would do, if you use in yourhomes or whateverwind up with the discussion on amplitude modulation,we will take up this small example.

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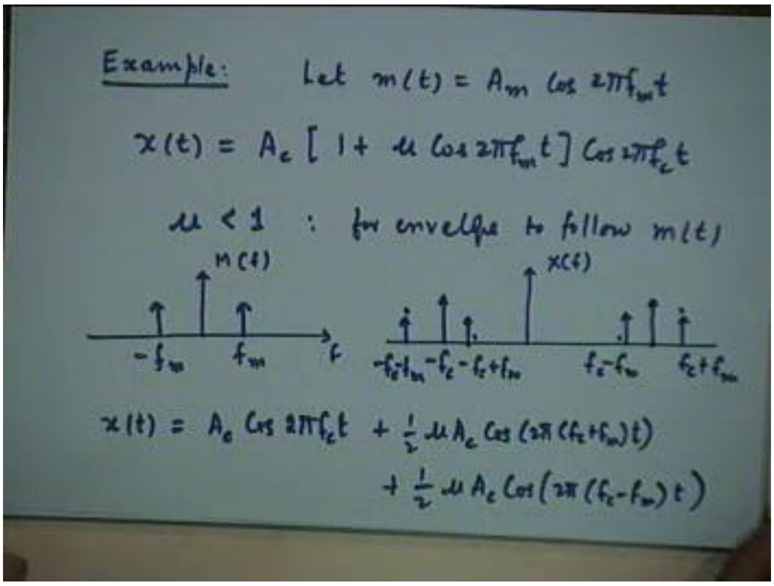

Let us say our message signal is a pure sinusoidal signal of frequency f sub m, sothat your modulated signal x of t is given by, what will it be given by something like this,1 plus mew times the message waveform m of t into the carrier. So, the first term is a carrier component, the second term is the modulated the DSB SC kind of component which together forms this, these two components may be together forms the AM signal, AM signal with carrier.

So, if you want toavoid or if you want the envelope of the signal to follow the message waveform, what should be the condition of mew, mew square should be less than 1, the modulation index should be less than 1 or the percentage modulation should be less than 100 percent.So, for the envelopeto follow m of t, m of t here is this what would what do the signal look like, what do these two signal look like in a frequency domain, what is the message spectrum like?

Student: ((Refer Time: 19:07))

Impulses at f sub m and f minus sub m, after modulation the spectrum of the modulated signal x of f, you will you have this components at fc f sub c plus f sub m f sub c minus sub m and also there will be a carrier component. Similarly, there will be components at minus fc plus fm minus fc and minus fc minus f m, this is what the spectrum will look like for this signal, plus do some power calculations now and therefore, power efficiency calculations.

This to do that, let us look at how much power is carried by the carrier and how much power is there in the sidebands, which are the side bands in this case, these are the two sidebands this one is the upper sideband this is the lower side band.Actually, these two together this and this together constitute the upper side band, this and this constitute the lower side band. Soif you want to write this expression in terms of the various components that are present in the signal.

Then, you have this is the carrier componentwhich is Ac cosine 2 pi fc t, and by using the trigonometric identities, we can write the rest of them in terms of the two side band components. The upper side band will have an amplitude, mew Ac by 2 and the signal there is 2 pi fc plus f m t. Similarly you have a lower side band which of amplitude half mew Ac, and sine 2 pi fc minus fm t, this by simple trigonometric identities you can write this, now how much power is carried by the carrier.

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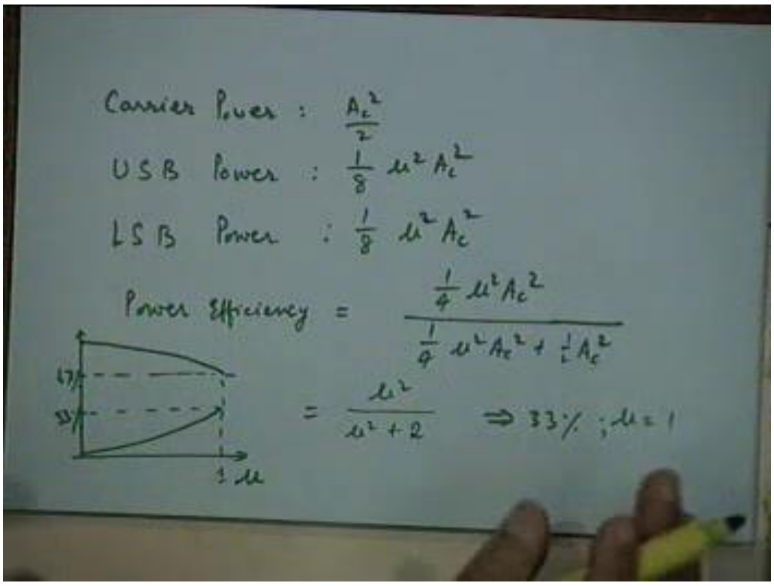

So, what is the carrier power to keep this there,carrier power will be Ac square by 2 A sub c square by 2, what about the upper side band power, this will be 1 by 8 mew square A sub c square, half of the square value of this amplitude similarly, the lower side band power would be also the same.And then, you can calculate the power efficiency now,what is the power efficiency or how should we define power efficiency, the useful power transmitted as a fraction of the total power transmitted.

What is the useful power transmitted here is, this plus this, the two side bands power in the two sidebands 1 by 4 mew square A sub c square upon 1 by 4 mew square A sub c square plus half A sub c square.

Student: ((Refer Time: 23:10))

Which A sub c square cancels out and this simplifies to mew square upon mew square plus 2 and therefore, that is the efficiency that you will have power efficiency you will have, for a modulation index of mew.And, what is the best power efficiency you can have will be obtained by mew equal to 1, soyou take mew equal to 1 and what is the power efficiency then, so33 percent approximately for mew is equal to 1.

So, if you want to plot this power efficiency in the form of a picture in power efficiency, but various power that we talked about as a function of mew. Let us say, and the profile of the carrier power comes down like that, if you have mew equal to 0 all the powers are in the carrier. So, we take mew equal to 1, 67 percent of the power is in the carrier, as far as in the side band square, at mew equal to 0 there is no power in the sidebands and, at mew equal to 1,33 percent power is there in the sideband.

So, that is the peak profile that you have, this discussion we are carrying out in the modulating signal was a pure sine wave. One can prove that for more general kind of waveforms modulated waveforms, the modulation the power efficiency can be increased, but under no circumstances, it will be more than 50 percent like we discussed earlier.

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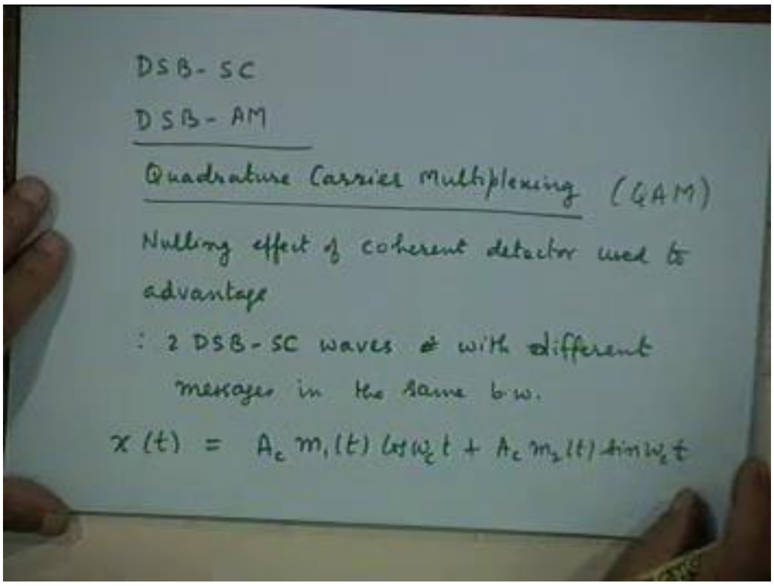

Now, we have sofar discussed two kinds of amplitude modulation which are the two kinds DSB SC, and for want of a better mean the second kind with carrier is easily referred to as DSB AM,that is a normal name. But a more precise way of would be to say double side band with carrier.So, that is a normal way we can be referring to it, what are the pros and cons of this, this is efficient in powerand bandwidth well bandwidth efficiency issame for both of them. Both of them would require twice the message bandwidth as the final transmitted bandwidth.

There is no difference between bandwidth efficiency of the two waveforms. However, in terms of power efficiency which one is better, DSB SC is much better. But we can we have said that in some situations, we will be ready to sacrifice for efficiency for an economical receiver. And, when you want to do that like in broad cast applications you can choose DSB SC. However, minimum power efficiency is important like in point to point communication, not in broadcast applications you always go for DSB SC rather DSB AM, evenat the cost of the more complex receiver, which requires synchronous carrier.

Student: ((Refer Time: 26:38))

No, we do not use anythingI think there isplease raise some of these basic doubts, that you haveyou do during tutorial classes. Sothat we can take care of this equation, if we have if we have lost any signal in anyway then, how would we able to reconstruct it. We have shown that synchronous demodulation completely recovers the signal. So, you maynot lose anything, we are just looking at the characteristic of the message waveform, the modulated waveform which has some properties.

Student: ((Refer Time: 27:13))

I think you are confusing, the question is in fact, I have not reallyfully understood the question fully, but roughly we try to imply that because of phase reversal at 0 crossing you have lost the message no,that is just a property of the modulated waveform.

Student: ((Refer Time: 27:40))

Yes, if you want to say that whether we can recover the message back by using envelope detection, the answer is no, we cannot recover the message back from a DSB SC waveform by using a diode detector because, what does the diode detector give you, it is not mtbut modulus of mt,socertainly we cannot recover the message waveform by using the diode detector.But,we have already seen that we can recover it by using synchronous demodulation that is, the price we need to pay from for efficiency that we will get here.

Student: ((Refer Time: 28:20))

Yes, please

Student: ((Refer Time: 28:24))

Yes of course, we are only talking about the modulation that you are working with now, if you remove the lower side band or the upper side band, we are working with a different kind of modulation which we have to still discuss.Certainly that is something that one can do, one canincrease the power efficiencyfurther by removing one of the side bands which is not required anyway, I think that is your point, certainly that is that is correct, and we will discuss it sometime later.

We have still to come to that situation in fact, I am leading towards that topic is thatcan I proceed further then. Solet me comeback to the discussion regarding these two, what are the nice properties of the suppressed carrier DSB waveform was, if you recollect that. In fact, it was not a nice property that we to introduce, we said that there is a disadvantage of DSB, that if your local carrier is out of phase than the incoming carrier, you intend to lose the signal.

Let us say, there are perfect frequencies synchronization, but there is loss of phase synchronizationthen the output is proportional to m t cosine theta, where theta is the phase difference.So, much are there, soif theta is pi by 2 the output will be 0 and this frequency there has a disadvantage of DSB SC, actually we can convert this disadvantage into advantage, can you say how?Anyone can make a suggestion to that, can I convert this disadvantage into advantage at sometime.

Student: ((Refer Time: 30:08))

I can put two signals on the same carrier, one using the cosine omega ct carrier, the other using a sine omega ct carrier and look at thereceiver I assure that there is a perfect phase synchronization for each of them.I can separate out the two, without interfering from interfering from the other because, of the nulling effect of the output at the output, due to a phase quadrature relation between the carriers.

So, this is a very nice thing one can do which is called quadrature carrier multiplexing, that is you can put two signals on the same carrier, now we do not thinkof putting two signals in the same carrier.So, we are here using the nulling effect of the coherent or synchronous detector to advantage.

Student: ((Refer Time: 31:28))

Pardon

Student: ((Refer Time: 31:32))

Let us not talk about PSK at the moment because, we are talking of analog modulations whereas PSK etceteraare digital modulations, yes it is relevant whatever we do, what we are discussing here is relevant to that,but I would not like to bring in that at this point.So, we have two DSB SC waveswith different messages, carrying different messages and both of them will be transmitted in a same bandwidth, isnot it.

The spectral occupancy of both the carries would be above the modulated signal would be in the same fc plus minus fmplus minus b hertz. So,if you can do that what would you do, you would increase your power efficiency by a section of 2,not power efficiency bandwidth efficiency by section of 2.In the same bandwidth, you are transmitting only one message now, you are transmitting two messages, sobasically what you are saying is suppose I use a modulated waveform which is x of t, equal to A sub c m 1 t cosine omega ct plus A sub c m 2 t sin omega ct.

I am transferring both of them together at the same carrier frequency,where I can reconstruct m 1 t separately in the time interval of m 2 and by vice-versa, sobasically you have multiplexed two messages waveform on to the same carrier.So, this we call quadrature carrier multiplexing or quadrature amplitude modulation, this is also called Quadrature Amplitude Modulation QAM.

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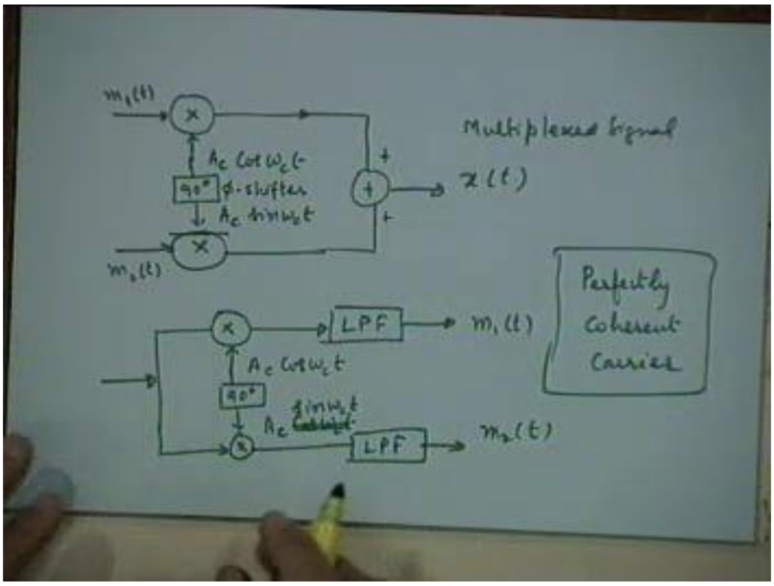

We will put in a form of figure, you have a multiplier called Ac cosine omega ct, let us say you have a 90 degree phase shift as here, a message signal m 1 t comes here, and this is your modulated signal m 1 t times Ac cosine omega ct.There you will have Ac sine omega ct, this is the 90 degree phase shift here, and the second message signal is coming here at m 2 t, we multiply this with Ac sine omega ct.

Now, these two are added together and transmitted as a multiplexed signal, sothis is a multiplexed signal and how will you de-multiplex them, how will you separate them of the receiver.When multiplexed signal is coming in, this might your synchronous demodulation, we have two synchronous demodulators one is for local carrier is Ac cosine omega ctfollowed by a low pass filter. Remember them that is the synchronous demodulator coherent the coherent detector.

The synchronous demodulator is also called a coherent detector unlike envelope detector, which is not coherent and which does not require a phase coherence of the carrier and the incoming signal.And, similarly if I use a second demodulator, the second coherent detector whose, this should be Ac sine omega ct followed by a low pass filter.So, what will this give a message waveform m 1 t, this will give m 2 t and there will be no interference. Because, ifsince there is a phase difference of 90 degrees between the second carrier and this carrier, this will not produce any output in this channel and in this path.

Similarly, the m 1 t will not have any component in this path, provided of course we have perfect phase coherence that is its cosine omega ct is in phase with the cosine omega ct component of the incoming signal. And sine omega ct is in phase with the sine omega ct component of the incoming signal.So, you require perfect phase synchronization a perfectly coherent carrieras before, soif you are ready to pay this cost. Always inmost systems most engineering systems in general and communication systems in particular, whatever you typically achieve it will be at the cost of something else.

So, the cost here is additional complexity, but if you are ready to pay for the cost of the additional complexity what do.We have, we have good bandwidth efficiency, the same message bandwidth that is used to transmit two messages rather than one,that is the advantage.

Student: ((Refer Time: 37:34))

Not in this context, I think you have something else in your mind which is not relevanthere, we are talking of analog modulations here, in the context of analog modulations.That is all we can do, I have a small request please do not mumble, there is a lot of sometimes mumbling in between, I think it is not good for the recording system then picks it upit and of course, disturbs me also.

So, I think they will have to edit this portion now for the distraction, sowe have looked atthe DSB SC, DSB AM and QAM, these three kinds of modulation amplitude modulation what is next.Is there anyvariation yes indeed if I keep just pointing out this a few minutes ago, while we can achieve a good or simple demodulation using DSB AM, the power efficiency of the system is very poor. In fact, the power efficiency needs to be definitely improved if possible, and one the simple way of doing that is, pulling in information which is redundant, and that is by removing one of the side bands.

So, in factif we do that you will kill two birds in one stone, soyou will improve your power requirements and also the bandwidth requirements so obviously, that is the right thing to do if it can be done.And, if you can work out suitablemethods ofboth transmitting as well as demodulating such signals.

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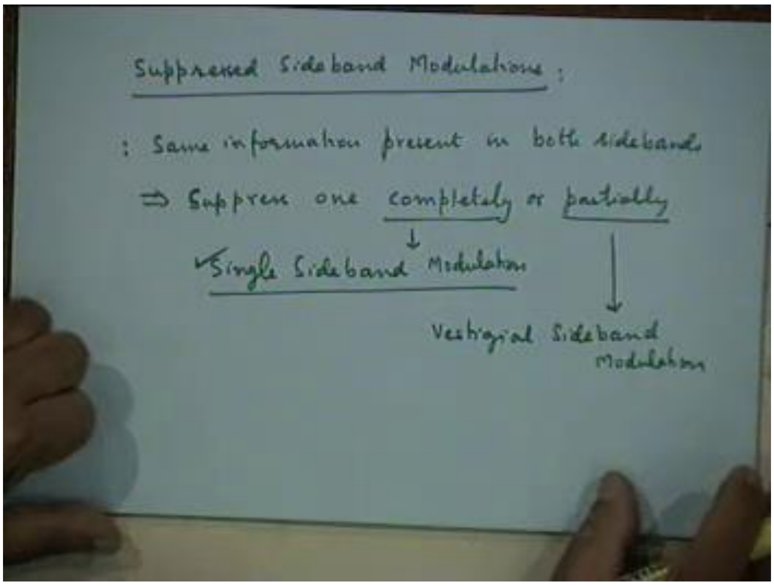

These classes of modulations are known by the name of suppressed side band modulation, and they are motivated by the fact that the two sidebands carry same information, identical information. So, we can suppress one of them either completely or atleast partially, nowwhy I am saying why I am giving this two options is because, they are pros and cons of each of them. Then at times it does make sense to talk of the suppressing the one of the side bands, completely at times it does not.

But, if we still want to save one bandwidth,we will sayif we cannot suppress it completely can you suppress it atleast partially. So,that we can save us some bandwidth, we will see the example of both this equation as we go along.So, when we suppress it completely, basically what are the two side bands goes and that leads to, what is called single side band modulation.

Because, we either transmitting the upper side band or transmitting the lower side band, will you suppress it only partially what you typically do is, you transmit more or less the entireone of the entire side bands more or less, and a small portion of the other also called vestigial theorem. And therefore, we call that by the name of vestigial side band modulation, sothere can be two kinds of suppressed side band modulations, the single side band modulation or the vestigial side band, so we will first discuss thesingle side band modulation.

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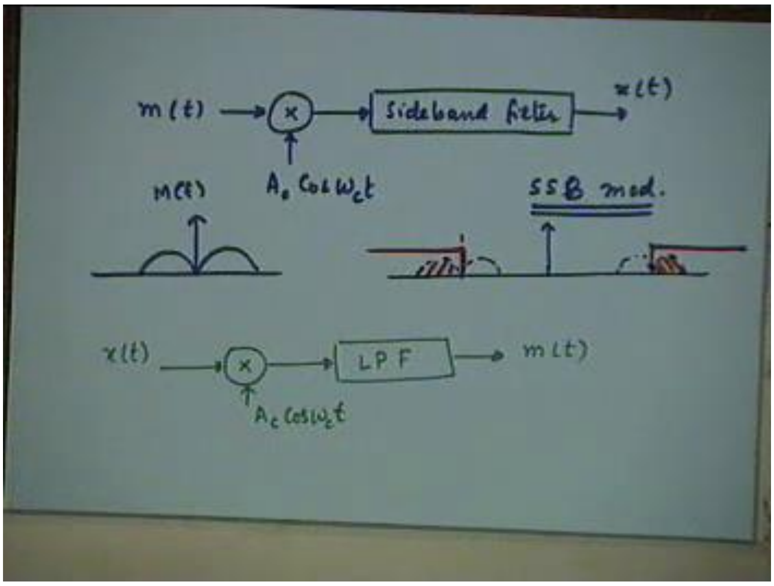

Now, in the single side band modulation as the name implies, what you have to do is first generate I mean, what it must be a fresh page, you start with the message signal mt, have a product modulator which multiplies with the carrier Ac cosine omega ct and what should we do next.This will generate the double side band signal, you want to removeany one of the side bands, you have to have some kind of filter a suitable side band filter, and that will be now yourmessage waveform x of t.

So, your transmitted waveform or modulated waveform x of t, so that is your SSB modulator, just look at the whole thing in a frequency domain. Let us say this is your message waveform a spectrum of the message waveform m f, and the modulator output if at this point,you would have got something like this.This is, this would have been the spectrum of the double side band signal that is coming here, soafter we take the side band filter, what are you retaining you are retaining either this, or you retaining this part or you retaining the other part. So, if you want to retain this part, what will you do what kind of a side band filter you should have?

Student: ((Refer Time: 44:53))

The high pass filter or we should have a band pass filter here, which will only pass this phase value spectrum and reject everything else, so either a high pass filter, let us say theoretically a high pass filter will do in practice of course, will do the band pass filter. So, theoretically ahigh pass filter would be able to separate out the upper side bands from the lower side band,we will require a filter with this kind of characteristic.

This transfer function is one for f greater than fc and is 0,between minus fc to plus fc is it clear, for mod of f greater than fc the transmission comes through 1. Soit will pass of this spectrum to the output and in this spectrum will be attenuated or suppressed eliminated. If you want the lower side band, you shouldhave the low pass filter with a cut off frequency of f c, sodepending on whether you want the lower side band or the upper side band, you can use appropriate filter which ideally could be either high pass or low pass is it clear.

In practice, we do not use low pass filters of such large bandwidth 0 to fc, or such high class filters because, many casethe signal has a finite small bandwidth, this is more convenient in band pass filters either of this kind or of this kind. That will be the actual, but for theoretical discussion here, it is preferable to think in terms of high pass and low pass filters as we will soon see, suppose weretain the upper side band.

Now, how do I get my, this message signal back, how do I do that demodulation can anyone suggest because, if I cannot demodulate then this whole exercise is a wastefulexercise, it does not help anything. What should I do either demodulate that, any answers. The demodulator remains the same synchronous demodulator that we had for DSB SC absolutely no difference, convince yourself.

So, what I am saying is as far as, the demodulation is concerned take your modulated signal x of t, multiply it with a coherent carrier which is in phase and frequency synchronism with the incoming carrier and pass it through a low pass filter.And, you will get your message signal back, is that obvious look at in the frequency domain, it should become obvious, when you are multiplying with Ac cosine omega ct you remember, what is the operation we are doing, we are carrying out a frequency translation by minus fc and plus fc.

So, let us say you have this component, when you translate it to by minus fc what happens it comes here, and this portion comes here. Soyou get this base band spectrum which you wanted, and the plus fc component goes to in the neighborhood of2 f c which will be eliminated by the low pass filter. So, there is absolutely no difference in the demodulation process, it remains the same, are you all with me.

So, the demodulator remains exactly the same that you had for the DSB SC, just apply frequency translation theorem on to this spectrum, and you can see that your base band spectrum comes back, along with the component around 2 fc which will occurs first. And, the same argument you can repeat when you retain the lower side band rather than the upper side band, please convince yourself that if you retain the lower side band transmit the lower side band, once again the same demodulator would reconstruct your message signal back. So, whether you are transmitting the upper side the lower side band or the double side band, your demodulator will be the same.We will start from this point next time.

Thank you very much.