Electronics for Analog Signal Processing - II
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Lecture 38
PLL (Phase Locked Loop) (Continued)

So, we have understood what lock range in P L L is. That is nothing but the D C loop gain into pi by 2 Delta Omega L, Omega naught Q being the free running frequency of the P L L. Omega naught Q minus Delta Omega L to Omega naught Q plus Delta Omega L is the lock range. Then, capturing Delta Omega C is...that is approximated as root of Delta Omega L into Delta Omega L p, if Delta Omega C by Omega L p is much greater than 1.

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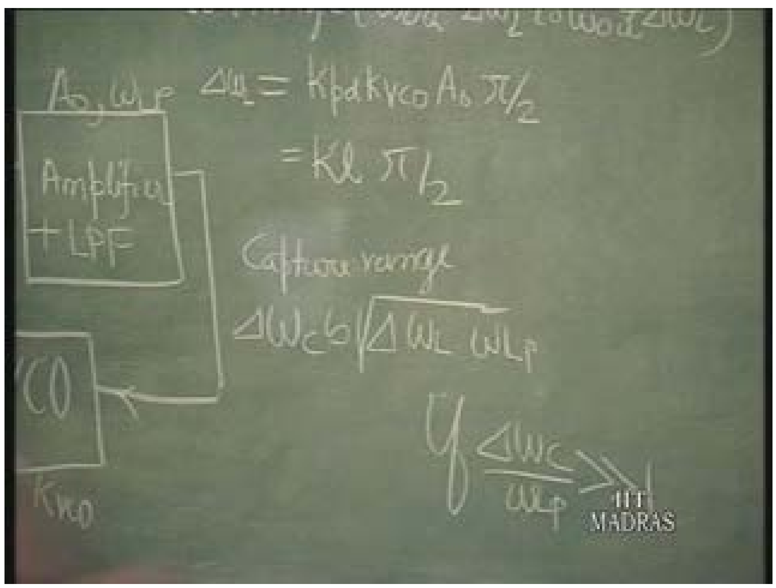

Otherwise, it is to be evaluated from the quadratic equation here and the capture range is again Omega naught Q minus Delta Omega C to Omega naught Q plus Delta Omega C.

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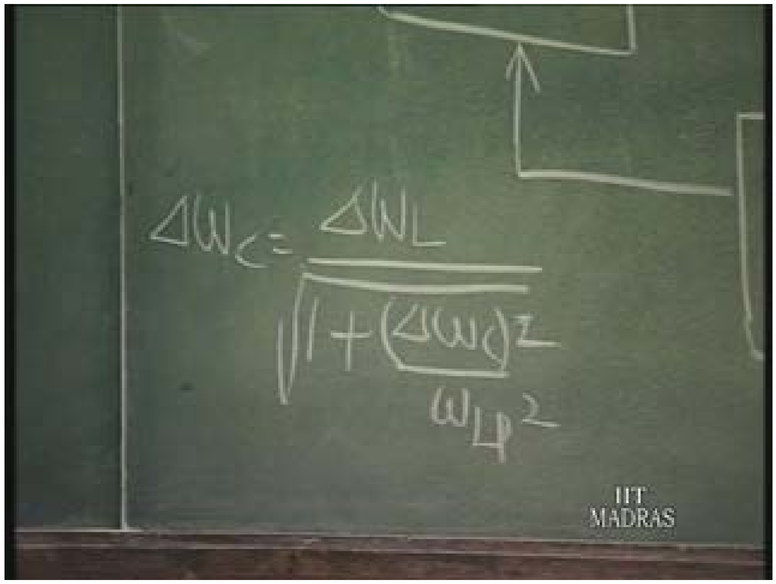

Now that we have understood how the capture takes place and how it is maintaining itself in lock, let us try to understand how much time it will take for it to capture, if the signal at the input is within the capture range. Initially, this is free running at Omega naught Q. So, I am going to plot the so called V c here.

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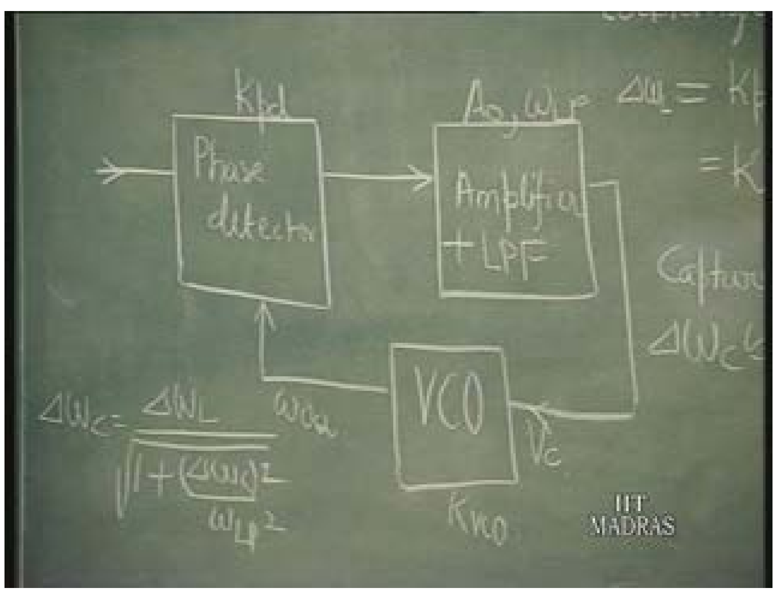

It will be at V C Q so that our V C O output is at Omega naught Q. Then, the moment this particular thing is getting an input which is within the capture range, at that instant of time, the waveform is going to look like this and it will be widening here, assuming that ultimately, let us say the D C should shift in such a manner that it should go from V...V C Q to some other value, which is going to change the frequency to that value.

So that value of frequency let it...let us say, is this corresponding to V c final. So, it should settle that...at that D C value. So, how does it really create that D C? It will...the frequency will continuously change in such a manner that this is going to be giving a spike here and this will broaden so that a D C gets generated, which will keep on progressively increasing and become ultimately equal to this value.

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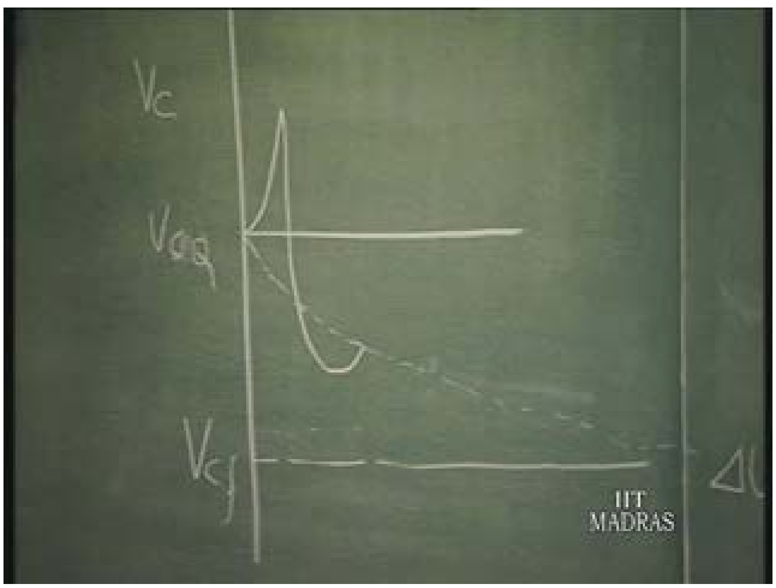

So, this particular waveform is going to be something like this and the other one may be going in and may not cross this. Already it has crossed and broadened here further; and then...this is the capture phenomenon.

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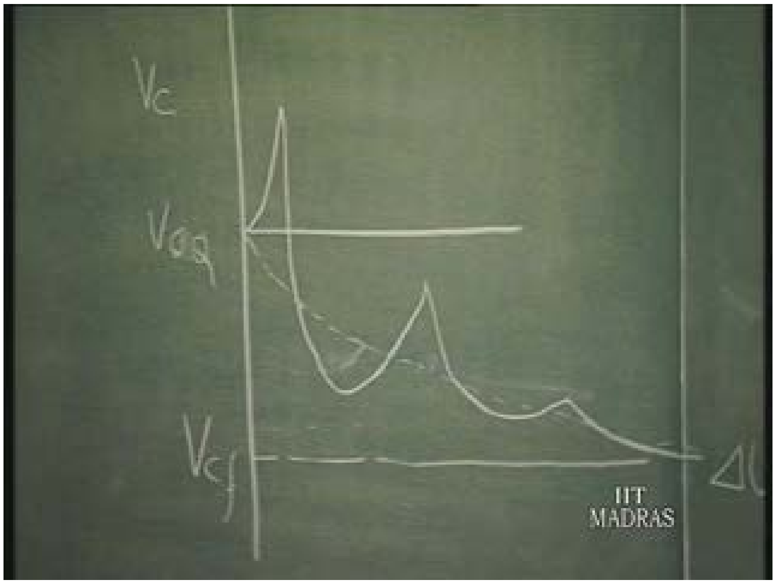

That this waveform which if observed here will be having a low frequency component which will be generating a D C at every instant of time in the direction in which this ultimate D C is going to be maintained. So, this is the D C level at which it will finally settle and therefore this is the way the control voltage here will vary.

Obviously, the time it takes for it to reach depends upon the low pass filter cut-off frequency here. So, if the low pass filter cut-off frequency is such that the...it is a very narrow low pass filter, then it will take lot of time for it to reach this value. So, this particular thing or this type of waveform is important to understand and capture time is when it takes...let us say, time to reach 90 percent of the final value from the 10 percent of the initial value, we can say that is the time for capture. So, this is the capture time.

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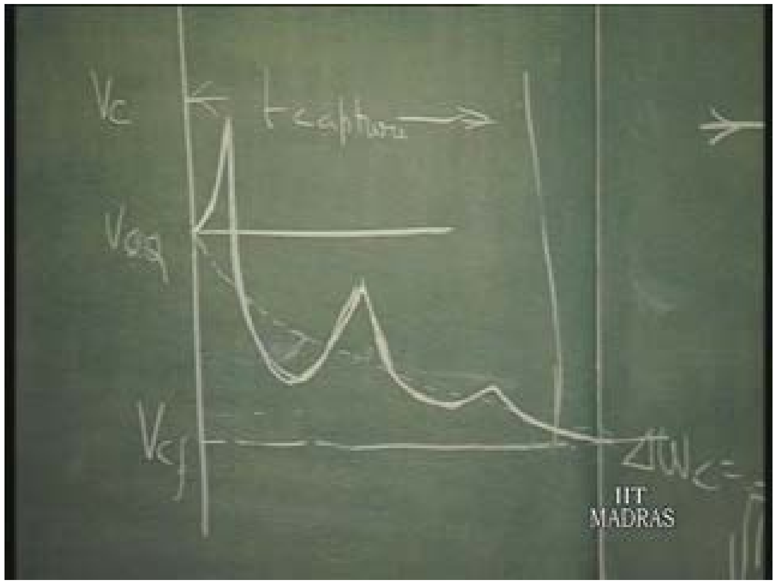

This is the process of... that means at this point of time, it is not swinging both above this V C Q and below this V C Q in a sinusoid manner at all, as we had earlier assumed. The frequency is continuously changing; but it will peak here and broaden here. Suppose this is at this point. It will start peaking here and broaden here. This is the waveform which will be looking like that.

So, once you understand the process of capture and you now know that once it is captured, it is going to be maintained under lock and it is going to, sort of...at this point, it is capturing the whole thing and it will go on like this...may be, go on almost up to this point. This is the lock range, this is the capture range; and this is the way it will follow this. And again while coming back, it will be following like this. It will capture and then maintain itself under lock all the way up to the lock range here.

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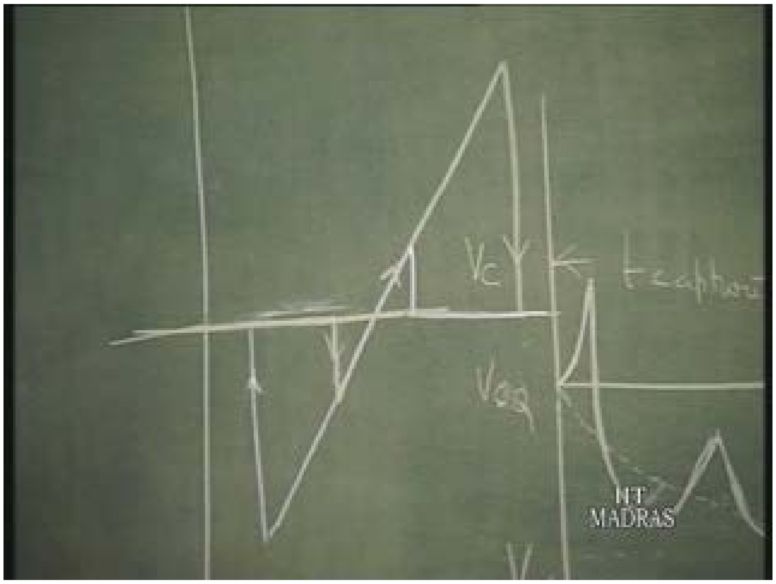

So, this kind of behavior occurs in the case of a phase locked loop, if you are approaching the phase locked loop from this side and this side; and this I have explained to you, When the capture phenomena is taking place at this particular point or even it is changing from one frequency to another frequency, the capture phenomena has to occur in the following manner. This is the so called transient.

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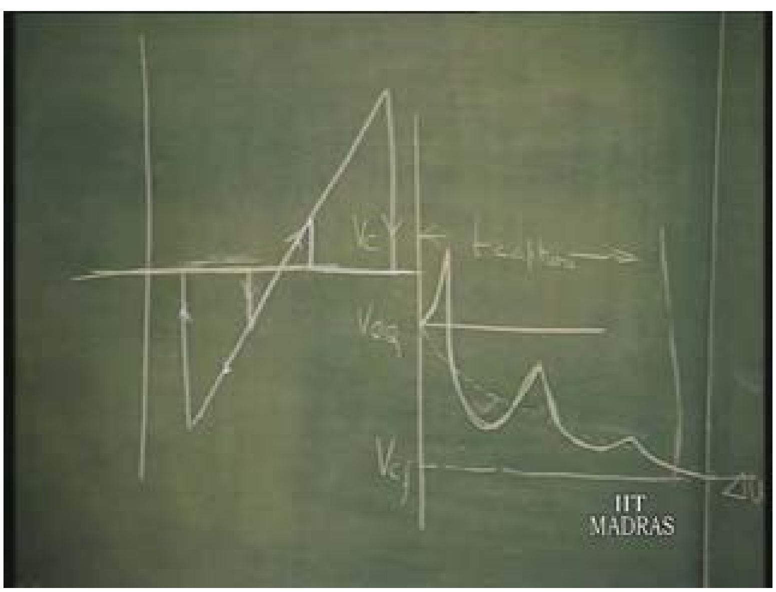

Now that we know all about how a P L L functions, we can understand how and where exactly the P L L is going to be used. One important application of P L L is one what is called signal conditioning. Let us try to understand what it is. Assume that we have the signal; that is F M signal in this case. Let us say F M signal, Frequency Modulation signal or F S K signal.

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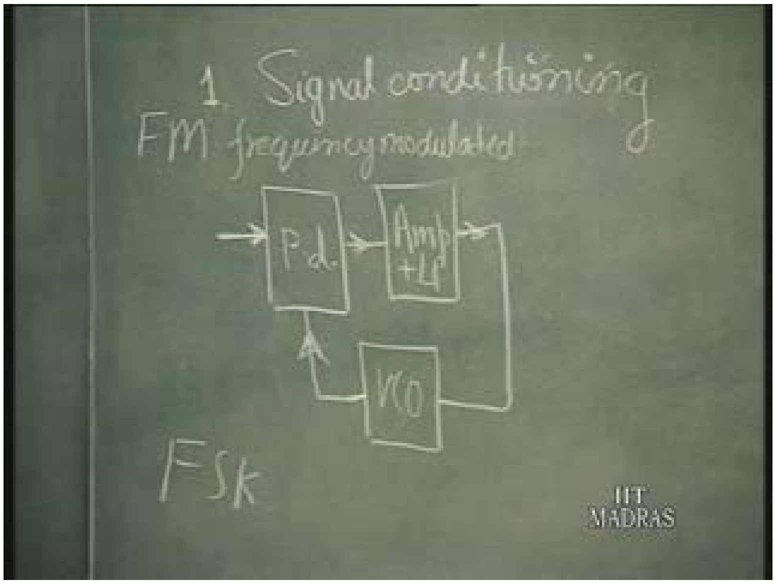

Most of the data, present day data of the computer, computer to computer communication or computer to a central point communication, all these things are done by what are called frequency shift keying, frequency shift keying. This is the basic principle of all the modems here now. So, these FMs or F S K signals over transmission in the line may get sort of weakened, get attenuated. So, we want to bring it back to life, strengthen the power level and get rid of the noise that is going to be added to the the signal.

So, in order to improve what is called the signal to noise ratio, you have repeater stations and these repeater stations will be simply receiving the signal and retransmitting it in the same line after strengthening it and that is done by a P L L. In this case, the signal is F M, frequency modulated or F S K, frequency shift keyed.

What is done is this signal is applied at the input. So, according to our sort of theory now, that the phase locked loop will be producing the same Omega naught as equal Omega i... So, if Omega i is F M, Omega naught also is going to be F M but with a difference, because this F M that it has captured falls within the capture range of the P L L which can be made...kept narrow; and therefore the F M that is produced here is devoid of the additional signals that have added on to this. And this is going to be a pure, highly, sort of improved signal to noise ratio signal here with power level also high because the VCO can be at a higher power level, oscillating at a higher power level. So, this particular thing can be retransmitted. So, this is called signal conditioning. So, you are strengthening the signal here. If it is F S K, you will get F S K here.

So, what you have to note here is that it has eliminated all unwanted stuff here and therefore the signal that is appearing here is going to be vastly improved in signal to noise ratio compared to signal that is appearing here. Signal to noise ratio improvement has occurred here. So, this is a straight forward application of phase lockeded loop in signal conditioning.

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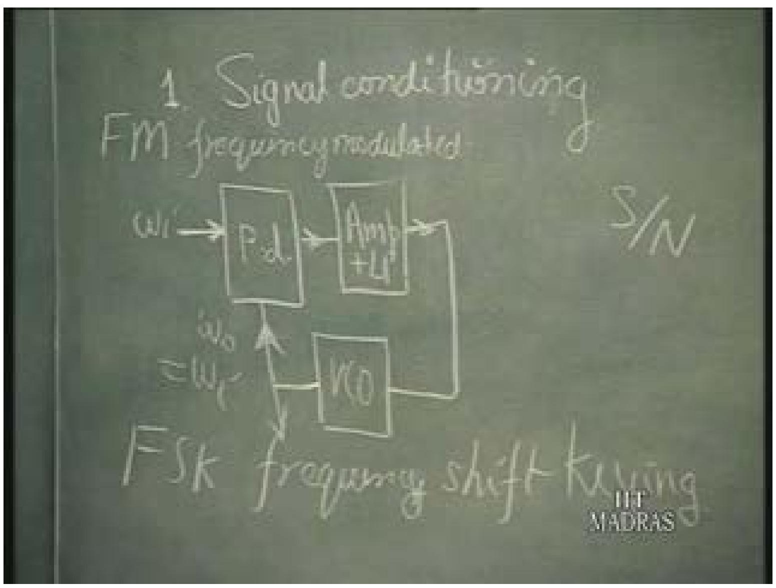

Another indirect way is, this can be considered as something that is similar to signal conditioning. This is called synchronization; extracting the synchronization pulse or synchronization frequency from a composite video signal. Now, a composite video comprises of the picture signal as well as the horizontal and vertical synchronization pulses. Now, the old conventional way of detecting these has been replaced by P L Ls for both of these.

So, what will happen is the composite video will appear here at a P L L input whose free running frequency corresponds to, let us say, horizontal synchronization frequency. So, we know the horizontal synchronization frequency of the television signal. So, make the P L L have free running frequency of the horizontal synchronization pulse.

Then, the input which is corresponding to composite video will also have the information about horizontal synchronization. At that particular point, this will get locked on to the incoming horizontal synchronization pulse frequency. So, this frequency will be adjusted exactly to be the same as the transmitted horizontal frequency signal. So, this will learn about what kind of D C voltage it has to maintain.

During other times, this gets disconnected or it will slowly discharge that because there is a large amount of capacitor here; and therefore, it will not deviate from that value until the next set of pulses come into picture and again it is restored.

So, extracting the horizontal or the vertical synchronization pulse from the composite video signal can also be done by using a phase locked loop. Correspondingly, the VCO should be free running either at horizontal free running...horizontal synchronization frequency or vertical synchronization frequency. This is another way to get rid of noise. The other part of the signal is called noise for this particular circuit. So, signal to noise ratio improvement has occurred drastically here.

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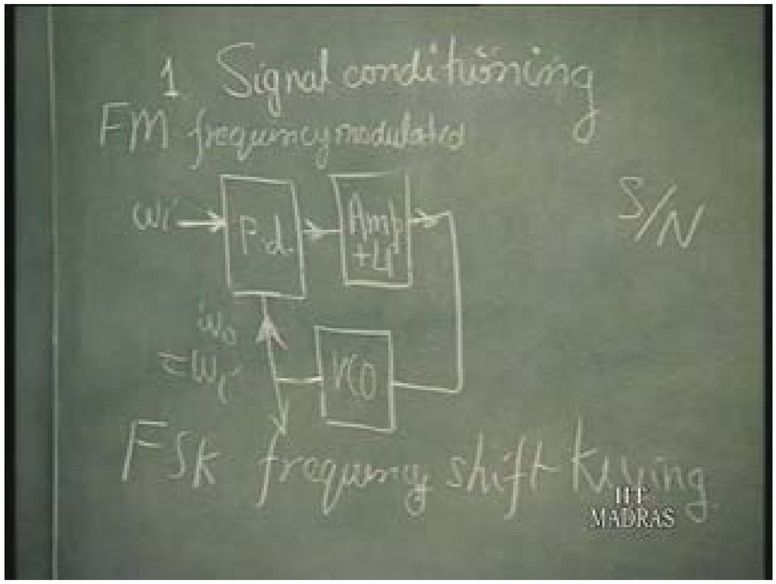

So, the third application of the P L L is in what is called...very important application called frequency synthesis. What is it? We know that we can generate stable frequency oscillators using crystals but these are going to be at specific frequencies. How to generate a variety of frequency from a reference frequency which is nothing but the crystal frequency? That is what is called frequency synthesis.

This is another important area, particularly in transmitters. Where secrecy has to be maintained, they would like to keep on changing the carrier frequency so that the enemy is not able to detect your signal; but one should be able to really synthesize this exactly so that the person who is wanting to receive this, the friend should be able to receive it. So, frequency synthesis is an important area of a particularly military communication. So, frequency synthesis - how is it done?

We all know that if I use a counter...give a frequency input here, Omega i, I can divide this by an integer n. This is possible using a digital count. This is the easiest way I can synthesize other frequencies. Give Omega i and you can get Omega i by n. This can be made a programmable digital counter so that n can be varied.

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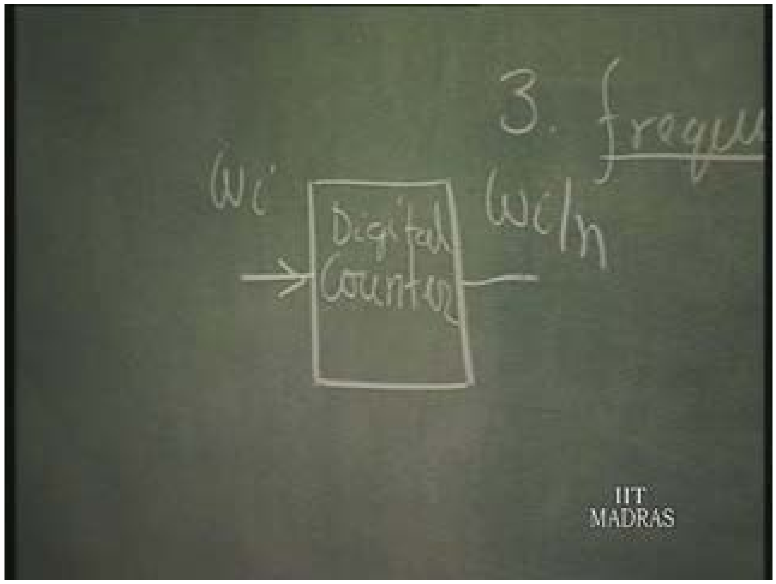

Now, this particular thing let us say is fed to a P L L, P d and then the amplifier plus low pass filter; and then this VCO is going to be replaced by another counter with the usual VCO. This is going to be dividing by m. Now, let us see what happens.

If this is Omega i, this is going to be Omega i by n. If this is Omega naught, this is going to be Omega naught by m. This is equal to another VCO. As far as the PLL is concerned, whether you are giving this VCO or this VCO, it works in the same manner. What is that manner?

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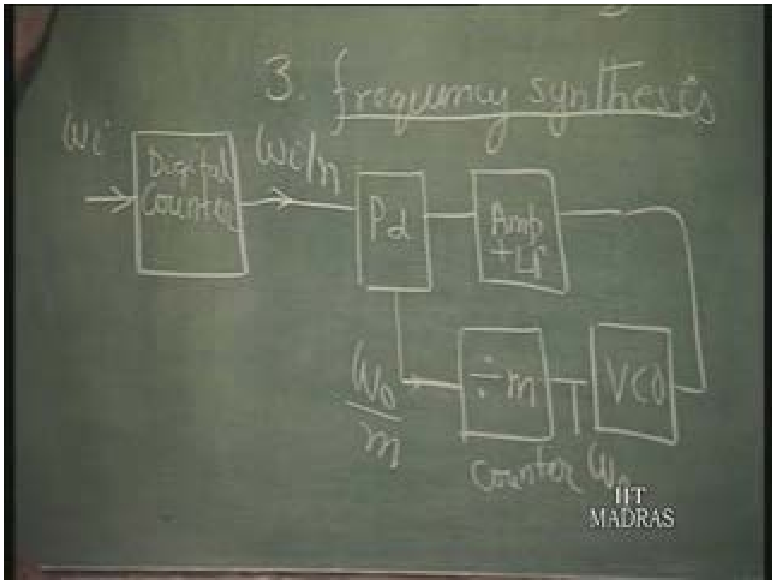

Omega i by n should be equal to Omega naught by m. What it means is Omega naught therefore is going to be equal to m an integer, n an integer into Omega i which is going to be the crystal frequency.

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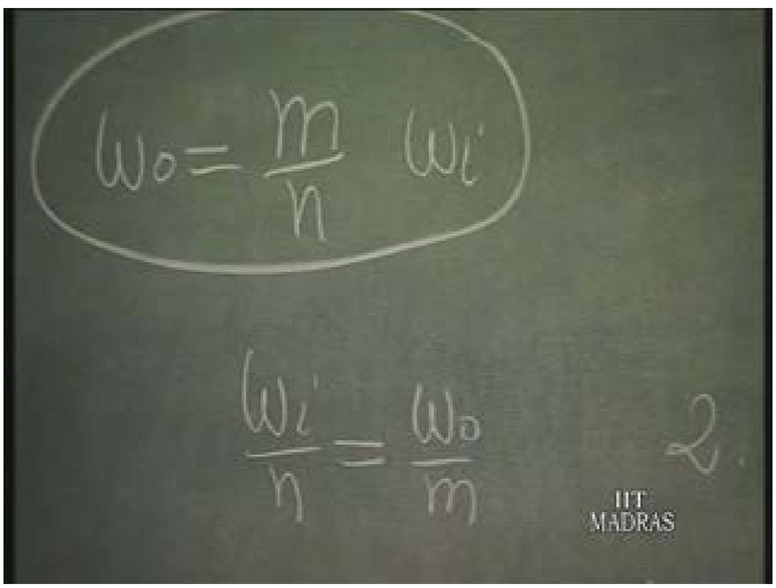

So, by selecting m and n as integers you can generate any frequencies, theoretically. For example, let us say you want m by n to be 2 point 3. So best way is, this will be 23 divided by 10. You want this to be 2.303. So, this when...multiply by 2303, divide by...this kind of thing...it is 1000, yes. That is 2 point 3. So, this kind of thing is not very good because this is all...it may be multiplied by 23 and this is divided... Decimal counters are available. So, dividing by 10 is quite easy. Multiplying by 23 may be slightly difficult.

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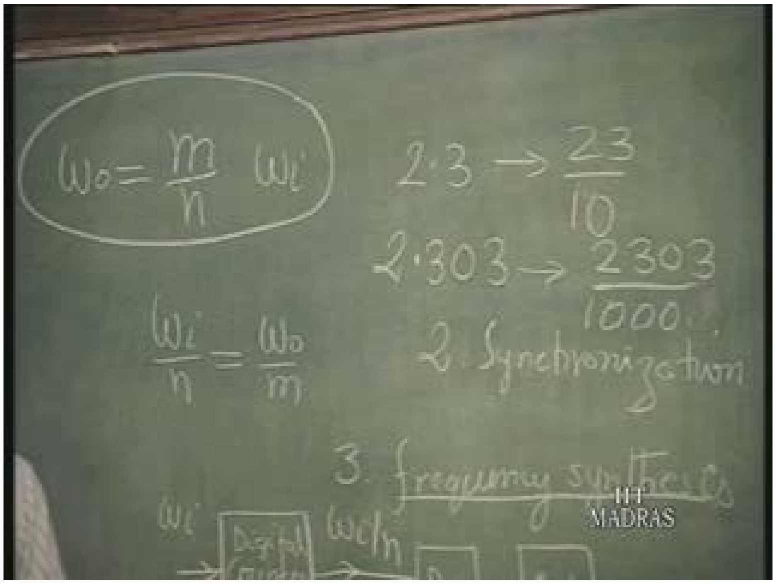

Now, in order to get 2.303, multiplying by 2303, dividing by 1000 is not going to be the best way. So, this is not a good way. Even though it is theoretically possible, practically it is not very good. So, how to do this? That means given problem is I have to get 2.303. One way is I can get 2.3 just as I got it here and add point 003 to it.

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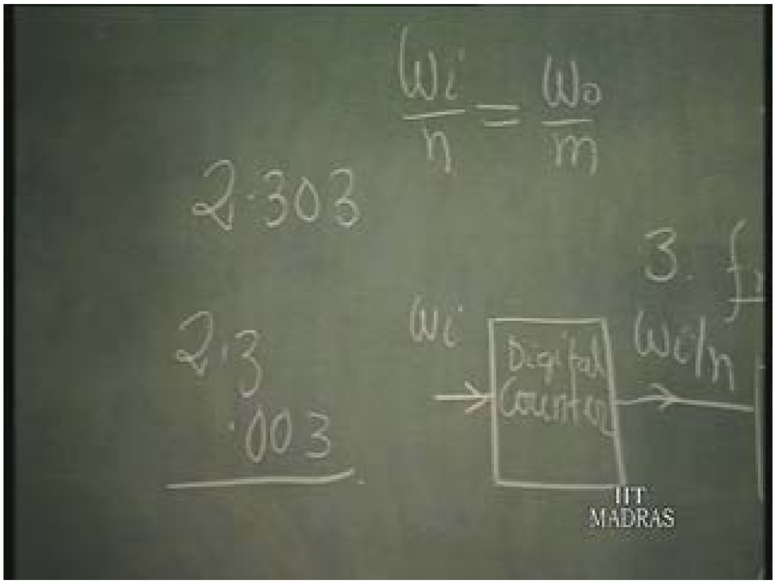

So, this will be 2.303. So, apart from obtaining a multiplier-divider arrangement for the frequency, you have to also do what is called frequency translation. This is called frequency multiplication and division. Frequency division is easy using counters. Frequency multiplication needs the help of a P L L within which you use a counter. Both of these can be programmable so that m and n can be varied according to your desire; but you have to have what is also called as frequency translator. This is...I want to shift this frequency by 3 hertz, translate. So, frequency translation is another requirement for frequency synthesis. How is it done?

That is done by using two multipliers. These phase detectors are all multipliers - please remember that - within the phase locked loop. This is the V C O. This is going to be the amplifier plus low pass filter. Now, let us see.

This is Omega i and this is, let us say Delta Omega i. If this is 1 megahertz, let us say this is 1 hertz kind of thing, like that. That is why I am putting that... I want to change this 1 megahertz by 1 hertz. That is possible by this. Let us see.

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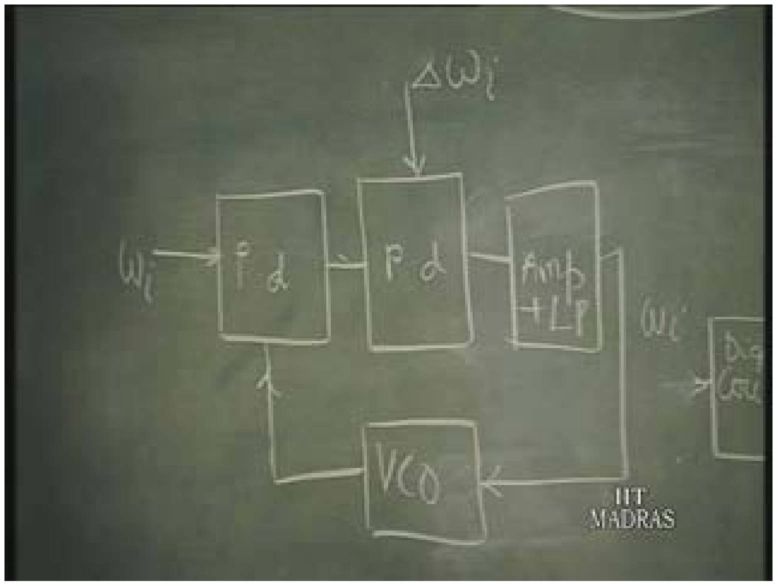

If this is Omega i and this is Omega naught, we know that output here is Omega i plus or minus Omega naught out of which, Omega i plus Omega naught is a high frequency and Omega i minus Omega naught is a low frequency. And therefore, this is going to respond to Omega i minus Omega naught and another input is Delta Omega. So, that will be plus or minus Delta Omega i. Both components will be there. One will be Omega i minus Omega naught plus Delta Omega i; another will be Omega i minus Omega naught minus Delta Omega i.

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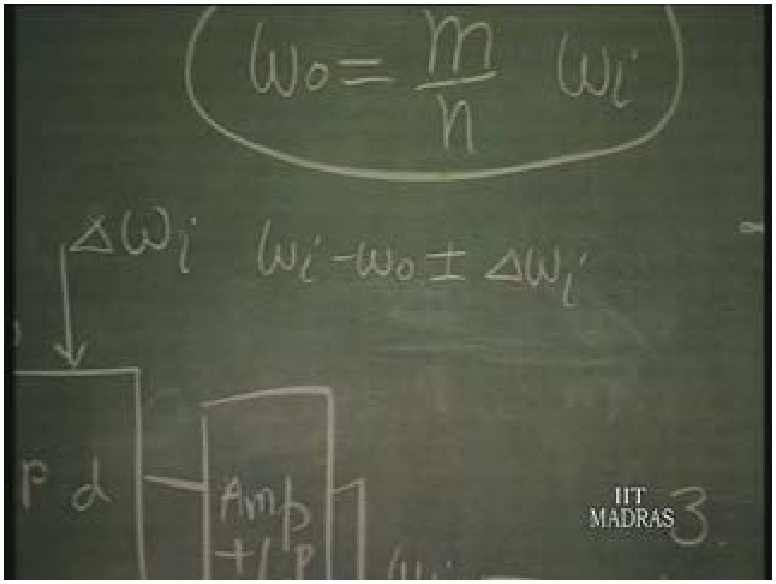

Any one of these can become equal to zero frequency. That is what this amplifier plus low pass filter will do. It will convert it into a D C and this D C should remain constant here. This is going to be another D C. That means, at this particular point, let us say Omega i minus Omega naught minus Delta Omega i is equal to zero; zero means D C. That is what happens. That means Omega naught is equal to Omega i minus Delta Omega.

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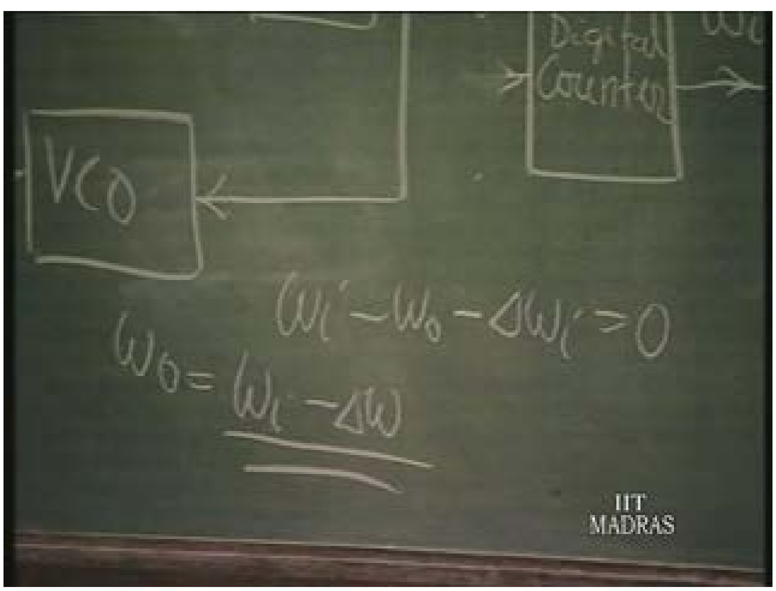

So, output frequency will correspond to a translated frequency of Omega i minus Delta Omega i. Suppose I have taken the other one as the D C; Omega i minus Omega naught plus Delta Omega i is equal to zero. If that is the case, if Omega i minus Omega naught plus Delta Omega i is equal to zero, then Omega naught would have been Omega i plus Delta Omega i. So, either this or that can be the output.

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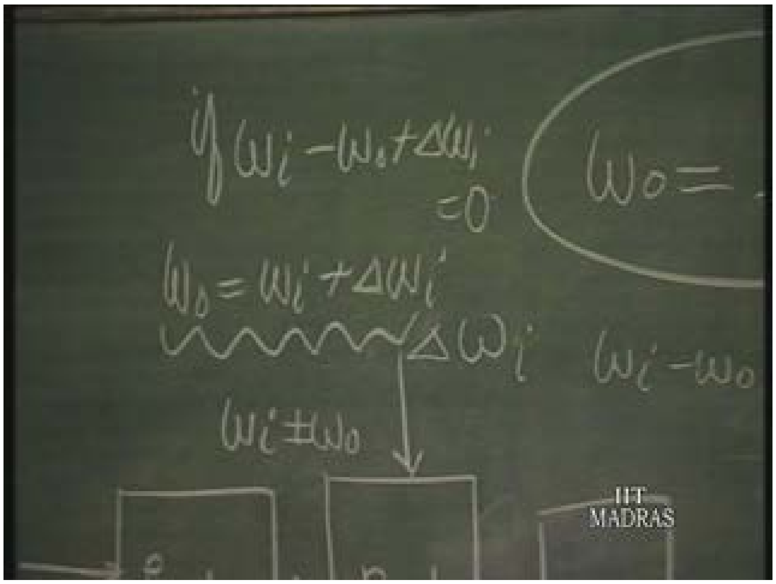

How do I make sure that it is going to be that or this? That can be made sure by making Omega naught Q remain on this side of Omega i or the other side of Omega naught, that is initial frequency, so that the closest will be this or that to which it will get locked. So, this is another powerful technique of frequency synthesis. Let us say I would like to generate from 1 megahertz a frequency of 9.009 megahertz. Take this as a problem. From 1 megahertz, generate 9.009 megahertz.

Let us consider this Example 28. Synthesize 9.009 megahertz from 1 megahertz.

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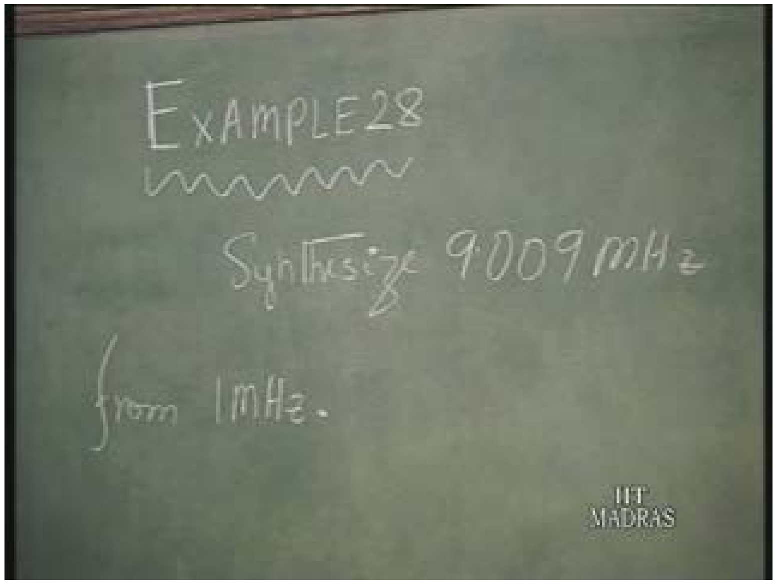

So, 1 megahertz is the crystal frequency, let us say. That is given to you and I have to generate first, 9 megahertz. That is fairly easy - by putting it through a phase locked loop wherein I am putting in the feedback loop a divider by, let us say 9; divide by 9 counter and then the V C O and take the output here. So, in this phase locked loop, this output is going to be 1 megahertz and this is the division of this. So, this has to be 9 megahertz.

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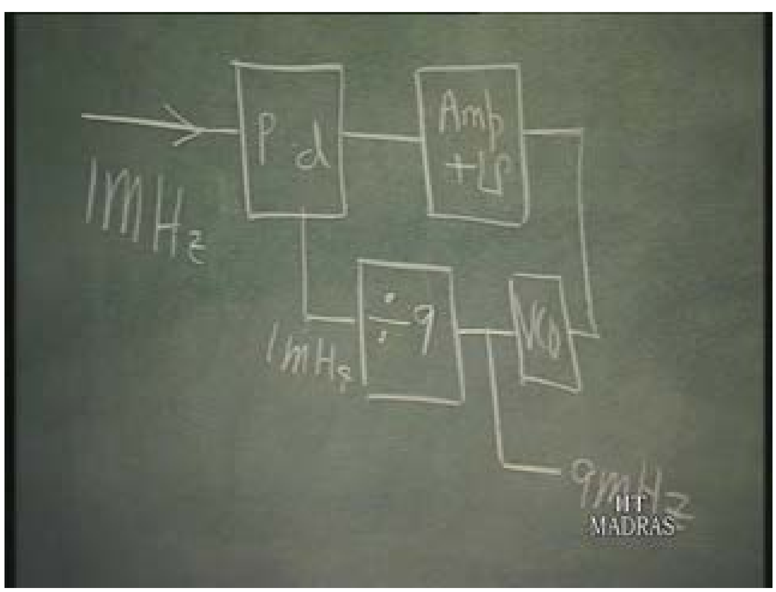

So, I have achieved a multiplication by 9 easily by putting a counter, divide by 9 counter here. So, 9 megahertz has been obtained. Now, this 9 megahertz is going to be used and using, let us say 3 decimal counters divided by 1000 can be done. So, you get point 009. So, divided by 1000 gives you point 009.

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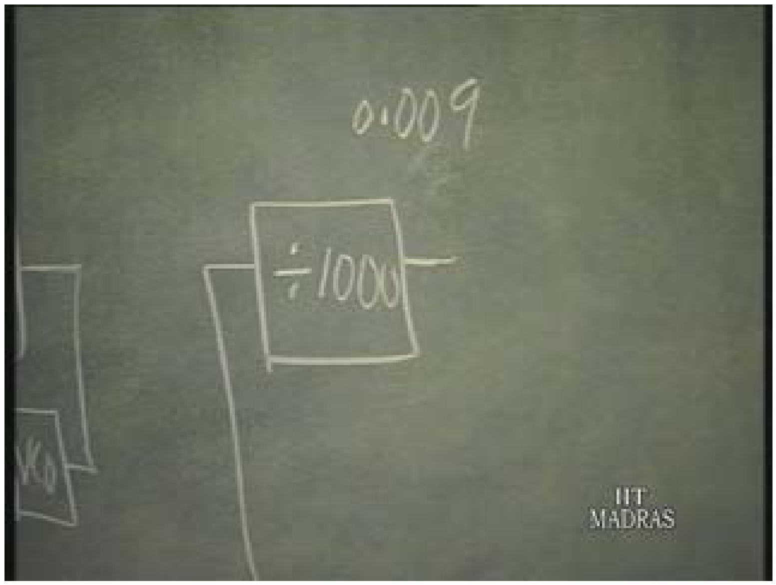

Now, I have to add this. So, I put again the 9 megahertz along with this point 009 here as one input. This is so, P d, P d and then this amplifier plus low pass filter plus VCO. At this point therefore, I should get an output corresponding to 9 point 00...009.

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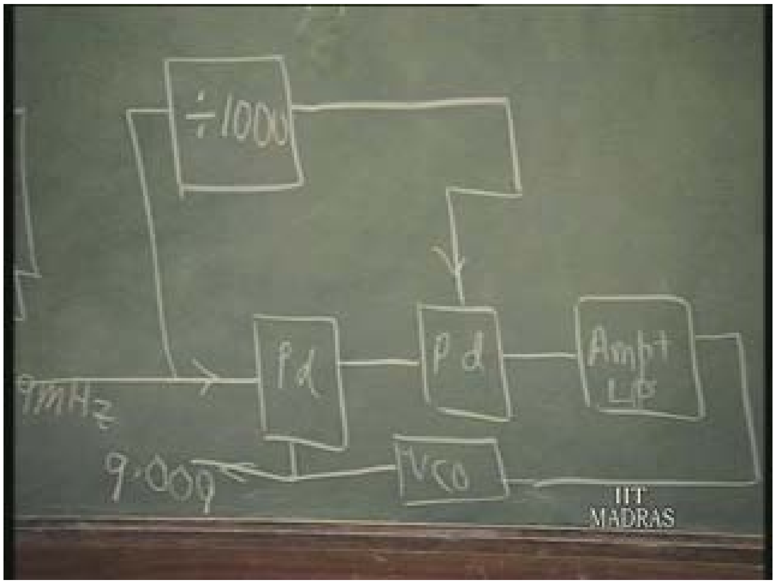

So, this is megahertz, the complete system for synthesizing this and you can therefore see that any such problem of synthesis can be easily tackled by using multipliers, dividers and translators.

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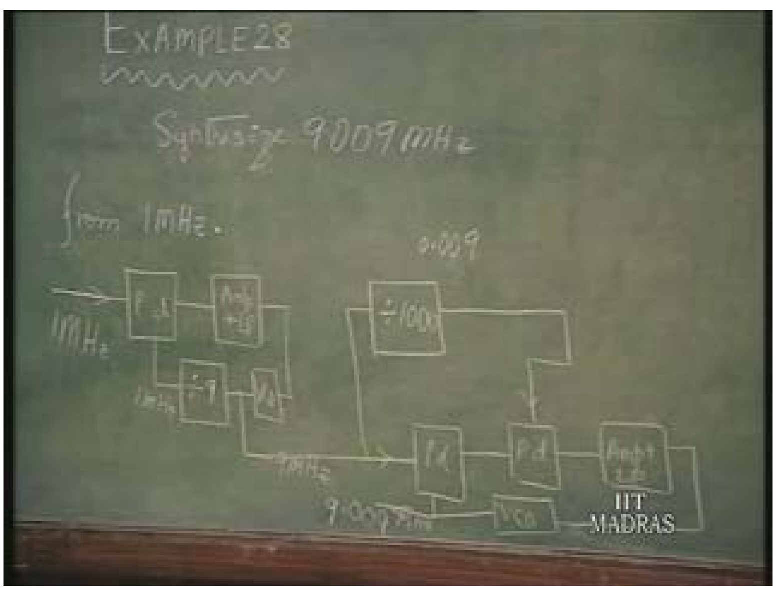

And this has been utilized in commercial synthesizers for obtaining this kind of frequency synthesized output.

Now, we have another way of frequency synthesis. This is called harmonic locking. Let us understand this. Both are square waves. If this is Omega i, this has to be Omega i; but all...both the square waves will contain their harmonics. This has its third harmonic, fifth harmonic, etcetera; or, if it is let us say not symmetric; it may have even the second harmonic, etcetera. Similarly, this will have its harmonic.

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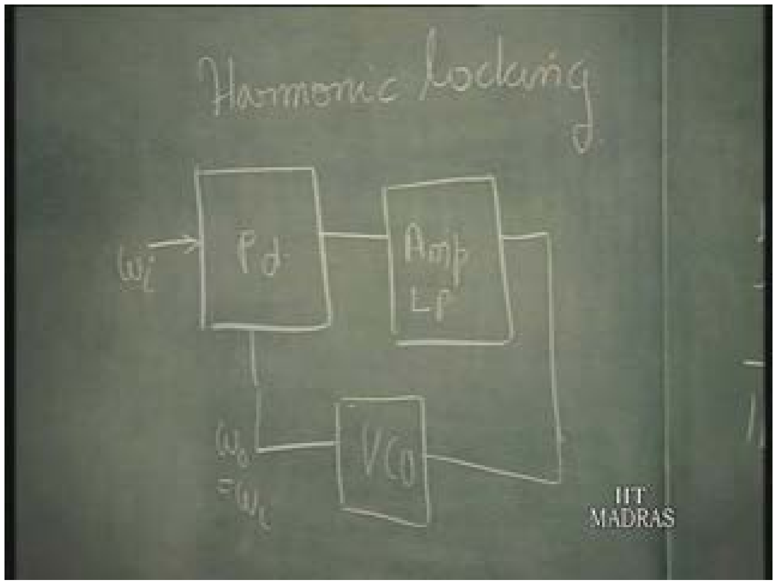

So, we can do what is called harmonic locking. What does it mean? If this is, let us say 1 megahertz, we can have this getting locked to the harmonic of the VCO output, which is 3 megahertz. So, since the VCO has a 3 megahertz component, this 1 megahertz can be locking itself with the 3 megahertz of the...that is the harmonic of the VCO. So, this particular thing called harmonic locking also can result in frequency multiplication. It can be the other way about. The 3 megahertz here can get locked to 1 megahertz here.

So, this kind of locking is also possible. But these are all going to be inefficient way of locking because the harmonic content in the wave form keeps on decreasing as the harmonic number keeps increasing. So, this is not an efficient way of frequency synthesis.

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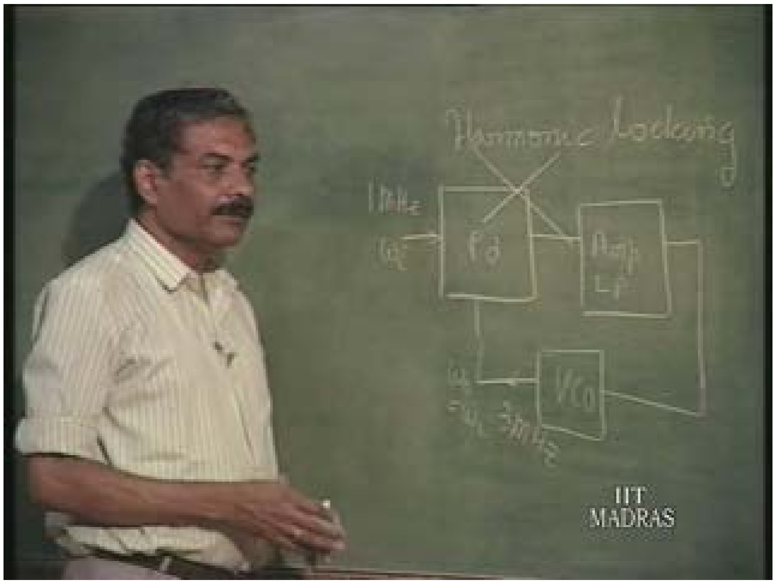

The best way of frequency synthesis is what we have mentioned there. Just in order to complete the whole thing, I had mentioned about this way of frequency synthesis as well. So, that much should be sufficient for the application - that is frequency synthesis.

Now, the next application is FM detection or FSK detection.

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This is one of the most important applications of the PLL. What is done here is, this is the phase detector; you have the amplifier plus low pass filter, and then the VCO. So, if this is FM, this has to be FM. What it means is therefore...this is the FM detected output, because we know that in order to generate an FM, we have to use a VCO. So, the input to the VCO must be the FM detected output. So, this is a linear FM detector, straightaway. So, this is the straight forward application of phase locked loop for which it has been used in communication for a long time now.

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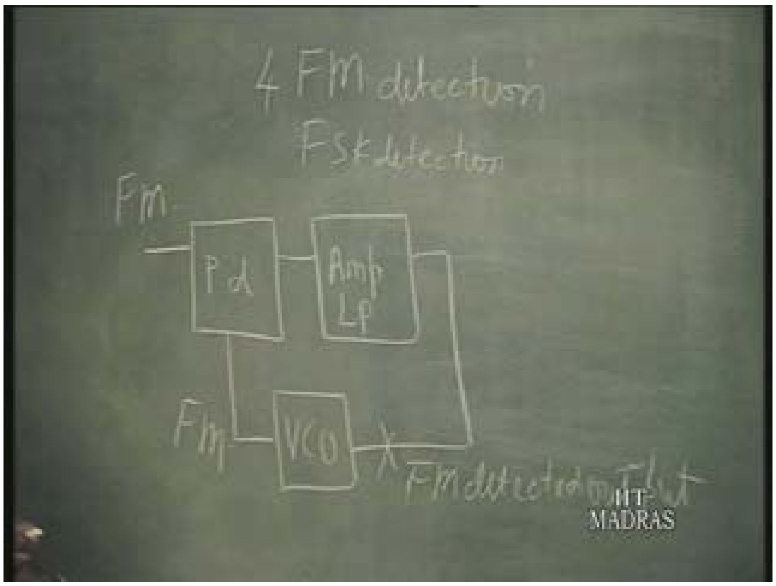

So, if this is FSK, this will be FSK. That means this is FSK detected signal. So, these are being used in large numbers in modems nowadays. The demodulator path is nothing but this PLL tuned to the corresponding...the frequency, so that it can select that particular channel. So, this FSK detection is very common. This output can be further low pass filtered by using filters outside because the single low pass filter may not be sufficient here and other low pass filters therefore can be put here so that FM detection output can be better detected at this end.

So, this being a very good FM detector, it is used for wide band FM detection universally. All the other FM detectors are mostly narrow band FM detectors.

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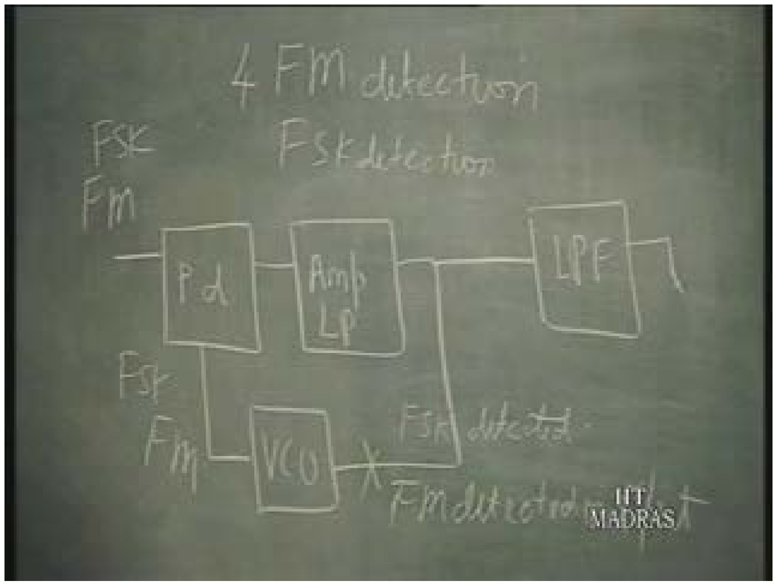

Now, can we do FM...like FM detection, AM detection using phase locked loop? This is another question that we have to answer. AM detection. Yes. Answer is yes. How do we do AM detection? Normally, AM detection is done using a diode. In this case, we can use a multiplier. That is nothing but a phase detector to detect AM as long as we can generate the carrier.

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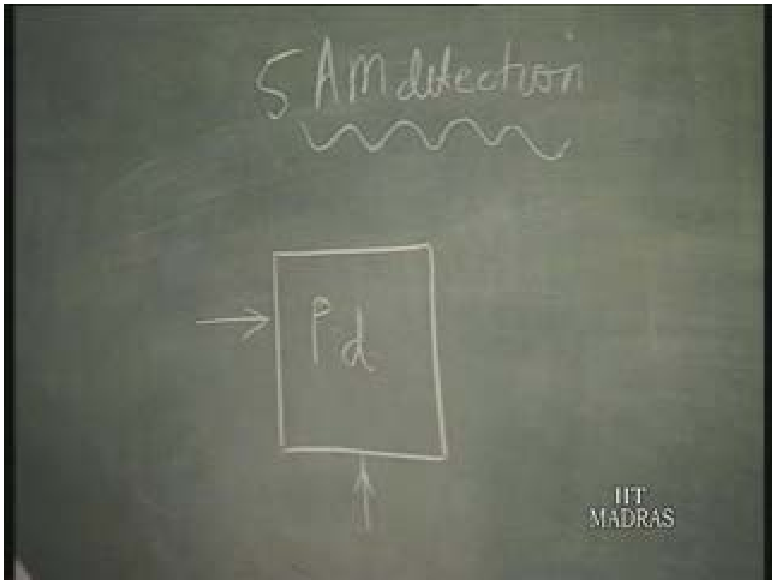

Now, this generation of the carrier is easily carried out by using the phase locked loop and giving the input that is given to the phase detector to PLL also after limiting, of course... Therefore, you have to put a limiter here and it is fed to this PLL and subjected to another phase shift because this will generate an output which might be 90 degree out of phase with this carrier. So, we have to shift it by 90 degrees in order to bring it back to the original carrier without any phase shift; and then you can obtain AM detection.

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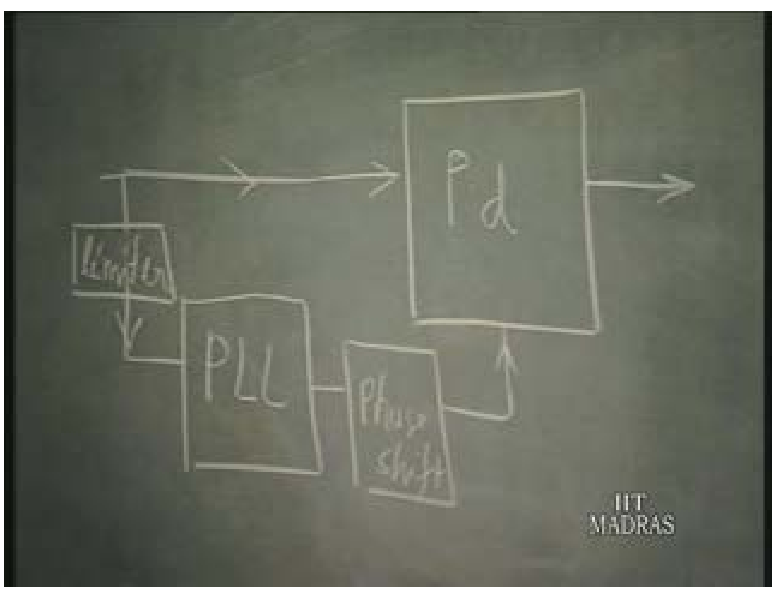

So, if this is cos Omega Ct, this will be sine Omega Ct here because of the basic feature of the phase locked loop which has a 90 degree phase shift compared to this, when it is locked to the frequency. So, the frequency is detected here. This amplitude information is eliminated using the limiter and then additional phase shift of 90 degree is given to this and... or, you can use another PLL here so that additional phase shift of 90 degree is obtained here and this particular thing is cos Omega Ct.

So, this cos Omega Ct gets multiplied with this cos Omega C plus or minus Omega mt; and this is... this is the AM. So, here we get cos Omega Ct by this process; and that is how we can get cos Omega mt out of this.

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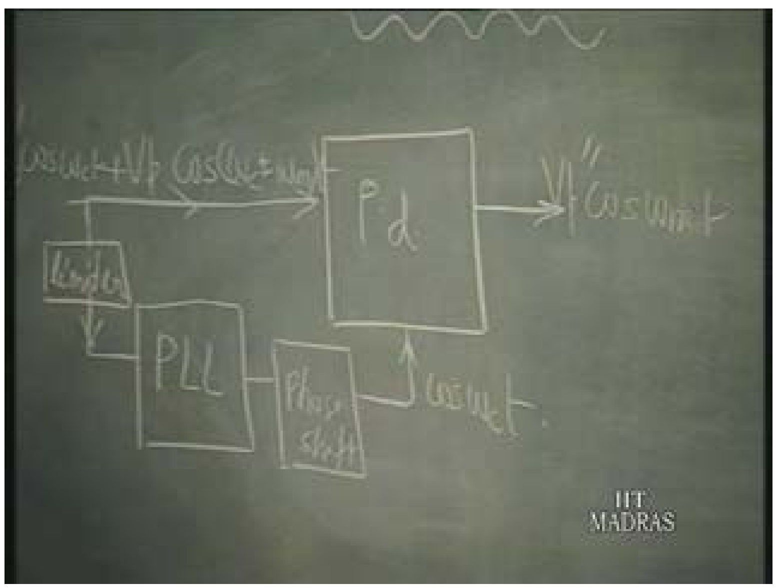

So, this kind of AM detection is called synchronous detection. This is also adopted here.

Next, final application that we have to consider is phase locked loop being used as speed controller.

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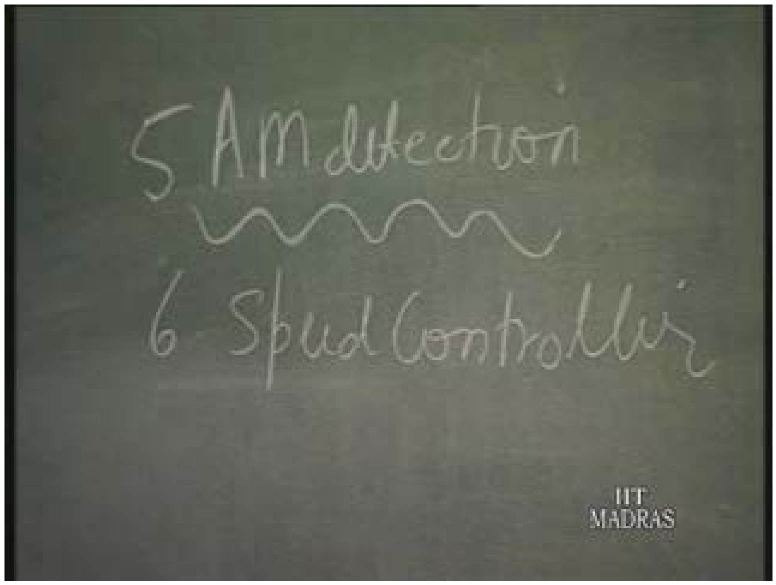

Now we know that a motor...typically its speed can be controlled by using the conventional feedback. The tachogenerator is put. The generator, tachogenerator output which is a D C voltage is compared with a reference voltage and that is amplified and fed to the winding.

This kind of control circuit has become out of date. What is being nowadays used for precision speed control in tape drives and other things is the principle of phase locked loop. What is it? We have the winding control, let us say, control winding. Through this control winding, we are going to give the amplifier output and this itself is going to act as a low pass filter. The motor winding along with the motor characteristic will be acting like a low pass filter. So, this is amplifier plus low pass filter.

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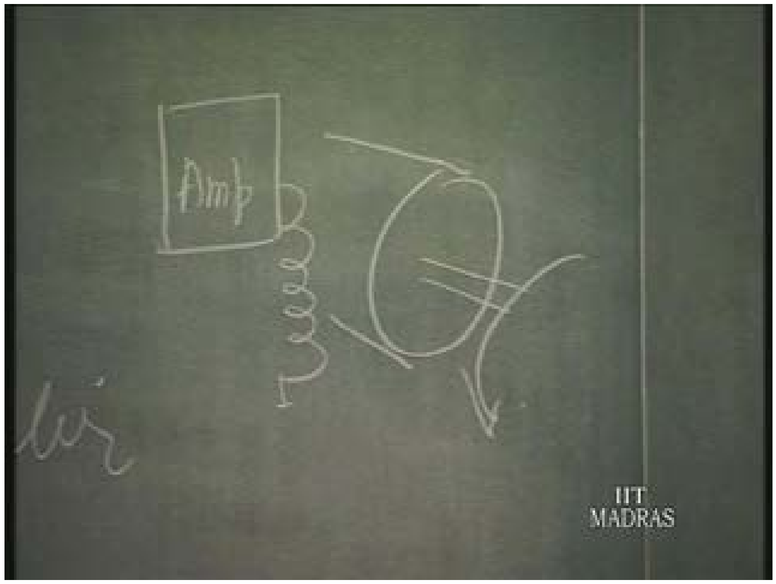

This is generating high speed here at a certain speed and you connect a disk here. This is called Optical Tachogenerator. What is done is a disk is connected to the shaft and you have slits in the circumference, exactly done. That is done by photolithographic technique so that the spacing of the slide must be exactly equal and it should be located in the circumference and then you put what is called optocoupler. It is a device which is available where there is an LED at this end; and there will be a detector, light detector on the other end; and there will be a slit in this so that the light that is emitted from the LED passes through the slit and gets detected by the detector.

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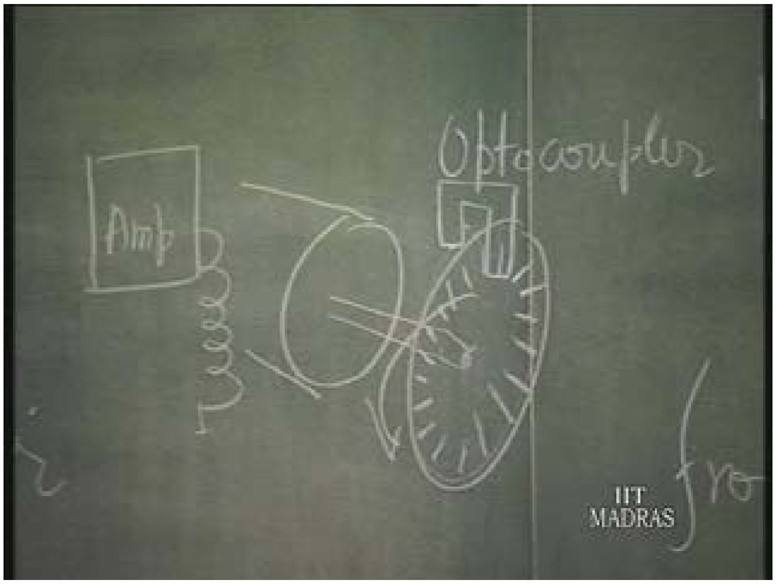

The entire arrangement is available as an I C along with the slit so that this disk can go into the slit and therefore the light can exactly fall on the light detector. This optocoupler with this kind of slit is available in the market. So, the optocoupler output now is going to be...as and when the light comes exactly through the slit there will be an output.

So, this will be the output from this electrical signal. This electrical signal passes through a Schmitt trigger and develops into a square wave. The whole thing therefore... this coming to a Schmitt trigger, developing a square wave is nothing but a voltage controlled oscillator because this is the control voltage and this D C voltage will change the speed of the motor and the motor speed will change the frequency of the Schmitt trigger output.

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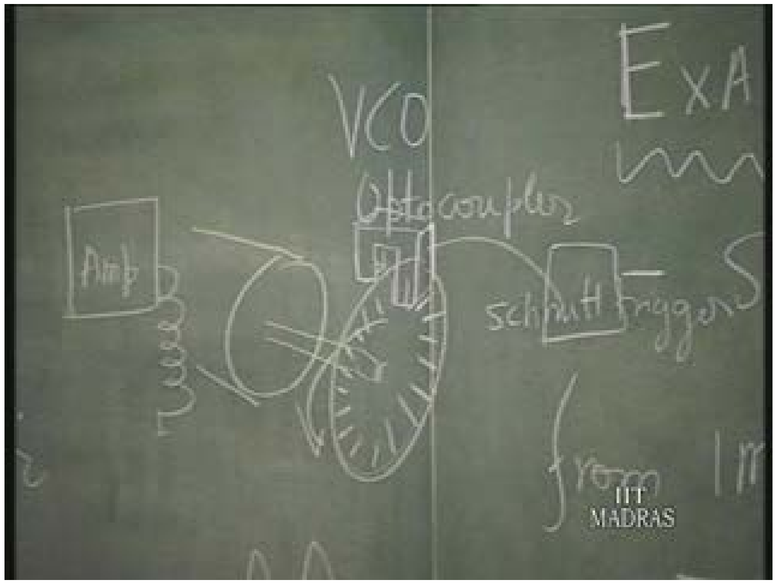

So, this frequency is directly changed by this D C voltage. So, the entire combination can be treated as a voltage controlled oscillator. So, this voltage controlled oscillator output is connected to the phase detector. This is frequency synthesizer output. This is now compared with the Schmitt trigger output here. So, this is connected to the amplifier. So, this becomes a P L L.

Let us once again understand. The amplifier plus low pass filter is formulated by amplifier plus the winding of the motor. The motor with the shaft and the optocoupler disk forms along with the Schmitt trigger, the voltage controlled oscillator.

The output of the Schmitt trigger is connected to the phase detector. So, this itself is a phase locked load. What happens? If frequency synthesized output is connected here so that the frequency can be programmed, this frequency will be same as this frequency. If this frequency is same as this frequency, Omega naught is going to be equal to Omega reference, Omega reference.

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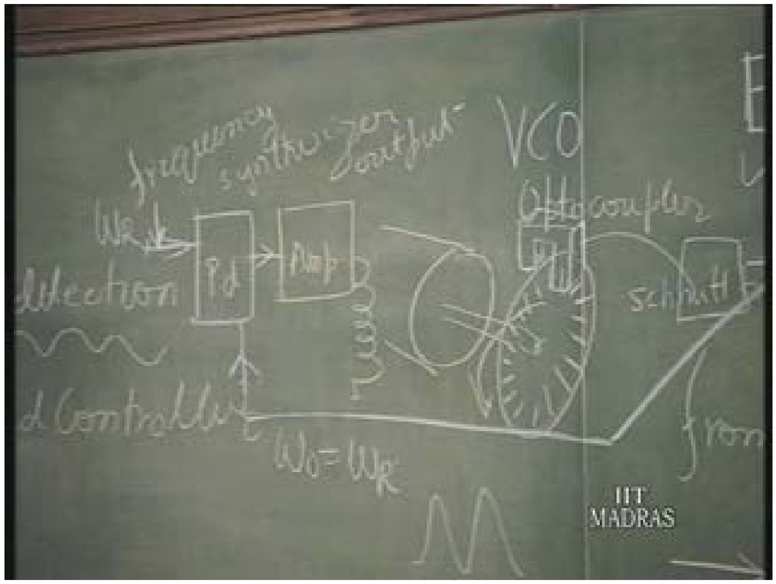

So, this is constant. That means the Schmitt trigger output is constant. That means this speed is constant. So, speed becomes absolutely constant, once we have this incorporated in the phase locked loop system. This kind of speed control is very popular nowadays.

That completes all the applications of phase locked loop that we can think of. There are other minor applications. For example, the phase locked loop...if you give a constant output here, Omega reference, output is going to be Omega reference and output will have a phase shift of 90 degree with the input, if V C O frequency is same as Omega reference. Therefore, let us have a means of changing this V, V naught Q. So, a D C input here is applied so that V C O, free running frequency is changed. Then the phase shift of this will change but the frequency will remain constant.

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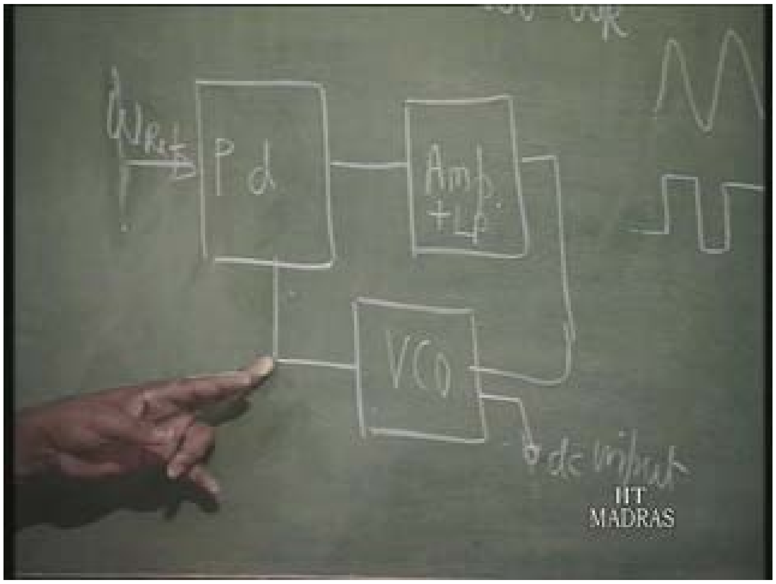

So, if you take the output here when this is the modulating D C input, the output will be exactly phase modulated output as this phase will change around 90 degrees based on the D C modulating input here. So, this is a unique circuit where I can directly achieve phase modulation rather than frequency modulation.

Frequency modulation, you can directly achieve by applying the modulating frequency to the V C O input. So, this is direct frequency modulate, modulating signal. This is F M, the frequency; but this is phase modulation. That means the same V C O put within the phase... phase locked loop and Omega reference being kept constant, output will be phase modulation. But, once this frequency gets modulated, phase also is modulated; or once the phase gets modulated, frequency is also modulated.

So, you will not find much difference between the output of this signal and this signal. But this is one way of achieving phase variation with the modulating signal which used to be done using tube circuits earlier; but using circuit concept, this is the best way of achieving phase modulation. There is no other circuit by which we can directly give phase modulation like this circuit here.

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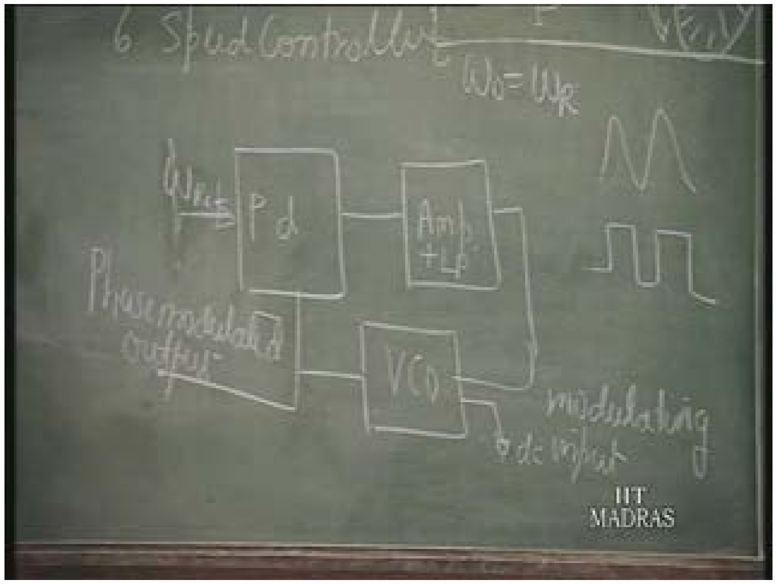

Finally, I want to discuss another important filter which is called self-tuned filter. Unlike phase locked loop, this particular thing is used in improving signal to noise ratio of basic signals; narrow band A M signals, narrow band A M; not F M. So, this kind of arrangement is quite common when we are receiving signal from extra-terrestrial objects. We know that some signal is coming. We do not know whether it is intelligible or not; but there is no point in somebody being engaged to look at it.

It will be automatically recorded and this frequency may be drifting somewhat with time, etcetera. But all the time, we would like the signal to be received. So, what is done is the...this is submerged in noise. So, let us say High Q band pass filter it is. That means actually, it is going to be narrow band selection; but we do not know the center frequency exactly.

So, we keep scanning and once we get it, we want it to track...with that. So, this interring signal, if it is band pass filter, we will subject it to a phase shift of 90 degrees; or, if it is the low pass high Q, you can use that itself. Otherwise, if it is band pass filter, we subject it to a phase shift of 90 degree in order to do the phase detection and compare it with the input and we have put a phase detector.

So, when this is exactly tuned to be sort of band pass filter, center frequency, that is it. That is the control signal which will tune this to some center frequency V C. Therefore, it is directly proportional to Omega p. That is, Omega p is the center frequency of this, whole frequency of this.

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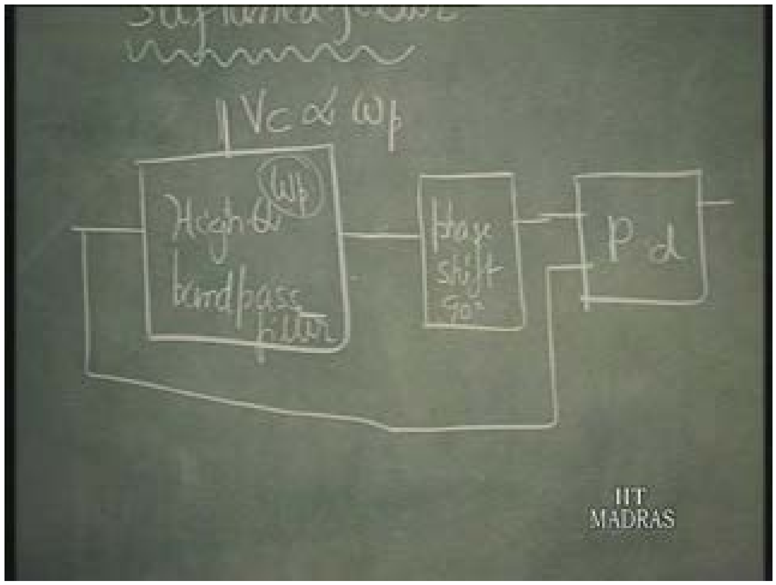

So, we will compare this with a reference and then it is fed to this control signal. So here, please see that this output is going to be the filtered output compared to the input. So, only that narrow band filtered output will appear here, if it is locked on to the incoming frequency now. So, this is similar. We can see there is a phase detector and the comparator. This is the amplifier plus low pass filter here. Actually this - the amplifier plus low pass filter here and this is nothing but voltage control filter, instead of V C O.

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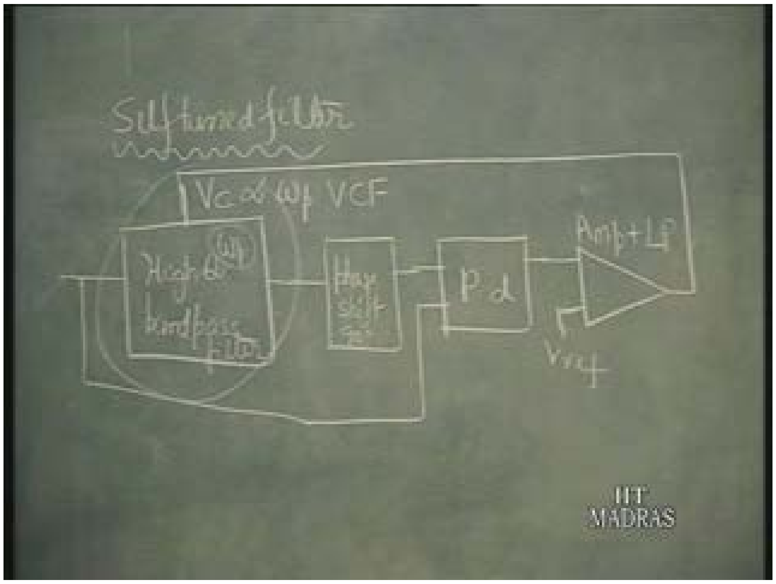

So, you have the phase detector, amplifier plus low pass filter and instead of V C O, we have voltage controlled filter. Then it becomes a self-tuned filter. In the case of phase locked loop, it was phase detector, amplifier plus low pass filter and V C O. Here, it is V C F.

So, this is nothing but voltage control filter which has become self-tuned. So, this kind of self-tuned concept is used whenever signal to noise ratio improvement has to occur drastically. This is applicable to...for narrow band A M signals so that the high Q filter can be used here.

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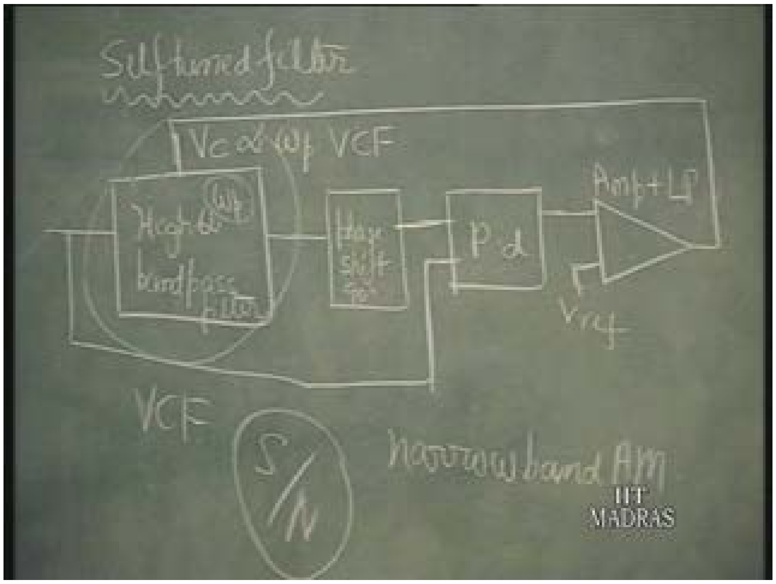

Now, this same concept also can be used in what is called a spectrum analyzer. This gets the composite waveform and it is made to tune it...itself to the harmonics; or the fundamental output will be the Q harmonic or the fundamental. So, you can now find out the extent of the harmonic. So, the same concept of self-tuning can be used in also what is called spectrum analyzers.

So, this completes our discussion about both communication and control circuits using electronic basic building blocks.