Analog ICs
Prof. K. Radhakrishna Rao
Department of Electrical Engineering
Indian Institute of Technology, Madras
Lecture - 27
Phase Locked Loop (Continued)
Digital to Analog Converters

So we were discussing about the AM detection using Phase Locked Loop. AM detection is a synchronous detection and not the kind of detection we are talking of which is there in the conventional radio receiver which is peak detection. In such a situation we have the carrier that has to be produced exactly at the receiving end. If you can produce the carrier with the same amount of stability that the transmitter end has then you can use synchronous detection for AM purposes.

What is synchronous detection?
Simply multiply the carrier with the AM and you get the detected output if you put a low pass filter and that is AM detection. Now, as far as the Phase Locked Loop is concerned this Phase Locked Loop is used in order to extract the carrier from the AM receiver. So what is done is AM input is supposed to go to the multiplier, the same AM input goes through a limiter so that all the amplitude information is remote and the carrier frequency is applied to the phase detector, this is nothing but the PLL. Obviously this produces the carrier at a phase shift of 90 degrees if it is originally tuned to the carrier.

Now, if you use the phase shifted carrier itself for multiplication you will not get an average because this is cos, this will be sine and average will not be there.

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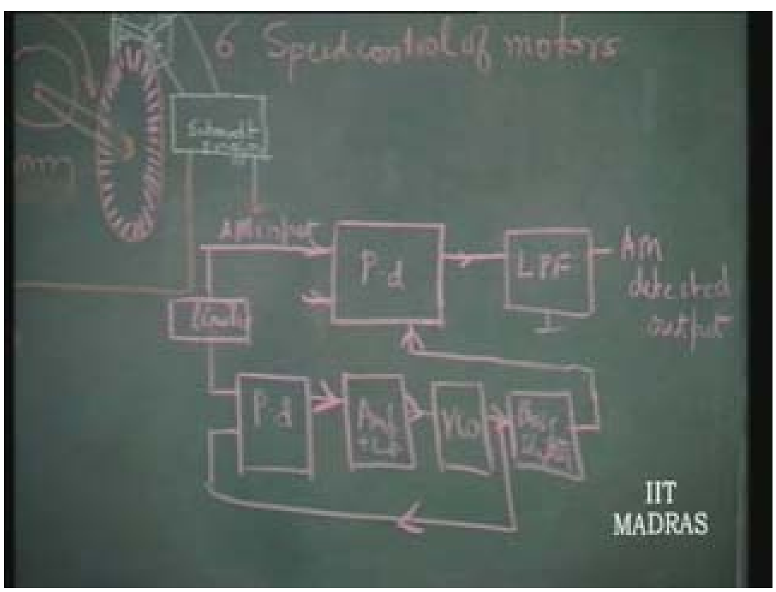

Therefore you have to additionally phase shift the so called generated carrier at this end by a further angle of 90 degrees if possible. Even if it is 90 degrees it does not matter there will be an average. Therefore additional phase shifter has to be put here before you multiply using another phase detector.

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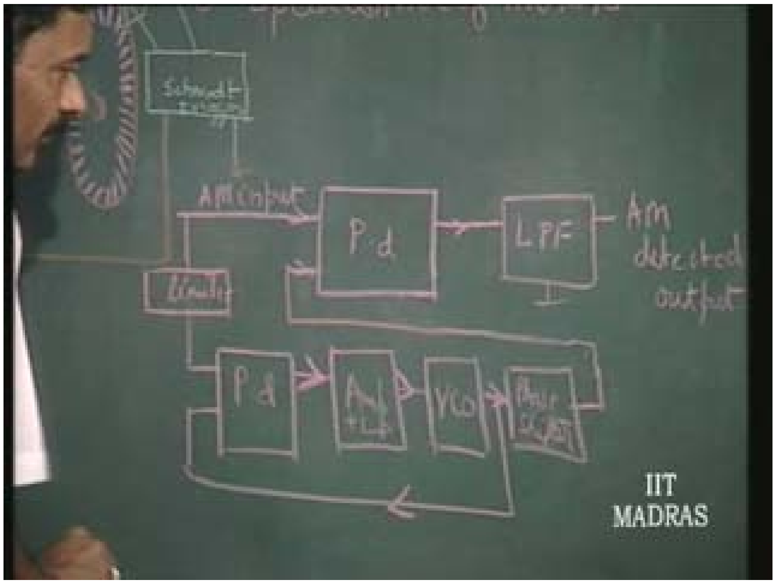

Actually speaking this is coming here as a second input. Essentially you are generating the carrier getting rid of the amplitude information here by putting a limiter, generating the carrier using a PLL and subjecting it to additional phase shift and then multiply it. Now this particular thing becomes a selective AM detector because here you might get AM inputs of all varieties of these carriers the signal strength. And what is selected out of this is the one that is tuned by the PLL to the specific carrier that you want to select. So this is a selective circuit with AM being detected corresponding to the frequency to which PLL is tuned. So this is the scheme for AM detection using PLL.

One of the most important applications today in Phase Locked Loop is precision speed control. Almost all computer drives today are controlled with this kind of speed control scheme. Earlier it was voltage reference that was used for speed control, now it is frequency reference. And we have already seen how stable frequencies can be synthesized. So, from a given frequency reference I can exactly synthesize other frequency components in it to the same stability. Therefore using frequency synthesize technique we can obtain any frequency input from a reference.

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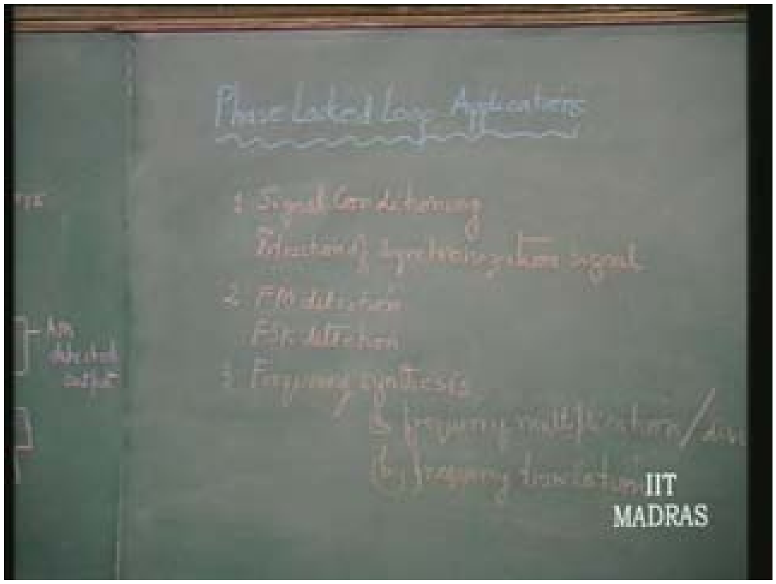

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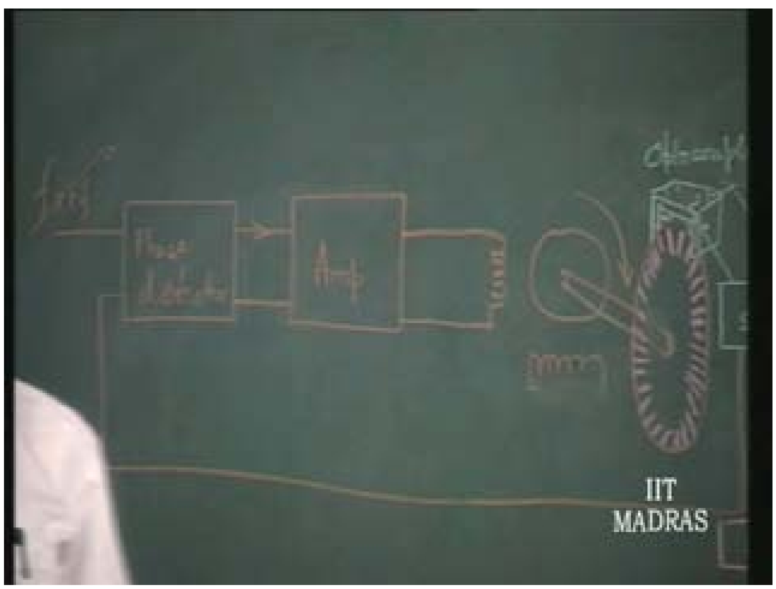

This is the reference frequency coming through frequency synthesized scheme and that can be adjusted. This is applied to the phase detector, amplifier. Now the low pass filter is nothing but the winding of the motor itself. Control winding of the motor itself acts as a low pass filter, you do not have to specially put any low pass filter. So this is applied through a power stage if necessary to drive the field winding of a motor and this is the other winding. These are the two control windings of a motor here. If constant voltage is given here this is going to be the control voltage where the speed and the direction can be controlled using this.

Now, the speed of this motor is converted to frequency using what is called optical taco. This optical taco is like this on the shaft of the motor a dial like this is put with slots in the circumference which are equidistant. So, on this dial you cut slots which are equidistant on the circumference of the dial. Then you put what is called an optocoupler such that the light being emitted by the LED here is collected exactly by the light detector on the other side.

These optocouplers are already available in this form with the slot. They can go into the slot, the advantage is they have the hole here so that the light emitted just exactly falls on the light detector that is what is called as an optocoupler. This kind of optocoupler suitable for this optical taco generator is readily available in the market. These disks also can be made by using what is called photolithographic technique so that you have slots cut exactly equidistant and around the circumference.

What happens as this rotate?
The light will be cutoff or permitted depending upon whether the slot is right in font of the beam or not. So you will get an output here at this LED point.

What kind of output you get?
The output will be almost looking like a sinusoid because whenever it reaches exactly the slot center there will be peak output so you will almost get a sinusoidal signal. This has to pass through Schmitt trigger that means it will become a square wave of the same frequency. Therefore after it goes through a Schmitt trigger this whole thing now can be treated as nothing but voltage controlled oscillator.

This voltage controlled oscillator is now designed not using electronic circuitry but using a motor as part of the whole scheme. So this voltage is now simply controlling the frequency of the output pulses. Once this becomes an integral part of the PLL system this VCO becomes an integral part of the PLL system. What is going to happen is just as what happened in our ordinary PLL, this frequency will be exactly same as the input frequency. So, irrespective of the load on the motor the frequency is going to remain constant. That means speed is going to remain constant. This kind of speed control is now-a-days universally applied in almost all precision speed control schemes. This frequency is going to be extracted once again from a crystal oscillator frequency coming through a frequency synthesis network which again will comprise of Phase Locked Loops, multipliers, phase detectors etc.

So you can see that this whole scheme is very interesting and you can try this out for any of your small motors in the laboratory itself. There is no difficulty in trying out this kind of speed control schemes in laboratories. These are the important applications of Phase Locked Loop. There are lots of other applications which are available. For example, Phase Locked Loop by its very nature can modulate the phase itself obviously. There is a subtle difference between frequency modulation and phase modulation. Even though they are linearly related if you do phase modulation you get a frequency modulated output. But only during the days of tubes there where tubes which were directly doing phase modulation, the electron tubes. But after that with the advent of transistors etc the schemes for making available any direct phase modulation technique was not there until Phase Locked Loop came into picture.

What can you do with it?
We know that the Phase Locked Loop has a phase shift of 90 degrees between its input and output if it is tuned, if the incoming frequency is omega$_{0Q}$ itself then the phase shift if 90 degrees.

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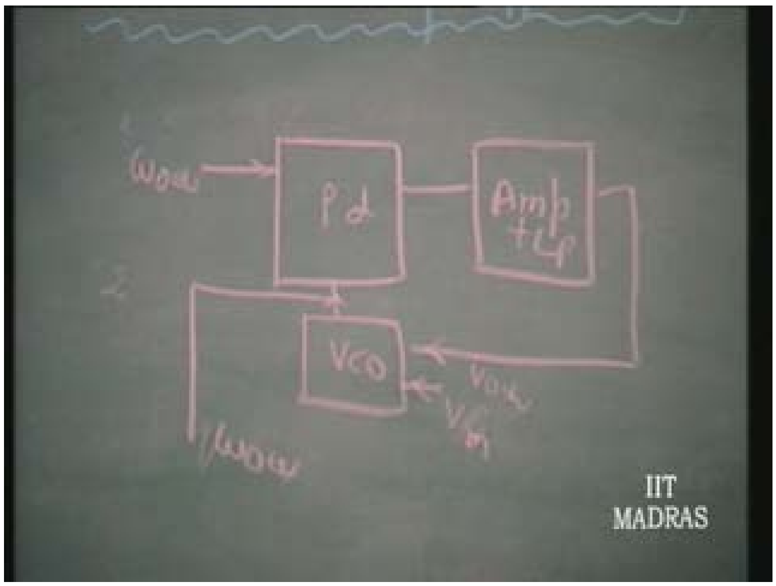

This is V_{OQ}, therefore now you can superimpose V_{0Q} over another DC voltage so that this V_{DC} and V_{0Q} together will determine the DC voltage of the VCO so this V_{DC} is V modulating. What happens is V_{0Q} will correspond to omega$_{0Q}$ and let us say this is having omega$_{0Q}$ as the input then there is a phase shift of 90 degrees. Now when V_m comes into picture you are tuning the VCO to a different frequency compared to omega$_{0Q}$. So automatically the phase shift should change, frequency will remain the same. Now the phase can be changed linearly by changing V_m. So the output can be taken here, this will correspond to omega$_{0Q}$ but it is space modulated. Obviously this is also a frequency modulated waveform, it can be used because once you apply DC here and vary the DC here of the VCO you will get an FM that is because f_i is changing with respect to time.

This particular scheme is directly modulating the phase of the structure. This is one such scheme which is there in as one of the applications of Phase Locked Loop. This can also be used as an idea to generate particular phase shift. This can be a good phase shifting network. As far as the phase shift is concerned for any particular specific frequency you can obtain a desired phase by adjusting V_m.

Now we will start one of the most important blocks. I would categorize this block in that of analog circuits because this is what is called D to A converter from digitally word controlled switches where digital word is the input to this, and those switches which are controlled by digital word are now responsible to activate the circuit and give you an analog output. So let us see one of the important schemes of D to A converters.

This is called weighted resistor scheme. As the name implies this op amp is used for summing up the currents. These are weighted currents weighted according to the switch positions. So these switches are the control switches, these switches are controlled by the digital word the input. So when these are closed obviously they pump in currents of the respective magnitude which are binary weighted in this scheme. Therefore we have an output V_0 which is V_{ref} by R. And depending upon these the coefficients here can take either 1 or 0 so a_3 let us say where a_3 is the coefficient operated by S_3 which is going to take on 1 or 0. If S_3 is closed it is 1 otherwise it is 0.

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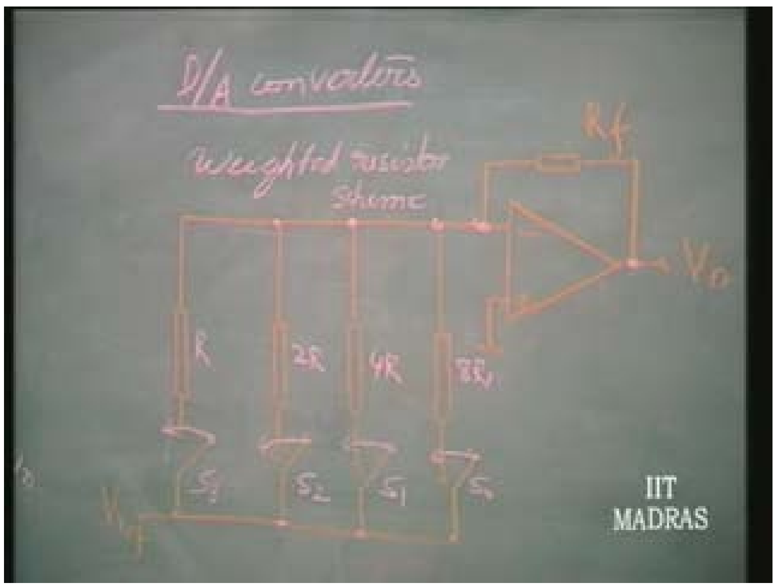

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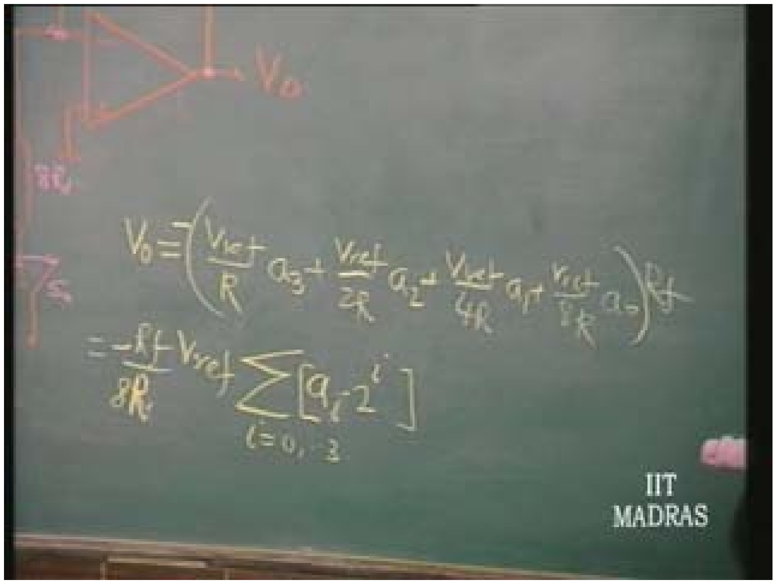

So V0 is equal to minus (V_{ref} by R a_3 plus V_{ref} by 2R a_2 V_{ref} by 4R a_1 V_{ref} by 8R a_0)R_f or in a sense we have R_f by R coming out into V_{ref} and this is sigma. In fact we can take out 8R so you get a_i 2 power i is equal to 0 to 3. So this is an important thing. In any D to A converter we have this for the analog expression, sigma a_i 2 power i this is the weighted scale and this corresponds to the analog output, these constants may vary depending upon the scheme of addition.

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It may be ratio of resistors or ratio of capacitors, if it is switched capacitor network it will be ratio of capacitors and there will be always a voltage reference.

Therefore what are the integral parts of D to A converter?
One of the important block necessary to make D to A converter IC is the weighted scale. It could be the weighted resistor, weighted capacitor or anything. It is the one that determines the weights as given in this expression. It is important that these resistors have got to be precision temperature independent etc.

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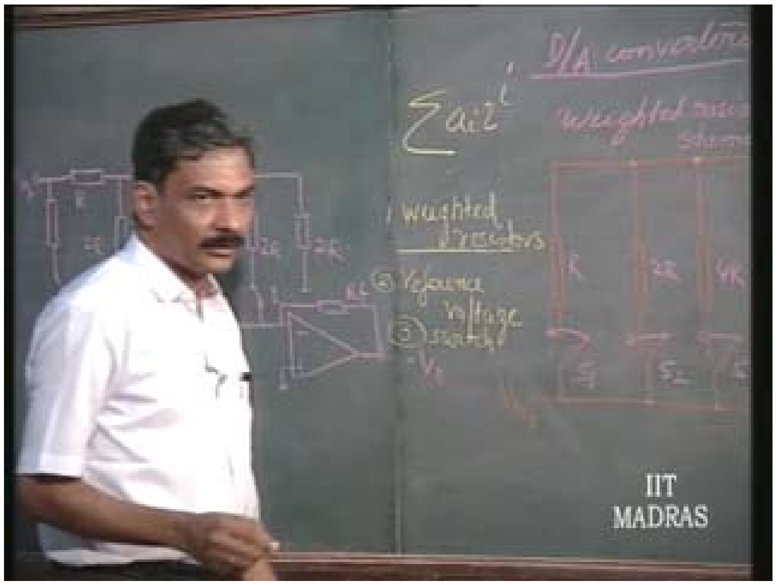

The resistor ratio here is the ratio that has to be temperature independent and the tolerance of this should be good. That means if you want a precision D to A converter you cannot normally go in for monolithic D to A converters. If you want very precise D to A converters you have to go in for thin film thick film components as resistors in this because we have seen that the resistors in monolithic form have very poor ratio tolerance. Even though it is better than absolute value tolerance it is not acceptable it is hardly something like 2 to 3% which is not acceptable for precision converters. You might have to go for ratio of capacitors which has a better temperature coefficient effect. That means this weighted resistor scheme has to turn itself into weighted capacitor scheme so those will be switched capacitor networks and we have to have a precise V_{ref} the reference voltage.

We have also understood how to generate precise voltage references independent of supply voltage as well as temperature. In D to A converter a voltage reference circuit is put, you have weighted resistor or weighted capacitor and the third important part is the switch which is controlled by the digital inputs word and obviously its on resistance off resistance its stray capacitor all these things matter as far as the accuracy and speed of operation of D to A converters are concerned. So the switch is something we have to learn about. The most important aspect is switching in D to A converters.

Now this scheme of switching here, as you close this the current flowing in this is the V_{ref} by R. The currents keep on changing depending upon the current drawn from V reference will keep changing depending upon the position of the switch. Therefore if this is not an ideal source if it has a source resistance here this voltage itself will change. So that will appear as a noise which will be purely dependent upon the switch position. So this voltage will change in a very random fashion depending upon the switch position so that causes an error in this. This kind of error is primarily because you are drawing different currents from the same V reference depending upon the switch position. And V reference may have certain output resistance however small. And obviously these switch resistances also will come to picture. When it is closed its on resistance will be adding on to R, this is another source of error in this.

When it is off it will still leak some current into R. So the on resistance and the off resistance of the switch is also going to contribute to the error in the output. Therefore we have to see how these things can be improved. This scheme of switching is called voltage switch.

Why is it called voltage switch?
It is because when the switch is closed the voltage across the switch is 0 but when the switch is open the voltage across the switch is V reference itself. So, as speed is concerned when the switch is open it is a capacitor until the capacitor is fully charged to V reference we cannot take the output. That means the speed of the D to A converter is going to be limited by the fact that you are using a voltage switch here. The voltage across the switch is 0 or V reference. That means the capacitor across the switch has to be charged up to V reference. So before you take the output there is going to be some limitation due to the nature of the switch itself.

So how do you get over this problem?
This problem of the switch can be got over neatly by doing what is called current switching. It means simply put the switch.

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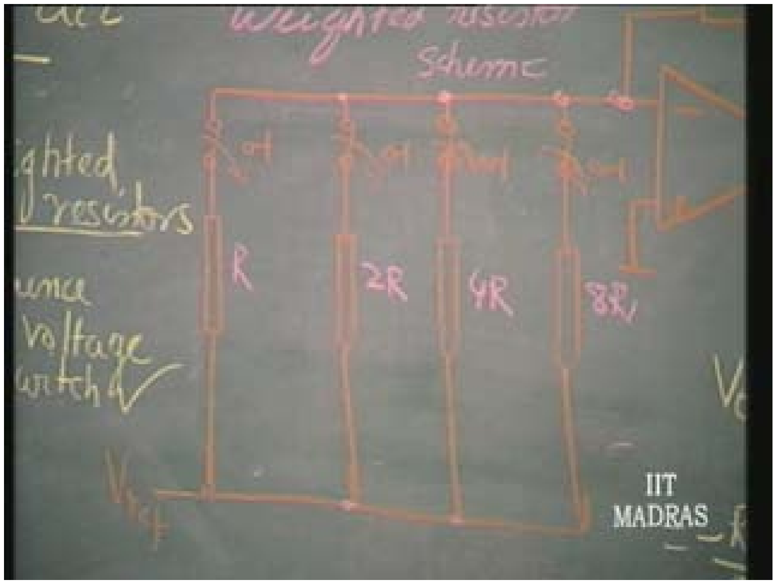

This voltage will be constantly there but then what is going to be done is the location of the switch is changing. Instead of single pole single throw switch we will use single pole double throw switch here. These are all not mechanical switches these are electronic switches. Instead of 1 FET we have to use 2 FETs. And now the switch is either here or connected to ground. That means the current V_{ref} by R is all the time flowing into virtual ground or into actual ground. So this is the scheme of this. This is what is called current switching and it is this current switching which is now responsible for the increased speed.

You can see here the subtle difference between locations of the switch resulting in improved speed of operation. The price you are paying is obviously in terms of number of electronic components that does not matter in an IC. Not only that but you will automatically notice that now the V reference is giving the constant current irrespective of the switch position. Therefore even if there is some output impedance it is going to be resulting in a constant error rather than a random changing time dependent error. This constant error can be easily compensated for whereas the random error which earlier existed cannot be compensated. So, location of the switch here making it double throw single pole is going to work very well in resulting in current switch.

Now, the switches themselves could be simply MOS switches. One gets Q as its input and another gets Q bar. So you have MOS switch or it could be even diode switches. For example, using diodes one can make a switch like this and we get this arrangement.

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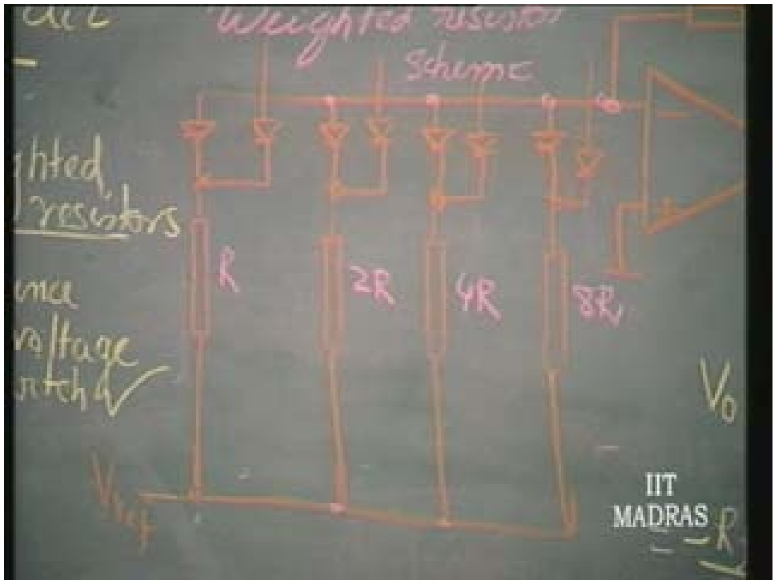

If this voltage here is negative this is off, the current will be forced to flow through this like this. If this voltage is raised to a higher level positive immediately you see that the current will be diverted on to this and this is going to be off. So, by making these this could be your digital output themselves directly. You can therefore invert part of the digital if you want the thing to exist this will have to be low then it will exist. If your actual input is 1 0 1 1 then what you have to apply to this will be 0 1 0 0 which is inverted. So this kind of switch can work very well as the switch for this weighted resistor scheme or we can use MOSFETs instead of the diodes. Wherein like this you can replace each of these by MOSFETs getting Q and Q bar as the input corresponding to the word.

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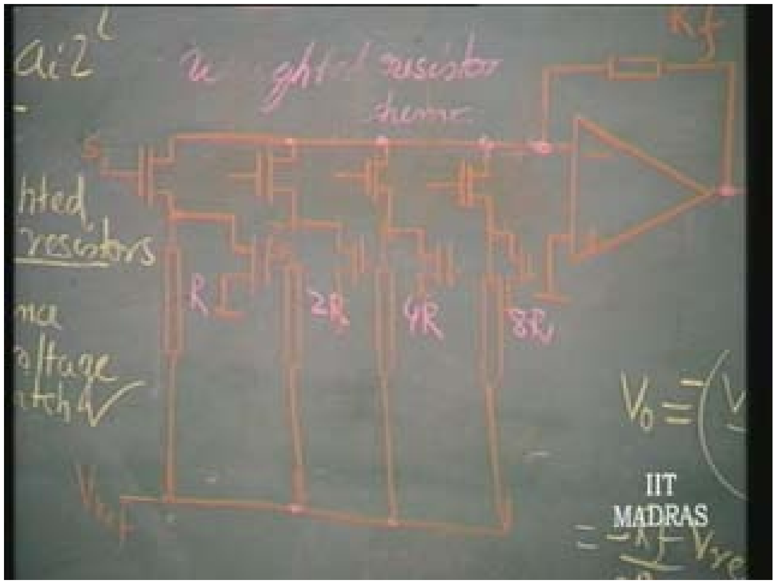

If this is S_3 this will be S_3 bar and so on. This is another scheme for switching. Now I would like to normally avoid this switch resistance coming in series with the resistance because this is again a random variation which is going to occur and which is going to cause serious problem. So how do I really do current switching with switch not coming in series with the resistance but switch coming in series with the current source. If you put the switch in series with the current source then the switch resistance is not coming into picture.

So instead of this kind of scheme what is therefore recommended is for avoiding the error due to the switch resistance why not use a transistor current source and now you will put the resistance here and appropriately apply a voltage here which maybe V_{ref} plus V_{gamma} so that the V_{gamma} continues. So the voltage you apply here is going to be V_{ref} plus V_{gamma}. Then the current in this is V_{ref} by R. Now you can introduce your switch at this point either switching to virtual ground or actual ground.

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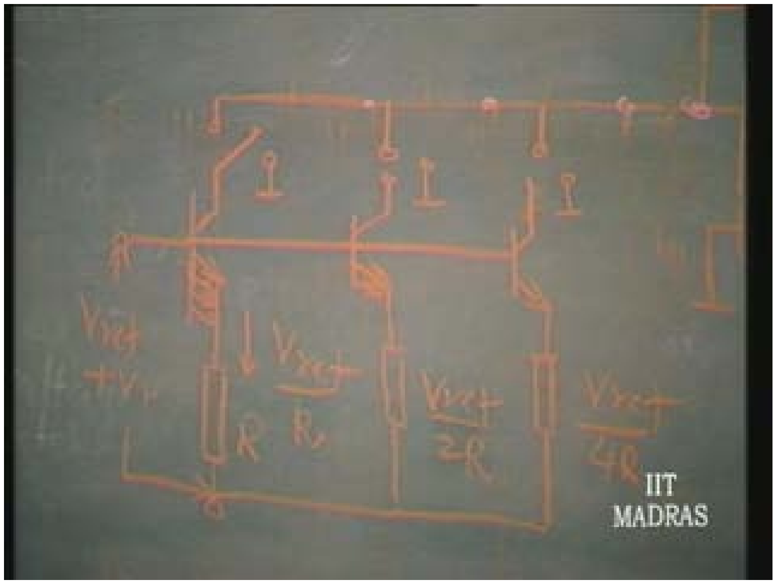

This scheme is normally adopted in most of the D to A converters. Here it is avoiding what the resistance of the switch coming in series with R and the current obtained by the current generator is going to be switched either to the virtual ground or to the ground. Now you might say the same voltage is going to be applied to another. Now there is a subtle difference here, the current here if this is V_{ref} by R the next current is going to be V_{ref} by 2R. It is an established fact that when the current in these transistors vary the voltages will be different.

If I have carefully adjusted this V_{gamma} to be such that it is going to compensate for this transistor then it will not do for this transistor because all these transistors are operating at different current, the currents varying by a factor of 2. So that is easily compensated for by making this particular thing, for example this is V_{ref} by 2R. So I make another here, so actual current here is V_{ref} by 2R there are two emitters of this type that means this is going to give V_{ref} by 2R and the other one is going to give V_{ref} by 2R. In effect the V_{gamma} of these transistors coming in parallel will be the same as that of V_{gamma} of this because all the transistors are operating at the same current. So you make this area twice that of this. Now this has to be carried through because if you are using the next one this is going to be again V_{ref} by 4R that means this has to be double that and this has to be four times that.

We will stop at this stage because it is just a routine thing here V_{ref} by 4R. So you can see a nice 3 bit converter using current sources which are being switched and the areas adjusted accordingly so that the compensation is exact. This is done for 3 bit but you might have some 12 bit or 8 bit converters. You can see the circuit diagram given in the manual or something it will exactly look like this. And basically we have seen that it has weighted resistor scheme and transistor current sources and switches and V reference.

Now this forms the essence of the internal circuitry of D to A converter, there is a small difference here. There are two schemes of getting the required weights for the summation. One is the weighted resistor scheme and the other is called R to R ladder scheme. It is an established fact that when you have 2R and 2R in parallel combination here results in R. This R comes in series with this R results in 2R and that 2R comes in parallel with this 2R so on and so forth. So at any point here if you look in through this you will see the impedance which is always going to be R. So the resultant effect now is, if this is V_{ref} by 2R current this is going to be V reference by 2 and this is going to be V_{ref} by 2 square. So, at all these nodes you will get the so called weighted voltages automatically necessary for summing up.

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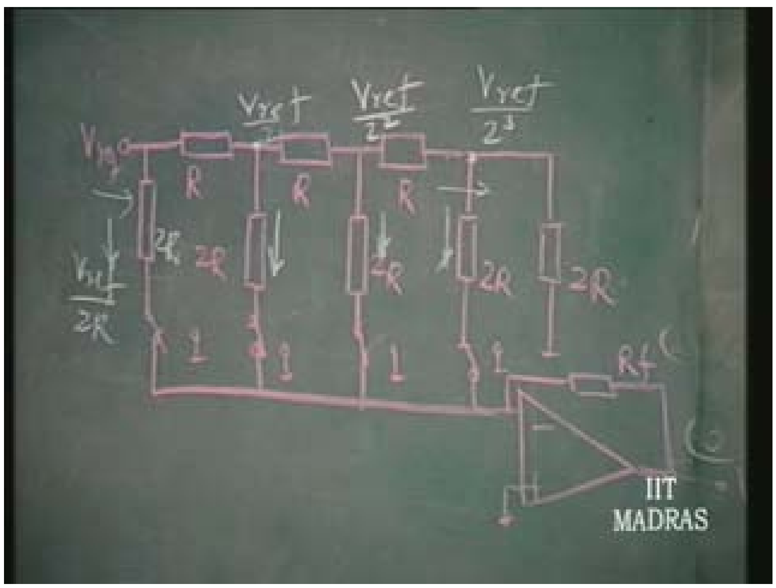

So using these currents now by the same process of switching either to the virtual ground or to the ground so this V reference takes always the same current here and weighted resistor currents remain undisturbed either they go into the ground or go into the virtual ground we can get the same output that we got from the weighted resistor scheme. The only thing is for 3 bits here we need 3 plus 1 resistor whereas here for 3 bits we double the resistors plus 1.

Here you need N plus 1 for N bit D to A converter, here you get 2N plus 1 as the output so it is double. But the advantage here is the spread in resistance is only by a factor of 2 here whereas it is going to be the whole factor here. Either it is this scheme or that scheme is what is normally seen in your D to A converters. The same scheme can be obtained here by replacing the resistors by capacitors.

In switched capacitor networks there is no question of current business. It is the capacitor that is charged to a certain voltage using a switch and then the entire charge is transferred to the feedback or the output and that way you can bring in more number of capacitors at the input and pump in the current that is necessary to charge this feedback capacitor. Switched capacitor networks will be discussed later.