Automation in Manufacturing
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Week – 05
Signal conditioning and Microprocessor Technology
Lecture - 03
Signal conversion

In this lecture, we will be studying various techniques associated with the Signal conversion.

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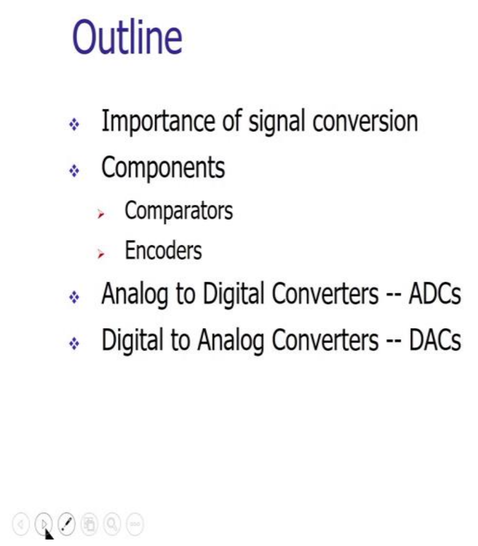

The outline of this lecture is as follows, at start of the lecture, we will see the importance of signal conversion, why it is needed, various components associated with the signal convergent devices like comparators and encoders. In a typical mechatronics based system, we need to convert the analog signals into digital format or we have to convert the digital signals into analog format.

Where we need to convert the analog to digital and where we need to convert digital to analog format that we will see in details in this lecture and what are the various techniques.

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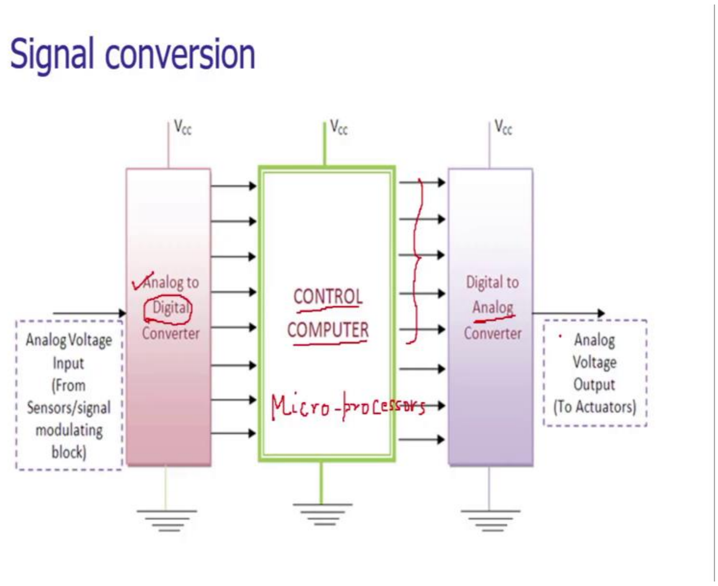

In this lecture, we are studying the signal conversion operations. Any automated system is being controlled by a computer; the computer has microprocessor. The computers are working basically on the microprocessor technology.

The microprocessor is able to process the digital data, but we are getting the analog data from the sensors. Variety of sensors and signal modulating blocks are used in the automated systems and the analog signals are needed to be converted into the digital form.

The microprocessors are generating the digital signals and that digital signals need to be further converted into the analog form which can be utilized to actuate the actuators. In automated systems, specially we need to actuate the drives, it may be the electrical drives or pneumatic drives or the hydraulic drives. Therefore, it is very essential for us to understand the fundamentals of analog to digital converter and the digital to analog converter.

In this lecture, we will be studying some of the basic concepts of the signal conversion devices.

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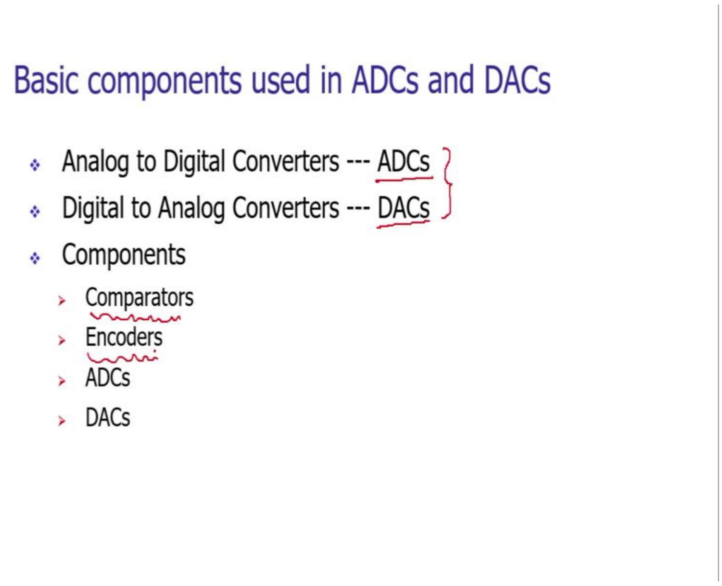

The components are ADCs that is analog to digital converter and the DACs. The other components which are needed to build a DAC or ADC are comparators and encoders. Comparators and the encoders are needed to build the DACs and ADCs.

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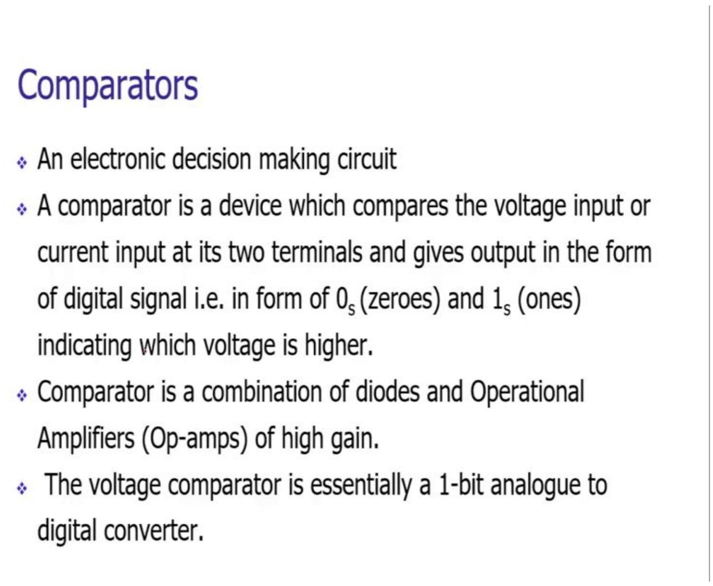

Comparator is an electronic decision-making circuit. As the name suggest, the device is comparing the input voltage or it is comparing the input current at its two terminals and it just produces a digital signal in the form of 0 or 1. Basically, it compares the input voltages and it gives the result that which is the higher one.

The comparator has a combination of the semiconductor devices that is diode and an operational amplifier. The operational amplifier should have the high gain. A typical voltage comparator is essentially a 1-bit analogue to digital converter. The meaning is that a simple voltage comparator will take the input at its input terminals and we will generate the analog signal into 1-bit digital signal.

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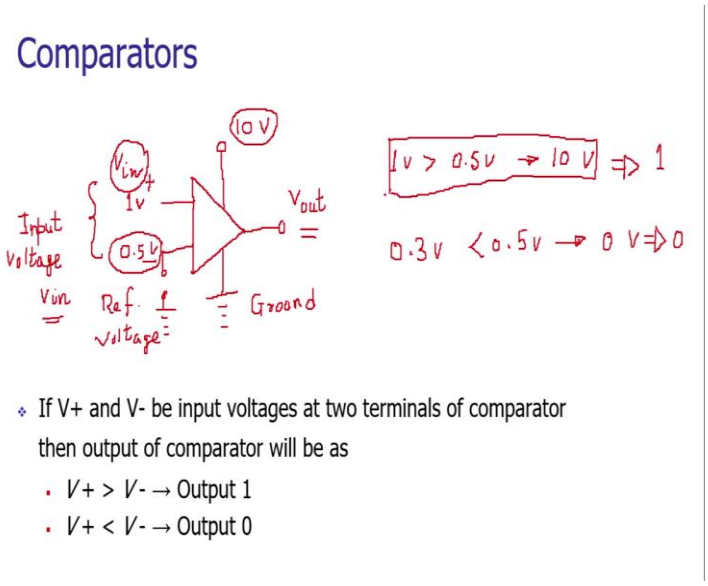

The comparator has an operational amplifier, it has two input terminals which is non-inverting, and there is the inverting terminal. Though operational amplifier has the output terminal V o. Consider a supply voltage is given of 10 volts and the other terminal of the supply voltage is grounded. Now, what the comparator does? It compares the voltages which are applied at these two terminals and it gives the output. If 1 volt is applied at the positive input terminal which is called the non-inverting terminal and 0.5 volts at the inverting terminal.

The comparator compares these two values, if we consider these as the V in, the input value at the non-inverting terminal is more than the input value at the inverting terminal, then the output will be the 10 volts; the output is nothing, but a supply voltage that we applied.

If in this case the voltage at non-inverting terminal is more than the inverting terminal, then it is leading to the output as 10 volts. The comparison is based upon the values that we are entering at the input terminals.

If one of the input values is fixed as the reference voltage, which will be kept constant, then whatever the input voltage we are getting from the sensors or the signal modulating devices the op-amp we will just compare the input voltage with the reference voltage and accordingly, it will produce the amplified output.

If the input is say 0.3 volts, 0.3 volts is less than the reference voltage 0.5, the op-amp will generate the signal 0 volt. The 10 volts would be considered digitally as 1 and the 0 volt will be considered digitally as 0.

If we consider the inverting terminal as the reference voltage with certain fixed voltage value and if we apply the input which are coming from the sensors or the signal modulating blocks at the non-inverting terminal continuously, then we can generate the outputs accordingly.

If the input is more than the reference voltage, we are getting the signal 1 and if the input is less than the reference voltage, we are getting the signal 0. If we combine such comparators together, then we can generate the signal in multiple bits.

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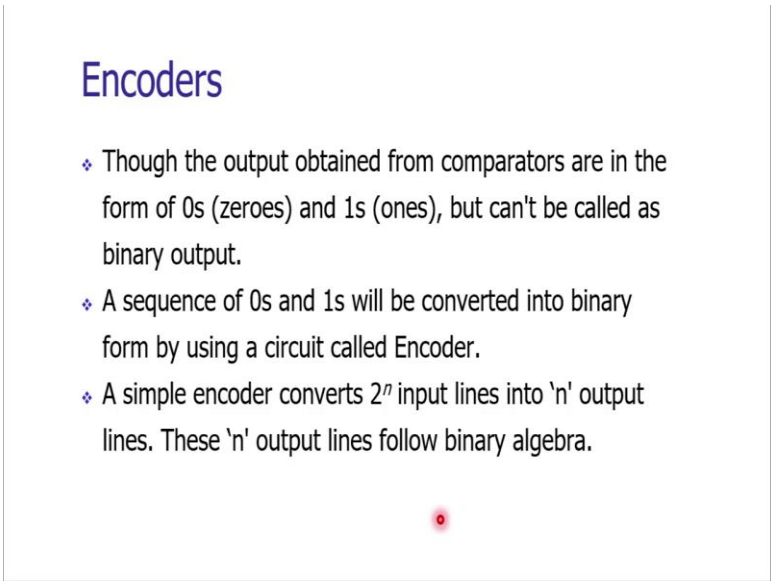

The comparators are comparing the inputs and they are generating the digital output. A 1-bit comparator is generating 1-bit digital output. But the outputs which are coming out or the outputs which are given by the comparators though are in the form of 0s and 1s, but we cannot call them as the binary output. The microprocessor is essentially required to have the binary output which is having certain meaning.

A sequence of 0s and 1s, no voltage and the positive voltage we need to convert that into a binary form. A digital circuit which is carrying out this function is called as the encoder.

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A simple encoder is the device that converts 2^n input lines into n number of output lines. These n output lines are following the binary algebra.

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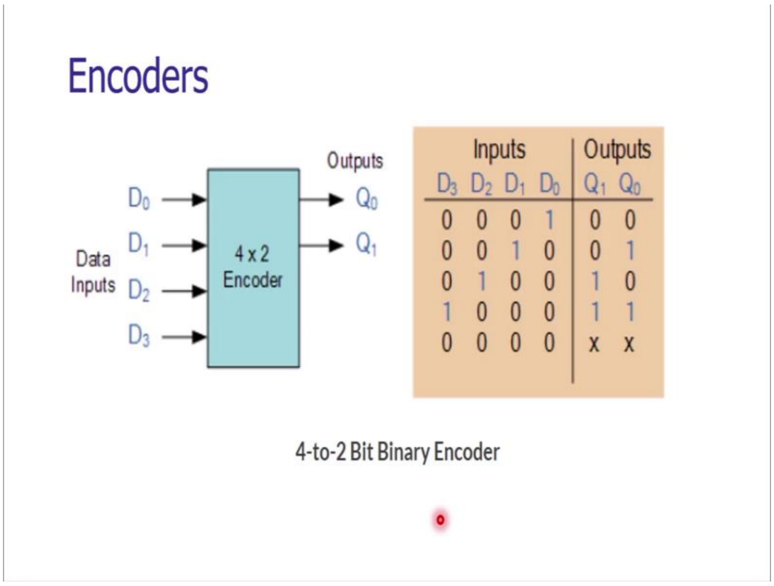

To understand this concept, let us look at a typical arrangement of 4 to 2-bit binary encoder. Here, we are having four input data lines D 0, D 1, D 2 and D 3. These input data lines are nothing, but the output of the comparator. We are having four comparators attached here, comparator 0, comparator 1, comparator 2, comparator 3. These comparators are op-amp based comparators.

As we have seen based upon the input voltage given to the operational amplifiers and based upon the reference values of the operational amplifiers, the operational amplifiers are giving us certain output. That output at c0 will be utilized to generate the input data line D 0. Similarly, for D 1, D 2 and D 3.

When 4 input data lines are there, we will be having 2 output data lines. So, 2^n is equal to 4; 4 input lines are giving 2 output lines.To have this type of binary encoder, we have to generate a truth table, we have to use the logic operations to get the required output.

A truth table is there on the screen. We have an arrangement where D 0, D 1, D 2 and D 3 are written from right to left and Q 0 and Q 1 outputs are written from right to the left. If we say that the comparator output or the data input line D 0 is a positive i.e 1, then the output at both the data lines would be 00.

If the data input line is 1 positive voltage, then we are saying that the output line is 1 at Q 0 and the output line would be 0 at Q 1. For D 2, the Q 1 is 1, Q 0 is 0. For D 3, Q 1 is 1 and Q 0 is also 1.

But in case all the input data lines are giving us no data 0 volts so, then invalid output will be obtained. But let us consider the case when we are having two data lines are giving positive input. If suppose, the D 1 and D 2 both are giving us the positive input, then the output Q 1 and Q 0 will also give the result as 1, 1 which is clashing, which is same as the D 3 input line.

So, for D 1 is equal to 1, D 2 is equal to 1, Q 1 and Q 0 would be 1, the same would be there for the D 3 it is a clashing which creates the confusion and is the major drawback of 4-to-2 bit binary encoder. To solve this problem, we have to prioritize the input data lines and based on the priority, we can generate the output.

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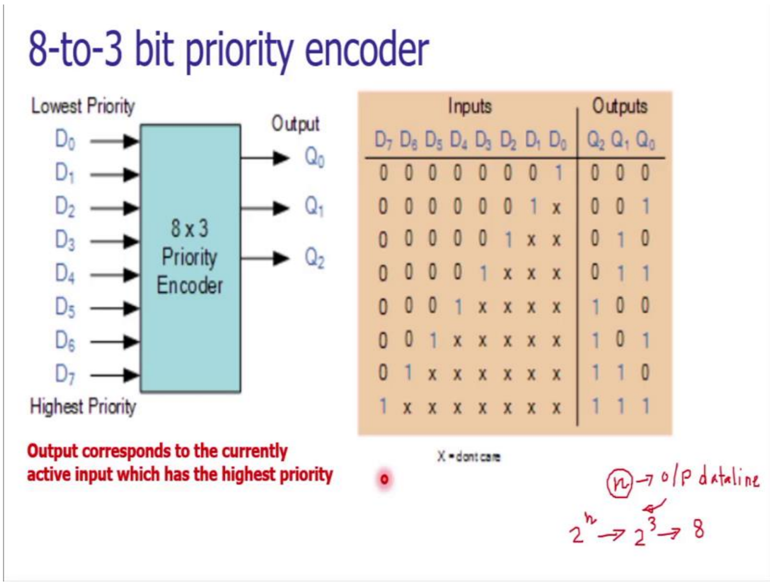

The drawback associated with 4 2 bit binary encoder can be solved by applying priority to the input data lines. How this priority encoding works that we will see by taking an example.

In this case, we are taking 8 to 3-bit priority encoder. The output data lines that are required are 3. When we want output data lines equal to 3, what should be the number of input data lines are required? If the number of outputs are n so, to have n output data lines, we should have 2^n input data lines. In this case, the output data lines are 3. Therefore, the input data lines would be 2^3 i.e 8. Thus, we have to have 8 input data lines to get 3 output data lines.

We apply the same methodology as we applied for 4 2 bit. We have to develop a truth table for this. Before getting the truth table, let us arrange the input data lines as seen on the screen. Again, we are arranging the input data lines as D 0 to D 7 from right to left and the output data lines as Q 0 to Q 2 from right to left.

We are providing the priority level to each data line. The lowest priority is given to the D 0 data line and the highest priority is given to the D 7 data line. Now let us see one example to understand the concept of the priority. Look at the row number two. Here, the data input line 1 is showing the high level input value. The comparator is giving high level input value at D 1 that is a positive. There is a comparator at D 0 as well, but we are ignoring the input value at D 0; that means, we are giving priority to D 1 although we may have certain high input at D 0.

The meaning is that if we are having D 0 as 1, but we do not use that value, we are just simply ignoring; we are simply ignoring the presence of any signal at D 0. Thus, for this row number two, the priority is given to D 1.

If in certain case, the data line 4 is showing the high level input that is 1, then though there are input data lines, though they are high input at D 3, D 2, D 1, D 0 all these would be neglected, they would be crossed, we are not considering them for the conversion application, but in case, the D 6 is showing the positive level, the high level, then we are ignoring the D 5, D 4.

In this way, we are prioritizing the input data lines and when we give the priority to that input data lines, we are ignoring all the input data lines which are lower to that data line.

If D 6 is having the priority, then all the other input data lines will be ignored. Based on this, we develop this input table and for each and every row, we will be having the output by using the logic gates. We have to develop the logic gates AND OR gates if D 1 to D 7 are showing low level input and only D 0 is showing high level input that is 1, then the logic gates based circuitry will give the output as 0, 0, 0.

In the next case, the logic circuitry will produce the signal as 0, 0, 1; at the output data line Q 0 it will produce high level output that is 1. If D 1 is giving the high-level input and from D 2 to D 7 we are applying low level input, the encoder will not consider the input at D 0. The same logic will be applied, the same methodology will be applied for all other cases and accordingly we are getting the output based upon the logic gate operations.

For example, in the sixth row, the data line D 5 is having high in a high-level input. As per rule D 4, D 3, D 2, D 1 and D 0 will be ignored. If D 6 and D 7 are having 0 or the low-level input, then the logic gate will generate the signal as 1 at Q 2, 0 at Q 1 and 1 at Q 0.

In this way, we can say that the output is corresponding to the currently active input which has the highest priority. The output corresponding to the currently active input.

In this case the currently active input is D 4. In this row the currently active input is D 4 and it has the highest priority for this row. Accordingly we are getting the output as 1, 0, 0. If the comparator corresponding to either D 7, D 6 or D 5 is also showing the high-level input value, then this would be ignored and the output would be changed.

In this way, the priority level of the input data lines is giving the output and thus, we are converting the input as the analog signal that is a continuous function of the time into the digital output that is 0s and 1s.

To convert the analog signal, we are taking help of the operational amplifiers and then, we are converting them into the high-level signals and low-level signals using comparators in association with the encoding device, encoding circuitry, we are generating the digital outputs.

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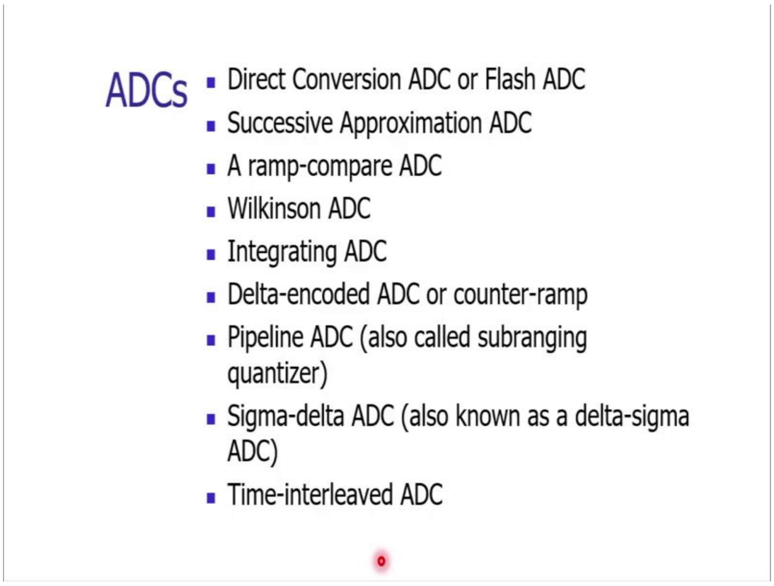

Analog to digital converters can be seen on the screen. These are direct conversion ADC or flash ADC, successive approximation ADC, a ramp-compare ADC, Wilkinson ADC, integrating ADC, delta encoded ADC and many more. In this lecture, we will look at the direct conversion ADC, its constructional details and the working principle.

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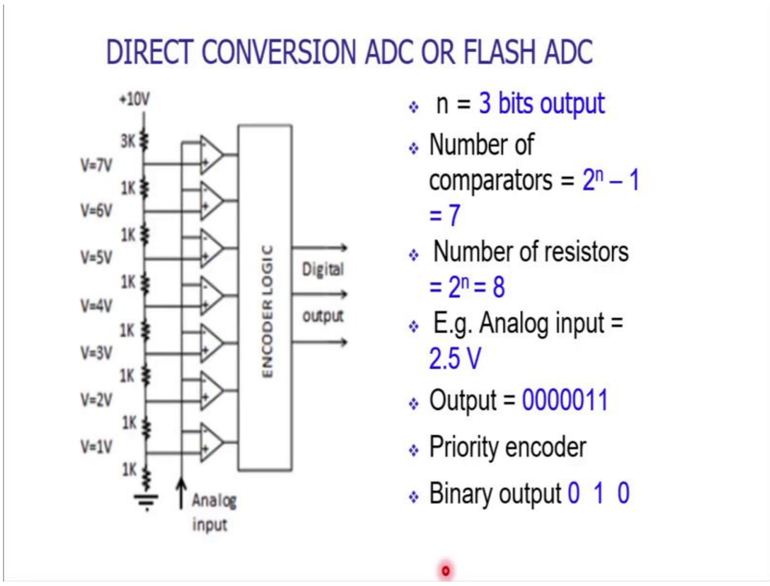

We can see the electric circuit of the direct conversion ADC or the flash ADC. It is called as flash ADC, flash analog to digital converter because it is very fast. This type of ADCs have three elements, set of comparators, set of resistors and encoder logic circuitry. To understand the construction and working of a typical ADC, let us consider that we want to have a conversion of a signal maximum up to 10 volts into the digital binary output format. We want to convert maximum 10 volts into the digital output binary format which will be useful for the microprocessor. For that purpose, we are using 8 to 3 priority encoder.

To have the 3 output data lines, we need to have around 8 input data connections, 8 input data lines. The number of outputs required are 3 therefore, we are computing the number of comparators are $2^n - 1$ i.e. 7 and the number of resistor values are 8, number of reference voltages are 8. Here we can see the number of reference voltages are 1, 2, 3, 4, 5, 6, 7 and 10.

To understand the working principle of ADC, let us see what will happen if you want to convert the analog signal of 2.5 volts into its binary digital output. The 7 comparators which are having the op-amp as the basic units are joined in the fashion shown on the screen.

At the inverting input terminal; analog inputs are attached. The analog inputs are given at the inverting terminals. The non-inverting terminal is attached to the reference voltage and these reference voltages are computing based upon the final voltage that we want that is 10 volts.

It is decided that the first comparator will have the reference voltage of 1 volt, the second will have the 2 volts, there is increment of 1 voltage from the first comparator to the second comparator. Then, there is an increment of 1 volt and we are making it 3 volts, then 4 volts, 5, 6, 7 and at the last it would be increased by 3 to have the maximum value of 10 voltage for the conversion.

Now to have the increment of 1 volt; 1 volt as a reference volt, we are attaching 1 kilo ohm resistance value for each comparator except the last comparator. At the last comparator, we are attaching 3 kilo ohm as a resistor value. The reference voltages are attached to the non-inverting terminal and analog input will be given to the inverting terminal.

Now, let us see how exactly ADC is converting the analog input into the digital binary output. We are applying the analog input 2.5 volt. The input is applied to the first comparator. Here, the reference voltage is 1 volt. We are applying the analog input to the inverting terminal of comparator 1 here that is 2.5 volts. 2.5 volts is more than 1 volt so, the output from the comparator 1 would be of high level that is 1.

Now, the input will be passed to the second comparator. 2.5 volt will be given to the second comparator. At the inverting terminal of the second comparator, the input will be given that is a 2.5 volt, its reference voltage is 2 volt so, 2.5 volt is more than the reference voltage 2 volt, then we are getting the output as high level 1. This comparator is giving output 1, this comparator is also giving the output 1.

Now, we are going for the third comparator the 2.5 volt is further applied to the third comparator here. Its reference voltage is 3 volt. We are inputting 2.5 volts over here. Now, the input voltage at inverting terminal is less than the reference voltage 3 volts. Since, it is less than the reference voltage, the output at the third comparator would be 0, at 4th it would be 0, then so on and so forth all other comparators, the output would be 0.

Now, here we are getting 1 high-level output at second; second comparator and high; high-level output at first level comparator. We are using 8 to 3 priority encoder. This comparator we are setting at the least priority and the upper comparators we are setting at the highest priority.

Since, the lowermost comparator is having the least priority, the next comparator to the lowermost comparator that is a comparator number two which is having the high-level that would be considered and the high output at comparator number one will be ignored as we have seen in the priority encoder.

After giving the input to all the comparators, we are getting the output in this format 0000011. This 1 belongs to the comparator number one and the rest of the comparators are showing 0 output. Now, if we apply the principle of the priority encoder, we are considering the effect of this location only.

The effect of first location will not be considered. Accordingly, the encoder logic circuitry will convert the signal into the digital output signal based upon the truth table that we have seen earlier.

If D 2 is 1, then we are getting the output as 0, 1, 0; the same can be seen here based upon the truth table the binary output is 0, 1, 0. This binary output will be sent to the microprocessor for its further application.

In a similar way, we can solve a problem by considering voltage of 6.8. Let us consider this. 6.8 the analog input is applied at comparator number one, we are getting 1. It will be further compared at comparator number two output is 1. Here, the output is 1, here as well the output is 1 because 6.8 is more than 4 volts. Here again the output would be 1, here as well we are getting the output is equal to 1, but at this juncture, we are not getting any output it would be 0.

For D 1, D 2, D 3, D 4, D 5 and D 6 so, here the sixth comparator is giving you the high-level output that is 1. For that purpose, if you go back to the truth table, the D 6 is 1. If the D 6 is 1 and giving high-level output, then the effects at D 5 to D 0 would be ignored. In this case, we are getting the output as 1, 1, 0 binary digital output for voltage equal to 6.8 volts. In this way we can easily and simply convert the analog signals into the digital binary signals.

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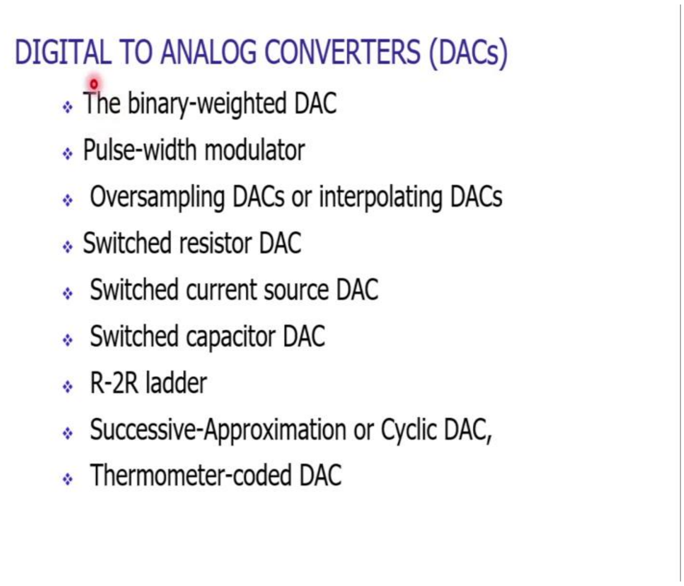

Now, let us see how we can convert the digital signals into the analog format. As we have seen that the microprocessors are generating the signals into digital binary format. But the actuators need the signals in terms of the analog format. To convert the digital signals into analog format, there are variety of devices, variety of configurations available.

Some of the configurations are listed. The first one is binary-weighted digital to analog converter, pulse-width modulator, oversampling DACs or interpolating DACs, switched resistor DAC, switched current source DAC so on and so forth.

In this lecture, we will be studying the binary-weighted DAC, how it is useful to convert the digital signals into its equivalent analog output signal.

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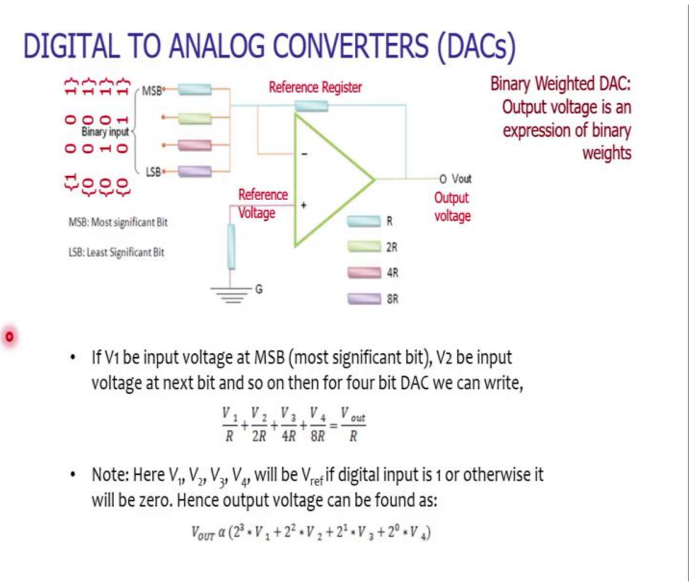

The electronic circuitry for digital to analog converter that is the binary weighted based digital to analog converter is seen. It is called as binary weighted because we are getting the output in terms of an expression of binary weights. The basic element of these converter is an operational amplifier.

The operational amplifier has the output voltage terminal and there are two input terminals. We are taking the feedback from the output and we are attaching that feedback to or we are giving that feedback to the inverting input terminal. This operational amplifier is used in inverting mode. In the path of feedback, we are attaching a reference resister to the non-inverting input terminal, the reference voltage is attached. At the inverting terminal, we are applying the input.

The input is in the form of binary number. The binary number will have the bits. Here, we are considering a binary input with 4-bits. In this case, the most significant bit is 1, then we are having 1 to the next bit, 0 to the next one and the least significant bit is 0.

This binary input is given to the inverting terminal through a series of resistors. The values of these resistors are shown. The most significant bit is attached with resistor value of R. The next one who is having less significance than the most significant one will have a resistor value of twice the R, twice of the resistance of the MSB.

The third one will be having the increase in resistance that is 4 times the resistance of the MSB and the least significant bit will have the maximum resistance attached that is 8 times of the resistor value. The most significant bit is attached to the least resistance value while the least significant bit is attached to the most resistance value.

Now, let us see how this binary weighted DAC is working. Now, if we take the example, as 1, 1, 0, 0 as the binary input, when the MSB value is 1 that is high-level input, then voltage belongs to the MSB will be the reference voltage. If V_1 is the voltage associated with MSB with resistor R, V_2 is associated with the resistor 2R, V_3 is associated with the resistor 4R and V_4 is associated with the LSB with 8R.

If the value of MSB is 1; that means, the voltage 1 will be the reference voltage. If the value of the second bit is 1, then the voltage of V_2 would be the reference voltage and that reference voltage will be amplified based upon the correlation of the reference resistor and the input resistor.

If V_1 be the input voltageat MSB (most significant bit), V_2 be the voltage at the next bit and so on, then for the four bit DAC we can write

$$\frac{V_1}{R}+\frac{V_2}{2R}+\frac{V_3}{4R}+\frac{V_4}{8R}=\frac{V_{out}}{R}$$

Here, the V_1 which is associated with the MSB (most significant bit) is divided with least resistance; which means, more priority is given to the most significant bit.

On the other hand, if V_4 is associated with the least significant bit, but it has been divided by the maximum resistance value; that means, we are trying to reduce the influence of the least significant bit in the conversion of the binary signal into the analog value.

Now, V_1, V_2, V_3, V_4 will have the reference voltage value if the digital input is 1 or otherwise it will be 0. V_1, V_2, V_3, V_4 will have the reference value voltage if the input is 1 otherwise it will be 0. Hence, the output voltage is proportional to the binary conversion of the input values of the voltages at the bits of the input.

Thus, $V_{out} \infty \left(2^3 * V_1 + 2^2 * V_2 + 2^1 * V_3 + 2^0 * V_4\right)$

V_1, V_2, V_3, V_4 will be the reference values if that corresponding bits are giving the digital input of 1. The proportional is written because the actual values will be dependent upon the gain of the operational amplifier and the gain is dependent upon the value of reference register and the value of the input resistors.

When we choose the appropriate values of input resistors and the reference registers accordingly, we can precisely compute the value of the output voltage based upon the signal given in terms of the digital input. In this way, we can easily convert the digital signals into the analog value and that analog value will be given to the actuators to carry out the desired purpose that is actuation of the devices.

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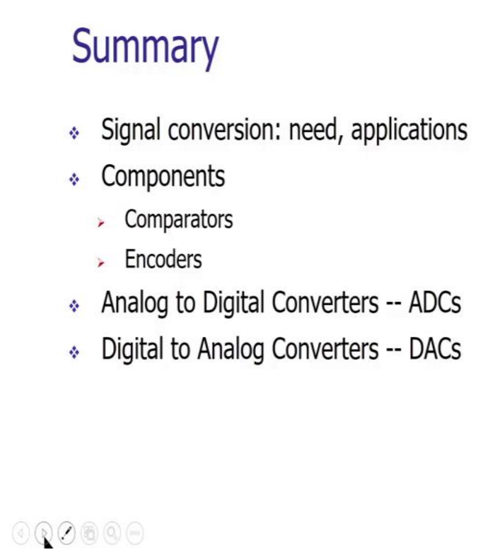

In this lecture, we have seen the signal conversion, its need an application in the development of mechatronics base systems. Various components of a typical signal conversion device such as comparators and encoders, we have seen how they do work and what are their applications.

Then, we saw how to convert analog to digital form of the signals and how to convert the digital format into the analog format. For that purpose, what are the various techniques that we have seen and at preliminary, we have discussed two techniques.

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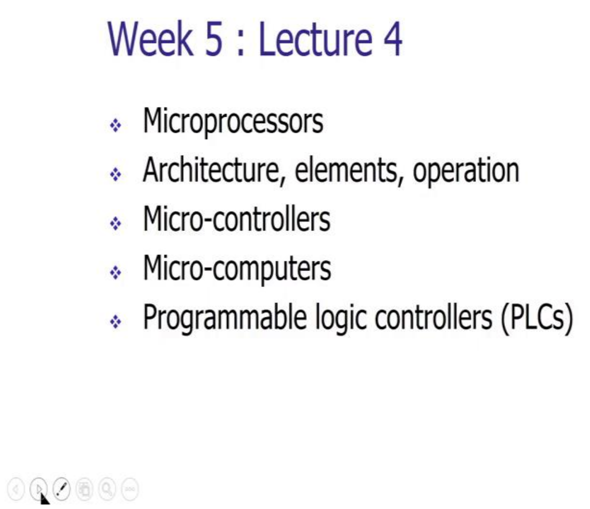

In lecture 4 of week 5, we will be studying the microprocessor technology that is the brain of a mechatronics based automated system. The definition of a microprocessor system, its architecture, it has variety of elements, we will see the functions of all the elements.

Then, we will study the meaning of a microcontroller, how the microcontroller is different than the microprocessor, what is the meaning of a microcomputer and at the end, we will see the PLCs that is programmable logic controllers which are often used in automation.