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Lec 22: Introduction to Digital circuits

I welcome you all to the session on engine systems and performance. Today, we shall discuss digital circuits. In the last few classes, we have talked about semiconductor devices, mainly diodes and transistors. We have seen that these two semiconductor devices are very important for modern electronic systems or circuits. In our previous class, we discussed the use of diodes as rectifiers to convert periodic or sinusoidal signals into DC signals.

We also discussed transistors, which are very important and have a few distinct advantages. Transistors are essentially used to amplify signals or currents and can also be used as switches. We also discussed the modes of operation of transistors. Today, we shall briefly discuss digital circuits. This is itself a subject, but in the context of engine systems, we have seen that the electronic control unit or engine management system is essentially housed with a few electronic circuits. To operate the engine smoothly—or rather, to operate it under optimal conditions to reduce emission levels and maximize efficiency—we need a very efficient electronic control unit or engine management system. So, what is a digital circuit?

Basically, digital circuits are formed from binary circuits, which are circuits whose output can have only one of two different states, typically 0 and 1. These two states are indicated by a specific current or voltage. You have studied digital circuits in your basic electronics course. Today, we shall note a few important points essential for any system engineer to improve engine control systems. Let us list those points first, and then we'll discuss them.

As I mentioned earlier, Digital circuits are formed from binary circuit. and this binary circuits are those circuits or are the circuits whose output can be only one or two different states. And these two different states are indicated by a particular value of current or voltage. if I write here these two states typically 0 and 1 are indicated.

So, basically on and off. So, we shall see are indicated by 0 means off, 1 means on. So, 0 and 1 these two numbers. So, these two states are indicated by a particular voltage or current.

But now let us write a few points of this particular circuit. So, we have seen in digital electronic circuit transistors are used as a switch. We have studied in our previous class that transistors can be operated in three different regimes which are cut-off, active or linear and last one is the saturation. So, if the transistors are operated both in cut-off and saturation regimes then transistors can be used as a electronic solid state switch that is what we have discussed in the previous class that is on and off. In electronic digital circuit transistors are used as a switch if we need to use transistors as a switch essentially transistors will be operated in cut-off and saturation resistance. So that means from here we can write transistors will be operated cut-off and saturation regimes. That is on and off. If it is cut-off, off. If it is saturation, on.

So that is switch. It is acting like a switch. As I told you in the previous class that, even a small base current, that is base to emitter, current flowing from base to emitter, beyond a threshold value, even if we increase the voltage in this base emitter circuit, that will increase base current and even if you increase base current beyond a threshold value the increase in collector current will be very minimal because this is the resistance should be very high that is between this collector to emitter that resistance is very high. So, it is saturated.

So, now no further current can be increased. So, it is on just on. So, this is saturation reasons. We know that saturation means when transistor is saturation very low resistance. So, as I said you that a further increase in I_B will not increase conduction collector current I_C.

That is, it is saturated. So, cut-off, so when transistor is in cut-off regime, certainly you can understand resistance is very high. As I told you that if the voltage that V_B that is base emitter circuit if the voltage is less than 0.7 volt, it is not possible to break the barrier that will form when p-type, n-type junction will reach at equilibrium.

So, the resistance is very high. When transistor is in saturation, you can understand the resistance is low. So that is why huge current will flow from collector terminal to emitter terminal and of small, even an increase in base emitter current will not allow to increase collector current significantly. So that is the saturation.

So that is what we have learned. Now the question is, in digital electronic circuits, the control input to the transistor because the transistor will be acting as a switch. So, the control input to the transistor switch will be capable of running the transistor, or the control input to the transistor should be capable of running the transistor either in off mode or in the saturation mode, that is, on mode. It will not allow the transistor to run in the active or linear region, so that is very important.

So, let me write here, in fact, that in digital electronic circuits or digital circuits, the control input to the transistor switch must be capable of running the transistor either in off mode or in the saturation mode without allowing the transistor to run in the active or linear region. That is very important. Now, digital circuits, as I had written before, digital circuits are formed from binary circuits. So digital circuits function by representing various quantities.

So digital circuits, which are formed from binary circuits, and binary circuits are the circuits which can only be in one or two different states, typically 0 and 1, and these two states are indicated by two particular values of current and voltage. So, these digital circuits function by representing various quantities numerically, using a binary number system. So that means digital circuits can operate by representing various quantities numerically. Digital circuits will understand different or various quantities numerically by using binary numbers. So, whenever we are trying to send some signal to the digital circuit, the digital circuit will understand these two numbers. Various quantities may be signals, may be any current, whatever it is, any input quantities. The digital circuit will understand and then it will function by representing quantities numerically using the binary number system. So, then we have to understand a bit about the binary number system.

So, in a binary number of systems, all numbers are represented by using only the symbols, symbols 1 (one) and 0 (zero) arranged in a form of a place position number system. We shall discuss this, take an example.

So, in a binary number system, all numbers are represented by using only symbols 1 and 0. So, two states, it is called binary two states, 0 arranged in a form of a place position number system. In electronic digital circuits, electronically these symbols can be represented in transistors either in switch off and on, that is cut-off and saturation level.

So, if I write here again electronically, these symbols can be represented by transistors in either saturation or cut-off. So, that is very important. So now you can understand the need for transistors in digital circuits. A few minutes back, we said that transistors are used as switches.

So, between, just to have on and off modes. So, we can understand that in the binary system, all numbers are represented using only two symbols, that is, one and zero, arranged in the form of a positional number system. And these symbols can be represented electronically by transistors in either saturation or cut-off.

So, that is what we have understood. So, if you go to the next slide. Now, we shall discuss today about digital systems. Digital circuits, we will take up an example, but before discussing digital circuits, let us discuss the binary system, let us review a few things. So, binary numbers. If we need to discuss digital circuits, it is instructive to review the binary number system first.

So, we will discuss the binary number system briefly. So, binary number So now, as I told you, the binary number system uses two digits, 0 and 1, it is called a base-2 system. Basically, the binary number uses 2 digits and it is called a base-2 system.

The decimal system uses, 10 digits (0 through 9), and is called, a base-10 system. So, basically, what we can see is that the binary number uses two digits, 0 and 1, and it is called a base-2 system. And we have seen, basically, the decimal number system, which is 0 through 9, and it is called a base-10 system. So, what we can do now is take an example to discuss this part. If we go to the next slide, so if we write

$$(1010)_2$$

So, this number is a base 2 or binary number. This number is a base 2 or binary number and if we write

$$(1010)_{10}$$

So, this is base 10. Number is a decimal number means the number is a base 10 or decimal number. So, this indicates number is a base 10 or decimal number. So, let me clarify this part.

So, this is base 2 of this number. Now, question is we will take an example to see how we can write this any numerical number in the form of 0 and 1 that is binary numbers. So, that we will write.

So, conversion of decimal to binary with the help of an example. So, say for example why do we need to do it? So, whenever digital circuit will understand the binary numbers that is what we have been discussing today. So, essentially digital circuit will understand 0 and 1 that is the transistor will help switch because transistor will be acting as a switch.

So, it will operate in cut-off and saturation regimes. So, 0 and 1. So, any decimal number has to be converted into binary number to allow digital circuit understand. So, let us take an example for the conversion of this decimal to binary number.

So, take an example. So, conversion from a decimal to binary number. So, we take decimal to binary with the following example.

So, if we take this example let us say 50 base 10. So, as I said you if we take this example 50 is a number base 10. So, following our previous discussion this is a number base number is a base 10 or decimal number. Base 10 is decimal number because it has numbers if you go to the previous slide 10 digits 0 through 9.

So, to convert it into binary number let us write like this. So, the what is if we write 50. So, this is a base 2 number. So, divide it 2 then we will be having 25, if we try to write the remainder is 0 then 25 by 2. It is having 12, remainder is 1 then 12 by 2, 6, remainder 0, 6 by 2 equal to 3, remainder 0, 3 by 2 that is 1, remainder 1. So, that is what we can write. So, we can write. So, now the equivalent form of the binary number should be 50 by 2 we have to base 2 system. So, binary number is a base 2 or binary number.

So, divide by 2, is 25, no remainder, 25 by 2, if it is 12, then remainder is 1, 12 by 2, 6, remainder is 0, 6 by 2, remainder is 0, and then 3 by 2, remainder is 1. So, essentially if we write this, so if we write remainder 0, then 1, 0, 0, 1, and then this is 1, because 2, it is base 2, 1. So, this is basically base 2 number. because we have used 2 to divide all this.

$$(50)_{10} = (110010)_2$$

So, the first remainder is 0, the second remainder is 1, the third is 0, the fourth is 0, the fifth is 1, and then 2, which is 1. So, this is the binary conversion. Now, let us recheck whether we could really represent 50, which is a base 10 number—that is, a decimal number—as a binary number. So, this is basically, if I take this So, this is the 2^0 position, this is 2^1, 2^2, 2^3, 2^4, and this is 2^5.

So now, if we write

$$= 2^5 \times 1 + 2^4 \times 1 + 2^3 \times 0 + 2^2 \times 0 + 2^1 \times 1 + 2^0 \times 0$$

$$= 32 + 16 + 0 + 0 + 2 + 0 = 50$$

So, that means using this method, we could write a decimal number as a binary number. So, this is the method by which we can convert a decimal number into a binary number, because we need to convert binary numbers; otherwise, digital circuits will not be able to understand the inputs, as they can only have outputs. As, 0 or 1. So, this is the method. Now, the very important part is the manipulation of all these numbers—we need to perform multiplication, subtraction, division, all these things.

So, digit, that is bit in digital systems, this binary digit or binary bit, these manipulations are done very easily using some logic gates. So, we'll briefly discuss about a few logic gates. So, digital systems, it can be computer also, perform binary digit (bit) manipulations very easily by using three logic circuits or gate.

we need to manipulate. We need to go for multiplication. We need to go for division. All these things, all these manipulations are done very easily by the logic circuit. So, we shall be discussing all these circuits one by one.

The first is logic circuits or gate. So, we shall be discussing about an AND gate. These three gates are: first is AND, number two is OR, number three is NOT or inverter. So, for all these three gates truth travel is used to describe what combination of input will produce a particular output. So, we shall be using this truth table.

So, let us discuss these three logic gates briefly. So, the first logic gate is AND. So, the AND gate, if we write it symbolically, AND gates are like this. So, the output is Y. It has two inputs, say A and B, and this is the AND gate. So, the AND gate, what we can see is that it has at least two inputs and one output. So, basically, if we go to the truth table, so A, B, and Y. Thus, the feature of this particular gate is that the output is high (1), because it has only a base-2 system with 0 and 1. So, the output is high when both inputs are high (1). If either or both inputs are low.

The output is low. So, that means if we erase this and write the truth table here, that is A, B, then Y as the output. So, when both inputs are high, so if it is 0, if it is 0, then 0. If it is 1, 0, then also 0. If it is 0, 1, then also 0. If it is 1, 1, then also 1. So, that is the output, truth table. Either or both inputs are low, that is low means 0.

So, if go to the OR gate. if we write the schematic OR is, so this is Y again it if we have two input A and B output is Y, this is OR gate.

So, OR gate it has at least two inputs and one output. So, a few points about this particular gate. So, output is high. that is 1, when one or any both inputs are high (1), and the output is low (0), when both inputs are low (0). So, if we now write the OR. Construct, the truth table we will be getting like this: A, B inputs, and the output is Y. So, what we can see from here is, when both inputs are low, that is 0 0 0, 1 0 1, 0 1 1, and if it is 1 and 1, then also 1. So, the output is high when 1 or both inputs are high.

So, both inputs are high, so 1, 1, that is 1. So, this is the truth table. So, now, if we have the NOT gate, that is the last one, NOT, so symbolically it is shown like this. This is A. The NOT gate is a logic converter. The NOT gate is a logic inverter. So, if it has one input, it has one input and one output.

So, we can see it has only one input A and output is Y. Now, if the input is logical 0, so let me write a few points. If the input is logical 1, the output is logical 0, and if the input is logical 0, the input is logical 0, the output is logical one. So, this is the NOT gate, and if we construct the truth table, then we have A and Y. So, when A is 1, this is 0; when A is 0, this is 1.

So, this is the NOT gate. So, we have discussed three important logic gates. These logic gates are used for binary number manipulations in digital systems. Now the question is, the last part of this lecture should be the representation of the equivalent digital form of this binary system.

So basically, we have discussed OR, AND, and NOT—these three gates. In fact, there are many others: XOR, NAND, and also NOR. So, all these gates are very useful in the context of digital circuit configuration, and I am not going to discuss all of them. If you need to know more about it, you can consult any basic electronics book. So, just to give you some ideas, we need to have an equivalent form of any logic gate.

Ideally, we should discuss or you should know about the equivalent form of all three logic gates we have discussed, but in today's class, I will discuss only the OR gate and its electronic equivalent form. The electronic equivalent forms of all three gates are important to know—that is the digital representation—but we shall discuss only the equivalent electronic form of the OR gate. So, as such that whenever any signal is received by a sensor, it is analog. Analog is basically continuous, but whenever we convert analog to digital, ADC is discrete.

So, there must be some quantization of noise. So, noise should be eliminated. Isn't it? Because any analog is continuous, but essentially digital is discrete, 0, 1 or some numbers. So, 0 and 1, so discrete.

So, this, there will be some, it is not possible to have equal conversion of this continuous information to the discrete information. So, there must be some quantization of the noise, but noise should be eliminated. That is very important that we have discussed so many times. So, let us discuss about discrete OR gates. So equivalent or electronic equivalent of OR gate.

That is what we should discuss. So, as equivalent electronic circuit discrete, analog is always continuous, but OR is, this is discrete. Basically, we are having zero and one. So, this discrete OR gates may be realized by using diodes and transistors.

So, that is an electronic circuit. So, discrete OR gates may be realized by using diodes or transistors. We had seen that first, switches, this utility, we can use transistors. The use of transistors for logic gates depends on the utility of first switches. So, first, we consider, diode-based equivalent circuits. The number one is Diode-based equivalent electronic circuits, and later on, we will be discussing transistors. So, the use of transistors for logic gates depends on the utility of first switches. That depends upon their utility.

Transistors can be used as logic gates based on or depending on their utility as first switches. So, diode-based and then we should discuss transistor-based equivalent electronic circuits. We are discussing all these because we need to know essentially that the signal we will be receiving from different parts of the engine is an analog signal. That signal should be converted into a digital one, that is, in the form of 0 and 1. Then, this digital circuit will give some input to all those parts again to adjust so as to operate the engine always at its optimum condition.

So, if we write the diode-based two-input diode gate. So, first is two-input diode OR gate. So, let me draw the circuit with two diodes. So, this is D_1, and we have another diode, D_2.

So, then is grounded if it is resistor R_L, and this is Z. So, if we have X and Y. So, these are the inputs, and the output is Z. So, inputs may be either 0 or 5. So, a base-2 system uses 0 and 1: 0 is used to represent 0 volt, and 1 is used to indicate 5 or 3.3 volts.

So, these two inputs would be 0 volt or 5 volts and we are having this electronic equivalent circuit. Let us revisit whether we are getting the same truth table or not. So, in the diode OR gate, when both inputs are the same—say, 0 volt, then both diodes are off, then are off, and the output will be 0. So, if both diodes are off, no current will flow, and the output will be 0.

So, when both diodes are off no current will flow. So, output is 0. So, and there will be no voltage drop when both inputs are 0 volt. Output will be 0, but when both inputs or either of the inputs such as X and Y are equal to 5 volts.

So, when both, any or either the input such as X and Y are equal to 5 volts, then the corresponding diode if it is X is 5 volts, then D_1 will be in active mode. If Y is 5 volts, then D_2 will be in active mode. And if both are 5 volts, then both diodes will be in active mode.

That is what we can see from the circuit. So, when then corresponding diodes are both are on state, so voltage across, so either or both diodes are at ON state right and net voltage across R_L resistance that R_L that is what we have here R_L will be 5 volts. So, output will be 5 volts (1), logic 1 state.

So, that means we can see if both are 0, it is 0 if any one of them is 5 or other one is 0 or both are 5 then output is 5. So, that is 1. So, that means we could retrieve the truth table that we have discussed few minutes back. If both of them are 0, inputs are 0, then output is 0. So, 0, 0, 0.

If either of the input is 5 volts or both inputs are 5 volts, then voltage across R_L will be 5 and output will be 5. For all these cases, then that is the logic one state. So, it is 0. 0, 0 then 0, if it is 0 and 1 then also 1. 1, 0 is also 1. 1 and 1 is also 1. So, basically it could retrieve the logic state. So, this is the equivalent representation of the electronic equivalent form of the logic gate and that is the OR gate that we have taken for today's example.

So, with this, if we would like to summarize, we would like to summarize our today's discussion. We have discussed about the digital circuit. We have discussed a bit about digital circuits. And then we have discussed about binary number system. We have discussed three important logic gates. And finally, we have discussed the electronic equivalents of all logic gates. So, with this, I will stop here today, and we shall continue our discussion in the next class.