Introduction to Electronic Circuit
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Lecture 39
Digital Circuits

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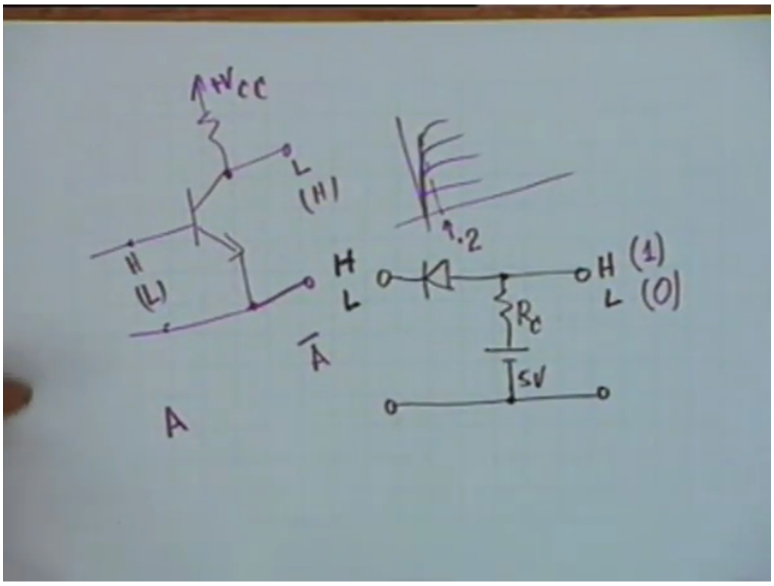

39^{th} lecture on digital circuits we shall not be able to do much of digital circuits and we will learn a bit of Boolean algebra in the last 2 lectures 39 and 40 but the basics only. All you have seen is that a diode as well as the transistor can act as a switch and a diode circuit is, if you have a diode like this with let say a resistance and a battery, let say 5 volt battery and some resistance R sub C then we have shown in the previous class that if this is higher than 5 volts then this will also be high.

Whereas if this is low that is less than 5 volts then this diode shall come back and if this diode is ideal that will be 0 volt drop and that shall also be low. A high-level is characterized by a digital or Boolean 1 and low-level is given the status of Boolean 0, logic 0, 1 and 0 error philosophical interpretations of this, in fact the Boolean logic arose in philosophy to start Western philosophy.

One is for true, 0 is for not true or false but in our context since a circuit is either on or off that is a voltage level at each point the digital circuit is either high or low. If it is high its term status 1 if it is low its term status 0. The low-level can have a range of let say 0 to 0.6, the high-level can also have a range may be between 4 and 5.5, right and therefore the exact level is not important, what is important is whether it is high or low.

In a similar manner if we take a transistor circuit, a transistor then you know that if VBE, if this voltage is high then this voltage shall be low, if this is high then the transistor we conduct heavily the collector current will be large and therefore this voltage will be VCC minus the drop in the collector resistance and therefore this voltage shall be low and if we overdrive the transistor then we shall be operating in this region of transistor characteristic which is the saturation region and this voltage is usually taken as 0.2 for silicon and therefore a low-level for a transistor switch is approximately 0.2 volts.

On the other hand if this voltage is lower than 0.7 the threshold than the transistor does not conduct and therefore this voltage shall be high. If the transistor does not conduct then the total VCC shall appear at this output point and therefore the voltage shall be high. You notice that there is an inversion in the transistor circuit that means the input is high and output is low, if the input is low the output is high.

And in general if the input is denoted by the Boolean variable capital A and the output is the compliment of A, that is if this is high then this is low, if this is low then this is high, capital A can take on, a Boolean variable can take on 2 values either 0 or 1, this is a basis of digital circuits and all that you see in the modern world, whichever walk of life you are in computers are mass, computers operate with these 2 basic components.

There are modifications to make the switch in speed that is from low to high, switching speed large or small interconnections length also decides whether switching should occur properly or not those are matters of (()) (5:32) and the decision circuits are made in the form of chips very small, they occupy very small space and therefore they are very popular and the other reason is the accuracy. Accuracy, that is the actual voltage (()) (5:47) there is important, what is important is whether it is low or it is high.

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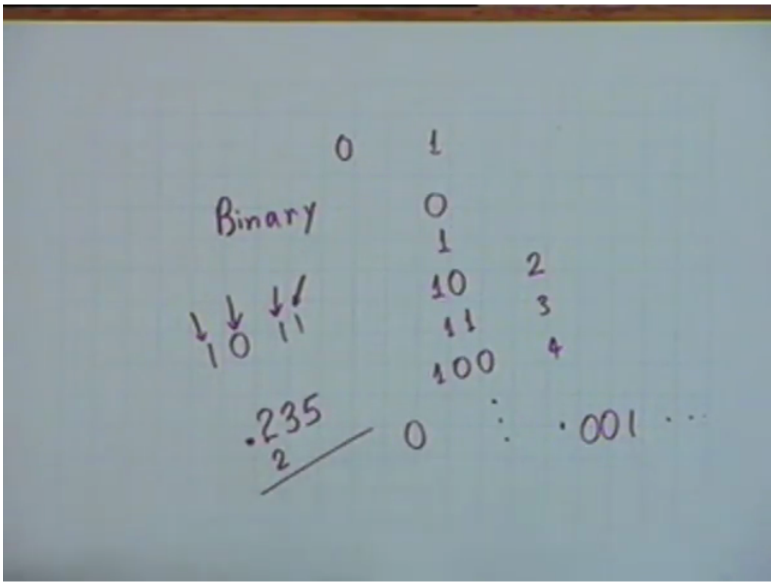

Naturally the arithmetic that is to be used for analysis and synthesis of such circuits because there are only 2 levels 0 and 1, the most eminent kind of mathematics is the binary arithmetic. The binary arithmetic in which there are only 2 digits namely 0 and 1 therefore decimal 0 is 0, decimal 1 is 1, decimal 2 phase 10, decimal 3 is 11, decimal 4 shall be 100 and so on, okay.

And you know how to convert a given binary number into a decimal number, alright. A given binary number for example 1 0 1 1, what you will do is multiply 1 by 2 to the 1, 0 by 2 to the 2 and 1 by 2 to 3 and add all of them that is the binary. Giving a decibel number let say 235 to convert it into binary you know what you do, you go on dividing by 2 and note down the remainders then you arrange the remainders in the reverse fashion.

On the other hand if this is a fraction let say 0.235 you go on multiplying by 2 and collect the carries and not the remainders, collect the carries for example the first multiplication will give a carry of 0, second multiplication also shall give a carry of 0, third one 1 and therefore this would be 0.0 0 1 and so on.

For converting a decimal fraction to a binary fraction the carries are arranged as they appear. On the other hand if it is an integer number, if it is an integer number then the remainders are arranged in the reverse order, okay.

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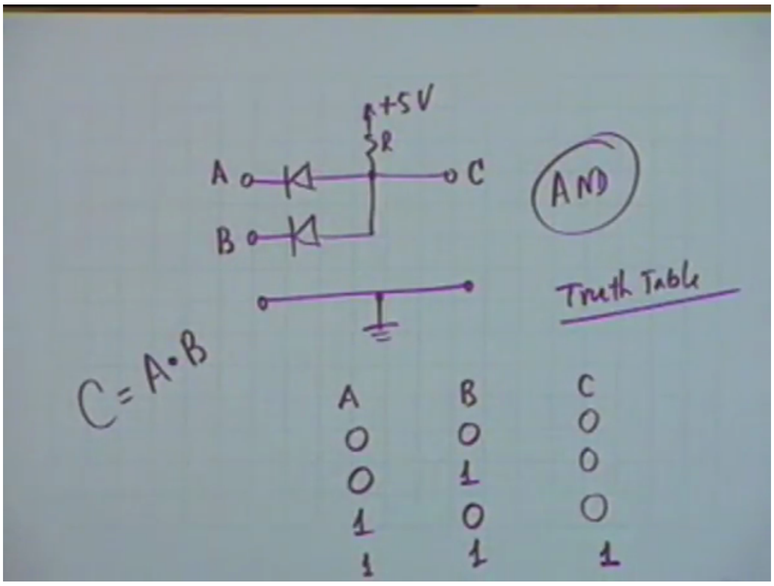

These are known to you, most of the discussion that we are doing today, in fact are known to you and if we arrange 2 diodes like this and this is connected to plus 5 volts through a resistance R, alright. Then obviously there is a ground because voltages have to have 2 terminals, voltage is a potential difference has to have 2 terminals. This 5 volt battery has a ground then you see that if the state of this input is called A.

And if the state of this input is called B then the state of the output which we shall call C shall be determined the states of A and B and you see that C shall be high then both A and B are high and this is represented by the so-called truth table as you already know and the possibilities are capital A and B both can be 0, this can be 0 1, this can be an 0 or this can be 1 1 these are the only 4 possibilities, alright.

And C is high only when both are 1, so all the rest must be 0 and this in terms of Boolean algebra is represented by C equal to A and B this is called an AND operation and this is an AND circuit and this is usually represented by A dot B, dot stands for the AND operation but for brevity when you have to write it again and again we usually omit the dot, alright. Even if it is omitted when A and B are written at adjacent to each other it means that A is ended with B, alright. This is the AND operation.

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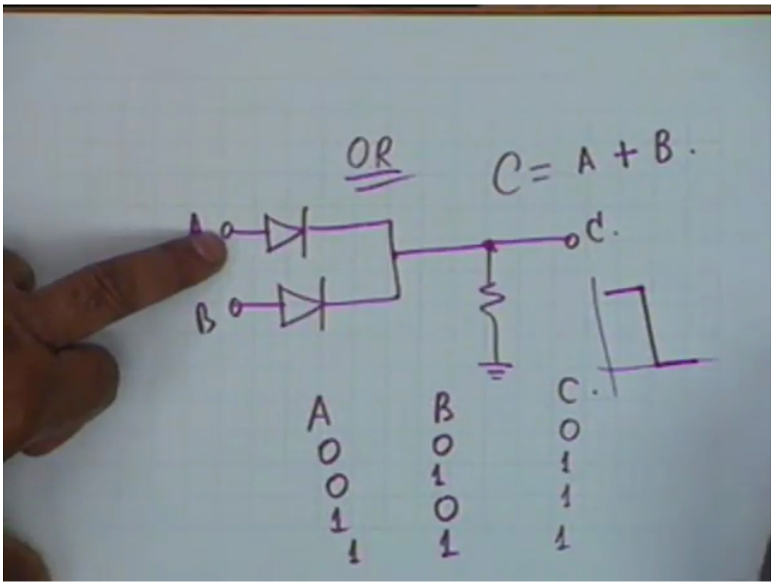

This is one of the basic logical operation, the second basic logical operation is OR and the circuit is very similar except that the diodes are reversed and there is a battery needed, there is simply resistance needed this is C, this is A and this is B and you can see that C shall be high either A or B is high when A is high diode is the short-circuit, A this diode is a short-circuit irrespective of what this diode is and the high voltage appears across C.

Or when B is high then this diode conducts it is a short-circuit, so the high-voltage appears at C. When both of them are high there also it is high but if both of them are low then obviously C shall be at 0 potential that shall be low and therefore the truth table is, once again the possibility of the variables are 0 1, 10, 1 1 and the output shall be 1 when either or both are 1 and therefore this is the only situation in which it is 0 and all others are 1.

And in terms of Boolean algebra this operation is represented by the plus sign. Now we cannot omit the plus sign, okay. This plus stands for logical or operation, so it is A or B and this is simple diode logic, usually one does not use diode to realize such case one uses transistors and in various kinds of families the most popular family at the present time is the MOS family metal oxide semiconductor that which we have not discussed in the class.

Metal oxide semiconductor because they occupy the least amount of space but as far as speed is concerned, now speed is important here for example if A is high, alright. Then C is high, suppose from high A reduces to 0, how quickly C can follow this operation? Obviously it cannot, why? How quickly C can follow? Because if A is high then the diode conducts which means that the, what does diode contention mean?

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It means that the space charge barrier, the charges come close together, alright. So the diode conducts, now as soon as the voltages withdrawn cannot recede instantaneously the take some time, alright. And this time determines the so-called speed of operation or the speed of the circuit and in high-speed digital computers as they are at the present time diodes logic is out of fashion, diode logic cannot be used. We are using it simply to illustrate the basic circuit, to understand the phenomena of the OR operation.

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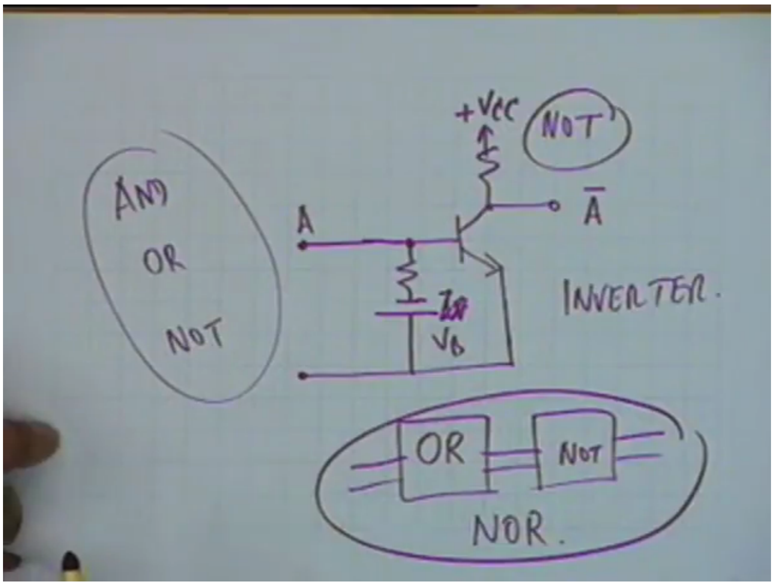

And the third basic gate, first is AND, second is OR and the third basic gate is the NOT gate or the inverter which is simply a transistor in which in order to make sure that a low voltage and there is no ambiguity in the low or high operation, what we do is besides R sub C what we do is we use a resistance here and biased the base negatively, alright. Maybe 1 volt is good enough, alright.

So that only when, while usually this is also set at the same value as plus VCC, alright. We will call this VB some voltages VB but then you see this voltage has to overcome the negative voltage in order that without conducts, alright. And as I have already told you if this is A then this is A bar and this is called NOT gate or an inverter. One can make a combination of these 3 basic gates that is AND, OR and NOT to be able to derive more complicated gates.

You understand why we are called gates because they either allow high-level to pass for the do not allow, so they are called gates logic gates or digital gates, alright. One can make combination of this for example if an OR is followed by NOT. Well, the operation is NOR, alright.

“Professor -Student conversation starts”

Student: (()) (16:00)

Professor: (()) (16:01)

Student: (()) (16:04)

Professor: Yes okay so this kind of circuit drawing will not be valid in the case of digital circuit, we will have to give symbols this is why I drew it to be able to create confusion. This will not hold in the case of digital circuits we must draw a symbol we must indicate the number of inputs. For NOT gate there is only one input and there is one output and therefore this type of circuit shall not be valid.

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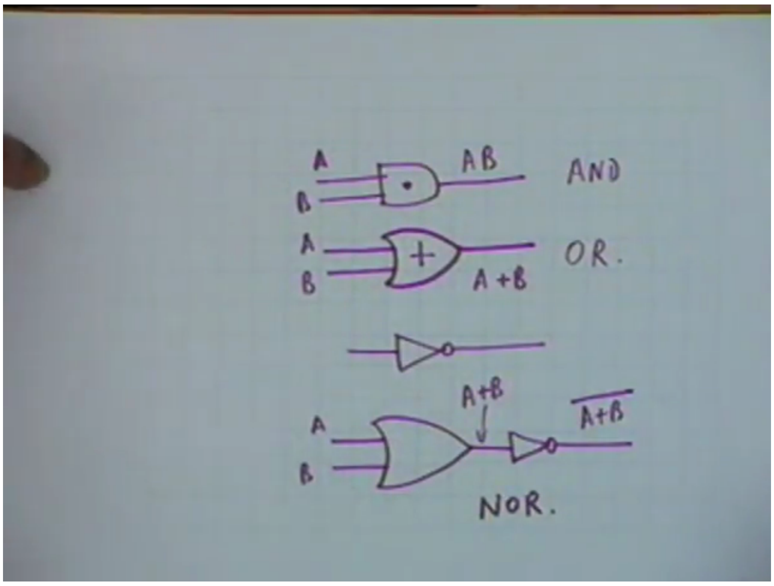

Our universal representation or I triple E representation is for an AND gate this is the representation, this is AND, to make it specific that this is AND sometimes a dot is put here, sometimes it is not needed. For an OR gate the input line is curved and the 2 sidelines are also curved and there are 2 inputs this is called an OR gate. So if this is A and this is B then the output is the ANDED form of A and B.

Whereas in the OR operation to make it specific that is OR sometimes plus sign is put but whenever you see the peculiar shape, well you know it is an OR and if this is A, this is B than the output is A or B. For a NOT gate one input and one output and this is usually represented by a triangle.

A triangle is used for amplifier in analogue circuits, in digital circuits it represents an in water triangle with a dot, this plot represents complementing or inversion, alright. And gate shall be represented by NOR an OR, to start with it takes 2 inputs AB and then an inverter. So this is A or B and this is A or B compliment.

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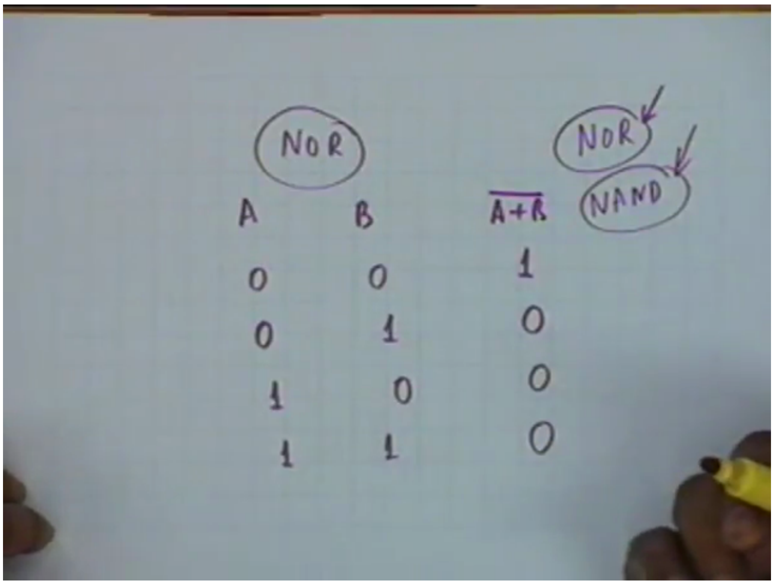

This is a NOR gate and naturally for a NOR gate the truth table shall be AB and then A or B compliment, it will be simply the compliment of the truth table truth of the OR gate for example 0 0 shall give you 1, 01 shall give you 0, 1 0 shall give you 0 and 1 1 shall give you 0 this is the NOR gate, alright. I must mention here that in modern integrated circuits the manufacturers do not make all the 3 kinds of gates.

A particular company usually makes only one kind of gate it's either NOR or NAND. A NAND is AND followed by a NOT gate and the argument is, the logic is that the production of 3 different or 4 different kinds of gates is much more costlier than producing the same gate maybe 4 times or 5 times because each process step in integrated circuit technology, each process step variation costs you a lot of money, alright. And therefore fabrication companies before either to manufacture NOR or NAND.

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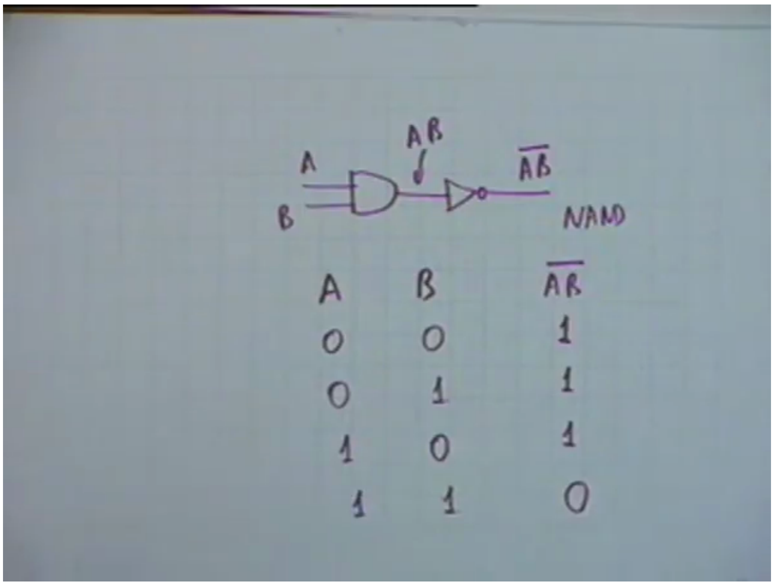

However there are companies which manufacture both NOR as well as (()) (19:50) gates. Okay a NAND gate as I said is an AND with 2 inputs A and B followed by a NOT, this is AB and this is AB bar, this is a NAND gate and the truth table can be written as the compliment of the AND that is 0, 0 shall be 1, 0 1 shall be 1, 1 0 obviously shall be 1 and 1 1 shall be 0, okay.

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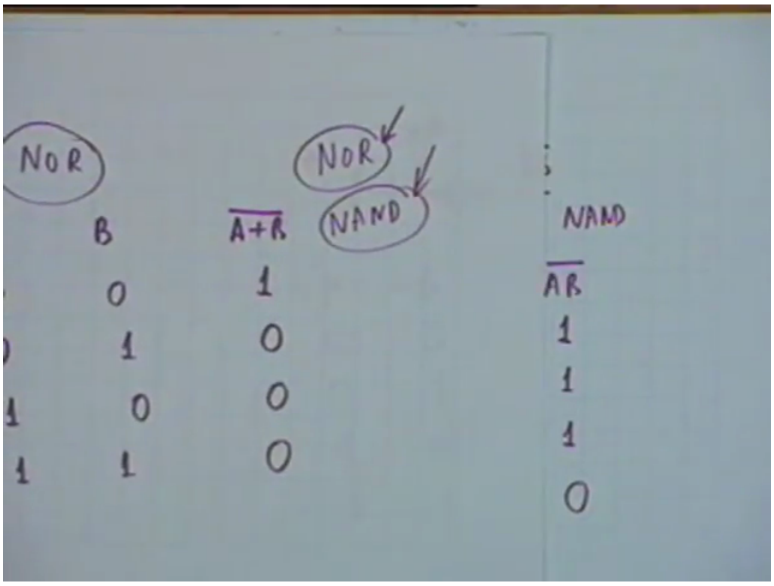

If you compare the NOR and the NAND, do not you see a similarity? Yes or no? 0 0 is the same, no there is no similarity, there is no complementarily either nor a NAND but nevertheless one can revise a NOR function if you have only NAND gates.

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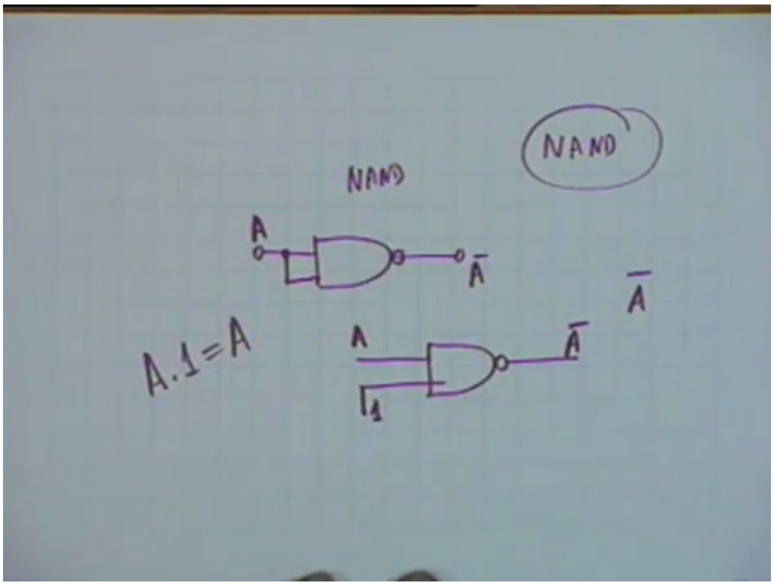

In fact it can be shown and you try this out this must be several tutorial problems in the textbook that given a NAND gates you can realize any other gate including a NOR gate. For example if you want to convert a NAND into let say inverter not gate all that you do is.

“Professor -Student conversation starts”

Student: (()) (21:26)

Professor: You connect the 2 inputs together, alright. Then this is A and this is A bar, is there any other way that I can make it? I have a NAND gate I want to make an inverter.

Student: Using only one.

Professor: Yes you see only one (()) (21:49), this is my input A, what should I do in the other? One of the ways is I connected to A, pardon me. Even 1 here then A and 1 is A and pardon me. A and 1 is A, alright that’s it and therefore the output shall be A bar. This is another way, alright.

“Professor-Student conversation ends”

There are alternatives also but anyway the point that is interesting is it only one type of gates suffices to realize any other function.

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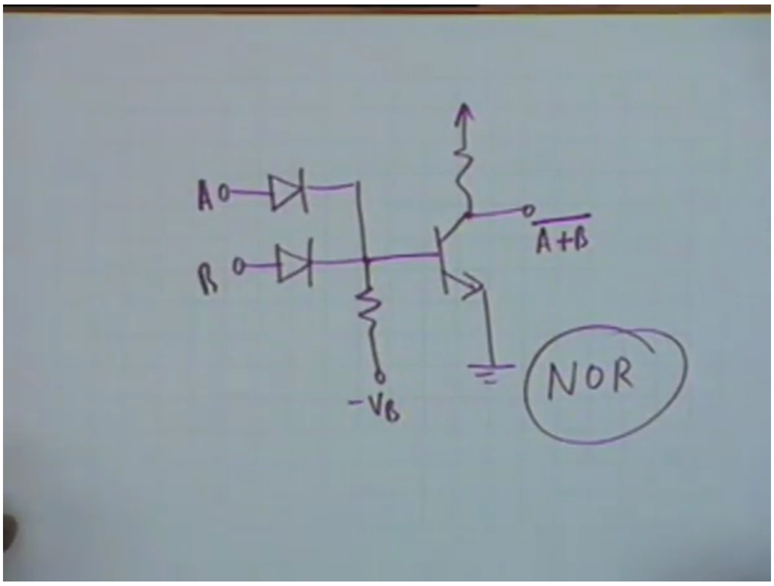

And before I go further let us see the NOR gate the circuit shall be first in odd minus VB and then a NOT, did we say NOR or A or B, if either was high then this will be high therefore this will be low, yes, this is the output shall be A or B complimented. Given a circuit you must be able to detect what kind of a gate is this, this is an NOR gate alright.

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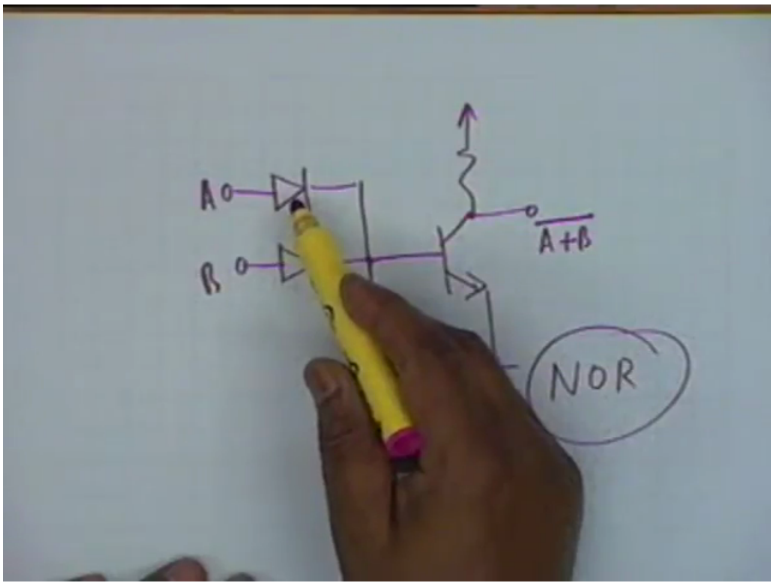

On the other hand if I want to make NAND all that I shall have to do is to reverse 2 diode polarities, alright.

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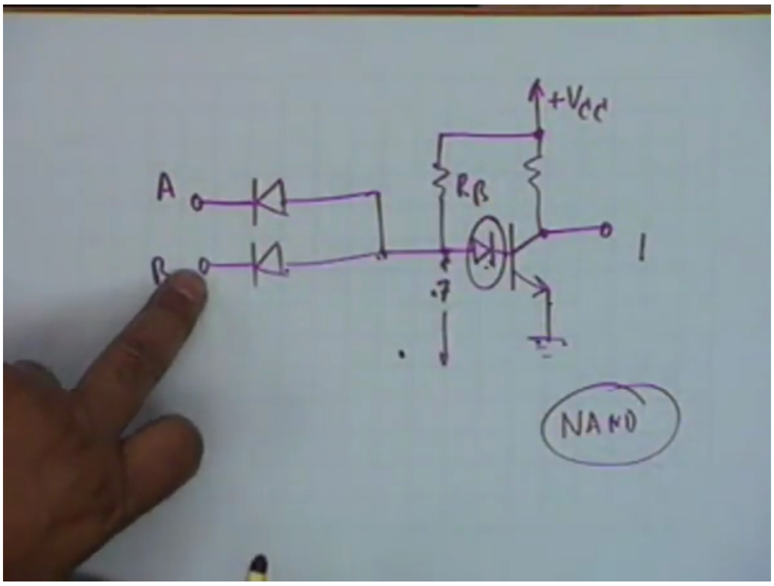

Let see this AB then do I need a negative bias here? No, I need, let me draw the circuit then I will tell you why it is so, RB then this requires a little bit of experience to appreciate why it is so and this is connected through a diode, the base is connected; this is the practical circuit for a NAND gate. Now why are all these paraphernalia needed? Why a diode and RB needed? You see when both recede is a NAND gate, when both A and B then the 2 diodes do not conduct, alright.

And therefore VCC through RB and this diode drives the transistor and the output shall be high or low? Low, the output shall be low. When A and B are both low when they are both low what happens is, both low or one low it does not matter, right? One of them low then this becomes approximately connected to ground, if it is an ideal diode than it is 0 voltage drop, if it is nonideal as is the case in practice it is a practical diode then there is simply a drop-off 0.7 volts.

Now if this diode was not there then these transistors are conducted because 0.7 is the voltage required here this is why another diode is inserted, so that when this voltage is 0.7 this combination requires 1.4 volts to be able to conduct, is not that right? 0.7 here and 0.7 here, so it makes sure this diode, you must understand the function of this diode, this diode makes sure that when one or both of these diodes conduct that is when A is low or B is low or both low the transistor does not conduct and the output is indeed high. Transistor does not conduct and so the output shall be high, is the point clear? Why a diode is needed here? It was not needed in the NOR circuit, alright. So this is a NAND circuit.

“Professor -Student conversation starts”

Student: Sir the diode network is there.

Professor: Yes.

Student: Would it have deducted?

Professor: yes, if the diode was not there and this is low then this would have conducted this diode and because it is a practical diode the drop across the (()) (26:45) approximately 0.7 and if this droppage 0.7 from here to ground obviously transistor would have conducted we want to make sure that it does not conduct, so you put another diode it will require 1.4 volts and for this diode to conduct we require 0.7 and therefore the diode indeed is needed.

“Professor-Student conversation ends”

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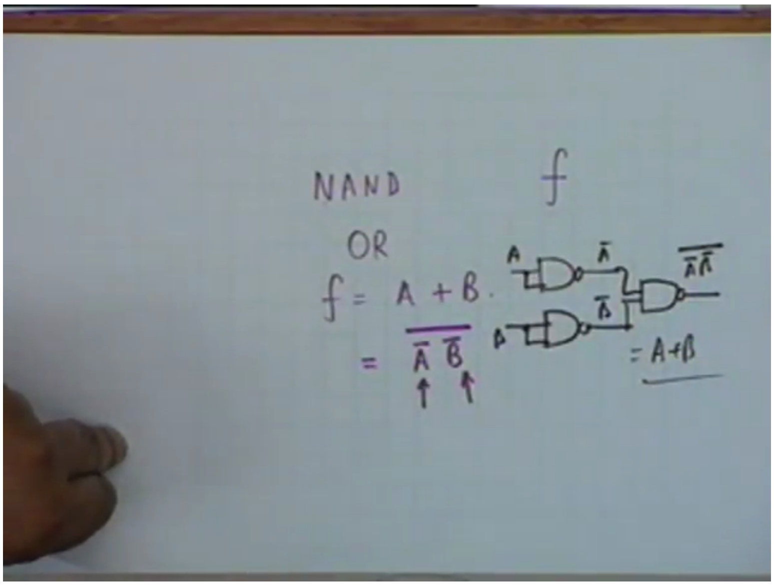

As an illustration of how a NAND gate can be used to realize any operation anyway can end out of NAND yes, all that you require is another 2 NAND gates shall be required, one is NAND and then another inversion. For an OR circuit for example where what you require is, for now on we shall represent the output of a logic circuit, digital circuit a small f, alright function.

If I want the OR operation what I want is that f should be equal to A or B, I want to convert this into NAND type of operation, so what I do is, we shall do a little later (()) (27:58) theorem. What we do is not A not B then compliment, alright. That is what we shall implement now, one NOT gate, one NAND shall be for a bar, one for B bar and 3rd for NAND that is A bar B bar NAND.

I can draw them very easily what I have is, this is A, so this is A bar similarly this is B, so this is B bar and then I put them together to the 3rd NAND, so I shall get A bar B bar whole bar which is equal to A or B. Similarly try it out, how to make other functions, well, what are the other functions left? AND, OR, NOT all the 3 can (()) (29:07) by NAND gate. Similarly trying for NOR, from NOR to OR is very simple from NOR to AND is not difficult either.

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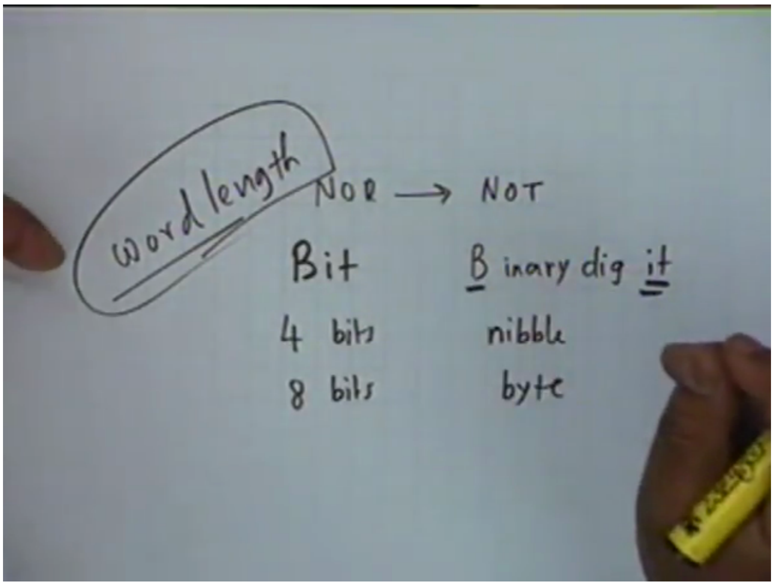

From NOR to NOT, how you do that?

“Professor -Student conversation starts”

Student: (()) (29:27)

Professor: That means you connect the 2 (()) (29:31). There is still another way one of them is to be connected to 0, alright.

“Professor-Student conversation ends”

Then some terms are used the computer science guy should be very familiar with this, a Bit terminology is used in digital circuits, a bit is an application of binary digit, alright. This B and it, binary digit 1 or 0 is a bit. A word of 4 bits is called a nibble, okay and the word of 8 bits is called a byte, alright. Word means a number, a binary number consisting of 8 bits, well, you understand what we mean by word.

By word we mean the number of, well, it is a binary number and the number of bits making it is called the word length. What is the word length permitted by the ICL system here? How many bits are permitted? 32 bits, okay.

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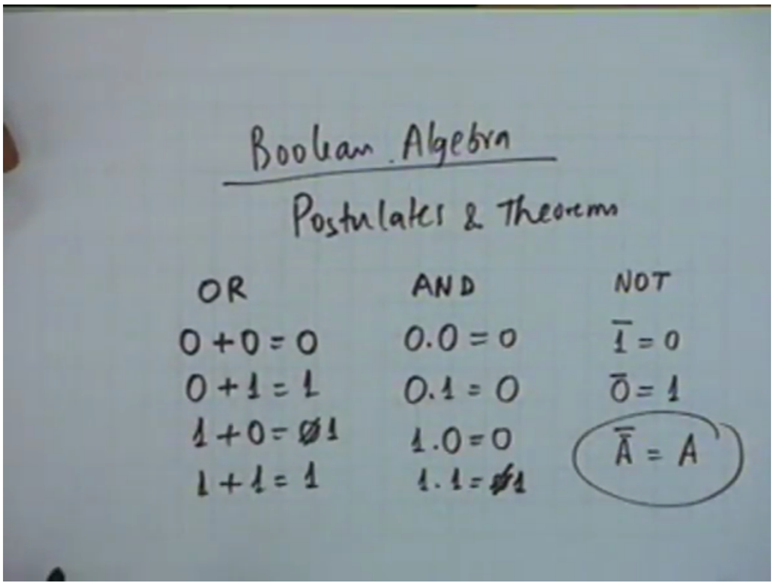

Some standard terminology then some postulates or Boolean algebra, postulates and theorems, the basic postulate are of course the 3 operations that means OR AND and NOT, okay. OR operation is 0 or 0 is 0 without the postulate this is what it starts from and you see this can be converted into a digital circuit either the diodes or transistors are combinations. 0 or 1 is 1, 1 or 0 is 0 and 1 or 1.

“Professor -Student conversation starts”

Student: (()) (31:45)

Professor: Okay, thank you.

“Professor-Student conversation ends”

And in AND 0 and 0 is 0, 0 and 1 is 0, 1 and 0 is 0 and 1 and 1 is 0.

“Professor -Student conversation starts”

Student: Sir 1 by 1 is 1.

Professor: Okay.

"Professor-Student conversation ends"

Alright in the NOT operation compliment to 1 is 0 and the compliment of 0 is 1, I live very simple but in complicated Boolean expression sometimes one is to refer to this, sometimes one is to recall the roots but it is obvious that if I compliment A and compliment a gain it should be the original A, alright. This is the relationship in 1 variable and if I generalize this, these postulates, these are specific values that we have taken 0 and 1.

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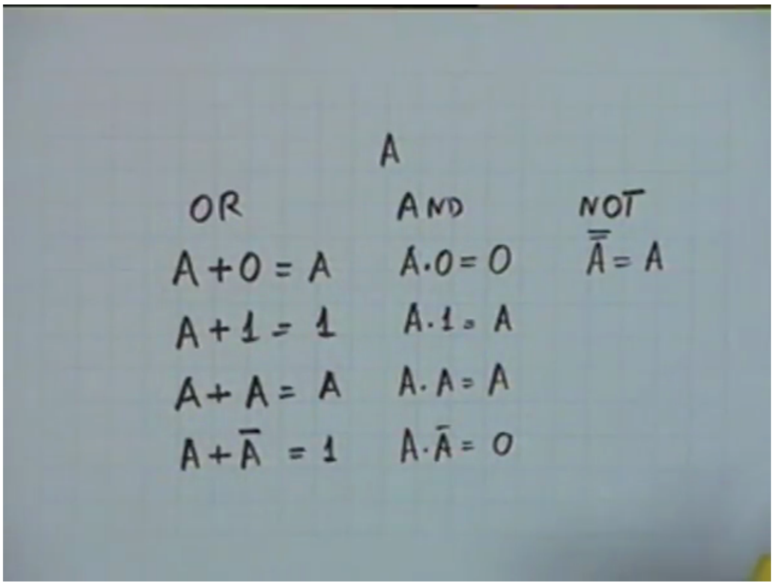

Suppose I take a Boolean variable A which can be either 0 or 1 then it is operation with the 2 bits that are available that is if we OR A with 0 we shall get A, okay. A with 1, we shall get?

"Professor -Student conversation starts"

Student: 1.

Professor: Sure? Not A.

Student: Yes.

Professor: Okay 1.

"Professor-Student conversation ends"

If we OR A with A we get A and if we OR A with compliment of A it is still 1, alright. On the other hand if we AND A and 0 it would be 0, A and 1 is A, A and A is A and A and A bar is 0 and NOT operation of course there is only 1 that is double compliment of A is A, alright.

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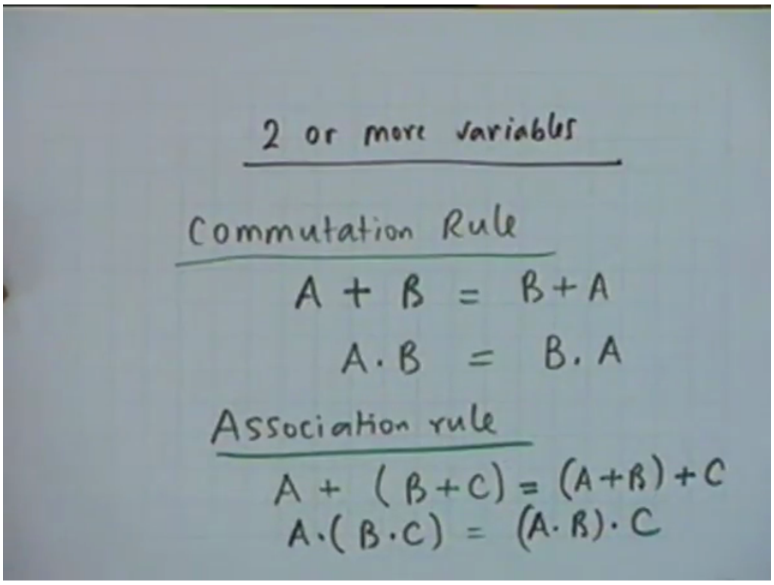

Let us take 2 variables or 2 or more variables, okay. If we wish to write such rules or such consequences we will take a long list. So we will group them into rules or laws as they are called, one is the commutation rule which says that the order of operation is not important that is whether you OR A with B or B with A is not important, alright. They are identical this is called computation rule because bring B first and then OR with A.

1 plus 1 or 0 and 0 or 1 are the same, okay. And the other is if you AND A with B result is the same as B ANDED with A this is commutation rule this is true in ordinary arithmetic also this is an arithmetic also, okay. Then the second rule is Association, in association A or B or C there are more than 2 variables A or B or C that is this operation says that we should be OR with C first then OR with A, well, this happens to be the same as if A is OR with B and then the total is OR with C or we can make any other combination.

For example it could be B or with A instead of A or with B, okay. Similarly the case of AND operation that A AND B and C which in the case that B and C have to be ANDED first and then the result is to be ANDED with A while you can write as A and B and C, alright which is the rule of association while so far they are all trivial and revisions.

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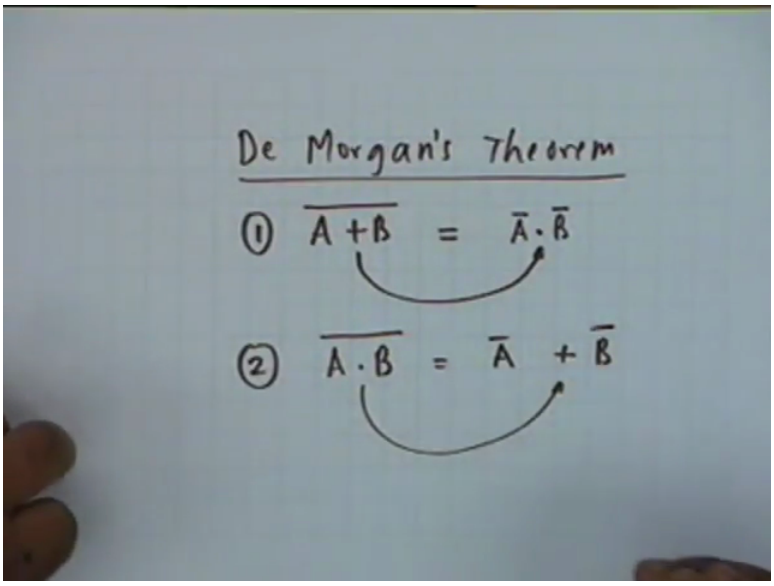

De Morgan's the 3rd set of rules is given by the De Morgan's theorem and it states that if you have an OR operation followed by a complementation then this is complementation of the 2 variables and AND operation the 2 are equal this is one form of De Morgan theorem you must follow this, OR operation is converted to an AND and the result is that both the variables have to be complemented first and easiest proof of this is that I can be (()) (37:12).

In fact you cannot make a mistake in proof, if you go by the table but sometimes truth table are very long to write and things may be obvious will show you the examples of this. The other is that if A is Anded with B and the whole thing complemented this will be one form of De Morgan's theorem, the second is A and B the result is complimented then this is simply OR operation they can complement of A then compliment of B.

Once again AND is being converted to OR but complementing is a part of De Morgan, is an inherent part of De Morgan's theorem, wherever you want to convert one operation to the other or AND operation to OR you must compliment, okay. And De Morgan's theorem without complementation is not valid, okay. One has to remember this.

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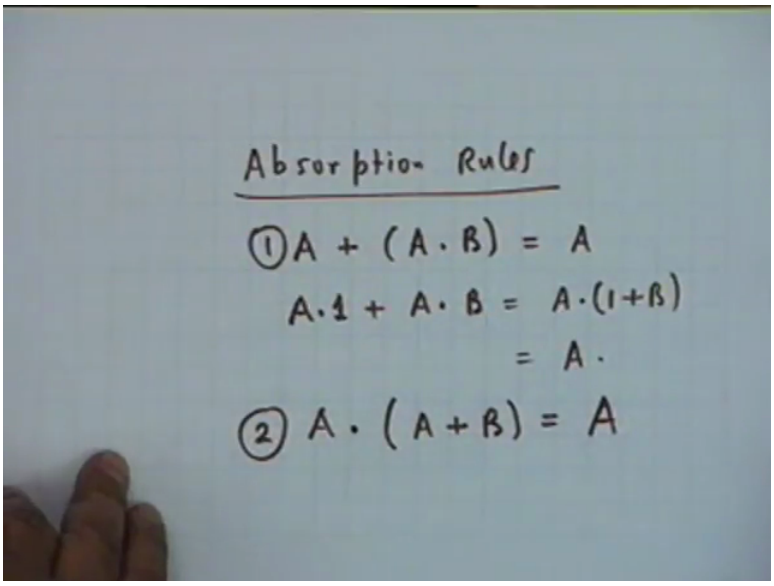

Then the 4th set of rules are the absorption rules and these are interesting that is A or A and B is simply equal to A and the proof here is very simple. A can be written as A AND 1 and this can be written as A and B and by how can I do this? A AND 1 OR B association distribution which you have not proved yet, okay. But anyway 1 OR B 1 and therefore this is A and the second distribution law.

Second absorption rule, this is one the second follows from this, here is an OR operation, so increase this by AND, this OR by AND and this AND by OR. A AND A OR B is equal to A, why is it so? A and A is A, A AND B and A plus AB is A it takes account of the first rule and without distribution the easiest way to prove is to write the truth table if you do not want to take distribution, okay.

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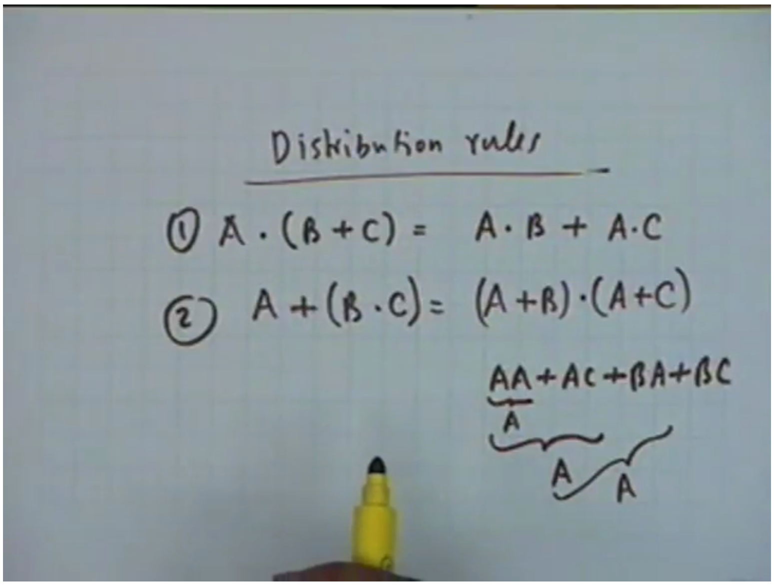

If you are barred from using distribution then this is what you do, we write the truth table and then the distribution finally you could do distribution earlier. Distribution rules are again bent number that is if you have A and B OR C you can write this as A and B or A and C exactly like ordinary decimal arithmetic. However there is a difference, if this is replaced by OR this is first formed, the second form is this is replaced by OR and this is replaced by AND.

Then this is equal to A OR B and A OR C and a proof of this is easier proof is to go from here to the left. If you expand this you get AA AC BA BC, AA is A absorption, A plus AC is A, A plus BA is and therefore this is arithmetic, is that okay?

You can have fun there are several problems in the tutorial sheet which asks you to prove that the right-hand side is equal to left hand side. Important thing is you should be able to do it blindly if you proceed by through table. So suppose there are 3 variables, 3 inputs like how many lines will be there in the truth table 8, 4, 16, if it is more than 4 then you have had it. We have one page we will not be able to accommodate it. It is better to look for simplifications and it is important to see which side should we start with and this will come through experience that is if you work out more and more problems.

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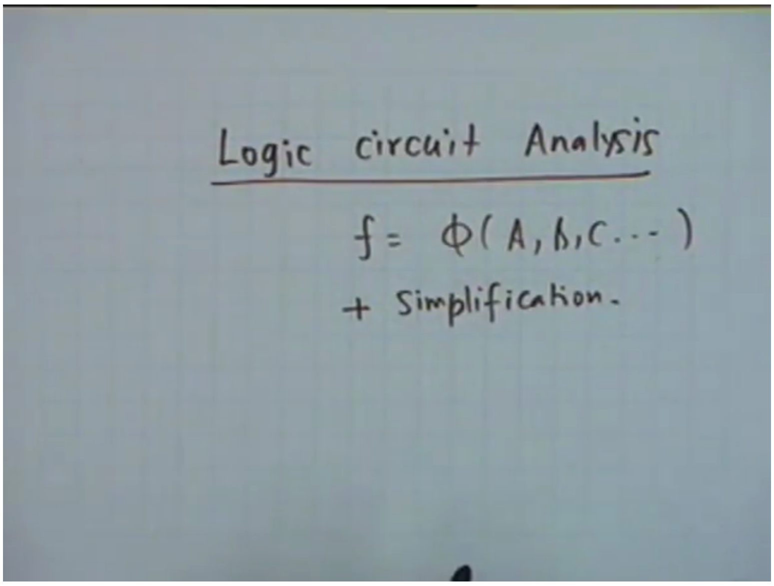

Now as in analogue circuits we can have 2 kinds of problems, we can have analyses or we can have synthesis, alright. Logic circuit analysis means given a logic circuit find out the output variable in terms of the input variable exactly that is what I do in analogue circuits, given an analogue circuit find the output in terms of the inputs or inputs union of more than one input, alright.

For example in a transistor amplifier what do you find out? The output consist of 2 parts the AC and the DC, there are 2 inputs one is the DC, what is the DC? VCC and the signal, alright. There are 2 inputs, okay. So logic circuit analysis means that you want to find the output in terms of the input or inputs, alright. Another objective of logic circuit analysis is simplification.

It just does not stop at finding f as a function of let say the inputs A, B, C etc it does not stop there. It is logic circuit analysis in this term is in try whether you can simplify the expression that is plus simplification that is one might have, what you call an immature percent? An immature might have constructed a circuit which can be done with less numbers or gates and therefore one should look at whether you can simplify this number.

And we shall illustrate this by means of a specific problem that you understand the difference between analogue circuit analysis and digital circuit analysis, logic circuit analysis. Logic circuit analysis in addition to finding the output variable it also implies whether the same output variable could be obtained from the same inputs by a simpler circuit, alright.

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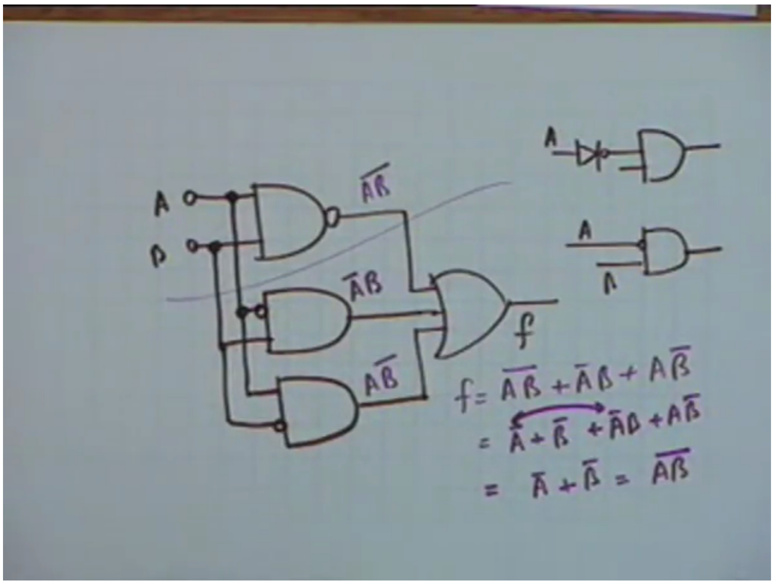

An example, suppose we have 2 variables AB and we have a series of NAND gates, one, now let me tell you what I mean by this and B this means, this dot here means that a inversion has occurred to start it. For example if I have let say A and then I apply to an AND gate I represent this sometimes it is convenient to represent it not by joining another gate but by simply doing this which means that the actual input to this it is compliment of A not A, alright. NOT A N O T, N capital O capital T capital not the English not, alright.

Okay, so this is another gate this is an AND gate and the 3rd is, well, you see I am not bothered into draw this twiddles whenever there is a connection I will show it by means big dots like this, if there is a crossing like this that means they are not connected to each other. You can rather (()) (45:49) to draw so many twiddle I do not want to do that, alright. And the third gate is a similar one but the inversion operation is in B, okay.

All these 3 are brought to an orbit and this is what is f, one can vary simply say that this is AB compliment, there is a NAND gate, this output is A Bar B is an AND gate with A complemented and this gate is AB bar and therefore f should be simply equal to the OR between these 2 that is AB bar plus A bar B plus AB bar. Now this is as far as analysis is concerned you have optimal expression, can it be simplified?

Well, try this by De Morgan's theorem this is A bar plus B bar then A bar B plus AB bar. Now you combine these 2 this is A bar and these 2 will be the B bar which is you can write as, alright. And therefore all this is redundant, what we could do simply it is NAND gate, is not it right? This is AB bar and therefore all this is redundant which is the work of an immature and you must look at it, alright.

It is very important for a company that they have expert logic circuit designers because if one is not an expert logic circuit designer the company might go bankrupt, alright. We shall have a few minutes break before we take the 40th lecture. We shall assemble here again at 5:03, alright.