Control System Training

MODULE 4 – Combinatorial Logic

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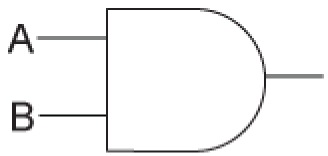
Combinatorial Logic

- **Boolean – ZERO / ONE – Logic**
- **Outcome depends only on the CURRENT inputs.**
  - No “time” dependency.

AND Gate

AND GATE

Input		
A	B	Output
0	0	0
0	1	0
1	0	0
1	1	1

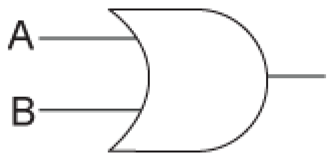


- **Output is true when all inputs are true.**
- **Boolean algebra written as AB or A· B**

OR Gate

OR GATE

Input		
A	B	Output
0	0	0
0	1	1
1	0	1
1	1	1

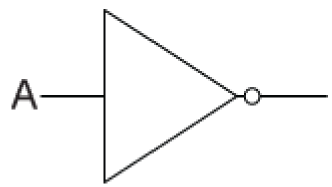


- **Output is true when any input is true**
- **Boolean algebra written as A+B**

NOT Gate

NOT GATE

INPUT	Output
0	1
1	0

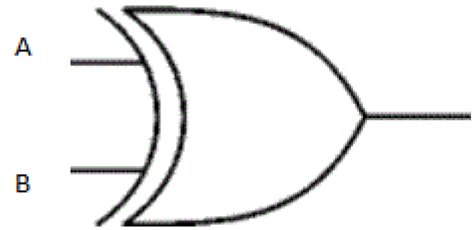


- **Output is the opposite of the input.**
- **Boolean algebra written as ^A or $\overline{A}$**

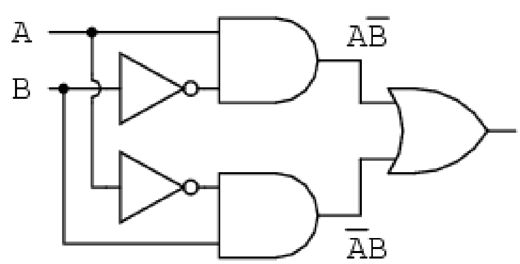
XOR (Exclusive OR) Gate

XOR GATE

Input		
A	B	Output
0	0	0
0	1	1
1	0	1
1	1	0



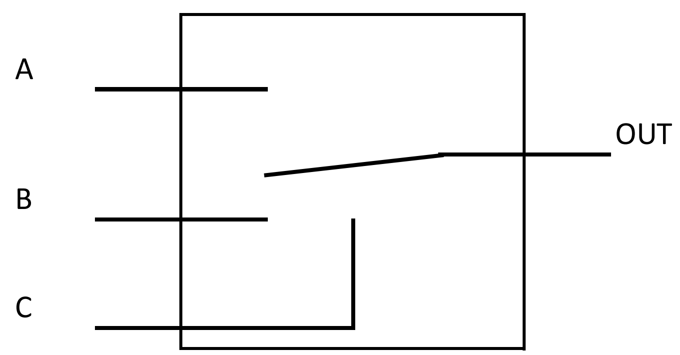
- **Output is true when inputs are different.**
- **Boolean algebra written as A⊕B**
- **Equivalent to:**



Special - Digital Switch

Digital Switch

Input			
A	B	C	Output
?	?	0	A
?	?	1	B



- **Switches between inputs A and B based on C.**
- **Doesn’t care what the values of A or B are.**
- **Could also be implemented with “normal” gates.**

Special – Analog Test Switch

- **EQUAL MONITOR – Output is true when analog value A = B (Best used with integer values!)**
- **HI MONITOR – Output is true when analog value A >= B**
- **LO MONITOR – Output is true when analog value B <= A**
- **HI-LO MONITOR – Output is true when analog value >= A and <= B. For the output to ever be true B must be > A.**
- **These functions often have a deadband value to reduce chatter.**

Boolean Algebra

- **Write out as regular algebra**
- **Do this as part of the simplification process**
- **Symbols**
  - \+ means OR
  - * means AND
  - • means AND
  - Line over term or ^ means NOT
  - ⊕ means XOR (exclusive OR)
  - = means equals
- **Samples**
  - OUT = PERM • INPUT
  - E = A • B + C • D

Boolean Algebra - Rules

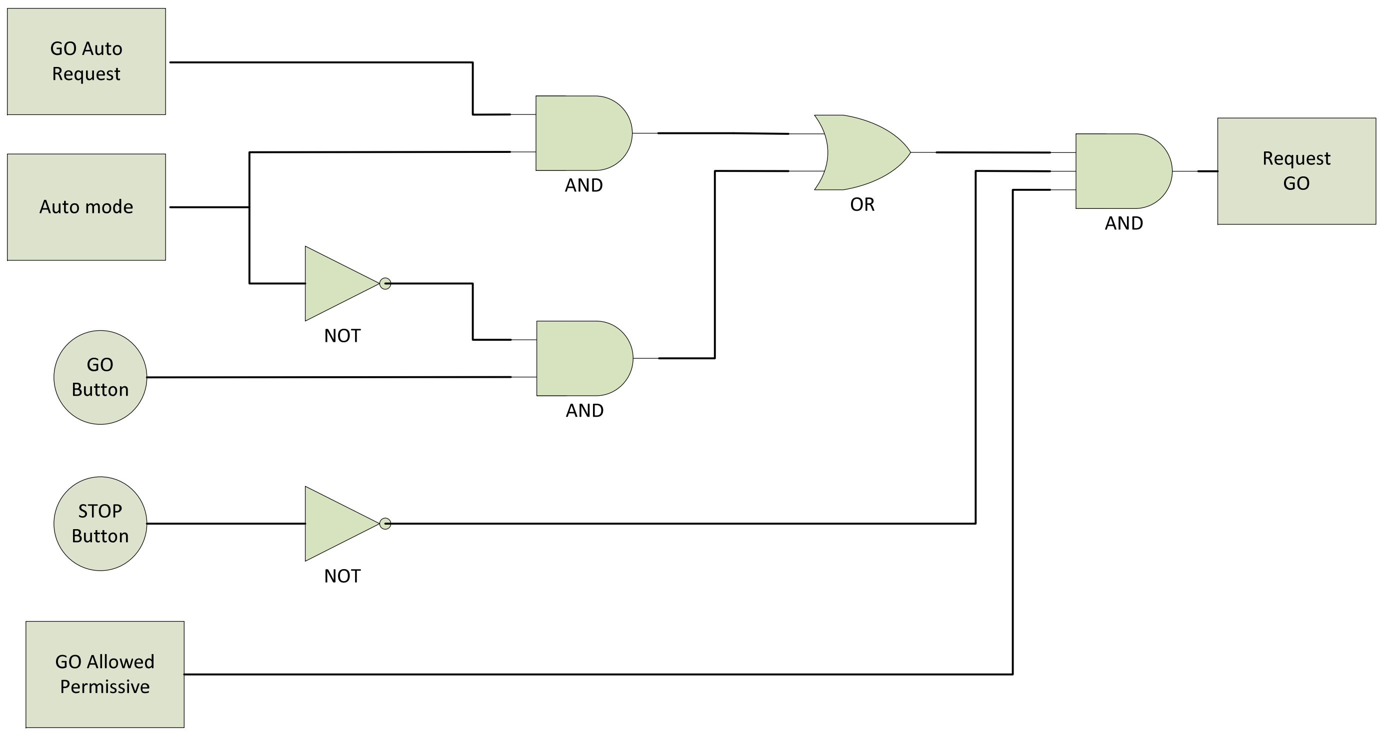
1a.	$X \bullet 0 = 0$	1b.	$X + 1 = 1$	Annulment Law
2a.	$X \bullet 1 = X$	2b.	$X + 0 = X$	Identity Law
3a.	$X \bullet X = X$	3b.	$X + X = X$	Idempotent Law
4a.	$X \bullet \overline{X} = 0$	4b.	$X + \overline{X} = 1$	Complement Law
5.	$\overline{\overline{X}} = X$			Double Negation Law
6a.	$X \bullet Y = Y \bullet X$	6b.	$X + Y = Y + X$	Commutative Law
7a.	$X\,(Y\,Z) = (X\,Y)\,Z = (X\,Z)\,Y = X\,Y\,Z$			Associative Law
7b.	$X + (Y + Z) = (X + Y) + Z = (X + Z) + Y = X + Y + Z$			Associative Law
8a.	$X \bullet (Y + Z) = X\,Y + X\,Z$	8b.	$X + Y\,Z = (X + Y) \bullet (X + Z)$	Distributive Law
9a.	$\overline{X \bullet Y} = \overline{X} + \overline{Y}$	9b.	$\overline{X + Y} = \overline{X} \bullet \overline{Y}$	de Morgan's Theorem
10a.	$X \bullet (X + Y) = X$	10b.	$X + X\,Y = X$	Absorption Law
11a.	$(X + Y) \bullet (X + \overline{Y}) = X$	11b.	$X\,Y + X\,\overline{Y} = X$	Redundancy Law
12a.	$(X + \overline{Y}) \bullet Y = XY$	12b.	$X\,\overline{Y} + Y = X + Y$	Redundancy Law
13a.	$(X + Y) \bullet (\overline{X} + Z) \bullet (Y + Z) = (X + Y) \bullet (\overline{X} + Z)$			Consensus Law
13b.	$X\,Y + \overline{X}\,Z + Y\,Z = X\,Y + \overline{X}\,Z$			Consensus Law
14a.	$X \oplus Y = (X + \overline{Y}) \bullet (\overline{X} + Y)$	14b.	$X \oplus Y = \overline{X}\,Y + X\,\overline{Y}$	XOR Gate
15a.	$X \odot Y = (X + Y) \bullet (\overline{X \bullet Y})$	15b.	$X \odot Y = \overline{X}\,\overline{Y} + X\,Y$	XNOR Gate
15c.	$X \odot Y = (X + Y) \bullet (\overline{X} + \overline{Y})$			XNOR Gate

- **There are others.**

Boolean Algebra – Simplification

- **Simplify to Product of Sums or Sum of Products**
  - Often for control systems, “product of sums” is better than “sum of products”.
    - Conditions AND permissives
- **There is much, much, more about this online.**

Sample 4.1



GO_Request = GO_Perm • GO_allowed • ^STOP_Button •
(GO_Auto • Auto_mode + GO_Button • ^Auto_Mode)

Exercise 4.1 – Ball shooter size detector

- **Floor contains 3 sizes of balls. Only the middle size can be shot correctly.**
  - The small balls have 80% the diameter of the middle ball
  - The large balls have 120% the diameter of the middle ball.
- **Have three digital sensors.**
  - One at front of ball.
  - One at 97% diameter of middle ball
  - One at 103% diameter of middle ball
- **The balls roll along a belt.**
- **If robot is disabled, reject all the balls.**
- **Create a circuit to reject all but the middle balls. Draw the logic diagram.**

Exercise 4.2 – List Programming Objects

- **Create a list of potential objects from this chapter to program.**