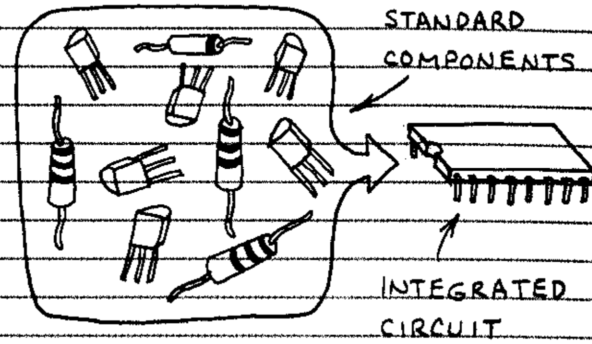
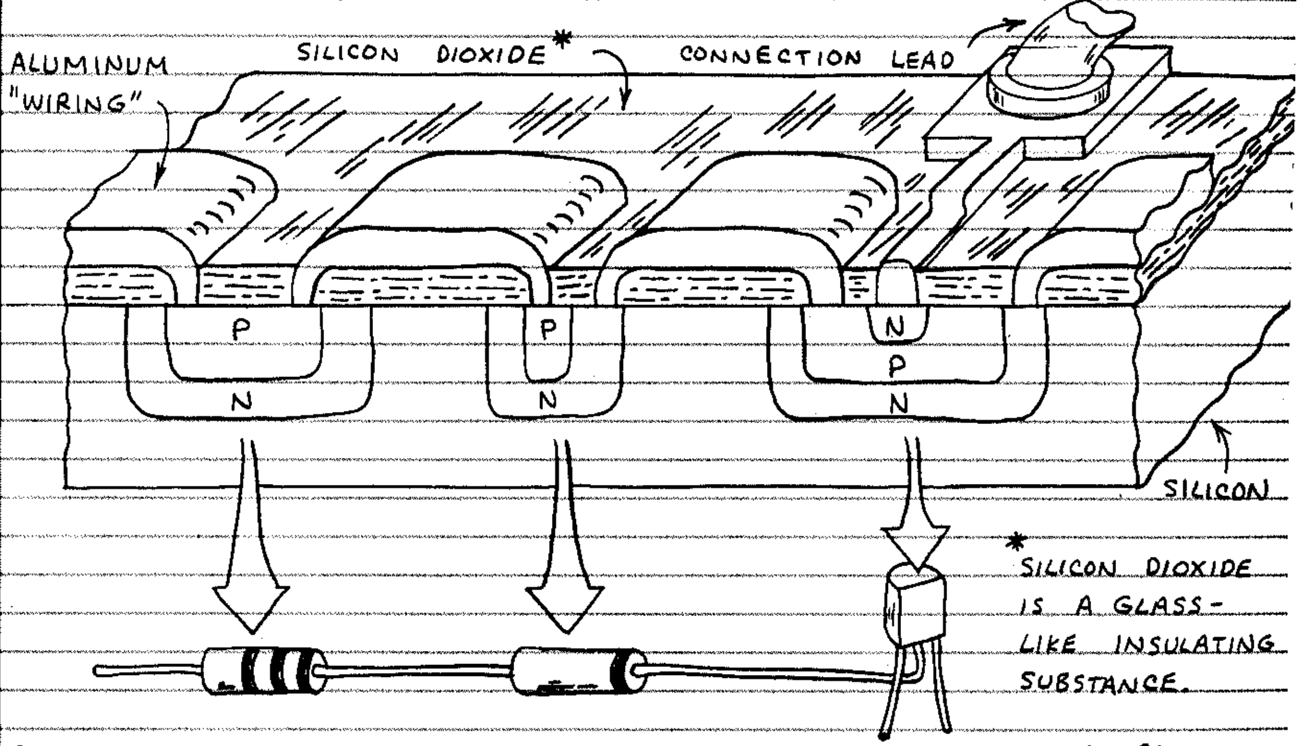
5. INTEGRATED CIRCUITS



ELECTRONIC CIRCUITS CAN BE MADE BY SIMULTANEOUSLY FORMING INDIVIDUAL TRANSISTORS, DIODES AND RESISTORS ON A SMALL CHIP OF SILICON. THE COMPONENTS ARE CONNECTED TO ONE ANOTHER WITH ALUMINUM "WIRES" DEPOSITED ON THE SURFACE OF THE CHIP. THE RESULT IS AN INTEGRATED CIRCUIT.

INTEGRATED CIRCUITS (OR IC's) CAN CONTAIN AS FEW AS SEVERAL TO AS MANY AS HUNDREDS OF THOUSANDS OF TRANSISTORS. THEY HAVE MADE POSSIBLE VIDEO GAMES, DIGITAL WATCHES, AFFORDABLE COMPUTERS AND MANY OTHER VERY SOPHISTICATED PRODUCTS. HERE'S A SIMPLIFIED AND HIGHLY MAGNIFIED VIEW OF A SECTION OF A *BIPOLAR* INTEGRATED CIRCUIT:



RESISTOR — A SMALL SECTION OF P-TYPE SILICON FORMS A RESISTOR.

DIODE — A PN JUNCTION FORMS A DIODE.

TRANSISTOR — A PAIR OF PN JUNCTIONS FORMS AN NPN TRANSISTOR

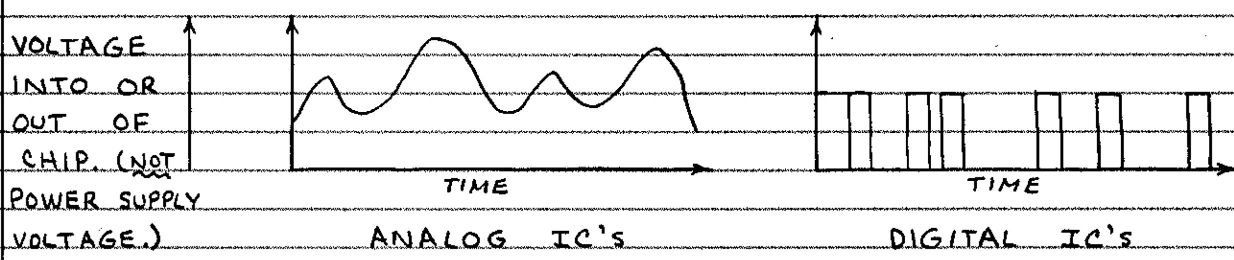
OF COURSE THE CONVENTIONAL COMPONENTS SHOWN BELOW THE HIGHLY MAGNIFIED SECTION OF THE IC ARE NOT DRAWN TO THE SAME SCALE. FOR EXAMPLE, ONE KIND OF IC INCLUDES 262,144 TRANSISTORS ON A SILICON CHIP ONLY ABOUT 1/4 INCH SQUARE!

□ KINDS OF INTEGRATED CIRCUITS — INTEGRATED CIRCUITS ARE GROUPED INTO TWO MAJOR CATEGORIES:

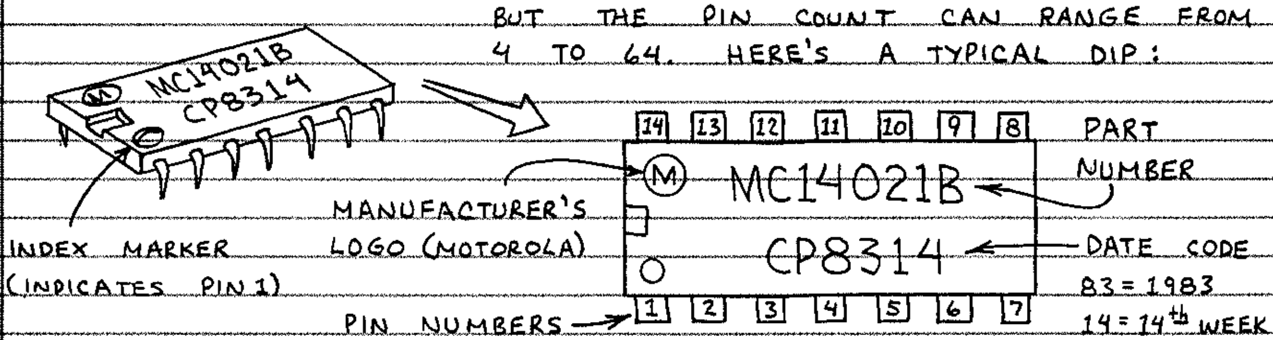
1. ANALOG (OR LINEAR) IC'S PRODUCE, AMPLIFY OR RESPOND TO VARIABLE VOLTAGES. ANALOG IC'S INCLUDE MANY KINDS OF AMPLIFIERS, TIMERS, OSCILLATORS AND VOLTAGE REGULATORS.

2. DIGITAL (OR LOGIC) IC'S RESPOND TO OR PRODUCE SIGNALS HAVING ONLY TWO VOLTAGE LEVELS. DIGITAL IC'S INCLUDE MICROPROCESSORS, MEMORIES, MICROCOMPUTERS AND MANY KINDS OF SIMPLER CHIPS.

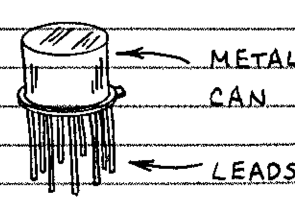
SOME IC'S COMBINE ANALOG AND DIGITAL FUNCTIONS ON A SINGLE CHIP. FOR EXAMPLE, A DIGITAL CHIP MAY INCLUDE A BUILT-IN ANALOG VOLTAGE REGULATOR SECTION. AND AN ANALOG TIMER CHIP MAY INCLUDE AN ON-CHIP DIGITAL COUNTER TO GIVE MUCH LONGER TIME DELAYS THAN POSSIBLE WITH THE TIMER ALONE.



□ KINDS OF INTEGRATED CIRCUIT PACKAGES — IC CHIPS ARE SUPPLIED IN MANY DIFFERENT PACKAGES. BY FAR THE MOST COMMON ARE VARIATIONS OF THE DUAL IN-LINE PACKAGE (OR DIP). THE DIP IS MADE FROM PLASTIC (CHEAP) OR CERAMIC (MORE ROBUST). MOST DIPS HAVE 14 OR 16 PINS, BUT THE PIN COUNT CAN RANGE FROM 4 TO 64. HERE'S A TYPICAL DIP:



ANOTHER IC PACKAGE IS THE TO-5 METAL CAN. THOUGH VERY STURDY, IT'S BEING REPLACED IN MANY CASES BY CHEAPER PLASTIC DIPS.



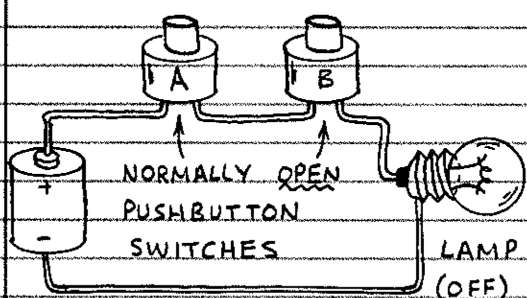
6. DIGITAL INTEGRATED CIRCUITS

NO MATTER HOW COMPLICATED, ALL DIGITAL INTEGRATED CIRCUITS ARE MADE FROM SIMPLE BUILDING BLOCKS CALLED GATES. GATES ARE LIKE ELECTRONICALLY CONTROLLED SWITCHES. THEY ARE EITHER ON OR OFF. HOW DO GATES WORK? LET'S START WITH THE BASICS...

MECHANICAL SWITCH GATES

THE THREE SIMPLEST GATES CAN BE DEMONSTRATED WITH SOME PUSHBUTTON SWITCHES, A BATTERY AND A LAMP.

☐ SWITCH "AND" GATE.



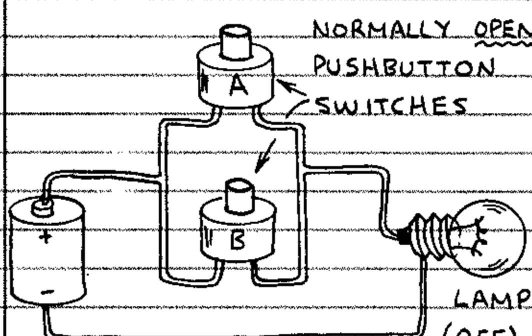
THE LAMP GLOWS ONLY WHEN SWITCHES A AND B ARE CLOSED. THE TABLE SUMMARIZES THE GATE'S OPERATION. IT'S CALLED A TRUTH TABLE.

OPEN SWITCH = OFF
CLOSED SWITCH = ON

A	B	OUT
OFF	OFF	OFF
OFF	ON	OFF
ON	OFF	OFF
ON	ON	ON

ALL POSSIBLE ON-OFF COMBINATIONS

☐ SWITCH "OR" GATE.

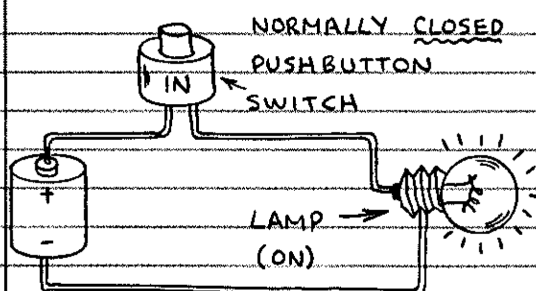


THE LAMP GLOWS ONLY WHEN SWITCH A OR SWITCH B OR BOTH SWITCHES A AND B ARE CLOSED. HERE'S THE TRUTH TABLE:

A	B	OUT
OFF	OFF	OFF
OFF	ON	ON
ON	OFF	ON
ON	ON	ON

THE SWITCHES ARE THE GATE'S INPUTS. THE LEAD WITHOUT SWITCHES IS THE COMMON OR GROUND LEAD.

☐ SWITCH "NOT" GATE.



THE LAMP NORMALLY GLOWS. ONLY WHEN THE SWITCH IS OPENED IS THE LAMP OFF. IN OTHER WORDS, THE "NOT" GATE REVERSES (INVERTS) THE USUAL ACTION OF A SWITCH. HERE'S THE TRUTH TABLE:

THE "NOT" GATE IS USUALLY CALLED THE INVERTER.

IN	OUT
OFF	ON
ON	OFF

THE BINARY CONNECTION

IT'S POSSIBLE TO SUBSTITUTE THE DIGITS 0 AND 1 FOR THE OFF AND ON STATES OF A SWITCH. THE TRUTH TABLES FOR THE GATES ON THE PREVIOUS PAGE THEN BECOME:

"AND" GATE

A	B	OUT
0	0	0
0	1	0
1	0	0
1	1	1

"OR" GATE

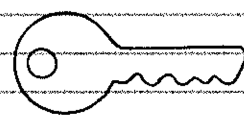
A	B	OUT
0	0	0
0	1	1
1	0	1
1	1	1

"NOT" GATE

IN	OUT
0	1
1	0

THE 0 AND 1 INPUT (A & B) COMBINATIONS FORM NUMBERS IN THE TWO DIGIT (OR BIT) BINARY NUMBER SYSTEM. IN DIGITAL ELECTRONICS, BINARY NUMBERS SERVE AS CODES THAT REPRESENT DECIMAL NUMBERS, LETTERS OF THE ALPHABET, VOLTAGES AND MANY OTHER KINDS OF INFORMATION.

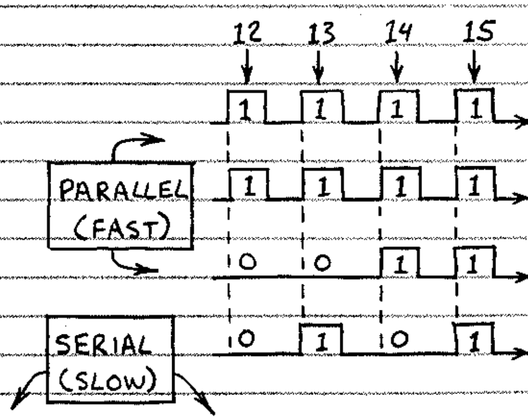
DECIMAL	BINARY	BINARY-CODED DECIMAL (BCD)
0	0	0000 0000
1	1	0000 0001
2	10	0000 0010
3	11	0000 0011
4	100	0000 0100
5	101	0000 0101
6	110	0000 0110
7	111	0000 0111
8	1000	0000 1000
9	1001	0000 1001
10	1010	0001 0000
11	1011	0001 0001
12	1100	0001 0010
13	1101	0001 0011
14	1110	0001 0100
15	1111	0001 0101



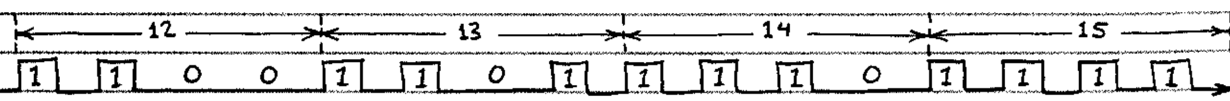
BINARY FACTS

A BINARY 0 OR 1 IS A BIT.
A PATTERN OF 4 BITS IS A NIBBLE.
A PATTERN OF 8 BITS IS A BYTE.

BCD— EACH DECIMAL DIGIT IS ASSIGNED ITS BINARY EQUIVALENT. NOTE THAT LEADING ZEROS ARE SHOWN. IN DIGITAL ELECTRONICS ALL BIT LOCATIONS ARE OCCUPIED.



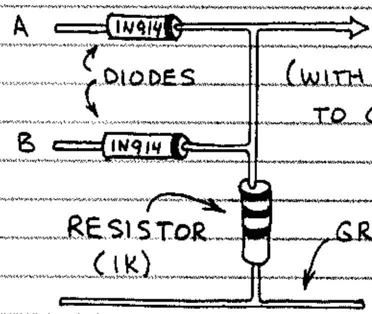
BINARY NUMBERS CAN BE SENT THROUGH WIRES (BUSES) ALL AT ONCE (PARALLEL) OR A BIT AT A TIME (SERIAL). SHOWN HERE ARE SERIAL AND PARALLEL TRANSMISSION OF 15... 14... 13... 12.



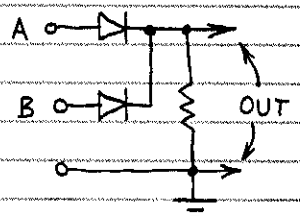
DIODE GATES

OFTEN IT'S DESIRABLE TO CONTROL A GATE ELECTRICALLY RATHER THAN MECHANICALLY. THE SIMPLEST ELECTRICALLY CONTROLLED GATE USES PN JUNCTION DIODES THAT ARE SWITCHED ON (FORWARD BIAS) OR OFF (REVERSE BIAS) BY AN INPUT SIGNAL OF SEVERAL VOLTS (BINARY 1 OR HIGH) OR AN INPUT NEAR OR AT GROUND (BINARY 0 OR LOW).

☐ DIODE "OR" GATE



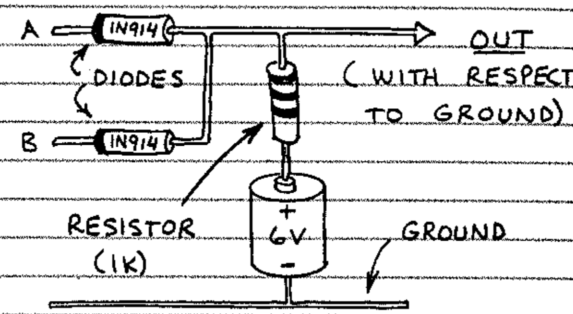
WHEN THE INPUT VOLTAGE AT A OR B IS MORE POSITIVE THAN GROUND, IT PASSES THROUGH THE FORWARD BIASED DIODE(S) AND APPEARS AT THE OUTPUT. OTHERWISE THE OUTPUT IS AT OR NEAR GROUND. THE TRUTH TABLE IS VALID FOR INPUTS OF 0 VOLT (0 OR LOW) AND +6 VOLTS (1 OR HIGH).



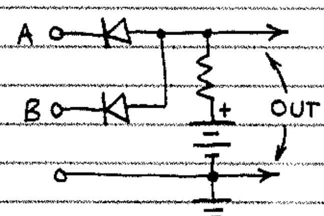
A	B	OUT
0V	0V	0V
0V	6V	5.4V
6V	0V	5.4V
6V	6V	5.4V

THE OUTPUT DOES NOT REACH A FULL 6 VOLTS WHEN HIGH BECAUSE THE DIODES REQUIRE A FORWARD VOLTAGE OF 0.6 VOLT. THIS VOLTAGE IS SUBTRACTED FROM THE OUTPUT VOLTAGE. (IN ELECTRONICS JARGON A SILICON DIODE CAUSES A "VOLTAGE DROP" OF 0.6 VOLT.)

☐ DIODE "AND" GATE



WHEN THE INPUT VOLTAGE AT A AND B IS MORE POSITIVE THAN GROUND, CURRENT FLOWS FROM THE BATTERY THROUGH THE RESISTOR TO THE OUTPUT. IF EITHER A OR B IS AT OR NEAR GROUND, ONE OR BOTH DIODES BECOME FORWARD BIASED AND CURRENT FLOWS AWAY FROM THE OUTPUT.



A	B	OUT
0V	0V	0V
0V	6V	.5V
6V	0V	.5V
6V	6V	5.4V

AS CIRCUITS BECOME MORE COMPLICATED, PICTORIAL VIEWS ARE NOT PRACTICAL. THAT'S WHY THIS PAGE INTRODUCES CIRCUIT DIAGRAMS FOR EACH OF THE TWO PICTORIALS SHOWN ABOVE. WE'LL FIND OUT MORE ABOUT CIRCUIT DIAGRAMS LATER. IN THE MEANTIME, THE NEXT PAGE SHOWS MORE OF THEM...

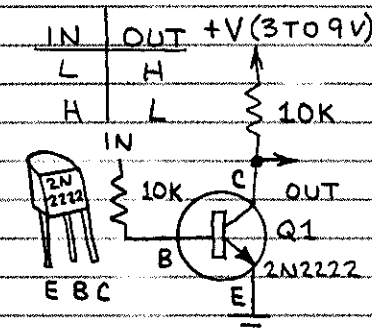
TRANSISTOR GATES

THE VOLTAGE DROP OF DIODE GATES MEANS AMPLIFICATION IS REQUIRED IN ORDER TO CONNECT TOGETHER A SERIES OF GATES. WHILE TRANSISTORS CAN PROVIDE THE NECESSARY AMPLIFICATION, TRANSISTORS CAN FUNCTION AS GATES! BOTH BIPOLAR AND FIELD-EFFECT TRANSISTORS CAN BE USED. ON THIS PAGE ARE SHOWN CIRCUIT DIAGRAMS FOR SOME OF THE SIMPLEST BIPOLAR TRANSISTOR GATES. TOGETHER THEY FORM THE RESISTOR-TRANSISTOR DIGITAL LOGIC FAMILY. YOU CAN ACTUALLY MAKE THESE GATES. BUT THE MAIN REASON THEY'RE HERE IS TO GIVE YOU AN APPRECIATION FOR THE INTEGRATED CIRCUIT GATES WE'LL BE LOOKING AT SHORTLY....

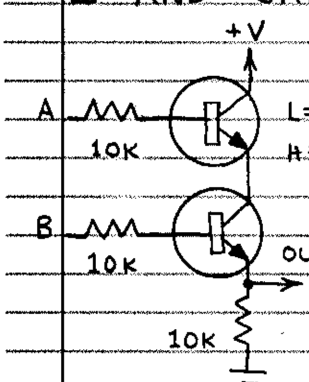
☐ "NOT" GATE (INVERTER)

WHEN IN IS AT +V (BINARY 1 OR HIGH), TRANSISTOR Q1 SWITCHES ON AND CONNECTS OUT DIRECTLY TO GROUND (BINARY 0 OR LOW). WHEN IN IS LOW, Q1 SWITCHES OFF AND OUT BECOMES (THROUGH R1) +V. "NOT" GATES LIKE THIS MAKE POSSIBLE IMPORTANT NEW LOGIC GATES.

IN	OUT
L	H
H	L



☐ "AND" GATE

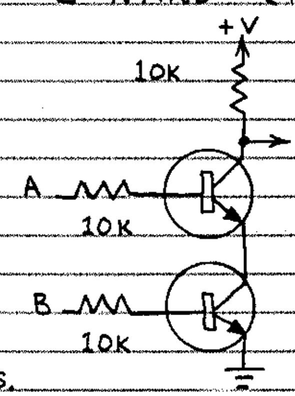


L = LOW
H = HIGH

A	B	OUT
L	L	L
L	H	L
H	L	L
H	H	H

USE 2N2222 OR ANY COMMON NPN TRANSISTOR FOR ALL THESE GATES.

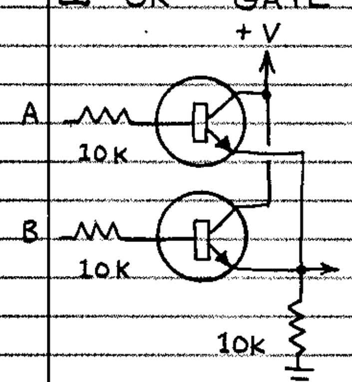
☐ "NAND" (NOT-AND) GATE



A	B	OUT
L	L	H
L	H	H
H	L	H
H	H	L

THE "NOT" FUNCTION IS "BUILT-IN" (NO EXTRA TRANSISTOR REQUIRED).

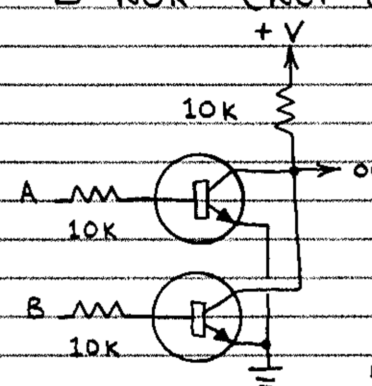
☐ "OR" GATE



A	B	OUT
L	L	L
L	H	H
H	L	H
H	H	H

+V FOR ALL THESE GATES CAN BE +3 TO +9 VOLTS.

☐ "NOR" (NOT-OR) GATE



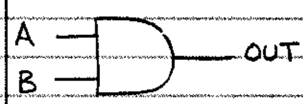
A	B	OUT
L	L	H
L	H	L
H	L	L
H	H	L

LIKE THE "NAND" GATE, THE "NOT" FUNCTION IS "BUILT-IN."

GATE SYMBOLS

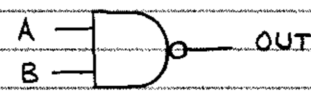
BEFORE MOVING ON TO DIGITAL INTEGRATED CIRCUITS, LET'S LOOK AT THE SYMBOLS FOR THE VARIOUS KINDS OF GATES. THIS IS ALSO A GOOD PLACE TO INTRODUCE SEVERAL GATES WE'VE NOT YET ENCOUNTERED.

☐ "AND" GATE



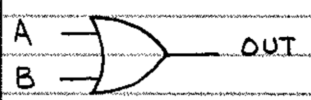
A	B	OUT
L	L	L
L	H	L
H	L	L
H	H	H

☐ "NAND" GATE



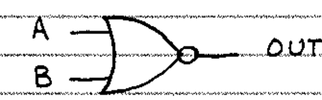
A	B	OUT
L	L	H
L	H	H
H	L	H
H	H	L

☐ "OR" GATE



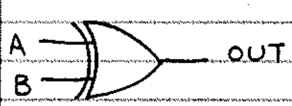
A	B	OUT
L	L	L
L	H	H
H	L	H
H	H	H

☐ "NOR" GATE



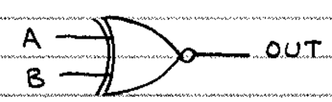
A	B	OUT
L	L	H
L	H	L
H	L	L
H	H	L

☐ "EXCLUSIVE-OR" GATE



A	B	OUT
L	L	L
L	H	H
H	L	H
H	H	L

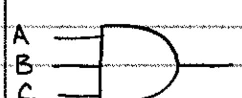
☐ "EXCLUSIVE - NOR" GATE



A	B	OUT
L	L	H
L	H	L
H	L	L
H	H	H

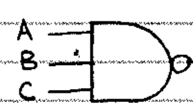
☐ LOGIC GATES WITH MORE THAN TWO INPUTS — THE GATES SHOWN ABOVE ARE CALLED LOGIC CIRCUITS BECAUSE THEY MAKE LOGICAL DECISIONS. LOGIC GATES OFTEN HAVE MORE THAN TWO INPUTS. ADDITIONAL INPUTS INCREASE THE DECISION MAKING POWER OF A GATE. THEY ALSO INCREASE THE NUMBER OF WAYS GATES CAN BE CONNECTED TO ONE ANOTHER TO FORM ADVANCED DIGITAL LOGIC CIRCUITS. HERE ARE TWO EXAMPLES:

3-INPUT "AND" GATE



A	B	C	OUT
L	L	L	L
L	L	H	L
L	H	L	L
L	H	H	L
H	L	L	L
H	L	H	L
H	H	L	L
H	H	H	H

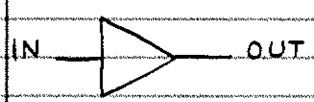
3-INPUT "NAND" GATE



A	B	C	OUT
L	L	L	H
L	L	H	H
L	H	L	H
L	H	H	H
H	L	L	H
H	L	H	H
H	H	L	H
H	H	H	L

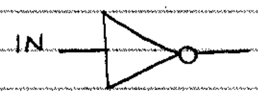
☐ SINGLE-INPUT GATES — THE "NOT" GATE OR INVERTER IS VERY IMPORTANT SINCE IT CAN INVERT (REVERSE) THE OUTPUT FROM ANOTHER GATE. STRICTLY SPEAKING, HOWEVER, THE INVERTER IS NOT A DECISION MAKING CIRCUIT (LIKE GATES WITH TWO OR MORE INPUTS). A CLOSE RELATIVE OF THE INVERTER IS THE BUFFER, A NON-INVERTING CIRCUIT THAT ISOLATES GATES FROM OTHER CIRCUITS OR ALLOWS THEM TO DRIVE HIGHER THAN NORMAL LOADS. THREE-STATE INVERTERS AND BUFFERS HAVE AN OUTPUT THAT CAN BE ELECTRONICALLY DISCONNECTED FROM THE REMAINDER OF THE CIRCUIT. THE OUTPUT IS THEN NEITHER HIGH NOR LOW. INSTEAD IT "FLOATS" AND APPEARS AS A VERY HIGH RESISTANCE.

☐ BUFFER



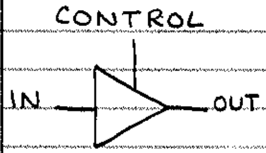
IN	OUT
L	L
H	H

☐ INVERTER ("NOT" GATE)



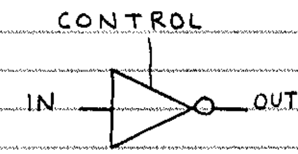
IN	OUT
L	H
H	L

☐ 3-STATE BUFFER



CONTROL	IN	OUT
L	L	L
L	H	H
H	X	HI-Z

☐ 3-STATE INVERTER



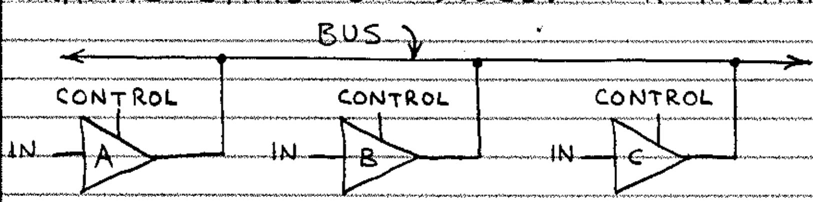
CONTROL	IN	OUT
L	L	H
L	H	L
H	X	HI-Z

"X" MEANS "DOESN'T MATTER." HI-Z MEANS HIGH OUTPUT RESISTANCE.

DATA "HIGHWAYS"

OFTEN CIRCUITS MADE FROM GATES EXCHANGE INFORMATION (BINARY 0'S AND 1'S ENCODED AS LOW AND HIGH VOLTAGE LEVELS). THE INFORMATION IS USUALLY SENT OVER WIRES CALLED BUSES. A BUS IS LIKE A DATA HIGHWAY. IT MAY BE ONE WIRE THROUGH WHICH INFORMATION IS SENT SERIALLY (BIT BY BIT). OR IT MAY BE UP TO EIGHT (OR MORE) WIRES THROUGH WHICH INFORMATION IS SENT IN PARALLEL (A BYTE OR MORE AT A TIME). IN BOTH CASES, OF COURSE, A GROUND IS REQUIRED TO COMPLETE THE CIRCUIT.

☐ 3-STATE TRAFFIC COPS — 3-STATE GATES CAN STOP "TRAFFIC JAMS" ON BUSES. FOR INSTANCE:



ONLY DATA ENTERING THE SELECTED BUFFER (CONTROL = L) GETS ON THE BUS.

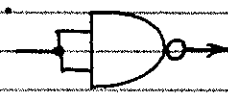
HOW GATES ARE USED

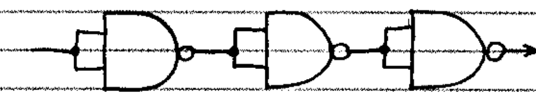
GATES CAN BE USED INDIVIDUALLY OR CONNECTED TOGETHER TO FORM A "NETWORK" OF GATES CALLED A LOGIC CIRCUIT. ALMOST ALL LOGIC CIRCUITS CAN BE PLACED IN ONE OF TWO CATEGORIES: COMBINATIONAL OR SEQUENTIAL.

COMBINATIONAL LOGIC CIRCUITS

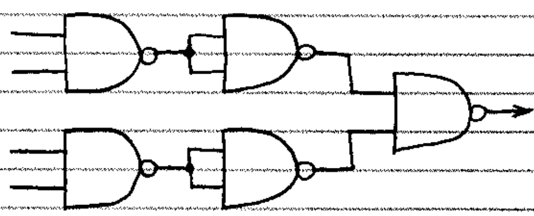
COMBINATIONAL LOGIC CIRCUITS RESPOND TO INCOMING DATA (0's AND 1's) ALMOST IMMEDIATELY AND WITHOUT REGARD TO EARLIER EVENTS. (THIS WILL MAKE MORE SENSE WHEN YOU READ ABOUT SEQUENTIAL CIRCUITS...) COMBINATIONAL LOGIC CIRCUITS CAN BE VERY SIMPLE OR IMMENSELY COMPLICATED. VIRTUALLY ANY COMBINATIONAL CIRCUIT CAN BE IMPLEMENTED WITH ONLY "NAND" OR "NOR" GATES. LIKE THESE "NAND" GATE CIRCUITS...

INVERTERS

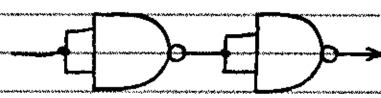




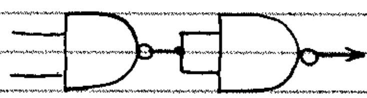
4-INPUT "NAND" GATE



BUFFER

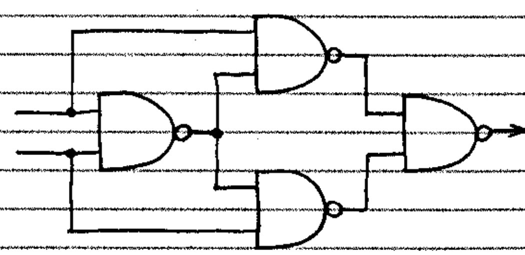


"AND" GATE

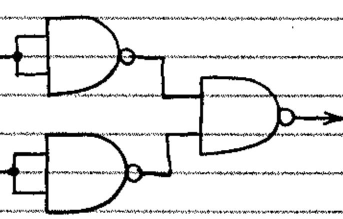


NOTE: THESE CIRCUITS DO NOT SHOW THE GROUND CONNECTION THAT MUST BE PRESENT. USUALLY THE GROUND IS COMMON TO THE INPUT AND OUTPUT.

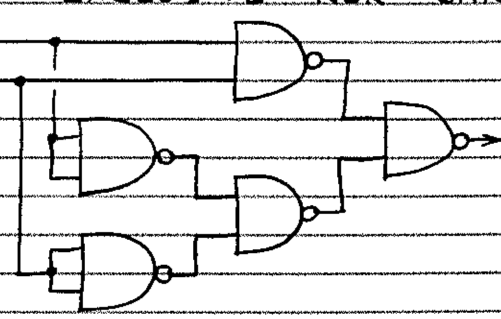
"EXCLUSIVE-OR" GATE



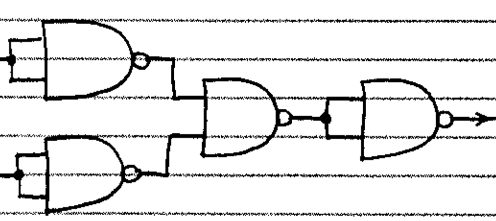
"OR" GATE



"EXCLUSIVE - NOR" GATE

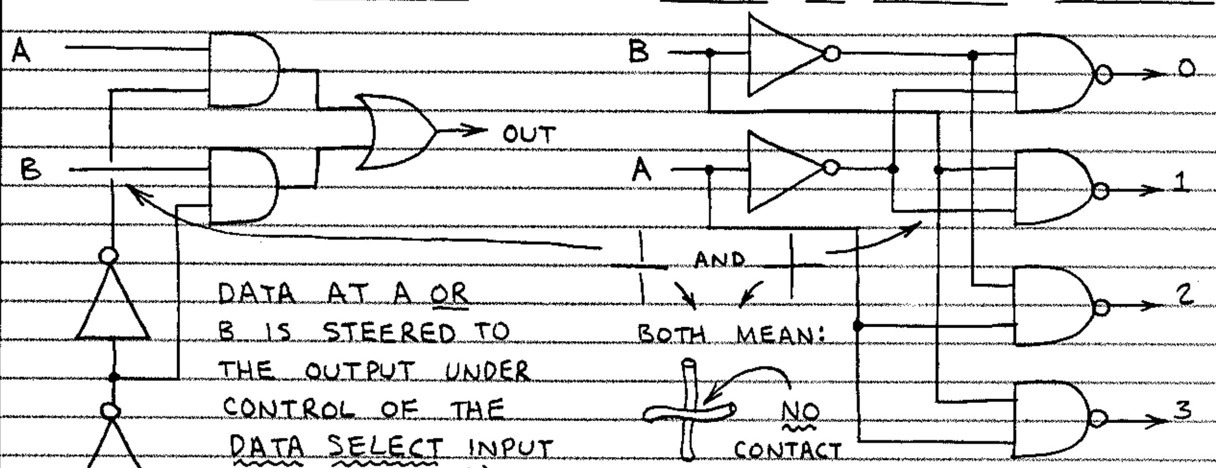


"NOR" GATE



☐ COMBINING DIFFERENT GATES — HERE ARE TWO EXAMPLES OF COMBINATIONAL NETWORKS THAT USE MORE THAN ONE KIND OF GATE. (REMEMBER, BOTH THESE CIRCUITS CAN ALSO BE MADE ENTIRELY FROM "NAND" GATES!)

DATA SELECTOR — BINARY TO DECIMAL DECODER



DATA AT A OR B IS STEERED TO THE OUTPUT UNDER CONTROL OF THE DATA SELECT INPUT (THE "ADDRESS").

THIS CIRCUIT CAN BE EXPANDED TO INCLUDE MANY MORE INPUTS AND ADDRESSES.

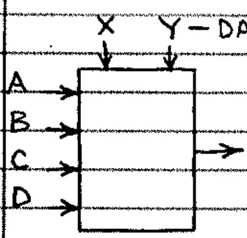
DATA SELECT:
L SELECTS A
H SELECTS B

THIS CONVERTS A TWO-BIT BINARY NUMBER TO ITS DECIMAL EQUIVALENT.

A	B	0	1	2	3
L	L	L	H	H	H
L	H	H	L	H	H
H	L	H	H	L	H
H	H	H	H	H	L

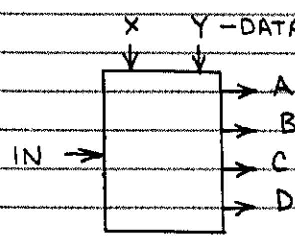
☐ ADVANCED COMBINATIONAL NETWORKS — HERE ARE SOME SIMPLE EXAMPLES FROM FOUR MAJOR FAMILIES OF COMBINATIONAL NETWORKS. THESE AND MANY OTHER NETWORK FAMILIES ARE AVAILABLE AS INTEGRATED CIRCUITS. BOXES LIKE THOSE SHOWN ARE LOGIC CIRCUIT SYMBOLS THAT REPRESENT COMPLICATED NETWORKS OF GATES.

MULTIPLEXER (DATA SELECTOR)



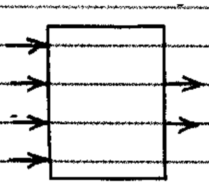
X	Y	OUT
L	L	A
L	H	B
H	L	C
H	H	D

DEMULTIPLEXER



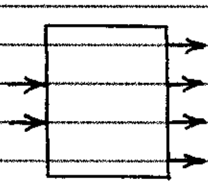
X	Y	IN TO...
L	L	A
L	H	B
H	L	C
H	H	D

ENCODER



CONVERTS DECIMAL AND OTHER DATA TO BINARY. USES "OR" GATES.

DECODER



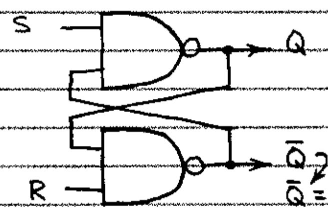
CONVERTS BINARY TO DECIMAL AND BCD TO DECIMAL DIGITS ON DIGITAL READOUTS.

SEQUENTIAL LOGIC CIRCUITS

THE OUTPUT STATE OF A SEQUENTIAL LOGIC CIRCUIT IS DETERMINED BY THE PREVIOUS STATE OF THE INPUT. IN OTHER WORDS, BITS OF DATA MOVE THROUGH SEQUENTIAL CIRCUITS STEP-BY-STEP. OFTEN THE DATA ADVANCES ONE STEP WHEN A PULSE IS RECEIVED FROM A "CLOCK" (A CIRCUIT THAT EMITS A STEADY STREAM OF PULSES). THE SEQUENTIAL LOGIC BUILDING BLOCK IS THE FLIP-FLOP. HERE'S A QUICK FLIP-FLOP REVIEW:

□ THE BASIC "RS" (RESET-SET) FLIP-FLOP

ALSO CALLED A LATCH. THE OUTPUTS (Q AND $\bar{Q}$) ARE ALWAYS IN OPPOSITE STATES. ($\bar{Q}$ MEANS "NOT Q".)

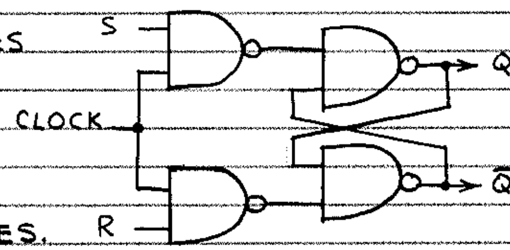


S	R	Q	$\bar{Q}$
L	L	(DISALLOWED)	
L	H	H	L
H	L	L	H
H	H	NO CHANGE	

$\bar{Q}$ = NOT Q (IF Q = 0, $\bar{Q}$ = 1).

□ CLOCKED "RS" FLIP-FLOP

THIS LATCH IGNORES DATA AT S AND R UNTIL A "CLOCK" (OR ENABLE) PULSE ARRIVES. THEN IT CHANGES STATES.

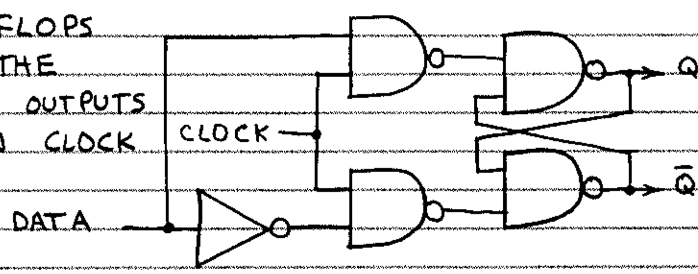


S	R	Q	$\bar{Q}$
L	L	NO CHANGE	
L	H	L	H
H	L	H	L
H	H	(DISALLOWED)	

VALID AFTER CLOCK PULSE ARRIVES.

□ "D" (DATA OR DELAY) FLIP-FLOP

D FLIP-FLOPS STORE THE CURRENT OUTPUTS BETWEEN CLOCK PULSES.

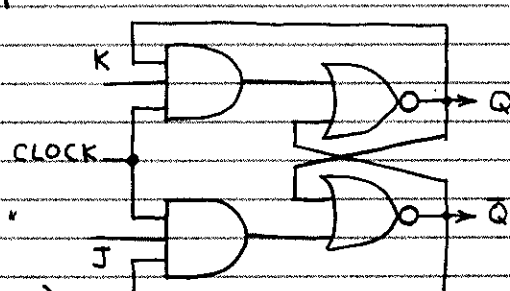


D	Q	$\bar{Q}$
L	L	H
H	H	L
	(OR)	
0	0	1
1	1	0

VALID AFTER CLOCK PULSE ARRIVES.

□ "JK" FLIP-FLOP

THE "JK" FLIP-FLOP ALLOWS BOTH INPUTS TO BE H. (IN WHICH CASE ITS OUTPUTS "TOGGLE" OR SWITCH STATES AT EACH CLOCK PULSE.)

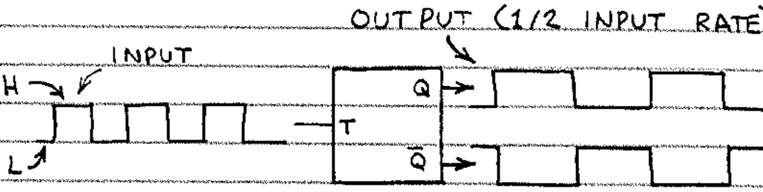


J	K	Q	$\bar{Q}$
L	L	NO CHANGE	
L	H	L	H
H	L	H	L
H	H	"TOGGLE"	

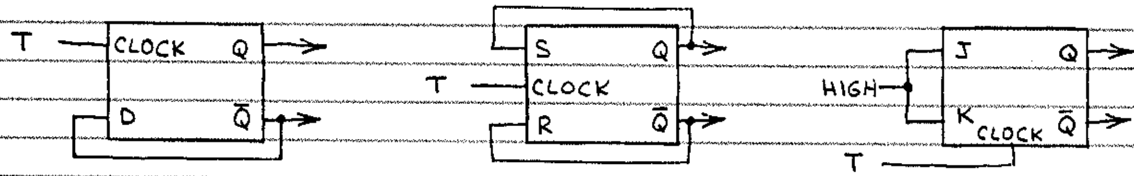
VALID AFTER CLOCK PULSE ARRIVES.

☐ "T" (TOGGLE) FLIP-FLOP

THE Q (OR $\bar{Q}$) OUTPUT IS L (OR H) FOR EVERY OTHER INPUT PULSE. THEREFORE THE INPUT PULSES ARE DIVIDED BY TWO.



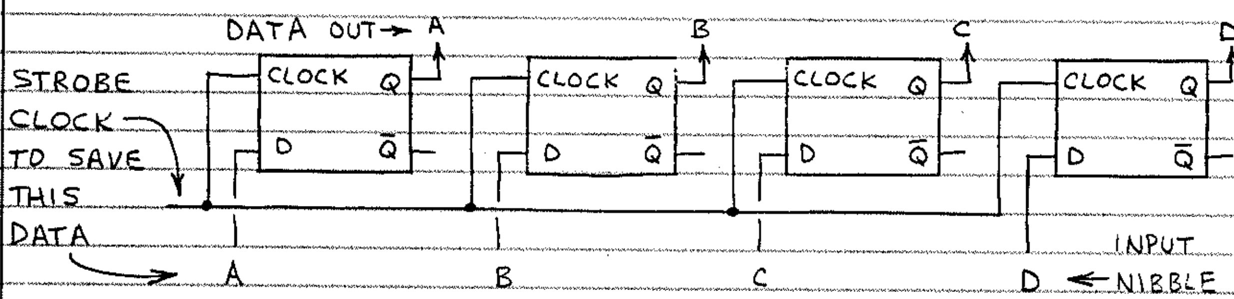
HERE ARE SEVERAL WAYS TO MAKE A "T" FLIP-FLOP:



"D" FLIP-FLOP CLOCKED "RS" FLIP-FLOP JK FLIP-FLOP

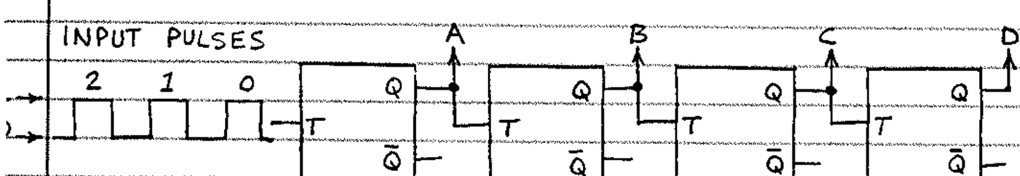
☐ "D" FLIP-FLOP DATA STORAGE REGISTER

HERE'S HOW FOUR "D" FLIP-FLOPS FORM A STORAGE REGISTER OR MEMORY THAT "LOADS" (SAVES) THE 4-BIT BINARY NIBBLE AT INPUTS A-D WHEN THE "CLOCK" INPUT IS "STROBED" (PULSED). MANY TYPES OF IC REGISTERS ARE AVAILABLE.



☐ "T" FLIP-FLOP COUNTER

HERE'S HOW FOUR "T" FLIP-FLOPS FORM A 4-BIT BINARY COUNTER:



EACH "T" FLIP-FLOP DIVIDES INCOMING PULSES BY TWO. AS THE BINARY TRUTH TABLE REVEALS, THE RESULT IS A 0000 → 1111 BINARY COUNT. (THE COUNT RECYCLES TO 0000 AFTER THE 16TH INCOMING PULSE.) THERE ARE MANY TYPES OF IC COUNTERS, MOST OF WHICH INCLUDE SPECIAL FEATURES (COUNT UP OR DOWN, RESET, ETC.).

COUNT	D C B A
0	0 0 0 0
1	0 0 0 1
2	0 0 1 0
3	0 0 1 1
4	0 1 0 0
5	0 1 0 1
6	0 1 1 0
7	0 1 1 1
8	1 0 0 0
9	1 0 0 1
10	1 0 1 0
11	1 0 1 1
12	1 1 0 0
13	1 1 0 1
14	1 1 1 0
15	1 1 1 1

A COMBINATIONAL – SEQUENTIAL LOGIC SYSTEM

HERE'S HOW COMBINATIONAL AND SEQUENTIAL LOGIC IC's CAN FORM A DECIMAL COUNTING CIRCUIT, A VERY SIMPLE DIGITAL LOGIC SYSTEM.

1. THE BLOCK DIAGRAM

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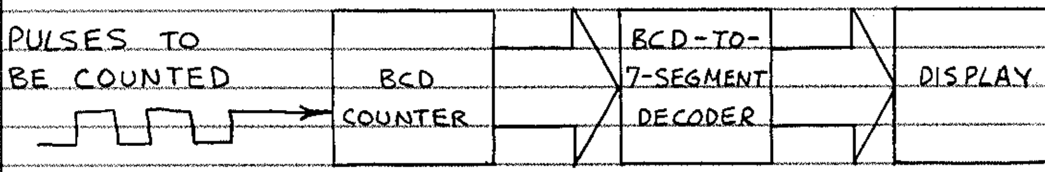
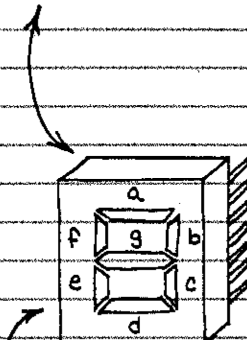
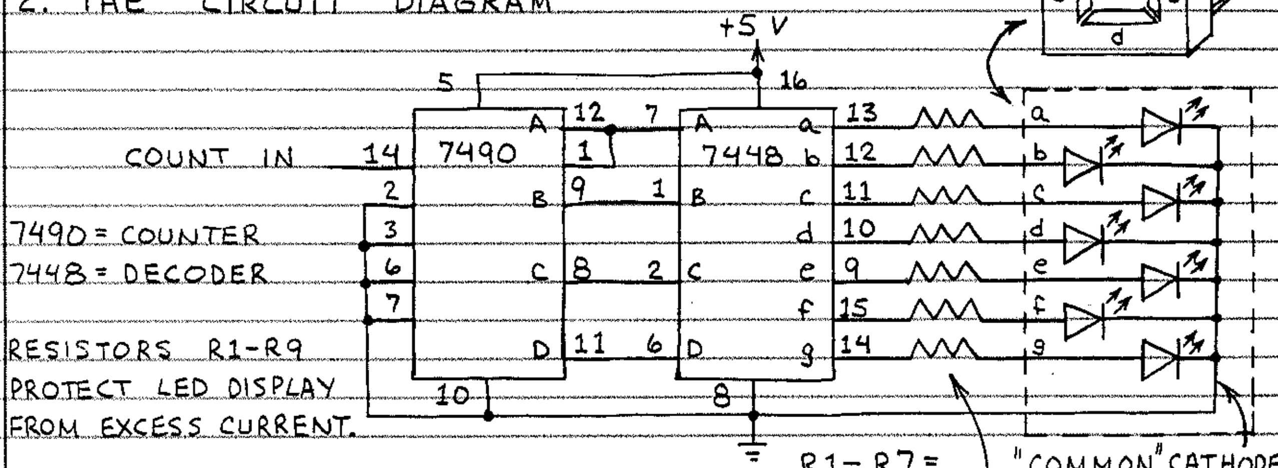


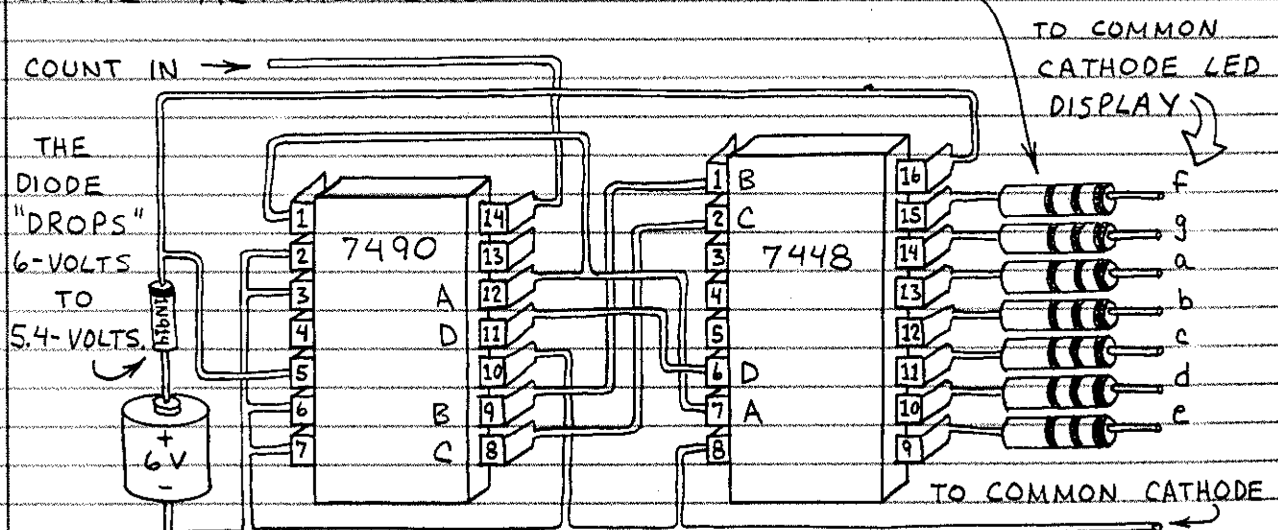
THE BCD COUNTER ADVANCES ONE COUNT FOR EACH INCOMING PULSE. WHEN THE COUNT REACHES 1001 (DECIMAL 9), THE COUNTER RECYCLES TO 0000. THE DECODER ACTIVATES THE APPROPRIATE SEGMENTS OF AN LED DISPLAY.



2. THE CIRCUIT DIAGRAM

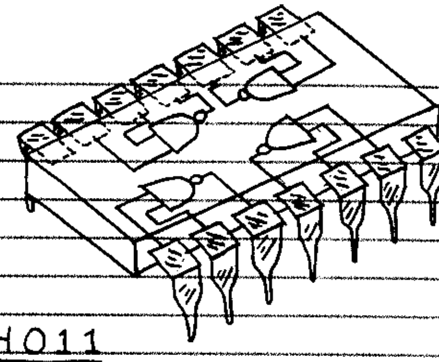


3. THE ACTUAL CIRCUIT



DIGITAL IC FAMILIES

THERE ARE MORE THAN A DOZEN MAJOR FAMILIES OF BIPOLAR AND MOS INTEGRATED CIRCUITS. EACH IC (OR "CHIP") CONTAINS A SPECIFIC LOGIC NETWORK OR ASSORTMENT OF VARIOUS LOGIC FUNCTIONS. HERE ARE SOME OF THE MAJOR DIGITAL IC FAMILIES:



4011

A "QUAD" (FOUR) OF 2-INPUT CMOS "NAND" GATES

☐ BIPOLAR DIGITAL IC's

1. TRANSISTOR-TRANSISTOR LOGIC (TTL OR T^2L). THE LARGEST AND FORMERLY MOST POPULAR DIGITAL IC FAMILY. CAN CHANGE STATES MORE THAN 20,000,000 TIMES PER SECOND. VERY INEXPENSIVE. DRAWBACKS: MUST BE POWERED BY 5-VOLT SUPPLY. USES LOTS OF POWER. (INDIVIDUAL GATES REQUIRE 3 OR 4 MILLIAMPERES.) MOST WIDELY USED IS THE 7400 SERIES. THE 7404, FOR EXAMPLE, CONTAINS FOUR INVERTERS.

2. LOW-POWER SCHOTTKY TTL (LS). A NEWER KIND OF TTL THAT CONSUMES ONLY 20% AS MUCH POWER. DRAWBACK: MORE EXPENSIVE THAN STANDARD TTL. MOST WIDELY USED IS THE 74LS00 SERIES.

☐ MOSFET DIGITAL IC's

1. P- AND N-CHANNEL MOS (PMOS AND NMOS). CONTAIN MORE GATES PER CHIP THAN TTL. MANY SPECIAL PURPOSE CHIPS (MICROPROCESSORS, MEMORIES, ETC.). DRAWBACKS: FEW COUNTERPARTS TO POPULAR TTL CHIPS. SLOWER THAN TTL. MAY REQUIRE TWO OR MORE SUPPLY VOLTAGES. MAY BE DAMAGED BY STATIC ELECTRICAL DISCHARGE.

2. COMPLEMENTARY MOS (CMOS). FASTEST GROWING AND MOST VERSATILE DIGITAL IC FAMILY. THERE ARE CMOS VERSIONS OF MOST POPULAR TTL CHIPS. ONE SERIES USES THE SAME DESIGNATION NUMBERS. THE 74C04, FOR EXAMPLE, IS THE CMOS EQUIVALENT OF THE TTL 7404. NEW HIGH-SPEED CMOS JUST AS FAST AS TTL. MOST CMOS HAS A WIDE SUPPLY VOLTAGE RANGE (TYPICALLY +3 TO +18 VOLTS). USES LESS POWER THAN ANY OTHER DIGITAL IC FAMILY. (INDIVIDUAL GATES REQUIRE 0.1 MILLIAMPERE.) DRAWBACK: MAY BE DAMAGED BY STATIC ELECTRICAL DISCHARGE. MOST WIDELY USED ARE 74C00 AND 4000 SERIES.