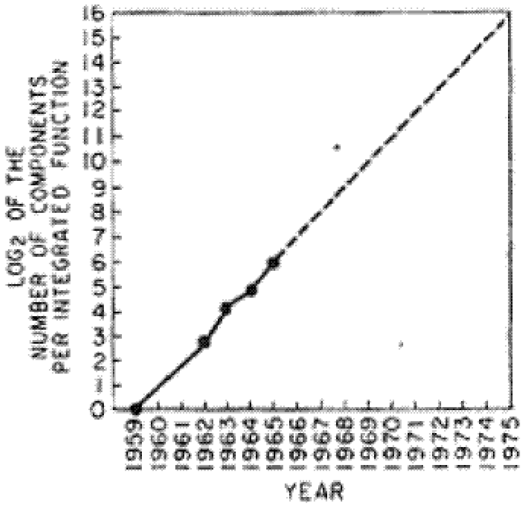
History of Intel microprocessors

Processor	Transistor count	Date of introduction	Process
Intel 4004	2,300	1971	10 µm
Intel 8008	3,500	1972	10 µm
Intel 8080	4,500	1974	6 µm
Intel 8085	6,500	1976	3 µm
Zilog Z80	8,500	1976	4 µm
Intel 8086	29,000	1978	3 µm
Intel 8088	29,000	1979	3 µm
Intel 80186	55,000	1982	
Intel 80286	134,000	1982	1.5 µm
Intel 80386	275,000	1985	1.5 µm
Intel 80486	1,180,000	1989	1 µm
Pentium	3,100,000	1993	0.8 µm
Pentium II	7,500,000	1997	0.35 µm
Pentium III	9,500,000	1999	0.25 µm
Pentium 4	42,000,000	2000	180 nm
Atom	47,000,000	2008	45 nm
Itanium 2	220,000,000	2003	130 nm
Core 2 Duo	291,000,000	2006	65 nm
Itanium 2 with 9MB cache	592,000,000	2004	130 nm
Core i7 (Quad)	731,000,000	2008	45 nm
Six-Core Xeon 7400	1,900,000,000	2008	45 nm
Six-Core Core i7	1,170,000,000	2010	32 nm
Dual-Core Itanium 2	1,700,000,000	2006	90 nm
Quad-Core Itanium Tukwila	2,000,000,000	2010	65 nm
8-Core Xeon Nehalem-EX	2,300,000,000	2010	45 nm

Moore's law



The complexity for minimum component costs has increased at a rate of roughly a factor of two per year (see graph on next page). Certainly over the short term this rate can be expected to continue, if not to increase. Over the longer term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least 10 years. That means by 1975, the number of components per integrated circuit for minimum cost will be 65,000.

I believe that such a large circuit can be built on a single wafer.

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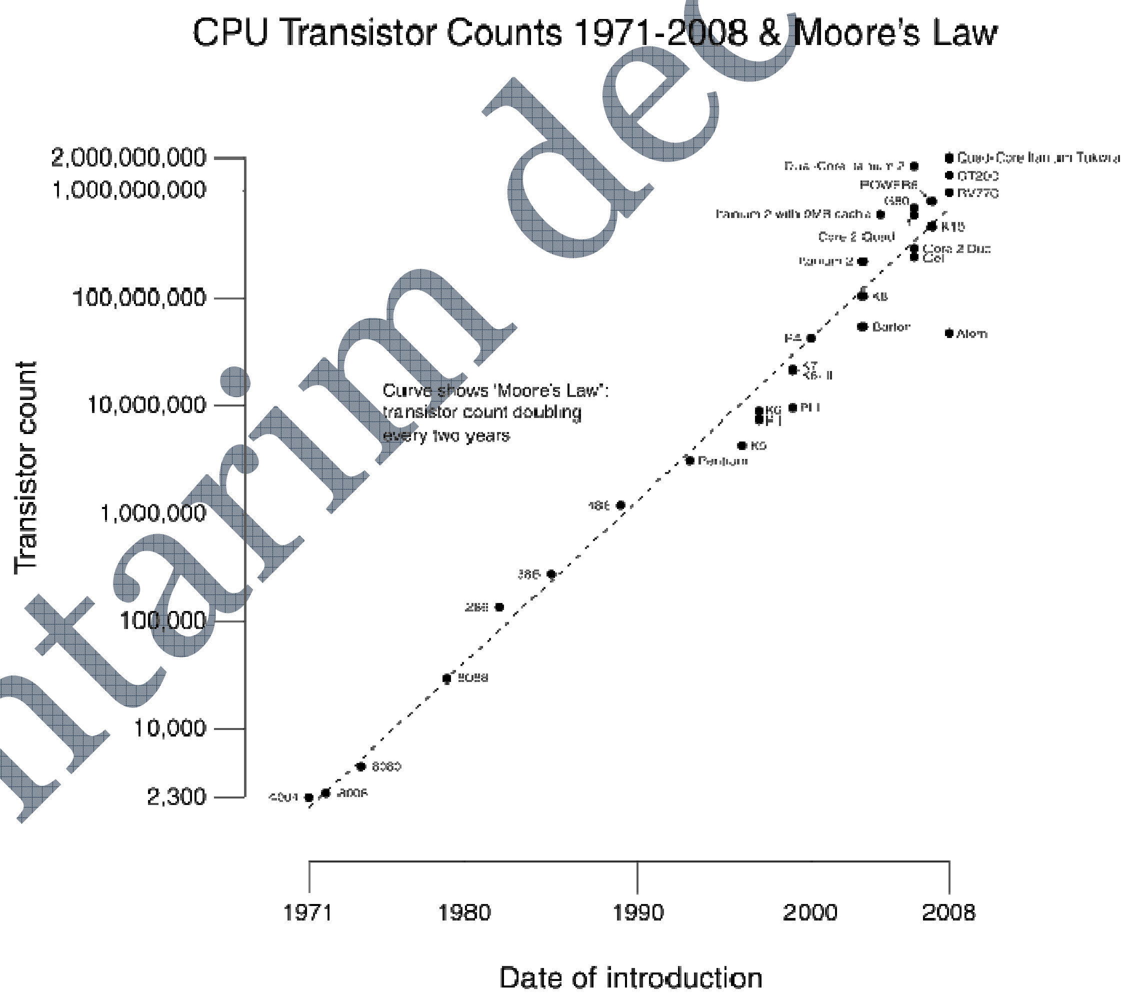
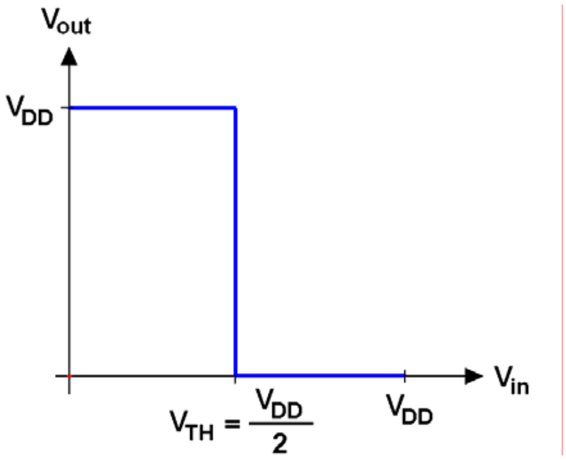
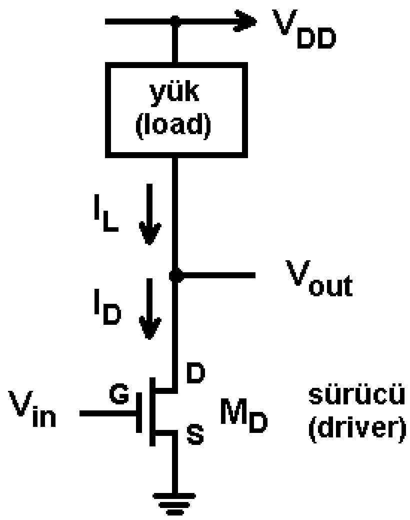
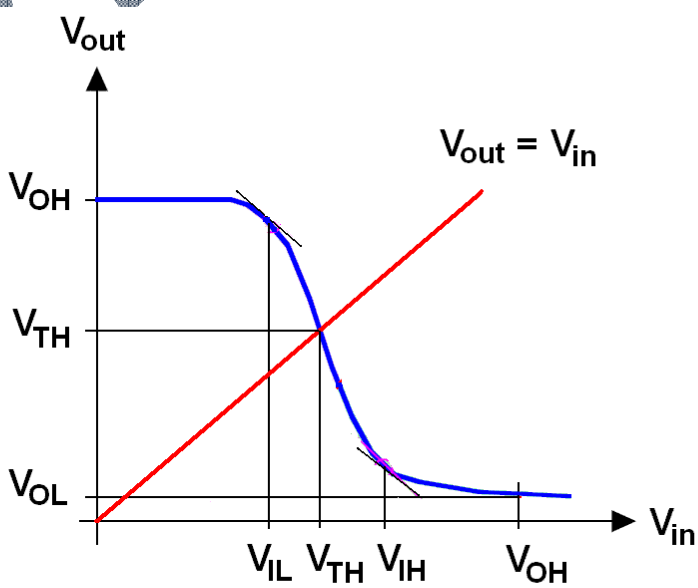




Voltage transfer characteristic (VTC) of an ideal inverter

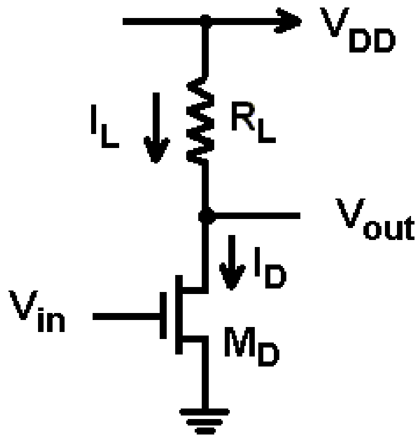


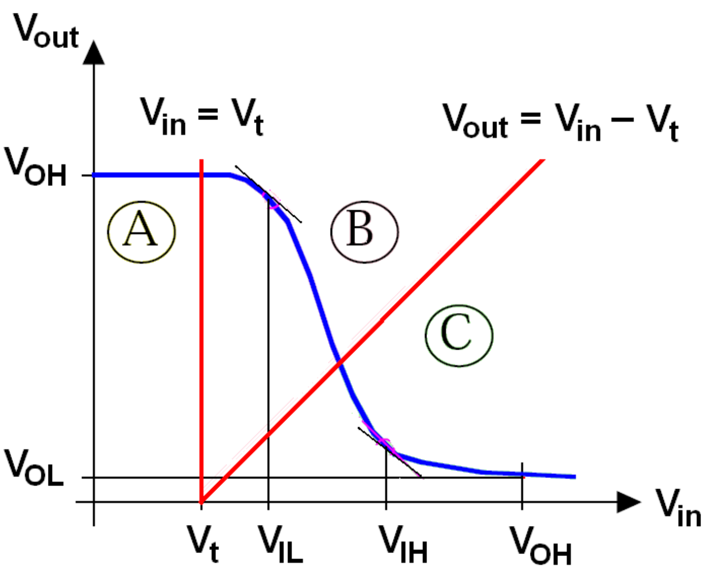
General structure of an inverter



VTC of a real inverter

Inverters with resistive load





$$V_{OH} = V_{DD}$$

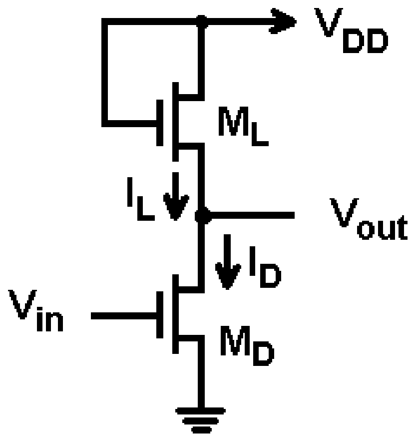
$$V_{OL} = V_{DD} - V_t + \frac{1}{k_D R_L} \pm \sqrt{\left(V_{DD} - V_t + \frac{1}{k_D R_L}\right)^2 - \frac{2V_{DD}}{k_D R_L}}$$

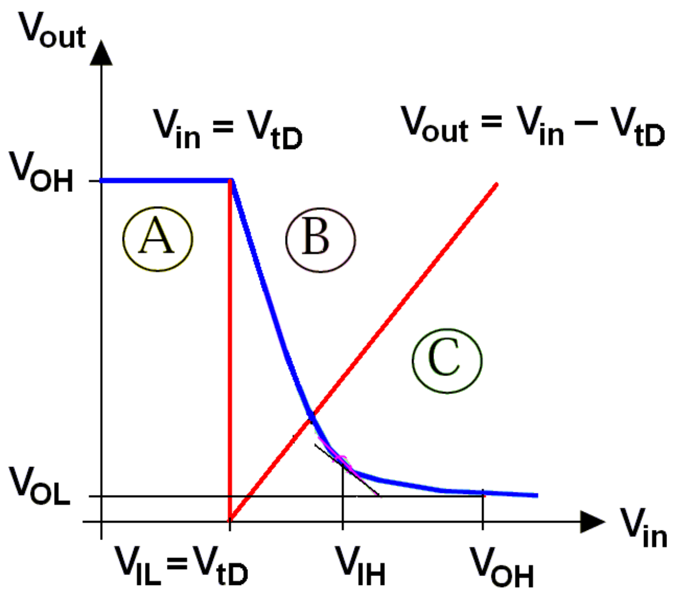
$$V_{IH} = V_t + 2\sqrt{\frac{2V_{DD}}{3k_D R_L}} - \frac{1}{k_D R_L}, \quad V_{out}(V_{IH}) = \sqrt{\frac{2V_{DD}}{3k_D R_L}}$$

$$V_{IL} = V_t + \frac{1}{k_D R_L}, \quad V_{out}(V_{IL}) = V_{DD} - \frac{1}{2k_D R_L}$$

$$V_{TH} = V_t - \frac{1}{k_D R_L} + \sqrt{\left(V_t - \frac{1}{k_D R_L}\right)^2 + \frac{2V_{DD}}{k_D R_L} - V_t^2}$$

Inverters with saturated enhancement-mode NMOS loads





$$V_{OH} = V_{DD} - V_{tL}\,,\quad V_{tL} = V_{toL} + \gamma\left(\sqrt{V_{OH} + 2|\phi_F|} - \sqrt{2|\phi_F|}\right)$$

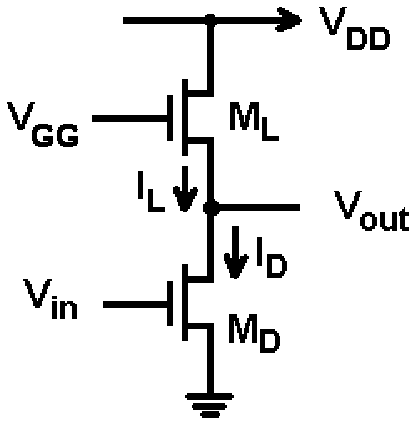
$$V_{OH} = V_{tD} + \frac{1}{2}V_{OL} + \frac{(V_{DD} - V_{OL} - V_{tL})^2}{2k_R V_{OL}}\,,\quad V_{tL} = V_{toL} + \gamma\left(\sqrt{V_{OL} + 2|\phi_F|} - \sqrt{2|\phi_F|}\right),\quad k_R = \frac{k_D}{k_L}$$

$$k_R >> 1 \Rightarrow\quad V_{IH} = V_{tD} + \frac{2(V_{DD} - V_{tL})}{\sqrt{3k_R} + 1}\,,\quad V_{out} = \frac{1}{2}(V_{IH} - V_{tD})\,,\quad V_{tL} = V_{toL} + \gamma\left(\sqrt{V_{out} + 2|\phi_F|} - \sqrt{2|\phi_F|}\right)$$

$$V_{IL} = V_{tD}$$

$$V_{TH} = \frac{V_{DD} + \sqrt{k_R}V_{tD} - V_{tL}}{1 + \sqrt{k_R}}\,,\quad V_{tL} = V_{toL} + \gamma\left(\sqrt{V_{TH} + 2|\phi_F|} - \sqrt{2|\phi_F|}\right)$$

Inverters with nonsaturated enhancement-mode NMOS loads



$$V_{OH} = V_{DD}$$

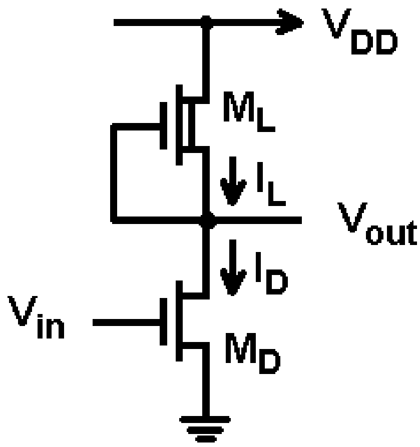
$$V_{OH} = V_{tD} + \frac{1}{2}V_{OL} + \frac{2(V_{GG} - V_{OL} - V_{tL})(V_{DD} - V_{OL}) - (V_{DD} - V_{OL})^2}{2k_R V_{OL}}, \quad V_{tL} = V_{toL} + \gamma\left(\sqrt{V_{OL} + 2|\phi_F|} - \sqrt{2|\phi_F|}\right)$$

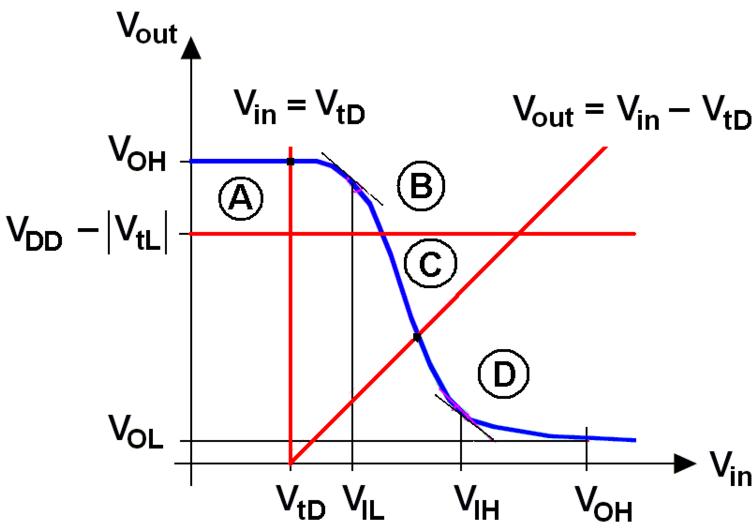
$$V_{IH} = V_{tD} + \frac{2k_R + 1}{k_R}V_{out} - \frac{V_{GG} - V_{tL}}{k_R}, \quad V_{out} = \sqrt{\frac{2(V_{GG} - V_{tL})V_{DD} - V_{DD}^{\ 2}}{3k_R + 1}}, \quad V_{tL} = f(V_{out})$$

$$V_{IL} = V_{tD} + \frac{V_{GG} - V_{tL} - V_{out}}{k_R}, \quad V_{out} = V_{GG} - V_{tL} - \frac{k_R}{\sqrt{k_R(k_R - 1)}}(V_{GG} - V_{DD} - V_{tL}), \quad V_{tL} = f(V_{out})$$

$$k_R = \frac{2(V_{GG} - V_{tL} - V_{TH})(V_{DD} - V_{TH}) - (V_{DD} - V_{TH})^2}{(V_{TH} - V_{tD})^2}, \quad V_{tL} = f(V_{TH})$$

Inverters with depletion-mode NMOS loads





$$V_{OH} = V_{DD}$$

$$V_{OL} = V_{OH} - V_{tD} \pm \sqrt{(V_{OH} - V_{tD})^2 - \frac{|V_{tL}|^2}{k_R}}, \quad V_{tL} = V_{toL} + \gamma_L \left(\sqrt{V_{OL} + 2|\phi_{FL}|} - \sqrt{2|\phi_{FL}|} \right)$$

$$V_{IH} = V_{tD} + 2V_{out} + \frac{\eta |V_{tL}|}{k_R}, \quad V_{out} = \frac{|V_{tL}|}{\sqrt{3k_R}}, \quad V_{tL} = f(V_{out}), \quad \eta = \frac{\gamma_L}{2\sqrt{V_{out} + 2|\phi_{FL}|}}$$

$$V_{IL} = V_{tD} + \frac{|V_{tL}|}{\sqrt{k_R(k_R+1)}}, \quad V_{out} = V_{DD} - |V_{tL}| \left(1 - \frac{k_R}{\sqrt{k_R(k_R+1)}} \right), \quad V_{tL} = f(V_{out})$$

$$V_{TH} = V_{tD} + \frac{|V_{tL}|}{\sqrt{k_R}}, \quad V_{tL} = f(V_{TH}) \quad \textbf{or} \quad k_R = \frac{2|V_{tL}|(V_{DD} - V_{TH}) - (V_{DD} - V_{TH})^2}{(V_{TH} - V_{tD})^2}, \quad V_{tL} = f(V_{TH})$$

CMOS inverters