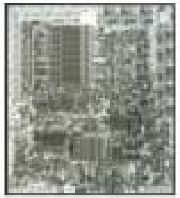
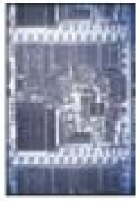
Intel® Microprocessors.

4004 Processor
Introduced: **1971**
Initial clock speed: 108 KHz
Number of transistors: 2,300
Circuit line width: 10 micron

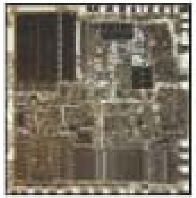
8008 Processor
Introduced: **1972**
Initial clock speed: 500-800 KHz
Number of transistors: 3,500
Circuit line width: 10 micron



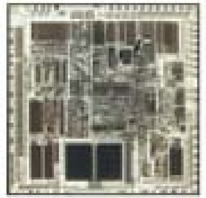
8080 Processor
Introduced: **1974**
Initial clock speed: 2 MHz
Number of transistors: 4,500
Circuit line width: 6 micron



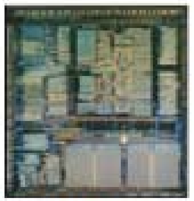
8086 Processor
Introduced: **1978**
Initial clock speed: 5 MHz
Number of transistors: 29,000
Circuit line width: 3 micron



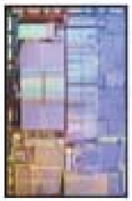
8088 Processor
Introduced: **1979**
Initial clock speed: 5 MHz
Number of transistors: 29,000
Circuit line width: 3 micron



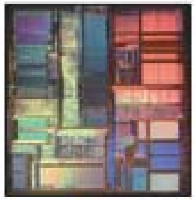
Intel286 Processor
Introduced: **1982**
Initial clock speed: 6 MHz
Number of transistors: 134,000
Circuit line width: 1.5 micron



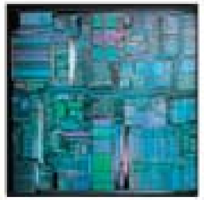
Intel386™ Processor
Introduced: **1985**
Initial clock speed: 16 MHz
Number of transistors: 275,000
Circuit line width: 1.5 micron



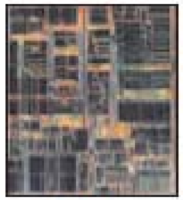
Intel486™ Processor
Introduced: **1989**
Initial clock speed: 25 MHz
Number of transistors: 1.2 million
Circuit line width: 1 micron



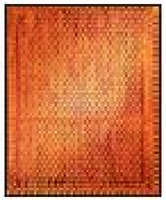
Pentium® Processor
Introduced: **1993**
Initial clock speed: 66 MHz
Number of transistors: 3.1 million
Circuit line width: 0.8 micron



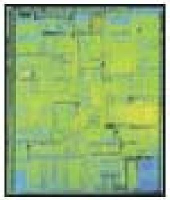
Pentium® Pro Processor
Introduced: **1995**
Initial clock speed: 200 MHz
Number of transistors: 5.5 million
Circuit line width: 0.35 micron



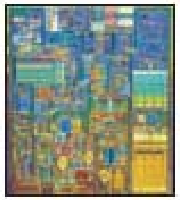
Pentium® II Processor
Introduced: **1997**
Initial clock speed: 300 MHz
Number of transistors: 7.5 million
Circuit line width: 0.25 micron



Celeron® Processor
Introduced: **1998**
Initial clock speed: 266 MHz
Number of transistors: 7.5 million
Circuit line width: 0.25 micron

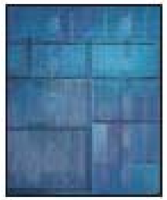


Pentium® III Processor
Introduced: **1999**
Initial clock speed: 500 MHz
Number of transistors: 9.5 million
Circuit line width: 0.25 micron

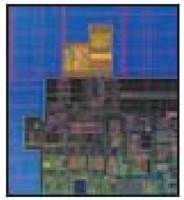


Pentium® 4 Processor
Introduced: **2000**
Initial clock speed: 1.5 GHz
Number of transistors: 42 million
Circuit line width: 0.18 micron

Itanium® Processor
Introduced: **2001**
Initial clock speed: 800 MHz
Number of transistors: 25 million
Circuit line width: 0.18 micron

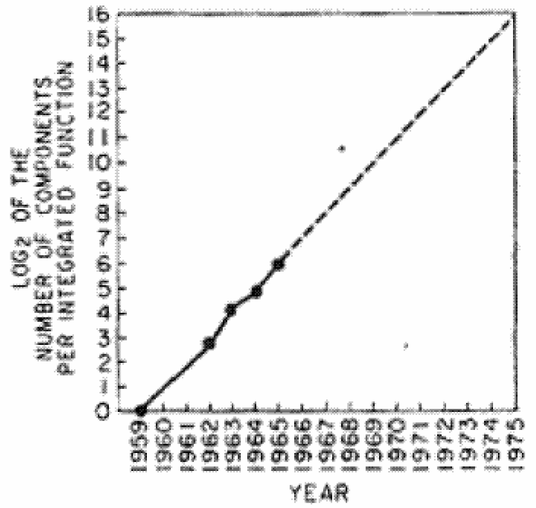


Intel® Xeon™ Processor
Introduced: **2001**
Initial clock speed: 1.7 GHz
Number of transistors: 42 million
Circuit line width: 0.18 micron



Itanium® 2 Processor
Introduced: **2002**
Initial clock speed: 1 GHz
Number of transistors: 220 million
Circuit line width: 0.18 micron

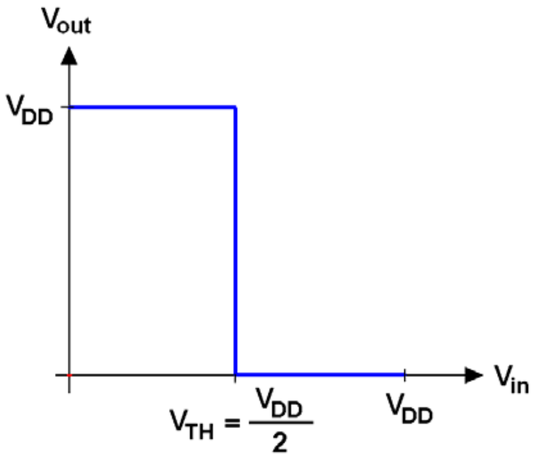
Moore's law



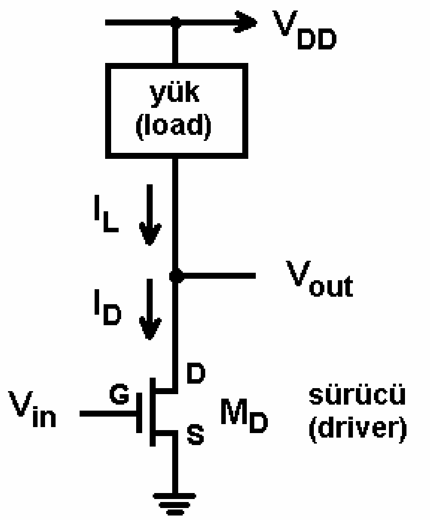
The complexity for minimum component costs has increased at a rate of roughly a factor of two per year (see graph on next page). Certainly over the short term this rate can be expected to continue, if not to increase. Over the longer term, the rate of increase is a bit more uncertain, although there 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.

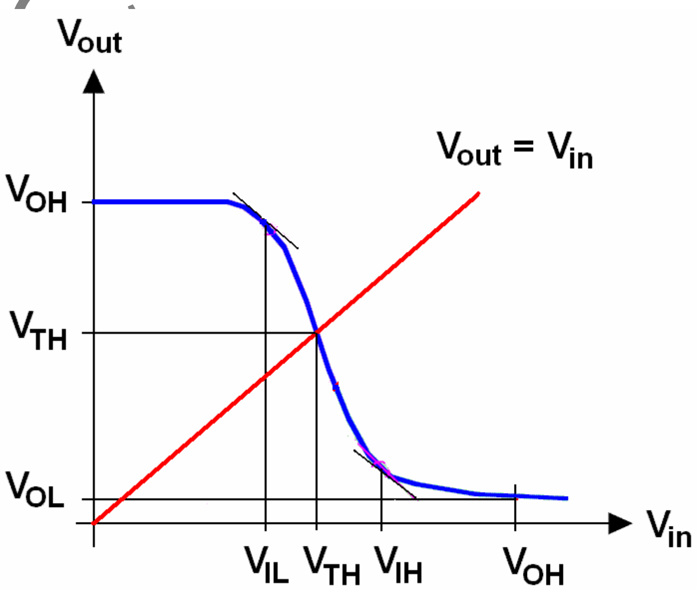
Electronics, Volume 38, Number 8, April 19, 1965



Voltage transfer characteristic (VTC) of an ideal inverter

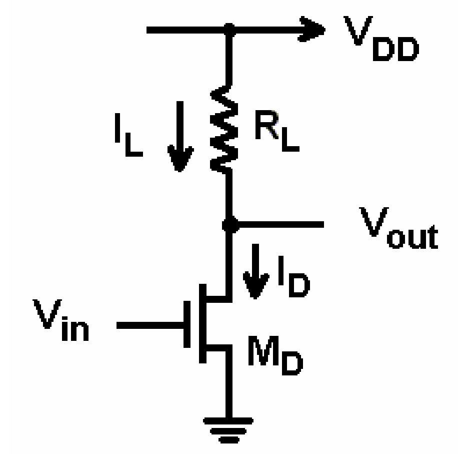


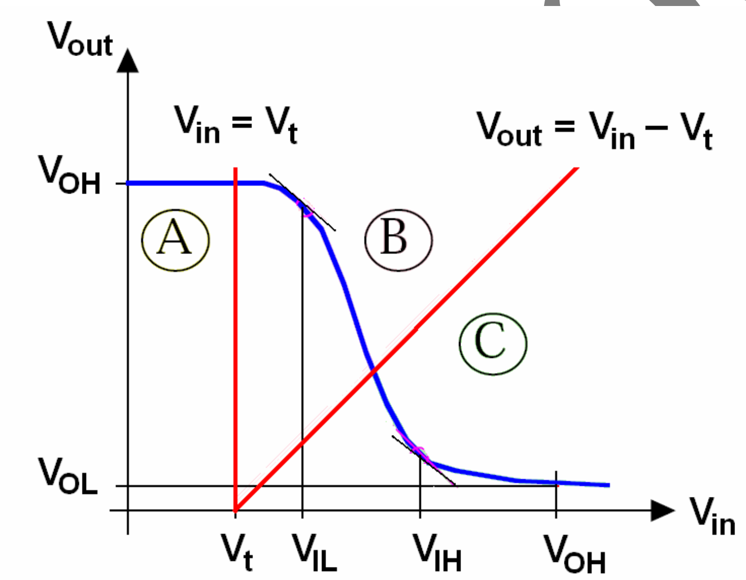
General structure of an inverter



VTC of a real inverter

Inverters with resistive load





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

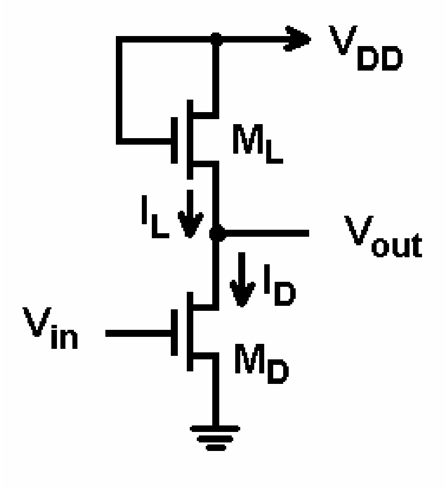
$$V_{OL} = V_{DD} - V_t + \frac{1}{k_D R_L} \pm \sqrt{\left(V_{DD} - V_t + \frac{1}{k_D R_L}\right)^2 - \frac{2V_{DD}}{k_D R_L}}$$

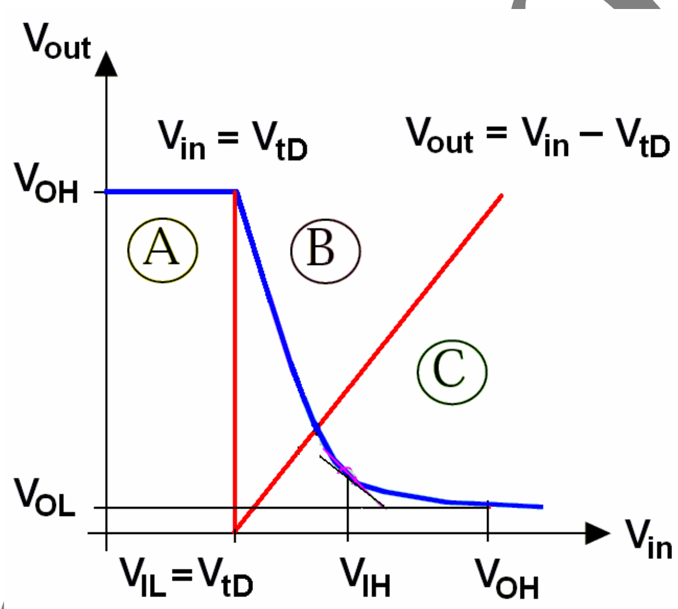
$$V_{IH} = V_t + 2\sqrt{\frac{2V_{DD}}{3k_D R_L}} - \frac{1}{k_D R_L}, \quad V_{out}(V_{IH}) = \sqrt{\frac{2V_{DD}}{3k_D R_L}}$$

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

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

Inverters with saturated enhancement mode MOSFETs





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

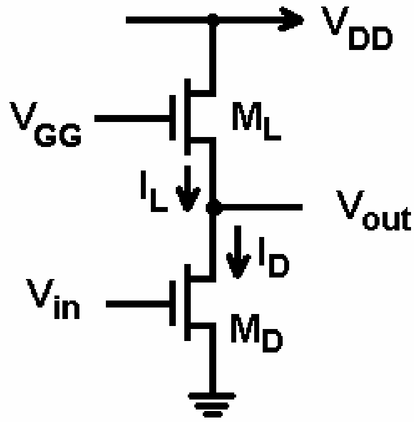
$$V_{OH} = V_{tD} + \frac{1}{2}V_{OL} + \frac{(V_{DD} - V_{OL} - V_{tL})^2}{2k_R V_{OL}}\,, \quad V_{tL} = V_{toL} + \gamma\left(\sqrt{V_{OL} + 2|\phi_F|} - \sqrt{2|\phi_F|}\right), \quad k_R = \frac{k_D}{k_L}$$

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

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

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

Inverters with nonsaturated enhancement mode MOSFETs



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

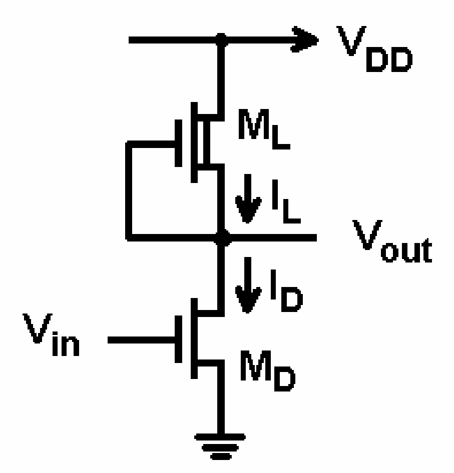
$$V_{OH} = V_{tD} + \frac{1}{2}V_{OL} + \frac{2(V_{GG} - V_{OL} - V_{tL})(V_{DD} - V_{OL}) - (V_{DD} - V_{OL})^2}{2k_R V_{OL}}, \quad V_{tL} = V_{toL} + \gamma\left(\sqrt{V_{OL} + 2|\phi_F|} - \sqrt{2|\phi_F|}\right)$$

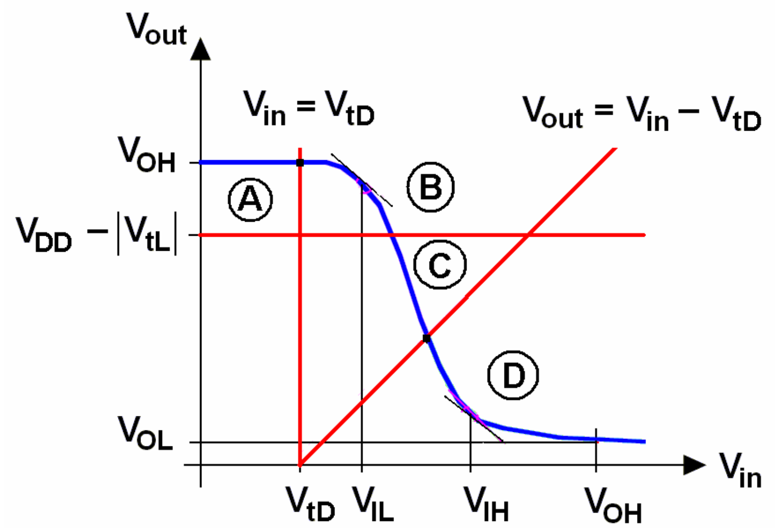
$$V_{IH} = V_{tD} + \frac{2k_R + 1}{k_R}V_{out} - \frac{V_{GG} - V_{tL}}{k_R}, \quad V_{out} = \sqrt{\frac{2(V_{GG} - V_{tL})V_{DD} - V_{DD}{}^2}{3k_R + 1}}, \quad V_{tL} = f(V_{out})$$

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

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

Inverters with depletion mode MOSFETs





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

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

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

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

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

CMOS inverter