Important CMOS Inverters Formulas PDF

Formulas
Examples
with Units

List of 16
Important CMOS Inverters Formulas

1) Average Power Dissipation CMOS Formula

Evaluate Formula

Formula

$$P_{avg} = C_{load} \cdot \left(V_{DD} \right)^2 \cdot f$$

Example with Units

$$0.4041\,\text{mW} = 0.93\,\text{fF} \cdot \left(3.3\,\text{V} \right)^2 \cdot 39.9\,\text{GHz}$$

2) Average Propagation Delay CMOS Formula

Evaluate Formula

Formula

$$\zeta_P = \frac{\zeta_{PHL} + \zeta_{PLH}}{2}$$

Example with Units

$$0.0042\,\text{ns} = \frac{0.00229\,\text{ns} + 0.006182\,\text{ns}}{2}$$

3) Load Capacitance of Cascaded Inverter CMOS Formula

Evaluate Formula

Formula

$$C_{load} = C_{gd,p} + C_{gd,n} + C_{db,p} + C_{db,n} + C_{in} + C_g$$

Example with Units

$$0.93\,\text{fF} = 0.15\,\text{fF} + 0.1\,\text{fF} + 0.25\,\text{fF} + 0.2\,\text{fF} + 0.05\,\text{fF} + 0.18\,\text{fF}$$

4) Maximum Input Voltage CMOS Formula

Evaluate Formula

Formula

$$V_{IL} = \frac{2 \cdot V_{output} + \left(V_{T0,p} \right) - V_{DD} + K_r \cdot V_{T0,n}}{1 + K_r}$$

Example with Units

$$1.08\,\text{V} = \frac{2 \cdot 3.14\,\text{V} + \left(-0.7\,\text{V} \right) - 3.3\,\text{V} + 2.5 \cdot 0.6\,\text{V}}{1 + 2.5}$$

5) Maximum Input Voltage for Symmetric CMOS Formula

Evaluate Formula

Formula

$$V_{IL(sym)} = \frac{3 \cdot V_{DD} + 2 \cdot V_{T0,n}}{8}$$

Example with Units

$$1.3875\,\text{V} = \frac{3 \cdot 3.3\,\text{V} + 2 \cdot 0.6\,\text{V}}{8}$$

6) Minimum Input Voltage CMOS Formula

Evaluate Formula

Formula

$$V_{IH} = \frac{V_{DD} + \left(V_{T0,p}\right) + K_r \cdot \left(2 \cdot V_{out} + V_{T0,n}\right)}{1 + K_r}$$

Example with Units

$$1.5571\,\text{V} = \frac{3.3\,\text{V} + \left(-0.7\,\text{V}\right) + 2.5 \cdot \left(2 \cdot 0.27\,\text{V} + 0.6\,\text{V}\right)}{1 + 2.5}$$

7) Minimum Input Voltage for Symmetric CMOS Formula

Evaluate Formula

Formula

$$V_{IH(sym)} = \frac{5 \cdot V_{DD} - 2 \cdot V_{T0,n}}{8}$$

Example with Units

$$1.9125\,\text{V} = \frac{5 \cdot 3.3\,\text{V} - 2 \cdot 0.6\,\text{V}}{8}$$

8) Noise Margin for High Signal CMOS Formula

Evaluate Formula

Formula

$$N_{MH} = V_{OH} - V_{IH}$$

Example with Units

$$1.8\,\text{V} = 3.35\,\text{V} - 1.55\,\text{V}$$

9) Oscillation Period Ring Oscillator CMOS Formula

Evaluate Formula

Formula

$$T_{osc} = 2 \cdot n \cdot \zeta_P$$

Example with Units

$$0.0252\,\text{ns} = 2 \cdot 3 \cdot 0.0042\,\text{ns}$$

10) Propagation Delay for High to Low Output Transition CMOS Formula

Evaluate Formula

Formula

$$\zeta_{PHL} = \left(\frac{C_{load}}{K_n \cdot \left(V_{DD} - V_{T,n}\right)}\right) \cdot \left(\left(2 \cdot \frac{V_{T,n}}{V_{DD} - V_{T,n}}\right) + \ln\left(\left(4 \cdot \frac{V_{DD} - V_{T,n}}{V_{DD}}\right) - 1\right)\right)$$

Example with Units

$$0.0025\,\text{ns} = \left(\frac{0.93\,\text{fF}}{200\,\mu\text{A/V}^2 \cdot \left(3.3\,\text{V} - 0.8\,\text{V}\right)}\right) \cdot \left(\left(2 \cdot \frac{0.8\,\text{V}}{3.3\,\text{V} - 0.8\,\text{V}}\right) + \ln\left(\left(4 \cdot \frac{3.3\,\text{V} - 0.8\,\text{V}}{3.3\,\text{V}}\right) - 1\right)\right)$$

11) Propagation Delay for Low to High Output Transition CMOS Formula

Evaluate Formula

Formula

$$\zeta_{PLH} = \left(\frac{C_{load}}{K_p \cdot \left(V_{DD} - \left|V_{T,p}\right|\right)}\right) \cdot \left(\left(\frac{2 \cdot \left|V_{T,p}\right|}{V_{DD} - \left|V_{T,p}\right|}\right) + \ln\left(\left(4 \cdot \frac{V_{DD} - \left|V_{T,p}\right|}{V_{DD}}\right) - 1\right)\right)$$

Example with Units

$$0.0068\,\text{ns} = \left(\frac{0.93\,\text{fF}}{80\,\mu\text{A/V}^2 \cdot \left(3.3\,\text{V} - \left|-0.9\,\text{V}\right|\right)}\right) \cdot \left(\left(\frac{2 \cdot \left|-0.9\,\text{V}\right|}{3.3\,\text{V} - \left|-0.9\,\text{V}\right|}\right) + \ln\left(\left(4 \cdot \frac{3.3\,\text{V} - \left|-0.9\,\text{V}\right|}{3.3\,\text{V}}\right) - 1\right)\right)$$

12) Resistive Load Maximum Input Voltage CMOS Formula

Evaluate Formula

Formula

$$V_{IL(RL)} = V_{T0} + \left(\frac{1}{K_n \cdot R_L}\right)$$

Example with Units

$$1.4025\,\text{V} = 1.4\,\text{V} + \left(\frac{1}{200\,\mu\text{A/V}^2 \cdot 2\,\text{M}\Omega}\right)$$

13) Resistive Load Minimum Input Voltage CMOS Formula

Evaluate Formula

Formula

$$V_{IH(RL)} = V_{T0} + \sqrt{\frac{8 \cdot V_{DD}}{3 \cdot K_n \cdot R_L}} - \left(\frac{1}{K_n \cdot R_L}\right)$$

Example with Units

$$1.5458\,\text{V} = 1.4\,\text{V} + \sqrt{\frac{8 \cdot 3.3\,\text{V}}{3 \cdot 200\,\mu\text{A/V}^2 \cdot 2\,\text{M}\Omega}} - \left(\frac{1}{200\,\mu\text{A/V}^2 \cdot 2\,\text{M}\Omega}\right)$$

14) Resistive Load Minimum Output Voltage CMOS Formula

Evaluate Formula

Formula

$$V_{OL(RL)} = V_{DD} - V_{T0} + \left(\frac{1}{K_n \cdot R_L}\right) - \sqrt{\left(V_{DD} - V_{T0} + \left(\frac{1}{K_n \cdot R_L}\right)\right)^2 - \left(2 \cdot \frac{V_{DD}}{K_n \cdot R_L}\right)}$$

Example with Units

$$0.0043\,\text{V} = 3.3\,\text{V} - 1.4\,\text{V} + \left(\frac{1}{200\,\mu\text{A/V}^2 \cdot 2\,\text{M}\Omega}\right) - \sqrt{\left(3.3\,\text{V} - 1.4\,\text{V} + \left(\frac{1}{200\,\mu\text{A/V}^2 \cdot 2\,\text{M}\Omega}\right)\right)^2 - \left(2 \cdot \frac{3.3\,\text{V}}{200\,\mu\text{A/V}^2 \cdot 2\,\text{M}\Omega}\right)}$$

15) Threshold Voltage CMOS Formula

Evaluate Formula

Formula

$$V_{th} = \frac{V_{T0,n} + \sqrt{\frac{1}{K_r}} \cdot \left(V_{DD} + \left(V_{T0,p}\right)\right)}{1 + \sqrt{\frac{1}{K_r}}}$$

Example with Units

$$1.3749\,\text{V} = \frac{0.6\,\text{V} + \sqrt{\frac{1}{2.5}} \cdot \left(3.3\,\text{V} + \left(-0.7\,\text{V}\right)\right)}{1 + \sqrt{\frac{1}{2.5}}}$$

16) Transconductance Ratio CMOS Formula

Evaluate Formula

Formula

$$K_r = \frac{K_n}{K_p}$$

Example with Units

$$2.5 = \frac{200\,\mu A/V^2}{80\,\mu A/V^2}$$

Variables used in list of CMOS Inverters Formulas above

- $C_{db,n}$ NMOS Drain Bulk Capacitance *(Femtofarad)*
- $C_{db,p}$ PMOS Drain Bulk Capacitance *(Femtofarad)*
- C_g Inverter CMOS Gate Capacitance *(Femtofarad)*
- $C_{gd,n}$ NMOS Gate Drain Capacitance *(Femtofarad)*
- $C_{gd,p}$ PMOS Gate Drain Capacitance *(Femtofarad)*
- C_{in} Inverter CMOS Internal Capacitance *(Femtofarad)*
- C_{load} Inverter CMOS Load Capacitance *(Femtofarad)*
- f Frequency *(Gigahertz)*
- K_n Transconductance of NMOS *(Microampere per Square Volt)*
- K_p Transconductance of PMOS *(Microampere per Square Volt)*
- K_r Transconductance Ratio
- n Number of Stages Ring Oscillator
- N_{MH} Noise Margin for High Signal *(Volt)*
- P_{avg} Average Power Dissipation *(Milliwatt)*
- R_L Load Resistance *(Megohm)*
- T_{osc} Oscillation Period *(Nanosecond)*
- V_{DD} Supply Voltage *(Volt)*
- V_{IH} Minimum Input Voltage *(Volt)*
- $V_{IH(RL)}$ Resistive Load Minimum Input Voltage *(Volt)*
- $V_{IH(sym)}$ Minimum Input Voltage Symmetric CMOS *(Volt)*
- V_{IL} Maximum Input Voltage CMOS *(Volt)*
- $V_{IL(RL)}$ Resistive Load Maximum Input Voltage CMOS *(Volt)*

Constants, Functions, Measurements used in list of CMOS Inverters Formulas above

- Functions: **abs**, abs(Number)
  The absolute value of a number is its distance from zero on the number line. It's always a positive value, as it represents the magnitude of a number without considering its direction.
- Functions: **ln**, ln(Number)
  The natural logarithm, also known as the logarithm to the base e, is the inverse function of the natural exponential function.
- Functions: **sqrt**, sqrt(Number)
  A square root function is a function that takes a non-negative number as an input and returns the square root of the given input number.
- Measurement: **Time** in Nanosecond (ns)
  Time Unit Conversion
- Measurement: **Power** in Milliwatt (mW)
  Power Unit Conversion
- Measurement: **Frequency** in Gigahertz (GHz)
  Frequency Unit Conversion
- Measurement: **Capacitance** in Femtofarad (fF)
  Capacitance Unit Conversion
- Measurement: **Electric Resistance** in Megohm (MΩ)
  Electric Resistance Unit Conversion
- Measurement: **Electric Potential** in Volt (V)
  Electric Potential Unit Conversion
- Measurement: **Transconductance Parameter** in Microampere per Square Volt (µA/V²)
  Transconductance Parameter Unit Conversion

- $V_{IL(sym)}$ Maximum Input Voltage Symmetric CMOS *(Volt)*
- V_{OH} Maximum Output Voltage *(Volt)*
- $V_{OL(RL)}$ Resistive Load Minimum Output Voltage *(Volt)*
- V_{out} Output Voltage *(Volt)*
- V_{output} Output Voltage for Max Input *(Volt)*
- $V_{T,n}$ Threshold Voltage of NMOS with Body Bias *(Volt)*
- $V_{T,p}$ Threshold Voltage of PMOS with Body Bias *(Volt)*
- V_{T0} Zero Bias Threshold Voltage *(Volt)*
- $V_{T0,n}$ Threshold Voltage of NMOS Without Body Bias *(Volt)*
- $V_{T0,p}$ Threshold Voltage of PMOS Without Body Bias *(Volt)*
- V_{th} Threshold Voltage *(Volt)*
- ζ_P Average Propagation Delay *(Nanosecond)*
- ζ_{PHL} Time for High to Low Transition of Output *(Nanosecond)*
- ζ_{PLH} Time for Low to High Transition of Output *(Nanosecond)*

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