Oscillator using a CMOS Schmitt-trigger Inverter

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Abstract

For non-critical applications, a CMOS Schmitt-trigger inverter may be used to generate a clock signal. This document explores the use and calculations of such a clock generator using a HEF40106B integrated circuit.

1 Introduction

A CMOS Schmitt-trigger inverter can be use as a non-critical clock signal generator with a frequency range from 10 Hz to 1 MHz. A Schmitt trigger inverter has the property that the trigger voltage at the input is different for high-to-low and low-to-high. A simple circuit is shown in Figure 1.

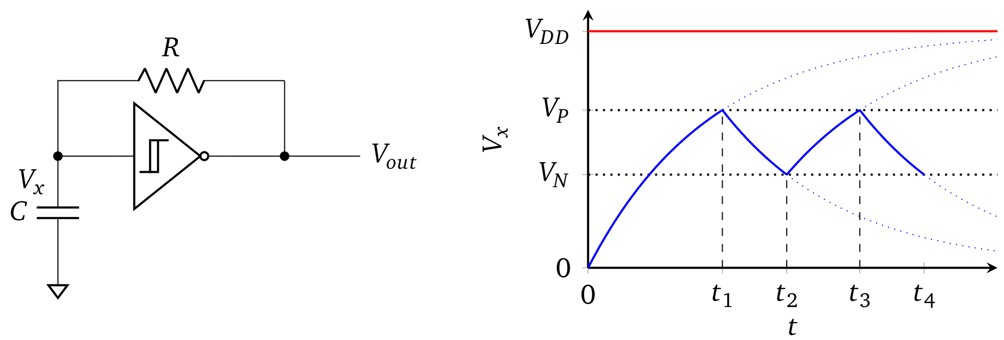

Figure 1: Oscillator schematic and the progress of the voltage across the capacitance.

2 Principle of operation

When the power is first asserted, the initial voltage across the capacitance is 0 V and so is the voltage at the input of the inverter V_x. The output voltage V_{out} of the inverter almost the same as the voltage of the power supply that we will designate V_{DD}. We will neglect the input current of the inverter, which is true for CMOS integrated circuits. The voltage across the capacitance will slowly rise as is shown in Figure 1 from time $t = 0$ to $t = t_1$. When the input voltage V_x is equal to the positive threshold voltage V_P, the output of the inverter will go low, making the output act as a ground reference. The input voltage V_x will slowly decay as shown in Figure 1 from $t = t_1$ to $t = t_2$. When the input voltage is as low as the negative threshold voltage V_N at time $t = t_2$ the output will rise from low to high, so the output is acting as the power supply. From now on, the load and unload curve of the capacitance will repeat. Futhermore, we will neglect the propagation delay of the output. The rate at which the output oscillates depends on the values of R, C, V_P, V_N and V_{DD}.

3 Determining the oscillation time period

We will neglect the startup phase which is from time $t = 0$ to $t = t_1$. From the progression of the voltage V_x over the capacitance, it can be seen that the oscillation time period is:

$$t_{osc} = t_3 - t_1 = (t_3 - t_2) + (t_2 - t_1) \tag{1}$$

First, we will investigate the behaviour of V_x from $t = t_1$ to $t - t_2$. We can state that:

$$V_x[t_1, t_2] = V_P \cdot \mathrm{e}^{-\frac{t-t_1}{RC}} \tag{2}$$

where $t_1 \leq t \leq t_2$. We can write that $V_x(t_2) = V_N$. So we can deduce that:

$$\begin{aligned} V_N &= V_P \cdot \mathrm{e}^{-\frac{t_2-t_1}{RC}} \\ \frac{V_N}{V_P} &= \mathrm{e}^{-\frac{t_2-t_1}{RC}} \\ \ln\frac{V_P}{V_N} &= -\frac{t_2-t_1}{RC} \\ t_2 - t_1 &= RC\ln\frac{V_P}{V_N} \end{aligned} \tag{3}$$

For time t_2 to t_3, the behavour of V_x we can deduce that:

$$\begin{aligned} V_X(t_3) &= V_N \\ V_P &= V_N + (V_{DD} - V_N)\cdot(1 - \mathrm{e}^{-\frac{t_3-t_2}{RC}}) \\ V_P - V_N &= V_{DD} - V_N - (V_{DD} - V_N)\mathrm{e}^{-\frac{t_3-t_2}{RC}} \\ \frac{V_P - V_{DD}}{V_{DD} - V_N} &= -\mathrm{e}^{-\frac{t_3-t_2}{RC}} \end{aligned} \tag{4}$$

Changing signs leads us to:

$$
\begin{aligned}
\frac{V_{DD}-V_P}{V_{DD}-V_N} &= \mathrm{e}^{-\frac{t_3-t_2}{RC}} \\
\ln\frac{V_{DD}-V_P}{V_{DD}-V_N} &= -\frac{t_3-t_2}{RC} \\
t_3-t_2 &= RC\ln\frac{V_{DD}-V_N}{V_{DD}-V_P}
\end{aligned} \tag{5}
$$

So the total period time is:

$$
\begin{aligned}
t_{period} &= (t_2-t_1)+(t_3-t_2) \\
&= RC\ln\frac{V_{DD}-V_N}{V_{DD}-V_P} + RC\ln\frac{V_P}{V_N} \\
&= RC\left(ln\frac{V_{DD}-V_N}{V_{DD}-V_P} + \ln\frac{V_P}{V_N}\right) \\
&= RC\ln\left(\frac{V_P}{V_N}\cdot\frac{V_{DD}-V_N}{V_{DD}-V_P}\right) \\
&= RC\cdot Z
\end{aligned} \tag{6}
$$

were Z represents the logarithm term.

4 Typical values

For a HEF40106B, the values are: $V_{DD} = 5.0\,\mathrm{V}$, $V_P = 3.0\,\mathrm{V}$, $V_N = 2.2\,\mathrm{V}$ and $R = 39\,\mathrm{k\Omega}$, $C = 2.2\,\mathrm{nF}$, $Z = 0.647$:

$$
f_{osc} = 18\,\mathrm{kHz} \tag{7}
$$

For a SN74AHC14, the values are $V_{DD} = 3.3\,\mathrm{V}$, $V_P = 1.7\,\mathrm{V}$, $V_N = 1.2\,\mathrm{V}$ and $R = 33\,\mathrm{k\Omega}$, $C = 33\,\mathrm{nF}$, $Z = 0.62$:

$$
f_{osc} = 1.5\,\mathrm{kHz} \tag{8}
$$

In both cases, Z ranges from 0.6 to 0.65.