# A simple circuit that generates two non-overlapping pulse waveforms

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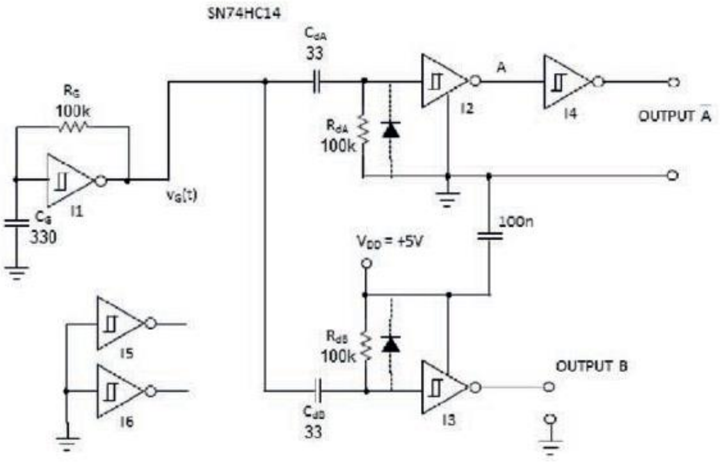

**Figure 1: Rectangular voltage pulses occur in an alternating manner at the A, B outputs of the generator, built around only one IC**

In electronics, there's often a need for a two-output generator with alternating voltage pulses that don't overlap. One simple generator that delivers on these requirements is shown in Figure 1. The circuit uses a single IC – the SN74HC14 by Texas Instruments – comprising six Schmitt-trigger-input inverters. Inverter I1 with resistor $R_G$ and capacitor $C_G$ form a generator of a rectangular waveform with a duty factor of around 0.5. Inverters I2 and I3 are fed by I1's output through derivative circuits. The required pulse waveforms are outputted at channels A and B.

## Circuit analysis

The duration $T_H$ of the high at output I1 is determined by:

$$T_H \cong R_G C_G \ln\frac{V_{DD} - V_{T-}}{V_{DD} - V_{T+}}$$

whilst the duration $T_L$ of the low at I1 is determined by:

$$T_L \cong R_G C_G \ln\frac{V_{T+}}{V_{T-}}$$

where $V_{DD} = +5V$, the supply voltage, and $V_{T+}$ and $V_{T-}$ are the respective higher and lower threshold levels of the Schmitt-trigger inputs. For this $V_{DD}$ these thresholds have typical values of $V_{T+} \cong 2.5V$, $V_{T-} \cong 1.6V$ and, thus, from the above equations it follows:

$$T_H \cong R_G C_G \times 0.3075,\ T_L \cong R_G C_G \times 0.4463$$

Period T at the I1 output is:

$$T = T_H + T_L \cong 0.7538 R_G C_G$$

For $R_G = 99.37\text{k}\Omega$ and $C_G = 331\text{pF}$, $T = 24.78\mu\text{s}$; the measured value is $T = 24.5\mu\text{s}$. The theoretical value of the waveform's duty factor at I1's output is $\frac{T_H}{T} \doteq 0.408$; experimentally, however, it was observed to be 0.469.

Two derivative circuits are connected to the I1 output. The $C_{dA}$, $R_{dA}$ circuit is referenced to ground, and the $C_{dB}$, $R_{dB}$ is referenced to the supply voltage terminal. $C_{dA}$, $R_{dA}$ output is connected to the input of inverter I2, and the $C_{dB}$, $R_{dB}$ output to inverter I3's input. At a low-to-high transition at the I1 output, the I2's input voltage rises abruptly from zero to a

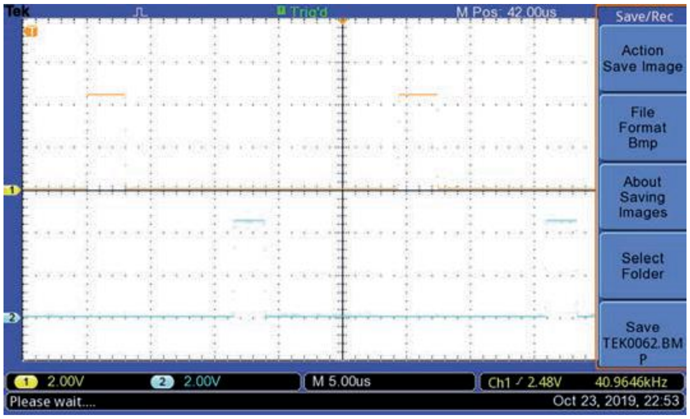

**Figure 2: Oscilloscope record of voltage waveforms at the generator outputs; the yellow trace corresponds to channel A and the blue to channel B. Note that the ground level of the blue trace is shifted downward by -6V**

positive value, exceeding the threshold $V_{T+} = 2.5$; consequently, I2's output goes low.

The voltage at the I2 input decreases exponentially with time constant $R_{dA} \times C_{dA}$. When this voltage decreases below the lower threshold $V_{T-} = 1.6V$, I2's output returns to high. Similarly, at H → L transition at the I1 output, the input voltage of I3 drops abruptly below the $V_{T-}$ threshold, so the I3 output goes high. Capacitor $C_{dB}$ charges from the supply voltage through resistor $R_{dB}$, and the I3 input voltage rises. When the input voltage of I3 reaches the $V_{T+}$ threshold, I3's output goes low.

Capacitor $C_{dB}$, which has charged to about $V_{DD}$, is discharged at a subsequent L → H transition at the output of I1 through a protective reverse-polarised diode at the I3 input. Protective reverse-polarised diodes are internal to the IC and limit its input voltage to an interval $\langle 0V, V_{DD} \rangle$. The allowed value of the current through these diodes is 20mA. For $C_{dB} = 33pF$ and rise-time $t_r$ of $v_G(t)$ of 10ns, the current through protective diode can be determined using:

$$I_D \cong C_{dB} \frac{V_{DD}}{t_r}$$

In this case, $I_D$ is about 15mA. If the value of capacitor $C_{dB}$ were considerably higher, however, then an external protective diode should be connected, with its anode to the input of I3 and its cathode at $V_{DD}$.

## Pulse-widths of the output signals

The width of pulse at the I2 output (which here represents the A channel) can be determined using:

$$T_{wA} \cong R_{dA} C_{dA} \ln \frac{V_{DD}}{V_{T-}}$$

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The pulse in this case is low level and is therefore inverted by inverter I4.

The width of the pulse at B channel is roughly:

$$T_{wB} \cong R_{dB} C_{dB} \ln \frac{V_{DD}}{V_{DD} - V_{T+}}$$

For used values of $R_{dA} = 100.57k\Omega$, $C_{dA} = 33pF$ and $R_{dB} = 99.25k\Omega$, $C_{dB} = 33pF$ is $T_{wA} \doteq 3.319\mu s$ and $T_{wB} \doteq 2.27\mu s$. These results correspond well with the experimental ones, shown in Figure 2.

When necessary, pulse-widths $T_{wA}$ and $T_{wB}$ can be increased independently of each other by increasing the values of $C_{dA}$ and $C_{dB}$. Similarly, the repetition frequency of these pulses can be decreased by increasing the $C_G$ value.

The inverters' input capacitances $C_i$ were neglected in this analysis since their typical value is 3pF, i.e. much lower than the applied values of $C_{dA}$ and $C_{dB}$. The virtue of $C_i$ is that it lowers the voltage peaks at the derivative circuits' output by factors of $\frac{C_{dA}}{C_{dA}+C_i}$ and $\frac{C_{dB}}{C_{dB}+C_i}$. Another of its benefits is increasing time constants of derivative circuits by factors $1 + \frac{C_i}{C_{dA}}$, $1 + \frac{C_i}{C_{dB}}$.

If inverted waveforms are required, then inverter I2's output A can be used directly, whilst its B output should be connected to the input of one of the two unused inverters I5 or I6, with the output of this fifth inverter used in place of the B output.

## Circuit construction

Sizes of logic IC packages have shrunk significantly since the original DIL (dual in-line) packages with a lead pitch of 2.5mm. Today's packages mostly have a lead pitch of 0.65mm and smaller, such as the TSSOP (thin-shrink small outline package). For small projects, without access to expensive automatic component-placing machines, it's better to forget about IC packages with a pitch below 0.5mm. A good compromise in this case is the SOIC (small outline integrated circuit) package with a pitch of 1.27mm. Of course, the leads of

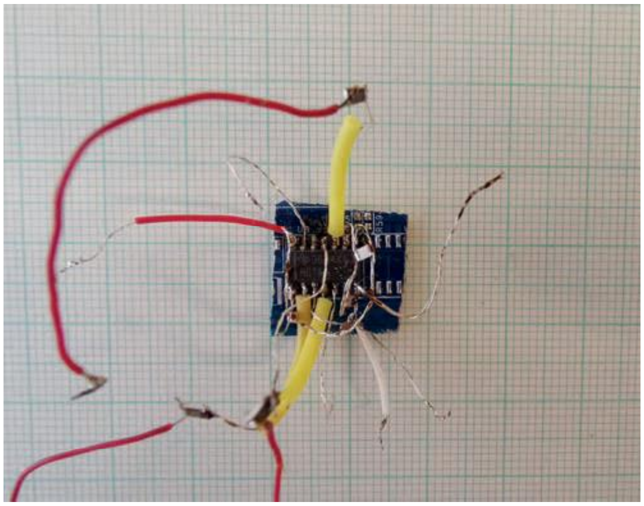

Figure 3: The circuit was built with SMD devices

a SOIC package are much finer than those of a DIL, so the IC is more easily damaged.

Paradoxically, also for small projects, reusing electronic scrap can make the circuit's mechanically more resilient. For our project, a small part of a PCB, with a through-hole SN74HC14 soldered in place, was cut from a failed motherboard, as shown in Figure 3. The leads of the IC are already soldered to the PCB, protecting it from damage.

This approach, however, introduces the risk of hidden interconnections between one or more IC pins, which may not be immediately obvious. Unwanted connections can even be hidden in the PCB's interior, since boards can have several conductive layers. For a PCB-mounted IC like SN74HC14 it was a must to electronically check if the inverter inputs were entirely free from hidden connections.

The procedure is simple: the IC is supplied with a +5V source, and a DVM was connected to the input of the IC to be checked. The checked input is then connected through a 100kΩ resistor, first to +5V and then to ground. If the measured voltages, referred to ground, differ significantly from +5V and 0V respectively, it indicates an unwanted connection of the pin.

However, it is possible to resolve the problem of a still-connected pin by carefully de-soldering it and creating a small space between the pin and the copper trace under it. We detected an unwanted connection in this project at one of the inverters' inputs; this procedure resolved the problem. The pin was then soldered "in air" to a thin interconnecting wire.

All the passive components in this circuit are surface-mount devices, yielding a circuit footprint of about 15×15mm.

## Circuit application

This particular circuit can be used for periodic pulse control of two devices, which have to be turned on in an alternating manner, without overlapping pulses. Perhaps a most illustrative example is the control of a main thyristor in a DC circuit. A thyristor is a switching device, which remains in steady on-state when a control pulse of sufficient width (typically microseconds) is applied to it.

To turn the thyristor off with DC flowing, a charged capacitor with an opposite sign to that of the voltage drop across the main thyristor is paralleled to the main thyristor by an auxiliary thyristor. The auxiliary thyristor requires a control pulse from a separate control channel. And, again, a sufficient pulse width is microseconds long.

This technique of thyristors switching DC circuits is over 50 years old. However, it's worth noting that, in practice, emitter followers with NPN transistors must be placed between outputs A and B and the thyristors' gate. The reason is that even a "small" thyristor, rated from one to ten amperes, requires gate currents of several tens of mA. The load current at the designed circuit's outputs should not exceed 4mA.

This circuit is of small size, low component count, low power consumption and low cost. Its alternative might be an astable driving two monostables: one at the leading edges of the astable's output, with the monostable at the trailing edges. However, this approach requires more than one IC.

## About the Schmitt trigger

A Schmitt trigger is an electronic circuit that converts an analogue signal into a two-level one. It has two input-voltage thresholds, with the output voltage level changing in steps. The circuit was invented by Otto H. Schmitt, and published in 1938. It was originally built with two tubes, which remained its main feature for a long time – even in the era of bipolar germanium transistors since about 1950 and then their silicon successors in the 1960s.

Since the threshold at the rise of the input voltage is higher than that of the decreasing input voltage, hysteresis is achieved, exhibited in the input-output characteristics. Of course, resistors were also a part of the Schmitt trigger: five of them for Ge transistors and only three for the Si version.

When the CMOS IC families started to prevail over IC families based on bipolar technology around 1980, MOS transistors were used to form a Schmitt trigger. This is because in CMOS technology both N-channel and P-channel transistors are used, with some replacing resistors, forming constant-current sources. Thus, a CMOS Schmitt trigger consists of six or more MOS transistors.

At present, a Schmitt trigger is considered to be any electronic circuit that converts an analogue input signal into a two-level one, and exhibits hysteresis in its input-output characteristics in a wide band of frequencies – from DC to an upper-limit frequency. EW