# AN1755
# APPLICATION NOTE

# A HIGH RESOLUTION / PRECISION THERMOMETER USING ST7 AND NE555

## INTRODUCTION

The goal of this application note is to present a realistic example of a thermometer using an ST7 and an NE555.

The NE555 is operating in the a-stable mode. Its frequency is controlled by the resistance changes of a NTC-thermistor. The frequency, as well as the duty cycle, are measured by the ST7 timer. The NE555 output is connected to the timer input capture pin.

Rev. 1.0

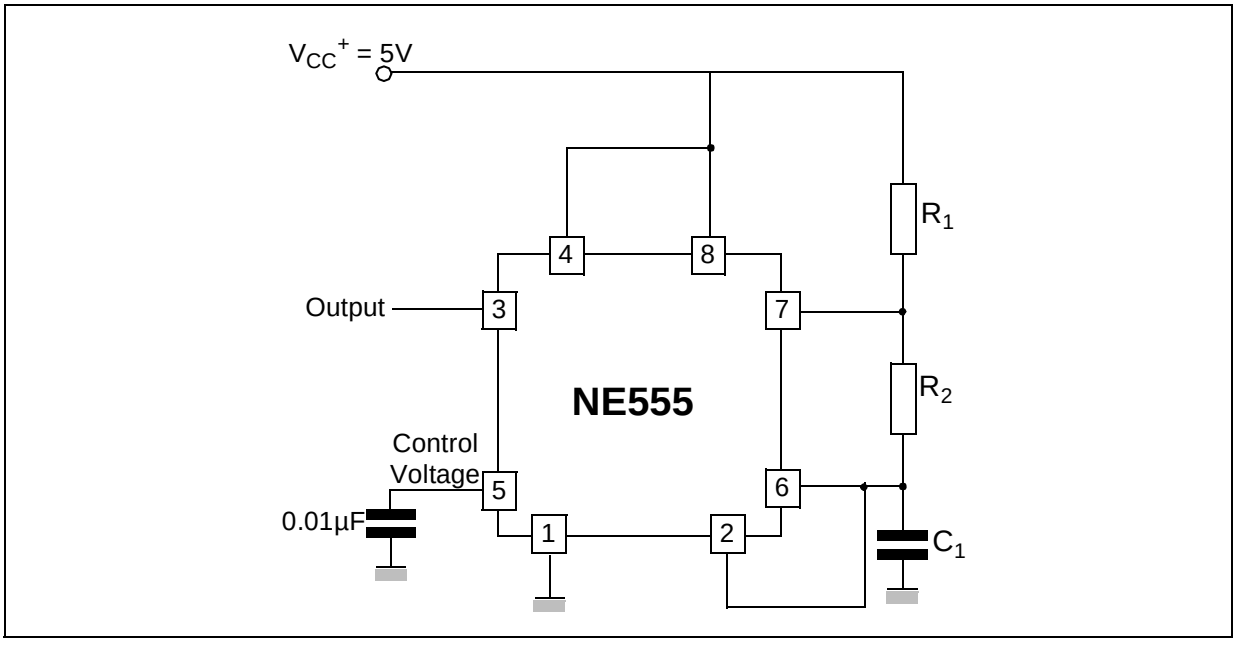
## 1 DESCRIPTION OF NE555

The NE555 monolithic timing circuit is a highly stable controller capable of producing accurate time delays or oscillation. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For a stable operation as an oscillator, the free running frequency and the duty cycle are both accurately controlled with two external resistors and one capacitor. For more details see NE555 datasheet.

## 2 ASTABLE OPERATION

The circuit is shown in Figure 1. (pin 2 and 6 connected). It triggers itself and operates as a free running multi vibrator. The external capacitor charges through $R_1$ and $R_2$ and discharges through $R_2$. Thus the duty cycle is precisely set by the ratio of these two resistors. In the a-stable mode of operation, $C_1$ charges and discharges between 1/3 $V_{CC}$ and 2/3 $V_{CC}$. Due to the self-triggered mode, the charge and discharge times and therefore frequency are independent of the supply voltage.

**Figure 1. Circuit Diagram of NE555 in a-stable mode**




The charge time (output HIGH) is given by

(1) $t_1 = 0.693\ (R_1 + R_2)\ C_1$

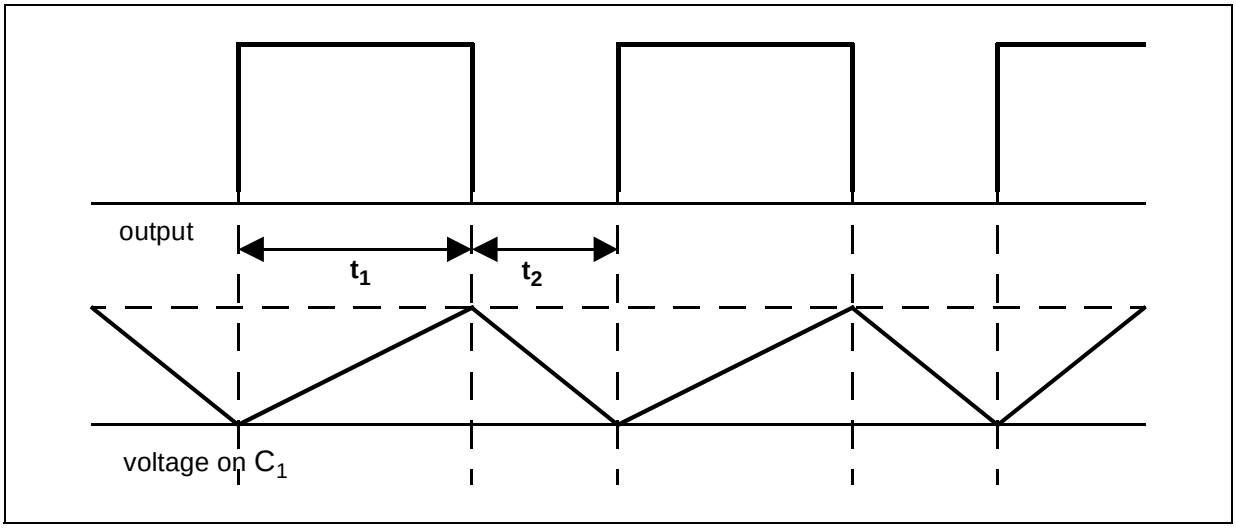
and the discharge time (output LOW) by

(2) $t_2 = 0.693\ (R_2)\ C_1$

Thus the total period T is given by

(3) $T = t_1 + t_2 = 0.693\ (R_1 + 2R_2)\ C_1$

**Figure 2. NE555 Timing Diagram**




## 3 THEORY OF OPERATION - NE555

In general we can use the $R_{ntc}$ in place of $R_1$ as well as in place of $R_2$. We assume $R_{ntc}$ in place of $R_1$. The times needed to charge (1) and to discharge (2) the capacitor will be

(4) $t_1 = 0.693\ (R_{ntc} + R_2)\ C_1$

(5) $t_2 = 0.693\ (R_2)\ C_1$

The result of the measurement should be dependent on the value of $R_{ntc}$ only. For that $R_2$ and $C_1$ should not vary with temperature or age. That is why the capacitor $C_1$ is to be eliminated from the equations.The periods $t_1$ and $t_2$ are measured with the ST7 timer. From formula (4) and (5) we can calculate two variables.

Expressing $C_1$ from (5) and putting it in (4) we obtain

(6) $R_{ntc} = R_2\ (t_1\text{-}t_2) / t_2$

The result depends on the precision of the time measuring ($t_1$, $t_2$) and tolerance of $R_2$ only. It depends neither on $C_1$ nor the supply voltage.

## 4 THEORY OF OPERATION - ST7

The rising and falling edges of the input signal are captured by the micro and periods $t_1$, $t_2$ are measured with the built-in timer. The timer resolution (125 ns @ 8MHz) is sufficient to capture these edges.

**Note**: To calculate equation (6) we can use multiples of 125ns for simplicity.

## 5 DESIGN

To design our circuit, we need to choose the right values of $R_2$ and $C_1$. These two values determine the frequency of the output signal (3).

For the given temperature range (0 - 40 °C) and a 10KΩ NTC resistor, the chosen values are 40kΩ for $R_2$ and 100nF for $C_1$.

**Table 1. Table of theoretical values of designed thermometer**

| Temperature (°C) | $R_{ntc}$ (Ω) | $t_1$ (ms) | $t_2$ (ms) | $t_1$ (tics) | $t_2$ (tics) | $\Delta t_1$ (tics) |
|---|---|---|---|---|---|---|
| 0 | 27279 | 4,662 | 2,772 | 37299 | 22176 | 635 |
| 1 | 26134 | 4,583 | 2,772 | 36665 | 22176 | 605 |
| 2 | 25043 | 4,507 | 2,772 | 36060 | 22176 | 577 |
| 3 | 24003 | 4,435 | 2,772 | 35483 | 22176 | 549 |
| 4 | 23012 | 4,367 | 2,772 | 34934 | 22176 | 524 |
| 5 | 22067 | 4,301 | 2,772 | 34410 | 22176 | 500 |
| 6 | 21166 | 4,239 | 2,772 | 33910 | 22176 | 477 |
| 7 | 20306 | 4,179 | 2,772 | 33434 | 22176 | 455 |
| 8 | 19486 | 4,122 | 2,772 | 32979 | 22176 | 434 |
| 9 | 18703 | 4,068 | 2,772 | 32545 | 22176 | 414 |
| 10 | 17956 | 4,016 | 2,772 | 32131 | 22176 | 395 |
| 11 | 17243 | 3,967 | 2,772 | 31736 | 22176 | 378 |
| 12 | 16561 | 3,920 | 2,772 | 31357 | 22176 | 361 |
| 13 | 15910 | 3,875 | 2,772 | 30997 | 22176 | 345 |
| 14 | 15288 | 3,831 | 2,772 | 30652 | 22176 | 329 |
| 15 | 14694 | 3,790 | 2,772 | 30322 | 22176 | 315 |
| 16 | 14126 | 3,751 | 2,772 | 30007 | 22176 | 302 |
| 17 | 13582 | 3,713 | 2,772 | 29706 | 22176 | 288 |
| 18 | 13063 | 3,677 | 2,772 | 29418 | 22176 | 276 |
| 19 | 12565 | 3,643 | 2,772 | 29142 | 22176 | 263 |
| 20 | 12090 | 3,610 | 2,772 | 28879 | 22176 | 252 |
| 21 | 11635 | 3,578 | 2,772 | 28626 | 22176 | 242 |
| 22 | 11199 | 3,548 | 2,772 | 28385 | 22176 | 231 |
| 23 | 10782 | 3,519 | 2,772 | 28154 | 22176 | 222 |
| 24 | 10382 | 3,491 | 2,772 | 27932 | 22176 | 212 |
| 25 | 10000 | 3,465 | 2,772 | 27720 | 22176 | 203 |
| 26 | 9633 | 3,440 | 2,772 | 27517 | 22176 | 195 |
| 27 | 9282 | 3,415 | 2,772 | 27322 | 22176 | 187 |
| 28 | 8945 | 3,392 | 2,772 | 27135 | 22176 | 179 |
| 29 | 8622 | 3,370 | 2,772 | 26956 | 22176 | 172 |
| 30 | 8312 | 3,348 | 2,772 | 26784 | 22176 | 164 |
| 31 | 8016 | 3,328 | 2,772 | 26620 | 22176 | 158 |
| 32 | 7731 | 3,308 | 2,772 | 26462 | 22176 | 151 |
| 33 | 7458 | 3,289 | 2,772 | 26311 | 22176 | 146 |
| 34 | 7195 | 3,271 | 2,772 | 26165 | 22176 | 139 |

| Temperature (°C) | $R_{ntc}$ (Ω) | $t_1$ (ms) | $t_2$ (ms) | $t_1$ (tics) | $t_2$ (tics) | $\Delta t_1$ (tics) |
|---|---|---|---|---|---|---|
| 35 | 6944 | 3,253 | 2,772 | 26026 | 22176 | 134 |
| 36 | 6702 | 3,236 | 2,772 | 25892 | 22176 | 129 |
| 37 | 6470 | 3,220 | 2,772 | 25763 | 22176 | 124 |
| 38 | 6247 | 3,205 | 2,772 | 25639 | 22176 | 119 |
| 39 | 6033 | 3,190 | 2,772 | 25521 | 22176 | 114 |
| 40 | 5827 | 3,176 | 2,772 | 25406 | 22176 | |

**Table 2. Parameters and their meanings**

| Parameter | Comments |
|---|---|
| $R_{ntc}$ (Ω) | Value of 10KΩ NTC-Resistor at particular temperature<br>Example: $R_{ntc}$ (25 °C) = 10KΩ |
| $t_1$, $t_2$ (ms) | Values of the time corresponding to measured temperature, please refer to equations (4), (5).<br>Example:<br>$t_1$ (25°C) = 0.693 * (10 kΩ + 40 kΩ) * 100nF = 3.465 ms<br>$t_2$ (25°C) = 0.693 * 40 kΩ * 100nF = 2.772 ms |
| $t_1$, $t_2$ (tics) | Values of the time in 125ns timer tics (@8 MHz)<br>Example:<br>$t_1$ (25°C) = 3.465 ms / 125 ns = 27720 tics<br>$t_2$ (25°C) = 2.772 ms / 125 ns = 22176 tics<br>1 tic = Time period of timer |
| $\Delta t_1$ (tics) | Represents achieved resolution. It's the difference of the values per one degree Celsius $\Delta t_1 = t_1(n) - t_1(n+1)$.<br>Example:<br>$\Delta t_1$ (25°C) = $t_1$ (25°C) - $t_1$ (26°C) = 27720 - 27517 = 203 tics |

## 6 PRACTICAL ISSUES

It is possible to implement this algorithm with any ST7 family micro (2K of program memory is required). In general you can choose:

- 12-bit autoreload timer allowing configuration to $f_{cpu}$ (~125ns), for ex. ST7LITE @8MHz
- 16-bit timer allowing configuration to $f_{cpu/2}$ (~250ns), for ex. ST72264 @8MHz

In the second case we are able to do the time measuring in one timer cycle.

Averaging of measured results is recommended but not needed. The frequency is quite stable.

You can use bipolar SA555, SE555 instead of NE555 (the difference is in the operating temperature range only). Recommended values are 40k for $R_2$ and 100nF for $C_1$. If you use CMOS TS555 you should redesign the resistor and capacitor values to match its electrical characteristics.

## 7 CONCLUSION

With this method we are able to achieve high resolution temperature measurement. The main advantages are the independence from variations in capacitor $C_1$ and the supply voltage. Only the precision of the used resistor and the NTC affects the final result.