



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.

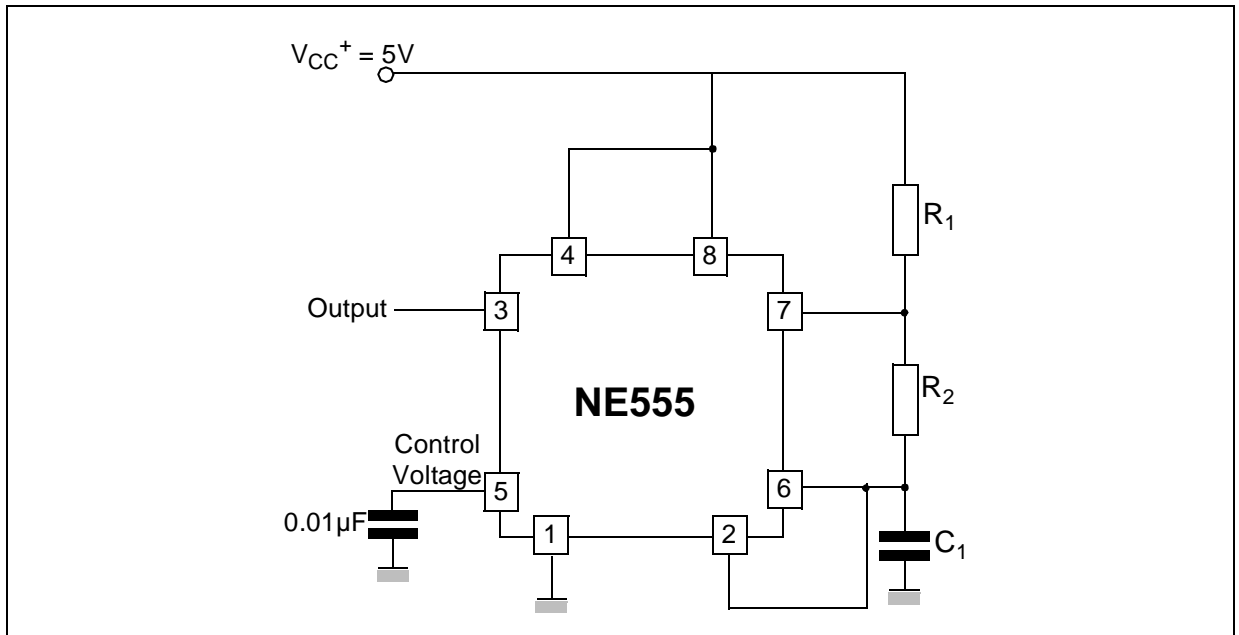
1 DESCRIPTION OF NE555

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

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

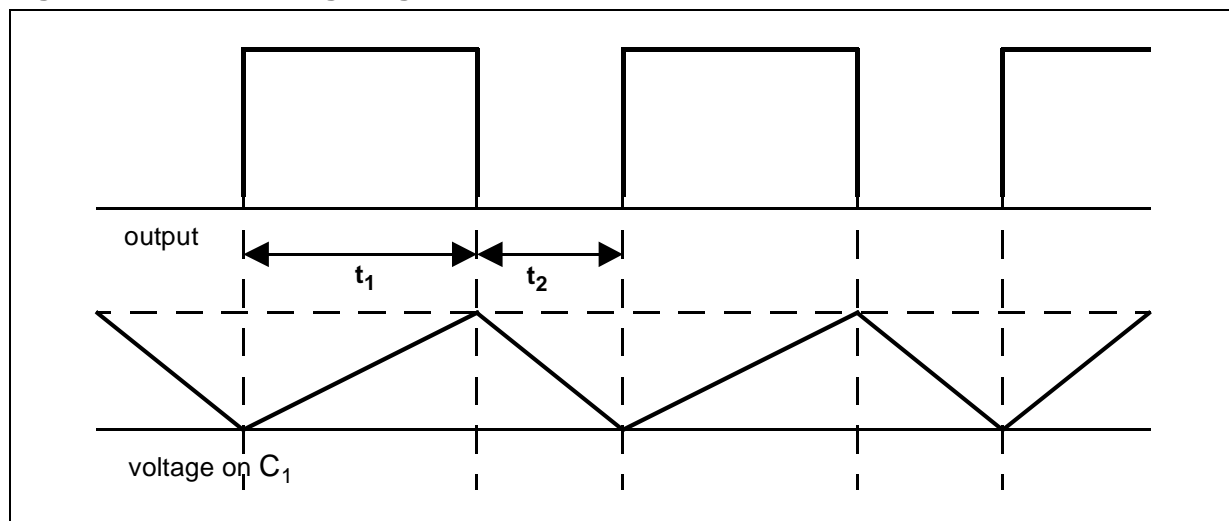
and the discharge time (output LOW) by

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

Thus the total period T is given by

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

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

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

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

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

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

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 10K Ω NTC resistor, the chosen values are 40k Ω 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)	Δt_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)	Δt 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 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). Example: t ₁ (25°C) = 0.693 * (10 kΩ + 40 kΩ) * 100nF = 3.465 ms 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) Example: t ₁ (25°C) = 3.465 ms / 125 ns = 27720 tics t ₂ (25°C) = 2.772 ms / 125 ns = 22176 tics 1 tic = Time period of timer
Δt ₁ (tics)	Represents achieved resolution. It's the difference of the values per one degree Celsius Δt ₁ = t ₁ (n) - t ₁ (n+1). Example: Δt 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 R₂ and 100nF for C₁. 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.

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