Engineer's Mini-Notebook

555 Timer IC Circuits

Forrest M. Mims III

Radio Shack

RADIO SHACK, A DIVISION OF TANDY CORPORATION

U.S.A.: FORT WORTH, TEXAS 76102
CANADA: BARRIE, ONTARIO, CANADA L4M 4W5

TANDY CORPORATION

AUSTRALIA:
290-314 ALBERT ROAD
PRES ADJ UST THE DECEMBER
31-132 JUNI

U.K.
GILTON ROAD
WEDNESBURY, WEST MIDLANDS WS10 7JN

PRINTED IN U.S.A.
555/556 PIN OUTLINES

THE 556 CONTAINS TWO 555 TIMERS.

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>555</th>
<th>556 (1)</th>
<th>556 (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROUND</td>
<td>1</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>TRIGGER</td>
<td>2</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>OUTPUT</td>
<td>3</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>RESET</td>
<td>4</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>CONTROL V</td>
<td>5</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>THRESHOLD</td>
<td>6</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>DISCHARGE Vcc</td>
<td>7</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>14</td>
<td>14</td>
</tr>
</tbody>
</table>

555 SPECIFICATIONS

<table>
<thead>
<tr>
<th>SPECIFICATION</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUPPLY VOLTAGE (Vcc)</td>
<td>4.5 TO 15 V</td>
</tr>
<tr>
<td>SUPPLY CURRENT (Vcc = +5V)</td>
<td>3 TO 6 mA</td>
</tr>
<tr>
<td>SUPPLY CURRENT (Vcc = +15V)</td>
<td>10 TO 15 mA</td>
</tr>
<tr>
<td>OUTPUT CURRENT (MAXIMUM)</td>
<td>200 mA</td>
</tr>
<tr>
<td>POWER DISSIPATION</td>
<td>600 mW</td>
</tr>
<tr>
<td>OPERATING TEMPERATURE</td>
<td>0 TO 70 °C</td>
</tr>
</tbody>
</table>

1 VALUES SHOWN APPLY TO NE555.
PLEASE READ THIS FIRST...

This book is for the entertainment and edification of its readers. While reasonable care has been exercised with respect to its accuracy, the author and radio shack assume no responsibility for errors, omissions or suitability of its contents for any application. Nor do we assume any liability for any damages resulting from use of information in this book. It is your responsibility to determine if use, sale, or manufacture of any device that incorporates information in this book infringes any patents, copyrights or other rights.

Due to the many customer inquiries received by radio shack and the author, it is impossible to answer requests for additional information (custom circuit designs, technical advice, troubleshooting advice, etc.) but though we cannot acknowledge individual inquiries, we will be happy to receive any comments, impressions, suggestions and information about suspected errors in this book.

Thanks in advance to those of you who write, but please remember we will be unable to respond personally.

CONTENTS

INTRODUCTION 4
CIRCUIT ASSEMBLY TIPS 4
555 SPECIFICATIONS 5
555 BLOCK DIAGRAM 5
CIRCUITS

BASIC MONOSTABLE 6
BASIC ASTABLE 7
BouceFREE Switch 8
TOUCH ACTIVATED Switch 8
TIMER PLUS RELAY 19
CASCADED TIMER 10
INTERVALOMETER 11
MISSING PULSE DETECTOR 12
EVENT FAILURE ALARM 13
FREQUENCY DIVIDER 14
VOLTAGE-CONTROLLED OSCILLATOR 15
PULSE GENERATOR 16
FREQUENCY METER 17
AUDIO OSCILLATOR/METRONOME 18
TOY ORGAN 19
GATED OSCILLATOR 20
CHIRP GENERATOR 21
STEPDED-TONE GENERATOR 22
3 STATE TONE GENERATOR 23
TONE BURST GENERATOR 24
SOUND EFFECTS GENERATOR 25
LED FLASHER 26
POWER FET LAMP DIMMER 27
LIGHT/DARK DETECTOR 28
INFRARED SECURITY ALARM 29
ANALOG LIGHTWAVE TRANSMITTER 30
ANALOG LIGHTWAVE RECEIVER 31
DC-DC CONVERTER 32
INTRODUCTION

The 555 timer is one of the most popular and versatile integrated circuits ever produced. It includes 23 transistors, 2 diodes, and 16 resistors on a silicon chip installed in an 8-pin mini dual-in-line package (DIP). The 555 is a 21-pin DIP that combines two 555's on a single chip. Also available are ultra-low power versions of the 555. The 555 has two principle operating modes:

Monostable mode — In this mode the 555 functions as a "one-shot." Applications include timers, missing pulse detection, bounce free switches, touch switches, etc.

Astable mode — The 555 can operate as an oscillator. Uses include LED and lamp flashers, pulse generation, logic clocks, tone generation, security alarms, etc.

Circuit Assembly Tips

Build test versions of circuits on plastic solderless breadboard before making them permanent. In monostable circuits where false triggering might cause problems, tie pin 5 to ground via a 0.1 µF capacitor. If power leads are long or if a circuit seems to malfunction, place a 0.1 µF capacitor across pins 8 and 1. A 1 µF capacitor may also be necessary. Be sure to experiment with values of timing resistors and capacitors. The basic circuits on pp 6-7 explain the role these components play. Remember that the 555 replaces two 555's. Low-power versions of the 555 may require some revisions to standard 555 circuits. For more tips, see the Radio Shack book "Getting Started in Electronics."
**BASIC MONOSTABLE CIRCUIT**

A negative trigger pulse at Pin 2 turns off a transistor that otherwise shorts C1 to ground. The output then goes high as C1 charges through R1. When the charge on C1 is $\frac{2}{3}V_{cc}$, the 555 discharges C1 to ground, the output then goes low.

**BASIC ASTABLE CIRCUIT**

Here Pins 2 and 6 are connected so the circuit will trigger itself each timing cycle, thereby functioning as an oscillator. C1 charges through R1 and R2 but discharges through R2. The charge on C1 ranges from $\frac{1}{3}V_{cc}$ to $\frac{2}{3}V_{cc}$. The oscillation frequency is independent of $V_{cc}$. The frequency formula is:

$$f = \frac{1.44}{(R1 + 2R2)C1}$$
BOUNCEFREEm SWITCH

+5 to +15V

R1 100K

555

C1 .01 - 10 µF

C2 .01 µF

C1 (µF) | DELAY (SEC)
--------|----------
 0.1    | 0.01
 1      | 1
 10     | 1.0

OUTPUT PULSE

DELAY

CLOSE S1

OPEN R2 100K

R1 100K

OUTPUT PULSE

DELAY

TOUCH RELEASE

MAY ALSO WORK WHEN ONLY PIN 2 IS TOUCHED.

TIMER PLUS RELAY

+9V

R1 1.1M

D1 1N914

D2 1N914

R2 10K

555

C1 10 µF

C2 0.01 µF

RELAY (6V, 500 Ω, 12 mA)

* RADIO SHACK 275-004

closing S1 momentarily begins a timing cycle. the relay is actuated during the entire cycle. R1 and C1 control time delay. C2 prevents false triggering. D1 absorbs voltage generated by relay coil. when relay is switched off, use caution when connecting line-powered devices to relay connections.

TYPICAL DELAYS (SECONDS)

<table>
<thead>
<tr>
<th>R1</th>
<th>C1 = 10 µF</th>
<th>C1 = 100 µF</th>
</tr>
</thead>
<tbody>
<tr>
<td>100K</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>220K</td>
<td>3</td>
<td>33</td>
</tr>
<tr>
<td>470K</td>
<td>6</td>
<td>70</td>
</tr>
<tr>
<td>1M</td>
<td>15</td>
<td>175</td>
</tr>
</tbody>
</table>
**Cascaded Timer**

Both timers are connected in their one-shot mode. Grounding the trigger input starts timer 1 which then starts timer 2.

**Intervalometer**

Timer 1 is connected as astable oscillator which oscillates at a frequency determined by R1 and C1. Timer 2 is a one-shot that drives a relay via D1. Timer 1 triggers timer 2 once per cycle for 3 to 5 seconds.

- Timer 1 (Pin 3)
- Timer 2 (Relay)
MISSING PULSE DETECTOR

INCOMING PULSES CONTINUALLY RESET THE TIMING CYCLE. A MISSING PULSE ALLOWS THE TIMING CYCLE TO BE COMPLETED, CHANGING THE OUTPUT STATE.

EVENT FAILURE ALARM

WHEN POWER IS APPLIED, C1 BEGINS TO CHARGE THROUGH R2. UNLESS S1 IS CLOSED BEFORE THE 555 TIMING CYCLE IS COMPLETED, THE BUZZER WILL SOUND. S1 CAN BE ANY EXTERNAL SWITCH.
**FREQUENCY DIVIDER**

This circuit also squares slowly rising input pulses.

For typical input and output waveforms shown, output frequency = \( \frac{1}{2} \) input frequency.

In this circuit, the 555 is connected as a monostable multivibrator. Once a timing cycle is initiated by an input pulse, subsequent input pulses have no effect until cycle is completed. Shown below are typical input and output waveforms (C1 = 0.1 \( \mu F \), R1 varied in value).

**VOLTAGE-CONTROLLED OSCILLATOR**

The 555 oscillates at a frequency determined by R2 and C1. A voltage applied to the input changes the oscillation frequency of the 555. As the input voltage increases, the oscillation frequency decreases. For more volume, omit R1 and connect SPKR to ground through 4.7 \( \mu F \) capacitor.
PULSE GENERATOR

![Circuit diagram of a 555 timer circuit for generating pulses.]

Use frequency table to select R1 and C1. OK to connect pin 3 to frequency meter on facing page.

Use as digital logic clock pulse generator, signal generator, etc.

FREQUENCY TABLE (FREQUENCIES IN Hz)

<table>
<thead>
<tr>
<th>C1 (uF)</th>
<th>R1 = 10K</th>
<th>R1 = 100K</th>
<th>R1 = 1M</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.002</td>
<td>47.420</td>
<td>5.240</td>
<td>520</td>
</tr>
<tr>
<td>0.0033</td>
<td>30.490</td>
<td>3.740</td>
<td>313</td>
</tr>
<tr>
<td>0.0047</td>
<td>21.522</td>
<td>2.630</td>
<td>233</td>
</tr>
<tr>
<td>0.0068</td>
<td>16.300</td>
<td>1.987</td>
<td>139</td>
</tr>
<tr>
<td>0.01</td>
<td>11.622</td>
<td>1.414</td>
<td>140</td>
</tr>
<tr>
<td>0.015</td>
<td>7.210</td>
<td>8.96</td>
<td>87</td>
</tr>
<tr>
<td>0.022</td>
<td>4.959</td>
<td>6.01</td>
<td>60</td>
</tr>
<tr>
<td>0.033</td>
<td>3.530</td>
<td>4.28</td>
<td>42</td>
</tr>
<tr>
<td>0.047</td>
<td>2.351</td>
<td>2.85</td>
<td>28</td>
</tr>
<tr>
<td>0.068</td>
<td>1.737</td>
<td>2.10</td>
<td>20</td>
</tr>
<tr>
<td>0.1</td>
<td>1.139</td>
<td>1.38</td>
<td>14</td>
</tr>
<tr>
<td>0.15</td>
<td>0.804</td>
<td>0.97</td>
<td>10</td>
</tr>
<tr>
<td>0.22</td>
<td>0.540</td>
<td>0.65</td>
<td>6</td>
</tr>
</tbody>
</table>

FREQUENCY METER

![Circuit diagram of a frequency meter using a 555 timer.]

This ultra-simple circuit measures audio frequency signals. Input signal should range from 2.5 to 5 volts. For testing, connect pulse generator on facing page directly to pin 2 (omit C1). R3 and C3 determine frequency range.

Note non-linear response at 1kHz.

<table>
<thead>
<tr>
<th>C3 = 1uF</th>
<th>R3 = 10K</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

Frequency (kHz)
**Audio Oscillator / Metronome**

This circuit will function with either or both output devices. The speaker gives more volume, but uses more current. Use R3 to reduce volume.

Here are typical frequencies for various settings of R1:

<table>
<thead>
<tr>
<th>R1</th>
<th>Frequency (Hz)</th>
<th>R1</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1M</td>
<td>17</td>
<td>1M</td>
<td>1.2</td>
</tr>
<tr>
<td>470K</td>
<td>40</td>
<td>680K</td>
<td>2.8</td>
</tr>
<tr>
<td>220K</td>
<td>85</td>
<td>220K</td>
<td>2.9</td>
</tr>
<tr>
<td>100K</td>
<td>177</td>
<td>100K</td>
<td>6.1</td>
</tr>
<tr>
<td>47K</td>
<td>410</td>
<td>22K</td>
<td>9.4</td>
</tr>
<tr>
<td>22K</td>
<td>838</td>
<td>10K</td>
<td>1570</td>
</tr>
<tr>
<td>10K</td>
<td>570</td>
<td>4.7K</td>
<td>2246</td>
</tr>
<tr>
<td>2.2K</td>
<td>4600</td>
<td>1K</td>
<td>6283</td>
</tr>
</tbody>
</table>

Note: Your values may vary.

Piezo gives intense sound.

**Toy Organ**

Table gives frequencies when R1 = 100K.

Insert 1K potentiometer between C8 and SPKR to control volume.

<table>
<thead>
<tr>
<th>C (μF)</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.022</td>
<td>72</td>
</tr>
<tr>
<td>.015</td>
<td>78</td>
</tr>
<tr>
<td>.033</td>
<td>111</td>
</tr>
<tr>
<td>.068</td>
<td>78</td>
</tr>
<tr>
<td>.047</td>
<td>179</td>
</tr>
<tr>
<td>.033</td>
<td>230</td>
</tr>
<tr>
<td>.022</td>
<td>348</td>
</tr>
<tr>
<td>.015</td>
<td>390</td>
</tr>
<tr>
<td>.01</td>
<td>490</td>
</tr>
<tr>
<td>.0068</td>
<td>718</td>
</tr>
<tr>
<td>.0047</td>
<td>1173</td>
</tr>
<tr>
<td>.0035</td>
<td>1670</td>
</tr>
<tr>
<td>.0035</td>
<td>2240</td>
</tr>
<tr>
<td>.0022</td>
<td>2852</td>
</tr>
<tr>
<td>.0015</td>
<td>4.671</td>
</tr>
<tr>
<td>.001</td>
<td>6.336</td>
</tr>
<tr>
<td>.01</td>
<td>9.237</td>
</tr>
</tbody>
</table>
GATED OSCILLATOR

THIS CIRCUIT WILL ALLOW YOU TO SWITCH THE TONE GENERATED BY THE 555 BY MEANS OF AN EXTERNAL LOGIC SIGNAL. THE TRIANGULAR SYMBOL IS ANY EXTERNAL LOGIC GATE. Q1 TO +V OR GROUND THROUGH 1M RESISTOR. R1 AND C1 CONTROL TONE FREQUENCY. Q1 CAN BE CONNECTED AS A SWITCHABLE GATE ELSEWHERE IN CIRCUIT.

IN  | TONE
LOW | OFF
HIGH| ON

CAUTION: Q1 CAN BE DESTROYED BY STATIC ELECTRICITY! DO NOT TOUCH EXPOSED LEADS. FOLLOW HANDLING PRECAUTIONS ON PACKAGE.

CHIRP GENERATOR

THIS CIRCUIT APPLIES BRIEF PULSES OF CURRENT TO A PIEZO BUZZER (RADIO SHACK 273-065 OR SIMILAR). THIS CAUSES THE BUZZER TO EMIT ATTENTION-GETTING CHIRPS. THE CIRCUIT MAKES A GOOD WARNING DEVICE.

R1 CONTROLS RATE OF CHIRPS, USE 100K FIXED RESISTOR FOR ABOUT 2-3 CHIRPS PER SECOND. C3 CONTROLS DURATION OF CHIRPS. FOR LONG DURATION PULSES (WHICH BECOME TONE BURSTS), INCREASE C3 TO 0.22uF OR MORE. REDUCE VOLUME BY INSERTING 100-10,000Ω RESISTOR BETWEEN PIN 9 AND PIEZO BUZZER. TRY USING C45 PHOTORESISTOR FOR R1.
STEPPED-TONE GENERATOR

This circuit produces sounds resembling plucked violin strings to drum as R1 and R3 are adjusted. Frequency of stepped output decreases in progressively smaller increments as R3 is reduced in value. Graph shown here is typical for values shown. OK to change C1, C2, and R1.

Frequency falls as R3 reduced.

43K

R3 (TYPICAL)

31K

0 .5KHz 1KHz 15KHz 2KHz

FREQUENCY OUT

51 (CENTER OFF):
1 - TONE BURST
2 - STEADY TONE
3 - TWO-TONE

3-STATE TONE GENERATOR

Experiment with values of R1, C1, R4, and C2.
TONE BURST GENERATOR

WHEN S1 IS CLOSED, THE SPEAKER EMITS A TONE WHOSE FREQUENCY IS DETERMINED BY R1 AND C1. WHEN S1 IS OPENED, THE TONE CONTINUES FOR SEVERAL SECONDS. THE TIME REQUIRED FOR C2 TO DISCHARGE THROUGH R4, INCREASE C2 TO INCREASE BURST DURATION.

CLOSE S1
OPEN S1
TONE ON
TONE OFF

SOUND EFFECTS GENERATOR

THE FIRST 555 OSCILLATES AT A FREQUENCY DETERMINED BY R1 AND C1. ITS OUTPUT CHARGES C2 THROUGH R3. THE SECOND 555 OSCILLATES AT A FREQUENCY DETERMINED BY R7, C3 AND THE VOLTAGE AT PIN 5 (i.e. THE CHARGE ON C2). EXPERIMENT WITH THE SETTINGS OF R1 AND R7 AND THE VALUES OF R3 AND C2 TO OBTAIN WAXBLE EFFECTS.

CHARGE ON C2
SPEAKER TONE FREQUENCY
**LED FLASHER**

This circuit will drive both visible light and infrared-emitting diodes. Use red, green or yellow LED to make a visible light flasher. Use near-infrared emitter to make powerful transmitter. Connect solar cell, photodiode or phototransistor to amplifier to receive signal.

<table>
<thead>
<tr>
<th>R1</th>
<th>Rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10K</td>
<td>1.0</td>
</tr>
<tr>
<td>47K</td>
<td>1.6</td>
</tr>
<tr>
<td>22K</td>
<td>1.1</td>
</tr>
<tr>
<td>10K</td>
<td>2.1</td>
</tr>
<tr>
<td>4.7K</td>
<td>3.6</td>
</tr>
<tr>
<td>2.2K</td>
<td>6.1</td>
</tr>
<tr>
<td>1.0K</td>
<td>8.3</td>
</tr>
</tbody>
</table>

Connect piezo buzzer across LED for light/sound darkroom timer.

Reduce C1 for faster pulse rates, especially when infrared emitter is used. See "Getting Started in Electronics" (Radio Shack, pp.64-49).

**POWER FET LAMP DIMMER**

Some versions may operate when 555 is powered by +12V.

This circuit is a linear lamp dimmer. In operation, the 555 switches Q1 on and off at a rate determined by R1 + R2 and C11. When Q1 is on, L1 is also on. The switching rate is so fast L1 appears to glow continuously. Increasing the switching rate increases the apparent brightness of L1.

Q1 must be properly rated. For example, a PR13 6-volt flashlight lamp consumes 0.5 ampere or 3 watts. Therefore use an IRF711 or similar power FET. Attach a TO-220 heatsink to dissipate excess heat.
LIGHT / DARK DETECTOR

When S1 is in position "L" the speaker emits a tone when light strikes the photoresistor. When S1 is in position "D" the speaker emits a tone when the photoresistor is not illuminated.

S1 POSITION:  

LIGHT  
DARK  

tone on  
tone off

INFRARED SECURITY ALARM

When the insert is moved from between LED (infrared emitter) and the piezo buzzer Q1, the monitor doors, etc.
ANALOG LIGHTWAVE TRANSMITTER

R1 CAN BE ANY SENSOR HAVING VARIABLE RESISTANCE. WHEN R1 IS A CADMIUM SULFIDE (CdS) PHOTORESISTOR, THE FREQUENCY OF THE SIGNAL RISES WITH LIGHT LEVEL.

THIS CIRCUIT PULSES AN INFRARED-EMITTING DIODE AT A FREQUENCY DETERMINED BY R1 AND C1. THE RECEIVER ON THE FACING PAGE RECEIVES AND AMPLIFIES THE INFRARED SIGNAL, IT THEN CONVERTS THE SIGNAL’S FREQUENCY INTO A CURRENT WHICH IS DISPLAYED ON A 0-1 mA METER. USE LENSES TO INCREASE RANGE. FOR FULL DETAILS, SEE "THE FORREST MIMS CIRCUIT SCRAPBOOK" (McGRAW-HILL, 1983).

RECEIVER CURRENT (mA)

1 9
2 8
3 7
4 6
5 5
6 4
7 3
8 2
9 1

RECEIVER CURRENT VS. FREQUENCY

CALIBRATE RECEIVER METER WITH R9.

TRANSMITTER FREQUENCY (kHz)

1 2 3 4 5 6 7 8 9 10 11 12

30

ANALOG LIGHTWAVE RECEIVER

THIS CIRCUIT RECEIVES PFM SIGNALS FROM THE TRANSMITTER ON FACING PAGE.

CONNECT C2 DIRECTLY ACROSS PINS 8 & 4 OF THE 1458.

CALIBRATE

+9V

R5 47K
R7 10K
R8 47K
R9 10K
R6 40K
R10 220

M1 0-1 mA
DC-DC CONVERTER

+5V to 9V (V_in)

CAUTION: HIGH VOLTAGE!

R1 4.7k
R2 1k
C1 0.01uF

T1 IN4004

C2 1m
R3 1M

120V WINDING
6.3V WINDING

*R1: MINIATURE 6.3V: 120V POWER TRANSFORMER (RADIO SHACK 273-1384 OR SIMILAR).

THIS CIRCUIT APPLIES A PULSATING CURRENT TO A TRANSFORMER WINDING. THE INPUT VOLTAGE IS THEN BOOSTED BY THE TRANSFORMER'S SECOND WINDING. USE TO POWER NEON LAMPS, PLASMA DISPLAYS, ETC.

CAUTION: DO NOT TOUCH OUTPUT LEADS! (R3 BLOWS CHARGE FROM C2 WHEN V_in IS REMOVED.)

RESISTOR COLOR CODE

BLACK 0 0 x 1
BROWN 1 1 x 10
RED 2 2 x 100
ORANGE 3 3 x 1,000
YELLOW 4 4 x 10,000
GREEN 5 5 x 100,000
BLUE 6 6 x 1,000,000
VIOLET 7 7 x 10,000,000
GRAY 8 8 x 100,000,000
WHITE 9 9

FOURTH BAND INDICATES TOLERANCE (ACCURACY):
GOLD = ± 0.5%  SILVER = ± 10%  NICKEL = ± 20%

OHM'S LAW: V = IR  R = V/I  P = VI = I^2R

ABBREVIATIONS

A = AMPERE  R = RESISTANCE
F = FARAD  V = VOLT
I = CURRENT  W = WATT
P = POWER  Q = OHM

M (MEG-) = x 1,000,000
K (KILO-) = x 1,000
m (MILL-) = .001
μ (MICRO-) = .000 001
n (NANO-) = .000 000 001
p (PICO-) = .000 000 000 001