PAPER FIREFLY

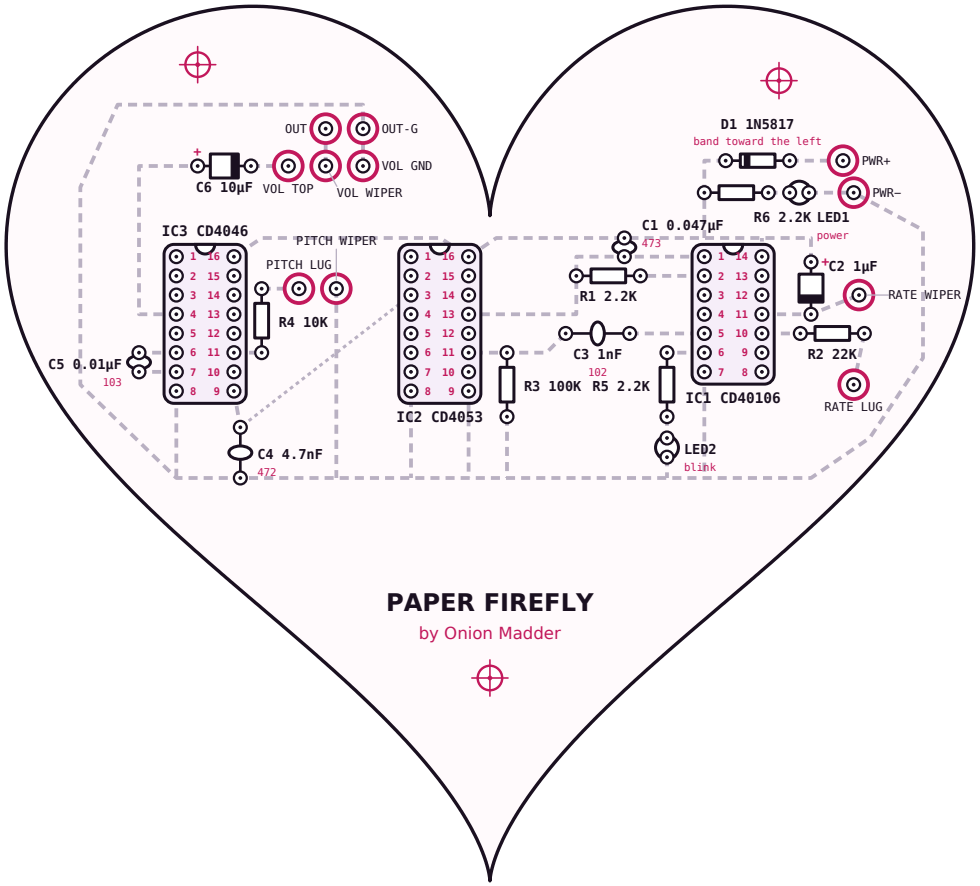
a random-note box as a paper circuit · two hearts, print at 100% / Actual size

Onion Madder // messopedals.com · paper-circuit method after Peter Blasser / Ciat-Lonbarde

this bar must measure 100 mm

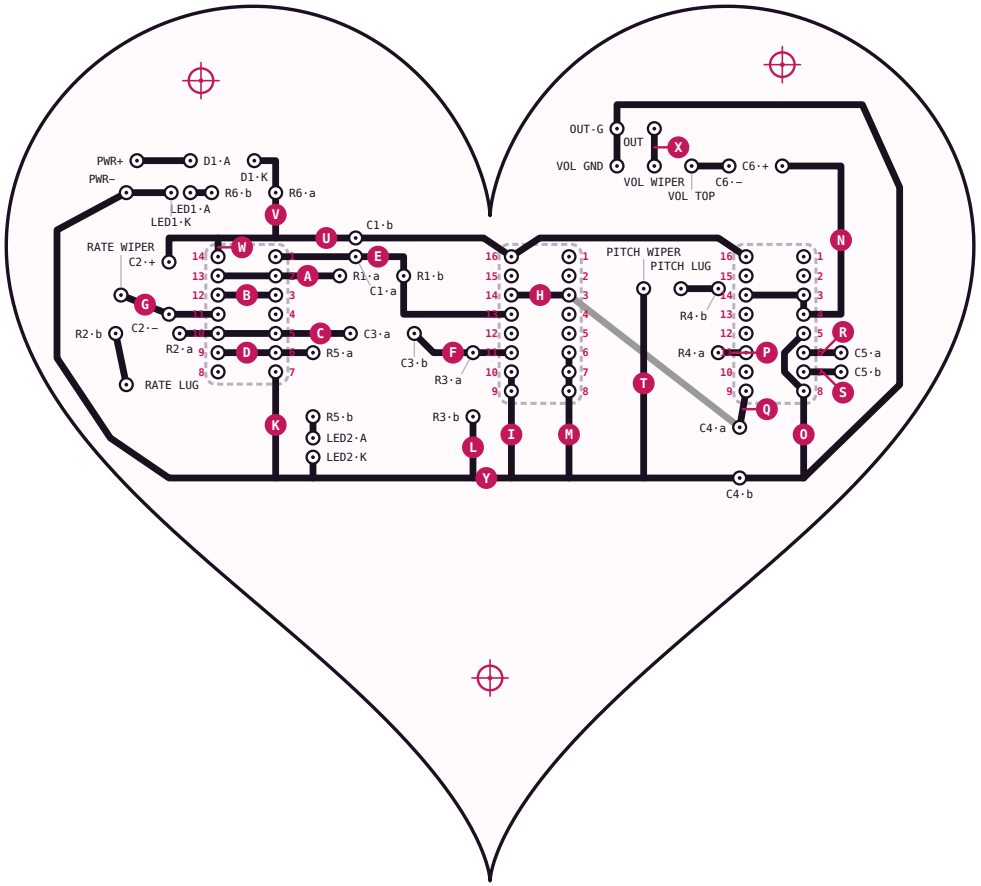
FRONT - parts side

parts go in from this face · the rate, pitch and volume pots, the jack and power on wires



BACK - solder side

glued behind the front · mirror image · bare wire along every line



Cut each heart out on its own outline. Never fold this sheet and cut both at once: the two sides come out misaligned.

Build-up: a blank sheet folded in half and glued shut is the core. Glue the FRONT heart on one face, cut the core to its edge, then glue the BACK heart on the other face with its outline matching that edge. Lay it on a cardboard box and poke every hole from the front with pointed tweezers. Four layers: front, two core layers, back. The target marks are an extra check for the very careful.

Paper Firefly

a random-note box: a sample-and-hold on a slow clock plays a new note every blink, as a full heart-shaped paper circuit

This one plays **random notes**. A fast oscillator runs far too high to hear, and on every tick of a slow clock a switch grabs whatever voltage it happens to be at and holds it. That held voltage sets the pitch of a third oscillator, so every tick is a new note, and the clock blinks an LED as it goes.

The RATE knob sets how often the note changes, from about two a second to a fast warble. The PITCH knob sets where the notes land; each one falls somewhere within about eight semitones of it. Each step starts with a tiny chirp while the switch is closed, which is where the name comes from.

What a paper circuit is

A paper circuit is a circuit board made of paper. The sheet you print is the board: the FRONT shows where every part sits, and the BACK is the same drawing mirrored, with the wiring on it. The printed front and back are glued to the two faces of a plain sheet folded in half, so the board is four sheets of paper thick, and every hole is poked through all four layers. The parts go in from the front, chips included, soldered straight to the paper. On the back, part legs bend along the printed lines, and bare wire covers the lines a leg cannot reach. Where one line has to cross another, an insulated wire hops over it. The power switch and the jacks hang off the board on wires. Nothing is etched and nothing is cut but paper: a printer, a glue stick, scissors, pointed tweezers, a cardboard box and a soldering iron are the whole kit.

The method is Peter Blasser’s, from Ciat-Lonbarde. His paper circuits are a great idea, but they are complicated, full of unusual parts and hard to troubleshoot. This series takes circuits people already know, built from common parts, and makes a paper circuit something a beginner can try.

66 steps. Page 1 is the board itself; everything after it is the recipe.

Reading the sheet

Front: each part is drawn where it sits, with its value printed next to it. The faint dashed lines are only a preview of what connects on the back. The ringed holes are for wires going off the board: PWR+ and PWR− for power; RATE LUG and RATE WIPER for the rate pot; PITCH LUG and PITCH WIPER for the pitch pot; VOL TOP, VOL WIPER and VOL GND for the volume pot; OUT and OUT-G for the output jack. The three target marks are an extra check for the very careful: on the finished heart they sit on top of each other.

Back: every bold black line is bare wire or a bent part leg. The lines with a letter in a circle are bare wire, and the steps name them by that letter; the short unlettered ones are a part’s own leg, bent along the line. The one lighter, thicker line is J1, the only insulated wire. Small pink numbers beside the chip holes are pin numbers. Several lettered wires run straight across a chip between its two rows of legs: that is on purpose, and the steps say which pins each one joins.

Sample-and-hold random notes from a fast oscillator and a slow clock is an old synth trick, and the 40106 oscillator and the 4046 VCO are out of every CMOS cookbook. The paper-circuit method is Peter Blasser’s / Ciat-Lonbarde’s. This layout and the words are Onion Madder’s.

What you'll need

- **1× CD40106 hex Schmitt inverter (IC1)** · *spot it:* 40106 printed on top, notch or dot at pin 1, 14 pins. All three chips solder straight to the paper, no socket.
- **1× CD4053 triple analog switch (IC2)** · *spot it:* 4053 printed on top, 16 pins.
- **1× CD4046 PLL (IC3)** · *spot it:* 4046 printed on top, 16 pins. Only its oscillator is used.
- **Resistors: 3× 2.2K (R1, R5, R6), 10K (R4), 22K (R2), 100K (R3)** · *spot it:* 2.2K red-red-red, 10K brown-black-orange, 22K red-red-orange, 100K brown-black-yellow
- **Ceramic caps: 1 nF (C3), 4.7 nF (C4), 0.01 µF (C5), 0.047 µF (C1)** · *spot it:* printed 102, 472, 103 and 473. Each one matters: check the print before it goes in.
- **Electrolytics: 1 µF (C2), 10 µF (C6)** · *spot it:* little cans; the stripe marks the − leg
- **1× 1N5817 Schottky diode (D1)** · *spot it:* small black body, gray or silver band marks the cathode
- **2× LEDs (LED1, LED2)** · *spot it:* LED1 is the power light, LED2 the firefly that blinks with the clock. Long leg +, flat side of the rim −.
- **3× pots: B500K for RATE, B500K for PITCH, A100K for volume** · *spot it:* B is linear, A is log. They hang off the board on wires, so any style fits. RATE and PITCH use two lugs each, volume all three.
- **1× SPST toggle, 1× jack** · *spot it:* power and the output, on wires
- **Bare tinned wire, and insulated wire** · *spot it:* bare for the traces on the back, insulated for J1 and every wire off the board
- **Power: a 9V battery and snap, or a 2.1 mm DC jack and a 9V pedal supply** · *spot it:* the usual pedal supply is center-negative
- **A second sheet of plain printer paper, a glue stick, scissors, pointed tweezers and a cardboard box** · *spot it:* the blank sheet becomes the core; the tweezers poke the holes and the box takes the points

The chips, from above

```
CD40106, IC1
              ┌──U──┐
      1 IN ─┤ 1   14 ├─ VDD
     1 OUT ─┤ 2   13 ├─ 6 IN
      2 IN ─┤ 3   12 ├─ 6 OUT
     2 OUT ─┤ 4   11 ├─ 5 IN
      3 IN ─┤ 5   10 ├─ 5 OUT
     3 OUT ─┤ 6    9 ├─ 4 IN
       VSS ─┤ 7    8 ├─ 4 OUT
              └─────┘

CD4053, IC2
              ┌──U──┐
        BY ─┤ 1   16 ├─ VDD
        BX ─┤ 2   15 ├─ B COM
        CY ─┤ 3   14 ├─ A COM
    C COM ─┤ 4   13 ├─ AY
        CX ─┤ 5   12 ├─ AX
       INH ─┤ 6   11 ├─ SEL A
       VEE ─┤ 7   10 ├─ SEL B
       VSS ─┤ 8    9 ├─ SEL C
              └─────┘

CD4046, IC3
              ┌──U──┐
   PHASE P ─┤ 1   16 ├─ VDD
   PC1 OUT ─┤ 2   15 ├─ ZENER
   COMP IN ─┤ 3   14 ├─ SIG IN
   VCO OUT ─┤ 4   13 ├─ PC2 OUT
   INHIBIT ─┤ 5   12 ├─ R2
       C1A ─┤ 6   11 ├─ R1
       C1B ─┤ 7   10 ├─ DEMOD
       VSS ─┤ 8    9 ├─ VCO IN
              └─────┘
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All three chips sit on the sheet exactly like this, notch toward the top edge: IC3, the 4046, on the left, IC2, the 4053, in the middle, and IC1, the 40106, on the right. Pins with nothing on them stay empty on purpose, and on IC3 pin 15 must stay empty: it is a zener to ground inside the chip.

Before you start

Paper burns. Keep the iron moving, quick joints, and don't rest it on the sheet. Work over something that isn't flammable, and keep a damp sponge handy.

Three chips. All three solder straight to the paper with no socket, notch up, and bare wires cross between their rows of legs on the back. Keep each joint quick: touch, flow, lift.

Leave IC3 pin 15 alone. Nothing touches it. It is a zener inside the 4046, and a wire from it to +V shorts the supply.

Mind the cans. C2 and C6 are polarized: the stripe is the − leg, and the sheet marks each + hole.

Assembly

The sheet is the circuit board, four sheets of paper thick: the two printed hearts glued to the two faces of a plain sheet folded in half. Each heart is cut out on its own, and the back lines up with the front by its edge, so there is nothing to fold and nothing to misalign.

> Print at 100% / "Actual size". Fit-to-page shrinks it and the holes stop matching the chips' legs.

STEP	DO
1	Print page 1 on plain printer paper at 100% / Actual size.
2	Measure the 100 mm bar at the top right of the sheet. If it isn't 100 mm, fix the print scale and print again.
3	Cut out the FRONT heart along its outline. Then cut out the BACK heart along its own outline. Don't fold the printed sheet and cut both at once: the two sides come out misaligned.
4	Fold a second, blank sheet of printer paper in half. Glue-stick the whole inside, close it, and press it flat. That's the core: two sheets thick.
5	Glue-stick the back of the FRONT heart.
6	Press the FRONT heart onto one face of the core, smoothing it flat from the middle out.
7	Cut the core away around the FRONT heart, following its edge, so the core is the same heart shape.
8	Glue-stick the bare side of the core.
9	Lay the BACK heart on it, printed side out, with its outline matching the edge all the way around, and press it flat. Now it's four sheets thick. The 3 target marks are there for the very careful: hold the heart up to a light and the targets on the two sides should sit on top of each other.
10	Let the glue set for a few minutes. Then lay the heart front side up on a cardboard box, and poke the 46 chip holes straight down through all four layers with pointed tweezers, held closed. The box takes the points.
11	Poke the other 41 dots and rings the same way. Check the back and open any hole that didn't come all the way through.
12	Check the fit: push each chip into its holes until its legs come through on the back. If a leg won't go, open that hole a little more.

Start in the middle: three chips and the wires through them

Everything builds outward from the chips. Several wires cross a chip straight from one row to the other on the back; solder each at its pins now, and the far ends as their parts go in.

> Quick dabs only. Paper scorches if you sit on it: touch, flow, lift.

STEP	DO
13	Push the CD40106 into the IC1 holes (right), the CD4053 into the IC2 holes (middle) and the CD4046 into the IC3 holes (left), all notch toward the top edge.
14	On the back, bend each chip’s corner pins outward slightly so the chips can’t fall out.
15	Trace A: bare wire straight across IC1 from pin 13 to pin 2, and on out to the left to the R1·a hole. Solder at pins 13 and 2.
16	Trace B: bare wire straight across IC1 from pin 3 to pin 12. Solder at both.
17	Trace C: bare wire from the C3·a hole straight across IC1 through pin 5 and pin 10 to the R2·a hole. Solder at pins 5 and 10.
18	Trace D: bare wire straight across IC1 from pin 9 through pin 6 and out to the left to the R5·a hole. Solder at pins 9 and 6.
19	Trace H: bare wire straight across IC2 from pin 14 to pin 3. Solder at both.
20	Trace M: bare wire down IC2’s left row through pins 6, 7 and 8, and on down to the ground line. Solder at all three pins.
21	Trace I: bare wire down IC2’s right row through pins 10 and 9, and on down to the ground line. Solder at both pins.
22	Trace N: bare wire straight across IC3 from pin 14 to pin 3, down to pin 4, out to the left and up to the C6·+ hole. Solder at pins 14, 3 and 4.
23	Trace O: bare wire from IC3 pin 5 a little way in between the rows, down past pins 6 and 7 without touching them, back out to pin 8 and on down to the ground line. Solder at pins 5 and 8.
24	Check with a meter: on IC3, pin 15 must not beep to anything, and pins 6 and 7 must not beep to trace O.

The fast oscillator

One inverter of IC1, R1 and C1 make an oscillator around 12 kHz. Nobody hears it: its capacitor’s voltage is what gets sampled.

STEP	DO
25	R1, 2.2K (red-red-red): legs into R1·a and R1·b. Solder R1·a where trace A ends.
26	C1, 0.047 µF (473): legs into C1·a and C1·b.
27	Trace E: bare wire from IC1 pin 1 out to the left through C1·a, down through R1·b, and across to IC2 pin 13. Solder at all four.

The clock and its blink

Another inverter of IC1, the RATE pot, R2 and C2 make the slow clock. It blinks LED2 as it goes.

> C2’s stripe goes toward the bottom of the heart.

STEP	DO
28	C2, 1 µF: long + leg into C2·+, striped leg into C2·−.
29	Trace G: bare wire from IC1 pin 11 out to the right through C2·− to the RATE WIPER pad. Solder at all three.
30	R2, 22K (red-red-orange): legs into R2·a and R2·b. Solder R2·a where trace C ends. Bend R2·b’s leg to the RATE LUG pad and solder at both.
31	R5, 2.2K: legs into R5·a and R5·b. Solder R5·a where trace D ends.
32	LED2: long leg into LED2·A, short leg into LED2·K. Bend R5·b’s leg to LED2·A and solder. Bend LED2·K’s leg down to the ground line; it gets soldered with the line.

The sample and the hold

C3 and R3 turn each clock tick into a spike that closes IC2’s switch for an instant. C4 holds what it grabbed.

STEP	DO
33	C3, 1 nF (102): legs into C3·a and C3·b. Solder C3·a where trace C starts.
34	R3, 100K (brown-black-yellow): legs into R3·a and R3·b.
35	Trace F: bare wire from C3·b across through R3·a to IC2 pin 11. Solder at all three.
36	Trace L: bare wire from R3·b straight down to the ground line. Solder at R3·b.
37	C4, 4.7 nF (472): legs into C4·a and C4·b.
38	Trace Q: bare wire from IC3 pin 9 down to C4·a. Solder at both.
39	J1: an insulated wire from IC2 pin 3 to C4·a. It crosses bare wires on the way, which is why it is insulated. Strip just the ends and solder at both.

The VCO and the output

IC3’s oscillator plays the held voltage as a note. C5 and the PITCH pot set where the notes land.

> C6’s stripe goes toward the right, the VOL TOP side.

STEP	DO
40	C5, 0.01 µF (103): legs into C5·a and C5·b, left of IC3.
41	Trace R: bare wire from IC3 pin 6 out to C5·a. Solder at both.
42	Trace S: bare wire from IC3 pin 7 out to C5·b. Solder at both.
43	R4, 10K (brown-black-orange): legs into R4·a and R4·b. Bend R4·b’s leg to the PITCH LUG pad and solder at both.

44	Trace P: bare wire from IC3 pin 11 out to R4·a. Solder at both.
45	Trace T: bare wire from the PITCH WIPER pad straight down to the ground line. Solder at PITCH WIPER.
46	C6, 10 µF: long + leg into C6·+, striped leg into C6·−. Solder C6·+ where trace N ends. Bend C6·−'s leg to the VOL TOP pad and solder at both.
47	Trace X: bare wire from the VOL WIPER pad up to the OUT pad. Solder at both.

Power corner and the +V line

Power comes in on two pads at the top right. D1 only lets current through one way, so power hooked up backwards does nothing, and LED1 says it's on. +V runs over the tops of all three chips.

> D1's band goes in D1·K, toward the left.

STEP	DO
48	D1, 1N5817: band end into D1·K, plain end into D1·A. Bend D1·A's leg to the PWR+ pad and solder at both.
49	Trace U, the +V line: bare wire from C2·+ up and along over the tops of the chips, dipping to IC2 pin 16 and ending at IC3 pin 16. Solder at C2·+, C1·b, IC2 pin 16 and IC3 pin 16.
50	Trace V: bare wire from D1·K down to the +V line. Solder at D1·K and where it meets U.
51	Trace W: bare wire from IC1 pin 14 straight up to the +V line. Solder at pin 14 and where it meets U.
52	R6, 2.2K: legs into R6·a and R6·b. Solder R6·a on trace V.
53	LED1: long leg into LED1·A, short leg into LED1·K. Bend R6·b's leg to LED1·A and solder at both. Bend LED1·K's leg to the PWR− pad and solder at both.

The ground line

One ground wire starts at the volume pads in the left lobe, runs down the left side, along the bottom and up the right side to PWR−. Everything that goes to ground drops onto it.

STEP	DO
54	Trace Y, ground: bare wire from the VOL GND pad through the OUT-G pad, over to the left, down the left side, along the bottom through C4·b, and up the right side to PWR−. Solder at VOL GND, OUT-G, C4·b and PWR−, and where traces M, I, L, O and T meet it, and LED2·K.
55	Trace K: bare wire from IC1 pin 7 straight down to the ground line. Solder at pin 7 and where it meets Y.
56	Snip every leg tail that sticks past its joint.

Off the board

The three pots, the jack, the toggle and the power hang off the pads on insulated wire.

> If a knob runs backwards, move its LUG wire to the other outer lug (or for volume, swap the two outer wires).

STEP	DO
57	RATE pot: the middle lug (the wiper) to RATE WIPER and one outer lug to RATE LUG. The other outer lug stays empty.
58	PITCH pot: the middle lug to PITCH WIPER and one outer lug to PITCH LUG. The other outer lug stays empty.
59	Volume pot: one outer lug to VOL TOP, the middle lug to VOL WIPER, the other outer lug to VOL GND. No pot? A short wire from VOL TOP to VOL WIPER and it plays at full volume.
60	Output jack tip to OUT, sleeve to OUT-G.
61	A wire from one lug of the power toggle to the PWR+ pad.
62	Battery: the snap’s red (+) wire to the toggle’s other lug, its black (−) wire to PWR−. Or a DC jack for a center-negative 9V pedal supply: the jack’s sleeve (+) lug to the toggle’s other lug, its center-pin (−) lug to PWR−.

Check, then play

Meter it before you play it. These readings come from the datasheets and the arithmetic, not off my board.

STEP	DO
63	Turn the volume all the way down. Clip the battery on or plug the supply in, and toggle on. LED1 should light and LED2 should blink.
64	Meter IC1 pin 14, IC2 pin 16 and IC3 pin 16 to the ground line: the supply minus about 0.3 V each.
65	Meter IC3 pin 9 to ground with the RATE knob slow: it jumps to a new value, between about 3 V and 5.5 V, every time LED2 blinks.
66	Bring the volume up slowly. Turn RATE for how fast the notes change and PITCH for where they land.

Voltage check

METER BETWEEN	EXPECT (toggle on)
PWR+ pad → PWR− pad	supply voltage
IC1 pin 14, IC2 pin 16, IC3 pin 16 → ground	supply voltage minus about 0.3 V
IC1 pin 1 → ground	about half the supply, steady: the fast oscillator running
IC1 pin 10 → ground	swinging between zero and the supply with the blink, at a slow RATE

METER BETWEEN	EXPECT (toggle on)
IC3 pin 9 → ground	a new value between about 3 V and 5.5 V at each blink, steady between

If it won’t sing

SYMPTOM	CHECK
Dead, LED dark	D1 in backwards (the band goes in D1·K), the power wires reversed, or the toggle not between the supply’s + and PWR+.
LED1 lit, LED2 never blinks	The clock: C2 the right way up, trace G to RATE WIPER, R2 and the RATE pot wires, and trace C through IC1 pins 5 and 10.
Blinks, but one steady note	The sample isn’t landing. C3 is the 102 and R3 the 100K; trace F to IC2 pin 11; J1 at both ends; trace E to IC2 pin 13. Then IC1 pin 1: it should sit near half the supply.
Blinks, silent	IC3: C5 across pins 6 and 7, R4 and the PITCH pot wires, trace O grounding pin 5, then trace N to C6 and the volume pot.
The notes drift between blinks	C4 is leaking its charge away: it should be the 472, and nothing but J1 and trace Q may touch C4·a.
Paper scorched or a hole tore	Glue a scrap of paper over the back, re-poke, carry on. It is paper.

Things to try

- **Wider leaps:** R4 smaller lets each note jump further, but keep it 10K or more. Untried.
- **A photocell for RATE.** An LDR across RATE LUG and RATE WIPER, and the notes speed up in the light. Untried.
- **Into the Paper Ring Mod.** Random notes against a steady drone. Untried.