HOMELAB PROJECT

Ultimate Bugblaster

No more flabby flyswatters

Graphic: shutterstock.com

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For some time electric flyswatters have been available at giveaway prices. Made with a metal grid and a plastic handle, they look rather like miniature tennis racquets. Two AA-size batteries produce a voltage in the region of 1 to 3 kV and use this to charge a small capacitor. This level of energy is just enough to annihilate mozzies (mosquitoes) and render house flies unflightworthy for just a short while. This project describes some improved high-voltage electronics that take us right to the limits of what is technically achievable.

Figure 1. The second prototype (center) compared with some commercial flyswatters.

Electric flyswatters have a number of advantages over their clumsier mechanical counterparts. These weapons of mozz destruction are an elegant means of denying mozzies permission to fly — without leaving unsightly evidence of these encounters on your white-painted walls. Even fruit flies, which are smaller than the separation between the electrified wires (about 4 mm), are unfailingly terminated. They bridge enough of the spark gap to cause a flashover and initiate their new incarnation. The style of grid that uses parallel wires (**Figure 1**) has proven itself in practice better than those variants with three mesh gratings in which the voltage is applied between the gratings.

Larger flying insects pose a greater problem, however. Whilst mosquitoes and fruit flies are eliminated quite reliably, houseflies and bluebottles usually fall to the ground, then fly back and forth again within a few seconds. If they are not 'dispatched' while on the ground level, your labors are in vain. At this stage every electronicist will ask the obvious question: can we achieve greater effect with more volts and amps?

Contact between fly and grid sets off an immediate flashover (electric arc). In **Figure 2** you can see how the voltage between the wires of the grid collapses immediately on contact with a fly, and consequently the storage capacitor (C in the simplified diagram = **Figure 3**) is drained of its energy. It stands to reason now that we need to increase the stored energy and intensify the arc. It's clear that a minimum firing voltage is necessary to trigger a spark, even with smaller fruit flies. In our experience, around 3 kV is a good value with 4 mm separation between the wires.

Optimization

Commercial products use a flyback converter that generates about 2.8 kV from a battery voltage of 3 V at best. Cheap models manage barely 1.6 kV. In the best flyswatters the HT (high tension or high voltage) is loaded with a 22 MΩ resistor (R in Figure 3). Presumably this has two functions: on one hand it limits the voltage, simply because the flyback converter has only a restricted output, and on the other this ensures rapid discharge of the storage capacitor when the pushbutton is released. Some models, however, have a mechanical contact (S_b in Figure 3) installed, which, after the pushbutton is released, simply short-circuits the voltage — a very elegant and safe solution.

Two conceivable improvements could be implemented quickly:

- Connecting additional capacitors in parallel for more stored charge. For testing we installed an additional 22 nF with 2 kV load capacity.
- Increasing the value of the resistor. A good 2 kV is feasible with 100 MΩ, even using low-cost swatters.

As simple as these optimizations were, they remained equally ineffective. Our experiments showed that these improvements were measurably detectable, but this did not really impress or scare the flying insects we confronted. At this point our investigative spirit was really challenged.

The case molding of the swatter we first used did not have any room for extra capacitors. So another flyswatter was procured that offered more space for after-market add-ons. Unfortunately the flyback generator in this specimen was not quite as effective, as it delivered only 1.6 kV. **Figure 4** shows that room was found for several additional 2-kV capacitors. This measure alone increased the stored charge from originally 45 µC (micro-coulombs) to at least 465 µC, which meant more than a tenfold improvement!

This step-up may sound impressive but once again the emergence of quality from quantity did not produce much of an experience overall. The zap was louder but that was it. The desired goal of a far better flyswatter was still not achieved.

Brute force

The motto 'more is better' is a fundamental rule of thumb for every electronics. If the previous 'more' is still insufficient, then we must increase the quantity all the more so. The next consideration was therefore: how far can we raise the voltage? What will this achieve? How can we increase the capacitive charge more effectively?

As you know, and as **Figure 5** demonstrates impressively, for the same physical volume electrolytics deliver appreciably greater capacity than foil capacitors. The high-voltage capacitor used can develop a charge of 44 µC using 22 nF at 2 kV, corresponding to a stored energy of 88 mJ. Believe it or not, at 450 V a 10-µF electrolytic stores 2,000 mJ. In terms of volume, the electrolytic contains 62 µC/cm³ against a pitiful 2.7 µC/cm³ in the blue casing. Energetically speaking, that's a ratio of 124 to 1.2 J/cm³. Using an electrolytic capacitor, you can store an entire order of magnitude more energy

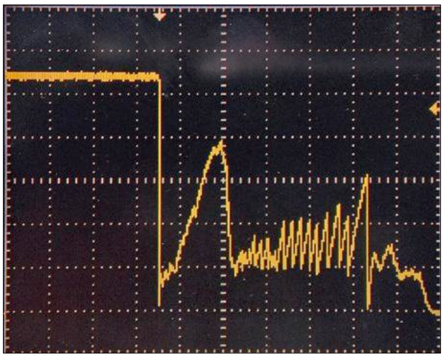

Figure 2. Voltage characteristics on the grid when a fly makes contact.

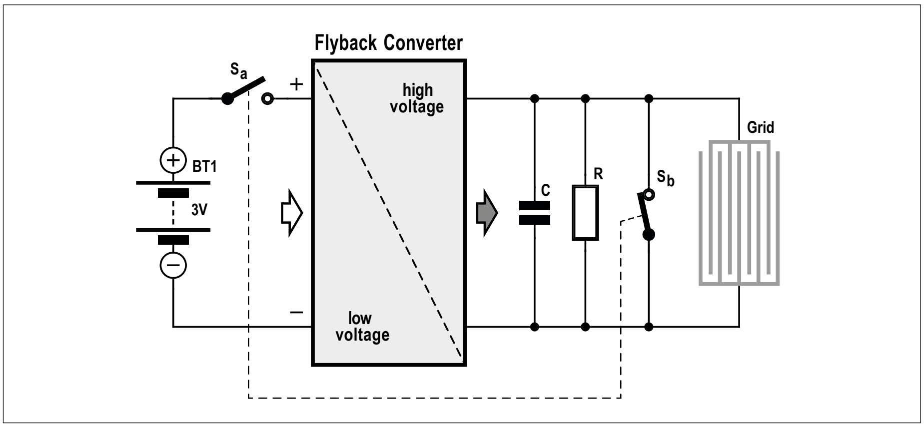

Figure 3. Simplified diagram of the internals of a commercial flyswatter. These either include a resistor R for slowly discharging the storage capacitor or else a secondary contact S_b short-circuits the capacitor when S1 is released.

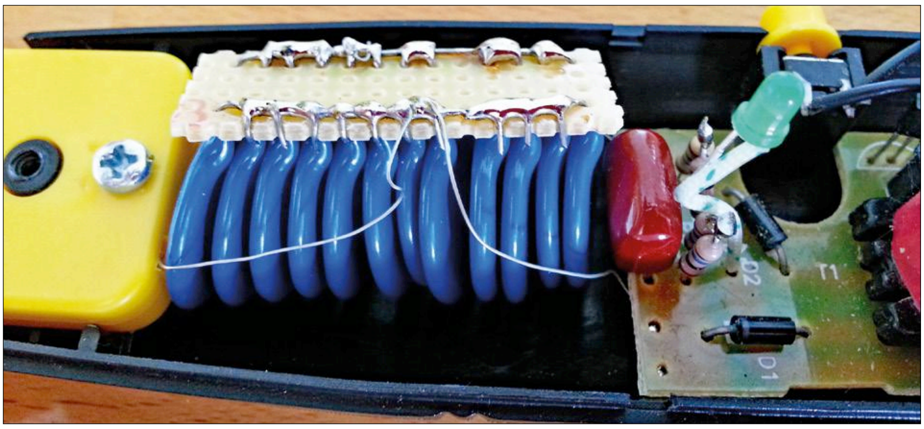

Figure 4. This flyswatter had enough room for a number of additional capacitors.

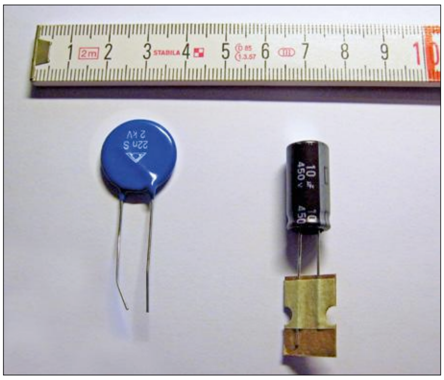

Figure 5. Size comparison of electrolytic and normal HT capacitors.

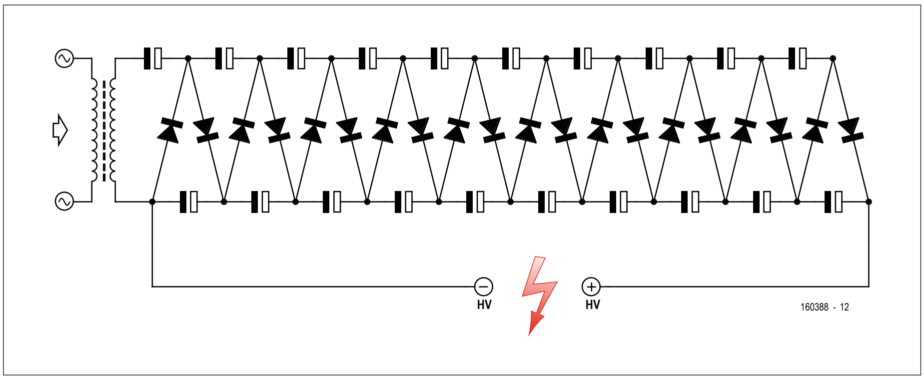

Figure 6. Voltage multiplier for a factor of 10 in a Villard circuit. Each electrolytic is charged to no more than 450 V.

with a given volume. And that should go a long way in delivering the 'more' that we need...
General-purpose electrolytics are available only up to 450 V rating. Since our preliminary tests indicated that we should aim for a total voltage of at least 4 kV, a series chain of electrolytics is mandatory. Accordingly and to have a little in reserve, we must connect ten electrolytic capacitors in series, which is adequate even for 4.5 kV. Together with the charging capacitors in the Villard circuit [1] (**Figure 6**), we need to incorporate 20 electrolytic capacitors! When electrolytics are connected in series it is vital that the voltage is distributed evenly and no single capacitor is overloaded.

A further requirement was the ability to still produce the specified HT voltage with partly discharged batteries. The flyswatter should operate constantly up to a certain limit independently of the state of the batteries. Initially it was planned to use two AA cells for powering it, as with off-the-shelf swatters. Problems arose with this approach, however:

- the voltage transition from 3 to 1.6 V (from fresh to flat batteries) was equivalent to virtually halving the supply voltage;
- the microcontroller management system (this is after all a hi-tech flyswatter) required a minimum of 2.7 V;
- with 20 electrolytics rated 450 V and 10 µF, the stored energy level amounted to around 20 Ws (watt-seconds). For a 10-s charging time the HT generator would require an output capacity of 2 W. To this you would need to factor in the conversion losses. The resulting current draw (around 1 A) would be impossible with partly discharged AA cells;
- the voltage ratio required of the transformer would be high, particularly when a demand of 450 V_{pp} needs to be produced from below 2 V.

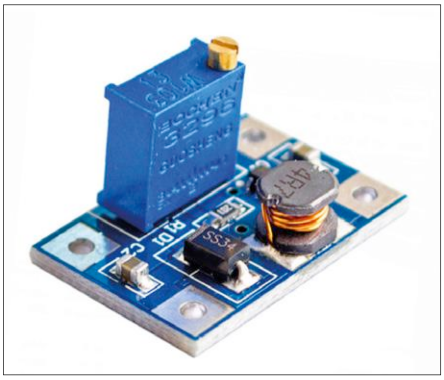

Figure 7. The SX1308 step-up converter module provides up to 2 A and can be bought cheaply on eBay.

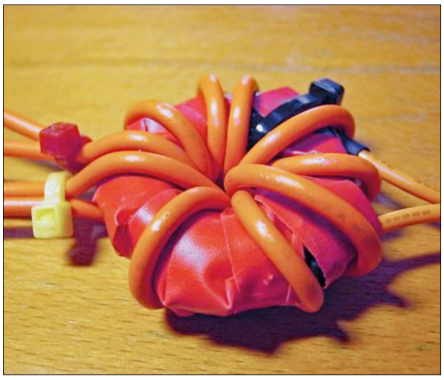

Figure 8. Homebrew HT ring core transformer. Note the insulation between the secondary and primary sides.

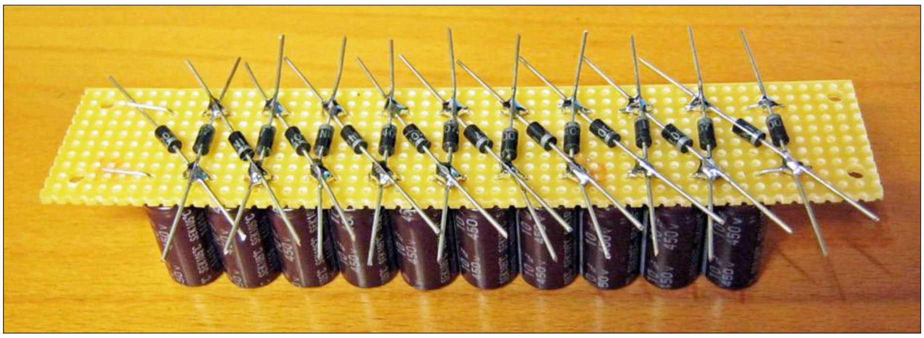

Figure 9. HT cascade made up of 20 diodes and 20 HT electrolytics.

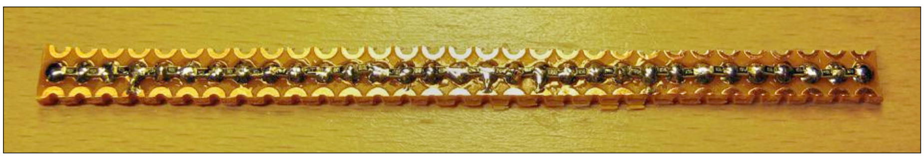

Figure 10. Voltage divider made up of 30 × 10 MΩ and a 100 kΩ precision resistor in the center.

The first solution was to raise the voltage to a constant 4 V using a 2 A step-up converter module of the type SX1308 (**Figure 7**), which you can find on eBay for €2 to €3 / £2 to £3 / $2.5 to $3.5. The step-up converters tested were unable to produce 1 A across the entire discharge range of the batteries, however. So this strategy was rejected.

Developing the circuitry

In place of AA cells we now changed to lithium rechargeables. As well as the advantage of a higher nominal voltage of 3.6 V, the discharge rate of these batteries remains desirably stable over a broad range. In addition the internal resistance is really low. So the circuit was dimensioned for an operating voltage range of from 3.3 to 4.2 V. And why not go the whole hog? Two 18650-type Li-Ion batteries were wired in parallel. Additionally the SX1308 step-up converter was called into service to produce a constant operating voltage of 4 V for generating the HT.

Our first notion was to drive the primary winding with a normal half or full-wave bridge. Using bipolar transistors, we lose approx. 2 x 0.2 V in saturation voltage. MOSFETs would reduce the loss but they are more demanding in terms of drive circuitry. The converter can be simplified and made more efficient if we use two bipolar transistors in push-pull to drive the two primary windings. Then the transformer needs only to raise around 4 V to 225 V_p = 450 V_{pp}.

We were unable to find a suitable transformer with the 2x1:65 turns ratio required for this. AC line (mains) transformers have significantly smaller voltage ratios. This also applies to the transformers that we removed from switch-mode power supplies for testing out. So we had to make the necessary transformer ourselves. Using a ring core that we had available (outer diameter 28.9 mm, inner diameter = 8.7 mm, width = 7.7 mm) we made 2×5 turns for the primary and 325 turns for the secondary winding. The cross-section of the wire is not really critical and conforms to the size of the core. We used 0.2 mm diam. (34 AWG) enameled copper for the secondary and 1 mm diam. (18 AWG) for the primary winding. **Figure 8** shows the result of these efforts. Following the transformer comes the classic HT cascade of Figure 6 with 20 1-kV diodes of the type 1N4007 each plus one high-voltage electrolytic each (**Figure 9**).

For measuring the resulting HT and reducing it to a voltage usable with the A-to-D converter of the microcontroller we initially provided a voltage divider from 300 MΩ to 100 kΩ. With this arrangement, however, the bulk of the electronics would lie at the potential of one of the two high-voltage sections. If you now touched grounded material like a radiator or a water tap (faucet), the insulation of the handle and the transformer would then have to withstand 4 kV, increasing the risk of electric shock for the person using the flyswatter unnecessarily. A better idea would be to divide the series resistor into 2 x 150 MΩ units and put the precision resistor and ground centrally. The potential difference between the grid wires and the electronics (and consequently the handle as well) is then halved to a little over 2 kV. Incidentally, with such high voltages and resistance, the number of resistors connected in series is determined not by their power loss but by their dielectric strength. For safety reasons, 30 units of 10 MΩ resistors in 0603 SMD format were employed (**Figure 10**). Then 'only' 150 V needs to be dropped per resistor. According to Adam Riese mathematics, on the 100 kΩ precision resistor formula we have just 1.5 V — suitable the measuring range of the A-to-D input of a microcontroller.

The control center of the circuit (**Figure 11**) is an ATtiny26. This monitors the battery and HT voltages and controls the status information LEDs. Once the defined HT voltage is reached, the drive to the transistors is stopped.

In the circuit's quiescent (inactive) state the microcontroller is in sleep mode, consuming less than 1 µA. It can therefore remain permanently connected to the battery. Operating pushbutton S1 activates the Controller using an Interrupt and applies power via MOSFET T3 to the step-up converter driven with around 1.2 MHz, also to T1 and T2. Our self-wound transformer is driven at around 90 kHz. S1 doesn't have to stand up to any great current therefore. Diodes D4 to D7 serve to produce the gate voltage (charge pump), in which all the voltage drop across D2 to D4 does is to ensure the maximum allowed gate voltage for T3 is not exceeded. With a somewhat more expensive MOSFET with a lower 'on' threshold you drop the need for the charge pump. The step-up converter is adjusted for 4 V. When T3 is switched on, the voltage multiplier is initially supplied directly from the battery

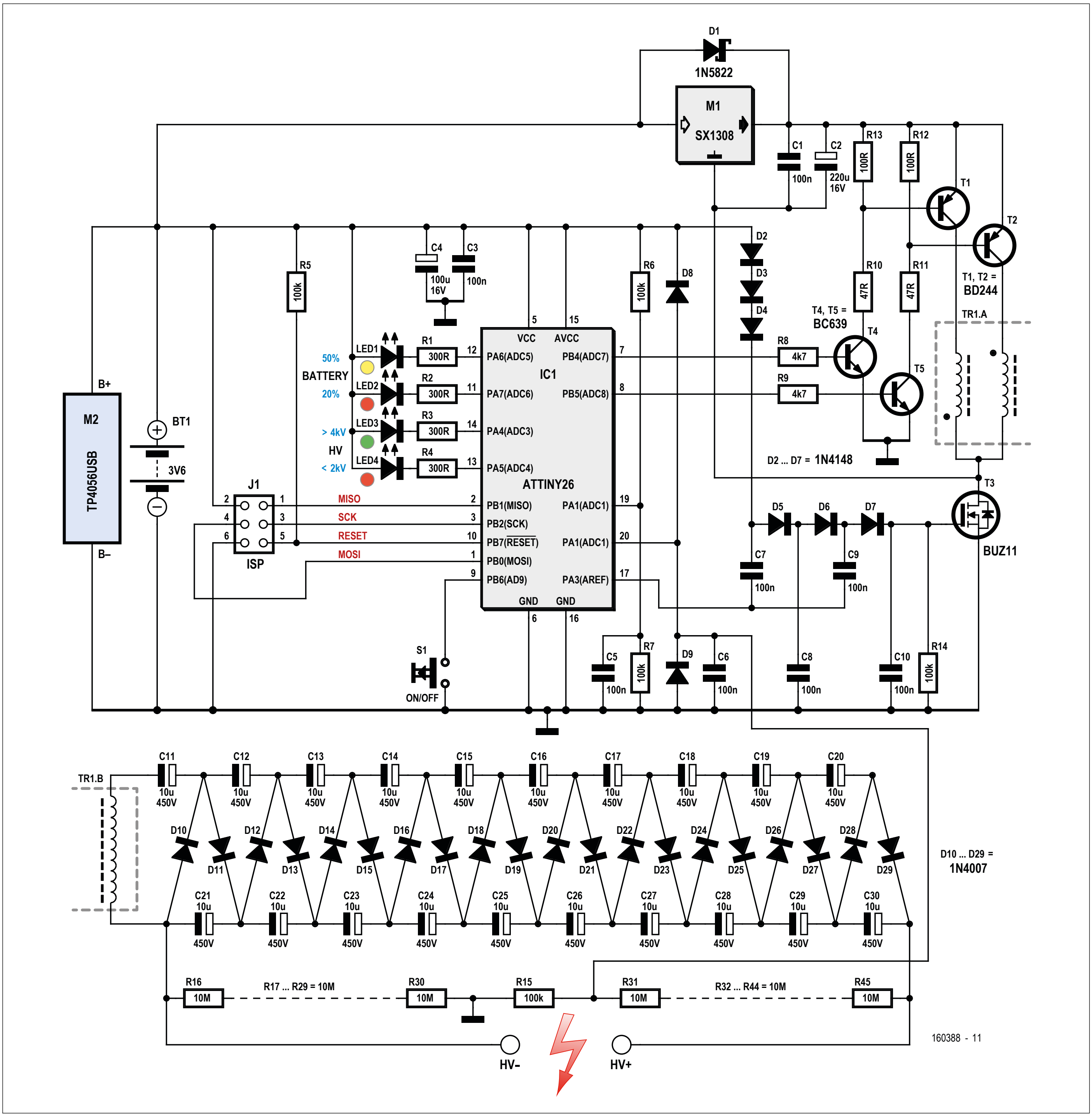

Figure 11. Complete schematic of the power swatter.

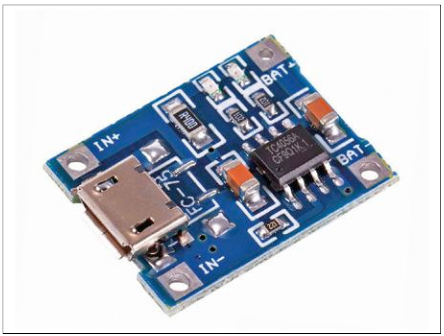

Figure 12. This ready-built module using a TP4056USB can charge a Li-Ion rechargeable battery via USB correctly with a current of up to 500 mA and is very affordable.

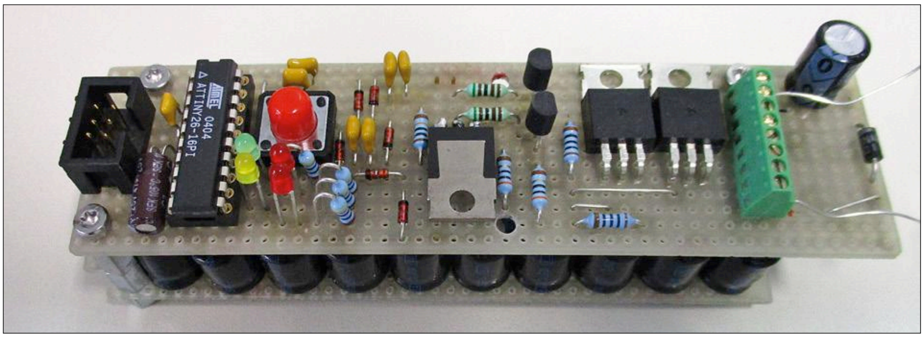

Figure 13. This is how the finished electronics look when mounted on perf board. On the lower deck is the HT section.

via D1; until the step-up converter turns on the voltage, it is bypassed by D1. Charging the Li-Ion batteries is done by USB, using the TP4056 charge controller. This ready-made module (**Figure 12**) is another thing that can be had on eBay for very little money. The completed electronics (without the HT voltage divider) are shown in **Figure 13**.

Firmware for the little Atmel microcontroller was written in Atmel Studio; the source code can be downloaded from the Elektor web page for this article [2]. IC1 is programmed for using the internal 4 MHz clock generator by Fuses (**Figure 14**).

So far two prototypes have been built, which demonstrated that the mechanical construction is not totally uncritical. With the grid style used flashovers took place in the framework and between the wires at voltages above 4.2 kV. Two measures will mitigate this:

- encasing the framework in electrical potting resin;
- limiting the maximum HT voltage to 4 kV by software.

With these two precautionary measures you can stay on the safe side and zapping will take place only when an insect approaches the grid wires.

Test results

As already mentioned, the authors constructed two prototypes for test purposes using perf board. The larger 'man size' construction on a wooden batten (**Figure 15**) was simply a feasibility study. It does work but its practicality is limited by its length and the additional mass of the batten, both of which make it somewhat unwieldy.

Swiping house flies with such a monster swatter is not a good idea, especially if you don't want your furnishings to suffer too much.

The second version built (**Figure 16**) is visibly easier to handle and more compact. The electronics are fixed above the high-voltage unit. So you can get a fix on the difference between this and the commercial flyswatters, we produced a graphic (**Figure 17**) showing the voltage characteristics of the devices in Figure 1. Incidentally the 'bug zapper' (far right in the photo) now comes in a better version. This chart shows how our flyswatter (gray line) produces more than 4 kV over the entire usable voltage range and is thus vastly superior to the commercial products.

In fact our swatter works brilliantly. It

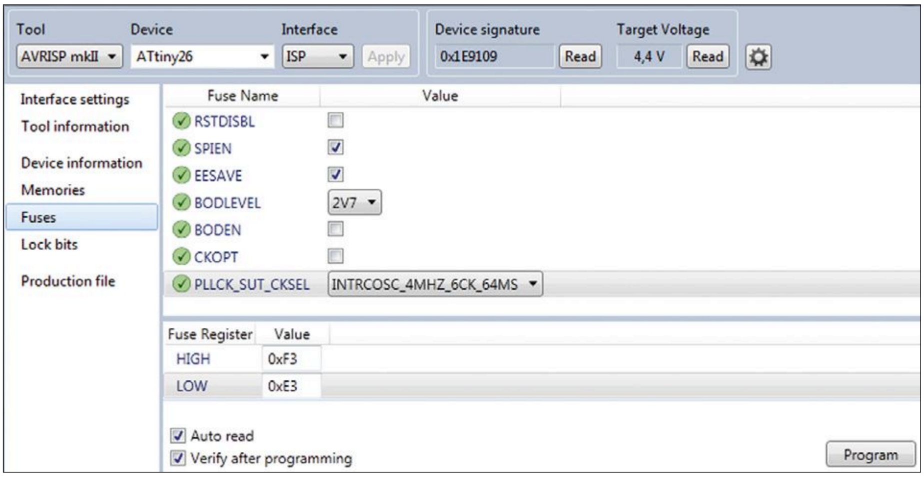

Figure 14. The Fuses for the ATtiny26 are set like this. The 4-MHz clock frequency is crucial.

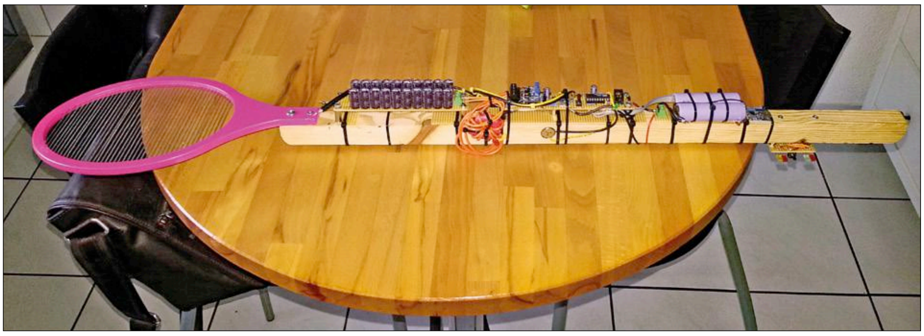

Figure 15. This monster prototype on a wooden batten turned out rather long and thus unwieldy. It is rather just a feasibility study.

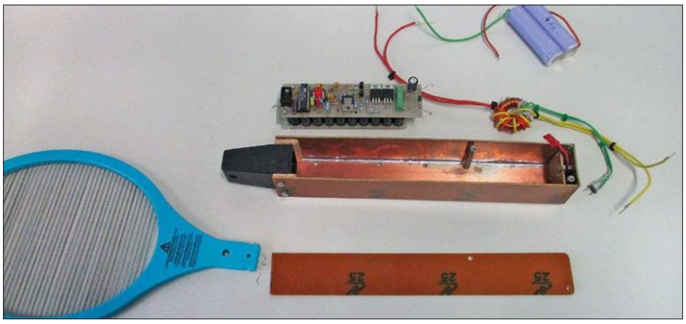

Figure 16. The second prototype is already significantly smaller and more practical to use.

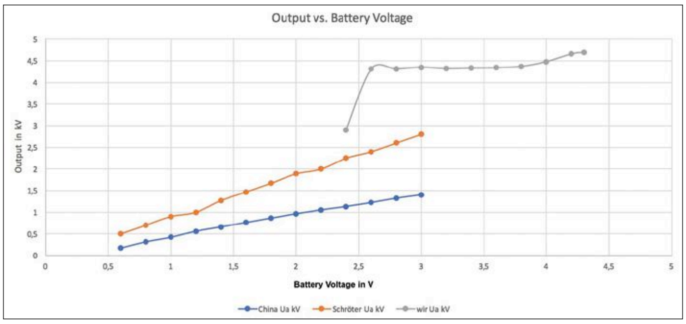

Figure 17. Comparison of the HT from a low-cost flyswatter, a better-class example and our self-built design in relation to the battery voltage. Building your own is definitely worthwhile, as you can see.

Hi-tech + high tension = ultimate bug blaster

terminates fruit flies, gnats and midges dependably. On the other hand its effect on flies is unfortunately not quite so convincing as hoped. Even so, it takes them a couple of minutes to wake from their coma and fly away. This gives you adequate time to deal with them.

Currently the voltage is indicated with two status LEDs but in practice you follow flies with your eyes and don't look at the LEDs. An audible means of indicating the status of the HT might be better, for example by varying the pitch of a tone.

The high resistance of the voltage divider means that loading on the HT cascade is minimal, which is also why a substantial voltage persists for a good minute after use. It would be pretty unpleasant to touch, so this is certainly an area for improvement.

The authors will continue to look into the effect on house flies too. It's likely the size of the capacitors will need to be increased drastically or else a new strategy may occur to us. If you have a bright idea, please share it with all of us!

And finally: play safe

This must be said and heeded without fail: it is absolutely *not* safe to fool with electrolytics charged at 4 kV! With circuits like this, loud bangs may not be the only outcome, even at the construction test. If capacitors discharge themselves through the human body, the effect will be similar to what happens to a fly. It's only our larger size that protects us humans from the truly horrendous things that may occur. Even then our skin is not a perfect insulator and you can probably imagine the pain of an intense electric shock. And if someone has a weak heart, you may well get a visit from the emergency physician and later on from the police.

High-power flyswatters of this kind belong *only* in the hands of competent and responsible people. So never leave them lying around and far less ever allow children to operate them. All too often they cannot resist 'looking with their fingers' and when you hear a loud scream, it may already be too late for resuscitation. Their death will be forever on your conscience. So please be sensible.

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Web Links

[1] Voltage multipliers: https://en.wikipedia.org/wiki/Voltage_multiplier

[2] Firmware: www.elektormagazine.com/160388

About the authors

Bernhard Schriefer and Hannes Stein are keen engineers and radio amateurs from Berlin. Like many other engineers, both of them have enjoyed an interest in electronics since childhood.