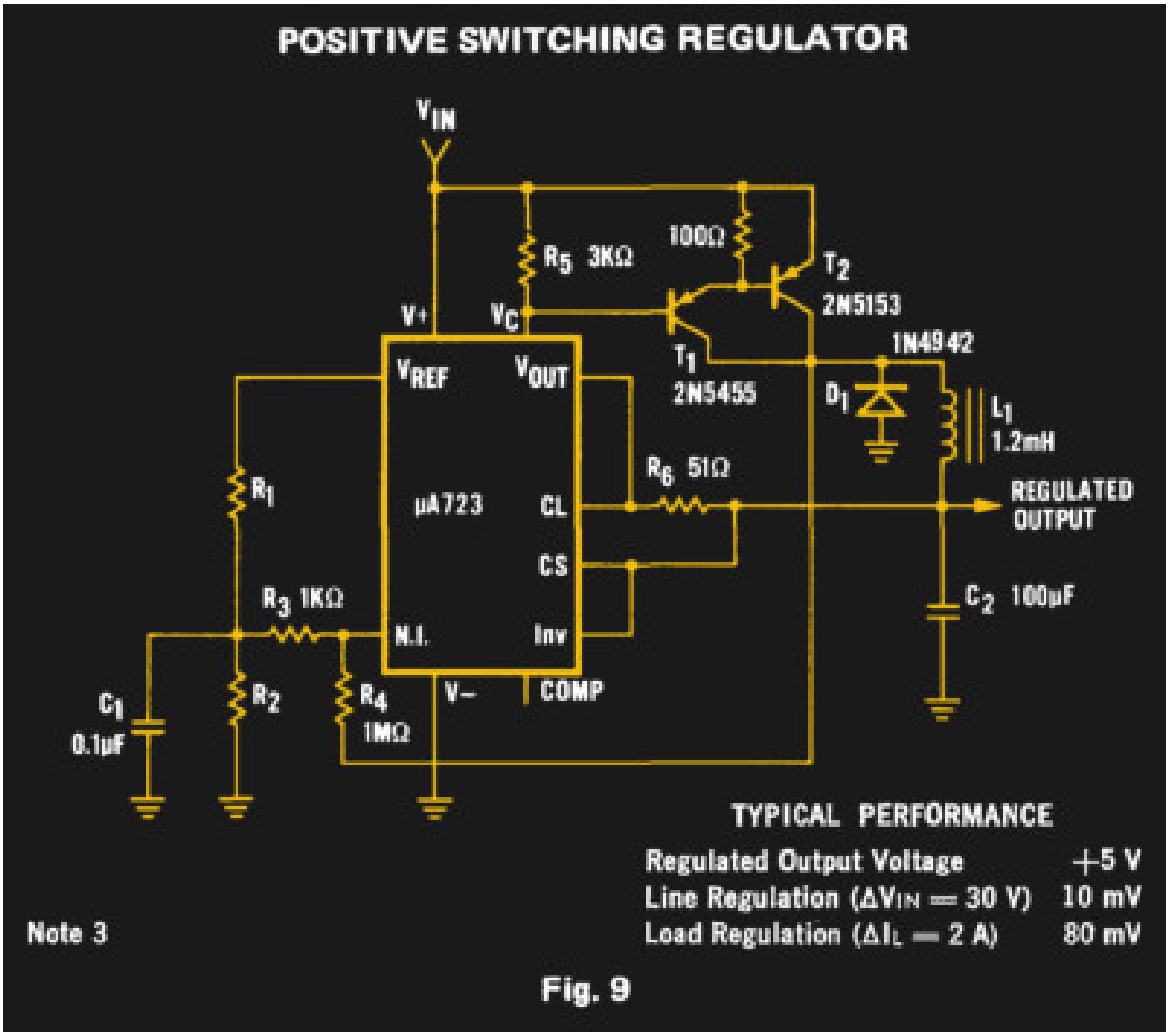
The uA723 As A Switch Mode Regulator

If you are an electronic engineer or received an education in electronics that went beyond the very basics, there is a good chance that you will be familiar with the Fairchild µA723. This chip designed by the legendary Bob Widlar and released in 1967 is a kit-of-parts for building all sorts of voltage regulators. Aside from being a very useful device, it may owe some of its long life to appearing as a teaching example in Paul Horowitz and Winfield Hill's seminal text, *The Art Of Electronics*. It's a favourite chip of mine, and I have written about it extensively both on these pages and elsewhere.



The Fairchild switching regulator circuit. From the µA723 data sheet in their 1973 linear IC databook, page 194 onwards.

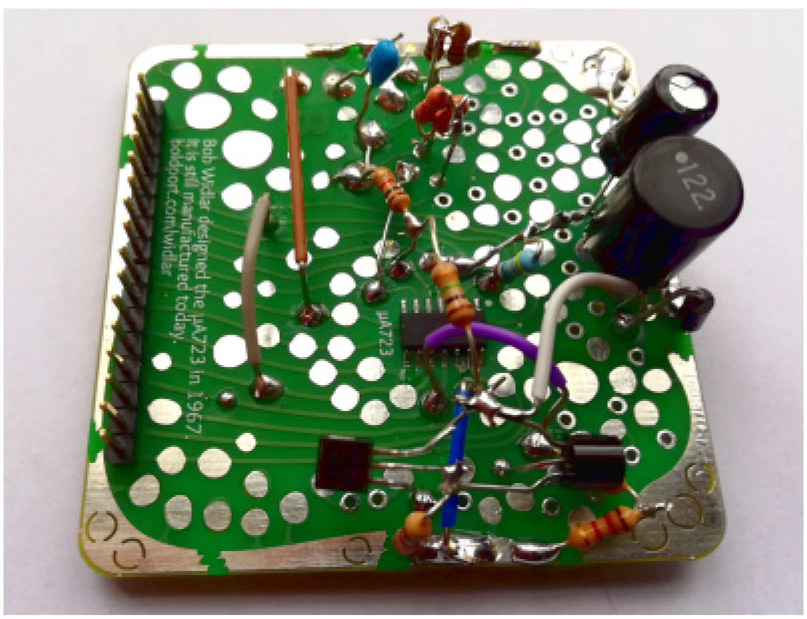
For all my experimenting with a µA723 over the decades there is one intriguing circuit on its data sheet that I have never had the opportunity to build. Figure 9 on the original Fairchild data sheet is a switching regulator, a buck converter using a pair of PNP transistors along with the diode and inductor you would expect. Its performance will almost certainly be eclipsed by a multitude of more recent dedicated converter chips, but it remains the one µA723 circuit I have never built. Clearly something must be done to rectify this situation.

Looking at the circuit and referring to the data sheet, it becomes obvious that the µA723 is configured as an oscillator through the feedback provided by the 1 MΩ resistor R4. Extra loop gain is provided by the combination of the PNP Darlington pair of external transistors and the µA723's internal output transistor, and pulse-width modulation is achieved through the internal comparator seeing the output voltage on its inverting input in comparison to the reference voltage derived through R1 and R2. The resulting oscillation switches the current into the network composed of D1, L1, and C2, forming a textbook buck converter.

Dusting Off an Old Circuit Design

Fifty years has passed since that data sheet was published, and in that time the electronics industry has moved on to the extent that many of today's components would be unrecognisable to an engineer from the 1960s. The resistors and capacitors perform the same function, but the µA723 is a rare survivor in semiconductor catalogues while the two transistors and the diode have passed into history. Meanwhile there are a plethora of ready-wound inductors to replace the suggested hand-wound one in the original.

To build a µA723 switcher for 2018 then it is necessary to perform a few searches for modern equivalents to the 1967 parts. For the semiconductors, this means taking a look at the data sheets for the originals, and matching modern parts with similar gain, current handling, power dissipation, and speed. I settled upon the 2N4403 as a replacement for the 2N5545 and an MPS751 as a 2N5153 equivalent, though since transistors have improved so much in five decades I could have picked from many others. You'd expect the diode to be a fast rectifier, and I settled upon a 1N4837. The most recent Texas Instruments datasheet has an unexpected choice though in a 1N4005 general purpose rectifier, so perhaps speed isn't as critical after all. There are multiple manufacturers of inductors suitable for small buck converters, the Taiyo Yuden part I selected is simply one of many.



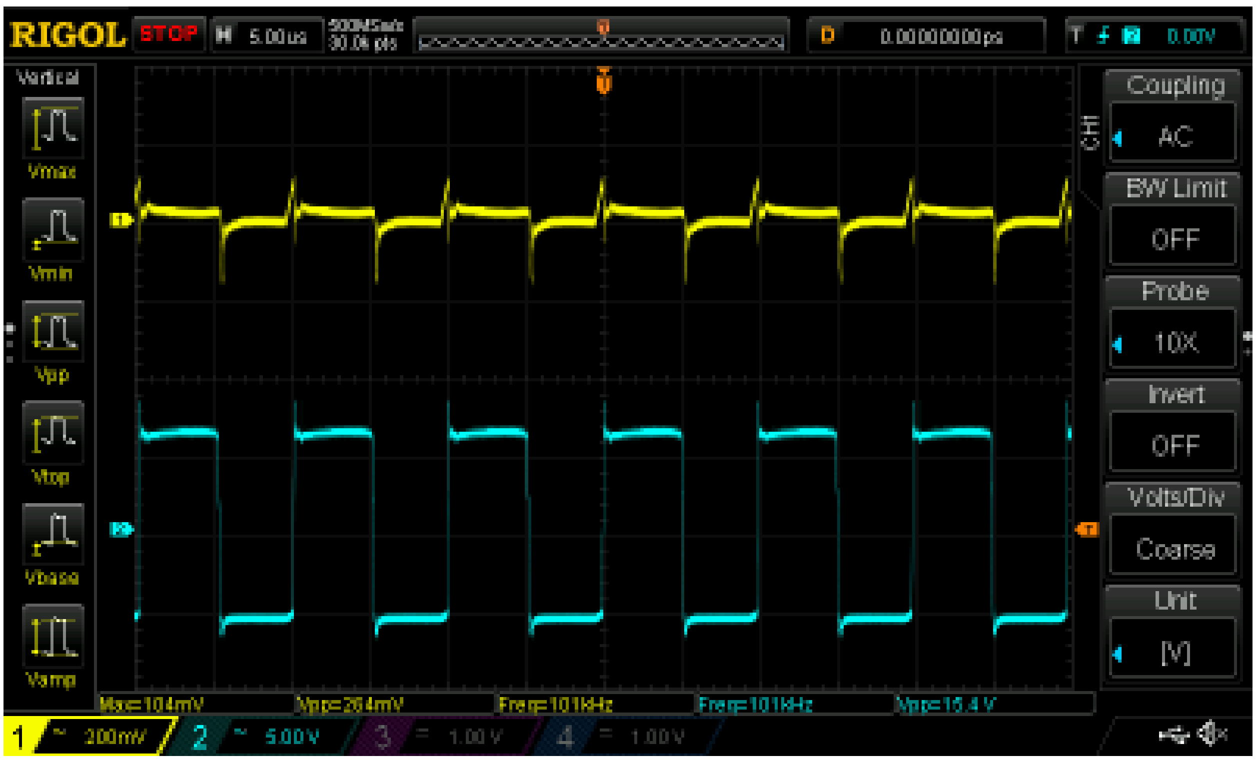
My take on the µA723 switcher, on a Boldport Club board.

Building the circuit took advantage of a recent Boldport Club project, a µA723 dev board and Widlar tribute. Regular Hackaday readers will know Boldport's Saar Drimer for his distinctive artistic PCB design, and the Widlar project is typical of his aesthetic. The switcher takes it slightly *off-piste*, but the board has been designed to accommodate any circuit. Time for a bit of responsible disclosure: it's a board I'm intimately familiar with because Saar asked me to write its instructions when he designed it a few months ago.

My take on prototype construction is a little rough-and-ready, and I apologise if it offends your delicate electronic sensibilities. A mixture of through-hole and pads on the board to support a piecemeal spider-web of components, it's not exactly pretty. It places the voltage reference divider R1/R2 and associated components to the left of the µA723, the inductor and diode above it, and the two transistors to its right. The divider is chosen for a 5 V output, and the 1 MΩ feedback resistor loops in an ungainly manner over the top of the chip.

Success, Partially

Astoundingly, my µA723 switcher build worked on first switch-on, rewarding me with a 5.01 V DC output into a 50 Ω load from my 12 V input. Connecting up the oscilloscope though revealed another side to this regulator though, and demonstrated why you might rarely see a µA723 in this configuration.



The yellow trace shows ripple on the DC output, while the blue one shows the waveform at the transistor collectors.

The yellow trace in the screenshot to the right shows the ripple on the DC output, while the blue trace shows the waveform on the transistor collectors. The circuit is oscillating at just over 100 kHz, higher than might be expected until it is realised that the whole thing is a free-running with a frequency dictated only by the characteristics of its loop rather than being derived from a separate oscillator as might be the case in a more recent design.

The 260 mV peak-to-peak ripple on the DC output is the killer with this circuit, an unacceptably high figure for all but the most undemanding of applications. It provides an object lesson in how more recent devices with significant thought put into how they handle their PWM generation have improved performance in this respect. I'd urge anyone with an interest in this topic to read some of the Linear Technology application notes written by Jim Williams, particularly AN35 and AN29. Despite the free-running μA723's rather basic PWM generation, it is easily possible to see the duty cycle change with the conditions. Dropping the input voltage to just before it starts to lose regulation at a rather high value of about 9 V, the duty cycle increases from 50% to about 70%.

So the μA723 is no star as a switching regulator, which is hardly surprising. There is another feature of the circuit that makes it entirely unsuitable for a modern environment, being a somewhat powerful 100 kHz source it produces a significant quantity of RF radiation. An AM radio anywhere within range is wiped out as soon as it is powered up, reminiscent of the effect of some older CRT TV sets. It's extremely unlikely that this would make it through an EMC test.

This has been an interesting foray into switching regulator construction and a chance to fill that last gap in the μA723 data sheet. It's a design that works, but one has the sense that it made it to the data sheet because the chip had the capability rather than because it was a sensible choice even by the standards of 1967. One wonders whether this is a hardware hack from Bob Widlar, pushing the chip beyond its design, one that has survived beyond expectation in every μA723 data sheet since. If that is the case then I metaphorically take off my hat to him, it's a circuit I wouldn't have had the *chutzpah* to publish had I been the sheet's author.