“Souping up” the ZC-1’s audio output power by a factor of 5- with no modifications to the actual radio:

Introducing the E6U7. (H. Holden. March 2020.)

It is interesting that out of all the radios ever made, probably one of the most modified of all would have been the ZC-1. This article is about improving the performance of the audio output stage, by plugging in a “device” (the E6U7) instead of the standard 6u7 valve. It is better to avoid any modification to the original set’s circuitry, this helps preserve their history.

The ZC1 is a Military style radio, built to exacting standards by Collier & Beale for the WW2 effort in New Zealand, my original home. They could receive and transmit over the frequency range from 2 to 8MHz. After the war, especially in the period of the 1950’s to 1960’s, the ZC-1 radio appeared in Army Surplus stores throughout NZ.

Probably very few people at the time realized the significance of them or the value for money when they paid some shillings for an entire radio. But they were a great platform for a radio enthusiast to cut their teeth. Once the components were stripped out of them, these components could be used for all manner of other radio projects.

The construction quality of the ZC-1 was astonishing and in my opinion was superior to other sets (like the WS.19) made overseas, especially the mechanical engineering aspects.

As these ZC1 radios fell into the hands of Amateur Radio operators in the post war period, they acquired all manner of modifications. For example some were modified to

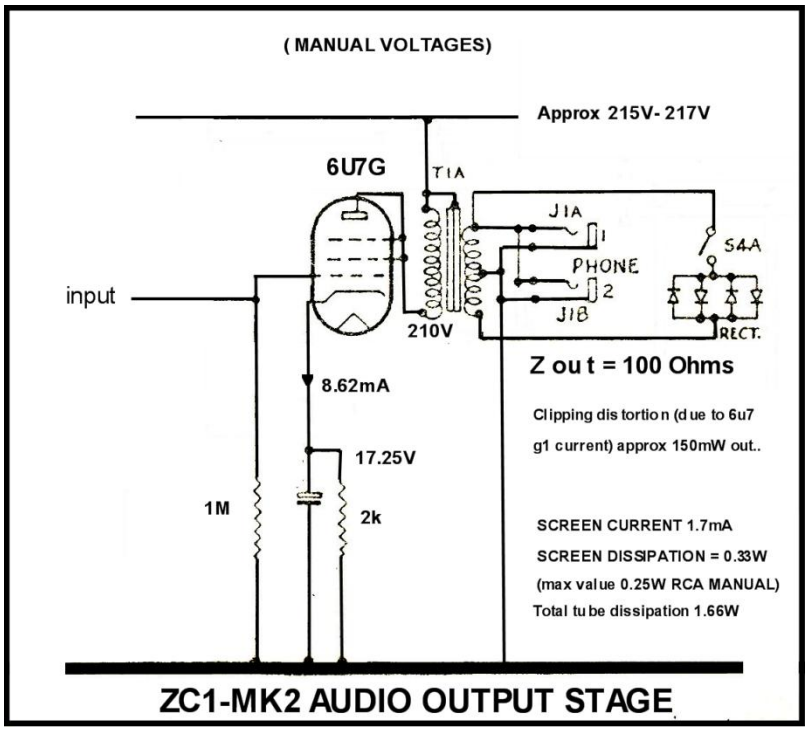
Marine Band use. Often extra valve stages were added to help receive SSB signals as another example. And sometimes the RF output stage was “souped up” for more RF transmission power. It became hard to find unmodified ones. Subsequently radio restorers & historians sought to convert them back to their original state.

A photo below shows the amazing ZC-1 mark 2.

The ZC1’s original Audio Output stage:

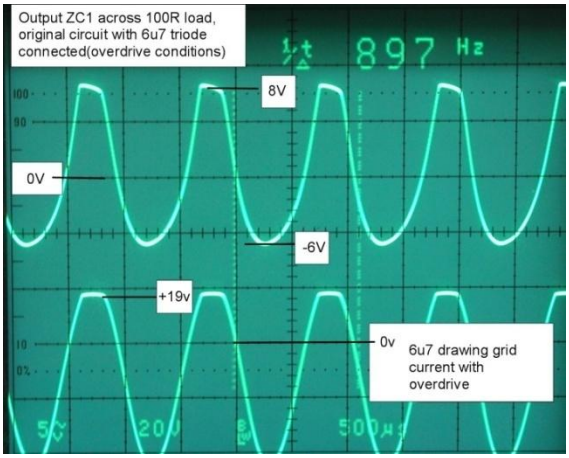
The original audio output stage was intended to drive headphones, not speakers. On account of this the audio output power was fairly low. The manufacturers used an RF tube, the 6U7G pentode, as an audio output device. They “Triode connected” it, by connecting the plate, suppressor grid & screen grids together.

The power output of this circuit, into a 100 Ohm load was about 60mW to about 150mW where severe distortion (peak clipping) occurred. The reason for this was that as the power output approached this higher level, the g1 grid of the 6U7 was driven into grid current, as the drive peak voltage exceeded about 17 to 18V. The high level of drive was needed to allow for the lower gain of the triode connection. The circuit is shown below:



The scope recording below shows the performance of the 6U7G in the ZC-1.The drive voltage to the 6U7 is high enough so as to push the 6U7 into g1 grid current.

The output (headphone connection) is loaded with a 100R resistor. (This is the optimal impedance for the load on the audio output transformer in the ZC-1)



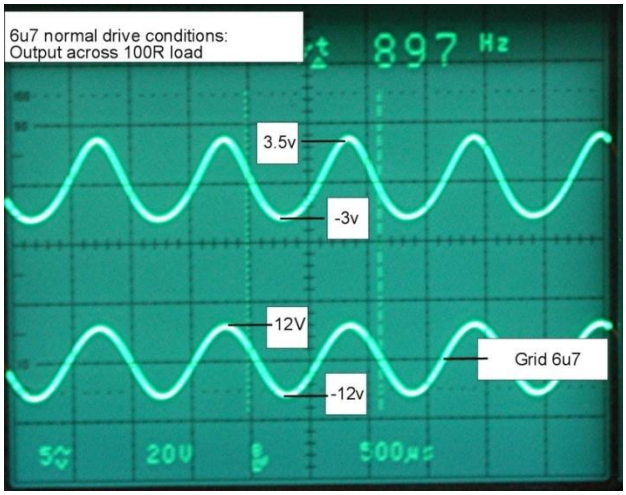
When the drive voltage at the grid of the 6u7 exceeds around 19V peak, the tube draws grid current. This is because the cathode voltage of the 6U7 sits around 17V due to its bias conditions.

As can be seen from the scope recording, the output voltage across the 100R resistor is quite distorted. At absolute best, prior to distortion, the triode connected output stage in

the ZC1 (combined with the original output transformer T1A) can produce only around about 5v peak or about $(5 \text{ x } 0.7)^2/100$ = 122mW, or perhaps 150mW at best.

Of course that audio power output is perfectly fine for a set of 100 Ohm headphones. But what if you want your ZC-1 to drive something like a 100 Ohm external speaker and you need more output ?

The following recording shows the situation on the standard ZC-1 with the audio drive reduced, prior to clipping. The output waveform is still moderately distorted (the drive waveform to the 6U7 is not) even when the peak output voltage is fairly low (3.5V) corresponding to a power output of about 60mW. Again this power would be perfectly fine with headphones and the distortion “tolerable for voice”:



I experimented with the 6U7G (an RF pentode) and found that to get more audio output power from it, without distortion, it required that the screen grid dissipation would be far too high. In fact it turns out that the designers of the ZC-1 had already pushed the 6U7G and exceeded the manufacturer’s maximum screen grid dissipation.

The RCA manual states the max screen voltage of 100V and a maximum screen dissipation of 0.25W.They pushed the screen dissipation in the ZC-1 for the 6U7 (V1C) to about 0.33W.

However, at the same time, they had a lower than maximum plate dissipation being about 1.3W (the max in the manual being 2.25W). Whether or not that is “acceptable design practice” to push the screen current just over the max rating, is an interesting

question, because exceeding any of a tube's maximum ratings will likely shorten its life, but in this case, probably not a lot as the powers involved are fairly low.

I did some experiments to attempt more audio output power:

Firstly I changed to 6u7G (V1C) to a 6k7G. The reason is that the 6k7 has higher dissipation ratings to the 6u7. The max plate dissipation of the 6k7 is 2.75W and the max screen dissipation 0.35W. I moved to a Pentode connection which also provided more gain and allowed for global negative feedback to reduce distortion.

The problem though quickly became obvious:

To get any reasonable power output, above 200mW for example (targeting a 500mW audio output) the screen dissipation of the 6k7 would have to be exceeded. That is a little uncomfortable.

With a screen voltage on the 6k7 of around 235V and a screen current of around 3mA, about 500mW of audio output could be attained. But this resulted in a screen grid dissipation in the 6k7 of over half a watt, significantly violating the max values in the 6k7's data sheet, even though the anode dissipation could be kept within a reasonable range. So clearly this was not an ideal solution.

The next move was to try an output tube more suited to the application of audio output power than the 6U7, a 6k6 and a 6V6 for example, which are rated for much higher screen dissipation & output power.

However, it is not possible to use these tubes without modifying the radio, the wiring connections on V1C's socket. In addition these tubes had higher heater current than the 6U7 and it would require a balancing resistor added across V1D's heater connections (as its heater is in series with V1C) again having to modify the radio. The aim of the game was to get the audio power output up, with no modifications to the radio.

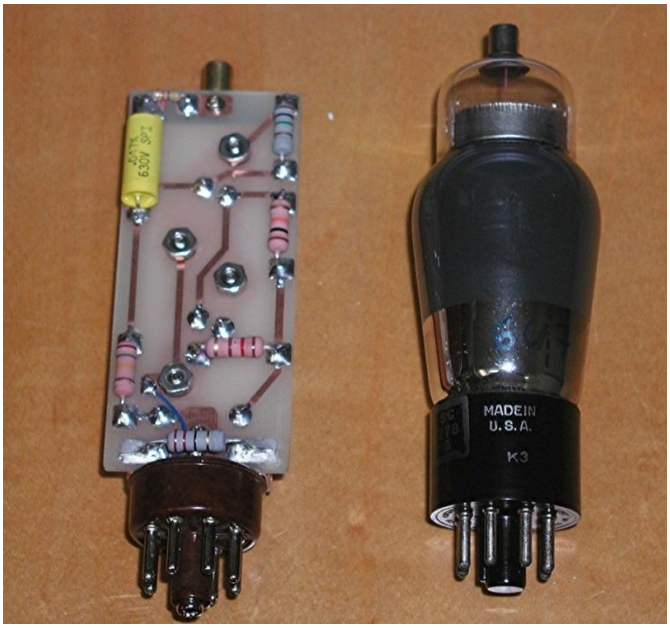
After some research, I found there was no existing tube I could plug into V1C's socket that would allow more power output, prior to excessive distortion, without modifying the ZC-1's wiring or circuitry in some way or other.

So I decided to design a device which could simply plug in, in place of the 6U7 audio output tube (V1C).

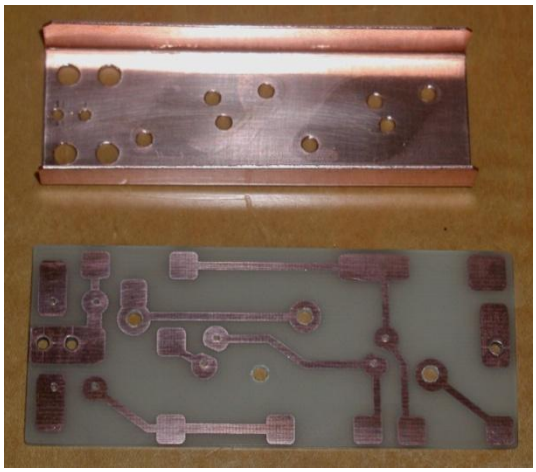
This "device" generates 700mW audio output and a very clean undistorted 500mW output. A photo below shows it next to the 6U7 it replaces.

Of note: this device only replaces the 6U7 in a Triode connected audio application, not in a Pentode application or an RF application, so this device is very specific to replacing

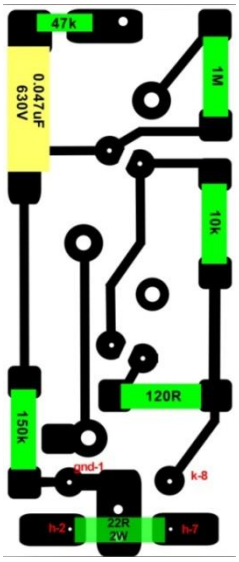
the 6U7 in the audio output stage of the ZC-1 Radio. For want of a better name, this device is called the **E6U7**, or electronic 6U7:

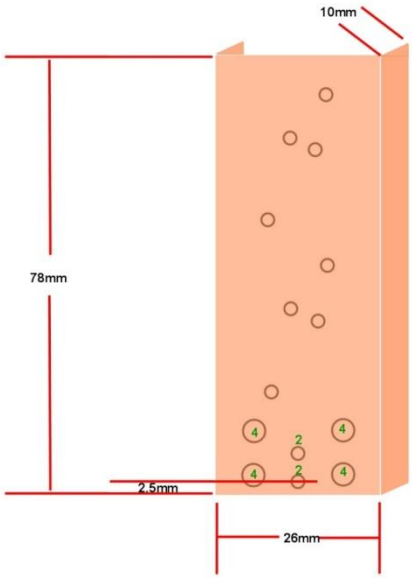


This device has a 22 Ohm resistor connected across pins 2 & 7, to act as a dummy heater resistance, so the heater it is in series with, (V1D), still runs normally.

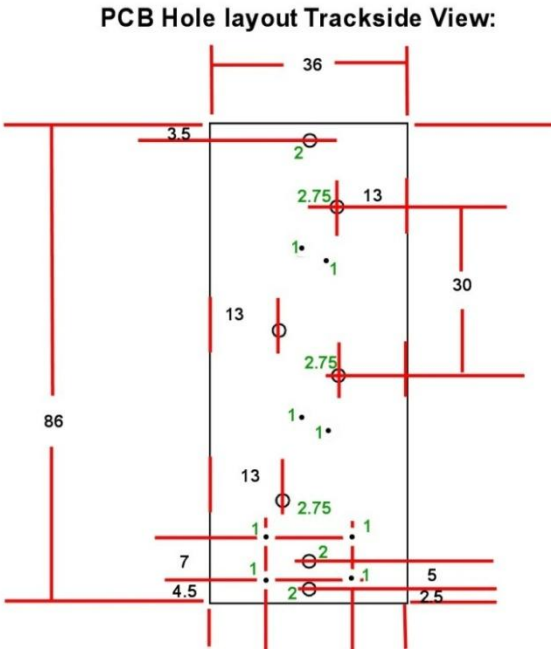


The diagrams below show aspects of the E6U7's construction:

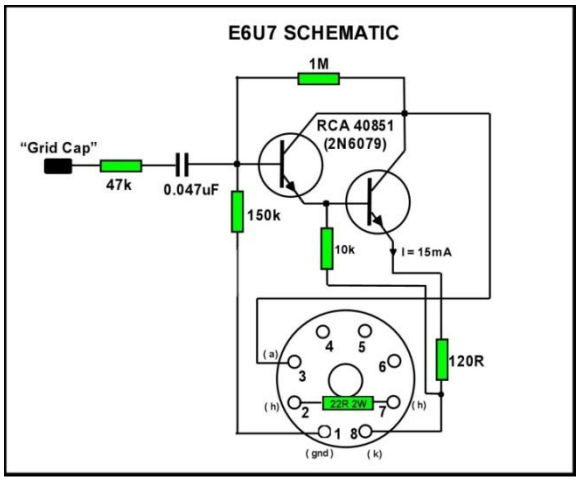




The photo below shows the unit running in the ZC-1. The standard shield fits around it but is removed for the photo:

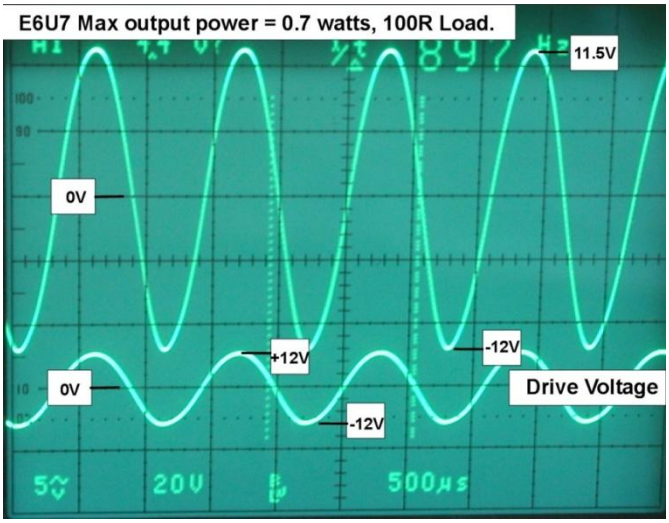


Schematic of the E6U7:



Performance of the E6U7:

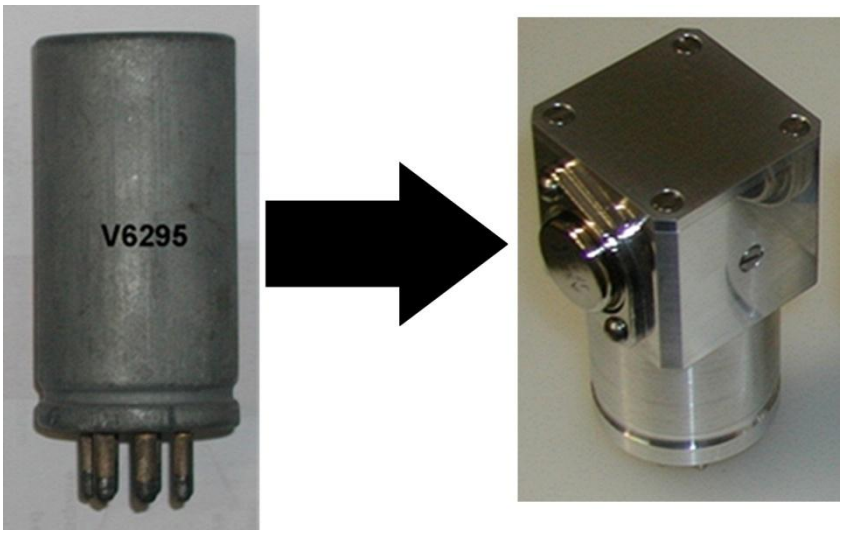
The recording below shows the output across a 100R load just entering overdrive conditions with peak clipping just starting to appear on the top of the output waveform:

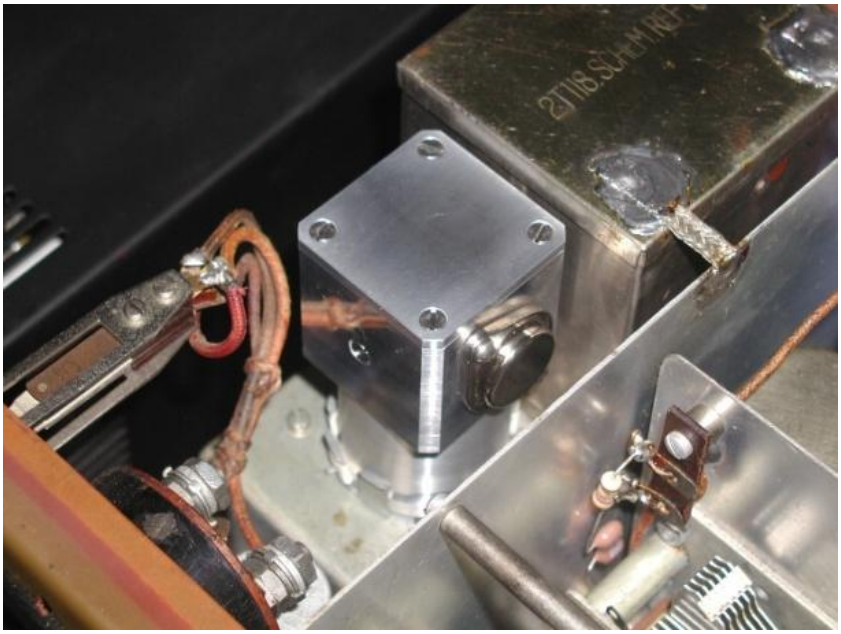


The E6U7 produces a solid 700mW output with only 12V peak drive. At 500 mW output it appears distortion free. The 47k on the input raises the input resistance a little and provides an LPF with the input capacitance of the first transistor, which makes the frequency response about 3dB down at 10kHz, which helps to improve the tonal quality of the sound and makes it more pleasant for listening to music rather than voice using a small 4 inch speaker.

Other modifications without modifying the ZC-1:

My ZC-1 runs an electronic vibrator unit (based on a self oscillating circuit with ASZ17 germanium power transistors) which lifts the HT voltages a little compared to the original electro-mechanical vibrator:

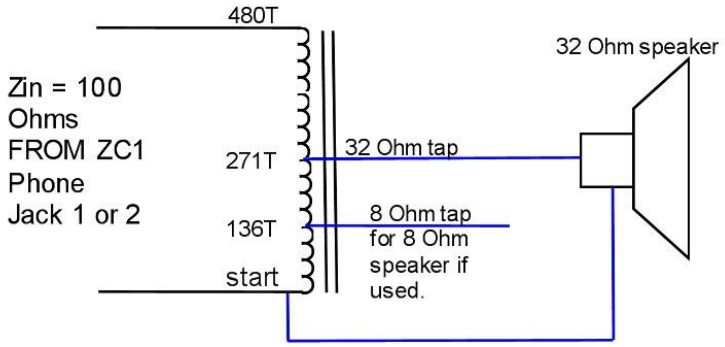




In addition, the “100 Ohm speaker” I used for my ZC-1 is composed of a 32 Ohm speaker & matching transformer:

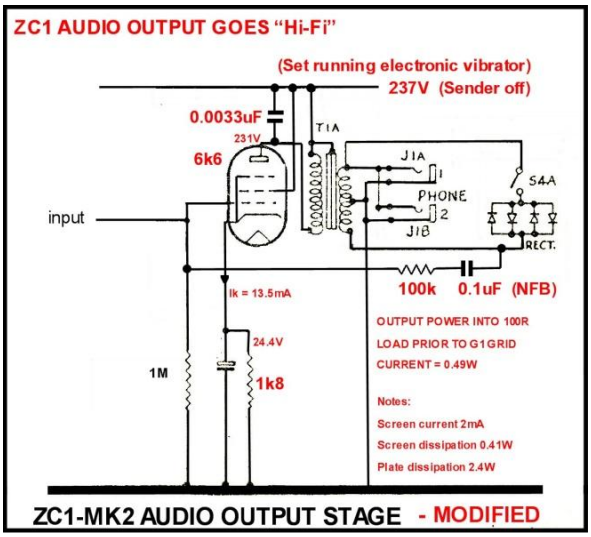
Audio Autotransformer for ZC1 External Speaker:

1 cm square inside the bobbin.
Total 480 turns of 0.315mm diameter wire(0.35mm with enamel)
Taps at 136 and 217 turns.
(DC Resistance of 480T = 6 Ohms).

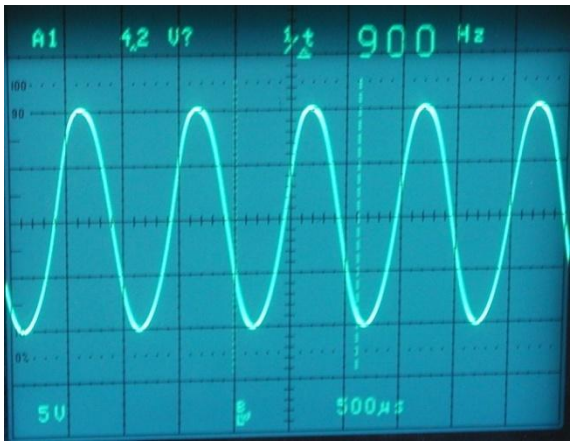


Modifying the ZC-1 itself for more Audio Output:

This is less favourable as the ZC-1 set requires modifications, but I have included this information for those who wish to use a tube to do it. I found that a 6k6 gave a good result. It does require of course that the ZC-1 socket connections are modified and that a current balancing resistor of around 60 Ohms is added across the heater connections of V1D, because the 6k6 has a 400mA heater, unlike the 300mA heater of the original 6U7G. Also the Screen Grid connection of the 6k6 requires connecting to HT. The 0.0033uF was added to improve the tonal quality for music by providing a very small amount of HF cut and NFB added to lower the distortion (It was interesting that the E6U7 did not require the NFB for low distortion):



This arrangement can produce 10v peak into a 100R load, or just close to 500mW output free from significant distortion. The recording below shows the level generated across a 100R load at the phone socket:



It is possible to gain more power output power with the 6k6 with a higher cathode current, but possibly this might stress the small audio output transformer (T1A) that was really only designed to drive headphones to a level around 100mW, with a primary winding current around 9mA. So pushing it much past 15mA could be risky.

****