U2008B - a few empirical notes

The U2008B is a popular phase controller, intended to drive a triac in dimmers and single-phase AC motor speed controllers. Despite being so popular, its datasheet is fairly brief - often too brief to explain things in detail. It does contain references to a more in-depth U211B datasheet, but even that one perhaps lacks due clarity in a few areas.

On the web you can find many notes from different people, reporting that the chip either didn't work at all in a particular circuit (even very close to the datasheet-based schematics), or that it doesn't perform quite right in particular applications (such as a transformer-based welder).

Being a novice myself, I had to find my own way around several gotchas. In the end, the chip does work for me, even though there are still marginal issues that are not easy to work around, related to my improper application of the chip.

To the point now.

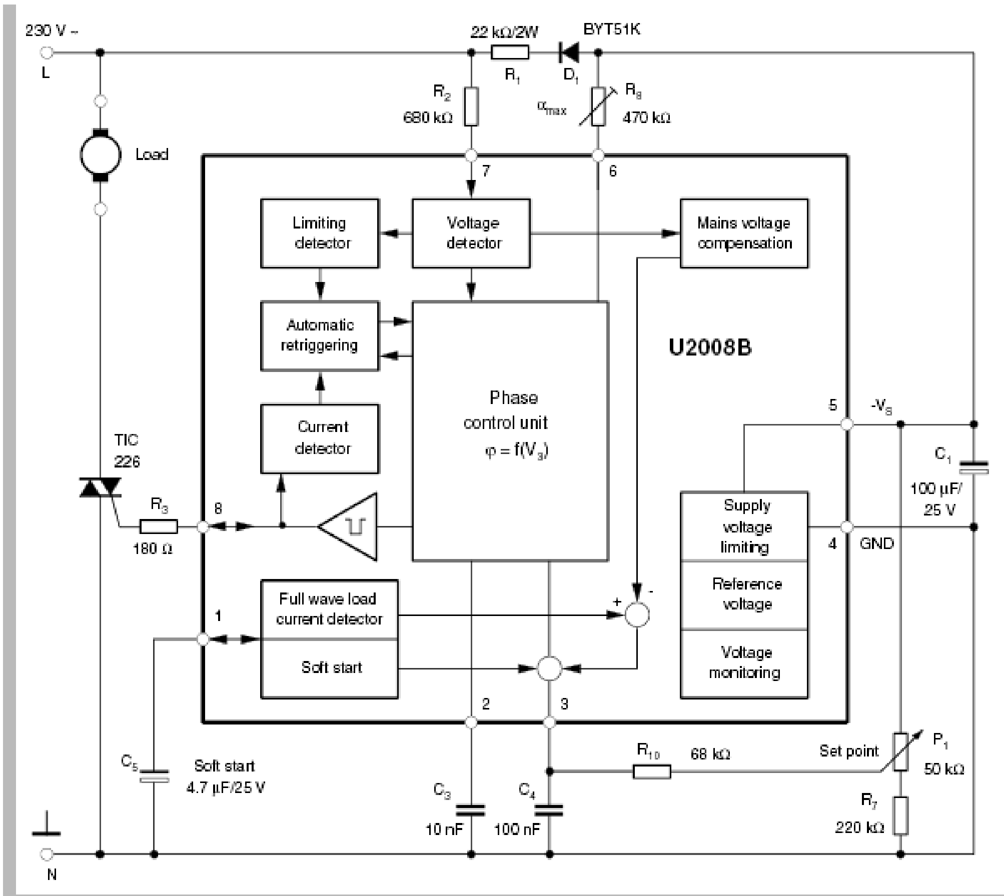
Firstly, it took me some time to find out why my datasheet-based circuit was completely dead. The triac would never open, never at all - no response to turning the two trimmers, no sign of life. I started out by measuring the voltage at the trivial power supply (filter cap and an internal zener at pin 5), and by finding a nice sawtooth signal at pin 2, using an oscilloscope. So the chip did show some signs of life, after all. Then I tried pulling the control voltage to -Ucc and GND, trying to find an extreme control point where the triac would fully open. I wasn't able to achieve that. Then I checked if there were some pulses on the chip's output - pin 8, the one driving the triac gate. Surprise, no pulses there. My last guess was this: perhaps the chip does some startup check at the output pin, to detect the presence of a triac? After all, I was using a BTA20/600 instead of the triac model from the datasheet (TIC226), to achieve higher load capacity - so maybe the U2008B just couldn't see the triac. (Triac driving current was not a problem, as I took care to observe that parameter.) I tried adding a shunt resistor between the triac's gate and GND. 3.3k didn't work, but voila, 910 Ohms did the trick. Suddenly the gate drive output started to work! There were clear pulses and even re-trigger attempts. Especially when I detached the triac's gate just to see what happens, the chip's output consisted of retrigger pulses only.

Secondly, another problem is with the regulation range of the control voltage input. This range is relatively narrow, and the upper and lower bound are somewhere between the low-voltage power supply rails (cca -20 V and GND). The regulation range is about 3V wide, corresponding to the reference sawtooth signal's amplitude. The triac opens with the control voltage moving towards GND. The datasheet-based circuit for soft start does have some chance of successful operation, having the regulation range closer to the -20V power rail. Caveat, for the "current-sensing" mode, the regulation range is different, apparently shifted a lot towards GND. So that if you use a jumper or a switch to easily reconfigure your circuit for this or that mode, you have yet to take care of the different regulation ranges. Maybe use a single 250k trimpot connected rail-to-rail, and replace that with an adjusted divider network once you decide which mode you're gona be using.

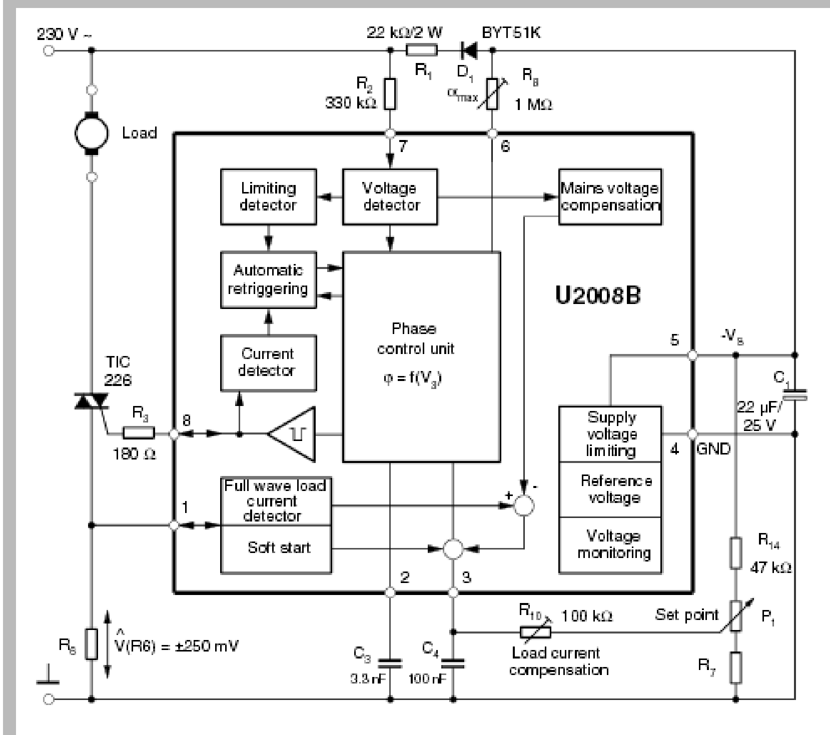
I myself was intending to use the U2008B to control a simple unstabilized lab PSU, i.e. the primary side of a transformer, with a graetz bridge and filter capacitors on the secondary. I was planning essentially a soft-start circuit, with an option to set a partial output voltage via the trimpot in special cases. This approach has highlighted several other features of the U2008B and ultimately meant that my attempt was only half-way successful.

The chip has two modes:

1. the soft-start mode
2. the current sensing mode



U2008B soft start mode
A snapshot from the Atmel U2008B datasheet



U2008B current sensing mode
A snapshot from the Atmel U2008B datasheet

These two modes are mutually exclusive, because they're selected by the same pin that's actually used for current sensing in the respective mode! This has more implications than what the manual may directly imply.

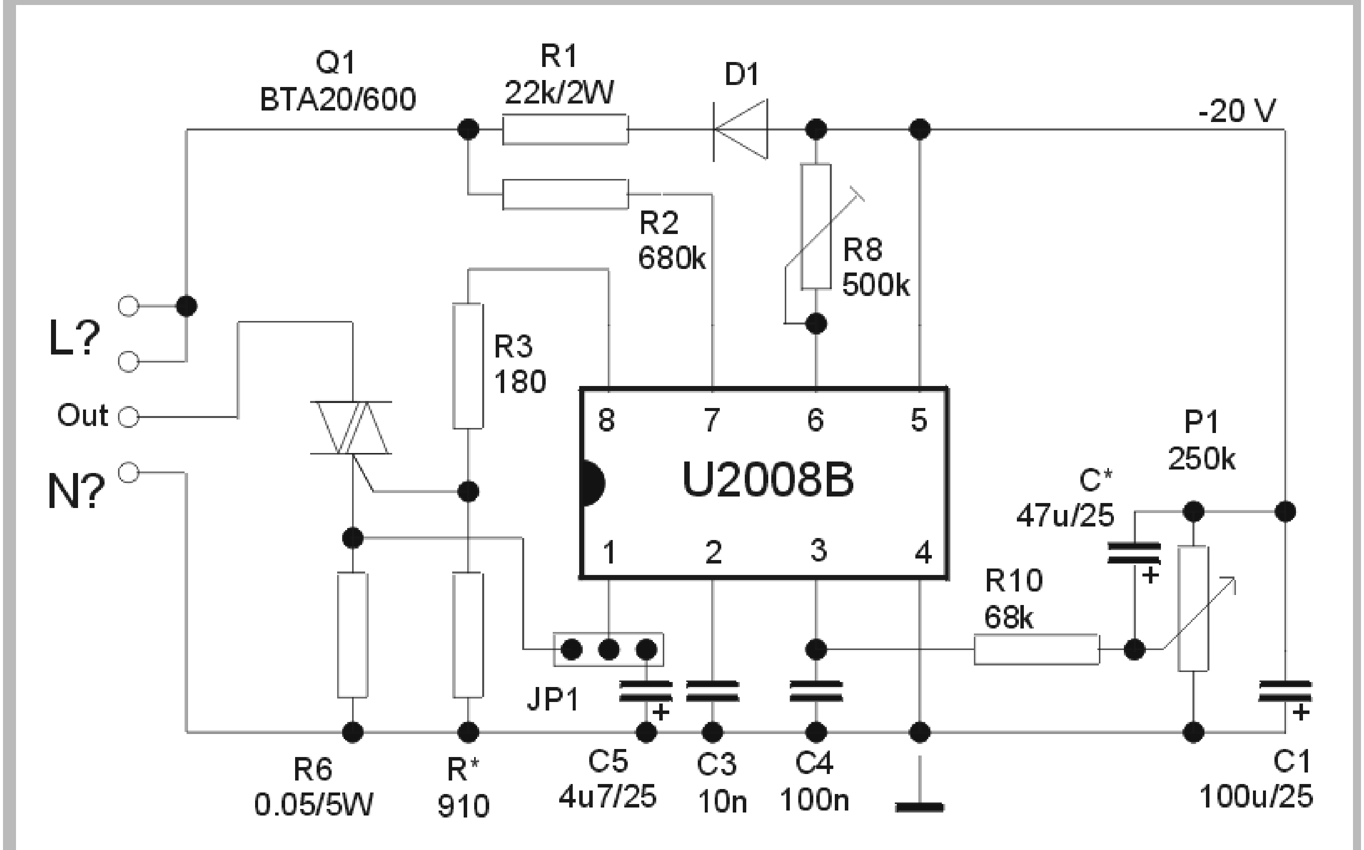
In the **soft-start mode**, the chip cannot sense current. You can adjust the soft-start ramp (duration) by the capacity of C5 - but you can't change anything about the fact that this built-in soft-start mode can only be used for resistive loads (light bulbs), and not for inductive loads (motors, transformers).

Inductive loads exhibit a phase shift between the voltage applied and the resulting current. With inductive loads that transform energy, this phase shift is variable - but essentially the current waveform always lags behind the voltage waveform (with a resistive load, they're in sync). The lack of current sensing means, that the chip does not check for current-wise zero transition. Hence, as the regulation level approaches 100%, it may trigger the triac prematurely, while it's still open since the last half-wave. Then the triac properly closes during the delayed zero transition, and stays closed, as the trigger pulse is already over. This results in an outage in the output waveform, lasting for one half-wave...

In the **current-sensing mode**, the built-in soft start capacitor has no effect, the chip starts immediately. As the chip now senses the current flowing through the triac, it checks for zero transitions, and delays the triggering pulse until after a zero transition. It can also re-trigger the triac if it finds that it didn't open in response to the proper first trigger pulse.

The one last thing that needs to be adjusted in the current-sensing mode is the "maximum alpha" angle. This is the maximum phase shift of the zero transition that the chip will be willing to accomodate. Improper setting to the "alpha max" results in outages, characteristic to zero transition misdetections. In other words, as you turn the regulator output power up, suddenly the output sags when you reach maybe 50% throttle. It really looks like a non-linearity in the regulation curve. But the cause is improper alpha-max setting. Check it out on a 'scope if you have one. To get rid of this effect, adjust the alpha-max trimpot, R8. Please note that when this trimpot is set to *maximum* resistance (500k), alpha-max is *minimum*. In my case, my conservative initial setting was exactly that. Adjust the trimpot to *lower* resistance in order to *increase* alpha-max.

I wanted my triac circuit to control input power to a transformer (inductive load), yet I also wanted it to provide a soft start. My workaround hinges on an obvious legacy technique: add a capacitor to the steering voltage input pin of the IC (pin 3). This should add a delay/ramp to the control voltage. In my case, I added a 47uF capacitor to the center pin of my 250k regulation trimpot. On startup, for a soft start, you want the voltage to fade in from the -20 V power rail, rather than from the ground. Therefore, your timing capacitor has to be referenced to the -20V power rail, rather than to ground.
This workaround actually works - thus, the circuit can provide a soft start to an inductive load.



My way - a universal experimental setup

Please note the jumper that I was using to switch between the current-sensing and the built-in soft-start mode.
Also, notice the recommended wiring of the neutral and live mains conductors. Using the recommended wiring, your regulation potentiometer is close to ground (the nominally neutral conductor), but your load is tied permanently to the live wire and only switched to the neutral wire. My preferred way is to swap the live and neutral terminals - thus, your load is permanently wired to the neutral wire, and if you only have a trimpot in place of the regulation pot, that you don't need to touch at all in production operation, you're on the safe side.

If you expect that this is the end of our lengthy story, you're wrong, there's more.

When in the current-sensing mode (for inductive load), and when the regulation trimpot is set to some non-zero level, the chip provides a startup "kick" to the load. This makes sense when the chip is used to drive a motor - the mechanical system attached to the motor always has to overcome some static friction on startup, and once motion, the dynamic friction is lower. Therefore, the sustained power level can be relatively low, but the system needs a "kick" to get started. This is true about all motor-driven systems, from a 5W PC ventilator fan to a railway train.

In my case, I wanted the chip to provide a soft start to a PSU, which contains a relatively large capacitor. I wanted to prevent the high initial inrush current. Therefore, the initial kick is something I definitely wanted to avoid. Unfortunately, there's no explicit way of telling the chip to skip the initial kick. The only way is to provide, on startup, a control voltage that is safely below the opening treshold, and fade in only after the U2008B has started up. This way, the initial kick gets skipped. In other words, this is a matter of selecting the right value for the soft-start workaround capacitor.

And there's yet another gotcha. In the current-sensing mode, apart from following the zero transition, the chip also tries to infer changes in motor load (based on variations in current and phase) and increases output power in order to keep a constant RPM.

In my special case, this is yet another factor that's able to ruin a soft start. My PSU performs a proper soft start when the capacitors are half charged, but does get an initial kick now and then, when the capacitors are completely discharged (after a longer period of inactivity). Yet it seems that at least the U2008B does something to limit the inrush current, so the initial kick doesn't trip my mains circuit breakers. Otherwise I'd probably try replacing the soft-start workaround capacitor by an even bigger capacity, which would however prolong my delay on startup...

Conclusion:
The U2008B has been designed to control two types of loads:

1. purely resistive loads, such as light bulbs, including a slow start
2. motors, including an initial kick, and a feedback-based boost to provide constant RPM under load

With these types of loads, it is a very nice component. It provides a short safety delay on startup and intelligent re-trigger capability.

The chip is not good at driving nonlinear loads such as direct-rectification PSU's or welders, and not quite appropriate for soft-starting non-motor inductive loads!

If you need more fine-grained control over the features of the phase controller, check out other chips, such as the U211.