# The Making of a Current Sensor

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In an ongoing project associated with the University of Oregon's Cognitive Impairment Research program, I was recently asked to develop a device that could determine if a television was turned on or not.

If presented such a request in 2004 I would simply have provided a device that detected the EMI from a television's CRT. After all, it's not that difficult to detect the static field of a 10kV+ aquadag. But this is 2007, and a lot has changed in the past few years, including the dismissal of old CRT technology in favor of new plasma and LCD alternatives. No more CRT means no more large static fields, which means a new approach to television on/off detection is required.

Though I dislike working with household AC, it turns out that directly monitoring the television's current consumption provides the shortest route to determine on/off status.

You know, there's good reason why I hate mucking with 120VAC power—first it opens the can of worms associated with UL certification, and second it can kill you. To me, both prospects are equally unpleasant.

**PASSIVE DETECTION**

Fortunately, risks can be minimized by passively monitoring the current using a torroidal transformer. A quick search of Jameco (www.jameco.com) provides a bevy of torroids to choose from, and I selected the MTC30101 as a small, inexpensive, and fully insulated starting point for my endeavor.

According to my old electronics school manuals, I should be able to pass the power line through the torroid's donut hole and get a diminutive 60hz AC output that is proportional to the current flowing through the line. It follows that by simply rectifying the output, and smoothing it to DC with a capacitor, I should wind up with a DC voltage proportional to current.

In January of 2006, I assembled my first current sensing circuit based on the schematic illustrated in Figure 1. To verify proper operation, I measured the current of such ordinary household devices as toasters, televisions, radios, and even my soldering iron. In all cases, I observed DC values that looked reasonable given the tested load.

My current sensing device was put into operation in February 2006, and was duplicated in three trial systems.

## TROUBLE IN PARADISE

An unexplained reading was noted in October 2006, where a television was observed to consume more power in the standby state than the fully on state. This event took place at a hotel hosting the SigAccess/Portland exhibition. Unfortunately, we were at the event

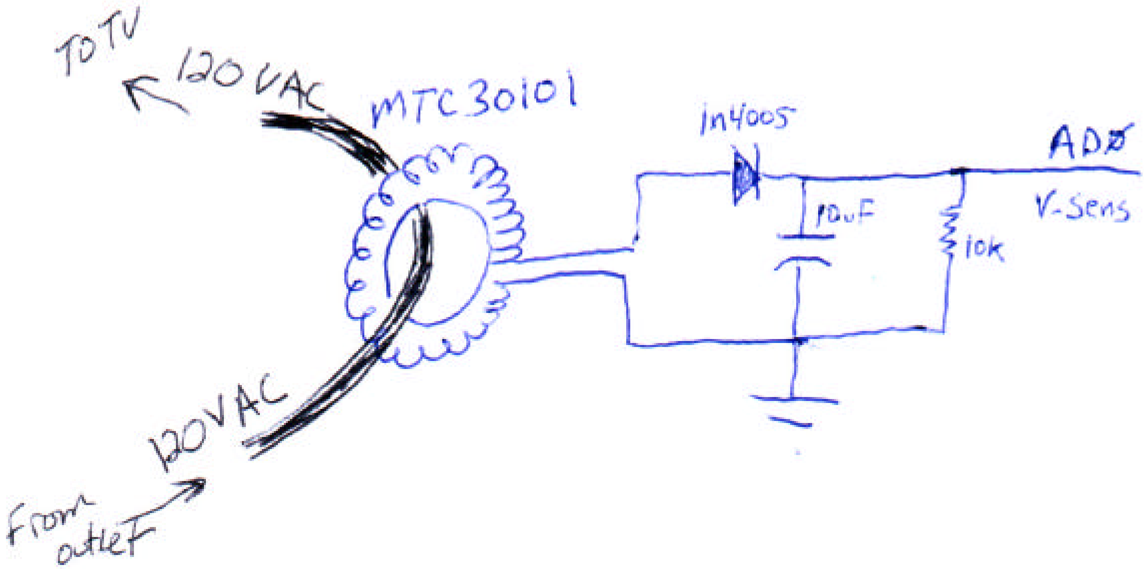


**Fig 1:** The theoretical solution to the current sensing problem. Indeed, nothing could be simpler, and it really does work in the lab.

for only a few hours and when we returned to our offices in Eugene I was unable to duplicate the problem. I reasoned that something peculiar must be associated with the hotel's power outlets, and dismissed the problem.

In mid December 2006, a coworker experienced similar power anomalies with a system in our lab. It was discovered that if a certain appliance was plugged into any outlet in the office, power readings reported by my device would be affected. That an appliance connected to an entirely different outlet would in any way affect my simple sensor device was baffling—preposterous, even.

## FINDING THE CULPRIT

Recovering from a period of disbelief, I scoped the torroid and observed a total maelstrom of electrical noise. There was absolutely nothing resembling the diminutive 60hz waveform expected. A spectrum analyzer provided a better picture, clearly showing noise across the spectrum yet with a spike centered at about 13khz.

It now made sense that the reported power errors were the result of the faulty appliance inducing a powerful13khz noise spike into the household electrical system. It should be noted that the term "faulty" is from an engineering perspective only. As far as a user is

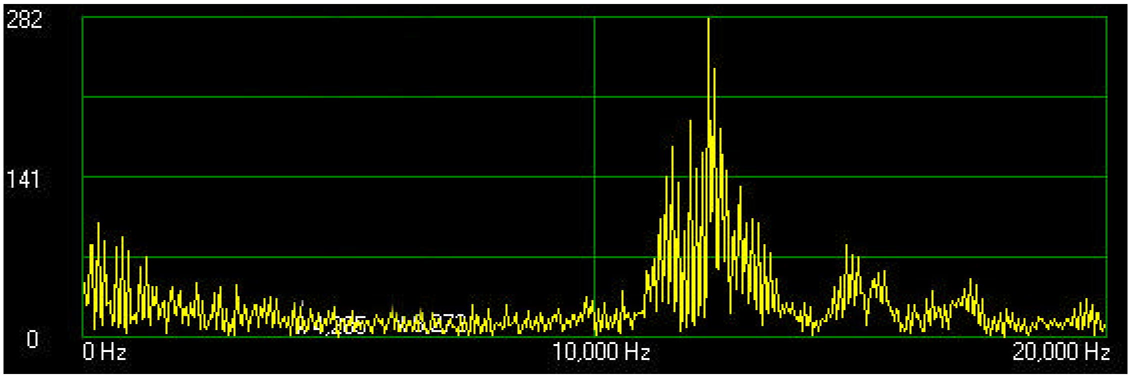


**Fig 2:** Switching my scope to spectrum analysis mode, I can readily visualize the scenario playing out in my sensor.

concerned, that "faulty" appliance worked just fine. Of course, no such appliance would pass UL or CE certification, but such technicalities provide no comfort when its my sensor apparently failing as a result.

**RUGGEDIZATION**

The greatest lesson immediately learned was that the "real world" is full of nasty little gotchas and that any system deployed should have built-in defenses. In the case of my device, it needed to somehow ignore the relatively high-frequency noise.

The hints for a solution came by examining an Extech CA310 clip-on ammeter. Like my sensor, the Extech used a torroid to convert current to a diminutive AC output. But in addition, they placed a resistor and capacitor in parallel with the torroid, which apparently eliminated the unwanted interference.

I don't know the exact resistor and capacitor values used by Extech. Simply finding the components in the probe was enough of a hint. For my device, I placed a 1uF capacitor and 1K resistor across the torroid's leads and voila—no more interference.

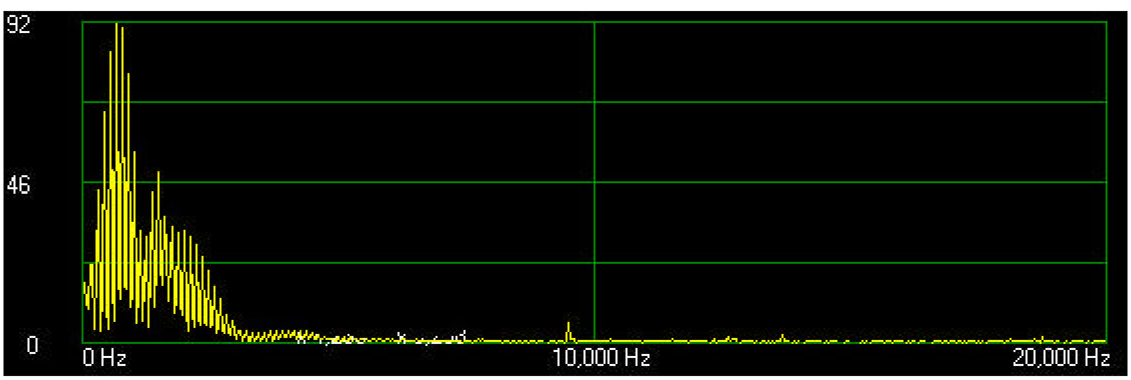


**Fig 3:** Placing an RC filter across the torroid's leads solves the problem.

The selection of RC values was actually an educated guess, and I am sure that more research could probably go into determining a more optimum pairing. The values of 1uF and 1K result in a low pass filter, with a knee at about 1Khz, so I suppose the system could still be vulnerable to some noise.  In the pragmatic short term, however, the device has shown to be invulnerable to typical noise sources including vacuum cleaners, fans, and microwave ovens.

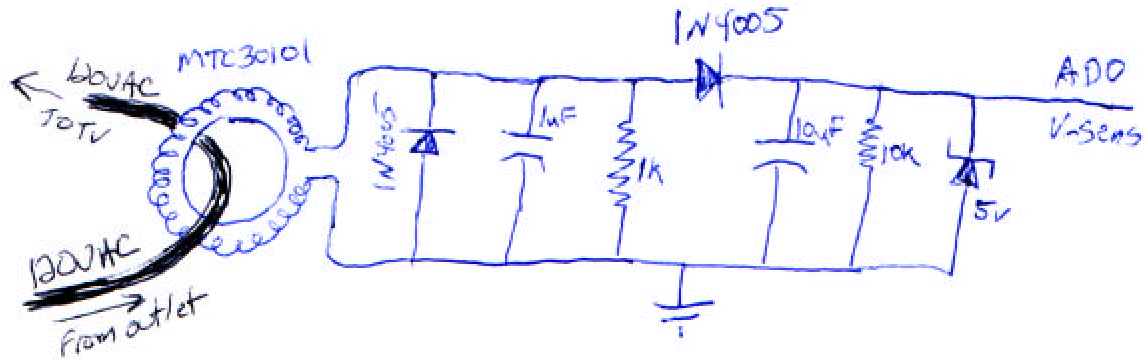


**Fig 4:** The current sensor with filtering installed.  To guard against overvoltage, I also applied a 5V zener to the rectified DC.

Most importantly, the device is now invulnerable to the unlikely appliance that caused the problem to show in the first place—a defective LCD monitor.

**THE FUTURE**

Since developing this device, I have begun considering the potential of using a microcontroller to perform a FFT on the torroid's raw output in a manner similar to that of my spectrum analyzer.  This would allow me to perform filtering in software, and perhaps allow for more elaborate appliance detection.

It remains disturbing that I never observed a clean, diminutive 60hz output from the MTC30101 torroid.  I wonder if the torroid requires load resistors to achieve this and, if so, what the values should be.

Unanswered questions and the desire for improvement are normal for any project, but this one I find particularly haunting because the problem caught me so off guard.

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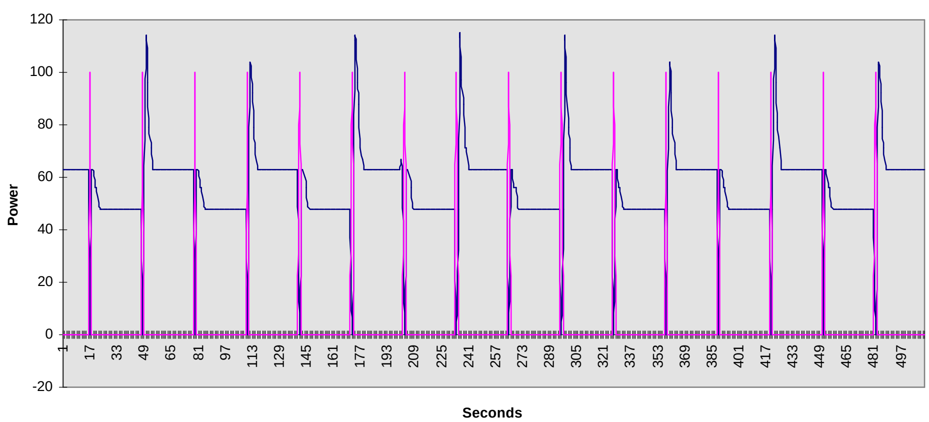
## **Appendix A: Observed behavior of televisions**.

I set up a test to verify the predictive behavior of three televisions being repeatedly cycled between on and off. During the period of test, the televisions' power consumption was measured every second and the power was toggled about every 30 seconds. In the following graphs, the blue trace reflects the power as read by the sensor at the time period sampled. The pink vertical bars represent the transmission of a "toggle power" command sent by an IR remote control to the television.

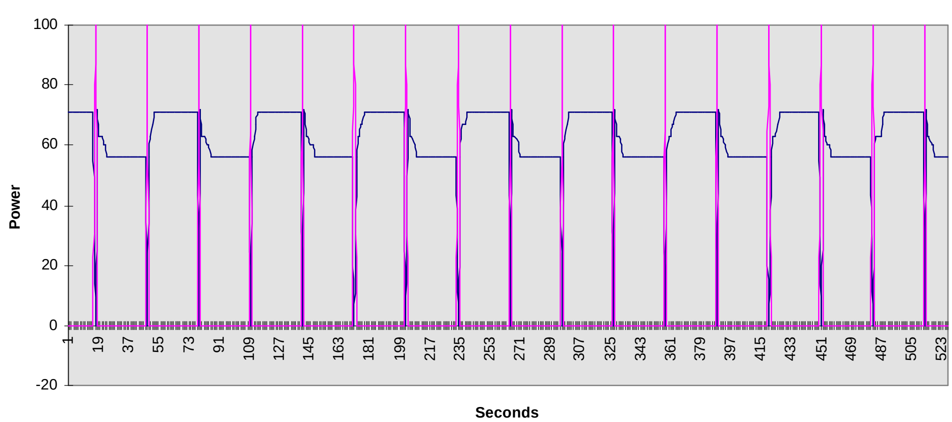
A few immediate conclusions resulting from this test include:

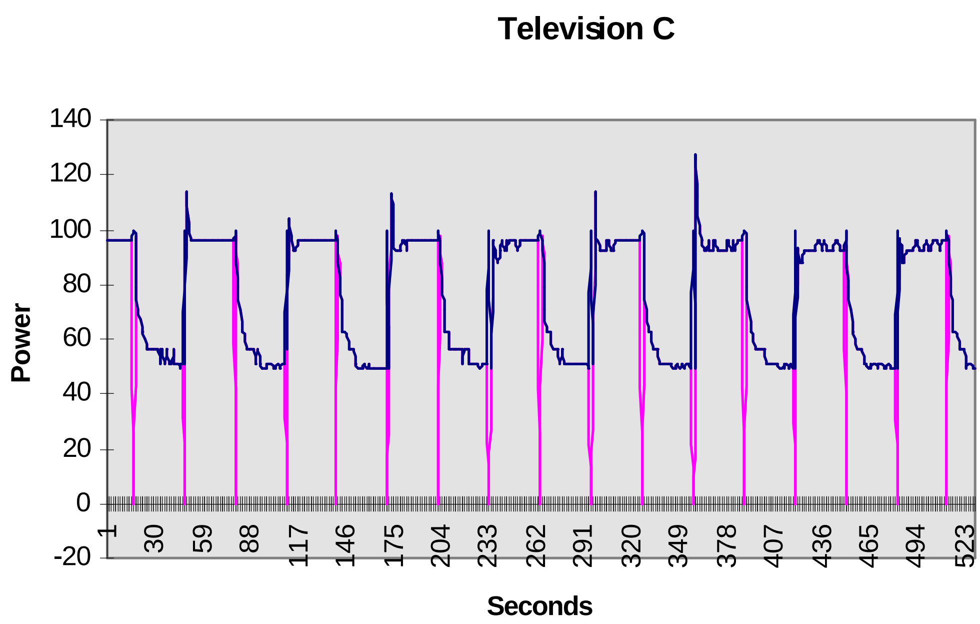
1) Televisions draw a predictable amount of current that reflects their state.
2) Current consumption varies by television model.
3) The IR remote control used in this test is reliable.

**Television A**




**Television B**




Television C
Power
140
120
100
80
60
40
20
0
-20
1
30
59
88
117
146
175
204
233
262
291
320
349
378
407
436
465
494
523
Seconds