Computer/Electronics Workbench

COMPUTERS, ELECTRONICS, AND AMATEUR RADIO FROM KC3XM

Analysis Of A Failed Class-E Amplifier

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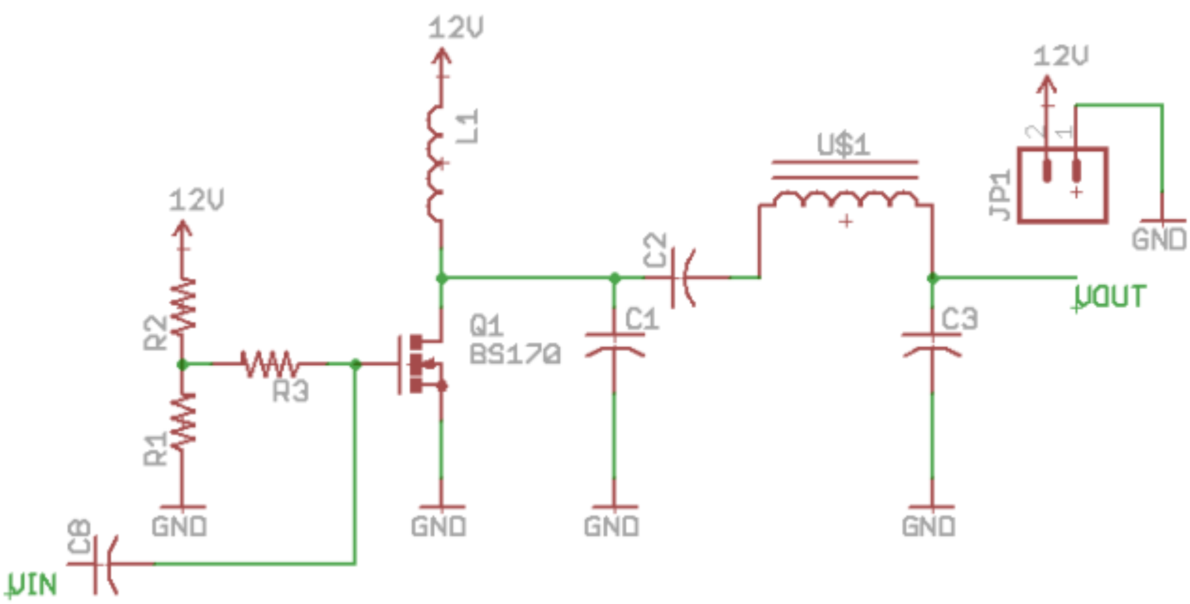
For the last couple of weeks I've gone back to my electronics roots and have been working on an amateur radio related project. Specifically, I've been working on a low power transceiver to use as a WSPR beacon.

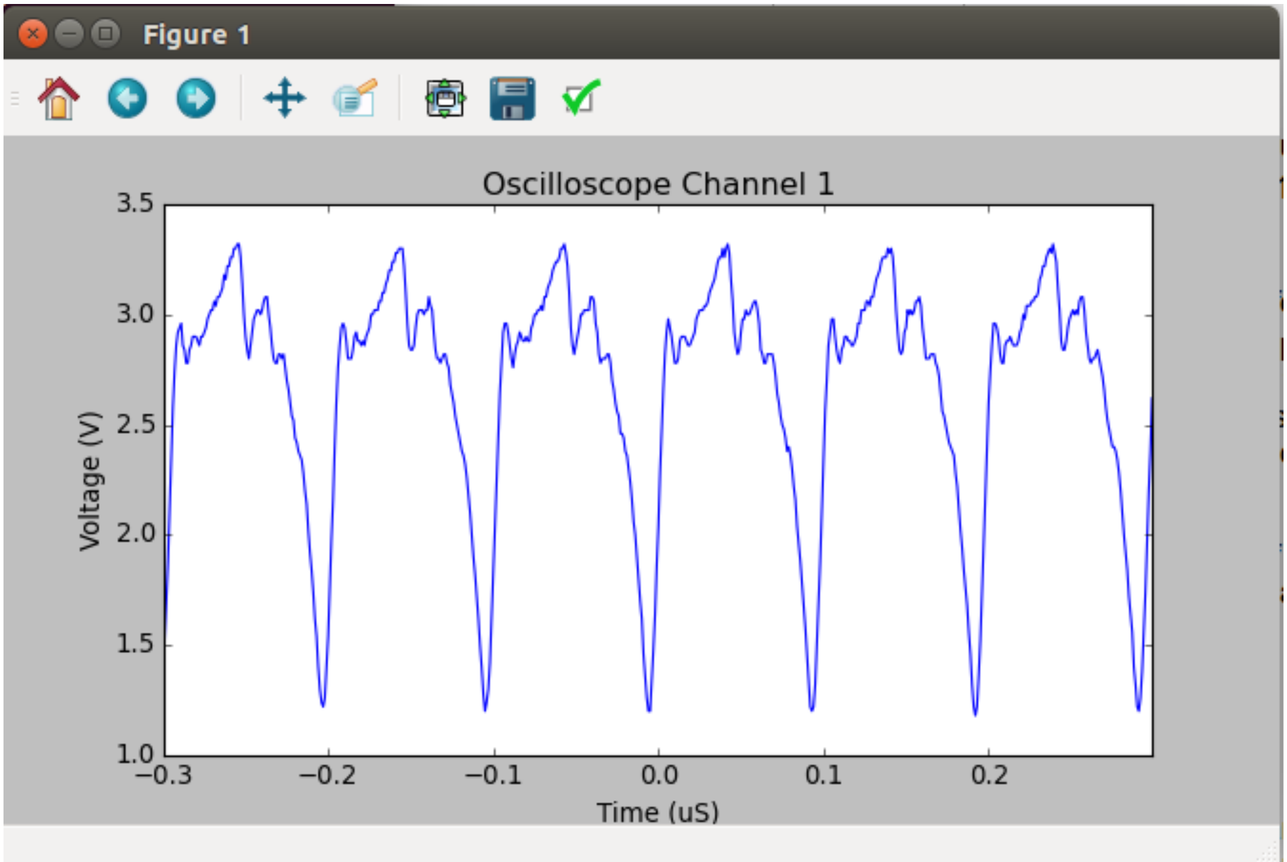
The schematic for the transmit portion is shown below, a class E amplifier intended to be driven by an Si5351 clock oscillator. The class E design is a standard one based on the BS170 MOSET. Circuit values were calculated using Tonne Software's free [“Class E Designer”] software.



However, when I connected it all together the output power was much less than I expected. I designed it for $1\,{}^{1}/_{2}$ watts but was only getting about ${}^{1}/_{3}$ watt out. So what's going on?

What Makes A Class E Amplifier?

One of the main assumptions in the design and analysis of a class E amplifier is the transistor will function as a hard switch, all the way on or all the way off. To see why this circuit didn't function as intended, look at the measured BS170 gate voltage in Figure 1 below.



You can see the increase in gate voltage when the drive signal from the Si5351 goes high. However, there is no corresponding drop when the drive goes low. Instead, the voltage falls off slowly until it's time for the drive to go high again.

This is probably caused by charge on the BS170 gate capacitance. When you read about drivers for class E amplifiers it's usually mentioned the transistor gate needs to be driven hard so this capacitance is charged quickly and the transistor goes through its linear region as quickly as possible. Mentioned less often is the need to discharge this capacitance quickly as well.

That's why so many MOSFET-based low-power class E amplifiers use logic gates as drivers. A logic gate's totem pole output effectively functions a couple of switches, alternately connecting the MOSFET gate to V_{CC} and shorting it to ground. It appears the Si5351 just doesn't have the ability to drive the gate low as needed. Instead it's output floats as the gate charge slowly drains off. Figure 2 shows the BS170 gate voltage when the Si5351 output is buffered by a 7402 logic gate. The signal has a 50% duty cycle as expected and the amplifier output power has risen to just about 1 watt.

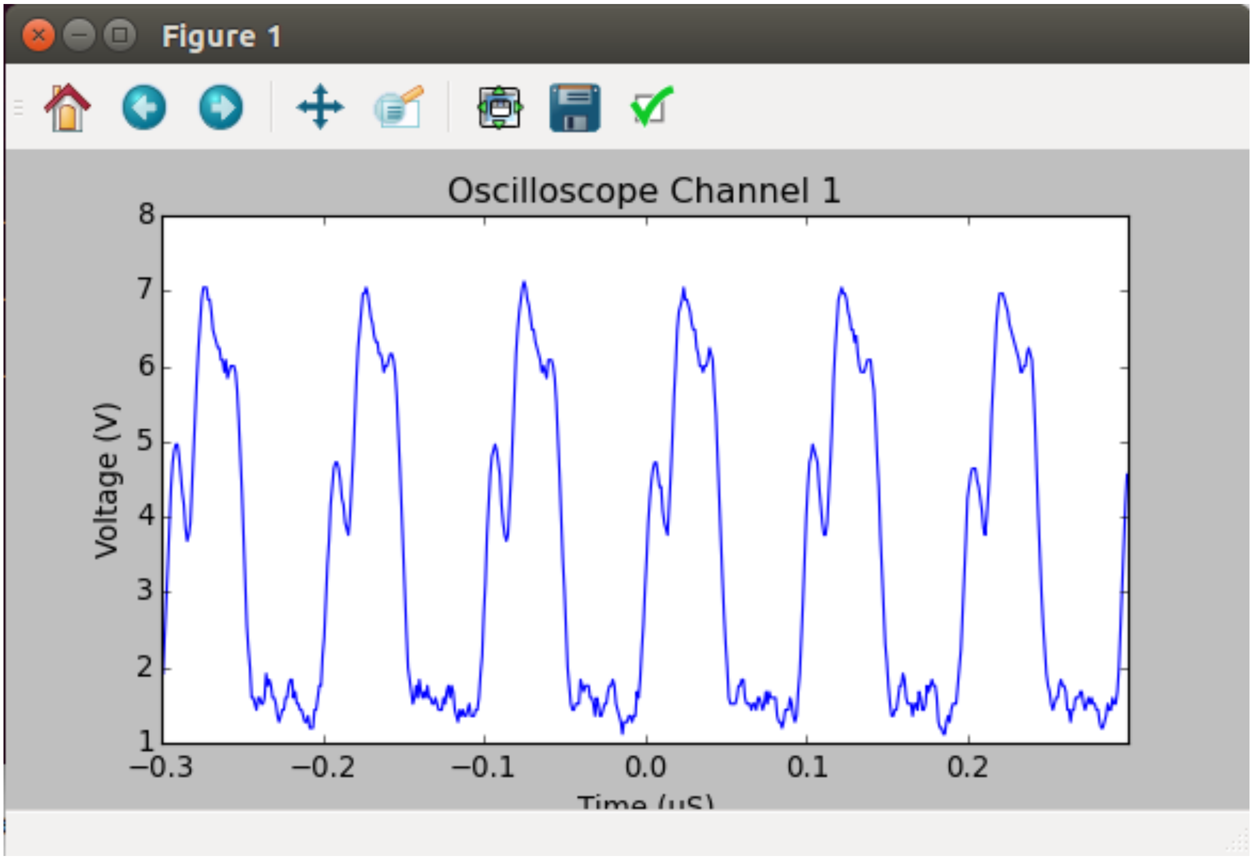
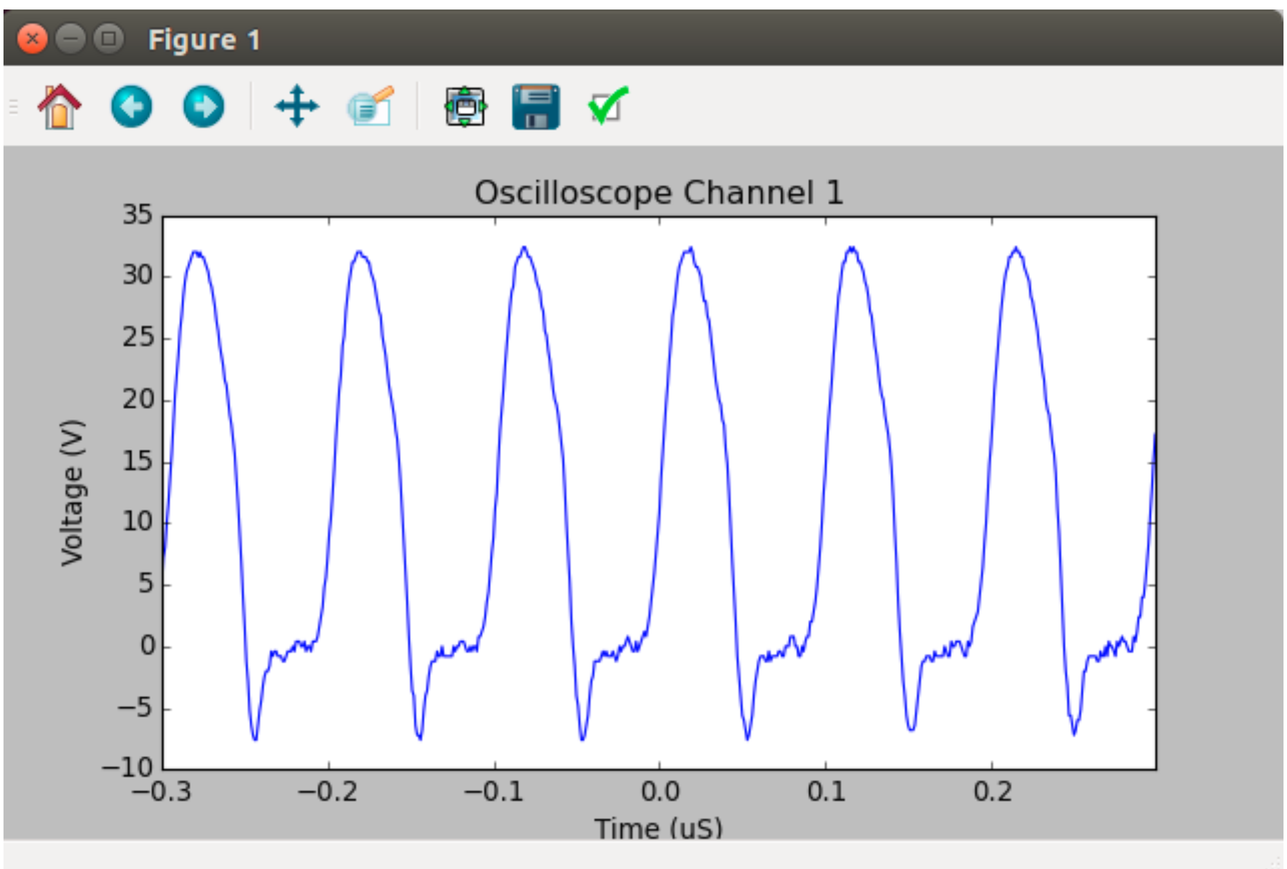


Figure 3 shows the drain voltage, which rises to ~32V as expected.



What About The Rest Of The Power?

I mentioned above the amplifier component values were calculated based upon an expected $1^1/_2$ watt output but after fixing the drive problem I'm only getting 1 watt out. Where's the rest of the power?

Well, it's important to remember that $1^1/_2$ watt output power assumes a perfect switch and component values that are spot on. Out of curiosity I loaded the circuit provided by "Class E Designer" into LTSpice for analysis. After varying the component values I came to the conclusion that output power from this circuit just isn't that sensitive to them. However, the BS170 MOSFET is by no means a perfect switch. In fact, in VE3MKC's description of this circuit he says

> *"I generally design my Class E networks with a Q of 3-5 and 150% of the power I want. For some reason my real world power output is almost always 30% less than the program predicts."*

So I guess 1 watt out of a 1.5 watt design is just about right.

Some Final Thoughts

This writeup wasn't intended to be a summary of how to design a class E amplifier. There are plenty of those out there. Instead, it was intended to be some thoughts on something that gets much less attention; what do you do when the circuit you've put together doesn't function as intended? Hopefully you'll find it useful should you run into similar issues.

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