Push-Pull Class E Transmitter

Design of a Higher Efficiency Transmitter

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Abstract

A class E transmitter was created to operate with a simple output circuit that anyone could build. Reasonable efficiency of 67% was easy to achieve, and operation at 7.1MHz was well within tolerable for amateur radio operation. Additionally, the switching nature of the amplifier makes the onboard clock source and MOSFET driver a simple replacement for input amplifiers for low-efficiency alternatives such as Class A amplifiers.

Introduction

High frequency transmitters, or high frequency amplifiers, can be a difficult circuit to miniaturize and make efficient. Traditional amplifiers have low efficiency when it comes to the high frequency (HF) modes of operation. Additionally, they may require a high power driving source due to low input impedance.

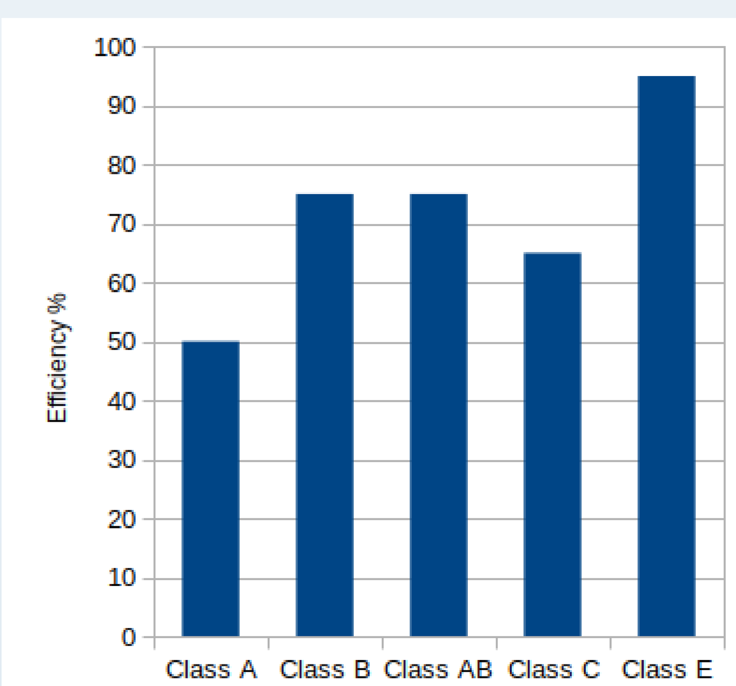

Fig. 1 Rough depiction of near-theoretical efficiencies for different classes, versus actual efficiency of a 44kW amplifier. [1]

Power is related to the voltage and current product. A class E design seeks to minimize the power dissipation through the switching device by making the current low while the voltage is high, and vice-versa [1]. By minimizing how much power is dissipated in the switching device, higher efficiency can be achieved than almost any class for frequencies well into the microwave range. [2]

By utilizing a push-pull design with the outputs coupled with transformers, the harmonic performance of the switching amplifier can be helped [1]. For ham bands, the second harmonic must below a certain threshold, and utilizing a push-pull design both increases possible power and removes the need for a lossy output filter network.

Objectives

The objective of this project was to design and implement a shrinkable RF transmitter working on the basis of Class E operation. With an onboard programmable oscillator the transmitter should be capable of both on/off keying and Frequency Shift Keying (FSK). Operating the board with a microcontroller allows future functionality to be added, such as Phase Shift Keying (PSK).

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Hardware Design

The entire transmitter is based off of a switching design. A clock source is told by a MCU to produce a square wave output of the desired frequency which is then fed to the Class E Amplifier.

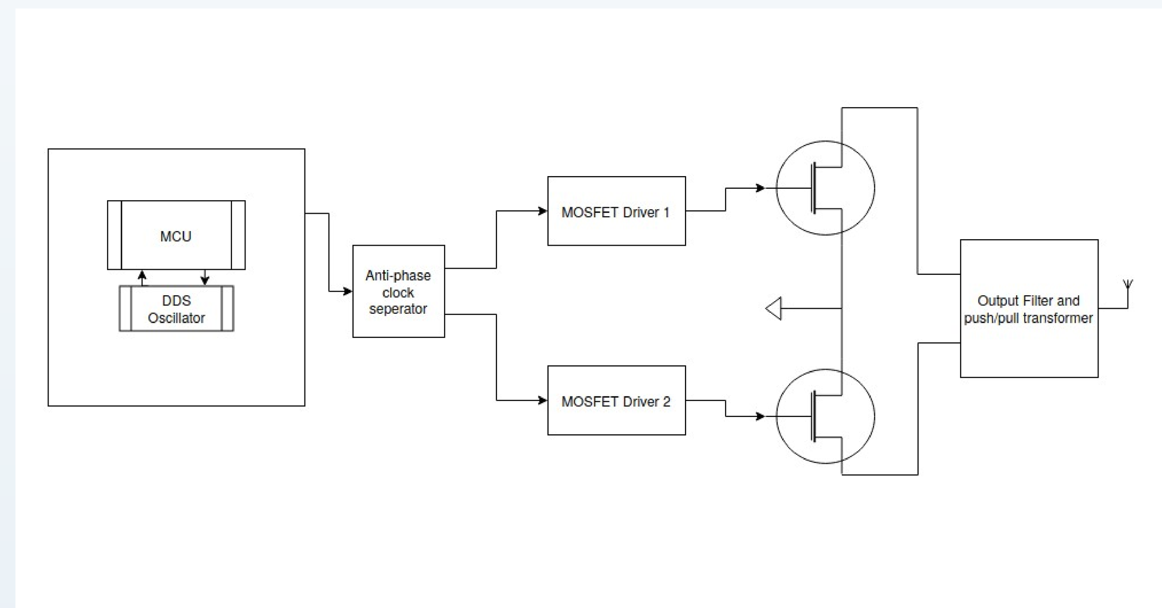

Fig. 2 System block diagram, showing the basic theory of the circuit layout.

KiCad and LTSpice were used in the design of the amplifier components. Additionally, multiple publicly available class E calculators were cross-referenced with each-other to verify the design values and learn about the effect of variables on circuit performance. Equations supplied by Nathan Sokal define the component values of the amplifier itself. The transformer(s) act as the RF choke to prevent the RF from entering the power supply.

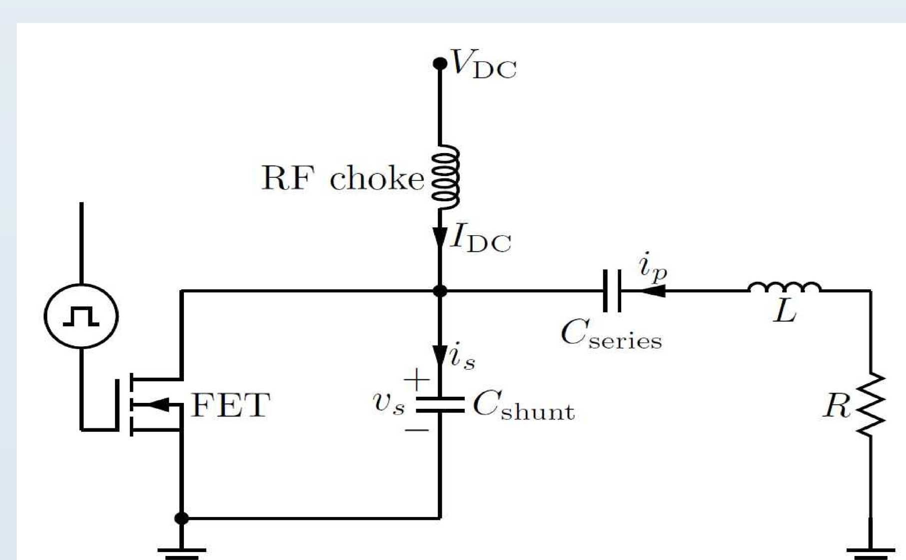

Fig. 3 Basic circuit for a class E amplifier

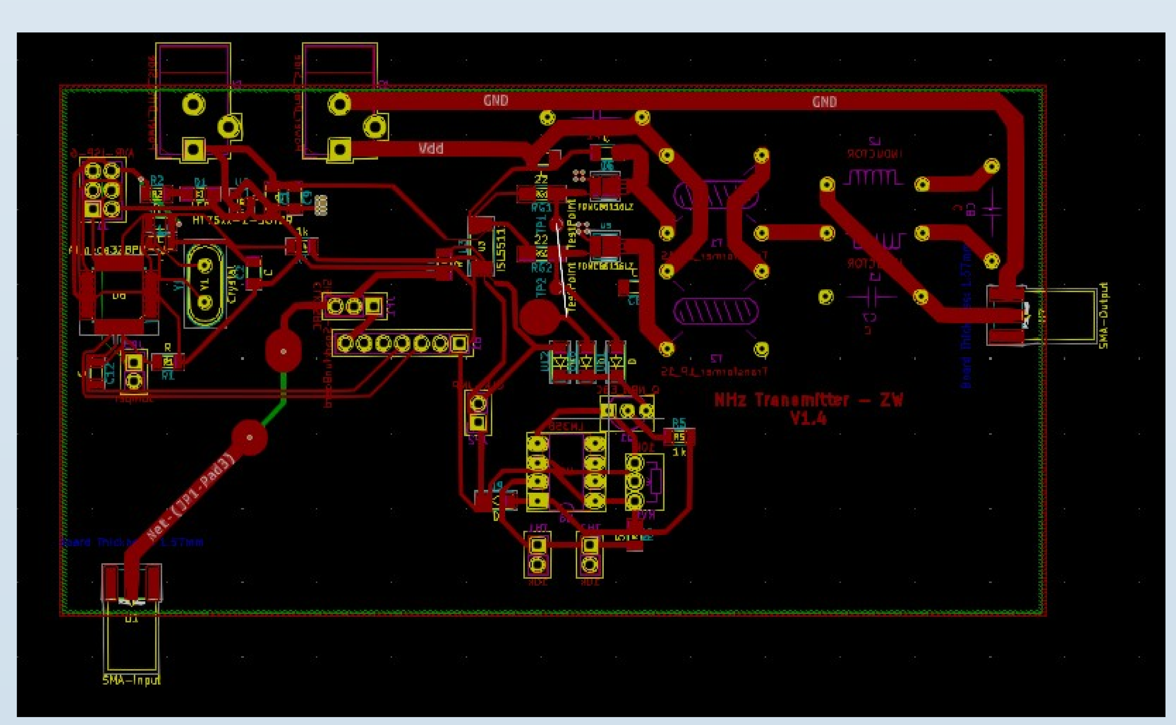

Fig. 4 The PCB layout was done using KiCad. FlatCAM and CamBam were used in scribing the circuit with a Bridgeport milling machine with homemade tools. The circuits were then etched with an acid and then a UV curable solder mask was applied.

Circuit

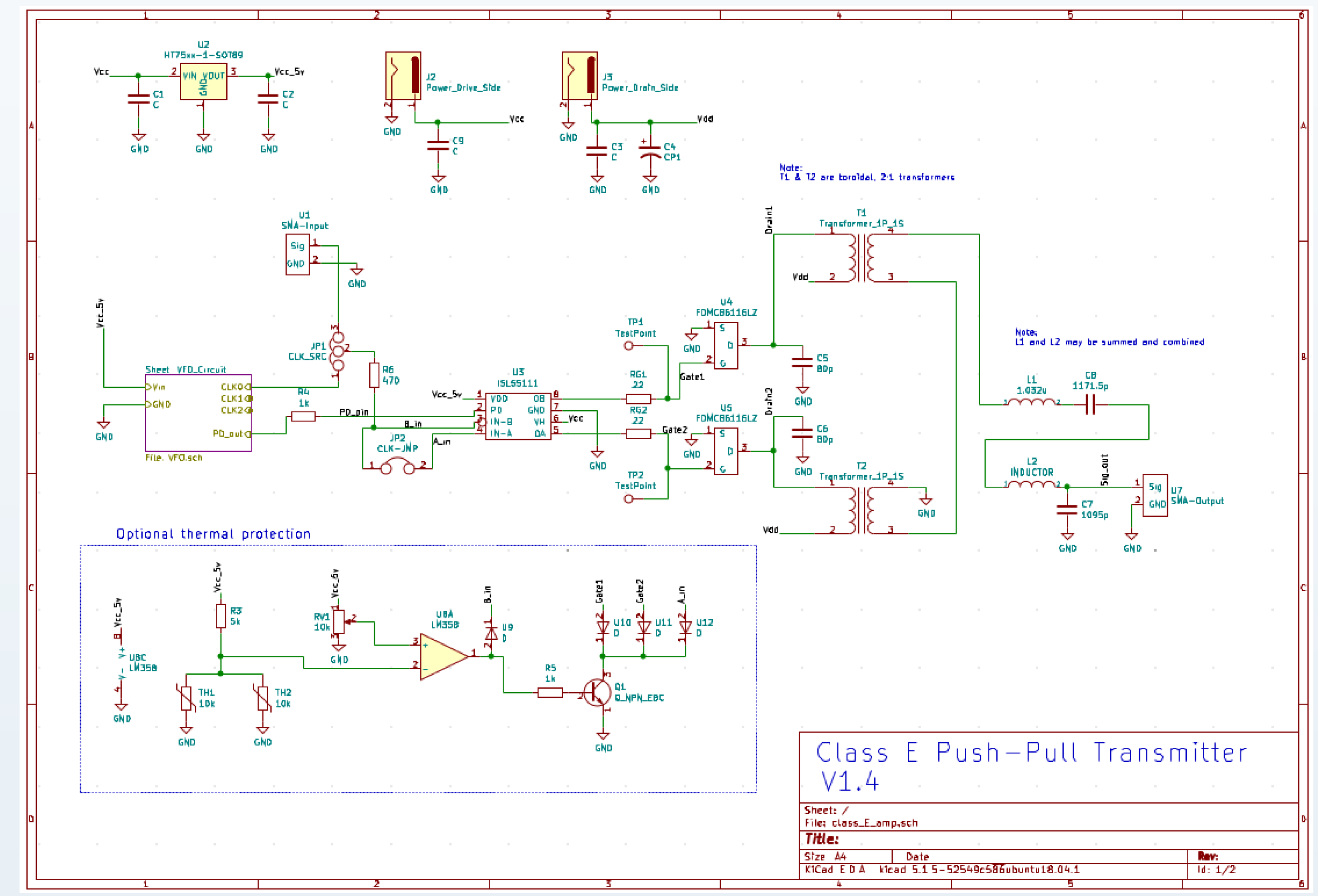

Fig. 5 Class E amplifier and schematic diagram of driving circuitry

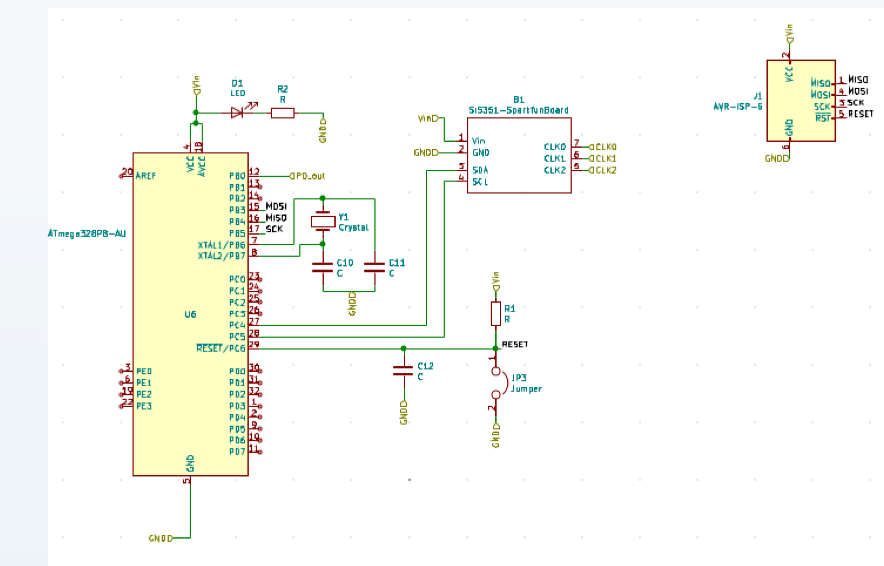

Fig. 6 ATMega328p and Si5351 (oscillator) circuit layout

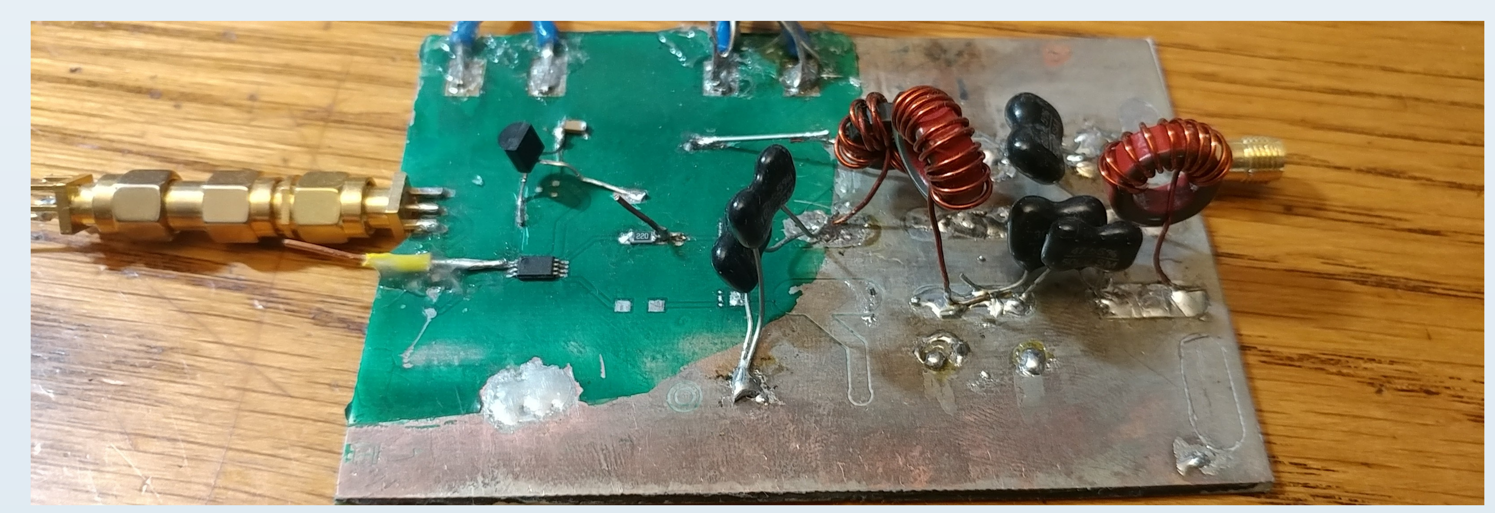

Fig. 7 Single-ended class E amplifier only.

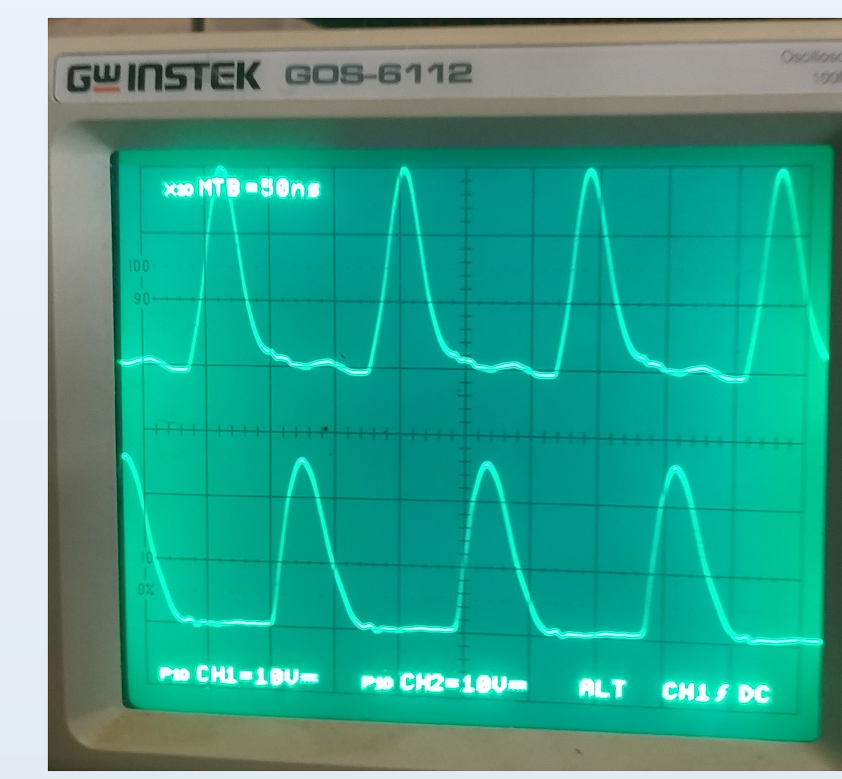

Fig. 6 Drain voltage waveforms for a push-pull amplifier.

Results

The resulting Class E designs that were tried varied in quality both in frequency accuracy and output efficiency. Without careful tuning, and a hand-built PCB, efficiency of 67%+ was easily obtained. With a push-pull amplifier, the second harmonic was lowered to fit FCC regulations by being 40dB down even without a low-pass filter on the output. The ATMega328 chip was proven to be capable of driving the circuit even with a non-ideal RF circuit. With a single-ended design (pictured above) 3W output could be sustained at 67% efficiency.

Conclusion

One of the major design advantages of the class E amplifier design is that the circuit can be almost entirely described by derivable equations instead of something complicated like lumped element analysis. With the exception of Q, all values can be calculated easily and the resulting amplifier typically requires very little effort to get into operation.

Using a digitally programmable clock source and a microcontroller to run the switching amplifier worked well, and more features are simple to add. Frequency shift keying of the transmitter was as simple as a few lines of code and the output could be disabled to do On/Off keying such as CW.

References

[1] N. Sokal. (2003). “Class-E High-Efficiency Rf/Microwave Power Amplifiers: Principles Of Operation, Design Procedures, And Experimental Verification”, *IEEE Life Fellow Design Automation, Inc.* https://people.eecs.berkeley.edu/~culler/AIIT/papers/radio/Sokal%20AACD5-poweramps.pdf

[2] S. D. Kee, I. Aoki, A. Hajimiri and D. Rutledge, "The class-E/F family of ZVS switching amplifiers," in IEEE Transactions on Microwave Theory and Techniques, vol. 51, no. 6, pp. 1677-1690, June 2003, doi: 10.1109/TMTT.2003.812564.