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APPLICATION NOTE

LOW COST 1000 WATT, 300 VOLT RF POWER AMPLIFIER FOR 13.56 MHz

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Low Cost 1000 Watt, 300 Volt RF Power Amplifier for 13.56MHz

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ABSTRACT

This paper details the design, development , assembly and performance of a low cost, high-efficiency, 1000Watt, 13.56MHz RF power amplifier (PA) operated from a 300VDC supply, with an efficiency of 80%. The PA is built around a "symmetric Pair" of low cost RF power MOSFETs from Advanced Power Technology (APT). The transistors are from a new generation of high quality, commercial, HF/VHF, silicon, 900V RF power MOSFETs in TO-247 packages. The paper addresses both the theoretical design and physical construction of the amplifier. The paper also contains a technical description of the RF power transistors.

INTRODUCTION

Most transistorized RF Power Amplifiers operate from a DC to DC converter. This supply is usually low voltage, about 50V, and requires a down regulator when operated from AC mains. This converter is a significant portion of the overall cost of the RF amplifier system.

As a result of IEC555-2, all electronic equipment sold in Europe with a power draw of greater than 250W will require power factor correction (PFC). The addition of a PFC preregulator to the system could add 50 to 100% to the cost of the power supply portion. The requirement for PFC is soon to follow in the USA and the rest of the world.

The use of a new high voltage RF MOSFETs from Advanced Power Technology (APT) makes possible a new RF amplifier design which can be operated at 300V, allowing for the direct use of regulated output, thus eliminating the DC to DC converter, reducing the cost of the RF amplifier system.

The new devices, like their predecessors, utilize the high performance of APT's Power MOS IV® technology and the "symmetric pair" package.

AMPLIFIER DESCRIPTION

The amplifier is a 1000 Watt, 13.56MHz design operating in class C with a 300VDC power supply. Efficiency of the amplifier is 80 percent. The power amplifier is built around two "symmetric pair" of ARF444/ARF445 900V RF power MOSFETs provided in TO-247 plastic packages. The devices are electrically identical, except that they are packaged in "mirror image" pairs to facilitate a symmetrical layout that helps maintain the electrical symmetry required for push-pull operation. Figure 1 shows the circuit diagram of the amplifier, with the parts list given in Table 1. The amplifier is a classical push-pull configuration of a straight forward nature, using a simple L-C network for impedance matching and transformer-coupling to achieve the required complementary gate drive signals. A wideband wire wound transformer output circuit is used, with a conventional bifilar-wound RF choke for DC power supply isolation.

Short, low inductance interconnections are easily made using the ARF444/ARF445 devices, because they can be mounted symmetrically in a common source configuration. In particular, the gate circuit should minimize inductance to avoid instability and losses when that inductance is combined with the high capacitance of the gates. Similarly, the frequency response of the output circuitry is improved with minimum stray inductance due to interconnections[1].

The amplifier is operated directly from the PFC 300VDC power supply, eliminating the DC-DC converter, and is constructed on a heat sink sized for proper dissipation at the expected power levels. Figure 2 shows the component placement on the PC board and heat sink. The common source design of the package allows the device mounting to be accomplished without an insulator thus allowing good heat transfer to the heat sink with the use of thermal grease.

INPUT NETWORK

The input network provides a 50Ω impedance to the driver source and transformation of the MOSFET gate impedance, as well as balanced drive for push-pull operation. The input network comprises capacitor C1, the input capacitance of the power MOSFETs and the series gate resistors, both transformed by T1. The proper selection of C1 tunes the input network for minimum input return loss at maximum power output [2].

Transformer T1 provides a 9:1 impedance transformation of the MOSFET input impedance. It is constructed using two Fair-Rite cores #2643540002, μ=850 with 3 turns of stranded

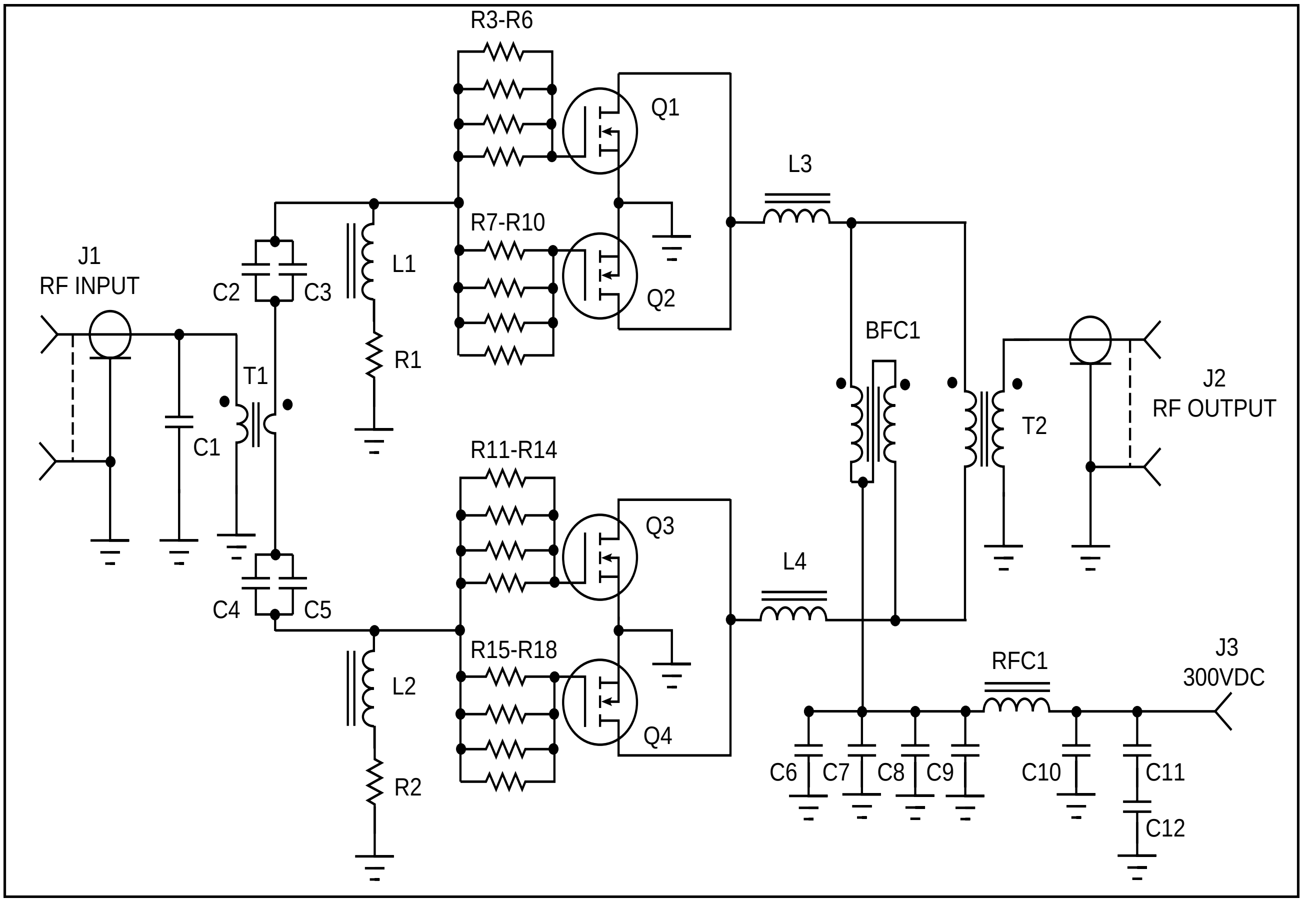

Figure 1. Circuit Diagram of the 1000 Watt Class C Amplifier

Part Number	Description
R1,R2	10Ω 1W
R3-R18	4.7Ω 1W
C1	200pF Chip Capacitors
C2-C5	0.1µF Chip Capacitors
C6-C10	0.1µF Disk Ceramic
C11, C12	0.01 Disk Ceramic
Q1, Q3	ARF444
Q2, Q4	ARF445
L1, L2	VK200-19/4B
L3, L4	0.37µH: 6T, #18AWG, ID=0.438
RFC1	2T, #14 PTFE coated twisted pair on a Fair-Rite #2643665702 shield bead, µi=850
T1	9:1(Z) conventional transformer; 3:1(T), #18 stranded PTFE coated wire on two Fair-Rite #2643540002, µi=850
T2	1:1(Z) conventional transformer; 2:2(T), #14 stranded PTFE coated wire on two stacks of three Fair-Rite #2643102002 shielded bead, µi-850
BFC1	6T, #18 Twisted pair stranded PTFE coated wire on three stacked Indiana General Toroid #F624-19-Q1, µi=125

Table 1. Parts List for the 1000 Watt Power Amplifier

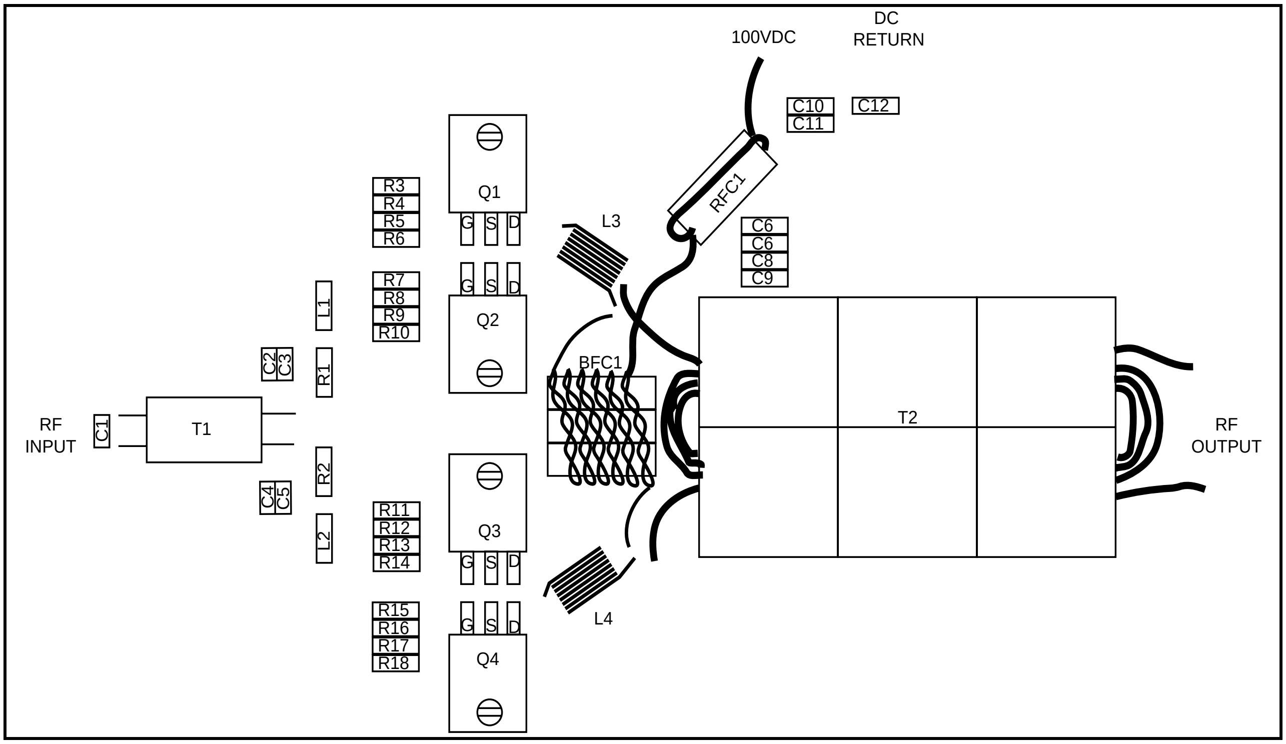

Figure 2. 1000 Watt Class C Power Amplifier Layout

PTFE coated #18 wire on the primary and 1 turn of stranded PTFE coated #18 wire on the secondary. The secondary is coupled through the DC blocking capacitors C1-C2 and C3-C4 and resistors R3 through R18 to the gates of the MOSFETs. The resistor-inductor combination R1-L1 and R2-L2 stabilize the push-pull amplifier at lower frequency and provide the MOSFETs with a DC ground reference to insure the gates do not float to a DC potential thus unbalancing the amplifier bias points. The parallel resistors R3-R6, R7-R10, R11-R14 and R15-R18 in series with the gates of the MOSFET, prevent high frequency oscillation common when paralleling MOSFETs [3].

OUTPUT CIRCUIT

The 300VDC power input is delivered through a balanced feed choke [4]. The choke is designed to create a zero DC magnetic bias in the core when both transistors draw the same average current. With the devices operating 180 degrees out of phase, the construction of the windings presents a high impedance at 13.56MHz to the drain of each MOSFET. The choke is constructed by winding 6 turns of #18 stranded PTFE coated twisted pair around three stacked Indiana General Toroids #F624-19-Q1, µi=125.

The output of the power devices is coupled to the output transformer T2 through two 0.37 µH inductors. The transformer is a wideband 1:1 conventional transformer. No output filtering was used in the test amplifier, which has the third harmonic 30db down and the second harmonic 55db below the 1000 watt output power level.

The transformer is constructed by winding 2 turns of #14 stranded PTFE coated wire for the primary and 2 turns of #14 stranded PTFE coated wire for the secondary around two stacks of three Fair-Rite #2643102002 shield beads, μi=850.

PERFORMANCE MEASUREMENTS

The amplifier was operated under two conditions. First the amplifier was driven with a 13.56MHz RF signal, modulated by a 1kHz square wave, at a 50% duty cycle, up to a peak power out of 1200W. Second the amplifier was driven with a 13.56HMz CW RF signal up to a continuous power out of 1000W. Due to the close correlation of the modulated data and the CW data, it was concluded that there is significant thermal margin from using four 300W devices at 1000W CW.

Figures 3 through 6 show the performance data for this amplifier. Figure 3 is a plot of P_{in} versus P_{out} and Figure 4 shows gain versus P_{out}. The curves show the classical class C characteristics, with a low gain at low power output, improving as the output power increases. The gain peaks at 16.9db when the amplifier output is 800W, with a roll-off to 15.9db at 1200W.

Efficiency versus P_{out} is shown in Figure 5. As would be expected in class C, the efficiency is over 50% at power output above 300W. The efficiency rises to an outstanding 80.4% at 1000W, continuing upward to 84.4% at 1000W, continuing upward to 84.4% at 1200W output. Figure 6 is total amplifier power dissipation versus P_{out}.

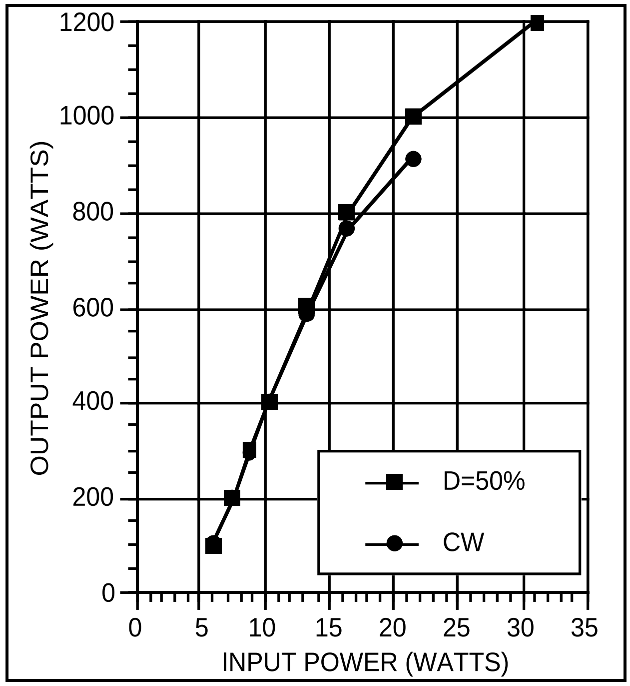

Figure 3. Input Power versus Output Power

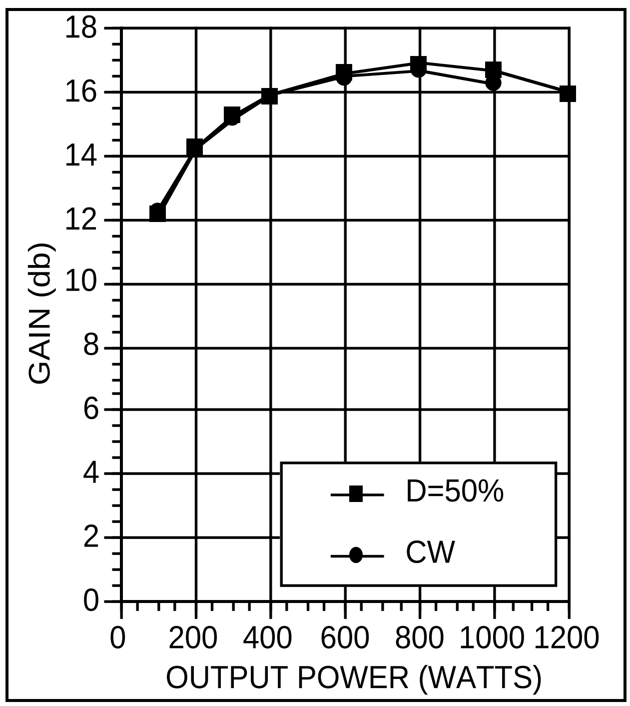

Figure 4. Gain versus Output Power

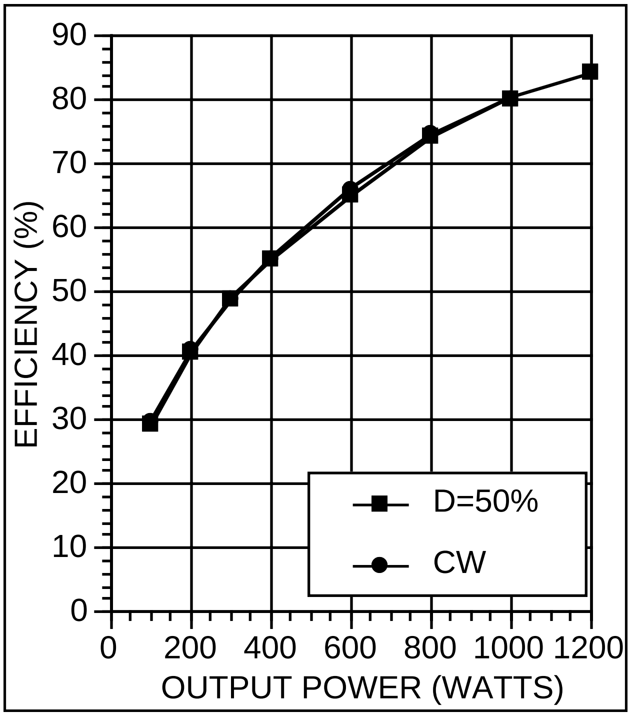

Figure 5. Efficiency versus Output Power

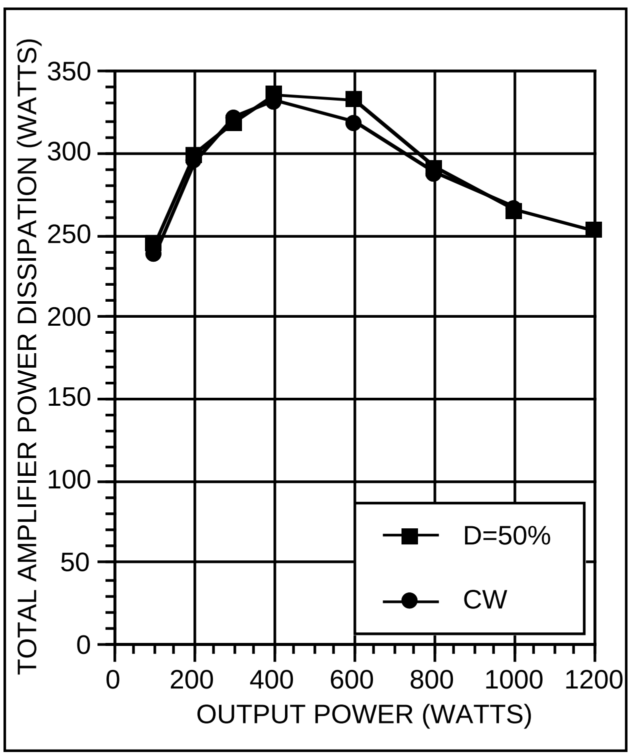

Figure 6. Total Amplifier Power Dissipation versus Output Power

300 VOLT POWER SUPPLY

The topology chosen for the 300 Volt PFC power supply is the commonly used continuous mode boost converter. This topology is the most popular where power requirements are greater than 750W. Figure 7 is a simplified schematic of the regulator which is implemented using an APT5012JNU2 and a Unitrode U3854 controller IC [5] [6] [7].

The regulator operates by the controller sensing the rectified DC input and controlling the ON and OFF time of Q1 such that the current in L1 closely follows a sine wave which is in phase with the AC line voltage. During the OFF time of Q1, the inductor fly back transfers some of the stored energy in the inductor to the output storage capacitor. The controller senses the output voltage and adjusts the average current in the inductor such that the regulated voltage on the output capacitor is maintained at 300V.

CONCLUSION

This paper demonstrated a recent breakthrough in commercial solid state RF power device and circuit technology. The high quality, low cost, components and circuits described here, now make it possible to deliver solid state, 10,000 watt (or more), 13.56MHz power supplies costing less than an equivalent tube RF power supply.

The combination of high voltage operation, high gain, and efficiency of 80 percent make this technology exciting just for performance alone. Combine that performance with component costs that allow for multi-kilowatt, 13.56MHz amplifiers to be built at less than $0.25 per watt and you now have the first real breakthrough in commercial HF, RF power technology in over a decade.

This is only the beginning. The commercial technology detailed in this paper will be evolving quickly into solid state devices and circuits for higher frequency, higher power, and even higher operating voltages.

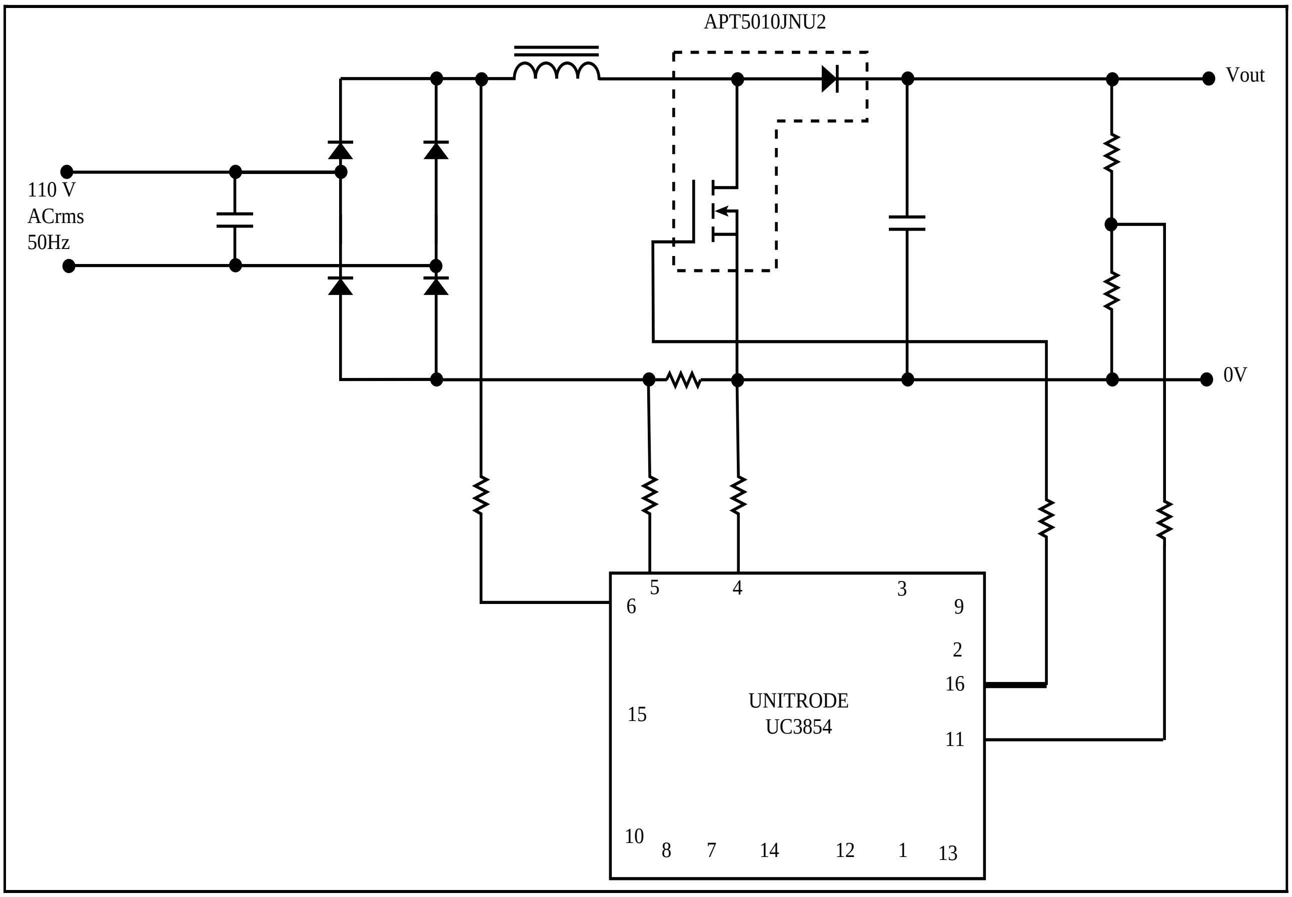

Figure 7. Simplified Circuit Diagram of the Power Factor Correction Power Supply

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