Application Note

13.56 MHz, CLASS-E, 1KW RF Generator using a Microsemi DRF1200 Driver / MOSFET Hybrid

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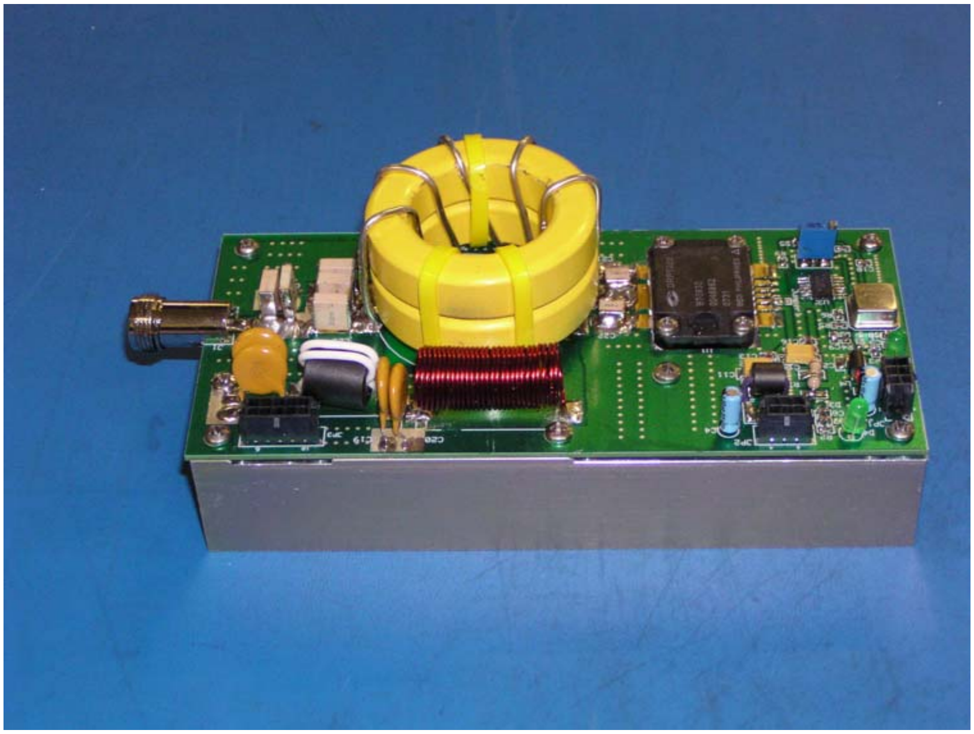


Contents

1. INTRODUCTION

This reference design discusses the design procedures and test results for a 13.56MHz, 1KW, CLASS-E generator that is ideal for ISM applications. To maximize efficiency and reliability a Microsemi DRF1200 Driver/MOSFET Hybrid was selected. The DRF1200 can generate over 1KW of output power and consists of a MOSFET driver, high power MOSFET and internal bypass capacitors in an air cavity flangeless package. The flangeless package design optimizes reliability, provides increased flexibility, and minimizes parasitic inductance while still providing an overall cost efficient solution. A reference design board (DRF1200/CLASS-E) is available for purchase to facilitate the immediate evaluation of the principles of this application note.

A CLASS-E RF generator design was chosen to demonstrate optimum efficiency. It is essential that care is taken to use adequate circuitry, clean PCB layout and good ground connections on the PCB to ensure proper output waveforms.

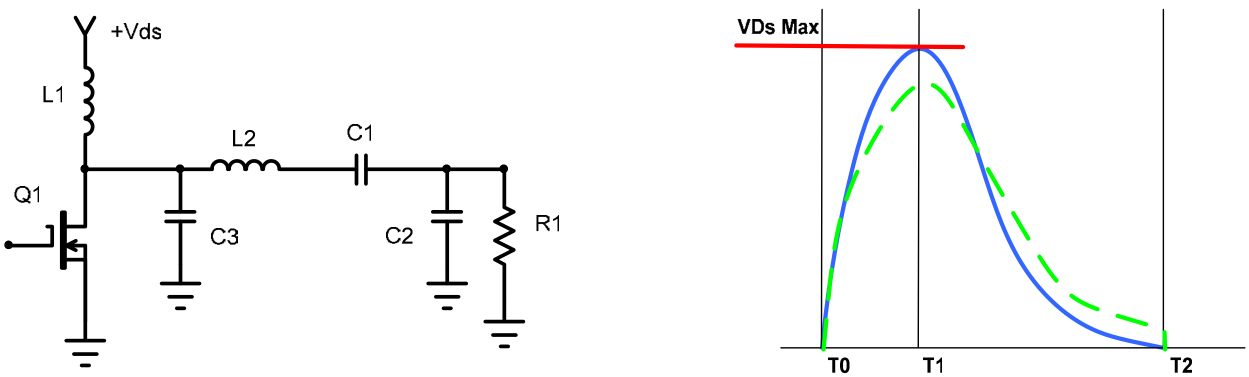


Figure 1 Simplified Class-E circuit and Wave Forms

Figure 1. L1 is a RFC (RF Choke) that when Q1 opens causes the voltage across Q1 (Vds) to swing in excess of PS HV. C3 is selected so that combined with the Coss of Q1 the drain wave form is optimally tuned as shown by the solid blue line. The dashed green line represents a suboptimum tune. See References. L2 and C1 form a resonate circuit. C2 is the Load capacitor. An external load resistance R1= 50Ω (1000W) is used in this application and for the purpose of this discussion.

2. DESIGN CONSIDERATIONS

The following issues should be considered in the design of a high efficiency, high power RF generator.

a. CLASS-E operation to optimize high-efficiency.

b. Adequate output matching circuit. Software matching tools were used to achieve the required power and efficiency.

c. Parts that are capable of handling RF output of 1KW. This includes the bypass capacitor in the DC circuit and selecting a toroidal inductor and capacitors for output matching circuit.

d. A heatsink that is sufficient to dissipate the required power. The DRF1200/CLASS-E comes mounted on an aluminum heat sink and the user must use fans to help dissipate the heat (see Appendix IV). This heatsink is adequate for short periods of operation and should be used for evaluation only. It is recommended that a more adequate heatsink, such as a water cooled heat sink be used for extended operation.

e. PCB designed for good ground connections, especially for the output matching circuit.

f. PCB lay out optimizing the isolation between power output and input signal generation circuit.

Table 1 shows the output achieved for this RF Power Generator.

Freq	Output Power	Voltage	Current	Efficiency
13.56Mhz	1KW	320V	3.7A	86%

Table 1. Key Specification

3. CIRCUIT DIAGRAM

Figure 2 shows the circuit diagram without power supply connectors. This high efficiency RF power generator uses a DRF1200 to minimize layout parasitics and optimize efficiency for CLASS-E operation.

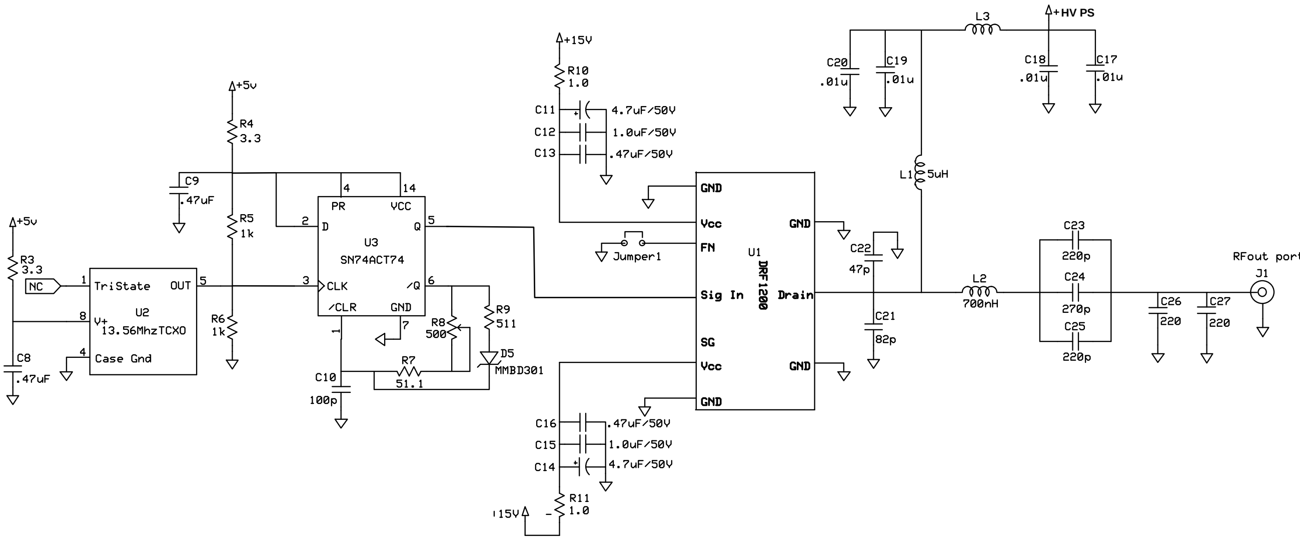


Figure 2, Class-E RF Generator

4. CIRCUIT DESCRIPTION

a. RF pulse generator circuit

The pulse oscillator and pulse control circuit, U2 and U3 in Figure 2, is designed to create an ISM frequency of 13.56MHz. R8 sets the Flip Flop IC timing, changing the pulse width from 14nS to 35nS at the signal input of DRF1200. For this application, the pulse width is set at 17nS. The fine tuning of the pulse width is essential to maximize efficiency and power output as shown in Fig 1. R8 and R7 must have a TC of ≤ 100 PPM and C10 must be a NPO type with a ± ≤5% tolerance.

To minimize conductive EMI, it is crucial to use a good ground plane layout with respect to the signal lines.

b. RF output matching circuit

The DRF1200 has a switching speed of 3~4nS, BVds of 1KV and Ids of 13A max.
To achieve high efficiency operation, the RF generator uses CLASS-E operation and at full power the efficiency is approximately 86% at 13.56MHz. The MOSFET output capacitance must be considered when tuning the external shunt capacitance to get the desired performance. See DRF1200 data sheet for output capacitance.

The matching circuit was calculated with a RF software tool to maximize power transfer to 50 Ohm load (via J1 and should be able to handle 1000W). The circuit was then tuned by the selection of L2, C23, C24 and C25. This output matching circuit is a series resonant circuit combined with a reactive circuit consisting of an "L" match Toroidal Inductor (L2) and Capacitors in series (C23, C24 and C25) and shunt (C26 and C27) to ground. Capacitors C26 and C27 are the load capacitors and inductor L1 is the RF choke.

c. DC Supply

The HV DC supply input circuit utilizes an inductor (L3) and by-pass capacitors (C17 thru C20)to isolate the RF from the DC power. The inductor was calculated to be approximately 1K Ohm impedance at 13.56MHz using 30 turns of 20AWG wire. The By-pass capacitor should have a minimum 1KV rating.

5. TEST REQUIREMENTS.

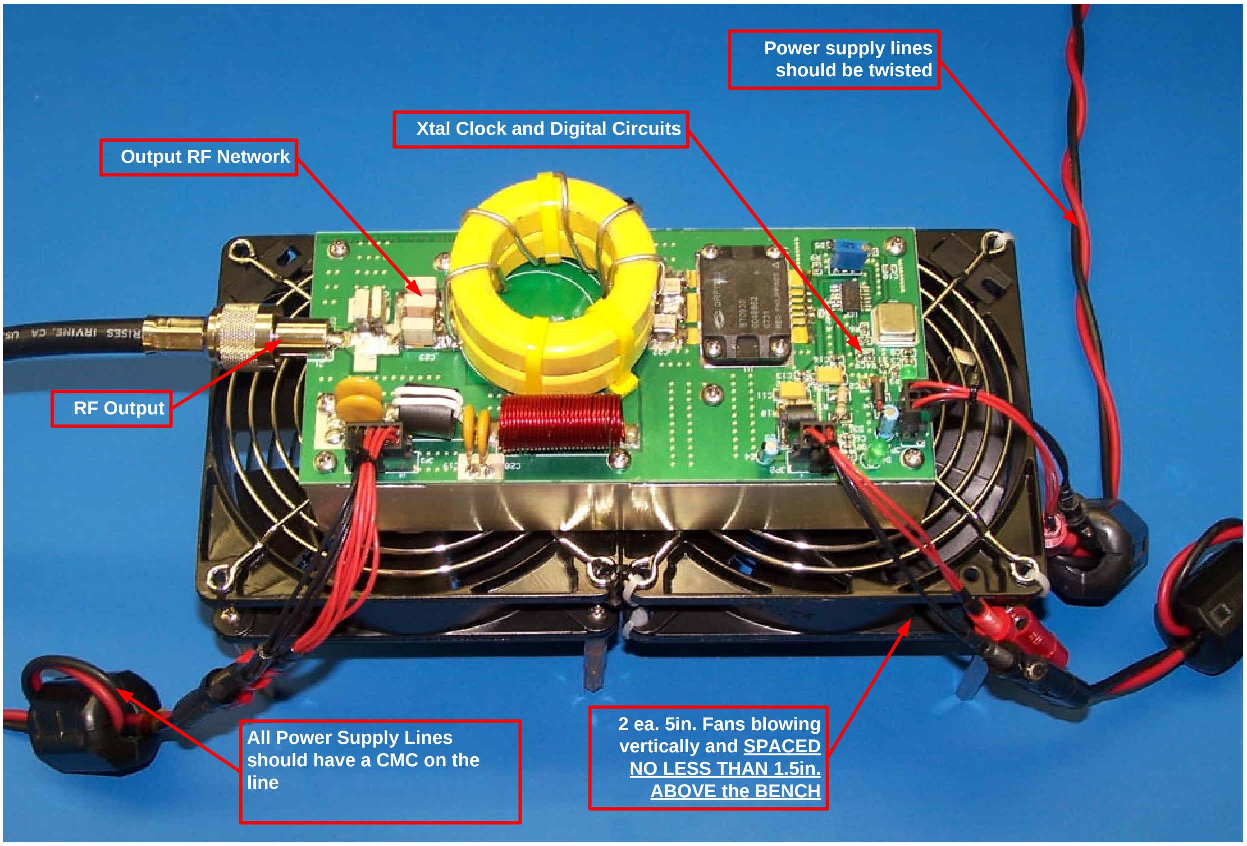


Figure 3 DRF1200 Class-E Bench Test Setup

The Test bed is shown as a red amplifier block in Figure 4 on the following page.

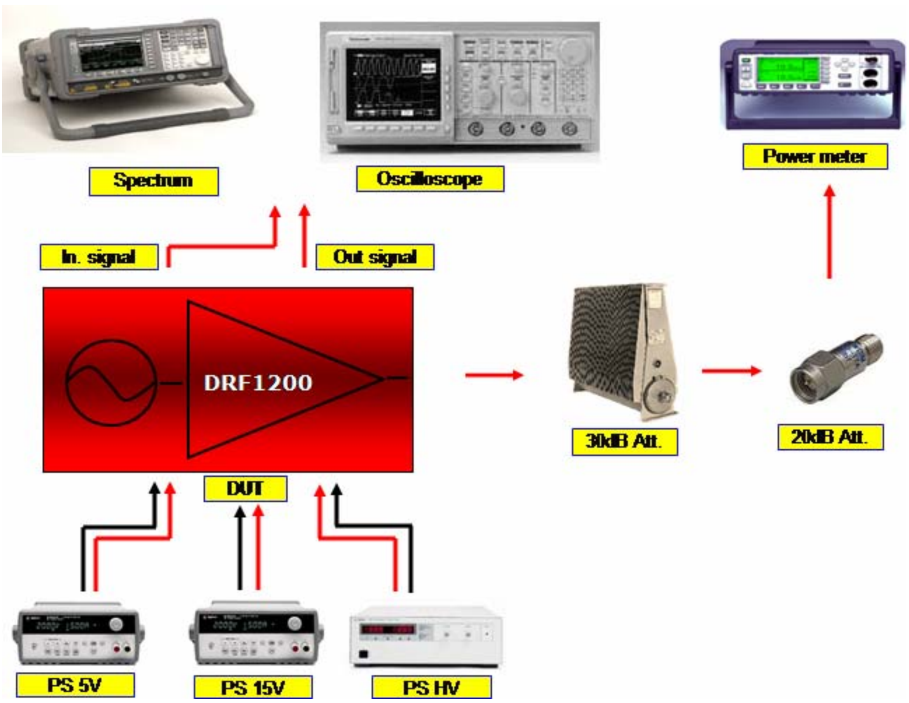


Fig. 4 Test Set-Up diagram.

a. Hardware and power sequencing requirements

- Air cooling requirement: Testing should be performed using a minimum of two 150 CFM, 5 inch fans attached to the bottom and sides of the generator to maximize air flow directed across the heat sink fins in order to dissipate the heat. A space of approximately 1.5 inches or higher between the fans and the bench floor should be allowed so that air flow is not impeded.
- Sequential steps for Turn-On/Turn Off of Power Supplies
  1. Turn on Driver power supply PS 15V (via JP2)
  2. Then, turn on MOSFET supply (PS HV) and slowly increase to 40V (via JP3)
  3. Then, turn on RF pulse circuitry supply (PS 5V) (via JP1)
  4. While monitoring the RF power from power meter and output waveform of the Drain, ramp up MOSFET power supply (PS HV) to the values per Table 2 making sure that output is stable for each supply voltage before proceeding to the next higher voltage.
  5. To turn-off, turn power supplies off in the reverse order.
- If RF output waveform, Vds and/or RF power level from power meter fluctuate, immediate shut down of PS HV for safety and determine fault before resuming test.

6. PERFORMANCE

6.1 Data summary (Power sequencing)

No\Para.	PS HV (V)	Id (A)	Pin (W)	Pout (W)	H (%)	Vds (V)
1	100	1.1	110.00	104	94.5	276
2	110	1.19	130.90	124	94.7	
3	120	1.3	156.00	149	95.5	
4	130	1.4	182.00	175	96.2	
5	140	1.51	211.40	204	96.5	
6	150	1.63	244.50	235	96.1	
7	160	1.75	280.00	268	95.7	
8	170	1.87	317.90	303	95.3	
9	180	2	360.00	342	95.0	
10	190	2.13	404.70	383	94.6	
11	200	2.25	450.00	424	94.2	576
12	210	2.4	504.00	472	93.7	
13	220	2.52	554.40	515	92.9	
14	230	2.66	611.80	564	92.2	
15	240	2.8	672.00	615	91.5	
16	250	2.95	737.50	669	90.7	
17	260	3.09	803.40	723	90.0	
18	270	3.23	872.10	775	88.9	
19	280	3.38	946.40	830	87.7	
20	290	3.52	1,020.80	882	86.4	
21	300	3.66	1,098.00	940	85.6	
22	320	3.7	1155.00	1000	86.1	925

Table 2. Power Sequencing Data

Initial application of PS HV is shown in Table 2. These various steps should be observed from low voltage to high voltage to ensure that the generator is acting properly. The table shows the effects of varying the PS HV on MOSFET current, RF power, efficiency, and peak Vds. Efficiency vs. Pout is shown in Fig. 5 and peak Vds vs. PS HV is shown in Fig. 6. The efficiency is calculated using RF power output and DC input power of the power MOSFET. Efficiency remains higher than 94% up to RF power of 500W and 90% up to 800W. At RF output power of 1KW, the efficiency is reduced to approximately 86%.

Figure 6 shows that the peak drain voltage (Vds) is approximately 3 times the PS HV voltage. This is close to the ideal value of 3.5 times PS HV voltage.

Figure 7 shows that the peak Vds is 276V when the PS HV voltage is 100V. Fig 8 shows that a peak Vds of 576V is achieved with a PS HV voltage setting of 200V. Fig 9 shows that a peak Vds of 876V is achieved with a PS HV voltage setting of 300V.

6.2 Chart of data sheet

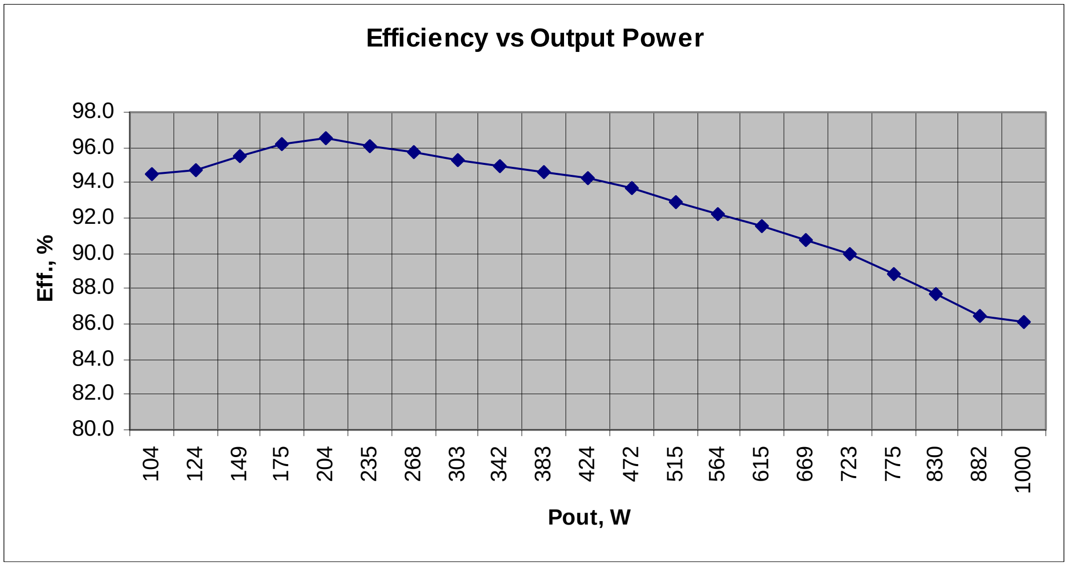


Fig. 5. Efficiency. vs Pout

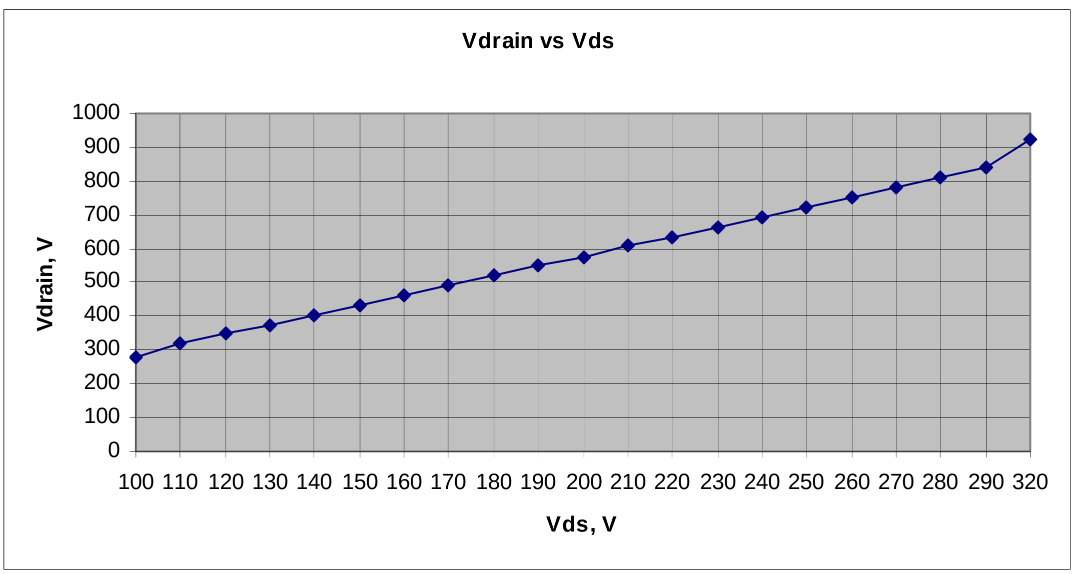


Fig. 6. Vds vs. HV

6.3 Waveform at MOSFET Drain for various settings of the HV PS

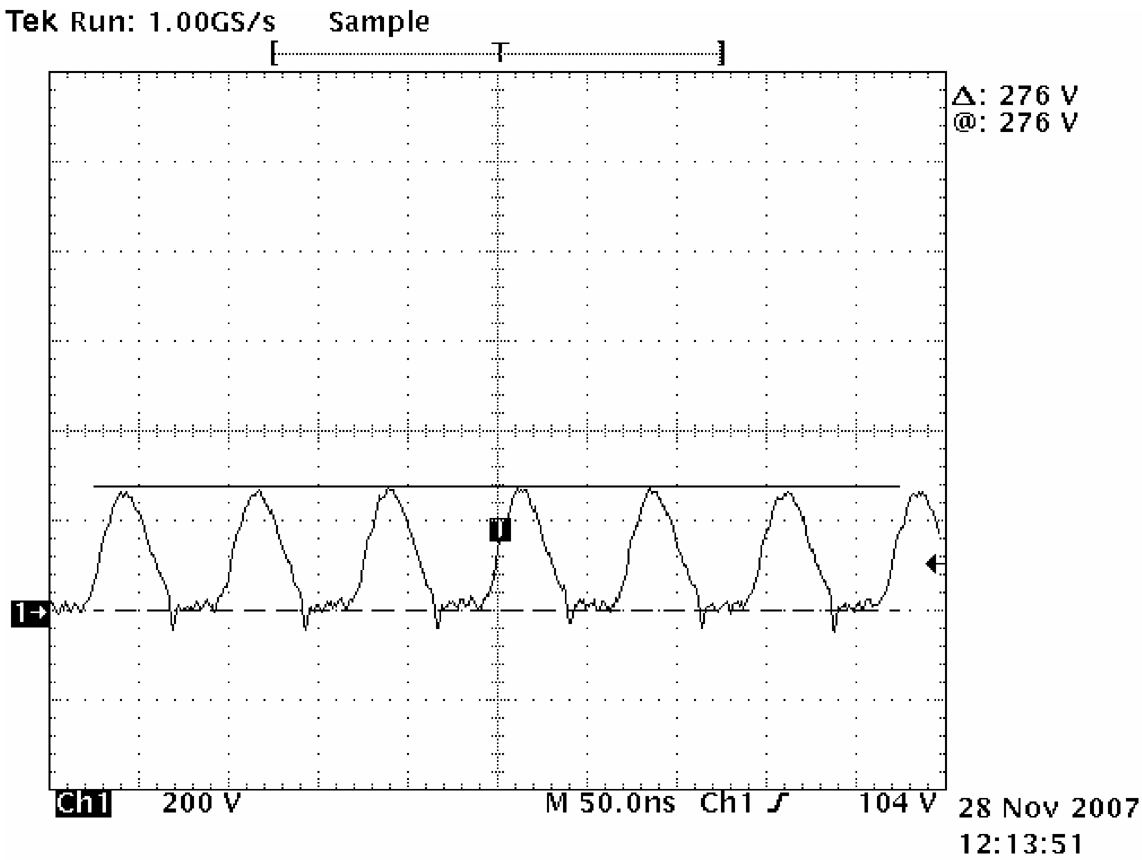


Fig. 7. Peak VDS (PS HV = 100V)

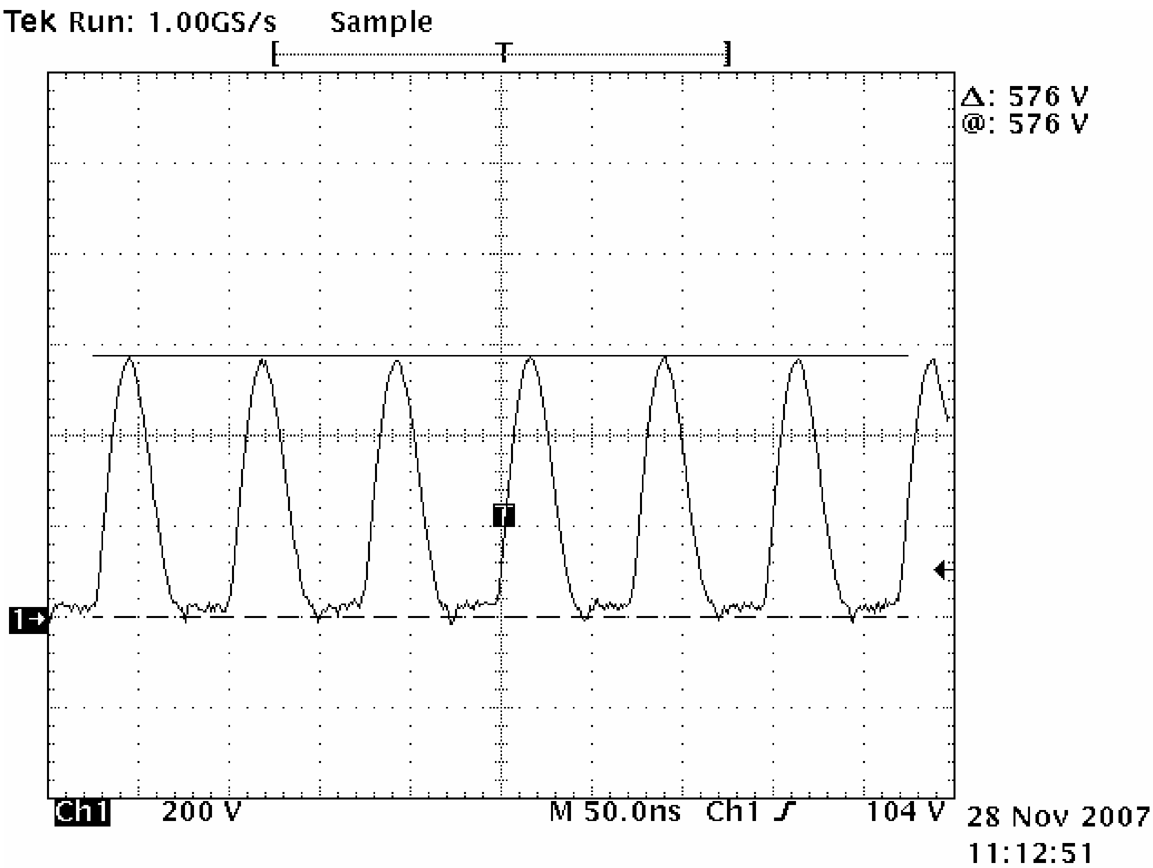


Fig. 8. Peak VDS (PS HV = 200V)

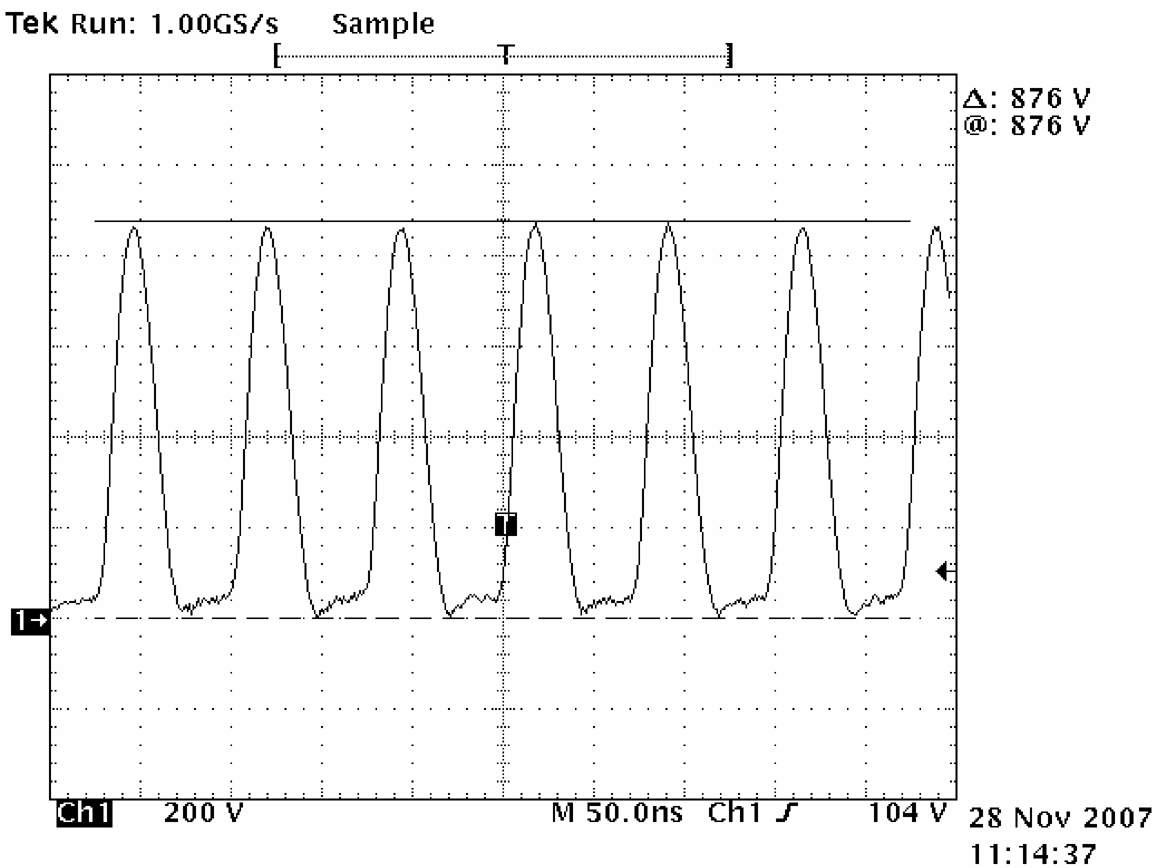


Fig. 9. Peak VDS (PS HV = 300V)

7. CONCLUSIONS

This reference design utilizes a DRF1200 as a CLASS-E RF generator. The DRF1200 Hybrid demonstrated in the preceding discussion that it can deliver both power and efficiency. The critical aspects such as the layout of components for efficient power generation, testing, and air cooling requirements were also discussed. This reference design is available as a complete and tested module from Microsemi PN=DRF1200/CLASS-E.

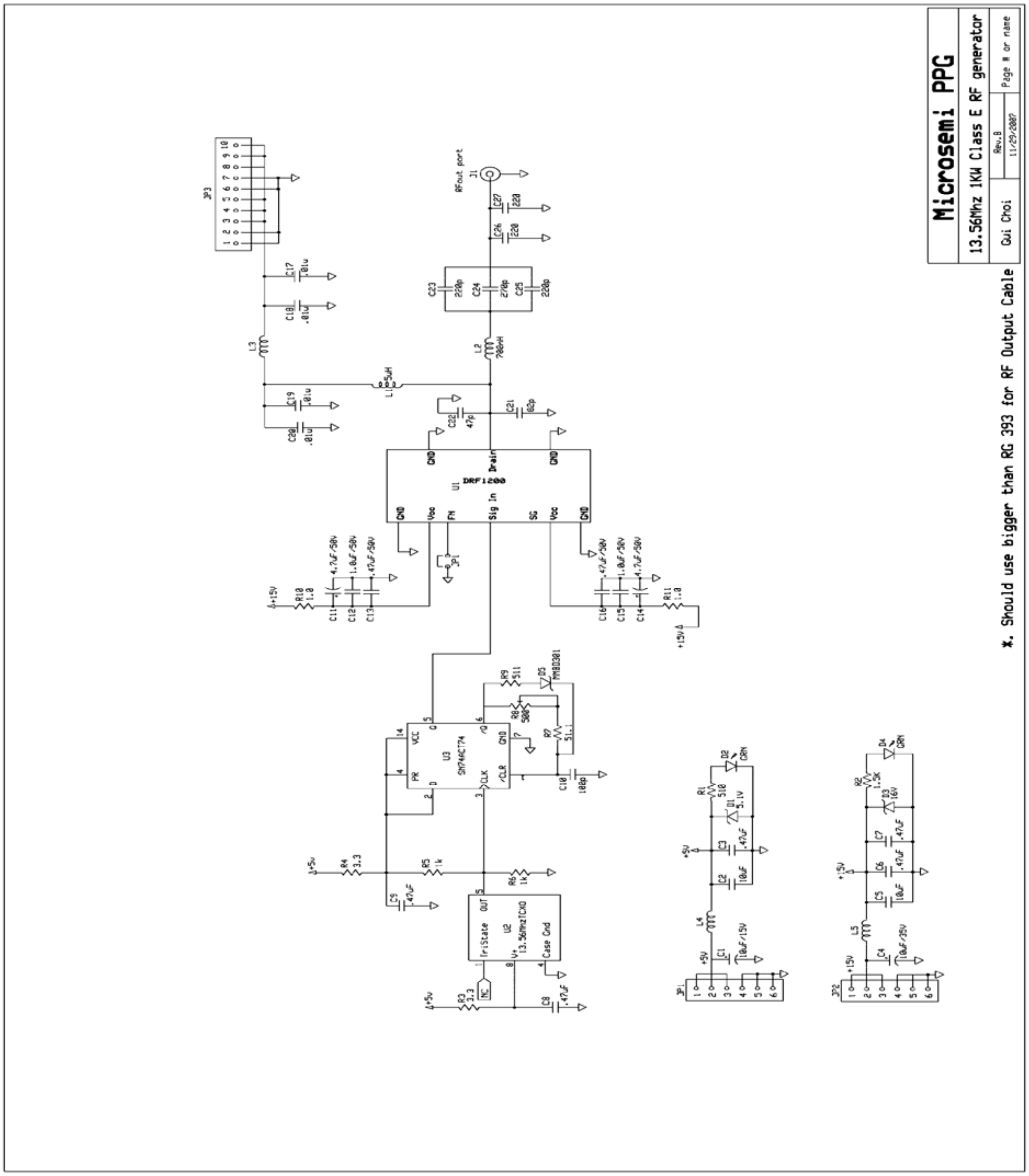
8. References

"Solid State Radio Engineering" – Herbert L. Krauss and Charles W. Bostian, (Chapter 14). John Wiley& Sons Inc. 1980 ISBN 0-471-0318-X

Application Note: Simple and Inexpensive High Efficiency Power Amp using New APT MOSFET – Kenneth Dierberger 1994

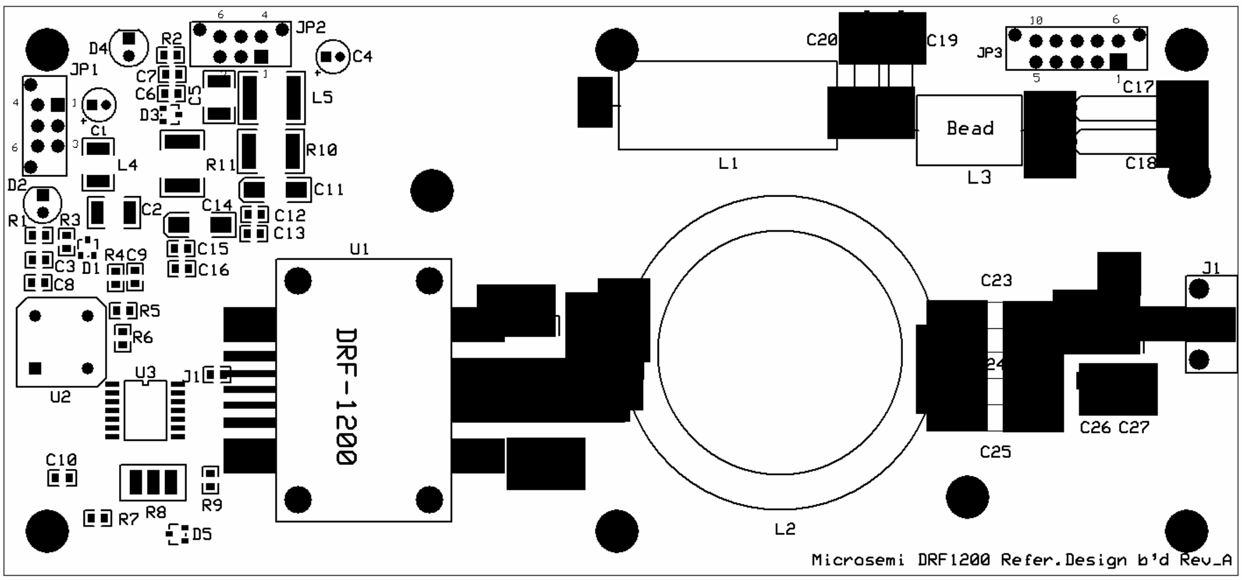
Application Note: PRF-1150 1KW 13.56MHz Class E RF Generator Evaluation Module – Matthew W. Vanis IXYSRF 2002

Appendix I. Overall Schematic



Appendix II. PCB Lay-out

PCB size: 3.25W * 7.00L in inch
PCB: FR-4, 65mil T



Appendix III. Parts List

Part ID	Description	Size	Supplier	Supplier PN	Manufacturer	Manuf. PN
U1	RF MOSFET Hybrid	T3B	Microsemi	DRF1200	Microsemi	DRF1200
C1	10uF/16V(Elec cap)	5*11	Mouser	140-XRL16V10-RC	Xicon	140-XRL16V10-RC
C2	10uF/35V(Cer. cap)	1812	Digi-key	pcc2183ct-nd		
C3	.47uF/50V(Cer. Cap)	0805	Digi-key	490-3328-1-ND		GRM21BR71H474KA88L
C4	10uF/35V(Elec cap)	5*11	Mouser	140-XRL35V10-RC	Xicon	140-XRL35V10-RC
C5	10uF/35V(Cer. cap)	1812	Digi-key	pcc2183ct-nd		
C6	.47uF/50V(Cer. Cap)	0805	Digi-key	490-3328-1-ND		GRM21BR71H474KA88L
C7	.47uF/50V(Cer. Cap)	0805	Digi-key	490-3328-1-ND		GRM21BR71H474KA88L
C8	.47uF/50V(Cer. Cap)	0805	Digi-key	490-3328-1-ND		GRM21BR71H474KA88L
C9	.47uF/50V(Cer. Cap)	0805	Digi-key	490-3328-1-ND		GRM21BR71H474KA88L
C10	100pF/50V(Cer. Cap)	0805	Digi-key	PCC101CGCT-ND		
C11	4.7uF/35V(Tant cap)	6032-28	Digi-key	478-1717-1-ND	AvX	TAJC475K035R
C12	1.0uF/50V(Cer. Cap)	0805	Digi-key	587-1438-1-ND	Taiyo Yuden	GMK212BJ105KG-T
C13	.47uF/50V(Cer. Cap)	0805	Digi-key	490-3328-1-ND		GRM21BR71H474KA88L
C14	4.7uF/35V(Tant cap)	6032-28	Digi-key	478-1717-1-ND	AvX	TAJC475K035R
C15	1.0uF/50V(Cer. Cap)	0805	Digi-key	587-1438-1-ND	Taiyo Yuden	GMK212BJ105KG-T
C16	.47uF/50V(Cer. Cap)	0805	Digi-key	490-3328-1-ND		GRM21BR71H474KA88L
C17	0.01uF/1KV	Cer. Disc	Allied Elec.	507-0721	Vishay	562R5GAS10
C18	0.01uF/1KV	Cer. Disc	Allied Elec.	507-0721	Vishay	562R5GAS10
C19	0.01uF/1KV	Cer. Disc	Allied Elec.	507-0721	Vishay	562R5GAS10
C20	0.01uF/1KV	Cer. Disc	Allied Elec.	507-0721	Vishay	562R5GAS10
C21	47PF/2500V	3838	ATC	700C470JW2500X	ATC	700C470JW2500X
C22	82PF/2500V	3838	ATC	700C820JW2500X	ATC	700C820JW2500X
C23	220PF/3600V	3838	ATC	100E221KW3600X	ATC	100E221KW36ooX
C24	270PF/3600V	3838	ATC	100E271KW3600X	ATC	100E271KW36ooX
C25	220PF/3600V	3838	ATC	100E221KW3600X	ATC	100E221KW36ooX
C26	220PF/3600V	3838	ATC	100E221KW3600X	ATC	100E221KW36ooX
C27	220PF/3600V	3838	ATC	100E221KW3600X	ATC	100E221KW36ooX
R1	51Oohm/1/8W	0805	Digi-key	P510ATR-ND	Panasonic	ERJ-6GEYJ511V
R2	1.5Kohm 1/8W 5%	0805	Digi-key	P1.5KACT-ND	Panasonic	ERJ-6GEYJ152V
R3	3.3ohm 1/8W 5%	0805	Digi-key	P3.3ACT-ND	Panasonic	ERJ-6GEYJ3R3V
R4	3.3ohm 1/8W 5%	0805	Digi-key	P3.3ACT-ND	Panasonic	ERJ-6GEYJ3R3V
R5	1.0K ohm 1/8W 1%	0805	Digi-key	P1.00KCCT-ND	Panasonic	ERJ-ENF1001V
R6	1.0K ohm 1/8W 1%	0805	Digi-key	P1.00KCCT-ND	Panasonic	ERJ-ENF1001V
R7	51.1ohm 1/8W 1%	0805	Digi-key	P51.1CCT-ND	Panasonic	ERJ-6ENF51R1V
R8	POT 500ohm 1W	3/8" sq	Digi-key	3292W-501-ND	Bourns	SM:3269W-1 501
R9	511ohm 1/8W 1%	0805	Digi-key	P511CCT-ND	Panasonic	ERJ-6ENF5110V
R10	1ohm 1/2W 5%	Axial	Digi-key	P1.0BBCT-ND	Panasonic	ERD-S1TJ1R0V
R11	1ohm 1/2W 5%	Axial	Digi-key	P1.0BBCT-ND	Panasonic	ERD-S1TJ1R0V
D1	5.1V(Diode Zener)	SOT23	Digi-key	BZX84C5V1-LT1GOSCT-	On Semi.	BZX84C5V1-7-F
D2	LED, green	5mm	Digi-key	P375-ND	Panasonic	LN31GPH
D3	16V (Diode Zener)	SOT23	Digi-key	BZX84C16-FDICT-ND	Diodes	BZX84C16-7-F
D4	LED, green	5mm	Digi-key	P375-ND	Panasonic	LN31GPH
D5	30V/300mA(Sch.)	SOT23	Digi-key	MMBD301LT1GOSCT-ND	On Semi.	MMBD301LT1G
Jumper1	0 ohm 1/8W 5%	0805	Digi-key	P0.0ACR-ND	Panasonic	ERJ-6GEY0R00V
J1	RFout port		Newark	12M4398	Bomar	161V504E
JP1	6 pin DC connector		Digikey	A33221-ND	Tyco	3-794630-6
JP2	6 pin DC connector		Digikey	A33221-ND	Molex	3-794630-6
JP3	10 pin DC connector		Arrow	0430451027	Molex	0430451027
L1	Inductor w/ 28T AWG18	ID:.5"	Newark	05H7486	MCM	18PE 1/4LB
L2	Toroid Inductor 5T 12AWG		Micrometals Alpha	T225-6 5 289 SV001	Micrometals Alpha	T225-6 5 289 SV001
L3	Toroid Inductor 2T 18AWG		Allied Elec. Digikey	2643540302 A5857R-100-ND	Fair-Rite Alpha	2643540302 5857 RD005
L4	Toroid RFC 1T AWG22		Allied Elec. Digikey	2643001301 A2016R-100-ND	Fair-Rite Alpha	2643001301 3051RD005
L5	Toroid RFC 1T AWG20		Allied Elec. Digikey	2643000801 A2040R-100-ND	Fair-Rite Alpha	2643000801 3053RD005
U2	13.56 MHz Osc	Half	Allied Elec.	EP1100HSTSC-13.56M	Ecliptek Co.	EP1100HSTSC-13.560M
U3	Dual Flip-Flop IC	14SOP	Digi-key	296-13131-1-ND	TI	SN74ACT74NSR

Appendix IV. Outline drawing of Heatsink