Application Note

13.56 MHz, Class D Push-Pull, 1.7KW RF Generator with Microsemi DRF1300 Power MOSFET Hybrid

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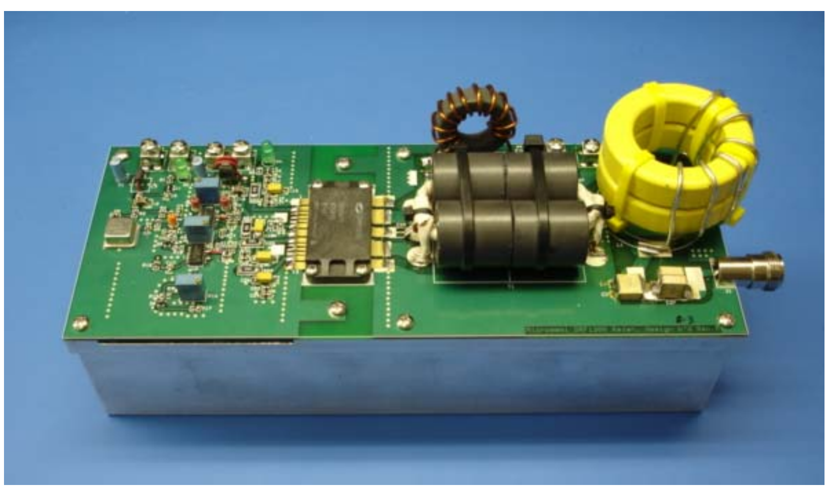
The DRF1300/CLASS-D Reference design is available to expedite the evaluation of the DRF1300 push-pull MOSFET hybrid. This application note or the reference design does not represent a finished commercial-ready design. It is only an engineering tool to demonstrate the capability of the DRF1300 under 50 Ohm, flat line conditions. Each reference design has been verified to perform to the specifications of the application note. The application note contains a parts list, board layout and schematic that enables the user to facilitate any repairs resulting beyond its intended use. By purchasing this reference design the user takes full responsibility for repair and any modifications. No warranties, repairs or returns will be accepted.



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1. INTRODUCTION

This application note contains the design procedures and measurement results for a 1.7KW 13.56MHz RF generator using a CLASS D Push-Pull amplifier. To optimize efficiency and minimize cost the design uses a DRF1300 Power MOSFET Hybrid from Microsemi. The DRF1300 consists of two high power gate drivers, two 500V 30A MOSFETs, and several internal bypass capacitors. The internal layout of the T4 hybrid package has been optimized to minimize stray inductances allowing the DRF1300 to operate at frequencies of over 30MHz.

To support this application note the DRF1300/CLASS-D reference design is available from Microsemi. It allows designers to readily verify the principals of this application note and save weeks or even months of design work. It illustrates the high efficiency operation and critical PCB signal-ground layout required to minimize output/input noise interference. The reference design comes complete and is mounted to an aluminum heat sink. The user only needs to provide is power supplies, cooling fans and a load.

2. DESIGN CONSIDERATIONS

To design the high-efficiency high-power RF generator the following issues were addressed.

a. Choice of design complexity and efficiency trade offs.

b. Selection of an adequate output matching circuit using a matching tool, to achieve the wanted power, drain waveform and efficiency.

c. Selecting parts capable of handling RF output of 1.7KW including by-pass capacitors in the DC circuit, design and construction of a wide-bandwidth, high-current toroidal inductor and transformer, and sufficient capacitors for output matching circuit.

d. The design of a heat sink for the amount of power dissipated.

e. The design of the printed wiring board for a good ground, especially for the output matching circuit.

f. Isolation techniques between power output and signal generation circuit

The table below is for the major specification of this RF Power Generator.

Freq	Output Power	Voltage	Current	Efficiency
13.56Mhz	1.7KW	250V	9.2A	85%

Table 1. Key Specification

3. THEORY OF OPERATION

A Class D push-pull amp requires control circuitry, a pair of MOSFET switches, a transformer for combining two outputs that are 180° out of phase, and an output matching network for tuning/creating a sinusoidal output signal. Class D operation theoretically can provide 100% efficiency, but because of the MOSFET on resistance, switching cross over transients, and magnetic loses, applications with approximately 85% efficiency is more achievable.

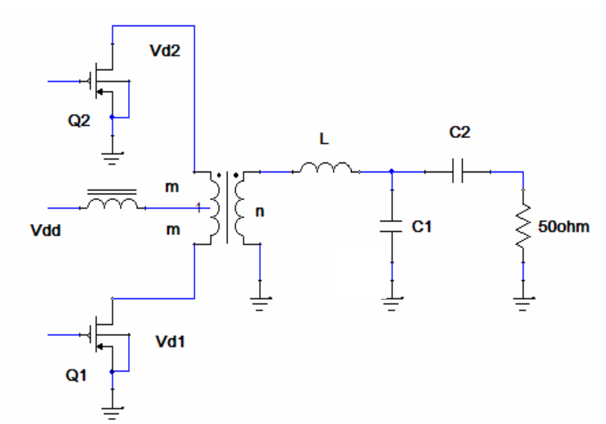

Fig. 1 Simplified Push-Pull Circuit

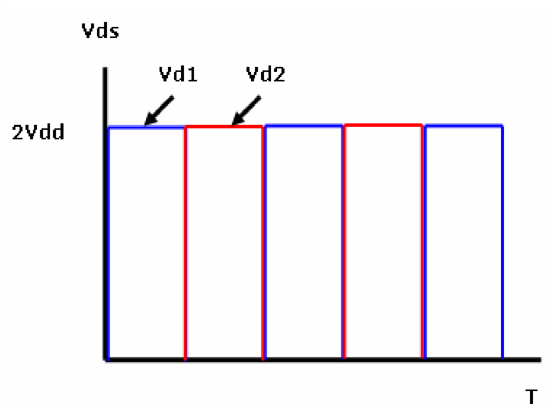

Fig. 2 Waveforms at drains

Fig. 1 shows a simplified CLASS D push-pull circuit. The two input signals are 180° out of phase causing Q1 and Q2 to switch ON and OFF alternately. The turn ratio of Transformer (n/m) is 2/1 for this application. For an ideal switch, when Q1 is ON, its drain voltage Vd1 is zero and the Vdd on the center tap of the primary of transformer, is transformed to (2/1) Vdd on the secondary. Alternately, when Q2 is ON, the reverse polarity of (2/1) Vdd appears on the secondary. The ideal waveforms are shown in Fig.2. A key technical difficulty for this push pull RF application is the transformer. The high current, high frequency and high voltage require careful design considerations. The inductor (L) and capacitors (C1 and C2) form a tank circuit to form a sinusoidal RF signal into the 50 Ohm load.

4. CIRCUIT DESCRIPTION

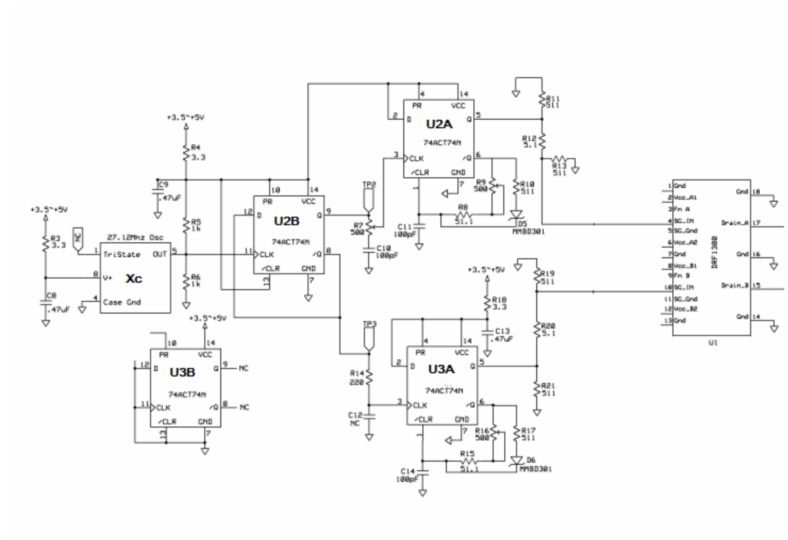

Fig. 3 Pulse Generation Circuit

a. Pulse Generation

The Pulse generation circuit operates from a 3.0VDC~5.5VDC supply. The 27.12MHz TCXO is divided down to 13.56MHz and split into two 180 out of phase signals by U2B. U2A and U3A allow pulse width adjustment of the two signal inputs to the DRF1300. The pulse width of each signal can be adjusted from 15nS to 35nS using Potentiometer R9 and R16 respectively. To minimize a conductive EMI, it is crucial to observe proper circuit layout with good ground conditions along signal lines, taking care to isolate them from the output switching noise. Fig. 4 shows waveforms of outputs of pulse generation circuit at pin 4 and pin 10 of U1.

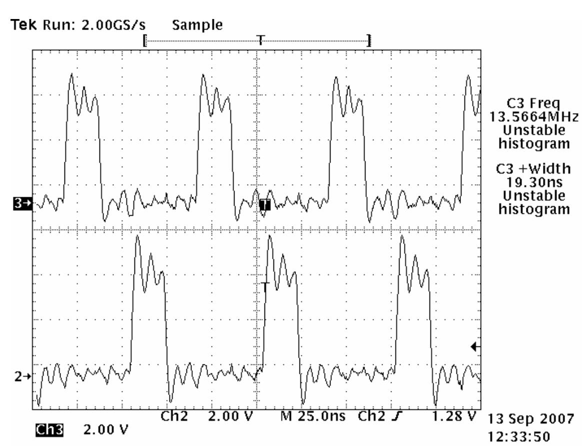

Fig. 4. Waveforms into DRF1300

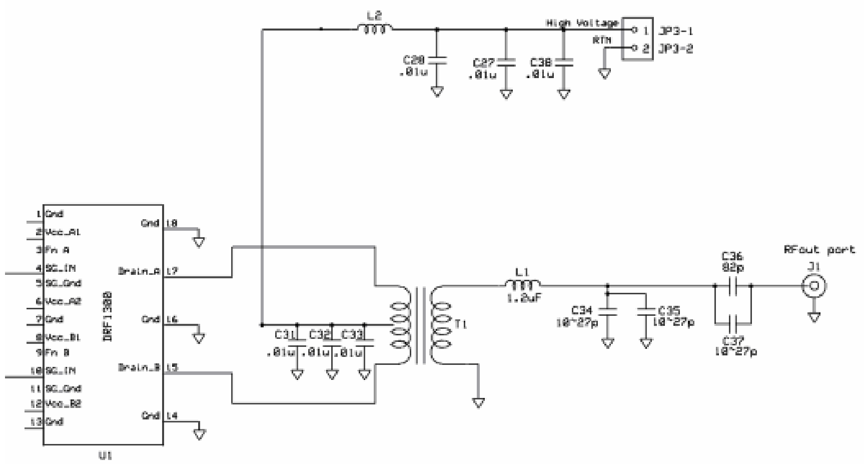

Fig. 5 RF Output Matching and DC Supply Circuit

b. RF Output Matching

The output matching circuit was calculated by means of RF matching software tool (Smith Chart) to maximize power transfer to a 50 Ohm load at J1. The matching circuit consists of a custom built transformer (T1), shunt/series capacitors (C34 through C37) and a custom built series inductor (L1). The capacitors and inductor form a tank circuit that is used for matching and tuning. It is critical that the output stage consists of inductors, capacitors, wires, toroids and ferrite cores that can handle the high currents and voltages associated with a 1.7KW RF Generator.

Transformers T1 for this type of application are not commercially available. The design of the transformer used in the DRF1300/CLASS-D took several iterations to overcome bandwidth and power issues. The low cutoff frequency was overcome by selection of a specialized core. Minimizing the transformer turn ratio to 1:2 or 1:3 was required to avoid power loss. Refer to the following equations.

$Po=(8/\Pi^2)*(Veff^2/2R)$ for Class D Push-Pull

For the Drain load line $R=(m/n)^2*Ro$
m = number of primary turns and n = number of secondary turns

Ro=Output load
In this app note, Ro = 50Ω, m=1, n=2 therefore R=12.5Ω

The transformer design is comprised of four (material 61) ferrite cores and was wound with double enameled wire. It is highly recommendation to use AWG16 wire for both the primary and secondary winding of the transformer and then apply glass electrical tape, such as 3M 27, before winding on the core. The tape will provide added protection against voltage breakdown and arcing and avoid any interference between the twisted wire bundles.

Fig. 6 shows plots for output matching which consists of transformer and "L" match of Toroidal Inductor and Capacitors in series and Capacitors in shunt to ground.

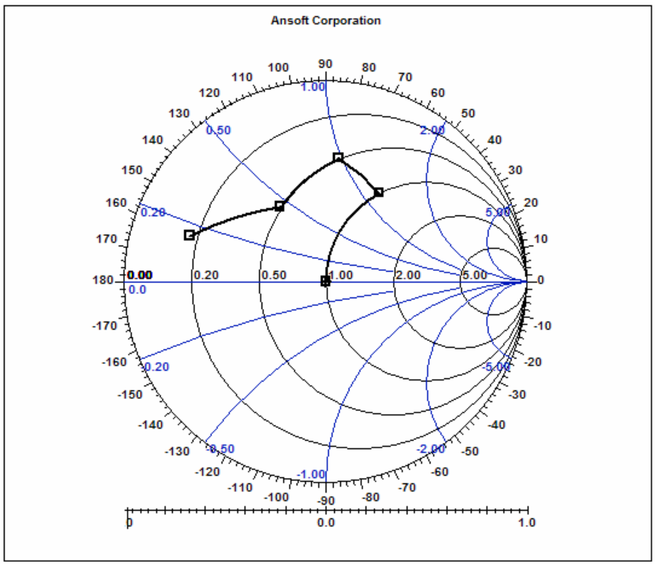

Fig. 6 Plots for Output matching

c. DC Supply

The high voltage DC supply (PS HV JP3) circuit employs a RF choke coil (L2) and bypass capacitors (C27, C28 and C38) to minimize an interference with AC signal. Refer to Fig 5. The RFC of this coil L2 was designed for approximately 1K ohm at 13.56MHz with 11 turns AWG 14 enameled wire. The by-pass capacitors should be selected for a 2KV voltage rating. It is very crucial that the capacitors (C31 through C33) be located as close as possible to the center tap of the primary winding of power transformer T1 have a good RF ground. Fig 7 illustrates the capacitor location to T1 and the red circles indicate ground connections through a via to the bottom ground plane.

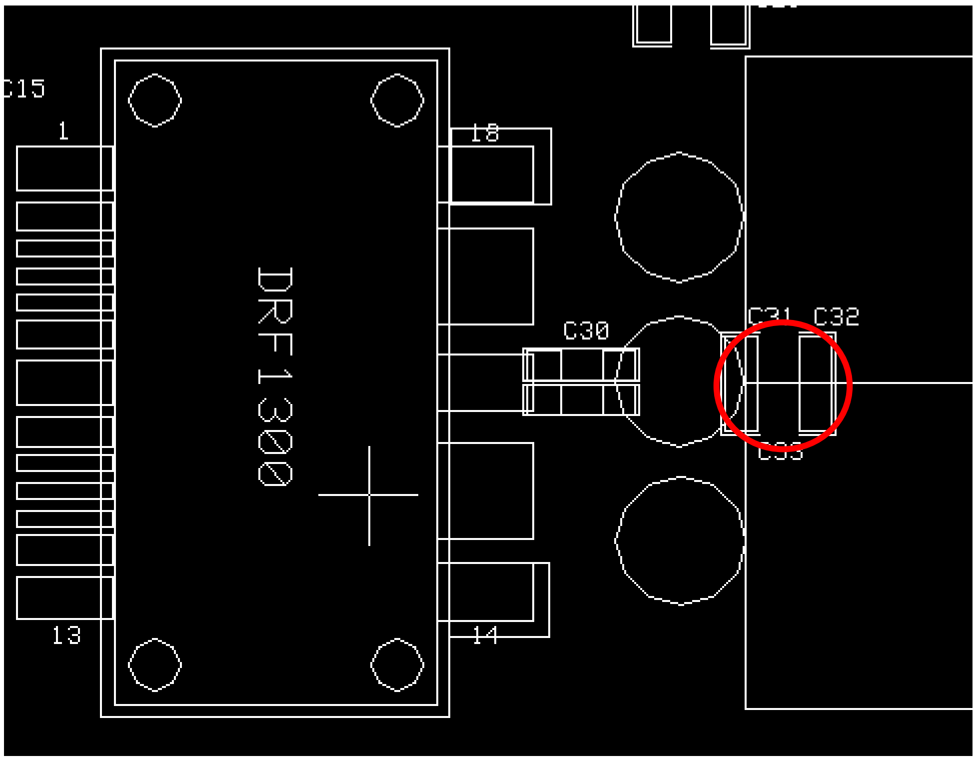

Fig. 7 Location of Capacitors for DC circuit

5. TEST REQUIREMENT.

a. Test Set-Up Diagram.

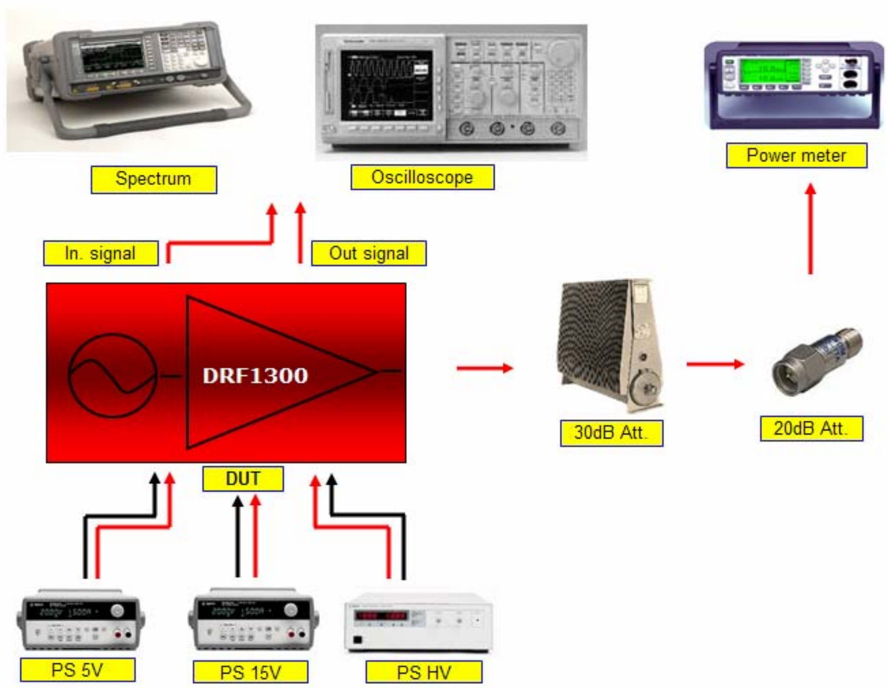

Fig. 8 Test Set-Up diagram

b. Test requirement

- Air cooling requirement: Testing should be performed using a minimum of two 150 CFM (5 inches) fans directed towards the bottom of the heat sink with a least 2.5in of clearance (so as not to impede air flow) from the bench floor. It is recommended that an additional fan be directed onto the transformer (150CFM, 5 inch fan) to provide cooling for the magnetics that will extend allowable test time.

- Process for Turn-On/Off Power Supplies
  - i. Turn on Driver PS 15V (JP2) and set 11V~15V based on circuit requirement
  - ii. Then, turn on MOSFET PS HV (JP3) and slowly set to 40V
  - iii. Then, turn on pulse generator PS 5V (JP1) and set to 3~5V based on circuit requirement.
  - iv. While monitoring the RF power and waveform from Drain, ramp up PS HV in steps, verifying the outputs are stable before proceeding to the next step.
  - v. To turn off reverse the turn on procedure.

If the RF output waveform (Vds) and/or RF power level fluctuates, immediate shut down of MOSFET PS and determine fault before resuming test.

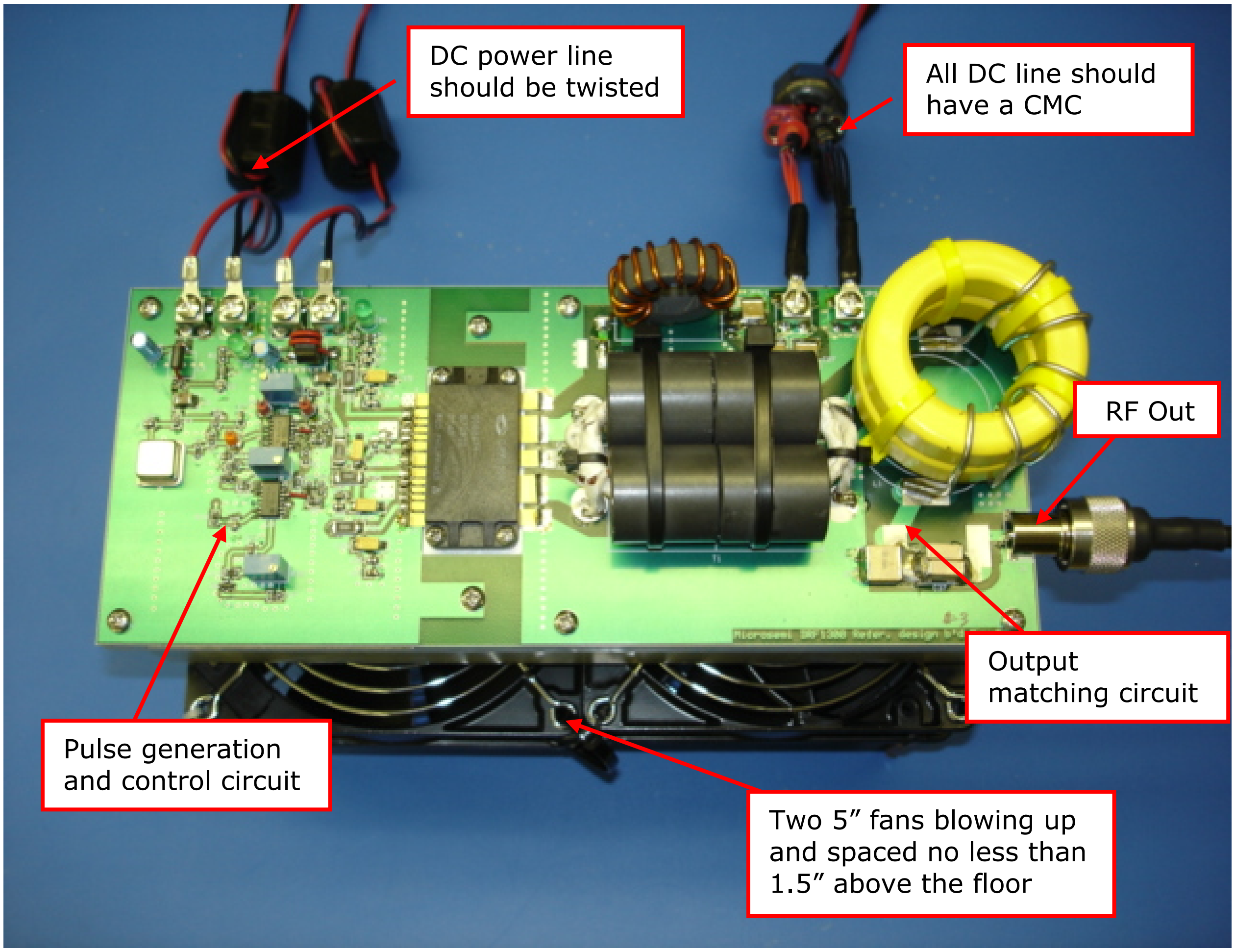

Fig. 9 Bench Test Set-up for DRF1300

6. PERFORMANCE

Step	PS HV, V	Id, A	Pin, W	RF out, W	η, %	Vds, V
1	100	4.31	431	344	79.8	200
2	120	4.91	589	486	82.5	232
3	140	5.54	776	653	84.2	270
4	160	6.18	989	842	85.2	310
5	170	6.48	1,102	939	85.2	340
6	180	6.79	1,222	1044	85.4	360
7	190	7.11	1,351	1152	85.3	370
8	200	7.43	1,486	1270	85.5	390
9	210	7.75	1,628	1400	86.0	420
10	220	8.00	1,760	1500	85.2	430
11	230	8.36	1,923	1630	84.8	480
12	240	8.67	2,081	1770	85.1	506
13	250	9.18	2,295	1950	85.0	535

Table 2. Typical Performance Data

Table 2 shows the typical performance and the several steps that should be observed before proceeding to the next step and ultimately to over 1.7KW. The table list the input high voltage supply (PS HV), MOSFET drain current (Id), power in and power out with efficiency, and the voltage observed at MOSFET drain (Vds). Variation of efficiency vs. Pout is shown in Fig. 10 and PS HV vs. Vds is shown in Fig. 11. Efficiency is calculated using RF power output and DC input power of the power MOSFET. The efficiency in the table is at 13.56Mhz.

It should be noted that Vds exceeded the maximum BVdss (500V) of the MOSFETs in steps 12 and 13. The excess voltage required to achieve greater than 1.7KW output power resulted from transformer leakage inductance and lack of the broadband transfer characteristics of the wire-coupled transformer. A 2KW power output can be achieved with a Vds less than 500V by further tuning and optimization of the transformer.

a. Power and voltage graphs

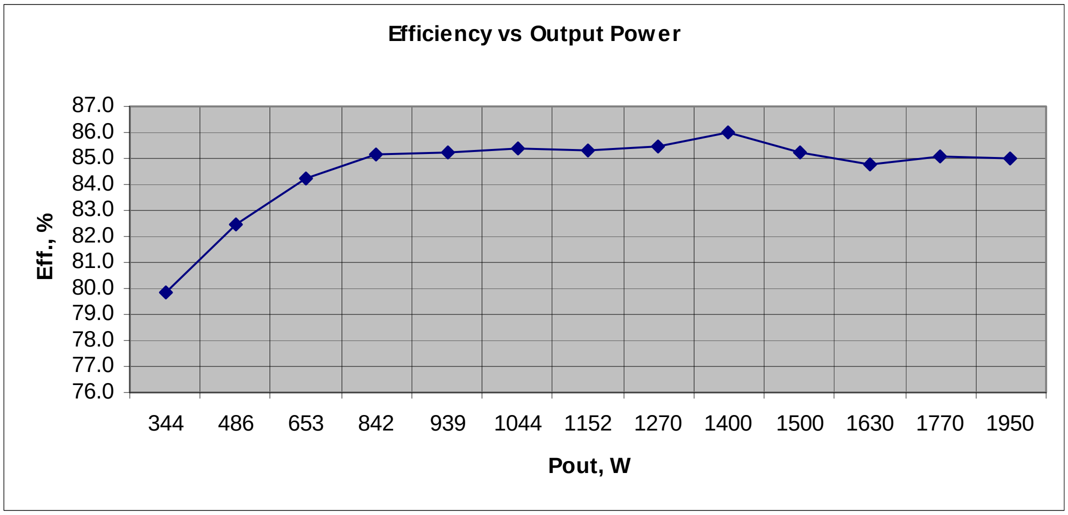

Fig. 10 Efficiency vs. Power

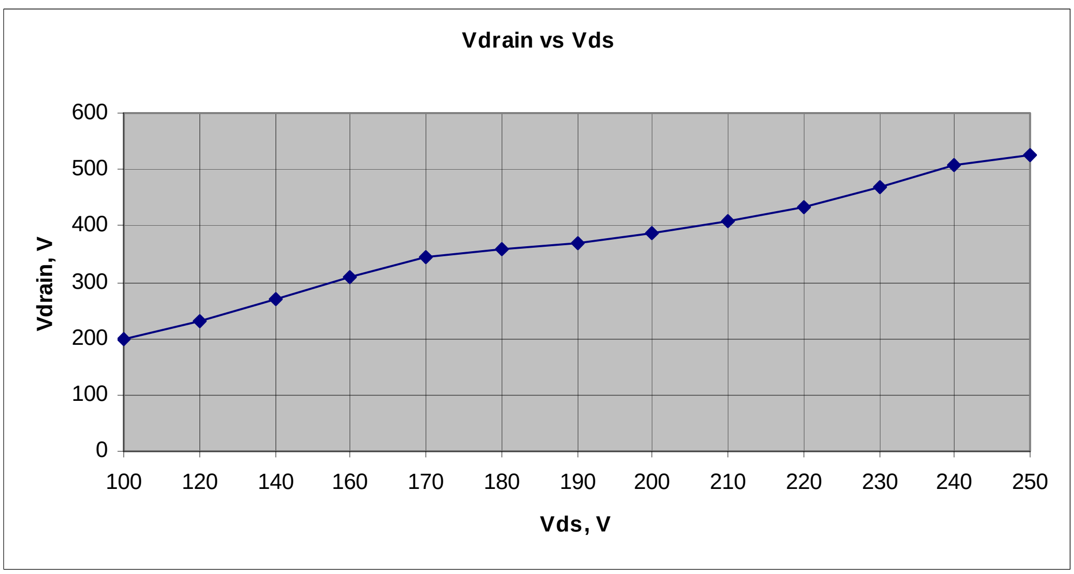

Fig. 11 HV PS vs. Vds

b. **Vds waveforms for various HV PS voltages**

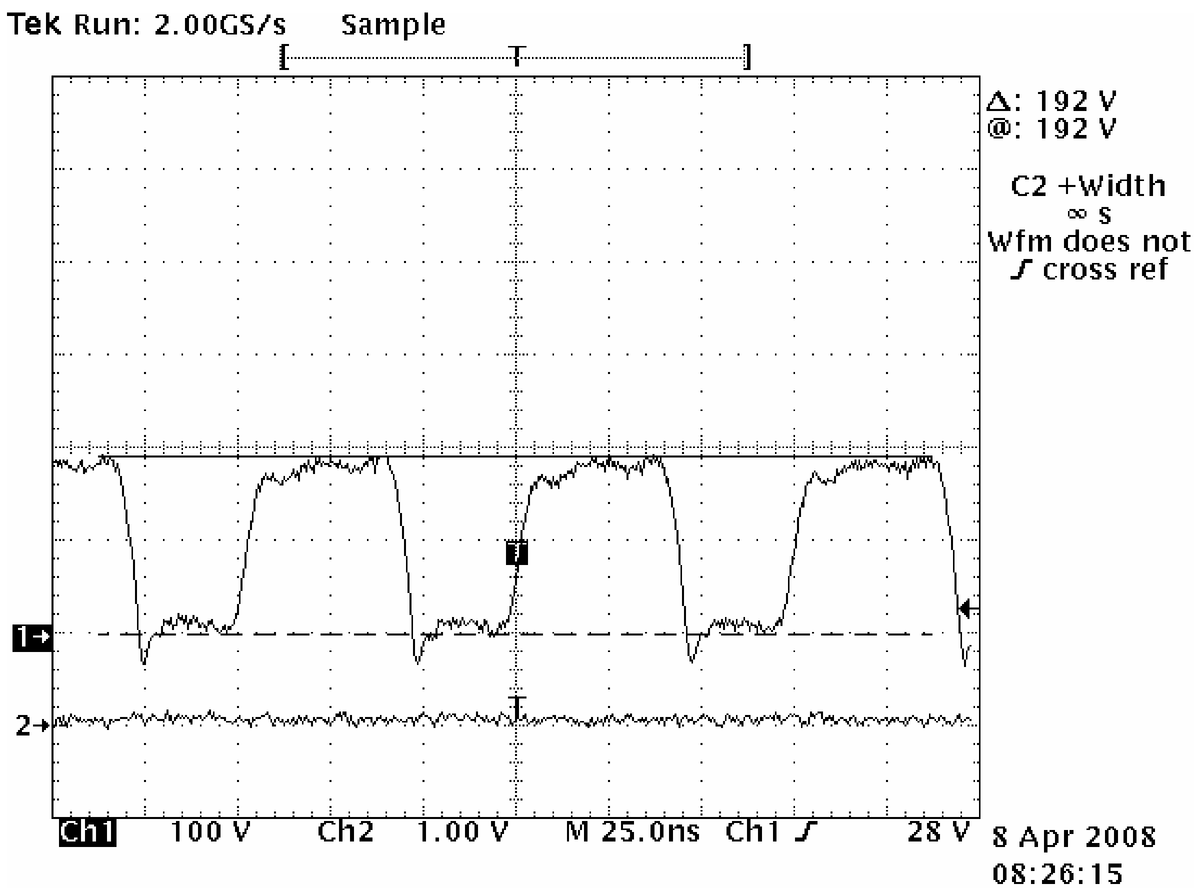

Fig. 12 Waveform when HV PS =100V

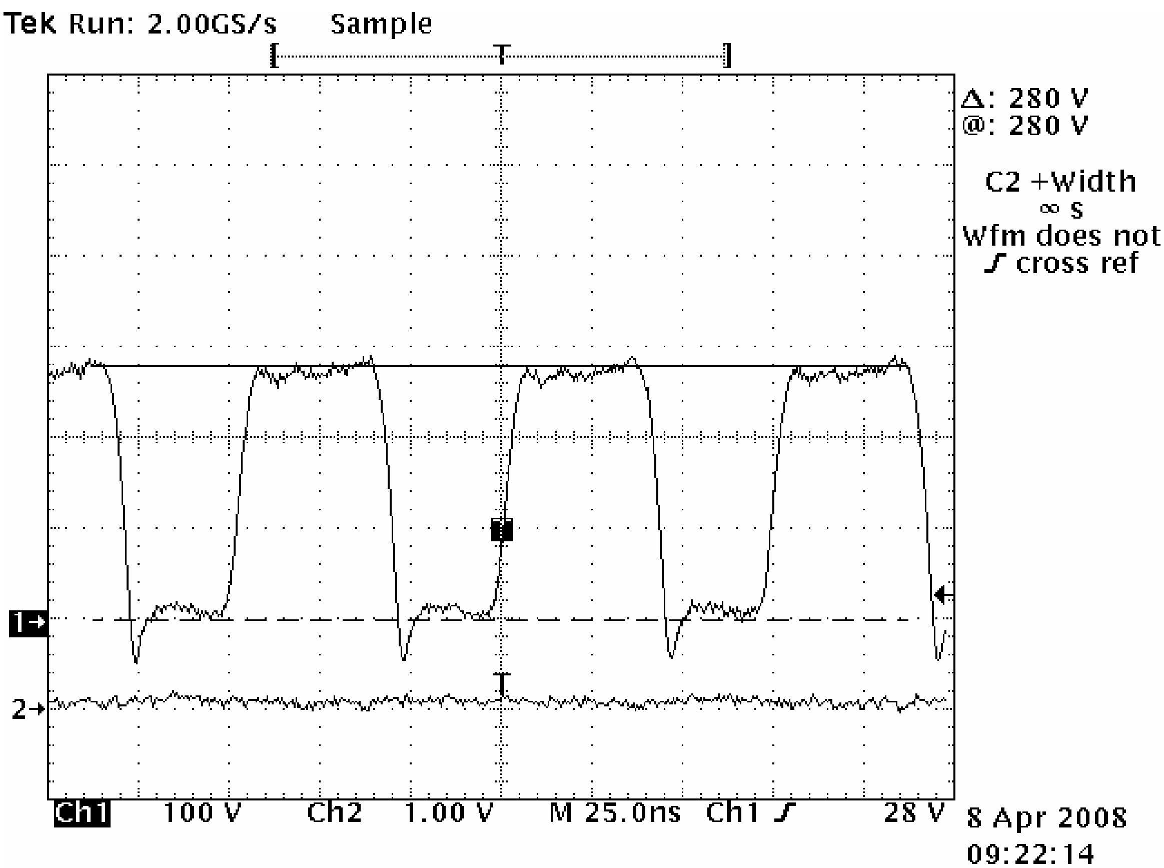

Fig. 13 Waveform when HV PS = 150V

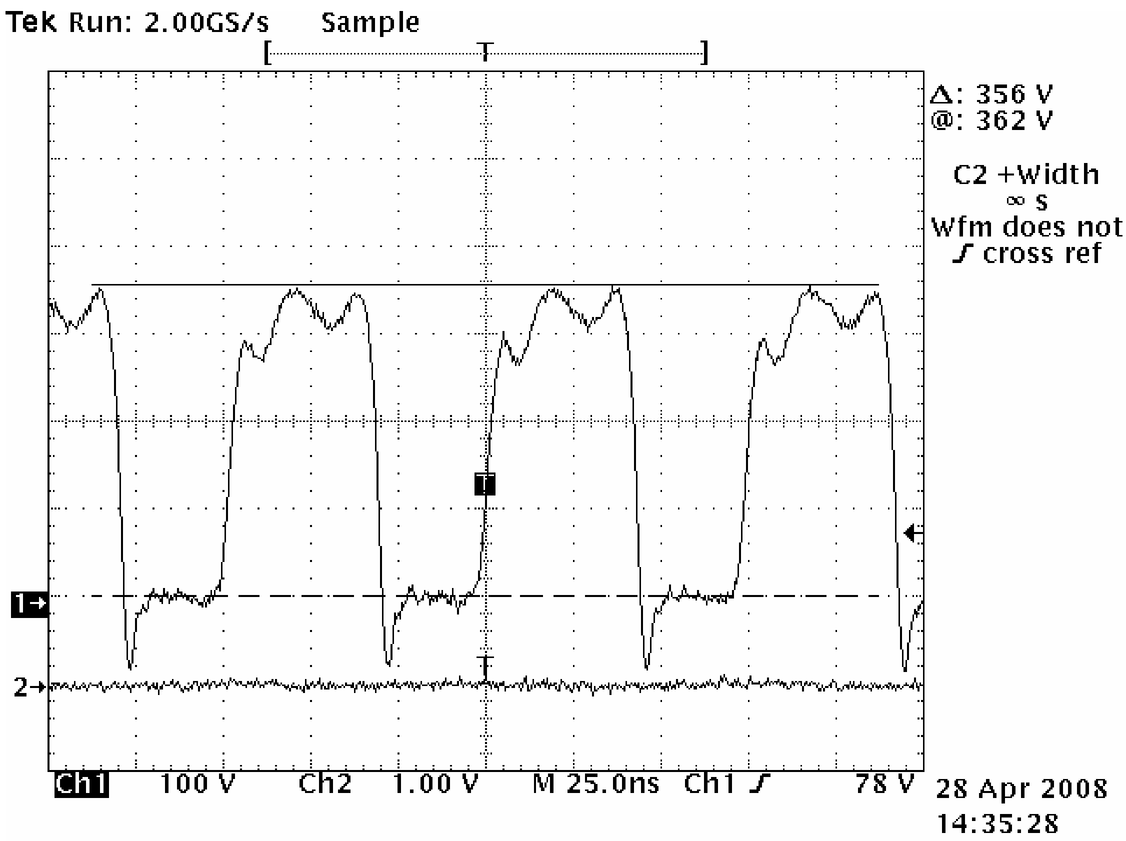

Fig. 14 Waveform when HV PS = 180V

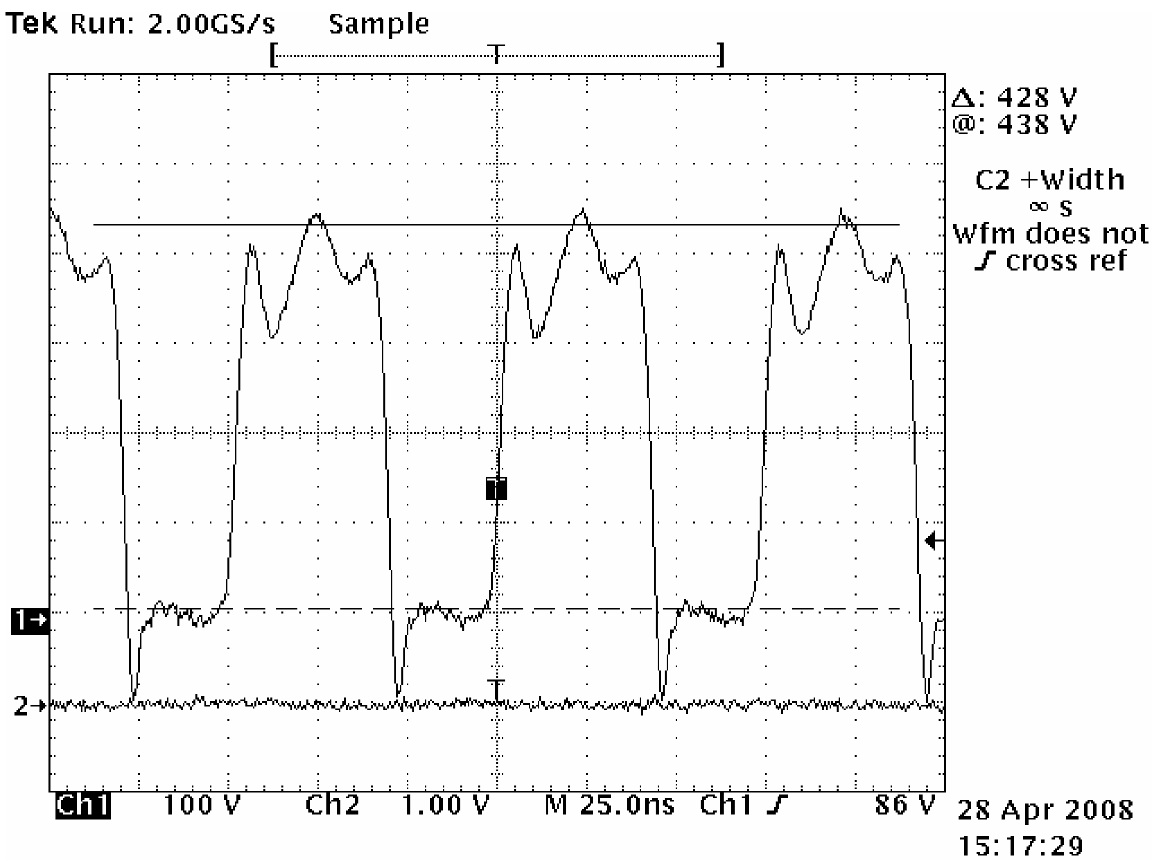

Fig. 15 Waveform when HV PS =220V

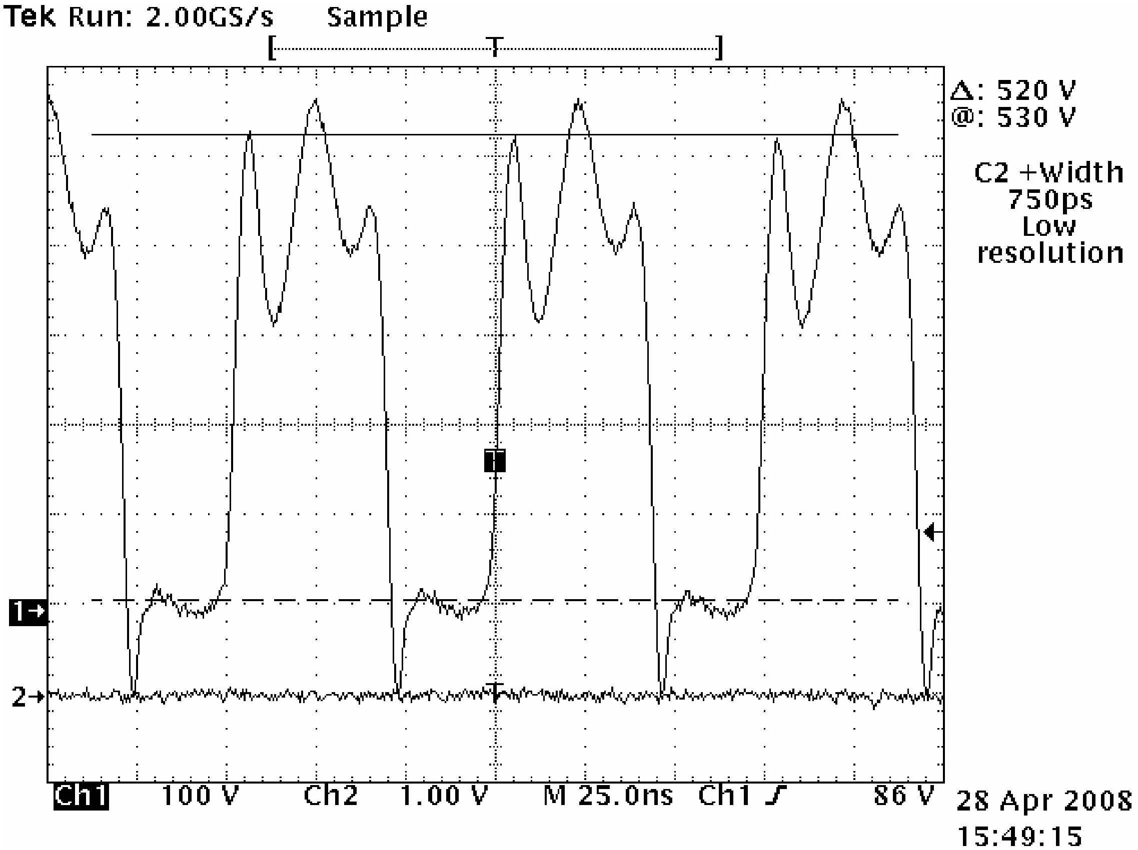

Fig. 16 Waveform when HV PS =250V

7. CONCLUSION

This Application Note describes design of a 1.7KW, 13.56MHz, Class D Push-Pull, RF generator. A Microsemi DRF1300 Hybrid was used to overcome layout parasitics that simplified the design and providing a single low cost, high efficiency RF generator. Limitations in transformer bandwidth caused this application to exceed the 500V breakdown voltage of the MOSFETs while achieving greater than 1.7KW. Transformer design can be further optimized to eliminate the peaking as shown in the Vds waveforms. The principles of this application note can be verified with the DRF1300/CLASS-D reference design from Microsemi. The reference design minimizes design time by allowing an engineer to evaluate the performance into a 50 Ohm load and provides a platform for more complex load matching.

8. REFERENCES

-. Solid State Radio Engineering – Herbert L. Krauss and Charles W. Bostian

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

-. Application Note: 3KW and 5KW Half-Bridge Class-D RF Generator at 13.56Mhz with 89% Efficiency and Limited frequency Agility – DEI, Inc