27.12 MHz, CLASS-E, 600W RF Generator using a Microsemi DRF1200 Driver/MOSFET Hybrid

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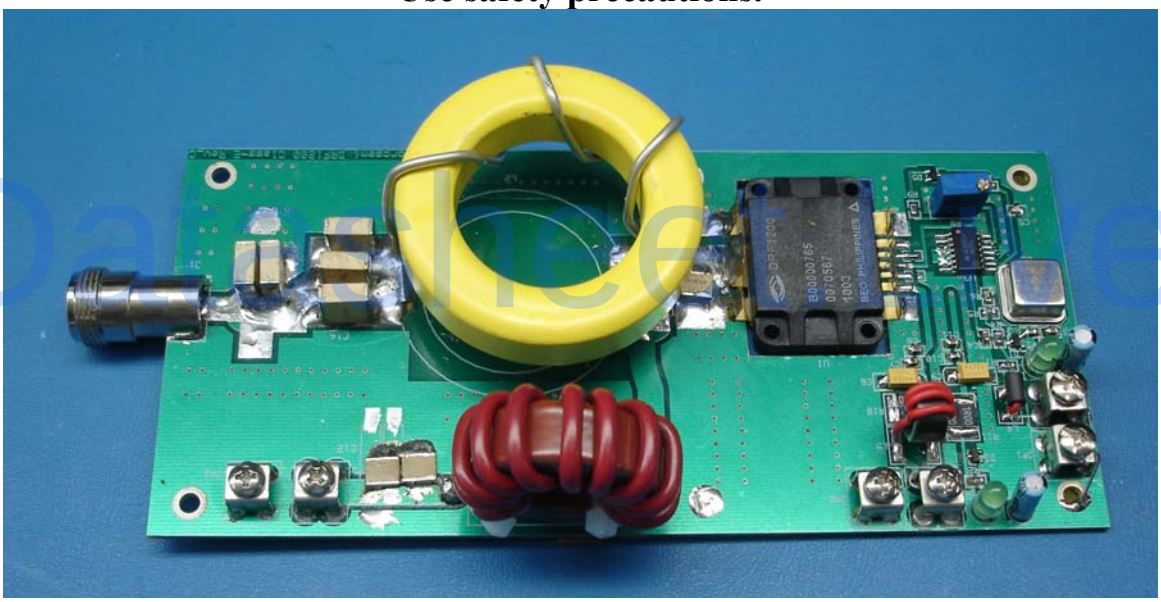
The DRF1200/Class-E 27M Reference design is available to expedite the evaluation of the DRF1200 Driver MOSFET hybrid. This Application Note or Reference Design Kit does not represent a finished commercial-ready design. It is only a teaching tool to demonstrate the capability of the DRF1200 under 50 Ohm, flat line condition. Each reference design kit has been verified to perform to the specifications of the application note. By purchasing the reference design kit the user takes full responsibility for repair and any modification. No warranties, repair and returns will be accepted.

The reference design kit contains lethal voltages and high power RF. Use safety precautions.



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INTRODUCTION

This application note discusses the design procedures and test results for a 27.12MHz, 600W, Class-E generator ideal for ISM applications. To achieve high efficiency and low cost, a Microsemi DRF1200 Driver/MOSFET was selected. The DRF1200 can generate over 600W 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 was designed to optimize reliability, provide increased flexibility while still providing a low cost solution. A reference design board (DRF1200/CLASS-E 27M) is available for purchase to facilitate the immediate evaluation of the principles of this application note.

To optimize efficiency performance, a CLASS-E RF generator was chosen. 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.

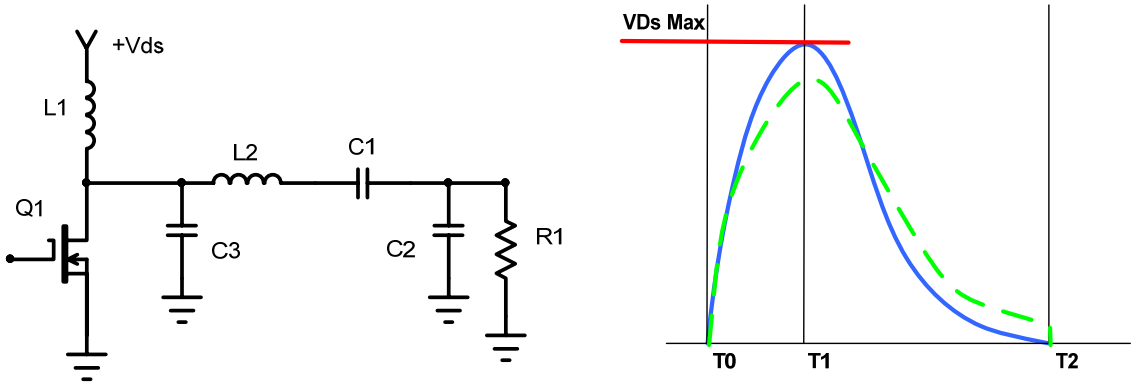

Figure 1. Simplified Class-E circuit and waveform

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 is used in this application and for the purpose of this discussion.

DESIGN CONSIDERATIONS

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

a. Class-E operation for high-efficiency.
b. Adequate output matching circuit. Matching tools were used to achieve the required power and efficiency.
c. Parts that are capable of handling RF output over several kW. This includes the bypass capacitor in the DC circuit and selecting a toroidal inductor and capacitors for output matching circuit.
d. Water cooling system is highly recommended for testing.
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.

OVERALL CONCEPT

This high efficiency RF power generator uses a DRF1200 to minimize layout parasitic and optimize efficiency for CLASS-E operation.

a. **RF pulse generator circuit**
   The pulse oscillator and pulse control circuit is designed to create an ISM frequency of 27.12MHz and adjust the pulse width and phase according to circuit power requirements.
b. **RF output matching circuit**
   The matching circuit was calculated with a RF matching software tool to maximize power transfer to 50 Ohm load. The circuit was then tuned using the inductor, capacitor and RF choke coil (RFC).

CIRCUIT DESCRIPTIONS

a. **RF Pulse Generation**
The Pulse generation circuit employs 27.12MHz TCXO and Flip Flop IC to adjust Pulse Width from 8nS to 18nS at the signal input of DRF1200. For this application, the pulse width is set at **10nS**. To minimize conductive EMI, it is crucial to use a good ground plane layout with respect to the signal lines.

b. **RF Output Matching**
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. At full power, the efficiency is approximately 80% at 27.12MHz. The MOSFET output capacitance was considered when tuning the external shunt capacitance to get the desired performance. See DRF1200 data sheet for output capacitance. The RF output matching circuit was designed using a RF matching tool and was optimized to achieve maximize power transfer to 50 Ohm Load. The output matching circuit is a series resistive circuit combined with a reactive circuit consisting of an "L" match Toroidal Inductor and Capacitors in series and shunt to ground.

c. **DC Supply**
The PS HV DC supply input circuit utilizes a RFC and by-pass capacitors to minimize interference with AC signal. The RFC was calculated to be approximately 1k Ohm impedance at 27.12MHz using 20 turns of 18AWG wire with metal powder core. The By-pass capacitor should have a minimum 1kV rating.

TEST REQUIREMENTS.

a. **Set-Up Diagram**

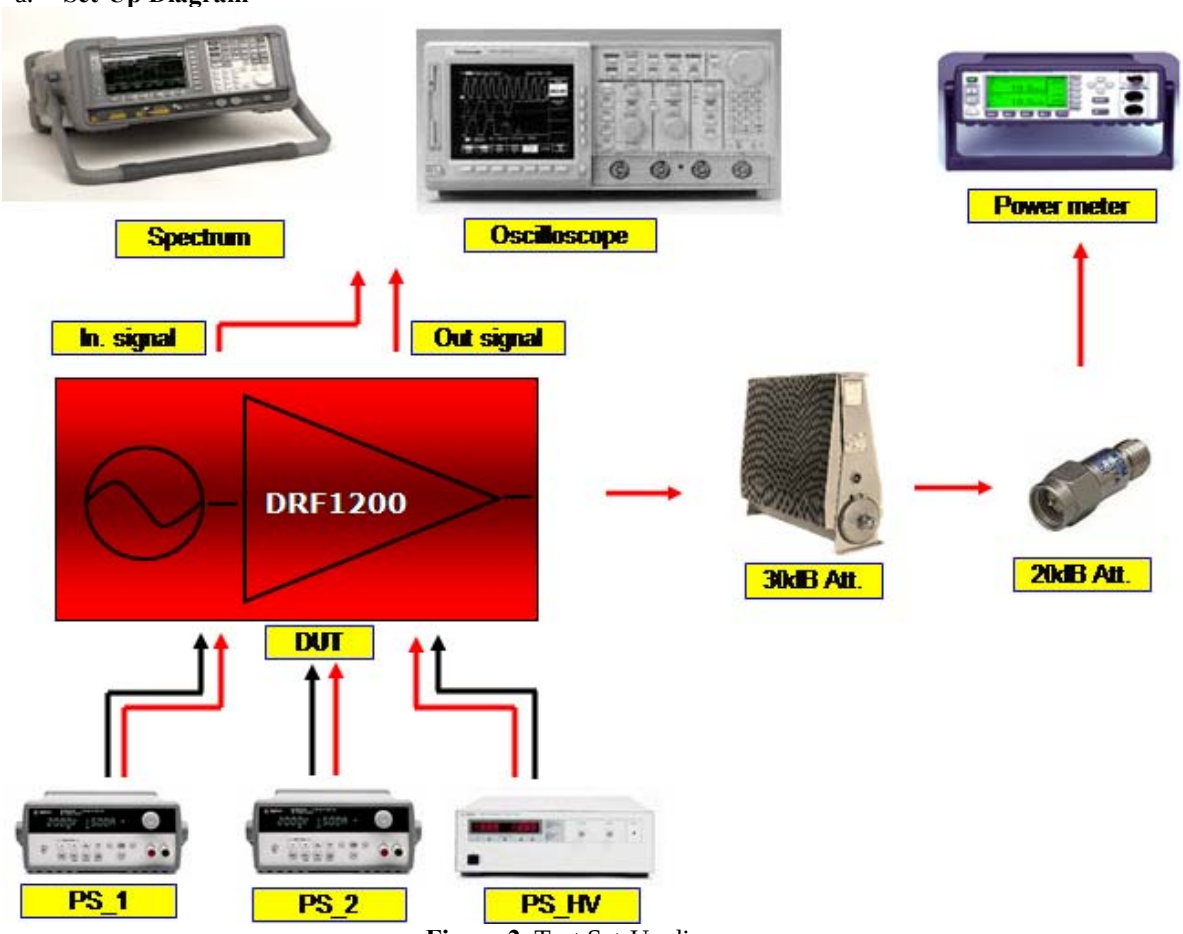

Figure 2. Test Set-Up diagram

a. Hardware and power sequencing requirements

- Cooling requirement: Testing is recommended to be performed using a water cooling system.

- Sequential steps for Turn-On/Turn-Off of Power Supplies.
  1. Turn on Driver power supply PS_2 (14V via JP2).
  2. Then, turn on MOSFET supply (PS HV) and slowly increase to 50V (via JP3).
  3. Then, turn on RF pulse circuitry supply (PS_1) (4V 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 1 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, immediately shut down PS_HV for safety, and determine fault before resuming test.

PERFORMANCE

a. **Data summary**

No\Para.	PS HV (V)	Id (A)	Pin (W)	Pout (W)	H (%)	Vpk ds (V)
1	100	2.9	290	265	91	
2	110	3.1	341	314	93	
3	120	3.3	396	365	94	
4	130	3.4	442	414	94	
5	140	3.5	490	461	93	
6	150	3.7	555	508	92	
7	160	3.9	624	552	90	
8	170	4.0	680	586	87	
9	180	4.1	738	617	84	510

Table 1. Power Sequencing Data Summary

Table 1 shows the effects of varying the PS HV on MOSFET current, RF power, efficiency, and peak Vds. The chart of Efficiency vs. Pout is shown in Figure 3. The efficiency is calculated using RF power output and DC input power of the power MOSFET.

b. **Chart of data sheet**

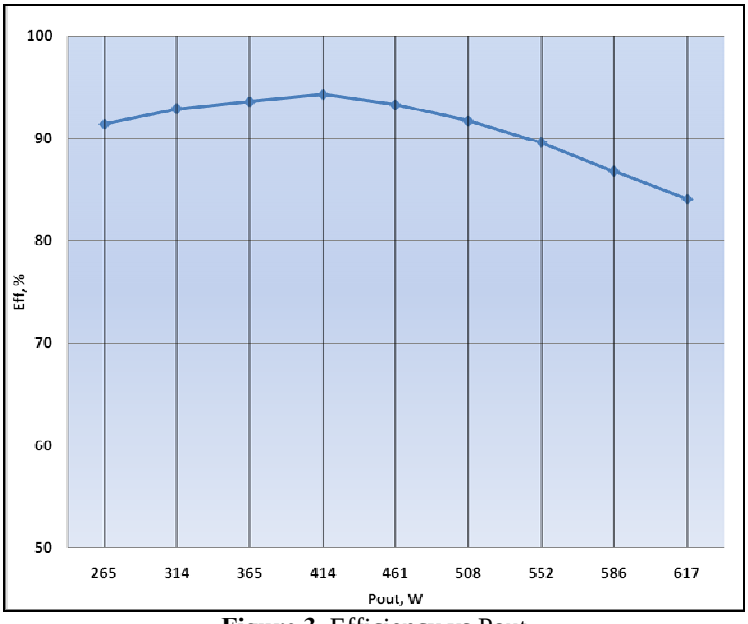

Figure 3. Efficiency vs Pout

CONCLUSIONS

This Application Note is for a reference design using a DRF1200 as a CLASS-E RF generator. The high performances DRF1200 Hybrid was used because it includes both the driver, Power MOSFET, and by-pass capacitors optimized to reduce inductance and achieve a single low cost solution. A reference design board is available to demonstrate this high efficiency of 80%, Pout 600W, Freq 27.12MHz RF generator.

The critical aspects such as the layout of components for efficient power generation, testing, and water cooling requirements are also discussed.

Appendix I. Overall Schematic

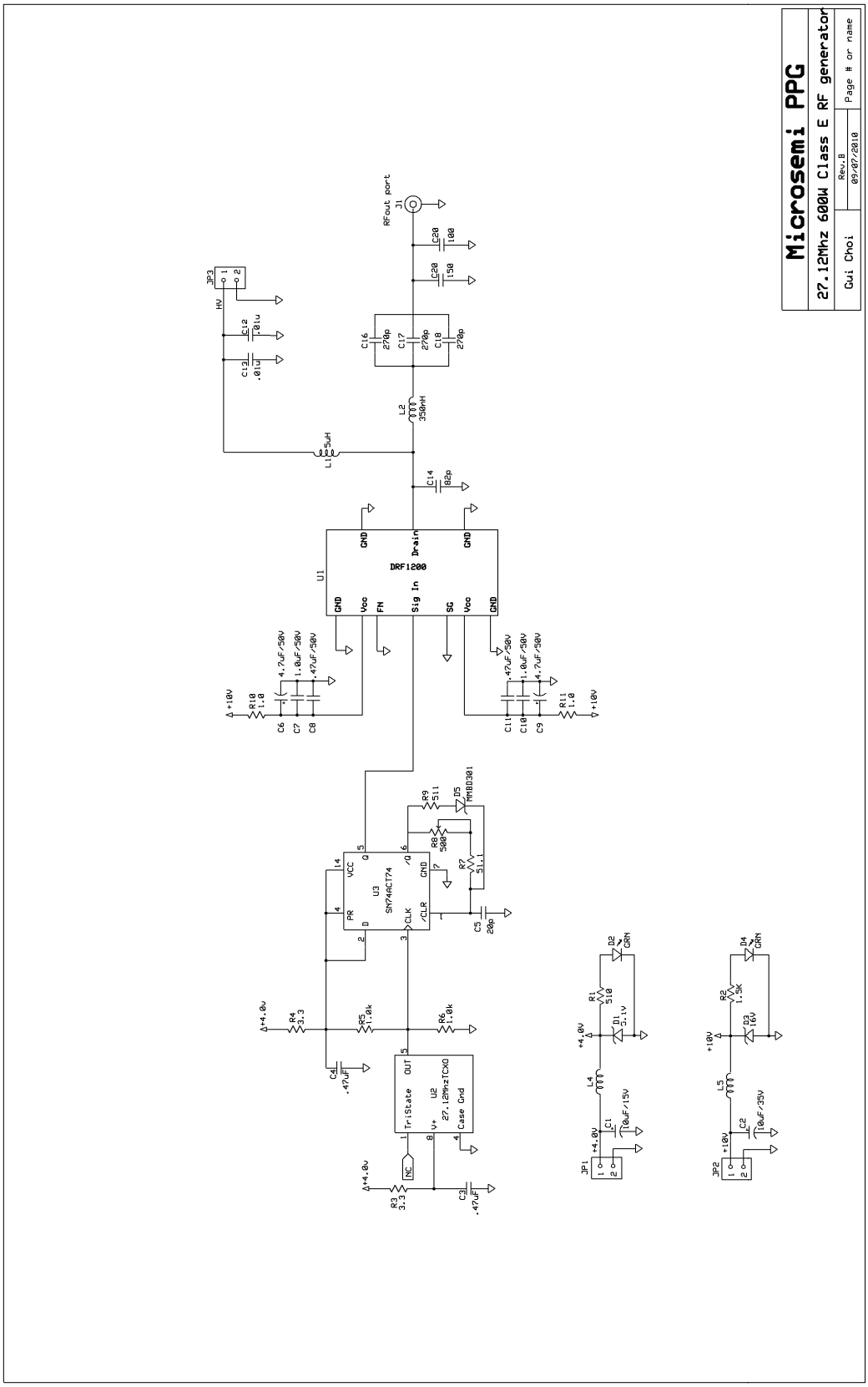

Figure 4. Overall schematic

Appendix II. PCB Lay-out

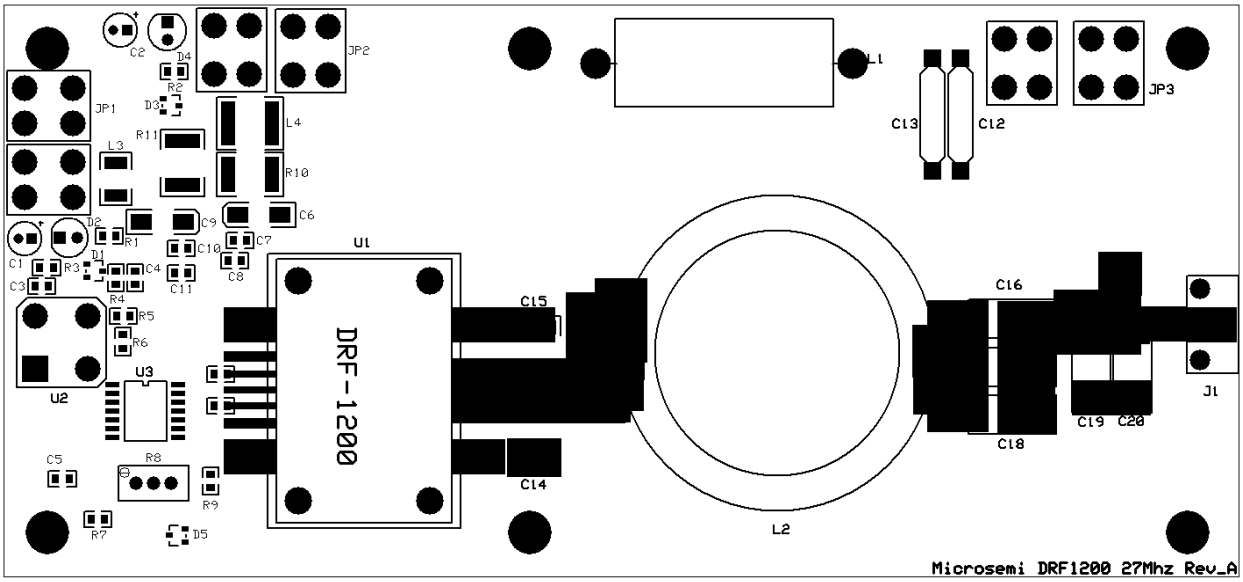

Figure 5. PCB Lay-out

Appendix III. Parts List

Des.	Description	Size	Supplier	Supplier PN	Manuf.	Manuf. PN
U1	RF MOSFET	T3B	Microsemi	DRF1200	Microsemi	DRF1200
C1, 4	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)	805	Digi-key	490-3328-1-ND		GRM21BR71H474KA88L
C5	10uF/35V (Cer_cap)	1812	Digi-key	pcc2183ct-nd		
C6~9	.47uF/50V(Cer_cap)	805	Digi-key	490-3328-1-ND		GRM21BR71H474KA88L
C10	100pF/50V(Cer_cap)	805	Digi-key	PCC101CGCT-ND		
C11	4.7uF/35V(Tan_cap)	6032	Digi-key	478-1717-1-ND	AVX	TAJC475K035R
C12	1.0uF/50V(Cer_cap)	805	Digi-key	587-1438-1-ND	Taiyo Yuden	GMK212BJ105KG-T
C13	.47uF/50V(Cer_cap)	805	Digi-key	490-3328-1-ND		GRM21BR71H474KA88L
C14	4.7uF/35V(Tan_cap)	6032	Digi-key	478-1717-1-ND	AVX	TAJC475K035R
C15	1.0uF/50V(Cer_cap)	805	Digi-key	587-1438-1-ND	Taiyo Yuden	GMK212BJ105KG-T
C16	.47uF/50V(Cer_cap)	805	Digi-key	490-3328-1-ND		GRM21BR71H474KA88L
C17~20	0.01uF/1KV	Disc	Allied Elec.	507-0721	Vishay	562R5GAS10
C22	82PF/2500V	3838	ATC	700C820JW2500X	ATC	700C820JW2500X
C23	220PF/3600V	3838	ATC	100E221KW3600X	ATC	100E221KW36ooX
C24	220PF/3600V	3838	ATC	100E271KW3600X	ATC	100E271KW36ooX
C25	220PF/3600V	3838	ATC	100E221KW3600X	ATC	100E221KW36ooX
C26	150PF/3600V	3838	ATC	100E221KW3600X	ATC	100E221KW36ooX
C27	100PF/3600V	3838	ATC	100E221KW3600X	ATC	100E221KW36ooX
R1	510ohm/1/8W	805	Digi-key	P510ATR-ND	Panasonic	ERJ-6GEYJ511V
R2	1.5Kohm 1/8W 5%	805	Digi-key	P1.5KACT-ND	Panasonic	ERJ-6GEYJ152V
R3	3.3ohm 1/8W 5%	805	Digi-key	P3.3ACT-ND	Panasonic	ERJ-6GEYJ3R3V
R4	3.3ohm 1/8W 5%	805	Digi-key	P3.3ACT-ND	Panasonic	ERJ-6GEYJ3R3V
R5	1.0K ohm 1/8W 1%	805	Digi-key	P1.00KCCT-ND	Panasonic	ERJ-ENF1001V
R6	1.0K ohm 1/8W 1%	805	Digi-key	P1.00KCCT-ND	Panasonic	ERJ-ENF1001V
R7	51.1ohm 1/8W 1%	805	Digi-key	P51.1CCT-ND	Panasonic	ERJ-6ENF51R1V
R8	POT 500ohm 1W	3/8"	Digi-key	3292W-501-ND	Bourns	SM:3269W-1 501
R9	511ohm 1/8W 1%	805	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	On Semi.	MMBD301LT1G
J1	RFout port		Newark	12M4398	Bomar	161V504E
JP1~3	DC Terminal		Allied	839-0309	Keystone	8191
L1	Ind. w/28T AWG18	ID:.5"	Newark	05H7486	MCM	18PE 1/4LB
L2	Toroid Inductor 5T 12AWG		Micrometals Mouser	T225-6 5 --- 2ea 602-289-100	Micrometals Alpha	T225-6 5 289
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	27.12 MHz Osc	Half	Allied Elec.	EP1100HSTSC-27.12M	Ecliptek Co.	EP1100HSTSC-27.120M
U3	Dual Flip-Flop IC	14SOP	Digi-key	296-13131-1-ND	TI	SN74ACT74NSR

References

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