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A 300 W Power Amplifier for the 88 to 108 MHz FM Broadcast Band

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This article describes an FM band power amplifier, including circuit design, thermal considerations, construction notes and performance measurements

The intention of this article is to present a 300 watt single-ended RF power amplifier for the FM broadcast band, used in small to medium radio stations in which economy and flexibility are important to the user.

With the recent availability of low cost overmolded plastic LDMOS RF power amplifier transistors, such as the Freescale family of MRF6VXXXXN devices, it is possible to design and build a low cost, compact, broadband power amplifier offering simplicity and reliability.

In this article, an RF power amplifier using the low cost OMP Freescale MRF6V2300N LDMOS transistor is presented (photo in Figure 1). It operates at V_{dd} = 50 VDC with an average drain efficiency in excess of 60% and a gain of 24 dB with a 1 dB gain flatness over the 88 MHz to 108 MHz band. No tuning is required as the amplifier is broadband. This makes it very attractive for FCC Class A stations [1] with a HAAT such that the coverage area and ERP has a minimum field strength of 70 dBµV or 3.16 mV/m [2].

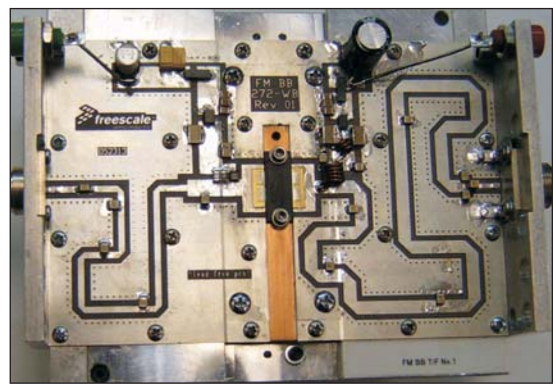

Figure 1 · Assembled test fixture (top view).

Introduction

The Freescale MRF6V2300N is a 10 to 450 MHz 300 W LDMOS RF transistor in a TO-272 WB plastic package featuring 25.5 dB gain and 68% efficiency at 220 MHz, operating in Class AB_2 with a 50 VDC V_{dd} power supply and I_{dq} of 900 mA [3].

It is capable of handling 10:1 VSWR oper-

Acronyms and Abbreviations

Class A Station: As defined by the FCC, minimum ERP of 100 W
Class AB_2: Operation of a power amplifier that is DC biased between Class A and B, which requires input power and the conduction angle is between π and 2π radians.
ACPR: Adjacent Channel Power Ratio
CW: Continuous Wave, i.e. no modulation
dBµV: Decibels referred to 1 µV/m
ERP: Effective Radiated Power
FCC: Federal Communications Commission, the US telecommunications regulatory agency.
FM: Frequency Modulation
HAAT: Height Above Average Terrain
IRL: Input Return Loss
LDMOS: Lateral Diffused Metal Oxide Semiconductor
OFDM: Orthogonal Frequency Division Multiplex
OMP: Over Molded Plastic, i.e., epoxy package
PC: Printed circuit
P_{1dB}: RF power level at 1 dB gain compression
VSWR: Voltage Standing Wave Ratio

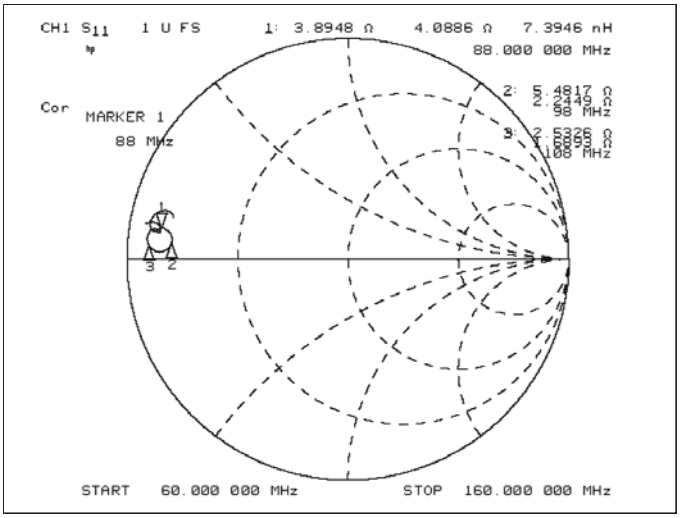

Figure 2 · Impedance measurements, Z_{source} at f_0.

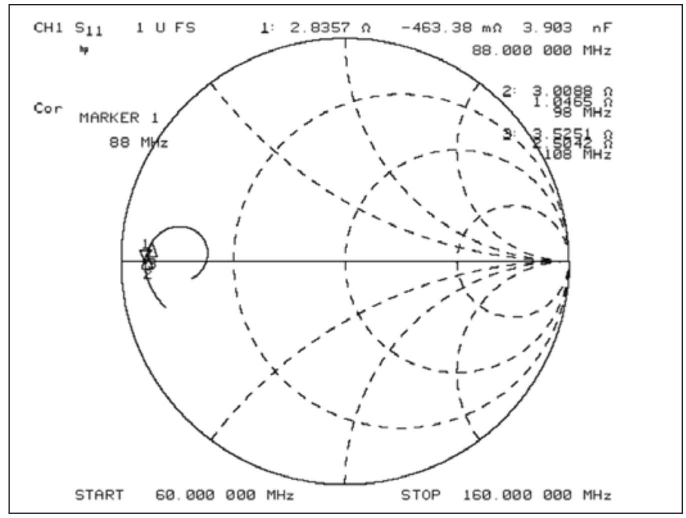

Figure 3 · Impedance measurements, Z_{load} at f_0.

ating at 220 MHz with V_{dd} = 50 VDC and 300 W. Integral ESD protection on the gate circuit makes it safe to handle in the lab or production floor. Because the device is not internally matched, external matching components are required to bring the input and output impedance level to the standard value of 50 ohms at the RF connectors.

Operation in the 88 MHz to 108 MHz band requires broadband matching both at the input and output. This is usually accomplished with a combination of lumped elements (L and C) and lengths of microstrip transmission line. The result is a compact design in a standard PC board material.

Design Objectives

The following is a partial list of desired features:

1. Power amplifier device: MRF6V2300N LDMOS RF OMP transistor
2. Single ended design
3. DC supply 50 VDC
4. Class AB_2 operation, I_{dq} = 900 mA
5. P_{1dB} = 300 W across the band
6. Gain ≈ 24 dB; IRL ≤ –10 dB across the band
7. Efficiency ≈60% across the band
8. 50 Ω input and output impedances at the test fixture RF connectors
9. Must fit into a standard Freescale 4” × 6” test fixture PC board space
10. Must be compatible with standard hardware, heat sink, Cu heat spreader, mounting plates and N type RF connectors.

Design Considerations

In order to achieve the desired broadband performance over 88 to 108 MHz, a five-section input network is used since the input impedance of the device is low, as shown on the Smith chart in Figure 2. The input section is an 80 mil wide microstrip.

Also, a five-section output matching network is used to increase the device output impedance up to the 50-ohm load. Due to the high RF currents involved, a 170 mil wide microstrip is favored to reduce losses.

In both cases, the microstrip is bent around in a meandering shape to fit into the available PC board space. The layout is a compromise between the number of impedance discontinuities, associated losses and fit.

The output impedance is also low, as given in the Smith chart in Figure 3. Please note that these are test fixture impedances defined as Z_{source} and Z_{load} in the data sheet [3] and measured with probes and a calibrated network analyzer.

After tuning, both networks were implemented in a printed circuit board using Arlon® CuClad 250 GX-0300 material [4] with an ε_r = 2.55, a nominal dielectric thickness of 30 mil and 2.8 mil thick copper trace.

Figure 4 gives the PC board and assembly diagram for the finished RF power amplifier.

A Note on the Thermal Design

At a predicted drain efficiency of 68%, that is 32% of the input DC power is dissipated in heat. Thus using the equations $P_{dc} = P_{out}/\eta_d$, where η_d is the drain efficiency and $P_{diss} = (1 - \eta_d) \cdot P_{dc}$, the values are 3 P_{dc} = 441.18 W and P_{diss} = 141.18 W. These are somewhat optimistic as the η_d used is for narrow band 220 MHz design to provide an estimate. A slight loss in efficiency is expected for broadband operation.

The thermal and heat sink must be carefully considered so that the case temperature T_c < 200°C and the junction temperature T_j < 200°C, otherwise the reliability

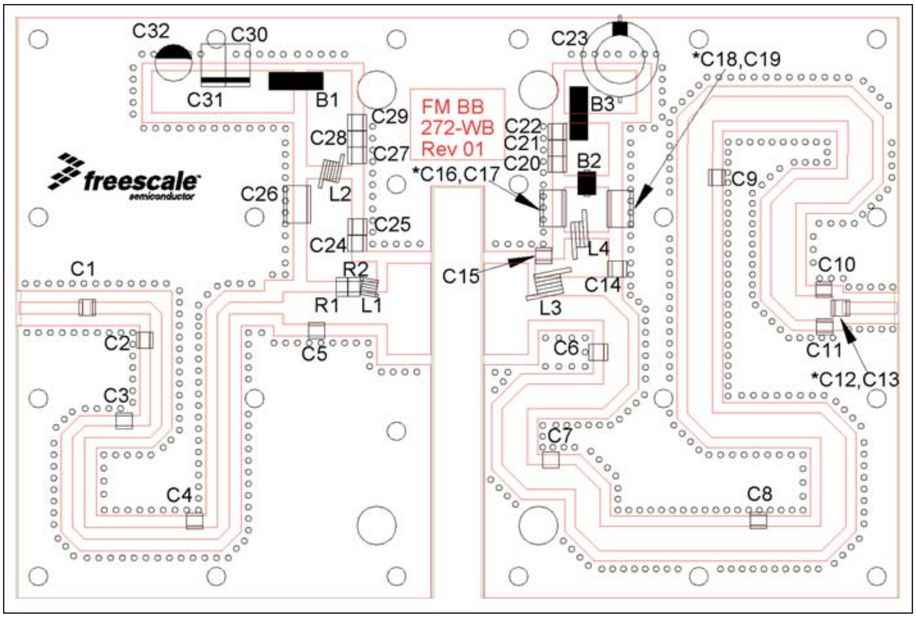

Figure 4 · PC board layout and assembly diagram.

in terms of MTTF will be affected [5].

In this design, the MRF6V2300N device is thermally coupled to the aluminum pin-fin type UltraCool III heat sink by Cool Innovations® [6] through a copper plate heat spreader. In order to minimize the source contact thermal impedance and the electrical contact impedance, a small piece of TGON-805® material [7] of equal footprint to the RF transistor is placed under the device before bolt mounting [8] to the copper heat spreader.

Results

The final fully assembled test fixture is shown in Figure 1. Note input gate bias decoupling circuit and output drain decoupling network. These assure stable amplifier operation and prevent RF fields from reaching the gate area. The copper heat spreader and LDMOS power transistor is visible in the center.

Figures 5 and 5 show the gain, IRL, drain current and efficiency under a power sweep at low, mid and high frequency channels. Figures 7 and 7 are graphs giving the gain, IRL, drain current and efficiency under a frequency sweep at two power levels: 150 W and 300 W. Intermodulation performance is

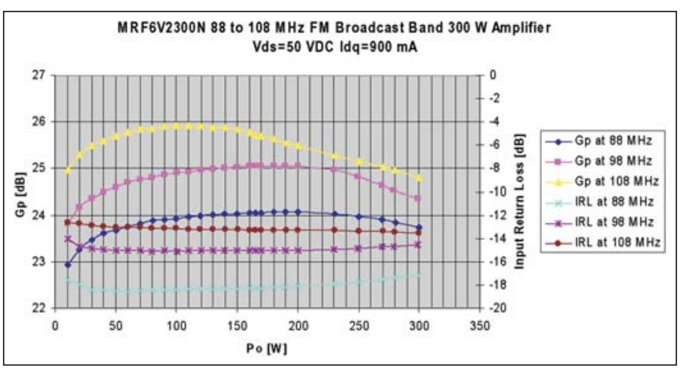

Figure 5 · Power sweep, gain and IRL at 88 MHz, 98 MHz and 108 MHz.

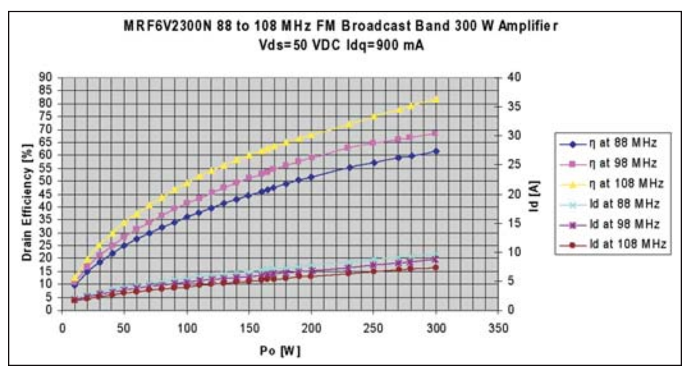

Figure 6 · Power sweep, drain current and efficiency at 88 MHz, 98 MHz and 108 MHz.

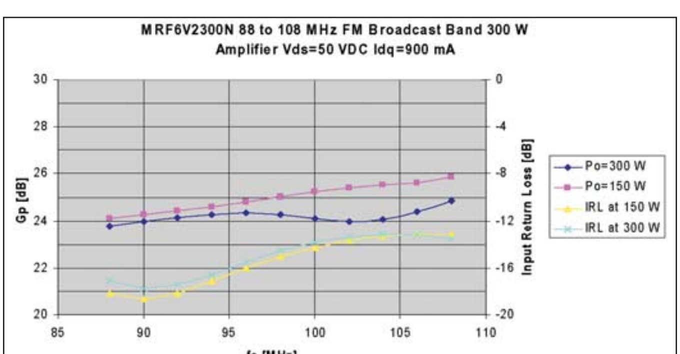

Figure 7 · Frequency sweep, gain and IRL at P_{out} = 150 W and 300 W.

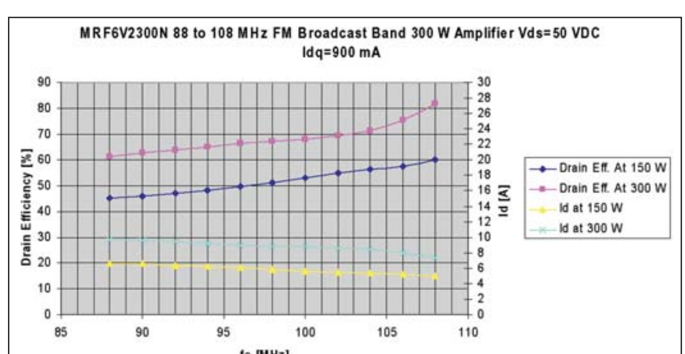

Figure 8 · Frequency sweep, drain current and efficiency at P_{out} = 150 W and 300 W.

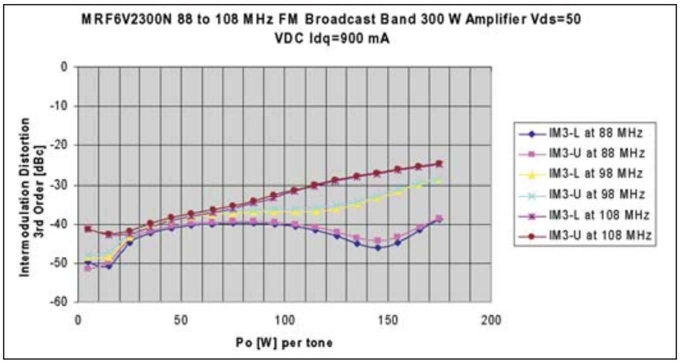

Figure 9 · Inter-modulation distortion 3rd order (two tone test).

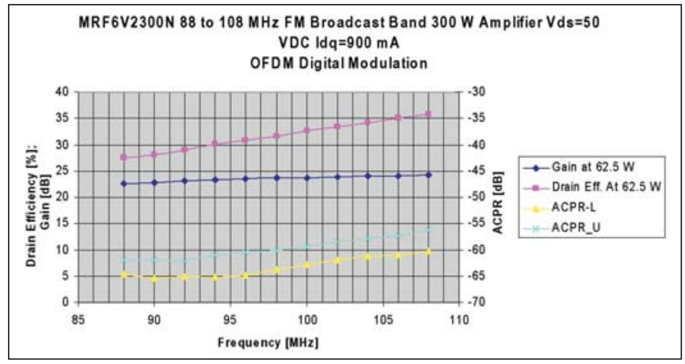

Figure 10 · OFDM digital modulation (8K mode, 64 QAM, 5 symbols).

shown in Figure 9. Digital modulation performance with 7 dB back-off under DVB-T OFDM with 64 QAM and five symbols is given in Figure 10.

Table 1 summarizes the results obtained from a CW test conducted in a lab environment with a 50-ohm load at low, mid and high channels. At full output power this design exhibits 24 dB gain, a drain efficiency better than 61% with a fairly good IRL over the band. Gain compression is kept close to 1 dB or better. As in most single-ended designs, the harmonic level is elevated and further steps can be taken with an external passive LC low pass filter to reduce their level even more, in particular the 2nd harmonic and keeping in mind the insertion loss of the filter. Figure 11 is a spectrum plot of harmonics while operating at 88 MHz.

Table 2 summarizes the data from the two tone inter-modulation test, showing reasonably good performance over the band (low, mid and high channels) and at a power level exceeding 300 W.

	Po [W]	Gp [dB]	IRL [dB]	η [%]	Compression (|$Gp_{[300W]}$ – $Gp_{[150 W]}$|) [dB]	Harmonics 2^{nd}; 3^{rd} [dBc]
88 MHz	300	23.6	-17.3	61.3	0.38	-12; -23
98 MHz	300	24.2	-14.7	68	0.76	-15; -23
108 MHz	300	24.6	-13.6	81.5	1.03	-17; -12

Table 1. 300W performance data and harmonic levels.

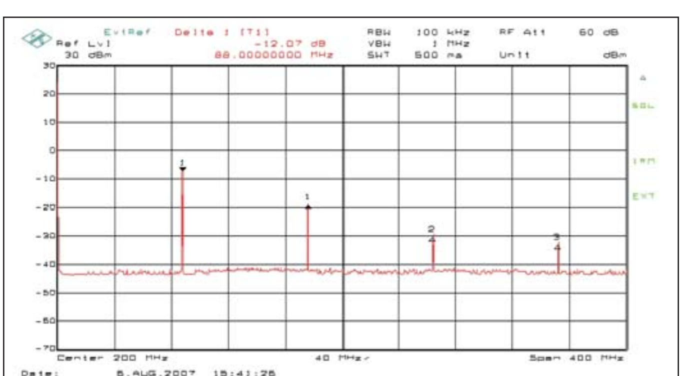

Figure 11 · Harmonics at 88 MHz.

Table 3 summarizes the data from an OFDM digital modulation signal (8K mode DVBT, 64 QAM data carrier modulation, 5 symbols) simulating the digital FM band broadcast signal for future applications. The ACPR is measured at 4 MHz offset from the center frequency. Power level is at 7 dB back-off.

The total parts cost (in quantity) is less than US$480, as detailed in Table 4.

References

1. US CFR 47 part 73, §73.211 “Power and antenna height requirements,” FCC regulations, available from www.fcc.gov.

2. US CFR 47 part 73, §73.315 “FM transmitter location,” FCC regulations, available from www.fcc.gov.

3. MRF6V2300N Data Sheet, available from

	Po per tone [W]	Gp [dB]	IRL [dB]	η [%]	Compression |ΔGain| [dB]	IMD3 2 tone [dBc] LSB / USB
88 MHz	155	24	-17	48.8	0.06	-44.7 / -43.4
98 MHz	155	24.7	-14.6	53.9	0.26	-31.5 / -31.2
108 MHz	155	25.3	-13.1	63.7	0.54	-26.4 / -26.2

Table 2 · Two-tone IMD test, 155W per tone.

	Po [W]	Gp [dB]	IRL [dB]	η [%]	ACPR LSB / USB (at 4 MHz offset) [dBc]	
88 MHz	62.5	22.6	-17	27.6	-64.7 / -61.9	
98 MHz	62.5	23.6	-15.2	31.6	-63.7 / 60.7	
108 MHz	62.5	24.1	-13.4	35.8	-60.2 / -56.2	

Table 3 · OFDM test at 7 dB backoff.

www.freescale.com/rf

4. Arlon Microwave Materials Div., www.arlon-med.com

5. A Freescale MTTF calculator is available at http://www.freescale.com/rf; select options for Tools/Software/Application Software/Calculators to access the MTTF calculator.

6. Model 3-505019RX is available from www.coolinnovations.com

7. Thermagon Inc. is now Laird Technologies: www.lairdtech.com.

8. Freescale Application Notes AN1907, "Solder Reflow Attach Method for High Power RF Devices in Plastic Packages," and AN3263, "Bolt Down Mounting Method for High Power RF Transistors and RFICs in Over-Molded Plastic Packages," both available at www.freescale.com/rf.

Author Information

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88-108 MHz REV3			
Designator	**Description**	**Part Number**	**Manufacturer**
B1, B3	95 ohm, 100 MHz Long Ferrite Bead SMT	2743021447	Fair-Rite
B2	47 ohm, 100 MHz Short Ferrite Bead SMT	2743019447	Fair-Rite
C1, C15, C24	1000 pF Chip Capacitor	ATC100B102JT50X	ATC
C2	30 pF Chip Capacitor	ATC100B300JT500X	ATC
C3, C9	33 pF Chip Capacitor	ATC100B330JT500X	ATC
C4	15 pF Chip Capacitor	180R150JW 500X	ATC
C5	47 pF Chip Capacitor	ATC100B470JT500X	ATC
C6	82 pF Chip Capacitor	ATC100B820JT 500X	ATC
C7	75 pF Chip Capacitor	ATC100B750JT 500X	ATC
C8	51 pF Chip Capacitor	ATC100B510GT500X	ATC
C10	4.7 pF Chip Capacitor	ATC100B4R7CT500X	ATC
C11	10 pF Chip Capacitor	ATC100B100JT500X	ATC
C12, C13	510 pF Chip Capacitor	ATC100B511JT100X	ATC
C14 C16, C17, C18	240 pF Chip Capacitor	ATC100B241JT200X	ATC
C19, C26	2.2 µF Chip Capacitor	C1825C225J5RAC	Kemet
C20, C29	10K pF Chip Capacitor	ATC200B103KT50X	ATC
C21, C28	20K pF Chip Capacitor	ATC200B203KT50X	ATC
C22, C25, C27	0.1 µF Chip Capacitor	CDR33BX104AKWS	AVX
C23	330 µF, 63V Electrolytic Capacitor	MCRH63V337M13X21-RH	Multicomp
C30	10 µF, 35V Tantalum Capacitor	T491D106K035AS	Kemet
C31	22 µF, 35V Tantalum Capacitor	T491X226K035AS	Kemet
C32	47 µF, 50V Electrolytic Capacitor	476KXM050M	Illinois Cap
L1	8 nH Inductor	A03T	CoilCraft
L2	82 nH Inductor	1812SMS-82NJ	CoilCraft
L3	5 Turn #18AWG Inductor, ID = 0.185"	Handwound	Freescale
L4	3 Turn #18AWG Inductor, ID = 0.090"	Handwound	Freescale
R1, R2	18-ohm 2010 Chip Resistor	CRCW201018RFKEA	Vishay
Q1	LDMOS RF Power Transistor	MRF6V2300N	Freescale
Hardware	Printed Circuit Board	DS2313	DS Electronics
Hardware	Endplates	Machine shop	Freescale
Hardware	Copper insert	Machine shop	Freescale
Hardware	Heatsink	UltraCool III	Cool Innovation
Hardware	RF N type female connectors	3052-1648-10	Amphenol/Tycoz

Table 4 · Part list for the MRF6V2300N FM band power amplifier.