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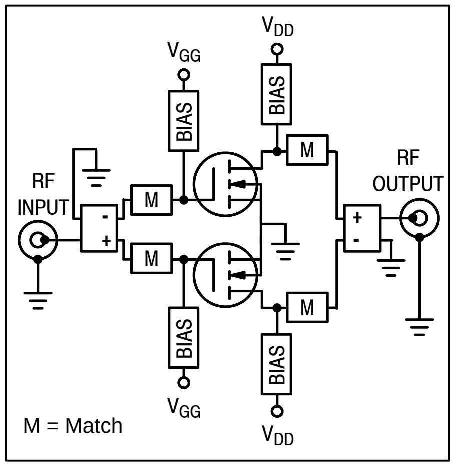
RF Power Reference Design Library

2 Meter Amateur Reference Design

High Ruggedness N–Channel Enhancement–Mode Lateral MOSFETs

MRFE6VP61K25H
MRFE6VP61K25HS
2 Meter Amateur

144–148 MHz, 1250 W CW, 50 V
2 METER AMATEUR
REFERENCE DESIGN



Reference Design Characteristics

This document describes a high efficiency, rugged linear amplifier reference design for 2 meter amateur band (144 MHz – 148 MHz) operation. Because of the ruggedness and low thermal resistance of the MRFE6VP61K25H transistor used in the design. the design can output high power even when operating into high VSWR. The amplifier can be biased for Class AB linear or Class C operation and is suitable for both analog and digital waveforms (AM/SSB or WSJT/FM/CW).

- Frequency Band: 144–148 MHz
- Output Power: >1250 Watts CW
- Supply Voltage: 50 Vdc
- Power Gain (Typ): 26 dB
- Class C Drain Efficiency (Min): >78%
- IMD @ 1 kW Output: < –28.5 dB

The MRFE6VP61K25H transistor used in this design is one of the devices in Freescale's RF power enhanced ruggedness 50 volt LDMOS product line. These devices, including the 600 watt MRFE6VP5600H and the 300 watt MRFE6VP6300H, are all specifically designed for 50 volt operation under harsh conditions.

2 METER AMATEUR REFERENCE DESIGN

This reference design is designed to demonstrate the RF performance characteristics of the MRFE6VP61K25H/HS devices operating in 144–148 MHz amateur radio band. The reference design shows two operational modes with different optimizations, V_{DD} = 50 volts, I_{DQ} = 2500 mA for Class AB linear operation or V_{DD} = 43 volts, I_{DQ} = 200 mA for Class C operation.

REFERENCE DESIGN LIBRARY TERMS AND CONDITIONS

Freescale is pleased to make this reference design available for your use in development and testing of your own product or products. The reference design contains an easy–to–copy, fully functional amplifier design. It consists of "no tune" distributed element matching circuits designed to be as small as possible, and is designed to be used as a "building block" by our customers.

HEATSINKING

When operating this fixture it is critical that adequate heatsinking is provided for the device. Excessive heating of the device may prevent duplication of the included measurements and/or destruction of the device.

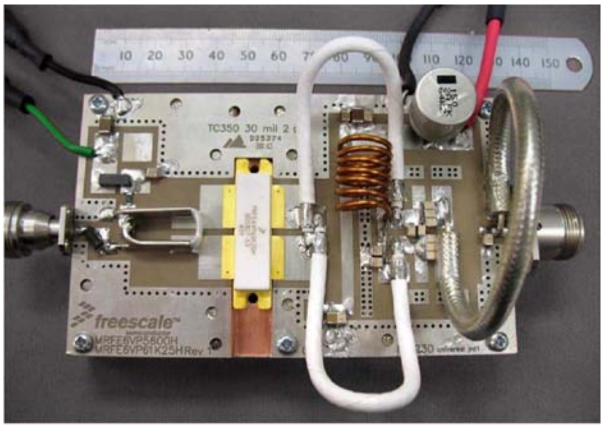


Figure 1. 2 Meter Amateur Reference Design Fixture

PERFORMANCE AND RF MEASUREMENTS

Measurement is done using a CW (single tone) signal unless specified otherwise.

Data was taken using an automated characterization system, ensuring repeatable measurements.

The reference design was tuned with a trade-off between linearity and efficiency. Other tuning optimizations are possible.

Table 1. 50 V Drain Supply, IDQ = 2500 mA (for Class AB, linear operation)

Freq. (MHz)	P_{in} (W)	P_{out} (W)	Gain (dB)	IRL (dB)	Eff. (%)	V_{DD} (v)	I_{DD} (A)
144	0.1	73	28.6	−17.6	19.6	50	7.5
144	0.3	178	28.5	−18.1	31.8	50	11.2
144	0.5	392	28.9	−17.7	48.0	50	16.3
144	0.7	573	28.8	−17.1	57.8	50	19.8
144	1.0	724	28.6	−16.0	64.2	50	22.5
144 P1dB	1.5	920	27.9	−14.2	70.7	50	26.0
144	1.75	1003	27.6	−13.4	73.0	50	27.4
144	2.25	1135	27.0	−12.1	76.4	50	29.7
144	2.5	1201	26.8	−11.3	78.0	50	31.0
144	3.0	1250	26.2	−11.3	78.8	50	31.7
144 P3dB	3.5	1311	25.7	−10.9	79.9	50	32.8

Table 2. 50 V Drain Supply, IDQ = 200 mA (for Class C, non-linear operation, without board retuning)

Freq. (MHz)	P_{in} (W)	P_{out} (W)	Gain (dB)	IRL (dB)	Eff. (%)	V_{DD} (v)	I_{DD} (A)
144	0.1	19	22.9	−14.5	11.6	50	3.3
144	0.3	79	25.0	−16.2	23.6	50	6.8
144	0.5	271	27.3	−16.7	42.7	50	12.7
144	0.8	372	27.0	−17.5	49.8	50	14.9
144	1.0	513	27.1	−17.4	57.6	50	17.8
144	1.5	771	27.1	−15.6	68.2	50	22.6
144	1.7	821	26.7	−15.3	69.8	50	23.5
144	2.2	975	26.4	−13.8	74.2	50	26.2
144	2.5	1059	26.3	−12.8	76.3	50	27.7
144	3.0	1118	25.7	−12.6	77.8	50	28.7
144	3.5	1195	25.3	−12.0	79.5	50	30.0
144	4.0	1255	25.0	−11.6	80.7	50	31.0
144	4.5	1301	24.6	−11.4	81.6	50	31.8
144	5.0	1339	24.3	−11.2	82.4	50	32.5

Table 3. 43 V Drain Supply, IDQ = 200 mA (for Class C, non-linear operation, without board retuning)

Freq. (MHz)	P_{in} (W)	P_{out} (W)	Gain (dB)	IRL (dB)	Eff. (%)	V_{DD} (v)	I_{DD} (A)
144	0.1	17	22.5	−14.2	12.9	43	3.2
144	0.3	74	24.8	−16.2	26.9	43	6.5
144	0.5	254	27.1	−16.7	48.4	43	12.2
144	0.8	337	26.5	−17.5	55.1	43	14.2
144	1.0	459	26.6	−16.9	62.8	43	17.0
144	1.5	640	26.3	−14.7	71.2	43	20.9
144	1.8	708	26.1	−13.8	73.8	43	22.3
144	2.3	797	25.5	−12.9	76.8	43	24.1
144	2.5	752	24.8	−14.3	75.3	43	23.2
144	3.0	900	24.8	−11.8	79.7	43	26.2
144	3.5	953	24.3	−11.4	81.1	43	27.3
144	4.0	991	24.0	−11.1	81.9	43	28.1
144	4.5	1038	23.6	−11.0	83.1	43	29.0
144	5.0	1060	23.3	−10.9	83.5	43	29.5

CIRCUIT DESCRIPTION

The input circuit uses a 9/1 balun transformer with a prematch done by a series inductor and a shunt capacitor. The shunt capacitor is optional but is useful to center the input return loss (IRL). The input circuit return loss is always better than 10.5 dB, equivalent to a worst case VSWR of 1.8.

The output circuit consists of a 4/1 transformer using two 4.7″ lengths of 10 Ω coaxial cable. It is also recommended that three DC blocks in parallel be used in order to lower the total equivalent series resistance (ESR) which is critical at this high power.

The output balun is made from a 6.7″ length of “Sucoform 250” 50 Ω coaxial cable, and acts as a Pi match with 2 x 15 pF at the input and 5.6 pF at the output.

FIXTURE IMPEDANCE

V_{DD} = 50 Vdc, I_{DQ} = 200 mA, P_{out} = 1100 W CW

f MHz	Z_{source} Ω	Z_{load} Ω
144	1.6 + j5.0	3.9 + j1.5

Z_{source} = Test circuit impedance as measured from gate to gate, balanced configuration.

Z_{load} = Test circuit impedance as measured from drain to drain, balanced configuration.

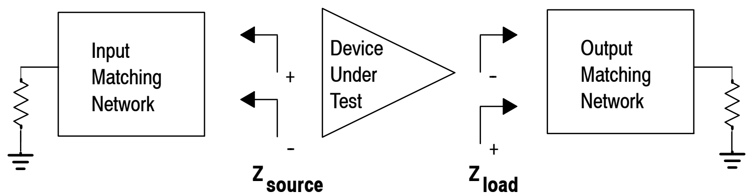


Figure 2. Series Equivalent Source and Load Impedance

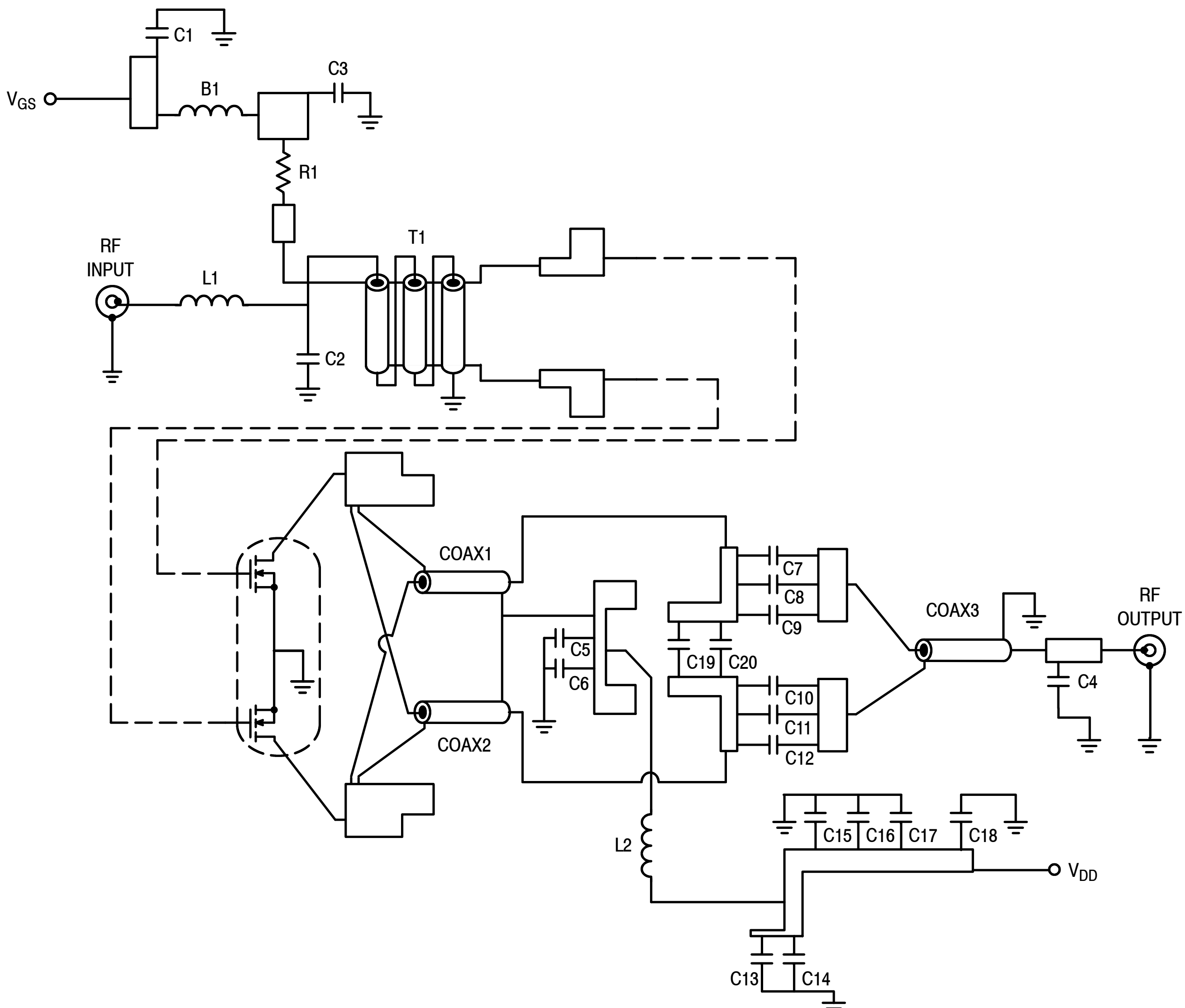
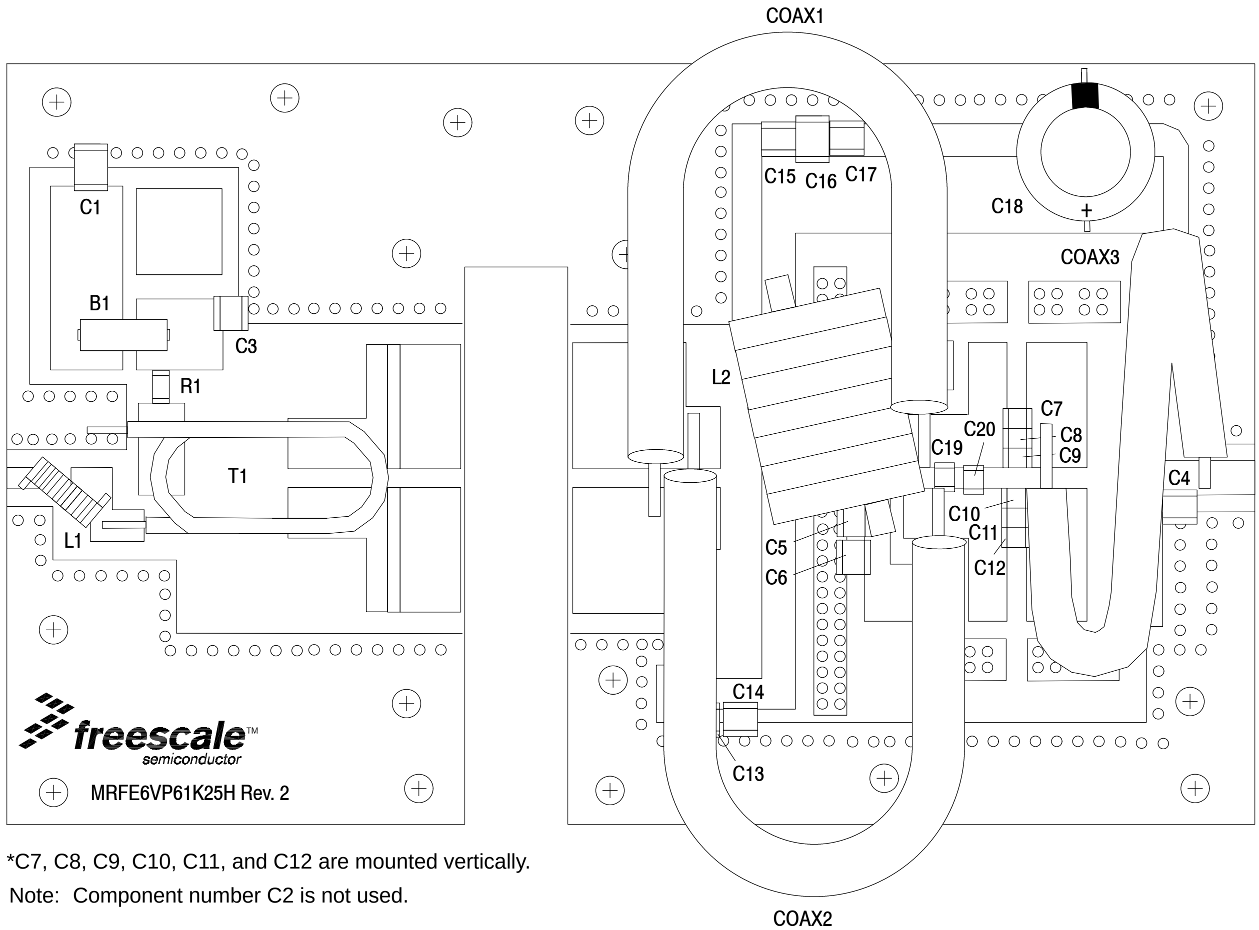


Figure 3. 2 Meter Amateur Reference Design Schematic Diagram



*C7, C8, C9, C10, C11, and C12 are mounted vertically.

Note: Component number C2 is not used.

Figure 4. 2 Meter Amateur Reference Design Component Layout

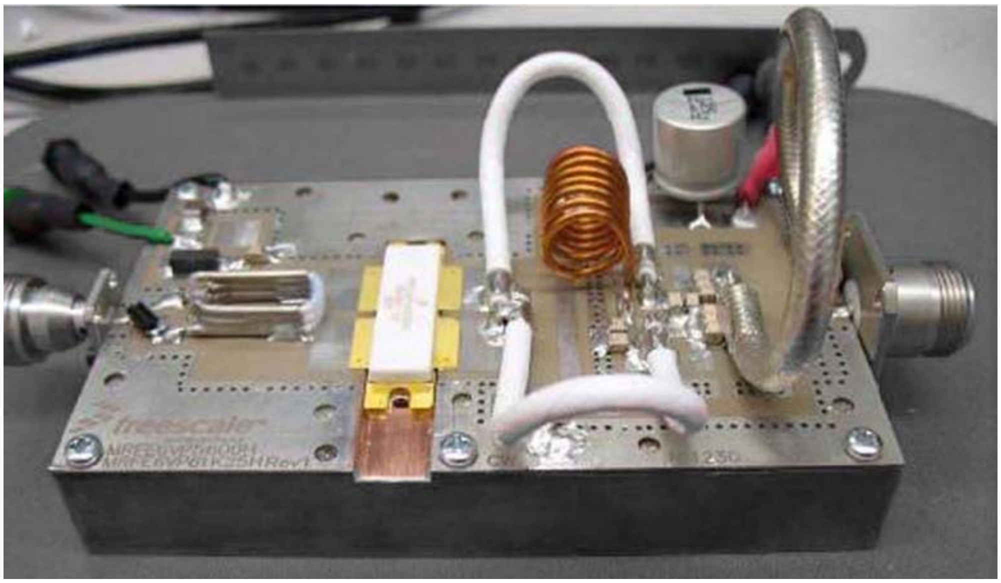
Table 4. 2 Meter Amateur Reference Design Component Designations and Values

Part	Description	Part Number	Manufacturer
B–	95 Ω, 100 MHz Long Ferrite Bead	2743021447	Fair–Rite
C1	6.8 μF, 50 V Chip Capacitor	C4532X7R1H685K	TDK
C3, C5, C7, C8, C9, C10, C11, C12, C13, C15	1000 pF Chip Capacitors	ATC100B102KT50XT	ATC
C4	5.6 pF Chip Capacitor	ATC100B5R6CT500XT	ATC
C6	470 pF Chip Capacitor	ATC100B471JT200XT	ATC
C14, C16	1 μF, 100 V Chip Capacitors	C3225JB2A105KT	TDK
C17	2.2 μF, 100 V Chip Capacitor	HMK432B7225KM–T	Taiyo Yuden
C18	470 μF, 100 V Electrolytic Capacitor	MCGPR100V477M16X32–RH	Multicomp
C19, C20	15 pF Chip Capacitors	ATC100B150JT500XT	ATC
L1	43 nH Inductor	B10TJLC	CoilCraft
L2	7 Turn, #14 AWG, ID = 0.4″ Inductor	Handwound	Freescale
R1	11 Ω, 1/4 W Chip Resistor	CRCW120611R0FKEA	Vishay
T1	Balun	TUI–9	Comm Concepts
Coax1, Coax2	Flex Cables, 10.2 Ω, 4.7″	TC–12	Comm Concepts
Coax3	Coax Cable, 50 Ω, 6.7″	SUCOFORM250–01	Huber+Suhner
PCB	0.030”, ε_r = 3.50	TC–350	Arlon

* PCB artwork for this reference design is available at http://freescale.com/RFindustrial > Design Support > Reference Designs or http://freescale.com/RFbroadcast > Design Support > Reference Designs.

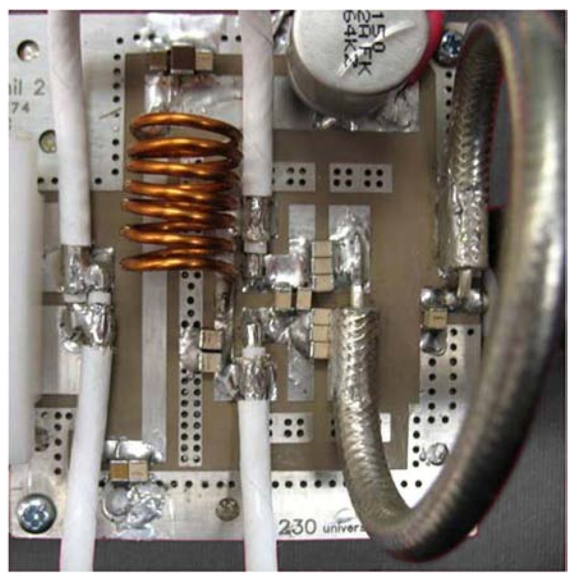
Note: See Appendix B for Mounting Tips.

VIEWS OF 2 METER AMATEUR REFERENCE DESIGN



Overall

Input



Output

Figure 5. 2 Meter Amateur Reference Design Detailed Views

IMD MEASUREMENT

IMD measurement was done using two signal generator with a tone spacing of 1 kHz. Quiescent current was set for 2.5 A under 50 volts with no RF signal at input. 2.5 A was choosen as a good compromise between gain, linearity and efficiency.

In order to get optimal linearity, a thermal compensation circuit was used that tracks the quiescent current of the board over the temperature range (not shown on picture). Refer to Freescale's AN1643 *RF LDMOS Power Modules for GSM Base Station Application: Optimum Biasing Circuit* application note[1] or the VHF Broadcast reference design for more information.[2]

The two-tone IMD values are referenced to the peak envelope power (PEP) and are spaced 1 kHz apart.

Table 5. Two-Tone IMD

P_{out} (W) PEP	IM3-L	IM3-U	IM5-L	IM5-U	IM7-L	IM7-U	IM9-L	IM9-U
100.0	-42.2	-42.2	-61.3	-64.1	-72.5	-74.4	-85.1	-85.1
199.5	-42.0	-42.3	-57.8	-59.6	-69.9	-70.6	-75.2	-78.0
399.8	-44.8	-44.0	-50.8	-51.7	-66.6	-68.2	-73.3	-72.1
599.3	-41.7	-41.5	-45.1	-45.5	-68.1	-71.7	-68.1	-68.9
797.1	-33.7	-33.7	-42.4	-42.2	-56.5	-57.3	-68.5	-65.9
899.8	-30.8	-30.9	-42.0	-41.8	-51.9	-52.4	-68.0	-69.5
997.8	-28.7	-28.6	-42.7	-42.3	-48.6	-48.7	-73.7	-73.4

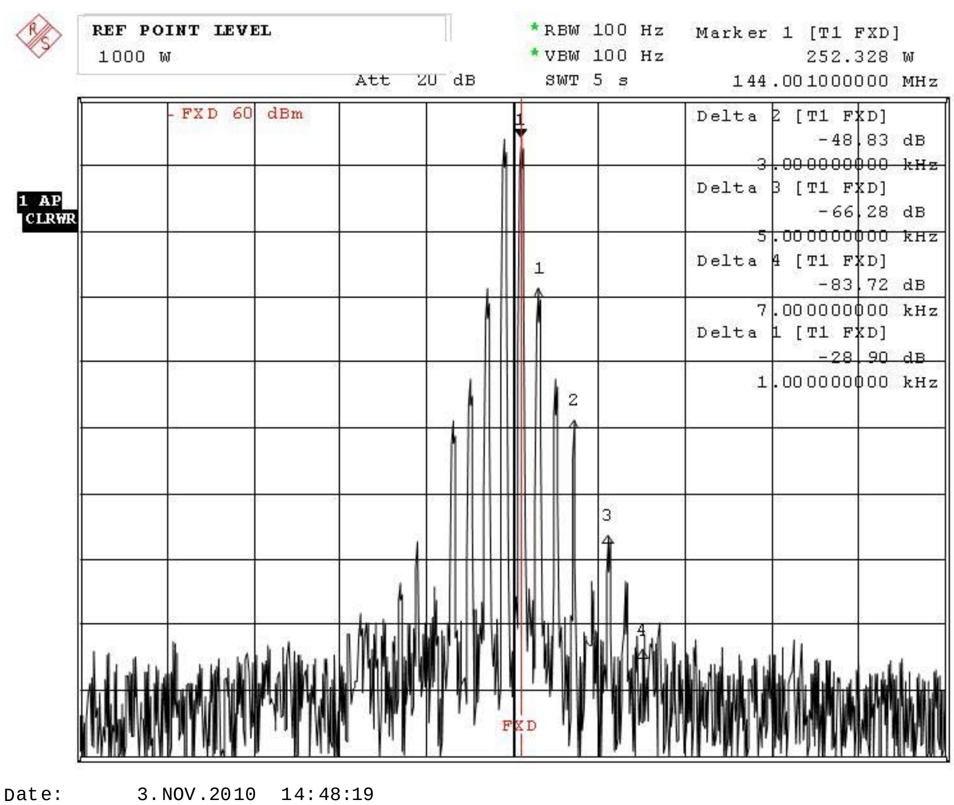


Figure 6. 1000 W PEP Two-Tone Spectrum

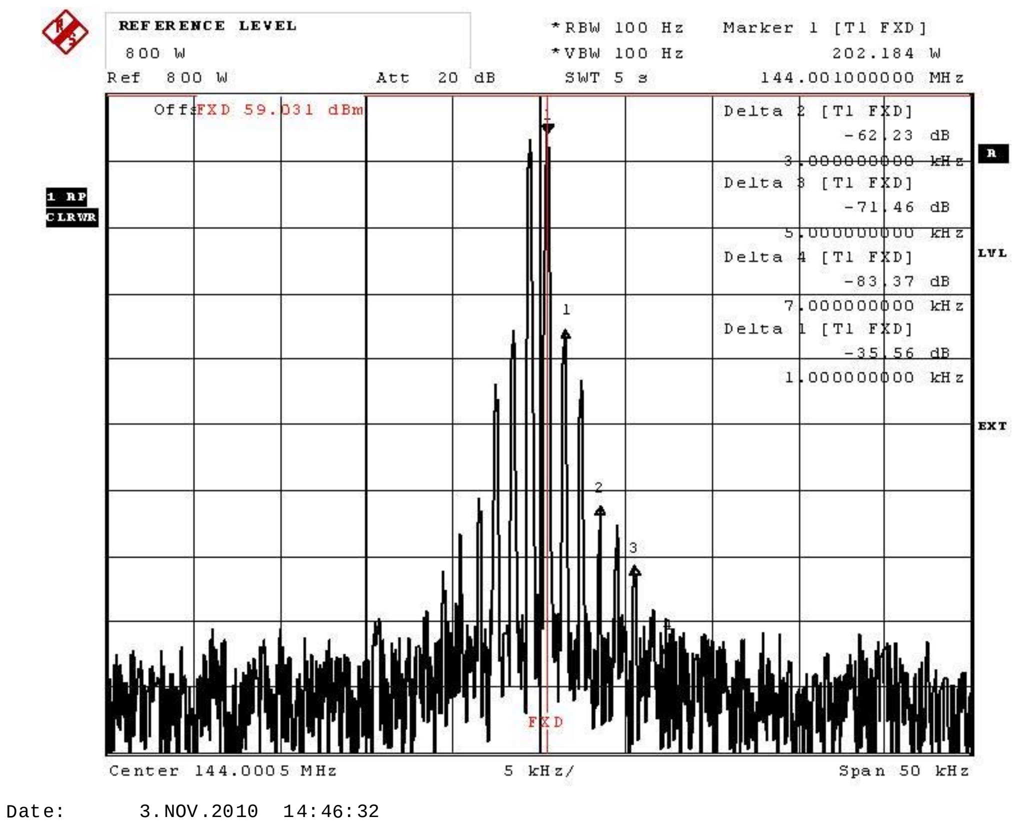


Figure 7. 800 W Two‑Tone Spectrum

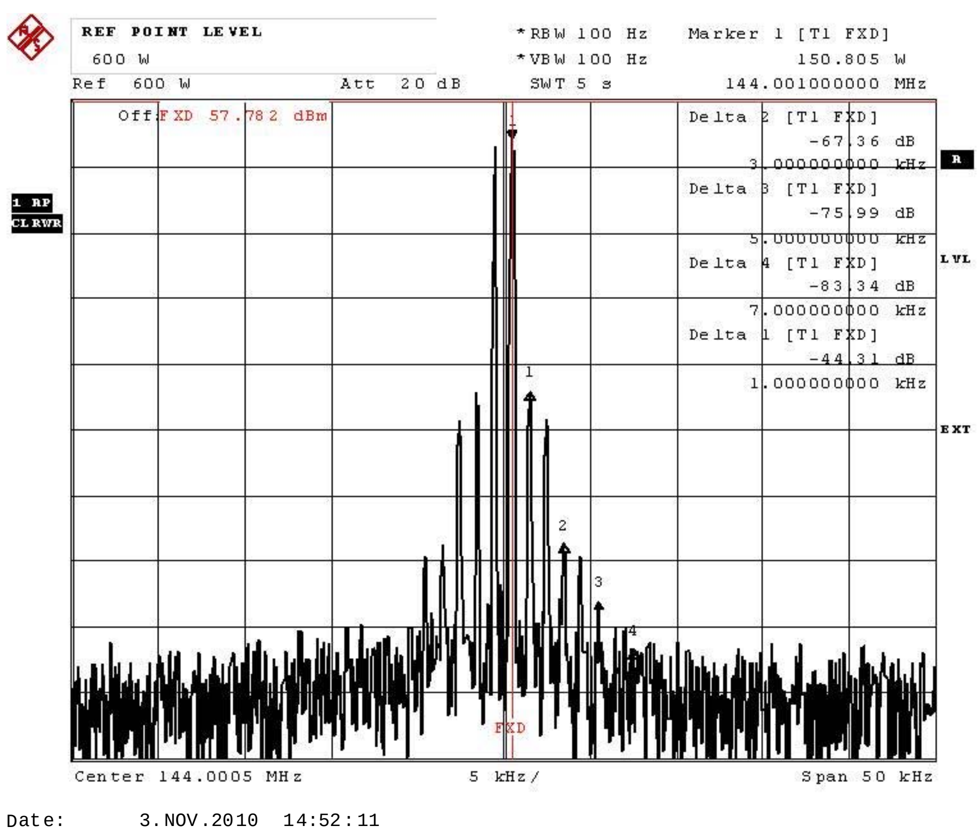


Figure 8. 600 W Two‑Tone spectrum

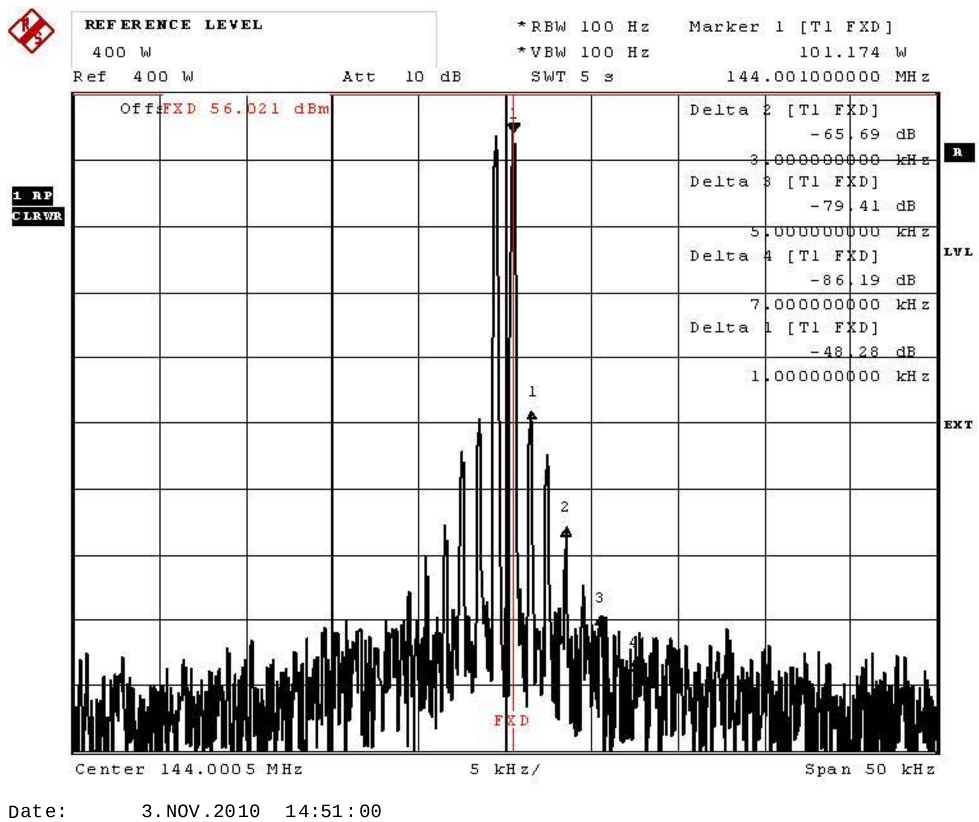


Figure 9. 400 W Two‐Tone SPectrum

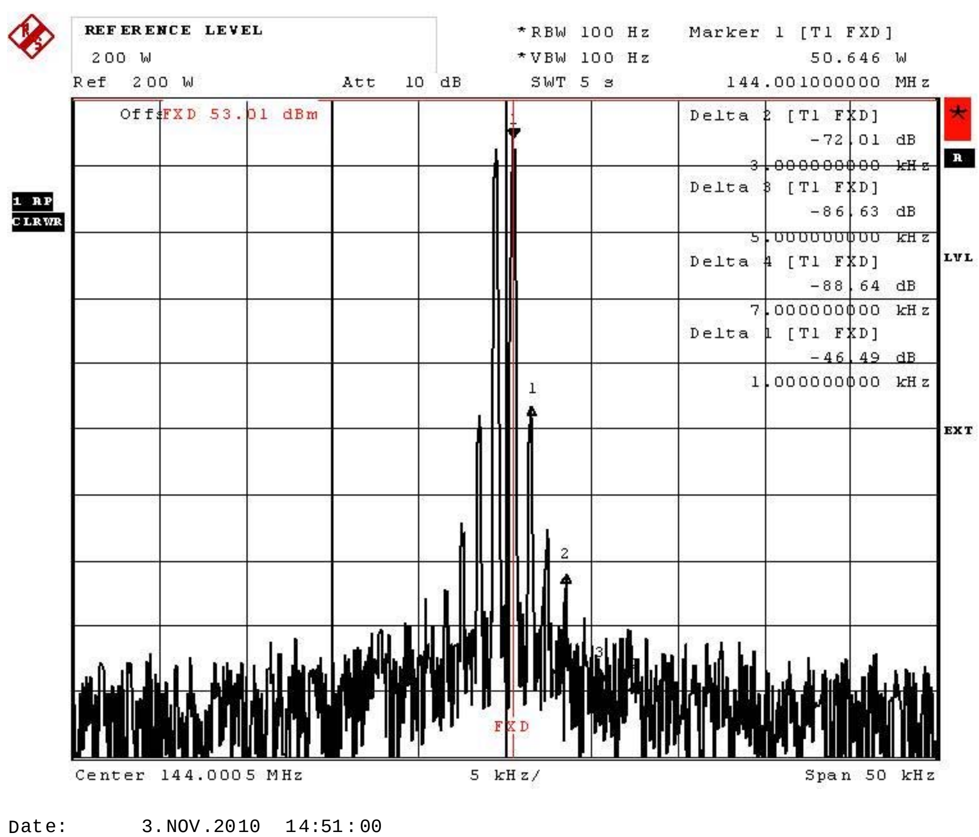


Figure 10. 200 W Two‐Tone Spectrum

HARMONIC MEASUREMENTS

At the one kW level, second harmonic is −42 dBc, third harmonic is −32 dBc, and fourth harmonic is −37 dBc.

To be used “on the AIR” this amplifier will likely need a filter to be compliant with local regulations. A diplexer could give better results than a simple low pass filter because harmonics are absorbed in a resistive load instead of being reflected to the transistor.

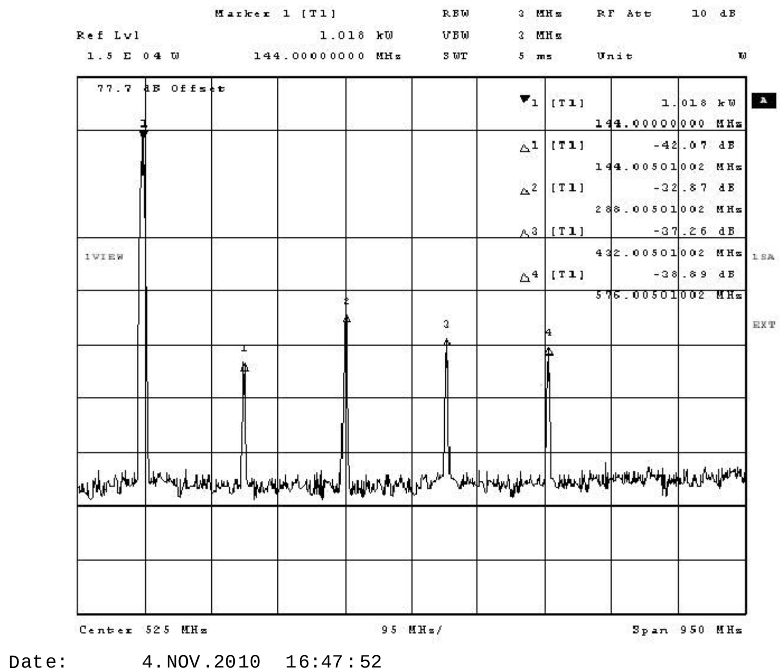


Figure 11. Harmonics @ 1 kW

FREESCALE RF POWER 50 V TECHNICAL ADVANTAGES

50 V Drain Voltage

50 volt operation offers benefits over lower voltage operation because the output impedance of the device for the same output power is much greater, so the output match circuitry is simpler and has lower loss. IMD performance is better and supply current will also be lower than with low voltage operation.

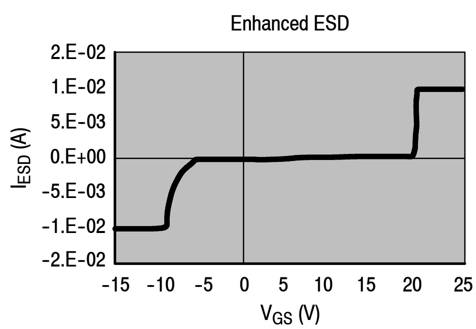
The reference fixture was designed with the market standard power supply, allowing the amplifier to utilize a standard 48 volt power supply (most are adjustable from 43 to 54 volts).

Extended Gate Voltage Range

The enhanced electro−static discharge protection structure at the gate of the transistor is a Freescale innovation pioneered in the cellular infrastructure market that is incorporated into the 50 V LDMOS RF power product portfolios. This ESD structure can tolerate moderate reverse bias conditions applied to the gate lead up to −6 volts (see Figure 12). This allows Freescale transistors to be used in applications where the gate voltage needs to be set as low as −6 volts.

This feature can dramatically simplify protection circuits, as it allows the transistor to be shut down because of high VSWR or PLL unlock without shutting down the drive power.

Setting the gate bias voltage to around −4 volts will totally block the transistor even if the RF input signal is still there.



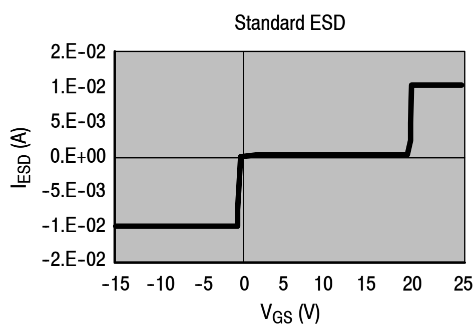


Figure 12. Gate Voltage Breakdown with ESD

Ruggedness

MRFE6VP61K25H is a very rugged part capable of handling 65:1 VSWR, provided thermal limits are not exceeded.

It was designed for high mismatch applications, such as laser and plasma exciters, that under normal operation exhibit high VSWR values at startup and then come back to a more friendly impedance. In CW at high VSWR values and simultaneously at rated power, the limiting factor is the maximum DC power dissipation.

VSWR protection that shuts down the gate voltage within 10 ms will protect the transistor effectively.

The amplifier presented here was tested at full power with all phase angles with 10 ms pulsed 5% duty cycle without failure or degradation in RF performance.

Reliability

MTTF is defined as the mean time to failure of 50% of the device within a sample size, the primary factor in device reliability failure is due to electromigration. Once average operating condition for the applicatin is set, MTTF can be calculated using the R_{th} found on the offical Freescale data sheet.

Example: If desired operating output power is 1000 watts, with 82% drain efficiency at 43 volts:

- I_{Drain} @ 1 kW 82% eff = 28.2 A
- MRFE6VP61K25H R_{th} = 0.15°C/W, case temperature = 63°C
- Dissipated power = 219 Watts
- Temperature rise (junction to case) = 219 Watts × 0.15°C/W = 32.8°C
- $T_J = T_{rise} + T_{case}$ = 63°C + 32.8°C = 95.8°C

Utilizing the graph below which cacluates MTTF versus I_{Drain} and $T_{J;}$ I_{Drain} = 28 A, MTTF for this example was 8000 years.

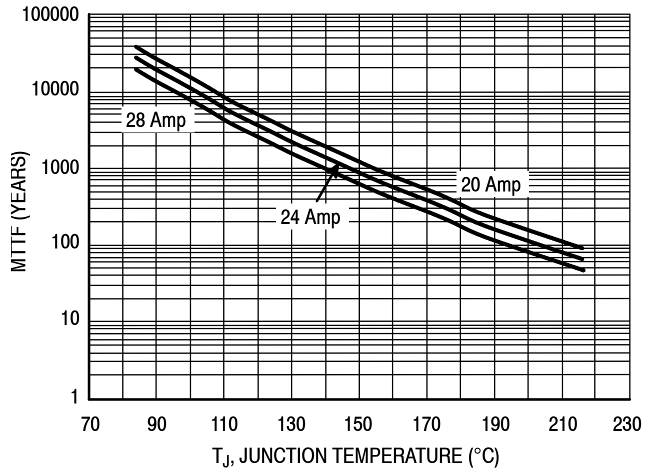


Figure 13. MTTF versus Junction Temperature

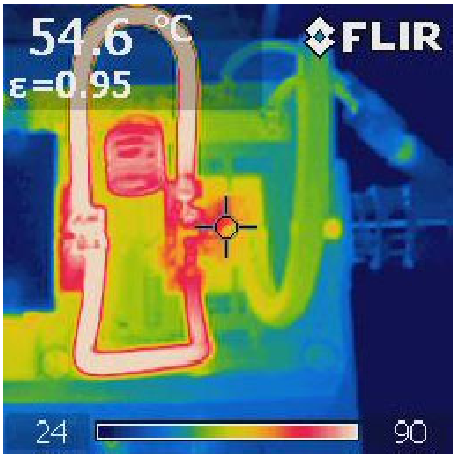
There is an MTTF (Median–Time–To–Failure) calculator(3) available to assist the customers in estimating the MRFE6VP61K25H device reliability in terms of electromigration wear–out mechanism.

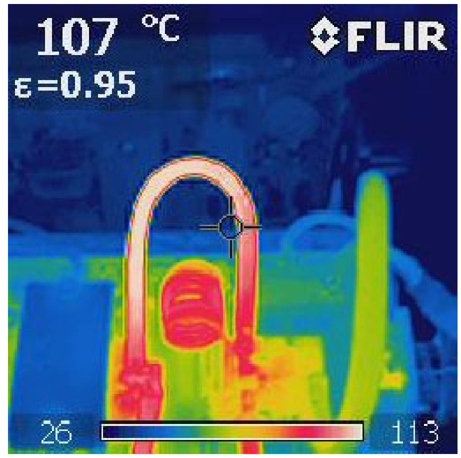
THERMAL MEASUREMENTS

After one minute at 1 kW CW 44 volt supply at 80% efficiency, with no airflow on the top of the board, the output capacitor matching runs at 55°C, and the 10 Ω coax section is around 90°C.

After 5 minutes “key down” CW, the highest temperature is 113°C on the 10 Ω coax section (Teflon cable is rated up to 200°C), output match capacitors do not show signs of overheating.

If the board is run at levels higher than 1 kW CW or digital mode, airflow over the top side of the board could help to cool down coax and improve reliability.





As shown in Figure 14, the board was painted with black coating to correct for variations in emissivity

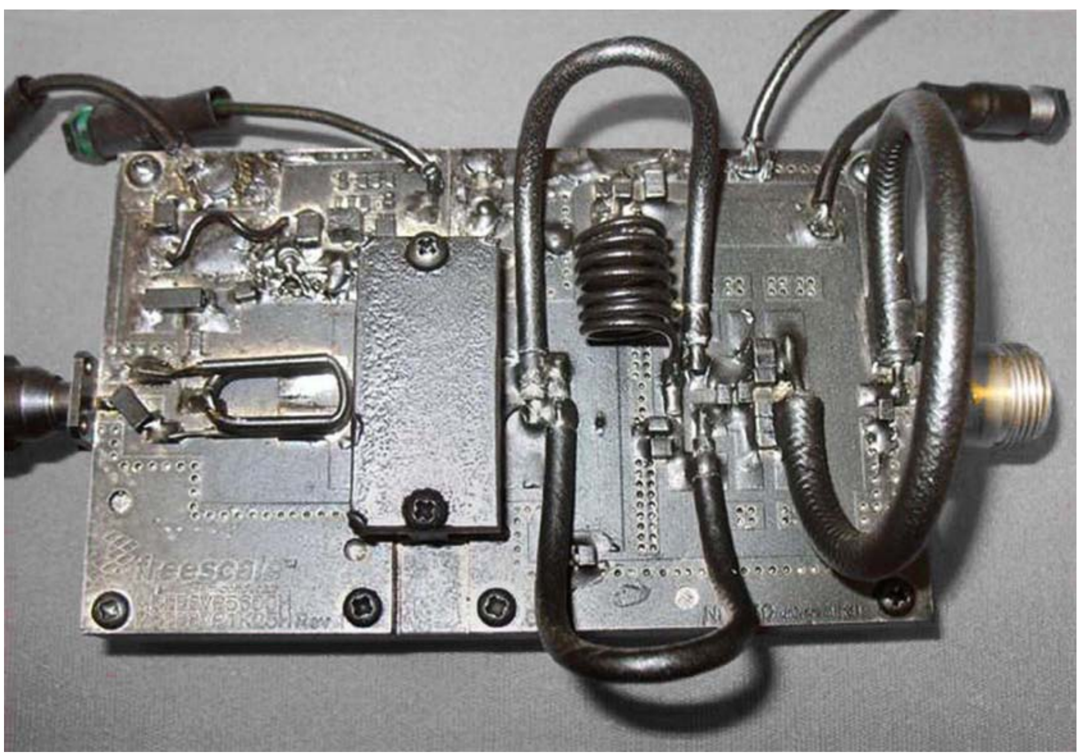


Figure 14. Reference design with black coating needed to obtain accurate thermograph images

REFERENCES

1. "RF LDMOS Power Modules for GSM Base Station Application: Optimum Biasing Circuit." (Document Number: AN1643) Application Note, 1998.
2. VHF Broadcast Reference Design available at http://freescale.com/RFbroadcast > Design Support > Reference Designs.
3. MRFE6VP61K25H MTTF calculator available at http://freescale.com/RFpower > Software & Tools > Development Tools > Simulations and Models > Calculators. Enter the "part number" into the Search field for quickest results.
4. "Mounting Recommendations for Copper Tungsten Flanged Transistors." (Document Number: AN1617) Application Note, 1997.

Technical documentation, including data sheets and application notes, for Freescale RF Power product can be found at: http://freescale.com/RFpower. Enter the applicable Document Number into "Keyword" search for quickest results.

APPENDIX A

Cautions

The board drive level is very low and excessive drive level will destroy the transistor. If used with a transmitter, be careful with your power control as some transmitters have very high power spikes at startup due to a badly designed ALC. It is a better idea is to put a power attenuator ahead of this amplifier to protect against overdrive.

APPENDIX B

Mounting Tips

An Arlon TC350 PCB was chosen for its high thermal conductivity.

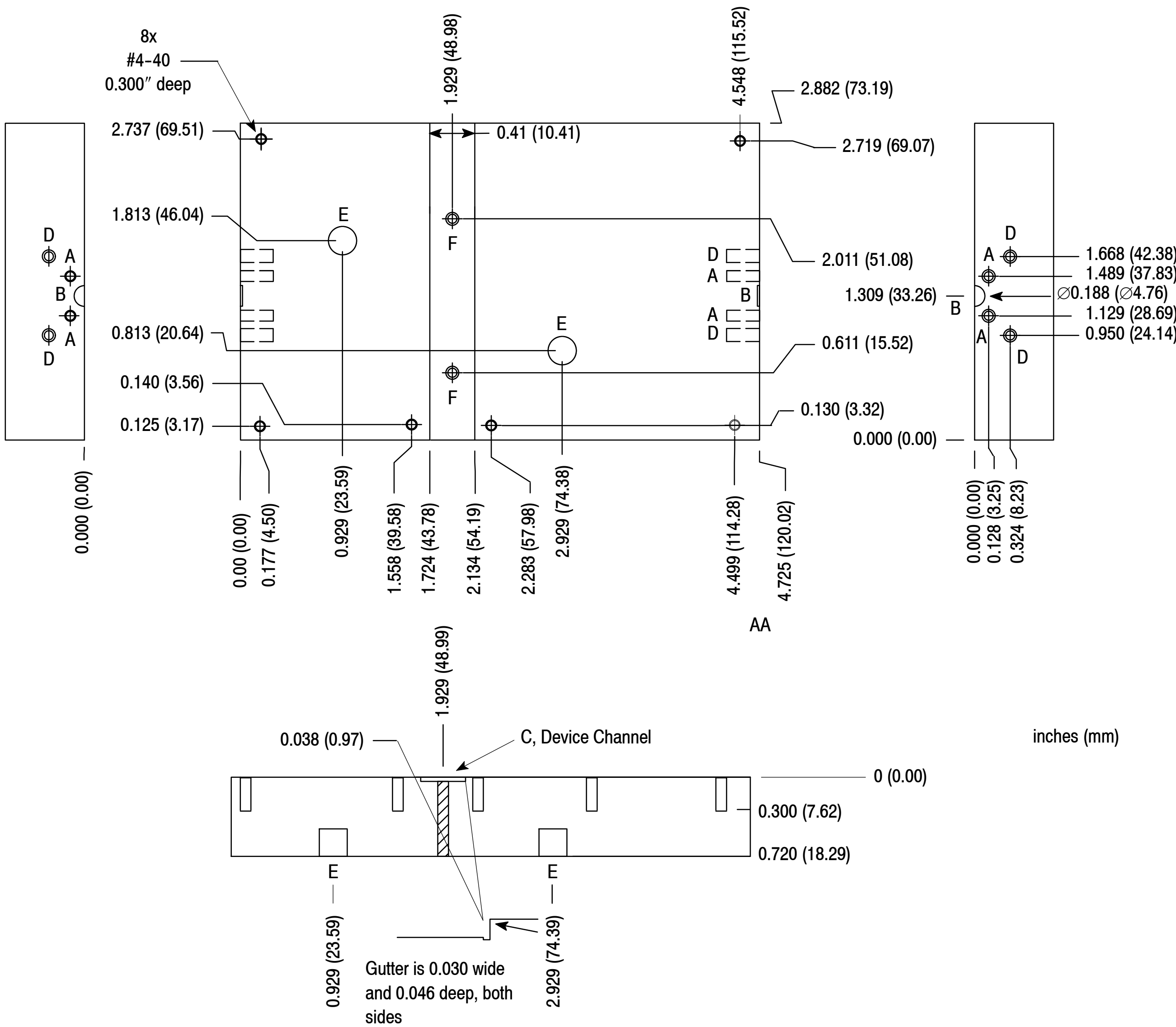
Mounting is done on a copper heat spreader. Flatness under the transistor flange is critical; good flatness is mandatory for both RF and thermal performance. The transistor is mounted on the heat spreader using a thin layer of thermal compound.

When using bolt-down mounting do not over-torque the part. Over tightening the fasteners can deform the transistor flange and degrade both the RF and thermal performance, as well as long term reliability.

To reach optimum performance, the PCB must be soldered to the copper heat spreader. This is usually done using a hotplate and solder paste. It is critical that the soldering near the transistor and connectors is free of voids and is of high quality in to order to achieve best performance and reliability.

Refer to Freescale's AN1617 *Mounting Recommendations for Copper Tungsten Flanged Transistors* application note for more information.[4]

Copper Heatsink for 2 Meter Amateur Fixture



0.720″ Copper Heatsink Hole Details

Designators	Details
A	2 places, both sides, drill and tap, #2-56 screw depth 0.300″
B	2 places, both sides, 0.1875″ diameter notch 0.020″ deep
C	NI-1230 channel 0.410″ wide by 0.0380″ deep
D	2 places, both sides, drill depth 0.250″ and tap for #4-40 screw
E	Locator holes from bottom diameter = 0.257″, depth = 0.400″
F	2 places, drill through and tap for #4-40 screw

Figure 15. Heatspreader Design

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