Get 1.5 kW from a New RF MOSFET: A Legal Limit HF Linear, Tokyo Style

Legal limit output power on all amateur MF and HF bands from a pair of RF power MOSFETs in push-pull configuration.

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More than two decades have passed since Motorola introduced their T-MOS RF power FETs. Helge Granberg, K7ES, described a 1.5 kW amplifier using those transistors for *QEX* readers.[1] Since then, devices equivalent to the Motorola MRF150 as well as other new devices have been developed by several semiconductor manufacturers. Among them there is one interesting device called the ARF1500 developed by Advanced Power Technology, Inc of Bend, Oregon, USA (**www.advancedpower.com**). This device has a 500 V drain-to-source breakdown voltage rating and 1500 W of power dissipation capability. After looking at this specification, we thought a full-legal-limit HF power amplifier would be possible without any power combining. After many experiments, we have succeeded in designing a compact push-pull broadband amplifier with 1.5 kW output over 1.8 to 30 MHz.

The ARF1500 package has a unique construction, very different from conventional high power RF power transistors. Instead of the conventional ceramic package and copper-tungsten flange, a large rectangular plastic molded cover and a special base material are used. The base material is berylia (beryllium oxide — BeO) ceramic. It is a very good electrical insulator with very low thermal resistance, between that of copper and aluminum. It conducts the dissipated heat away from the transistor into the heat sink on which it is mounted. BeO is lethal if inhaled so you must never scratch the bottom surface.

Some excellent features of the ARF1500 are as follows:

• *High power*: It has a high enough power-handling capability that a single push-pull amplifier can build a practical amplifier with one kilowatt minimum output.

• *High voltage*: With a breakdown voltage rating of 500 V, the operating voltage can be at least two times higher than conventional RF devices. At the higher voltage, the drain impedance is much higher and the performance is less subject to dc power supply regulation, greatly simplifying the design of the power supply.

• *High current*: The maximum drain current specification is 60 A, a wide SOA (safe operating area) can be expected. This, along with the high V_{dd} rating, makes it much more rugged than conventional power devices.

In addition, the internal structure is optimized for stable RF and dc performance. The mounting surface area is much larger than conventional transistors and this greatly facilitates heat sinking.

On the other hand, some tough points in the application are:

• *Low input impedance*: With 5000 pF of input capacitance, the gate input impedance becomes so low that matching it over a wide frequency bandwidth is much more difficult than with lower power devices.

• *Peripheral components selection*: The higher RF current will cause more heat generation due to the I^2R losses in the passive components used around the ARF1500. Capacitor dielectric loss, magnetic saturation and heat dissipation of ferrite cores, etcetera must all be carefully considered.

• *Heat-sink design*: Due to the high dissipated power in the devices, the heat sink and cooling system must be very efficient to keep the junction temperature of the ARF1500 below a reasonable limit.

We set a design goal for a single stage push-pull pair of ARF1500s as follows:

Output power: 1.5 kW.

Frequency range: 1.8 ~ 30 MHz (amateur

[1]Notes appear on page 13.

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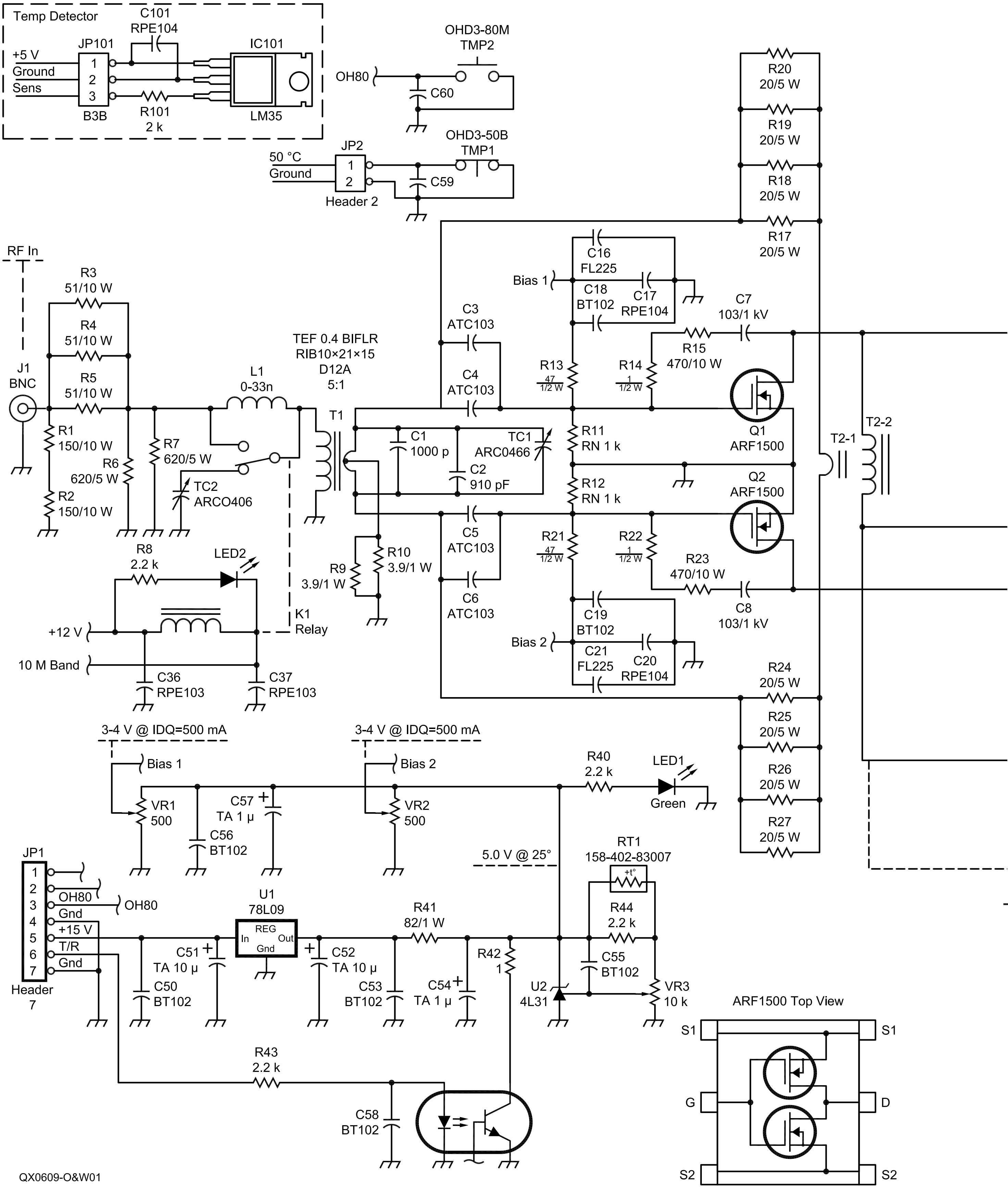
Temp Detector
C101
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R20
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R4
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R5
51/10 W
J1
BNC
C16
FL225
Bias 1
C18
BT102
C17
RPE104
C7
103/1 kV
C3
ATC103
TEF 0.4 BIFLR
RIB10×21×15
D12A
5:1
L1
0-33n
R15
470/10 W
R13
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1/2 W
R14
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1/2 W
C4
ATC103
T1
R1
150/10 W
R7
620/5 W
R6
620/5 W
C1
1000 p
TC1
ARC0466
C2
910 pF
R11
RN 1 k
Q1
ARF1500
T2-1
T2-2
Q2
ARF1500
R12
RN 1 k
TC2
ARCO406
R2
150/10 W
C5
ATC103
R21
47
1/2 W
R22
1
1/2 W
R8
2.2 k
LED2
R10
3.9/1 W
R9
3.9/1 W
R23
470/10 W
C6
ATC103
C8
103/1 kV
K1
Relay
+12 V
C19
BT102
Bias 2
C21
FL225
C20
RPE104
10 M Band
C36
RPE103
C37
RPE103
R24
20/5 W
R25
20/5 W
3-4 V @ IDQ=500 mA
3-4 V @ IDQ=500 mA
Bias 1
Bias 2
R40
2.2 k
LED1
Green
R26
20/5 W
VR1
500
C57
TA 1 µ
VR2
500
C56
BT102
R27
20/5 W
JP1
5.0 V @ 25°
RT1
158-402-83007
+t°
1
2
3
4
5
6
7
OH80
Gnd
+15 V
T/R
Gnd
OH80
U1
78L09
REG
In
Out
Gnd
R41
82/1 W
R44
2.2 k
C51
TA 10 µ
C52
TA 10 µ
R42
1
C55
BT102
Header
7
C50
BT102
C53
BT102
C54
TA 1 µ
U2
4L31
VR3
10 k
ARF1500 Top View
S1
S1
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R43
2.2 k
C58
BT102
QX0609-O&W01

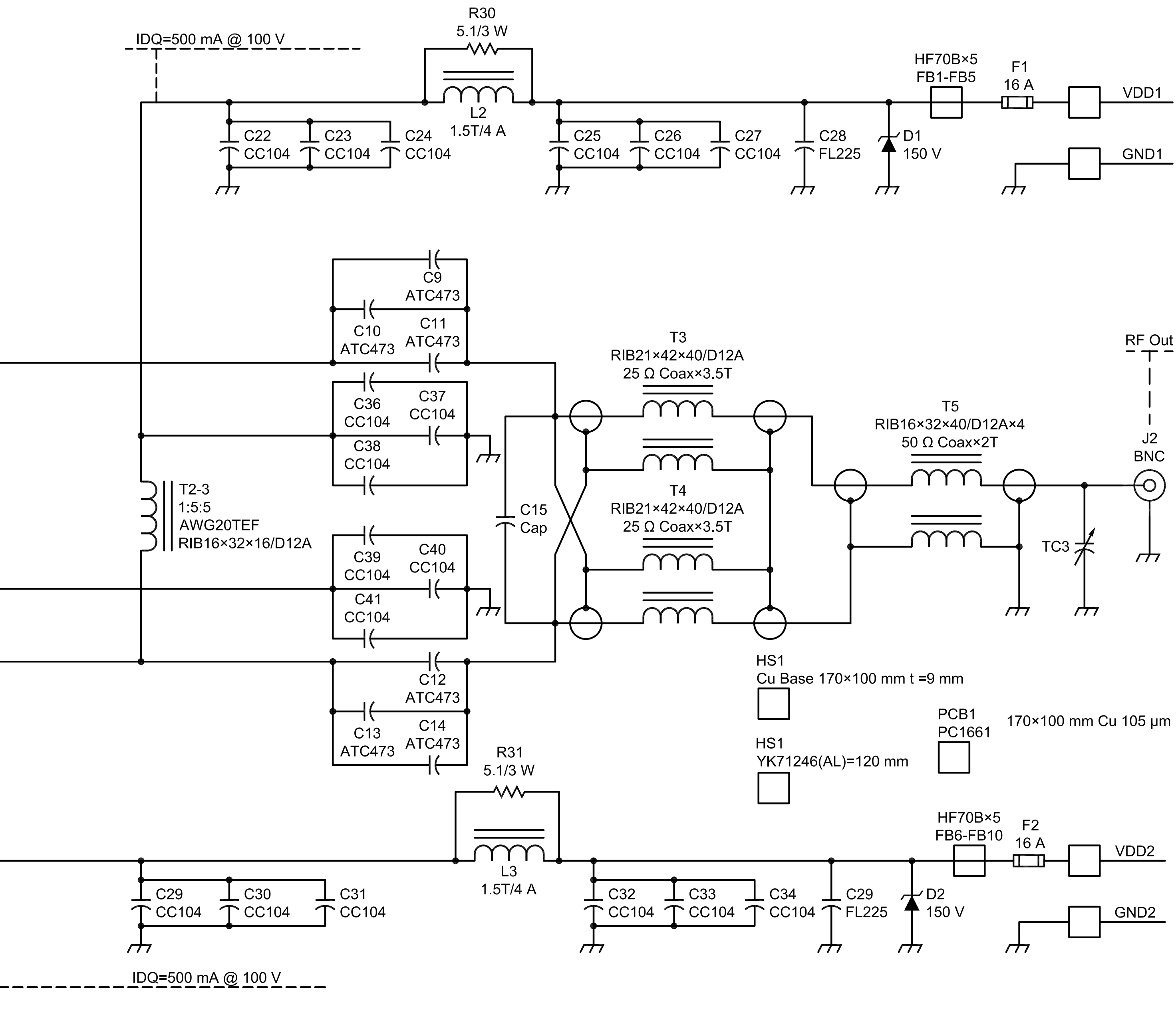

Figure 1 — Schematic diagram of the ARF1500 amplifier.

bands 160 m-10 m)

Power gain: 13 dB minimum.

DC supply voltage (V_{dd}): 100 V dc.

Efficiency: 40% minimum.

The Input Circuit Design

Refer to Figure 1, a schematic diagram of the amplifier. The input circuit of this amplifier has a distinctive feature and has been designed with some calculations and estimations as stated below. See Table 1 for the ARF1500 input/output impedances, as given on the data sheet.[2]

Table 1
Input Impedance versus Output Impedance

F (MHz)	Z_{in} Ω	Z_{out} Ω
2.0	6.7 – *j*12	7.5 – *j*0.8
13.5	0.45 – *j*2.5	7.1 – *j*1.7
27	0.22 – *j*0.67	6.1 – *j*3.0
40	0.2 + *j*0.19	5.0 – *j*3.6

From that data, we made an approximate calculation to obtain an estimated equivalent series input circuit with the following parameters:

C_{in} = 4,800 pF

R_{in} = 30 Ω

R_s = 0.2 Ω

L_s = 3.5 nH

That is a rough approximation and it is

advised that readers should not directly apply the above data parameters for *SPICE* simulation.

With those impedance characteristics it is almost impossible to design an input network that is entirely flat over the desired frequency range. After various experimental tries, and taking R_s and L_s into account, we have incorporated the following features in the design:

1) Input transformer T1 has a 5:1 winding ratio for low impedance drive.

2) At the high-frequency band edge, on 10 m, a tuned matching network is inserted to compensate for the device input capacitance and the inductance of printed circuit board patterns.

3) At the low-frequency end, gain and input impedance are lowered using negative feedback.

4) At midband, impedance matching and gain are improved by resonating the transformer leakage inductances with the coupling capacitors to form a broad series resonance.

5) Drain-to-gate RC feedback is applied directly on each ARF1500 to suppress low-frequency gain and further control the gate impedance.

Using these techniques, the input SWR is < 2:1 and the amplifier is stable and flat over 2 to 28 MHz. It still had plenty of gain, so a 3-dB attenuator was added on the input. This lowers the input SWR below 1.5:1, sets the maximum gain at 13 dB, within regulatory limits, and also protects the amplifier from overdrive.

Circuit Description

Under the conditions of V_{dd} = 100 V and P_{out} = 1500 W, the 12.5-Ω drain-drain load requires a 1:4 impedance ratio on the output transformer. This easily obtained ratio also provides, from our experience, the best broadband performance and efficiency. We have employed a transmission line type transformer, followed by a floating balun to enhance the symmetrical characteristics of the push-pull circuit. A conventionally wound "bead and tube" type transformer may be used in place of this output transformer chain at lower cost and lower performance.

The T2 secondary has a four-turn bifilar winding of AWG 20 wire. This transformer has a minimum inductance requirement for feeding the drains and the winding ratio provides most of the feedback as mentioned above. The mutual coupling between the primary and secondary windings is particularly important. To maximize the coupling, brass tubing was used for the negative feedback (NFB) winding. High permeability (μ_i) ferrite core material was selected to achieve high inductance per turn. The ferrite used for this application has a μ_i of 250 and a high Curie temperature. The core size should be relatively small but with a large cross-sectional area. Note that the primary winding center tap is isolated.

The RF voltage at the drains is divided by eight by the dc feed transformer (T2) turns ratio and is fed back to the gates through the feedback resistors. This feedback controls both the gain and input impedance. This method also minimizes the heat dissipated in the feedback resistors.

Feeding DC Power

Special care has been taken on following points:

1) High current. Drain current reaches 30 A at peak. The printed circuit board pattern and windings in series with the dc supply circuit must all carry this current. To reduce current loading on the pc board pattern, the dc power feed is split between two channels. This also improves RF stability.

2) High voltage: 100 V dc is fairly high for a transistor circuit. The rated working voltage of most surface mount capacitors is usually 50 V or 100 V, not enough for this application. We also have to be careful with pattern spacings on the pc board and with the insulation (bulk resistivity) of the ferrite materials.

3) RF current: Most RF bypass capacitors, Z5U or X5V types, have a relatively high dielectric loss. Capacitors will overheat from the high RF current and burn up. For this reason, several capacitors are placed in parallel to split the bypass and coupling currents. These capacitors should be placed and grounded close to the FET source leads. The ideal decoupling choke will have small internal loss and no in-band resonance points. A Q-damping resistor may improve the total stability in some cases. Improperly designed decoupling circuits can often induce a parasitic oscillation. Electrolytic capacitors may explode with RF current applied. Low-loss film capacitors are recommended for large bypass capacitance values.

4) Surge protection: Transient high voltage spikes may be generated when switching the amplifier supply on and off. Surge absorbing Zener diodes have been inserted at the dc input terminal area.

5) Fuse: For safety, fast-acting, self-extinguishing fuses are suggested — high voltage types, not slow-blow.

Gate Bias Supply Circuit

The dc bias supply is constructed separately from the main dc power supply. A simple circuit is often seen where only a potentiometer is used to provide the necessary gate voltage. For this amplifier, a regulated and thermally compensated voltage supply provided the best performance. The FET gates have both RF and dc present. Special care is taken to provide a well-filtered low source impedance. Otherwise the bias voltage can become RF-modulated resulting in degraded IMD performance.

Although MOSFETs are generally considered to have high impedance characteristics, we have designed the impedance of the bias supply circuit as low as possible. A TL 431 regulator IC provides both voltage regulation and temperature compensation. The thermistor value was determined by a series of cut and try experiments. This compensation may take much time and should be done cautiously. It needs an adequate temperature time constant. If its thermal response is too fast it can lead to over compensation, which will cause distortion. The ideal case is to use a matched pair with the MOSFET V_{th} and g_m parameters matched within ten percent. However, in the ARF1500's construction, the g_m is controlled and you may compensate for V_{th} characteristics of the devices you have obtained by adjustment of the bias controls. A solid state opto-isolator is connected in parallel with the bias supply circuit to obtain a high speed shutdown function as well as a means to remove bias during receive.

Attenuator Circuit

An attenuator on the input provides gain adjustment overall and improves the input SWR. After considering the total gain requirement, 3 dB was chosen. The attenuator must be able to dissipate 50 W. Thin film power resistors in the rugged TO-220 heat sink package were used in this experimental model. Even with all the efforts with feedback and the input attenuator, the input SWR was still unacceptable on 10 m. We added a 10-m impedance matching section inserted by relay between the attenuator and input transformer T1. It is switched at the same time as the 10-m low-pass filter.

Output Harmonics Filter

To remove the unwanted harmonics, six low-pass filters follow the PA stage. Five-element Chebyshev low-pass filters and five-branch elliptic filters were satisfactory for this purpose. Design data are available in the *ARRL Handbook*, *IRE Transaction on Circuit Theory 1958*, and other references.

Final adjustment and trimming of LPF elements are usually required to obtain the best results.

1) To optimize the output power and efficiency.

2) To keep the harmonics within the FCC limits.

3) To keep the in-band output power flatness reasonable.

LPF capacitor elements should be carefully selected for the working voltage and currents. In our experimental model, newly developed chip mica capacitors with 1,000 V rating were used. (These are from Soshin Electric, Japan.)

Printed Circuit Board

The PC board used is glass epoxy, double sided with 1-oz copper foil (4 mil, 105 µm thickness). In designing the circuit pattern, one should carefully design with regard to both RF loss and dc resistance. The island area for source leads should be as large as possible. The back side should be a continuous ground plane to achieve the maximum amplifier stability.

Heat Sink Design

An aluminum heat sink with a thermal

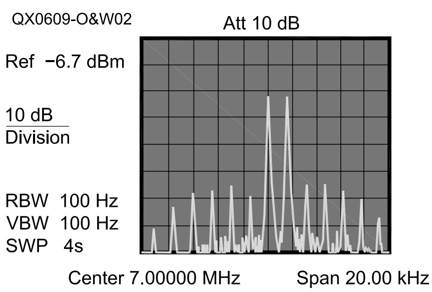

Figure 2 — This spectrum analyzer photo shows the IMD performance of the amplifier.

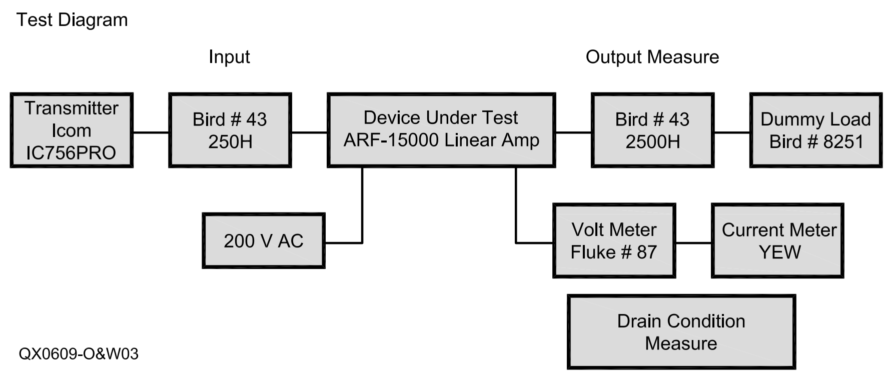

Figure 3 — This diagram shows the test-equipment setup used to measure the performance of the ARF-1500 amplifier.

Table 2
ARF-1500 Linear Amplifier Characteristics
Frequency versus P_{in} - P_{out} Characteristics

Frequency / *Input Power (W)*	*1.8 MHz*	*3.5 MHz*	*7 MHz*	*10 MHz*	*14 MHz*	*18 MHz*	*21 MHz*	*24 MHz*	*28 MHz*
	Output Power (W)								
10	230	220	220	220	250	280	340	200	300
20	440	400	400	420	490	500	600	380	600
30	638	580	540	650	720	730	860	550	800
40	800	750	700	850	880	950	1050	700	980
50	950	897	850	1000	1060	1080	1250	850	1120
60	1100	1030	990	1160	1220	1200	1400	950	1230
70	1220	1150	1150	1350	1350	1300	1550	1070	1320
80	1310	1280	1300	1600	1520	1480	1700	1200	1430
90	1350	1380	1470	1800	1650	1600	1800	1300	1500
100	1400	1470	1600	2050	1800	1750	1980	1450	1600

Table 3
ARF-1500 Linear Amplifier Characteristics, 1.8 MHz

Input Power (W)	*Output Power (W)*	*Drain Voltage (V)*	*Drain Current (A)*	*Drain Input (W)*	*Efficiency (%)*	*Drain Dissipation (W)*
0	0	127.3	0.6	76.38	0	76.38
10	230	117	7.4	866	27	636
20	440	114	10	1140	39	700
30	638	110	12.6	1386	46	748
40	800	109	14	1526	52	726
50	950	108	16	1728	55	778
60	1100	106	17.8	1887	58	787
70	1220	105	19.5	2048	60	828
80	1310	104	21	2184	60	874
90	1350	103	22.5	2318	58	968
100	1400	101	24.5	2475	57	1075

resistance of 0.05°C/W is forced-air cooled by a high-pressure muffin fan. The sink's tight-pitch bonded fins are relatively thin and a 9-mm 3/8-inch) thick copper heat spreader is used between the transistors and the aluminum heat sink. (Sink area = 170 × 100 mm, 6.7 × 4 inch.)

DC Power Supply

DC power is provided by a simple unregulated supply consisting of a hypersil type transformer, rectifier, and capacitor filter. Because the FETs have a 500-V breakdown voltage spec, we have plenty of voltage margin, so a regulated supply was not required

Table 4
ARF-1500 Linear Amplifier Characteristics, 3.5 MHz

Input Power (W)	*Output Power (W)*	*Drain Voltage (V)*	*Drain Current (A)*	*Drain Input (W)*	*Efficiency (%)*	*Drain Dissipation (W)*
0	0	127.3	0.6	76	0	76
10	220	117	7.6	889	25	669
20	400	113	10.8	1220	33	820
30	580	111	13.2	1465	40	885
40	750	109	15	1635	46	885
50	897	107	16.5	1766	51	869
60	1030	105	18	1890	54	860
70	1150	105	19.4	2037	56	887
80	1280	104	20.8	2163	59	883
90	1380	103	22	2266	61	886
100	1470	102	23.2	2366	62	896

Table 5
ARF-1500 Linear Amplifier Characteristics, 7 MHz

Input Power (W)	*Output Power (W)*	*Drain Voltage (V)*	*Drain Current (A)*	*Drain Input (W)*	*Efficiency (%)*	*Drain Dissipation (W)*
0	0	127.3	0.6	76	0	76
10	220	115	8.9	1024	21	804
20	400	112	12	1344	30	944
30	540	109	14.9	1624	33	1084
40	700	107	16.8	1798	39	1098
50	850	105	18.8	1974	43	1124
60	990	104	20	2080	48	1090
70	1150	102	21.5	2193	52	1043
80	1300	102	23	2346	55	1046
90	1470	100	24.2	2420	61	950
100	1600	100	25.6	2560	63	960

Table 6
ARF-1500 Linear Amplifier Characteristics, 10 MHz

Input Power (W)	*Output Power (W)*	*Drain Voltage (V)*	*Drain Current (A)*	*Drain Input (W)*	*Efficiency (%)*	*Drain Dissipation (W)*
0	0	127.3	0.6	76	0	76
10	220	114	9.8	1117	20	897
20	420	111	13.2	1465	29	1045
30	650	107	16.3	1744	37	1094
40	850	105	18.8	1974	43	1124
50	1000	103.8	20.5	2128	47	1128
60	1160	102	22.2	2264	51	1104
70	1350	101	24	2424	56	1074
80	1600	99	25.5	2525	63	925
90	1800	99	27	2673	67	873
100	2050	97	28.8	2794	73	744

for this application. The filter capacitor is 18,000 μF / 160 V. A solid state relay switches the primary ac line and a power thermistor solves the inrush current problem.

Cooling Fan

The high air-volume muffin fan is powered from the dc drain voltage supply. When the ac switch is turned off, the energy in the filter capacitor is bled off by the cooling fan and works as a delayed off-time cooler.

Protection Circuits

If the heat sink temperature reaches the maximum limit, the T/R system is shut down by a high-temperature thermostat at 70°C. The amplifier is shut down if the reflected RF power exceeds the limit. (270 W P_{ref} = 2.49 SWR) The drain current is an important indicator of the amplifier status. The bias voltage supply is shut down if the drain

Table 7
ARF-1500 Linear Amplifier Characteristics, 14 MHz

Input Power (W)	Output Power (W)	Drain Voltage (V)	Drain Current (A)	Drain Input (W)	Efficiency (%)	Drain Dissipation (W)
0	0	127.3	0.6	76	0	76
10	250	112	10.8	1210	21	960
20	490	109	14.8	1613	30	1123
30	720	105	18	1890	38	1170
40	880	103.9	20	2078	42	1198
50	1060	102	22.2	2264	47	1204
60	1220	100.8	24	2419	50	1199
70	1350	99	25.5	2525	53	1175
80	1520	98.8	27	2668	57	1148
90	1650	97	28.5	2765	60	1115
100	1800	96	29.8	2861	63	1061

Table 8
ARF-1500 Linear Amplifier Characteristics, 18 MHz

Input Power (W)	Output Power (W)	Drain Voltage (V)	Drain Current (A)	Drain Input (W)	Efficiency (%)	Drain Dissipation (W)
0	0	127.3	0.6	76	0	76
10	280	114	12.5	1425	20	1145
20	500	110	16.5	1815	28	1315
30	730	107	20.4	2183	33	1453
40	950	105	22.5	2363	40	1413
50	1080	103	25	2575	42	1495
60	1200	101	26.5	2677	45	1477
70	1300	98.6	28	2761	47	1461
80	1480	98	29.8	2920	51	1440
90	1600	97.8	30	2934	55	1334
100	1750	96	32	3072	57	1322

Table 9
ARF-1500 Linear Amplifier Characteristics, 21 MHz

Input Power (W)	Output Power (W)	Drain Voltage (V)	Drain Current (A)	Drain Input (W)	Efficiency (%)	Drain Dissipation (W)
0	0	127.3	0.6	76	0	76
10	340	113	11.8	1333	25	993
20	600	110	15.8	1738	35	1138
30	860	107	19	2033	42	1173
40	1050	105	21.5	2258	47	1208
50	1250	103	23.2	2390	52	1140
60	1400	101	25	2525	55	1125
70	1550	100	26.5	2650	58	1100
80	1700	99	28	2772	61	1072
90	1800	99	29	2871	63	1071
100	1980	96	30	2880	69	900

current exceeds a certain limit (27 A). This is done using a high speed opto-coupler rather than conventional fuses. The dc supply is protected by 30-A fuses in case of a short circuit.

Since the drain voltage supply is not regulated, the supply cannot shut down easily if drain dc voltage exceeds the limit. With a 500-V limit on the MOSFETs, however, the

Table 10
ARF-1500 Linear Amplifier Characteristics, 24 MHz

Input Power (W)	*Output Power (W)*	*Drain Voltage (V)*	*Drain Current (A)*	*Drain Input (W)*	*Efficiency (%)*	*Drain Dissipation (W)*
0	0	127.3	0.6	76	0	76
10	200	115	10	1150	17	950
20	380	111	14	1554	24	1174
30	550	108	16.7	1804	30	1254
40	700	106	19	2014	35	1314
50	850	105	20.8	2184	39	1334
60	950	103	22.1	2276	42	1326
70	1070	102.7	23.8	2444	44	1374
80	1200	100.6	25.5	2565	47	1365
90	1300	99.6	26.5	2639	49	1339
100	1450	99	28.4	2812	52	1362

Table 11
ARF-1500 Linear Amplifier Characteristics, 28 MHz

Input Power (W)	*Output Power (W)*	*Drain Voltage (V)*	*Drain Current (A)*	*Drain Input (W)*	*Efficiency (%)*	*Drain Dissipation (W)*
0	0	127.3	0.6	76	0	76
10	300	115	10	1150	26	850
20	600	111	13.6	1510	40	910
30	800	109	16	1744	46	944
40	980	107	17.5	1873	52	893
50	1120	106	19	2014	56	894
60	1230	105	20	2100	59	870
70	1320	104	21	2184	60	864
80	1430	103	22	2266	63	836
90	1500	103	22.5	2318	65	818
100	1600	102.8	23	2364	68	764

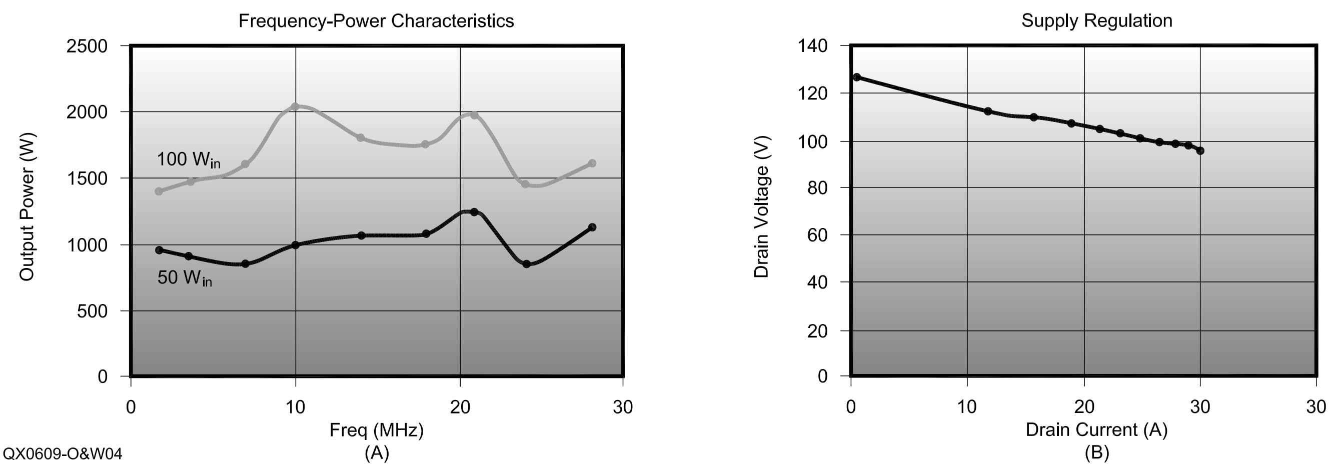

Figure 4 — Part A is a graph of the measured amplifier output power across the amateur bands from 1.8 to 28 MHz. Input powers of 50 W and 100 W are shown. Part B compares the transistor drain current versus drain voltage.

150-V Zener diode clamp is enough to protect the other components from any transient spikes that might come past the supply filtering.

Details of Major Components

T1 Input Transformer

Ferrite core material: Tomita Electric (See **www.tomita-electric.com/enghp** or **www.tomita-electric.com/pdf/RIB_RIType.pdf**), RIB 10 × 21 × 15,

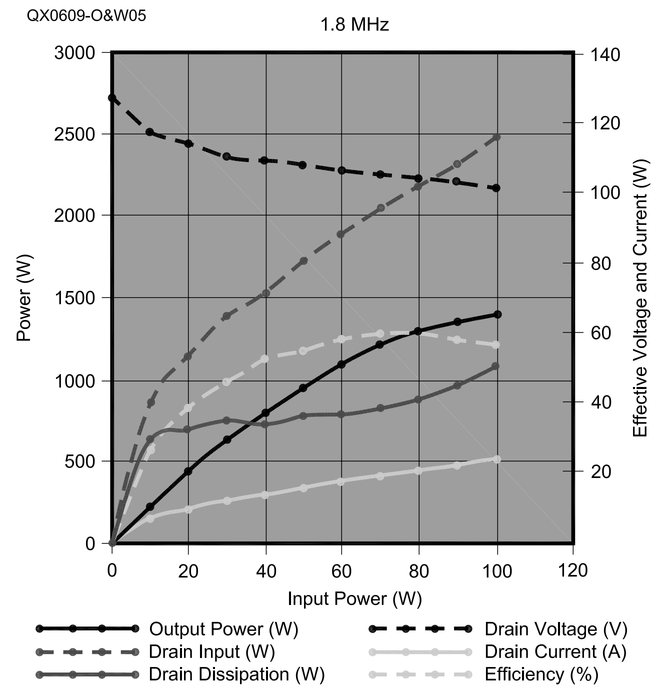

Figure 5 — This graph shows the amplifier characteristics on the 160-m band (1.8 MHz).

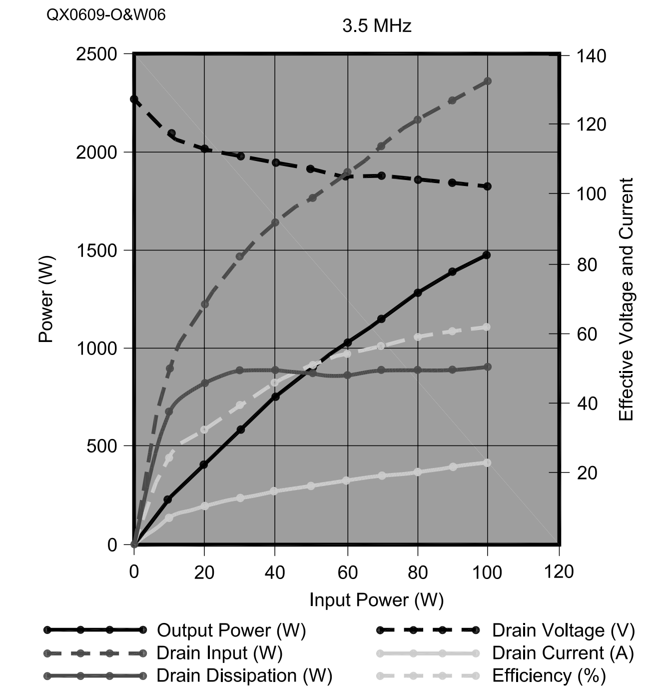

Figure 6 — This graph shows the amplifier characteristics on the 80-m band (3.5 MHz).

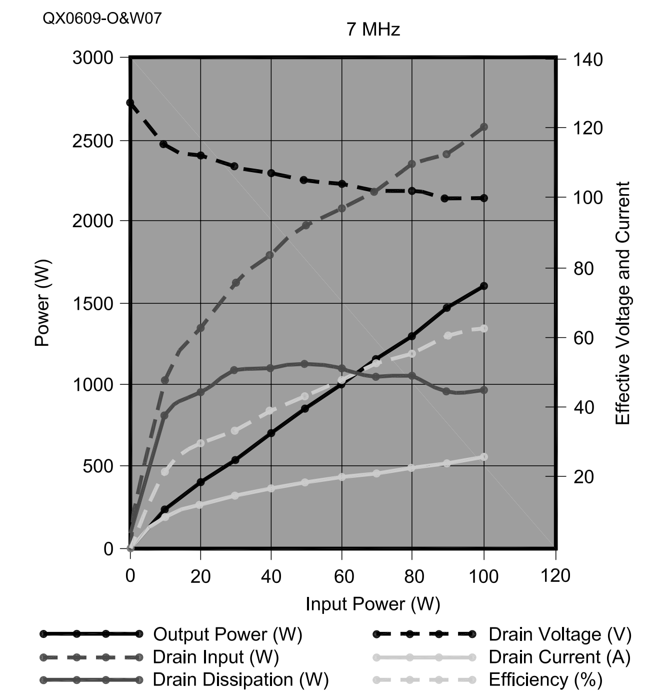

Figure 7 — This graph shows the amplifier characteristics on the 40-m band (7 MHz).

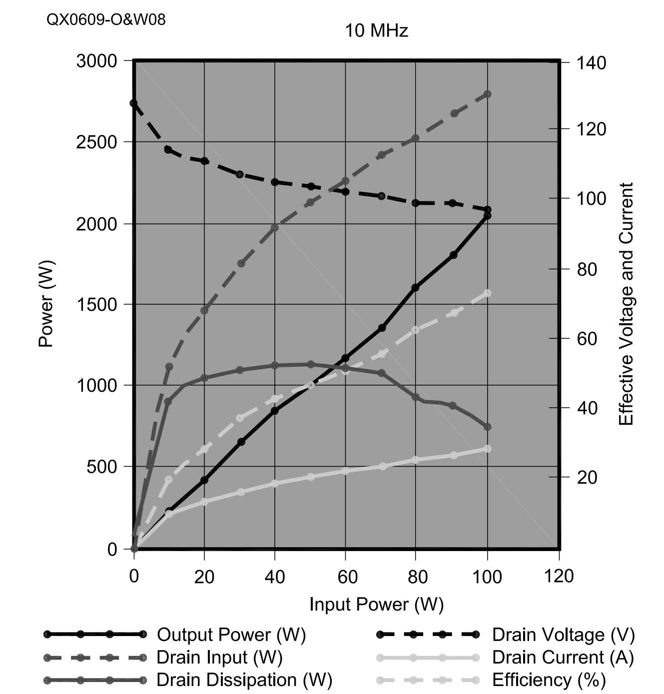

Figure 8 — This graph shows the amplifier characteristics on the 30-m band (10 MHz).

Material D12A, 2-hole balun core.
Primary winding: 5 turns 0.4 mm diameter (AWG no. 26) Teflon wire.
Secondary winding: Brass tube 5 mm diameter, 18.5 mm long, 0.3 mm wall.

T2: DC Supply Transformer

Ferrite core: Tomita RIB 16 × 32 × 16, D12A, 2-hole balun core.
Drain winding: 4 turns bifilar AWG no. 20 Teflon wire.
NFB winding: Brass tube 8 mm diameter, 21 mm long , 0.8 mm thickness.

T3, T4 Output Transformers

Ferrite core: Tomita RIB 21 × 42 × 40, D12A, 2-hole balun core.

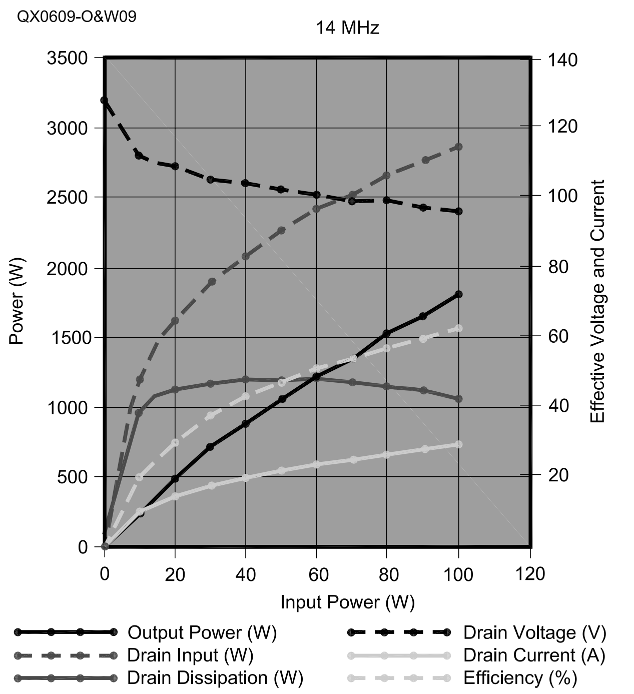

Figure 9 — This graph shows the amplifier characteristics on the 20-m band (14 MHz).

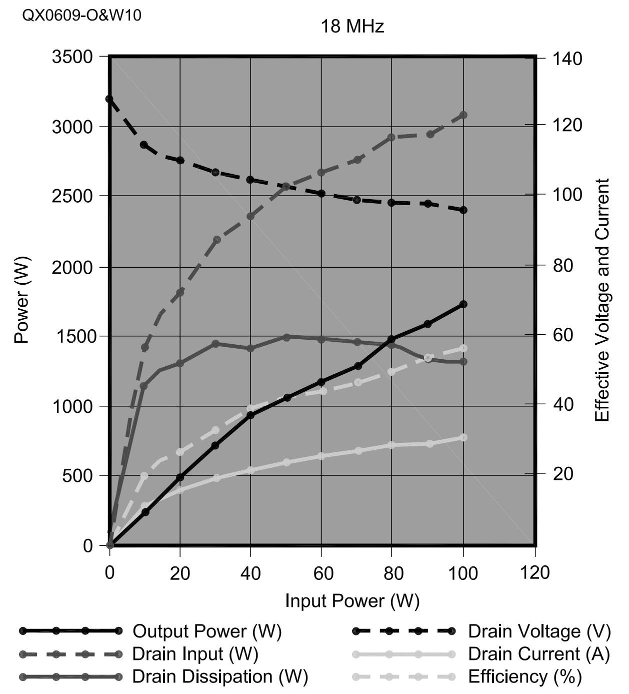

Figure 10 — This graph shows the amplifier characteristics on the 17-m band (18 MHz).

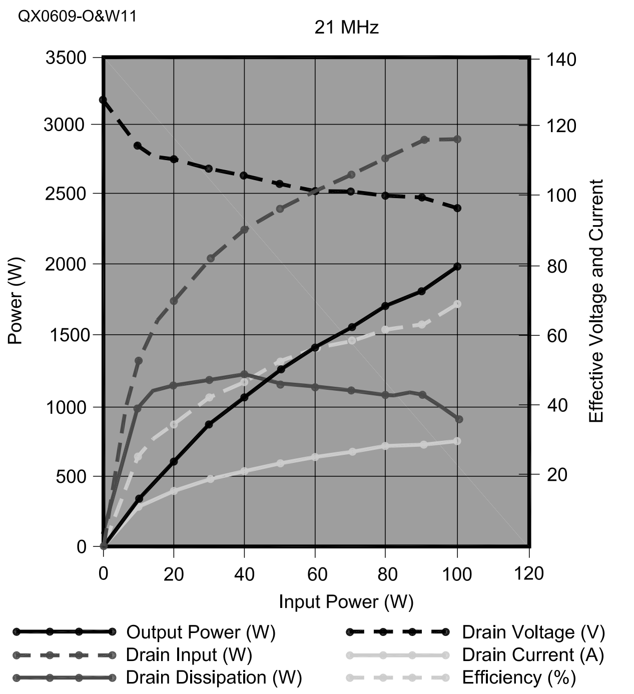

Figure 11 — This graph shows the amplifier characteristics on the 15-m band (21 MHz).

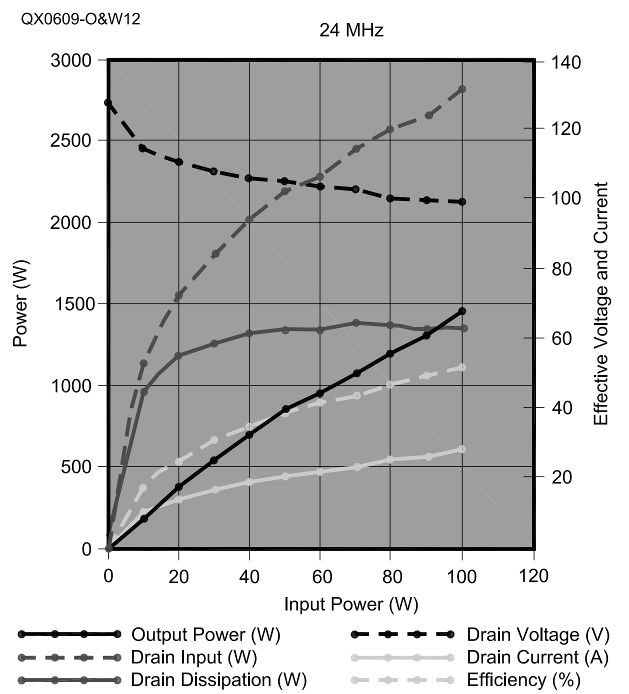

Figure 12 — This graph shows the amplifier characteristics on the 12-m band (24 MHz).

Winding: 3.5 turns of 50 cm long 25 Ω Teflon coaxial cable, DFS014 by Junkohsha, Japan.

T5: Output Balun

Core: 4 pieces Tomita RIB 16 × 32 × 16, D12A, 2-hole balun core.

Winding: 2 turns of 50 Ω Teflon coax cable, DFS040 (RG-303).

L2, L3 Choke Coil

Core: Tomita RIB 8 × 14 × 13, 4 A material 2-hole bead.

Winding: 1.5 turns of AWG no. 20 Teflon wire.

Capacitors

C3-C6 Input coupling: ATC ceramic chip 900C103MW300.

C9-C14 Output coupling: ATC ceramic chip 900C473MW250.

CC104, all: 0.1µF 250 V Murata ceramic chip GHM2145X7R104MAC250.

Conclusion

The circuit described in this article demonstrates a simple 1.5-kW HF amplifier built with a pair of the latest MOSFET devices. Figure 2 shows IMD performance. Table 2 summarizes the input power and output power of the amplifier across the Amateur MF and HF bands. Figure 3 shows the test set-up for the performance measurements we made. Further performance data by band are shown in Tables 3 through 11. Figures 4 through 13 show the corresponding graphs of the performance data.

The authors would like to express a word of gratitude to Mr. Richard Frey, K4XU, and Mr. Bert Butz, DJ9WH, for their kind advice given to us during the experiments.

Notes

[1]Helge Granberg, K7ES, "A compact 1-kW 2 - 50 MHz Solid-State Linear Amplifier," *QEX*, July 1990, pp 3 - 8. (Reprinted as Motorola Application Report AR-347)

[2]ARF1500 Data sheet, Advanced Power Technology, Inc. **www.advancedpower.com**.

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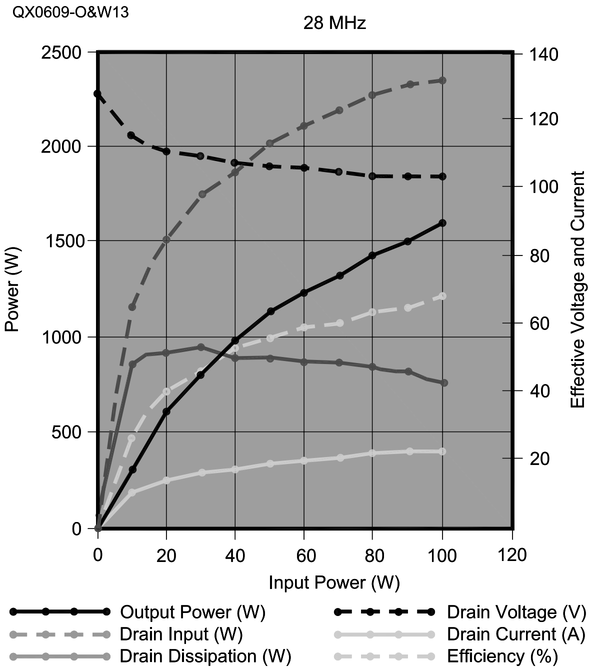

Figure 13 — This graph shows the amplifier characteristics on the 10-m band (28 MHz).

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