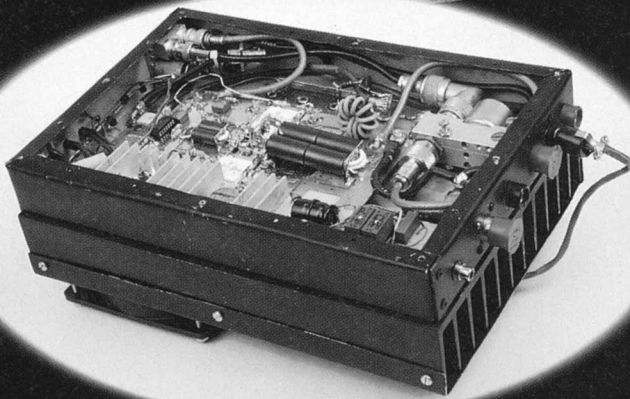


An Experimental Solid-State Kilowatt Linear Amplifier for 2 to 54 MHz

Many kilowatt amplifiers could anchor a small boat, and don't cover 6 meters. Combined with its power supply, *this* kilowatt weighs less than 35 pounds.

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After seeing N6AMG's story about this project in the 1991 Central States VHF Conference Proceedings, we thought QST readers would like to read about the SSKW, an amplifier constructed to prove that a small, compact package can produce significant RF power. Although many details remain to be worked out before the SSKW can move out of its role as an experimental DXpedition amplifier to more mainstream applications, it has already played well under tough away-from-home conditions. This article also spotlights the 6-meter DXpeditioning the SSKW makes more successful.

This article describes progress toward achieving a well-defined goal: building the smallest possible MF/HF/VHF amplifier capable of at least 1000 watts output. Nicknamed the Solid State Kilowatt (SSKW), the project has its roots in an article by Helge Granberg of Motorola in October 1986 *RF Design*.¹ Two water-cooled amplifiers of that design, built by Mike Staal (K6MYC) of M², had many problems. Some of them were device-related; others, power-supply related. (More about these issues later.) In February 1990 I rebuilt one of the water-cooled units using the old design and two new transistors. Optimized for 50 MHz, this amplifier could just reach the 1000-watt level. After using it for three weeks of South Pacific DXpeditioning, I decided to construct an air-cooled unit. I spent the spring, summer and fall of 1990 building the SSKW and getting it ready for

another DXpedition in the fall.

Circuit Description

Motorola's article reprint AR-347 describes the basic amplifier design. July 1990 *QEX* also carried an article about it.² Fig 1 shows the amplifier schematic. Briefly, the circuit consists of two MRF154 RF power MOSFETs in push-pull. Each of these transistors is capable of 600 watts output up to 100 MHz. The input and output transformers, 9:1 and 1:9, respectively, use cores of #67 ferrite material. The output transformer's 1:9 ratio is a compromise that is optimum at about 800 watts.

Incorporating the Motorola building block into a DXpedition-ready package required experimentation and problem-solving, as I described at the 1991 Central States VHF Conference.³ Here's where the system stands today.

TR Switching

The SSKW includes TR relays that

bypass the Fig 1 circuitry in receive mode. I designed their control circuitry to eliminate the possibility of the high RF fields in the amplifier compartment causing relay falsing problems, and to simplify field repair by keeping parts count low. The relays are sequenced to allow the output relay to close before the amplifier puts out power. Because relays take a few milliseconds to operate, sequencing is necessary to keep the relay from hot-switching the amplifier output. (Hot-switching 1 kW will destroy a relay rapidly!)

This design has two small problems. For the short time it takes the amplifier's input relay to close on switching from receive to transmit, the exciter operates without a load. This can be remedied by delaying the exciter keying. The other problem is the relay's closure time changes as the relay heats. This can be solved two ways: Use external electronics to do the delay, or temperature-compensate for the resistance change.

¹Notes appear on page 23.

6-Meters: DXpeditioning with a Difference

Making the most of 6-meter DXpeditioning depends on knowing where and when to go. If you want to work Europe from the Canary Islands, summertime is best because sporadic-E propagation is best then. If you want to work the US from EA8, go when fall shifts into winter to take advantage of east/west F₂-layer propagation. It's always more exciting to go to a rare place, but not necessarily more fun!

Once you've decided on a DXpedition site, plan your travel on the assumption that you'll want to stay on site for at least two weeks. This gives you about a 50% better chance of having good openings within a given month.

Pay particular attention to the RF prospects of your accommodations. Ideally, you'd be able to see ocean in all directions. If that's not possible, all's not lost. A direct oceanic path isn't always the best; propagation may be better over the backscatter path. You'll want to get your antenna up as high as possible to minimize radiation angle and RFI. And consider EMI and TVI possibilities *carefully*. Some areas of the world use NTSC channel 2; others, PAL on channel 1—right in the middle of the band! If your RF gets into a resort's CATV system you'll drive 60 televisions crazy rather than one or two.

Chapter 6 of *The ARRL Operating Manual* covers DXpedition power, health, licensing and logistical concerns in detail, so see that book for more about those topics. I'll add one thing, though: It helps to find a local ham, with FAX capability as well as HF, who can help you with questions on licensing and living accommodations.



The author's setup at CN2JP, Rabat, Morocco. Efficiency counts more than neatness while you're busy making 900 contacts on 6 and 20 on 2-meter EME! (DXpedition photos courtesy of the author)

This can take 80% of the surprises out of the expedition!

Equipment

What I bring and use on 6-meter DXpeditions is based largely on the experiences of Jim Treybig, W6JKV, in his many years of 6-meter DXpeditioning. The core of the approach is pretty much this: Run as much power as permitted and bring as big an antenna as possible. There are practical limits to this, but let your ingenuity direct your thoughts. I consider 100 W as a minimum, 500 watts good, and 1000 watts as optimum. High power lets you take advantage of scatter paths that simply won't work at 100 watts. It's very frustrating to hear a well-equipped station that you cannot work!

Which Antenna?

A DXpedition antenna must be compact, light and reproducible. The Yagi I use has six elements on a 30-foot boom. Optimized by Brian (K6STI) Beezley's Yagi optimization program YO, it's fed with a T match and a half-wave balun. Its boom folds down to two 40-inch sections, each 2 inches in diameter. Most of the element pieces fit inside the two 40-inch sections. The antenna is light enough to lift with one hand.

A rotatable antenna is *mandatory*. You'll need to turn your antenna to find the best direction of propagation. The antenna mast, 20 feet long overall, consists of 40-inch sections of 2-inch aluminum tubing joined with internal sleeves. The rotator is at the *most bottom*, and there's a slip ring at the mast top, just below the Yagi. (Having the



DXpeditioning would be no fun at all without antenna work!

SWR Protection

I haven't yet built SWR protection into the amplifier. In January 1983 *QST*, Helge Granberg described an SWR-protection circuit for a 2- to 30-MHz amplifier.⁴ A phone conversation with Helge indicated that this circuit will work to 54 MHz, so it should suffice. How much mismatch the MRF154s can tolerate is unknown, however, so I don't want to use the SSKW to calibrate its own SWR-protection circuitry!

The amplifier's output can be reduced two ways: by turning down the exciter power via amplifier-generated ALC, or by reducing the amplifier bias. (These are enhancement-mode FETs, so positive bias is necessary to turn them on.) The ALC option is better because it does not affect

the amplifier's linearity. A no-output-load condition must shut down the amplifier as quickly as possible.

Overdrive Protection

Overdrive can destroy power MOSFETs instantly, so a drive limit control is essential. A threshold detector should be incorporated. The SSKW's input includes a 5-dB attenuator so 100-watt exciters can drive the amplifier without damaging it. If the 5-dB pad fails to attenuate, or if the exciter puts out too much power, the amplifier must be shut down rapidly.

The amplifier must also be shut down if the transistors' flange temperature exceeds 40 °C. Shutdown can be done two ways, depending on how the amplifier is used. The first way is to just turn down the bias,

which changes the amplifier's linearity. The second way is to totally turn off the amplifier. This must be done gracefully so the amplifier does not shut down while producing full power. The following shutdown sequence is essential: (1) Turn down the bias; (2) open the input relay; and (3) open the output relay.

Bias

The SSKW's bias circuitry is straightforward. R8's value must be tailored to the particular MRF154s used. If the bias decreases too fast with rising temperature, increase the value of R8. The LM723's input voltage must never exceed 40 volts.

Output Filtering

Filtering *must* be added to make the

rotator at the bottom makes putting the antenna up easier by minimizing weight at the upper end of the mast.)

I use Dacron rope for guying. How much rope should you take? Simple: Estimate what you need, multiply by 2.5 and you *might* make it! I usually bring two diameters, 3/16 and 1/8 inch.

Radios

Bring at least two radios: one for HF liaison (usually at 10 meters) and another for 6 meters. I recommend maximizing redundancy by taking two radios that *both* cover 10 and 6. At least one of the 6-meter rigs should include an excellent noise blanker for power-line problems and motorbikes. It must also be able to drive a kilowatt amplifier to full output on 6. (I use one Kenwood TS-680S and one ICOM IC-575.) Receive coverage between 10 and 6 meters is another plus. Where it's allowed, listening to nonamateur services between 45 and 50 MHz can be very important in determining the direction of propagation.

Additional Gear

Bring 12-volt supplies capable of operating at the line voltage and frequency at your DXpedition destination. The supplies should also be able to handle wide line-voltage variations around nominal. Carry two of them—one for each radio. I modify mine by adding line filtering and fusing. Parallel a standard receptacle of some kind with your supplies' rig plug or cable. Two-prong, polarized Jones plugs work well. You can use them on everything for quick setup and breakdown.

Bring a memory keyer for use as a beacon and in normal CW operation. Also consider taking a laptop computer. I now use a computer for logging, taking notes, calculating beam headings, and determining the footprint of the sun.

Operating

Several operating subjects are of prime importance. Ten-meter liaison comes first. You must use 10 meters to get up-to-date propagation information and find out who's being heard. When you're feeling your way through a pile of stations, you can sometimes miss very rare propagation opportunities if you don't check 10 meters often.

Six-meter contact procedures come next. It's very difficult making everyone happy on 6 meters when you're the DX. You must set rules and stick to them. Pick a frequency and do your best to keep it when the band gets busy. Try to not work the same stations over and over again, especially during pileups. *Your goal is to give as many people as possible a new country.* Work each station as quickly as possible. Don't discuss names and grid squares—the time it takes just gives fewer people a



DXpeditioning is also about meeting people. Here's Tarik Skiredj, CN8ST, and friends.

chance to work you. Leave that info to the QSL cards!

Which should you operate—phone or CW? The answer is "Probably both." CW penetrates weak conditions better than phone, and it gives more people at the edge of propagation a chance at working you. Then, when you go to phone, everyone who can will work you again. I favor CW DXpedition operation because of my experiences on the non-DX end.

Should you operate on a single frequency or split? Go to split when there's a massive opening and you're being QRMed by people calling you. This usually happens during intense backscatter openings. Hams on the 10-meter liaison frequency can tell you when QRM gets too heavy.

Conclusion

Six-meter DXpeditioning is a blast. And the SSKW makes it even more fun: I can devote more weight to antennas!—N6AMG

amplifier comply with FCC signal-purity regulations. The reactance of these filters away from their intended passbands must be taken into account. Absorptive low-pass filters should be considered. Such filters dissipate harmonic energy as heat rather than reflecting it back to the amplifier transistors.

Packaging

I intended to make this amplifier as small and light as possible. Most of the amplifier's weight is its aluminum heat sink and copper heat spreader. How much heat sinking is needed depends on the duty cycle required. I decided that a duty cycle of 50% or less was acceptable. The resulting weight for the package, 14 pounds, is *very* acceptable. The SSKW is 8 inches wide, 12 inches long and 5 inches high.

The key to making the package light was to use the smallest possible heat spreader. I decided to use enough 1/4-inch-thick copper to surround each MRF154 with at least 1 inch of spreader. I machined the spreader flat and attached it to the heat sink, also machined flat. After attaching the copper to the aluminum, I resurfaced the copper again at the transistor contact points to insure flatness. I spread a thin layer of heat-sink compound between the copper and aluminum, and another layer between the copper and the transistors.

With two high-pressure, 24-volt fans blowing on the sink, the resultant duty cycle limit is a little less than 50%. These fans are in series across the amplifier's 50-volt supply. The small fan in the compartment is a 12-volt unit that just barely fits. (The compartment needs to be a little

deeper.) A fan is necessary here, however, because compartment airflow dramatically keeps the output transformer's ferrite from getting hot.

A heat sink with more fins and a thicker base, but the same fin depth, would raise the duty-cycle limit. (The copper spreader should be made larger as well.) These changes would also make the amplifier heavier.

Construction Techniques

A milling machine is required for surfacing all of the amplifier's heat-conductive interfaces. Physical flatness is essential for maximum heat conductivity and to avoid warping the transistor cases. The Motorola bulletin specifies the torque of the screws on the MRF154s' flanges. Tightening these screws uniformly assures that the flanges

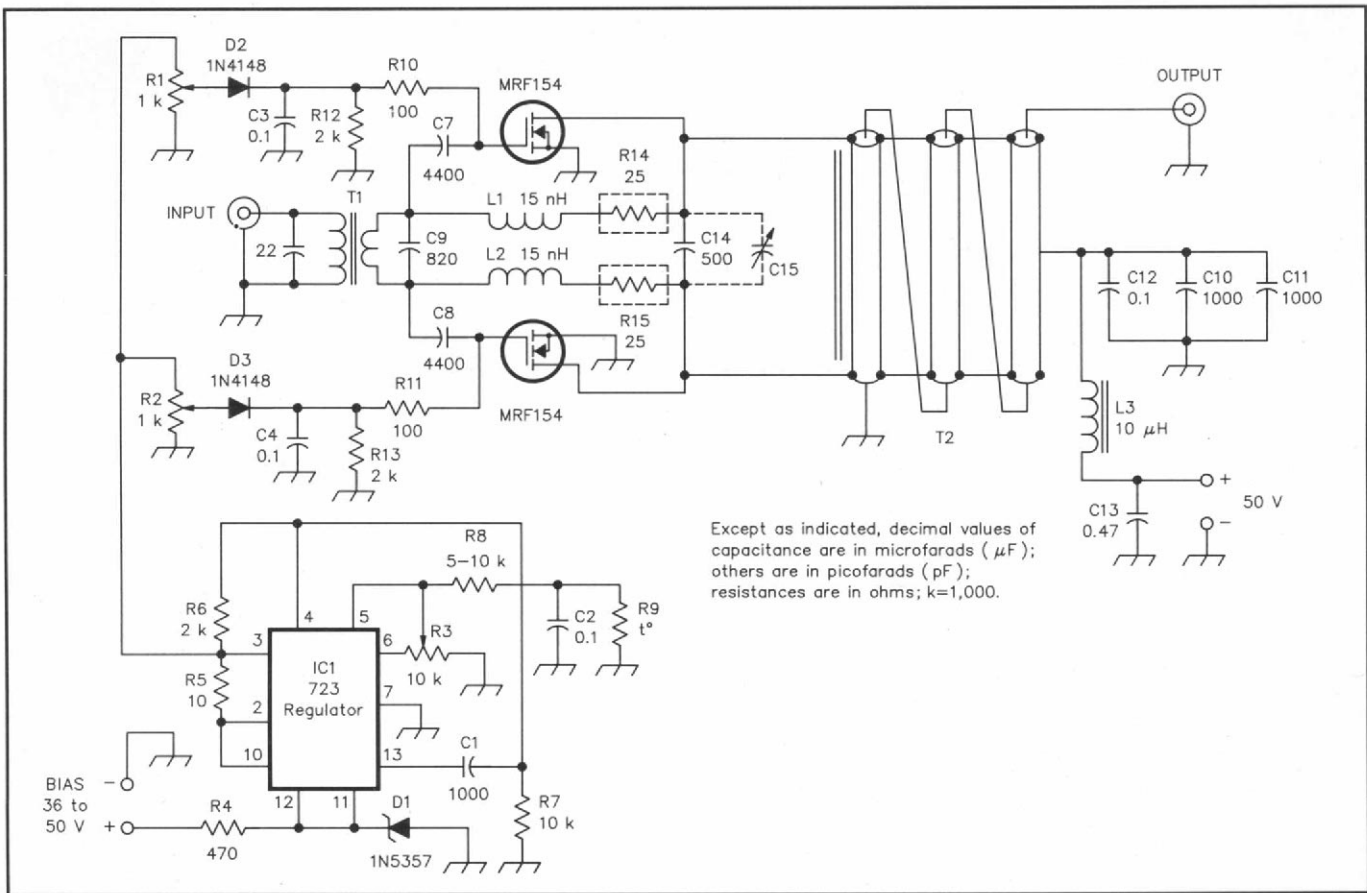


Fig 1—The basic SSKW circuit can produce at least 1 kW from 2 to 54 MHz. Duplicating this circuit requires additional information not given here. Output filtering is also necessary to ensure compliance with FCC emission-purity rules. See the text, Motorola Application Note AN-287, July 1990 QEX and the 1991 Central States VHF Conference Proceedings for details. The Central States write-up includes SSKW performance graphs and spectrograms in addition to a diagram of the amplifier's relay-control circuitry.

won't warp during temperature cycling.

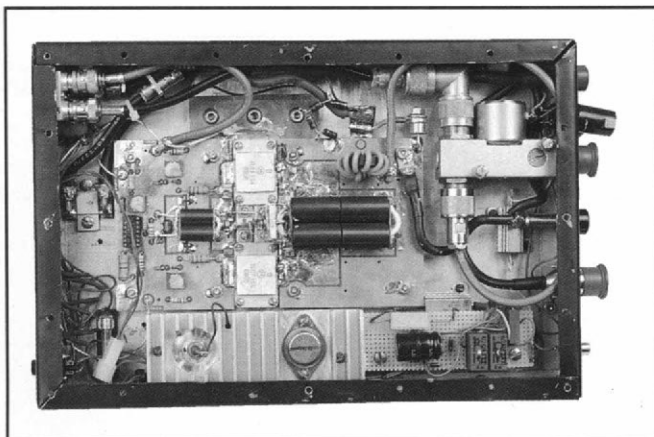
R14 and R15, the feedback resistors, are flange-mounted. Their beryllium copper leads cannot be flexed very many times before they break. (According to their manufacturer, that may be only once!) These two resistors just barely fit. So, make

sure the two MRF154s are separated properly.

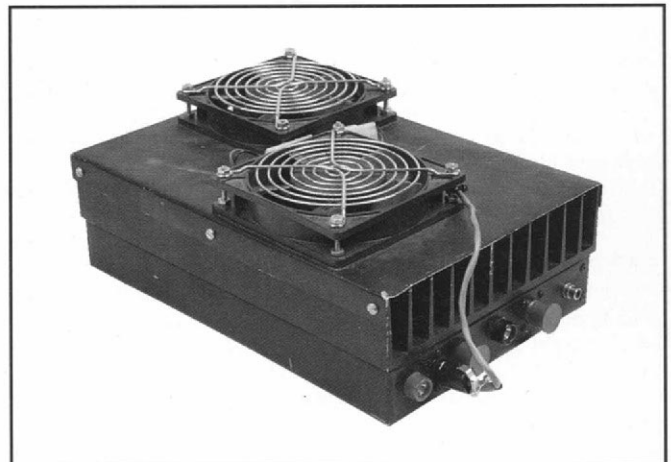
Power Supply

To keep the amplifier small and light, I use a switching power supply. A Lambda LFS-50-48 (net weight, 20 pounds) does the

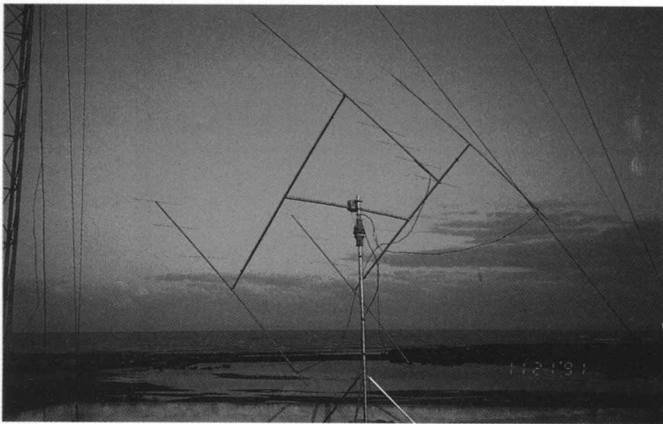
job, with good results. Sized at 15 inches long, 7.5 inches wide and 5 inches high, it can source 50 amperes at 50 volts. This power supply produces significant radio noise up to 30 MHz, most of it radiating from the supply's ac-line leads. I EMI-filtered the supply's leads with good suc-



Two Motorola MRF154 RF power MOSFETs in push-pull make the SSKW perk. A 20-watt exciter drives the amplifier to full output. (amplifier photos by Kirk Kleinschmidt, NT0Z)



Without its two 24-volt fans, the SSKW's heat sink and spreader would have to be much larger.



What luggage weight the SSKW amplifier conserves can be put to other uses—2-meter moonbounce gear, for instance. Operating as CN2JP, the author completed 20 EME contacts—Morocco's first—in November 1991. On the same trip, the SSKW performed like a heavyweight through 900 contacts with 56 countries on 6 meters.

cess. (We need better, RF-quieter switching supplies!) Because linear supplies generate little or no RF EMI, they are superior to switching supplies for fixed-station use.

Overshoot is a regulated power supply characteristic that's particularly troublesome in switching supplies. Overshoot occurs when a regulator responds too slowly to keep its output voltage down in response to short-duration, high-current loading. In a 50-volt switching supply, and depending on the load, overshoot transients of more than 100 volts may result. I've seen overshoot destroy expensive transistors! The SSKW supply must be able to safely handle the variable power-supply demand that occurs during SSB and CW transmission.

Power-supply RF sensitivity is another consideration. Some power supplies are sensitive to RF. Their output voltages may vary with the presence and amplitude of RF on their input and output leads. The SSKW's supply must be free of such effects.

Hints and Kinks

Be careful when applying dc to the amplifier for the first time. Do not use a high-current supply for initial tests. Use a current-limited, 3- or 4-ampere supply to check the regulator and set the bias. The amplifier should have a reverse polarity protection diode rated at a voltage appropriate to the supply.

Make sure that you have a 50-ohm load on the amplifier output. The bias circuitry may not act correctly if there is no load. Slowly increase drive. Watch the output power and the current drain to make sure they are in line with efficiency. If the input match is bad, check C7 and C8. If the amplifier does not achieve its efficiency capability, RF that doesn't make it to the load may try to leave via the dc input line. This can cause C12 to explode off of the underside of the board. Also, under normal operation, the single unit Motorola

specifies for C12 can barely handle the RF current that passes through it. I recommend paralleling 100-volt, 0.05- or 0.1- μ F chip capacitors instead of using a single 0.1- μ F chip.⁵ This problem is difficult to analyze because C12 is on the underside of the board.

As mentioned earlier, the SSKW's bias circuitry may have to be tailored to the particular MRF154s used. One thing not mentioned on the schematics is the addition of an Arco 365 variable capacitor (C15 in Fig 1) across C14 to cancel some of the inductive reactance in the output transformer at 6 meters.

Performance

With a 50-volt power supply, the SSKW can produce over 1.1 kW from 2 to 54 MHz. At this power level, the MOSFETs' drain current runs at around 40 amperes, depending on the operating frequency. Table 1 shows amplifier performance data taken at six different frequencies. The SSKW can produce up to 1.5 kW below 30 MHz.

Especially below 30 MHz, the SSKW's harmonic output rises with output power. It may be possible to use only four low-pass filters to cover the 2 to 54 MHz range if a second harmonic of -40 dB can be tolerated. Since the transistors operate in push-pull, the second harmonic is usually not a problem.

Without its 5-dB input pad and operating with a 50-volt supply, the amplifier exhibits an input SWR of less than 2:1 (referred to 50 ohms) throughout its frequency range. Only below 5 MHz does its input SWR exceed 1.6:1. Inserting the 5-dB pad adds 10 dB of return loss and keeps the input SWR below 1.3:1 through the amplifier's operating range. I have not yet measured the amplifier's two-tone, third-order IMD performance.

Final Notes

For now, I can say that my goal of a compact, lightweight amplifier capable of

Table 1
SSKW Performance Versus Frequency

Freq (MHz)	Drive Power (W)	Power Output (W)	I_D (A)	Gain (dB)	Efficiency (%)	Input SWR	V_{CC} (V)
2	24.5	1000	39.1	16.1	51.2	1.41	50
4	21.0	1000	33.4	16.8	59.9	1.39	50
8	17	1000	32.4	16.8	59.9	1.39	50
15	15.5	1000	32.3	17.7	61.9	1.36	50
30	19.5	1000	41.5	17.1	48.2	1.87	50
50	29	1000	39.7	15.4	50.4	1.51	50

at least 1 kW output is a reality. The SSKW has served me well in its intended DXpeditionary application. Nonetheless, the amplifier in its present form is still experimental. Before the SSKW could be acceptable for general use, output filtering and failureproof protection circuitry would have to be added. The next generation is on its way. The next project? Use the same 50-volt supply with power FETs capable of covering 144 to 432 MHz, and build it into a similar package!

Acknowledgment

I thank Helge Granberg for spending considerable time answering questions about this project.

Notes

¹H. Granberg, "New MOSFETs Simplify High Power RF Amplifier Design," *RF Design*, Oct 1986, pp 43-48, 50, 52.

²H. Granberg, "A Compact 1-kW 2-50 MHz Solid-State Amplifier," *QEX*, Jul 1990, pp 3-8.

³J. Paladino, "A Rapid Deployment Prototype Solid-State Kilowatt Linear Amplifier for 2 to 50 MHz Using MRF-154s," 1991 Central States VHF Conference Proceedings (Newington: ARRL, 1991), pp 61-70. Available from the ARRL Bookshelf as #3614.

⁴H. Granberg, "MOSFET RF Power—An Update," Part 2, *QST*, Jan 1983, pp 30-33; also see Feedback, *QST*, Mar 1983, p 44. (Part 1 appeared in *QST*, Dec 1982, pp 13-16; also see Feedback, *QST*, Jan 1983, p 48.)

⁵American Technical Ceramics (ATC) has some new chip caps (the 900 series) that have higher voltage and current ratings than the capacitor Motorola specifies. I have samples but have not tried them yet.

Joel Paladino became a radio amateur in 1977 and holds an Extra Class license. His present interests are split between small-signal DXing from 50 MHz (his favorite) to 24 GHz, and 440- and 902-MHz repeater networks. Joel has also operated EME on 50, 144, 220 and 432 MHz. He presently has a 10-meter-wide computer-controlled dish for 432-MHz EME and two 50-foot 6-meter Yagis at 100 feet for F₂ DXing and EME.

During the most recent solar-cycle peak, he DXpeditioned to rare 6-meter countries and operated CN2JP (the SSKW amplifier has been to Morocco twice), CU3/N6AMG, KH8/N6AMG, 5W1JP and VK9LG. Joel assisted with ARRL's Radio Frequency Interference: How to Find It and Fix It and intends to write on repeater topics.

After over ten years of engineering and installation work for Motorola and Chevron, Joel has worked full time in his own land mobile and microwave consulting business since 1990. He is unmarried and has no children. His other hobby is mountain-bike riding.

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