VHF/UHF/Microwave High-Power LDMOS Amplifiers

Greg McIntire, AA5C

Vacuum tubes were the technology mainstay for legal limit amateur high-power HF, VHF, UHF, and microwave amplifiers for many years. During the mid-1980s I built kilowatt amplifiers for 6m, 2m, and 70cm using pairs of 4X150A (6m) and 4CX250B tubes (2m and 70cm). A modified surplus Federal Aviation Administration (FAA) cavity with a single 4CX250R was my amplifier for 1.25 m operation. These amps served me well for decades in CW and SSB service. The use of digital modes has become ubiquitous, however, and the high duty cycle of these modes required backing off on the output power. The need to limit on-time duration became particularly obvious when the Teflon insulating tube in which the high voltage supply line is run for the FAA cavity amp melted resulting in a high voltage short during a meteor scatter run on 222 MHz. This "exciting" event reinforced the limitations of my amps. Since I want to be able run high power for relatively long on periods, e.g., 1 minute for JT65, I decided it was time for a technology refresh. My goal was to replace the four tube amplifiers in my VHF/UHF rack with solid state amps capable of running JT65 with at least 1KW output on each band and to replace my traveling wave tube amplifier (TWTA) on 2.3 GHz.

I started doing some research and the Laterally Diffused Metal Oxide Semiconductor (LDMOS) power FET technology seemed to be the best to turn to for high power VHF/UHF amplifiers. The cell phone industry helped drive the development of this technology in the late 1990s and the technology has continued to advance to this day. Early devices, during the 1990s, operated with a 28 VDC drain supply. That increased to 50 VDC during the 2000s and early 2010s. Now devices operating with a 65 VDC drain supply are available. One benefit of the higher drain voltage is the more manageable drain current compared to lower voltage devices running comparable output power. Another is that the matching networks are not as difficult to design because the output impedances aren't as low. LDMOS has excellent linear performance when operated Class AB and this makes it possible to built linear amplifiers with high gain and good efficiency at a reasonable cost. The high peak power capability of the devices makes them suitable for the multicarrier CDMA systems often used in the cell phone industry. Another advantage of modern LDMOS devices is that they are very tolerant of high output VSWR with a specification of surviving up to 65:1 VSWR being common (for a 100 us pulse, 20% duty cycle). The high gain helps reduce the number of stages required to achieve a desired output power in a system. Another factor that simplifies the overall system is that they are enhancement mode devices so a single positive supply can be used with a step down regulator or other arrangement for the gate bias supply. Most devices are dual to facilitate push-pull operation. The Ampleon BLF188XR is in a typical dual LDMOS package (Figure 1).

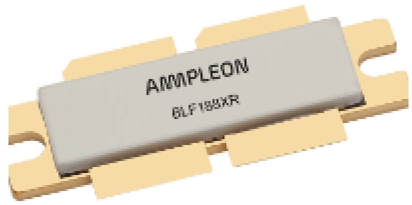

Figure 1 Ampleon BLF188XR Dual LDMOS Transistor

The primary disadvantage of LDMOS devices is that they are very sensitive to excessive gate voltage or drive power. I took out several devices in one 2.3 GHz amplifier because the potentiometer I was using to set the gate bias (from a regulated 5 VDC supply) turned out to be noisy. Some radios put out an RF glitch when first going into the transmit mode and this can also take them out. The typical dynamic means of controlling drive, automatic gain control (AGC), is woefully too slow to protect devices. Check your driver before applying input power.

A few of the key specifications for some common VHF/UHF/microwave LDMOS transistors are shown in Table 1. The high power capability, high gain, and high operating frequency of some of the more current devices are noteworthy. Also note that current devices are generally available from distributors like Digi-Key and Mouser. I've had good luck finding some of the obsolete parts on eBay.

Device	Manufacturer	Drain Supply	Gain (dB)	Pout @ Frequency	Sources
MRF151G	MaCOM	50V	14	150W/FET up to 175 MHz (300W total)	Mouser, eBay
MRF1K50	NXP	50V	23	1.5 KW total@ 144 MHz	Mouser
MRFX1K80	NXP	65V	24	1.8 KW total@ 144 MHz	Mouser
BLF578XR	Ampleon (NXP)	50V	23.5	1.4 KW @ 225 MHz	Digi-Key
BLF184XP	Ampleon (NXP)	50V	23.9	700 W @ 432 MHz	Digi-Key
MRF13750	NXP	50V	17.2 @ 1.3 GHz	750W @ 1.3 GHz	Mouser
MRF19125	NXP (Freescale)	26V	13.6	125W @ 2 GHz	Obsolete (eBay)

Table 1 Key Parameters of a Few LDMOS Power Transistors

The popularity of the technology is evidenced by the number of LDMOS transistor manufacturers. Consolidations, buyouts, and mergers make the list dynamic. It includes: NXP

Semiconductors, Ampleon, Infineon Technologies, Qorvo (RFMD), STMicroelectronics, Freescale Semiconductors, TSMC, LFoundry, Tower Semiconductor, Globalfoundries, Vanguard International Semiconductor Corporation, SMIC, MK Semiconductors, and Polyfet.

There are varied approaches one can take in getting high power LDMOS amplifier capability in the shack. Several hams, including Rob McCance, N4GA (Reference 1) and Jim Klitzing, W6PQL have designed and built LDMOS-based amplifiers. Jim Klitzing, W6PQL wrote an article on one 2m KW LDMOS amp he built. The article was published in the October 2012 issue of QST (Reference 2). He built it using an MRFE6VP62K25H LMDOS transistor and notes the cost advantage compared to tubes to generate comparable power in his article. Jim offers turn-key amplifiers and when I was putting together my 2m EME station in 2018 I chose a custom 1.5 KW amplifier from him. Jim also offers the basic parts and RF input/output splitter/combiner boards, copper heat spreaders, and so forth so that you can build your own RF deck from scratch at whatever level you want to start from. For 432 MHz I got a 1 KW deck from Jim and built up the amplifier with a few other pieces he offers, e.g., a control board, filter/dual direction coupler, and high current FET switch for the drain. There are still a number of surplus commercial LDMOS amplifier decks available from different sources. The switchover from analog to digital television resulted in a lot of LDMOS 1 KW and 1.5 KW amplifier decks becoming available. Most notable of these are amplifiers built by Harris and Larcan. I'm most familiar with the Larcan amplifiers of which there are 1 KW amplifier decks with 4 dual LDMOS transistors and 1.5 KW decks with 6 dual LDMOS transistors. One set of circuit boards covers the 54 to 88 MHz range: 54-72 MHz and 76-88 MHz depending on capacitor selection and strapping of printed inductors. These are referred to as the VHF LO and VHF Lo/Hi amplifiers, respectively. Another set of circuit boards is used for the VHF Hi Band amplifier that is designed to cover 174-216 MHz. In my case, I started with two 1.5 KW Larcan decks. One deck is a VHF Lo/Hi deck (Figure 2)Figure 2 Larcan VHF Lo/Hi 1.5 KW Deck and the other a 1.5 KW VHF Hi deck (Figure 3). Many excellent articles on modifying these amplifiers have been written. The Minute Man Repeater Association web site (Reference 3) is a particularly good repository of schematics, modification articles, and other information for Larcan amplifiers.

Careful study of the tables in the Larcan schematics and review of an article by David Olean, K1WHS (Reference 4) led me to an approach of changing 36 ATC capacitors and removing the straps on 12 strip line inductors to get the VHF Lo/Hi deck to efficiently operate on 50 MHz. The VHF Lo version will go down to 54 MHz but further modifications are needed to get efficient operation at 50 MHz. The capacitor modifications were a combination of changing out ATC caps and stacking (paralleling) ATC caps to achieve the desired value. Brian Justin, WA1ZMS has taken the VHF Lo/Hi deck up in frequency and shows how to put it on 2 meters in one of his articles (Reference 5). The Larcan Hi band amplifier works directly on 222 MHz so matching circuit modifications were not required. The other modification I made to the basic

RF deck is to replace the input connector with a conventional female BNC connector and the output connector with a conventional N connector.   This was relatively straightforward, requiring the fabrication of a few adapter plates. The stock Larcan amplifiers have input and output RF connectors that are designed for hot switching the decks by sliding them into a powered rack but they are not easily adapted to for use with common connector types. DC power is supplied to the deck through pins on the back side. I found that different sized terminal lugs fit the different power pins. The crimp side of the lug made a good compression fit on the power pin leaving the hole or spade end of the lug available as an attachment point.

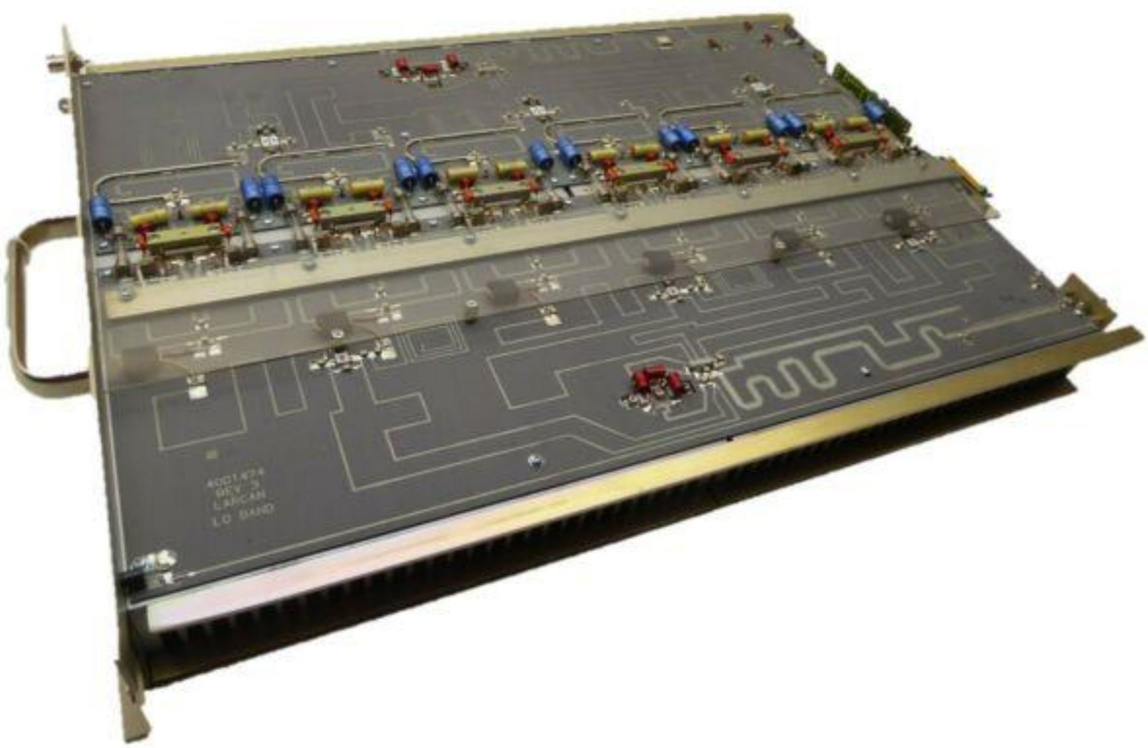

Figure 2 Larcan VHF Lo/Hi 1.5 KW Deck

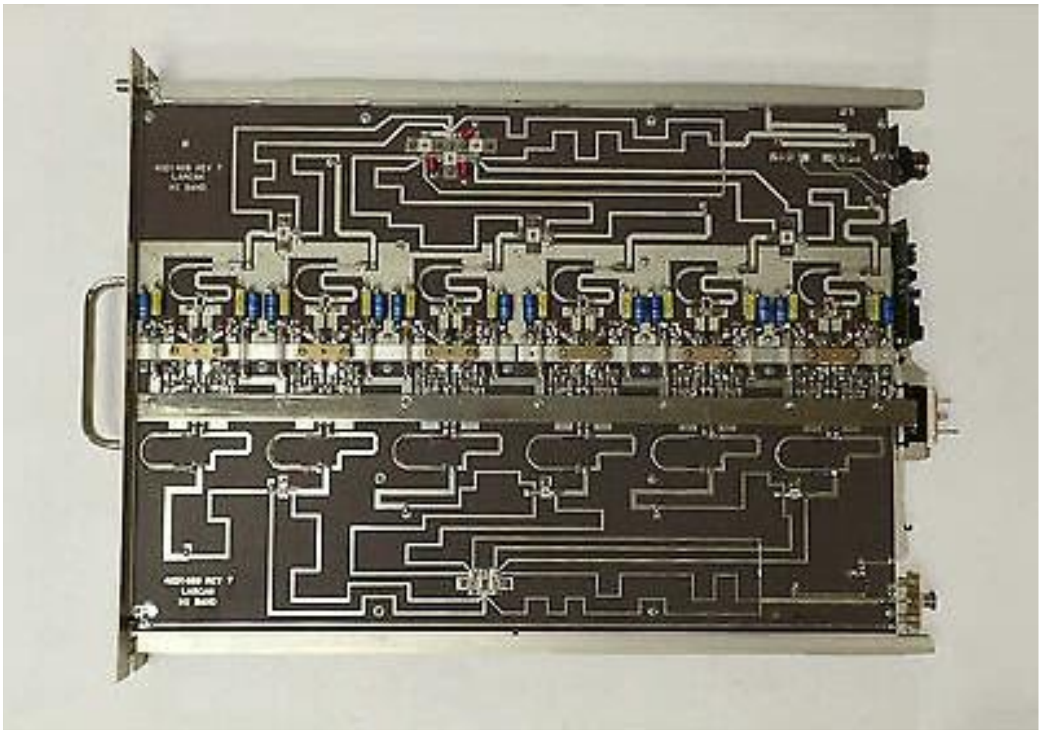

Figure 3 Larcan VHF Hi 1.5 KW RF Deck

Surplus “blade” computer server power supplies are a great main component of a power supply for the LDMOS amplifiers. The supplies are typically rated at 51.4V at 57A. They operate from a 220 VAC supply and one or two jumpers can be added to make them operate outside the racks they normally plug into. Rob McCance, N4GA (Reference 1) shows one way to jumper the units so that they turn on outside their intended rack connections. Other circuits are needed to safely operate the amplifier deck with the power supply. Another good supply I’ve recently become aware of is the Eltek 48V/3000 HE Flatpak. The Larcan decks have 2 sets of power pins. One set (the longer ones) are for supplying 50 VDC to the step-start circuit. This basically allows the 12 large electrolytic capacitors to charge through a limiting power resistor before direct 50 VDC power is applied. This helps avoid blowing the fuses that are in series with the drain of each device. The second set of pins, the shorter and larger diameter ones, supply 50 VDC at high current to each stage via a bus bar. The arrangement of the power supply pins is a clever means of mechanically accomplishing the sequencing as the amplifier is plugged into a rack but without a rack, an external sequencer is needed. I built up two sequencer boards, one for the 50-54 MHz amp and another for the 222 MHz amplifier. These sequencers are based on the venerable W5LUA design that uses an LM324. The sequence I use for going from receive to transmit is:

1st: switch the T/R relays to the transmit state

2nd: apply 50 VDC to the step-start circuit

3rd: apply 50 VDC to the full amplifier

The reverse sequence should be followed when going from transmit to receive.

One of the power supply trays I built is shown in Figure 4. The 50 VDC power supply is the long unit at the top of the picture. The tray includes 24 VDC and 12 VDC power supplies for T/R relays, control relays, and the sequencers. A 50A ammeter and shunt are included for monitoring current. LEDs on the front panel indicate the status of each power supply.

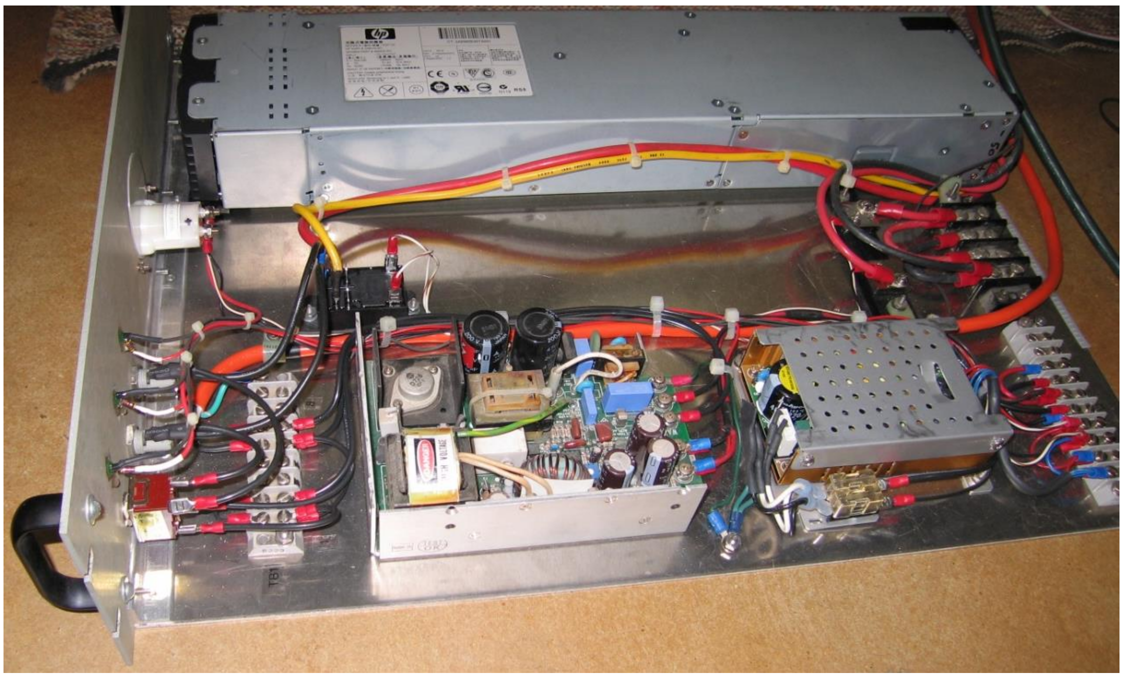

Figure 4 Power Supply Tray for High Power LDMOS Amplifiers

Each complete amplifier should include a circuit for shutting down the amp if the output VSWR is too high, typically over 1.5:1. The Larcan amplifiers include a control board located along the back side of the deck between the input and output connectors. This control board includes the current limiting resistor for charging the electrolytic capacitors and a VSWR monitoring circuit. The strip line couplers for detecting forward and reverse power are part of the two main RF circuit boards. The control board also feeds a front panel LED that illuminates when the VSWR is lower than 1.5:1 and output power is more than several hundred watts. I find this useful for a quick check when operating. The Ultimate Control Board designed by Jim Klitzing, W6PQL includes a shut down circuit for high VSWR. He also designed boards for the different bands that combine a low pass filter and forward and reverse power detectors. A front panel

10-LED bar graph indicator for forward power and another for reverse power fed by the detectors make good quick reference indicators during operation. The reverse power signal from the detector also feeds the control board high VSWR shut down circuit.

I used 0.125 inch thick aluminum sheet metal for the base plates and 6U (10.5 inch) aluminum rack panels to build up the amplifiers mechanically. Four 120 mm 54 CFM cooling fans are mounted to the underside (heat sink side) of each deck using ¾ inch aluminum angle. The sequencer and control relays and interconnect wiring are mounted on the base plate along with the input and output RF coaxial relays for T/R switching. Fuses, switches, and indicators are mounted on the front panel. An RF attenuator on the RF input to the amplifier is included. The attenuator is sized to make sure that full output power from the transceiver cannot overdrive the amplifier. A starting point for calculating each attenuator value is the maximum output power of the transceiver and the maximum gain of the LDMOS amplifier. Expected gain of each Larcan deck is listed in the manual for that version. I measured the gain of the modified VHF Lo/Hi amp to be 20 dB at 50 MHz and that of the VHF Hi amplifier to be 16 dB at 222 MHz. Be cautious and start with higher attenuator values than you think you will ultimately need.

I pulled all of the tube amplifiers and power supplies from my VHF/UHF amplifier rack and installed the necessary supports and rack hardware to complete the installation. The final result is shown in Figure 5. The top half of the rack includes the 1.5 KW 6m and 1.25m amplifiers fed from a common power supply tray. The bottom half of the rack includes the 4U (7 inch) sized 1.5 KW 2m amplifier (W6PQL) and the 1 KW 70 cm (AA5C using a W6PQL RF deck) amplifier. These two amplifiers are fed by a second common power supply tray. A single power supply tray could have been used with good bussing of the 50V lines but this arrangement lets me switch supplies if I have a failure.

Figure 5 AA5C LDMOS KW Amplifier Rack

The output power versus operating frequency curve continues to increase as the LDMOS technology advances.   Jim Klitzing, W6PQL has designed a 600 W 1296 MHz LDMOS amplifiers. The RF deck (Figure 6) is built around the MRF13750 LDMOS dual transistor. This amplifier produces 600 Watts output with 10 Watts drive.

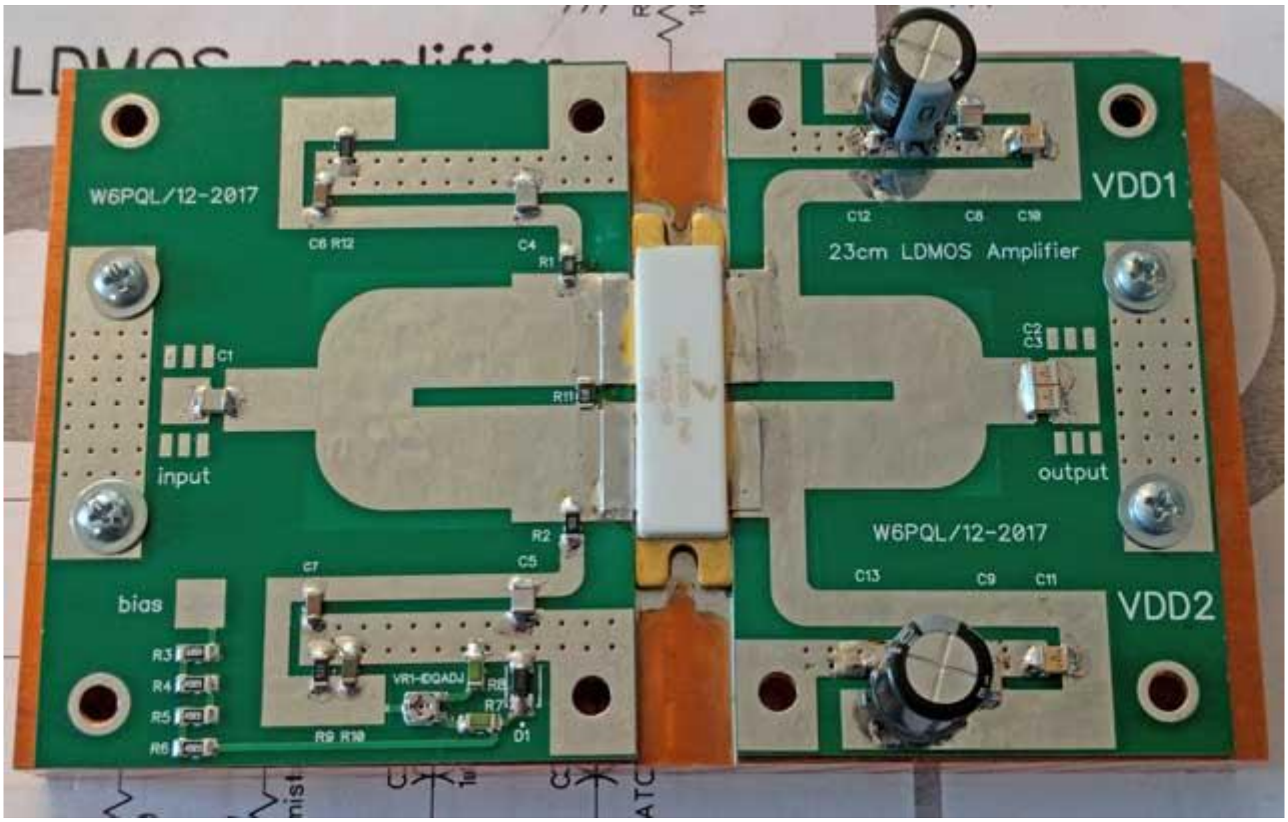

Figure 6 LDMOS 600 Watt 1296 MHz Amplifier Deck (photo courteous W6PQL)

My experience with LDMOS on the microwave bands has primarily been from adapting surplus commercial Personal Communications Service (PCS) amplifiers to the amateur bands.   One PCS band, 824-894 MHz, is close to the 902 MHz amateur band and the other PCS band, 1850-1990 MHz is close to the 2.3 GHz amateur band. The surplus commercial amps tend to be a generation or two behind and generally run on 28 VDC with output power in the 100 Watt range. One amp I converted for 902 MHz yielded 125 Watts output with a few Watts drive. For 2304 MHz I converted an AML amplifier based on an article R.L Frey published in the 2006 Eastern VHF/UHF Conference Proceedings (Reference 6). Plans are to replace my old 25W TWTA with it once I design and build a suitable driver amp.

My objective has been to provide information and references for you to be able to start working with LDMOS transistors and amplifiers. LDMOS technology is rapidly replacing tube technology and solid state operation has some distinct advantages over tubes. The front panels of my solid state amplifiers are devoid of tuning controls and the instant operation is very convenient.

References:

1. http://www.n4ga.com/
2. "Solid State 1 kW Linear Amplifier for 2 Meters", James Klitzing, W6PQL, October 2012 QST.
3. https://www.mmra.org/larcan/
4. "Improving the Larcan Amplifier at 50.0 MHz", David Olean, K1WHS
5. "VHF-LO Larcan Amp Conversion to VHF-HI Band (Amateur 2m band)", Brian Justin, WA1ZMS
6. "70 Watts Cheap on 2304 MHz – Modifying a 1900 MHz PCS Amplifier for 2304 MHz", R.R. Frey, WA2AAU, Eastern VHF/UHF Conference, April 22, 2006