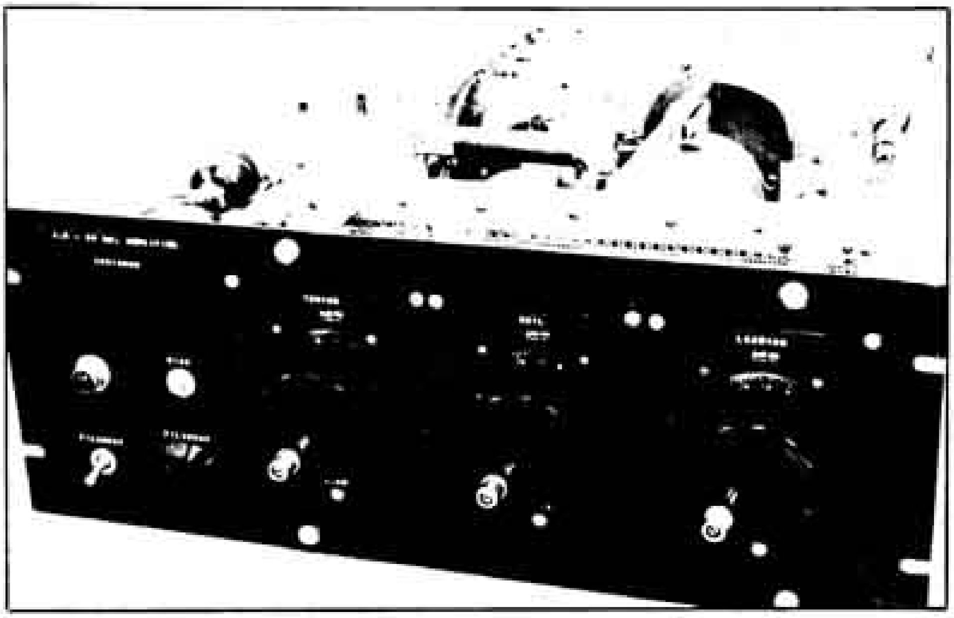
Here's a project that will get your imagination soaring and your workbench cleared almost as fast. KN5S presents us with an amplifier requiring only 30 watts of drive that delivers 1500 watts from 160 through 6 meters.

A Low-Drive, High-Power All-Band Tetrode Linear Amplifier

BY MARK MANDELKERN*, KN5S

Here's an amplifier project that demonstrates the simplicity you can obtain using a high gain tetrode with an untuned passive grid input circuit. This amp delivers 1500 watts output with 30 watts drive on all bands from 1.8 to 54 MHz. There's no bandswitch, just a rotary coil and two vacuum variables. Even if new bands are granted in the future, this amp won't become obsolete. It was fun to build and has given smooth and reliable service.

The drive required in class AB1 consists only of circuit losses, usually less than a watt. To use such super high gain you'd need input matching and tuning circuits, and neutralization. By including a 50 ohm resistor in the grid circuit, you can obtain absolute stability without neutralization, while avoiding input tuning. For a 4CX1000A, the resistor absorbs just 30 watts. This is well within the CCS limits of almost any exciter—even on RTTY. In the end, you've traded super high gain for absolute stability and simplicity. However, you still have all the gain you need—17 dB.



The front panel features the three turns-counter dials and a minimum of controls. The metering and protective circuitry are on another panel, as described in the text.

The amplifier is built in three sections: RF deck, control and metering panel, and HV supply. I built the control panel separately so I could add RF decks for VHF and UHF (when I have the time) without duplicating all the protective and metering circuits. Tetrodes are very rugged, but they do need adequate protective circuitry. They are easily destroyed if run beyond their control grid and screen grid limits. I've described the protecting control panel in another article.[1]

The project took a year to complete. In the years that followed, I spent many hours improving the design. The HV supply for this amplifier is borrowed from an older amplifier.[2,3] You may want to use your old HV supply, or build one described in the *The ARRL Handbook*.[4]

The RF deck circuit is shown in fig. 1; it's very straightforward. Some of the tank components are more expensive and harder to find on the surplus market than they were when I first built this rig, but you can substitute any suitable components. The blower cool-down delay circuit isn't shown here; you'll find it in the March 1989 issue of *QST*, page 35. The low pass filter and antenna relay are separate. The sequencing control for the antenna relay and amplifier is also separate. You'll find it in *Ham Radio*, November 1987, page 17.

I built the amplifier before high power was allowed on 160 meters. Thus, the provision for high power is strictly a retrofit. A padding capacitor is switched by S2 at the rear of the amplifier. Use a long shaft and switch it from the front panel. A 600 pF vacuum variable would alleviate the need for the padder, but it may be difficult to find such a capacitor with the low minimum capacity (10 pF) needed on 6 meters. This low capacity is absolutely essential for efficiency on this band.

In most amplifiers, the power output drops off on the higher bands. The drop-off is usually caused by excessive minimum plate-tuning capacity. This high Q results in high circulating tank currents. In short, heat is produced in the tank circuit rather than RF at the antenna. For example, I recently rebuilt an SB-220 for 6 meters. Before rebuilding, it put out only 800 watts on 10 meters. With a new VHF high voltage plate tuning capacitor, it delivers 1200 watts output on 6 meters. There were no other changes that could account for this increase in efficiency. I used the same 3-500Zs, along with a portion of the old 10 meter tank coil. The new capacitor covers about 4 to 16 pF and resonates near the low capacity end. If I use less coil and force the capacitor to resonate near full capacity, the output begins to drop.

The 6 meter provision was an after-

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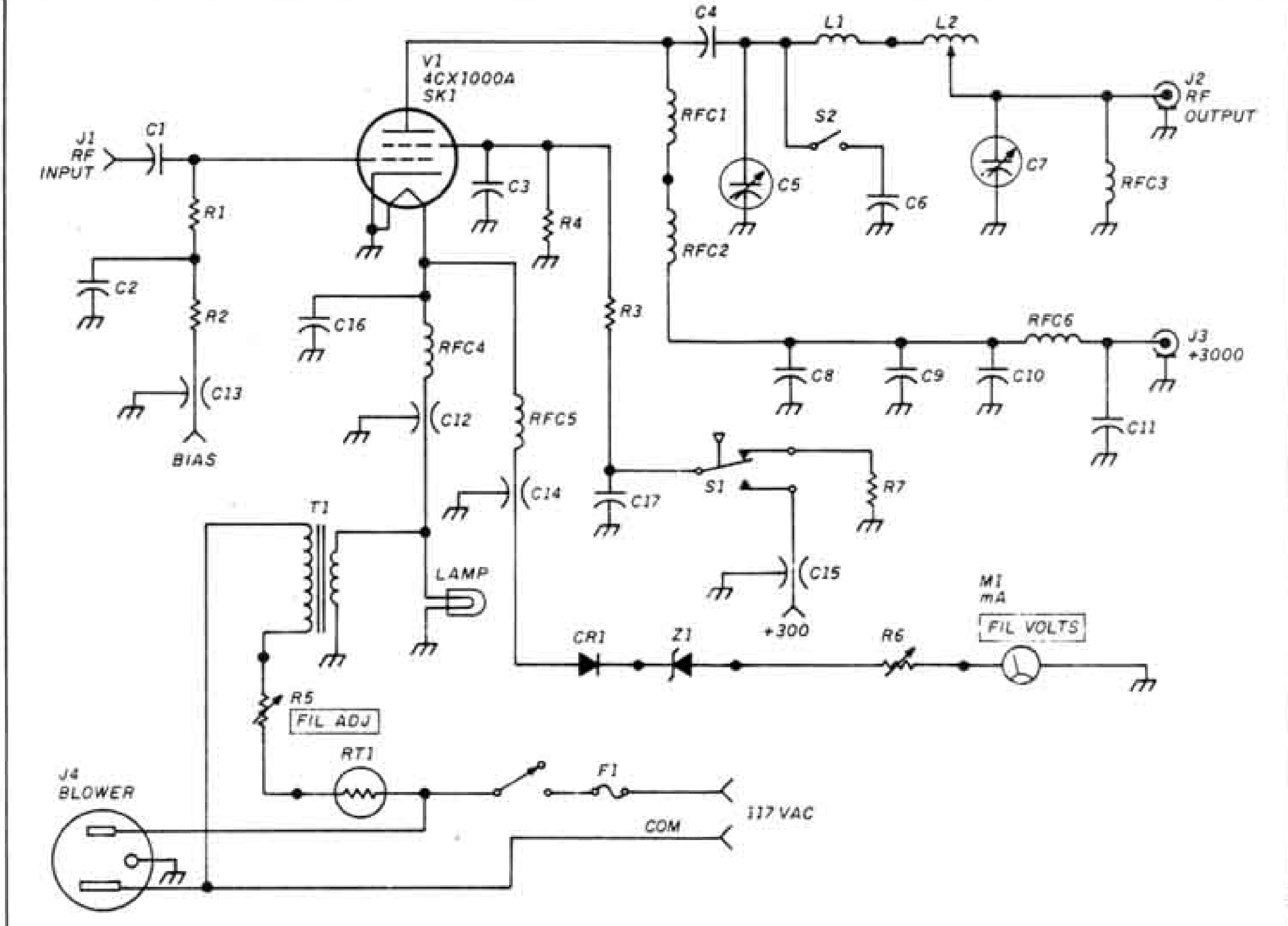


Parts List

C1,2—0.01 µF silver mica transmitting capacitor
C3—1500 pF screen grid bypass (internal to tube socket)
C4—2000 pF, 5 kV, two 858S capacitors in parallel, Centralab
C5—Vacuum variable, 10 to 300 pF, 10 kV, Jennings UCS-300 (plate tuning)
C6—300 pF, 5 kV, Centralab-type 858S
C7—Vacuum variable, 3000 pF maximum, 3 kV, Jennings UCSL-3000 (loading)
C8—0.0014 µF, 10 kV (EM)
C9—0.005 µF, 15 kV oil capacitor
C10,11—500 pF, 20 kV "TV doorknob," Centralab
C12—0.05 µF, 20 A feedthrough, Sprague
C13,14,15—1000 pF feedthrough
C16—0.1 µF, 100 volts DC disc ceramic
D1—Silicon diode, 1N4148 or 1N914
F1—3 A fuse
J1—BNC chassis mount
J2—N chassis mount
J3—HN chassis mount, used with RG213 for 3 kV feed
J4—Chassis-mount AC outlet, Amphenol 160-2N, AL part no. 713-5202
Lamp—No. 47 6.3 volt lamp
L1—3.5 turns no. 10 silver-plated wire, 1 inch ID, 2 inches long, self-supporting
L2—24 H roller inductor, Johnson 226-1 (EM, CC)
M1—1 mA DC meter movement, filament voltage
R1—50 ohm, 60 watt noninductive resistor, thirty 1500 ohm 2 watt carbon composition resistors connected in parallel (see text)
2—1000 ohm, 2 watt carbon composition
R3—100 ohm, 2 watt carbon composition
R4—220 K, 2 watt carbon composition
R5—25 ohm, 25 watt wirewound adjustable
R6—1000 ohm, 2 watt carbon or wirewound pot
R7—10,000 ohm, 2 watt carbon composition
RFC1—28 turns no. 18 wire solenoid wound on 0.5 inch OD by 2.5 inch ceramic form (plate choke)
RFC2—Plate choke, surplus part (suggest B&W 801)
RFC3—74 turns no. 20 wire solenoid wound on 0.75 OD by 3 inch ceramic form
RFC4—9 µH 15 A RF choke, surplus part (suggest Dale no. IH15, HF no. 18-105)
RFC5—1.0 mH RF choke
RFC6—10 H, 1 A RF choke
RT1—Surgistor, GC 25-933-S
S1—Air flow switch, Rotron 2A-1350
SK1—Eimac socket, Sk-810B; chimney SK-806 (BY)
T1—Transformer, 6.3 volts AC at 10 A second—ary, Thordarson 21F12, AL 704-2019
Z1—Zener diode, 6.2 volts, 1N473

Fig. 1- The RF deck circuit. The feed-through capacitors indicate the boundaries of the shielded grid compartment. Most of the parts can be garnered from fleamarkets and the sources indicated in Table II.

thought in this 4CX1000A amplifier, as I already had a homebrew 6 meter kilowatt. After several years of use, I noticed that I was still using three and a half turns of the coil—even on 10 meters. I wondered how high it would tune. A few minutes later, to my great surprise, it was running almost 1500 watts on 6 meters with no special plate choke or plate coil! I added these later, as a matter of principle, with little effect. You might also arrange for operation on 2 meters using a switch, and a completely separate tank circuit.

For input grid loading resistor R1, I use thirty 1500 ohm 2 watt carbon composition resistors in parallel. This is a 60 watt resistor pack. The actual power dissipated is calculated as follows:

At a grid bias voltage of −55 volts, the grid will just begin to draw current when the *peak* positive RF driving voltage is 55 volts. But the RMS driving voltage is only about 70 percent of this, or 38.5 volts. Using $P = E^2/R$, this works out to close to 30 watts. If the correct bias setting works out a bit higher or lower for your particular tube, the driving power will vary slightly from this figure.

Resistors R2 and R3 help isolate the grid and screen circuits, and are quite important for stability. They should be carbon composition types, for good RF characteristics. Notice their position in the circuit. C2 is the RF return for 50 ohm input resistor R1; R2 is positioned *after* C2 (in the direction leading away from the tube). R3 is positioned *before* any other bypass capacitor, leaving socket bypass capacitor C3 free from any other reactances which might upset the socket balance worked out by Eimac. I wouldn't use RF chokes in place of R2 and R3; their self-resonant frequencies are likely to introduce instabilities. The other resistors in the screen circuit are protective devices for holding down the screen potential (that which it might pick up from the plate) in any condition where it might not be connected to the resistors in the control panel. This protects the socket bypass capacitor. The 220 K resistor does draw a bit over 1 mA, but this is barely noticeable on the screen meter.

RT1, an in-rush current limiter, provides gradual heater warm-up. Using a 6.3 volt, 10 A transformer for a 6 volt, 9 A tube lets you adjust the heater voltage by varying the potentiometer, R5. It also allows for some drop in RT1. The use of a zener diode in the heater voltage meter circuit results in an expanded scale effect, with readings from 5 to 6 volts. You'll note that the heater voltage sampling line is connected directly to the tube socket and has its own feedthrough capacitor. Zener diodes behave strangely at low currents; it may be necessary to try diodes of different ratings from different manufacturers. I obtained linearity from only 5.4 to 6.0 volts, which is more than adequate. (For those who demand precision, an op amp expanded scale metering circuit might be easier.)

Calibration at only a few points is sufficient because the meter is used merely for reference, as you'll see in a moment. However, the expanded scale is certainly worthwhile. The heater voltage should be set just above the point where lower voltage results in reduced power output. This will give your tube the longest life.[5] For my tubes, 5.7 to 5.8 volts has been best. The required 3 minute warm-up period is provided by a thermal delay relay in the bias circuit, using a normally open 3 minute Amperite no. 6NO180 tube. The bias control and delay tube are located on the RF deck, while the circuit is shown in conjunction with the control switch on the control panel schematic.[1]

Table I gives the operating parameters. These were taken partly from the data sheet and partly from my experience with this amplifier. The bias is set with the "key" line closed and full screen voltage, but with **no** drive applied. The blower, Dayton no. 1C982 (rated 93 cfm at 0.4 inches of water), is supplied by Grainger (listed in Table II). It's separate from the RF deck and connected by a short length of household clothes dryer exhaust hose. This allows it to be acoustically mounted and results in a lower noise level.

Heater voltage	5.7 to 6.0 (see text).
Warm-up time	**3 minutes—failure to observe this may destroy the tube.**
Grid voltage	Standby – 150 volts Operating – 55 volts; adjust to obtain correct idling current
Screen voltage	300 volts; adjust to obtain correct key-down plate current under full drive conditions.
Plate voltage	3000 volts, key-down
Grid current	0 mA; adjust drive for normal ALC indications. Without ALC, adjust drive until slight grid current indications are seen on voice peaks; then reduce drive so that the grid current meter *never* indicates while operating.
Screen current	– 30 mA to + 10 mA
Plate current	Standby 0 mA Idle 250 mA quiescent or carrier Key-down 800 mA
Output	1500 watts

Table I - Operating parameters, 4CX1000A.

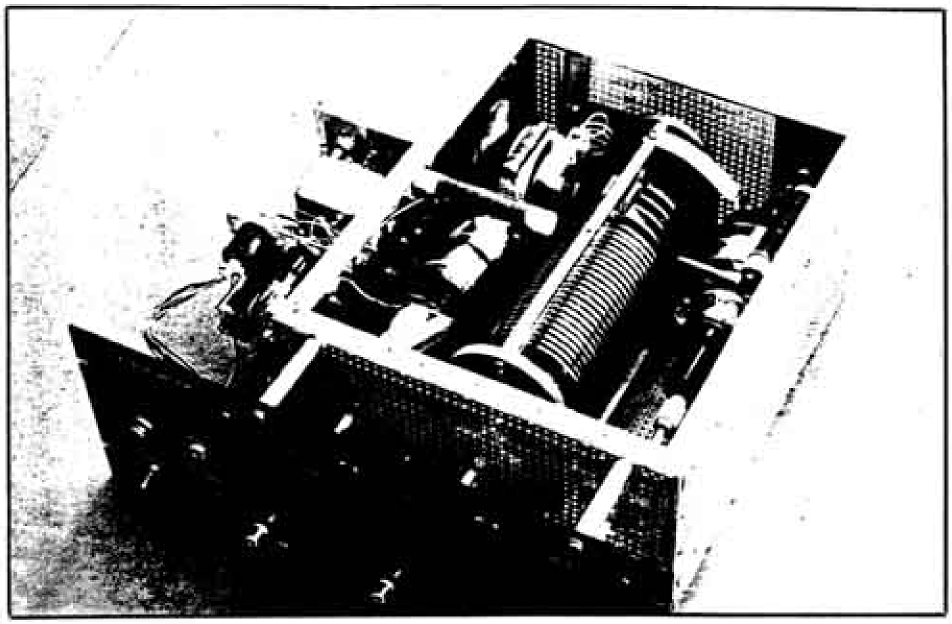
Tuning up key-down with **low** drive *isn't* recommended; it can produce over 100 mA negative screen current. The constant current curves do have small ellipses in places, representing poles. If you get into these regions, it's normal for the screen current to soar to destructive levels. This is one very important reason for complete protective circuitry.[1] For tuneup, a pulsed driving signal is best.

Tuneup is easy using dits from a keyer at 60 wpm and full drive level. Always use a monitor scope. Set the rotary coil for a total circuit inductance of about 0.15 μH per meter. For example, use 6 μH at 7 MHz. With the screen voltage switch on **zero**, adjust the drive level for about 0.1 mA grid current, or normal ALC indication. It's very difficult to hold the grid at 0.1 mA without ALC. Consequently, ALC is necessary for maintaining peak power without splattering. The ALC circuit is located on the control panel and is described in another article.[6] I've heard that operators using tetrodes in homebrew amplifiers sometimes receive splatter complaints from neighbors. While some might blame the tetrode, I think the trouble is caused by overdrive due to lack of ALC. Improper tuning will also cause trouble. With the **zero** screen voltage setting, it's now easy to adjust the drive level and check out the ALC while running no plate dissipation. Otherwise, you face the dilemma of either driving the tube to high plate current before you resonate the tank circuit, or trying to resonate the tank at low drive level—causing the excessive negative screen current noted above.

Now that you've set the proper drive level, set the screen voltage switch to **TUNE** (150 volts) and adjust for maximum output. Then *increase* loading to obtain a 20-percent **decrease** in power output. This 20-percent figure gives you a loading condition, with 150 volts on the screen, roughly corresponding to the proper loading for 300 volts. Consequently, you can now set the loading to a first approximation at a low dissipation level. With the bias set for 300 volts screen operation, the plate dissipation is quite low in the 150 volt tune position, and you can take your time resonating the tank circuit. There's

(AL)	Allied Electronics, 401 E. 8th Street, Fort Worth, TX 76102. Telephone: (800) 433-5700.
(BY)	Barry Electronics Corporation, 512 Broadway, New York, NY 10012. Telephone: (212) 925-7000 (Eimac tubes, sockets, chimneys).
(EM)	Alan Emerald, 8956 Swallow Avenue, Fountain Valley, CA 92708. Telephone: (714) 962-5940 (plate tank components).
(GR)	W.W. Grainger, Inc., many branches. Telephone: (800) 521-5585, in Illinois (800) 872-5585 (blowers).
(HF)	Hosfelt Electronics, Inc., 2700 Sunset Boulevard, Steubenville, OH 43952. Telephone: (800) 524-6464 (chokes, etc.)
(CC)	Cardwell Condenser Corporation, 80 E. Montauk Highway, Lindenhurst, NY 11757. Telephone: (516) 957-7200 (rotary inductors).

Table II - Component suppliers. (Two-letter designators before the company names are for use with the parts list which accompanies fig. 1.)



The grid and plate chambers are completely isolated. All leads into the grid compartment are routed through feed-through capacitors. The plate/output compartment is fairly straightforward and is made from standard aluminum stock available at local hardware stores. The front panel unplugs and is easily removable. This amplifier was built using a 7 inch rack panel, making contruction a rather intriguing exercise. A better method would have been to use an 8¾ inch panel. You can dress it up or detail it to suit your own taste.

no need to tune frantically while holding the key down for two seconds at a time!

Switch to 300 volts and read the screen current meter. The goal for a first approximation is something near 10 mA negative, although this varies from tube to tube. Adjust the loading accordingly. Increased loading (less output capacity) results in less (more negative) screen current. Tune for peak output with 300 volts on the screen. **Always** retune the input capacitor for resonance after adjusting the loading. Note that you're still running dits at 60 WPM. At this point you can touch the straight key for a second and check all the meters to get the key-down readings. (I always have a straight key on the bench plugged in and ready for emergencies.)

The screen current is the best indicator of resonance and loading conditions.[7] **Don't** try to dip the plate current yet. Resonate the input capacitor by tuning for maximum screen current. If this doesn't result in a reading very close to maximum output, somthing is wrong. A correspondence between a peak in screen current and maximum RF output indicates a stable, or neutralized, amplifier.[5] This doesn't just refer to amplifiers which have neutralizing adjustments, but also to those in which the in-phase feedback is kept very low by screen bypassing and/or grid loading. The screen current versus RF output check indicates an absence of regeneration. This amplifier uses both screen bypassing and grid loading. The screen bypass capacitor is built into the Eimac socket. If the capacitor were to open, you'd probably notice a discrepancy in the screen current and RF output peaks right away (if not more alarming symptoms!).

Adjust the output capacitor until this screen current peak is the value which yields the maximum output for your tube. About 10 to 20 mA negative screen current has been right for mine. After you've found the settings for maximum output, **increase** the loading so the output drops 50 watts. This procedure will give you the cleanest signal, and you lose only 0.1 dB. Record this optimum screen current value. Read both the dit tuneup and key-down values. The relation between these two values depends in part on the keyer characteristics and the meter damping. Once you find the proper values for your tube, you can use these to tune up on different frequencies. It's much easier than watching the output power, because it tells you *which way* to adjust the loading. After the dit tuneup, a quick key-down check will let you read input and output power. Record the counter dial settings. When you change bands, simply set the dials and do a quick dit test while you check the monitor scope and the screen current.

Results? You bet! This amp has given reliable service for 19 years under very strenuous contest operating by me and (some years ago) my junior op David, now N6IHC. The most important result is the "type acceptance" by local operators working only a few kHz away.

CAUTION: This project requires the use of high voltages and currents which are potentially lethal. Always remember to be aware that SAFETY comes before anything else.

Footnotes

1. Mark Mandelkern, KN5S, "Protecting Power Tetrodes," *QST*, November 1989, pages 22–25.
2. Mark Mandelkern, KN5S, "Plate-current Meter Over-load Protection," *QST*, November 1987, page 41.
3. Mark Mandelkern, KN5S, "Stable High-voltage Metering," *QST*, December 1988, page 43.
4. *The ARRL 1990 Handbook for the Radio Amateur*, American Radio Relay League, Newington, Connecticut, 1989.
5. R.I. Sutherland, *Care and Feeding of Power Grid Tubes*, Eimac Divison, Varian, San Carlos, California, 1967, pages 88 and 142.
6. Mark Mandelkern, KN5S, "ALC for Class AB1 Amplifiers," *QST*, July 1986, pages 38–39, 47.
7. D. Meacham, "Understanding Tetrode Screen Current," *QST*, July 1961, pages 26–29.

A Low-Drive, High-Power All-Band Tetrode Linear Amplifier

Corrections

page	col		
60	2	November, 1987	October, 1987
	2	provision for high power	provision for 160 meters
61	1	D1	CR1
	1		C17 – 0.001 μF, 1 kV disc ceramic
	2	L2 – 24 H	L2 – 24 μH
	2	2 – 1000 ohm	R2 – 1000 ohm
	2	R6 – 1000 ohm, 2 watt carbon or wirewound pot	R6 – 1000 ohm, mini trimpot
	3	RFC6 – 10 H	RFC6 – 10 μH
	3	Z1 . . . 1N473	Z1 . . . 1N4735
62	T.1	quiescent or carrier	quiescent, no drive
64	1	**Don't** try to dip the plate current yet.	**Never** try to dip the plate current.

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