QEX

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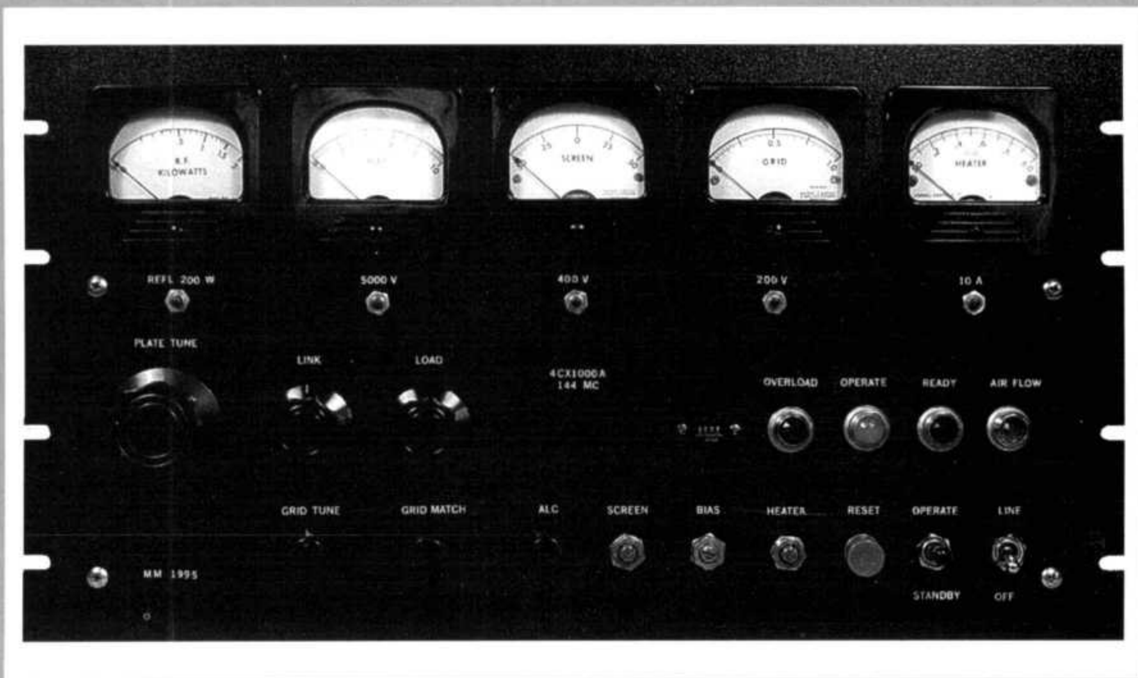
ARRL Experimenter's Exchange

May 1996



A Luxury 2-Meter Linear

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American Radio Relay League
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About the Cover

KN5S provides a design for a soup-to-nuts 2-meter linear. (Photo: Lisa Mandelkern)

ISSUE NO. 172

Features

Columns

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THE AMERICAN RADIO RELAY LEAGUE

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1) provide a medium for the exchange of ideas and information between Amateur Radio experimenters
2) document advanced technical work in the Amateur Radio field
3) support efforts to advance the state of the Amateur Radio art

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Both theoretical and practical technical articles are welcomed. Manuscripts should be typed and doubled spaced. Please use the standard ARRL abbreviations found in recent editions of *The ARRL Handbook*. Photos should be glossy, black and white positive prints of good definition and contrast, and should be the same size or larger than the size that is to appear in *QEX*.

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Empirically Speaking

VHF and Up, Anyone?

This month's *QEX* sports something of a theme. With a 2-m 4CX1000 amplifier by KN5S, a transverter T/R switch and sequencer by N1BWT and a no-tune 2-m transverter by KH6CP, you'll find much of what you need to get active on VHF and above right here.

There's something of a trend exemplified here: It has never been easier to get on the upper bands. With the availability of no-tune transverters, easily used surplus microwave components and equipment, suppliers who specialize in VHF+ devices and kits, increased commercial offerings and, not incidentally, the appearance of ever-better build-it-yourself designs, the barriers to occupancy of the bands above 30 MHz have never been lower.

Check out some of these articles, and past *QEX* and *QST* articles, too. You may find that VHF+ is an alternative whose time has come for you.

Periodicals at Your Fingertips

Although, as we reported here in our February issue, the *QEX* readership doesn't have much yen for electronic distribution of *QEX*, one thing we have heard consistently is that electronic archives of *QEX* and *QST* would be well received. Well, prepare to receive. The *1995 ARRL Periodicals CD-ROM* (see back cover) is now shipping. It contains the complete text of all 1995 issues of *QST*, *QEX* and the National Contest Journal (*NCJ*). It also contains all of the drawings and photos, as well as most of the advertisements, from each of these publications.

One of the features of the CD-ROM package is its full-text search capability. Not only does it do a complete search of the CD-ROM contents, it does it *fast*. So, if you can't remember which issue of *QEX* had that slick article on directional couplers, you can almost instantaneously discover that four 1995 *QEX* issues contained references to the topic, with two issues containing feature articles. And a mouse click or two will take you right to the article you want. You can scroll through the article text and display the figures, or print the article on your printer for leisurely reading. Pretty neat stuff.

And it takes up a lot less bookshelf space, too!

This Month in *QEX*

Want to be a "big gun" on 2 meters? Or maybe 2-m EME excites you. Either way, you need lots of watts. And you'd like them from an amplifier that coddles that expensive power tube. Ideally, you'd like an amplifier that can use an *in*expensive power tube. And, naturally, you want the amp to be easy to set up and use. Such "A Luxury Linear" is just what Mark Mandelkern, KN5S, describes.

Any time you connect two pieces of equipment together, there's a chance something will go wrong, emitting smoke from one of the units—or both. This is particularly true when using a transverter, especially if you mix and match IF transceivers, preamps, power amps and T/R relays. The only solution is to minimize the chance of error, something that Paul Wade, N1BWT, brings off nicely in "A 'Fool Resistant' Sequenced Controller and IF Switch for Microwave Transverters."

These days, a microwave transverter may be easier to produce than a 2-m transverter, thanks to etched no-tune circuits. That's just not fair! In this month's "RF" column, Zack Lau, KH6CP/1 presents his no-tune 2-m transverter design.—*KE3Z, email: jbloom@arrl.org.*

A Luxury Linear

This design includes circuit ideas you can use in any high power amplifier, triode or tetrode, HF or VHF, Eimac bottles or Svetlana butylki.

By Mark Mandelkern, KN5S

The magazine ad said to cruise the Caribbean on *a luxury liner*. I'd rather cruise the ham bands, but the ad did give me an idea of what to call my new 2-meter amplifier design that replaces an old homebrew amp. That amp put out 1000 W and was still working fine after 35 years (with the original Eimac 4-400A tubes), so there was no real hurry to get the new amp built. I had time to include—and update—all the special features I've used in my several homebrew amps. I added several new features, too. While all these features, especially the protection circuits, are

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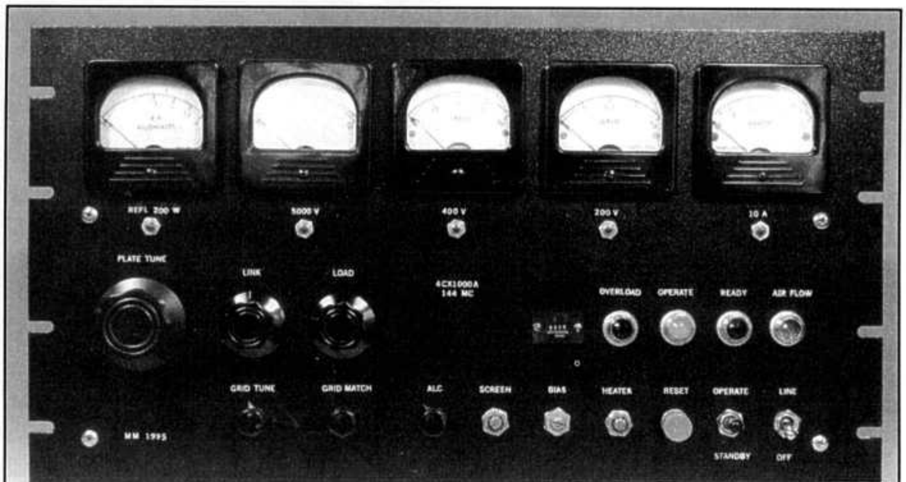


Photos by Lisa Mandelkern.

worthwhile (no frivolous bells and whistles here!), I can't claim they are all absolutely essential. On the other hand, you can get to the Caribbean on a tramp steamer, but the luxury liner's "features" are worth having!

This amp uses an Eimac 4CX1000A tetrode, with a socket and an air chimney that I found years ago at a hamfest flea market. While these tubes and sockets are now very expensive, the new low-price imported tetrodes and plain sockets could be used as easily. For example, the Svetlana 4CX1600B would work fine. Or a triode, such as the Eimac 8877, could be used: delete the screen and bias circuits, adjust the heater voltage and drive the cathode. While using triodes obviates the need for building screen and bias supplies, the recent availability of inexpensive imported tetrodes may make this seem less of a chore, so this is a good time to update the tetrode protection methods described in a previous article.[1]

Design Goals

The design goals are:

- The entire amplifier should be contained in one box, except for the HV supply. Even the blower will be inside the box.
- The heater must run on regulated dc, with automatic warm-up and cool-down timers.
- Complete metering of all parameters—without meter switches—including plate current and voltage, but without inconvenient metering connections (such as for B– metering) to the HV supply.
- Regulated grid-bias and screen-voltage supplies that are fully adjustable over a wide range, to allow adjustment for different tubes and conditions.
- Maintenance of regulation with line voltages down to 90 V ac and without failure or overheating at up to 130 V.
- Heater, bias, screen and ALC adjustments all on the front panel.
- Full protection circuits such that an overload condition puts the amp on standby, lights a flashing red panel lamp and connects the transceiver to the antenna.
- Plate tuning *and loading* controls, and grid input tuning *and matching* controls on the front panel, with no inconvenient top, bottom, side, rear or internal tuning adjustments.
- An internal regulated relay power supply and sequencing circuit to drive coax relays that can either be attached to the rear panel RF output jack or mast-mounted.

I managed to meet all the goals except the lower line voltage goal, but the regulators do operate down to 98 V.

Design Rationale

There are compelling reasons for each of these design requirements. One was that the amp was intended for VHF contest mountain-topping expeditions using generator power. On previous trips I'd found that while generator sag will drop the high voltage and reduce your power accordingly, the real killer is a drop in filament voltage whenever you hit the key. I saw a profound dimming of the 3-500Z filaments of a 6-meter amp under these conditions. This is the main reason for the regulated dc heater supply. Also, Rich Measures, AG6K, suggested using regulated voltage on the heater, and I wanted to try it.[2] A provision for filament voltage adjustment is required for long tube life.[3] My old amps all have rheostats on the filament transformer primaries and filament metering with at-the-socket sensing. But I got weary of adjusting the voltage every hour for 35 years and worried that I'd wear out the pots. Using regulated dc on the heater brought some unexpected additional advantages. For one thing, the current limit on the regulator is set to 10 A, just above operating current, which solves the inrush current problem with one tiny trimpot![4] The heater measures 80 mΩ cold; warming up at 10 A, it takes a whole 30 seconds just to get even near the operating voltage, where the current limiting phase ends and voltage regulation begins. (This suggests that the inrush current must be quite a bit higher in amplifiers where the filament meter jumps up in a second.) Measuring heater voltage and current accurately also allows heater resistance to be calculated—and relative cathode temperature inferred—under various conditions, such as during warm-up, or at the end

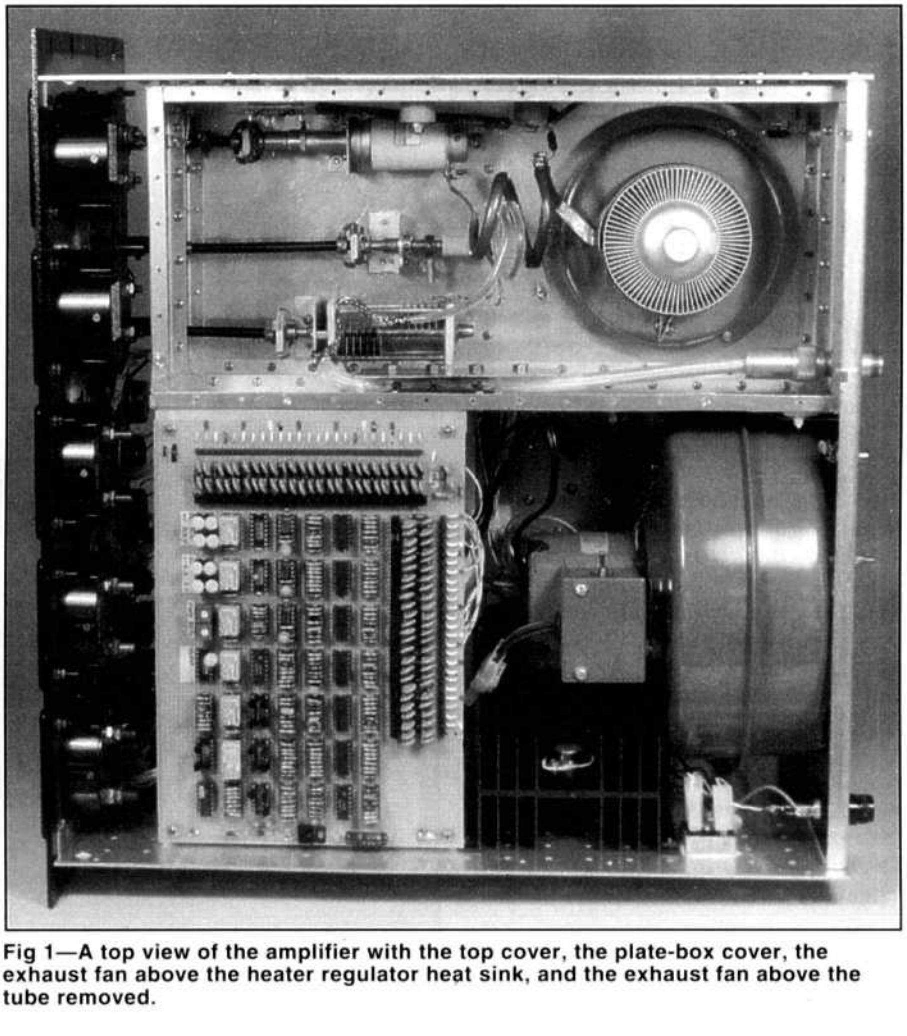


Fig 1—A top view of the amplifier with the top cover, the plate-box cover, the exhaust fan above the heater regulator heat sink, and the exhaust fan above the tube removed.

[1]Notes appear on page 12.

of a 15-second brick-on-the-key test.

The one-box requirement is to allow for easy truck loading before the contest and easy setup. The HV was to be stolen from the 6-m amp, using a single coax cable. No B– connection complication was permitted, so the new amp needed metering of both the cathode current and the high voltage. (Looking over at the meters on the 6-meter amp was thought to be an inelegant operating arrangement.)

I consider both the front-panel input tuning *and matching* controls essential. How essential depends on how much you love to pull a heavy amplifier out of the rack, remove the covers and tip it upside down to squeeze turns on a grid circuit coil. The little bit of extra work required to provide front-panel controls is offset a hundredfold by the convenience obtained. It's true, of course, that once tuned, these controls won't be touched until you change tubes.

The one-box feature and regulated supplies might also be useful in an amplifier intended for DXpeditions to exotic locations with fluctuating power systems.

RF Circuit

The RF circuit schematic is shown in Fig 4. The grid input matching circuit uses a T network. A proper matching circuit requires two controls, both accessible at the front panel. The grid itself requires zero driving power, but 30 W of amplifier drive is required; the loss occurs mainly in the internal electrode leads. Input-to-output isolation measures 30 dB, thanks to the Eimac socket with its built-in screen-bypass capacitor and to the extensive shielding and filtering used. With 17 dB of amplifier gain, this leaves a very wide margin of stability.

The plate circuit used here is a link-coupled, series-fed "series-tuned" half-wave tank.[5] This is a rather old-fashioned method, but it is very efficient and much easier to build, adjust and tune than other types. Think of a push-pull tank circuit with two tubes and a split-stator capacitor. Pull out one of the tubes and retune. (Will the amp still work? Ask anyone who's had one tube short out in the middle of a contest.) Now disconnect the capacitor on the side of the remaining tube and retune again. There you have it! At VHF, the tube output capacitance is a significant part of the circuit. Half the coil resonates with the tube, the other half with the tuning capacitor. The tank circuit is equivalent to a half-wave line, only with lumped inductance.[6] In the interest of efficiency, the no-tube side operates at half the Q, thus half the capacity (6 pF), as the tube side (12 pF), so the coil is larger on the side opposite the tube.

The resulting efficiency is excellent: 56% at an RF output of 1500 W, with 3000 V on the plate and a cathode cur-

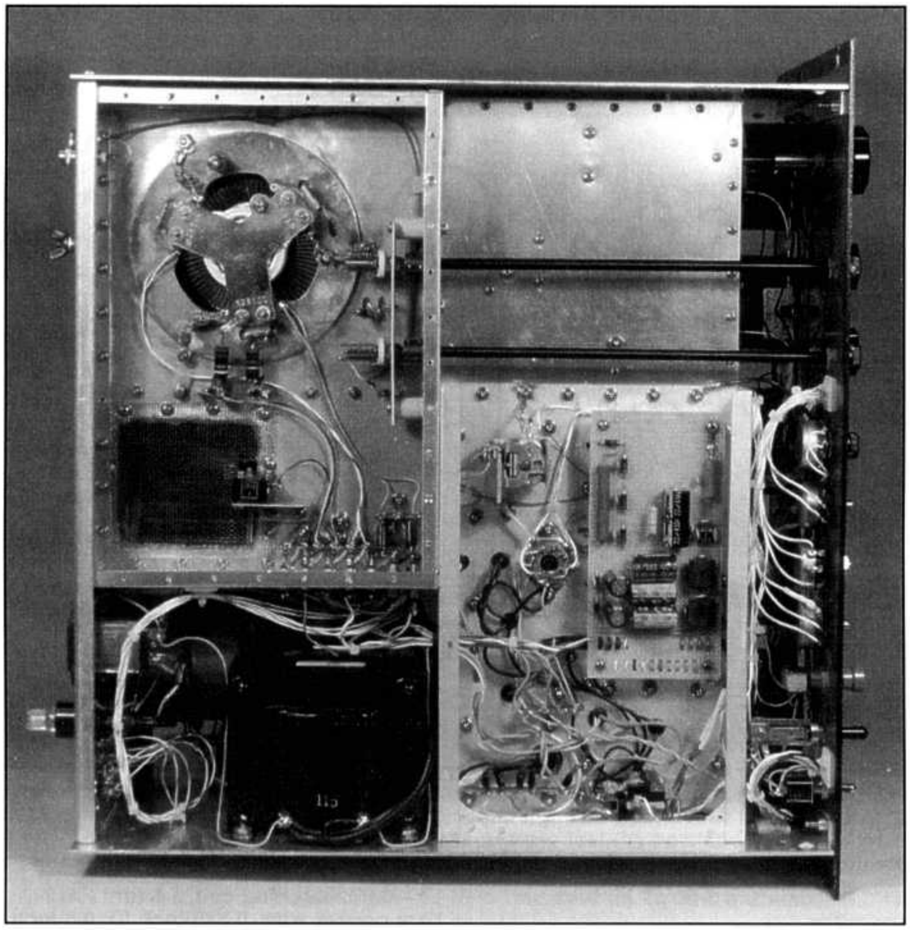


Fig 2—A bottom view with the cabinet bottom and the grid-box cover removed.

Fig 3—The rear panel of the amplifier shows the blower intake at the left. The CONTROL connector allows convenient one-cable connection of PTT, KEY and ALC lines to the transceiver, but the phono jacks can be used when, after the 6-hour 4WD trek up to the mountain top, the special cable can't be located.

rent of 900 mA. One reason for this good efficiency is that the plate tank on the tube side has no added capacitance—only the tube output capacitance is in the circuit—making the tank-circuit Q the absolute minimum possible. This is the main reason for using a half-wave "series-tuned" tank circuit. The Q on the opposite side is even lower. The low-Q circuit also results in negligible thermal drift. The link coupling allows wide-range

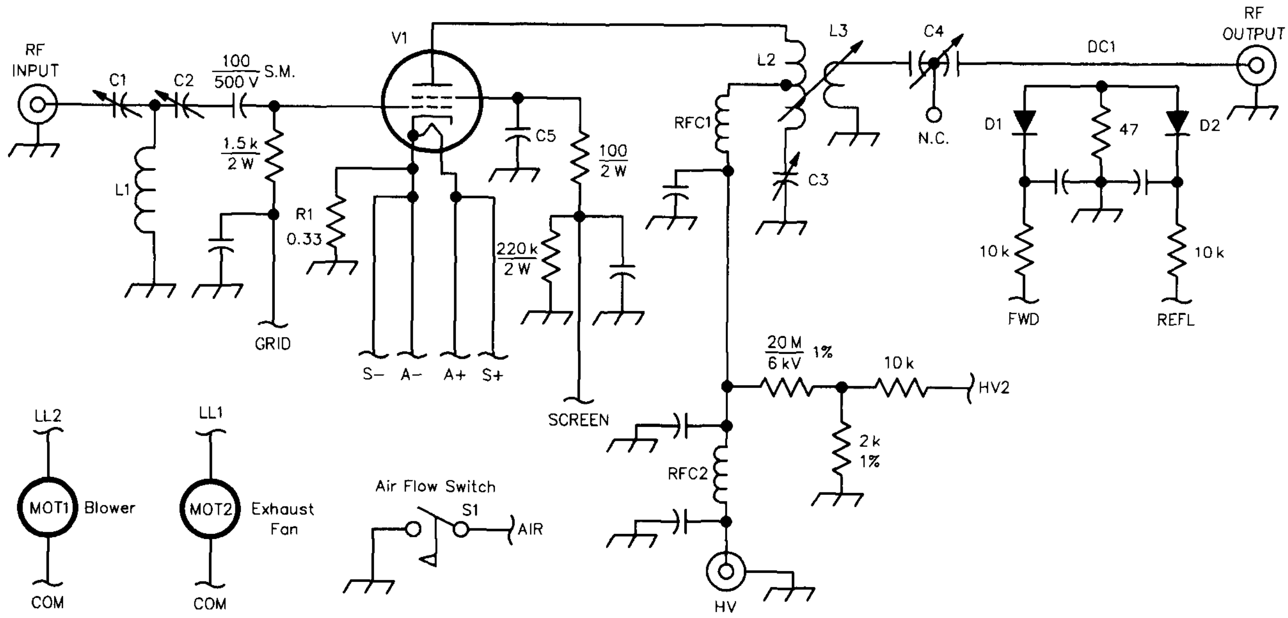
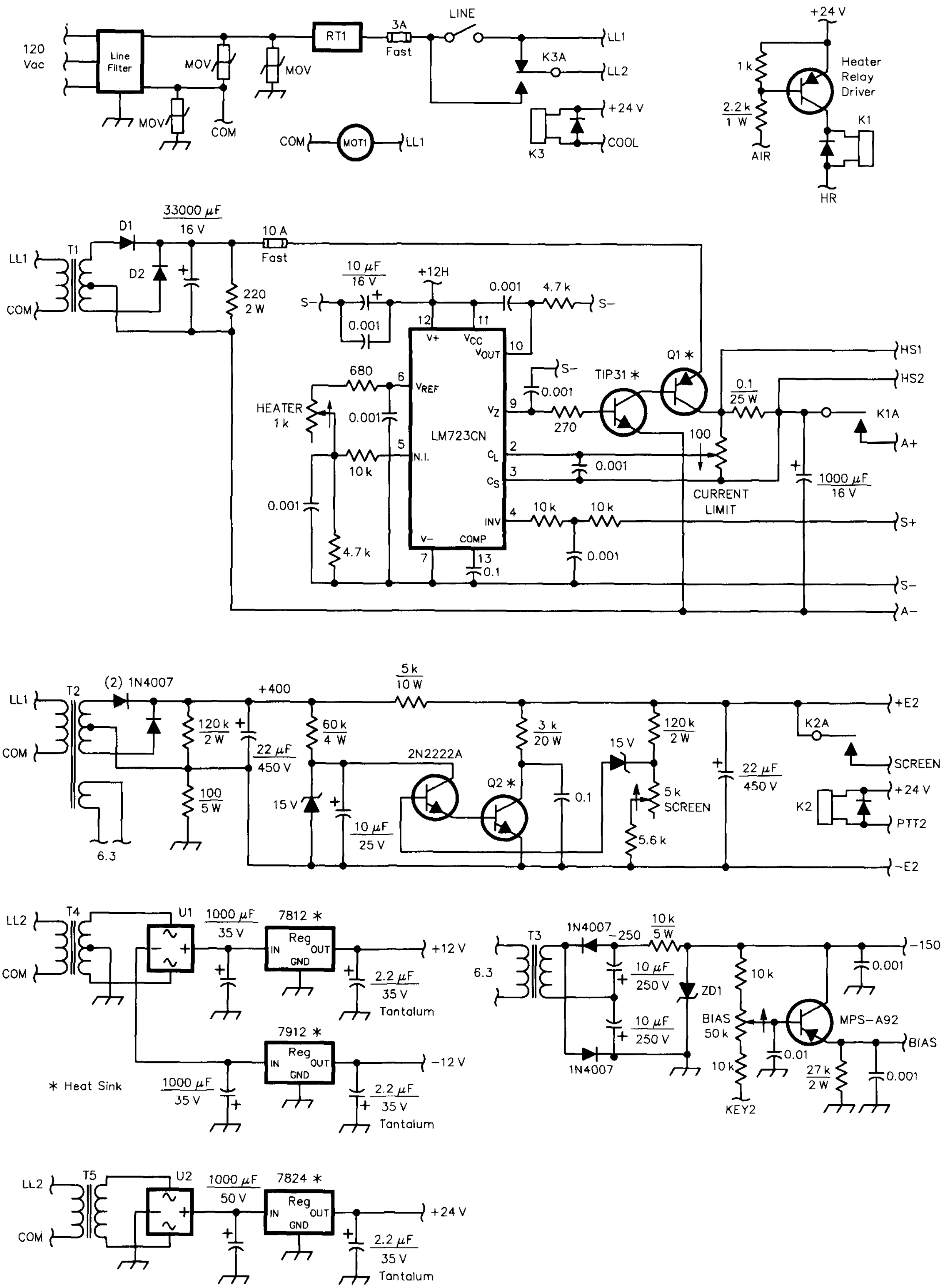


Fig 4—Schematic diagram of the RF section. Not shown is the extensive RF filtering. Each lead into the shielded grid and plate boxes is filtered with a feed-through capacitor and a π-section filter consisting of two bypass capacitors and an RF choke. At each of the three socket contact groups, the heater and cathode are bypassed with three bypass capacitors, across the terminals and from each terminal to ground. Unmarked bypass capacitors are 1 nF, with suitable voltage ratings.

C1,C2—Miniature 3-20 pF air variable capacitor.
C3—2-10 pF, 25 kV, vacuum variable capacitor. (Jennings #CAEB-10-25KV.) A homemade flapper capacitor would also be suitable.
C4—Split-stator air-variable capacitor, 5-20 pF per section, 0.040-inch spacing.
C5—1500 pF, 400 V, Mylar screen-bypass capacitor, built into the Eimac socket. Do not add any other bypass capacitors here.
D1, D2—Small-signal germanium diode, 1N270 or similar.
DC1—Directional coupler. #26 Teflon insulated wire, 2 inches long, inserted under the braid of Teflon-dielectric RG-225 coax.
L1—Grid matching coil, 1.5 turns #12 bare copper wire, 0.375-inch ID, 0.5 inch long.
L2—Plate tank. 2.5 turns 0.25-inch OD copper tubing, 1.5-inch ID, 2.5 inches long. Tap about 1 turn from the anode end (see text).
L3—Output link. 1.5 turns, #8 (3.3 mm) bare copper wire, 1.5-inch ID, close spaced, with 0.010-inch Teflon sleeving. The link is mounted on a 0.25-inch shaft with porcelain insulator and limit stops, and connections are made with bare copper braid taken from RG-8 cable.
MOT1—Blower, 117 V ac. (Dayton #1C982.) 1460 rpm, 125 cfm at a 0.3-inch static pressure. This blower is chosen for its low-speed (and low-noise!) operation. Call W. W. Grainger, Inc (800-473-3473) for a catalog and ordering information.
MOT2—117 V ac, 3.5×1-inch fan.
R1—0.33 Ω. Three 1-Ω, 2-W resistors, one at each cathode terminal.
RFC1, RFC2—1.8 μH RF choke. 33 turns #30 enameled wire, close wound on a 0.16-inch phenolic form.
S1—Air-flow switch. (Rotron #2A-1350.)
V1—Eimac 4CX1000A, with SK-800B socket and SK-806 air chimney, or similar tetrode with corresponding socket.

Fig 5 (see facing page)—Power supply circuit. Not shown are the 1-nF bypass capacitors across each diode, including those in the bridge rectifier blocks, and across each transistor base-emitter junction.

D1, D2—25 A, 50 V rectifier diode. It is convenient to use two of the diodes in an easily mounted "bridge" rectifier block.
K1—SPST relay, 24 V dc coil, 30 A contact.
K2—SPST relay, 24 V dc coil, 400 V contact.
K3—SPDT relay, 24 V dc coil, 10 A contacts.
MOT1—117 V ac, 3.5×1-inch fan.
Q1—MJ4502 PNP transistor, 30 A, 100 V, 200 W, with 48 in^3 heat sink and exhaust fan. (Hosfelt, see Note 19.)
Q2—NTE2325 NPN transistor, 800V. (Hosfelt, see Note 19.)
RT1—Inrush current limiter, 4 A. Keystone Carbon #CL-70. (Digi-Key #KC007L—see Note 20.)
T1—Filament transformer, 18 VCT, 10 A.
T2—Screen transformer. 600 VCT, 30 mA; 6.3 V, 1 A.
T3—Bias transformer, 6.3 V, 1 A; operated in reverse.
T4—Control transformer, 36 VCT, 1 A.
T5—Relay transformer, 28 V, 1 A.
U1, U2—Bridge rectifier, 3A, 200 V.
ZD1—Zener diode, 150 V, 15 W; three 1N5369B diodes in series.


120 Vac
Line Filter
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MOV
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COM
RT1
3A Fast
LINE
LL1
K3A
LL2
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COOL
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LL1
COM
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22 µF 450 V
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LL2
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1000 µF 35 V
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Reg IN OUT GND
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2.2 µF 35 V Tantalum
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MPS−A92
10 µF 250 V
BIAS
1N4007
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27 k 2 W
0.001
KEY2
LL2
T5
U2
1000 µF 50 V
7824 *
+24 V
COM
2.2 µF 35 V Tantalum

matching and smooth tuning, with the tuning, swinging-link and loading controls all on the front panel. Link coupling also results in excellent harmonic suppression—much better than capacitive coupling.[7] And the split-stator link tuning capacitor avoids rotor wiper problems. Note that the choke carrying the HV is attached at the RF, not the visual, center of the coil. This center is found after tuning the plate circuit (with no voltages present, see below), using a probe such as a pencil or a tuning tool with a metal tip. The RF center is the point you can touch without detuning the circuit.

These methods might even work at 222 MHz. For 6 meters, it would be very easy to substitute appropriate coils. For an MF/HF/50-MHz amplifier, suitable RF circuits are described in a previous article.[8]

Power Supply and Control Circuits

The power supply schematic is shown in Fig 5. The heater, screen and bias supplies are adjustable from 5.5 to 6 V, 200 to 350 V and −25 to −125 V, respectively.

The heater control circuit is shown in Fig 6. The circuitry must disable amplifier use during warm-up, maintain a regulated voltage at the heater and protect the heater in the case of an over-voltage failure of the regulator. Absolute over-voltage protection is provided by disabling the heater relay. In addition, an air-flow switch (Fig 4) in the grid box monitors the amplifier's blower. If air flow stops, the switch opens to disable the heater relay, shut down the heater regulator and extinguish the blue AIR FLOW panel lamp.

The warm-up timer—which also controls the green READY lamp—takes five minutes to activate. The spec sheet says three minutes is enough, but rumor has it that a longer warm-up will prolong tube life. The circuit will remain in the warm-up condition during a power line outage of about 10 seconds so you don't have to wait another five minutes. For longer power outages or other urgencies, when the operator will be responsible for timing a three-minute warm-up, there is a secret method for kicking the warm-up circuit (see schematic). If you want to eliminate the need for a warm-up period altogether, try using a 3CX1200Z7 tube.[9] Along with a warm-up timer, the amplifier needs a cool-down timer to keep the blower running after the amplifier is powered down. The cool-down timer in Fig 6 is a variation of a system described in a previous article.[10]

The OPERATE circuit (Fig 7), with its amber panel lamp, requires six go-ahead signals: air flow, OPERATE switch, warm-up ready, high voltage

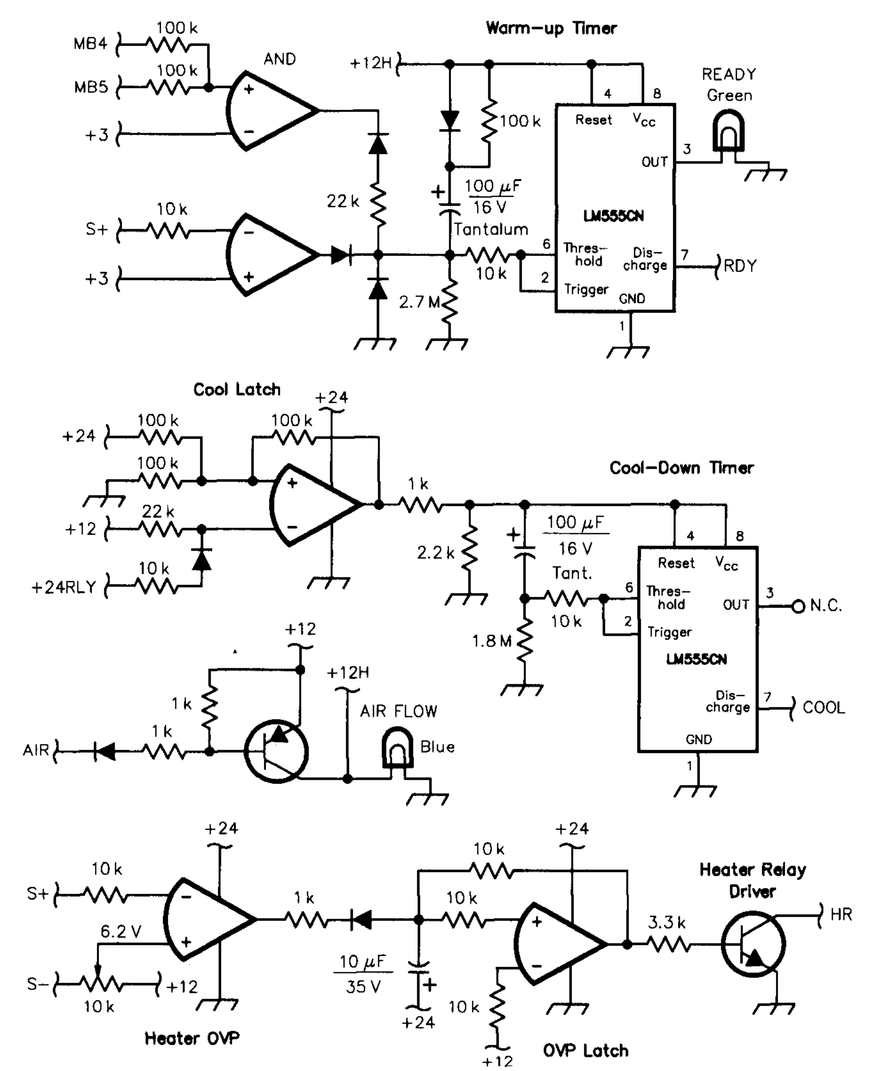

Fig 6—Schematic diagram of the heater control circuit. In the schematics of Figs 6-10, packaging and pin-outs are not shown since they will vary with individual construction methods. Except as indicated, the transistors are all small switching types, such as the NPN 2N4400 and the PNP 2N4402, the diodes are all small-signal silicon types, such as 1N4148, and each op amp is type LM324N, powered from the ±12 V rails. The 1-μF capacitors are monolithic ceramic. Not shown are the π-section filters, each consisting of two 1-nF bypass capacitors and a 1.6-μH RF choke, at each terminal on the control board. Similar filters are installed at the rear-panel jacks.

Table 1—Metering Functions

Meter	*Primary Function*	*Primary Range*	*Secondary Function*	*Secondary Range*
M1	Forward power	2 kW	Reflected power	200 W
M2	Cathode current	1 A	Plate voltage	5 kV
M3	Screen current	±50 mA	Screen voltage	400 V
M4	Grid current	1 mA	Grid voltage	200 V
M5	Heater voltage	5-6 V	Heater current	10 A

present, bias supply okay and overload circuit unlatched. Both PTT (screen and coax relays) and KEY (grid cut-off bias) lines are used to reduce plate dissipation to zero between dits (see below). If you wish, you can simply put a shorted plug in the KEY jack and use only the PTT line. The sequencing circuit provides 50 ms of delay for the screen relay (while the coax relays close), and 15 ms of hold-in time for the coax relays (while the screen relay opens). The circuit is an op-amp update of one described in a previous article.[11] The keying circuit is also sequenced so the keying waveform is determined solely by the transceiver. If vacuum relays are used, the relay timing may be easily changed for full QSK.

The ALC circuit (Fig 8) is also derived from a previous article.[12] The operation of the grid-current overload circuit is similar to that of the ALC circuit. If the ALC circuit is properly adjusted and connected, there will never be reason for the grid overload circuit to trip.

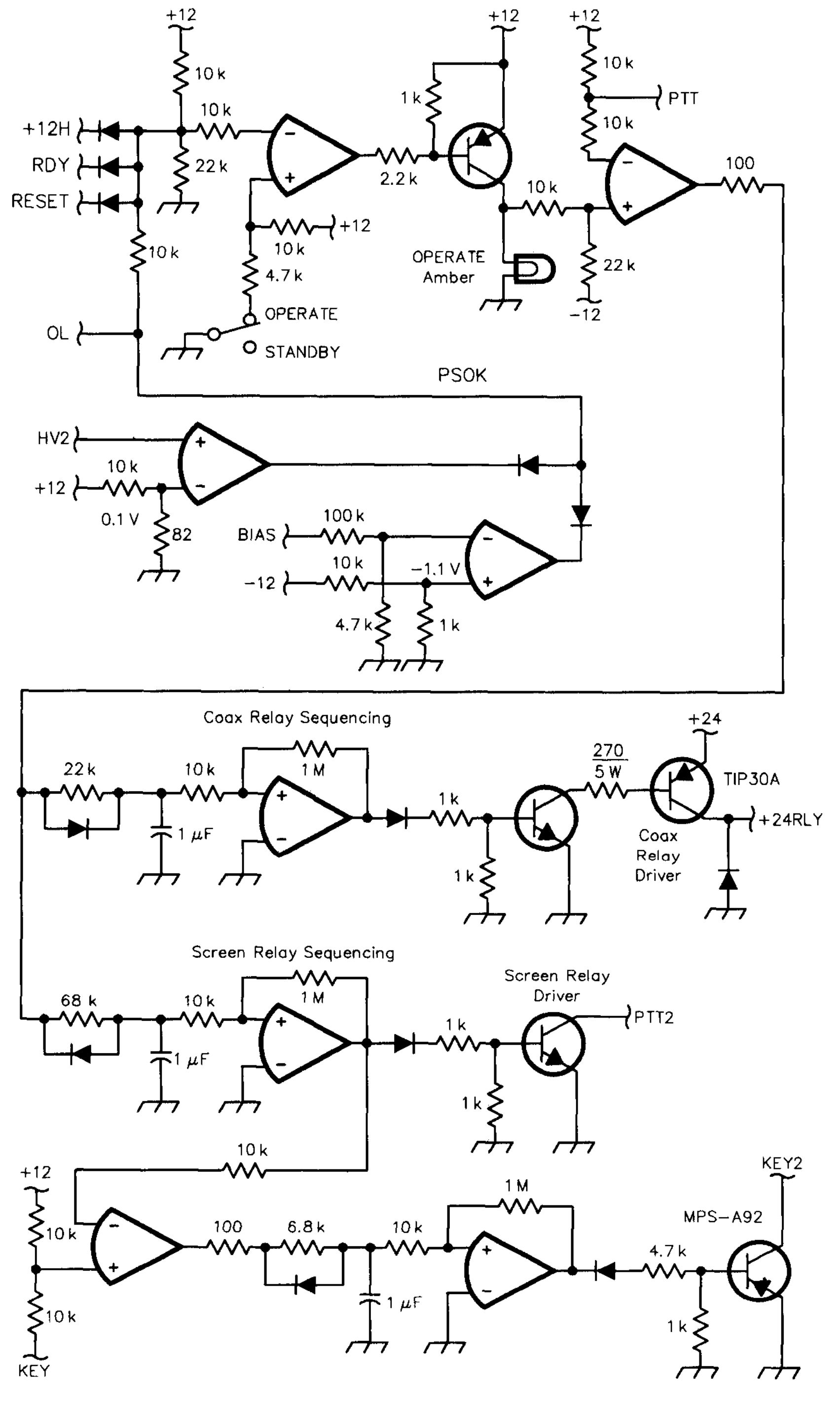

Fig 7—Schematic diagram of the operate circuit. Refer to the caption for Fig 6.

The overload latch (Fig 9) will be tripped by any of the grid, screen or plate overload circuits, which have limits of 1 mA, –30 mA and 1150 mA, and delay times of 200 ms, 500 ms and 100 ms, respectively. The screen and plate delay times automatically decrease for heavier overloads. The screen overload circuit protects only for negative screen current since the 5-kΩ resistor in the regulator circuit limits positive screen dissipation to well within the manu-facturer's specifications. When tripped, the overload latch disables the operate circuit, introduces a protecting grid-leak resistor into the bias line and lights the flashing red OVERLOAD panel lamp. The operate circuit is disabled while the RESET button is depressed, so your guest op can't defeat the overload circuits with duct tape on the button. This is a solid-state update of a feature implemented with mechanical relays in an amp built 25 years ago (see Note 1).

Metering

The design goal of metering 10 parameters with large meters while avoiding meter switches could not be taken literally. The compromise entails metering five primary parameters using five meters, with five secondary readings available using momentary push buttons. The main parameters should be instantly readable with utmost clarity, so the meter scales are labeled only for the main measurements—no confusing multiple scales! The buttons are labeled for the secondary ranges. Most of these allow obvious and immediate interpretation, while a few require a moment's thought—but all become second nature after a few minutes of use. The secondary readings are of great value for initial setup and for adjustments after changing tubes but are seldom used in normal operation. Table 1 shows the metering ranges.

Seven of the ten metering circuits (Fig 10), including all those where meter overload protection is required, are op-amp driven. Op-amp drive permits easy calibration, peak indicating RF metering, electronically damped plate metering, zero-center screen metering with a regular meter, expanded-scale heater metering and intrinsic meter overload limiting at about 110% of full scale. Also important, from a parts-scrounging point of view, is that op amps allow you to use dc meters of any range: simply remove the internal shunts and multipliers and relabel the scales.

Construction

Separate shielded and filtered grid and plate boxes are crucial for RF isolation; a third chassis carries most of the power-supply components. The three boxes bolt together and to the cabinet walls, forming a very rigid structure. The arrangement of the boxes is dictated by blower mounting, air-flow and front-panel control constraints. The blower discharges downward, pressurizing the grid box. Air then flows upward through the anode fins and out by way of the exhaust fan. This push-pull cooling system avoids the very common "hot box" problem. The 17×17×10.5-inch cabinet has vented top and bottom covers.[13] The front is a relay-rack style panel.[14] The grid box size is 8×11×2 inches, and the plate box is 7×15×6 inches.[15] The power-supply chassis is 7×10×2 inches. All wiring is Teflon insulated, and the hardware is all stainless steel or brass. PEM (self-clinching) nuts are used for the removable front panel and the top, bottom, grid-box and plate-box covers.[16]

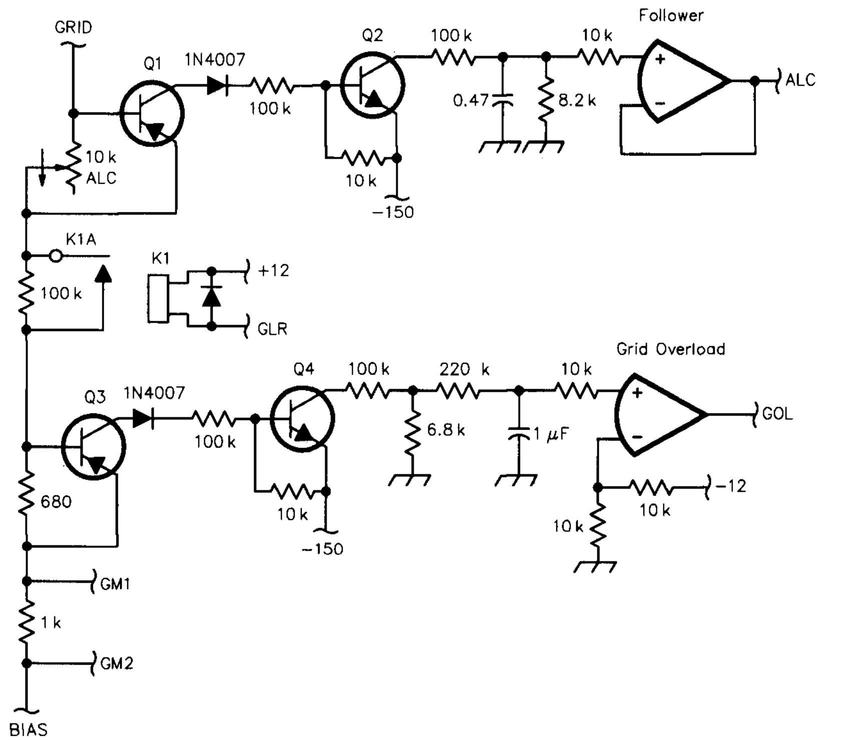

Fig 8—Schematic diagram of the ALC and grid overload circuits. Refer to the caption for Fig 6.

K1—SPST DIP relay, 12 V dc coil.
Q1, Q3—MPS-A92 PNP small-signal transistor, 300 V.
Q2, Q4—MPS-A42 NPN small-signal transistor, 300 V.

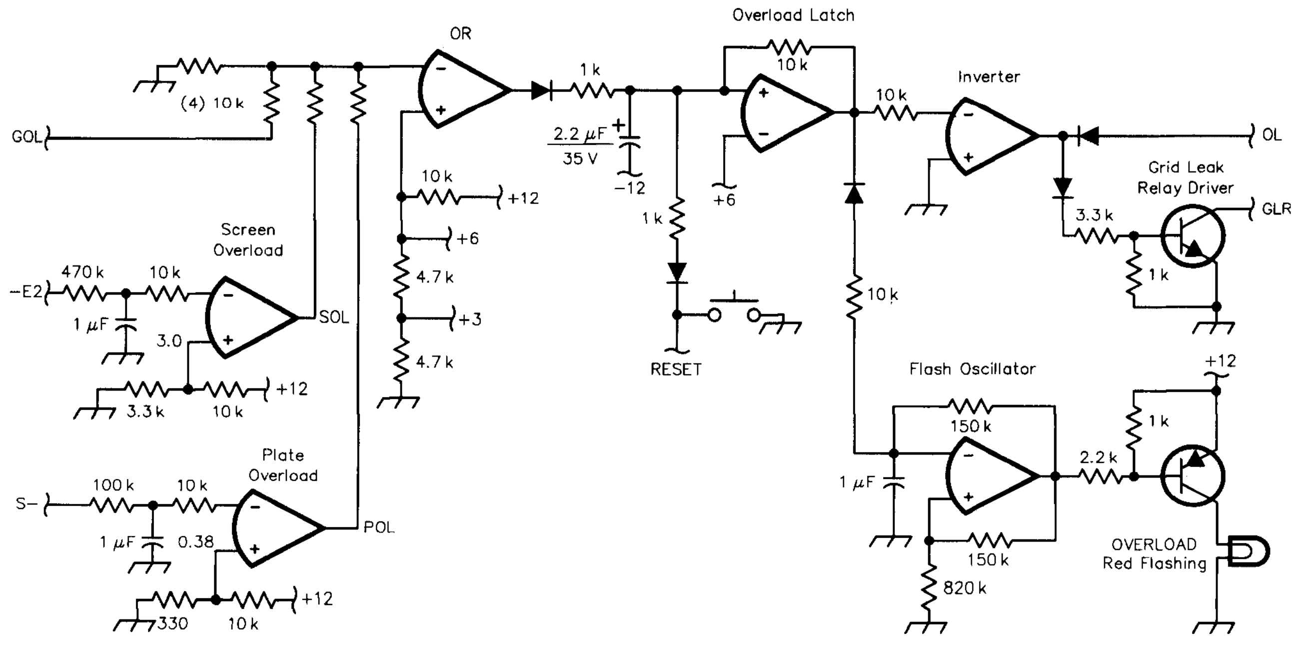

Fig 9—Schematic diagram of the overload circuit. Refer to the caption for Fig 6.

Initial Adjustment

It's very difficult to experiment with tuned circuits—trimming coils and changing tuning capacitors—with high voltage and heaps of RF power present, particularly with a sealed, inaccessible pressurized chassis. Here is a method that allows the coils to be preadjusted in a completely cold (and safe) condition on the bench, with no voltages applied. It can't possibly be a new idea, but I haven't seen it in the ham literature. For the plate circuit, first connect a 2700 Ω, ¼-W resistor from plate to chassis, to represent the plate load resistance. Now connect a return-loss bridge to the RF output jack and adjust the circuit for a match to 50 Ω.[17] The circuit is now converting 2700 Ω to 50 Ω; when the amp is up and running it will do the opposite. Varying the load resistor will test the ability of the circuit to match various loads, under various operating conditions. After trimming the coil and adjusting the range of the swinging link, I could easily use the tuning controls to get a match with different load resistors, corresponding to antenna loads with SWR far above 2.

The grid input circuit is prealigned in the same way, except that no load resistor is needed. For cathode-driven triodes, the same method could be used for the plate circuit, but tuning the cathode input circuit will require a load resistor and an estimate of the tube input resistance.

Operation

To be easy on the tube and the HV supply, it's best to tune up with dits at about 40 wpm. The peak-indicating output meter makes this easy. With the keying circuit used here, key-up plate

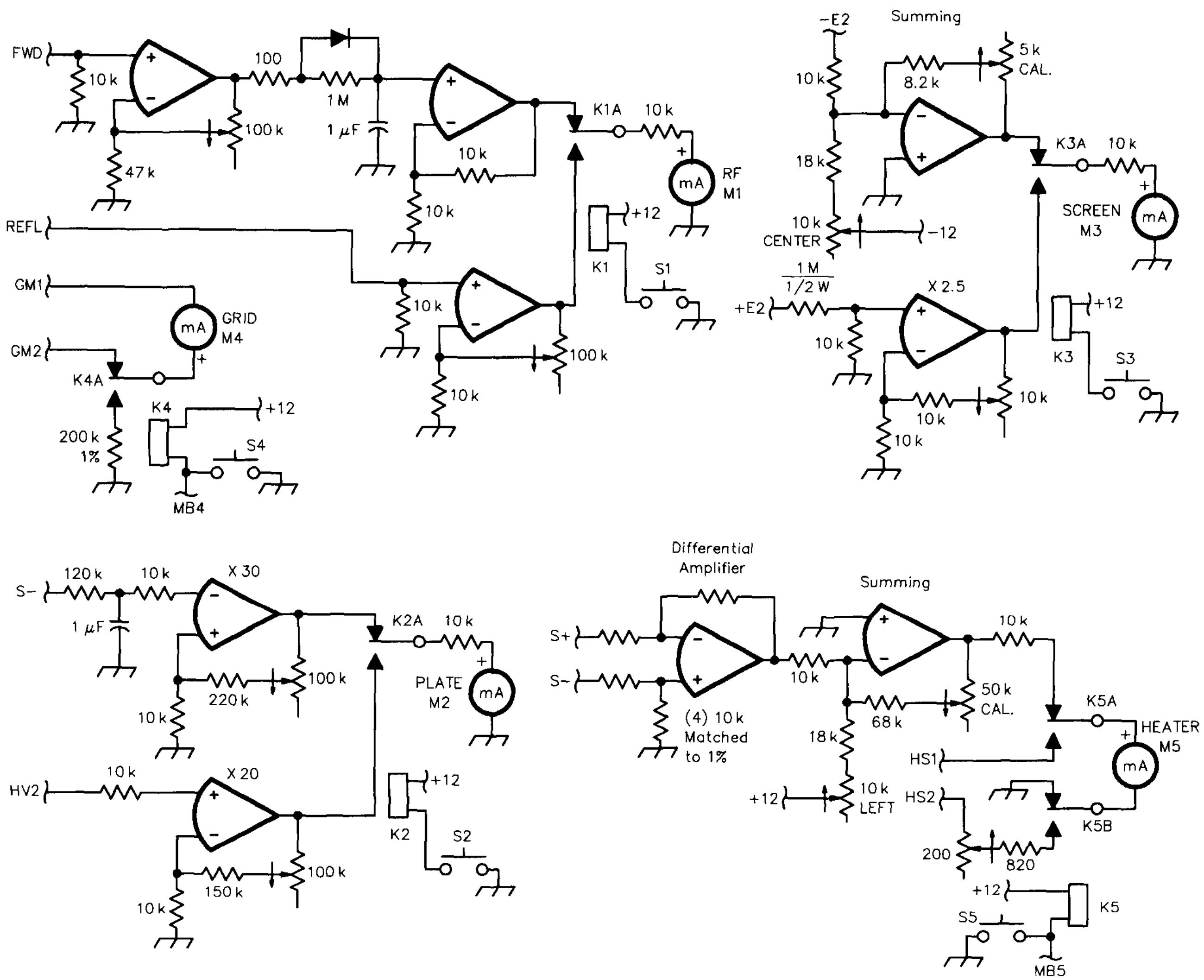

Fig 10—Schematic diagram of the metering circuits. Refer to the caption for Fig 6. The differential amplifier is required because the heater is operated above ground, due to the cathode metering shunt and the internal cathode-heater connection.
K1-K4—SPDT DIP relay, 12 V dc coil.
K5—DPDT DIP relay, 12 V dc coil.
M1-M5—0-1 mA meter. The op-amp-driven meters may have other ranges, up to 10 mA, by changing the series resistors.
S1-S5—SPST momentary push-button switch.

current is zero. The result is that testing at 1500 W PEP output involves only 600 W of average plate dissipation; the tube stays relatively cool. Without amplifier keying, there would be a dissipation of 975 W—key-down produces 1200 W of heat. It's only a hunch, but I think that most tube failures may be caused more by brick-on-the-key tuning than by normal operation.

The ALC is adjusted for 0.1 mA of grid current. Resonance is indicated by peak power output and loading by screen current. With the 4CX1000As I've used, the screen current under proper loading conditions hovers near zero during dit tuning, one-second key-down checks and on CW, but shows negative syllabic excursions on SSB. The severity of these negative excursions depends on the individual tube. See the references in notes 1, 3, 8 and 18 for general information concerning tetrode operation.

Summary

Building full protection, control, regulation and metering circuits into a linear amplifier does mean wrapping quite a bit of silicon cushioning around one little tube. But considering the cost of the tube and the reliability desired for DX and contest work, it's well worth the extra effort. You will never regret taking the time and trouble to build a linear that can watch out for itself.

Notes

[1]Mandelkern, M., "Protecting Power Tetrodes," *QST*, November, 1989, pp 22-25.

[2]Measures, R., "The Nearly Perfect Amplifier," *QST*, January 1994, pp 30-34.

[3]Sutherland, R. I., *Care and Feeding of Power Grid Tubes*, Eimac Division, Varian, San Carlos, CA, 1967, p 15, p 142.

[4]The inrush current problem is still controversial; see the discussion in "Revisiting 'The Nearly Perfect Amplifier,'" Technical Correspondence, *QST*, September 1994, pp 71-74. However, whatever the problem with inrush from an unregulated supply, regulation aggravates the inrush problem and makes inrush limiting mandatory.

[5]Orr, W. I. and Johnson, H. G., *VHF Handbook*, Wilton, CT, 1956, pp 167-168. As noted in this handbook, "series-tuned" is an inaccurate description of this circuit, referring only to its appearance on the schematic.

[6]Tilton, E. P., *The Radio Amateur's VHF Manual*, ARRL, Newington, CT, 1965, p 94.

[7]The second harmonic measures over 40 dB down on an HP spectrum analyzer. For even greater harmonic reduction, use the filter described in *The 1996 ARRL Handbook*, ARRL, Newington, CT, 1995, p 13.46.

[8]Mandelkern, M., "A Low-Drive, High-Power All-Band Tetrode Linear Amplifier," *CQ*, July, 1990, pp 60-65.

[9]Miller, R., "The Quick Powerhouse," *QST*, December, 1994, pp 33-37. See also the *Handbook* (note 7), pp 13.42-13.46.

[10]Mandelkern, M., "Three Amplifier Cool-down Circuits," *QST*, March 1989, pp 35-36.

[11]Mandelkern, M., "Antenna Relay Sequencing," *Ham Radio*, November 1987, pp 17-25.

[12]Mandelkern, M., "ALC for Class AB_1 Amplifiers," *QST*, July 1986, pp 38-39, 47.

[13]Bud cabinet #RM-14215, with covers #TBC-14262. Bud products are available from Electronic Parts Company, Inc, 2620 Rhode Island St NE, Albuquerque, NM 87110, tel: 800-456-0057 or 505-293-6161, fax: 505-299-3174.

[14]The Bud cabinet pack includes a plain aluminum panel. A pre-painted panel, LMB#1050 (black texture), can be obtained from LMB Heeger, Inc, 6400 Fleet St, Commerce, CA 90040, tel: 213-728-5108, fax: 213-728-4740. Ask for a catalog and information on direct ordering with free shipping.

[15]The grid and plate boxes are assembled using LMB *Omnichassis* components; see note 14.

[16]An extensive hardware selection is available from Small Parts Inc, Box 4650, Miami Lakes, FL 33014, tel: 800-220-4242 or 305-557-7955, fax: 800-423-9009; ask for a catalog.

[17]Use a hybrid combiner, as described in the *Handbook* (note 7), pp 26.37-26.39.

[18]Meacham, David D., "Understanding Tetrode Screen Current," *QST*, July 1961, pp 26-29.

[19]Hosfelt Electronics, 2700 Sunset Blvd, Steubenville, OH 43952-1158, tel: 800-524-6464 or 614-264-6464, fax: 800-524-5414.

[20]Digi-Key, Box 677, Thief River Falls, MN 56701-0677, tel: 800-344-4539 or 218-681-6674, fax: 218-681-3880.

A "Fool-Resistant" Sequenced Controller and IF Switch for Microwave Transverters

Feeling foolish since you blew up that nice new transverter because the T/R switching wasn't sequenced right? Here's a way to avoid that problem.

By Paul Wade, N1BWT

Last summer, I suffered the failures of two 10-GHz preamps and one coax relay. Fortunately, none occured at critical times, and I finally rigged up an inconvenient but safer two-switch scheme to prevent further problems. But I did resolve to come up with a better control system this winter. Ideally, it would be fool-proof, but fools are too resourceful for that, so I've tried to make it as fool-resistant as possible.

Discussion

For several years, I've been using variations of a transverter IF switch by KH6CP.[1] This has worked well in several of my transverters, and I've made various improvements, but it does not adequately sequence various switching functions.

Three sequencing techniques are commonly used. The first is to intercept the PTT line so the transceiver is controlled by the switch box. Often, this requires modification of the transceiver, particularly those that do break-in CW only, transmitting when the key is touched. I want to be able to interchange various transceivers without modification so I can lend spare equipment to willing rovers.

The second approach uses a fixed-sequence switch, usually a series of time delays, which, once started, go through the sequential operations without further safeguards.

The last, and least successful, method is to switch an external relay directly from a transceiver's PTT line. Often, the current available from the PTT line is inadequate for driving a relay, and I know of several cases where the transceiver has been damaged by this technique.

My preference would be a switch that goes through sequential operations but checks that appropriate conditions are met before proceeding to the next step—in logic design, this is called a *state machine*. As I started to sketch out the sequence of operations I wanted, I realized that ordinary T/R switches, such as relays, don't have an appropriate state to deal with break-in transceivers, which are delivering RF before the switch is ready for it. To deal with this, I use a PIN-diode IF switch and have designed the controller to have a third state, in addition to transmit and receive, in which all

[1]Notes appear on page 00.

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applied RF power is absorbed. I call this third state the *safe* state. Since one of the functions of the IF switch is to attenuate the transmitted power from the IF transceiver, the safe state is implemented by adding two PIN diodes that absorb the power.

Design

The first step in the design process is to sketch out the desired timing for the switching sequence. This evolved to the timing diagram shown in Fig 1, which goes through one cycle from receive to transmit and back to receive. The second step is to synthesize a logical state machine that generates the desired timing. The final step is to actually design a circuit that implements the logical state machine. Following this progression helps to ensure that the final circuit will operate as intended since there is a clear target to work toward.

The desired operation of the state machine sequence is shown in the *state diagram*, Fig 2. The system starts in the inactive receive state. When an activation signal is received, the system moves to the *safe* state, absorbing all RF power. The switching sequence can then continue at whatever speed is required, not releasing the RF power to the transmit circuitry until the system is ready to go to the transmit state. Normally, this would mean removing power from the receive section, then driving the microwave T/R relay, waiting long enough for it to switch (or to sense that the fail-safe contacts closed, if you are fortunate enough to have a relay with this feature) and finally, applying power to the transmit section. When the activation signal is removed, we go from the transmit state to the safe state, reverse the switching procedure, then return to the receive state.

Since this state machine is intended to be used in several transverters and with various IF transceivers, I added some options to increase flexibility:

1. RF sensing ensures that any RF power applied to the IF port will cause switching to the safe state—even if no control signal is applied—to protect the transverter from damage. Full RF switching may be enabled by setting the J17 jumper, allowing the use of any transceiver, even a hand-held, for the IF.
2. PTT polarity selection is provided since some transceivers ground the PTT output on transmit while others provide a positive voltage. There are separate inputs for these two PTT polarities; each requires low current and has a switching threshold of about 5 V.
3. Single-cable switching supports transceivers that put the dc PTT voltage on the RF output cable. Jumper J3 sets the PTT polarity for the IF cable.
4. A transmit-ready signal can be sensed. Some amplifiers require a warm-up period, so this input must be grounded to indicate that everything is ready to transmit; otherwise, the switching sequence will remain in the safe state and not continue. This input could be automatically or manually switched.
5. Fail-safe sensing detects when the fail-safe contacts on a coax or waveguide relay have closed—and prevents transmitting until they do. I've not yet found a good coax relay with this feature, but my 10-GHz wave-guide relay does have it. Jumper J15 selects between fail-safe operation and time-delay-only sequencing.
6. FET output drivers for the safe state activate a coax relay, activate dc power switching and drive LED indicators for the operator. I like to have three LEDs: TRANSMIT READY, SAFE, and TRANSMIT.
7. A DPDT relay may be jumpered to be switched by any of the FET drivers

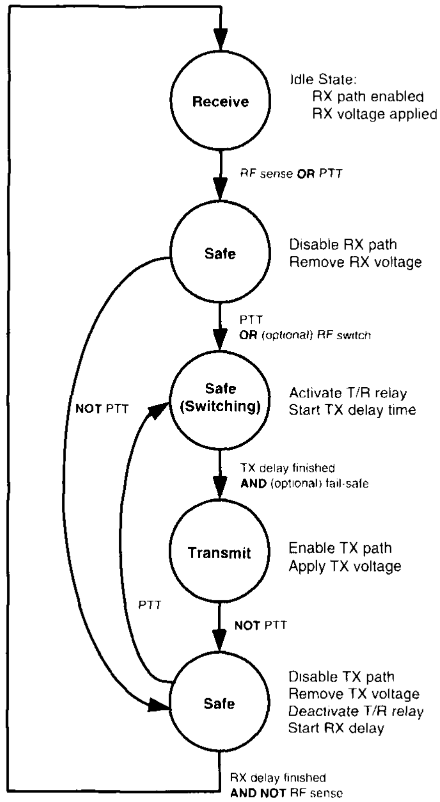


Fig 2—Sequencer state diagram. The circles show the individual states, while the text to the right of each circle shows the actions performed upon entering the state. The text next to each connecting line shows the conditions necessary to advance to the state the line goes to.

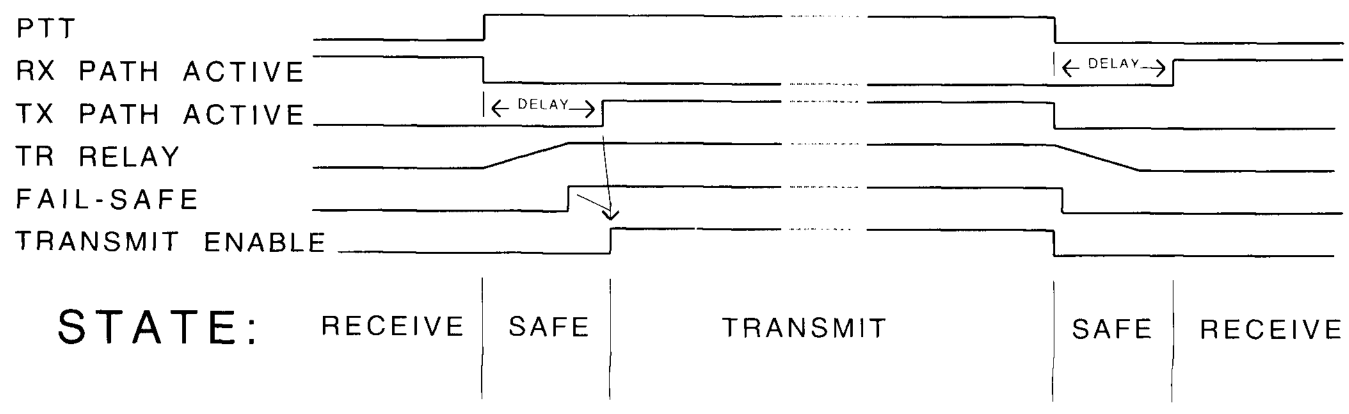


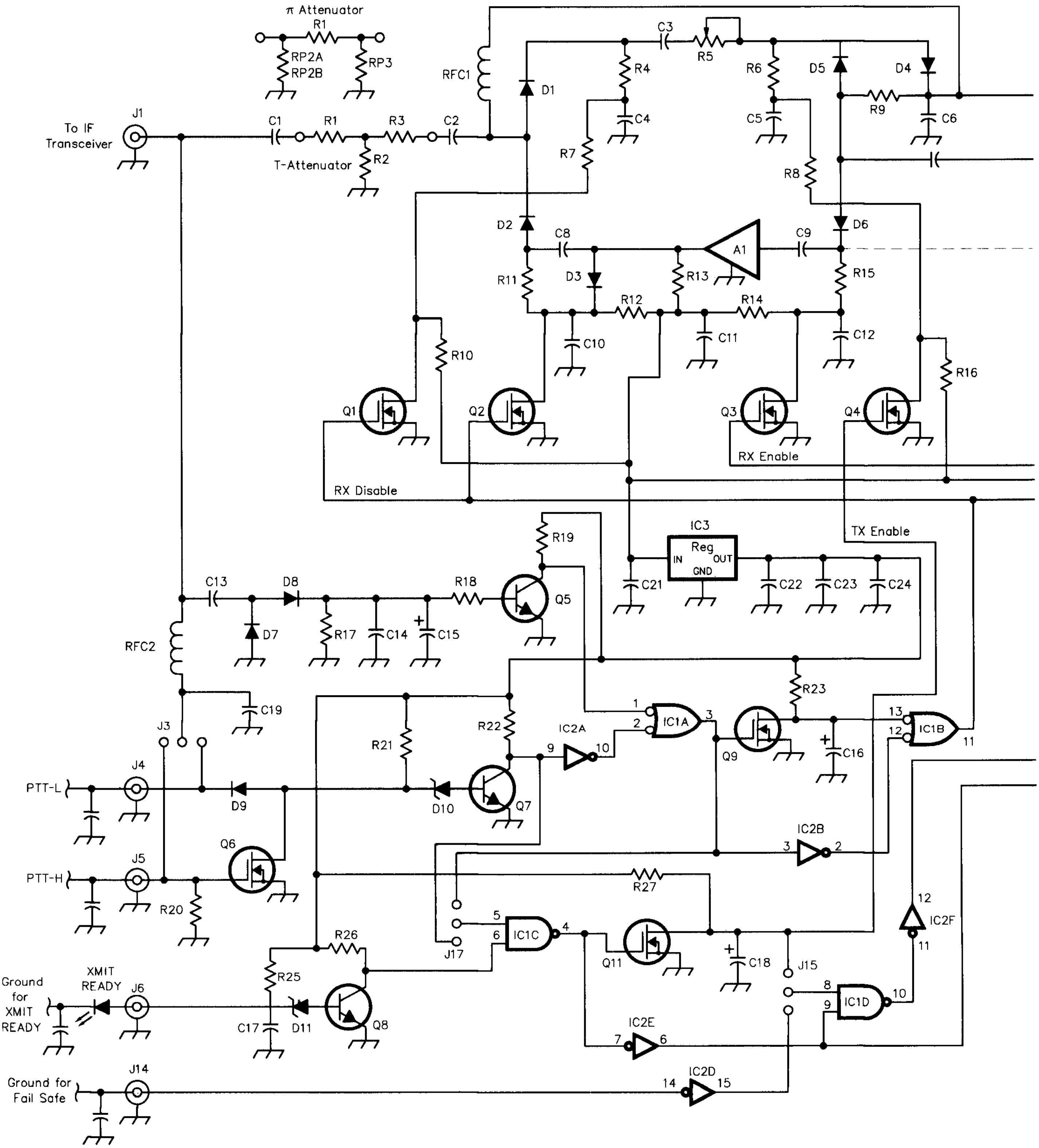
Fig 1—Sequencer timing diagram.

to operate at the desired point in the desired sequence.

The components for each of these options are indicated on the schematic diagram, Fig 3, and may be populated as desired.

Circuit Description

Some have suggested using a small microprocessor to implement switch sequencing. The flexibility and programmability of this approach would be great, but I am very cautious about putting microprocessors in high-intensity RF fields. Since my intent is



to include both the PIN-diode switch and the controlling state machine in a small metal box, there may be a significant amount of RF in the box. Therefore, I chose to design using components that are cheap, proven and readily available, and are also slow enough not to respond to RF. And wherever possible, I use these components in circuits I have used before and know to work well.

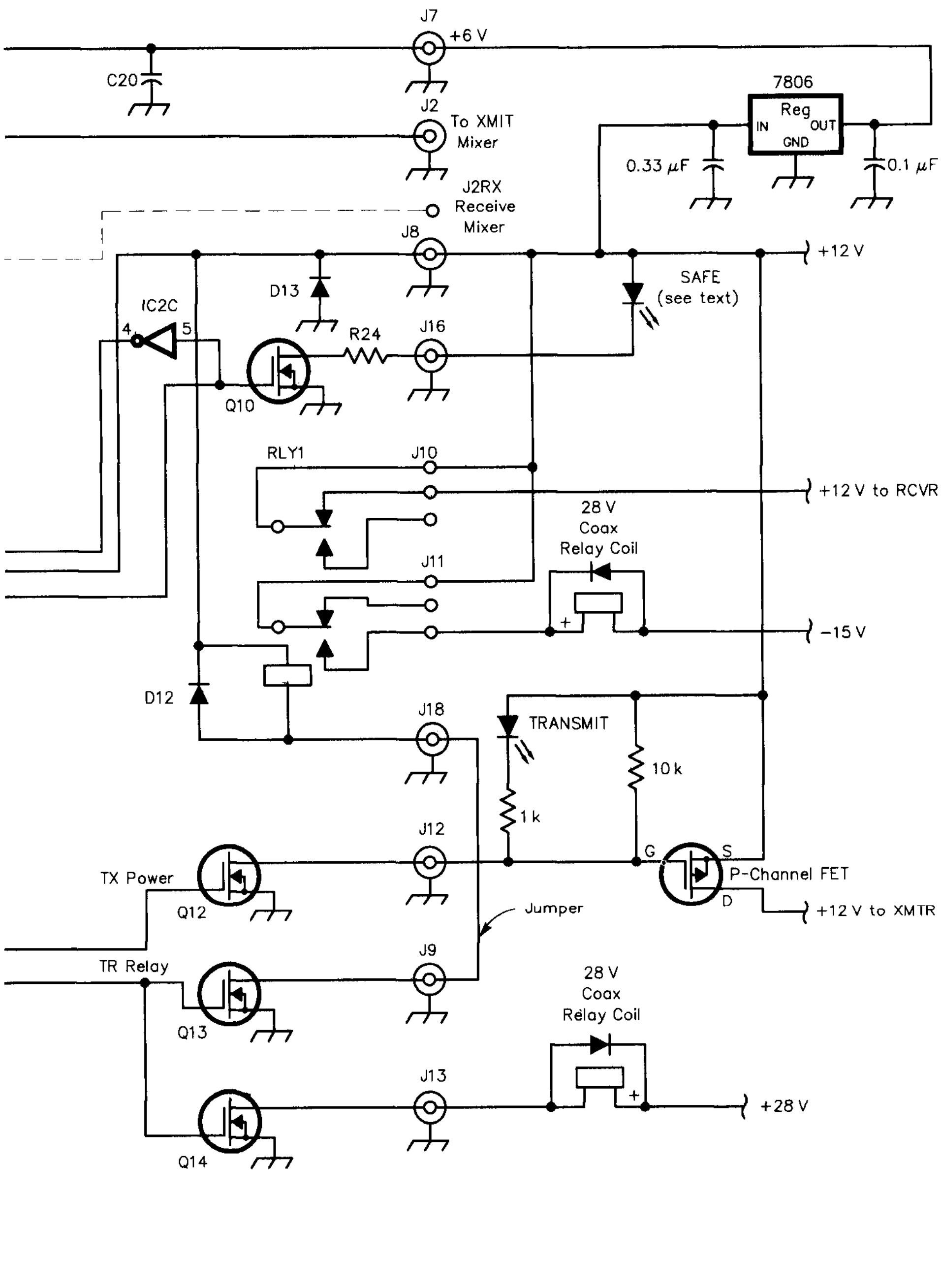


Fig 3—Schematic diagram of the IF switch and sequencer. (See Table 2 for parts list.)

Let's take a quick tour of the schematic diagram, Fig 3. The IF transceiver connects to J1, and its transmit power is reduced by the attenuator, R1, R2 and R3. The values shown provide about 14 dB of attenuation. Since low-inductance power resistors are becoming hard to locate, it may be necessary to adjust the attenuator design to fit the available component values. I described how to do this using a computer program, PAD.EXE, in *QEX*.[2] The program, which calculates resistor values and power ratings for attenuators, is available from the *QEX* web site, **http://www.arrl.org/files/qex/** in file qexpad.zip. The input attenuator used here is designed for the 2 to 3-W output available from small portable transceivers.

The attenuator is followed by the PIN-diode switch. A PIN diode acts as an RF conductor when dc is flowing through it, but acts as an RF open circuit when reverse-biased. Each PIN diode in this circuit is supplied with +6 V at one end, so the other end may be switched between +12 V and ground to reverse the bias. D1 and D2 select the transmit or receive path on the IF side, while D5 and D6 select the path on the transverter side. The transmit path goes through an adjustable attenuator that can be adjusted for 20 to 38 dB of total transmit attenuation. This is needed because most mixers require around 1 mW or less of power. The receive side uses an MMIC amplifier stage, A1, to overcome the loss of the input attenuator—the MAR6 provides enough gain to end up with 6 dB of net gain ahead of the transceiver, with a noise figure better than that of most transceivers.

The safe state is provided by PIN diode D4, which shorts the output end of the attenuator. Turning off FET Q4 causes current to flow through D4, making it an RF conductor, and causes D5 to be reverse-biased, making it an open circuit for RF. Thus, RF flowing into the transmit path has no output path and must be dissipated in the attenuators. The reflected power must pass through the attenuator twice, for a total loss of 60 dB, so essentially no reflected power is seen by the IF transceiver.

An additional safety feature is provided by D3, which is turned on by FET Q2. D3 shorts out any transmit energy that leaks through D2 (when it's off) and also disables MMIC amplifier A1 by reducing the dc voltage supplied to it.

The switching states for the PIN-diode switch are straightforward: in the receive state, FET Q3 is turned on, which causes D6 to turn on. FETs Q1, Q2 and Q4 are turned off, so D2 and D4 are on while D1, D3 and D5 are off—only the receive path is active. The next state is the safe state, reached by turning on FETs Q1 and Q2 and turning off Q3; this turns on D1 and D3 while turning off D2 and D6, so the IF input is switched to the transmit side but the output side is not connected and D4 shorts the attenuator output. Finally, the transmit state is reached by turning on Q4, which turns off D4 and turns on D5, completing the transmit path.

With the resistor values shown, the PIN-diode currents are adequate for an input power level of about 1/8 W, so the input attenuator should reduce the IF power to this level or lower. For higher powers, it would be necessary to increase the on current through the diodes, particularly D1. However, it shouldn't be necessary to switch much power, since the RF output to the mixer input should be milliwatts or less.

All the FETs used in this circuit are N-channel enhancement-mode MOSFETs used as switches. The sources are all grounded and the gate is the control element. When the gate voltage is close to the source voltage, or ground, the FET is turned off, and no current flows from drain to source. To turn the FET on, the gate voltage must be several volts more positive than the source voltage, allowing current to flow from drain to source with only a few ohms of resistance. For practical purposes, we may consider the drain to be shorted to ground when the FET is on and open circuited when the FET is off. Since these are insulated-gate FETs, no gate current is possible and no dc power is required for switching. The gate voltage required to switch the smaller FETs is roughly 2.5 to 3 volts, but larger power FETs such as Q14 require a somewhat higher voltage, so the whole switching circuit operates at 8 V, provided by the three-terminal regulator, IC3.

The rest of the schematic describes the control logic. The RF-detect section, from C13 to Q5, drives IC1A to force the system to the safe state as soon as RF input is detected. The PTT section, from Q6 and D9 to Q7, is a DTL (diode-transistor logic) gate with a switching threshold set by Zener diode D10. The PTT output is inverted by IC2A to also drive IC1A and force the safe state. Note that IC1A is drawn as an OR gate, with inversion bubbles on the inputs to show that they are asserted low; thus the output of IC1A is asserted when either input is in the low, or asserted, state. The output of IC1A is inverted by IC2B which activates OR gate IC1B, thus driving the *RX Disable* signal to turn FETs Q1 and Q2 on and put the PIN-diode switch in the safe state. The output of IC1B is also inverted by IC2C to drive the *RX Enable* signal. This turns FET Q3 off when Q1 and Q2 are turned on, and vice-versa. Finally, IC1B also drives

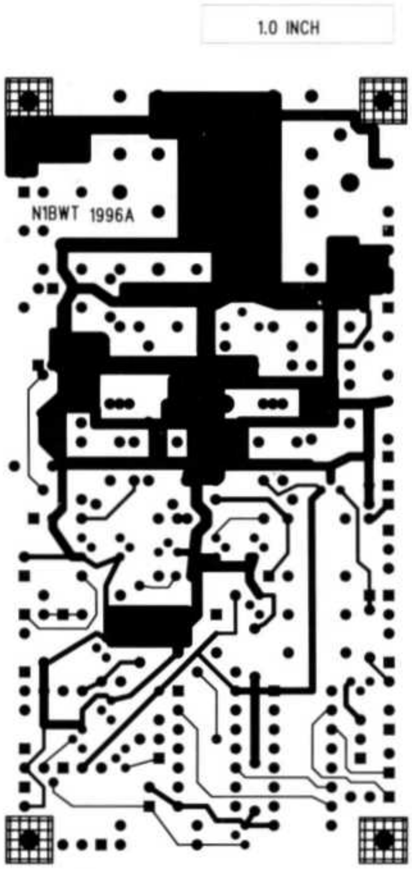


Fig 4—Top-layer printed-circuit board pattern.

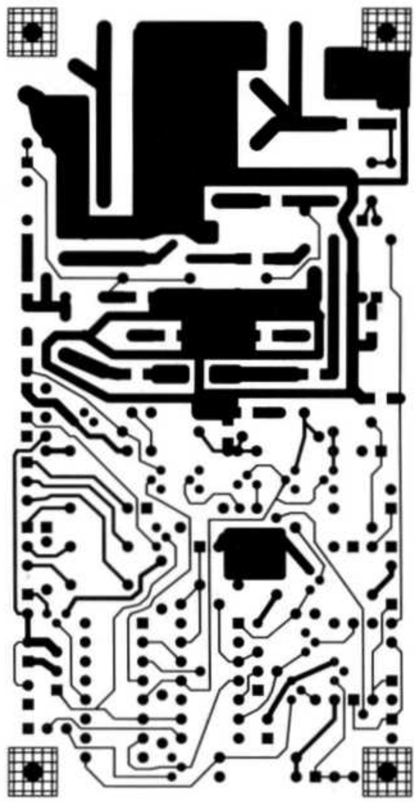


Fig 5—Bottom-layer printed-circuit board pattern. (Note: Board requires plated-through holes.)

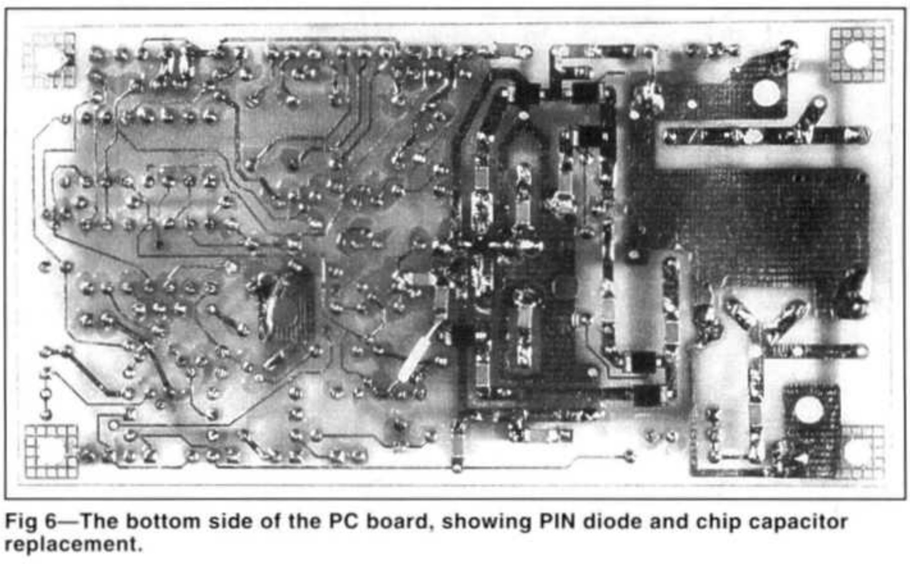


Fig 6—The bottom side of the PC board, showing PIN diode and chip capacitor replacement.

FET Q10, which is turned on in the safe and transmit states so it may be used as a signal to control the voltage supplied to receive stages and preamps.

The PTT section has two inputs, PTT-L on J4 and PTT-H on J5. PTT-L must be grounded, or asserted low, to activate, while PTT-H requires a positive voltage, or high assertion. Both inputs have an operating threshold in the 2 to 5-V range, so any input voltage below the threshold is considered low and any input above the threshold is considered high. The high threshold provides considerable tolerance for different rigs, dirty contacts, etc. The PTT section can also be activated through the IF cable input on J1—any dc voltage on J1 is delivered to the logic circuit through RFC2. Jumper J3 selects the polarity for the IF input; the right-hand position selects PTT-L and the left-hand position selects PTT-H.

The transmit-ready section, from J6 to Q8, is another DTL gate. Its output drives IC1C, which is drawn as a NAND gate; both inputs must be asserted high for the output to be asserted low. The other input to IC1C is selected by jumper J17; in the lower position, it is the output from the PTT circuit. Thus the IC1C logic function requires both transmit ready and PTT to be asserted. The upper jumper position takes the output from IC1A, which also includes the RF detection, making the logic require both transmit ready and either PTT or RF detect. This allows switching using only RF detection. Capacitor C15 sets the hang time for RF switching. With the values shown, switching time seems fast for SSB or for slow CW, so a bit of experimentation might be needed to find a time that feels right.

The output of IC1C is inverted by IC2E (note the inversion bubble on the input, to match the output of IC1C which is asserted low) to drive FETs Q13 and Q14, one of which should be used to enable the T/R relay. The IC1C output also drives FET Q11, which is an inverter with a time delay set by R28 and C18. Q11 drives the *TX Enable* signal, so completion of the time delay turns on FET Q4 to allow the transmit power to flow through J2. When jumper J15 is in the upper position, the completion of the time delay will also allow IC1D to switch, driving Q12 and enabling the transmit state. The lower position of the jumper forces IC1D to wait until J14 is grounded by the fail-safe contacts on the T/R relay.

When PTT is released and no RF is detected, the output of IC1A is deasserted. This voltage transition passes through FET Q9, an inverter with a time delay set by R24 and C16. Until the time delay completes, pin 13 of OR gate IC1B remains asserted, keeping the PIN-diode switch in the safe state while all the other switches are released. Since the safe state prevents any RF from getting through, sequencing of the switches isn't critical in this direction.

Finally, IC3 regulates the logic voltage to 8 V to maintain constant time delays. The R and C values specified yield time delays of 200 to 300 milliseconds, but the delay can be increased or decreased by changing the values. For instance, increasing C16 from 10 µF to 16 µF would increase the time delay by about 60%. Alternatively, increasing R24 from 33 kΩ to 51 kΩ would have the same effect.

Relay RLY1 may be driven by Q13 to operate at the same time as the T/R relay, during the safe state, or driven by Q12 to operate when entering the transmit state. Notice diode D12 across the relay coil. This serves to protect the FET from the reverse voltage spike caused by removing the current from the relay coil. All relay coils should have a diode to protect the driving circuitry; even a relay driving another relay can suffer contact damage from the switching spike.

Construction

I decided that this circuit is complex enough to justify layout of a printed-circuit board since my intent is to use copies in several transceivers. All the components between the two vertical rows of jacks on the schematic diagram, Fig 3, fit on the PC board. A double-sided board with plated-through holes was needed for full interconnection; the top-layer pattern is shown in Fig 4, and the bottom layer is in Fig 5. Boards are available from Down East Microwave.[3]

All the chip capacitors are mounted on the bottom of the board, as shown in the photograph of Fig 6, and I chose to

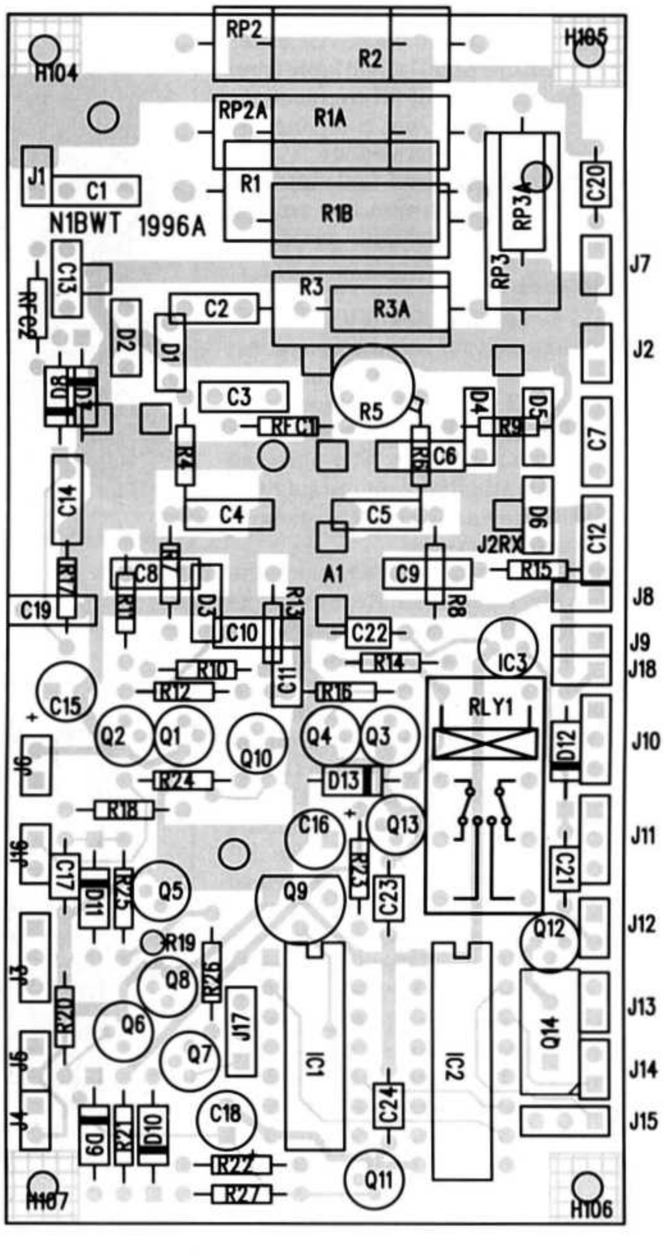


Fig 7—Parts-placement diagram for the printed-circuit board.

put the PIN diodes on the bottom also to keep lead lengths short in the RF path. All of the other components are on the top side of the board, as shown in Figs 7 and 8. Note that the smaller power FETs, such as Q1, have inconsistent pin-outs that vary with part number and manufacturer. Check the data sheet, and make sure that the source lead connects to ground, which is the wide trace running all over the top of the board. The gate lead connects to the middle pad of each footprint, leaving the drain at the far end.

Component values are not critical. I've tried to calculate optimum values, but any resistor or capacitor value could be changed to the next higher or lower standard value without significant effect. The RF diodes are stocked by Down East Microwave. All other components are readily available from Digi-Key.[4] The cost of all components totals less than $15, not counting the enclosure box and connectors.

The PC board is sized to fit inside a small die-cast aluminum box since a shielding enclosure is highly desirable.

Application

There is enough flexibility in this circuit that using it requires some decisions; on the other hand, it should be possible to fit it to your system needs rather than forcing the system design to match the controller. The portions of the schematic diagram outside the two vertical rows of jacks show some of the possible functions.

The first decision is whether the transverter uses a single mixer, as shown in Fig 9, or separate mixers for transmit and receive, as shown in Fig 10. A single mixer would connect to J2; otherwise, the transmit mixer connects to J2 and the receive mixer connects to J2RX, which is a hole in the PC board next to C9. In this case, D6 and R15 must be removed, and Q3, C12 and R14 may be removed or used for another switching function, as described below.

The next decision involves the control signals. I usually provide inputs for both polarities of PTT using different connector styles (RCA phono for PTT-H, subminiature phone for PTT-L). The transmit-ready and fail-safe inputs can go to connectors if they are used. Otherwise, they should be jumpered to ground to avoid floating inputs. Finally, jumpers J3, J15 and J17 must be installed as described in the circuit description. The switch will not operate without these jumpers.

Finally, we must decide how to use the control outputs. I chose to only provide outputs grounded by FET switches, except for the floating relay contacts, to keep unwanted voltages off the board. The signals that drive the FET switches are labeled on the schematic to indicate function. Some possibilities that I have used are shown in the right-hand side of the schematic. The internal relay, RLY1, can be driven by jumpering J18 either to J9, timed to switch a coax relay, or to J12, timed at the transmit state of the sequence. An external coax or waveguide relay usually requires 28 V for operation, which can be provided from a +28-V supply and switched with the larger power FET Q14, or connected between +12 V and a −15-V supply and switched with the internal relay contacts since many transverters already generate a negative voltage internally.

Power for the transmit stages may be switched with the internal relay contacts or with a solid-state switch using a P-channel power FET like the IRF-9130 or IRF-9530, which can switch several amperes with a small voltage drop. Note that the P-channel FET is used "upside-down," with the positive voltage connected to the source, as shown in the schematic,

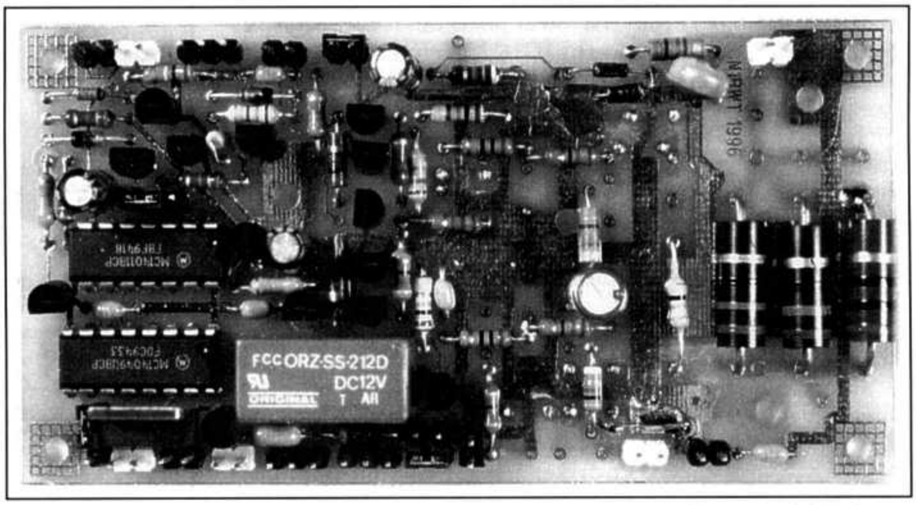


Fig 8—The top side of the PC board. The small power FETs are Motorola BS170.

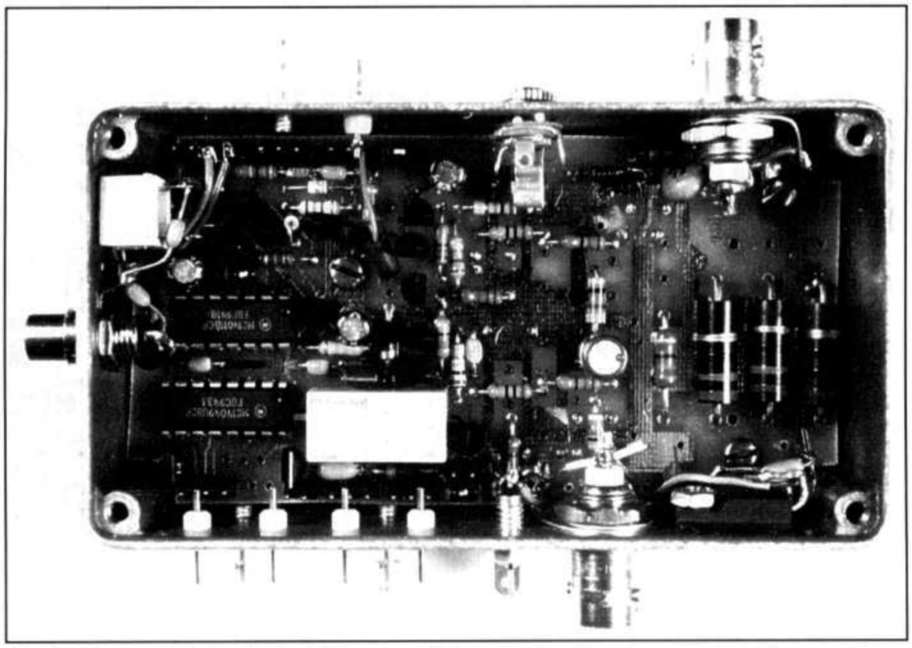


Fig 9—A completed unit, built for use with a single-mixer transverter. The small power FETs are Siliconix VN2222.

since a P-channel FET operates using voltages opposite those of the N-channel FETs described above.

Receive stages and preamps may be switched in several ways. The schematic shows the simplest, using the internal relay to disconnect the voltage at the same time that the T/R relay operates. A more robust sequence would be to remove power when entering the safe state; FET Q10 would be the appropriate driver, with R24 replaced with a jumper so the connection is directly to J16. FET Q10 is turned off during receive and on in all other states. If the receive voltage is set by a variable three-terminal voltage regulator, connecting the adjust pin of the regulator to Q10 would turn off the regulator output. Another alternative, for transverters with separate mixers for transmit and receive, would be to use FET Q3, which turns on during receive and off in all other states, the inverse of Q10. In the two-mixer configuration described above, Q3 is not needed, and R14 and R15 are removed so their pads are available as connection points.

Of course, one needn't be constrained by the printed wiring. If one of the FET switches is not used for the function shown, it can be used for a different function by connecting its gate to the appropriate switching line. All it takes is a hobby knife to cut the trace and a soldering iron to add a wire.

LED indicators may be driven by any output and can be driven by the same FET that drives a relay since the additional current is small. The schematic shows a TRANSMIT READY LED in series with J6, so grounding the transmit-ready line draws enough current to light the LED. If there is no LED in this line, R25 could be much larger to reduce current drain.

The PIN-diode switch requires +6 V to operate, which may be obtained from a three-terminal regulator if not otherwise available. This regulator easily fits inside the die-cast box, as can be seen in Figs 9 and 10.

Finally, all lines entering and leaving the box should be properly filtered. I strongly recommend a bypass capacitor on the inside of the box and a ferrite bead on the wire between the capacitor and the PC board, plus a ground wire from box to board for each connection. I've seen equipment lacking these components unable to operate properly in the high-intensity RF environments found at many mountaintop sites. Listening to TV sync buzz all day is no fun!

The RF connections at J1 and J2 must have closely coupled grounds from box to board; twisted-pair or coax is preferred. The mounting standoffs do not provide an adequate ground path for RF.

Performance

I have built five of these switches and made RF measurements on three of them over the range of frequencies normally used for transverter IFs, with the trimpot set for 30 dB of transmit attenuation at 144 MHz. The results shown in Table 1 are typical.

Clearly, the PIN-diode switch works well at up to 222 MHz, with more than 50 dB of attenuation in the safe state and about 6 dB of gain in the receive state. The trimpot range for setting total transmit attenuation was from 20 to 38 dB at 144 MHz. The switch is still usable at 432 MHz as long as the voltage supply to the transmit amplifiers is sequenced to augment the reduced attenuation in the safe state.

The RF-detect circuit operates reliably with the output from an IC202 transceiver, roughly 2 to 3 W, switching smoothly and ignoring glitches like double-clicking the mike button by remaining in the safe state. I added attenuation between the IC202 and the switch to reduce power. The RF-detect circuit continued to operate with 15 dB of attenuation, at a power level of about 100 mW, but not with 21 dB of attenuation, or roughly 25 mW. This should be adequate margin for safe operation.

Conclusion

The IF switch described here is sequenced to provide fool-resistant operation and is flexible enough for most transverter applications. This combination should make microwave operation more reliable and successful and

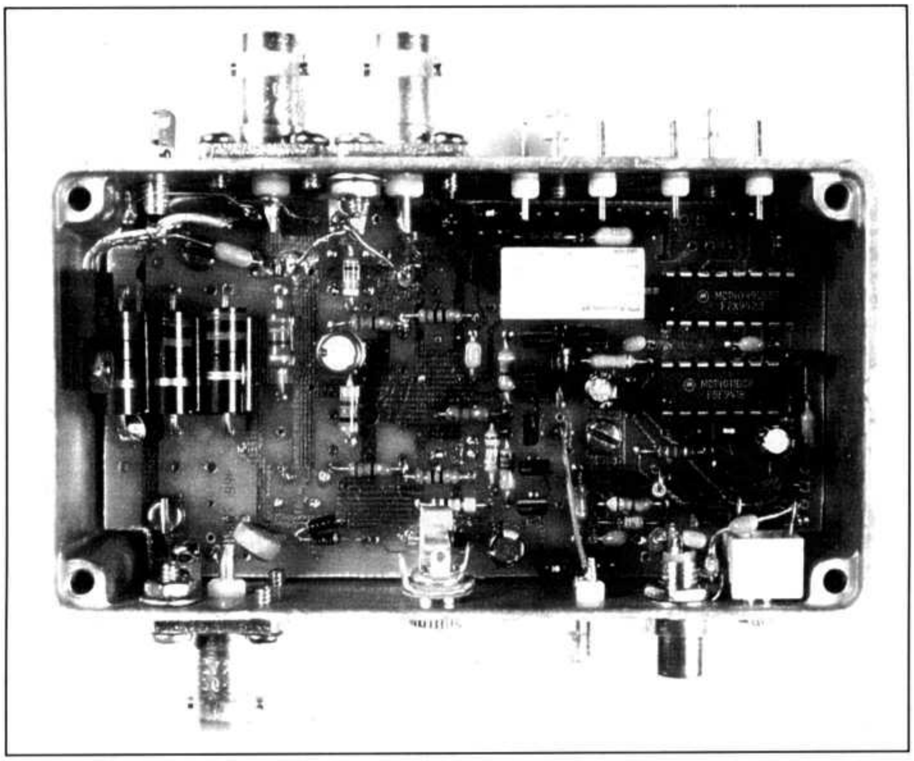


Fig 10—A completed unit, built for use with separate transmit and receive mixers. The small power FETs are Zetex BS170.

Table 1—Measured Performance

Frequency	*Receive Gain*	*Safe-mode gain*	*Transmit gain*
30 MHz	5.5 dB	−60 dB	−31 dB
50 MHz	5.5 dB	−63 dB	−31 dB
144 MHz	6.0 dB	−59 dB	−30 dB
222 MHz	6.5 dB	−50 dB	−29 dB
432 MHz	7.0 dB	−35 dB	−26 dB

Table 2—Parts List

A1	MAR-6 MMIC
C1,2,3,4,5,6,7,8,9,10,11,12,14,15, 19	470 to 2000-pF chip capacitor
C13	2.2-pF disc capacitor (at 50-432 MHz)
C15	22-µf electrolytic capacitor
C16,18	10-µf electrolytic capacitor
C17,20,22,23,24	0.1-µf capacitor
C21	0.33-µf capacitor
D1,2,3,4,5,6	1SS103 PIN diode
D7,D8	1N5711, 1N5712 or HP5082-2035 hot-carrier diode
D9	1N914 or 1N4148 small-signal diode
D10,11	5.1 or 5.6-V Zener diode (1N751, 1N752, 1N5231 or 1N5232)
D12,13	1N4001 rectifier diode
IC1	CA4011 or MC14011
IC2	CA4049 or MC14049
IC3	78L08 8-V regulator
Q1,2,3,4,6,9,10,11,12,13	BS170, VN2222 or VN10 small power switch FET (pinout varies—see text)
Q5	MPSA13 Darlington pair
Q7,8	2N3904, 2N2222, etc BJT
Q14	IRF841, IRF820, IRF830, etc N-channel power FET
T Attenuator	
R1	33-Ω, 2-W carbon resistor (two parallel 68-Ω, 1-W carbon resistors)
R2	22-Ω, 1-W carbon resistor
R3	33-Ω, 1/4 or 1/2-W carbon resistor
π Attenuator:	*add jumper in place of R3*
R1	120-Ω, 1-W carbon resistor
RP2	75-Ω, 2 W carbon resistor (two parallel 150-Ω, 1-W carbon resistors)
RP3	120-Ω, 1/4 or 1/2-W carbon resistor
R4,R6	68-Ω, 1/4-W carbon resistor
R5	500-Ω small trimpot
R7,R8	10-Ω, 1/4-W resistor
R9	300-Ω, 1/4-W resistor
R10	5.6-kΩ, 1/4-W resistor
R11,14	10-kΩ, 1/4-W resistor
R12	2.7-kΩ, 1/4-W resistor
R13	560-Ω, 1/4-W resistor
R15	360-Ω, 1/4-W resistor
R16	430-Ω, 1/4-W resistor
R17	47-kΩ, 1/4-W resistor
R18	8.2-kΩ, 1/4-W resistor
R19	4.7-kΩ, 1/4-W resistor
R20	100-kΩ, 1/4-W resistor
R21,22,26	6.8-kΩ, 1/4-W resistor
R23,27	33-kΩ, 1/4-W resistor
R24	with LED: 1-kΩ, 1/4-W resistor; without LED: 0-Ω jumper (wire)
R25	with LED: 680-Ω, 1/4-W, resistor; without LED: 10-kΩ, 1/4-W resistor
RFC1,2	1-µH RF choke, molded
RLY1	DPDT relay, Radio Shack #275-249
Enclosure	Bud CU-124 or Hammond 1590B die-cast box

help protect the environment by reducing the amount of smoke being released from our equipment.

Notes

[1]Lau, Z., KH6CP, "A VHF/UHF/Microwave Transverter IF Switch," *QEX*, August 1988, pp 3-4.

[2]Wade, P., N1BWT, "Building VHF Power Attenuators," *QEX*, April 1994, pp 28-29.

[3]Down East Microwave, 954 Rt 519, Frenchtown, NJ 08825, tel: 908-996-3584, fax: 908-946-3072.

[4]Digi-Key Corporation, 701 Brooks Ave S, PO Box 677, Thief River Falls, MN 56701-0677, tel: 800-344-4539 (800-DIGI-KEY), fax: 218-681-3380. Also on the World Wide Web at **http://www.digikey.com/**.

RF

By Zack Lau, KH6CP/1

A 2-Meter No-Tune Transverter: Why not?

It's surprising that no one has yet published a 2-m transverter based on no-tune technology. After all, 2 meters is the most popular amateur band. Perhaps the stringent spectral purity requirements are a factor. Currently, the FCC requires that all spurs be at least 60 dB down, although 56 dB is acceptable if you only run 10 W. Fortunately, this is quite attainable in a no-tune design if you choose the appropriate filters, shielding and signal levels. So, here's my no-tune 2-m transverter design.

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Filtering

As with all no-tune transverters, the keys to the design are the band-pass filters used to obtain spectral purity on transmit and image rejection on receive. These are implemented as microstrip resonators on the circuit board and are what makes the design no-tune. To keep the size of the board manageable, I loaded the resonators with capacitors, as shown in Fig 1. But size isn't everything. I decided to add room to make it easy to include shields, which increased the board size by about 50% over what it could have been. This should be worthwhile for the many builders who find it difficult to fabricate shielded enclosures. Merely putting a project in a metal box often isn't enough to keep out unwanted UHF signals, as they can easily get through long—but thin—gaps. This is why you find boxes held together by dozens of screws—all those screws are intended to break those long gaps into shorter ones. According to waveguide theory, you won't have much success keeping out unwanted signals unless the gaps are short.

By that reasoning, a shield at 2 meters is effective with screws spaced every couple of inches, but to effectively keep out UHF and microwave signals, you need to add more screws. So, you may not have to insert all the screws when doing prototype work in a benign workshop environment, but you'll need them in operation on that mountaintop, where all the high-power transmitters reside.

My testing shows that if the shield is too close to the filter, the filter response is moved upward in frequency. A shield height of 0.3 inches seems adequate for this 2-m filter design, but I recommend using a height of 0.4 inches to allow a bit of construction tolerance. As a bonus, separately shielded filters allow all the band-pass filtering to fit on a single board and still meet spectral-purity requirements. (Normally, the spurious and harmonic suppression of a single-board converter tops out at 50 or 60 dB due to unwanted coupling effects.)

I added an 8-V regulator to allow running the transverter from batteries. The National LM2940T-8.0 regulator not only allows operation at 9 V, but also adds reverse-polarity protection without requiring extra parts. The regulator does need good bypass capacitors—you can pretty much assume the regulator will oscillate if the output tantalum is reduced below 22 µF. Of course, the input capacitor has to be nonpolarized if you want everything to survive accidental reverse polarity.

Transmit Circuitry

Unfortunately, there is a limit to what filtering can accomplish in the way of removing unwanted signals. The mixing process usually generates unwanted mixing products, or spurious signals. Often, you will get several products that pass through the band edges as you vary the transmit frequency, so they are impossible to filter out unless you wish to restrict band coverage. For instance, you might design a transverter that covers only 145 to 147 MHz, even though you are legally allowed to use 144 to 148 MHz. Most people would consider this technical solution unacceptable, since they use transverters to cover the low end of the 144-MHz band, at one end of the legally allowed spectrum.

A more elegant solution is to reduce signal levels, as the unwanted mixing spurs typically drop faster than the desired signal. And as a bonus, using lower signal levels into the mixer also improves intermodulation performance. This doesn't decrease the LO harmonic levels—you *don't* reduce the LO level into the mixer—but assuming you've intelligently chosen the system frequencies, you can reduce LO feed-through by using better filtering and power-supply bypassing.

I did a number of tests with a

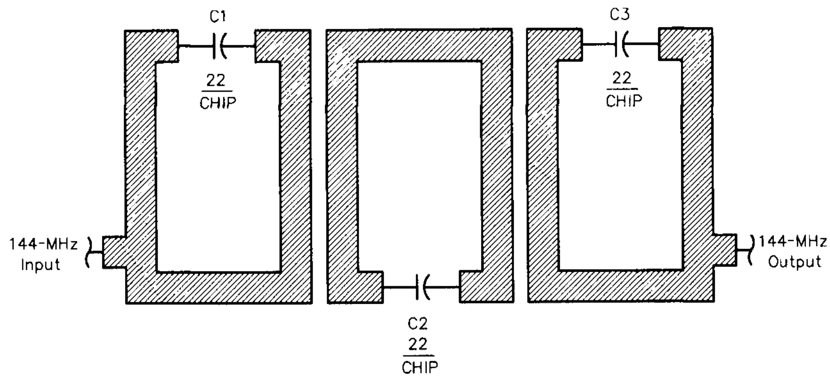

Fig 1—Microstrip 2-meter band-pass filter. The coupled microstrip lines are 2961 mils long and 109 mils wide, with a spacing of 50 mils. The board material is FR-4 with a dielectric thickness of 55 mils. The dielectric constant is 4.8.

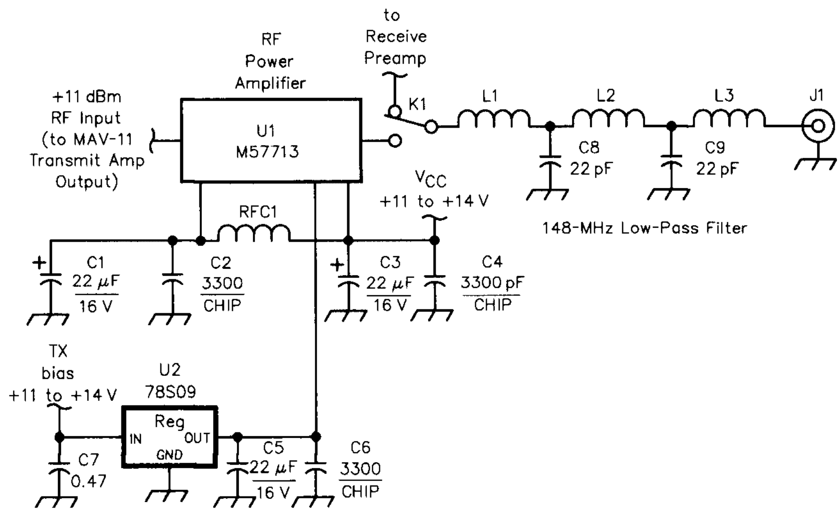

Fig 2—RF power amplifier and low-pass filter.

C8, C9—22 pF, with an estimated series inductance of 9 nH. Mouser 5982-15-500V22.
J1—UG-58 Type-N panel jack.
K1—Omron G5Y-1-DC12 relay (Digi-Key part Z24-ND).
L1, L3—29 nH. 3 turns no. 22, spaced 2 wire diameters, 0.156-inch inside diameter.
L2—79 nH. 6 turns no. 22, spaced 1wire diameter, 0.156-inch inside diameter.
RFC1—The required inductance is not specified by Mitsubishi. Americanized dimensions are 10 turns of no. 24 closewound, 11/64-inch inside diameter.
U1—Mitsubishi M57713 RF Power Module.
U2—78S09 9-V regulator.

Table 1—M57713 Power Module with 13.77-V Supply

Bias Voltage (volts)	*IMD (dB)*	*Power Output (PEP Watts)*	*Input Power (PEP dBm)*
7.90	–33	10.04	11
8.68	–41	10.06	10.5
9.11	–39	10.36	11
9.83	–31	10.29	10

Mitsubishi M57713 power module to figure out what I needed to use following the mixer to drive the power module. The tests show that the module needs +11 dBm to generate 10 W at the output of the T/R relay, using the circuit shown in Fig 2. The module I tested was surprisingly clean—when driven by the transverter board and an extra MAV-11 MMIC, the third-order IMD was 41 dB below the level of the output tones while putting out 10 W PEP. This was a surprise; many designs using power modules have significantly worse distortion. I suspect the module I was using is an unusually good sample. Unfortunately, while the third-order tones looked pretty good, the high-order tones rolled off rather slowly—it wasn't until the 15th-order products that the IMD was 60 dB down! Those interested in driving a high-power tetrode amplifier are better off using a class-A power MOSFET, such as the Motorola MRF 137. While the close-in distortion may actually be a little worse, the high-order products fall off quite rapidly, resulting in a much cleaner signal. Your fellow band occupants will thank you.

I experimented with changing the bias voltage on the module. Table 1 shows the results, which indicate that you should run the module at the suggested 9 V unless you have a spectrum analyzer available to tweak the voltage for the best possible performance. In these tests, I varied the input power to keep the output at around 10 W. I did the test using just the power amplifier, without the output filter. I didn't spend time calibrating the combiner and cable losses, so the input power values shown are only approximate. As you can see from the results, significantly changing the bias voltage up or down by a volt made the IMD worse. Since the measured IMD numbers were so much better than I expected, I looked at the effect of changing the tone spacing. I decided there wasn't much difference whether the spacing was 1 or 32 kHz. Similarly, there wasn't much of an improvement running the module at 5 W output instead of 10 W. I also didn't see much of a change in IMD when I varied the length of the cable between the low-pass filter and the power module.

I encountered a stability problem in driving the power module with an MRF 581A amplifier that used series and shunt feedback. A 2-dB resistive pad cleaned up the problem, but it makes more sense to just use an MAV-11 MMIC amplifier between the no-tune board and the power module, since the module requires so little

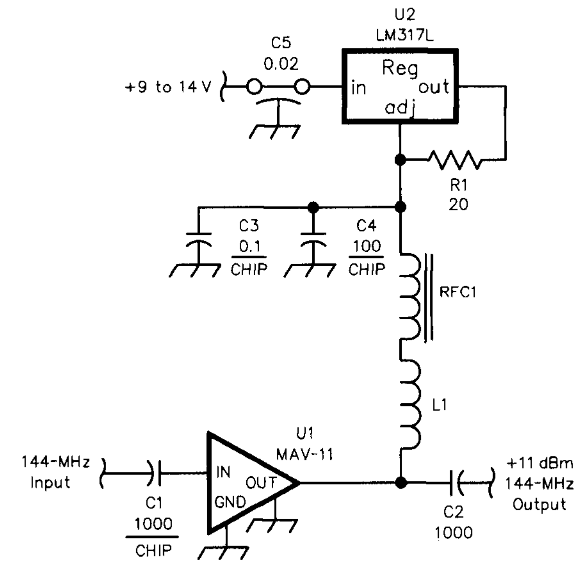

Fig 3—Transmit driver amplifier.
L1—3 turns no. 26, space-wound one wire diameter, 0.062-inch inside diameter. Not optimized for this application.
RFC1—7 turns no. 26 on FT-23-63 ferrite toroid.
U1—LM317L adjustable voltage regulator.

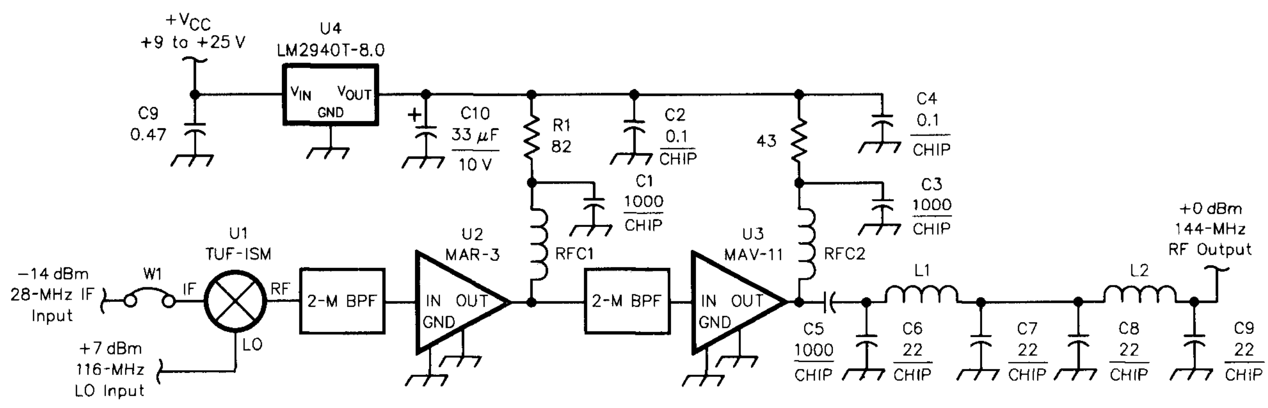

Fig 4—2-m transmit converter.

C10—33 µF tantalum, 10 V. Do not reduce below 22 µF.
L1, L2—55 nH. 5 turns no. 24, closewound, 0.11-inch inside diameter.
RFC1, RFC2—390 nH. 12 turns no. 24, closewound, 0.188-inch inside diameter.
U1—Mini-Circuits TUF-1SM mixer.
U2—MAR-3, MSA-0385 MMIC.
U3—MAV-11, MSA-1104 MMIC.
U4—National Semiconductor LM2940T-8.0 low-drop-out regulator.
W1—Copper foil to bridge circuit trace gaps.

drive. The design shown in Fig 3 uses an LM317 current source to bias the MAV-11, instead of the usual voltage source and bias resistor. This is one approach that gives consistent performance despite a supply voltage that varies. I use this amplifier as a general-purpose gain block; it isn't optimized for this application.

Testing the input of the M57713 with various lengths of open and shorted coax showed no sign of instability. A similar test on both the input and output of the MRF 581A amplifier also revealed no problems. This test tries to determine whether the amplifier is conditionally stable—some designs will oscillate when terminated with certain impedances. Other possible improvements, such as improved shielding and better power-supply decoupling, are rather time consuming, so I'll leave those to someone else to investigate, since I've already come up with two practical solutions.

The 2-m transmit converter is shown in Fig 4. A pair of MMICs between

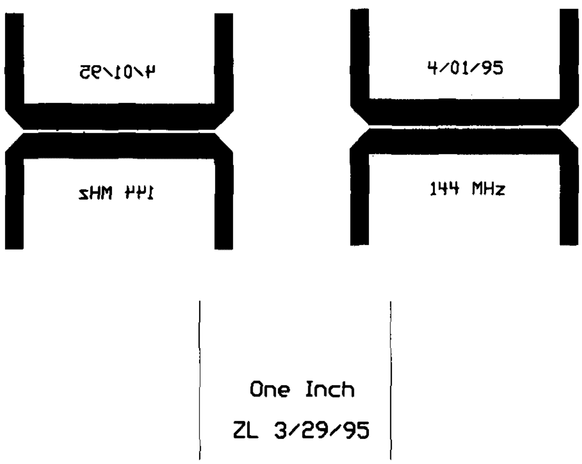

Fig 5—2-m microstrip coupler on 1/16-inch FR-4. See text for precise dimensions.

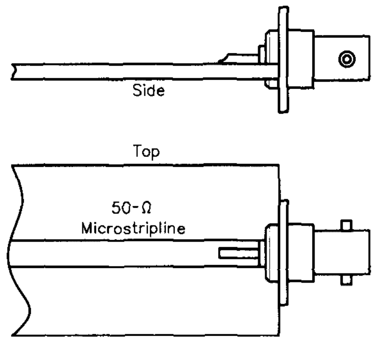

Fig 6—Microstrip to BNC end-launch transition.

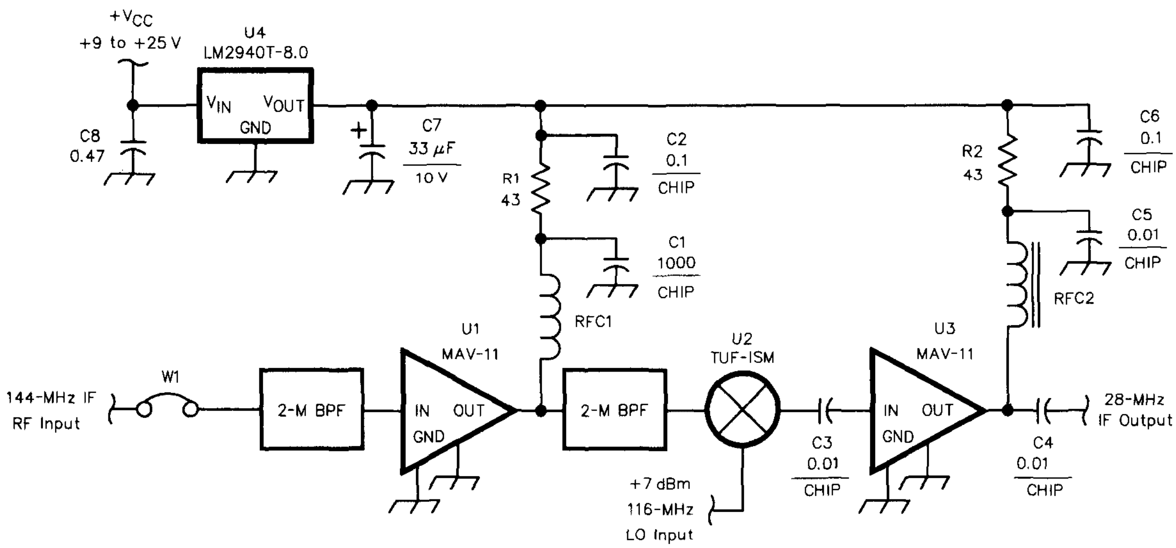

Fig 7—2-m receive converter.

C7—33 μF tantalum, 10 V. Do not reduce below 22 μF.
RFC1—390 nH. 12 turns no. 24, closewound, 0.188-inch inside diameter.
RFC2—14 turns no. 26 on FT-37-43 ferrite toroid. Inductance not critical—5 to 100 μH will work if the stray reactances are low.
U1, U3—MAV-11 or MSA-1104 MMIC.
U2—Mini-Circuits TUF-1SM mixer.
U4—National Semiconductor LM2940T-8.0 low-drop-out regulator.
W1—Copper wire or copper foil to bridge circuit board trace gaps. The filter will absorb the inductance of the wire.

the filters is enough to drive the MAV-11/M57713 power amplifier to an output of 10 W with acceptable spectral purity. I made sure the intercept points of the MMICs were adequate to cleanly amplify the signal. (This is why I used cascaded MAR-3 and MAV-11 MMICs, as opposed to using an MAR-2 and MAR-3.) The IF drive is −14 dBm for 0 dBm output. If you need more drive sensitivity, the board will easily accommodate another MMIC in front of the mixer. Alternately, I have fitted a resistive π-network attenuator to reduce the sensitivity, if that's needed. A 1-kΩ series potentiometer with 100-Ω shunts works well.

The 5-element low-pass filter is a bit marginal, as I've seen the 4th harmonic attenuated by only 59 dB. Using more parts will improve the harmonic attenuation at the expense of more loss. You do want to minimize the loss if you also use the filter on receive. I think having some low-pass filtering at the receiver input is a good idea, since many amateurs who use the 2-m band also use the 70-cm band, meaning that strong 70-cm signals may enter the 2-m receiver. Plus, many preamp input circuits have resonances close to the third harmonic. A huge incoming 432-MHz signal could damage your low-noise amplifier if it's not attenuated. Properly constructed, the output filter and T/R relay add a few tenths of a dB of insertion loss, which you can probably live with. Another option is to add additional transmitter low-pass filtering after the T/R relay. This has the bonus of providing a relatively clean signal for monitoring with a directional coupler.

Fig 5 shows a microstrip directional coupler for 2 meters. I measured the coupling at −31.5 dB, 0.03 dB of insertion loss and 33 dB of return loss. According to a manually optimized computer model, the coupled traces should be 130 mils wide and 1000 mils long, with a gap of 20 mils. The traces are etched on double-sided FR-4 circuit board with a dielectric constant of 4.8 and a thickness of 56 mils. I assumed a loss tangent of 0.02 for the dielectric.

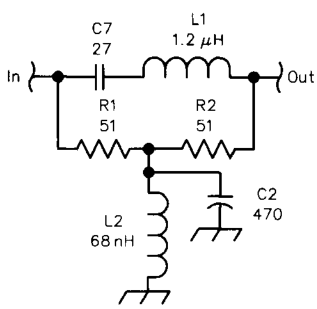

Fig 8—28-MHz diplexer.

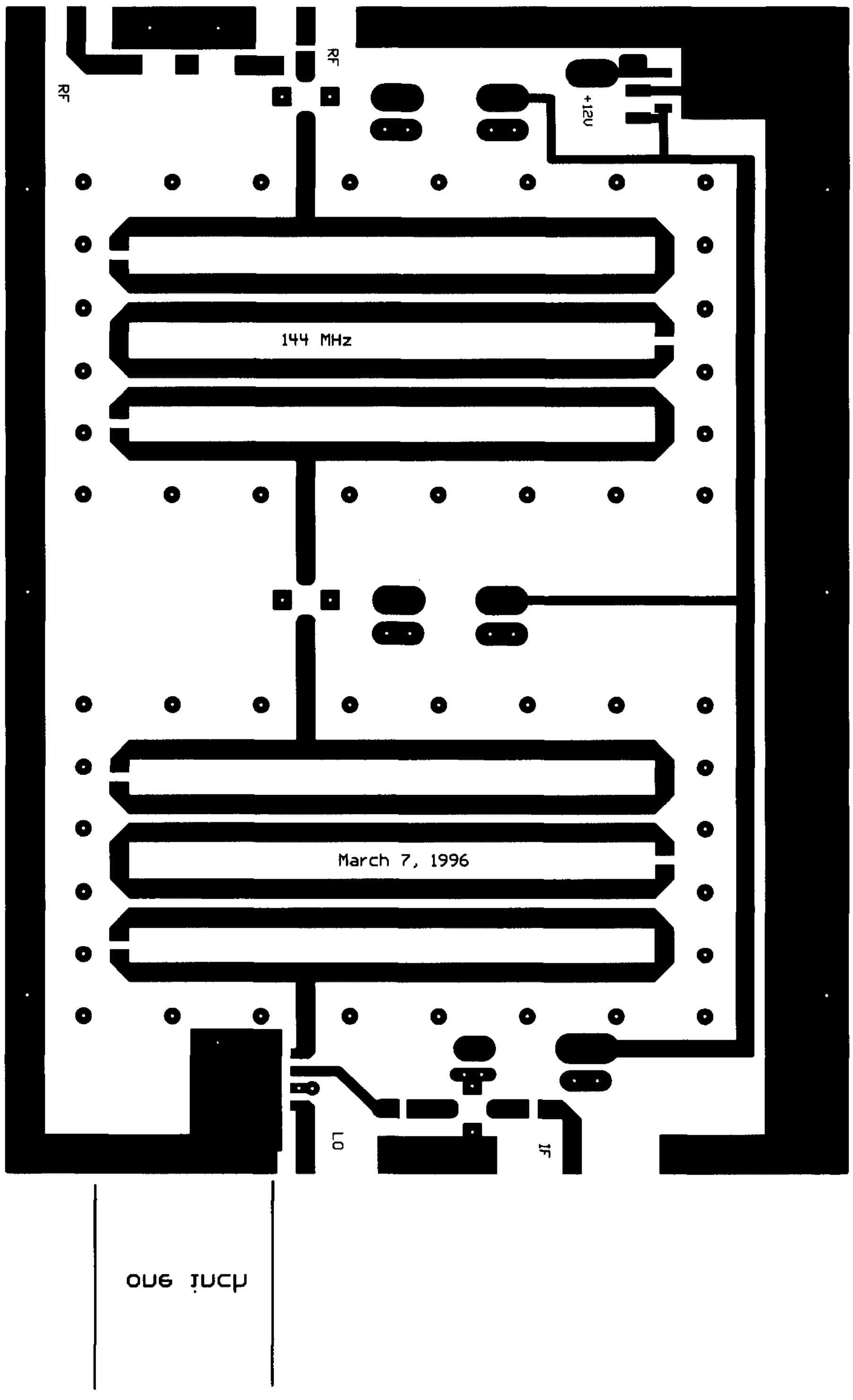

Fig 9—Etching pattern for the converter circuit board. The same pattern is used for transmit and receive. Use 1/16-inch G-10 or FR-4. See text for details about board thickness.

The 50-Ω traces are 98 mils wide and are brought out at right angles to reduce unwanted coupling. I used the expensive—but accurate—*Microwave Harmonica* 6.5 software to do the simulation. It predicts 29 dB of return loss at 144 MHz. I designed the coupler for best performance with all ports terminated in 50-Ω loads. Better performance is possible with reactive loads, but I wanted a simple design.

It is important to etch the board accurately. Those that have seen my prototypes up close at microwave and VHF conferences know that my etching technique does visibly vary a bit. A second sample, with a bit of trace smearing that narrowed the gap a bit, showed only 24.5 dB of directivity. However, either ought to be acceptable for a simple SWR monitoring or foldback circuit.

Long pigtails in the connections to the coupler are obviously unacceptable, as they will introduce impedance bumps that degrade directivity. The end-launch BNC connectors shown in Fig 6 may be acceptable. By trimming the Teflon on the connector and trimming the board to match the connector, I was able to measure a return loss degradation from 35 to 30 dB. The board is soldered directly to the connector for a good ground connection. In practice, you probably want to solder brass sheet stock around the board, then attach the BNC connector to the sheet stock with screws. This results in a much improved mechanical connection that should better withstand normal handling. In the past, I've also filed the BNC connector flange flat to avoid trimming the board, but it's just as much work either way.

Receive Circuitry

Most people will want to run their favorite FET preamp circuit in front of this receive converter to get the lowest possible noise figure. The converter board shown in Fig 7 provides a gain of 11 dB and about a 10-dB noise figure. With the output MMIC terminated in a resistive load, I measure output intercepts from +16 to +24 dBm. You have to be careful here. The MMIC isn't an ideal isolator, as I found that placing a band-pass filter between the MMIC and spectrum analyzer degraded the measured intercept point by about 8 dB. The filter reflected mixing products back at the MMIC, some of which made their way back to the mixer. Unwanted reflections often degrade diode-mixer performance. For better performance with reflective terminations, such as sharp filters, designers often add diplexer circuits.

A theoretical diplexer circuit is shown in Fig 8. C1 and L1 are series resonant at 28 MHz, while C2 and L2 are parallel resonant there. This allows the desired frequencies to pass through with little attenuation. Off resonance, the series circuit provides a high impedance while the parallel circuit provides a low impedance. This allows R1 and R2 to get rid of un-

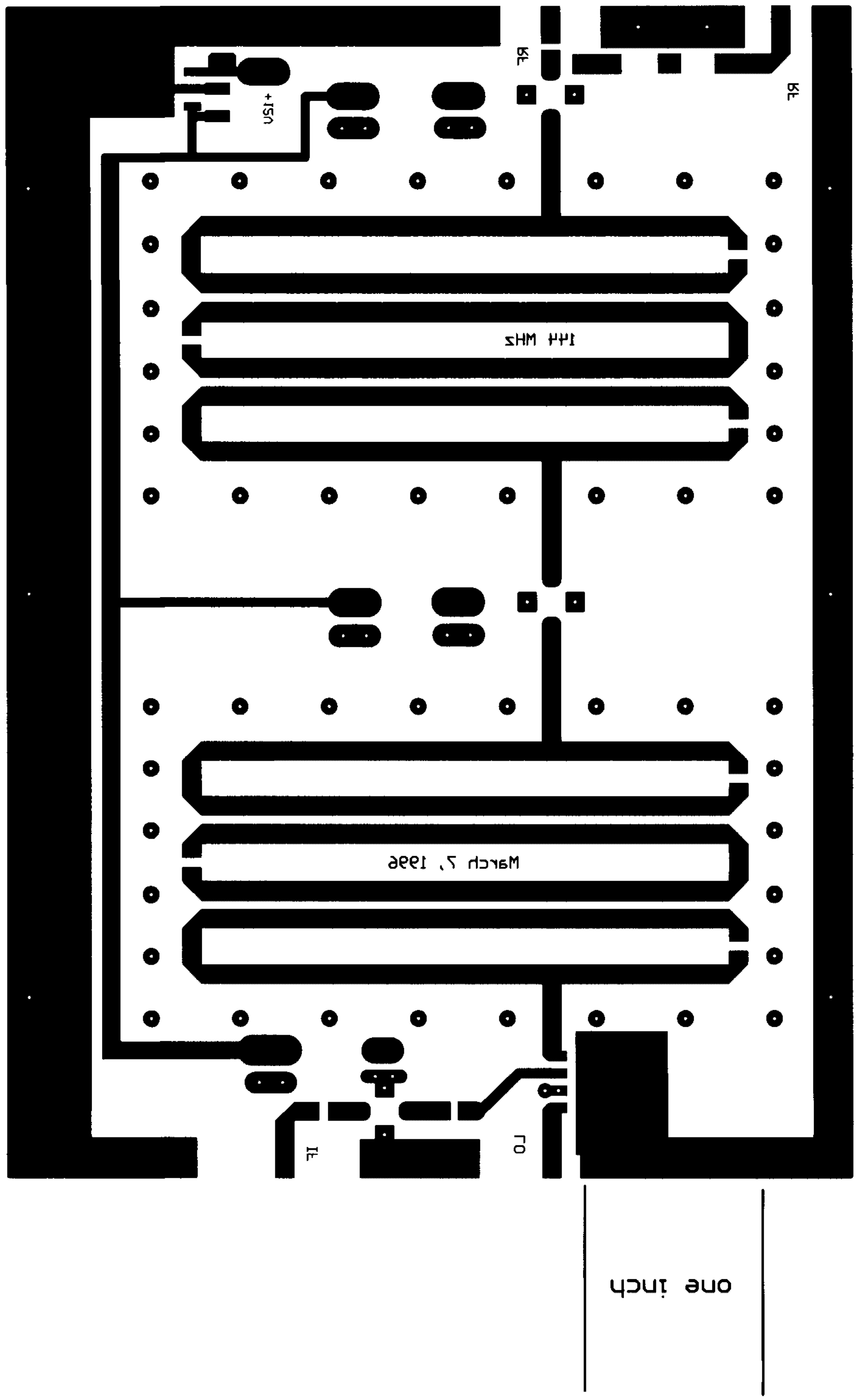

Fig 10—Mirror image of the converter circuit board etching pattern.

wanted signals as heat. This differs from normal filters, which reject frequencies merely by providing a high or low impedance that reflects signals.

Local Oscillator

I did all my testing using the standard diode-mixer LO level of +7 dBm. Normally, injection levels of +4 to +10 dBm work just fine with these diode mixers. LO frequencies between 116 and 120 MHz should work just fine, even with construction tolerances shifting the filters. These frequencies correspond to IFs at the 28 and 24-MHz amateur bands. Using a higher LO frequency will bring the LO too far up the skirt of the band-pass filter. By measurement, the unwanted LO signal was still down 70 dB with a 21-MHz IF, but with a 14-MHz IF, the LO was down only 57 dB and you could see mixing spurs 60 dB down.

An inexpensive LO option might be to use a cheap 60-MHz clock oscillator and double it to 120 MHz. However, there is no easy way to shift the frequency of these units to get an accurate frequency conversion of precisely 120.00000 MHz.

Construction Hints

There are two markedly different philosophies to building "no-tune" transverters. The first is to throw it together and perhaps stick in another MMIC if the gain is off a few dB due to the filter passbands being shifted by normal component tolerances. The other approach is to carefully measure and select components to get the filters exactly right. Both approaches work—choose the one that best suits your resources and needs.

The biggest variable when building no-tunes with G-10 or FR-4 circuit board is the thickness of the board: I've seen it vary by 14%. Fortunately, you can account for this by changing the resonating chip capacitors. If your board dielectric is significantly thinner than 55 mils, you may need to add capacitance to lower the resonant frequency. If your board is thicker, it should work just fine, though smaller capacitors will reduce the insertion loss of the filters. Adding a shield spaced 0.3 inches from the resonator raised the passband of an early 2-m filter prototype by 0.5 MHz.

I made the shields out of thin (0.01-inch) brass sheet stock and clipped resistor leads. You could substitute tinned bus wire, such as the 24-gauge wire sold by Radio Shack, for the resistor leads. The resistor leads suspend the brass shields 0.4 inches from the surface of the board. To accurately set the height, I made temporary spacers from the Teflon dielectric of UT-141 semi-rigid coax. Spacers made from of other heat- and solder-resistant materials, such as aluminum, should work just as well. I first soldered down the four corners of the shield, then filled in the rest of the shielding wires.

When drilling the holes for the MMICs, I find that #22 bits work well for the MAV-11s, and #41 bits work well for the MAR series MMICs. The resulting holes are big enough for bending the ground leads against the body of the MMIC and soldering them directly to the ground plane. Attaching the top grounding pads to the bottom ground plane with thin strips of copper foil also works well, though the ideal solution is to use plated-through holes to connect the grounding pads. Both of

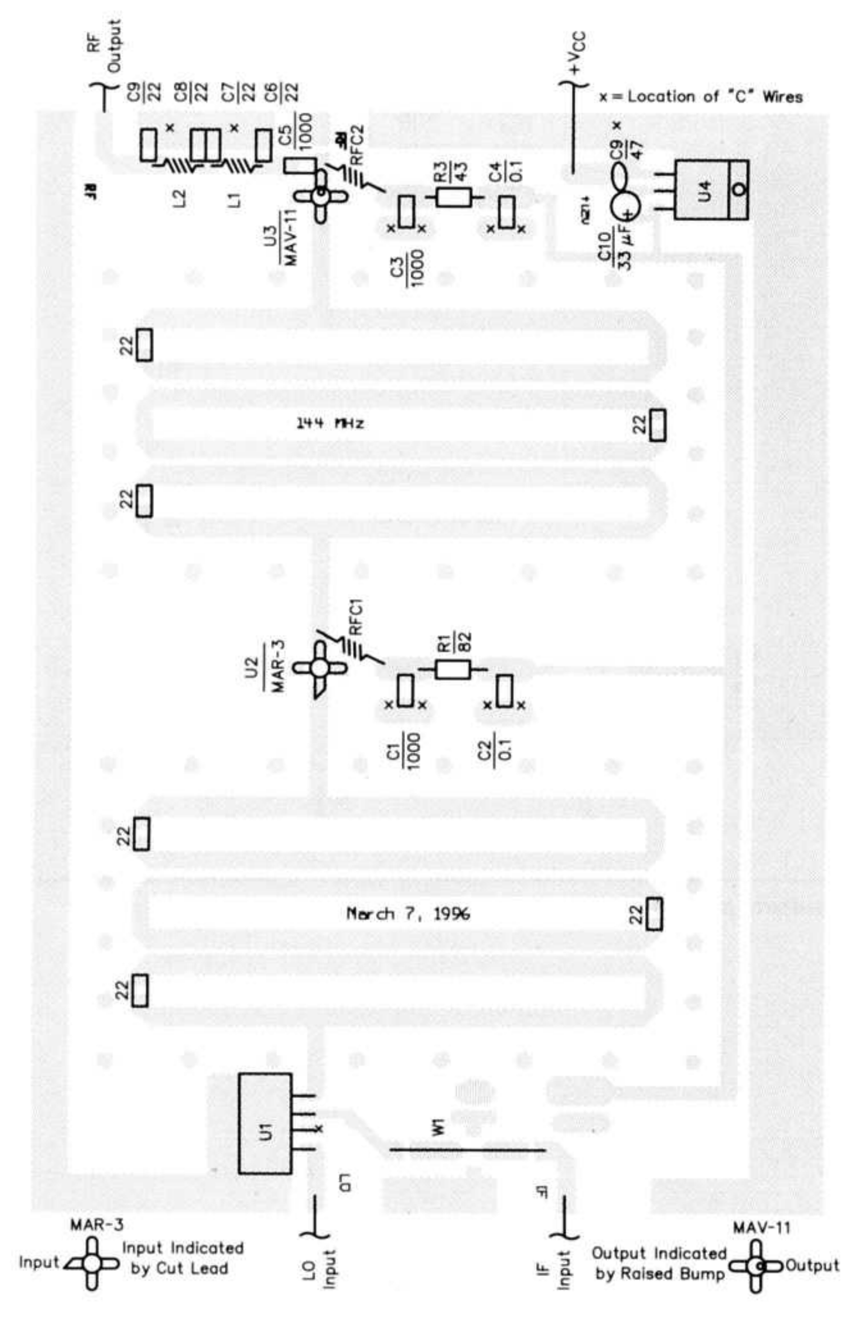

Fig 11—Parts-placement diagram for the transmit converter.

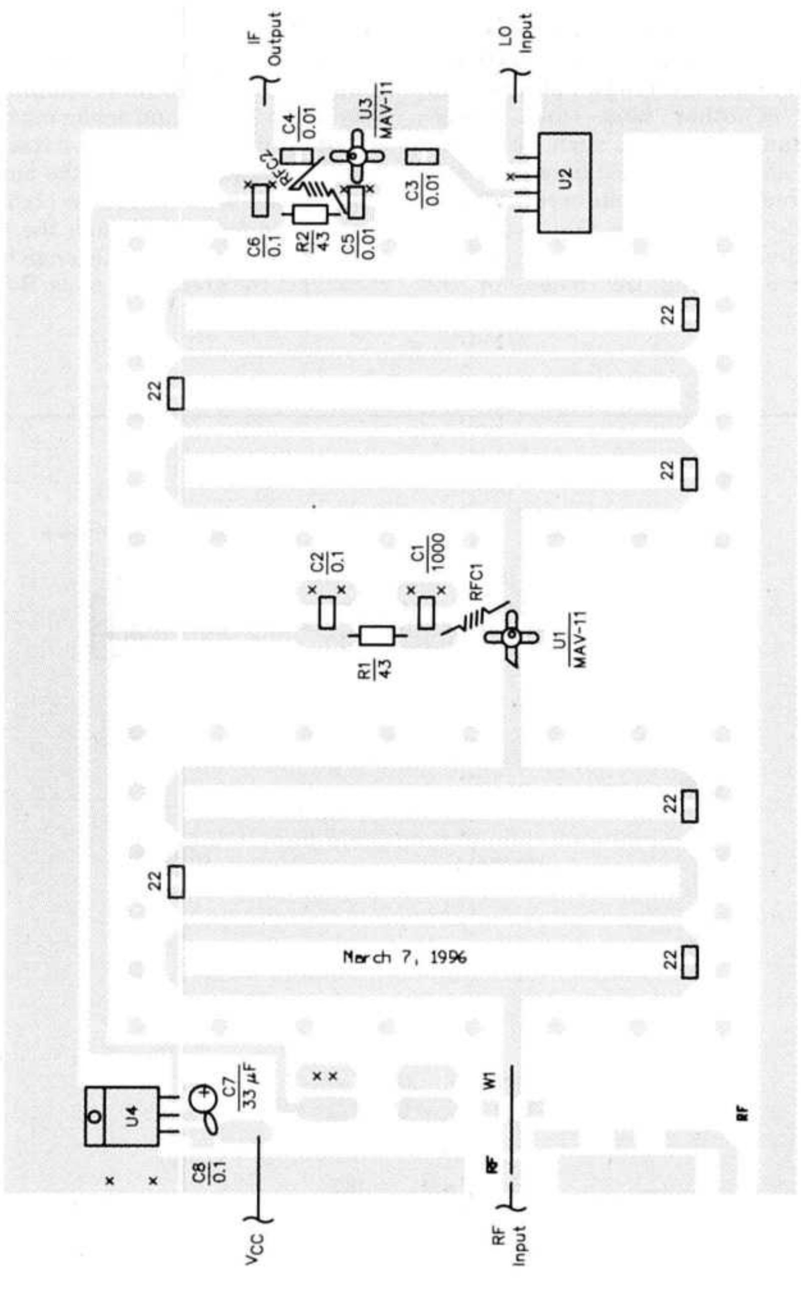

Fig 12—Parts-placement diagram for the receive converter.

these options allow you to just place and solder the MMIC, without the hassle of carefully bending the leads.

When installing the LM2940 regulator, don't forget to make sure that there is a path between its ground lead and the ground plane of the board. It's particularly easy to miss making this connection.

Integration Hints

Keeping the TX bias voltage separate from the other power connections allows you to turn off the power amplifier during receive. While many people have had good luck running the OMRON relay at the 10-W level, I don't recommend hot-switching the relay. A better choice is to use a sequencer, like that on page 22.53 of the *1996 ARRL Handbook* or the one by N1BWT, elsewhere in this issue of *QEX*. By turning circuits on and off in the proper order, you can avoid switching the relay while the transmit amplifiers are still active. If you are interested in interfacing a Uniden HR-2510 or need ideas on a 25-W, 10-m attenuator, see the January 1995 *QST* article, "Putting Your Uniden HR-2510 on VHF and UHF." A collection of HF transceiver interfacing articles appeared in the *Proceedings of the 20th Eastern VHF/UHF Conference.* ☐☐