A Strip-Line Kilowatt Amplifier for 432 MHz

Part I – Design Features and Construction

Hf Efficiency at Uhf, with 4CX250-Series Tubes in Parallel

BY RICHARD T. KNADLE, JR.,* K2RIW

HERE IS an amplifier that will run one kilowatt input conservatively at 432 MHz, with little evidence of the many problems that have plagued users of high power in this frequency range previously. Readily available 4CX250-series tubes are used in parallel in a unique strip-line arrangement which requires no neutralization or balancing. The amplifier is completely stable and remarkably free of spurious outputs, and it delivers more watts per dollar of construction cost than push-pull amplifiers previously described. Its performance has been verified with laboratory test equipment, and its reliability proven in extensive on-the-air use on 432 MHz.

The strip-line resonators, flashing copper in the grid circuit and copper-clad circuit board in the plate circuit, are contained in ordinary aluminum chassis. They are designed for unusually high *Q*, and are completely shielded, but they can be made with ordinary hand tools. Input and output coupling is capacitive, with loading controls conveniently located on the front panel. These controls have broad range and are a significant improvement over hard-to-optimize inductive coupling methods previously used at this frequency.

The parallel cooling arrangement differs from previous practice, decreasing the blower back-pressure requirement, and keeping the resonant components at room temperature. There seems little doubt that heat-cycling of tuned circuits has been responsible for at least part of the tuning drift so often reported in uhf amplifiers, both commercial and homebuilt.

The amplifier can be serviced quite readily. Both tubes can be changed and the amplifier put back on the air in about two minutes. This provides an excellent way of testing the uhf characteristics of used tubes of the external-anode family. A built-in relative-power indicator makes adjustment for optimum performance a simple matter.

Several features of the amplifier are usable on other frequencies, so some theory is included in the discussion, for readers who will wish to understand the basic principles and made logical variations using the versatile strip-line technique.

Why Parallel?

A solid-state exciter capable of 20 watts output at 144 MHz is part of the driver chain for the amplifier.[1] The output stage of the exciter uses a 2N5016 transistor, an overlay device having the equivalent of 408 small transistors in parallel within its package. Engineers working in the semiconductor field some years ago discovered that paralleling small devices yielded high power gain and efficiency in the uhf range, and this led me to wonder if amateur uhf tube users could not learn from the semiconductor experts. This amplifier is the result.

The parallel arrangement requires about half the number of resonant-circuit components needed for a push-pull stage, and it does away with the need for balancing. In this amplifier, 15 unmatched 4CX250B tubes have been tried. A 4CX250B was combined with a 4CX250R, which has higher capacitance. The amplifier has even been operated with one tube cold. After adjustment of the tuning and loading controls, all combinations achieved nearly 70 percent efficiency.

Consideration of all available types of tubes led me to believe that 4CX250Bs offer the best

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[1] The writer will gladly provide a schematic diagram of the 20-watt solid-state 2-meter exciter, on receipt of a stamped self-addressed envelope.

We have tended to rule out parallel operation of transmitting tubes as impractical above about 100 MHz or so, but K2RIW shows here that going higher is mainly a matter of virtual elimination of lead inductance. Using strip-line tank circuits of elementary simplicity, he has produced what is probably the first high-efficiency 432-MHz kilowatt amplifier that is within the capabilities of the average amateur uhf enthusiast. Even if you never intend to work on uhf, don't pass up this exceptional article. It is loaded with interesting ideas that are applicable wherever external-anode tubes are used.

combination of gain, efficiency, and watts-per-dollar. Various types in this tube family can be used without circuit changes, and some of these can be obtained at moderate prices on the surplus market. They seem preferable to other tubes usable at this frequency, including any larger single type, in both overall cost and maximum output with 1 Kw input.

Most designers of transmitters for the higher frequencies have felt that pushpull was necessary, in order to minimize the effects of tube and circuit capacitance. Except where a true resonant cavity or properly designed strip-lines are used, this is still true. In conventional coil-and-capacitor circuits especially, push-pull has marked advantages over parallel on frequencies near the maximum at which these techniques can be used.[2] But with the strip-line the inductance can be made as low as desired, simply by making the line wider. Any number of tubes can be put in parallel, and resonated, so long as the intertube resonances (push-pull modes) are controlled. With methods described in the next section, almost all configurations are controllable.

In this amplifier the parallel grid and plate networks force the rf voltages on the two tubes to be identical. If one tube has higher emission than the other, it may draw slightly higher current, but this is of little consequence because it happens to be the condition under which the amplifier will produce the greatest output with this pair of tubes.

Controlling Extraneous Resonances

Instability and low efficiency in some vhf and uhf amplifiers using tubes in parallel are believed to have been due largely to lack of control of push-pull resonances. A sad fact of tube design is that there is a certain electrical length within the tube, and this becomes an appreciable portion of the resonant circuit at frequencies above 100 MHz or so. Therefore, in a parallel amplifier there is always a push-pull-mode resonance between the tubes, regardless of how closely they are mounted. In the same vein, uhf push-pull amplifiers always have parallel resonances, which can be quite troublesome.[3]

The parallel amplifier described was checked carefully for stray resonances, in both plate and grid circuits. Both tune intentionally to 432, of course, in the parallel mode. The plate circuit has a push-pull resonance at 640 MHz, and the grid circuit one at 260 MHz. Such parasitic resonances exist in all amplifiers, but they are seldom recognized, and almost never actually measured. If extraneous resonances in the grid and plate circuits are close together in frequency there is the possibility of self-oscillation that cannot be neutralized out by conventional methods that would be effective at the intended operating frequency. In this amplifier the extraneous resonances are unrelated harmonically and unrelated to 432 MHz.

A special versatility of strip-line construction lies in the fact that a push-pull resonance can be shifted in frequency without affecting the parallel-mode operation. A slot could be cut along the centerline of the plate inductor, L1, shifting the push-pull resonance lower in frequency. Strip-line advocates call this "mode killing." Unless the builder is prepared to do this kind of work, adherence to the dimensions given for the inductors and their shielding compartments is recommended.

Tuning and Loading Methods

To those conditioned to the conventional 432-MHz coaxial tank circuit, the strip-line plate circuit and tuning method may seem strange. The coaxial plate circuit commonly used with single-ended 432-MHz amplifiers works well for up to 500 watts input, but it is rather difficult to make, and it is not adaptable to use of more than one tube. It cannot be over-emphasized that there is nothing sacred about its classical round shape, even though the tube anode itself is round. In fact, there is a considerable advantage in a wide, flat shape, which has very low current density, and hence low losses. Mounting the tubes vertical and the resonator horizontal is also of no consequence. The anode is an equipotential surface; all of it works equally.

(Photograph 1)
The K2RIW 432-MHz kilowatt amplifier is built in two standard chassis, making a package only 6 X 8 X 12 inches overall.

(2)
Strip-line resonator, with tubes and Mylar chimneys in place. Flapper-type tuning and loading capacitors, C5, right, and C4, above use the strip-line as their fixed plate. Chimneys fit into 3/8-inch brass collars attached to the underside of the cover plate.

(3)
Here the plate line, L1, is removed, to show the tuning and output-coupling capacitors. Both are controlled by fishlines, running through the chassis to Bakelite shafts in the lower compartment.

(4)
The half-wave grid line, L2, upper right, is made of flashing copper. The grid compartment, upper left, is a modified aluminum chassis. The plate line, L1, lower right, is two-sided circuit board. The 4CX250B tubes and their sheet Mylar chimneys are at the left.

(5)
Bottom of the amplifier, with the grid compartment and resonator, L2, in place. The two dark shafts at the right control the plate tuning (far right) and loading (longest shaft).

(6)
Grid compartment and resonator removed, to show input-loading capacitors, C3 (at 45-degree angle) and C2. Capacitor on short shaft is C1. All three have rotors ungrounded. Note slight intentional misalignment of the mounting plates for shaft bushings, to put some tension on the shafts that control C4 and C5, right.

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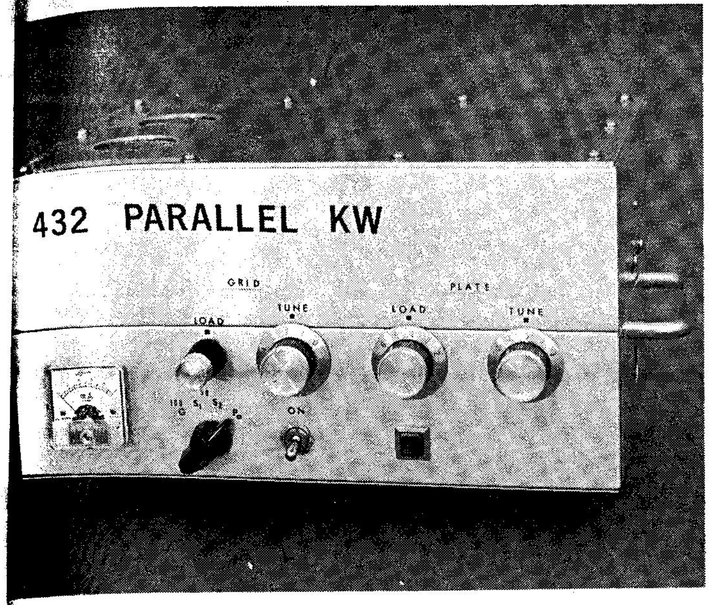
[2] *Radio Amateur's VHF Manual*, "Power Amplifiers — Single-Ended, Parallel or Pushpull?" All Editions, Chapter 5.

[3] Tilton, "Some Hints on Pushpull 432-MHz Power Amplifiers," *QST*, February, 1970, p. 44.



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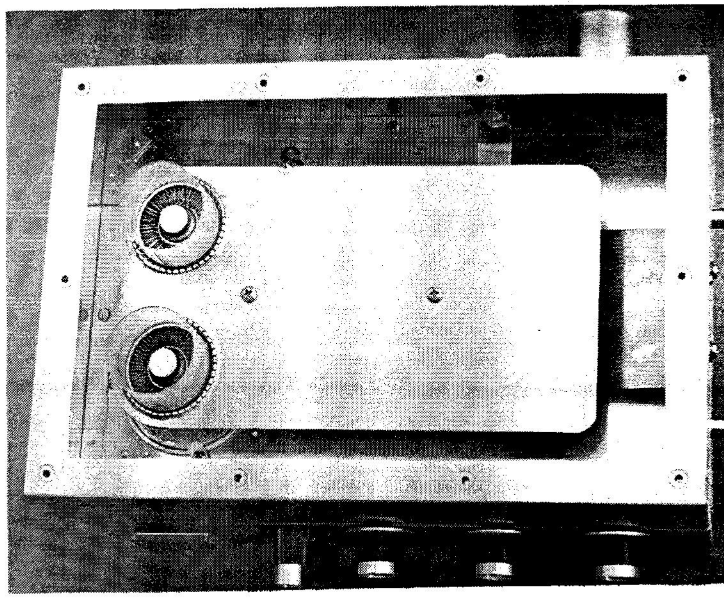

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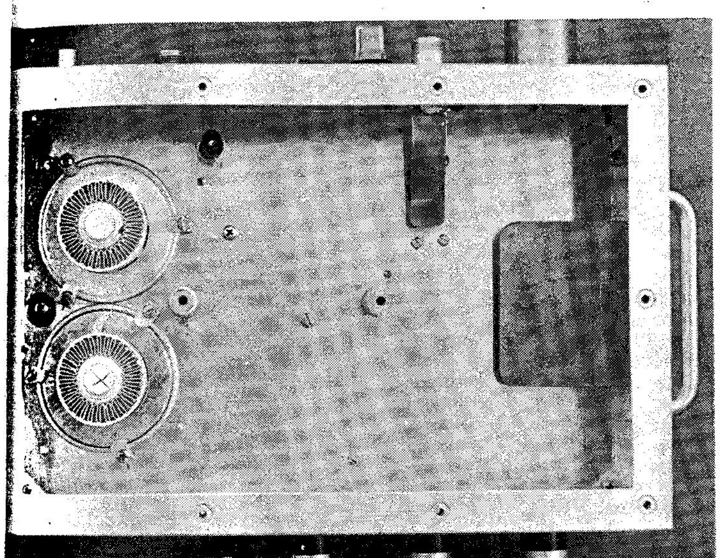

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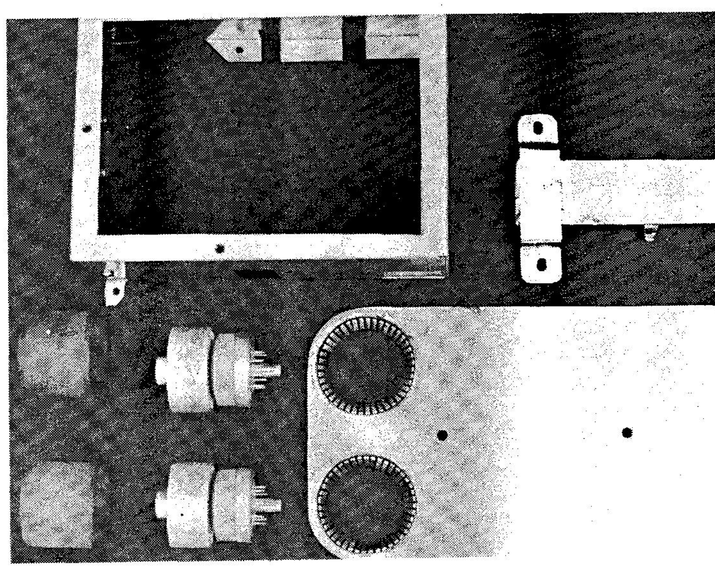

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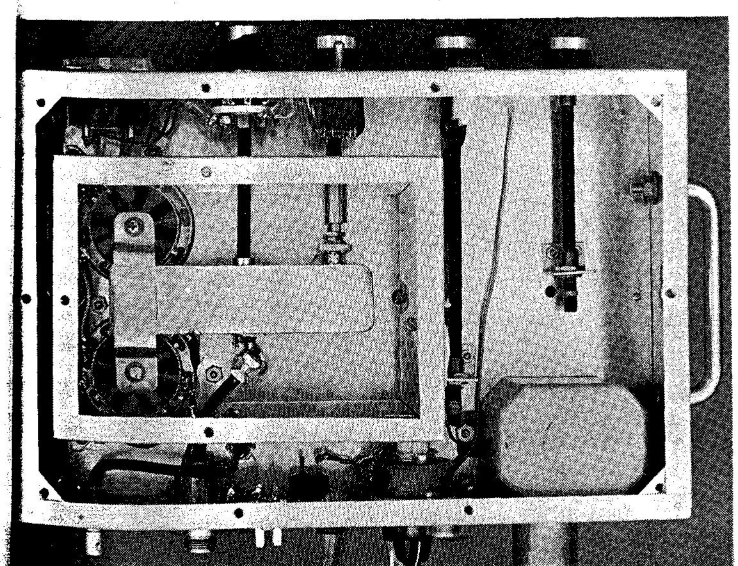

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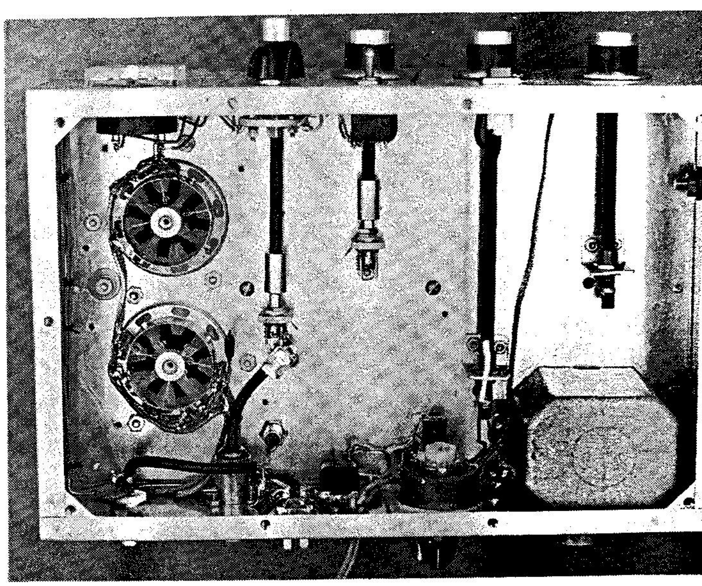

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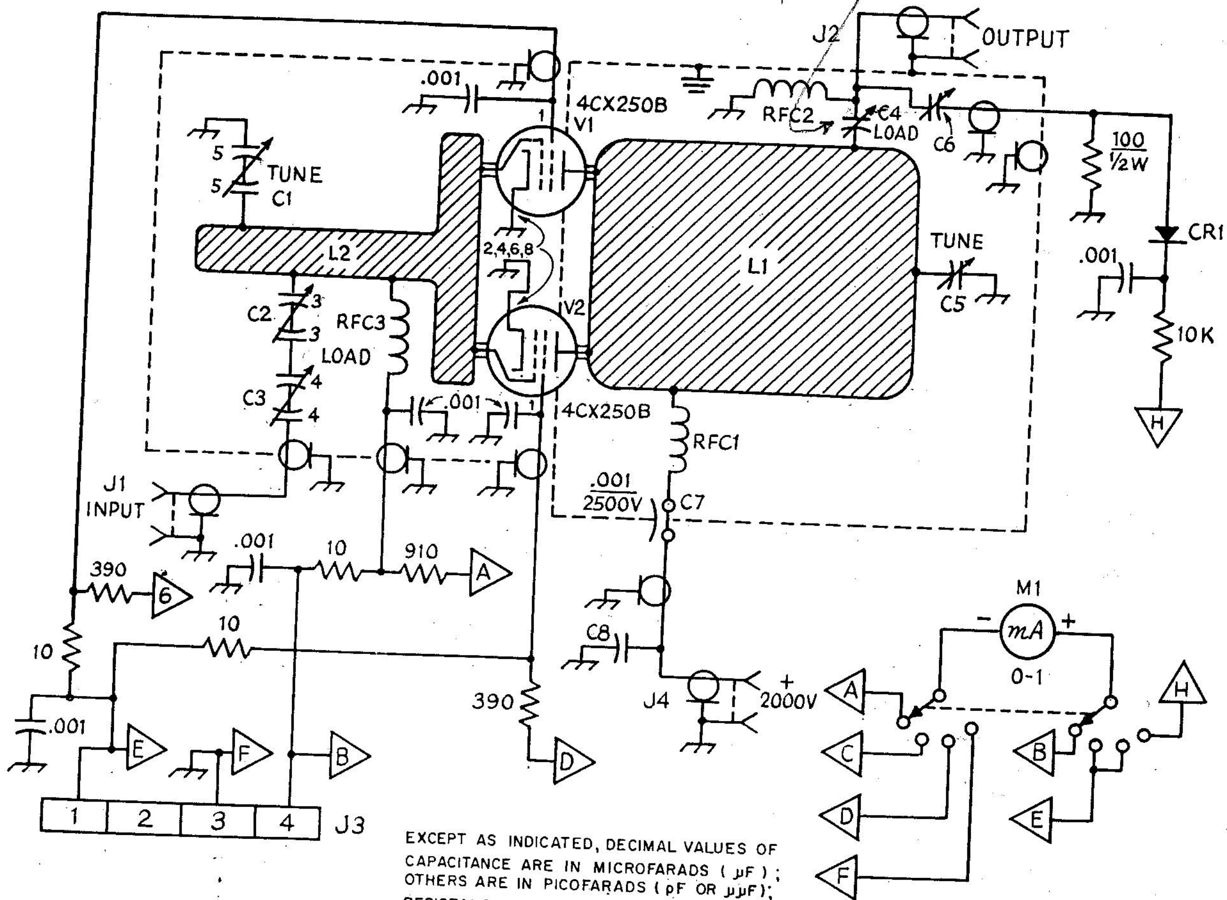


EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (μF) ; OTHERS ARE IN PICOFARADS (pF OR μμF); RESISTANCES ARE IN OHMS ; k = 1 000, M = 1 000 000.

Fig. 1 — Schematic diagram and parts information for the 432-MHz kilowatt amplifier. In the interest of conveying mechanical information, some parts are not shown in conventional schematic form.

C1 — 5-pF per section butterfly (Johnson 160-205).
C2 — 3-pF per section butterfly (Johnson 160-203).
C3 — 4.5-pF per section printed-circuit butterfly (Johnson 189-251-5).
C4 — String-driven loading capacitor. See text and Fig. 2.
C5 — String-driven tuning capacitor. See text and Fig. 2.
C6 — Copper disk, 1/4-inch dia, 3/16 inch below J2 center conductor.
C7 — .001-μF 2500-volt feedthrough (Erie CSK-711).
C8 — .001-μF 3000-volt disk ceramic.
CR1 — Hewlett-Packard HP-2301 diode.
J1, J2 — N-type coaxial fitting.
J3 — 4-pin male power connector.
J4 — High-voltage connector (MHV type).
L1 — 5 X 9-inch double-sided glass-epoxy circuit board. Round corners 5/16-inch radius. (Half-wave strip-line.)
L2 — Half-wave grid circuit, flashing copper. See Fig. 6.
RFC1 — 5 turns No. 18, 1/4-inch dia, 1 inch long, axis vertical.
RFC2 — Like RFC1, but 1/2 inch long.
RFC3 — 0.2-μH rf choke (Ohmite Z-460).
Meter functions: Position A-B — grid current, 100 mA; C-E — screen current, V1, 50 mA; D-E — screen current, V2; F-H — relative power output.

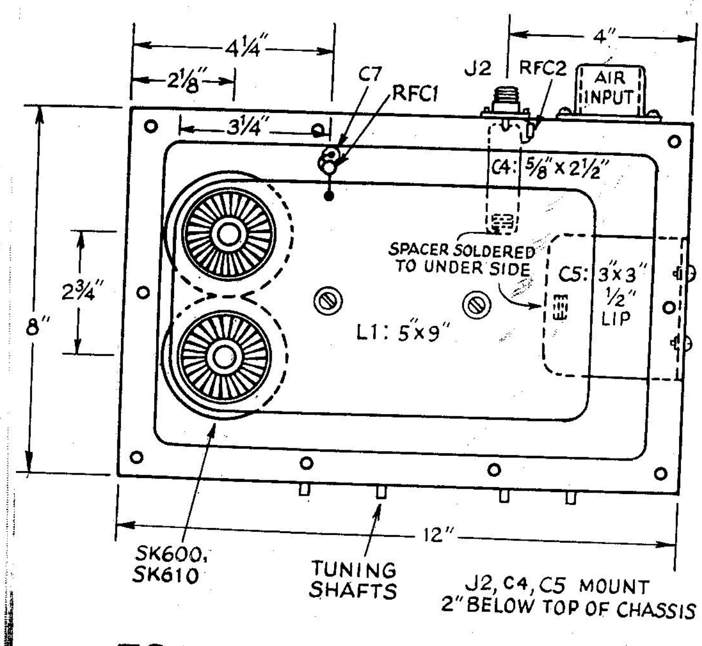
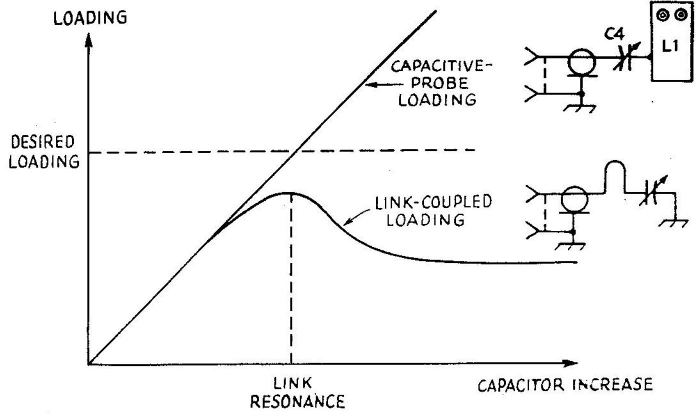


Fig. 2 — Details of the plate compartment, showing placement and dimensions of all major components.

Fig. 3 — Comparison of capacitive-probe and link-coupled loading methods. The latter may give a false indication of maximum output, at lower levels than might be obtainable with the capacitive method.



The plate circuit is tuned by C5, one plate of which is the strip-line itself. See Figs. 1 and 2, and photos 2 and 3. The movable element is a springy beryllium-copper flapper, whose position with respect to L1 is controlled by means of fishing string wrapped around a Bakelite rod which extends out to the front panel. This tuning method achieves very low loss, and eliminates problems resulting from the moving-contact surfaces and multiple ground paths inherent in most capacitors with rotating plates.

The output coupling capacitor, C4, is also a spring-type copper tab, controlled from the front panel in a similar manner. Major advantages of the capacitive-probe coupling are loading linearity and elimination of moving-contact surfaces. A possible pitfall with inductive coupling is illustrated in Fig. 3. A peak may occur in the middle of the tuning range of the link series capacitor, and the position of the link with respect to the plate inductor may appear to be set for optimum output, in that output decreases when it is moved closer. This can easily fool the operator into thinking that the maximum possible output has been obtained, especially at frequencies where accurate measurement of power levels is not possible with equipment available to the average amateur.

By contrast, with the capacitive-probe method the loading always increases as the capacitance between the probe and the line is increased. The range of loading is quite large, permitting matching to loads of from 20 to 200 ohms. Advocates of link coupling claim that it has the advantage of harmonic rejection, but typical link-coupling networks operate with a loaded *Q* close to unity, so there cannot be much difference.

There is a unique optimum plate loading for each drive level, if output efficiency is to be maximized. Loading must be readjusted carefully for any operating-condition change (plate voltage, screen voltage, bias) as well as drive level. Some amplifiers have inaccessible loading controls, making it hard to maintain maximum efficiency. The front-panel control for C4 is very helpful in this. Maximum efficiency occurs at the same settings as maximum output, if bias and plate voltage are held constant. The built-in relative-power metering makes the maximizing the output quite convenient.

When using the plate loading control it will be seen that there is some interaction with the plate tuning. This is a normal condition that exists to a degree with link coupling, as well. It may not be noticed in some link-coupled systems that are not working as well as they might, especially since link-coupled networks have a much smaller loading range.

The parallel amplifier, like all other 432-MHz amplifiers observed, does display a slight drift in plate-circuit resonance during long transmissions. After extensive testing I am convinced that the plate capacitance of the tubes increases slightly as the anode heats up. The effect decreases if the air flow is increased, or if the plate dissipation is decreased. Examination of circuit components as quickly as possible after a 15-minute key-down period shows perceptible temperature increase only in the tube anodes themselves, so it is apparent that circuit component heating is not responsible for any drift observed.*

Some builders of this amplifier have been mystified by the plate current rising more rapidly as C5 is moved in the high-capacitance direction than in the low. This is normal; as C5 moves closer to L1 the capacitance increases more rapidly than it decreases with similar movement in the

* [EDITOR'S NOTE: Severe detuning in some amplifiers, to the extent of a 50-percent change in output during each transmission, demonstrates that component cooling *is* important. It may well be that the unique cooling-air flow illustrated in Fig. 5 could be used to advantage in other amplifiers using external-anode tubes.

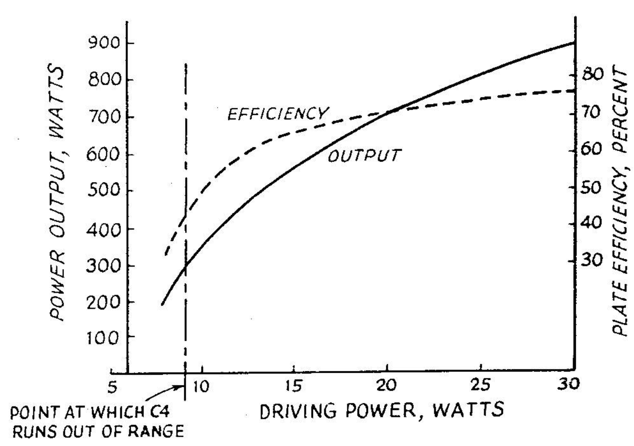


Fig. 4 — Output and plate efficiency of the 432-MHz amplifier when operated Class C, with bias, screen voltage, and plate voltage fixed at −90, +300, and +2000 volts, respectively, varying the drive level from 8 to 30 watts. Input drops with decreasing drive, so operation is always at safe levels of plate dissipation.

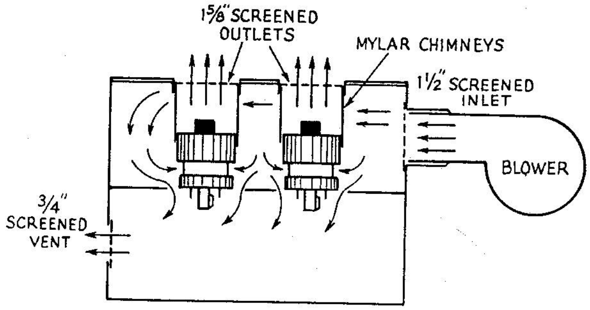


Fig. 5 — Cut-away end view of the amplifier, showing the air-flow division.

opposite direction. Detuning slightly on the low-capacitance side of resonance is recommended. The slight increase in tube capacitance with heating will then bring the circuit into resonance, reducing the effective change in operating conditions with repeated warming and cooling.

Construction

The amplifier was built in two Premier 8 X 12 X 3-inch chassis, screwed together top to bottom, as seen in Photo 1. The top surface of the upper chassis was cut away, leaving a 3/4-inch mounting surface around the edges for the cover plate. I made the cover of .091-inch aluminum, to insure mechanical stability in the plate circuit, but .061-inch would probably have been more than sufficient. The two 1-5/8-inch air exhaust holes placed directly above the tube anodes have copper screening soldered across them, on the inside, for rf shielding.

The screening was soldered by first tinning the inside of the box around the holes with Kester aluminum solder, using a soldering iron tip on a butane torch. The screening was then tacked in place. Collars made of 3/8-inch lengths of 1-5/8-inch ID brass tubing were then soldered to the screening, aligned with the exhaust holes. The collars hold the Mylar chimneys in place and create reasonably air-tight fit. The four butt-joint corners of the upper chassis were spot-soldered in the centers of the cracks on the inside, to insure good rf shielding.

I recommend using Pem-nuts, Rivnuts, or some other brand of blind fasteners for the cover plates. You will be removing the covers often, if for no other reason than to show the innards to fellow amateurs, and holes for sheet-metal screws will not survive this kind of use without stripping.

Placement of the tube sockets on the chassis and the holes in L1 should be done carefully. Misalignment will cause the tubes to skew in their sockets, which could result in poor contact to some of the screen-bypass fingers and also make proper tube insertion difficult.

The plate resonator is a 5 X 9-inch piece of 1/16-inch double-sided fiber glass circuit board. The conductor thickness is more than adequate, since the rf current skin depth in copper is 0.125 mil at 432 MHz. Almost any good conductor that is rigid and more than 1 mil thick will work well.

The finger stock around the anode holes is soldered to both sides of the copper-clad board. The intrinsic capacitance between the board sides eliminates the need for other connections. I like the soft folded-over silver-plated finger stock, for ease of tube removal, but stiffer brass or other materials should also do. Some builders of the amplifier have made anode connections with flashing copper and hose clamps, eliminating the finger stock, but this hampers tube replacement.

Two single-sided boards could be used if they are held together back-to-back with screws, or soldered together around the perimeter with copper or brass shim material. Some variation in board thickness makes little difference. Solid materials could be used, but cutting and soldering will be more difficult. The strip-line is supported above the ground plane on two 1-1/2-inch porcelain insulators. The rf choke is connected to the upper side only, for convenience.

Cooling air, brought into the upper chassis through a 1-1/2-inch screened hole, divides into two paths, as seen in Fig. 5. Three-fourths of the air goes through the tube anodes, the 1-5/8-inch Mylar chimneys, and out through the cover plate. The other fourth goes down through the tube sockets and out through the 3/4-inch screened hole in the side of the lower chassis. The cool air first runs past the plate circuit components, and the full air pressure is available at the tube anodes. The air back pressure is quartered, because normally the tube sockets create greater back pressure than the anodes, which need the most cooling.

The 6-inch diameter squirrel-cage blower is sound-proofed by mounting in a cardboard box, the air inlet side of the box being covered by a household air filter. The 2-inch car heater hose which is used as an air outlet is terminated in a tubular "Y." From there, two 1-1/2-inch hoses run to the kilowatt amplifier and the amplifier-tripler.[4]

[4] Knadle, "Dual Band Stripline Amplifier/Tripler for 144 and 432 MHz, *Ham Radio*, February, 1970, p. 6.

2½" x 1"

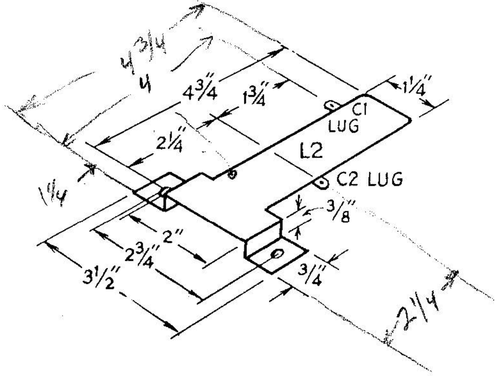


Fig. 6 — Details of the half-wave grid line, L2. Material is flashing copper or sheet brass. The principal surface is 7/8 inch above the chassis.

The 10-mil Mylar chimneys are shaped by using the two 4CX250B tubes as a form. A 1-5/16-inch Mylar strip is overlapped a quarter turn, glued with silicone rubber adhesive, and held until dry with rubber bands. The finished chimneys are seen in Photos 2 and 4. Be sure that they are not so long as to separate the finger stock from the tube anodes when the cover is tightened down. Sheets of 10-mil Mylar are often used by draftsmen, which should make it easy to obtain. If the air flow is insufficient, melting of the Mylar could be experienced. In this case a larger blower, or chimneys made of Teflon, should be used.

The tuning and loading flapper capacitors, C5 and C4 respectively, are made from .008-inch beryllium copper, but other springy conductive materials are usable, since the current density through these components is not extremely high.

Fishing string is fastened to the free end of each flapper, using a small wire loop, metal spacer, or short piece of 1/8-inch tubing soldered to the underside. The strings go through chassis holes and wrap around Bakelite rods in the lower chassis. The rods extend out through the front panel. Drill each rod and tie the string through it, to avoid slippage. Slight misalignment of the mounting brackets for the shaft bushings can be made to cause friction enough so that the capacitors will hold their settings.

The natural rest position of the flappers is slightly below L1, so that they do not make contact with it, regardless of knob settings. Originally a piece of Mylar was cemented to each plate, for short-circuit protection, but dielectric heating in this area caused some loss in efficiency. The choke, RFC2, is a protective measure, in case C4 should accidentally contact L1.

The power-sampling capacitor plate, C6, is suspended 3/16 inch below the center conductor of J2. It is soldered to the inner conductor of 1/8-inch semirigid coax, which carries the sampled power to the lower chassis, where it is rectified by CR1, to give a reading on the meter. The semirigid coax is placed as near the rear wall of the chassis as possible, and its outer conductor is soldered to the chassis at the point where it passes through. The chassis was first tinned with aluminum solder. The end of the outer conductor is also soldered to a ground lug, under one of the mounting screws for the UG-58/U connector, J2. The position or size of C6 should be adjusted to give approximately 3/4-scale deflection on the meter, when full power output is being developed. Suitable coax can be made by running insulated wire inside small copper tubing, if semirigid coax is not available. RG-58/U coax is also usable, if it is grounded to the chassis thoroughly.

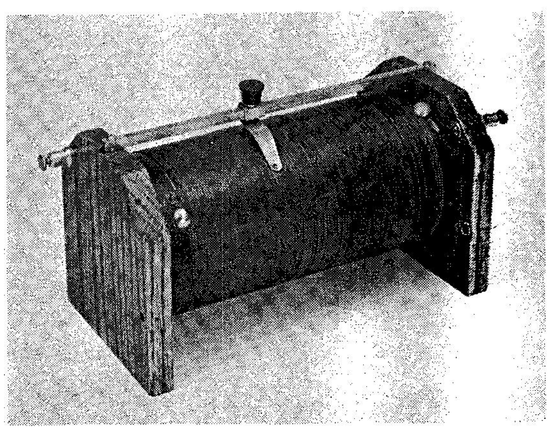
The grid circuit (Fig. 6 and Photos 4 and 5) is tuned and loaded by C1 and C2. These are butterfly capacitors with ungrounded rotors, so no rf current must flow through a sliding contact. One stator of C1 is soldered to a ground lug on the chassis floor, and the other is soldered to a lug on the lower side of L2. One stator of C2 is soldered to a lug on the lower side of L2. The other stator of C2 and one stator of C3 are soldered to a lug bolted to the top of a 3/8-inch threaded porcelain insulator, fastened to the chassis. The shield of the RG-58/U input cable is soldered to a ground lug under the insulator. C1 and C2 are tuned with Bakelite rods extending out through the front panel. Their proper adjustment will make the amplifier look like a 50-ohm load, over all reasonable drive levels. C3 is used to set the range of C2.

Very careful shielding and bypassing of all leads entering the grid compartment is required, if the drive requirement is to be kept low. There is a strong rf field in the vicinity of the grid connections, and it can couple some of the valuable driving power into the circuit wiring very readily. Note that no wiring is run close to the grid line at any point, as seen in Photo 6.

The grid shield is a modified standard 5 X 7 X 3-inch aluminum box, held in place with sheet-metal screws. The top of the box is cut away, leaving a 1/2-inch mounting flange. Slots are cut in the side of the box in the area of the shafts for C1 and C2, and around the input rf cable, for ease of box removal. Five 1/2-inch holes are drilled in the end closest to C1, for easy air flow.

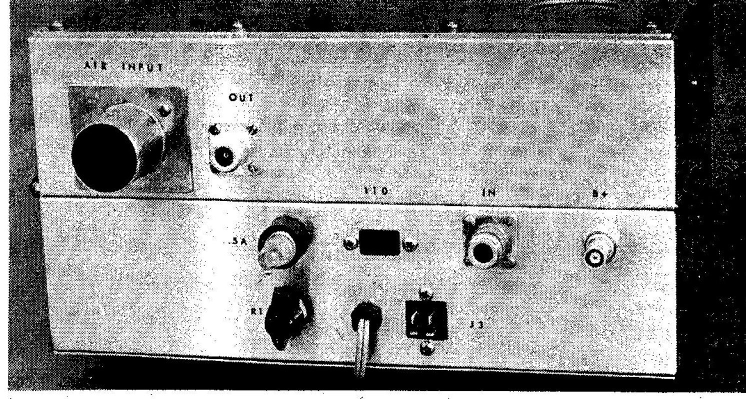
Part II, detailing power supplies, performance, and important uhf safety measures, will appear in an early issue.

From the Museum of Amateur Radio



This single slide tuner, built by Hunt and McCree, was the very first piece of wireless gear used by Hiram Percy Maxim and his son Hamilton. The latter, during a recent visit to the Museum, spotted this tuner and told us a little about it. The coil has been rewound at some time due to shrinkage of the cardboard tube. We believe it was in use as early as 1910. – *W1ANA*

Rear view of the 432-MHz amplifier. Note that, unlike most amplifiers requiring forced-air cooling, this one has the air input to the plate compartment.



A Strip-Line Kilowatt Amplifier for 432 MHz

Part II – Power Supplies, Performance, and Safety Measures

BY RICHARD T. KNADLE, JR.,* K2RIW

THE AMPLIFIER requires 2000 volts at 500 mA, 300 volts at 50 mA, and minus 90 volts with a 50-mA current-sinking capability. Fixed bias simplifies tuning adjustments, and negates the need for high-voltage switching relays, in that the amplifier will simply turn itself off when drive is removed.

The High-Voltage Supply

A reliable 2000-volt 500-mA supply requires considerable care in its design and construction. Handbooks extol the virtues of the choke-input supply (good regulation, smooth filtering, and no starting surge) but few of them give specific information on how to construct one. Choke input lowers the dissipation of the transformer and rectifiers considerably. I discovered this difference after burning up the secondary windings in two power transformers with a capacitor-input filter. A calculation disclosed that the transformer was dissipating over 300 watts, because of the high current peaks. The instantaneous dissipation equals I^2R, so the difference between the two kinds of supply can be 10:1. A good capacitor-input supply is possible, using a low-internal-resistance Hypersil transformer, a surge protector, a large capacitor bank, and high-peak-current diodes, but these components are not common on the surplus market and are quite expensive if bought new. Even this supply will not equal the regulation of a good choke-input supply.

Choke-input supplies with solid-state rectifiers have experienced diode failure. The usual cause is the inductive kickback of the power transformer due to stored magnetization energy, when the supply is turned off. A spike arrestor consisting of CR10, CR11 and C9 handles this. Putting the choke and meter in the grounded leg increases reliability, since they need not stand the B+ potential. The bleeder resistor is wired so that the meter does not indicate bleeder current.

The high voltage is carried to the amplifier with RG-59/U coaxial cable and MHV connectors. These are similar to BNC, except for the extended center insulator. They are rated to 5000 volts, and they automatically create a ground through the coaxial shield. Many amateurs use the SO-239 and PL-259 in this application. Though they may arc over, they at least meet the safety requirement.

Screen Supply

Screen-supply problems are common in amplifiers using the 4CX250-series tubes. In the supply of Fig. 7, R14 protects the supply and amplifier from high screen voltage, by draining off the negative screen current that can occur during conditions of excessive plate loading or low drive. R13 is very important because it prevents the screen dissipation from exceeding 12 watts, under all conditions. Without R13 the screens will fail in a few seconds, if drive power is applied without plate voltage, or if the loading is excessively light. Most tubes deliver maximum power in this amplifier with approximately 5 mA of positive screen current, so normally R13 is dropping only 10 volts of the 300-volt supply.

Bias Considerations

The control-grid bias supply need not furnish much current. In fact, it must act as a load for the 20 mA the tubes normally deliver when driven. This situation calls for a shunt regulator, which should be able to tolerate 100 mA without failure, in case drive is momentarily applied without high voltage.

* 316 Vanderbilt Pkwy, Dix Hills, NY 11746.

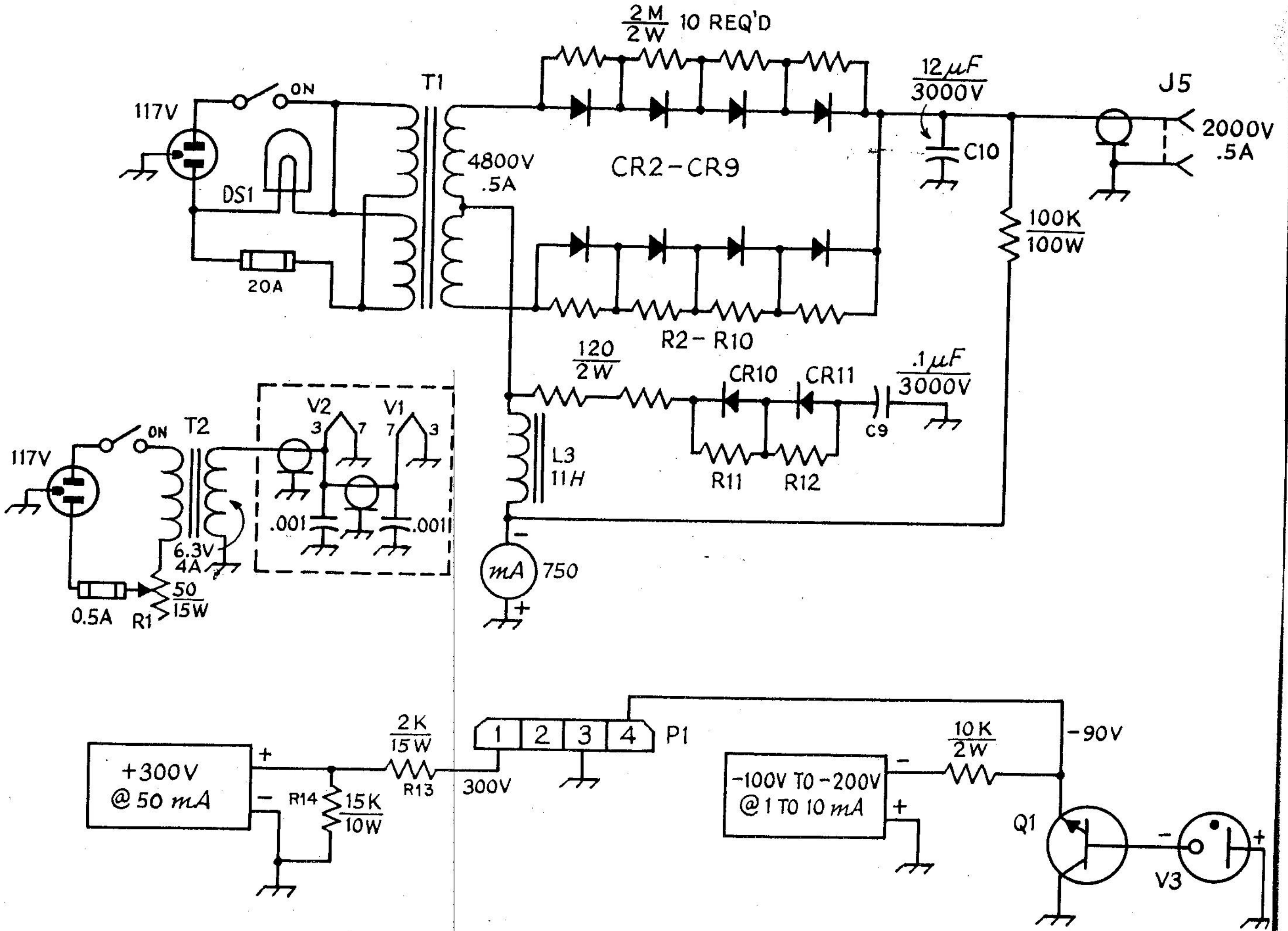


Fig. 7 — Schematic diagram and parts information for the power supplies needed for the 432-MHz amplifier. Heater transformer and circuitry are built into the amplifier. All other supplies are in a separate unit, not shown in the photographs.

C9 — .1-μF 3000-volt, oil-filled.
C10 — 12-μF 3000-volt (3 4-μF, 3000-volt oil-filled in parallel).
CR2-CR11, incl. — 3-kV 500-mA diode, 20-A surge rating (G.I. K6100F).
I1 — 117-volt pilot lamp.
J5 — MHV connector.
L3 — 11-H 500-mA filter choke (UTC D3227, surplus).
P1 — 4-pin female power connector.
Q1 — Npn 10-watt 100-V_{CE}, beta at least 15 (Delco DTS-401).
R1 — 50-ohm 15-watt control. Set for 5.5 V at sockets.
R2-R12, incl. — 2-megohm 2-watt.
T1 — 4800 V, ct, at 500 mA (UTC D3221, surplus). Lightweight type (new) available from Edco Electronics, 398 Bedford Ave., Brooklyn, NY 12111. Price $90.
T2 — 6.3-V 4-A filament transformer (UTC S-55).
V3 — 5651, VR-90, or 90-volt 1-watt Zener diode.

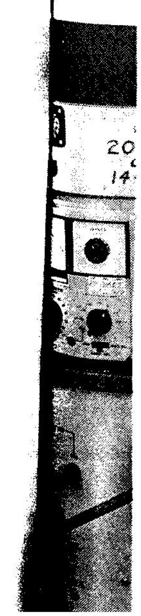
Without a shunt-regulated bias supply, the bias increases when the driving power is applied. This can increase the drive requirement for full output and back-bombardment of the tube cathodes. As an experiment to determine whether significant back-bombardment was occurring, I ran the amplifier key-down for ten minutes at full power, with 5.5 volts on the heaters. When I turned the heater voltage off, the power output began dropping within five seconds. If much back-bombardment had been present, the excess heating would have kept the cathodes hot enough to continue emitting with no heater voltage applied.

Performance

I used my 20-watt 144-MHz exciter[1] to drive the amplifier-tripler,[4] operating as a tripler to 432 MHz. I lowered the driving power and dropped the tripler screen voltage to 200, to lower the 432-MHz output to 22 watts, to be used to drive the parallel kilowatt amplfier.

As Fig. 4 shows, less than 22 watts will give acceptable results with cw or fm, though plate efficiency is slightly lower. A simple way of developing the 432-MHz drive is to use one of the

1 References are grouped at the ends of Parts I and II.



uhf fm transmitters currently available on the surplus market. I understand that a Motorola TU-204 fm transmitter strip can be made to deliver as much as 35 watts, with increased plate voltage, a blower, and modification of the 2E26 grid circuit to link coupling.

The amplifier-tripler, when used to full power as a tripler to 432 MHz, puts out 28 milliwatts on 144 MHz. Almost any tripler will have a similar or greater output on the driving frequency. In a good vhf location, this 144-MHz signal can be heard by 2-meter operators over a considerable area. The 432-MHz parallel amplifier attenuates the 144-MHz signal by 50 dB, while delivering 700 watts output on 432 MHz. For this reason I recommend using the amplifier at all times, rather than operating with the driver stage when lower power is desired. Since I use narrow-band fm, and fixed bias on the final amplifier, I can lower the power output continuously, from 700 watts to less than 1 watt, merely by detuning the grid capacitor, C1.

When the amplifier is running as described, and delivering 700 watts on 432 MHz, the 144-MHz output is 71 dB down, the 288-MHz component is 69 dB down, the 864-MHz component 45 dB down, and the 1296-MHz component 50 dB down, after corrections for the directional coupler. A spectrum analyzer showed no other significant components, from 0 to 12.4 GHz. The levels given represent 56 microwatts on 144, 89 microwatts on 288, 22 milliwatts on 864 and 7 milliwatts on 1296 MHz.

A Bendix 1200-watt power meter was my first method of power-output measurement. As a second method, I used a Hewlett-Packard Calorimeter, and X-band directional couplers as power samplers, because 30-dB directional couplers were not available to me. A well-designed directional coupler can be used below its designed frequency. This merely causes the attenuation on the directional port to increase. I calibrated the directional port at each of the frequencies of interest.

A third method of measuring the efficiency of the final stage was measurement of the temperature of the air which passes through the anodes, during 15 minutes operation at full power. The air temperature was found to be 217°F and 197°F at the two anodes. Then I removed the drive and adjusted the bias until the anode input was 300 watts, and ran this for 15 minutes. The anode air temperatures were then 217 and 202°F. This suggests that when 1 kW input is applied to the amplifier under rf conditions, the anodes are dissipating 296 watts, and the output should be 704 watts.

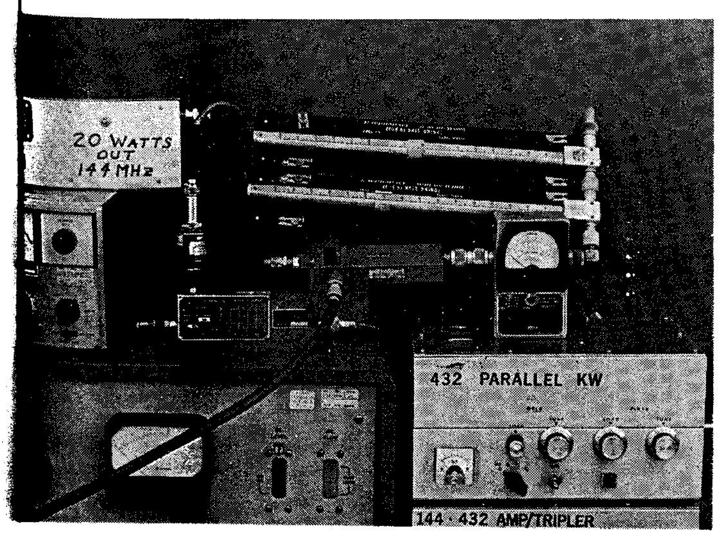
Safety

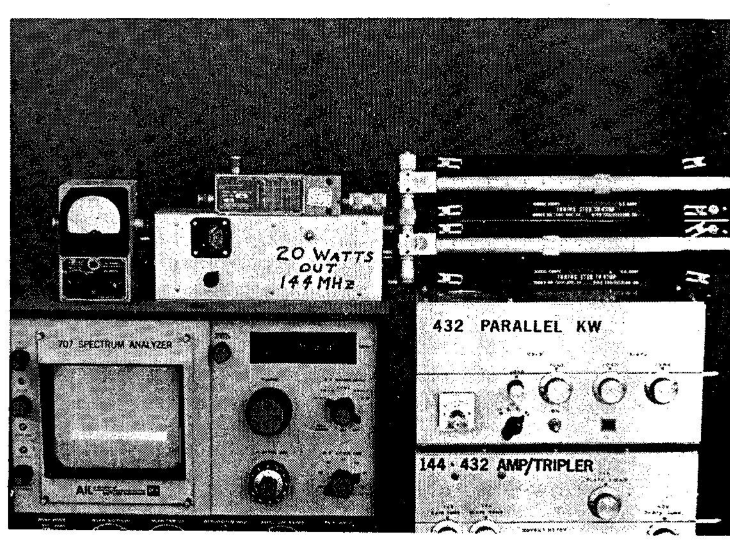
A uhf amplifier with 700 watts output, using a 2000-volt supply, represents several possible hazards, if some care is not exercised. In addition to the well-known safety precautions in working with dangerous voltages, it is good practice to avoid standing near to an antenna carrying more than 10 watts of rf power. The amplifier should never be operated with the plate compartment open, nor with the shield cover incompletely fastened down. An open compartment can radiate dangerous levels of uhf power at close range, and it is possible for a crack along one side to act as a slot radiator. Radiated uhf energy causes thermal heating of skin tissue. The U. S. Government has set a limit of 10 mW/cm^2, averaged over a six-minute period, as the maximum for human exposure. The heating effect is most dangerous to the eyes, as it can cause immediate injury and development of cataracts.

Along with thermal effects of rf radiation are some possible nonthermal dangers, such as disturbances to the nervous system, though these have

Two test setups used to document the performance of the K2RIW 432-MHz kilowatt amplifier. In both pictures are the 20-watt solid-state exciter for 2 meters,[1] upper left, strip-line amplifier or tripler,[3] and the 432-MHz parallel kilowatt amplifier. The left photo shows setup for measuring input-output characteristics. The large instrument is a Hewlett-Packard 434A Calorimeter. The middle row contains an HP-431C Power Meter, Narda Coaxial Directional Coupler, and a Bendix SWR and Wattmeter. At the upper right is a double-stub tuner.

The right setup includes several of the above items, plus an AIL Spectrum Analyzer, covering 0 to 12.4 GHz.





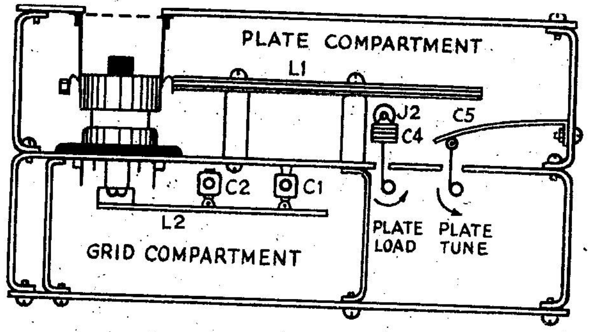


Fig. 8 – Cut-away view of the 432-MHz amplifier, showing all principal rf circuit components. C5 has a 1/2 by 3-inch stiffening plate bolted to its bent-over portion. C4 is soldered to the output fitting, J2. Both are 1/2-inch below L1 in their free positions.

not been confirmed in this country. The Soviet Union, Poland and Czechoslovakia have set standards of 2.5 microwatts/cm^2 to 1 mW/cm^2, because of these possible effects.[5]

Fred Telewski, WA2FSQ, found that radiation from 100 watts, into a 7-dB 432-MHz corner-reflector antenna, measured with a Narda Model B86B3 radiation monitor, was safely below the limit of 10 mW/cm^2 if you were more than 6 feet in front of the antenna.[6] The back and sides of the antenna were considerably safer. Since rf energy falls off by the inverse square law, this says that, by U. S. standards, you are safe 16 feet in front of that same antenna, with 700 watts going into it. It is well to be conservative, and I would recommend treating uhf energy with healthy respect. I would not operate this kilowatt amplifier into an antenna less than 30 feet from me, nor would I climb the tower with the transmitter operating.

I did some probing with an rf detector, with the parallel amplifier running full power, and I found that nowhere around the Premier boxes, cover plates, meter, knobs or connectors could more than one milliwatt of rf energy be detected. This level was found only within 1/4 inch of the screened air exhaust holes in the top cover plate. It should be emphasized again that these safe conditions apply only with the amplifier properly enclosed.

Summary

The techniques used in this 432-MHz parallel kilowatt amplifier have other applications. With judicious measuring of intertube resonances, and mode-killing, I am sure that more than two tubes could be used to achieve 2 kW PEP at 432 MHz. I know that two or more 4CX250B tubes in parallel could be used to simplify and reduce the cost of kilowatt amplifiers for all vhf bands. I have good reason to believe that we will be seeing such articles in the near future. For those who wish to become more familiar with the versatile technique called strip-line, there is an excellent text covering this subject.[7]

We are entering an exciting era of 432-MHz communication. The recent availability of very low-noise uhf receiving transistors, combined with advances in transmitter and antenna design, should soon contribute to the shattering of existing DX records.

A chart of overland tropospheric path loss observed on a 630-mile path, in winter, by Lincoln Laboratory,[8] shows an attenuation of 255 dB. This implies that 600-mile 432-MHz communication is realizable on an every-day basis to well-equipped stations. It is 6 dB easier than moonbounce, which has been demonstrated to be within the capabilities of amateurs at 432 MHz. Even longer-range 432-MHz communication will take place with the launching of Amsat-OSCAR-B sometime this year, or the SYNCART (Synchronous amateur radio transponder) satellite, scheduled for 1975.[9] Moon-based amateur transponders may eventually offer even more intriguing possibilities.

These developments, and the rapid growth of amateur television and fm communications in recent years, make the 420-MHz band a very interesting frontier that any amateur with pioneering spirit should enjoy. Concerning 432 and higher frequencies, I believe it safe to say, in the modern vernacular, "This is where it's happening!"

I would like to thank the Microwave Instruments Division of AIL for providing the test equipment used during the evaluation of this amplifier. I would also like to thank Fred Telewski, WA2FSQ, for suggestions concerning the text and the air-cooling method, James Buscemi, K2OVS, for his comments concerning text, and Rusty Holshouser, K4QIF, for his suggestion of efficiency determination by air temperature measurement.

[EDITOR'S NOTE: A condensation of this two-part article by K2RIW, with some different photographs and drawings, appears in *The Radio Amateur's VHF Manual*; Edition 3, 1972, Chapter 13.]

The following information, related to Part I of this article but received too late for inclusion with it, was supplied by the author:

If C7, a high-voltage feedthrough bypass capacitor, is not readily available, a good substitute can be made by hand. Mount two metal plates of four

(Continued on page 79)

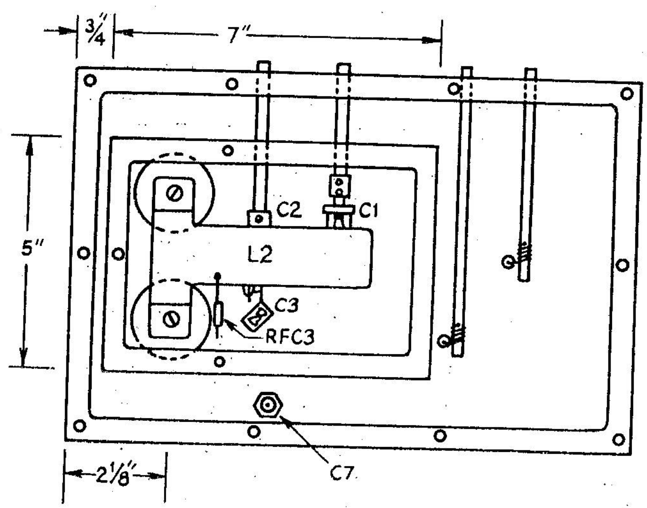


Fig. 9 – Bottom view of the amplifier, giving dimensions not available from Figs. 2 and 6.

9. **Miscellaneous Rules:**

a. Operators participating in the FD may not, from any other station, contact for point credit the FD portable station of a group with which they participated. This is intended to outlaw any kind of manufactured contacts.

b. A station used to contact one or more FD stations may not subsequently be used under any other call during the FD period. This rule is intended to outlaw multiple contacts on the same band with the same station, using different calls. It is not, however, intended to prohibit the use of jointly-owned stations which are normally used under different calls by members of the same family.

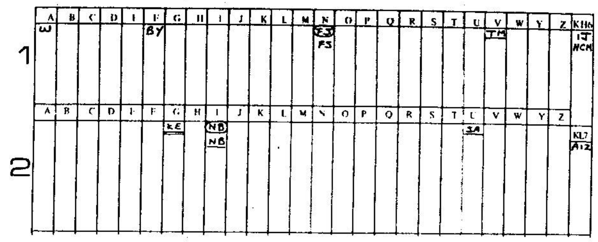
c. Any Class A group whose entry classification is three or more transmitters may also use one novice operating position (to be set up and operated only by novice class licensees) without changing their basic entry classification. The novice position must use a novice call sign and must keep their own logs and check sheets. The novice position QSO total may be added to the group QSO total before multiplier.

10. **Scoring:** Scoring is based on the number of valid contacts times the multiplier corresponding to the highest power used at any time during the FD period, plus bonus points. Power Multipliers. If all contacts are made using a dc input power of 10 watts or less *and* if a power source other than commercial mains or motor-driven generator is used (e.g. batteries, solar cells, water-driven generators, etc.), multiply by 3. If any or all contacts are made using a dc input power of 200 watts or less, multiply by 2. Multiply by 1 if any or all contacts are made using a dc input power over 200 watts up to 1000 watts. Over 1000 watts, multiply by ZERO! Power on ssb phone is considered to be half the peak envelope power. 1. Batteries may be charged while in use for Class C entries only. For other classes, batteries may be charged (during the FD period) from a power source independent of the commercial mains. Bonuses. The following bonus points may be added to the score (after the multiplier is applied) to determine the final score. Only Class A and B stations are eligible for bonuses.

1. 100 points for 100% emergency power, per transmitter classification. ALL equipment and facilities at the FD site must be operated from a source independent of the commercial mains.

2. 50 points for public relations. Publicity must be obtained or a bona fide attempt to obtain publicity must be made. Evidence must be submitted in the form of a clipping, a memo from a BC/TV station stating publicity was given or a copy of material sent to a news media for publicity purposes.

3. 50 points for message origination. A message must be originated by the club president or other FD leader, addressed to the SCM or SEC, stating the club name (or non-club group), number of operators, field location and number of AREC members participating. The message must be transmitted during the FD period and a fully serviced copy of it must be included with the Field Day report.



If the Op Aid 6 system is used (see sample above), enter the suffix of each station worked in the appropriate call area block under the first letter of the suffix. Just enter Ws; underline Ks; circle WAs; and double underline WBs. (For example, WA1NFS, would be listed by taking the letters FS, placing them under the N column and circling same since the prefix is WA.) Whatever dupe system you choose, be sure to submit a separate listing of stations worked *per band* in numerical order(by call area) and alphabetical order (by suffix within each call area). Remember, each phone and each cw segment is considered as a separate band.

4. 5 points for each message received and relayed during the FD period, up to a maximum of 50 points. Copies of each message, properly serviced, must be included with the Field Day report. Club Aggregate Mobile Score. Entries under Class C may be combined to form an aggregate score for their club, having no connection with the club's portable entry, if any. Individual reports must include the club name. The club secretary or other designated club official must submit the club aggregate mobile score claim. Only bona fide members of a club operating in the club territory (175 mile radius from the club headquarters address) may contribute to this aggregate mobile score.

11. **Reporting:** Entries must be received by ARRL Headquarters by August 1. The proper summary sheet, plus a list of stations worked on each band and appropriate proof(s) for bonuses constitute an entry. A copy of your FD log is *not* required unless specifically later requested by ARRL. This does not, of course, relieve you of the responsibility of keeping an operating log as required by FCC/DOC. Send a stamped addressed envelope to ARRL Hq. for FD forms which include the rules, a summary sheet and a sample of a suggested check sheet.

QST

Strip-Line Amplifier

(Continued from page 62)

square inches area, any shape, on opposite sides of the chassis wall. Insulate these from the chassis with 10-mil mylar. Drill a half-inch clearance hole for the metal screw which is to act as the through connection.

The diode, CR1, can be a Shottky-barrier type, HP-2800, as well as the 2301 specified.

K2RIW added a suggestion that should be helpful in obtaining maximum efficiency with any uhf power amplifier. Even with this highly-effective design, there is some slight increase in tube capacitance as the anodes heat during a transmission period. If the plate circuit is detuned slightly on the low-capacitance side of resonance, after the amplifier has reached its stable output condition, the stage will drift *into* maximum output rather than drifting out of it.

References

5 Scott, "Is Today's Standard for Microwave Radiation Safe for Humans?" *Microwaves*, January, 1971, p.9.

6 Telewski, "432-MHz Corner-Reflector Antenna," *Ham Radio*, November, 1971, p. 27.

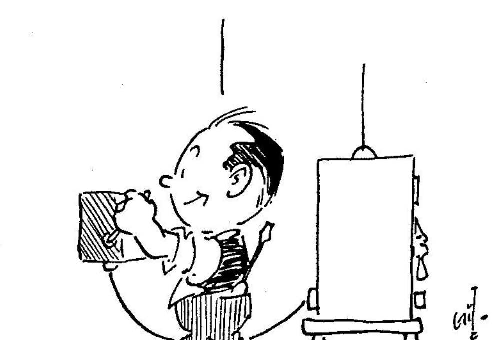
7 Wild, et al, "Handbook of Tri-Plate Microwave Components," Sanders Associates, Inc., November, 1956. Document AD110157, from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22151.

8 Chisholm, et al, "Properties of 400-Mc. Long-Distance Troposheric Circuits," *Proceedings of the IRE*, December, 1962, p. 2464.

9 Klein, "From the President's Desk," Amsat Newsletter, June, 1971.

10 Moonray references: November, 1967, *QST*; March, 1969, *CQ*.

QST



DO YOU KILL ALL TRANSMITTER CIRCUITS COMPLETELY BEFORE TOUCHING ANYTHING BEHIND THE PANEL?