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A High-Power Cavity Amplifier for the New 900-MHz Band

Be ready for the new 900-MHz amateur band when it's ours to use! The road to QRO is paved with resonant cavities and other forms of uhf plumbing.

By Robert I. Sutherland,* W6PO and William I. Orr,* W6SAI

The 1979 WARC (World Administrative Radio Conference) assigned a portion of the 900-MHz region to the Amateur Service in Region 2, which includes the United States, Mexico, Canada and the Central and South American countries. As of this writing, the band has not yet been positioned in the spectrum nor authorized for amateur use in the U.S. Even so, knowing that it will eventually be available raises questions of interest to vhf-minded amateurs.

What will the propagation characteristics of the new band be? Will it resemble 432 MHz or 1296 MHz, the companion bands? Or neither? What circuit techniques apply to the new band? How can power be generated at this frequency to make "tropo" and "moonbounce" (earth-moon-earth) communications practical?

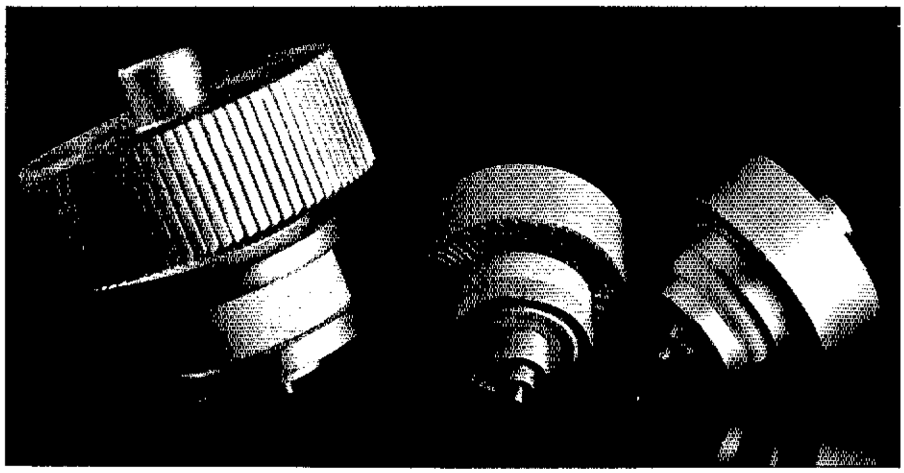

Fig. 1 — Uhf tubes, left to right: 8938 triode with a plate dissipation of 1500 W and rated for more than 1500 W of output at 400 MHz; the 3CX400U7, used in the CV-2805 cavity at 900 MHz; and a 3CX600U7, for over 380 W of output at 800 MHz (rated to 1000 MHz).

The 900-MHz Band Looks Good!

At first glance, the proposed 900-MHz band has a lot going for it. A given antenna type is about half as large as it would be at 432 MHz. That's good news for the enthusiast with the small back yard. Receiver noise figure can be as good at 900 MHz as it is at 432 MHz. Coaxial lines are less lossy at 900 MHz than they are at 1296 MHz. Standard antenna designs work well at 900 MHz, whereas some of them become "squirrely" at 1296 MHz. As every 1296-MHz enthusiast knows, generation of appreciable transmitter power at that frequency is a formidable task. Not so at 900 MHz. Several uhf transmitting tubes will deliver the goods at 900 MHz (Fig. 1), and circuit design is straightforward.

Taking everything into consideration, it seems as if the forthcoming 900-MHz assignment is a "natural" for radio amateurs, since the equipment required to make use of this portion of the rf spectrum is available now. All amateurs require is the *authority* to use this new, interesting band.

A 900-MHz Power Amplifier

Described in this article is a simple power amplifier that is intended for moonbounce communication at 900 MHz. In fm or cw service it provides over 200-W output, and in ssb service it provides over 300-W PEP output. Drive power is about 20 W peak in either case. For those interested, a block diagram of the complete EME station is given in Fig. 2.

The amplifier is essentially a quarter-wave rectangular resonator used in conjunction with a 3CX400U7 high-mu power triode. The tube operates at 1500 to 2000 V. A three-quarter-wave coaxial line assembly is used for the input circuit. Drive power is obtained from a solid-state circuit and a 3CX100A5 cavity amplifier. This is a basic uhf cavity amplifier design that was pioneered by EIMAC and used with success at frequencies above and below the forthcoming amateur band.[1]

The general operating characteristics of the 3CX400U7 tube are listed in Table 1. A combination of high amplification factor and minimum grid interception provide good power gain in cathode-driven service. Coaxial terminals and continuous cone-shaped internal supports for the grid

[1]Notes appear on page 16.

Table 1

Operating Characteristics of 3CX400U7 at 900 MHz

Tube Parameters	*Ssb*	*Fm/Cw*
Plate voltage	2000-V dc	1500-V dc
Cathode bias†	12.0-V dc	12.0-V dc
Filament voltage	6.3-V ac	5.0-V ac
Plate current	400-mA dc	400-mA dc
Grid current††	– 10 mA dc	– 10 mA dc
Useful power output	320 W	230 W

†Varies with class of service
††Approximate

*Varian/EIMAC Division, San Carlos, CA 94070

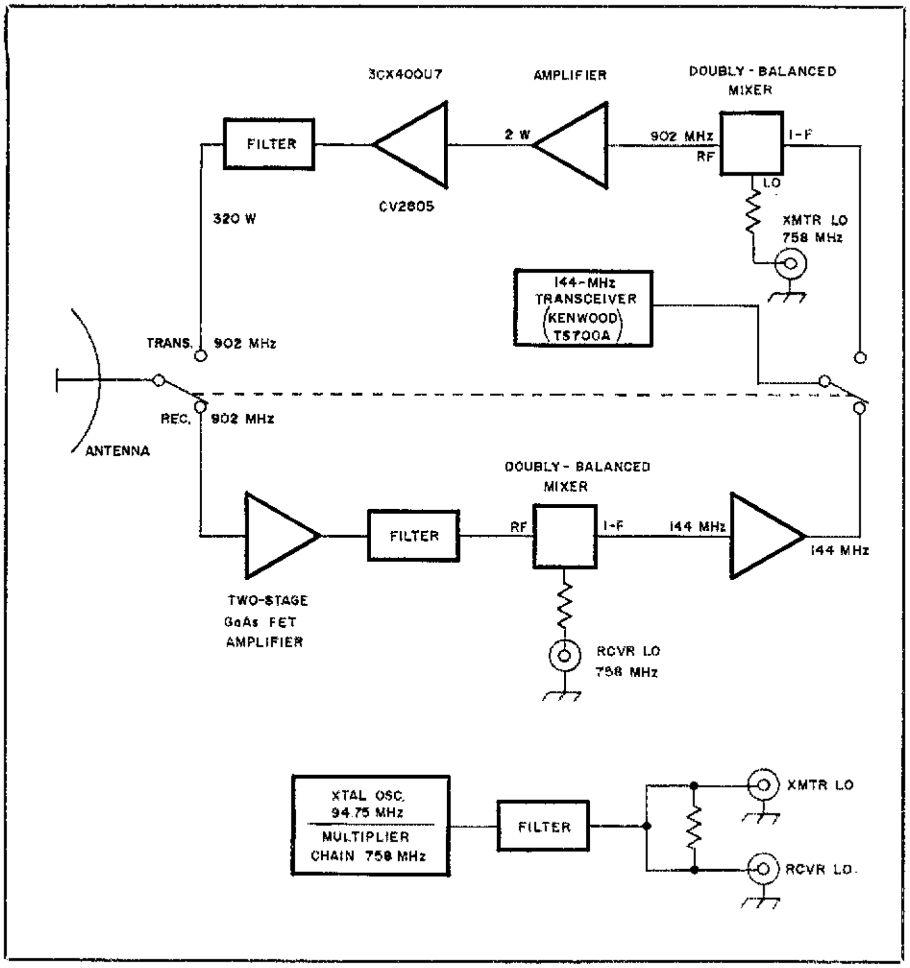

Fig. 2 — Block diagram of the planned EME station at W6PO. A 144-MHz transceiver is used as the station control unit.

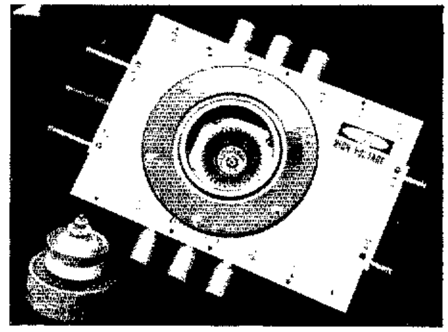

Fig. 3 — Top view of the CV-2805 cavity for 900 MHz. A 3CX400U7 provides more than 300 W of ssb output power. A phenolic ring surrounds the tube-anode collet and holds the circular plate-bypass capacitor (see text).

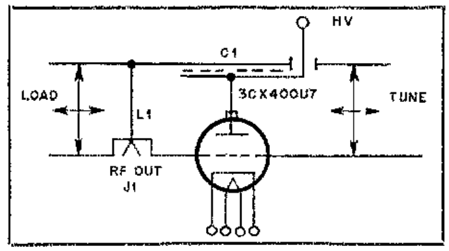

Fig. 4 — Plate circuit of the 1/4-wavelength rectangular resonator. Tuning is by means of sliding walls. The left wall (marked *load*) varies the output coupling by changing the cavity area between L1 and the wall. Resonance is obtained by moving the right wall *(tune)*, which varies the volume of the cavity. The two walls are adjusted in unison, much like the tuning and loading controls of an hf-band amplifier. A large plate is separated from the top of the resonator by means of a thin insulating sheet. It serves as a plate bypass capacitor.

and cathode elements of the 3CX400U7 provide the lowest possible inductance between tube elements and the external circuitry.

The Cavity Plate Circuit

The plate circuit of the CV-2805 amplifier (Fig. 3) is a quarter-wave adjustable cavity. Output coupling is magnetic. A loop is formed between the cavity walls and a post that terminates in the coaxial output connector. Coupling between the output loop and the cavity is varied by moving a wall of the cavity. A simple threaded drive shaft does the job. The degree of coupling is determined by the cavity area enclosed by the post and the cavity walls (Fig. 4). Plate-circuit resonance is established by changing the volume of the cavity by means of a second sliding wall. Contact between the movable walls and the cavity is maintained by preformed finger stock. The two walls are adjusted in unison, much like the conventional loading and tuning controls of an hf amplifier.

The Input Circuit

A simplified drawing of the input circuit is shown in Fig. 5. As shown at A, the circuit is a 3/4-wavelength-long coaxial line. Nearly a quarter wavelength of the circuit is inside the tube, loaded by the tube input capacitance, so that the use of a quarter-wave line is out of the question; insufficient line exists outside the tube to couple to or to effectively tune. An additional half wavelength of line is added to provide room for the tuning capacitor (C1) and the coupling capacitor (C2), which are both placed near the high-impedance portion of the line. The rf short at the bottom of the line is reflected one-half-wavelength up the line, placing the cathode and grid of the tube at a high-impedance point, with the proper 180° phase difference betwen the elements. Since the outside of the assembly is at dc ground potential (Fig. 6), the rf short at the bottom end of the line is made up of a very-low-impedance bypass capacitor, which provides dc isolation for the cathode-return circuit. Fig. 5B shows the same circuit folded back upon itself to conserve length. This is the configuration used in the CV-2805 cavity. The filament leads are brought out through concentric tubes at the center of the assembly; the tubes act as rf chokes to isolate the filament circuit.

Cooling The Cavity

Air for anode cooling is introduced from a cowl or chamber through the three short tubes on each side of the output cavity. The air then exhausts through the finned anode. The short tubes are dimensioned to serve as a "waveguide beyond cutoff" rf filter in the air openings. This prevents the loss of rf power through these ports. Approximately 11.5 cfm of air is required when the tube is operating at sea level and at the full anode dissipation rating of 400 W. The pressure drop across the anode cooler at this flow rate is about 0.2 inch of water. These figures are based on an incoming air temperature of 50° C and a maximum tube-anode temperature of 225° C.

Heater-Cathode Operation

The nominal heater voltage for the 3CX400U7 is 6.3. For operation above 300 MHz and at full power or key-down cw service, the voltage should be reduced as the cathode receives additional heat from rf charging currents and transit-time effects. In this cavity, operating heater voltage is 5.0 for continuous service. During warmup and standby periods, heater voltage is held at 6.3. Nominal heater voltage is applied for a minimum of 60 seconds before plate voltage is applied and operation commences. For best life expectancy and the most stable performance, it is suggested that the heater voltage be held to the final desired value with ±2%. For ssb service and low duty cycle cw, heater voltage is maintained at 6.3.

The Metering Circuits

Conventional grid- and plate-metering circuits are used, with protection provided for the meters by means of reverse-parallel shunt diodes. A zero-center meter is used in the grid circuit because a normal grid-current indication can be negative, depending on plate-circuit loading. This negative current is the result of tube characteristics and transit-time effects at the frequency of operation. A simplified metering diagram is shown in Fig. 7.

Amplifier Adjustment

Before operation is attempted, the cavity-amplifier controls should be set by means of a preturning chart. The cavity frequency rises as the tuning wall is moved inward toward the tube. During tuneup, an rf directional coupler should be placed in the drive line from the exciter. A Thruline® wattmeter, or equivalent monitor, is placed in the output line to the dummy load. Filament and bias voltages, and cooling air, are applied to the cavity. A filament voltage of 6.3 is applied for 60 seconds, followed by the anode voltage of 2000, maximum. Plate current with no drive signal will be approximately 50 mA. When about 10 W of drive is applied, the plate current should rise to 300 to 400 mA. There should be an indication of output power on the Thruline® wattmeter. Under no circumstances should there be rf drive with no plate voltage, as the full drive power will be dissipated in the grid. The tuning and loading controls are now adjusted for maximum output, and both of them are varied until maximum output is achieved. The filament voltage is now dropped to 5.0 for continuous duty or fm operation. It is held at 6.3 for ssb service.

The next step is to adjust the input tuning and matching controls under full-power conditions. The input probe capacitor and the tuning control are adjusted for minimum reflected power. These adjustments are interlocking, so they must be done alternately, tuning for minimum power reflection in the drive line. When this is achieved, the output tuning control should be reset for best power output.

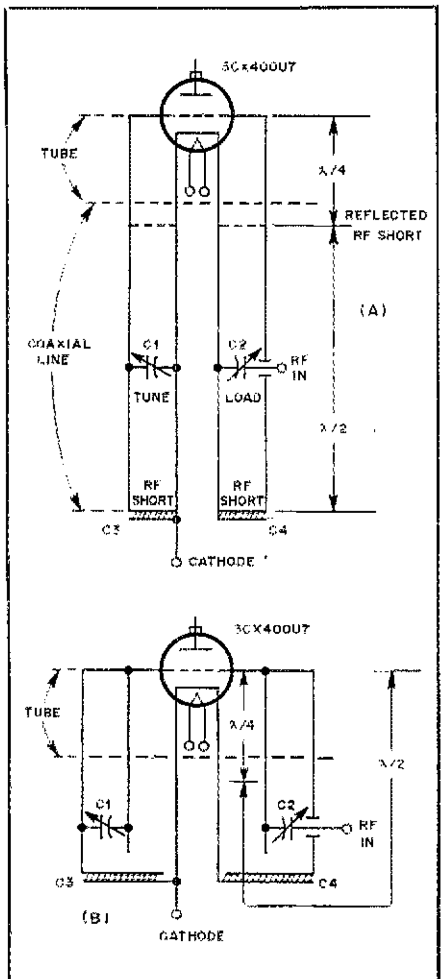

Fig. 5 — At A, the circuit is a 3/4-wavelength coaxial line. Nearly a quarter wavelength of the line is inside the tube — loaded by the tube input capacitance. It is difficult to couple to the short line section, which is external to the tube, so an additional half wavelength of line is added to provide room for tuning capacitor C1 and coupling capacitor C2. The rf short at the bottom of the line (C3, C4) is reflected a half wavelength up the line. This places the cathode and the grid at high impedance, with the proper phase difference between the elements. At B, the same circuit is folded back on itself to conserve length.

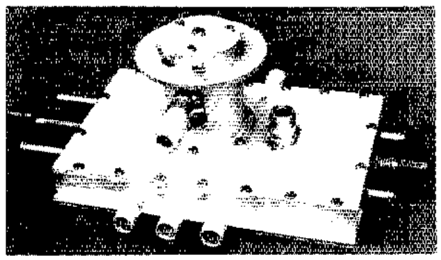

Fig. 6 — View below the CV-2805 cavity. Input-loading capacitor C2 is adjusted by sliding the coaxial fitting in and out of a sleeve. A clamp around the joint locks the adjustment. The plate rf connector is at the side of the input cavity. Filament and cathode connections are made at the end of the input cavity. The assembly is made from heavy silver-plated brass stock to limit thermal expansion.

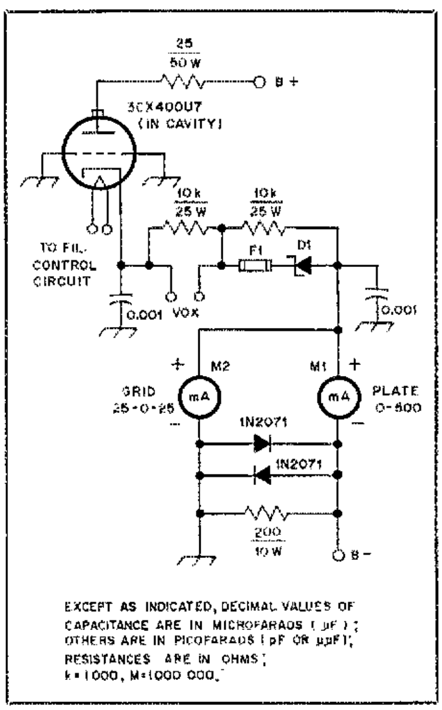

Fig. 7 — Amplifier metering circuit. Metering is done in the power supply return lead. The high-voltage negative line is a few mV above ground to allow insertion of the meters. Reverse-connected diodes protect the meters from overload.

Operation Notes

The tube anode is bypassed effectively in the cavity, so no special precautions are required for application of high voltage to the tube. Connection is made most easily to the center cap of the anode, and it is recommended that a 25-ohm, 50-W current-limiting resistor be used in the high-voltage lead to protect the tube in the cause of a fault condition.

Application of plate voltage should be interlocked with the rf drive in a suitable manner so that the drive signal cannot be applied to the cavity in the absence of plate voltage. It is suggested also that the equipment include an air interlock, so no voltages can be applied to the cavity unless there is an adequate flow of cooling air. For ssb service, the bias should be a fixed value and may be obtained with Zener diode(s) in the cathode circuit.

Finally, it must not be forgotten that absorption of rf energy by human tissue is dependent on frequency. Under 300 MHz, most of the energy will pass completely through the human body with little attenuation or heating effect. At 900 MHz, however, a noticeable heating effect exists, and a prudent operator will stay clear of the antenna field. More information on rf effects on the human body can be found in note 2.

Notes

[1]The brochure entitled "EIMAC Cavity Amplifiers," and data sheets for the CV-2805 and the 3CX400U7 are available at no cost by writing to: Application Engineering Dept., Varian/EIMAC Division, 301 Industrial Way, San Carlos, CA 94070.

[2]The following references should be helpful to those seeking further information:
ANSI C95.1-(1982), *Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields (300 kHz to 100 GHz)*. (New York: American National Standards Institute, 1982).
"ARRL Comments on the Biological Effects of RF Energy," Oct. 1982 *QST*, p. 53.
"How Dangerous is RF Radiation?" Technical Correspondence, Sept. 1978, p. 31.
Proceedings of the IEEE, Special issue on Biological Effects and Medical Applications of Electromagnetic Energy, Jan. 1980 (New York: IEEE, 1980).