capacitance, C_c. The parasitic reactances limit the maximum usable frequency of the varactor. Packages are available, however, for frequencies well into the higher microwave range. By choosing varactor packaging for the frequency range of interest, package reactances can be neglected. The simple equivalent circuit of 10-15D is then sufficient to describe the varactor.

Varactor units look very much like other diodes. The small glass-case version with pig-tail leads is useful only at frequencies below about 100 Mc., and at low power levels. A stud-mounted varactor of the type used in the frequency multipliers shown later in this chapter could be mistaken for a silicon rectifier diode, except for its price tag. It is useful up to 1500 Mc. or so, and at power levels up to 50 watts. Microwave packages commonly used for parametric applications include the 1N21 style and a related double-ended unit. Then there are tiny "pill" varactors for strip-line circuits, and various other mountings capable of working well up into the microwave region.

Varactor Terminology

In order to specify a varactor, certain measurable "parameters" are now in use:

C_{jV_B} or $C_{j\ \min}$—Junction capacitance at reverse breakdown.

$C_{j\,0}$—Junction capacitance at zero bias.

C_{j-6}—Junction capacitance at some specified value of reverse bias, in this instance—6 volts.

R_s—Series resistance, sometimes called "spreading" resistance.

V_B—Reverse breakdown voltage.

θ—Thermal resistance in Degrees C per watt. Useful for power dissipation calculations.

Junction capacitance is usually measured with a bridge at some low frequency, on the order of one megacycle. The value of R_s is usually determined indirectly, by Q measurements at 500 Mc. or higher. In addition, two commonly-used terms involve combinations of the above:

Cutoff Frequency, f_c, at a specified value of bias, and hence C_j.

Normalization Power, P_{norm}, $= \dfrac{(V_B)^2}{R_s}$

These terms equate roughly with maximum usable frequency and plate dissipation as the latter would be used with vacuum tubes. In general, for equal cutoff frequencies, varactors with higher P_{norm} will handle higher power in multiplier service. In parametric amplifiers, varactors with higher P_{norm} require more pump power.

Applications and Availability

Varactors are useful for a variety of frequency-changing and amplifying applications, including electronic tuning, phase or frequency modulators in place of a reactance tube, parametric amplifiers and frequency multipliers. Some mention was made of the first two possibilities in our discussion of f.m. in earlier chapters of this book. We will look into the latter two below.

Once it was necessary to test various rectifier diodes in order to find one that would make a good varactor. Now many companies are producing diodes specifically for varactor purposes. These include such familiar names as Microwave Associates, Sylvania, Motorola, Amperex and others. Most varactors now are made from silicon, rather than germanium, for better high-temperature performance. Varactors made from gallium arsenide are also available. These have extremely high cut-off frequencies, but are somewhat more expensive than the silicon types.

Familiarity with the terminology outlined above will enable the would-be user to sort out units of greatest interest from the catalog listings. Presently-available varactors have characteristics as follows:

V_B—ranges from –6 volts for most parametric-amplifier diodes to –250 volts for the higher-power frequency-multiplier types.

C_{j-6}—from 0.1 pf. (microwave types) to over 100 pf. for v.h.f. frequency multipliers.

f_c—10 to 300 Gc. for silicon, and up to 800 Gc. for gallium arsenide.

R_s—0.1 to 10 ohms; usually higher-capacitance units have lower R_s.

Price is roughly proportional to cutoff frequency and P_{norm}.

THE PARAMETRIC AMPLIFIER

Lowest-noise devices for u.h.f. reception include the maser, the travelling-wave tube, and the parametric amplifier. There is little point in dwelling on the first two here. The maser must operate in a strong magnetic field. It requires certain gases, or exotic substances like rubies or garnets. Worst of all, it must be cooled to very

This leaves the parametric amplifier, a development of some potential worth to the amateur, but one that has been little used and even less understood by most of us. Probably the best treatment of this admittedly involved subject, for the amateur reader, was a series of *QST* articles by W4AO and W4LTU [11] written at the

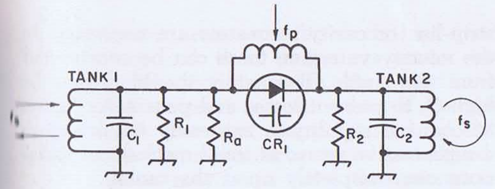


Fig. 10-16—Basic circuit of a parametric amplifier shows its similarity to a crystal mixer.

ence may not find them easy to assimilate, but they are about as simple as they could be without leaving the authors open to the charge of over-simplification. What follows is, to a large extent, a condensation of their excellent work.

Bateman and Bain made a valiant effort to stamp out the almost meaningless term, "parametric," in favor of "reactance amplifier," a name more indicative of the way the amplifier works, but "paramp" seems to have won out in the years since. There is a rather large family of parametric devices, and many mechanical and electrical analogies have been used to explain their operation. We will not go into these here, but they run all the way up from the children's swing, which is probably as apt (and as confusing) as any. Many systems are "pumped" in one way or another; we'll leave the analogies at this point.

The varactor is in effect a capacitor, the value of which changes with applied voltage. It can thus be used to modulate power from an external source, in relation to a signal voltage, and therefor amplify a signal applied to it. The parametric amplifier of most interest to amateurs is physically quite simple, being mainly a diode, fed at the signal frequency, and pumped at a higher frequency simultaneously. The basic circuit, Fig. 10-16, is quite similar to a conventional crystal mixer, and it may be used for either frequency conversion or straight-through amplification.

The signal frequency, f_s, is applied to *Tank 1*. In a frequency converter, *Tank 2* is tuned to the output frequency, f_o, which may be either higher (up-converter) or lower (down-converter) than the signal frequency. The pump tank, top, has only the job of providing an efficient means for exciting the diode capacitor (varactor). The terms "pump" and "pump frequency" are, in effect, merely new names for the more familiar local oscillator and its output frequency, in this case.

In an up-converter (output frequency higher than the pump frequency) a stable power gain equal to $\dfrac{f_o}{f_s}$ could be realized with ideal diodes and lossless circuits. If the output circuit

ing on conditions, very high gains can be achieved.

As a down-converter the output frequency is always lower than the signal frequency. Where the signal is higher than the pump the relationship $\dfrac{f_o}{f_s}$ remains, but since f_o is smaller than f_s, the device is an attenuator. When the signal frequency is below the pump frequency, and $\dfrac{f_o}{f_s}$ is still less than unity, the actual gain may be very high, because of regeneration, as in the up-converter.

In the regenerative arrangements the pump frequency is always the highest in the system, and is equal to the sum of the signal and output frequencies. In the regenerative conditions the signal in the input circuit is amplified by regenerative action, and the device may be used as an r.f. amplifier merely by taking the output from this point, instead of from the output circuit, *Tank 2*. The difference frequency must still appear in the output circuit, however. The terms "idler" and "idler frequency" have become standard names for the output tank and the energy therein. They have no purpose in our life, but they must exist.

For practical purposes, the approximate noise figure of the amplifier of Fig. 10-16 can be obtained from the formula:

$$F = 1 + \frac{R_a}{R_1} + \frac{f_s}{f_i}$$

where F is the noise figure, R_a is the shunt resistance across the input circuit represented by the antenna, R_1 is the shunt resistance represented by the losses directly associated with the tank circuit and diode, f_s is the signal frequency, and f_i the idler frequency.

The last two terms of the equation added together are a measure of the noise generated by the amplifier. Each should be kept small, so that their sum is a minimum. The second term can be kept small by coupling tightly to the antenna, so that R_a is much less than R_1. The third term may be kept small by using an idler frequency much higher than the signal frequency. This means, of course, a still higher pump frequency.

The way that the noise figure varies with pump frequency and various values of $\dfrac{R_a}{R_1}$ is shown in Fig. 10-17. The bottom curve, for $\dfrac{R_a}{R_1} = 0$, represents an idealized case in which R_1 is considered infinitely large. This curve illustrates the value of a high pump frequency. For example, if a pump frequency 5 times the signal frequency is used, the contribution from

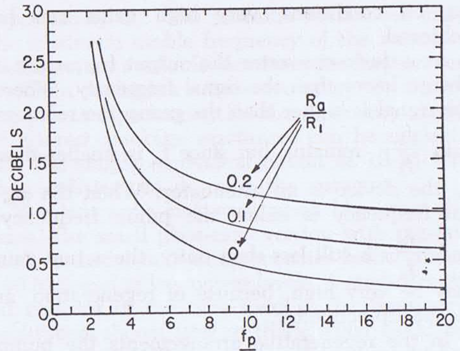


Fig. 10-17—Noise figure of the parametric amplifier of Fig. 10-16, as a function of frequency and antenna loading.

when you are straining for lowest possible noise figure it would be more practical to use a pump frequency in the range of 7 to 10 times the signal frequency. The contribution from idler noise will then be in the range of 0.11 to 0.17, leaving some room to maneuver in with respect to the contribution from $\frac{R_a}{R_1}$

From here on, analysis of the parametric amplifier is very involved, and will not be dealt with in detail in this text. Though the noise figure equation, even in the simplified form given above, gives us indications on how to keep noise figure to a minimum, it is by no means the whole story. Nothing has been said as to how much capacitance variation is required from the varactor and its pump, but it may be said that the following conditions are desirable in a practical device:

1. High idler and pump frequencies relative to signal frequency.
2. High tank-circuit Q.
3. High-Q semiconductor capacitor, or varactor, CR_1.
4. High available capacitance variation, ΔC, in the varactor.
5. Small values for C_1 and C_2.

Practical Considerations

For a given gain, the regenerative amplifier configuration (basic circuit, Fig. 10-16) is the least stable of the arrangements outlined above. Its noise performance, however, is quite good. Furthermore, it may be used directly ahead of an existing receiver or converter. Another big advantage is that instability in the pump does not affect the frequency stability of the output. Typically, 20 db. of fairly stable gain is available over a bandwidth of 100 to 200 kc. at 432 strip-line or cavity resonators are necessary. In the microwave region these can be constructed from waveguide. Resonators should always be high-Q, to prevent losses and poor noise figure. Mechanical stability is extremely important in a regenerative setup, as small mechanical variations can completely upset the tuning.

Varactors designed for paramp service have low breakdown voltage, usually between –5 and –10 volts. Typical zero-bias capacitances are on the order of 0.2 to 5 pf. Cutoff frequencies range from 20 Gc. up, but in general the higher the cutoff frequency the better the noise figure. Typical diodes are the Microwave Associates MA-450 and 460 series, and the Sylvania D4075, D4140 and D4141 series.

Paramp Limitations

Someone may be wondering about the noise associated with the amplifier output load, and whether it is amplified along with the signal by the regenerative action of the circuit. It is, and the coupling problems involved can be solved only by the use of an esoteric device known as a *circulator*. The circulator has the unique property of permitting power to flow in one direction only, between certain pairs of terminals. By properly connecting a circulator in a receiving system using a paramp, the noise generated in the load can be made harmless by dissipating it in a resistive system.

Without a circulator, checking noise figure by means of a noise generator can lead the worker astray, in that *apparent* noise figures much lower than the actual are indicated. Another "fudge factor" in noise generator measurement with a paramp is the low *indicated* noise figure obtained when a pump frequency only twice that of the signal frequency is used. Such an arrangement is fundamentally limited to a minimum noise figure of 3 db., but noise generator measurements may indicate a noise figure of *zero* db. These factors were undoubtedly at the bottom of some early amateur enthusiasm for paramps.

All this is not to say that the parametric amplifier has no place in the amateur u.h.f. picture. It certainly does have, for those amateurs sufficiently skilled in receiver work to assess what is being accomplished with the many adjustments required. The paramp as generally used in the amateur field is a very tricky item. The pump frequency and power level should both preferably be adjustable, in the interest of precise adjustment, yet both should be reasonably stable, so that they will stay put when other adjustments are made. These two attributes are not readily combined in r.f. power sources at several thousand megacycles!

Most paramps built by amateurs have used

The pump frequency and the diode bias must be adjusted, and then the pump power increased, while fiddling with the other two items. All three react on each other. If the operator finally does get things peaked up for optimum results, a slight change in load impedance (such as may occur when the antenna is rotated and objects of differing reflecting properties appear in its pattern) will throw the adjustments off, and the work starts all over.

Measurement of the various "parameters," an over-worked word we'll use this once, since we're talking about parametric amplifiers, is all but impossible. Adjustment for optimum results is cut-and-try, to a degree probably not encountered in any other amateur electronic endeavor.

Results can be worth the trouble. Even without the circulator (and not many amateurs have access to one) it should be possible to develop noise figures around 3 db. at 432 Mc., at least 2 db. better than is likely with vacuum tubes or crystal mixers. It is not easy, nor very permanent, but you will have fun along the way! It is worth noting that great progress is being made in the development and production of low-noise transistors for u.h.f. applications. It may be that they will pretty well take over the burden of low-noise reception at 432 Mc. and even higher frequencies before too long.

Until such times as they do, there is considerable to be gained from use of the paramp for 432 and up. External noise being the problem that it is at lower frequencies there is little practical value in a paramp for lower amateur bands, except for practice and experience. The principles are applicable at any frequency, and suitable pump sources for lower bands are readily obtained or constructed. The amateur who wants to learn more about paramp construction and adjustment might benefit from work with them at 50 or 144 Mc., where measurement of results is considerably easier than at u.h.f.

The Bateman-Bain series[11] describes practical paramp construction for 144 Mc. A paramp for 1296 Mc. that has enjoyed considerable success was described in January, 1961, *QST*.[12] A modification of this for 432 Mc. appears in October of the same year.[13]

FREQUENCY MULTIPLICATION
WITH POWER VARACTORS

We are indebted to Henry H. Cross, W1OOP, for the first practical information on use of varactors for frequency multipliers in transmitters for 432 Mc. The following is mainly from his *QST* treatment of this subject.[14]

Power varactors now available to amateurs will give up to 15 watts output on 432 Mc. when driven with 30 watts on 216 Mc. They will do almost as well tripling from 144 Mc. The tripler described below will give a substantial signal on 432 when driven by nothing more than any of the popular a.m. transmitters such as the Communicator. No auxilliary power or audio is required.

The d.c. voltage-capacitance characteristics and the output voltage as a function of time, for sine-wave current input, are shown in Fig. 10-18. Once the diode draws conduction current, the theory gets more complicated, but harmonic output does not cease, so the complications can be ignored for small currents. If the

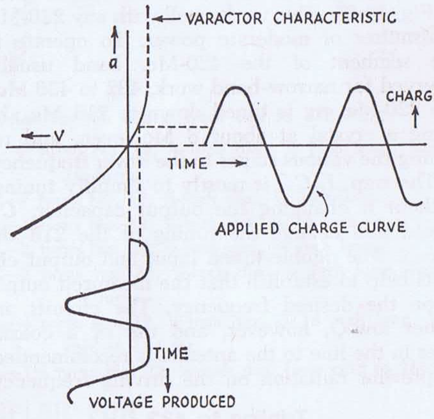


Fig. 10-18—D.c. voltage-capacitance characteristics, and output voltage as a function of time, of a varactor multiplier for sine-wave input current.

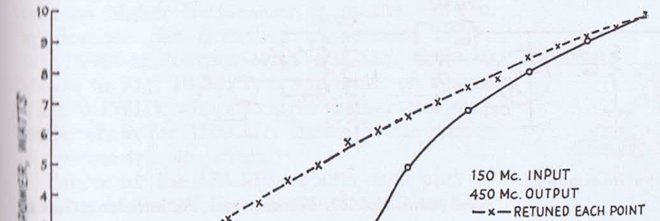
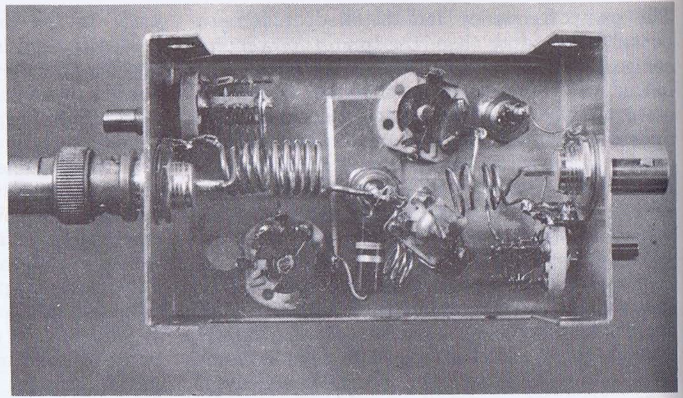


Fig. 10-19—Power output from a 450-Mc. tripler using a Type MA-4060A power varactor. The solid line shows the power available at various drive levels, when the tripler is tuned for maximum output with 20 watts drive. Uniform efficiency, up-per curve, is possible if the system is retuned for each power level

Fig. 10-20—Interior of a doubler stage using a power varactor. Driven with 20 watts on 216 Mc., it delivers 10 watts on 432, yet it requires no power supply or modulator.



multiplier is retuned each time the drive level is changed, an input-output curve similar to the upper curve of Fig. 10-19 is observed. For one tuning condition, the lower curve applies, and this is the case where a.m. is applied to the input. The function is not perfectly linear, but in on-the-air tests the 432-Mc. signal from a 2-meter phone rig and a varactor multiplier sounds quite satisfactory; better in fact than some 432-Mc. plate-modulated setups. Doubling from 216 Mc. to 432, with a unit like that in Fig. 10-20, the varactor does even better.

The circuit of the varactor doubler is given in Fig. 10-21. This works well with any 220-Mc. transmitter of moderate power. To operate in the segment of the 420-Mc. band usually reserved for narrow-band work, 432 to 436 Mc., the 220-Mc. rig is tuned down to 216 Mc., by using a crystal at about 8 Mc. even, and retuning the various stages to the lower frequency.

The trap, L_5C_5, is mostly to simplify tuning; without it changing the output capacitor, C_3, would also change the tuning of the 216-Mc. circuit. The double-tuned input and output circuits help to establish that the measured output is on the desired frequency. The circuits are rather low-Q, however, and use of a coaxial filter in the line to the antenna is recommended, to prevent radiation on the driving frequency.

Tripling to 432

A 432-Mc. tripler built by W1EHF is shown in Fig. 10-22, and the circuit in Fig. 10-23. There is an intermediate resonant loop on 288 Mc., and two traps, one on the input frequency and one to isolate the 288 from the output tuning. The "idler" at 288 gives improved 432-Mc. output. Theory stipulates that such in idler is needed, and tripling is not very satisfactory without it. Performance is shown in Fig. 10-19.

The traps can be tuned up with a dip meter before they are wired in place, and they should not require readjustment in the multipliers. The best way to tune the rest of the system is with an output indicator of some sort, on a dummy load. A directional coupler at the input is convenient for setting up the input network, which should be adjusted for zero reflected power. Maximum drive to the multiplier should then be obtained by adjustment of the driver output circuit, not L_1C_1.

When the driver is to be modulated the final peaking of the multiplier should be done while modulation is applied. Whistle loudly, while tuning for best linearity. This setting will *not* be the same as that for most carrier output. With a tripler, 20 watts of drive on 144 will give 8 watts c.w. on 432, and about 2 watts carrier for a.m., when tuned for best linearity.

The varactor multiplier is becoming increasingly popular as a means of developing power on 432 Mc., with f.m. and c.w., where its full capabilities are realized, and for low-powered a.m. with a modulated driver. A doubler similar to the one shown in Fig. 10-20 is used with the 220-Mc. transmitter of Fig. 6-20, to drive a 4CX300A amplifier at W1HDQ. With less than 20 watts output on 216 Mc. enough 432-Mc. drive is developed to give up to 150 watts output from the amplifier, on f.m. or c.w. The multiplier is also used occasionally for low-power work, feeding the antenna directly. The strip-line filter of Fig. 12-12 is then used in the line to the 432-Mc. array, to prevent radiation on 216 Mc.

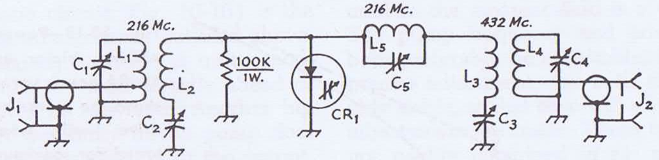


Fig. 10-21—Schematic diagram and parts information for the varactor doubler.

L1—4 turns No. 20, ⅜-inch diam., ⅜ inch long. Tap at

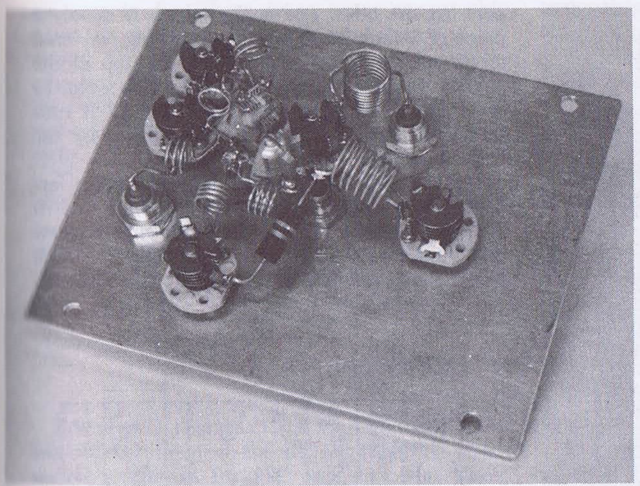


Fig. 10-22—Interior of the varactor tripler, for 432-Mc. output with 144-Mc. drive.

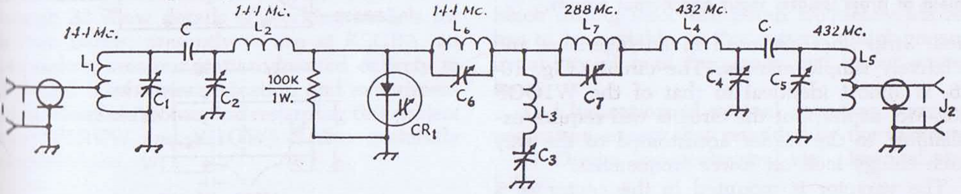


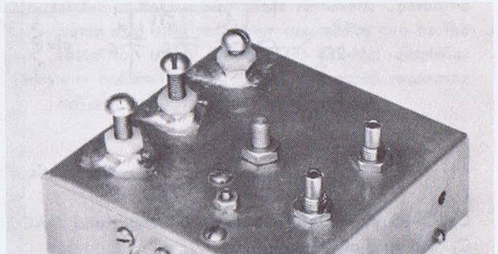
Fig. 10-23—Schematic diagram and parts information for the tripler from 144 to 432 Mc.

C_1, C_2, C_3—10-pf. miniature variable (Hammarlund MAC-10).
C_4, C_5—5-pf. miniature variable (Hammarlund MAC-5).
C_6—13-pf. subminiature variable (Johnson 189-6).
C_7—9-pf. subminiature variable (Johnson 189-4).
C—Leads of No. 26 insulated wire, twisted together for 2 turns.
CR_1—Power varactor (Microwave Associates MA-4060A).
J_1, J_2—BNC coaxial fitting.
L_1—9 turns No. 18, ⅜-inch dia., ½ inch long. Tap at 2½ turns.
L_2—7 turns No. 18, ⅜-inch dia., ½ inch long.
L_3—4 turns No. 18, ¼-inch dia., 3/16 inch long.
L_4—2 turns No. 20, ¼-inch dia., ⅛ inch long.
L_5—3 turns No. 20, ¼-inch dia., ¼ inch long. Tap at 1½ turns.
L_6—4 turns No. 22, ¼-inch dia., 5/16 inch long. Tune cold to 144 Mc.
L_7—1½ turns No. 22, ¼-inch dia. Tune cold to 288 Mc.

VARACTOR TRIPLER FOR 432 TO 1296 MC.

Happily varactor multipliers work almost as well on higher frequencies as in the 432-Mc. applications just described. A varactor tripler for 1296-Mc. output with 432-Mc. drive is shown in Fig. 10-24. It is the work of Wayne Taft, W1WID, who also built the varactor multiplier chain for 4100 Mc. shown in the section on parametric amplifiers.

Except for the 432-Mc. circuits, coils and capacitors are out of the question for this applica-



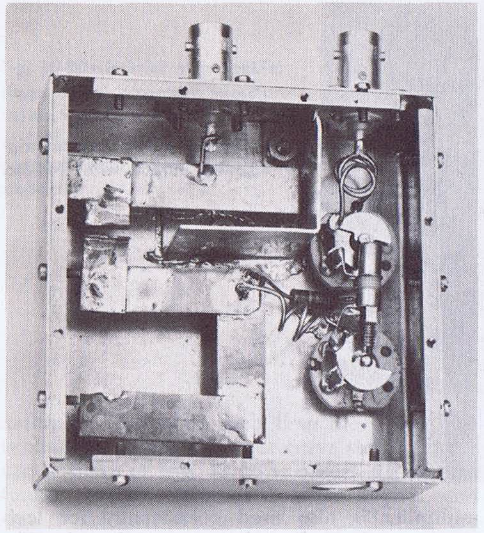


Fig. 10-25—Interior of the 1296-Mc. varactor tripler. Coils and variable capacitors are the 432-Mc circuits. Inductances for 1296 Mc. are copper strips. L-shaped shield of brass isolates input and output circuits.

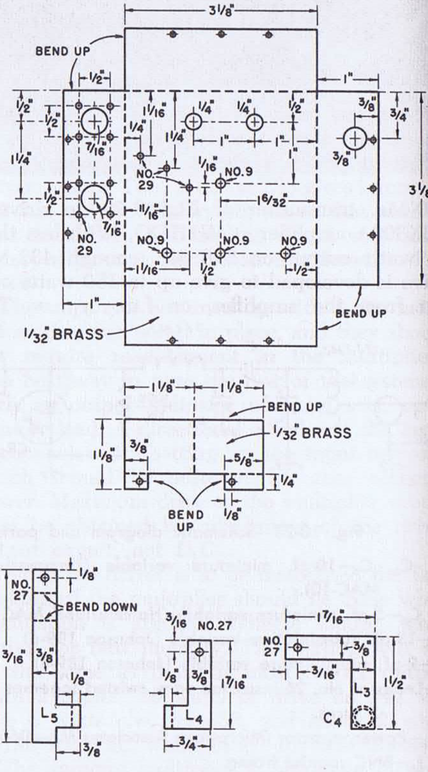
tion. Strip lines are used in an ingenious and relatively simple manner. The circuit, Fig. 10-26, is almost identical to that of the W1OOP 432-Mc. tripler, but the circuits will require explaining, to the reader accustomed to the way such things look on lower frequencies.

The varactor is mounted in the center of a brass box 3⅛ inches square and 1 inch high. Adjacent to the BNC input fitting near one corner of the box is the 432-Mc. input circuit, L_1C_1. A small piston-type trimmer, C_2, couples energy to C_3 and L_2. The latter may be seen connected to the varactor at the center, though the varactor itself is out of sight under the strip-line circuits for 1296 Mc.

The line circuits are cut from flashing copper ⅜ inch wide. In the model shown they are made of separate strips soldered together, but they could be cut as shown in Fig. 10-27. L_3 is an "L" in shape as well as in function. The ⅛-inch hole in one end fits over the varactor post. At the other end is C_4, which is merely a piece of ⅜-inch brass or copper tubing, soldered to the strip, and facing toward the top of the chassis. Running through the chassis is a No. 10 brass screw, which is the "rotor" of C_4. It runs into the cup formed at the end of L_3 by the brass tubing.

Construction of L_4 is somewhat similar, except that coupling capacitor C_6 is built into it. The capacitor C_5 is merely another No. 10 screw that runs down so that its end makes a small variable capacitance to ground at the right-angle turn in L_4. There is no brass cup at this point, as only a very small capacitance is required. Coupling between L_4 and L_5 (C_6 in the schematic) is made by bending up the ends of the short arms of L_4 and L_5. These ⅛-inch wide surfaces then face each other about 3/32 inch apart.

The output inductance, L_5, is the most complex piece. It is bent into U shape at one end to support itself at the same height from the chassis as the other inductances. The output tap for the BNC connector is made at a point 13/16 inch from this end. Capacitor C_7 is the third brass screw, the end of which provides variable capacitance in the same manner as described for C_5.



MATERIAL: FLASHING COPPER

Fig. 10-27—Details of the case and copper strip lines for the 1296-Mc. tripler.

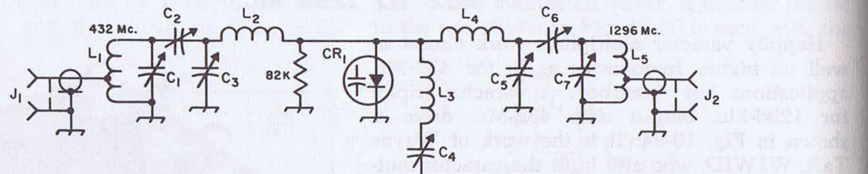


Fig. 10-26—Schematic diagram of the 1296-Mc. tripler.

C_1, C_3—5-pf, miniature trimmer (Hammarlund MAC-5).

C—0.5 to 5-pf, piston trimmer.

C_6—Bent-up tabs on L_4 and L_5, approximately 3/32 inch apart. Bend for adjustable capacitance.

All this is an involved way of saying that tuned circuits really reach an elementary simplicity at frequencies this high. They are confusing only when we think of "coils" and "capacitors" in their 3-to-30-Mc. connotation. The small shield visible in the photograph is the full height of the box. It isolates the 432-Mc. circuits from the output, thereby keeping the level of the unwanted 432-Mc. energy in the output lower than it would be with an open layout.

PRACTICAL PARAMP DESIGN

For several years K2CBA and W1WID have worked together on the development of parametric amplifiers for 220 and 432 Mc. Their experiences closely parallel those of other capable workers, except that they documented their results more carefully than most hams do. The information that follows is extracted from notes they kept, and then passed along for others interested in this complex subject. Figs. 10-28 through 33 show details of working models for the two bands, presently in use at K2CBA, an outstanding amateur station devoted entirely to v.h.f. and u.h.f. communication and experimentation. Helpful information regarding this project from W1RVW and W1QWJ is also gratefully acknowledged.

Background

Early paramp designs tried had all the usual limitations. Those pictured are still not the "last word," but they do represent usable devices, capable of being adjusted for optimum results with a minimum of fiddling required thereafter. Their practical usefulness stems from the following steps taken in the course of the K2CBA-W1WID program:

1) Use of a crystal-controlled pump source, so that the pumping level could be adjusted without causing a shift in pump frequency.

2) Use of separate resonators for each frequency of importance in the system. Most amateur paramps have a single assembly, with the signal, pump and idler resonances all tied in together. Tuning of such a setup smacks of black magic, since the pump frequency almost has to be variable in this system, which means instability of both frequency and pump power level.

3) Elimination of mutual coupling between resonators, except that provided by the varactor.

4) Design for mechanical and electrical stability.

Evolution

When a regenerative paramp (the type presently of interest to the amateur) is heavily pumped, the gain increases and the bandwidth decreases. The need for stability and independent adjustment of the various circuits thus becomes most vital under the conditions which

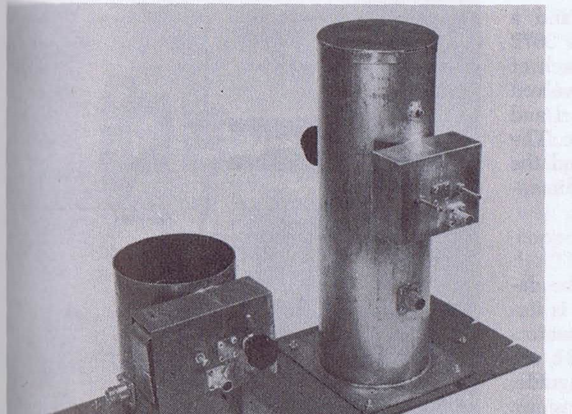


Fig. 10-28—Practical parametric amplifiers for 432 and 220 Mc. The 432-Mc. assembly, left, is shown with its cover plate removed. Combined pump and idler resonator assemblies can be the same for either band. The 432-Mc. amplifier was built with one end of the pump resonator adjustable, but this is not a necessity.

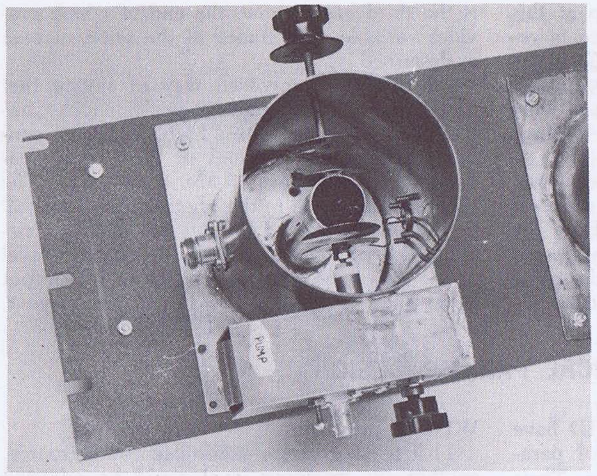


Fig. 10-29—Looking into the top of the 432-Mc. paramp. The choke assembly is visible in the lower portion of the coaxial signal tank, and the tuning disk for the 432-Mc. circuit is at the top. Input and output coupling loops for the 432-Mc. signal are on the lower left and right sides.

make stability almost impossible to attain with anything but crystal control. The amplifiers of Fig. 10-28 were used originally with pump power supplied by surplus Western Electric TD-2 Microwave Generators. The mortality rate of the 416Bs used in the output stages of these units was rather high, so eventually the solid-state pump system shown in Fig. 10-34 was developed.

The screened portion at the left of the picture is a conventional vacuum tube exciter, with a 6146 in the output stage, operating on 152 Mc. Then come three varactor multiplier units very similar to those described a few pages back in this manual. Each is a tripler, the frequency lineup being 152 to 456 Mc., 456 to 1368 Mc. and 1368 to 4104 Mc., this last being the injection frequency of the paramp for either 220 or 432-Mc. service. Some 100 milliwatts of power is obtained on the final frequency, enough so that the paramps can be operated with a 10-db. pad in the line between the final multiplier and the varactor pump input.

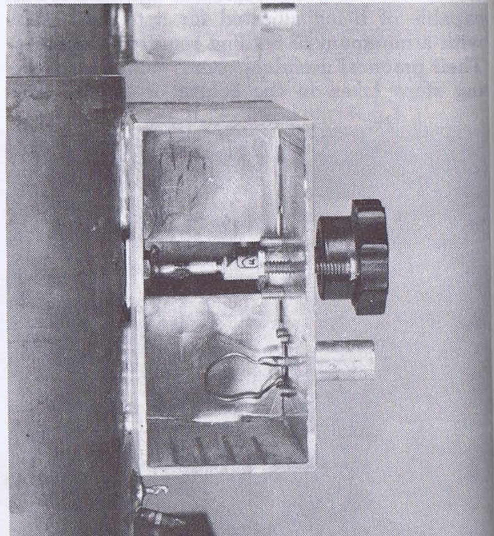
For a signal frequency of 432 Mc. and a pump on 4104 Mc. the idler frequency is 3672 Mc. The design required resonators for each of these frequencies. The techniques involved were basically those outlined by Troetschel and Heuer,[12] but adapted for 220 and 432 Mc. The same pump is used for both paramps, and the only difference between them is in the dimensions of the signal circuit.

Pump and Idler Cavities

The 432-Mc. paramp, Fig. 10-29, will be described in detail, as use of the technique is important only at this frequency. The resonators for 4104 and 3672 Mc., Figs. 10-30 and 31, are made from sections of S-Band waveguide, which is 1¼ by 3 inches in outside dimensions,

than $\lambda_g/2$, a screw threaded into the top wall of the cavity, at the center, can be used to tune it to resonance. W1QWJ and W1RVW added a vernier device to this in the form of a 4-40 brass screw alongside the 8-32 screw used for rough adjustment. The idler resonator is the one so tuned, since the pump cavity resonance merely affects the level of injection to the varactor. The signal circuit is a coaxial line, tuned with a disk capacitor, as may be seen from the pictures.

The idler and pump cavities can be made from a single section of waveguide 3¼ inches long, and 1¼ by 3 inches in external size. Brass cover plates are fitted to each end. In the model shown the end plate was made in U shape, to permit adjustment of the size of the cavity, but this was not done in the 220-Mc. unit alongside.



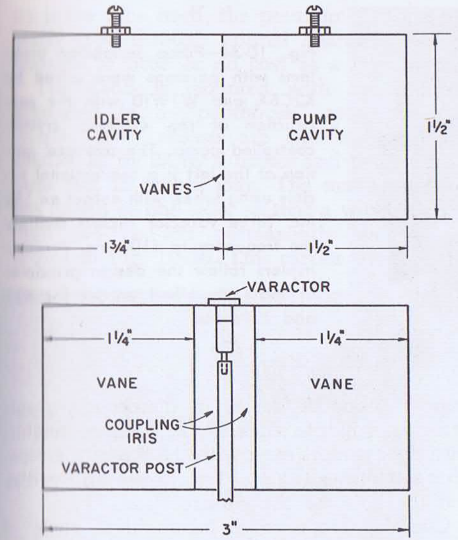
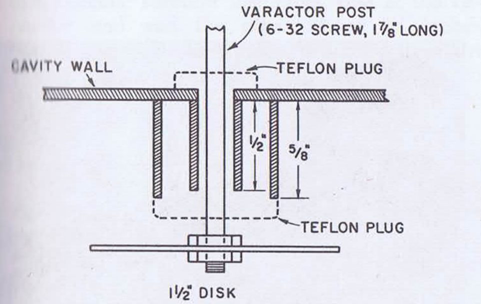


Fig. 10-31—Side view of the idler and pump resonator assembly (top) shows tuning adjustments mounted at the center of the top surface of each. Below this is an end view of the resonator, showing the vanes which isolate the pump and idler cavities. The varactor and its post are in the center of the space between the vanes.

A partial short across the guide divides it at 1¾ inches from one end. This takes the form of vanes 1¼ inches wide at each side. The opening (iris) at the middle has the varactor and its post mount lined up in it. A side view (top portion of the drawing) and end view (lower) of the resonator assembly are shown in Fig. 10-31. An end view with the cover plate removed is shown photographically in Fig. 10-30. The top flange of the varactor makes contact with the top of the assembly, and its tip connects to the post, which runs into the signal tank.

The iris-post-diode structure is resonant roughly between the idler and pump frequencies. This resonance is controlled by the width of the opening, but it does not appear critical.



The net effect is that the varactor is coupled to both cavities.

Power from the pump source may be coupled into the pump resonator through a loop and BNC fitting, anywhere on the side wall that is convenient. The fitting and half-inch loop for this purpose are visible in Fig. 10-30. Maximum coupling is with the loop vertical, when the signal tank is also vertical.

Coupling to the Signal Tank

The varactor is coupled to the signal circuit by extending the post through a hole in the waveguide resonator, into the signal tank. The post can be a 6-32 screw 1⅞ inches long, which makes the attachment of a coupling capacitor plate at the inner end a simple matter. The inner conductor of the signal tank has a fixed disk as part of this coupling capacitor. The position of the movable plate can be varied by adjusting

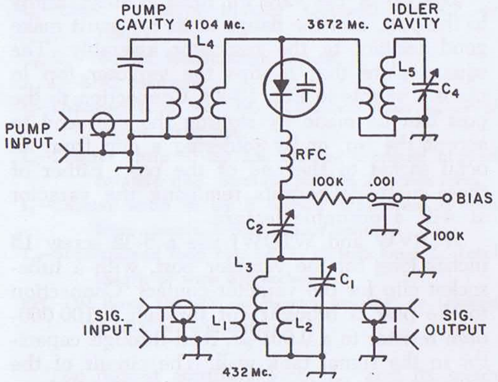


Fig. 10-33—Basic circuit of the 432-Mc. parametric amplifier shown in conventional terms. The r.f. choke is effective at the pump and idler frequencies, but not at the signal frequency. C_1 and C_2 are the tuning and coupling disk capacitors in the signal tank. C_3 and C_4 are tuning screws in the cavity resonators. L_1 and L_2 are signal input and output coupling loops, and L_3 is the coaxial-line tank circuit. L_4 and L_5 are the pump and idler cavity resonators.

the nuts that hold it in place, but it is not particularly critical.

At the point where the post enters the signal tank it is desirable to have chokes for the idler and pump frequencies. A cut-away view of the dual choke assembly is given in Fig. 10-32. This was made from pieces of ½-inch and 5⁄16-inch copper tubing, ⅝ and ½ inch long, respectively. The space between them, and between the inner one and the post was filled with Teflon plugs turned down for this purpose.

Dimensions of this choke are not critical, but its function is important. It keeps pump and idler energy out of the signal circuit, while not affecting the operation of the post as a device

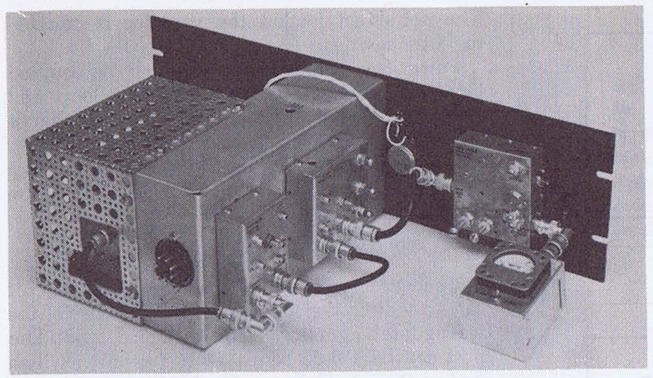


Fig. 10-34—Pump instability problems with paramps were solved by K2CBA and W1WID with the construction of the 4100-Mc. crystal-controlled pump. The screened portion at the left is a conventional exciter using tubes, with output on 152 Mc. Three varactor triplers multiply the frequency to 4104 Mc. Varactor triplers follow the design principles of those described earlier for 432 and 1296 Mc.

the overall stability and ease of adjustment of the system.

Varactor Mounting

The tip of the varactor must connect firmly to the post, and the flange at its top must make good contact to the resonator assembly. The square plate that clamps the varactor top in place is visible in Fig. 10-28. Connection to the post can be made by slotting the post end to accept the tip, or by soldering a clip from an octal socket to the end of the post. Either of these methods permits removing the varactor at will, a desirable feature.

W1RVW and W1QWJ use a 6-32 screw 1⅞ inches long for the varactor post, with a tube-socket clip for the varactor contact. Connection to the post is brought out through a 100,000-ohm resistor to a 0.001-μf. feed-through capacitor in the signal tank wall. The circuit of the entire paramp is expressed in conventional terms in Fig. 10-33.

The Coaxial Signal Tank

The coaxial signal assembly is made of 4-inch copper pipe, 6¼ inches high. The inner conductor is ⅞-inch copper pipe 4¼ inches long. Copper disks 1½ inches in diameter are soldered on opposite sides of the inner conductor, with their centers even with the top of the pipe. This establishes the positions of the tuning disk and the hole for the varactor post.

Coupling loops are 2 inches high, made of No. 14 wire. Instead of bringing the cold end of these loops down to ground, as was done in the models shown, W1RVW and W1QWJ put in series tuning capacitors. These are small glass cylindrical trimmers, mounted in the outer conductor, directly below the coaxial connectors, and at a point ⅜ inch up from the bottom. Being able to tune out the reactance of the coupling loops is undoubtedly a worthwhile feature, if adjustment is to be made for the ultimate in low noise figure.

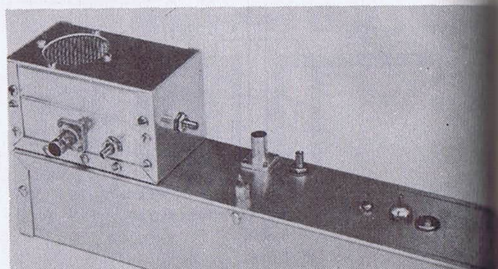
The main tuning disk is operated through a brass lead-screw with a tension adjustment similar to the one shown on the 500-watt 432-Mc. amplifier in this chapter.

In tuning up, a microammeter for reading varactor current is very helpful, as is a crystal-controlled signal source. The pump power should be about 100 milliwatts to start with, though only about 3 milliwatts is required when the paramp is properly tuned.

416B PREAMPLIFIER FOR 432 MC.

The preamplifier of Fig. 10-35 is about as good as can be built with vacuum tubes, at 432 Mc., and it has the advantage of being built largely of readily-available parts and materials. The principal exception to this ready availability is the tube itself, the premium 416B, a very costly type through normal channels, but obtainable at little or no cost as a used item.

Fig. 10-35—A 416B preamplifier for 432 Mc. built in two standard-sized aluminum boxes. The tube "penthouse" has 1½-inch screened holes in the top and rear portions of the cover, for ventilation. The input connector and series loading capacitor, C_1, are on the



The 416B is mounted with its grid ring grounded in a "penthouse" atop the main chassis. Both chassis are standard sizes, the smaller 2¼ by 2¼ by 4 inches and the larger the same but 12 inches long. The small box is cut the length of one side, so that a wall 1¼ inches high can be left permanently mounted, as shown in Fig. 10-36. This carries the input coaxial jack, J_1, the series capacitor, C_1, and the input coupling loop, L_1. The remaining portion of the U-shaped cover is removable for work on the input circuitry of the preamplifier.

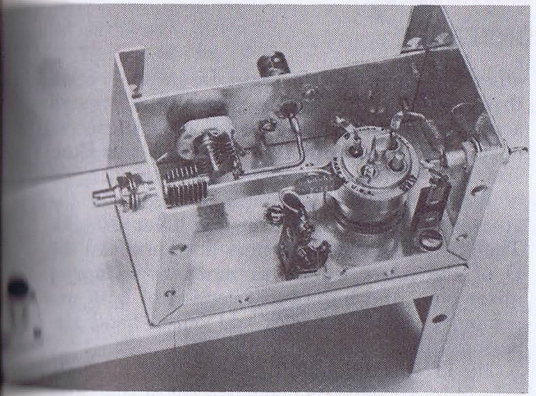


Fig. 10-36—Interior of the penthouse, showing the cathode circuitry and tube mounting.

The cathode tuned circuit, L_2, is a ⅜-inch copper strap wrapped around the r.f. cathode ring on the 416B and extending 2⅜ inches from the center of the tube to the stator lug of C_2, which is mounted on the end of the penthouse. Most other details should be discernible in the interior view, Fig. 10-36. Despite its short length, L_2 is a half-wave line.

The plate circuit, L_3C_3, is also a tuned half-wave line. The inductance is a strap of copper similar to L_2, 8 inches long, tuned at the far end by a glass trimmer, C_3. It is supported on ½-inch ceramic standoff insulators, one at the capacitor end and the other about 1¼ inches from the tube. A short piece of brass drilled out to take the plate pin of the 416B is soldered to the end of the strap, and it has a setscrew to bear against the tube pin.

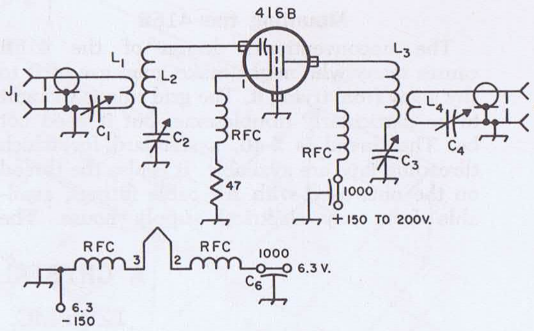


Fig. 10-38—Schematic diagram and parts information for the 416B preamplifier.

C_1, C_4—9-pf. miniature trimmer (Johnson 160-104 or 9M11).

C_3—5-pf. glass trimmer.

C_2—15-pf. miniature trimmer (Johnson 160-107 or 15M11).

C_5, C_6—1000-pf. feedthrough bypass.

J_1, J_2—BNC connector.

L_1—L-shaped loop No. 14, 1/16 inch from L_2. Total length 1½ inches.

L_2—Copper strap ⅜ by 5¾ inches, wrapped around cathode ring. Straight portion 2 inches long.

L_3—Copper strap ⅜ by 8 inches, supported ½ inch from chassis. B-plus tap at center.

L_4—Shoe-shaped loop No. 14, 1/16 inch from L_3. Total length of wire 3½ inches.

RFC—10 turns No. 22 on ½-watt resistor, or Ohmite Z-460. (4 required)

The output coupling loop, L_4 and its series capacitor, C_4 are visible in the bottom view, Fig. 10-37. Plate voltage is fed into the line through an r.f. choke and the feedthrough capacitor C_5, to the midpoint of the line. It can be seen that the main chassis is longer than necessary, but it was used because it was the nearest standard size. Anyone making his own could do with a case 2 inches shorter.

In putting the preamplifier into service, all circuits should first be tuned for maximum signal strength. The tuning of C_1 and C_2 should then be done carefully for best signal over noise. This will be found to be at a point on the high-capacitance side of the setting of C_2 that gives maximum gain, and the two capacitor settings should be juggled carefully while noting the margin of signal over noise.

Fig. 10-37—Bottom of the main chassis. The plate tuning capacitor, C_3, is at the far left.