M. F. Solo

LB-921

A CAPACITIVE TUNED UHF TUNER

RADIO CORPORATION OF AMERICA

RCA LABORATORIES DIVISION

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Approved

Stuart Wm Seeley

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Introduction

This bulletin describes a capacitive tuned circuit and its application to a u-h-f television tuner in the 470-890 Mc range. Essentially this tuned circuit consists of a closed metal box housing a variable air balanced split-stator capacitor commonly known as a butterfly capacitor, which spans opposite faces. The inductance of the tuned circuit contributed by the inside walls of the box is extremely small, making necessary a relatively large capacitor to cover the u-h-f television tuning range. The Q of this capacitive tuned box is between 1000 and 1500 over the band. A fundamental frequency oscillator using this type circuit exhibits unusual frequency stability because of the high capacity shunting the oscillator tube.

A u-h-f tuner using two of these tuned circuits for preselection, one tuned circuit for the oscillator, and a 1N82 crystal diode as the mixer provides a relatively high degree of performance. The circuit Q's attainable with this type of tuned box permit low insertion loss and high spurious signal rejection. Noise figures on the order of 13 db have been obtained, and spurious responses are more than 38 db below signal level.

The one to five minute oscillator warm-up drift is **less** than 150 kc at any frequency in the tuning range.

The Tuned Circuit

A practical tuned circuit for use in the 470 to 890 Mc u-h-f television band must provide means for readily tuning the frequency range with sufficiently high Q. Other factors influencing the choice of tuned circuit are the ease of construction, desirability of rotary or longitudinal motion, and elimination of contact problems.

A conventional capacitor-coil tuned circuit appears to offer some of the desirable electrical and mechanical characteristics but with certain limitations. Extending the frequency range of such a circuit to the u-h-f region is difficult because the physical size of the elements becomes impractically small.

The tuned circuit herein described and shown in Fig. 1 consists of a relatively large lumped variable capacitance and a small inductance which is actually a metal box housing a balanced split-stator or butterfly capacitor.

In describing its principle of operation, an analogy to a lower-frequency circuit is helpful. The inductance may be conceived of as a C-shaped loop of wire across the stator plates of the capacitor. By rotation of the loop about the capacitor a closed surface is generated. Electrically, the closed surface consists of a large number of parallel loops which together reduce the single-loop inductance to a value usable in the u-h-f range.

There are a number of possibilities for the form and dimensions of the generated surface. Among these, several cylindrical and rectangular parallelepiped forms were investigated. The dimensions were governed by requirements such as physical size of the capacitor, and the required value of inductance. In each case, the closed surface (or enclosure) was constructed of copper or silver-plated copper, and the capacitor chosen was one that was commercially available and of the proper value to tune the u-h-f range.

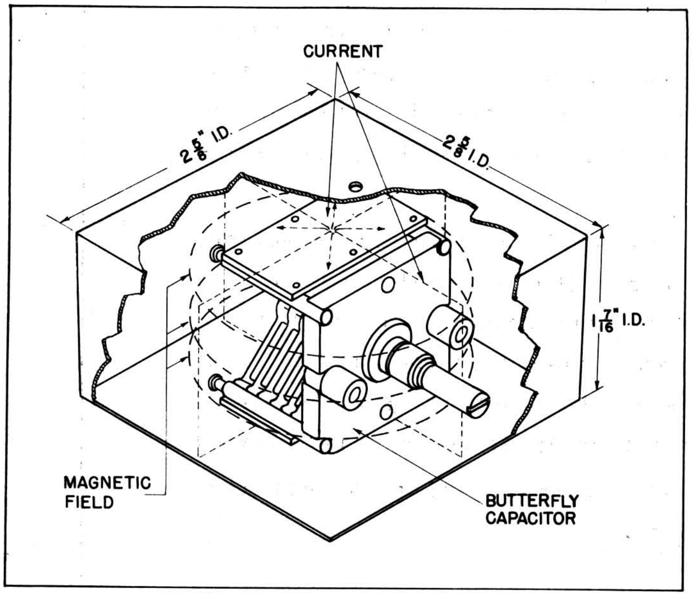


Fig. 1 - The basic tuned circuit.

Three different experimental box-type configurations, one larger, one smaller, and one identical to that shown in Fig. 1, were studied to determine which would provide the most desirable characteristics. Of these the design in Fig. 1 was chosen on the basis of maximum Q consistent with convenient physical size. A cylindrical enclosure of equivalent inductance, and using the same size capacitor yielded substantially the same performance. Since results were the same, the box type rather than the cylindrical construction was preferred because of its mechanical advantages.

During the experimental work, both single-stator and butterfly capacitors were used. A single-stator capacitor in the tuned circuit requires circulating currents to flow through its rotor shaft and wiping contacts. However, current need not flow through the rotor shaft of a butterfly capacitor operating in split-stator fashion. Considerably higher Q's were measured in the latter case, apparently because of the absence of contact resistance.

The capacitance range of the butterfly capacitor used is from 3 μμf to 15 μμf. At maximum capacitance, the tuned circuit resonates at 450 Mc and the effective inductance is calculated to be 0.008 μh. With the capacitance at minimum, the circuit resonates at 1200 Mc and the inductance computes to be 0.006 μh. The apparent change in inductance is due to the inductance of the capacitor plates. This change in inductance is of no particular consequence since adequate range appears to be no problem. However, its effect is in the direction of increasing the range.

An electromagnetic field surrounds the capacitor within the box. Its distribution is dependent upon the magnitude and density of the circulating currents on the inside surface. Consider first the magnitude of current flow. If the inside surface were to consist of a great number of parallel current paths, all of which are common at the center of the box, then the currents would flow outward from the capacitor, along these paths, down the sides and back again to the capacitor. The paths carrying the most current would be the shortest or those of least impedance, and within a symmetrical box would cross each of the four rectangular sides at their centers.

Consider next the current density, and assume, for the moment, that current flows equally in all directions from the center. The density on the inside surface is then inversely proportional to the distance from the capacitor. This means that the current density is greater at the center of each side of the box than at the corners. However, it was shown in the previous paragraph that current does not flow equally in all directions, but favors the shortest paths. The combined effect is further to increase the current density at the center of each side, and decrease the density in the corners.

A magnetic field is produced with a strength that is proportional to the current density, and in a direction that is at right angles to the current flow (Fig. 1). This implies that the magnetic field within the box is strong at the mid point of the sides, an weak in the corners. This information is useful in locating and orienting coupling loops which are described in a later section.

As previously explained, a butterfly capacitor is mounted in the center of a copper enclosure. It is of utmost importance that a good electrical contact be made between these two primary parts. Poor contact has resulted in severely decreased circuit Q. The measured unloaded Q of properly constructed units varied between 1000 and 1500 throughout the u-h-f television band. In the developmental model, a small amount of copper oxide between the capacitor and its contact surface caused a 50 per cent decrease in Q. Two possible methods that might avoid this difficulty are soldering the capacitor directly to each surface, or silver plating the box. In the tuning units described in this bulletin, the box was silver plated and the capacitor was fastened to the box by screws. Mounting plates were soldered to the two stator sections of the capacitor, and then each mounting plate was drilled and tapped to accommodate six 2-56 screws. This method was used so that the experimental unit might be readily assembled and disassembled.

The Oscillator

As the next step in the development of a u-h-f tuner, an oscillator based on the tuned circuit just described was designed. Its basic requirements were maximum frequency stability, minimum variation of output with frequency, and a tuning range of 510 Mc to 930 Mc for use with a 40 Mc i.f.

The most convenient type of oscillator for operating in the u-h-f frequency range appears to be the ultraudion, or modified Colpitts. In this type of circuit the interelectrode tube capacitances serve to provide the necessary feedback to maintain oscillation (Fig. 2). In addition, however, they act as partial frequency-determining elements. Variations of these tube capacitances caused by change in temperature and voltage will effect the frequency stability. The degree to which frequency stability is affected will depend upon oscillator design and circuit parameter values.

In constructing the oscillator, it was found necessary to mount the tube socket for the 6AF4 u-h-f triode on the last two stator plates of the butterfly-type capacitor (Figs. 3 and 4). Lead inductances are reduced to a minimum and the tube is brought closer to the center of the box and thereby nearest the highest impedance point in the tuned circuit.

The coupling capacitors between the tuned circuit and the tube each consist of a stator plate, four 0.005-inch layers of Teflon, and a brass tube-socket mounting plate. In adjusting the size of the capacitors it was found desirable to keep them equal so that electrical symmetry might be maintained between the tube and either side of the box. An approximate value of 4 μμf for each was required as a compromise between low and high frequency oscillator operation.

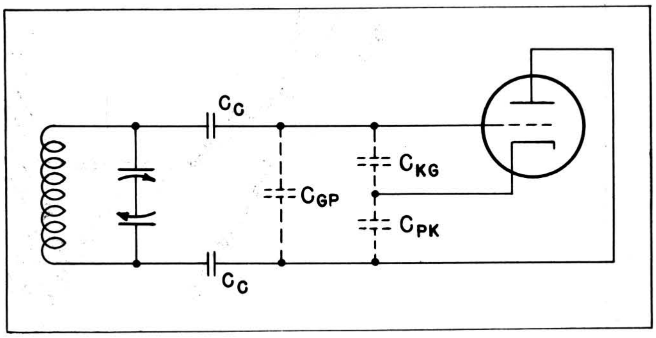


Fig. 2 - Basic oscillator circuit.

Two silver-mica button r-f bypass capacitors, soldered into holes of the proper size in the box wall, allow connecting leads to be brought into the enclosure. Chokes, oriented so that they will be perpendicular to the magnetic field within the box, as illustrated in Fig. 4, are connected between these capacitors and the tube socket terminals.

The choke sizes were arrived at by a trial-and-error process. Uniformity of plate current with frequency was the criterion, and the objective was to minimize or eliminate current dips indicating spurious resonances. As indicated by the curves in Fig. 5, the plate current variation over the tuning range is within ±20 per cent of the mean value. By orienting the chokes perpendicularly to the magnetic field (and, where possible, to one another) interaction and absorption of power is reduced.

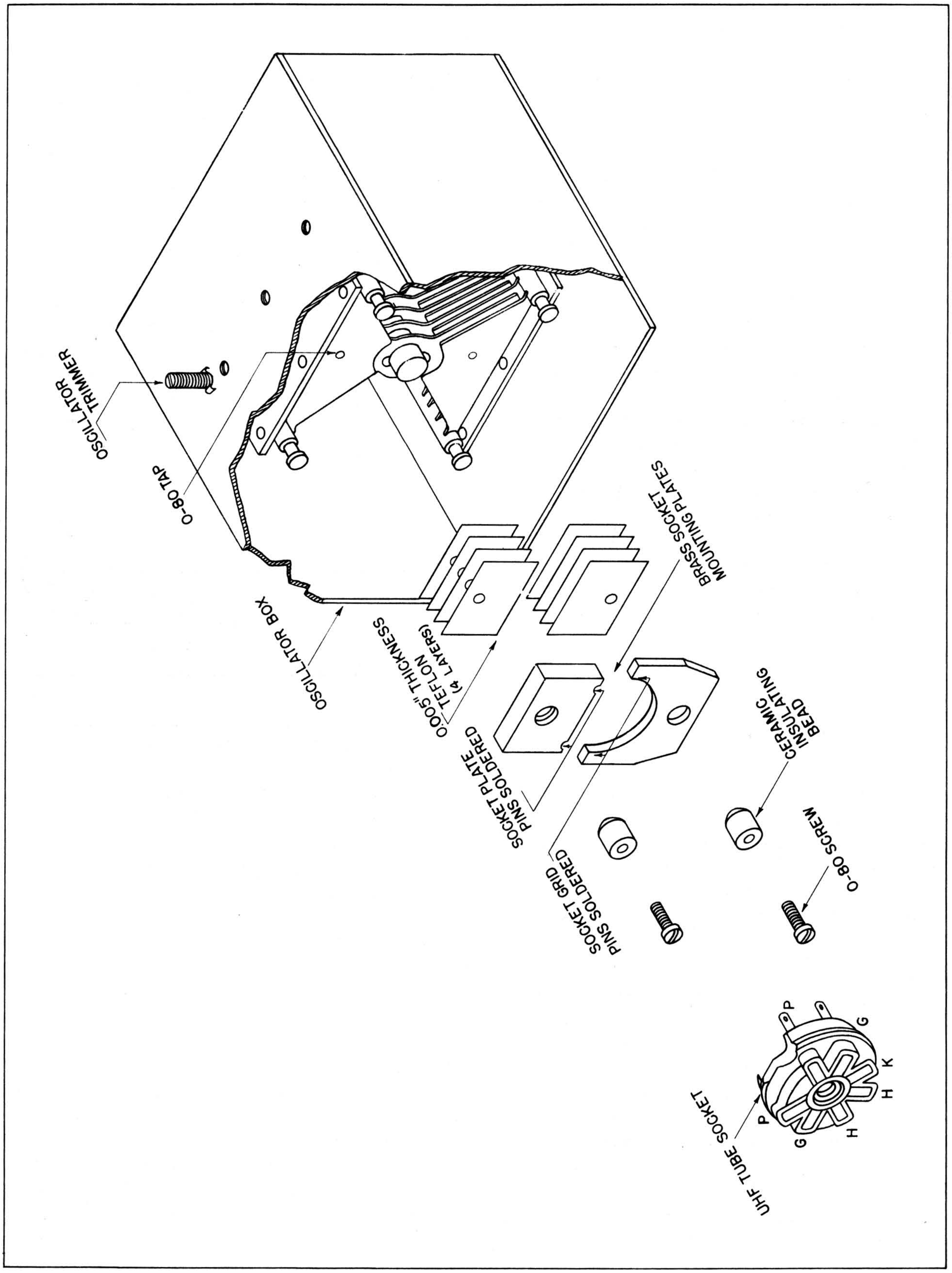
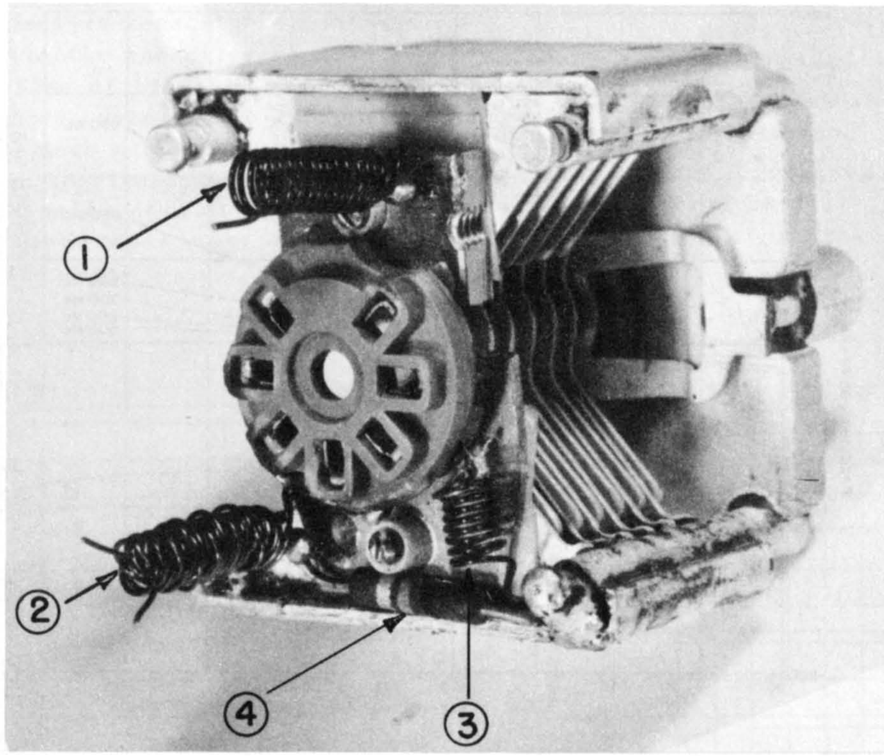


Fig. 3 – Development of oscillator tube mounting.



1. Plate choke, 15 turns 1/8" D., 1/2" L., No. 29 enam.
2. Heater choke, 15 turns twisted pair, wound. 1/8" D., 1/2" L., No. 28 Formvar
3. Cathode choke, 8 turns 1/8" D., 3/16" L., No. 29 enam.
4. 10K grid resistor

Fig. 4 - Oscillator tube mount.

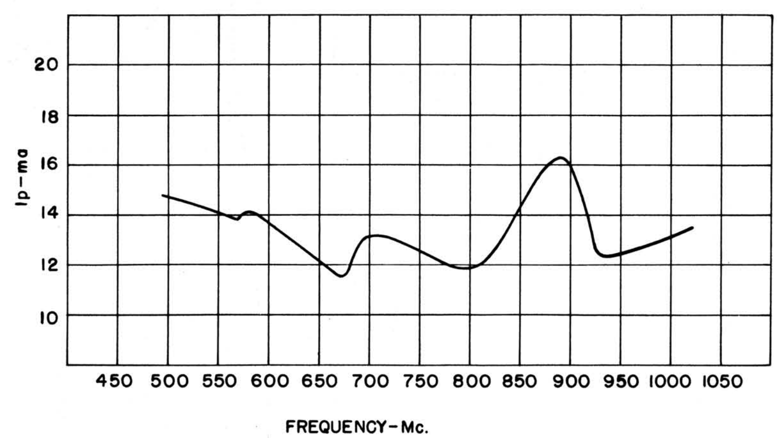


Fig. 5 - Oscillator plate current vs frequency.

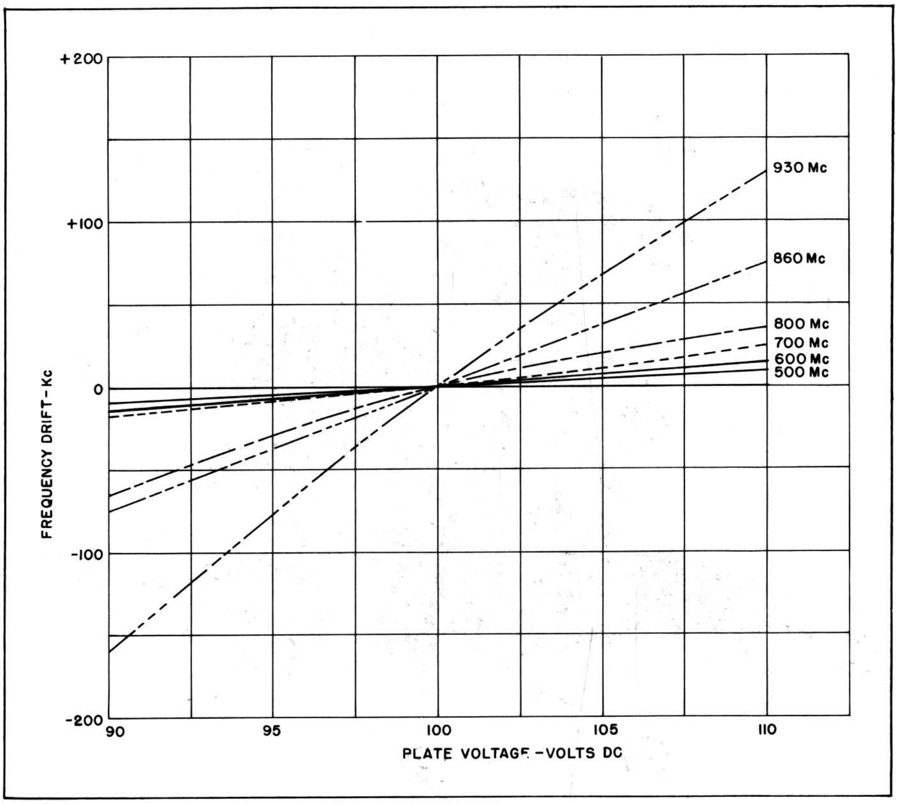


Fig. 6 - Oscillator frequency drift vs plate voltage.

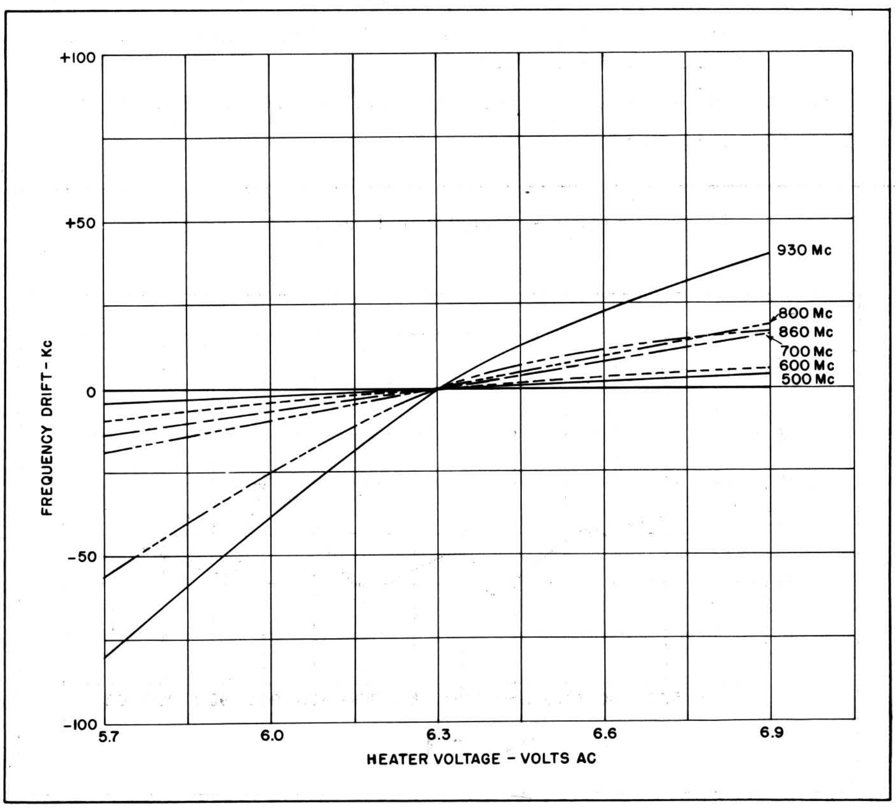


Fig. 7 - Oscillator frequency drift vs heater voltage.

Fig. 2 shows a schematic diagram of the basic frequency-determining elements in the oscillator. The effective capacitance consists of the 3-15 μμf butterfly capacitor shunted by the series combination of blocking and inter-electrode capacitances. Because the tube capacitances are tapped down on the tuned circuit, and their values are small compared to the main tuning capacitor, small variations in inter-electrode capacitance will have a minimum effect upon tuned frequency.

At 930 Mc, the effective tube capacitance is approximately half the total circuit capacitance. This means that there is an improvement of frequency stability by a factor of about two over the case where the tube is the only contributor of capacitance. As the tuning capacitance is increased, the stability is further improved until, at the low end of the band, a factor of approximately five is attained.

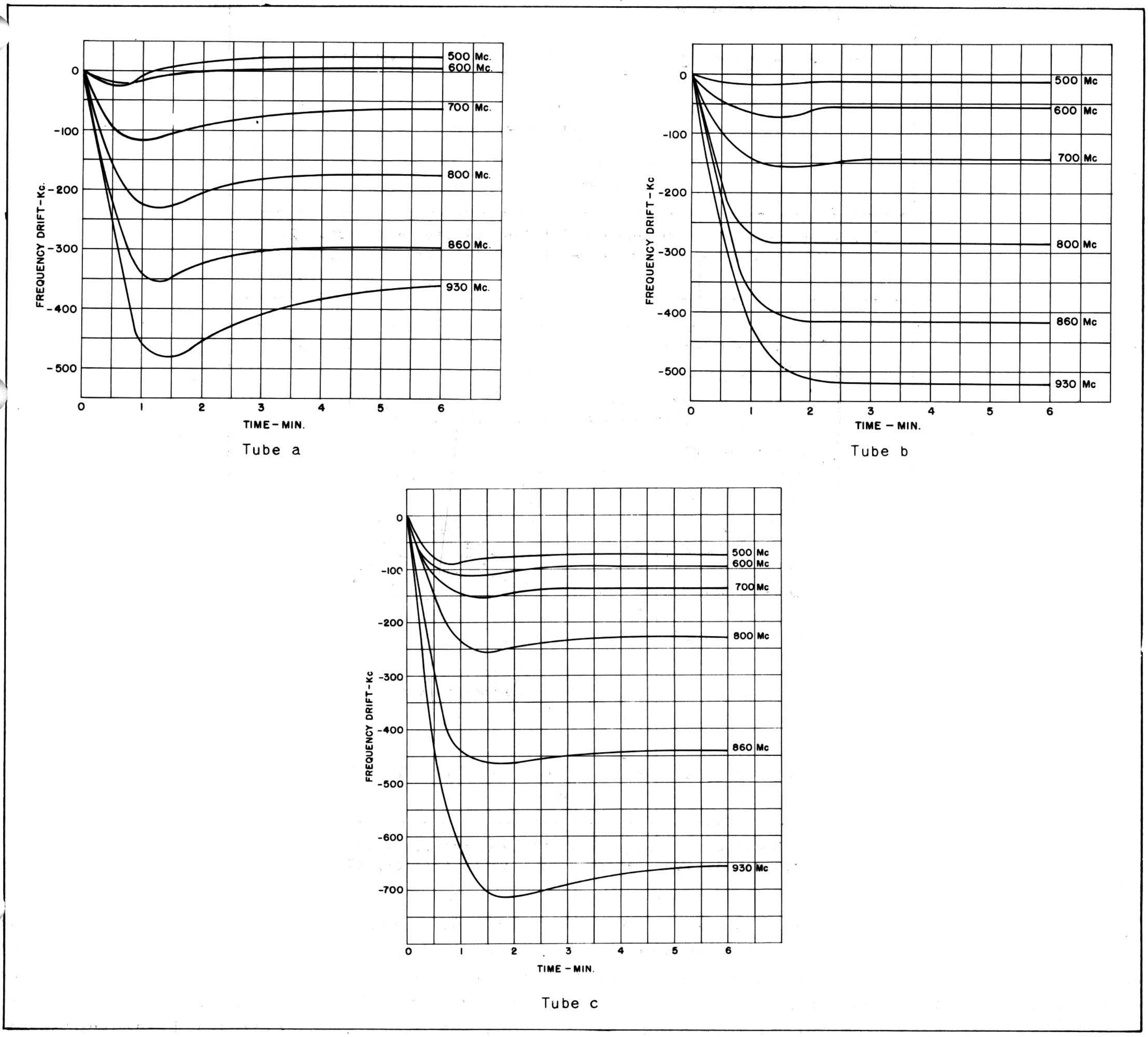


Fig. 8 - Oscillator warm-up frequency drift from 0-5 minutes for three representative tubes.

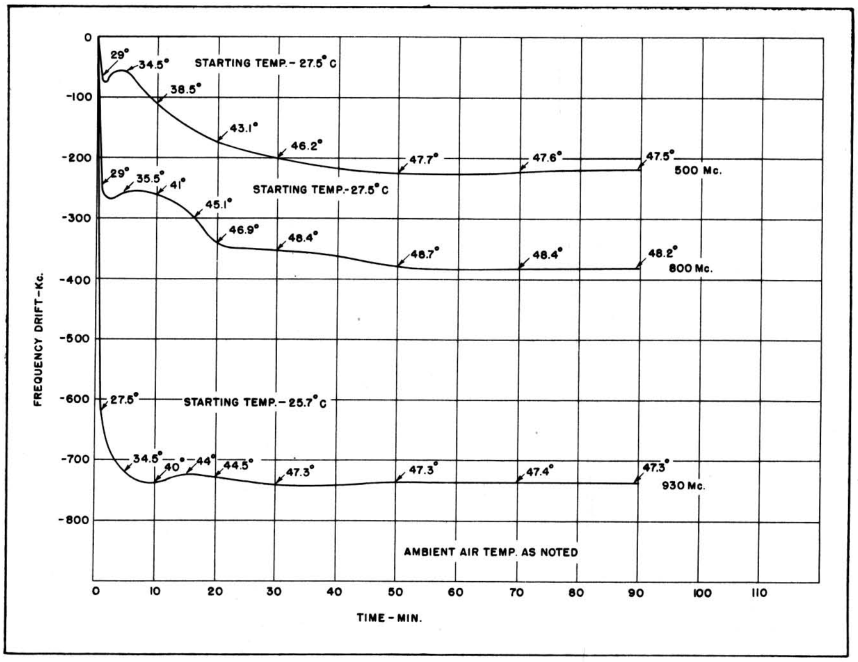


Fig. 9a - Oscillator frequency drift 0-90 minutes with about 21°C ambient air temperature rise without trimmer capacitor.

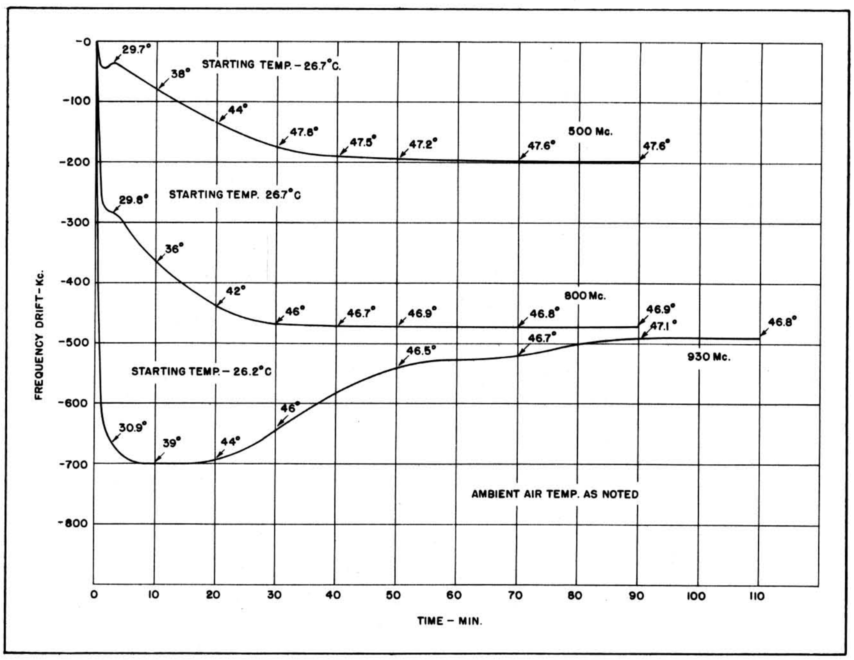


Fig. 9b - Oscillator frequency drift 0-90 minutes with about 21°C ambient air temperature rise with trimmer capacitor.

Several stability measurements were considered of interest. The plate and heater voltages were varied 10 per cent above and below their normal operating values, and warm-up drift was recorded from zero to five minutes. Results of these measurements are given in Figs. 6, 7 and 8. Fig. 8 shows that most of the warm-up drift occurs during the first minute after oscillation starts for constant ambient temperature. The three curves of Fig. 8 also show the oscillator drift for three representative tubes.

The curves in Fig. 9 were obtained by simulating a temperature rise that would be expected within a television receiver. With the oscillator enclosed in a cardboard box, the air temperature inside was slowly raised about 21 degrees C. Curve *a* shows oscillator drift without, and curve *b* with the trimmer capacitor.

The UHF Tuner

The u-h-f tuner which was developed is one of several possible configurations using the tuned circuit and oscillator just described. Basically the circuit is a common type, with a passive double-tuned preselector, an oscillator, a crystal mixer, and a driven-grounded-grid i-f amplifier. (Fig. 16).

As shown in Figs. 10 and 11, two tuning elements are placed in line as the preselector, the oscillator is located above the output preselector unit, and the i-f amplifier sub-chassis is mounted on one side.

The preselector tuning capacitor shafts are rigidly coupled together by a $\frac{1}{2}$-inch diameter Rexolite dowel fastened with set screws. A pulley and dial-cord system then couples the oscillator to the preselector shaft.

Mounted on the i-f amplifier side of the tuner is a crystal holder consisting of a phosphor-bronze tube and a polystyrene liner. (Fig. 12). To make the crystal easily accessible, the tube end is fluted and a feed-through capacitor is clipped into it. Rigid support, provided by the polystyrene liner, permits the crystal to be almost completely within the box, minimizing the capacitance across the crystal.

The two tuned preselector circuits couple the antenna signal to the crystal mixer and act as a selective frequency filter. The effectiveness of signal transfer depends upon the ratio of the tuned circuit unloaded to loaded Q. At 470 Mc, the r-f bandwidth is 8.5 Mc. As the

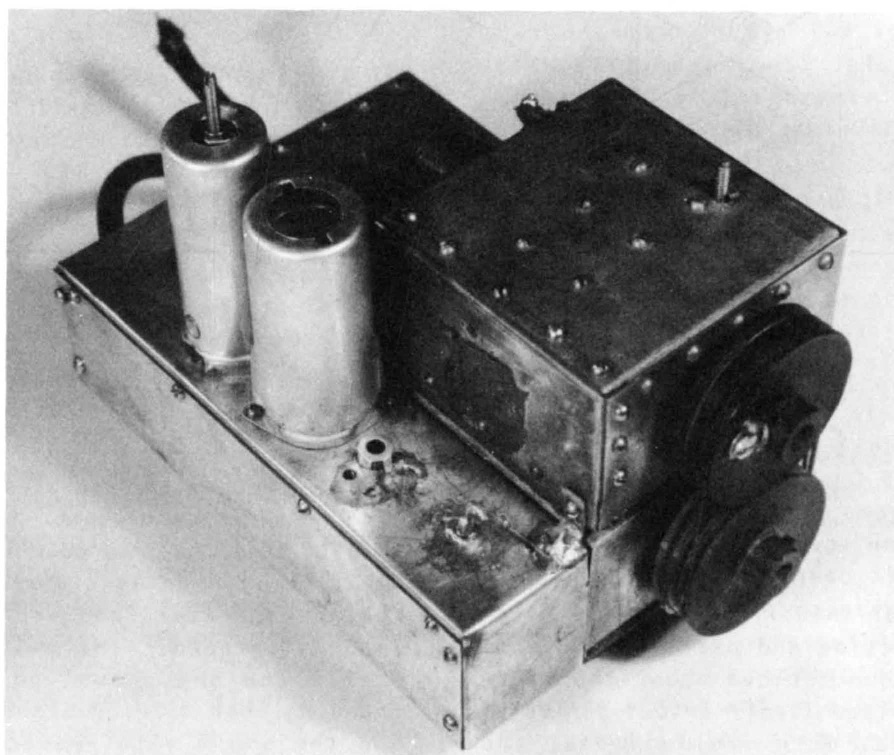


Fig. 10 - Developmental u-h-f tuner.

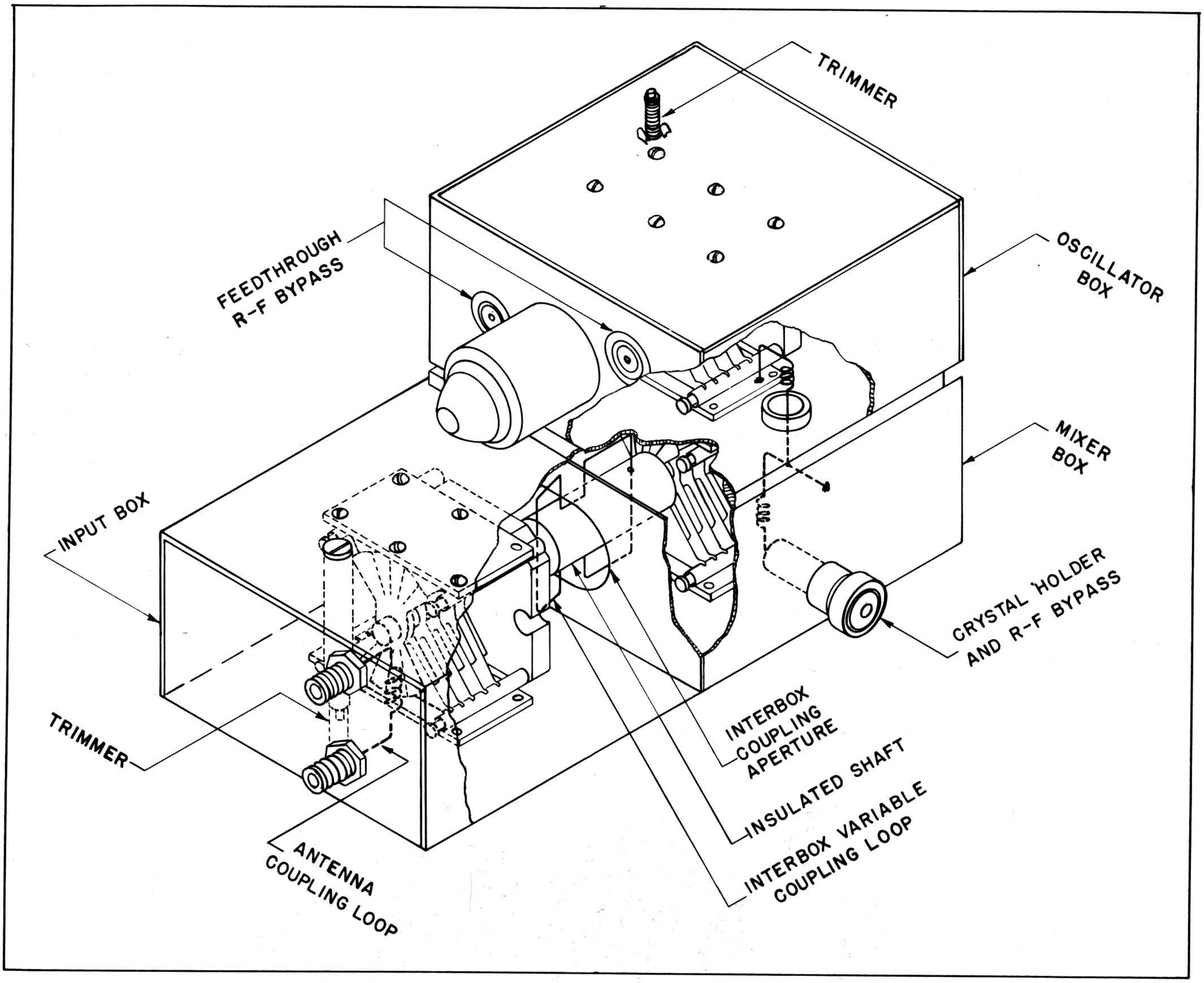


Fig. 11 – Isometric view of tuner showing coupling systems.

tuned frequency is increased to 890 Mc, the bandwidth broadens to 13 Mc and the individual loaded tuned circuit Q's remain below 100. Since the unloaded Q, determined by inherent circuit loss, ranges from 1000 to 1500, the calculated insertion loss is less than ½ db per tuned circuit at all operating frequencies.

In a system of this type, once the means of frequency selection and oscillator signal generation have been decided upon, the electrical design resolves itself into a series of coupling problems. With minimum loss, the signal is coupled into the first preselector box, next to the second box, then into the crystal where it is mixed with an injected oscillator signal, and finally, from the crystal to the i-f amplifier.

R-f coupling in any of the boxes may be accomplished by the use of a loop, an aperature or a combination of both. When a loop of fixed size is used, maximum coupling is obtained when it is positioned as close as possible to the tuning capacitor, and when the plane of the loop is perpendicular to the magnetic field within the box. Coupling may be varied by changing loop size, distance from the center, and the angle with respect to the magnetic field.

Aperture coupling implies that a common opening between two boxes provides a mutual

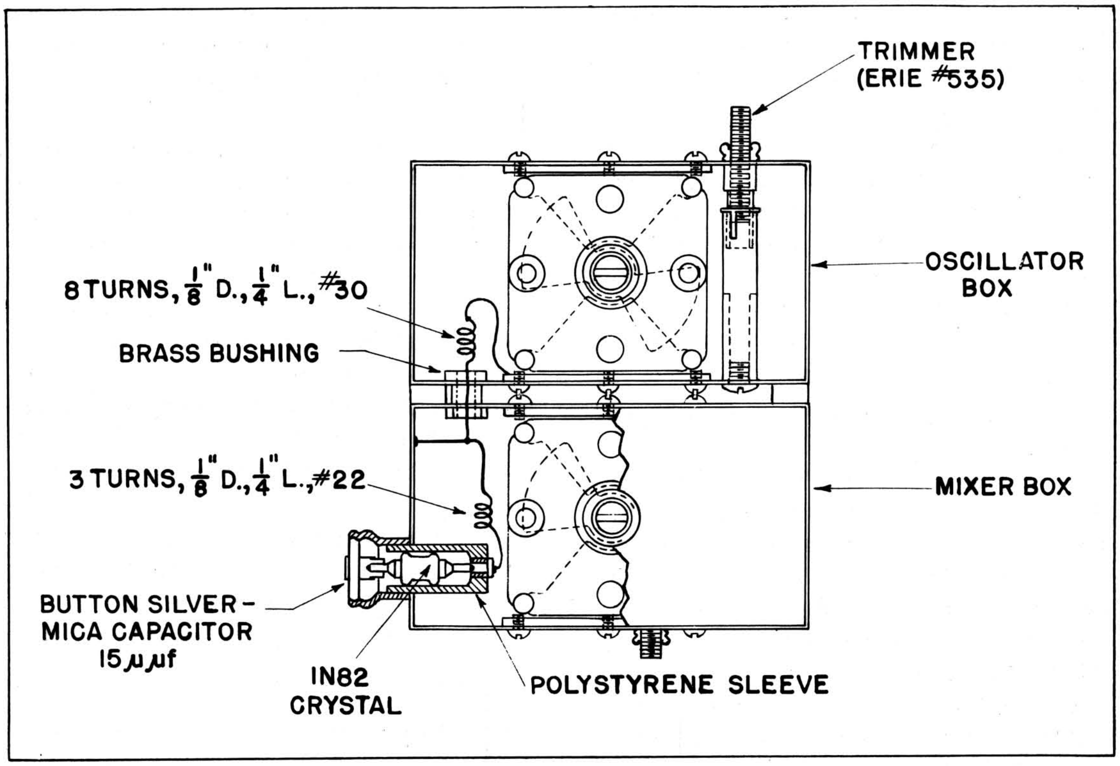


Fig. 12 - Details of oscillator injection and mixer coupling.

reactance, the amount of which is determined by aperture dimensions.

With this background information, the various coupling problems will be discussed in the order that they were encountered in developmental work. In a system of coupled tuned circuits, it is first necessary to consider output loading.

The crystal, a 1N82 u-h-f silicon diode, serves as the preselector load and as the non-linear device needed for frequency conversion. Its i-f impedance is on the order of 500 ohms. For experimental purposes a single-tuned circuit, with the oscillator mounted above it as shown in Fig. 12, was assembled specifically to study mixing and output loading.

Although the crystal input and output frequencies are different, there is a definite relationship between the load presented to the crystal at i.f.[1], and the load presented by the crystal to the preselector at r.f. The amount of interaction is a function of conversion loss. As an expedient, a very low Q i-f circuit having a tuned impedance of approximately 500 ohms was used as the i-f load. Then, over the r-f pass band, the i-f load remained substantially constant. This permitted proper adjustment of the crystal r-f coupling and associated oscillator injection circuits with minimum i-f reaction.

Crystal conversion loss, noise temperature, and internal impedances are a function of crystal current, but it was found that over a range of 0.5 to 3 ma the changes in operating characteristics were not large. The tuner noise figure, which is a general measure of system merit, changes less than 1 db as the crystal current is varied between the above limits. Below 0.5 ma the conversion efficiency decreases rapidly, and above 3 ma the crystal noise temperature becomes excessive.

Two requirements, then, are that the crystal current be relatively constant, and that the crystal present the proper load impedance to the preselector. Figs. 11 and 12 show the mixing and injection system configuration used in the single-tuned experimental model and also in the complete tuner.

As shown in Fig. 12, the oscillator injection loop is tapped into the output coupling

[1]E. W. Herold, "Frequency Mixing in Diodes", *Proc. IRE*, Oct. 1943.

loop at a low impedance point. Leakage reactance in series with the oscillator loop tends to reduce the crystal current change as the tuned frequency is increased.

For adjustment of the output coupling loop, the crystal i-f load was made 470 ohms and the r-f response was observed by placing a sensitive oscilloscope across a 47-ohm resistor in the crystal current return path. A sweep generator, lightly coupled into the experimental mixer box, provided the input signal.

Coupling to the crystal is a function of the loop area (Fig. 12) and distance from the center of the box. Three turns of leakage reactance are included in the loop to reduce loading with increasing tuned frequency. This is necessary because the operating Q of the tuned circuit varies inversely with frequency when coupled to a constant load. Unless the loading is variable, the bandwidths will change by approximately 3.5:1 as the circuit is tuned from 470 Mc to 890 Mc. It was decided to pursue the problem until the bandwidth remained within 1.5:1 over the u-h-f range.

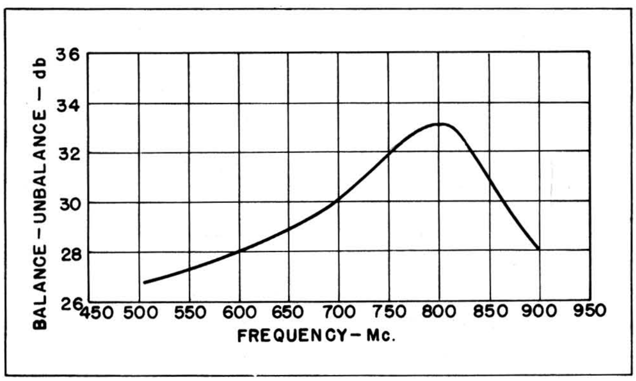


Fig. 13 - Balance to unbalance rejection ratio vs frequency.

Since only the output preselector box, loaded by the crystal, was used for experimental study of the crystal coupling problem, the loop size and number of turns of leakage inductance were adjusted to provide a single-tuned 3-db response varying from 6 Mc at the low end of the band to 9 Mc at the high end. When this tuned circuit was slightly overcoupled to the tuner input circuit, which had approximately the same operating Q (due to antenna loading) as the mixer tuned circuit at all frequencies, the bandwidth increased by a factor of about 1.4. To maintain the same r-f response shape, since the Q's change with tuned frequency, the mutual reactance between the two circuits must increase as the operating Q's decrease.

As shown in Fig. 11, the interbox coupling consists of a fixed aperture and a variable loop. The loop is rigidly mounted on the Rexolite shaft, and is rotated through 90 degrees as the capacitors are tuned through the u-h-f range. It is perpendicular to the magnetic field in each box when tuned to 470 Mc and parallel at 890 Mc. The coupling therefore increases with decreasing frequency. Combining variable loop and aperature coupling results in a fairly uniform response throughout the band.

The aperature size was adjusted to provide the required interbox coupling at the high end of the band and the loop was adjusted for the necessary additional coupling at the low end.

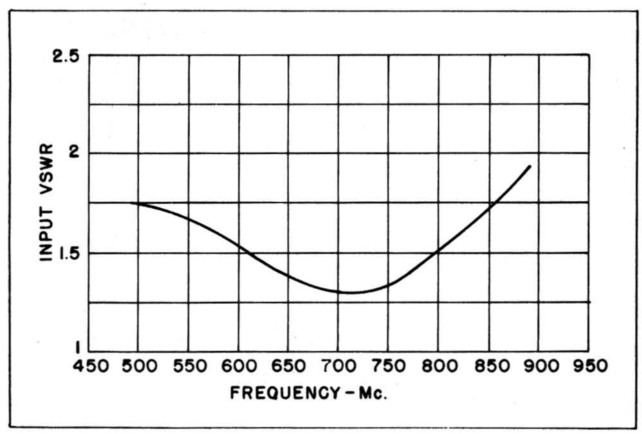


Fig. 14 - Input VSWR vs frequency.

The tuner provides a 300-ohm balanced input. Coupling is obtained by a floating loop of No. 18 wire with three turns of leakage reactance in the center. This provides loading by the antenna on the first box similar to that of the crystal on the second box. Adjustments of loop size and position were made using a panoramic SWR indicating device.[2] Figs. 13 and 14 show the curve of balance-to-unbalance ratio, and SWR vs frequency. Since the point-by-point SWR over the r-f passband will vary slightly, the tabulated values are the averaged SWR's between 3 db points at each tuned frequency.

[2] John A. Bauer, "Special Applications of UHF Wide Band Sweep Generators", *RCA Review*, Sept. 1947.

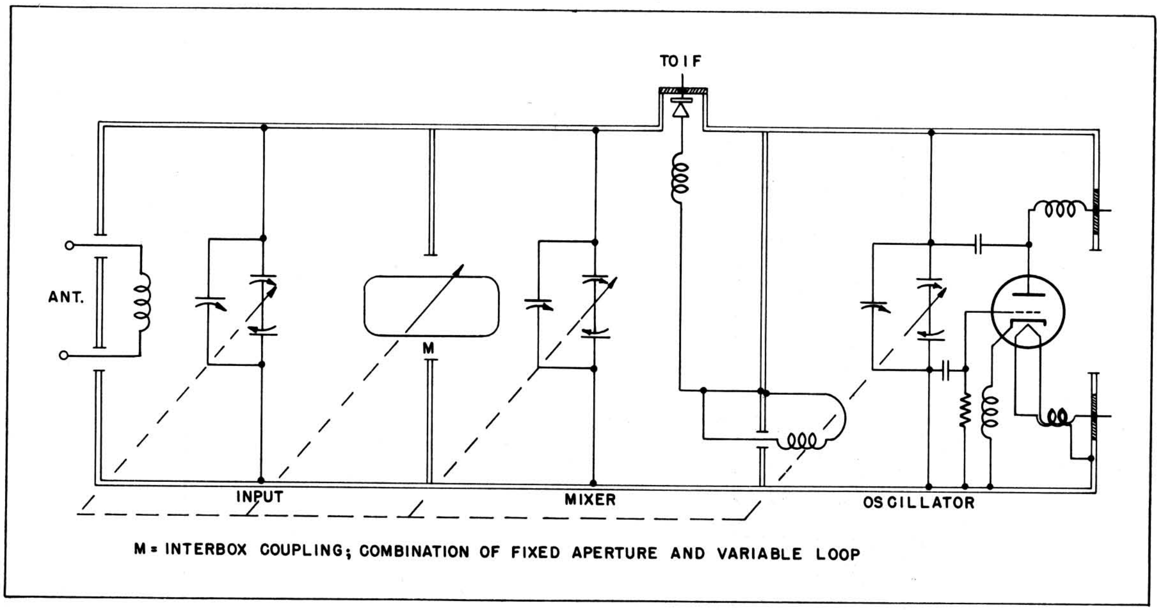


Fig. 15 - Schematic of the UHF tuner.

The i-f amplifier stage is a low-noise, driven-grounded-grid type,[3] making use of the 6BQ7. At 40 Mc the input impedance is on the order of 20K ohms. To match the 500-ohm crystal to the amplifier would require an impedance transformation of 40 to 1. However, to obtain minimum noise figure, an impedance match is not desirable. It can be shown[4] that a mismatch of approximately three to one is the best compromise between optimum signal power transfer (the matched case), and a minimum amplifier noise figure (a 10:1 mismatch).

As mentioned earlier, the interaction between the crystal input and output circuits make it desirable to have the i-f load resistive and constant. For test purposes, a resistively damped i-f circuit was placed across the output to provide a 3-db i-f bandwidth of 18 Mc. This was considered adequate for r-f adjustment because the r-f bandwidth never exceeded 18 Mc. If the loading is reduced so that the i-f response is narrower than the r-f response, the phase change of the voltage across the i-f circuit is reflected back into the r-f section as reactive rather than resistive loading. The effect is most pronounced when the i-f voltage is changing phase most rapidly, i.e., on each side of the i-f response. When the swept r-f response is observed across a 47-ohm resistor in the crystal-current return path, it appears distorted in comparison to the response that was recorded using a low-Q i-f bandwidth. It is this portion, showing i-f resistive loading, that is of importance. The remaining unused r-f response is merely to allow for tracking tolerance.

To meet the requirements for a coupling system between the crystal and i-f amplifier, a capacitance divider and double-tuned transformer are used. (Fig. 16). The transformer was adjusted so that the i-f response was slightly overcoupled and had about a 6.5-Mc bandwidth at the 3-db points. Additional resistive damping was not required.

For r-f alignment, the low-Q test conditions were restored by shunting the transformer primary with a 470-ohm resistor, and removing the amplifier tube from its socket to detune the secondary. Trimming was done by means of Erie No. 535, 0.7-to-3.0 μμf capacitors mounted in each of the three boxes. As shown in Fig. 12, the capacitor was press fitted into the fluted end of a brass tube. The threaded slugs protrude from the top of the oscillator box, and from the bottom of the two preselector boxes. In each case, the trimmers have the greatest effect when mounted closest to the tuning capacitors. As the distance from the

[3] LB-824, *Use of New Low-Noise Twin Triode in Television Tuners.*

[4] Van Voorhis, MICROWAVE RECEIVERS, Vol. 23, MIT Series, p. 87.

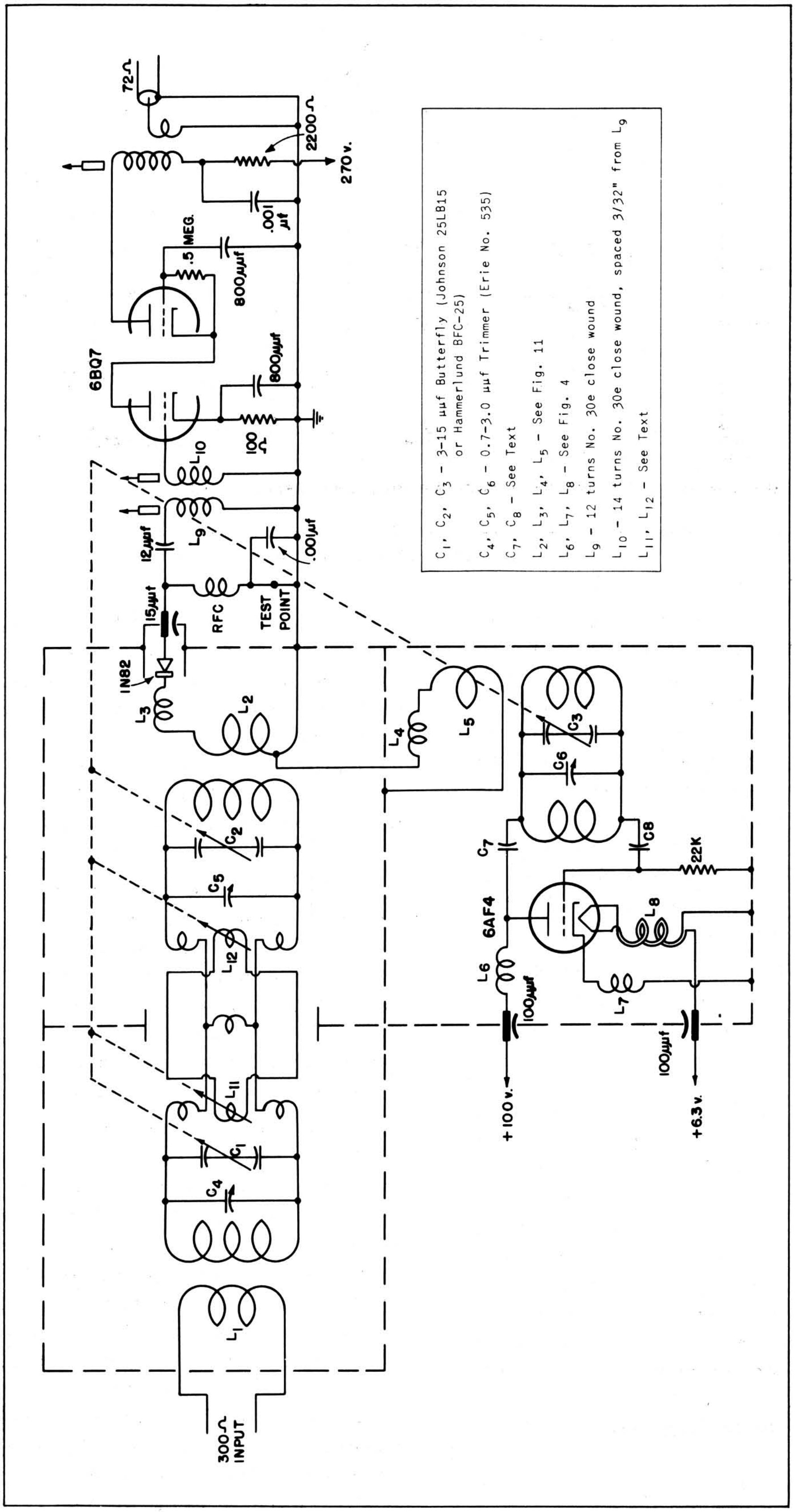
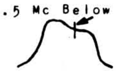
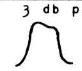


Fig. 16 - Equivalent circuit of the UHF tuner.

Table I

R-F and I-F Response, Crystal Current and Noise Figure vs Frequency With Tuner Aligned					
Freq. (Mc)	R-F Resp.*	BW 3 db pts.	IF resp. 3 db pts.	Xtl. Cur. ma	N_f-db
470	43.5 Mc Below Osc. 	8 Mc	 6 Mc	1.35	12.1
500		8.5	 6 Mc	1.6	12.0
550		11	 6 Mc	1.65	10.6
600		11.5	 7 Mc	1.75	10.7
650		12	 7 Mc	1.6	10.5
700		13	 7 Mc	1.25	11.3
750		13	 7 Mc	1.2	11.9
800		12	 7 Mc	1.0	12.6
850		13	 7 Mc	1.0	12.5
890		12	 7 Mc	0.9	13.0
*RF response observed with 470 ohms i-f load as described in text.					

center of the box is increased, a greater capacitance change is required to produce the same frequency variation. In addition to mounting the oscillator trimmer close to the tuning capacitor, it is also mounted at the farthest convenient distance from the tube socket. (Fig. 11).

To aid alignment at the low end or middle of the band, one rotor plate on each of the tuning capacitors was slotted. The resulting tabs were then bent as necessary.

After the tuner was aligned, measurements were made to determine its performance. Table I shows the r-f and i-f responses, crystal current, and noise figure at representative frequencies within the tuning range. The two-point noise-diode method[5] was employed for all noise figure measurements.

Since the tuner noise figure is largely dependent upon the crystal, it was found desirable to investigate this characteristic with a number of crystals. Noise figure measurements were made at 470 Mc, 700 Mc, and 890 Mc for a random sample group of 20 crystals. Average noise figures of 13.5 db, 11.5 db, and 13.8 db were obtained at these respective frequencies. The variation in noise figure between crystals was within ±1.5 db of the average at each of the test points.

Crystal current variation with frequency was also found to be dependent upon the crystal. Therefore, maximum and minimum crystal currents within the tuning range were measured for the 20 crystals. All currents were well within the limit of 0.5 ma to 3 ma with an average max/min ratio of 1.9 to 1.

[5]LB-866, *Noise Factor Considerations and Measurement Techniques at UHF.*

Spurious responses are given in Table II. Within the u-h-f television range the only responses less than 80 db below the desired signal were the image and one-half i.f.

Table II

Spurious Response Rejection Within UHF Range		
Freq	Image Rej db	½ IF Rej db
500	49.5 db	84.4 db
550	49.3	82
600	46.1	79
650	45.2	76
700	45.2	76
750	43	78
800	42.2	75
850	37	70.5
890	38.3	68

Oscillator radiation measurements indicated that the major source of leakage was the phospher bronze dial cord which was excited by energy coupled from the oscillator capacitor shaft.

Irwin D. Baumel (signature)

Irwin D. Baumel

E. M. Hinsdale Jr. (signature)

E. M. Hinsdale, Jr.