COST REDUCTION PROGRAM FOR

RADIO RECEIVERS, R-390/391( )/URR

Final Progress Report

Period Covered:

Object: The object of this contract is to study the Radio Receivers R-390/391( )/URR to make certain improvements and simplifications so as to reduce the cost of this equipment.

Signal Corps Contract No. DA36-039 sc-52584

Signal Corps Specification - MIL-R 10474 Dated 28 August 1950 and Amendment No. 3 Dated 15 January 1952

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PREPARED BY:

L. W. Couillard

APPROVED BY:

E W Pappenfus

Head, Department III

A PUBLICATION OF

THE RESEARCH AND DEVELOPMENT LABORATORIES

COLLINS RADIO COMPANY
Cedar Rapids, Iowa

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1.0 PURPOSE

This report covers all the work done on the Signal Corps Cost Reduction Contract DA36-039-sc-52584 which resulted in the redesign of the Radio Receivers R-390( )/URR and R-391( )/URR. Except for the automatic tuning facility of the R-391, the two receivers are similar. These receivers, particularly the R-390, are fulfilling many needs of the Armed Forces, and are being produced in quite large quantities. Since the unit cost of these receivers is high, this program of cost reduction should result in a considerable saving to the Government.

In addition to the primary purpose of reducing cost, every effort was made to improve the reliability, accessibility and performance of these receivers wherever it was possible to do so.

Two finished model R-390 and one R-391 receivers were built and delivered to the Signal Corps as called for in the contract. These are designated "A" models. One "B" model R-391 was also built and delivered to test all the new ideas and bring them together in one receiver.

The main task of the contract, then, was to reduce cost of the equipments and improve the reliability, accessibility and performance. The work done may be broken down into the following phases:

Phase A: Study of the Main Areas for Investigation.

Phase B: Cost Analysis of the R-390 and R-391 Receivers.

Phase C: Design and Experimentation.

Phase D: Construction of "B" Model Receiver.

Phase E: Construction of "A" Model Receiver.

Phase F: Delivery of Models.

Phase G: Preparation of Drawings and Final Cost Analysis.

2.0 ABSTRACT

This section contains a brief résumé of the report to follow, organized on a phase by phase arrangement. Emphasis is placed on the difficulties encountered and the progress made.

2.1 Phase A: Study of the Main Areas for Investigation

After a careful examination of the various units comprising the receiver, a list of promising items susceptible to either cost reduction or other improvement, was drawn up. This list was submitted to the Signal Corps and at a conference held September 10th, the problems to be investigated were drawn from this list and given an order of priority. Later as the work developed and possibilities for improvement became more apparent both SCEL engineers and Collins people made additional suggestions.

2.2 Phase B: Cost Analysis of the R-390 and R-391 Receivers

The contractor's Cost Accounting Department was furnished a tabulation of all the various purchased components and fabricated parts used in the R-390 and R-391 receivers. The standard cost on every item was determined, and lists were made up showing either fabrication or purchased costs of each component. These costs were added up for all the parts used in each of the individual units -- main frame, RF unit, IF unit, variable frequency oscillator, AF unit, crystal oscillator, crystal calibrator, power supply. This method of cost breakdown clearly showed which were the most expensive units of the receiver.

Some delays were encountered in obtaining cost information on parts used in units subcontracted to other companies. As a result, the cost analysis was submitted later than orginally planned.

After completion of the tabulated list, it was carefully examined to find those fabricated parts which had unduly high costs and these items were then further checked for possible less costly substitutes. In the field of components, capacitors in particular proved quite costly. In the case of fabricated parts, the main frame construction showed up to be very expensive.

After the design was completed on the cost reduction receivers a final cost analysis was made to show the savings effected by the new design.

2.3 Phase C: Design and Experimentation

As soon as possible, experimentation was begun on those items approved by the Signal Corps. This phase of the program took up a large part of the time devoted to this contract, but in return, it proved to offer a greater portion of cost savings than Phase B. In addition, most of the improvements in accessibility, reliability and performance are a direct result of work on this phase of the project As it turned out, the work authorized by the September 10, 1953 conference between SCEL representatives and Collins represented a large part of the investigation conducted on these receivers. Each of the projects authorized at that time were fully investigated and in the breakdown of this phase given below, the first 13 parts refer to the work done according to the letter of 7 October 1953 (reference SIGEL-CRB-3 Contract No. DA36-039-sc-52584, File No. 1322-PH-53-91, Project 805H). Following this, the additional work done to reduce cost and improve performance is listed.

2.3.1 Part 1 - B+ Filter

The purpose of this investigation was twofold. The primary purpose was the reduction of receiver temperature caused by location of the type 6082 tubes. The secondary purpose was that of reducing the cost of the B+ filter. The problem was attaked in two ways. One way was to substitute a single 6336 tube for the two 6082's. Since this tube took less space than the other two, it might have been possible to place it on the IF unit. Also, the higher mu of the 6336 made the elimination of one voltage reference tube possible. However this circuit still had about the same power dissipation as the two 6082 tubes. The second method of attack was to build an L-C type of filter and compare its performance with that of the electronically regulated supply. Power saving amounted to about 40 watts and in conjunction with electrolytic capacitors, the L-C filters afforded a considerable saving. Further testing showed that it was necessary to add a VR tube to get the required stability from the VFO and crystal oscillators.

2.3.2 Part 2 - Elimination of Certain Functions

As a result of the conference of September 10, 1953, it was decided to investigate the savings resulting from elimination of the squelch facility and remote control connector J-105. As a result of this investigation, the remote control connector was removed and the squelch facility was made optional.

2.3.3 Part 3 - IF Amplifier

Work had previously been started on mechanical filter designs on Contract DA36-039-sc-56636. This contract called for development of 455 kc filters, having bandwidths of 2 kc, 4 kc, 8 kc and 12 kc. Early in the cost reduction program, work was started to incorporate these filters into an IF strip. Tests on early models clearly showed the improvement in selectivity that the mechanical filters offered, but it was evident that further work was necessary to reduce spurious responses and feedthru around the filters. Blocking on strong off-tune signals also needed improvement. Later models showed substantial improvement in all these respects. Experiments were conducted to determine the performance of the mechanical filter IF for DF work. These tests showed that the mechanical filter IF was unsuitable for this application. As the receiver is tuned across the passband the apparent direction of the signal varies up to 10° or more.

2.3.4 Part 4 - Power Line Filter

Considerable time was spent investigating the efficiency of the line filter. The filter proved to be desirable in two respects - reducing receiver oscillator radiation into the power line and reduction of signal input to the receiver via the power line. Simpler filters were investigated leading to a design similar to that formerly in use but having fewer inductors. Tests revealed performances nearly as good at low frequencies and considerable improvement over the old filter at high frequencies. For use in the cost reduction receiver, the filter was repackaged, eliminating the 164-1 connector. The line cord now fastens to the filter by means of screw terminals protected by a cover. The power plug was changed at Signal Corps request to a U126/U type.

2.3.5 Part 5 - Tuning Control Stops

As a result of continuous difficulty with the tuning stops on production R-390 and R-391 receivers, this work was accelerated, resulting in a stop of improved design which was immediately incorporated into production receivers, and which will be used virtually unchanged in the cost reduction receivers.

2.3.6 Part 6 - Crystal Oscillator

The frequency scheme of the receiver was carefully studied to determine if some of the crystals could be removed. It was found that if crystals up to 17 mc could be used it would be possible to substitute one crystal for the five in the first crystal oscillator, and reduce the number of crystals in the second oscillator to 15. This represents a saving of 7 crystals, besides the elimination of two 32 position switches. With the new scheme one 4th order spurious is introduced, along with the possibility of 1st and 2nd crystal oscillators beating together. This new frequency scheme permitted a greatly simplified mechanical construction, since the fixed first crystal oscillator was removed to the RF chassis.

2.3.7 Part 7 - RF Coils

Experimentation was started on the 16-32 mc band RF coil to improve its tracking A considerable improvement resulted from changing the length to diameter ratio and using a smaller diameter coil. As soon as the design was complete steps were taken to put this coil in production receivers. Later work showed that similar results could be obtained using the larger coil diameter with a ferrite core to replace the powdered iron slug. All the RF coils have since been redesigned to use the same ferrite core. These new coils also have a higher Q than those in the current R-390. The variable IF coils have also been redesigned to use a common core. This core however differs from that used in RF coils, because a lower permeability higher Q core was needed. Coil frames have been redesigned for simpler assembly, and teflon terminals are used to maintain high circuit Q. Antenna links have also been redesigned to attain a more uniform antenna input impedance.

2.3.8 Part 8 - Autotune Motor

An AC Autotune motor would be a real convenience on the R-391 receiver as well as saving the cost of the separate 28 volt DC power supply (such as the PP-629) required to run the Autotunes of the current production R-391 receivers. A suitable motor was obtained and tested in a model. Operation appears satisfactory althought setup time has been increased to a maximum of 25 seconds.

2.3.9 Part 9 - AF Filters

An investigation was made into the savings resulting from elimination of the 3500 cps low pass AF filter. Upon presentation of the cost information to the Signal Corps, authorization was granted for its removal on the final models. A twin-T feedback amplifier circuit was tested as a possible substitute for the 800 cps filter, but its performance was inferior to the filter, being narrower on the nose and wider on the skirts. By redesign of the one general 800 CPS filter for use at high impedance, it was possible to eliminate one interstage audio transformer while still retaining the filter's superior band-pass characterisitcs.

2.3.10 Part 10 - DC Operation of Equipment

Dropping the requirement for 28 volt DC operation results in savings due to elimination of the requirement for the power receptacle J-104, and the 28 volt line fuse. It also permitted the use of a parallel tube filament line and 6 volt dial lamps.

2.3.11 Part 11 - Main Frame

The cost analysis made on the main frame showed that the laminated type of construction was quite expensive. A new frame was built up using solid plates, similar to the R-392. This frame with the units mounted in place was tested at Evans Signal Lab with the cooperation of SCEL engineers. It was found to be generally quite satisfactory but it was apparent that the junction of floor plate and side brackets needed strengthening. Since then reinforcing strips have been added and no further trouble is expected. The new frame appears very much stronger and more rigid than the old.

2.3.12 Part 12 - Hum Balance Control

Substitution of the L-C filter for the electronically regulated B+ supply eliminated the need for this control.

2.3.13 Part 13 - VFO End Point Adjustment

By redesigning the output transformer can of the VFO and changing the VFO chassis slightly, the VFO end point adjustment was made more accessible. In the R-390A, holes were provided in the gear plate so that this adjustment could be made without removing the VFO or RF units. In the R-391A, the KC Autotune head gets in the way making necessary the removal of the VFO for end point adjustment.

2.3.14 Part 14 - Gear Train

The gear train represents the most complicated mechanism in the receiver and much time was spent in an effort to simplify it. This was made possible to a large extent by the change in frequency scheme which eliminated the necessity for the movable high VIF table and the step cam, substituting in its place a continuously variable high VIF, driven at the same rate as the 8-16 mc slug rack. Placement of these coils behind the 8-16 mc rack, and the 3-2 VIF behind the 1-2 mc RF coils eliminated a considerable number of gears. In addition, by coupling both kc counter and kc drive to one gear on the kc shaft, several other gears were eliminated. Other rearrangements were made where possible to simplify and improve the performance of the gear train. Slug racks have individual slug holders to permit better slug centering in the coils.

2.3.15 Part 15 - RF Unit

Tests were made to determine how much the 2nd RF stage with its coils was contributing to the performance of the receiver. Its advantages were that it afforded additional AGC control ahead of the mixers, and better image rejection above 8 mc. But because of the considerable saving resulting from the removal of this stage with its associated coils, SCEL representatives agreed it was worthwhile. In an attempt to regain some of the lost AGC control, the mixers were put on the AGC line. Attempts were made to restore some of the lost image rejection by improving coil Q and tracking, and by using better switch materials. Better antenna trimmer action on the 16-32 mc band was accomplished by mounting the trimmer closer to the high band antenna coil. This reduces stray C allowing the trimmer to be coupled tighter to the coil.

Field tests by SCEL engineers on current R-390 receivers revealed that cross modulation is a problem in the presence of strong interferring signals. Extensive tests were made on all available miniature RF pentodes to find a tube which best combined the characteristics of low noise and low cross modulation. Late in the investigation tube types 6DC6 and 6BZ6 became available. These had the most desirable characteristics of any tube tested. Because the 6DC6 affords slightly better AGC control, it was the one selected for use as the RF amplifier. Cross modulation tests were also run on various mixers, and the 6C4 proved to be very good in this respect, actually improving slightly in performance as the bias was increased up to about 14 volts. On this basis, it was deemed safe to use AGC on the mixers. Late tests show that cross modulation is largely confined to the first IF tube at medium high levels (.05-.2 volts input) and the RF amplifier at levels above this. Investigation carried out by E. Read on the R-392 receiver showed a substantial improvement in cross modulation at signal levels exceeding the normal operating bias of the 1st RF tube when a short-time constant circuit was placed in the 1st RF grid. Subsequent experimentation on the "A" model R-391 showed a small improvement particularly at antenna levels exceeding 2 volts. The results are not nearly as spectacular as on the R-392, however.

2.3.16 Part 16 - Calibrator

A calibrator using a 200 kc crystal was built and tested. In comparison to the former model using a 1 mc crystal, reliability was improved and harmonic output increased. The divider control was found to be unnecessary and was eliminated. Some difficulty has been experienced in obtaining a suitable 85°C crystal but a solution appears in sight.

2.3.17 Part 17 - VFO Stability

During the time of this contract, much trouble started to develop in production VFO's due to slight jumps in oscillator frequency. This was finally tracked down as being a result of driving the oscillator too hard. Reduction of screen voltage on the oscillator tube gave a great improvement but also reduced the oscillator output voltage. In cooperation with the oscillator department a lower loss output transformer was designed to restore the voltage to its original value. This change was immediately incorporated into the production receivers. In order to make the end point adjustment more accessible, the mounting can was made smaller on the cost reduction receiver. A few minor circuit changes were also required to adapt the VFO to the new B+ supply.

2.3.18 Part 18 - Tube Types

In an effort to improve reliability all tube types were examined and where possible replaced by more rugged types. Thus the 6BJ6 tubes were replaced by type 5749/6BA6W. 12AU7 and 12AT7 tubes were replaced by the 5814A and 6AJ5's were replaced by type 5654/6AK5W. Because of the high cost of superior replacements, the 6C4 and 6AK6 tubes were retained.

2.3.19 Part 19 - Antenna Relay

The poor attenuation characteristics of the antenna relay at high frequencies led to a search for a better unit. At first, it was hoped that an AC relay coil could be used. These relays were used on the "B" model and the two "A" model R-390 receivers but were not too satisfactory. Later, a DC operated relay was developed and installed in the "A" model R-391. A special selenium rectifier supplies the required DC power.

2.3.20 Part 20 - Mechanical and Electrical Components and Construction

Besides the changes made in components for cost reduction purposes, a number of other changes were made on the basis of greater reliability or convenience rather than cost. Among these are included the smaller coax cable and fittings, substitution of a selenium rectifier for the copper oxide type, and the use of AC relays for the Autotune and break-in function. Changes in mechanical construction were also made, such as the closer attention paid to electrolytic corrosion, the new means for chassis mtg. and the radical power supply unit redesign.

Finally a number of components were removed from the receiver entirely, such as the tube pullers and tube pin straightener.

2.4 Phase D: Construction of "B" Model Receiver

A complete receiver was constructed according to the results of the experimentation of Phase C to check the overall performance of the new design and uncover the new problems which would result. Since it is the most complicated mechanically, it was decided to make the "B" model an R-391. This would make it possible to test the AC Autotune performance as well as all other electrical and mechanical characteristics. These tests revealed a need for improvement in some respects as detailed in paragraph 4.4. The basic design seemed sound, however, so work proceeded on the final design of the "A" models.

2.5 Phase E: Construction of "A" Model Receivers

Upon Signal Corps approval of the proposed changes, two "A" model R-390 and one "A" model R-391 receivers were built according to the terms of the contract. Actual external appearance of these receivers is very similar to present R-390 and R-391 receivers. Overall dimensions and location of most of the controls have been retained. Tests of the completed models show some changes in performance from production models. For instance, improvement has been made on selectivity and cross modulation performance, while image rejection has deteriorated above 8 mc.

2.6 Phase F: Delivery of Models

In accordance with the terms of the contract, 2 "B" model R-390 receivers (Item 5) and one "A" model R-390 receiver (part of Item 3) were shipped February 24th. The two "B" models were actually two of the receivers supplied by Signal Corps for use on this job, unmodified. On March 10th another "A" model R-390 (rest of Item 3) was shipped. In September the "A" model R-391 (Item 4) and the "B" model R-391 (Item 6) were delivered.

2.7 Phase G: Preparation of Drawings and Final Cost Analysis

Shortly after the "B" model was constructed, work was begun on preparing manufacturing drawings. As far as possible, the "A" model receivers were built from these drawings. However, construction of the "A" models showed up possible improvements and minor errors which were immediately incorporated in the drawings. The "A" model R-391, since it was the last receiver to be built, is very close to being constructed entirely off the drawings. These drawings have been completed and duplicate tracings will be shipped in November. A set of these drawings has also been delivered to the Cost Accounting Department for a final cost analysis. Final figures on the cost reduction receivers are shown in figures 40 and 41.

3.0 PUBLICATIONS AND CONFERENCES

3.1 Publications

This report stresses only the new features of the cost reduction receivers and largely disregards those circuits and mechanical features which were left unchanged from the original R-390 and R-391 receivers. For a complete background on the development and operation of these receivers the following publication should be consulted.

1. Engineering Proposal for R-219 Receiver - Collins Radio Company

2. Monthly Reports Contract DA36-039-sc-44552 - Collins Radio Company

3. Final Report Contract W36-039-sc-44552, Collins Radio Company

4. Instruction Book, R-390 - Collins Radio Company

5. Instruction Book, R-391 - Collins Radio Company

6. R-389 - R-390 Specification SCL-1134-B (Development)

7. R-389 - R-390 Specification MIL-R-10474 (Production)

8. R-390 Type Test Procedures - Collins Radio Company

9. R-390 Production Test Procedures - Collins Radio Company

Further information on the cost reduction contract is available in these publications:

10. Engineering Proposal for Cost Reduction Program R-390 and R-391 Receivers - Collins Radio Company

11. Monthly Reports Contract DA36-039-sc-52584 - Collins Radio Company

12. Quarterly Reports Contract DA36-039-sc-52584 - Collins Radio Company

13. Cost Reduction Specification SCL-1390-A

3.2 Conferences

Frequent conferences were held during this contract to insure close cooperation between Collins and SCEL engineers. Following is a brief summary of these conferences. More detailed information can be obtained from the quarterly reports.

3.2.1 Date: July 16, 1953
Place: Collins Radio Company
Subject: Broad approaches to the cost reduction contract.

3.2.2 Date: July 22, 1953
Place: Coles Signal Labs
Subject Discussed: Further approaches to the cost reduction contract and analysis of the available components costs.

3.2.3 Date: September 10, 1953
Place: Coles Signal Labs
Subject Discussed: Items for investigation under this contract.
Conclusions Reached: A priority list was established to indicate order of importance of the various problems.

3.2.4 Date: January 21, 1954
Place: Collins Radio Company
Subject Discussed: Review of progress; examination of cost analysis tabulation; plans for future work.
Conclusions Reached: Interchangeability of units between original receiver and cost reduction model not required.

3.2.5 Date: March 16, 1954
Place: Collins Radio Company
Subject Discussed: Plans for future investigation.
Conclusions Reached: It was apparent that substantial savings were possible only by a rather complete redesign of the receivers.

3.2.6 Date: May 27, 1954
Place: Collins Radio Company
Subject Discussed: Tools supplied with receivers; new components, Wasmandorf limiter, crystal oven, delivery dates.
Conclusions Reached: Tube pullers and straighteners to be eliminated. Wasmandorf limiter to be built and tested.

3.2.7 Date: July 17, 1954
Place: Coles Signal Labs
Subject Discussed: Design of "B" model receivers. Delivery date of "A" models.
Conclusions Reached: Final design is about stabilized.

3.2.8 Date: October 26, 1954
Place: Collins Radio Company
Subject Discussed: Final design of "A" models.

3.2.9 Date: December 12 and 13, 1954
Place: Coles Signal Labs
Subject Discussed: Mechanical design of "B" model receivers.
Conclusions Reached: Mechanical design is generally satisfactory except the junction of floor plate to side bracket needs strengthening.

4.0 FACTUAL DATA

This section presents a discussion of all the work accomplished during this contract. The work is organized into phases arranged in historical order. Each phase is the amount of work required to complete a progressive basic stage in the development of the entire cost reduction program.

4.1 Phase A: Study of the Main Areas for Investigation

The work accomplished in this initial phase of the project might most simply be termed "planning". In making a plan for a project of this sort, it must be decided which elements of the receivers are most amenable to cost reduction, and which characteristics are most susceptible to improvement. After making a careful analysis of the receiver, a list of possible projects was drawn up and submitted to the Signal Corps. At the conference held September 10, 1953, projects were selected from this list and given priority in this order:

4.1.1 Preliminary investigation into methods of reducing temperature rise of the receiver caused by present location of type 6082 tubes.

4.1.2 Cost analysis to estimate saving which could result by elimination of squelch facility and remote control connector J-105.

4.1.3 Preliminary work leading to redesign of IF amplifier to incorporate electromechanical filters.

4.1.4 Cost analysis to estimate saving which could result by elimination of power line filter and engineering study to determine effectiveness of this filter.

4.1.5 Complete investigation to obtain better protection to receiver tuning system when kilocycle and megacycle change knobs are forced against end stops. This project may include design of a clutch mechanism in the knobs.

4.1.6 Preliminary investigation leading to redesign of crystal oscillator sub-assembly for greater reliability, ease of maintenance and assembly. This project may include investigation into the cost of tooling for ceramic switches.

4.1.7 Complete study of improvement in the performance of RF coils to be secured by changing length to diameter ratio.

4.1.8 Preliminary investigation into the possibility of replacing the DC Autotune motor with an AC motor. This work should not proceed beyond the solicitation of bids on motor design at this time.

4.1.9 Complete investigation into savings which could result by elimination of the low-pass audio filter and redesign of the 800 cps band-pass filter for high impedance input to eliminate input transformer.

4.1.10 Complete investigation into the savings which would result by elimination of the requirements for DC operation of the equipment.

4.1.11 Complete investigation into the savings which could result by redesign of the main frame.

4.1.12 Complete investigation into the savings which could result by elimination of the hum balancing control.

4.1.13 Complete investigation into the extent of redesign required to provide access to VFO end point adjustment.

As work proceeded on the contract, and as the cost analysis became available, other areas for investigation were uncovered both by SCEL engineers and Collins. These may be classified as follows:

4.1.14 Investigation into simplification of the gear train.

4.1.15 Investigation into lower cost and improved performance of the RF unit.

4.1.16 Investigation of more reliable operation of the calibrator.

4.1.17 VFO stability.

4.1.18 Tube types.

4.1.19 Investigation to obtain an antenna relay having greater attenuation at high frequencies.

4.1.20 Investigation to obtain more suitable or reliable components.

4.2 Phase B: Cost Analysis of the R-390 and R-391 Receivers

An IBM tabulation of the various purchased components and fabricated parts was sent to the Cost Accounting Department. Vendors were contacted for electrical component costs and standard costs of fabricated parts were determined. A new IBM tabulation was drawn up showing the cost of every electrical component and fabricated part in the receiver. As the parts were assembled, labor costs and overhead were added. Costs were totaled for each of the units used in the receiver. The table below shows the percentage of total receiver cost for each unit of the R-390 as determined by the initial cost analysis.

Unit	Percentage of Total Cost
RF Unit	28.9
Main Frame and Final Assembly	21.2
Crystal Oscillator	15.3
IF Unit	14.4
AF Unit	9.0
VFO	4.8
Power Supply (PP-621)	3.0
Calibration Oscillator	2.5
Antenna Relay	.9
	100.0%

Figure 1 shows a more complete summary of the initial cost analysis by units showing actual cost of parts, raw materials, labor and overhead. Figure 2 gives the same information on the R-391 receiver.

Cost savings resulting from elimination of the squelch was determined to be about $14.00. The final decision to make the squelch an optional unit results in a saving of about $10.00 in component parts if the squelch is not installed.

A cost study was made on the removal of the remote control connector J-105. Results showed a saving of over $7.00 was possible if this plug were eliminated. Upon presentation of this data, to the Signal Corps, its removal was authorized on the models.

At this point, an estimate was made on the savings that could result on the current production R-390 without changing tooling. The estimate is based on substitution or deletion of components and parts, and resulted in a total cost reduction of about $70.00. Largely on the basis of this estimate, a final decision was made to go ahead with major changes where necessary to effect a greater cost reduction.

Allowing a change in tooling permitted a considerable number of circuit simplifications to be made, particularly in the RF and crystal oscillator. In many cases, different tooling also led to less costly means for making the fabricated parts. A cost analysis based on the design of June 1, 1954 showed the following estimated savings:

Unit	Savings
Audio Unit	$ 34.00
Antenna Relay	2.00
Power Supply	12.00
IF Unit	20.00
Crystal Calibrator	12.00
RF Unit	56.00
VFO	3.00
Crystal Oscillator	68.00
Final Assembly	26.00
Total	$233.00

Since that date, other changes have been made and the final detailed figures are considerably different. On the basis of the initial cost analysis, each electrical component was checked to find a cheaper replacement. Prices of the capacitors in particular seemed to be out of line. Where possible, ceramic capacitors were chosen to replace Vitamin Q types as bypasses, and Prokars to replace Vitamin Q's in low voltage, low impedance applications. Electrolytic capacitors were substituted for the paper dielectric types. Other electrical parts changed for cost reduction reasons are the rear terminal boards, made of plain black bakelite instead of the mica-filled type and the BFO on-off switch. A printed circuit terminal board has replaced the conventional type on the front panel. One dip soldering operation replaces 17 conventional soldered joints. The R-391 "A" model is the only one with this change. In addition, many other substitutions were made possible by changes in receiver circuitry.

These items will be discussed under Phase C. Mechanical redesign resulting in cost savings will also be discussed under Phase C.

With the completion of the manufacturing drawings, the final cost analysis was begun. Figures 40 and 41 show the final figures on the cost reduction receivers R-390 and R-391 respectively. These figures may be compared with Figures 1 and 2 to show the overall savings effected on each receiver by means of this cost reduction program.

4.3 Phase C: Design and Experimentation

With the completion of the planning phase, experimental work was begun. For the purpose of describing this work, the order of Phase A is followed more or less closely to show how the original plan was carried out.

4.3.1 Part 1 - B+ Filter

The main problem involving the B+ filter was the excessive amount of heat generated by the series regulator tubes. This is aggravated by the location of these tubes on the bottom deck where it is difficult to get good convection cooling. Two methods of approach were tried for this problem. One method sought to reduce the cubic volume required by the electronic regulator so that it could possibly be mounted on the IF chassis. A single high power regulator, the Chatham 6336 was tested for this purpose. The slightly higher mu of this tube permitted use of a single OA2 instead of the two 5651 VR tubes. Although there was a considerable saving in space, and some in cost, power dissipation was about the same as the old circuit.

The second method was to substitute an L-C filter plus a VR tube for the electronic regulator. This filter was designed for choke input which has the advantage that current flow in each rectifier is maintained over a complete half cycle. This eliminates the high peak current impulses found in capacitor input circuits, resulting in lower rectifier plate dissipation and improved tube life. Another advantage is that B+ voltage variation is less with change of load. This is important when the receiver is switched to various functions, particularly to "standby" where the B+ load is quite light. Too great a change in B+ voltage here would have an undesirable effect on oscillator stability.

In order to conserve space, this design requires the use of electrolytic capacitors. Because of low temperature requirements, the highest possible capacitance was used consistent with space and working voltage requirements. These capacitors are easily replaceable plug-in units. Main filter capacitors are 45 uf and AF decoupling capacitors are 30 uf each. Use of such size decoupling capacitors in the audio circuits along with a few wiring changes, virtually eliminates the remaining cross talk between line and local channels. The VR tube supplies current only to the screens of the VFO and crystal oscillator. Because of the wide line voltage tolerances, it was necessary to cut the regulated current as much as possible in order not to exceed the VR tube current rating and still maintain adequate starting voltage. Careful tests revealed that regulating the plate voltage of the oscillator had virtually no effect on oscillator stability. The BFO had been carefully designed for extremely low B+ voltage coefficients, and it was possible to operate it completely off the unregulated supply. With all these changes the receiver stability vs. line voltage has hardly changed over the voltage range 105-125. In contrast to the electronic regulator, the L-C filter permits receiver operation down to line voltages as low as 80 volts. This could prove to be a distinct advantage under some conditions. The power saving resulting from the L-C filter amounts to about 40 watts and the saving in cost is about $8.00. This saving in cost was the secondary objective of revising the B+ filter.

Figures 13 and 14 show the new filter inductors and electrolytic capacitors on the AF unit.

4.3.2 Part 2 - Elimination of Certain Functions

Because of the limited use of the remote control connector J-105, and the infrequent need for the squelch facility, consideration was given to the removal of these items. A cost study was made on the removal of the remote connector. Taking into account the savings in material and labor, the figure comes to nearly $8.00, a worthwhile saving considering the limited use made of this connector.

At the start of the contract it was considered desirable to drop the squelch requirement. An investigation was completed showing a cost saving of $14.00 by eliminating this function. Later on, the Signal Corps decided to make this an optional unit retaining the cable wiring and function switch and leaving out the parts in the AF unit. With this method a cost reduction of about $10.00 is still possible. An optional kit of parts can be made available for field installation of the squelch facility.

4.3.3 Part 3 - IF Unit

Redesign of the IF unit to employ electromechanical filters was the first project on which work started for this contract. Work had been completed on contract DA36-039-sc-56636 resulting in the development of 455 kc filters having bandwidths of 2 kc, 4 kc, 8 kc and 12 kc. These filters were incorporated into the first model IF units built at Burbank. These first units were strictly experimental, to show the superior selectivity characteristics of mechanical filters and to uncover the problems involved in adapting these filters to the R-390 receiver. The problems encountered in these first models were spurious responses, blocking on strong signals outside the IF passband, and feedthru around the filters. As the contract proceeded, further design work was done on these filters to improve their performance in these respects. At first it was thought that plug-in filters would be a great convenience, but tests showed that feedthru was aggravated by the close spacing between input and output pins. The IF strip built up using these plug-in filters was used in the "B" model receiver. Another IF strip was built up using single-ended filters but with solder lugs instead of plug-in pins. The better shielding improved the feedthru problem slightly but greater improvement was desirable. The next IF strip was built using double-ended filters and it proved to have about 20 db improvement in feedthru over the single-ended type. One "A" model R-390 and the "A" model R-391 were supplied with these filters. These later filters are also superior to earlier models in the matter of spurious responses. Seven disc filters are now employed for optimum shape factor. The improvement in shape factor over the tuned circuit IF is especially great at the narrower bandwidths.

Besides the improvement in filters, the circuitry was also carefully examined for possible improvements and simplifications. In order to improve the blocking characteristics, the first IF stage gain was greatly reduced by increasing its bias. This has two beneficial effects. First it reduces the strength of the signal at the input to the filter, and secondly the high bias improves the blocking and cross modulation characteristics of the first IF stage. Late in the program it became apparent that the Signal Corps required all tuning adjustments to be removed. This requires the use of very wideband transformers so that changes in tubes, temperature and humidity have no effect on circuit gain or tuning. New interstage coupling transformers were designed to give the required flat top over a wide frequency range. Tests were conducted to determine performance under conditions of capacitance change, temperature and humidity. Up to 2 uuf capacitance variation is permissible on either primary or secondary. This is sufficient to accommodate maximum and minimum limits on tube capacitance variation. Performance of the transformers under limits of temperature and humidity was very good. The R-391 "A" model IF strip incorporates all these latest improvements. Parts were rearranged on this chassis to afford greater accessibility underneath the unit. Brass shields were changed to aluminum, and the B+ decoupling network was also eliminated on this unit. It appears that an initial adjustment is necessary to align each transformer after the IF unit is built. After this initial adjustment, no further alignment should ever be necessary.

Figures 15 and 16 show the latest model IF unit as supplied with the R-391 receiver.

Other changes made in the IF unit include a more positive BW switch detent which at the same time is easier to operate, fewer switches and a toroid IF filter inductor in the diode load circuit. The magnetic field of the toroid is closely confined and causes less trouble with BFO voltage induction in the IF output circuit than the old pie-wound inductor it replaces. Shields in the IF are made of aluminum and a simpler method of mounting them is used. As a cost reduction item, the capacitor mounting clips were removed. The leads of all the capacitors are adequate to support them, even under conditions of shock and vibration. A carbon potentiometer is used in the carrier level meter adjustment circuit. It offers less erratic operation and smoother control than the wire wound control.

4.3.4 Part 4 - Power Line Filter

The AC line filter was tested for its effectiveness in preventing external signals from getting into the receiver through the power lines. At frequencies up to 15 mc the filter gave better than 50 db attenuation, falling off to 10 db attenuation at 30 mc. The filter also provides a considerable reduction to internal signals by not allowing them to be radiated out the power line. Attempts were made to get equivalent performance from a less expensive filter. The simplest type of filter, a Sprage Hypass feedthru capacitor, was placed in each side of the line and tested. Its performance was found to be considerably worse, particularly at low frequencies, although at frequencies above 25 mc it was slightly better than the old filter. A single L-C pi filter was then tried. It was similar to the old filter but had fewer inductive elements. The old filter was designed for a cutoff below 100 kc, but there was no real need for such low cutoff. Eliminating four of the inductors raised the cutoff frequency, but above .3 mc the new filter had just as good or superior attenuation characteristics as the old filter. This new filter was placed into the production receivers as soon as possible. After repackaging and elimination of the 164-1 connector, it now serves for the cost reduction receiver. The line cord now fastens to the filter by means of screw terminals protected by a cover. The power plug connector was changed to a U-120/U conforming to MIL-C-3767. Total saving on this line filter and power cord is about $17.00.

Figure 23 shows the new line filter.

4.3.5 Part 5 - KC and MC Band Stops

Early attempts to solve the problem of preventing damage to the gear train and VFO through failure of the kc and mc end stops resulted in various clutch designs for the kc and mc knobs. The theory was that for normal operation the clutch would be strong enough to provide solid mechanical coupling between the knob and shaft. Upon reaching the end stop, the extra torque would cause the clutch to slip and prevent damage to the gear train and VFO.

The simplest design consisted of a bronze clutch insert between the knob and shaft. Unfortunately it had a tendency after slipping several revolutions to gall up and grab the tuning shaft.

A later design used a more complex clutch assembly in the knob. This provided more reliable operation due the closer tolerances on the value of the slip torque. However, the greater cost of this clutch knob led to an investigation of simpler means to provide the required protection.

As a result of continuous difficulty with the end stops on the production R-390 receiver, this work was accelerated. A new ten-turn stop was developed having much greater strength than the old. Because of the urgency of the problem this new stop was immediately incorporated into the production receivers.

This same stop is used virtually unchanged in the "A" and "B" model receivers.

4.3.6 Part 6 - Crystal Oscillator

Simplification of the crystal oscillator depended largely on development of a new frequency scheme to reduce the number of crystals required to accomplish the desired frequency conversion. Substitution of a fixed first crystal oscillator would also eliminate two 32-position switches and four crystals. Investigation of possible frequency schemes showed that in order to avoid third order spurious responses a first oscillator would be required of no lower than 17 mc. This would allow one-fourth order spurious response, but the total number of spurious responses up to 8 mc and below 9th order would be reduced from 15 to 6 by the new frequency scheme. Use of crystals up to 17 mc in the second oscillator allows a further reduction in the number of crystals by three.

The first oscillator built up used CR-19/U crystals with no oven. Tests showed the stability over the required temperature range of -40 to +85°C was inadequate for Signal Corps requirements. All later models incorporated ovens to obtain the required stability.

Figures 18, 19 and 20 show the new crystal oscillator. In comparison to the oscillator in the production R-390 it has been greatly simplified. Since the first crystal oscillator is fixed in frequency it has been removed from this chassis and placed on the RF. This was found to be necessary also to prevent interaction between the two crystal oscillators. This interaction between oscillators takes the form of internal signals generated when both oscillators get into the first or second mixers and produce the VIF frequency. Removing the first crystal oscillator to the RF chassis greatly reduced the intensity of these internal signals. It has proven to be impossible to completely eliminate them, but they should all be lower than the 3.5 uv limit given for internal signals. The oven is easily removable with the crystal oscillator in place. Removal of the crystal oscillator itself requires dropping the front panel, but the RF unit need not be removed. However when taking the RF unit out it is most convenient to leave the crystal oscillators attached and remove both together. This is an advantage in that it allows the two to be tested together more conveniently.

The frequency scheme as finally adopted is shown in table I. The number of crystals in both oscillators has been reduced from 23 to 16.

Design of the oven proved to be a difficult problem. Since the crystal switch was removed from the oven, there was considerable heat loss through the crystal socket leads and at low temperatures the oven ran cold. Placing extra heater windings around the crystal mounting board counteracted this loss of heat and made much better temperature compensation possible over the range -40 to +65°C. A Fenwal thermostat is used in an effort to obtain more reliable operation. Several turns of wire wrapped around the thermostat reduces the temperature cycling to an average of about 1°C. This figure varies somewhat with the particular thermostat and ambient temperature, but is fairly representative at room temperature.

TABLE I

R-390A FREQUENCY SCHEME

Band	Freq. Range	Coil Range	1st. Mixer Crystal	High IF	Crystal	2nd. Mixer Inj. Freq.
0	.5-1	.5-1	17 mc.	17.5-18	10	20
1	1-2	1-2	17 mc.	18-19	10.5	21
2	2-3	2-4	17 mc.	19-20	11	22
3	3-4	2-4	17 mc.	20-21	11.5	23
4	4-5	4-8	17 mc.	21-22	12	24
5	5-6	4-8	17 mc.	22-23	12.5	25
6	6-7	4-8	17 mc.	23-24	13	26
7	7-8	4-8	17 mc	24-25	9	27
8	8-9	8-16			11	11
9	9-10	8-16			12	12
10	10-11	8-16			13	13
11	11-12	8-16			14	14
12	12-13	8-16			15	15
13	13-14	8-16			16	16
14	14-15	8-16			17	17
15	15-16	8-16			9	18
16	16-17	16-32			9.5	19
17	17-18	16-32			10	20
18	18-19	16-32			10.5	21
19	19-20	16-32			11	22
20	20-21	16-32			11.5	23
21	21-22	16-32			12	24
22	22-23	16-32			12.5	25
23	23-24	16-32			13	26
24	24-25	16-32			9	27
25	25-26	16-32			14	28
26	26-27	16-32			14.5	29
27	27-28	16-32			15	30
28	28-29	16-32			15.5	31
29	29-30	16-32			16	32
30	30-31	16-32			11	33
31	31-32	16-32			17	34

4.3.7 Part 7 - RF Coils

Since the 16-32 mc coils were causing considerable tracking difficulty in production, work was first begun on this band. The method of approach was to increase the length to diameter ratio of the coil by using a smaller core diameter. Reduction of the diameter from .25 to .20 inches accomplished the desired result. As soon as the design was completed, steps were taken to put this coil in production receivers. Later on as ferrite cores of improved characteristics became available, it was found that the same good tracking could be obtained with the larger diameter coil using the higher permeability ferrite core. Finally, all RF coils were designed to use this same type of ferrite core. In addition to their higher permeability, these cores also have a higher Q, helping to overcome the loss of image response resulting from the elimination of one RF stage. The VIF coils have also been redesigned for use of a common core. This core differs from that used in RF coils however because this application called for a lower permeability, higher Q core. Coil frames have been designed for simpler assembly, and teflon terminals are used to maintain higher circuit Q. The antenna links have been redesigned to attain a more uniform input impedance. The introduction of ferrite cores in the antenna coils raised the primary input impedance. This had a beneficial effect on noise figure but reduced the selecitivity. In order to return to an impedance near the nominal figure of 125 ohms, it was necessary in most cases to reduce the number of primary turns. This improved the image rejection and cross modulation characteristics of the receiver at a slight sacrifice in noise figure. Figures 9 and 10 show the new RF and antenna coils respectively.

4.3.8 Part 8 - Autotune Motor

One of the most important factors in cost reducing the R-391 receiver is the AC Autotune motor. Although the AC motor itself is more expensive, elimination of the PP-629, 28 VDC power supply required for the 28 volt motor, results in a great overall savings. Besides the saving in cost, elimination of the PP-629 results in far greater convenience and versatility for the receiver, to say nothing of the saving in weight and space.

A suitable motor was obtained and tested in the "B" model. Operation was satisfactory and more quiet than the current R-391 Autotunes. This is largely due to the lower speed at which the new Autotune motor runs. Being governor-controlled, this motor does not exceed 5000 RPM. As a result the set up time is increased to a maximum of 25 seconds which is 5 seconds longer than that of the current R-391 receiver. However this lower speed should result in longer life to the gear train.

Figure 32 shows the new Autotune motor mounted in place on the RF unit.

A front panel "Detent Release" control was added to this receiver. This control engages the mc detent in the "manual" position and opens the Autotune circuit so that it cannot operate. In the "Autotune" position, this control disengages the mc detent and closes the Autotune circuit for automatic tuning.

4.3.9 Part 9 - AF Filters

The need for a low pass AF filter with a cutoff of 3500 cps in this receiver was always rather questionable. It does provide the minimum bandwidth for maximum intelligibility of speech, but it was somewhat doubtful if it was worth the extra cost. Now that the IF employs mechanical filters with their flatter tops and steeper skirts, the AF filter becomes even less necessary. If, for instance, the IF bandwidth is set to 8 kc for speech reception and there is strong interference from a signal 4 kc away, it only requires a slight retuning to push the interfering signal off the edge of the passband while still maintaining the intelligibility of the desired signal. In extreme cases where interfering signals are found on both sides of the desired signal, the bandwidth may be set to 4 kc and the signal tuned for maximum intelligibility and rejection to interference. In many cases, this may result in tuning to one of the signal's sidebands for best reception. Under this condition the 4 kc filter provides a sufficient bandwidth for optimum speech intelligibility. It appears then that under most conditions of interference, careful tuning and judicious use of the bandwidth control eliminates the need for the 3500 cps filter. An investigation was made of the cost saving resulting from elimination of the 3500 cps low pass AF filter. Upon presentation of the cost information to the Signal Corps, authorization was granted for its removal on the final models.

A twin-T feedback amplifier circuit was tested as a possible substitute for the 800 cps filter. The shape of the response curve using such a circuit is very similar to that of a single tuned circuit. It is narrower at the nose and wider on the skirts than that obtainable with a band-pass filter. The band-pass filter was redesigned for use in the plate circuit of the first AF amplifier so that the interstage transformer could be eliminated. The high impedance filter has slightly greater bandwidth so that the beat note can be varied a little more and still remain within the passband.

Figure 34 shows a comparison of audio selectivities among the various bandwidths and the sharp AF filter.

4.3.10 <u>Part 10 - DC Operation of Equipment</u>

Since the development of the R-392 receiver, designed exclusively for operation from 28 volt DC, the need for providing 28 volt DC operation of the R-390 and R-391 receivers is almost eliminated. Dropping the 28 volt DC operational requirement results in savings due to elimination of the power receptacles J-104 and the 28 volt line fuse. In addition, it also permitted the use of parallel tube filament operation and 6 volt dial lamps. Parallel tube filament operation should do much to eliminate the trouble encountered in the current R-390 where difference in tube filaments cause some tubes to run higher than normal filament voltages and others lower. This has a bad effect on tube life and causes the receiver gain to fall off with time. The 6 volt dial lamps are more rugged than the 28 volt types and should cause less of a replacement problem.

4.3.11 <u>Part 11 - Main Frame</u>

Investigation into the cost of the main frame showed that the laminated type of construction used proved to be quite expensive due to the difficulty of holding the necessary tolerances. In addition, the frame was quite flexible, allowing movement of parts under shock. As a result the frame was redesigned to utilize plate type construction, similar to that used on the R-392. The floor plate is a solid 3/16 inch plate screwed to side brackets of 1/8 inch material and to the rear panel which has been increased in thickness to .081 inch. In addition the floor plate extends to the front panel along the front of the IF unit. The rib separating the AF unit from the VFO also screws down to the front panel. As a result of these changes the main frame is much sturdier and lower in cost too. Figures 29 and 30 show the main frame construction of the R-391 "A" model.

The "B" model R-391 was taken to Evans Signal Lab for vibration and hammer blow tests. The hammer blow test revealed a potential source of weakness at the junction of the floor plate and side bracket aside the RF unit. This was corrected by spot welding aluminum strips to the side brackets such that they help support the floor plate and remove some of the load from the screws.

By extending the side brackets by about half an inch it was possible to eliminate the rear bumpers. In order to simplify removal of the front panel, the handles mount only to the panel. It is no longer necessary to remove the handles to drop the panel. In order to reduce cost, etching of the front panel was dropped in favor of silk screening.

4.3.12 Part 12 - Hum Balance Control

Substitution of the L-C filter for the electronically regulated B+ supply eliminated the need for this control.

4.3.13 Part 13 - VFO End Point Adjustment

Location of the VFO output transformer and filter on the VFO of the current R-390 receiver made the end point adjustment somewhat awkward to reach. By reducing the size of the output filter can and moving it over slightly this adjustment becomes more accessible. Due to the redesigned gear plate of the R-390, it was necessary to provide an access hole for this purpose.

In the R-391 receiver, the location of the Autotune heads made this end point adjustment inaccessible when the VFO is mounted on the receiver. However, the VFO can easily be removed to make this adjustment.

4.3.14 Part 14 - Gear Train

One of the most logical places to look for cost reducing features is in the R-390 gear train. This unit is the most costly mechanical unit of the receiver, and any simplification would result in a considerable overall saving. This was made possible to a large extent by the simplification of the frequency scheme. Substitution of a single first crystal oscillator frequency for the old scheme which used five different crystals, eliminated the need for the step cam and movable high VIF coil table. In its place is a continuously variable high VIF driven from the 8-16 mc RF shaft. Placement of these coils behind the 8-16 rack and the 3-2 mc VIF coils behind the 1-2 mc RF coils eliminated a considerable number of gears. Repositioning the crystal oscillator aside of the RF unit instead of behind it also eliminated the drive shaft running under the RF chassis, and the worm and worm gear of the crystal oscillator. In addition by coupling both the kc counter and kc drive to one gear on the kc shaft, several other gears were eliminated. On the R-390 "A" model it was possible to extend the gear plates and mount the kc and mc shafts to them. This eliminated the casting from the R-390 on which these shafts were formerly mounted. An advantage of the new method is that there is no chance of losing synchronization between the kc and mc shafts and the gear train. This advantage also extends to the R-391 "A" model, but on this unit there is an Autotune casting which is an integral (though removable) part of the RF uni In building two R-390 "A" models, considerable misalignment was found between coils and slugs. As a result, the R-391 "A" model slug racks were modified to incorporate individual slug holders to permit better slug centering in the coils.

Figure 31 shows the RF and gear train of the R-391 receiver. Other views of the gears and slug racks appear in figures 5 and 26.

4.3.15 <u>Part 15 - RF Unit</u>

Incorporation of the new frequency scheme resulted in a considerable simplification of the gear train and crystal oscillator unit. Since it had little effect on the RF circuitry, however, other means were investigated to reduce the cost of the RF. Looking at the circuit with this point in mind, the second RF stage was questioned. Its advantages are that it affords additional AGC control ahead of the mixers, and with its extra coil it affords better image rejection above 8 mc. On the other hand, removal of this stage represents a saving of a tube, socket and associated parts, a switch and six coils. An estimate on the cost saving came to about $25.00. On the strength of this figure, the decision was made to eliminate the second RF stage. Attempts were made to restore some of the lost image rejection by improving coil Q and tracking and using better switch material. By this means it is still possible to maintain 80 db image rejection up to 16 mc, gradually tapering off to not less than 50 db at 32 mc. By placing the antenna trimmer close to the high band antenna coil it was possible to use the same coil for both the antenna and RF coil assemblies. Reduction of stray C also permits better antenna trimmer action on the 16-32 mc band.

In many applications it is necessary to operate the R-390 receiver in the vicinity of strong transmitters. Under this condition cross modulation becomes an important factor in receiver operation. Field tests by SCEL engineers indicated that the R-390 left something to be desired in this respect. Now that the 2nd RF tube was eliminated, extensive tests were conducted to determine the most suitable tube for the remaining RF amplifier. The four most important considerations were low noise, adequate gain, low cross modulation and good AGC control. Nearly all available miniature pentodes were tested under a variety of screen and grid voltages. Among those tested were the 6AG5, 6AJ5, 6AK5, 6BA6, 6BC5, 6BJ6, 6CB6, 5590, and 9003. Several cascode tubes, the 6386 and 6BZ7, were also tested. Late in the program two new RF pentodes the 6BZ6 and 6DC6 became available. More than any other tubes tested, these two had the most desirable combination of characteristics. In low noise and high gain they compared favorably with the 6CB6, while in low cross modulation and good AGC control they compared well with the 6BA6. Because the 6DC6 affords slightly stiffer AGC control it was finally selected for use as the RF amplifier. Further cross modulation tests were also run on various tubes as mixers. The 6C4 presently used showed itself to be best in this respect. As the grid bias was varied, cross modulation actually improved slightly up to -14 volts with these tubes. For this reason, as well as to try to regain some of the AGC control lost by elimination of the 2nd RF stage, it was decided to put AGC on the mixers. Late tests show that the cross modulation existing after all these changes were made is due largely to the first IF tube at levels of interference up to .2 volt and to the RF tube at signal levels above this. Incidentally, removal of the second RF stage also improved the cross modulation to some extent. Investigation carried out by E. Read on the R-392 receiver showed a substantial improvement in cross modulation at interference levels exceeding the operating bias of the first RF tube when a short time constant circuit was placed in the first RF grid. The improvement is apparently due to counter modulation by the rectified AF voltage on the first RF tube grid. A similar test was conducted on the R-391 "A" model, but the results were not nearly so spectacular. At levels of interference on the order of 5-10 volts, there is an improvement of about 4 db. This is considered good enough to justify its use, however.

4.3.16 Part 16 - Calibrator

The calibrator of the current R-390 uses a 100 kc multivibrator locked to a 1 mc crystal. Despite every effort to improve it, this circuit remained unstable over long periods of time. Substitution of a 200 kc crystal for the 1 mc unit stabilized the circuit completely, and eliminated the need for a separate locking adjustment. In order to economize, it was desirable to mount both the calibrator crystal and the 17 mc first oscillator crystal in the same oven. A 200 kc, 85°C crystal was developed for this purpose so a CR-36/U, 17 mc crystal could be used with it in an 85°C oven. The new oven is designed for closer temperature control, both in regards to cycling and operation over ambient temperature variations from -40 to +75°C.

The rearrangement of parts on the RF unit left considerable extra room. Using some of this space for the crystal calibrator eliminated one extra unit. It also made possible bringing the calibrator adjustment out the rear panel where it is easily accessible. The new calibrator has greater harmonic output and no "holes" have been found at any frequency. The calibrator section of the RF is at the extreme upper left of the receiver shown in figure 26.

4.3.17 Part 17 - VFO Stability

Late in the cost reduction program, much trouble began to occur in the production oscillators due to frequency jumps-slight changes in frequency which appeared to occur instantaneously for no apparent reason. After much research the oscillator department greatly improved the situation by operating the tube at a lower level of screen voltage. Since this meant that the output voltage was reduced, it was necessary to redesign the output filter for greater efficiency. This design was begun in the oscillator department, and later completed by this department in cooperation with them. Although the same circuitry is used in the output filter of the cost reduction receiver, the parts were mounted in a smaller can to make the end point adjustment more accessible.

Other minor changes in circuitry were made to adopt the oscillator for regulated screen and unregulated plate supply, and to get the maximum stability under such conditions. The chassis was also enlarged slightly to alleviate crowding of parts and to make the unit easier to work on.

At one point in the program, it seemed a good idea to combine the VFO and 3rd mixer in one tube as is done in the R-392 receiver. A model was built and tested in the receiver. Performance was satisfactory but the scheme was abandoned because of the requirement for master-slave operation. No simple way could be found either to lock the oscillators or to operate two mixers from one oscillator with this arrangement.

4.3.18 Part 18 - Tube Types

One of the main sources of trouble on the current R-390 receiver has been tu failures. One cause for failure is the use of nonreliable tube types. The 6BJ6 tubes used as the second RF amplifier and for many of the IF stages, proved to have a poor record for reliability. The 12AU7 tubes used in the crystal calibrator also caused trouble. In the cost reduction receiver these two tubes were replaced by JAN 5749 and 5814A tubes respectively. In addition, type 5654 tubes were used to replace the 6AJ5 as crystal oscillators. Replacement rate on the 6C4 and 6AK6 tubes is much lower and due to the high cost of superior replacements, the 6C4 and 6AK6 tubes were retained. Choice of the 6DC6 as RF amplifiers has already been mentioned. The only other new tube type is the OA2 voltage regulator tube used to provide regulated B+ voltage of 150 volts for the screens of the VFO and crystal oscillators.

4.3.19 Part 19 - Antenna Relay

The antenna relay of the current R-390 receiver has rather poor attenuation at high frequencies. A search was conducted to find a manufacturer specializing in construction of low power antenna relays. The problem was presented to them and samples were received and tested. With these new relays, no difficulty was encountered in obtaining up to 40 db attenuation at the highest frequencies. The original model had an AC operated coil, and these were supplied with the R-390 "A" models. However, the adjustment on these relays was very critical, and any misadjustment caused severe chatter and hum modulation of the signal. Later models are DC operated, and the operation has been changed slightly. In the AC relay, the relay was normally energized when the receiver was turned to MGC or AGC. Turning the receiver to off, standby or calibrate de-energized the relay and grounded the antenna. The DC relay is energized only in the standby and calibrate positions. In this case energizing the relay grounds the antenna. A relay of this type has been installed in the R-391 "A" model. A special selenium rectifier supplies the necessary DC power.

4.3.20 Part 20 - Mechanical and Electrical Components and Construction

All components of the R-390 receiver were examined for cost and suitability for the intended application. Those items substituted for cost reasons include the disc ceramic, electrolytic and Prokar capacitors, bakelite rear terminal boards, BFO switch, break-in switch, printed terminal board, cheaper Bristo wrench, and stamped out terminal board jumpers.

Other changes were made to improve performance or because they were needed with the new circuitry. Substitution of the L-C filter and VR tube for the electronically regulated B+ supply made necessary a change in the function switch to accomplish proper switching of the new B+ circuitry. Changing to a high impedance 800 cps filter and elimination of the 3500 cps filter required a change of the audio response switch. Due to redesign of the crystal oscillator, a shorter oscillator coil was required. Changing to a 110 volt AC Autotune motor presented a switching and fusing problem for the Autotune on 220 volt AC. For this reason it was necessary to substitute a terminal board for the 110 volt-220 volt switch. Connections to this board are changed according to whether 110 volt or 220 volt operation is desired. Originally it had been planned to use AC relays for all functions to eliminate the need for the copper oxide rectifier. After much difficulty with the AC operated antenna relay, it was changed to DC operation. A selenium rectifier was selected to supply the required DC power. Because it is easier to handle and cable, miniature coax cable is used in place of that used in the current R-390 and R-391 receivers. This type of cable requires the use of miniature connectors. A bayonet lock type connector, the IPC type MB was chosen because of its sturdy construction and easy operation. The new mechanical design of the receiver requires the use of a long screwdriver to remove some of the units. A long handled Phillips screwdriver was substituted for the short right angle type furnished with the current R-390.

Other changes were made in the mechanical construction of the receiver. Careful attention was paid to the matter of electrolytic corrosion due to dissimilar metals in contact. The plated brass shields were removed from the aluminum RF, IF and crystal oscillator chassis and aluminum shields were substituted in their place. The brass frames of the RF coils were carefully cadmium plated and chromate dipped. Since cadmium is next to aluminum in the electrolytic series, no trouble should be encountered due to corrosion between the frame and the aluminum can. The method of mounting the subunits in the receiver was changed both to reduce the cost and make the mounting more efficient. Each chassis has a lip bent out on the ends on which captive bushings were mounted. This can easily be seen in the photos of the IF and AF units. All captive bushings are identical, in contrast to the old R-390 which used different bushings for each unit. Mounting is by means of an ordinary 5/8" 8-32 machine screw held captive by a spring clip. If the screw thread becomes damaged the screw can be pulled out of the bushing, releasing the spring clip. A new screw may then be dropped in the bushing and the spring clip pushed on from underneath effectively captivating it.

Consideration was given to the awkward method of mounting the power supply in the R-390 receiver. It is mounted by screws in three different planes, creating a difficult alignment problem, and necessitating the use of floating bushings in one plane. Since all the weight of the power supply is concentrated in the transformer, it logically should be fastened to the floor plate, and the chassis fastened to the transformer. This was done in the new design as illustrated in figures 11 and 12. On the AF chassis, removal of the series regulator tubes eliminated the need for the step chassis, stainless steel heat shield and special clamps.

Finally, a number of components were removed from the receiver. The need for tube pullers and tube pin straighteners was questionable. Most radio repairmen will have these tools on hand anyway. Besides, all tubes can be removed by hand when cold and tube pins can be straightened with a pair of pliers, if necessary. For these reasons the tube pullers and tube pin straighteners were removed.

4.4 <u>Phase "D" Construction of "B" Model</u>

4.4.1 A "B" model receiver was built up to test the proposed changes in circuitry, components and mechanical construction. Since the R-391 is the most complex mechanically, the decision was made to make the "B" model an R-391 and test the Autotune operation right away. Electrical tests made on this receiver gave an idea of the performance to be expected on future receivers. In a number of respects, indications were that future models needed to be improved. These are the characteristics which showed need for improvement.

a. <u>Mistracking</u> - The worst point was at 8.0 mc where mistracking was 4.6 db. A mistracking limit of 4 db maximum is the goal for the set of RF coils.

b. Antenna Impedance - Antenna impedance was generally too high particularly on the high band. Design goal is impedance of less than 500 ohms on this band, and 375 ohms maximum on other bands. A certain amount of overcoupling is desirable for increased sensitivity, but this has the undesirable effect of degrading the selectivity. Because cross modulation characteristics are becoming more important, it is felt that the improvement in selectivity afforded by lower antenna input impedance is worth the sacrifice in sensitivity.

c. Overall Selectivity - Feedthru around the filters was apparent at levels 60-80 db down from the passband. A 20 db improvement is desirable here.

d. Peak-to-Valley Ratio - The 8 kc filter had a peak-to-valley ratio of 4.4 db. This is to be reduced to 3 db if possible.

e. Image Rejection - Image rejection was deteriorated above 8 mc as a result of removing one RF stage and coil. However, improved coil Q and looser antenna coupling will partially compensate for the loss.

f. Internal Signals - There were a considerable number of internal signals evident. Several of these were over the 3.5 uv limit. Further work was necessary to reduce the number and magnitude of these internal signals.

g. Radiation - At several frequencies, the radiation exceeded 400 uu watts. Further work is required to reduce this within limits.

h. Frequency Variation with Temperature - Oven design was unsatisfactory in this model. Further work aimed at keeping the oven temperature more constant with varying ambient temperature.

j. Main Frame Construction - The hammer blow test revealed a structural weakness at the junction of thefloor plate with the side bracket of the main frame. This was reinforced in later models to remove much of the strain from the mounting screws.

4.5 Phase "E" Construction of "A" Models

Upon completion of the "B" model, construction was begun on an "A" model R-390 receiver. The IF chassis was lengthened and rearranged to make it more accessible. The RF unit was rearranged to make better use of the space obtained by elimination of the second RF stage. Removal of the first crystal oscillator from the crystal oscillator chassis permitted a redesign of this unit, resulting in a slightly shorter chassis. The audio unit was lengthened somewhat and rearranged to accommodate the optional squelch function. Upon completion of the first receiver, the second "A" model R-390 was built and tested. Further work was done on these receivers to improve the electrical performance in those respects where deficiencies were noted on the "B" model.

Several additional changes were made on the R-391 "A" model. A DC antenna relay is used on this model with a selenium rectifier supplying the required DC power. Individual slug adjustments were made up for all the RF and VIF coils. This permits the slugs to be centered in the individual coil so that mechanical misalignment can be corrected. The RF dust cover was redesigned to cover the VIF coils as well as the RF coils. The 455 kc IF was rearranged to make it easier to wire and maintain. The circuitry was also modified to eliminate tuning adjustments on the IF coupling transformers, and to improve the performance with respect to blocking and cross modulation. Further work was done to improve the performance of the crystal oscillator oven, particularly to cut down the temperature cycling as the thermostat opens and closes. Although the radiation had been cut down on the R-390 "A" models, it was necessary to do further work on the R-391. It was found that due to the extrafloor plate cutout on the R-391 for the Autotune motors, part of the bottom of the crystal oscillator was exposed. The plate switch of this oscillator with its wiring was out in the open. Since the RF unit sits right beside it, the high voltage in the crystal oscillator plate circuit induced a voltage into the antenna coil circuit of the RF unit. Placing a bottom cover over the exposed part of the crystal oscillator solved the problem. Besides the tests run on the R-390, an extended test was run on the Autotunes to determine their resettability and useful life. A total of 20,000 operations was run.

During the first part of the test a small amount of metal flakes was found underneath the KC shaft. At the end of 6000 cycles the receiver was examined and it was found that those flakes were coming from the grounding strap on the VFO shaft. Further examination of the receiver disclosed aluminum powder underneath the grounding spring of the crystal oscillator also. Lubrication of both these points stopped the excessive wear. Soon after this, the switch contact for channel 4 of the Autotune control head broke off. It evidently was a defective contact because after it was replaced no further trouble was encountered. At 10,000 cycles the test was interrupted for lubrication maintenance and a check on wear. At that time, the only noticeable wear was in the line shaft end play which had increased by .002". Between 10,000 and 20,000 operations no mechanical failures occurred. At the end of 20,000 operations the Autotunes and gear train were carefully examined once more. There was no noticeable wear on the gears. End play of the line shaft increased .006". One of the rack slots increased in size by .0005". A certain amount of wear was noted on the motor brushes. However, they are designed for 50,000 operations and would probably last that long. Motor speed was reduced from 5000 to 4300 rpm. This seems to be due to the bad pitting of the governor contacts. On the basis of this test it became evident that these contacts should be shunted by a proper size capacitor and resistor for longest life. RF and crystal oscillator switches were in good condition. Set up accuracy was satisfactory throughout the test. Usually the Autotunes would run an 8-hour day at the rate of about 100 set ups per hour without a single frequency error of greater than 100 cps. In fact more often that not, the error was less than half this amount. Because of the bad pitting of the governor contacts the Autotune motor of the "A" model R-391 was replaced. Shunting these contacts with the proper size resistor and capacitor reduced arcing by about two thirds, this should result in a corresponding increase in contact life. Room to mount these extra parts was found near the Autotune motor.

4.6 Delivery of Models

It appeared that the R-390 receiver would find greater use than the R-391. Consequently the two "A" model R-390 receivers were built first. On February 24th, the first "A" model R-390 was shipped, together with the two "B" model R-390 receivers. These "B" models were actually unmodified R-390 receivers, as no actual experimental models of the R-390 cost reduction receiver were built. Since both the R-390 and R-391 receivers are nearly identical except for the R-391 Autotunes, the "B" model R-391 served as the "guinea pig" for all the mechanical and electrical features incorporated in both the R-390 and R-391 "A" models. On March 10th the other "A" model R-390 was shipped. After completion of the R-390 "A" models, the R-391 "A" model was built and tested. During this period it became necessary to divert attention to the forthcoming production contract for R-390A cost reduction receivers. As a result, construction and testing of this model proceeded at a much slower pace. The extended tests conducted on the Autotunes also added several weeks over the test time for the R-390 "A" model receiver. In September the "A" and "B" model R-391 cost reduction receivers were shipped.

4.7 Preparation of Drawings and Final Cost Analysis

As soon as the "B" model R-391 cost reduction receiver was constructed work was begun on preparing manufacturing drawings. The R-390 "A" models were built from these drawings as much as possible. During the construction of these models possible improvements and minor errors showed up. These were then immediately incorporated in the drawings. Because of the production contract which had been received, it was felt that rather than release the drawings to Signal Corps immediately after the "A" models were completed, it would be to their benefit to wait until preproduction models of the receiver had been built and tested. This would give some extra time to allow the drawings to be checked by manufacturing personnel, who were in a position to point out minor changes which would result in cost savings, easier fabrication and better quality. In the manufacture and assembly of the preproduction models, other minor errors and possible improvements also showed up. These were all incorporated into the final drawings for the R390A receiver. These drawings were released to production on June 1st, and are in a much higher state of perfection that they would have been immediately after the R-390 "A" models were built. A set of reproducible prints is being made from these drawings and should be ready for delivery in November. After completion of the R-390 drawings, it took just two weeks to finish the R-391 drawings because of their close similarity. A set of reproducible prints is also being made from these drawings, and should be ready for delivery about the same time as those for the R-390.

Little work could be done on the final cost analysis until the drawings were completed. Upon completion of the drawings, the cost for analysis of the final models was begun. Results are shown in figures 40 and 41, which should be compared with figures 1 and 2 to show the savings on each receiver resulting from this cost reduction program.

5.0 CONCLUSION

As a result of this cost reduction contract, the following results have been accomplished.

5.1 A complete cost analysis was made on the R-390 and R-391 receivers.

5.2 Cost reduction models of the R-390 and R-391 receivers were designed, built and delivered.

5.3 Manufacturing drawings have been prepared on both receivers and will be delivered in November.

6.0 RECOMMENDATIONS

The following recommendations are made as a result of the contractor's experience in redesigning this equipment.

6.1 Although the superior shape factor of the mechanical filter IF is desirable in most applications, consideration should also be given to an alternate tuned circuit design for use in special applications. The excellent shape factor of the mechanical filters precludes the possibility of linear phase shift across the passband. Where a linear phase characteristic is desired such as in direction finding equipment, a tuned circuit IF is necessary.

Such a tuned circuit IF was constructed by suitably modifying the IF unit of an original R-390 receiver. Modifications included rewiring tube filaments for parallel operation and substitution of tube types 5749 and 5814A for 6BJ6 and 12AU7 respectively. In addition, the RF gain control and AGC circuits were changed slightly to match that of the mechanical filter IF unit. With the extension leads supplied, the T.C. IF is directly interchangeable with the mechanical filter model. This tuned circuit IF unit was shipped along with the R-391 "A" model receiver to permit comparison with the mechanical filter model. Although this unit can be built using the same tooling as the R-390 IF, it may be desirable to design a new chassis incorporating aluminum shields, better layout of parts and less costly components. This would be especially true if there is a considerable demand for tuned circuit IF units.

6.2 In a cost reduction contract of this kind there is one problem always to be faced. That is, to decide at what point in time work can be stopped and it can definitely be said that this is it. The opportunities for cost reduction and improvement of performance are almost endless with new developments in materials and processes, electrical components and circuitry becoming available almost continuously. Already further areas of investigation have shown up for which there was no time to experiment and incorporate the results into the final equipment. One of these fields of investigation involves potting the RF coils in a solid block of resin. This type of construction has several advantages over conventional coils. Performance under humidity is improved because the coils are almost completely impervious to moisture.

Tests have been made showing the IF and AF units of the cost reduction receiver to be very good under humid conditions. If the RF could be improved to the same extent, it appears that very satisfactory operation could be expected in tropical climates. Besides the improved moisture protection, potted coils could actually be made cheaper than conventional types since no coil frame is necessary and the can becomes the mold for the resin.

Further investigation of the antenna relay design could probably lead to a satisfactory AC operated unit, eliminating the need for a selenium rectifier to supply the required DC power.

Since cross modulation is becoming of greater concern, further work might be desirable to find means for its reduction, particularly at strong undesired signal inputs.

Higher stability is another desirable feature which might possibly be obtained with redesign of the crystal and VFO oven.

In conclusion, it is recommended that further consideration be given these problems in order that optimum performance and minimum cost be achieved for these equipments.

7.0 IDENTIFICATION OF PERSONNEL

The following is a list of names and titles of key personnel assigned to the contract and taking part in the work covered by this report. This list also contains the approximate number of man hours spent and the major work of each man. Also includes a brief description of the background of each man.

L. W. Couillard - Section Head, Medium Frequency Receiver Section

Employed by Collins Radio Company for 14 years working mostly on receivers and receiving equipment. Graduate in Electrical Engineering, University of Minnesota, 1938. Approximately 300 hours spent on this project working on all phases in a supervisory capacity.

E. Schoenike - Project Engineer

Employed by Collins Radio for 6 years working on R-390 equipment. Graduate in Electrical Engineering from University of Wisconsin, 1949. Approximately 2800 hours spent on this project working mostly on the RF, crystal oscillator and IF.

J. P. Mullen - Mechanical Engineer

Employed by Collins Radio Company for 4 years. Graduate in Mechanical Engineering from Iowa State College in 1950. Approximately 2500 hours spent on this project working mostly on the mechanical design.

R. L. Scriven - Development Engineer

Served in World War II in the US Navy and detached to OSS to construct radio stations throughout the world. A graduate of Navy Radio Material School. Served in Korean War as Chief Electronic Technician aboard a destroyer. High school graduate and attended night school electronic courses sponsored by University of Iowa. Employed by Collins Radio for 15 years, less military leave, having worked in production, lab technician in aircraft communications and engineer in integrated flight systems. Approximately 2800 hours spent on this project working mostly on AF and power supply.

N. E. Hogue - Development Engineer

Employed by Collins Radio for five years working on R-390 equipment. Graduate in Electrical Engineering from University of Wisconsin in 1950. Approximately 500 hours spent on this project working on the final design of the IF.

D. M. Hodgin - Development Engineer

Employed by Collins Radio for 8 years working on oscillator development. Graduate in Electrical Engineering from Purdue University in 1947. Served two years as radio technician in U. S. Navy. Approximately 200 hours spent on this project, doing development work on variable frequency oscillators.

C. A. Rockwell - Development Engineer

Employed by Collins Radio for 15 years working as a laboratory technician, assembly foreman, and development engineer. Approximately 1300 hours spent on this project working mostly on RF coil design.

W. F. Williams - Mechanical Engineer

Employed by Collins Radio for 7 years. Attended University of Iowa until 1945. Approximately 400 hours spent on this project, working mostly on the mechanical design of the IF.

E. Lefebure - Cost Analysis Engineer

Employed by Collins Radio for two and one-half years. Graduate of Loras College in 1918 with a B.S. degree. Approximately 2800 hours spent on this project, working mostly on cost analysis.

Glenn Hykes - Development Engineer

Employed by Collins Radio for 8 years. Spent approximately two years in the Army Air Force of which 18 months was spent attending a radio engineering school in Chicago. Approximately 100 hours spent on this project, working mostly on the crystal oven.

Ronald Walder - Cost Analysis Engineer

Employed by Collins Radio for 5 and one-half years as a mechanical engineer. Graduate of University of Illinois in 1950 with a degree in Mechanical Engineering. Served approximately twenty-two months in the Infantry. Approximately 500 hours has been spent on this project, working mostly on cost analysis.

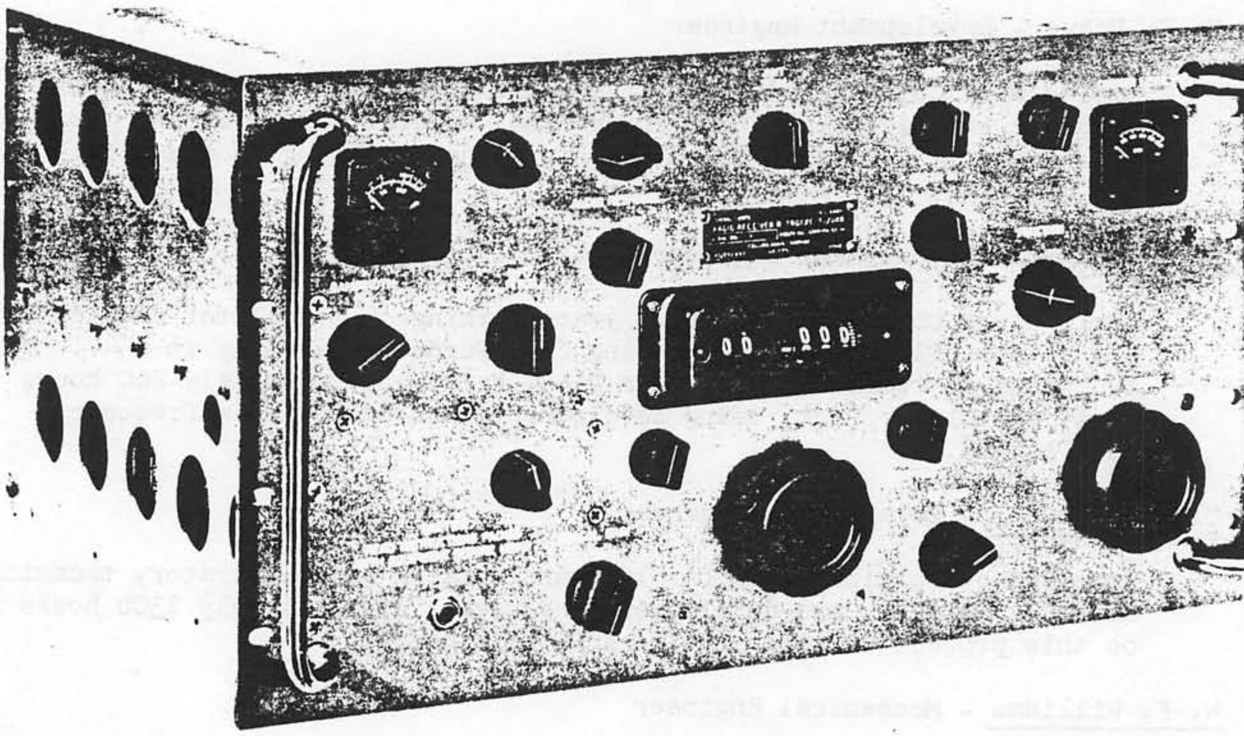

Figure 3 - Radio Receiver R-390(XC-3)/URR, Front View

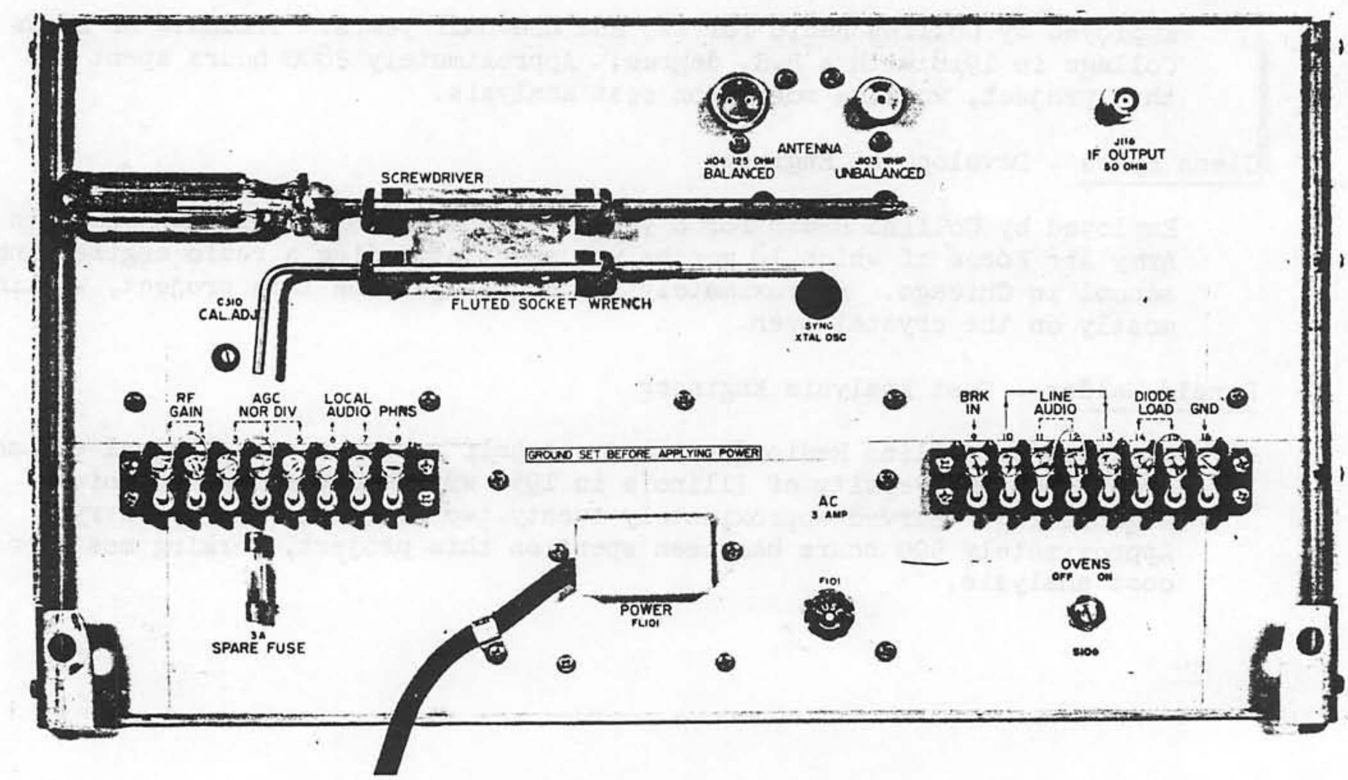

Figure 4 - Radio Receiver R-390(XC-3)/URR, Rear View

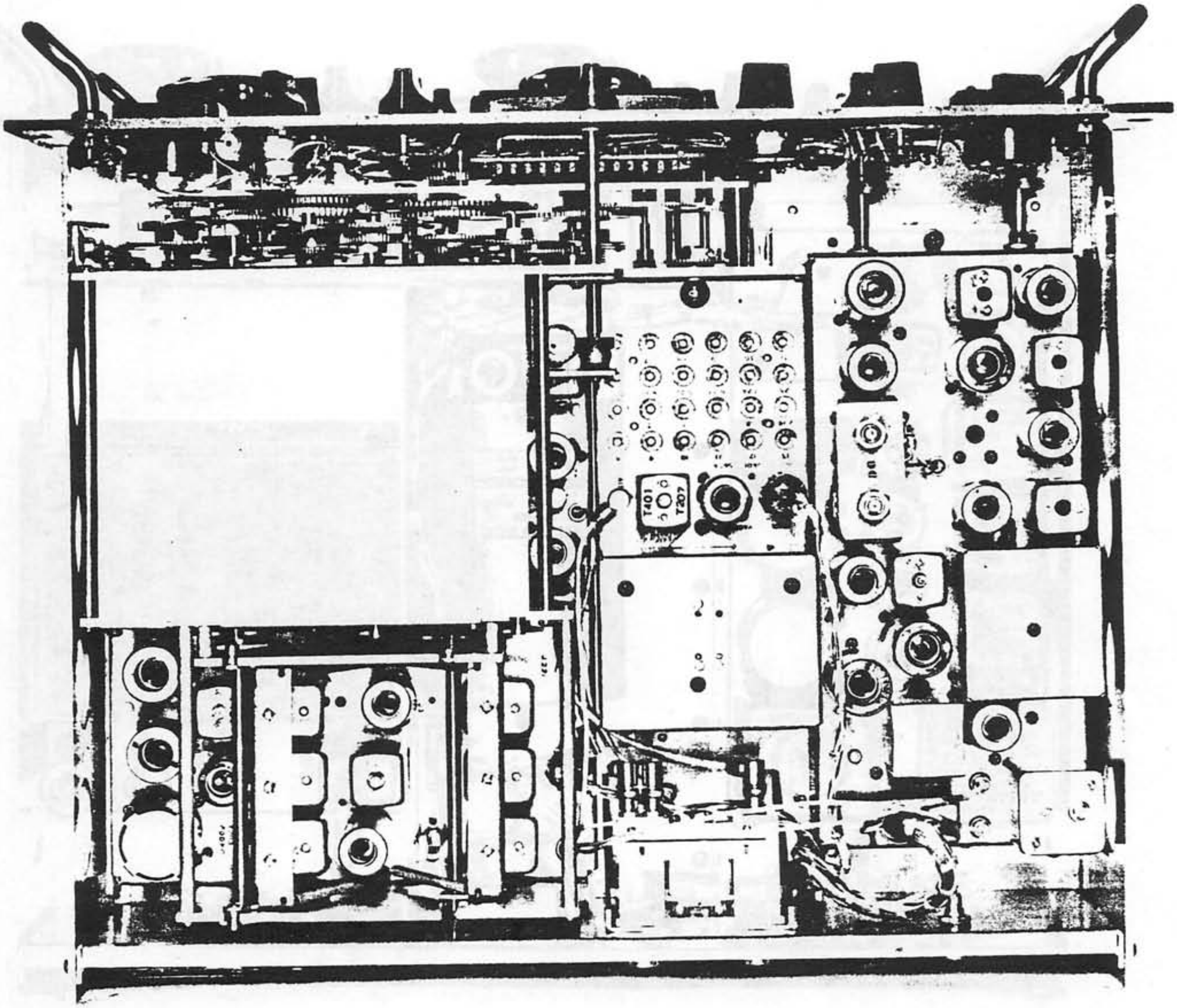

Figure 5 - Radio Receiver R-390(XC-3)/URR, Top View

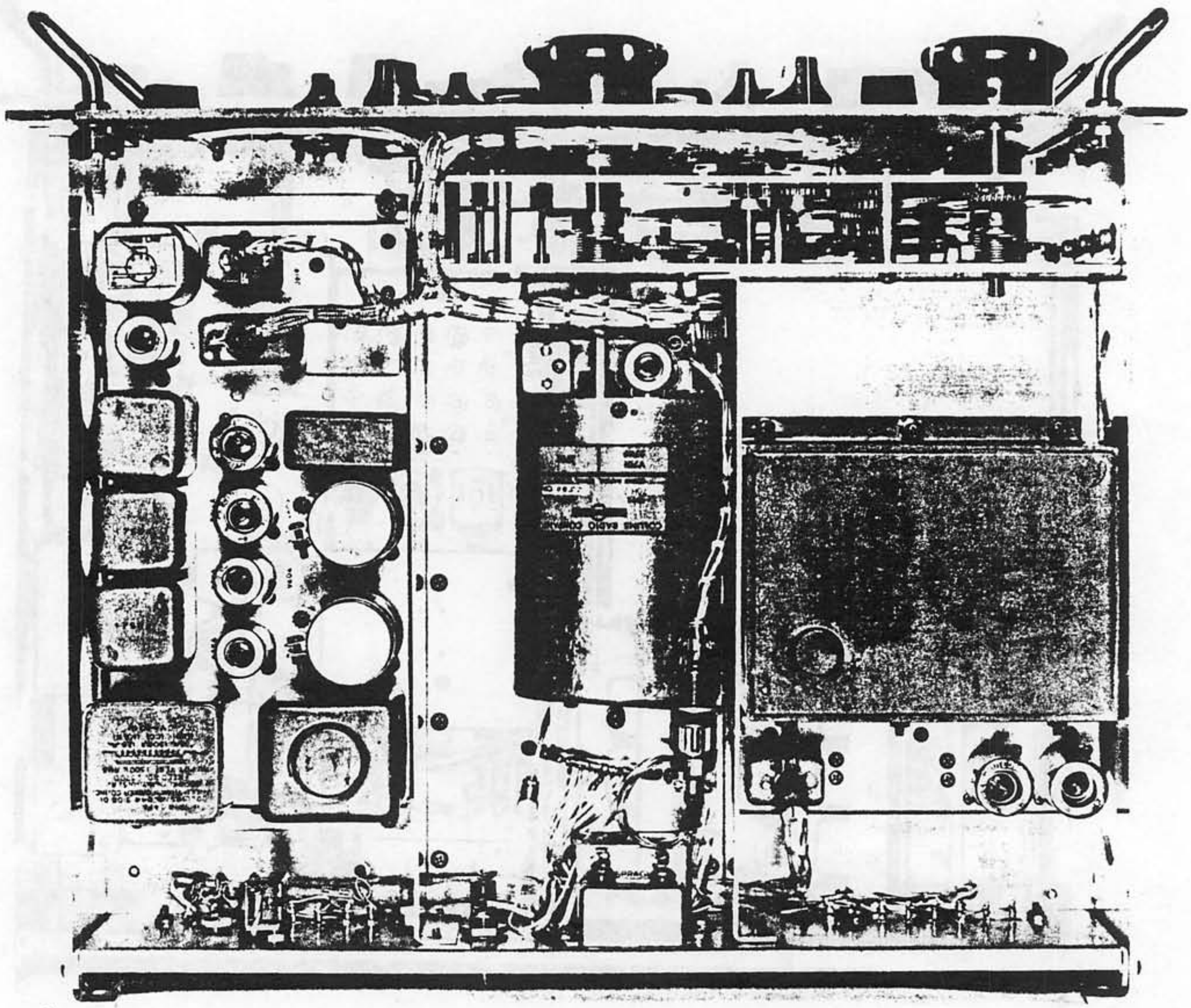

Figure 6 - Radio Receiver R-390(XC-3)/URR, Bottom View

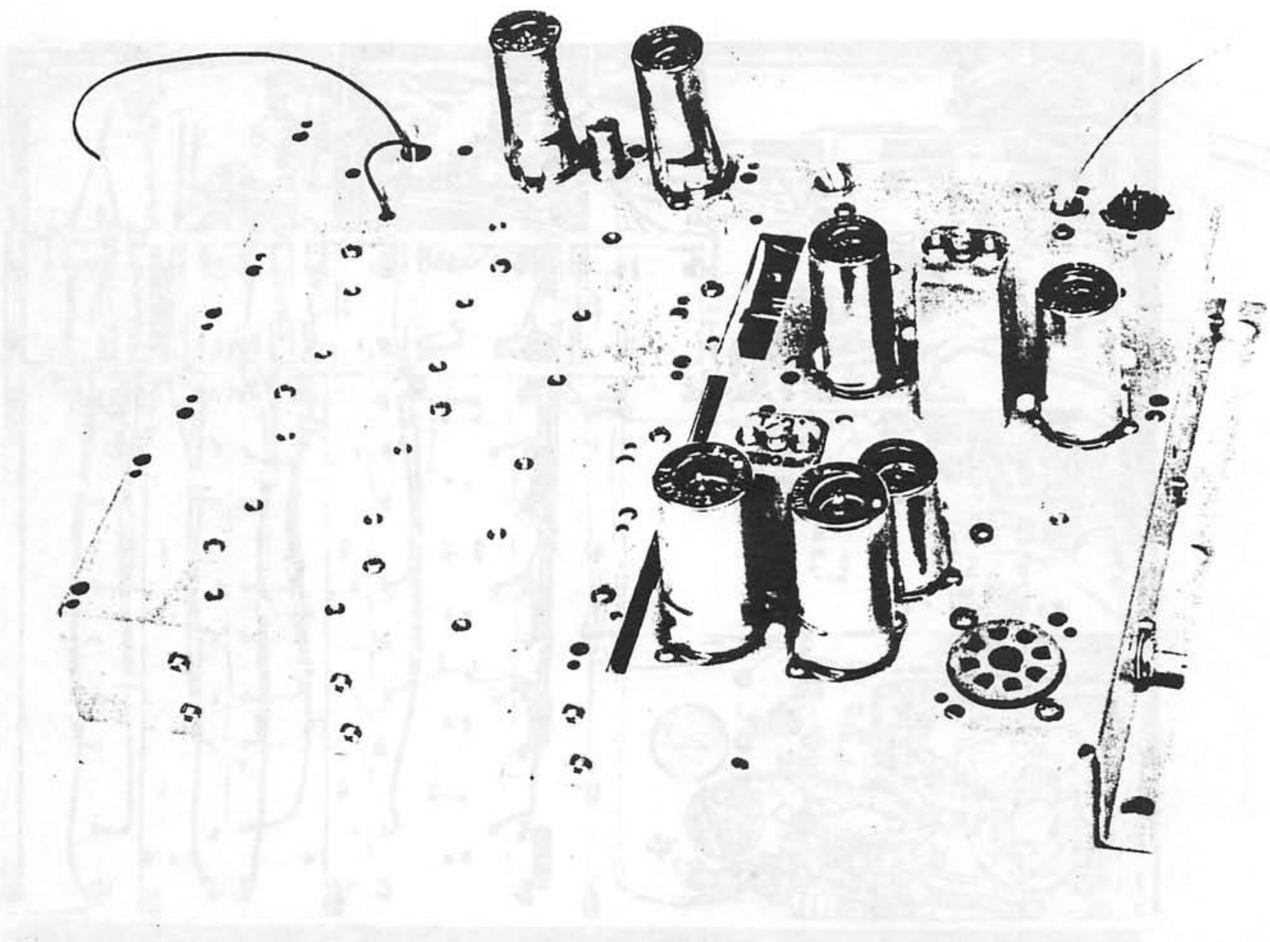

Figure 7 - RF Chassis, Top View

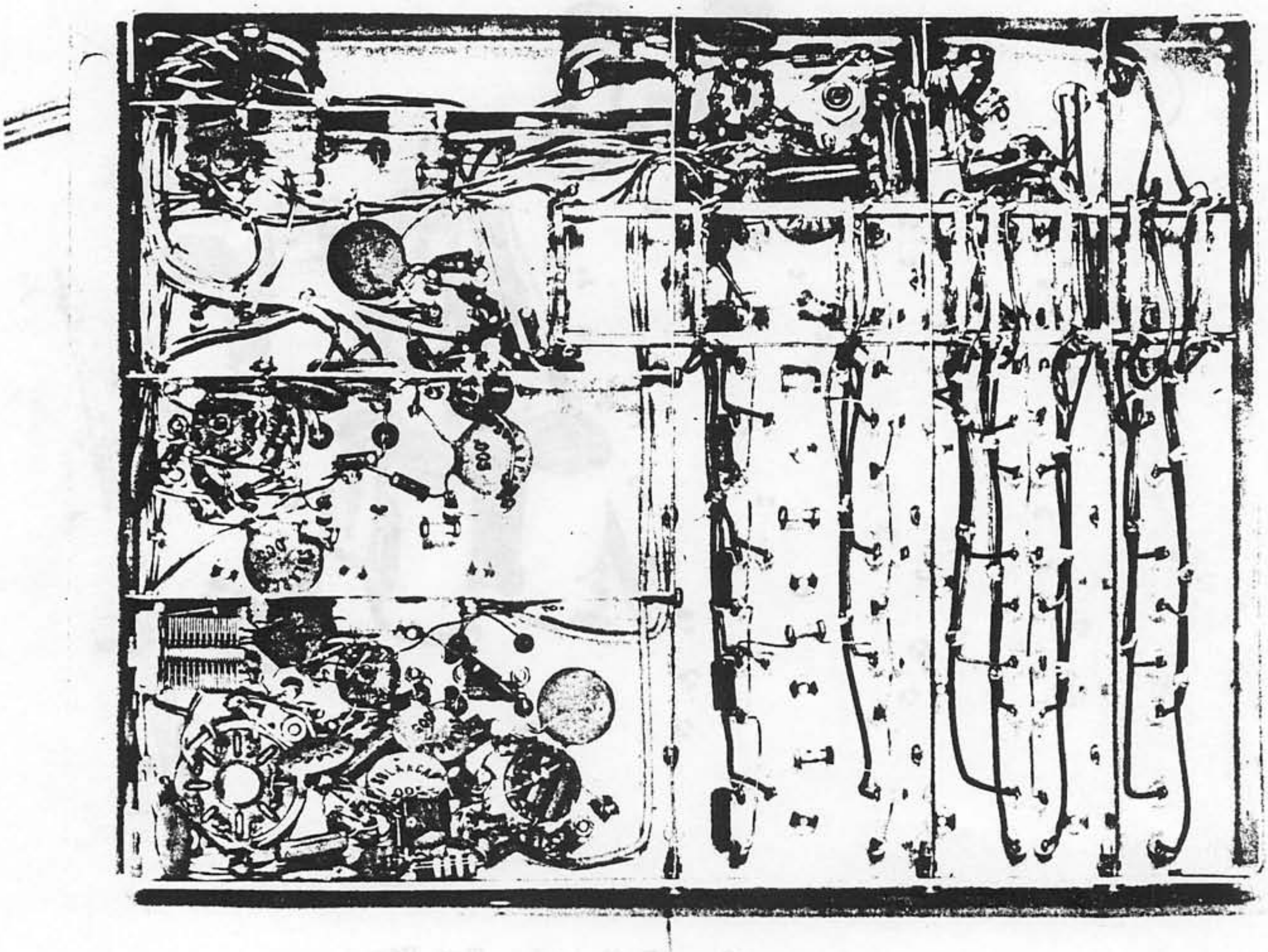

Figure 8 - RF Chassis, Bottom View

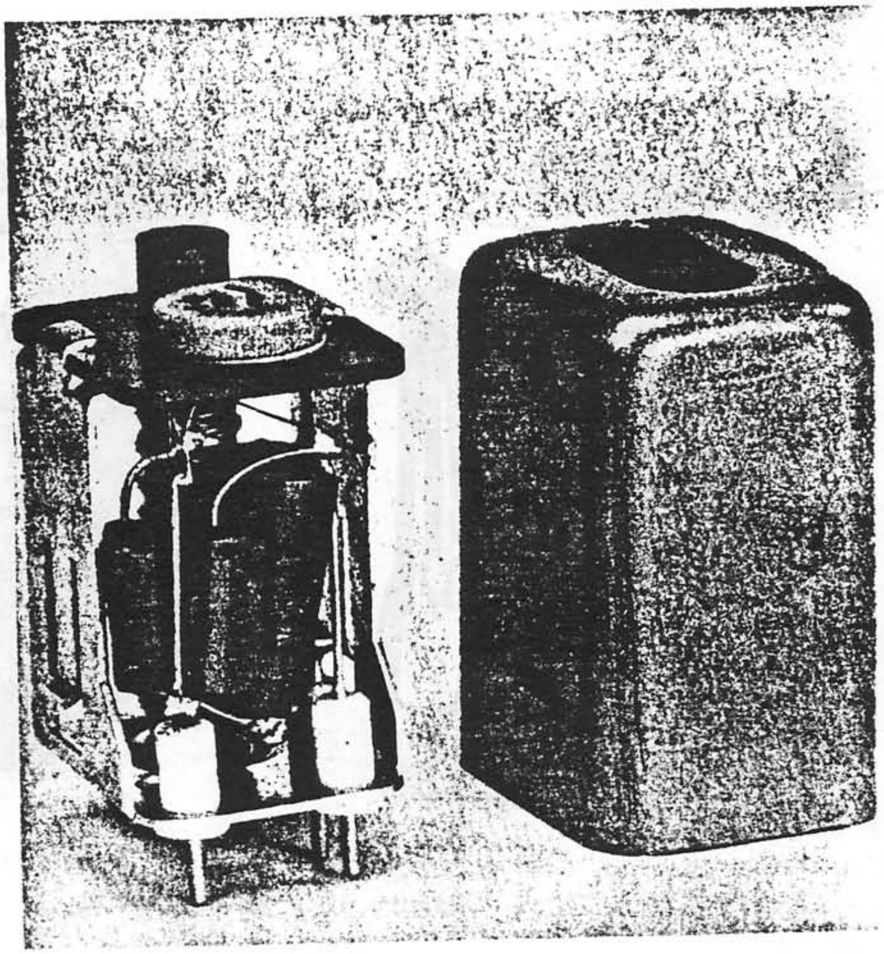

Figure 9 - RF Coil

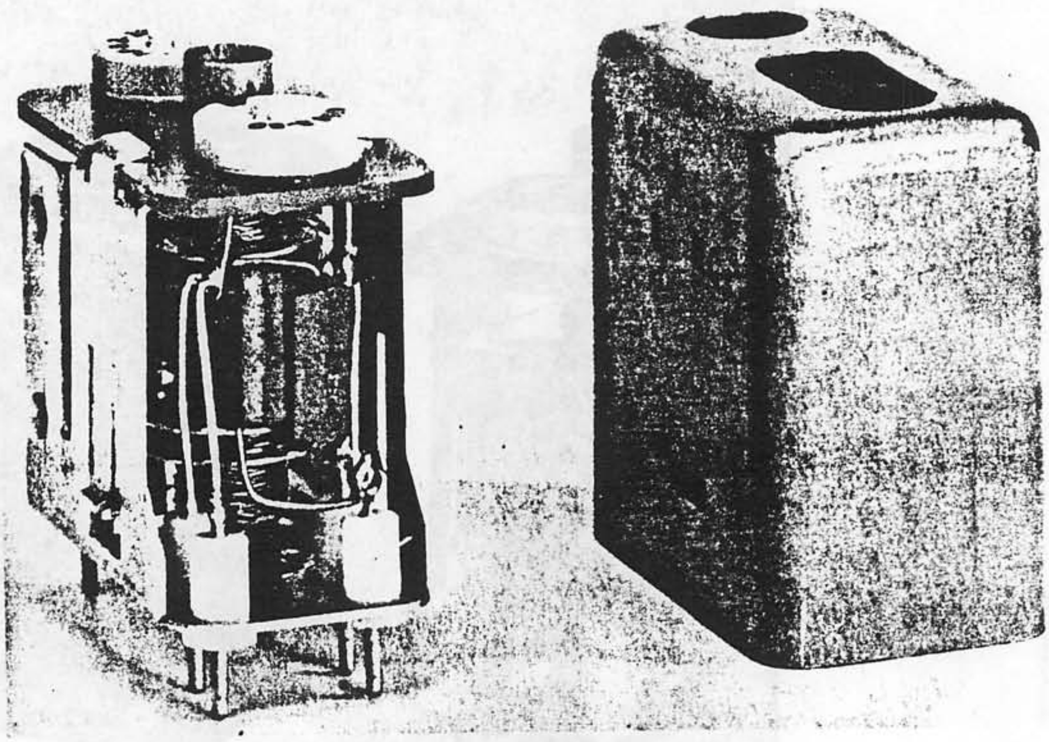

Figure 10 - Antenna Coil

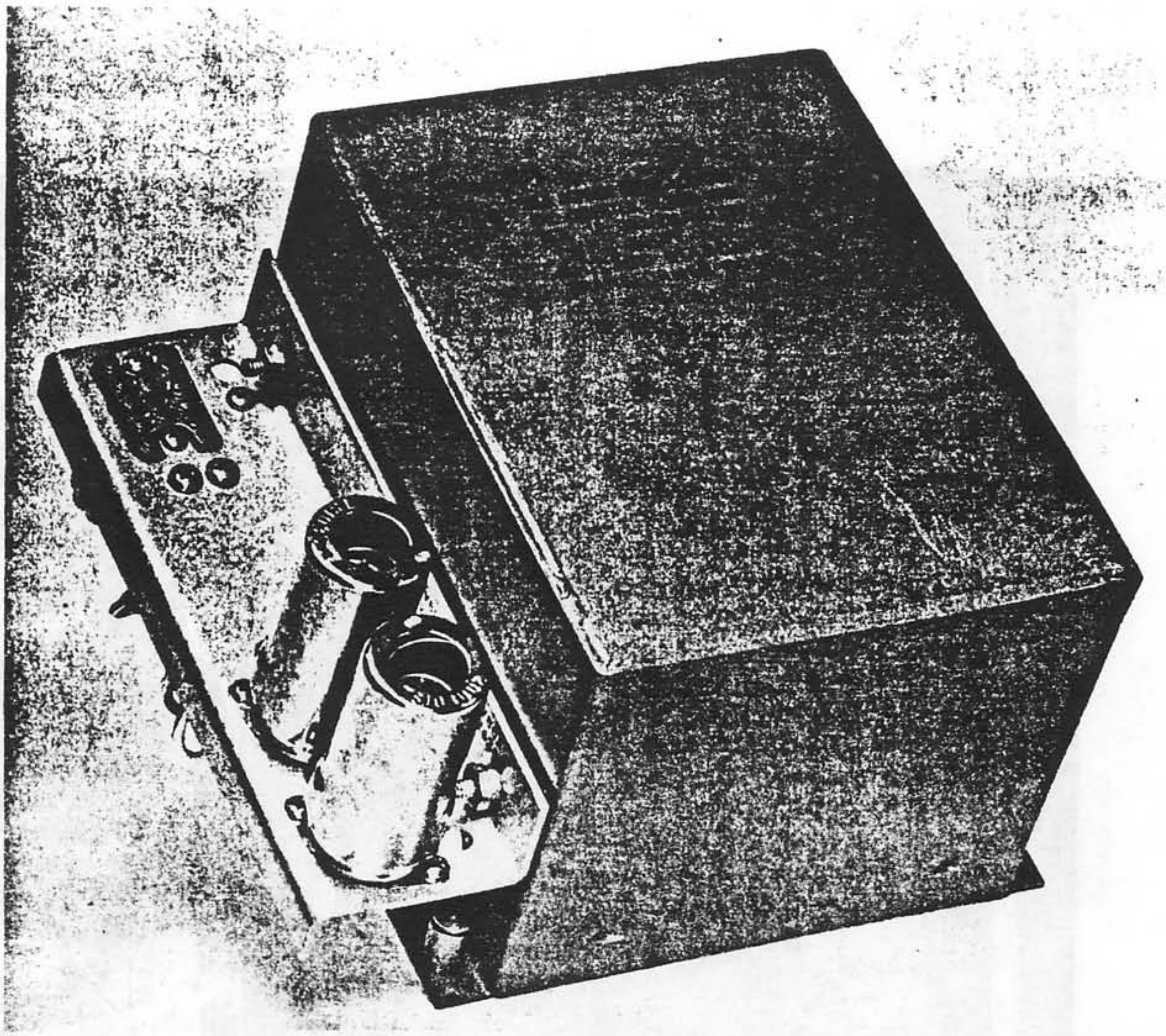

Figure 11 - Power Supply, Top View

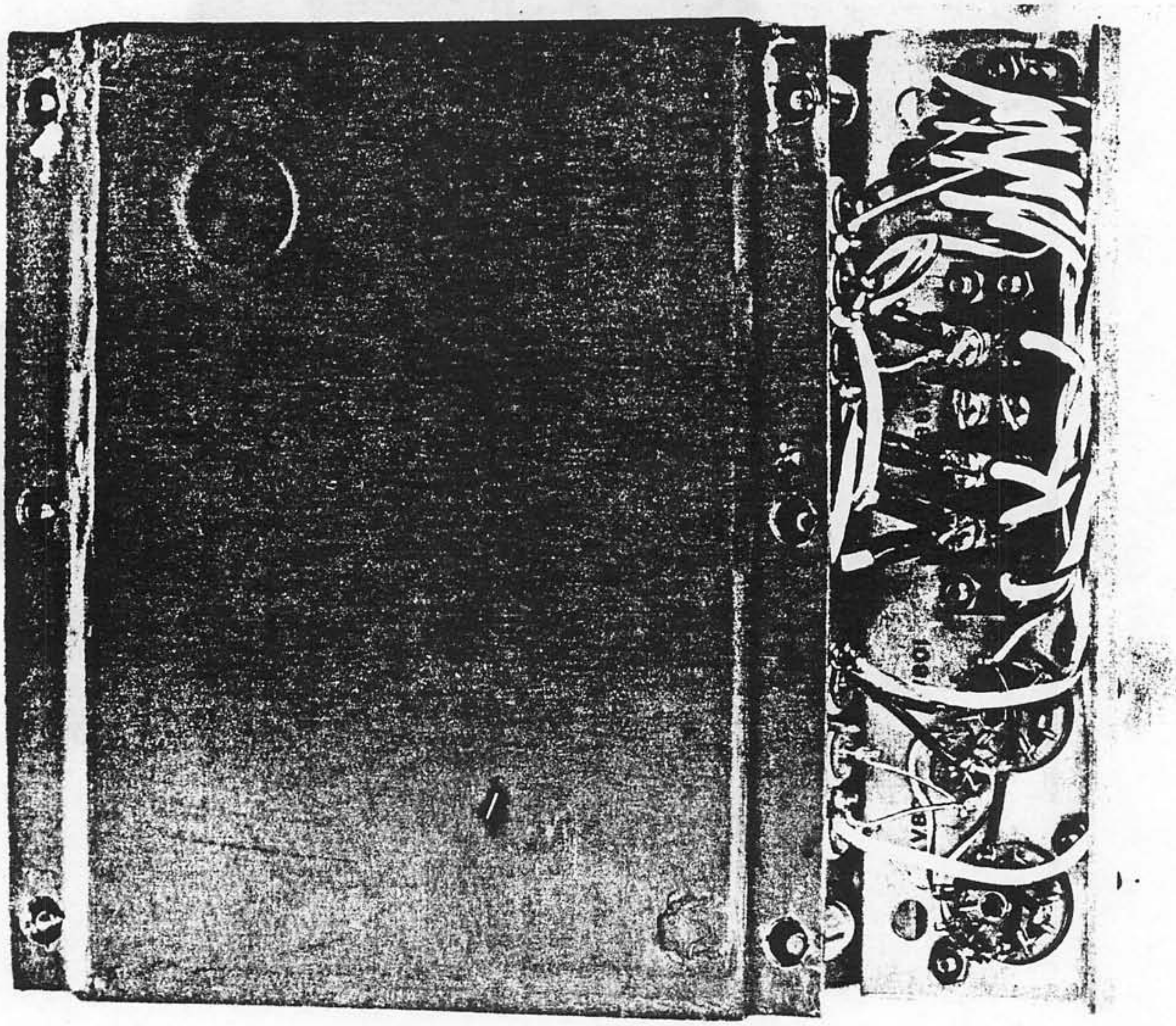

Figure 12 - Power Supply, Bottom View

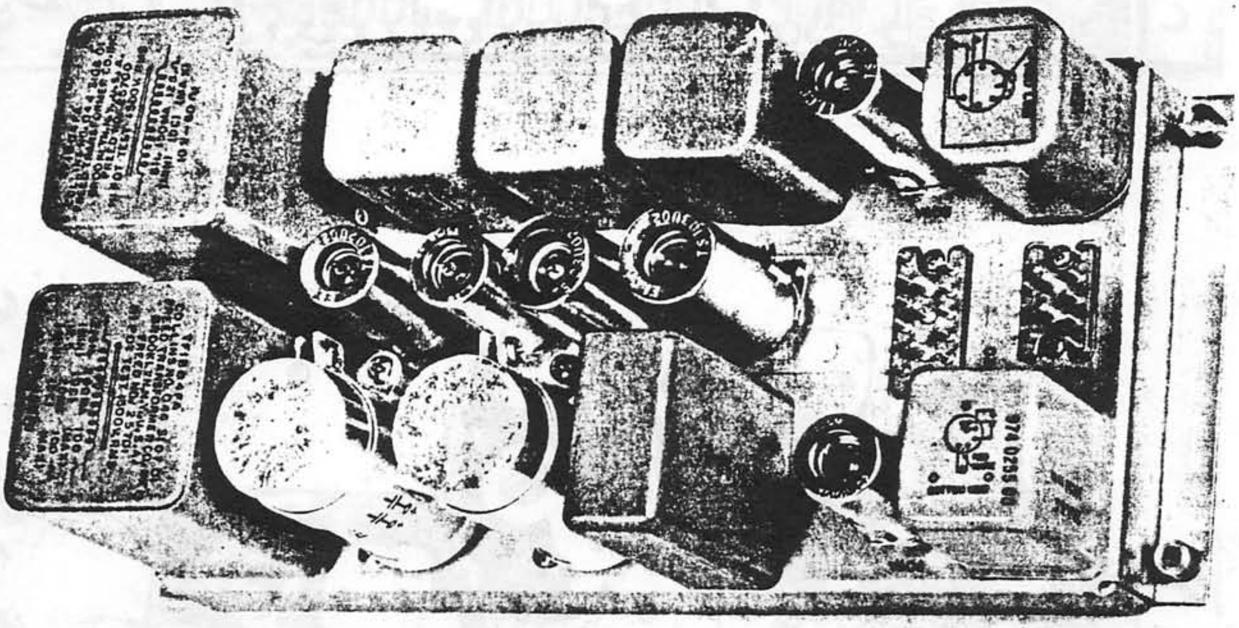

Figure 13 - AF Unit with Squelch, Top View

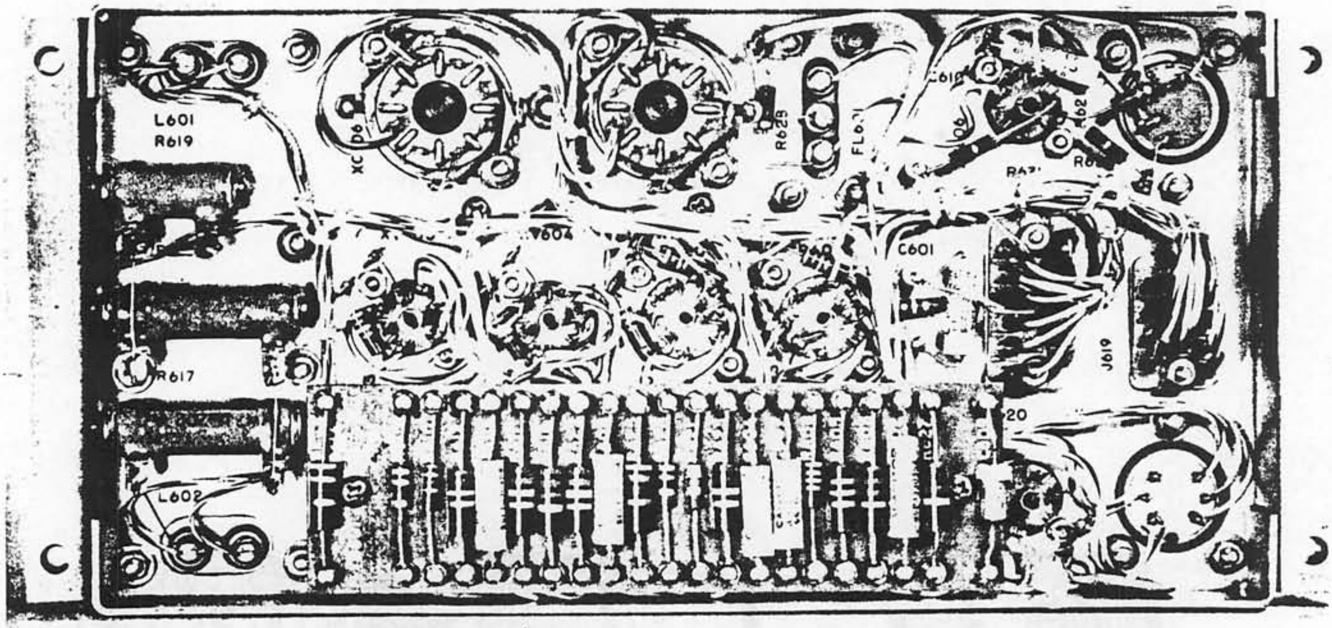

Figure 14 - AF Unit with Squelch, Bottom View

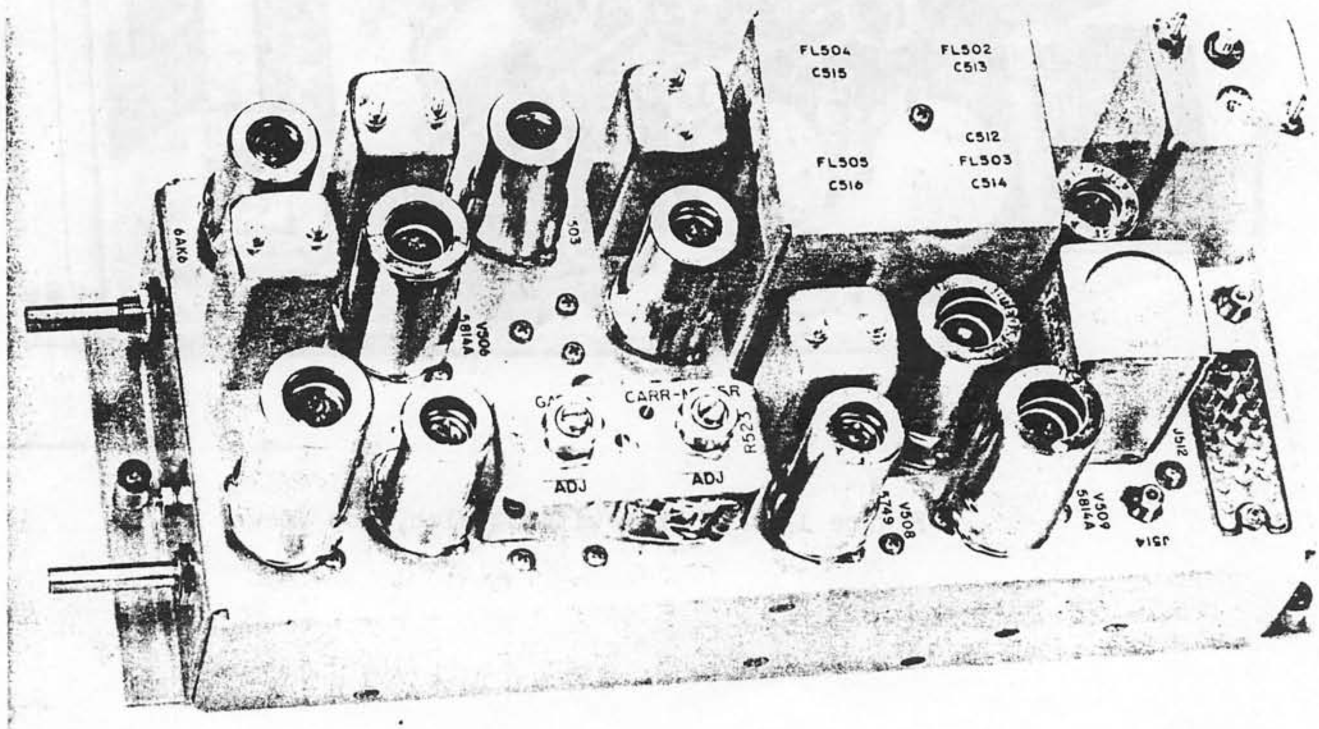

Figure 15 - IF Unit, Top View

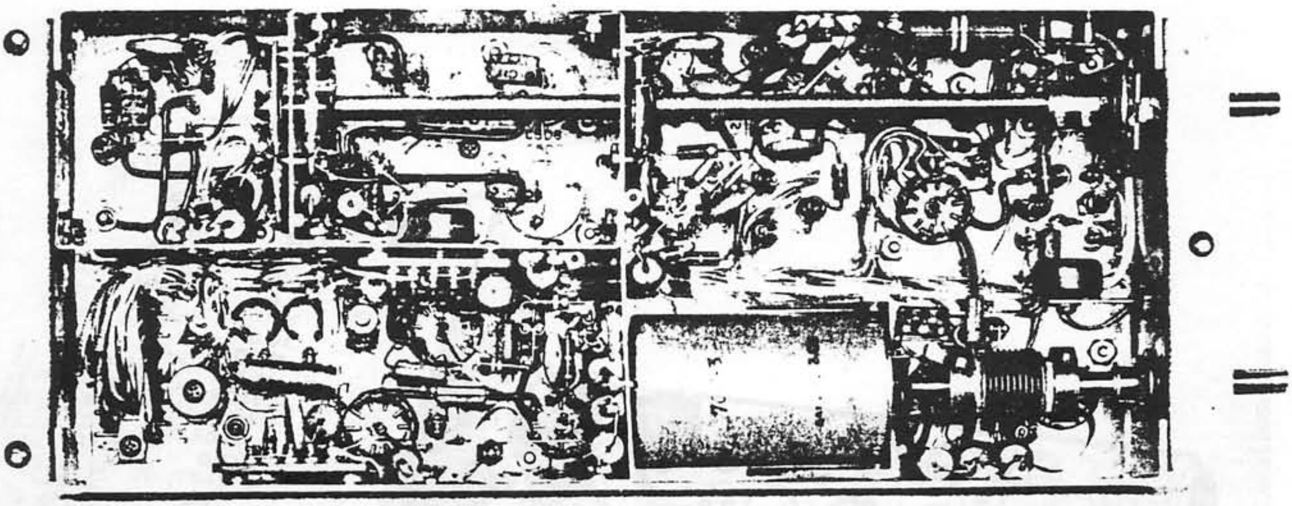

Figure 16 - IF Unit, Bottom View

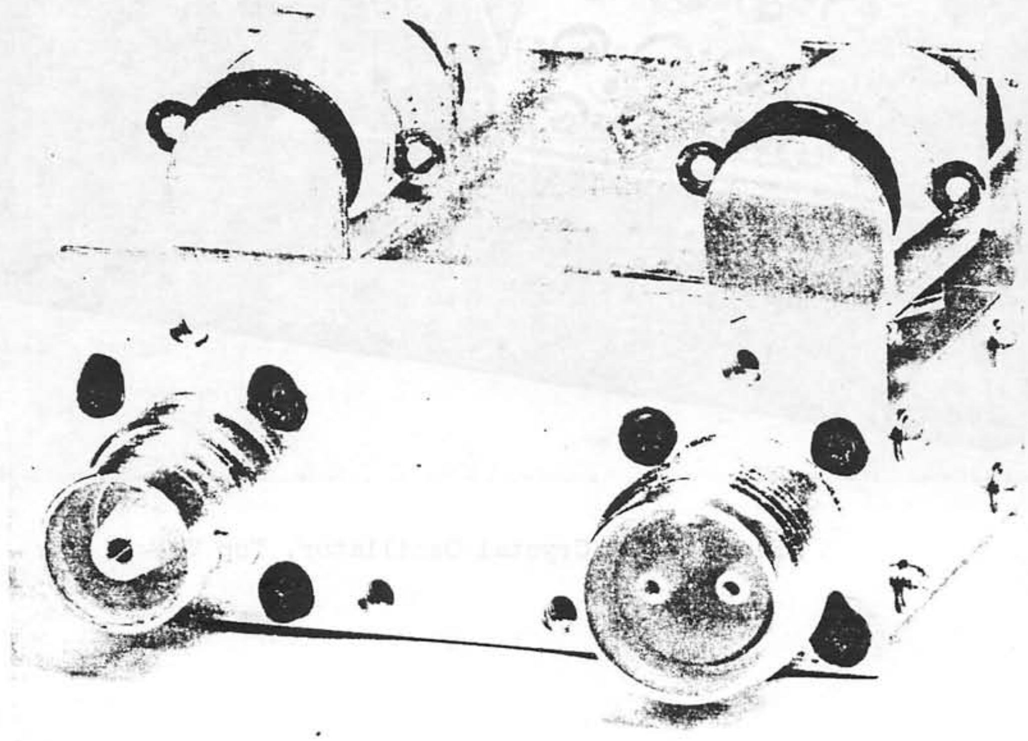

Figure 17 - Antenna Relay Unit

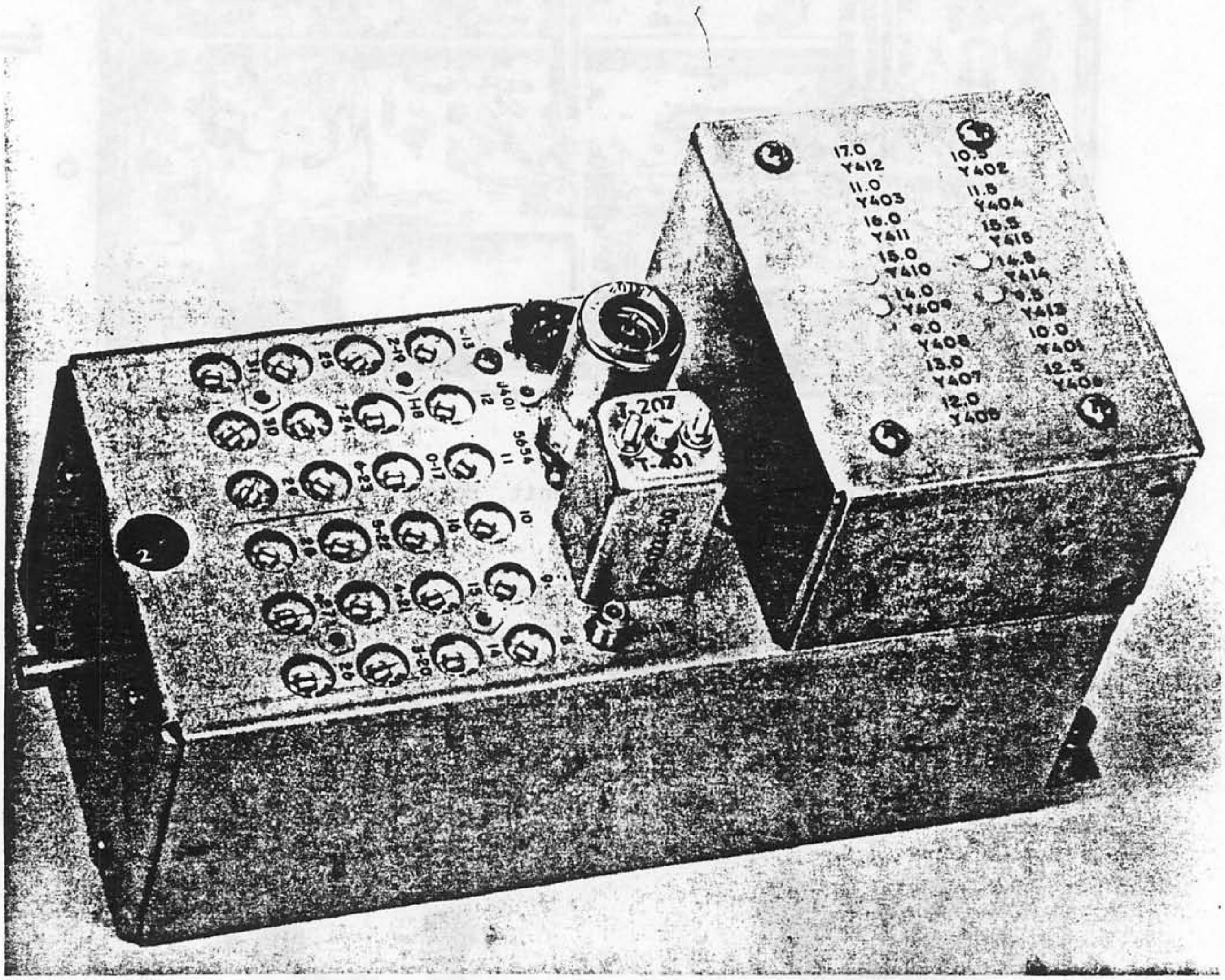

Figure 18 - Crystal Oscillator, Top View

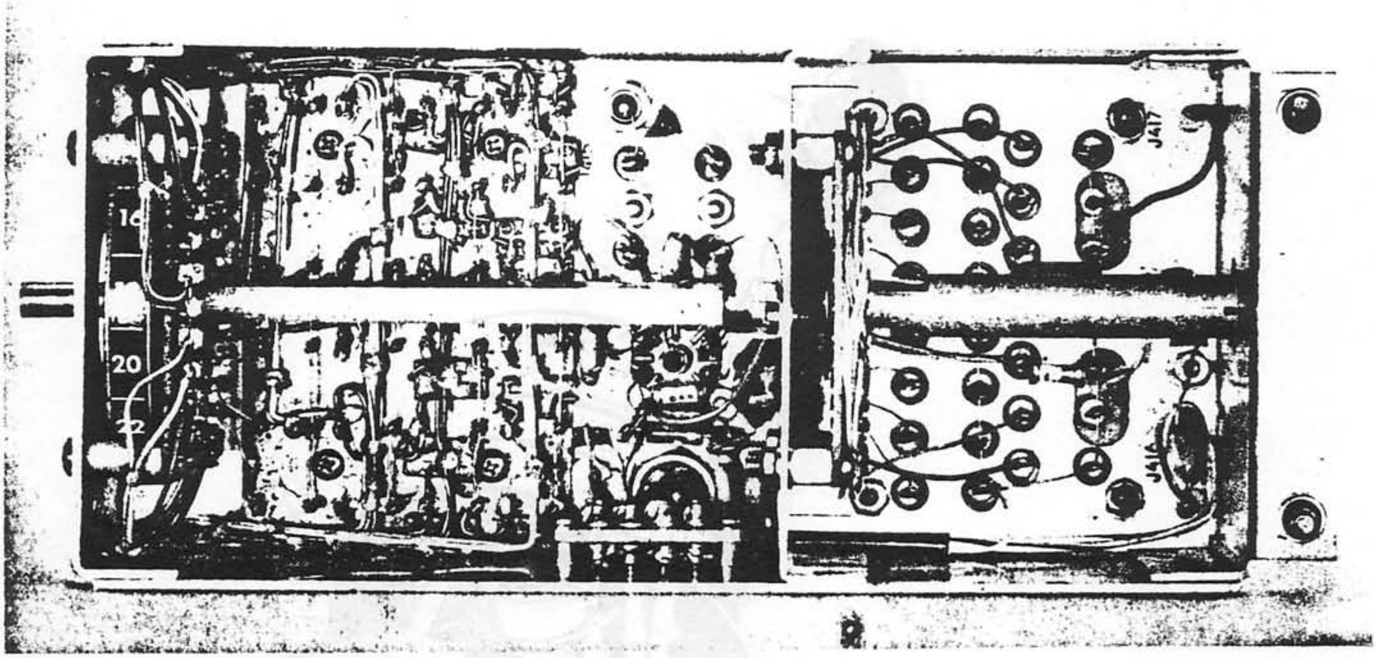

Figure 19 - Crystal Oscillator, Bottom View

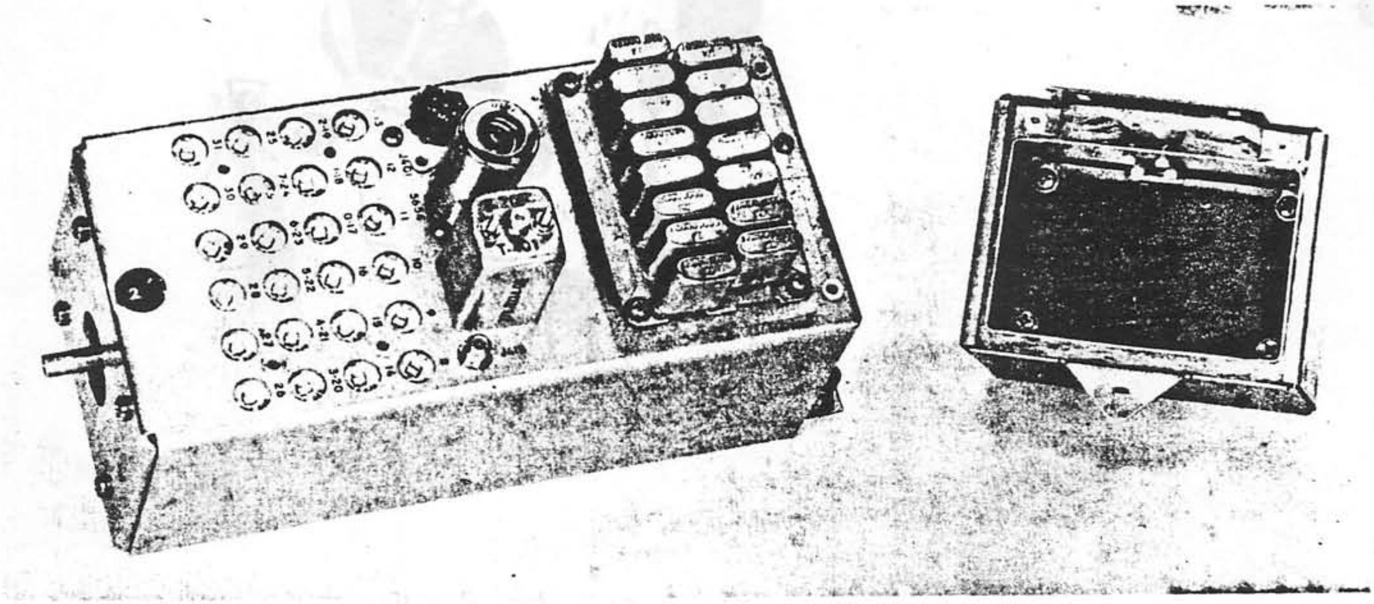

Figure 20 - Crystal Oscillator, Oven Removed

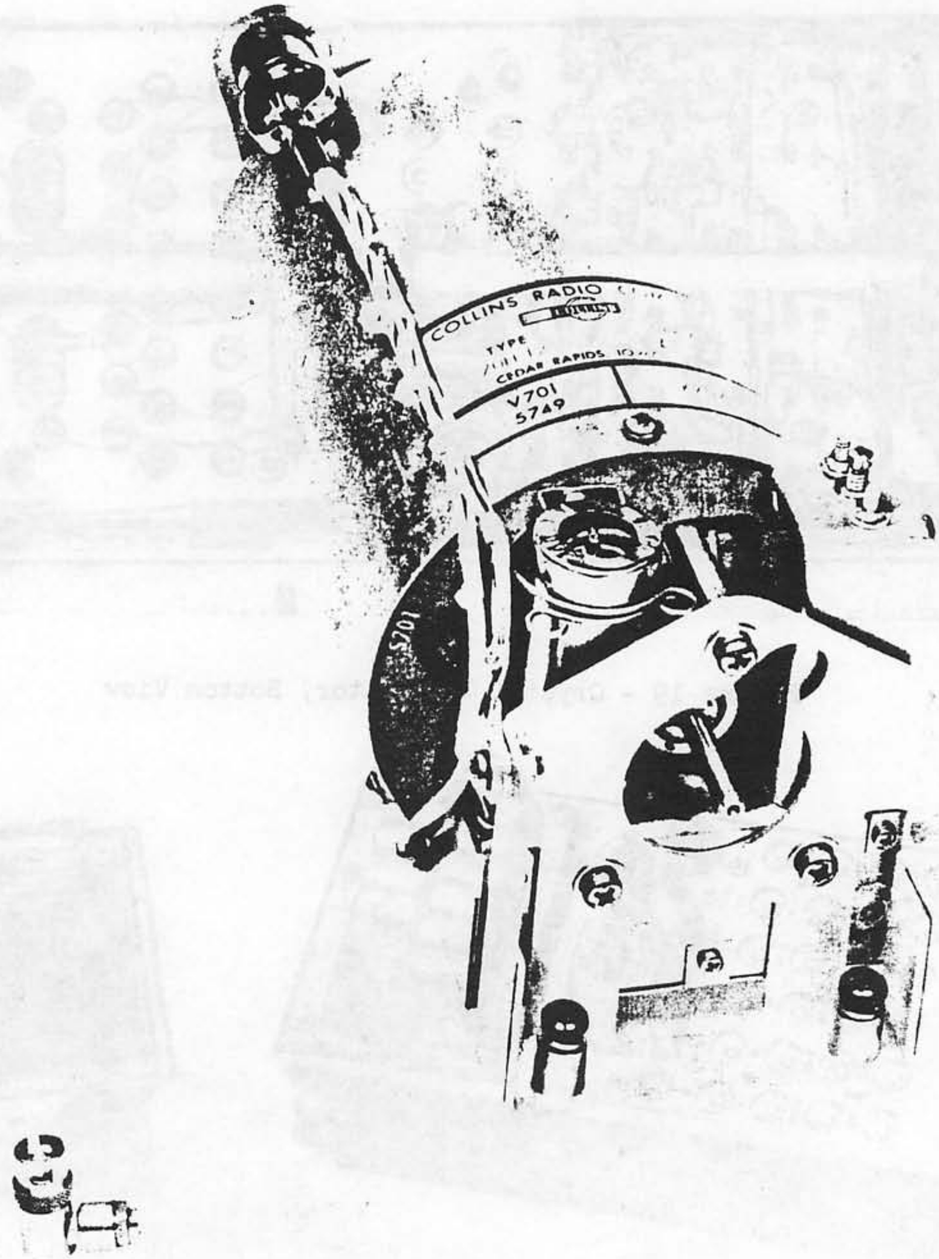

Figure 21 - VFO, Top View

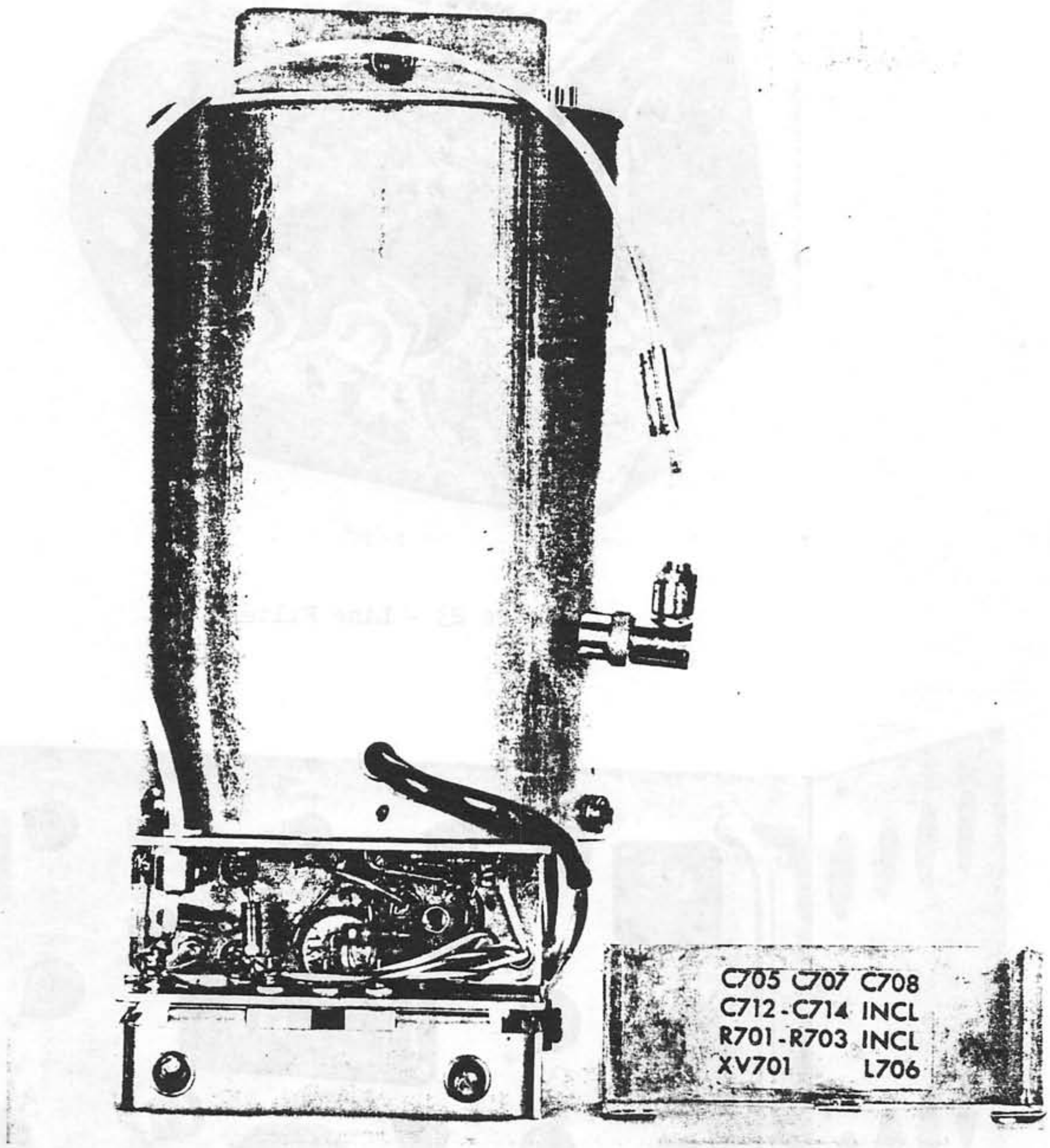

Figure 22 - VFO, Bottom View

Figure 23 - Line Filter

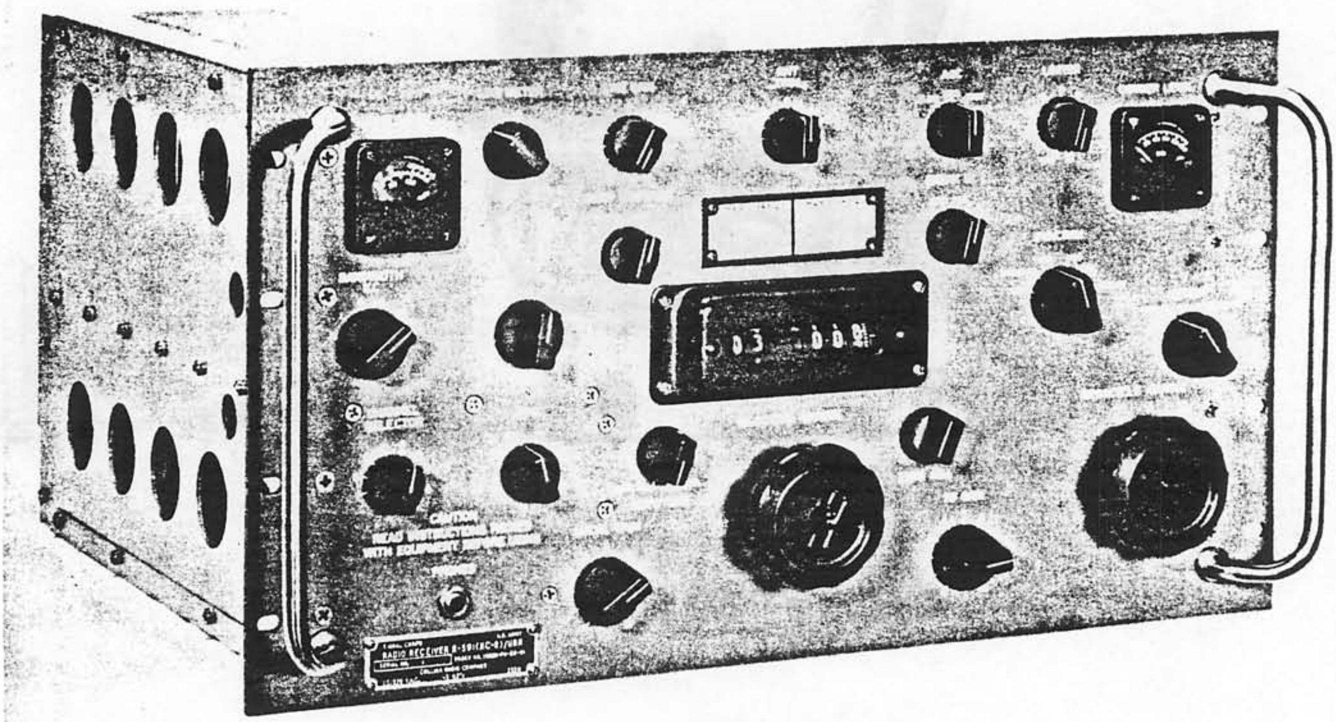

Figure 24 - Radio Receiver R-391(XC-2)/URR, Front View

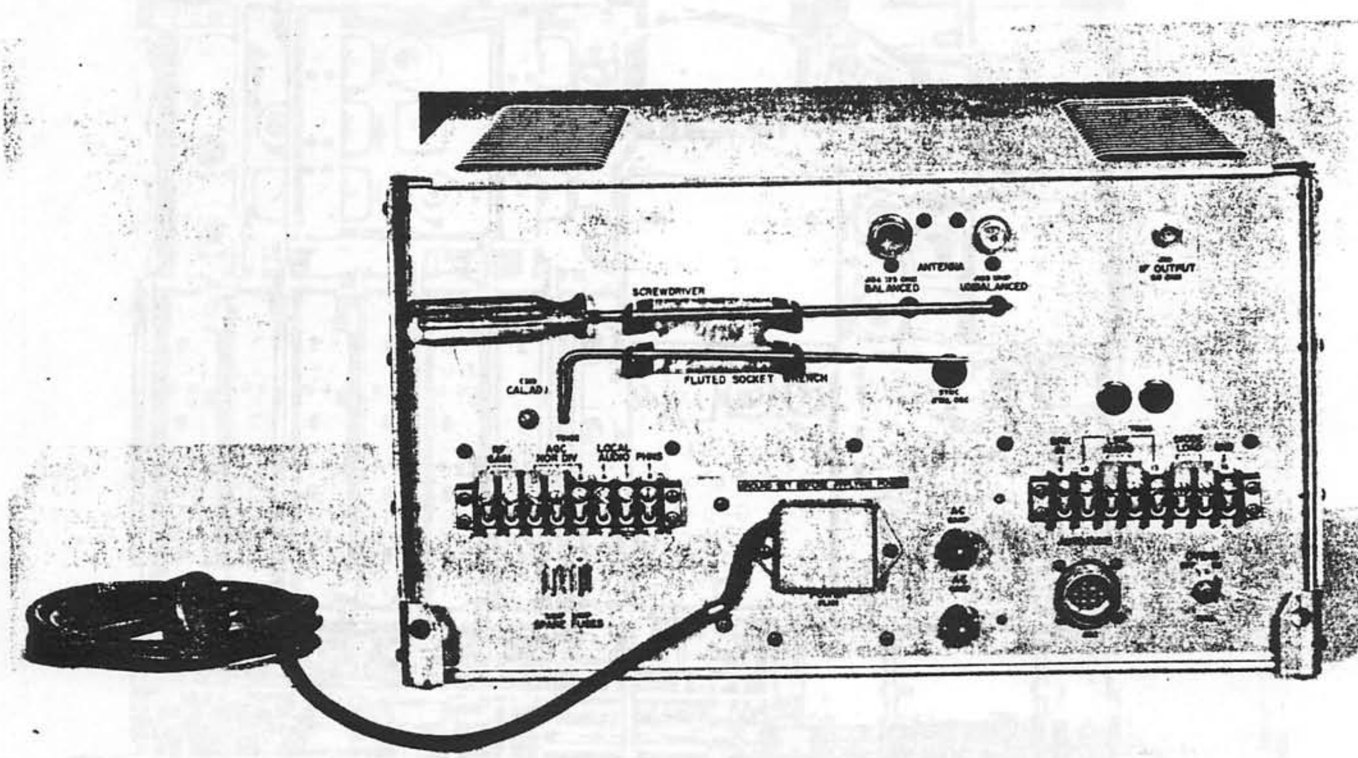

Figure 25 - Radio Receiver R-391(XC-2)/URR, Rear View

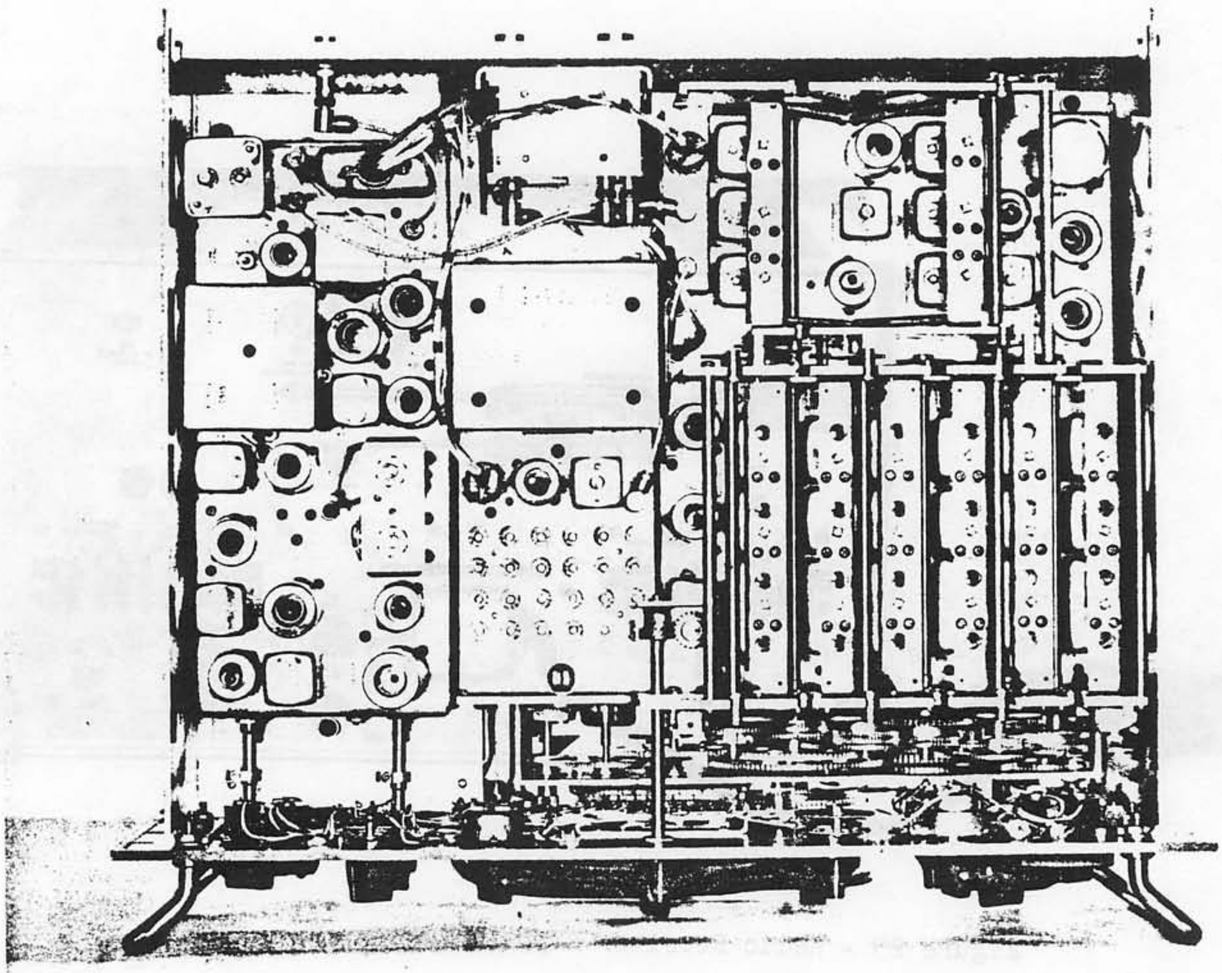

Figure 26 - Radio Receiver R-391(XC-2)/URR, Top View

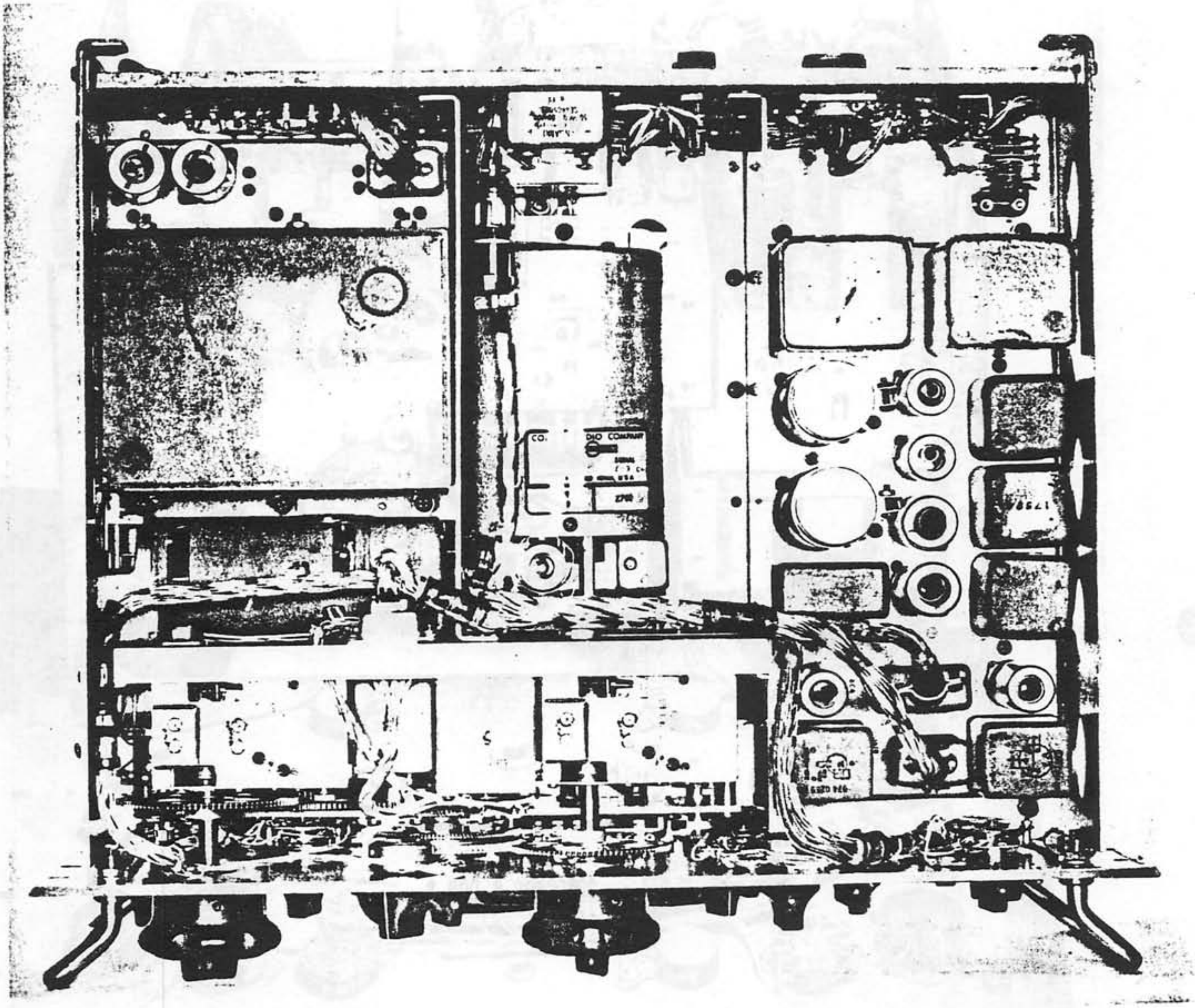

Figure 27 - Radio Receiver R-391(XC-2)/URR, Bottom View

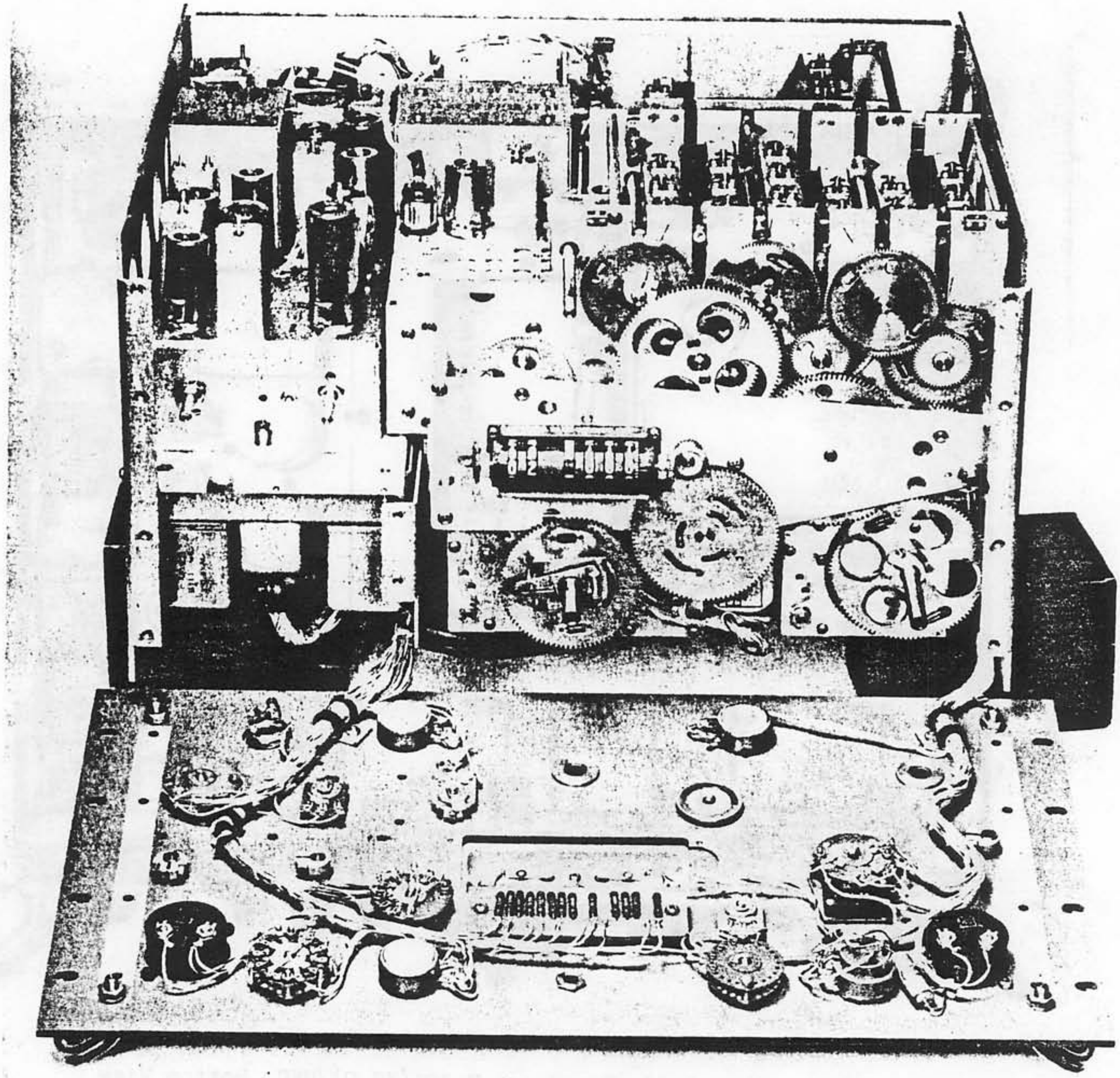

Figure 28 - Radio Receiver R-391(XC-2)/URR, Front Panel Down

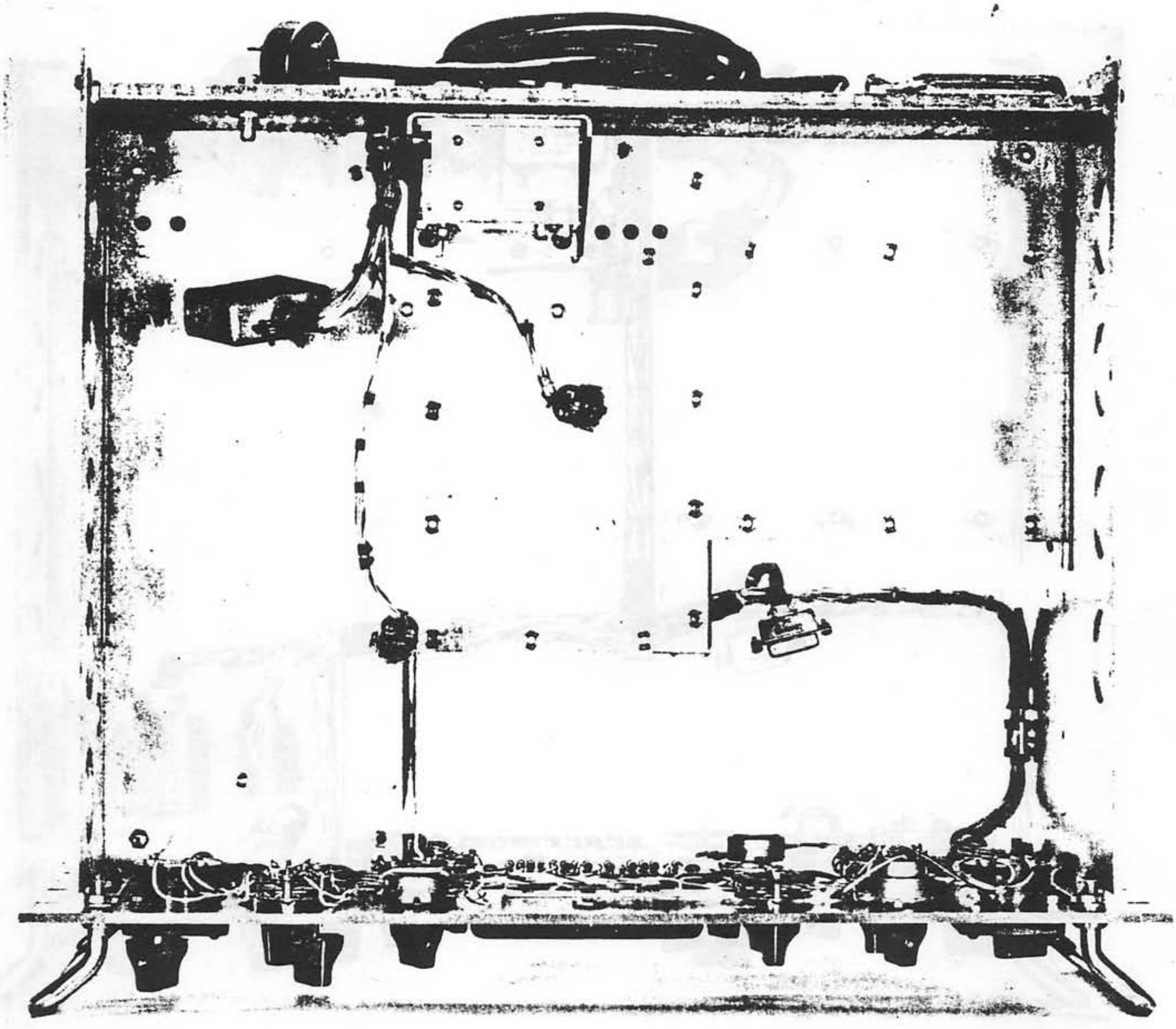

Figure 29 - Radio Receiver R-391(XC-2)/URR, Main Frame, Top View

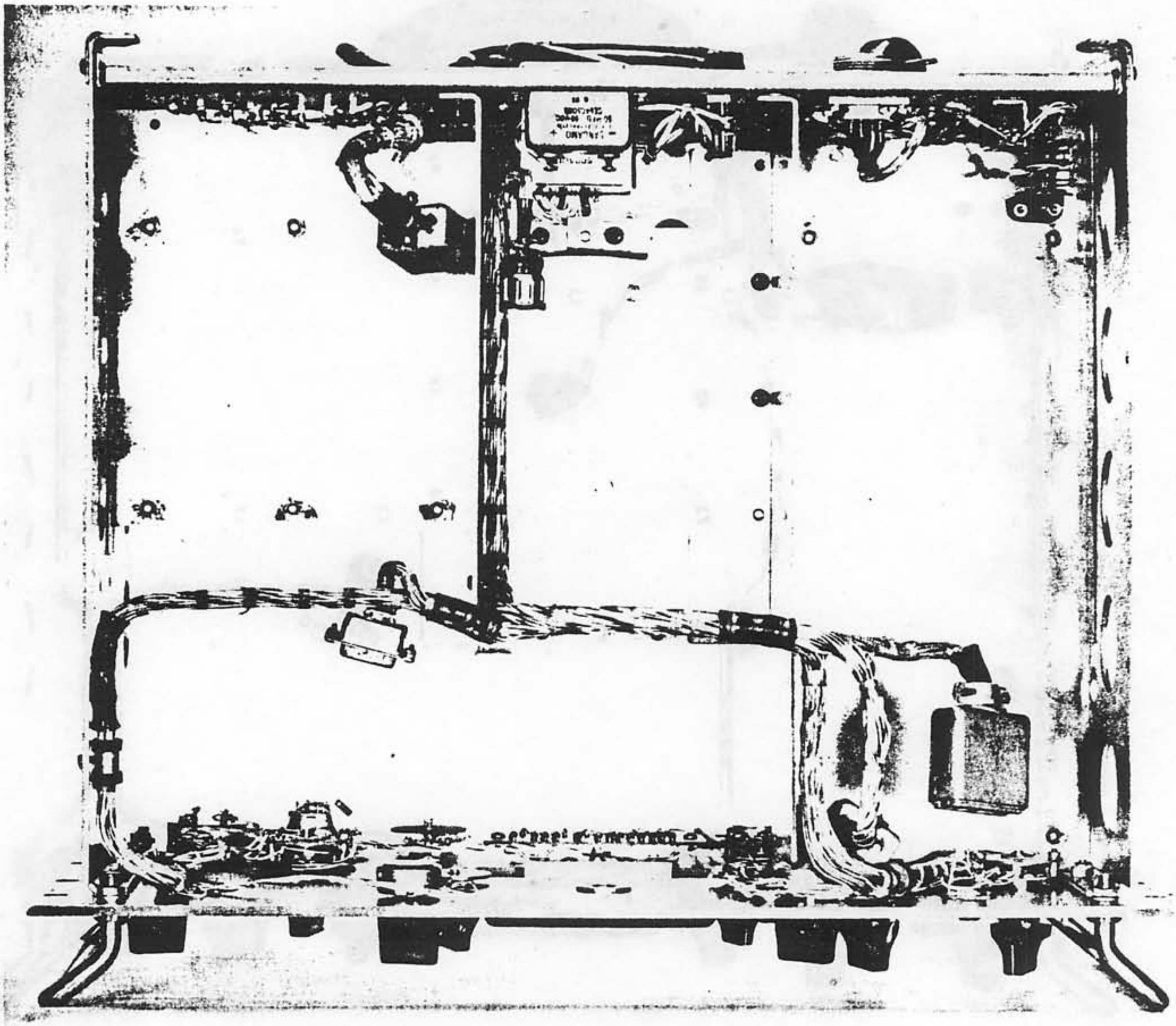

Figure 30 - Radio Receiver R-391(XC-2)/URR, Main Frame, Bottom View

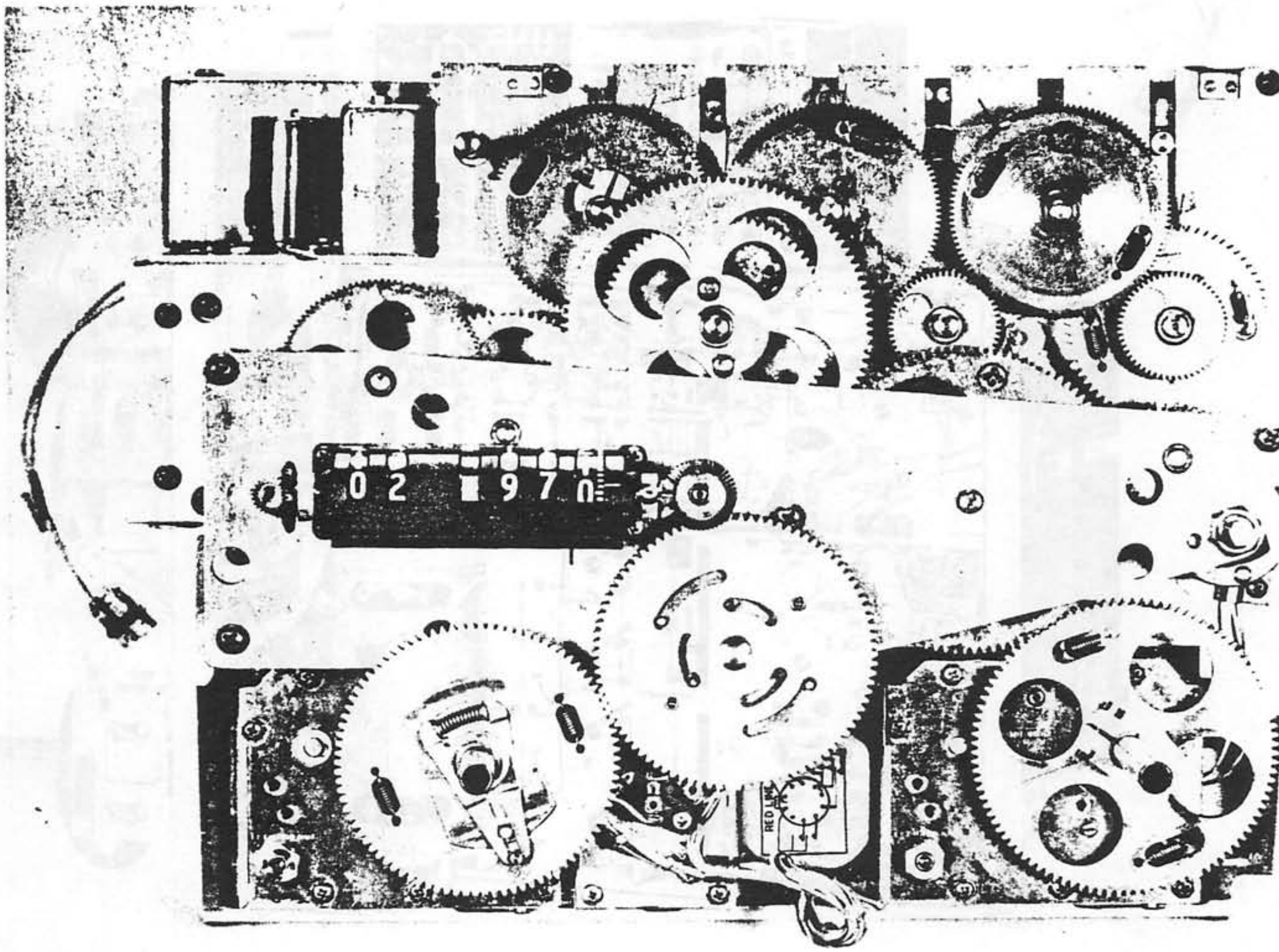

Figure 31 - Radio Receiver R-391(XC-2)/URR, RF Unit, Front View

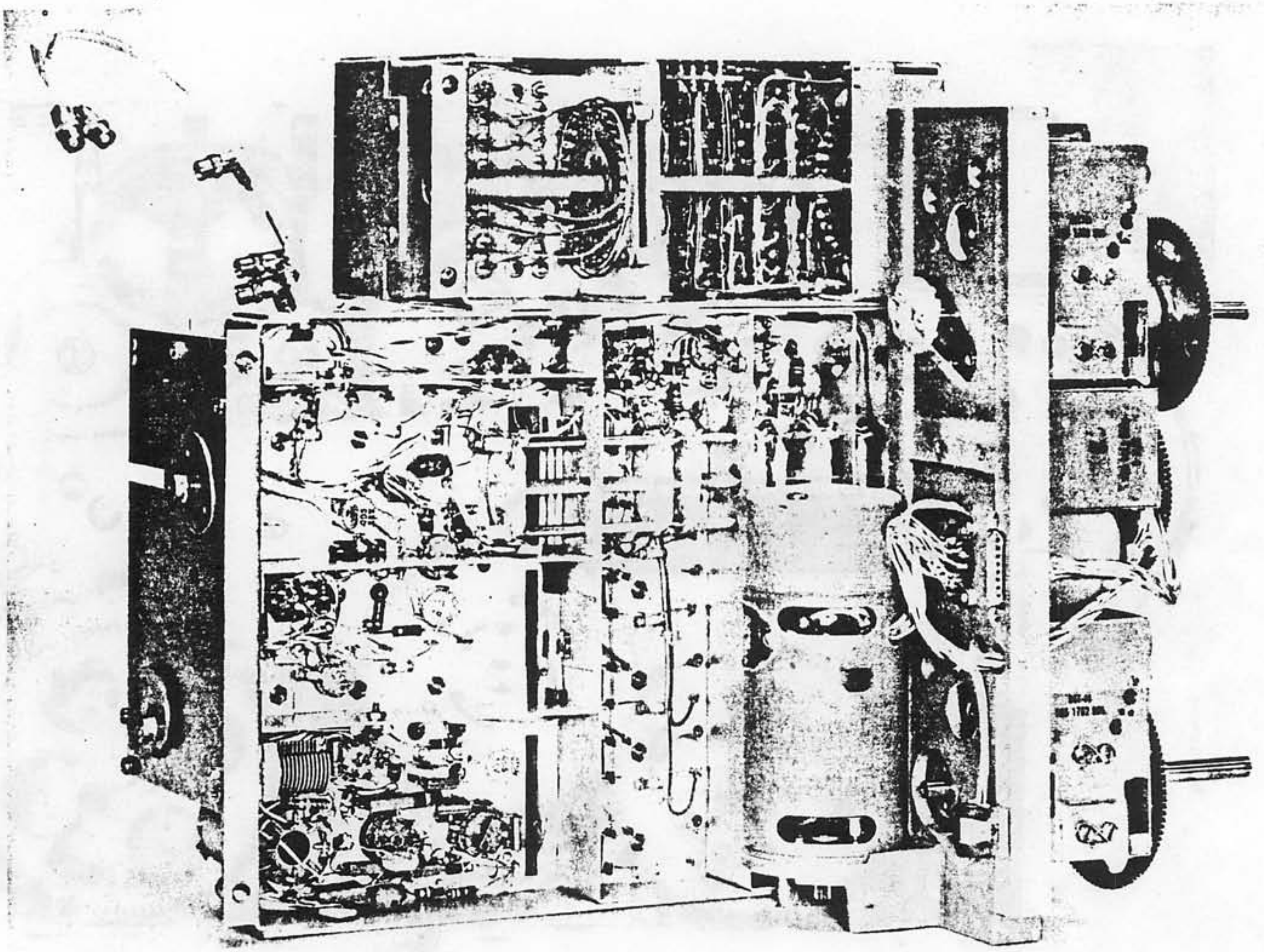

Figure 32 - Radio Receiver R-391(XC-2)/URR, RF Unit, Bottom View

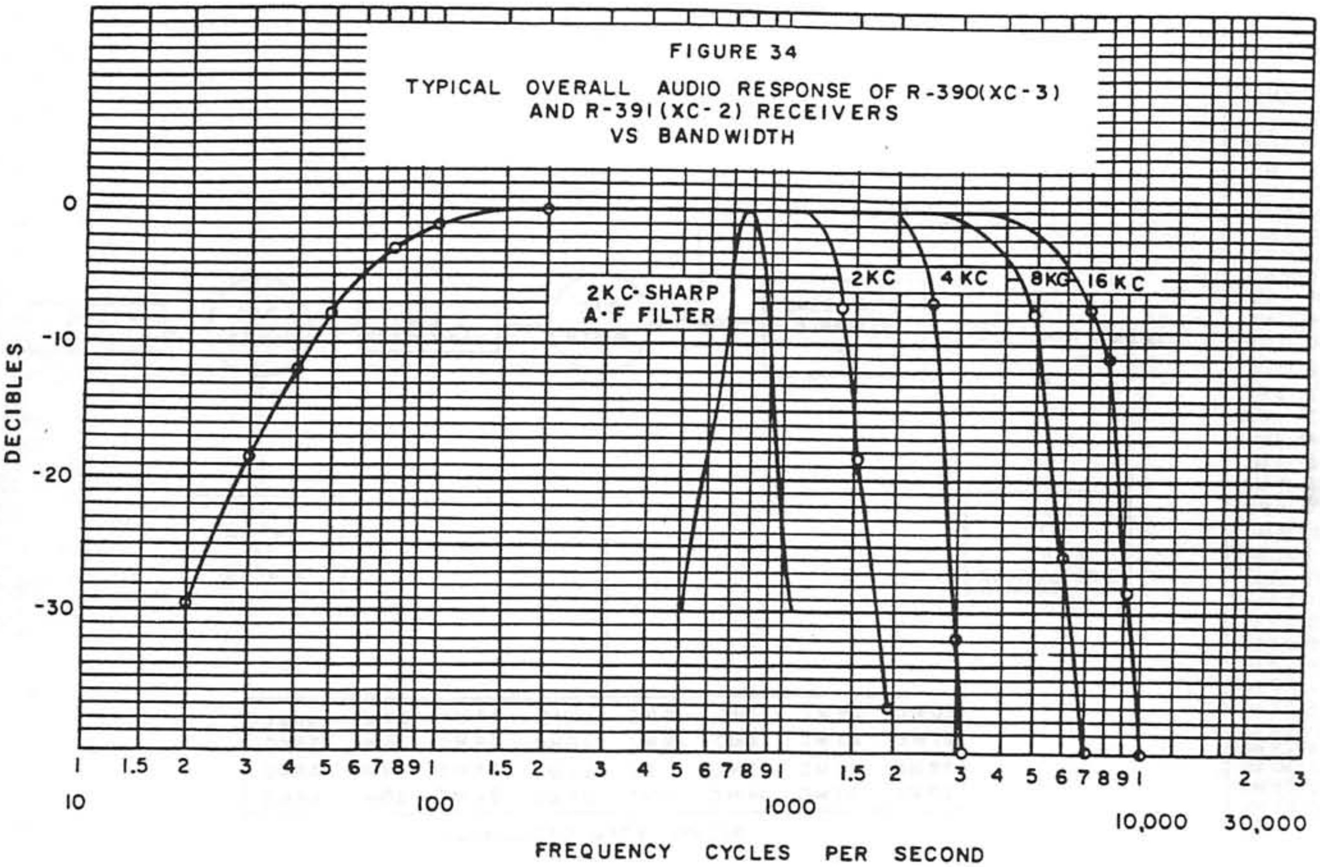

FIGURE 34

TYPICAL OVERALL AUDIO RESPONSE OF R-390(XC-3) AND R-391(XC-2) RECEIVERS VS BANDWIDTH

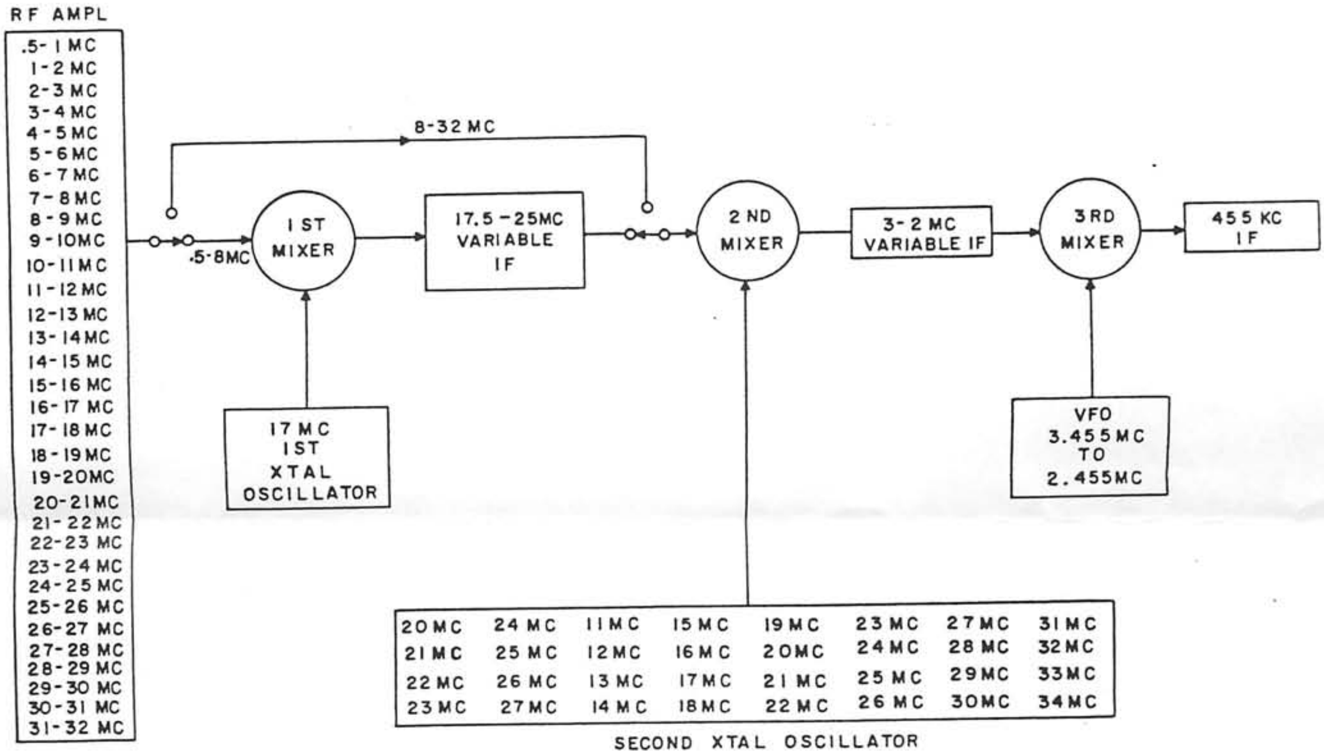

Figure 35 - Frequency Scheme of Receivers R-390(XC-3) and R-391(XC-2)