AD 406 628

- FINAL ENGINEERING REPORT -

RF PREAMPLIFIER AND CONVERTER

FOR TEST AND EVALUATION

This report is prepared for the
Federal Aviation Agency
Systems Research and Development Service

Contract ARDS 609

Dated 20 August 1962

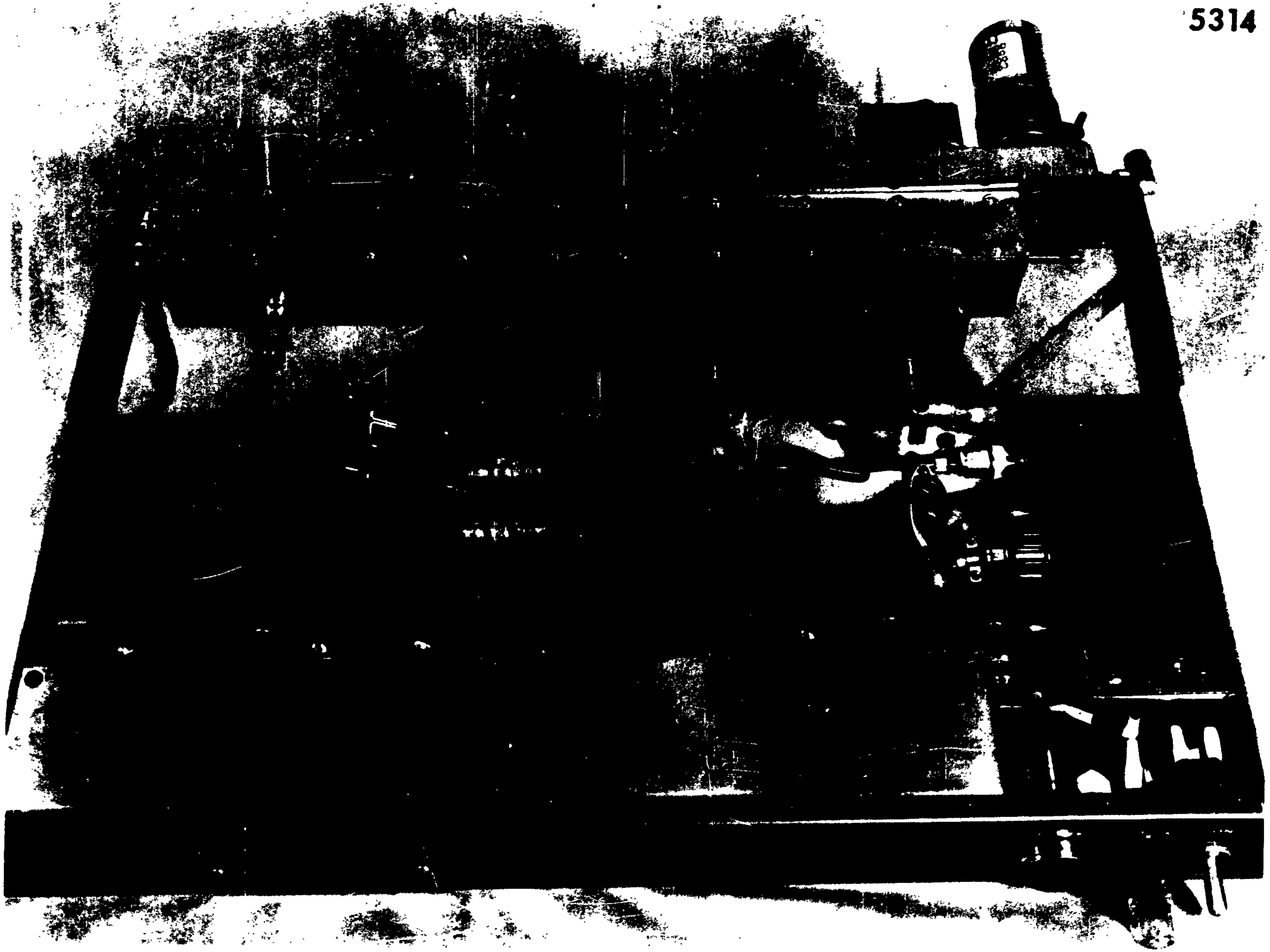
This report has been prepared by American Electronic Laboratories, Inc., for the Systems Research and Development Service, Federal Aviation Agency, under Contract No. ARDS-609. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the views or policy of the FAA.

20 March 1963

American Electronic Laboratories, Inc.
Colmar, Pennsylvania

TABLE OF CONTENTS

5314



RF Preamplifier and Converter (Top Cover Removed)

1. INTRODUCTION

Most presently used VHF fixed tuned receivers in the frequency range of 108 to 152 mc/s do not have the necessary R.F. Bandwidth and skirt selectivity needed to achieve operation with 50 kc channel separation. These receivers may still be utilized by employing the AEL SUPER-SELECT as a preselector. In addition to achieving the necessary R.F. Bandwidth and skirt selectivity the combination of the SUPER-SELECT and the VHF Receiver shows improved noise figure, sensitivity, dynamic range and spurious signal response.

Basically, the SUPER-SELECT is an R.F. Preselector which is inserted between the antenna and the VHF Receiver. It is fixed tuned adjustable over a frequency range of 108 to 152 mc/s. It consists of an R.F. Preselector Filter, R.F. Amplifier, Down-Converter, I.F. Amplifier, Up-Converter, and R.F. Output Filter with Power Supply.

The unit is 14 inches deep and mounted on a size A relay rack panel. The R.F. Amplifier, Converter/I.F. Section, and R.F. Output Filter are contained in a case mounted directly behind the front panel with the R.F. Preselector Filter and Power Supply mounted behind it.

During the course of this program, the R.F. Preselector, R.F. and I.F. Amplifier, Mixer, and Local Oscillator were carefully analyzed and optimum configurations selected which are applicable to this system.

The completed unit conforms to a 1 3/4" high configuration. This height necessitates a scaled-down filter resulting in lower than optimum Q. However, the final unit, as developed, performed in accordance with the basic specifications and established the feasibility of the basic concept.

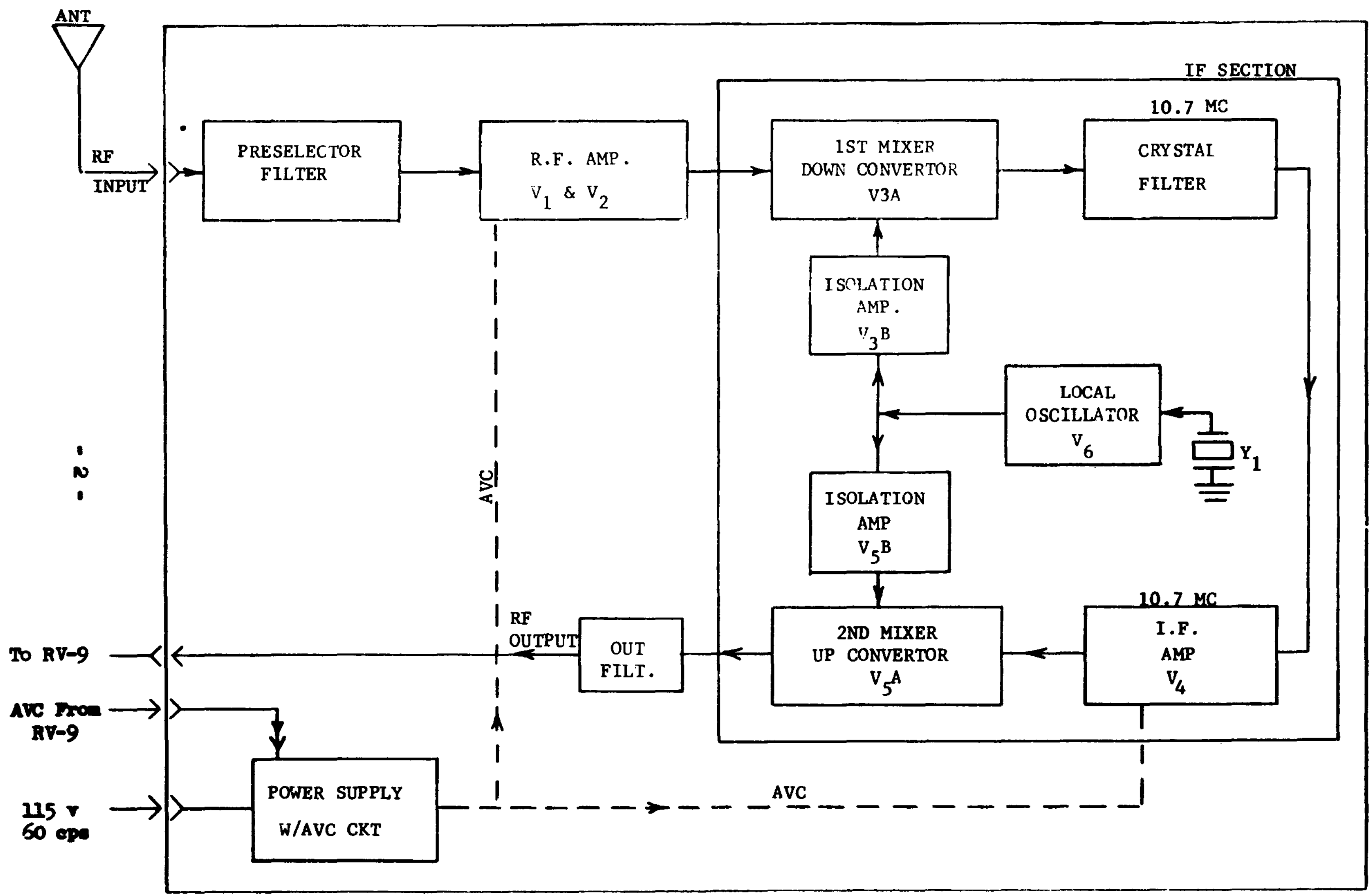


Figure 1. Block Diagram

2. TECHNICAL DETAIL

The design objective was to make a unit to insert between the antenna and a VHF receiver to improve the R.F. selectivity, dynamic range and the spurious signal rejection of that receiver.

This necessitated a high Q filter to precede the R.F. Amplifier to yield low cross modulation as shown in Figure 1 . An R.F. Amplifier with sufficient gain and low noise figure was required. The R.F. Bandwidth reduction to the VHF receiver was best obtained by a down conversion to 10.7 mc and a highly selective crystal filter. Then the signal was up-converted to the original frequency and fed to the receiver.

2.1 R.F. Preselector Filter

2.1.1 Initial Design Specifications

An inexpensive modularized unit was required occupying the maximum dimensions of 4" x 14" x 1 3/4". Two such preselectors would be required for the final FAA unit. Preselector A is the input unit for the R.F. Amplifier. Preselector B is the output unit from the I.F. Amplifier and must have its output match the FAA RV-9 receiver.

The following were preliminary design specifications:

Frequency:	108 to 152 mc (tunable over this range)
Number of Tuned Circuits:	3 or 4 (to reduce cost they should be tuned separately)
Bandwidth:	1 mc/s (or less) @ 3 db 5 mc/s (or less) @ 30 db 21.4 mc/s (or less) @ 60 db
Insertion Loss:	4 db (maximum)
Input Impedance of Preselector A:	50 ohms
Input Impedance of Preselector B:	50 ohms

Output Impedance of Preselector A:	230 ohms (approximately) - match input impedance of R.F. Amplifier tube for low N.F.
Output Impedance of Preselector B:	50 ohms
Connectors:	None, 50 ohms coaxial leads 6" long

The following are some of the concepts for investigation:

(a) Three or four gang-lumped constant preselectors.

(b) Helical resonators, trough cavities, loaded cavities.

2.1.2 Areas of Investigation

(a) Areas of investigation of the lumped constant approach indicated a basic limitation due to unsatisfactory unloaded Q's. The maximum unloaded Q achieved was approximately 400, using heavy silver plated straps as inductors. The following data, based on an unloaded Q of 400, explains the requirement for higher Q circuits.

Insertion Loss	Q (Loaded)
0.5	22
1	41
2	84
3	116
4	148
5	176
6	200

Thus, one can see that in order to achieve a reasonable loaded Q of approximately 150 (to achieve a 1 mc/s 3 db band at 150 mc/s) would entail an insertion loss of over 4 db per tuned section. If one would restrict the insertion loss of each section to 1 db, an unloaded Q of at least three times, or 1200, would have to be achieved. Despite the limitation placed on physical size of 1 3/4" calculations indicated that a Q of 1200 would be feasible if cavity techniques were utilized.

The number of tuned sections has a direct relationship on the selectivity characteristics of the R.F. Preselector. The following theoretical data illustrates this very vividly (Butterworth Coupling).

	BANDWIDTH				
Attenuation Level	1 Section	2 Section	3 Section	4 Section	5 Section
1 db	0.5 mc	0.72 mc	0.8 mc	0.84 mc	0.85 mc
3 db	1.0 mc	1.0 mc	1.0 mc	1.0 mc	1.0 mc
30 db	32 mc	5.6 mc	3.2 mc	2.3 mc	2.0 mc
40 db	100 mc	10 mc	4.7 mc	3.2 mc	2.6 mc
50 db	320 mc	18 mc	6.8 mc	4.3 mc	3.2 mc
60 db	1000 mc	32 mc	10.0 mc	5.6 mc	4.0 mc

In order to achieve reasonable skirt selectivity, a minimum of 3 and preferably 4 tuned circuits should be used. The use of only one tuned circuit at the 30 db attenuation level will permit a received bandwidth of 32 mc, virtually the full VHF communication bandwidth. The use of 3 tuned circuits would decrease this 30 db bandwidth by a factor of 10.

The comparison at the 60 db bandwidth is even more vivid. For all practical purposes, a single section filter has no selectivity at the 60 db bandwidth. A triple section filter would provide 10 mc/s bandwidth.

(b) Helical Resonators

Altogether, 6 various types of helical resonators were designed and constructed. First a fixed tuned section was built to investigate properties of coupling, mid-band insertion loss, and loaded Q.

The unloaded Q has, under 1 3/4" size limit, a finite maximum value which limits the insertion loss and bandwidth.

A three section unit was constructed in which interstage coupling could be varied as well as input and output coupling.

The primary difficulty encountered was, for a given adjustment of coupling, not constant over the tuning range. This necessitated abandoning this configuration.

A two section helical resonator was constructed. By a series of experimental measurements on tap point placement, a point was found where insertion loss was held to a small deviation throughout the frequency range of 108 to 152 mc/s. Coupling between the two coils was adjustable by overlapping the external case for each coil. The 3 db bandwidth was very good, in the order of .5 to .8 mc/s, the 30 db bandwidth was approximately 20.0 mc/s.

(c) Coaxial Re-entrant Cavity

Several designs of this form of filter were tried. The first was a three section cavity which used the middle filter upside down to eliminate feed-thru of the signal. This design gave satisfactory results in the breadboard form. However, when a unit suitable for economic production was built, many problems were encountered with feed-thru, matching sections inductively, and tuning. An ungrounded cover was used to aleviate problems, however, the cover radiated and this had to be abandoned.

A single section cavity, similar to the 3 section cavity, was built using direct coupling taps and a grounded cover. This unit proved quite satisfactory for selectivity.

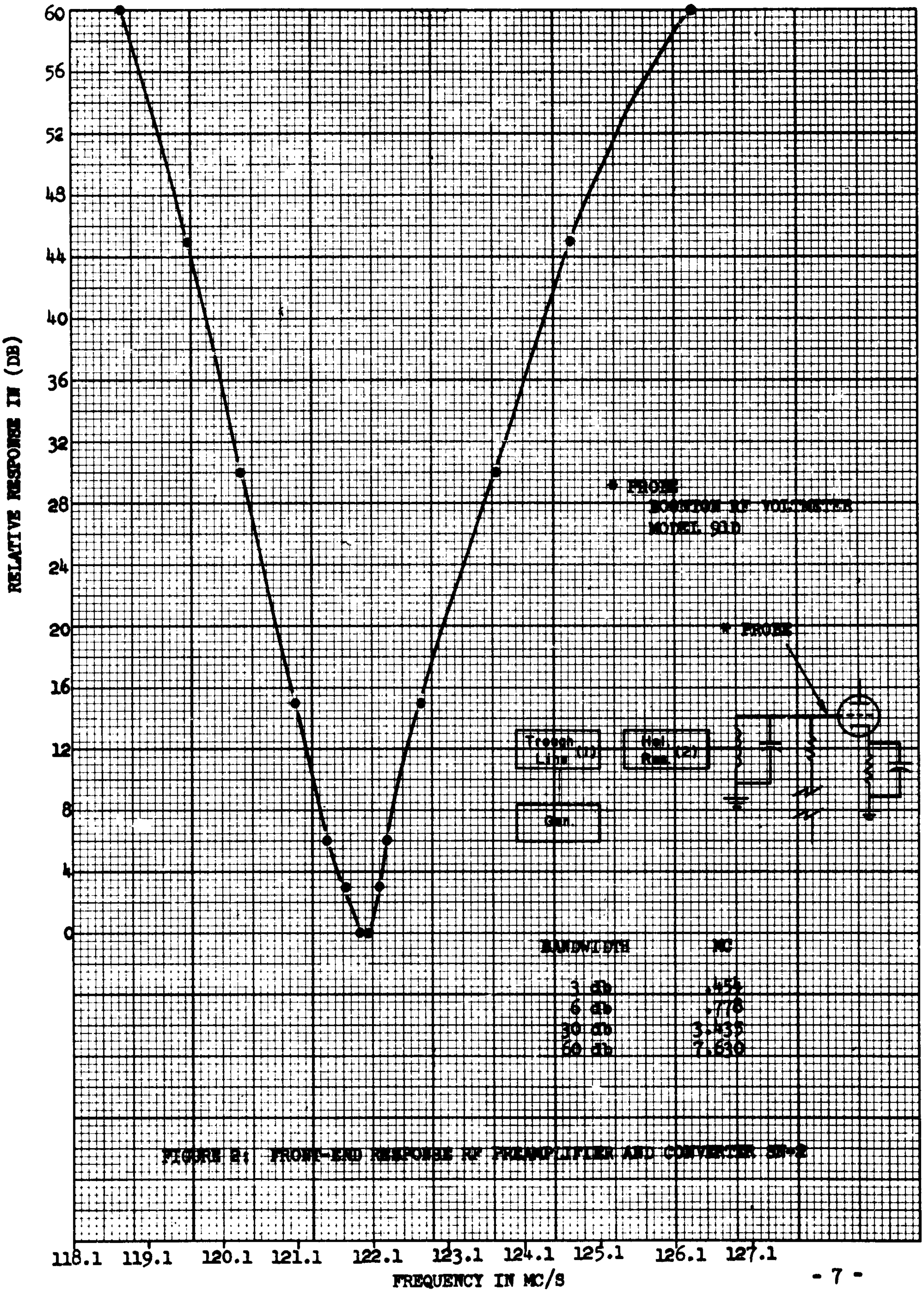


FIGURE 2: FRONT-END RESPONSE RF PREAMPLIFIER AND CONVERTER SN-2

2.1.3 Resolved Design

The finalized unit consisted of a single section coaxial re-entrant cavity and dual helical resonators. The advantages of this combination was that all filters were direct coupled, the cavity gave excellent skirt selectivity, and the helical resonator yielded good 3 db bandwidth. These two units, combined with the single section lumped constant filter in the grid of the R.F. Amplifier, gave an optimum combination for superior cross modulation reduction. Figure 2 is the response of the coaxial cavity, helical resonator, and L/C tank to the grid of the 6DS4 R.F. Amplifier.

2.2 R.F. Amplifier

2.2.1 Initial Design Specifications

A low noise figure vacuum tube amplifier was required with the following preliminary specifications:

Frequency Operating Range:	106 to 155 mc/s
Noise Figure:	4 db (Maximum)
Cross Modulation - Inter Modulation Distortion:	Absolute minimum
AVC:	Provision for external AVC, investigation of possible inclusion of AVC circuitry.
Circuitry:	Cascode, grounded grid, neutralized grounded cathode.
Typical Tubes:	6CW4, 6GK5, 6ER5, 6DJ8, 7962, 6DS4, 7587, 6AJ4, 6AMA, 6ANA, 6BC4, 417A

2.2.2 Areas of Investigation

Many types of R.F. Amplifiers were evaluated, the cascode and neutrode using both capacitive and inductive neutralization were of

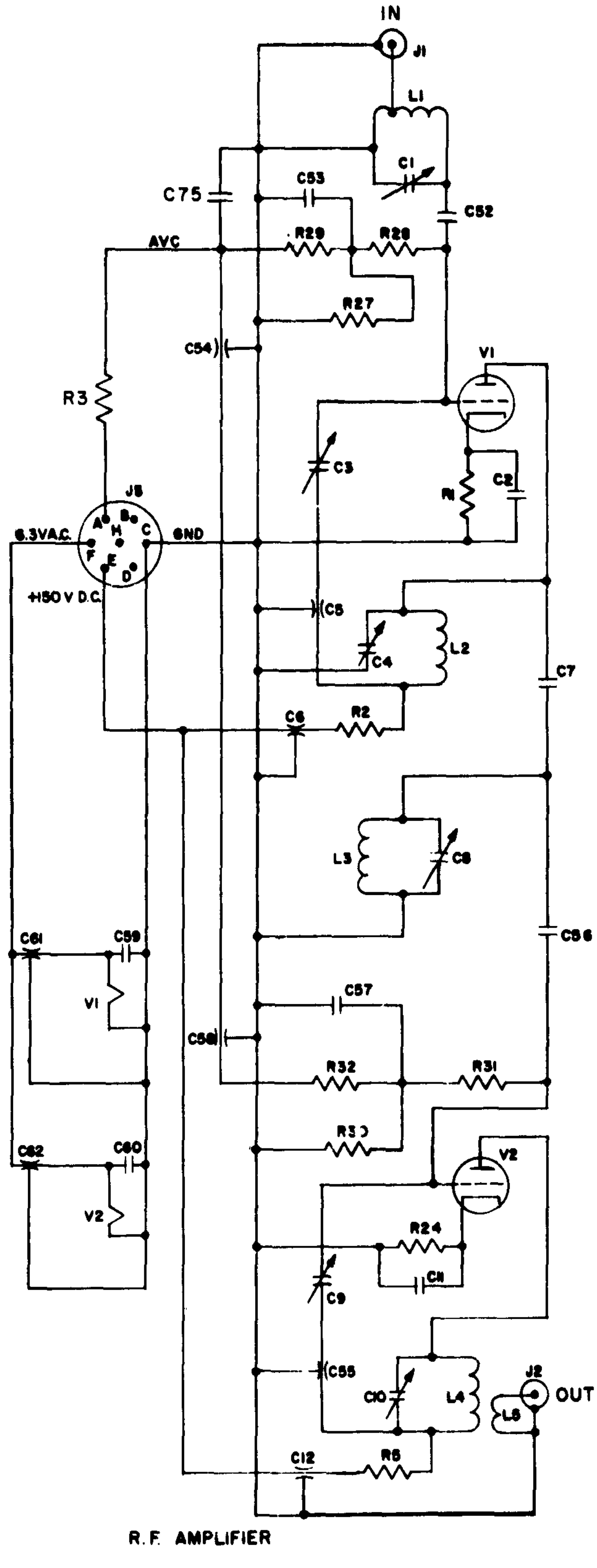


Figure 3. Schematic Diagram - RF Amplifier

primary interest. These two types proved to be the most promising for purposes of this program. Capacitive neutralization was chosen because of the compactness of the amplifier, and a large neutralizing coil was difficult to position so there was no mutual coupling between either the input or output tank and the neutralizing coil. A cascode amplifier has good noise figure and gain in the frequency area concerned, however, a dual cascaded neutrode has better gain with about the same noise figure.

2.2.3 Resolved Design

It was found that the dual neutrode provided more gain and better stability than the cascode. The design appears in Figure 3 . It incorporates a semi-remote cut-off 6DS4 nuvistor for V_1 and a Hi-mu 6CW4 at V_2. The input tank L_1C_1 has a 50 ohm match to the input and is noise-matched to the gain of V_1. R_{28} and R_{29} is an AVC divider network with R_{27} and R_1 setting the self-bias level with no AVC voltage applied. C_3 is the neutralizing capacitor. Tanks C_3L_2 and C_8L_3 provide further isolation to undesired signals. Similar circuitry appears in association with V_2.

2.3 I.F. Section

2.3.1 Down-Converter

2.3.1.1 Initial Design Specifications

First Mixer

Input Frequency:	106 to 155 mc/s
Output Frequency:	10.7 mc/s
Local Oscillator Input:	95.3 to 144.3 mc/s
Input to Mixer:	Double-tuned circuit
Typical Tubes:	6EA8, 6JC8, 6FG7, 6DJ8, 6CW4

Conversion Loss: 6 to 10 db

2.3.1.2 Areas of Investigation

Some of the techniques investigated here were a pentode mixer, a balanced triode modulator, and a beam switching tube.

The first pentode mixer tried was a 6U8 using signal and oscillator injection on the first grid. This tube did not have as good conversion gain and noise figure as required. Next, a 6BL8 and a 6EA8 were tried. The 6EA8 was slightly better than the 6BL8 and much improved over the 6U8. A dual purpose triode, pentode was chosen so that a L.O. isolation amplifier could be used with a minimum of envelopes.

A balanced mixer was tried using a 12AV7 dual triode. This appeared to be the most promising of the mixers and provided the additional advantage that the L.O. signal present in the I.F. was surpressed. However, the anticipated I.F. Strip offered excess attenuation to the L.O. and it was decided that a trade-off for an extra triode in the same envelope would be more useful in the circuitry.

Beam switching tubes operating above 100 mc were not available, and it was decided, therefore, that this type would be a border line design.

2.3.1.3 Resolved Design

The 6EA8 was chosen as the best suited triode-pentode, being just slightly better than the 6BL8. The circuit used appears in Figure 4 . The input tank is composed of L6, L7, C13, and is variable from 108 to 152 mc/s. The L.O. signal is injected between C14 and the grid. V3A is the pentode section of the 6EA8. The plate load is the primary side of a 10.7 mc I.F. transformer.

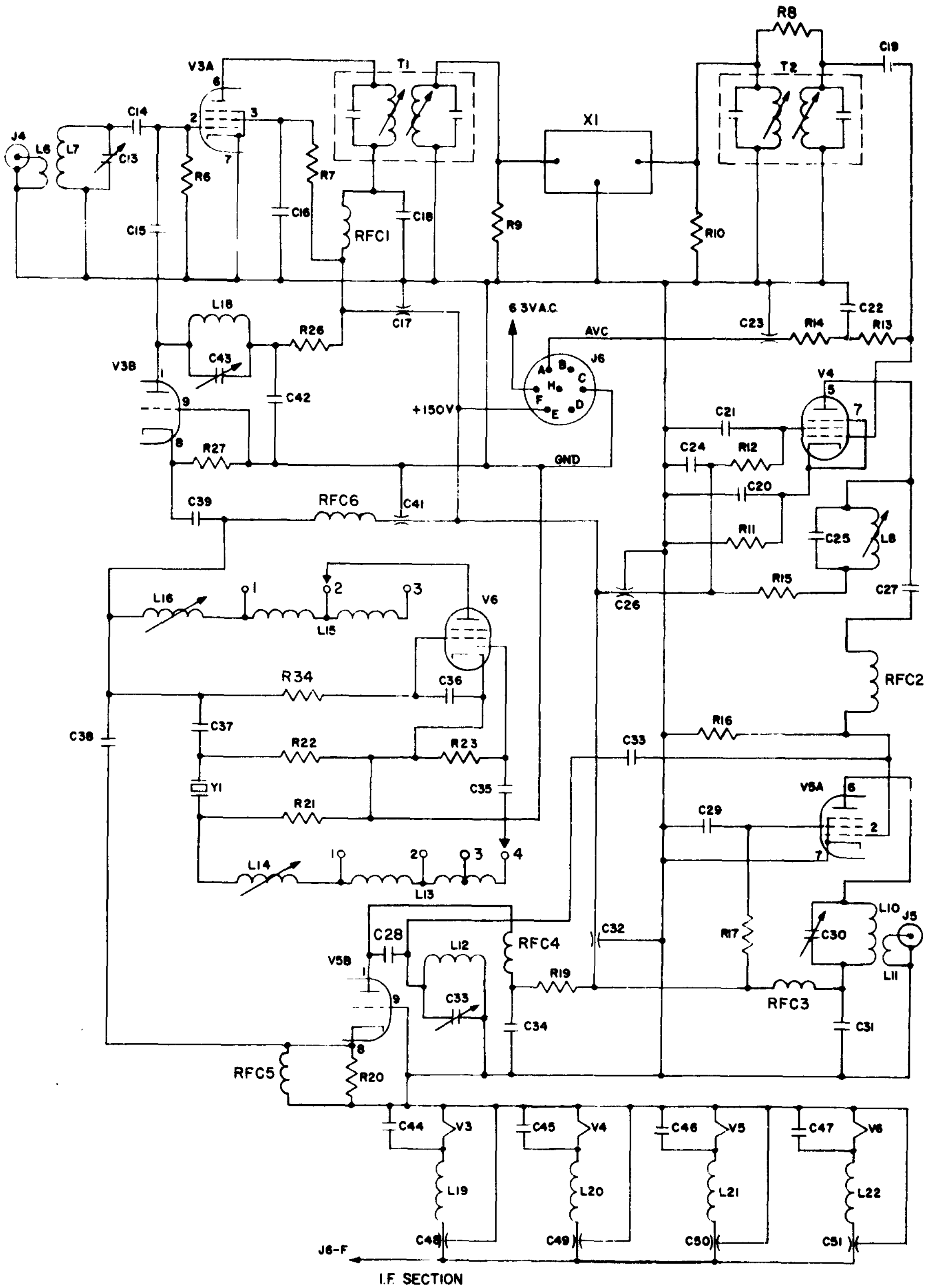


Figure 4. I. F. Section Schematic

2.3.2 Local Oscillator

2.3.2.1 Initial Design Specifications

Local Oscillator

Crystal:	7th overtone
Output:	Single tuned circuit coupled to two tuned circuits providing dual output to first and second mixer.
Typical Tube:	6CW4, 6AK5

2.3.2.2 Areas of Investigation

An oscillator injection frequency of 97.3 to 141.3 was required. Two types could be used here, a third overtone crystal and tripling or a 7th overtone. Due to the additional circuitry involved using a tripler, it was decided that a 7th overtone crystal would be more suitable. Of the few manufacturers that make 7th overtone crystals, all recommended only one type of circuit so this design was selected. During the development one problem arose due to the series resonant circuit in the grid and plate circuit. The variable inductor would not tune throughout the 97.3 to 141.3 range. Further development resulted in the use of tapped inductors in the grid and plate circuits.

Due to the inherent low drive level available from a 7th overtone crystal, it was necessary to use a triode amplifier to increase the L.O. level available at the mixer. This dictated the use of a triode-pentode combination as a choice of mixer tubes. A grounded grid configuration for the triode amplifier was used to provide better isolation to the incoming received signal frequency. A tunable tank was included in the plate to provide optimum L.O. level and to provide further isolation to the received frequency.

2.3.2.3 Resolved Design

The circuit in Figure 4 contains the local oscillator and triode isolation amplifiers. Tube V6 is a 6AK5 pentode. L13, L14, C35 and the tube capacity make up the grid tuned circuit, while L16, L15, C38, and C39 adjust the plate tuned frequency. The isolation stage V3B is a cathode drive grounded grid 6EA8. L18, C43 is tunable to the oscillator frequency V5B has similar associated circuitry.

2.3.3 I.F. Amplifier/Filter

2.3.3.1 Initial Design Specifications

I.F. Amplifier

Input:	Crystal filter
Output:	Double or single tuned circuit
Noise Frequency:	Minimum
Gain:	10 db (approximately)
Typical Tubes:	6AK5

2.3.3.2 Areas of Investigation

The crystal filter was an obvious choice since lumped constant filter would never accomplish the desired form factor without a prohibitive number of circuits.

2.3.3.3 Resolved Design

A crystal filter was chosen to operate at 10.7 mc/s with a 6/60 db bandwidth of 36/72 KC. R9, R10 in Figure 4 are the matching load resistors for the filter chosen to reduce the passband ripple and loss to a minimum. A semi-remote cut-off pentode V4 was required for an AGC controlled I.F. Amplifier. After investigation of many I.F. Amplifiers, the 6BZ6 was chosen as the best adapted to our circuit. Resistors

R13 and R14 set the AGC level from the RV-9, L8, and C25 for a tuned circuit at 10.7 mc/s

2.3.4 Up-Converter

2.3.4.1 Initial Design Specifications

Second Mixer

Input Frequency:	10.7 mc/s
Output Frequency:	106 to 155 mc/s
Local Oscillator Input:	95.3 to 144.3 mc/s
Input:	From I.F. Amplifier output tuned circuit.
Output:	To HF output preselector
Circuit:	Balanced Mixer to decrease L.O. leakage.
L.O. Rejection:	100 db
Typical Tubes:	6EA8, 6CW4, 6DS4, 6FC8, 6FG7

2.3.4.2 Areas of Investigation

The investigation of the Up-Converter and Down-Converter was identical. See Paragraph 2.3.1.2.

2.3.4.3 Resolved Design

Refer to Figure 4 . It was necessary to provide a high impedance load for the local oscillator to keep enough level at the mixer, hence the tank L9, C28 tuned to the oscillator frequency. The Up-Converter is basically like the Down-Converter. V5A is a 6EA8 pentode section. L10, C30 from a tank tunable to the output frequency.

2.3.5 Output R.F. Filter

A filter to remove the local oscillator to at least a 100 db level was necessary. Two tuned tanks are used to accomplish this. These tanks are tuned to the output frequency. Also, it is necessary to attenuate the noise output of the I.F. section (mixers and I.F. Amplifier) so as to maintain the sensitivity of the VHF Receiver. The output filter was made lossy to accomplish this, therefore, the insertion loss is set at 30 db.

3. CONCLUSIONS

The basic feasibility of the unit has been established and found to have satisfactory performance. All components and techniques could be made to meet low cost production standards. The limitation of a physical height of 1 3/4" prevented the use of large resonators with the resulting higher Q in the R.F. input filter.

It is felt that the RF Preselector will provide improved reception and should find wide acceptance. For many applications, the use of the RF Preselector and RF Amplifier might suffice. Certainly the use of higher Q preselectors and low noise figure preamplifier would be highly desirable.