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PHASE AND GAIN MATCHED TWO-CHANNEL RECEIVER WITH SIGNAL SELECTION BY LOCAL OSCILLATOR TUNING ONLY

by

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1 May 1956

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ABSTRACT

The principles of a matched-channel receiver for RDF applications are described wherein the incoming signal selection is made by local oscillator tuning only. This is accomplished by: (1) making the maximum--frequency-to-minimum-frequency ratio for any one band small, 1.525 in this case, (2) using the double superheterodyne principle, (3) selecting the first IF to give good image rejection, and (4) using a staggered-tuned RF amplifier with good skirt selectivity. By this scheme the frequency range 2 to 25 mc may be covered in six bands, although the receiver was made to work on only the 7.09 to 10.8 mc band. It is believed that a matched-channel receiver using these principles can be built and adjusted more easily than one using more conventional design.

Several of the design problems are discussed, especially those dealing with the input circuit and phase and gain matching. Some of these problems led to other reports, which are referenced. The design data and circuits for various parts of the receiver are given.

The receiver was a laboratory model not suitable for field testing. Laboratory tests indicate that the receiver is feasible in principle.

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ACKNOWLEDGMENT

FOREWORD

Most of the work leading to this report was performed under Contract N6 ori 07115. Since the work under Contract Nonr 1834(02) is a continuation of the work started under N6 ori 07115, this report is being issued under the new contract.

The receiver described in this report is a laboratory model which is not suitable for use as an operational receiver. Several laboratory tests were made which indicate that it is feasible in principle.

The purpose of this report is to point out and discuss some of the problems that arose during the design and testing of the various parts of the receiver. In many cases solutions to the problems were found, and these solutions are also pointed out and discussed or referenced. Some of the problems are discussed in reports previously issued under Contract N6 ori 07115, as is pointed out in the text.

The receiver described fits into some of the plans for future work under Nonr 1834(02). It is readily adaptable to a frequency-scanned type of RDF receiver because only the local oscillator need be varied.

1. INTRODUCTION

A radio direction finding (RDF) system which meets the requirement of an omnidirectional, instantaneous system is the Watson-Watt, or twin-channel cathode ray, direction finder. The principle of this system is well known, but for reference a block diagram is shown in Fig. 1.

In this system the difference signal from the north-south antenna pair is fed to a receiving channel, referred to as the NS channel, and the difference signal from the east-west antenna pair is fed to a second receiving channel, referred to as the EW channel. The outputs from the two receiving channels, at an intermediate frequency, are respectively fed to the vertical and horizontal deflection plates of a cathode ray tube. If the two receiving channels are matched in gain and phase, the CRT deflection for a single arriving signal component at one frequency will be a straight line, and an angular scale around the face of the CRT is used to read off the indicated direction of arrival. (The wave interference case, which, in general, gives an elliptical CRT deflection, need not be considered here.)

Designing and building radio receivers that are matched in gain and phase over a band of frequencies and that maintain the phase and gain match over a period of time is a difficult problem. Several of the factors that affect the design are described in Technical Report No. 21.[1] Among these are: (1) the effective capacitances, inductances, and resistances of corresponding stages in the channels must be made, as nearly as possible, respectively equal, i.e., $C = C$, $L = L$, and $R = R$ for each corresponding stage pair; (2) if the center frequencies of the two channels are made the same, the matching is less critical; (3) low Q circuits are more easily matched over a given frequency range than high Q circuits. From the second of these points it may be inferred that amplifiers with fixed center frequencies are more easily matched than amplifiers with variable center frequencies. From practical reasoning, it is easy to see that matching over a range of variable-tuned center frequencies would require very close tracking of the variable elements, which would probably be the variable capacitors. From other practical reasoning it is seen that large capacitances are desirable, since then the small changes in capacitance due to small changes within vacuum tubes, or replacement of vacuum tubes, would be a smaller percent of the total capacitance than would be the case for small values of tuning capacitance.
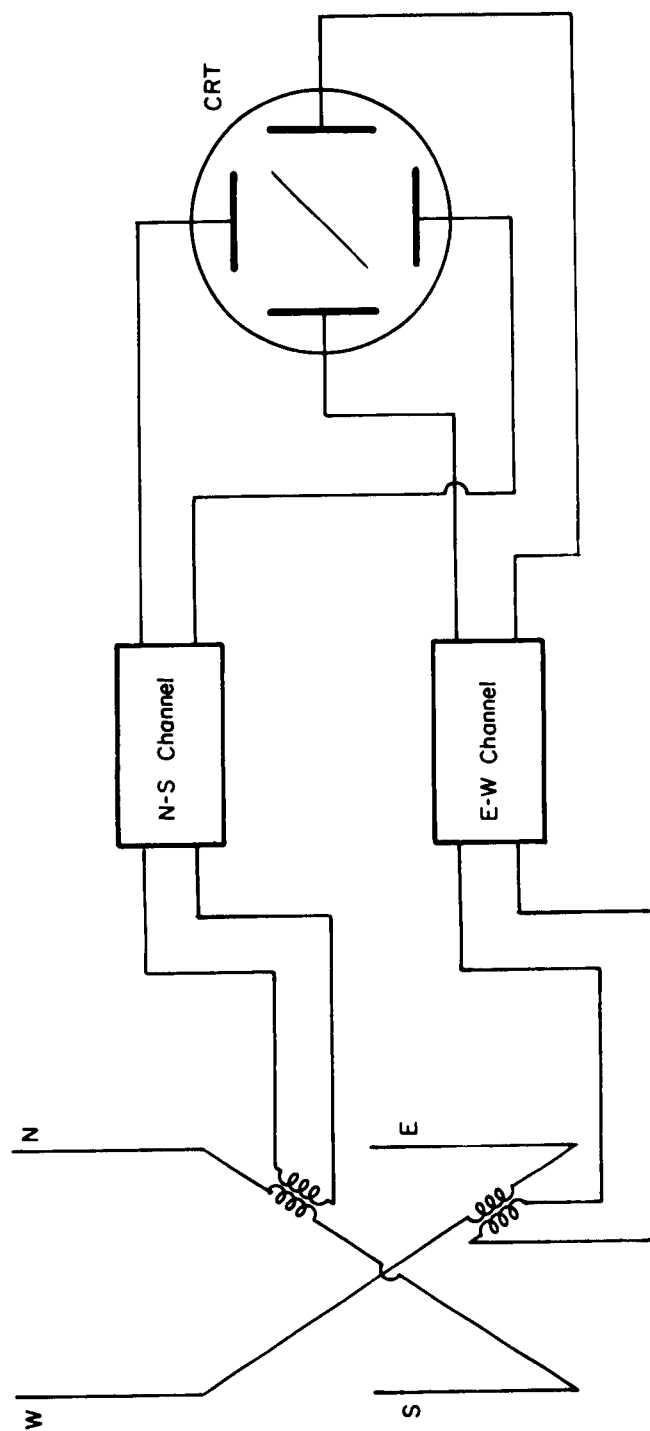
Figure 1. Watson-Watt RDF System

If a receiver could be built without variable-tuned RF amplifiers, it would seem that many of the matched channel receiver problems would be eliminated. The receiver described in this report is based on this principle. The manner in which the receiver operates can be explained by reference to Fig. 2, a block diagram of a proposed receiver which has been published earlier.[2] The principle was first mentioned in Report No. DF 15 on Project N6-ori-07115.[3] The RF selectivity for each channel is obtained from the staggered triplet, which is fixed-tuned to cover a bandwidth between half-power points given by the ratio $f_{max}/f_{min} = 1.525$, where f_{max} and f_{min} represent the upper and lower half-power frequencies of the staggered triplet in a given band. These frequencies are related to the center frequency for a given band, f_0, by the relation $f_{max} \times f_{min} = f_0{}^2$. With the staggered triplet design, the skirt selectivity defined as the 30 db down bandwidth divided by the 3 db down bandwidth is 3.2 as compared to a skirt selectivity of 5.9 for three synchronously tuned stages having the same overall bandwidth. By a proper selection of the first IF, a good image rejection ratio and a low amount of first IF feed-through can be obtained. Good image rejection ratio requires a large first IF, but a large first IF may occur at such a frequency that it will not be appreciably suppressed by the staggered triplet. The first IF center frequencies are, to a certain extent, a compromise between these conditions. The first IF must be selective enough to keep the RF and first local oscillator signals from being presented to the second mixer grid in sufficient amounts to cause undesired outputs from these frequencies. The 456 kc IF was chosen because it is a standard frequency for this application. The overall receiver selectivity is obtained mainly in the second IF amplifier.

The overall design presented many problems in phase and gain match-ing, spurious frequency responses, and phase and gain stability. These problems will be discussed in later sections.

Although the work began on this receiver in 1950, it has not been a continuous project. There have been several delays and interruptions for various reasons. One reason has been the various sideline projects that have come about as a result of the work on this receiver. Some of the sideline projects have resulted in reports,[4,5,6,7] and some have resulted in publications.[8,9,10] Also, several of the principles and devices learned and developed in connection with this receiver were put into practice in the matched three-channel receiver designed and built

Figure 2. Block Diagram of the Original Receiver, with Only Local Oscillator Tuning. Frequencies for the fourth band to cover 2-25 mc in six bands are shown.

for use at the University of Illinois RDF station and described in Technical Reports Nos. 18 and 23.[11,12] Thus it is seen that the receiver described in this report has been a sort of research laboratory in itself.

2. EARLY EXPERIMENTS

The first model receiver based on the block diagram of Fig 1 was built on a standard sheet metal chassis, 13 × 17 × 4 inches, with three channels approximately 5½ inches wide across the 13 inch dimension. Two channels were for the amplifiers and one was for the local oscillator and buffers. Sheet metal shields were placed across the socket for each tube. Band switching was accomplished by means of ceramic wafer switches, with six wafers switched by one control knob. The staggered triplet, first mixer, first IF amplifier, second mixer, and second IF output were placed on this chassis, as were the two local oscillators and associated buffer stages.

This amplifier was not successful, but some lessons were learned: (1) for a double superheterodyne, shielding of very high quality is required for both oscillators; (2) the type of mechanical construction used here was not adequate for the necessary stability; and (3) with the type of structure used, phase and gain matching was impossible

3. DESCRIPTION OF THE RECEIVER

With the experience learned in early attempts, it was decided to build a second model with much more rugged mechanical construction. Small unit chassis, 2 × 5 × 5½ inches, were available on the surplus market. These had wafer switches and components for six bands. It was therefore decided to plan the second model with unit stages, using six bands and wafer-type band switching. Due to difficulties mentioned in a later section, the wafer band switching was abandoned. Turret switching could have been used successfully, but, since the purpose of this receiver is to demonstrate that a matched channel receiver with fixed RF amplifier tuning is feasible, it was felt that band switching was not a requirement for the purpose intended.

3.1 Chassis Construction

The chassis was constructed in a manner that made it easy to remove individual stages. The overall dimensions were 28½ × 22½ × 8 inches. The framework was made with one quarter inch brass bars of various widths from one quarter inch to one inch. The chassis was divided into three channels 28½ inches long. The two side channels were for the receiver amplifiers. These were eight inches wide, and were made so that the individual stage boxes could be conveniently and securely mounted. The boxes were mounted with the wafer switch centers arranged coaxially, so that the wafers could be switched with one control rod. The center channel, six inches wide, was used for mounting the individual boxes for the local oscillators and buffer stages.

With the style of construction described, individual stages could be easily added, within the physical limits available, or removed, for adjustment or modification. This feature is highly desirable in an experimental receiver, especially one that is to be adjusted for phase and gain balance.

3.2 Staggered Triplet Design

Maximally flat staggered triplets were used, with the half-power points for each band at the f_{max} and f_{min} points. Since the design methods for such stages are well known,[13] only the design data are given here in Table 1. Table 2 shows the RF, IF, and local oscillator design data. The first IF amplifier center frequencies were arrived at on the

Staggered Triplet Design per Stage

Band	RF Amplifier Center Frequency (mc)	RF Amplifier Frequency Limits		Center Frequencies			Effective Capacitances			Effective Inductances			Effective R's		
		f_{max} (mc)	f_{min} (mc)	f_1 (mc)	f_2 (mc)	f_3 (mc)	C_1 (μμf)	C_2 (μμf)	C_3 (μμf)	L_1 (μh)	L_2 (μh)	L_3 (μh)	R_1 (ohms)	R_2 (ohms)	R_3 (ohms)
A	2.47	3.05	2.0	2.08	2.47	2.94	162.0	175.0	188.0	36.1	23.7	15.5	2240	865	1370
B	3.76	4.65	3.05	3.16	3.76	4.48	107.0	115.0	124.0	23.7	15.5	10.2	2240	865	1370
C	5.73	7.09	4.65	4.81	5.73	6.82	70.5	75.6	81.3	15.5	10.2	6.70	2240	865	1370
D	8.74	10.80	7.09	7.34	8.74	10.4	46.2	49.5	53.2	10.2	6.70	4.40	2240	865	1370
E	13.3	16.5	10.8	11.2	13.3	15.9	30.2	32.4	34.8	6.70	4.40	2.89	2240	865	1370
F	20.4	25.2	16.5	17.2	20.4	24.3	19.5	21.0	22.6	4.40	2.89	1.90	2240	865	1370

Table 1. Staggered Triplet Design Data for the Six Bands The R's, L's, and C's are chosen on the basis of the same gain from band to band.

Band	RF Amplifier Frequency Range		RF Amplifier Center Frequency (mc)	First Local Oscillator Frequency Range (mc)	First IF Amplifier Center Frequency (mc)	Second Local Oscillator Frequency (mc)	Second IF Amplifier Center Frequency (mc)
	f_{min} (mc)	f_{max} (mc)					
A	2.0	3.05	2.47	3.21- 4.26	1.21	1.666	0.456
B	3.05	4.65	3.76	5.15- 6.75	2.10	2.556	0.456
C	4.65	7.09	5.73	8.05-10.49	3.40	3.856	0.456
D	7.09	10.8	8.74	12.49-16.20	5.40	5.856	0.456
E	10.8	16.5	13.3	19.3 -25.0	8.50	8.956	0.456
F	16.5	25.2	20.4	29.8 -38.5	13.30	13.756	0.456

Table 2. Various Frequencies Used in the Receiver Design

basis of 30 db or more image rejection, based on a calculated response curve. The calculated response curve for the staggered triplet is shown in Fig. 3. The skirt selectivity, defined as the ratio of the bandwidth 30 db down to the bandwidth 3 db down, is 3.2.

Better skirt selectivity could have been obtained by means of other filter devices, such as, for example, double-tuned transformers. The staggered triplets were chosen because corresponding stages can be phase and gain matched much more easily than transformers, as is pointed out in Technical Report No. 21.[1] The phase and gain match was accomplished fairly easily by making the respective R's, L's, and C's of corresponding stages as nearly the same as seemed feasible. The adjustments did not maintain the phase and gain match over long time periods chiefly because of the change in component characteristics with temperature. Maintaining the phase and gain match does require precision components with good temperature coefficients. Also, vacuum tube aging will result in changes in the characteristics of the associated tuned circuits, chiefly due to changes in the effective capacitances that the tubes present to the tuned circuit. One sort of capacitance effect is due to a combination of space charge effect and Miller effect. The capacitance due to this cause can be eliminated by using a proper value of unbypassed cathode resistor.[12]

The input tube for the staggered-triplet was a 6BQ7, and the next two tubes were 6AH6's. The tuned circuits for the triplets were in the plate circuits for these tubes. The circuit diagram for the staggered triplet section is shown in Fig. 4.

The half power frequencies are
7.09 mc and 10.8 mc. The
calculations assume that Q is
constant over the band.

Amplitude Response in db.

Frequency in mc.

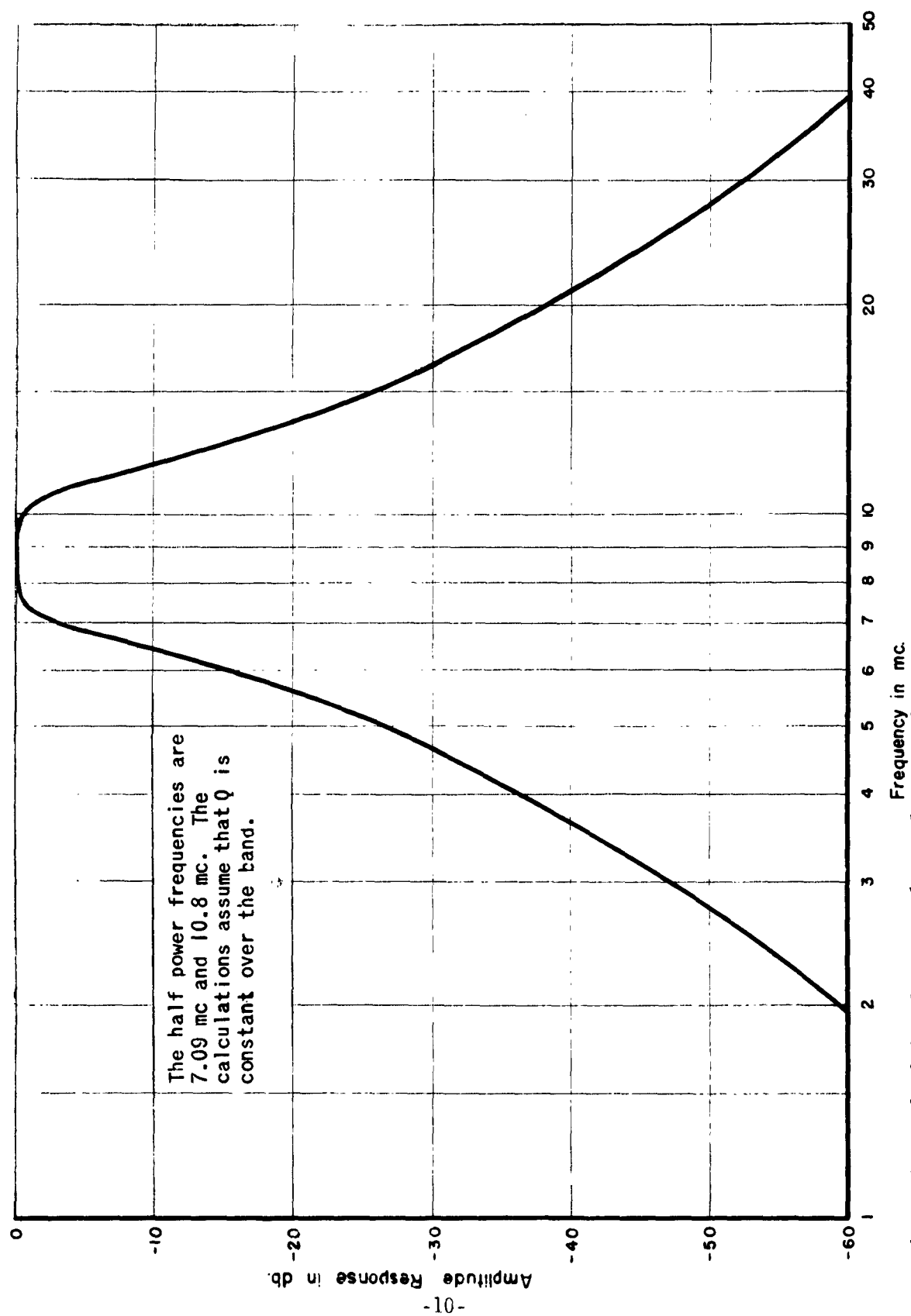Figure 3. Calculated Response Curve for a Maximally Flat Staggered Triplet, for $f_o = 8.74$ mc and $Q = 2.37$.

Figure 4. Circuit Diagram of the Staggered-Triplet Section for one Band of One Channel

NOTE: Effective values for $L_1, L_2, L_3, C_1, C_2, C_3, R_1, R_2,$ and R_3 are given in Table I.

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3.3 First Mixer, Local Oscillator, and Buffer

One of the most serious problems encountered in the development of this receiver was the spurious response problem. The spurious responses resulted chiefly from mixer action on undesired harmonics of the local oscillators and from product terms of higher degree than two in the mixer action. As a result of this problem a mixer design was worked out whereby the spurious responses due to harmonics of the local oscillator signal and higher order mixer products are considerably reduced.

Making the gain control operate in such a manner that the phase and gain match of the receiving channels is not appreciably affected by gain control setting was another serious problem. This problem was solved by varying the magnitude of the local oscillator injection to the mixers. This is possible because the IF portion of the output of a mixer is proportional to the product of the RF signal fed into the signal grid and the local oscillator signal fed into the local oscillator grid, if higher order terms are neglected. Varying the local oscillator signal causes the IF portion of the mixer output to vary accordingly. Since the same signal is fed to the mixers in both channels, the same gain control can be effected in each channel, provided that the higher order terms due to mixer action are suppressed.

In order to obtain the required type of mixer action, the mixer tubes are made to operate in such a manner that the mixer transconductance as a function of time is very nearly a sine wave. The manner in which the gain control operation and this type of mixer operation are accomplished is described in Technical Report No. 17.[4] The circuit diagram of the mixer and its input buffer stage is shown in Fig 5.

The gain control originally planned was a resistance ladder type network. It was placed in the output side of the buffer preceding the mixer. The buffer was included to give good isolation for the gain control. The resistance gain control was unsatisfactory from the phase and gain matching standpoint because of the variations of the resistances with temperature and because of the distributed capacitances between the resistors and the mounting. When the ladder-type gain control was removed, the buffer was left in so that the mixer would not affect the response shape of the staggered triplet.
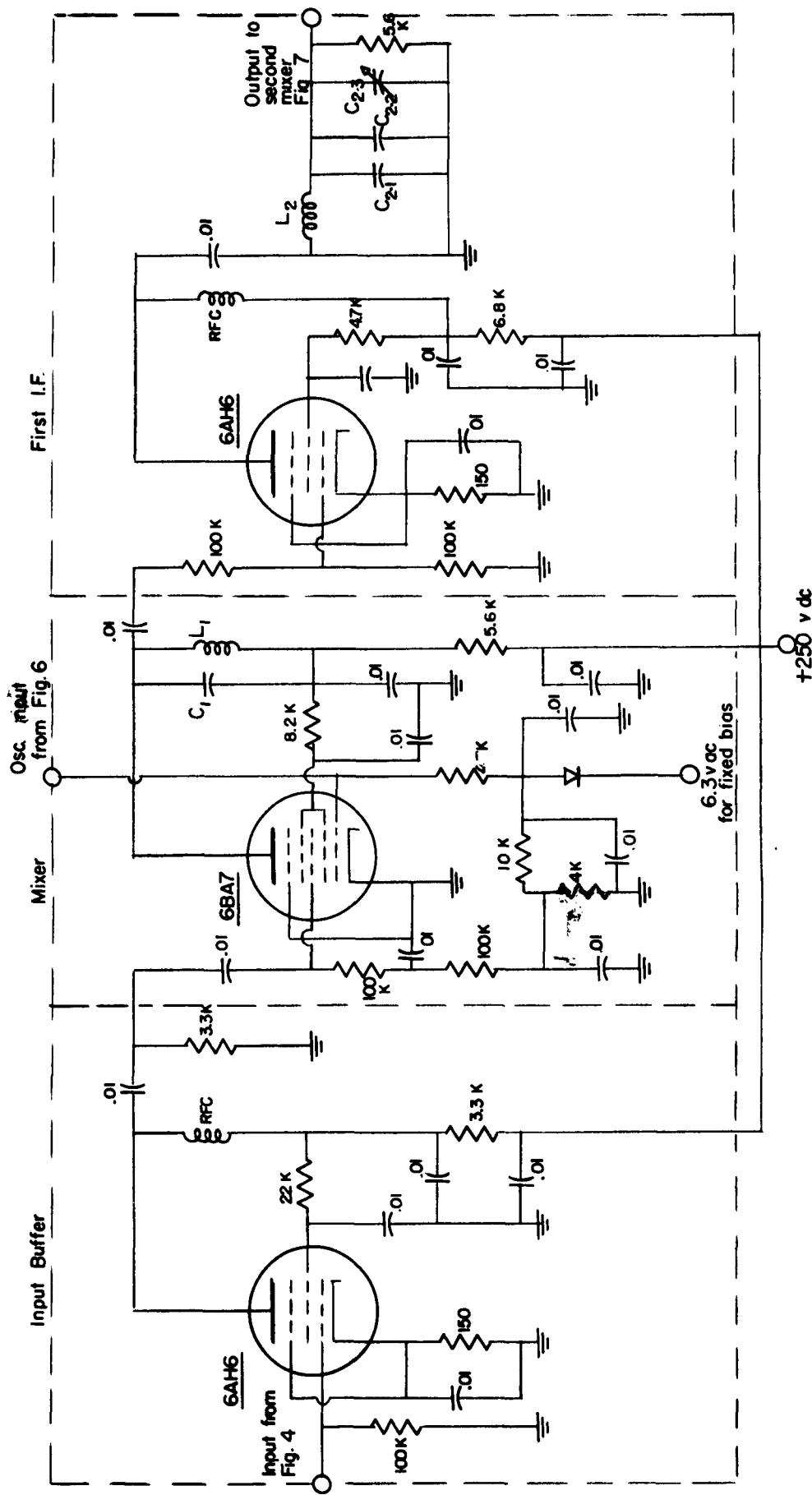
Figure 5. Circuit Diagram of the Input Buffer to the First Mixer, the First Mixer, and the First Intermediate Frequency Amplifier Stages. The C_1-L_1 circuit is tuned to peak at 5.4 mc. The circuit L_2 —$C_{2.1}$, $C_{2.2}$ and $C_{2.3}$ is tuned to the first IF, 5.4 mc for Band D.

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The usual biasing types of gain controls were also tried, both the grid bias type and the cathode bias type To get sufficiently good phase and gain match with gain control variation required carefully matched tubes. The local oscillator injection variation type of gain control was found to be better from the phase and gain matching standpoint than any other type tried, with the possible exception of the piston atten- uator type which is based on the waveguide-below-cut-off principle. The local oscillator injection variation type is simple mechanically, and for this reason has an advantage over the piston attenuator for this appli- cation.

The local oscillator was a Hartley type, using a 6AU6 pentode, as shown with the buffer stages in Fig. 6. The 0A2 was used to keep the screen of the oscillator 6AU6 at constant potential, and thereby help stabilize the oscillator, since the screen is operating as the oscil- lator plate. By using a pentode in this manner, the oscillator plate circuit current is kept small, so that the stabilization can be accomplished more easily than with a triode.

Two buffer stages were used to keep the oscillator well isolated from the load and to get a sufficient local oscillator voltage at a low impedance level. The low impedance output is accomplished by using both sections of a 6BQ7A in parallel This low impedance output is fed to both of the matched receiver channels In this manner the local oscil- lator signal fed to the two mixers is the same, and therefore the phase and gain matching problem is easier By keeping the impedance level low and by using mixer tubes with the proper kind of internal geometry, the cross-feed between channels due to this common shielded lead was kept sufficiently low to remain unnoticeable

The tuning of the receiver for incoming RF signals is accomplished by varying the capacitance, C_T, in the local oscillator tank circuit. The tuning control dial is located on the front panel of the receiver.

3.4 First IF Stages

The first IF amplifier tuned circuits are shown with the first mixer in Fig 5. The effective Q's are about 100 The tuning capaci- tances were kept large. The value for the capacitances for the 7.09 to 10.8 mc band, for which the first intermediate frequency amplifier center frequency is 5.4 mc, is about 800 $\mu\mu f$. Since the values of C and Q for the first IF in terms of overall phase and gain match are not

Figure 6. Circuit Diagram of the First Local Oscillator and Buffer. Capacitor C_T is the variable element controlled by the frequency selector dial.
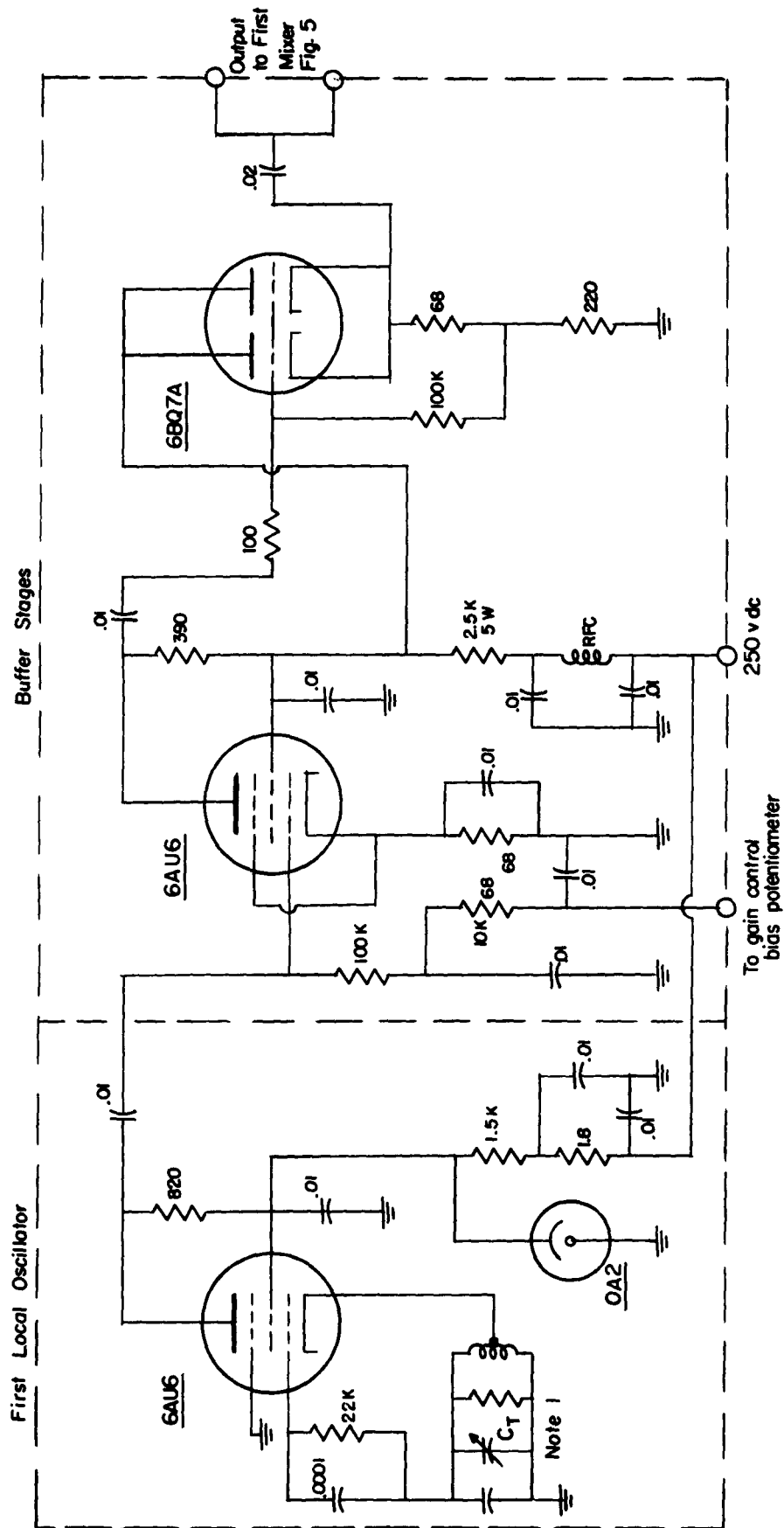
NOTE 1: Oscillator Tank Circuit, Tunable from 12.49 to 16.2 mc for Band 4

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important, accurate values need not be given here. It is important that the first IF stages in the two channels be as near alike as possible, in order to give response curves that are congruent (as nearly as possible) in the regions near resonance over a range equal in frequency width to the entire response curve of the second IF.

The pi section filter in the output side of the circuit of Fig. 5 was originally incorporated as a low pass filter unit to suppress undesired frequency responses. It was later abandoned because of the poor rejection of frequencies below the first IF range.

3 5 Second Mixer, Second Local Oscillator, and Buffers

The circuit diagram of the second local oscillator, buffer, and mixer is shown in Fig. 7. The oscillator is essentially the same as that shown in Fig. 6, but is fixed-tuned for a given band (at 5.856 mc for the 7.09 to 10.8 mc band). With the circuit shown, the gain control bias voltage is connected to the grid of the 6CL6. This bias voltage is made available from a potentiometer which is operated from the same shaft as the bias potentiometer for the gain control in the first local oscillator buffer stage. The two potentiometers operate together to adjust the overall receiver gain. The 6CL6 buffer is stabilized with two 0A2 voltage regulator tubes and the common outputs are fed to the respective second mixers. The second mixer for one channel is shown in Fig. 7. The second mixer operation is essentially the same as that for the first mixer.

3 6 The Second IF Amplifier and Output Stage

The circuit diagram of the second IF amplifier and output stage is shown in Fig. 8. The center frequency is 456 kc, and the effective shunt capacitance of the first two stages is 2300 μμf. The effective Q for each of the two tuned circuits is 72, and the gain per stage is 20.

Another feature of this section is the cathode feed-back by means of the unbypassed cathode bias resistors. This method of feed-back is not frequency dependent as long as the capacitive reactance in shunt with the cathode resistor is large compared to the resistor, say, at least ten times as large. Because it is not frequency dependent, no further complication is introduced as far as phase and gain matching are concerned. This feedback contributed considerably to stability of the

Figure 7. Circuit Diagram of the Second Local Oscillator, Buffer, and Second Mixer. Output circuit of the mixer is tuned to the second intermediate frequency of 456 kc.
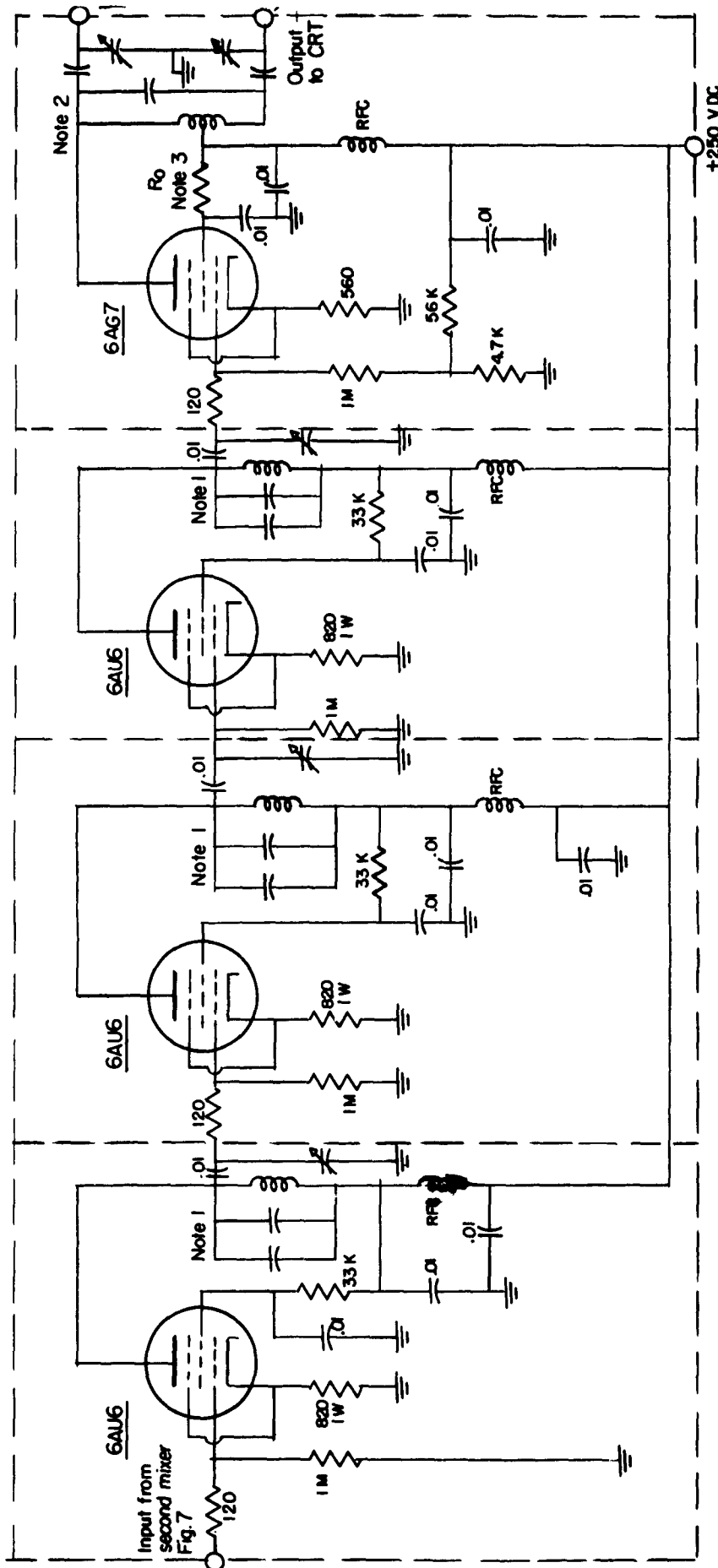
NOTE 1: C total per stage = 2300 μμf   NOTE 2: Circuit resonance at 456 kc, Effective Q = 73.

       Center frequency = 456 kc

       Effective Q = 72   NOTE 3: R_o = 12 K in one channel. 5K + 10K potentiometer in other channel.

Figure 8. Circuit Diagram of the Second Intermediate Frequency Amplifier and Output Stage

IF stages In fact it was possible to replace second IF tubes and have the indicated bearing from a test signal return to the same mark without any gain adjustments

3.7 Bandswitching Problems

The original receiver design called for covering 2 to 25 mc in six bands The bandswitching was to be done by means of wafer switches Because both coils and capacitors had to be switched in for each band, ten wafers were required for each of the two channels (two wafers per stage were needed for three RF stages, a mixer stage, and a first IF stage) and about six wafers were required for the oscillator channel The wafers for each channel were driven by a long, hardened steel bar 28 inches long, ¼ inch wide, and 1/16 inch thick The wafers for the three channels were gang operated with one detent mechanism per channel The ganging was accomplished by a gear arrangement

The ganging presented a difficult mechanical problem, and two or three different mechanical designs were tried, none of which was satis factory

Even with hardened steel, the torsion in the long rod was too great for satisfactory operation This, in combination with the wide position tolerances of the wafers themselves, resulted in a switching arrangement that never gave assurance that the correct coils would be connected in all stages of a channel It might have been possible to get better switching reliability by driving the wafer switching rod in a different manner say, from the center but this was not tried since another more disturbing, problem was encountered It was found that the phase mismatch between channels depended upon the point of contact between the moving arm and the fixed contact point of a wafer A very slight change of this position caused a noticeable change in ellipsing or phase mismatch, at the output The accumulation of this effect for all of the stages was considered hopeless

Because of these reasons the wafer type of bandswitching was dropped Since successful bandswitching by other means, namely, by means of turrets, has been used by others it was considered that bandswitching was not the important problem at hand Rather it was thought to be more important to demonstrate that the proposed method of realizing a matched channel receiver with fixed-tuned RF amplifier, for use over a band of

frequencies, is feasible. It was decided, therefore, to dispense with bandswitching and make the receiver operate on one band. The 7.09 to 10.8 mc band was chosen.

3.8 Input Circuit Design

The original input circuit was designed as indicated in Fig. 9.
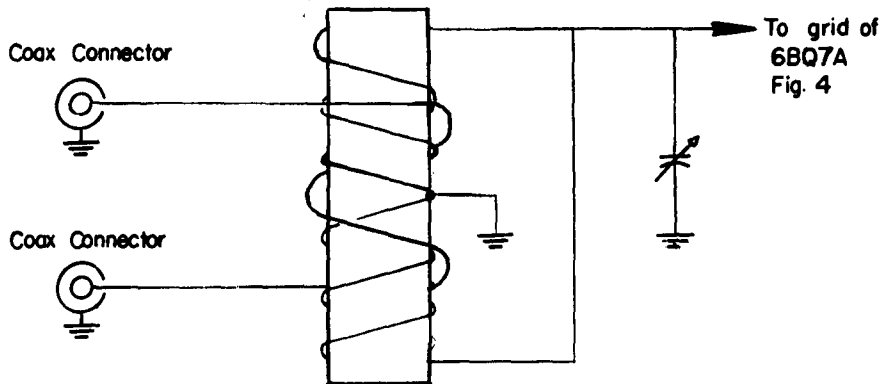
Figure 9. Aircore Coil for Balanced-to-Unbalanced Input

An aircore coil was used to convert the balanced input from the antenna cables to an unbalanced, or single ended, output to the grid of the first tube. The secondary coil was center-tapped, with the two halves wound in opposition. The two halves are then connected in parallel to the output. This sort of construction was used in order to present symmetrical loading to the balanced input coil. The coil worked fine from the standpoint of balance-to-unbalance and voltage step-up, but from the standpoint of phase and gain balance from channel to channel it was unsatisfactory, since the mutual impedance between the windings could not be controlled carefully enough from coil to coil.

For any kind of tuned circuit at the receiver input, the shape of the response curve for this circuit will be a function of the impedance seen looking back toward the antenna, or, in other words, the tuned

response will depend upon the impedance presented by the antenna cables. If the cables are lossless, or nearly equal in length, and terminated in their characteristic impedances at the antenna ends, they will present the same resistive impedance at all frequencies. If the cables are not equal in length and are not properly terminated at the antenna ends, the impedances presented to the receiver inputs are functions of frequency. Unless these impedances are exactly alike, phase and gain match of the effective input circuit becomes impossible.

The antenna input cables are not lossless and, therefore, regardless of their termination at the antenna ends, the impedances they present to the receiver input will be functions of frequency, which, in general, will not be matched. If the cables are terminated in their character-istic impedances at the receiver end, the impedance seen looking across the termination will be more nearly constant as a function of frequency than would be the case for a termination with some other impedance.

From the standpoint of cable termination alone, the easiest solu-tion to the problem is to use a pure resistance termination at the receiver input. A pure resistance input to the first tube is all right provided that the noise figure of the receiver is sufficiently good, which means, roughly, that the noise due to the receiver should be no greater than the noise fed to the receiver input from the antenna cables. To a good approximation at the frequencies of interest, the noise figure of an amplifier stage is given by $F = 1 + R_{eq}/R_{in}$, where R_{eq} is the equiv-alent noise resistance of the tube and R_{in} is the resistance seen look-ing back from the tube input terminals. If the mutual conductance of a triode is 4000 micromhos, its equivalent noise resistance is approxi-mately 500 ohms. For a 100 ohm cable terminated in its characteristic impedance at the antenna end and at the receiver end in a 100 ohm re-sistor, the value of R_{in} will be 50 ohms, so that $F = 11$. For a 50 ohm cable with the same sort of terminations, $F = 21$. It was thought that noise figures of this sort might be usable if the other noise contribu-tions were sufficiently low. Since the power gains of the early stages of this receiver are low, there is a considerable noise contribution from them. Also the antenna amplifiers were designed in such a manner that their noise figures were large and their power gains low. Consider-ing the noisiness of the antenna amplifiers, even if the receiver channels have low noise figures, the effective noise figure of the receiving system channels without the antennas is fairly large. It is

desirable to have the receiving system designed in such a manner that in the worst conditions its noise contribution is no greater than the noise entering the system from the outside. This means that the effective operating noise figure with the antennas should be at least twice the noise figure of the receiving system without the antennas.

Taking into account the above considerations, the noise figure of the first stage should be kept low, which can be done by using a first tube with a large transconductance and by making the value of R_{in}, seen looking back from the tube input terminals, as large as is feasible. This led to the construction and design of an input transformer of the ferrite-core type. The design consideration and details for the transformer are discussed in Reference 9.

The input circuit using a ferrite-core transformer and a coupling network is shown by diagram in Fig. 10. The coupling network was used in order to get a more nearly constant output versus frequency impedance characteristic over the frequency band. By using the 1000 ohm termination for the coupling network the input impedance was reasonably constant over the frequency range 2 to 25 mc, varying from about 140 to 180 ohms, and thus provided a fairly good termination for two 75 ohm coaxial cables. With the two 75-ohm inputs connected, the value of R_{in} looking back from the grid of the first tube is about 500 ohms, and therefore the noise figure of the first tube should be good, approximately two for a triode with gm = 5000 µmhos, and about 1.5 for gm = 10,000 µmhos. By using a 6BQ7 first tube connected as shown in Fig. 4, a noise figure of about 8 to 10 was obtained, which is sufficiently good for many kinds of operation in the 7.09 to 10.8 mc frequency range.

3.9 Complete Receiver

A stage-by-stage block diagram of the complete receiver for one band is shown in Fig. 11. The circuit diagrams of Figs. 4 through 8 and Fig. 10 may be used for the various stages indicated in Fig. 11.

No AGC detector and amplifier are discussed in this report. The AGC, if used, would be very much the same as that described in Reference 12.
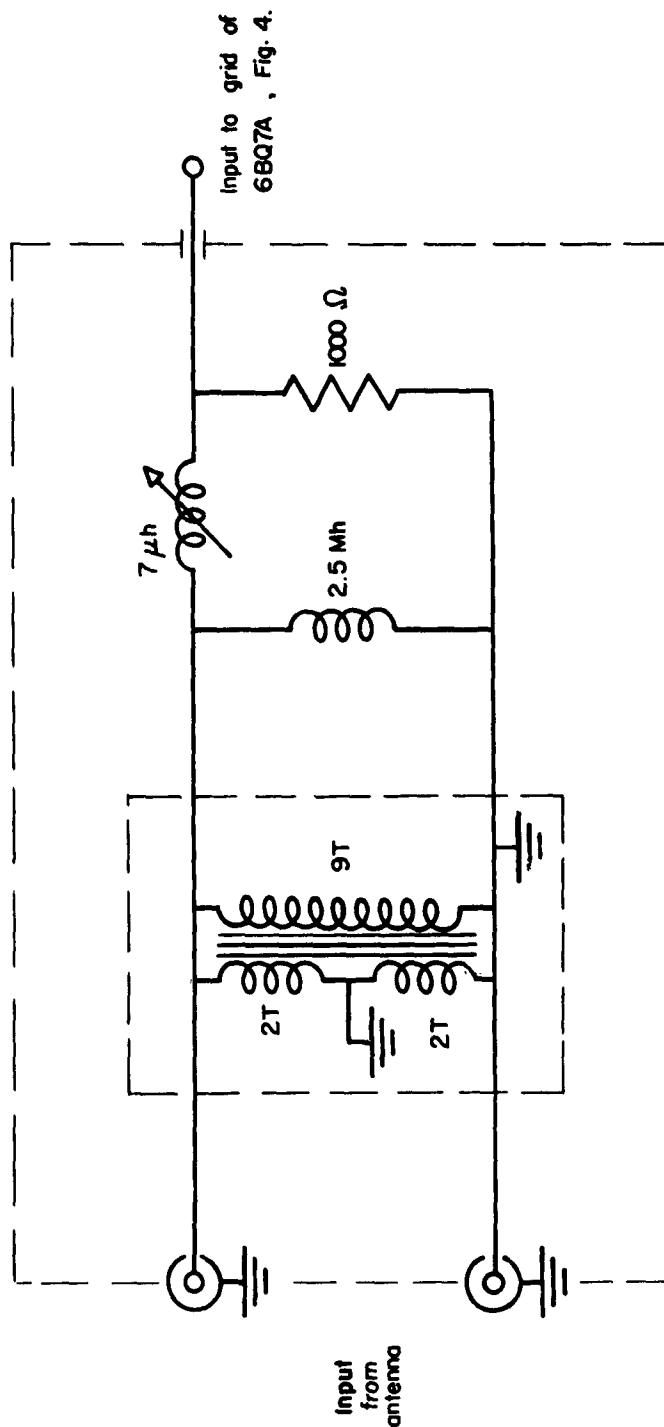
Figure 10. Circuit Diagram of Balanced-to-Unbalanced Input Network, Using a Ferrite-Core Transformer and Video Coupling

N-S Channel

Fig. 10 — Input Trans. — Input from N-S Antenna

Fig. 4
- First RF 6BQ7A
- Second RF 6AH6
- Third RF 6AH6

Fig. 5
- Buffer 6AH6
- First Mixer 6BA7
- First IF 6AH6

Fig. 7 — Second Mixer 6BA7

Fig. 8
- Second IF 6AU6
- Second IF 6AU6
- Second IF 6AU6
- Second IF Output (2)6AU6 — To vertical deflection plates of CRT

Fig. 6
- Receiver Tuning Cap
- First L.O. 6AU6 0A2
- First Buffer 6AU6 6BQ7

Fig. 7
- Second Buffer 6CL6 2-0A2
- Second ___ 6C4 0A2

E-W Channel (Same as N-S Channel)

Input from E-W Antenna — To horizontal deflection plates of CRT

Figure II Stage-by-Stage Block Diagram of the Complete Receiver for One Band. Circuit diagrams for the various parts are shown in the figures indicated in the dotted boxes.

4. TESTS ON ONE BAND OF THE RECEIVER

One band was chosen to use for a complete receiver, the 7.09 to 10.8 mc band. The problems encountered in making this band operate are considered representative, although the higher frequency bands may well present problems not encountered here.

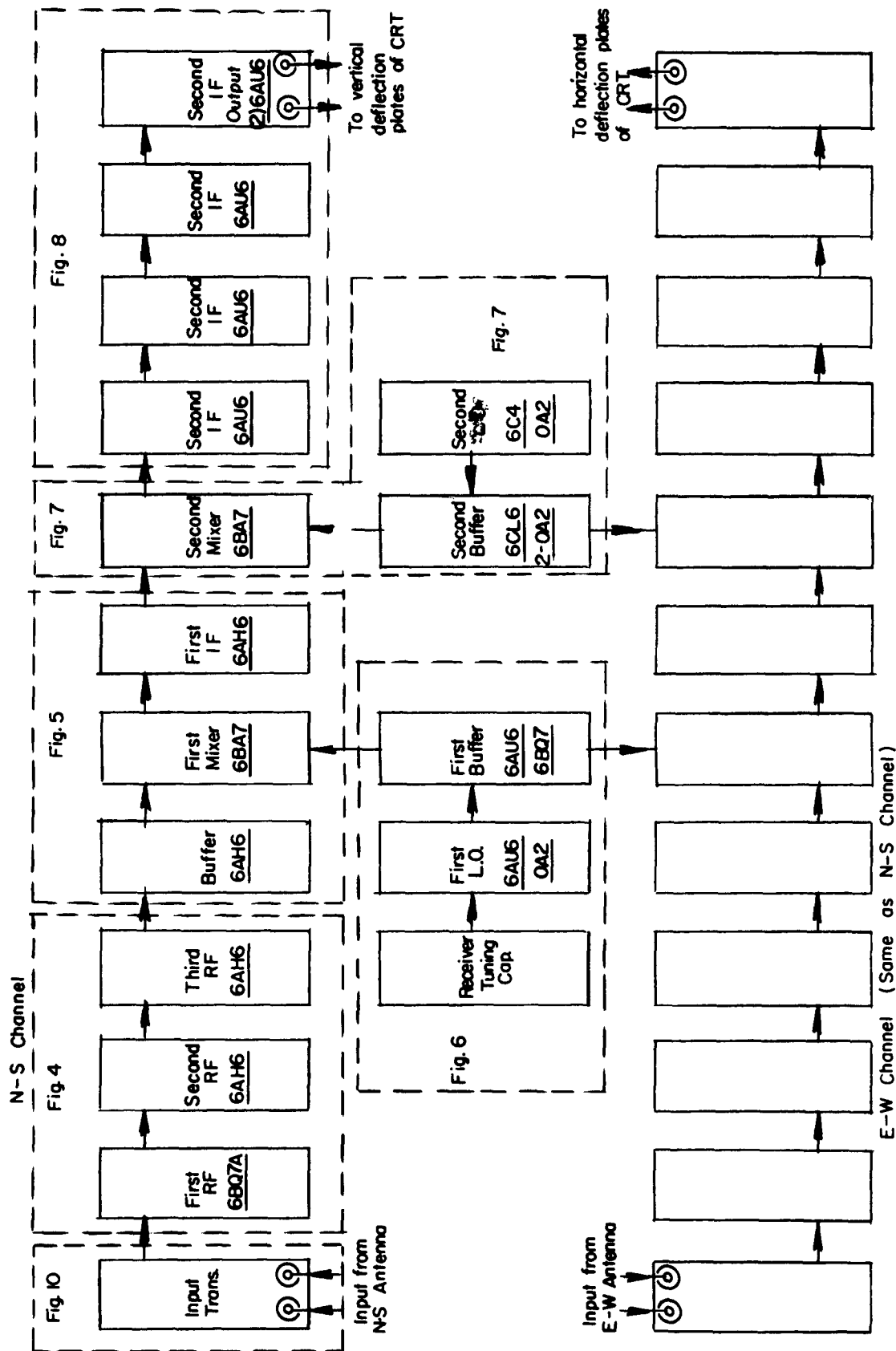All of the tests made on the receiver were completed in the laboratory. No field tests were made, partly because of the crowded condition of the facilities available at the RDF field station and partly because the form of the receiver was not well adapted to field testing. The laboratory tests showed that the receiver in the form described would not have been useful for field operation.

4.1 Spurious Responses

The most detrimental factor in connection with this receiver was the presence of several spurious responses - the ones which could not be eliminated by the type of mixer operation that was used. These responses were at the following frequencies: (a) the first intermediate frequency, (b) twice the first IF above the indicated incoming signal frequency (first local oscillator image response), (c) the first local oscillator frequency plus 456 kc (the second IF), and (d) the first local oscillator frequency minus 456 kc. The first of these was the most bothersome, but, since only one frequency is involved, it could be eliminated by a wave trap. The (c) and (d) responses give an output from the first mixer equal to 456 kc.

These spurious responses were measured at several tuning dial settings. The procedure was to use a standard output at the indicated frequency, then adjust the spurious input signal level to give the same output. The ratio of this signal level to the standard output reference level, called the injection ratio, was changed to decibels by taking $20 \log_{10}$ of the ratio, and the results were plotted versus dial indicated frequency in Fig. 12.

After the tests showed very poor rejection ratios, as shown in Fig. 12, it was decided to make modifications as described in the next section.
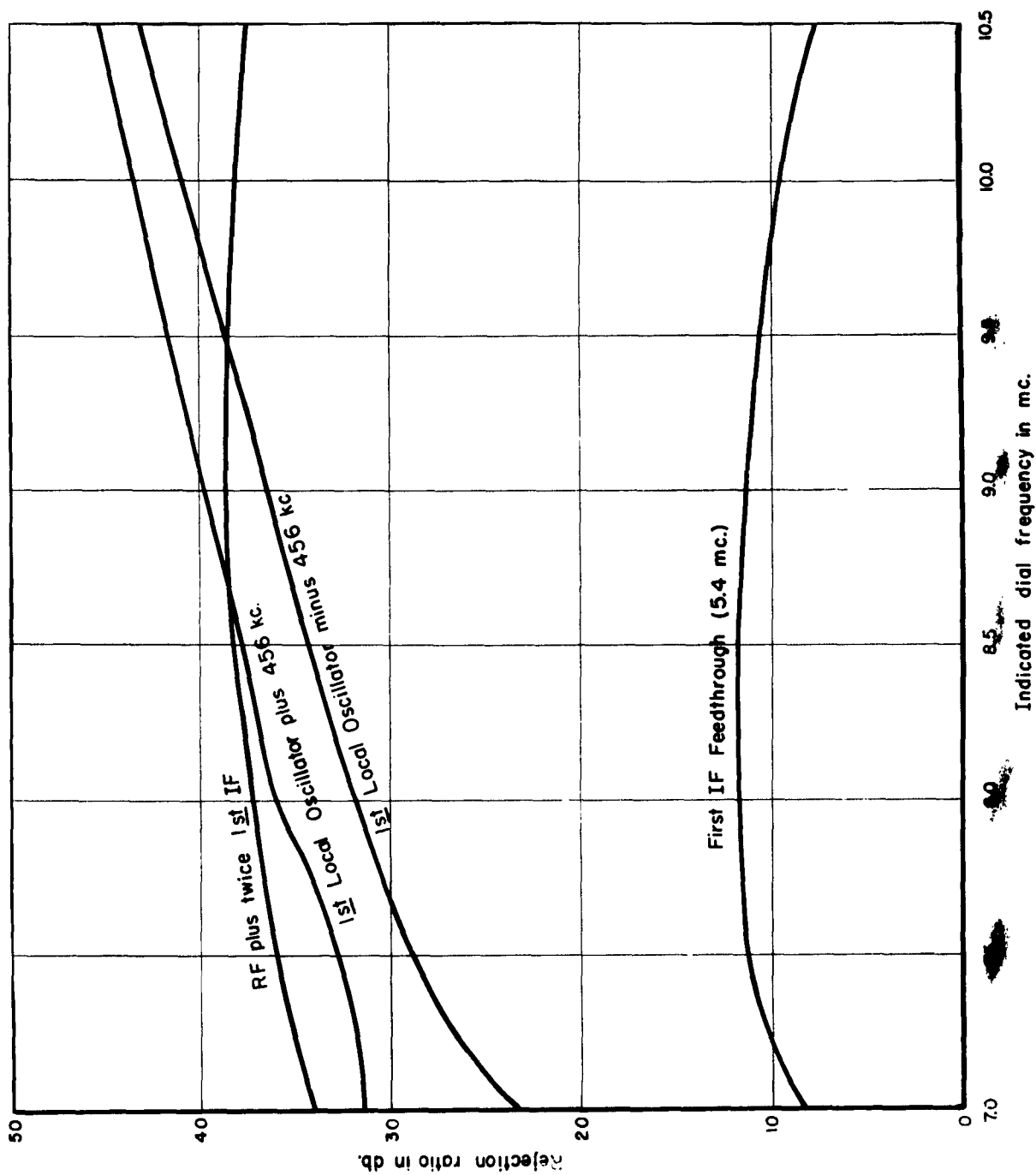
Figure 12. Rejection Ratio in Decibels versus Dial Frequency Indication for a Staggered Triplet RF Amplifier

5. MODIFICATIONS OF THE RECEIVER

5.1 Over-Staggered Doublets

It is obvious that another staggered triplet in cascade with the one already present would considerably improve the image rejection at the RF plus twice the first IF. Gain is not needed, however, so the possibility of using additional bands to cover 2 to 25 mc was considered. It was thought that more bands would not be advisable from an operational standpoint.

Using four stages instead of three would not increase the gain too much, so it was decided to use two staggered doublets in cascade instead of the staggered triplet. Furthermore it was decided to use over-staggering to further increase the steepness of the overall response curve for a given half-power bandwidth.

The design used called for an overall dip of one decibel or one-half decibel dip per doublet. The method of design is not discussed here, but design curves may be used.[14] The design data are given in Table 3. The theoretical response curve for the two cascaded doublets

Amount of Dip per Doublet:	0.5 db
Band Covered: 7.09 to 10.8 mc	f_o = 8.74 mc
Effective Bandwidth per Doublet:	4.25 mc
Center Frequency of Stages 1 and 3:	7.33 mc
Center Frequency of Stages 2 and 4:	10.39 mc
Q per stage:	4.6
Effective C per stage:	30 $\mu\mu$f
Effective R for Stages 1 and 3:	3325 ohms
Effective R for Stages 2 and 4:	2350 ohms
Effective L for Stages 1 and 3:	15.7 μh
Effective L for Stages 2 and 4:	7.83 μh

Table 3   Design Data for the Over-Staggered Doublets

is shown in Fig. 13. The skirt selectivity for this curve is about 2.4. The first IF image rejection for this curve is about 45 db.

The laboratory tests of the receiver modified with the two staggered doublets showed that the image frequency at RF plus twice the
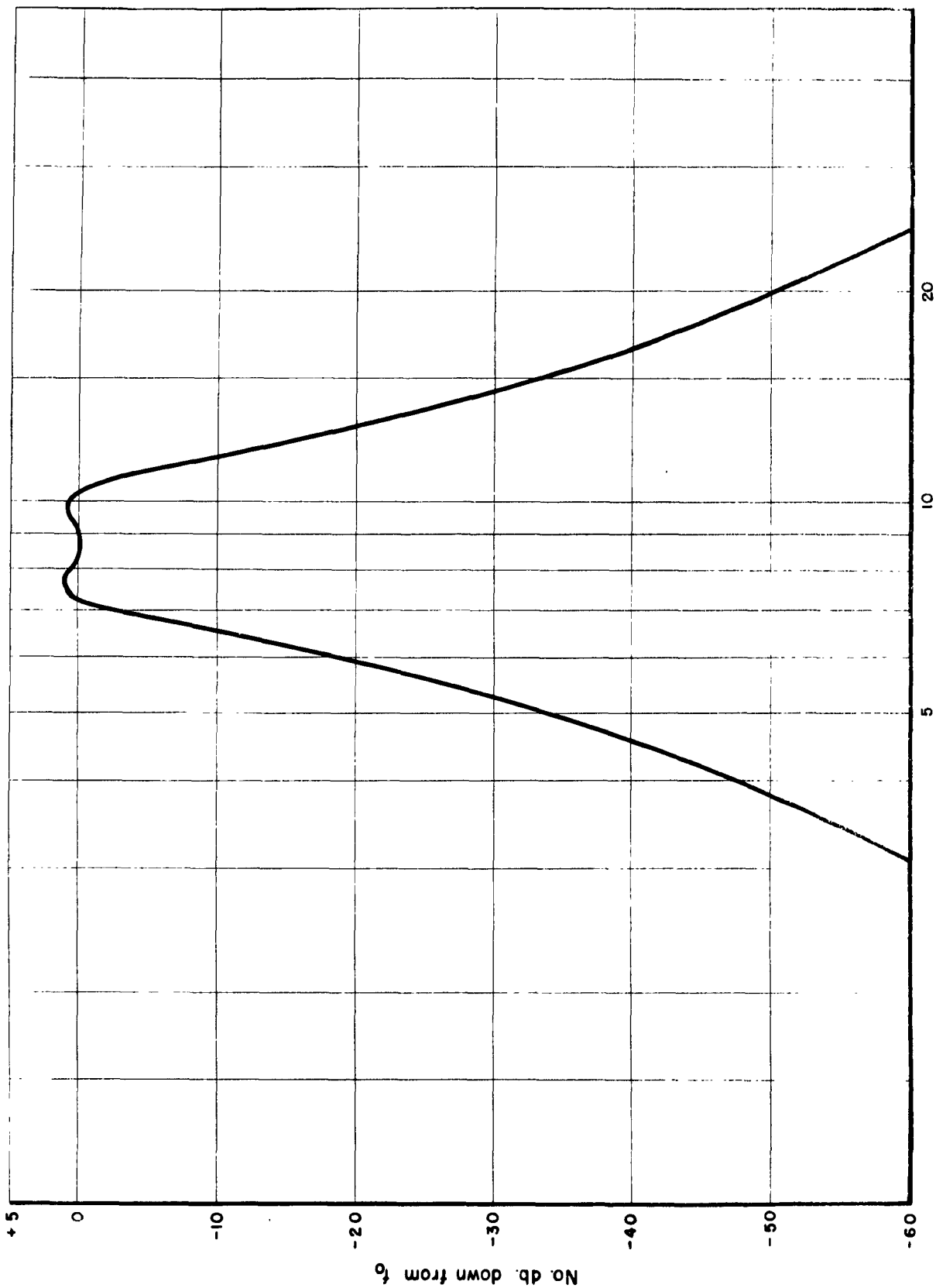
Figure 13. Theoretical Response Curve of Two Cascaded Over-Staggered Doublets
f_o = 8.74   Overall dip = 1 db   Overall Bandwidth = 3.71 mc

first IF was suppressed more than 80 db over the frequency range tested. The first IF feed-through and the other undesired frequencies discussed in Section 4.1 were not sufficiently suppressed, as is shown by the plots of rejection ratio versus frequency in Fig. 14. In fact, the first local oscillator frequency plus and minus 456 kc rejection is much poorer than in the previous case.

It was decided to use a wave trap to reject the first IF. The wave trap was placed in the plate circuit of the input buffer to the first mixer, the 6AH6 in Fig. 5. The circuit diagram of the 6AH6 with wave trap is shown in Fig. 15.

An investigation of the first IF stages revealed that the pi section filters are low pass filters which do not give good rejection of lower frequencies. Therefore the pi section filter of Fig. 5 was re placed by an L C tuned circuit.

After these modifications, tests were again made for spurious responses. The rejection of the first local oscillator frequency plus and minus 456 kc was greater than 80 db, and was found to be too small to measure. The first IF rejection ratio is shown plotted in Fig. 16. It is seen from the figure that the rejection ratio for the first IF is about 50 db or more. It could have been improved by placing another wave trap preceding the isolation buffer, that is, in one of the staggered doublet circuits, but this would have made the phase and gain matching more difficult. Therefore, the rejection ratio was considered sufficiently good for test purposes.

No observations of cross modulation in the fixed-tuned RF circuits have been made. Effects of this sort can best be observed during field tests.

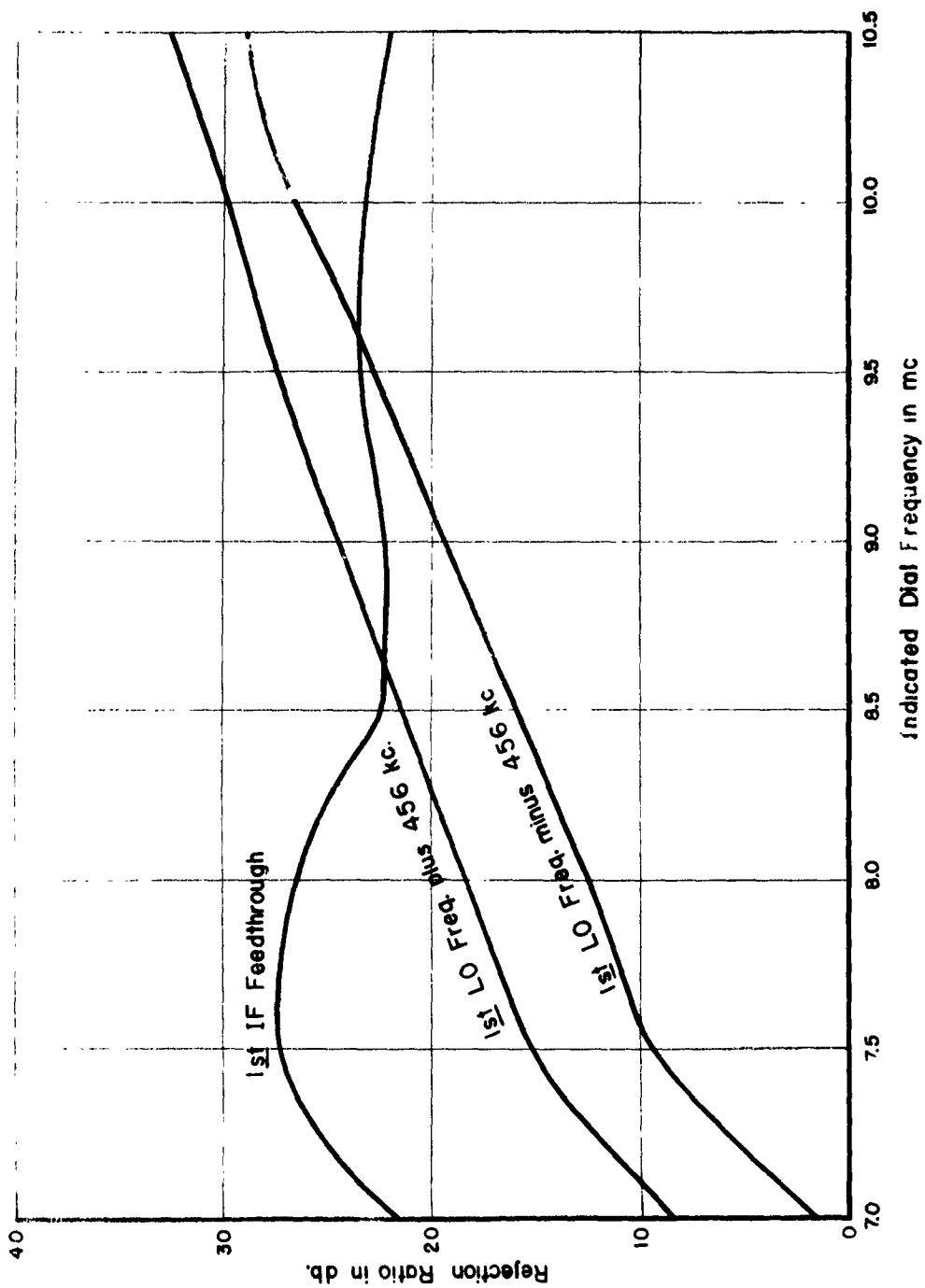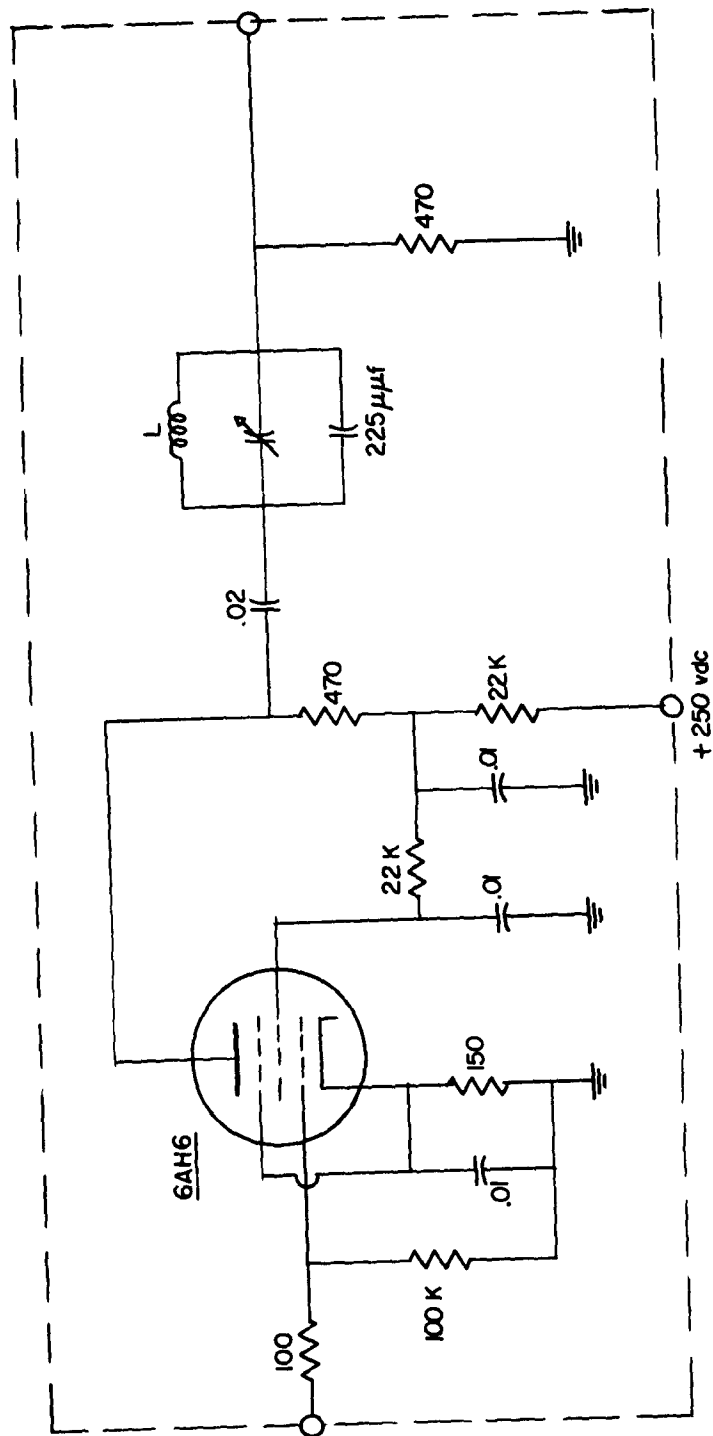Figure 14   Rejection Ratio in Decibels versus Dial Frequency Indication for Two
Cascaded Over-Staggered Doublets in the RF Amplifier
(1 db dip overall)

Figure 15. Circuit Diagram of the 5.4 mc Wave Trap Stage. This replaces the first stage of Figure 5.
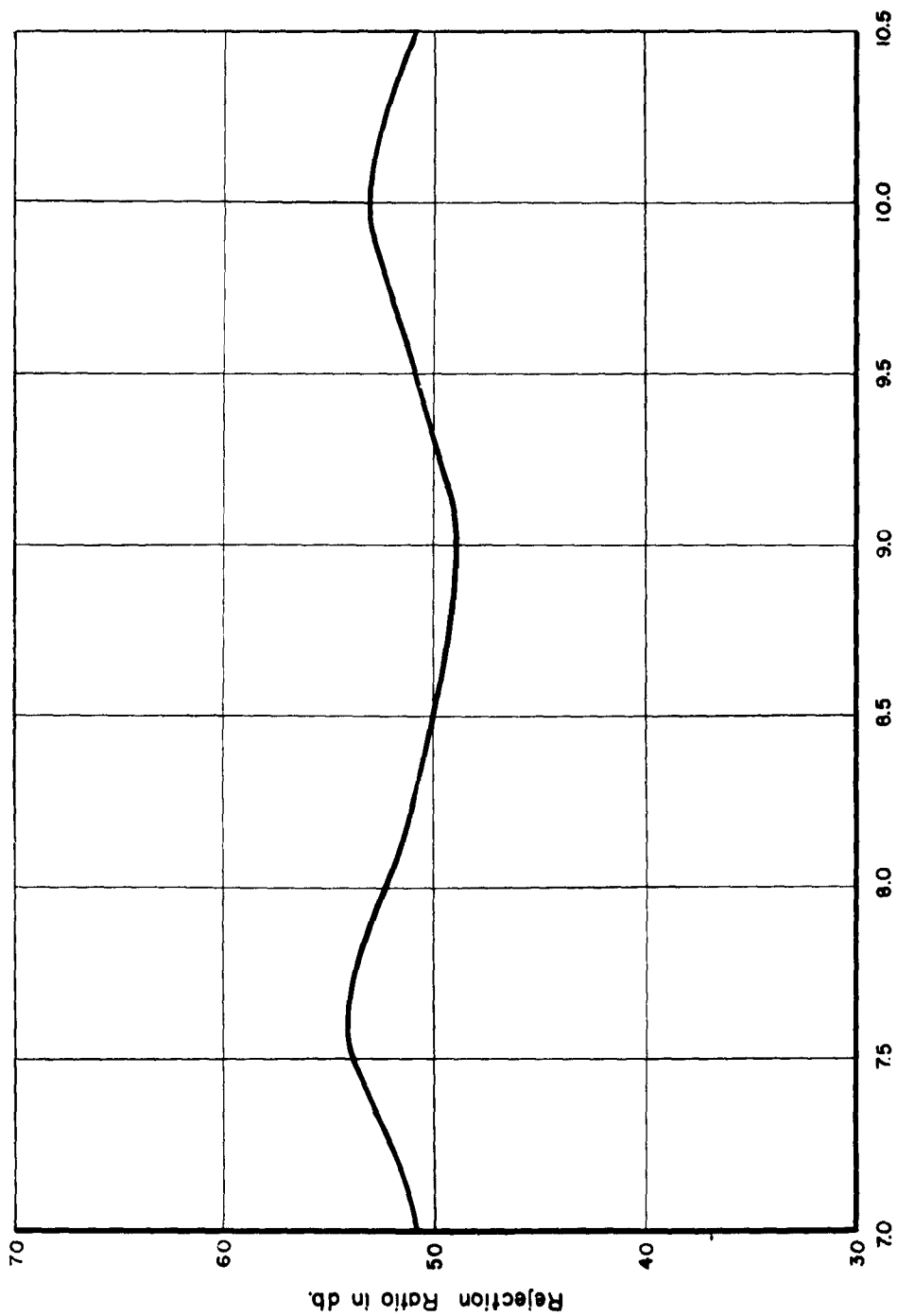
Figure 16.   First IF Rejection Ratio in db versus Dial Frequency Indication Using
the Wave Trap of Figure 15 and L-C Tuned First IF Stages

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6. FUTURE PLANS FOR THE RECEIVER

In view of the uniqueness of design for this receiver a field test would be desired. It has not been possible, however, to field test it because of its nature and because of the lack of proper facilities at the RDF field station.

Because of the fixed-tuned RF amplifier feature, the receiver is well suited for panoramic purposes, since only one tuned circuit need be varied to achieve the panoramic effect. The adaptation of the receiver to a panoramic dual channel RDF receiver is underway.

7. CONCLUSIONS

Laboratory tests indicate that a matched channel receiver based on the design principles described in this report is feasible. It does, however, require more tubes than a more conventional type of design in order to get the desired selectivity.

The phase and gain matching are achieved more easily in this type of receiver than in one with variable tuning over the RF band.

The noise figure of this type of receiver will be somewhat higher than for a more conventional type, but by proper design it can be kept low enough for effective operation in some types of application.

Since only the local oscillator is variable-tuned in selecting signal frequencies, this type of receiver is suitable for adaptation into a scanned frequency type of matched-channel panoramic receiver.

A receiver of the type described in this report can be used to cover 2 to 25 mc in six bands, using turret-type band switching. Turret switching is considered to be a solved problem, and therefore was not used in the receiver described here.

The work on the receiver has extended over several years. During this time several important things have been learned about matched channel receivers, and several ideas developed in connection with this receiver have been put to use in other matched channel receivers of more conventional design. These include receivers with local oscillator injection gain control, mixer action with low spurious response, unbypassed cathode resistor type of feed-back for gain stabilization, and wide band, ferrite-cored, balanced-to-unbalanced input transformers. In this sense the receiver described in this report has been a miniature laboratory in itself, rather than an end-result experimental or operational prototype receiver.

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