Proposed modifications for improved performance of AN/GRD-501
Burtnyk, N.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/21273576
Report (National Research Council of Canada. Radio and Electrical Engineering Division : ERB), 1959-03

ERB-516

~~CONFIDENTIAL~~

NATIONAL RESEARCH COUNCIL OF CANADA

RADIO AND ELECTRICAL ENGINEERING DIVISION

PROPOSED MODIFICATIONS FOR IMPROVED PERFORMANCE OF AN/GRD-501

N. BURTNYK

OTTAWA

MARCH 1959

ABSTRACT

Proposed modifications of the AN/GRD-501 receiver to improve the noise figure and selectivity are presented. The resulting performance with respect to overall sensitivity is discussed. Details of the modification in the circuitry and performance specifications are included.

CONTENTS

	Page
Introduction	1
Design Limits	1
Unit Performance	3
Overall Performance	4
Conclusions	7
References	7
Appendix A	8
Appendix B	10
Appendix C	11
Appendix D	13

FIGURES

1. Circuit of Crystal Filter
2. Suggested Chassis Layout of Filter Unit
3. Response of Crystal Filter
4. Circuit of Radio-frequency Input Stage
5. Receiver Noise Levels
6. Sensitivity of Receiver
7. Modified Circuit of Unit 100
8. Modifications to Unit 2800

PROPOSED MODIFICATIONS FOR IMPROVED PERFORMANCE OF AN/GRD-501

- N. Burtnyk -

INTRODUCTION

The AN/GRD-501 equipment was designed as an HF shore-based twin-channel direction-finding receiver fed by an Adcock antenna. After considerable use of a developmental prototype model for both operational and experimental purposes, it became apparent that some improvement in selectivity and sensitivity was desirable.

The present minimum bandwidth is 1 kc/s, obtained by the use of an under-coupled double-tuned transformer. Modifications to attain increased rejection of signals outside the bandpass, and the addition of a narrower bandwidth facility, such as could be provided by a crystal filter, were therefore considered desirable for eliminating interference and reducing the noise for weak signal reception.

The receiver produces a noise output between 0 and 6 db above atmospheric noise over the frequency band, so that an improvement in noise figure is also desirable. This is considered to be especially true at northern site locations where an improvement in noise figure would result in a direct improvement in overall sensitivity because of the somewhat lower atmospheric noise levels expected at those latitudes. The performance of the antenna and coupling circuits had already been optimized using both a four-element Adcock and an eight-element Adcock antenna. It appeared, therefore, that greater sensitivity could be gained more easily by reduction of the receiver noise figure rather than further improvement of the antenna and coupling system, especially since the first mixer of the receiver contributed about one-half of the total receiver noise.

The improvements outlined above were realized with a minimum number of modifications to the existing system.

DESIGN LIMITS

a) Crystal Filter

A compromise has already been accepted in the provision of three fixed bandwidths of 1 kc/s, 3 kc/s, and 9 kc/s in the present receiver instead of the continuously variable bandwidth control that was specified. A crystal filter with switch-selected 3-db bandwidths of about 200 c/s and 1 kc/s could thus be added and used in conjunction with the existing 1-kc bandwidth to provide the desired additional facilities. The only limits imposed on the design were the requirements of maintaining phase and gain balance across the passband in the two channels. An experimental investigation had already been made at ASRE with a conventional crystal filter to produce a narrow bandpass and the results were satisfactory. It therefore remained to construct similar units and adapt them for wider bandwidth operation (about 1 kc/s), as well as the narrow bandwidth. Lattice-type filters were not tried because of their relative complexity and extreme phase sensitivity along the skirts.

The two-channel filter was built in a single unit and mounted in the I.F. rack of the receiver. The "Audio Output" switch, whose function was being duplicated by the "Aural Gonio", was replaced by a "Xtal Filter" switch, since this location was operationally convenient. Details of the modifications to the receiver to accomodate this filter are listed in Appendix A.

b) R.F. Input Stage

The measured noise figure of the present receiver varies between 12 db and 16 db over the frequency range (3 to 30 mc/s). This limit on performance was partly imposed by other performance requirements, chiefly:

1) High noise contribution by the first mixer because of the low oscillator injection level necessary to keep spurious mixer products below the specified limit.

2) Limitation of available R.F. gain with the specified tube type. Coupling in the interstage single-tuned transformers could not be increased because of the phase and gain instability caused by the Miller effect.

3) Limitation of coupling efficiency at the input imposed by the restrictions on channel mismatch that occurred at the overall resonances of the antenna and primary input circuits.

There appeared to be two promising approaches for obtaining an improvement. First, by insertion of multicouplers between the antenna and the input circuits, antenna resonances could be separated from those of the R.F. selective circuits so that more efficient coupling could be achieved. Multicoupler designs having a low noise figure and sufficient gain to produce adequate improvement are available, but the complexity of the modification seemed excessive. Secondly, by replacement of the existing first R.F. tube type (6BA6) by another type whose equivalent noise resistance is smaller and transconductance greater, it would

CONFIDENTIAL

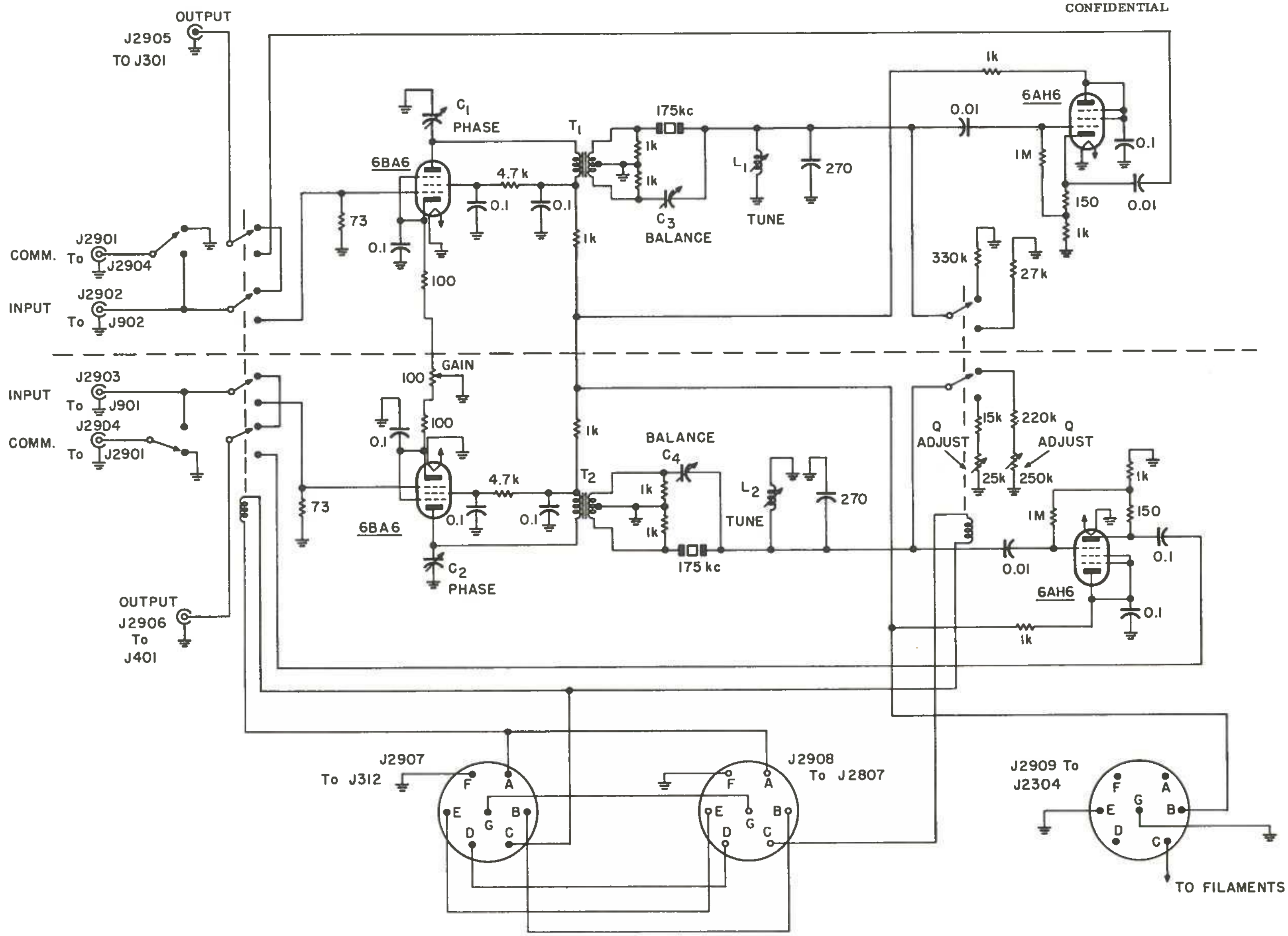

FIG. 1 CIRCUIT OF CRYSTAL FILTER

CONFIDENTIAL

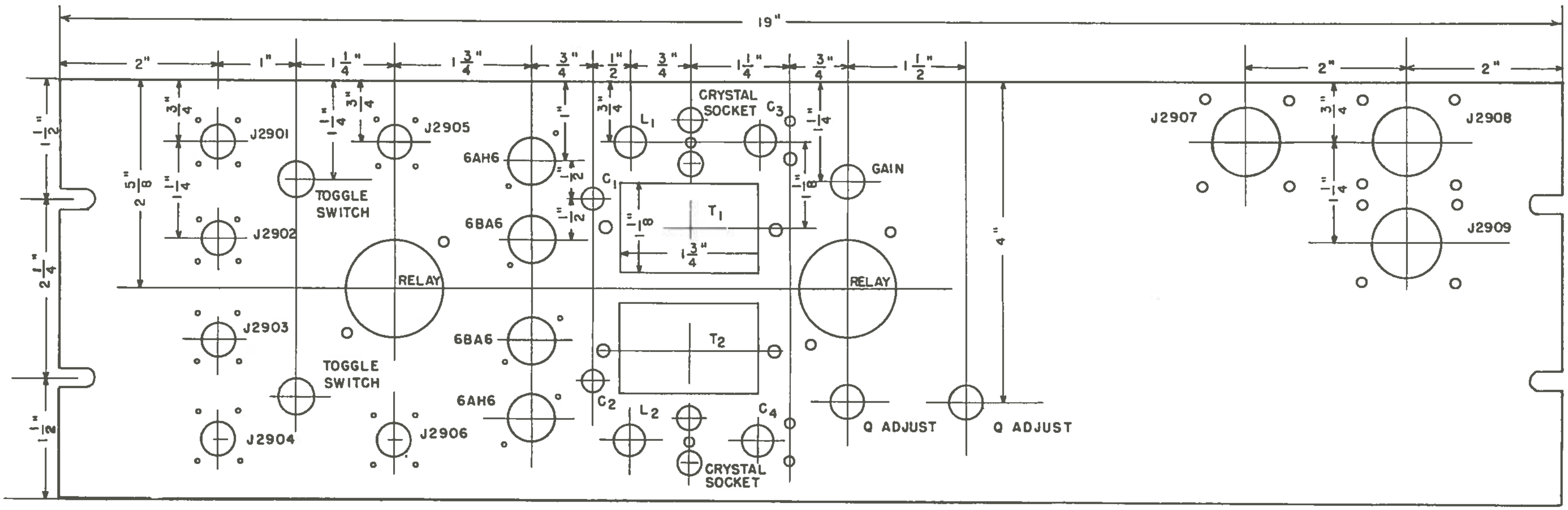

FIG. 2 SUGGESTED CHASSIS LAYOUT OF FILTER UNIT

be possible to achieve some improvement with minimum modification. Such performance was available in the high transconductance pentode type-6688 (Philips type-E180F). The specified noise output is about 8 db below that of type-6BA6 and the specified gain is about 12 db above that of type-6BA6. The modifications involved were thus limited to rebuilding the first R.F. unit using a 9-pin tube socket and adjusting several of the components to suitable values.

UNIT PERFORMANCE

a) Crystal Filter

The circuit of the crystal filter is shown in Fig. 1, a suggested chassis layout in Fig. 2, and a description of the special components is given in Appendix B.

The overall gain of the filter is about unity for both bandwidth positions when loaded by 73 ohms. The filter is bypassed by relay switching for operation of the wider bandwidths in the receiver. Bandwidth control in the filter is also achieved by varying the damping of the crystal circuit by relay switching.

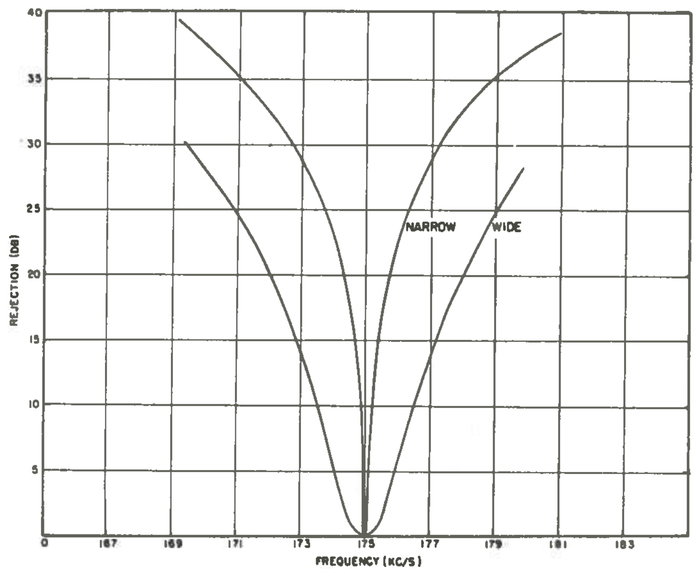

FIG. 3 RESPONSE OF CRYSTAL FILTER

The 3-db bandwidth of the filter is 200 c/s in the narrow position and 1.5 kc/s in the wide position. The response of the filter is shown in Fig. 3. Phase balance within 1° and gain balance within 1% are maintained over a 3-db bandwidth. The procedure for alignment of the filter is given in Appendix C. Appendix D gives the details of the corrections to the performance specification of the receiver to accommodate this unit.

b) R.F. Input Stage

The circuit of the new R.F. input stage is shown in Fig. 4. Gain control of the stage and alignment procedure are identical with that using the 6BA6 input stage.

The measured increase in gain is about 11 db, while the measured noise output is increased by only 5 or 6 db, thus resulting in a noise figure improvement of about 6 db. The measured values of noise figure of the modified receiver are shown in Fig. 5.

OVERALL PERFORMANCE

a) Selectivity

The overall selectivity of the receiver using the crystal filter is shown in Table I. Proper alignment of the filter produces symmetrical bandpass with sufficient gain and phase balance to maintain the required instrumental accuracy.

TABLE I

SELECTIVITY OF THE RECEIVER USING THE CRYSTAL FILTER

Relative Response	Bandwidth	
	"Xtal Narrow"	"Xtal Wide"
-3 db	200 c/s	950 c/s
-20 db	1200 c/s	2800 c/s
-60 db	7700 c/s	9500 c/s

Experimental use of the filter has indicated it is especially useful because of the additional rejection of nearby interfering signals provided by its steeper skirts.

b) Sensitivity

A limited number of observations with the modified receiver show that the external daytime background noise level as seen on the display is from 0 to 6 db above receiver noise in the absence of local storm areas at this location. The predicted levels of external noise relative to receiver noise using the eight-element

CONFIDENTIAL

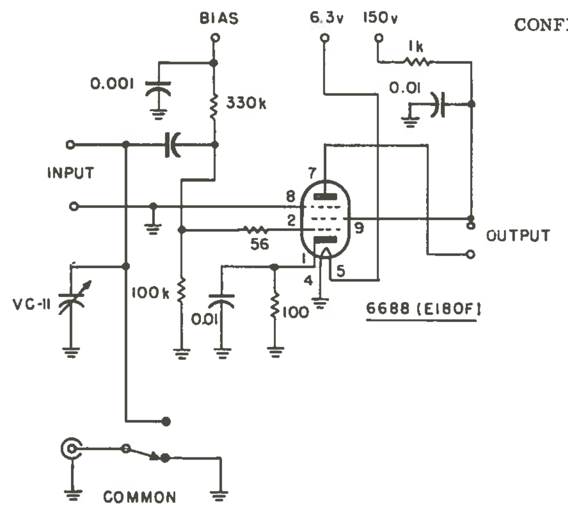

FIG. 4 CIRCUIT OF RADIO-FREQUENCY INPUT STAGE

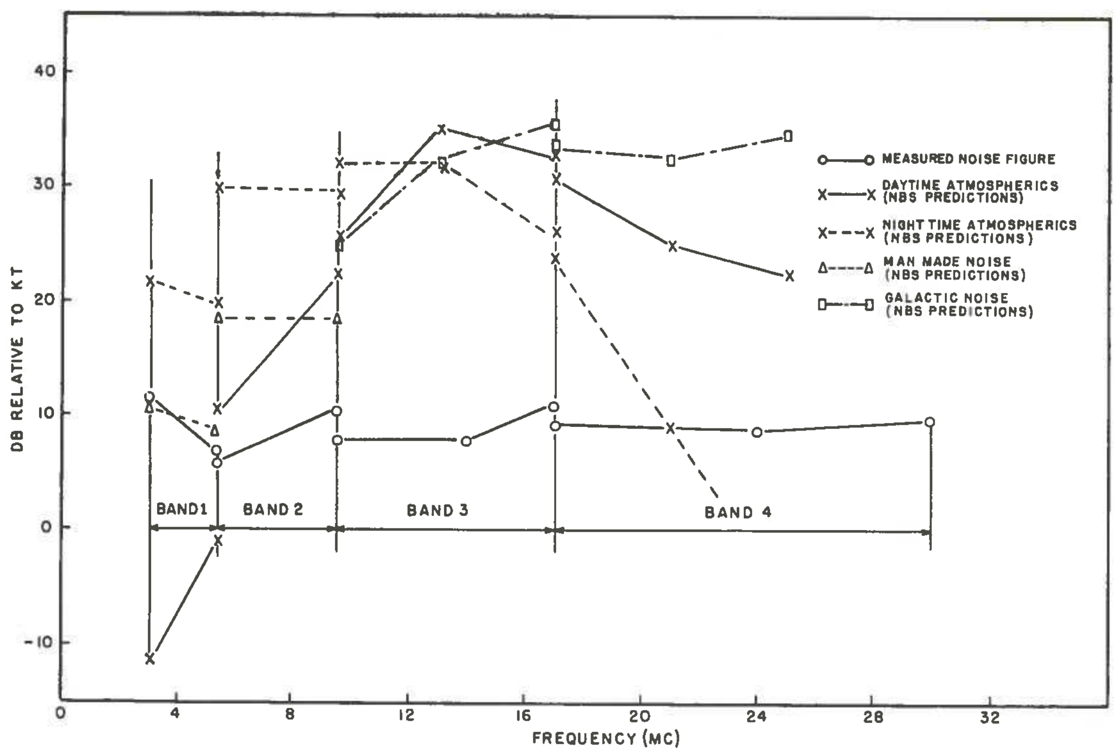

FIG. 5 RECEIVER NOISE LEVELS

Adcock antenna are shown in Fig. 5. These values were determined from the measured pickup factor of the antenna, the measured input impedance of the receiver, and the noise level predictions published by the National Bureau of Standards [1]. The actual levels of atmospheric noise observed on the direction-finding receiver display that limit sensitivity are considerably lower than the rms predicted levels, however, since the high-amplitude short bursts produce definite bearing deflections and are ignored on the display, though they make an important contribution to the rms level. A rough estimation of this limiting level of atmospheric noise may be made by assuming that the portion of the envelope distribution that is similar to thermal noise makes up this random background level that forms the round noise spot on the display. From the characteristics of atmospheric noise shown by Watt and Maxwell [2] and Watt, et al. [3], it appears that the rms value of that portion of atmospheric noise that has a Rayleigh distribution is about 8 to 10 db lower than the rms value of the complete noise envelope at these frequencies. Thus it may be expected that the levels of atmospheric noise that limit sensitivity on the display are 8 to 10 db below the levels predicted in the NBS curves.

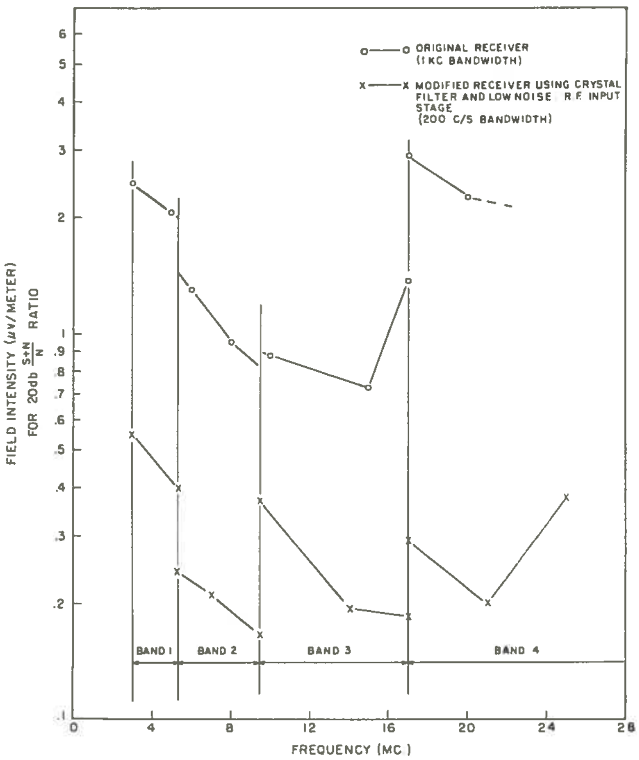

FIG. 6 SENSITIVITY OF RECEIVER

The predicted levels of galactic noise and man-made noise are also shown. The lowest frequency at which galactic noise will be present depends on prevailing ionospheric conditions. Reduction in level below the predicted values is expected because of the wider null in the vertical pattern of an Adcock antenna for near-vertical incidence compared with the vertical whip antenna used in the NBS measurements.

A further reduction of 3 db in observed noise is obtained by the directive pattern of the antenna system in the horizontal plane since the predicted values are referred to measurements made using an omnidirectional vertical whip antenna.

Fig. 6 shows the field intensity that will produce a 20-db signal-to-noise ratio using the minimum available bandwidth of the modified and unmodified receiver. The increased sensitivity is comprised of about 6 db noise figure improvement and 7 or 8 db reduction in noise power due to the decreased bandwidth of the crystal filter.

c) Dynamic Range

The increased gain of the R.F. stage made it necessary to extend the range of the R.F. gain control by 10 db in order to protect the mixer from distortion at the high level inputs. The noise figure improvement increased the sensitivity by 6 db at minimum signal levels, thus increasing the working dynamic range by 6 db. The additional gain of the type-6688 stage is useful at the maximum gain control setting to compensate for the decrease in noise spot diameter produced by insertion of the crystal filter.

d) Cross Modulation

For a wanted signal producing a full-scale 45° deflection on the cathode-ray tube display with a gain control setting at 6 db above minimum gain, the level of an unwanted signal, detuned 100 kc/s, required to produce a 2° shift in bearing is 15 db above the wanted signal at 5 mc/s. At a frequency of 10 mc/s, the level to produce the 2° shift for the same detuning is 20 db above the wanted signal.

e) Local Oscillator Stability

The stability of the local oscillator also came under review as a result of the narrow bandwidth provision. Measurements were made to determine the variation of frequency of the oscillator with line voltage. The stability of the existing circuit using the type-6AH6 tube as a triode was about 1000 c/s per 5-volt change of the mains regulator output voltage at 17 mc/s on band 3, and about

2000 c/s per 5-volt change of the mains regulator output voltage at 25 mc/s. One section of a type-12AT7 tube in the same circuit produced about the same results. The stability of the unit using a type-6C4 tube was improved by about 4 times to 200 c/s per 5-volt change at 17 mc/s, and 500 c/s per 5-volt change at 25 mc/s. Oscillation could not be maintained over the lower frequency portion of band 4 using the type-6C4 tube, however, as the impedance in the feedback circuit became excessively low compared with the internal impedance of the tube. Satisfactory operation could not be obtained by a modification in the coil, and it appeared that the only solution would be a major modification of the circuit to supply feedback from the plate instead of the cathode. No changes are being recommended presently, but this may be reconsidered if operational use of the receiver proves it a necessity.

CONCLUSIONS

The performance of the receiver with the suggested modifications is adequately improved to warrant their incorporation.

The improvement in noise figure of 5 or 6 db by the use of the type-6688 input stage results in a direct improvement in overall sensitivity. Addition of this new tube type to the receiver parts list is not considered to be a serious disadvantage.

The crystal filter provides a desirable feature in additional rejection of interfering signals without introducing any appreciable instrumental error to the system. The modifications required are simple and the resulting operation is convenient.

The reduction in noise power by the decrease in bandwidth and noise figure improvement has resulted in a sensitivity improvement of about 14 db in the case of the minimum available bandwidth of the modified and unmodified receivers.

Local oscillator stability appears to be inadequate, but corrective measures seem too involved at present. This problem may be reconsidered if operational use of the receiver indicates it is necessary.

References

1. W.Q. Crichlow, D.F. Smith, R.N. Morton, and W.R. Corliss. "World Wide Radio Noise Levels Expected in the Frequency Band 10 kc to 100 mc". National Bureau of Standards Circular 557.

2. A.D. Watt, and E.L. Maxwell. "Measured Statistical Characteristics of VLF Atmospheric Radio Noise". Proc. IRE, 45: 55, 1957

3. A.D. Watt, R.M. Coon, E.L. Maxwell, and R.W. Plush. "Performance of Some Radio Systems in the Presence of Thermal and Atmospheric Noise". Proc. IRE, 46: 1914, 1958

APPENDIX A

MODIFICATION OF RECEIVER FOR CRYSTAL FILTER OPERATION

The following circuit modifications are required to accommodate the crystal filter unit:

1) Unit 100 - I.F. Selector Unit

   a) Remove R129 and R116 and associated shielded leads.

   b) Remove relay K105.

   c) Remove all wiring to relay K104 except power.

   d) Feed from R109 through relay K104 to C115 and R123 as shown in Fig. 7.

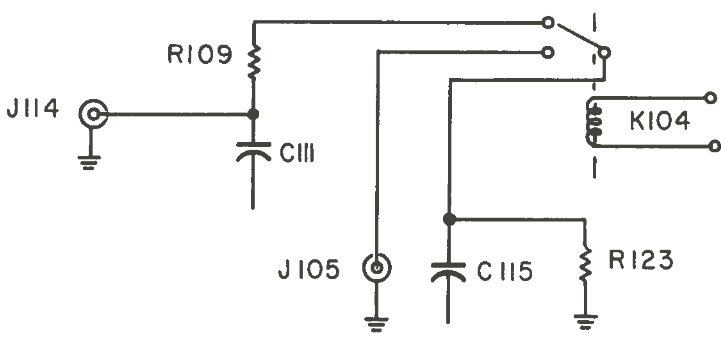

FIG. 7 MODIFIED CIRCUIT OF UNIT 100

2) Unit 2800 Audio and Switch Unit

   a) Remove all wiring from "Audio Output" switch.

b) Remove lead from "Aural Gonio" switch to J2805 (pin G).

c) Re-label "Audio Output" switch as "Xtal Filter".

d) Connect one pole of "Xtal Filter" switch to J2807 (pin F).

e) Connect lead from previously labelled "N-S" contact of "Audio Output" switch to J2807 (pin C).

f) Re-label "1kc" position of "Selectivity" switch to read "Xtal".

g) Re-label positions of "Xtal Filter" switch to read "Narrow" in extreme left position and "Wide" in center position.

h) Modify the "Xtal Filter" switch so that it cannot be thrown to the right of the center position.

The original and modified switch circuits are shown in Fig. 8.

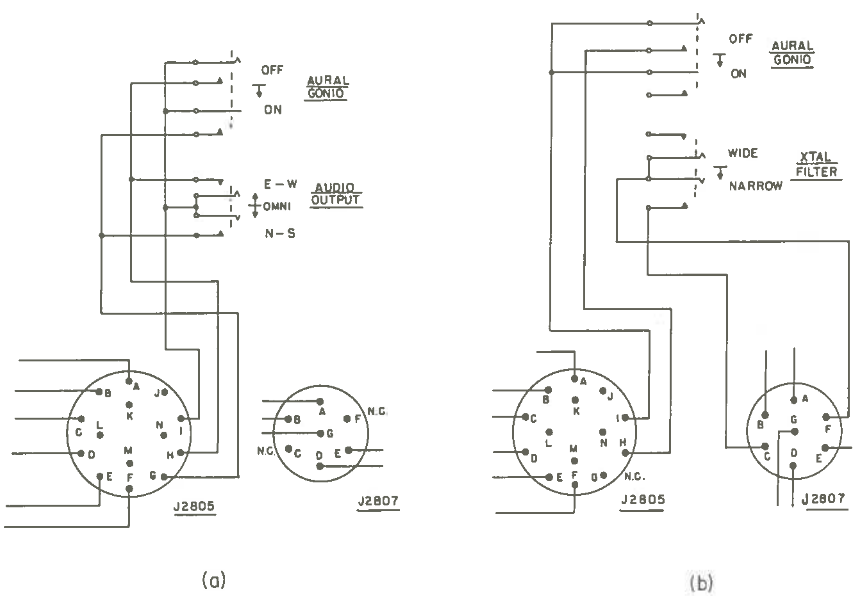

FIG. 8 MODIFICATIONS TO UNIT 2800

(a) original (b) modified

3) Unit 300 - E-W 175 kc/s Amplifier

a) Connect pin I of J313 to Pin C of J312.

b) Connect pin F of J312 to ground.

4) Cable Modifications

a) Cable from J2807 connects to J2908 of crystal filter.

b) Cable from J312 connects to J2907 of crystal filter.

c) Cable from J902 connects to J2902 of crystal filter.

d) Cable from J901 connects to J2903 of crystal filter.

e) Cable from J301 connects to J2905 of crystal filter.

f) Cable from J401 connects to J2906 of crystal filter.

g) A 7-core cable connects J2304 to J2909 of crystal filter.

APPENDIX B

DESCRIPTION OF SPECIAL COMPONENTS OF CRYSTAL FILTER UNIT

1) T_1 and T_2

Core — 2x-E34/10/12-21M Ferroxcube E-core assembly without coil form

Coil Form — Type-I 10 Polystyrene 4-section former manufactured by Neosid Ltd

Primary Winding — 65 turns No. 36E on each of the two center sections of coil form. Total inductance is approximately 6.6 mh with 0.004" core spacing.

Secondary Winding — 16 turns No. 36E on each of the two end sections of coil form. Total inductance is approximately 0.4 mh, with 0.004" core spacing.

2) L_1 and L_2

167 turns No. 36E in D-14/8-02-III Ferroxcube pot core assembly. Inductance tunes with 300 pf at 175 kc/s, with slug at mid-position. Q = 165 at 175 kc/s.

3) 175-kc/s Crystals

Crystal mounted in type-BH6 holder.

Crystal frequency = 175 kc/s ± 50 c/s.

Pair of crystals are matched to within ±4 c/s over a temperature range of 20° to 50° C.

4) Relays

4 p.d.t. Union-type FM relays

5) C_1 and C_2

1 to 11-pf type-JFD VC-11 variable capacitors

6) C_3 and C_4

7 to 45-pf variable ceramic capacitors

APPENDIX C

ALIGNMENT OF CRYSTAL FILTER

1) Feed a signal generator at 175 kc/s into the "commoned" input of the crystal filter unit. The outputs are connected in the conventional manner to the 175-kc/s I.F. amplifiers. Set both "phase" controls to minimum capacitance position. Set the filter bandwidth to the "narrow" position. Set both "balance" controls to a position midway between maximum and minimum capacitance positions. Set the "tuning" controls to approximately their mid-positions. Set the "Q adjust" controls and the "gain" control to their mid-positions.

2) Manually vary the tuning of the signal generator back and forth over a range of approximately 1 kc/s, about 175 kc/s. Adjust one of the "balance" controls with an insulated tool to reduce the bearing swing during this "rocking" of the signal generator frequency to a minimum.

3) Set the filter bandwidth to the "wide" position. Adjust the "tuning" control of one channel to produce "minimum peak deflection" in that channel; that is, the output at the peak of the response curve should be the lowest that can be obtained.

It will be noted that the frequency of the peak of the response curve will change with the tuning. This condition corresponds to maximum damping placed in series with the crystal circuit and results in maximum circuit bandwidth. Adjust the "tuning" control in the other channel also for minimum peak deflection in the same manner.

4) Set the filter bandwidth to the "narrow" position. Readjust the "balance" controls, if necessary, for minimum bearing wobble during frequency rocking of the signal generator. Adjust the "Q adjust" control if the bearing wobbles in the same direction on both sides of the resonant peak. The bearing trace should now remain stable and a straight line while the frequency is rocked over approximately a 1-kc/s range. If an ellipse is present, increase the capacitance in one of the "phase" controls until the ellipse disappears.

5) With the signal generator tuned to 175 kc/s, set the receiver bandwidth control to the 9-kc/s position and align the cursor with the trace. Then set the bandwidth control to the "narrow crystal" position and adjust the "gain" control to produce the same bearing as the cursor.

6) Set the signal generator accurately to the frequency of maximum response. Then detune the signal generator by an equal amount in both directions alternately and observe the relative response. The response should be equal on both sides off resonance to assure symmetry of the bandpass. If this is not so, readjust the "balance" controls to produce a symmetrical response that is free from bearing wobble.

7) Repeat step (3), and then make final adjustments to the "tune" controls to produce a minimum of bearing wobble while the frequency of the signal generator is varied back and forth. Adjust the "Q" control if bearing wobbles in the same direction on both sides off resonance.

8) Repeat steps 4 to 7 until sufficient stability of the bearing trace is obtained to meet the performance requirement in (9).

9) The bearing trace should remain stable within $\pm \frac{1}{2}°$ for both "narrow" and "wide" positions of the filter with the frequency varied between the 3 db points of the respective bandwidths. The center frequency gain of the two filter positions should be within 1 db of each other.

APPENDIX D

MODIFICATIONS AND CORRECTIONS TO PERFORMANCE SPECIFICATIONS OF AN/GRD-501

1) Add Section 3.9A after Section 3.9 as follows:

3.9A Crystal Filter

3.9A.1 Conditions— The unit shall be tested with supply voltages of 150 volts (DC), 6.3 volts (AC), and 28 volts (DC). This unit shall be allowed to operate for 15 minutes before testing.

Input to the filter shall be from a 73-ohm source (attenuator pad) and all R.F. voltages are to be measured with a VTVM. The output shall be terminated by a 73-ohm load. Measurements shall be made for each channel in turn.

3.9A.2 Gain— An input of 1 mv at 175 kc/s shall produce an output of 1 mv ± 20% for both narrow and wide positions of the filter.

3.9A.3 Bandwidth— Bandwidth shall be in accordance with the values given in Table II A.

TABLE II A

Selectivity Position	Relative Input Level (db)	Relative Output Level (db)	Deviation from Center Frequency (c/s)
	0	0	0
	+ 3	0	90 ± 10
Narrow	+ 3	0	90 ± 10
	+20	0	900 ± 100
	+20	0	900 ± 100
	0	0	0
	+ 3	0	700 ± 100
Wide	+ 3	0	700 ± 100
	+20	0	3000 ± 500
	+20	0	3000 ± 500

2) Modify paragraph 3.29.3 to read as follows:

3.29.3 Audio Output— With an input of 1 volt rms at J105 and the aural goniometer relay in the closed position, the output at J115 shall be 0.9 volts ± 0.1 volts.

3) Modify the fourth sentence in paragraph 4.1.4 to read:

Turn the "Sensitivity" control to minimum and increase the level by 90 db.

4) Modify the values (a), (c), (e), and (g) in Table VIII of paragraph 4.2.2 to the following:

(a)	76 db
(c)	76 db
(e)	75 db
(g)	72 db

5) Modify Table IX in paragraph 4.3.2 to read:

TABLE IX

Selectivity Position (kc/s)	Attenuation Required (db)	Bandwidth (kc/s)
	77	9 ± 1
9	60	27 ± 2
	20	50 ± 10
	77	3 ± 0.3
3	60	10.5 ± 1
	20	31 ± 3
Crystal Wide	60	2.8 ± 0.3
	20	9.5 ± 1
Crystal Narrow	60	1.2 ± 0.1
	20	7.7 ± 1

6) Modify paragraph 4.5.3 to read "Wide Xtal" position instead of "1 kc/s position".

7) Modify section 4.7 to read as follows:

4.7 Aural Aids

4.7.1 Audio Output Balance—— This measurement is to be made by means of a VTVM connected across a 3900-ohm load at the headphone terminal. Set the "BFO tone" to the "+" position. The output levels shall be within 3 db of each other when the Bearing Reference signal is in the 45° and 135° positions.

4.7.2 Aural Gonio—— The output stages of the I.F. amplifiers shall be commoned and accurately balanced in phase. The minimum output obtainable shall be at least 40 db below the maximum output obtainable by rotating the aural goniometer.

8) Modify the last sentence of paragraph 4.9.1 to read:

—— for all four selectivity settings ——

9) Modify the first sentence in paragraph 4.11.1 to read:

—— for all four settings of selectivity.

10) Modify the second last sentence in paragraph 4.12.1 to read:

—— with the "selectivity" in the "wide xtal" position.

11) Modify the first sentence in paragraph 4.12.2 to read:

—— with "selectivity" in the "wide xtal" position —— .

12) Modify the third sentence in paragraph 4.13.1 to read:

—— "Selectivity" shall be in the "wide xtal" position.

13) Modify the second last sentence of paragraph 4.14 to read:

—— with "selectivity" at "wide xtal" position using an —— .

14) Modify the last sentence of paragraph 4.15.1 to read:

—— and "selectivity" in the "wide xtal" position, the leakage —— .