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NRL REPORT R-3156

REDUCTION OF CROSS MODULATION AT D A J STATIONS BY THE USE OF ANTENNA COUPLING TRANSFORMERS

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NAVAL RESEARCH LABORATORY

Washington, D.C.

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REDUCTION OF CROSS MODULATION AT DAJ STATIONS BY THE USE OF ANTENNA COUPLING TRANSFORMERS

by

R. L. Haskins and M. L. Musselman

August 1946

Problem No. 39R06-27

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ABSTRACT

Cross modulation interference was experienced early in the operation of the DAJ direction finder stations. One of the stations most seriously affected was at San Juan, Puerto Rico, where three broadcast stations were within several miles of the d.f. arrays. Tuned filters were successfully employed between the antenna and the cathode follower to eliminate the interference but because of excessive attenuation (6-10 decibels) in the high frequency band they were considered unsatisfactory for general use. Studies were instigated to find means of improving the cathode follower and at the same time to develop a suitable replacement for it. Improvements in the cathode follower were found to be inadequate and a transformer type of network was developed for Bands 1, 2, and 3 which not only eliminated the interference but increased the sensitivity several decibels. Preliminary models of transformers for Bands 2 and 3 were sent to Adak, Alaska for installation and tests and results were very encouraging; the interference was eliminated and the sensitivity was better over most of the band. Because of the favorable results at Adak, additional units were constructed for installation and test at San Juan. An NRL engineer was sent to San Juan to supervise the tests and to determine the relative performance of the cathode follower and the transformers when tested under the same conditions. Results of tests show that the transformers were effective in eliminating the interference and at the same time improved the sensitivity by several decibels. It was also found that the accuracy of the station was not impaired by the substitution of the transformers for the cathode followers. Preliminary analysis on Band 4 transformers indicates that considerable more work will be required before a suitable design can be developed. It is suggested that consideration be given to the redesign of the antenna and receiver input circuits of Band 4 in order to improve its over-all sensitivity and at the same time allow a more efficient coupling network design.

AUTHORIZATION

Work on this problem was requested by the following BuShips letters to NRL:

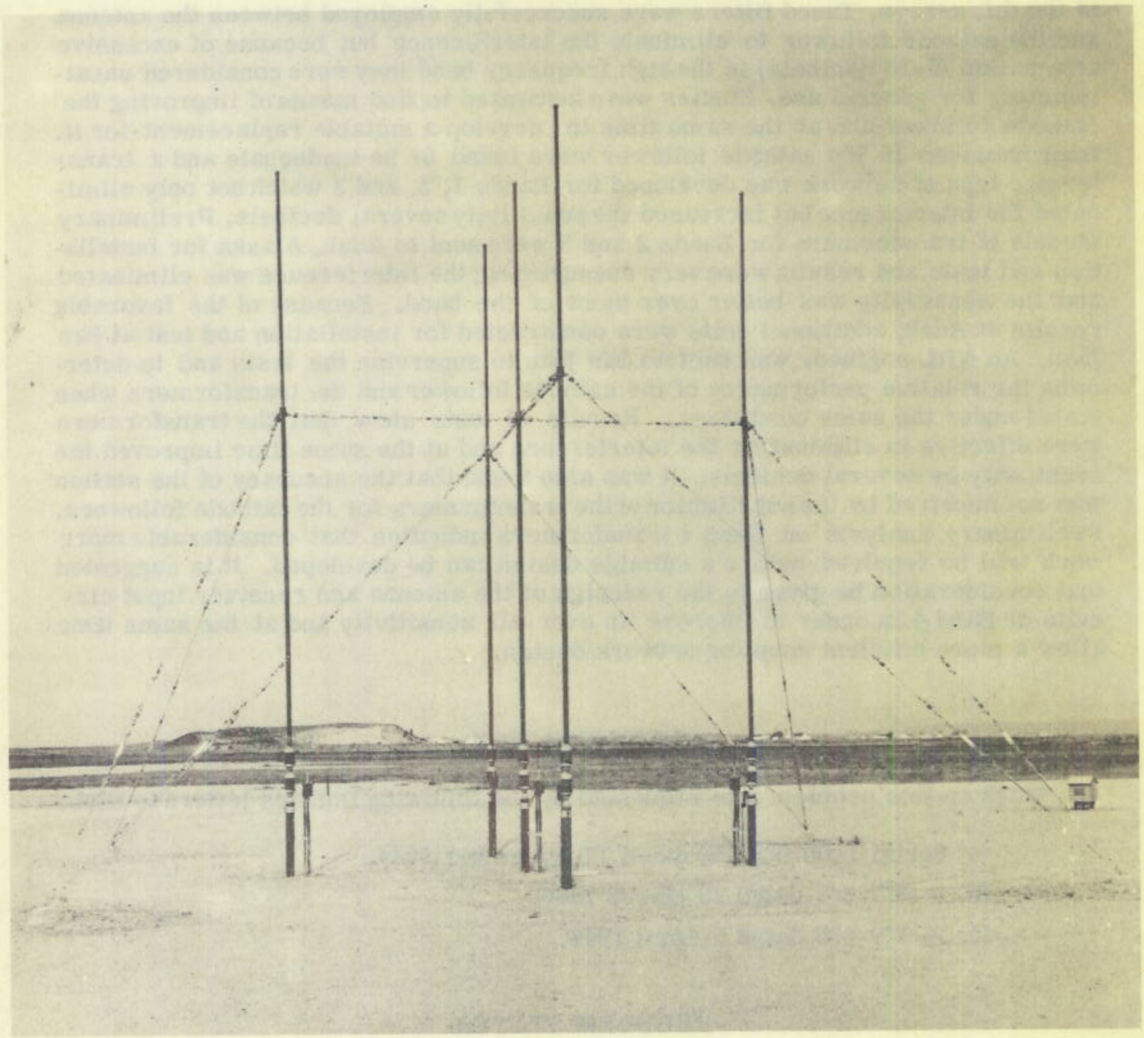
(a) Serial 1100 (925Db) dated 17 November 1944.

(b) R-977-241 dated 29 March 1946.

(c) R-977-455 dated 5 April 1946.

PROBLEM STATUS

This report concludes the work on Problem 39R06-27, and unless otherwise advised by the Bureau the problem will be closed one month from the mailing date of this report.



Typical DAJ Antenna Array

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REDUCTION OF CROSS MODULATION AT D A J STATIONS BY THE USE OF ANTENNA COUPLING TRANSFORMERS

INTRODUCTION

Early in the operation of the DAJ direction finder stations it was recognized that the cathode follower antenna coupling units were, under certain conditions, sources of cross modulation interference. This interference was the result of extremely high signal field intensities from local transmitting stations in the vicinity of the DAJ stations. One of the stations most seriously affected by this interference was the DAJ station at San Juan, Puerto Rico. Because of the importance of this station during the war an expedient approach to the elimination of this interference was used. Special filters were installed between each antenna and its cathode follower* and results were satisfactory as regards the reduction of cross modulation interference but the overall sensitivity of the station was reduced as the result of the filter insertion loss. As a consequence, the effectiveness of the station was not as great as it could have been had the filter loss been less. Shortly after the filter installation at San Juan, reports were received from Adak, Alaska stating that the DAJ station there was also experiencing cross modulation interference as the result of transmissions from a low frequency radio range station.

These specific complaints instigated a study† to find means of improving the cathode follower or replacing it with a more suitable coupling unit. As a result of this study, it was found that sufficient improvement could not be expected from the cathode follower itself in either a decrease of cross modulation interference or an increase in sensitivity. However, a transformer type coupling network to replace the cathode follower was developed that not only was extremely effective in reducing the cross modulation interference but also in most cases actually increased the sensitivity of the system by several decibels. Because of the satisfactory laboratory test, suitable transformer networks for Bands 2 and 3 were constructed and sent to Adak for tests. Results of these test‡ showed that the cross modulation interference was greatly reduced and in most cases the sensitivity of the system seemed to be improved since the sensitivity control of the receiver could be farther advanced when the transformers were in the circuit. Because of the lack of quantitative data, however, exact sensitivity comparisions were not possible.

As a consequence of the encouraging report from Adak it was decided§ to send an engineer to San Juan to supervise the installation of a similar set of transformers and to

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* NRL letter report C-S67/(342a), C342-39 to BuShips, "Elimination of Inter-Modulation Interference in Model DAJ HF Direction Finder at San Juan, P.R." (Confidential), 16 December 1944.

† BuShips letter Serial 1100 (925Db), "Assignment of Problem S618.1 R-C," 17 November 1944.

‡ Naval Supplementary Radio Station Adak, Alaska letter to BuShips, "Model DAJ Direction Finder Antenna Coupling Transformers, Performance Report on," 11 March 1946.

§ BuShips Restricted letter R-977-241 to NRL, "Authorization for San Juan Tests," 29 March 1946.

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run such tests as were required to evaluate the relative merits of the networks on the basis of cross modulation interference reduction, bearing accuracy and sensitivity. The results of these tests are given in this report and in addition the report also contains data on the main items of work leading up to the successful design of the transformers and will serve as the final report on problem S618.1R-C. A preliminary report on the San Juan installation was made in an NRL Letter Report.**

PRELIMINARY PLANNING

Work just prior to the trip of the NRL engineer to San Juan was primarily concerned with the improvement of the mechanical design of Bands 2 and 3 transformers and the development of Band 1 transformers since these bands carried the major part of the operating work load. Accordingly, complete sets of transformers for Bands 1, 2 and 3 were fabricated, temperature-cycled and tested prior to shipment to San Juan. Two Band 4 transformers were also constructed and preliminary tests made, but the results were not entirely satisfactory due to the lack of sensitivity. These transformers however, were taken along in the hope that field tests might prove them to be satisfactory.

Because of the unusual local conditions (high signal levels) at the d-f San Juan station it was realized that in addition to the normal tests (calibration) it would be necessary to expand these tests and perhaps to improvise certain tests after the engineer was on the job. Plans were made therefore, to include such measurements as accuracy, sensitivity, cross modulation reduction and electrical balance in the test programs. The following discussion pertains to these tests:

(a) Local calibrations and check bearings were deemed sufficient for the accuracy tests.

(b) The sensitivity tests were considered to be very important inasmuch as these measurements would largely determine the acceptance of the transformers over the cathode followers. Because of the high signal fields from the local broadcast stations and the possibility of high external noise (atmospherics) it was anticipated that accurate sensitivity measurements might be difficult to obtain, particularly a comparison between the transformer and the cathode follower without the filter. For this reason dummy antennas were taken along for each band in anticipation of these high signal and noise fields. Plans to run high-level gain tests and output noise measurements in addition to the sensitivity measurements were also contemplated.

(c) The measurement of cross modulation reduction was to be made on the number and amplitude of the spurious frequencies that were present before and after the installation of the transformers. Sufficient analysis was to be made to determine whether the cathode followers were the sole source of interference or whether the receiver was also responsible.

(d) Because of the criticalness of the amplitude and phase balance of the circuits prior to the receiver it was essential that the balance of the complete system be measured for both the transformer networks and the cathode followers. This was most easily accomplished by measuring one pair of antennas at a time with a target transmitter located 90 degrees to the plane of the antennas under test.

** NRL letter report R-S67/69 (1245:MIM), R-1240-266/46 to BuShips, "Interim Report on Transformer Tests at San Juan" (Restricted), 20 August 1946.

TESTS PERFORMED AT SAN JUAN

The tests as planned above were modified somewhat to meet existing local conditions but in general, the overall test program was carried out. The following tests were made at San Juan:

(a) Sensitivity and Gain Tests

(b) Bearing Accuracy Calibration

(c) Balance Tests

(d) Cross Modulation Interference Tests

RESULTS OF TESTS

Sensitivity and Gain

Ordinarily sensitivity measurements of a complete d-f system consist of determining the microvolts per meter input to give a certain signal to noise output. This type of measurement is valuable when comparing two stations separated by either time or distance; however, at San Juan comparative tests were quickly made between networks under the same conditions, that is, a reading was taken first on one unit then on the other. For this reason, absolute values of sensitivity are not required, thus reducing to a minimum the need of specialized equipment. As a consequence, a target transmitter (signal generator) was used as the signal source and a standard output meter as the output indicator. The transmitter was placed at the 45-degree position of each array; the transformers were placed in the N-S antennas and the cathode followers were placed in the E-W antennas. The goniometer was first coupled to one pair of antennas and then to the other pair of antennas, thus comparative results were quickly obtained without the necessity of exchanging the networks at each frequency. Consequently, relative sensitivity measurements were obtained but not in terms of microvolts per meter. These measurements are termed "differential" since pairs of antennas are involved in the measurement. Data were also taken on what may be called a modified differential or single system, that is, one antenna (farthest from transmitter) of each pair was shorted to ground. In addition to the "differential" and the "single" measurements, data were also taken on the sense circuit using a dummy antenna. Noise measurements were made differentially without antennas in circuit. These different types of measurements were taken in an effort to get around some local condition or to bring out certain aspects of the equipment not possible by any one method by itself.

Sensitivity and Gain - Band 1. Figure 1 shows the measured gain comparision between the transformer and the cathode follower with filter for the differential type of measurement. Because of local conditions, differential sensitivity measurements were not made on Band 1; however, sensitivity comparisons were calculated from the relative gain and output noise ratios. This curve is believed to be representative of the sensitivity ratios of the two networks and shows that the transformer improves the sensitivity by approximately 8 db. Figure 2 shows the comparison of the networks with and without the filter as measured with one antenna of each pair shorted to ground (single). These data show that over most of the band the transformers are better than the cathode followers both with and without the filter. Figure 3 shows the comparison between the networks as measured in the sense circuit. In general there seems to be better agreement between the differential, single and the sense type of measurement for Band 1 than for the other two arrays.

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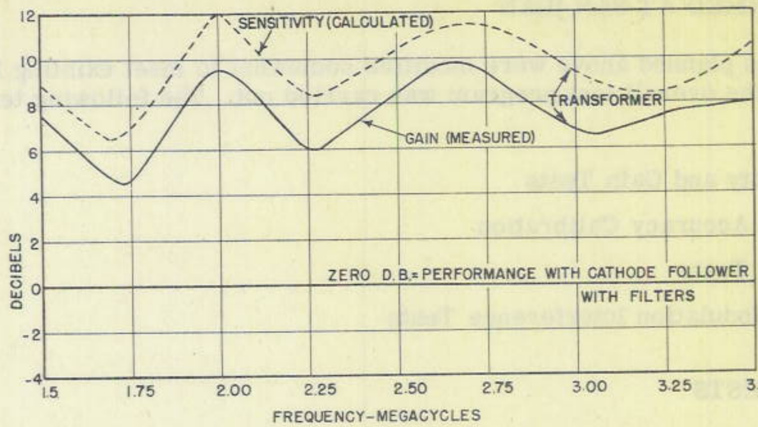

Figure 1. Sensitivity and Gain Comparisons—Band 1 (Differential Method)

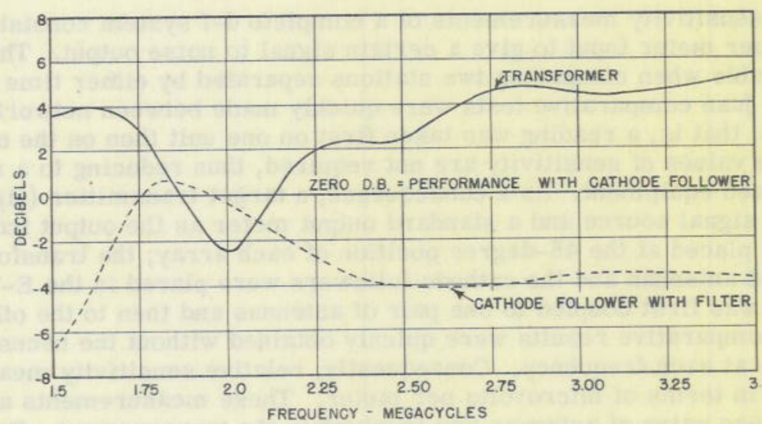

Figure 2. Gain Comparisons—Band 1 (Single Method)

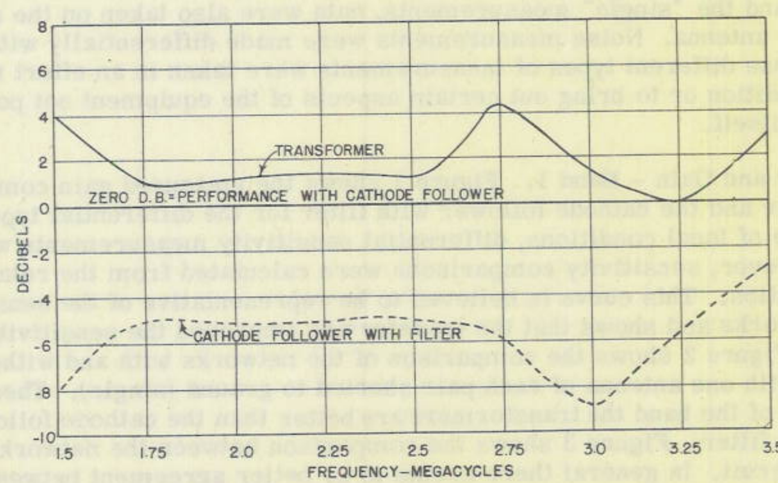

Figure 3. Sensitivity Comparisons—Band 1 (Sense Circuit)

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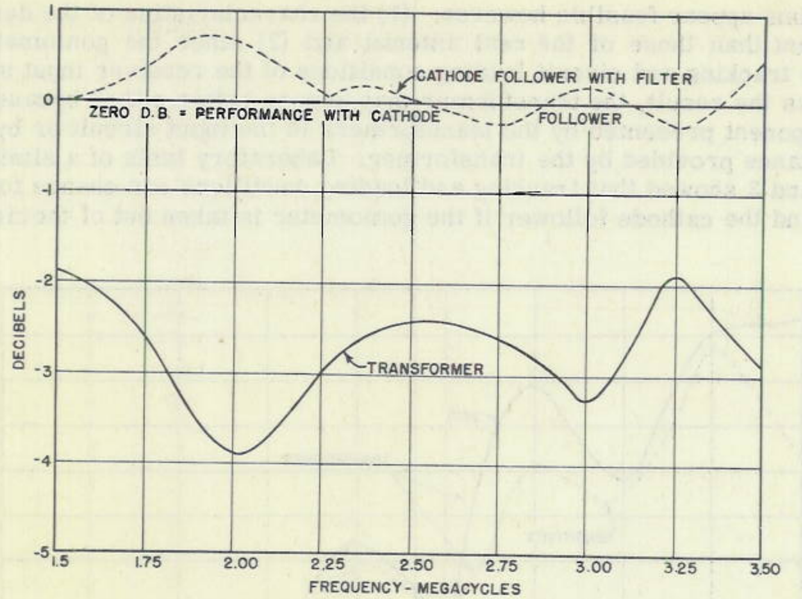

Figure 4. Output Noise Comparisons—Band 1 (Differential Method)

Figure 4 shows the relative noise output of the two types of networks and as can be seen the cathode followers on the average have about 3 decibels more noise output than the transformers.

Sensitivity and Gain - Band 2. Figure 5 shows a comparison between the transformers and the cathode followers with filters of Band 2 for the differential type of measurement. It will be noticed that the sensitivity and gain curves follow each other fairly closely which is as it should be since the overall noise of the system is not changed materially when the networks are interchanged. The transformer network has considerably more sensitivity at the low frequency end of the band but at the high end of the band the sensitivities are nearly equal. It will be noted that the sensitivity and gain ratios fluctuate with frequency and this is believed due to the reflections on the transmission line as the result of improper impedance match at the "T" junction. The frequency difference between peaks or valleys is consistent, being about one megacycle. Figure 6 shows the comparison in gain between the transformers and the cathode followers with and without the filters for the "single" (grounded antenna) type of measurement. It will be noted that the variations with frequency are even greater than those shown in Figure 5. Also, the difference in gain with and without the filter in circuit is not very great. Here again the transformers are quite a bit better at the low end of the band, tapering off to the high end. Figure 7 shows the sensitivity comparison between the networks as measure in the sense circuit also with and without the filter. These curves are included not only to show the relative performance of the networks as measured in the sense circuit but also to show the difference in results that may occur when test conditions are changed. For example, data as shown in Figure 7 were taken using a dummy antenna in place of the real antenna and without the goniometer in the circuit. It is rather difficult to account for the large difference in sensitivity between the transformers and the cathode followers particularly when the filters are in the circuit.

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Two explanations appear feasible however: (1) the characteristics of the dummy antenna may be different than those of the real antenna and (2) since the goniometer is out of the circuit the tracking and circuit loading conditions of the receiver input stage may be changed, and as the result, the transformer may appear better either because of the smaller resistive component presented by the transformers to the input circuit or by improved tracking reactance provided by the transformer. Laboratory tests of a similar nature but applying to Band 3 showed that tracking and loading conditions can change for both the transformer and the cathode follower if the goniometer is taken out of the circuit. Figure 8

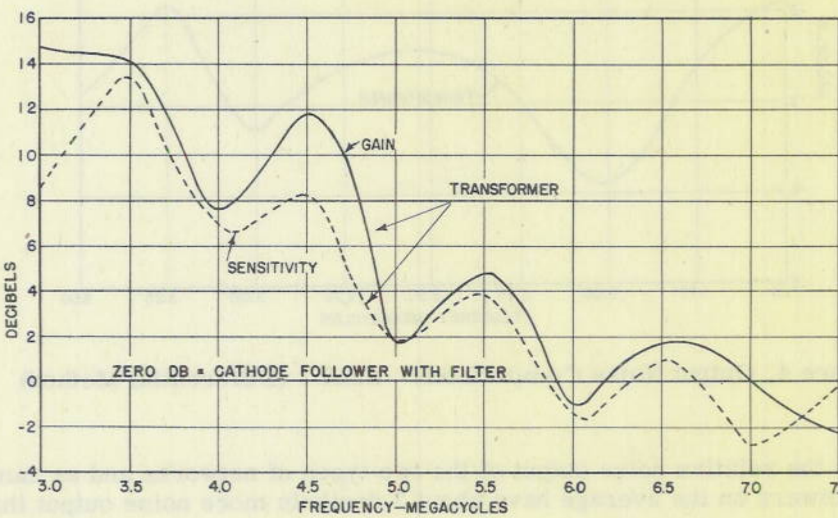

Figure 5. Sensitivity and Gain Comparisons—Band 2 (Differential Method)

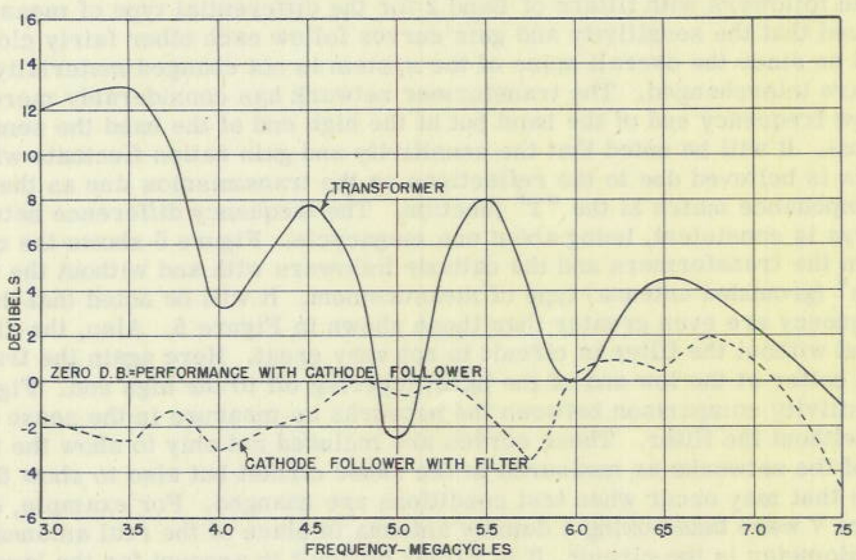

Figure 6. Gain Comparisons—Band 2 (Single Method)

shows the reduction in output noise level when the cathode followers are replaced by the transformers. On the average this reduction is in the order of two decibels. Although these data were taken without the real antennas it is believed that the output noise level would not be materially increased as the result of thermal noise of the antenna circuit.

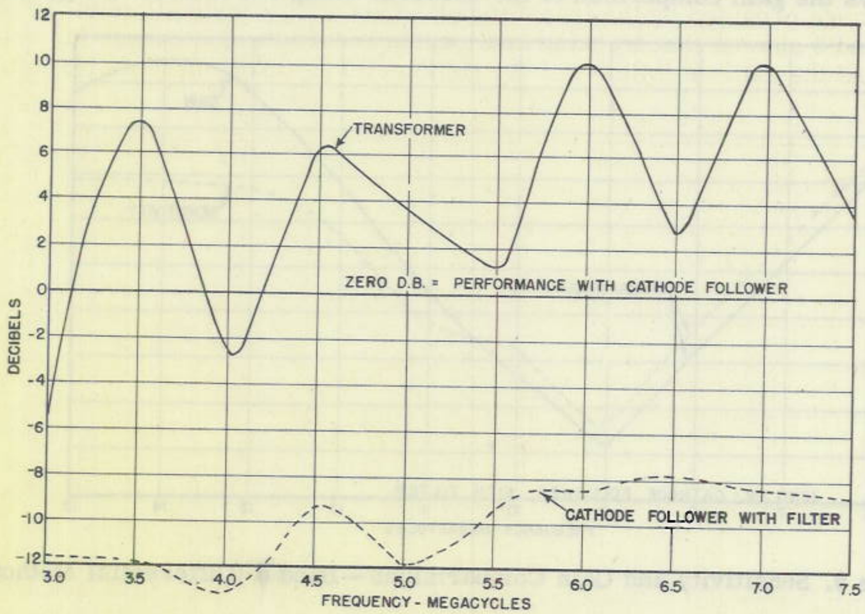

Figure 7. Sensitivity Comparisons—Band 2 (Sense Circuit)

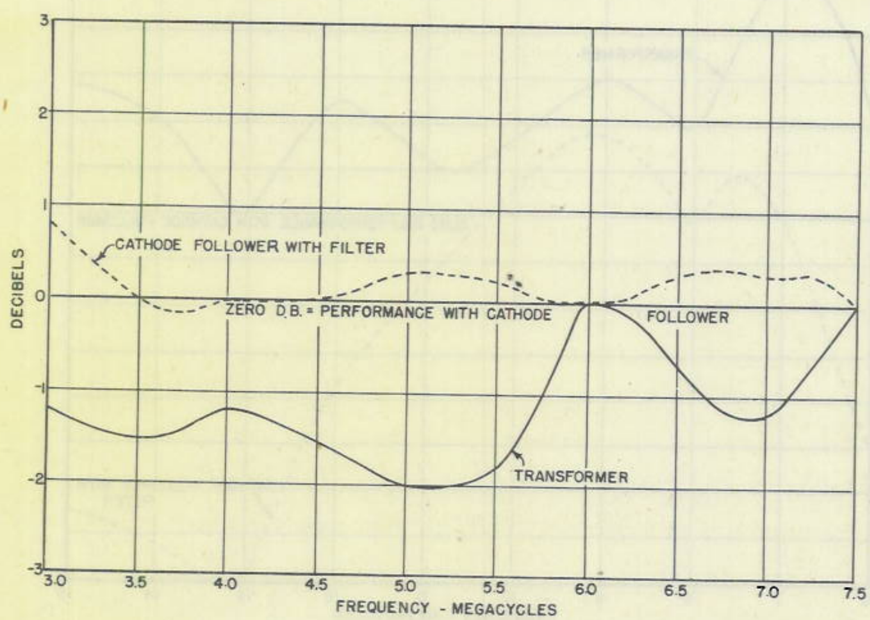

Figure 8. Output Noise Comparisions—Band 2 (Differential Method)

Sensitivity and Gain - Band 3. Figure 9 shows the sensitivity and gain comparison as measured differentially. Although the sensitivity and gain data agree over most of the frequency range they both show that the transformers offer considerable improvement over most of the band. Filter "design loss" is believed to be responsible for this difference. Figure 10 shows the gain comparison of the networks using one antenna (single measurement)

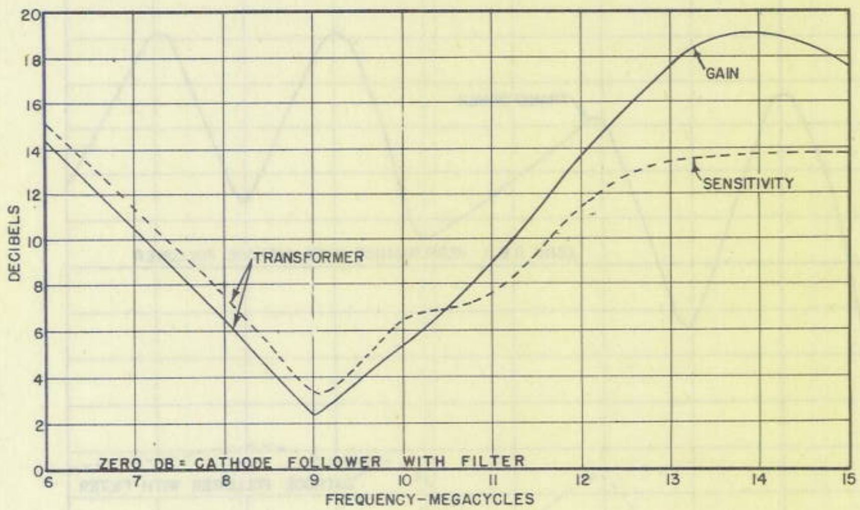

Figure 9. Sensitivity and Gain Comparisions—Band 3 (Differential Method)

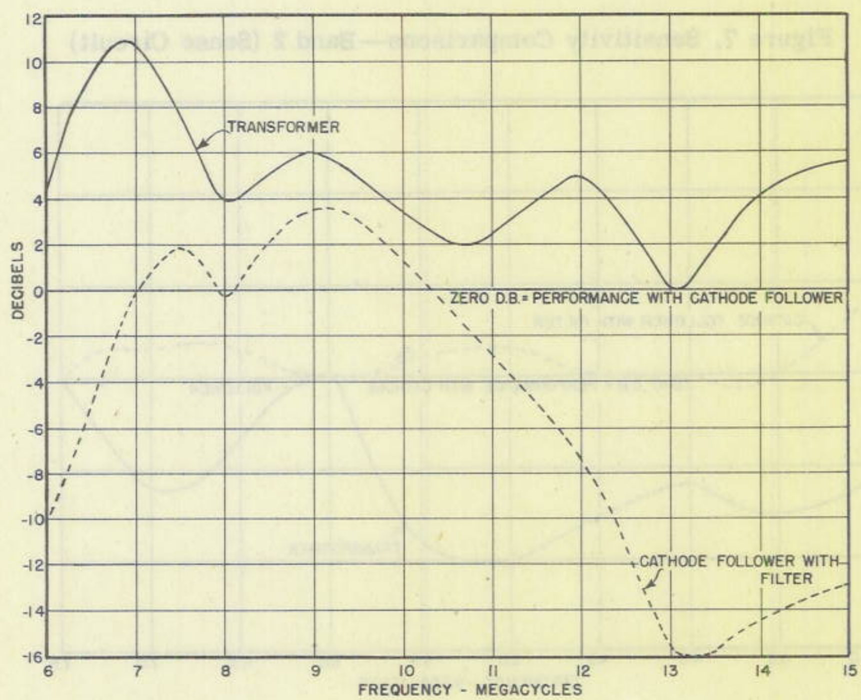

Figure 10. Gain Comparisions—Band 3 (Single Method)

both with and without the filter. The cathode followers without the filters on the average are poorer in sensitivity by about four decibels. Figure 11 shows the sensitivity comparisons as measured in the sense circuit with the dummy antenna. Again as already mentioned the sense circuit data do not agree too well with the data taken in the directional channel. The same reasons mentioned earlier may also apply here, in any event these data are believed to be representative of what happens in the sense circuit and should not necessarily be considered incorrect just because they do not agree with the directional channel data. The output noise, as shown in Figure 12, is decreased by about 2 decibels when the cathode followers are replaced by the transformers.

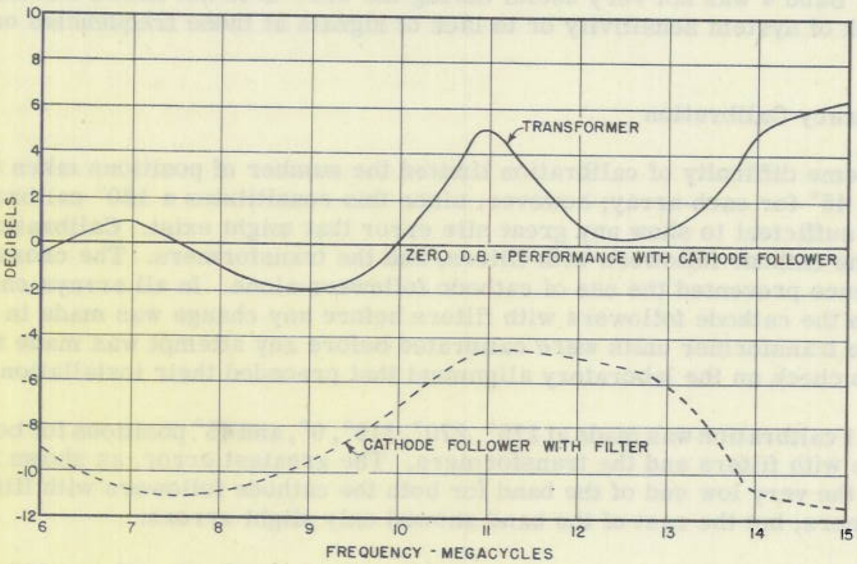

Figure 11. Gain Comparisions—Band 3 (Sense Circuit)

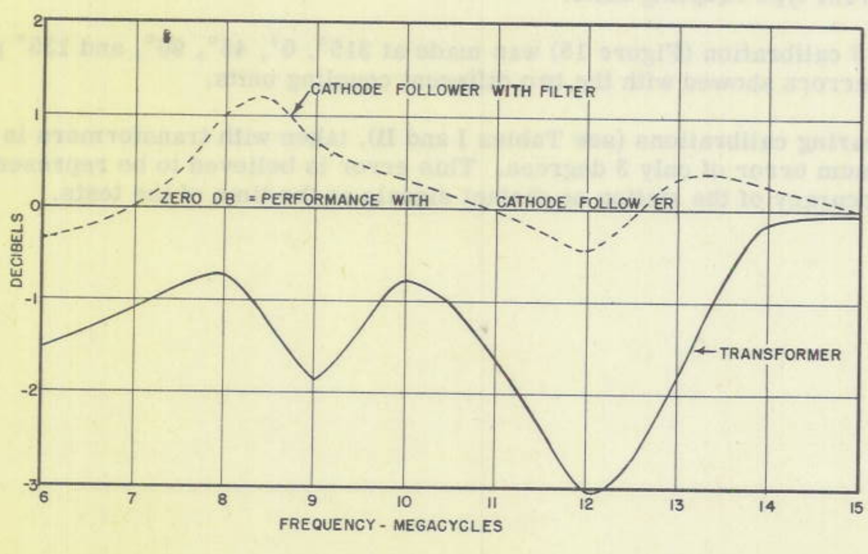

Figure 12. Output Noise Comparisions—Band 3 (Differential Method)

Sensitivity and Gain - Band 4. Gain measurements were taken comparing two Band 4 transformers with two cathode followers. Although the transformers were slightly better than the cathode followers at a few spots in the band, on the average they were considerably poorer over most of the band. These Band 4 transformers were not considered satisfactory and it is believed that a radically new design will be necessary in order to match the performance of the cathode follower over the entire band. Since the sensitivity of Band 4 is already poorer than it should be, it might be worth while at this time to consider the redesign of the antenna, coupling units and receiver input circuit, providing there is sufficient demand for better performance in this band. Past experience seems to indicate, however, that Band 4 was not very useful during the war. It is not known whether this was due to the lack of system sensitivity or to lack of signals at those frequencies or both.

Bearing Accuracy Calibration

The extreme difficulty of calibration limited the number of positions taken to five, spaced every 45° for each array; however, since this consititutes a 180° calibration it was believed sufficient to show any great site error that might exist. Calibrations were made using the cathode followers with filters, and the transformers. The cross modulation interference prevented the use of cathode followers alone. In all arrays calibrations were made on the cathode followers with filters before any change was made in the system. Similarly, the transformer units were calibrated before any attempt was made to align them so as to check on the laboratory alignment that preceded their installation.

(a) Band 1 calibration was made at 225°, 270°, 315°, 0°, and 45° positions for both the cathode followers with filters and the transformers. The greatest error, as shown in Figure 13, exists at the very low end of the band for both the cathode followers with filters and the transformers, but the rest of the band showed only slight errors.

(b) Band 2 calibration (Figure 14) was made at 270°, 315°, 0°, 45° and 90° positions. Only at the 315° position with the cathode followers with filters did any great error occur with the different type coupling units.

(c) Band 3 calibration (Figure 15) was made at 315°, 0°, 45°, 90°, and 135° positions and no great errors showed with the two different coupling units.

Check bearing calibrations (see Tables I and II), taken with transformers in circuit, show a maximum error of only 3 degrees. This error is believed to be representative of the overall accuracy of the station on distant signals at the time of the tests.

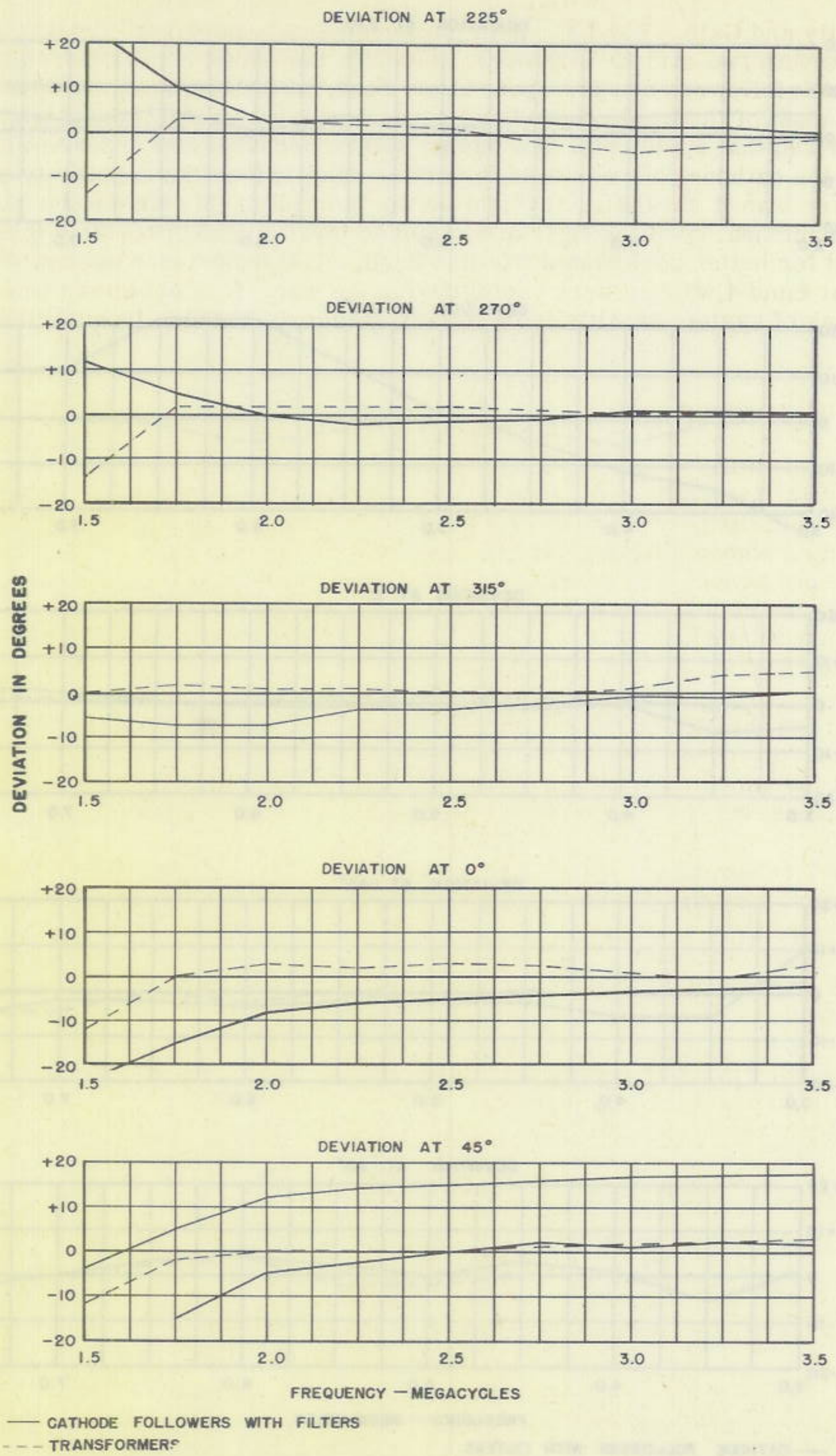

Figure 13. Deviation Curves on Band 1 for the Cathode Followers with Filters and the Transformers

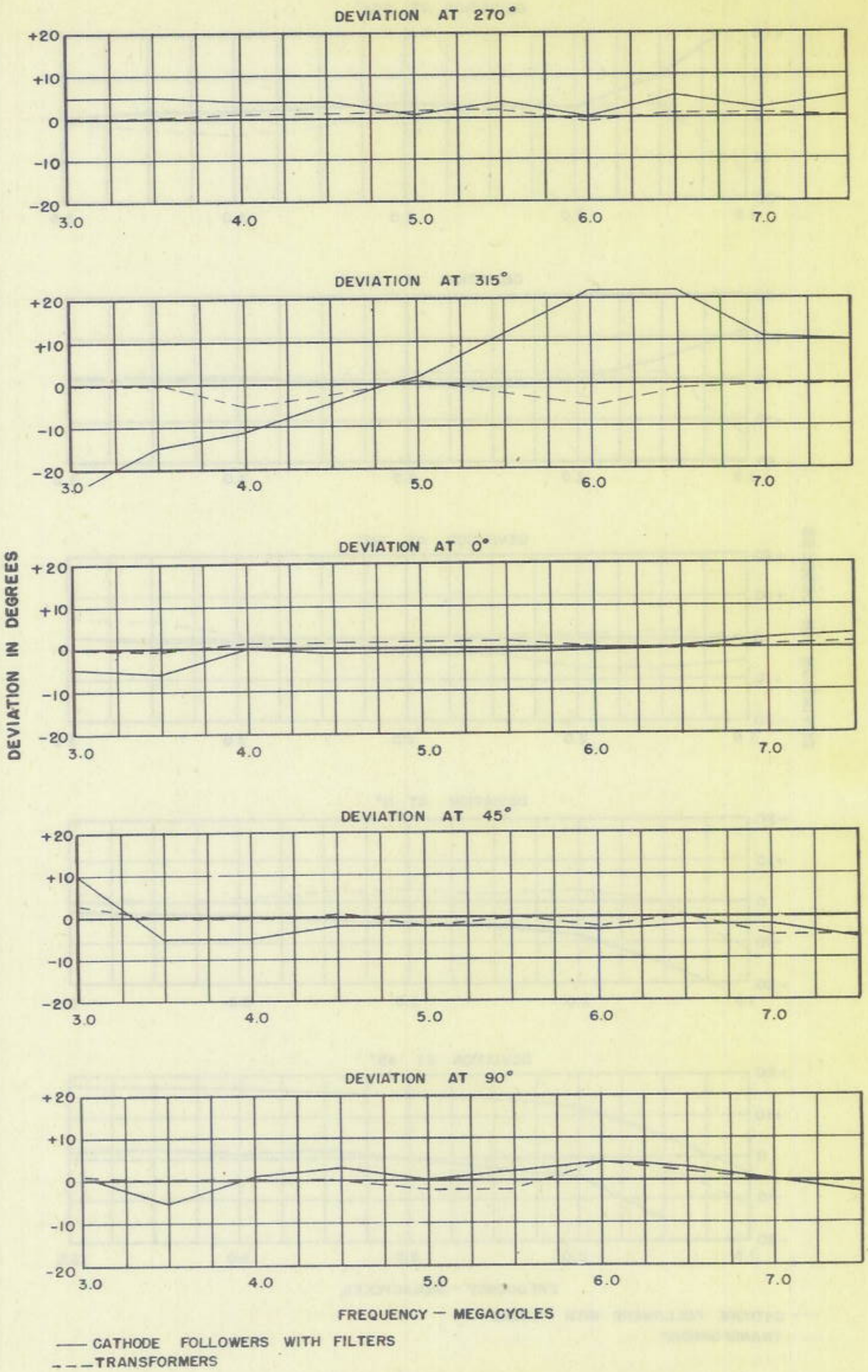

Figure 14. Deviation Curves on Band 2 for the Cathode Followers with Filters and the Transformers

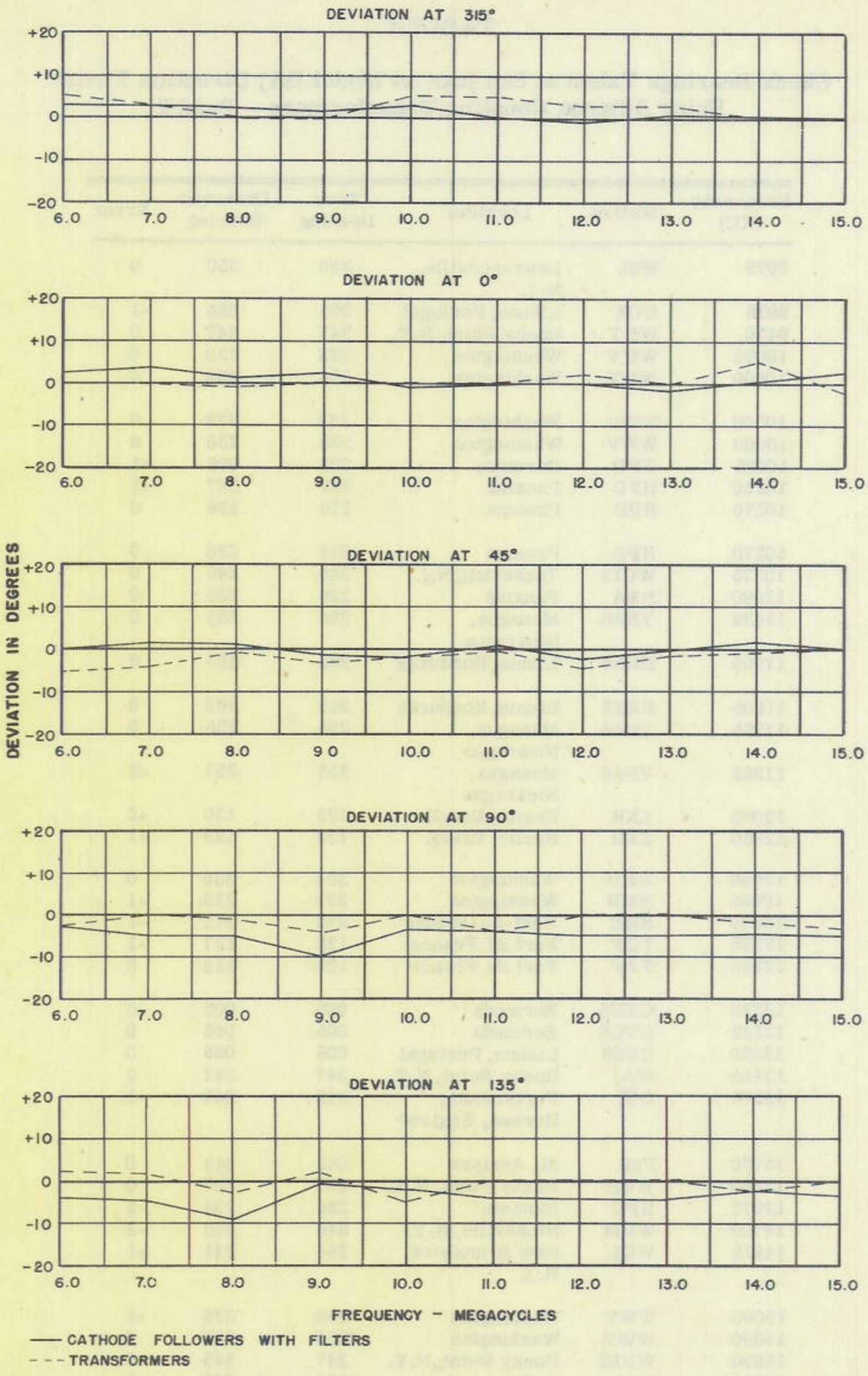

Figure 15. Deviation Curves on Band 3 for the Cathode Followers with Filters and the Transformers

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TABLE I

Check Bearings Taken at San Juan on Model DAJ Direction Finder Using Antenna Coupling Transformers - Band 2

Frequency (KC)	Station	Location	True Bearing	Observed Bearing	Error
7975	WSI	Lawrenceville, N. J.	350	350	0
8975	COX	Lisbon, Portugal	055	054	-1
9470	WET	Rocky Point, N.Y.	347	347	0
10000	WWV	Washington	338	338	0
10000	WWV	Washington	338	338	0
10000	WWV	Washington	338	338	0
10000	WWV	Washington	338	338	0
10055	ZFB	Bermuda	005	006	+1
10250	HPD	Panama	236	237	+1
10270	HPD	Panama	236	236	0
10270	HPD	Panama	236	236	0
10375	WC15	Tuckerton, N.J.	346	346	0
11080	NBA	Panama	236	236	0
11435	YNA6	Managua, Nicaragua	255	255	0
11905	HRX6	Limon, Honduras	265	265	0
11905	HRX6	Limon, Honduras	265	265	0
11935	YNA6	Managua, Nicaragua	255	255	0
11935	YNA6	Managua, Nicaragua	255	257	+2
12060	ZXH	Recife, Brazil	128	130	+2
12060	ZXH	Recife, Brazil	128	129	+1
12690	NMH	Washington	338	338	0
12690	NMH	Washington	338	339	+1
12870	HHH	Port-au-Prince	273	272	-1
12895	FZF	Fort de France	128	127	-1
12895	FZF	Fort de France	128	128	0
13225	GYG5	Bermuda	005	005	0
13225	GYG5	Bermuda	005	005	0
13350	CUO2	Lisbon, Portugal	005	055	0
13480	WAJ	Rocky Point, N.Y.	347	347	0
13575	GYJ	Portsmouth, Horsea, England	042	041	-1
13770	FSE	St. Assisse	043	043	0
13900	WQP	Rocky Point, N.Y.	347	347	0
13975	HPC	Panama	236	234	-2
14700	WRM	Hicksville, N.Y.	346	343	-3
14815	WQL	New Brunswick, N. J.	344	345	+1
15000	WWV	Washington	338	339	+1
15000	WWV	Washington	338	338	0
15890	WPE2	Rocky Point, N.Y.	347	345	-2
16020	HPE	Panama	236	237	+1
17210	WKR	Brentwood, N.Y.	346	346	0

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TABLE II

Check Bearings Taken at San Juan on Model DAJ Direction Finder Using Antenna Coupling Transformers - Band 3

Frequency (KC)	Time	Station	Location	True Bearing	Observed Bearing	Error
4235	0011	NSS	Annapolis	338	338	0
4295		GYD	Portsmouth, Horsea, England	042	042	0
4320	0452	TGAH	Guatemala	262	264	+2
4390	0042	NSS	Annapolis	338	338	0
4395	0100	TIH	Cartago, Costa Rica	245	243	-2
4500		WIB	Brentwood, New York	347	347	0
4700	0507	YNA3	Managua, Nicaragua	255	255	0
4700		YNA	Managua, Nicaragua	255	257	+2
4960		WAC	New Orleans	302	302	0
4960	0456	WAC	New Orleans	302	302	0
5000	0001	WWV	Washington	338	338	0
5000	0501	WWV	Washington	338	338	0
5000		WWV	Washington	338	338	0
5000	0040	WWV	Washington	338	338	0
5000	0454	WWV	Washington	338	338	0
5130	0016	HRX5	Limon, Honduras	265	265	0
5130		HRX5	Limon, Honduras	265	265	0
5130	0446	HRX5	Limon, Honduras	265	265	0
5160		GYZ	Rinella, Malta	042	042	0
5300		PYS	Brazil	128	129	+1
5300	0517	PYS	Brazil	128	128	0
5380	0509	VFN	Canada	344	344	0
5530		GYU1/5	Gibraltar	059	056	-3
5530	0500	GYU6	Gibraltar	059	059	0
6650	0050	GYE	Cleethordes, England	038	042	+4
6675	0435	GYC5	Portsmouth, Horsea, England	042	042	0
6790	0442	WBO	Hingham, Mass.	351	351	0
6970	0005	WKP	Rocky Point	347	347	0
6980		HPC	Panama	236	236	0

Balance Tests

The performance of the DAJ type of direction finder depends to a very large extent upon the electrical balance of the r-f circuits of the d-f system. The antenna coupling units in particular can be guilty of much unbalance if not properly designed. Consequently overall balance tests were made comparing the transformer antenna coupling units with the cathode followers. Tests showed that the transformers were not inferior to the cathode followers in this respect.

Cathode followers (with filters if any) are placed in the 0° and 180° monopoles, the 90° and 270° monopoles are disconnected completely from the system, the target transmitter is set at the 90° position approximately 300 feet from the array, and a milliammeter is connected to read the current of the cathode circuit of the deflection amplifier. With the target transmitter off, both monopoles in use, and the receiver tuned to the desired frequency, the bias on the cathode of the deflection amplifier tube is set so the meter reads 10 milliamperes. The target transmitter is then turned on and tuned to the frequency of the receiver. One monopole is disconnected and the input to its coupling unit shorted to ground. The sensitivity control is then adjusted so that the cathode current reads 2 milliamperes. Then the monopoles are reversed; that is, the one that was disconnected is put into use and the short to ground removed, the other one is disconnected and the input of its coupling unit shorted to ground. The meter reading on this monopole should still be 2 milliamperes if the system is balanced, so any difference is recorded. Then both monopoles are put into use at the same time and all shorts to ground removed. In this manner the signal in the one monopole should balance out the signal in the other so that the ammeter will read 10 milliamperes; however, unbalance will lower this so any difference is recorded. Figures 16, 17 and 18 show the electrical balance of the system when the cathode followers are in the circuit. Although in general the balance of the three arrays appears adequate, it is felt that the balance of arrays 2 and 3 is somewhat inferior to that which is expected at a high quality site. Array 1 on the other hand shows an entirely acceptable balance with the possible exception of the extreme low end of the band.

The same general procedure is repeated with the transformer with results as shown in Figures 19, 20 and 21. On the whole the balance of the system is as good with the transformers as with the cathode followers. It will be noted that for array 3 that although the balance over the band is about the same, the point of poor balance has been shifted from about 9 megacycles to about 11 megacycles. Previous experience at other DAJ stations indicate that the balance of Band 3 array is somewhat critical in this frequency range; this is believed due in a measure to the resonance of the antenna system.

Cross Modulation Interference Tests

The cross modulation interference resulting from the untuned grid of the cathode follower greatly limited the operation of the direction finder station. Cross modulation tests showed that the interference is almost continuous throughout the band of the DAJ when the receiver sensitivity control is set about three quarters of maximum sensitivity. Periodically, this interference may occur in some parts of the range in the form of voice modulation while at another part a series of audio beat notes or "birdies" is present when the receiver is being tuned. Although the tuned filters did remove the interference, the transformers served a better purpose in that they removed the instrument that produced the interfering cross modulation, namely, the cathode followers. The result indicated that the cathode followers were the sole source of cross modulation interference and that the receiver itself was not responsible.

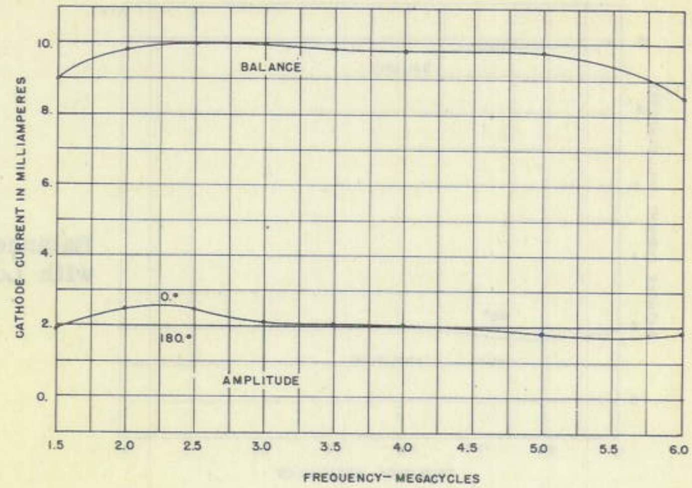


Figure 16
Balance Test on Band 1 for Cathode Followers and Filters with Local Transmitter at 90 Degrees

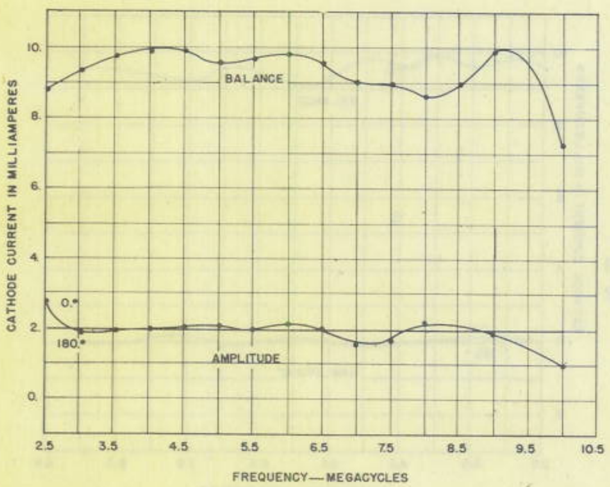


Figure 17
Balance Test on Band 2 for Cathode Followers and Filters with Local Transmitter at 90 Degrees

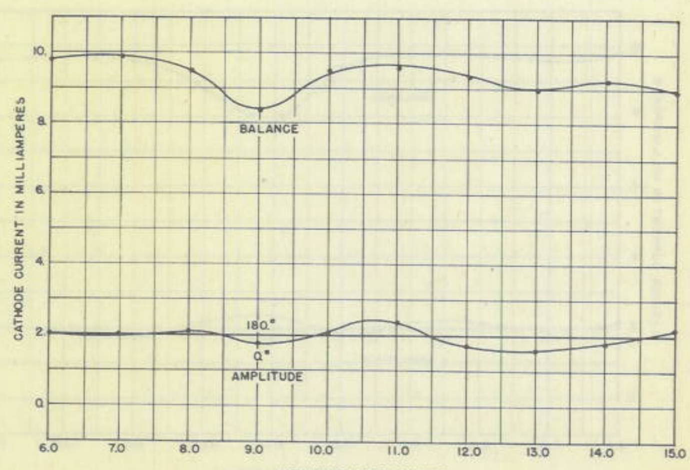


Figure 18
Balance Test on Band 3 for Cathode Followers and Filters with Local Transmitter at 90 Degrees

[redacted]

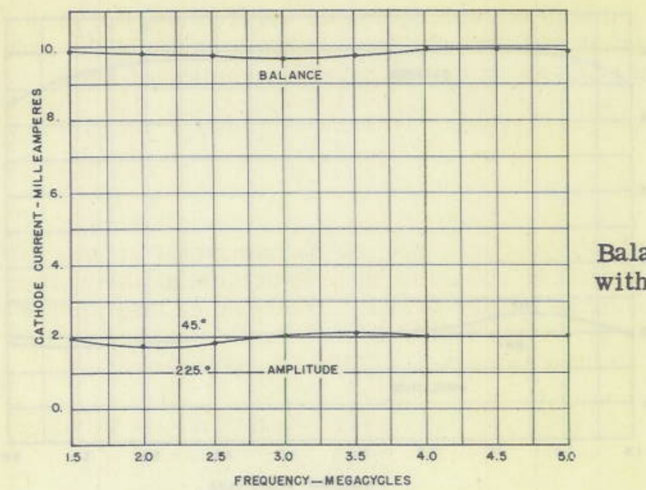


Figure 19
Balance Test on Band 1 for Transformers with Local Transmitter at 315 Degrees

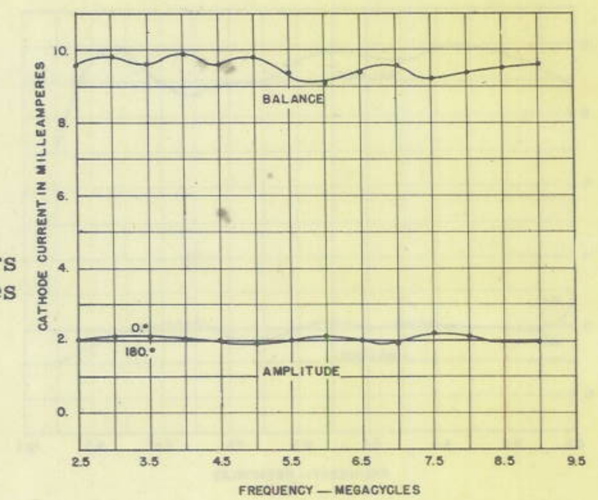


Figure 20
Balance Test on Band 2 for Transformers with Local Transmitter at 90 Degrees

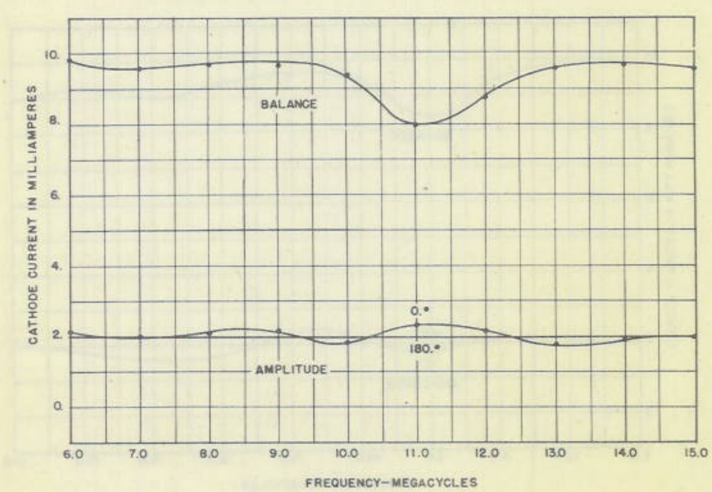


Figure 21
Balance Test on Band 3 for Transformers with Local Transmitter at 90 Degrees

Although attempts were made to catalog both the amplitude and the frequency of each of the interfering signals it became apparent that this was impossible because of the great number of such signals observed when the receiver was adjusted for reception of weak signals.

MAINTENANCE NOTES FOR SAN JUAN STATION

Whenever the transformer coupling units used at the base of the monopoles appear to be causing bearing errors, the following procedure should be used to determine the source of trouble and to correct it. Each step should be followed consecutively since they appear in the order of probable occurence and this will avoid unnecessary misalignment of the units in any haphazard attempt to find the cause of error.

(a) Check to find if any water has collected around the balanced output terminals of the transformer units. If this has happened the unit should be dried at a temperature not to exceed 150°F.

(b) Check the resistance of one balanced output terminal to the other; this should be a short circuit. Any measurement of high resistance indicates a broken lead which might be repaired at the station. Also check the resistance to ground of each balanced output lead of the transformer. These leads should measure infinite resistance to ground, so if any appreciable resistance (less than 100 megohms) does exist the units should be inspected for excess moisture, fungus or insulation breakdown. If dehydration, cleaning, or repair is required extreme care must be used in handling the units since any alteration will disturb the balance of the transformer. In the event that suitable repairs cannot be made locally, return units to NRL.

(c) Check the balance alignment of the transformer units to discover if any change in alignment has occured or if any components have broken down.

This balance test is made in the following manner:

(a) Place the transformer unit marked "standard" in the 180° monopole position leaving the antenna disconnected but putting the cover, with the feed-through insulator, on tightly.

(b) Place the transformer unit to be aligned in the 0° monopole position leaving the antenna disconnected, and a special cover with the insulated feed-through must be used in this case. This cover must have a hole about 3/4 in. in diameter drilled through the top of it so that it is possible to adjust the tuning elements readily when the cover is on the housing. It is necessary that the lids be used; therefore, this is the only way whereby adjustments can be made.

(c) Next connect a wire from the "feed-through" input of the one coupling unit at one monopole to that at the other monopole making sure it does not short to ground.

(d) Then set up an LP signal generator at the sense monopole and connect the output of the signal generator to the exact center of the wire connecting the inputs of the transformer units together.

(e) In order to make it possible to read the output of the receiver at the array a special device is used. Disconnect the LR frequency meter from the sense cable, remove the coupling unit at the sense monopole, and then feed the audio output from the receiver into the sense cable. By connecting an output meter to the sense cable out at the array it is possible for the person making the adjustments on the units to note any change in balance.

(f) Set the receiver for the frequency at which the transformer is to be aligned and turn the sensitivity control about 3/4 of the way open. At the array tune the signal generator to the frequency setting of the receiver, the right point will be indicated on the output meter. Adjust the capacitors and inductance with a non-metallic screw driver until the minimum output of the receiver has been reached; this is the point at which the units are balanced.

This test procedure must be repeated for all units when once one of a certain band has been changed, and all the steps hold for the first three bands. If any unit fails to balance, investigations should be made to see if repairs can be made at the station and if not the unit must be returned to the Naval Research Laboratory.

The frequencies at which the transformers are to be aligned are as follows:

Band 1 2.5 megacycles

Band 2 6.0 megacycles

Band 3 11.0 megacycles

TRANSFORMER NETWORK DESIGN CONSIDERATIONS—MECHANICAL

The transformer networks were constructed so that they could be easily interchanged with the cathode followers. Since the cathode followers were built as plug-in units as shown in Figure 22 it was decided to construct the transformers in a like manner. Figures 23, 24 and 25 show the general construction of these networks. Because of their experimental nature the effect of temperature, humidity, shock and vibration were not especially considered. Consequently, the units constructed for both Adak and San Juan were made up as experimental models and not as finished manufacturers' prototypes. Several constructional changes are now suggested however; chiefly, improved means of bringing the transformer leads out through the iron core to facilitate assembly, and also the application of a waterproofing material to the transformer windings. In the event that the transformers prove satisfactory (electrically) in service it may be desirable to redesign the units for permanent installation rather than keeping them as "plug-in" units. In this case a more rugged type of assembly would be obtainable.

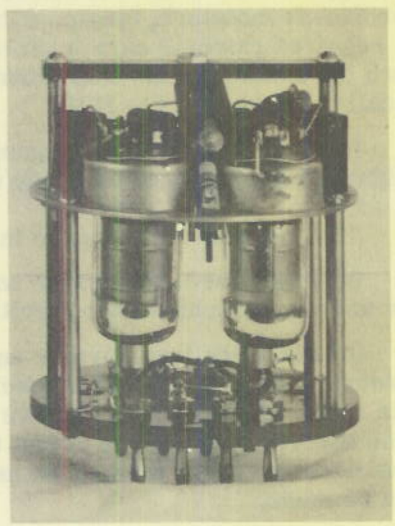


Figure 22. Cathode Follower Network Assembly

TRANSFORMER NETWORK DESIGN CONSIDERATIONS—ELECTRICAL

The electrical design requirements of the DAJ transformer coupling networks are much more stringent than that required for coupling a single vertical antenna to a transmission line. The reason for this is that not only must the network couple the antenna to the line with a minimum of loss but it must also match a similar network in amplitude and phase at all frequencies in the desired band. Because of the "unbalance-balance" requirements,

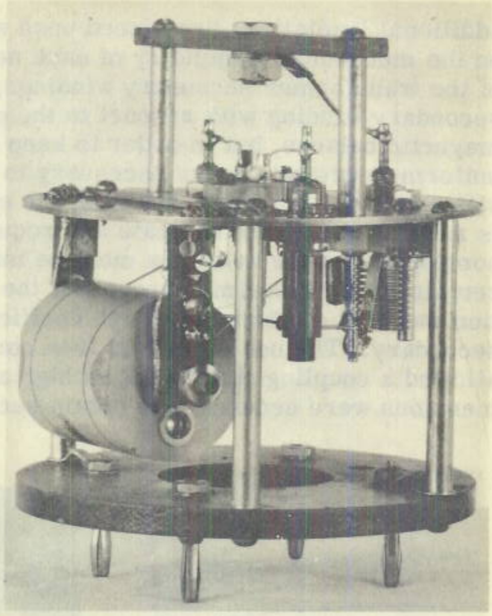


Figure 23.

Transformer Network Assembly—Band 1

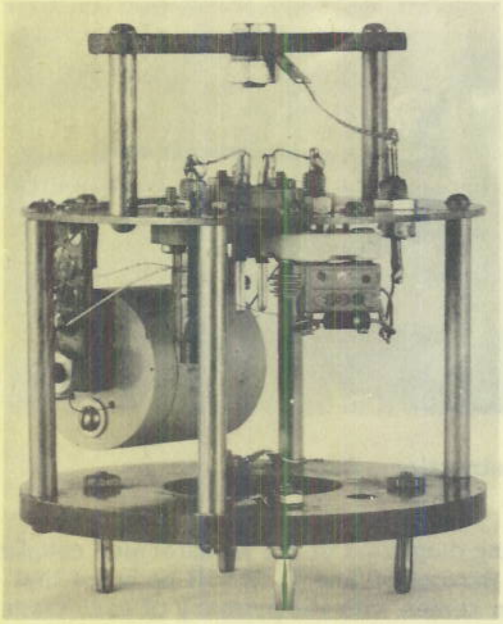


Figure 24.

Transformer Network Assembly—Band 2

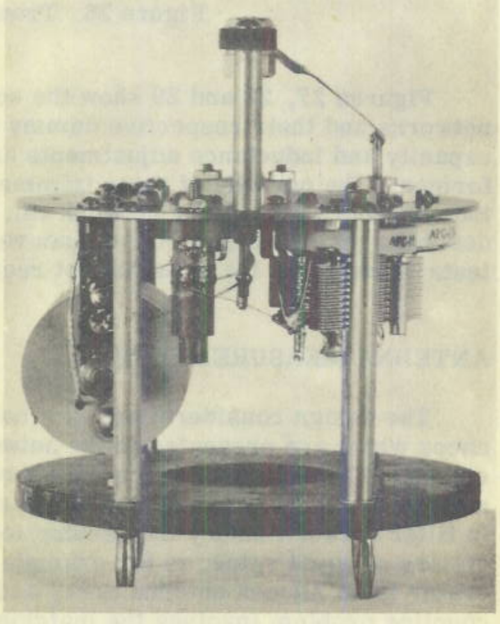


Figure 25.

Transformer Network Assembly—Band 3

additional limitations are placed upon electrical tolerances of the components and also upon the mechanical symmetry of each network. In order to permit proper balance to ground of the transformer secondary windings, a means was provided to change the position of the secondary winding with respect to the primary. This arrangement permitted the proper magnetic balance, but in order to keep the distributed capacity of the secondary winding uniform to ground, it was necessary to completely enclose the secondary in a split electrostatic shield. For these reasons, the entire transformer assembly, shown in Figure 26, is rather difficult to fabricate and requires very careful workmanship. The electrical components of the networks must be matched to within one percent of each other and should remain within this limit throughout the life of the units. Another very important consideration was that of obtaining a high coefficient of magnetic coupling between primary and secondary. The use of special iron core assemblies such as Aladdin's 10-127 type 520 allowed a coupling coefficient as high as 0.96 in some cases. Close tolerances in all dimensions were necessary to obtain such values.

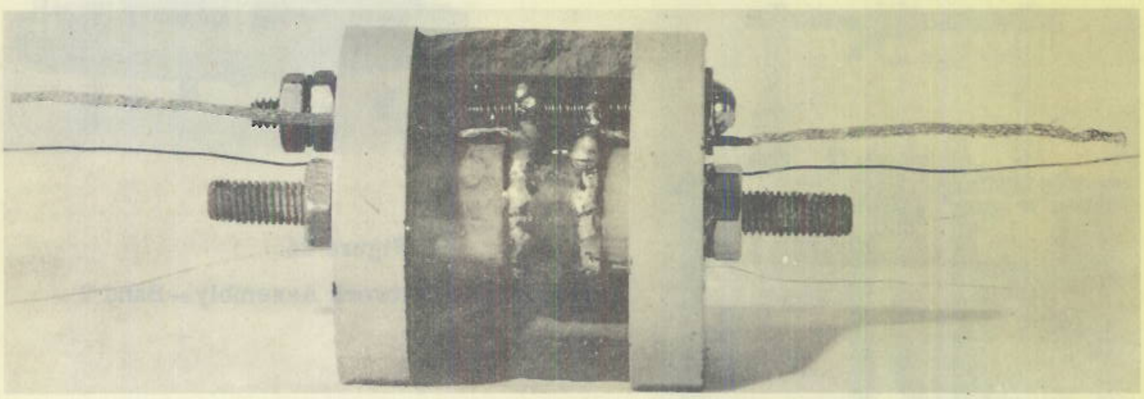
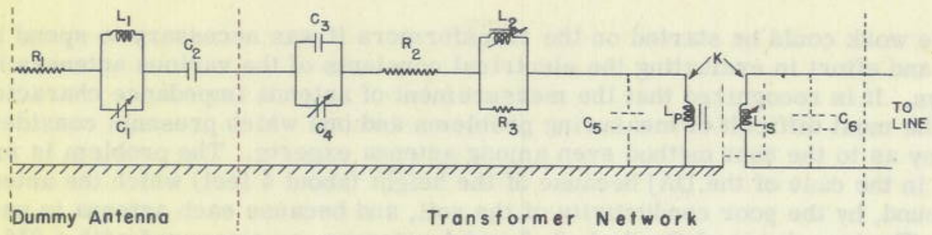


Figure 26. Transformer Construction—Band 3

Figures 27, 28 and 29 show the schematic wiring diagrams of the transformer coupling networks and their respective dummy antennas for Bands 1, 2 and 3. It will be noted that capacity and inductance adjustments are provided in series with the primary of each transformer. The purpose of these trimmers is to provide alignment controls so that the amplitude and the phase of any network can be matched with respect to that of any other. The networks that were sent to San Juan were aligned prior to shipment, and subsequent field tests showed that the units did not require realignment after installation in the field.

ANTENNA MEASUREMENTS

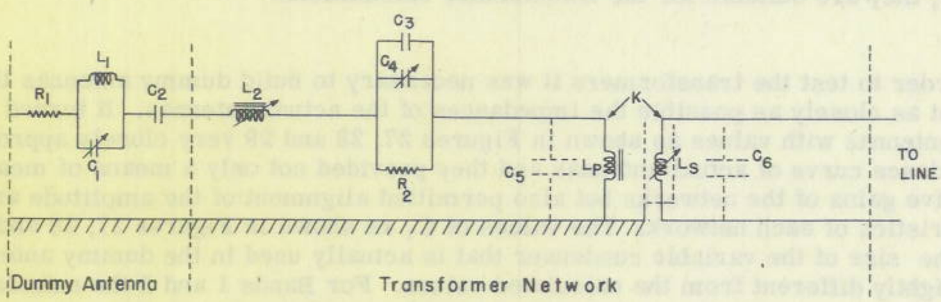
The design considerations of a network are greatly influenced by the terminal impedances which are presented to the network by the input (source) circuit and the output (load) circuit. The ease with which the network values are determined and the overall effectiveness of the network is determined to a considerable extent by these impedances. Usually in filter network theory the assumption is made that the filter is working between two resistors of equal value, as for example, 600 ohms. In the case of the DAJ however, the generator is an Adcock antenna array and moreover, five vertical antennas per array. The coupling problem involves the matching of each vertical antenna of the array to a balanced 140-ohm twin-coaxial transmission line.



PRIMARY—30 Turns 38 Formax Wire
SECONDARY—15 Turns 28 Formax Wire
IRON—Aladdin 10-127 Type 520

R_1 = 50 ohms	L_1 = 2.9 μh	C_1 = 50 μμf
R_2 = 60 ohms	L_2 = 21.0 μh	C_2 = 133 μμf
R_3 = 400 ohms	L_p = 82.3 μh	C_3 = 500 μμf
	L_S = 200 μh	C_4 = 17 μμf
	K = 0.96	C_6 = 63 μμf

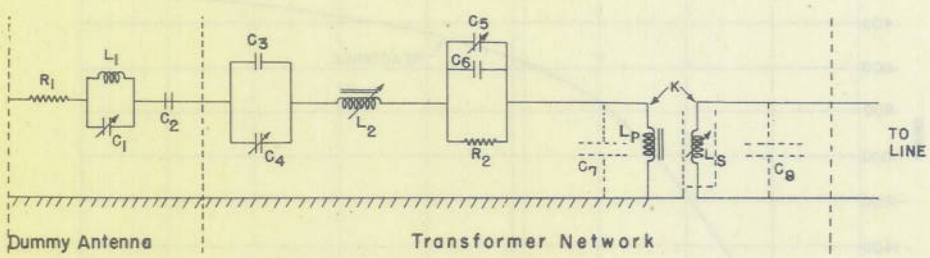
Figure 27. Circuit Diagram of Band 1 Transformer Network



PRIMARY—26 Turns 38 Formax Wire
SECONDARY—17 Turns 28 Formax Wire
IRON—Aladdin 10-127 Type 520

R_1 = 50 ohms	L_1 = 2.9 μh	C_1 = 50 μμf
R_2 = 120 ohms	L_2 = 100 μh (slug tuned)	C_2 = 133 μμf
	L_p = 52 μh	C_3 = 330 μμf
	L_S = 21 μh	C_4 = 25 μμf
	K = 0.93	C_5 = 26 μμf
		C_6 = 16 μμf

Figure 28. Circuit Diagram of Band 2 Transformer Network



PRIMARY—17 Turns 38 Formax Wire
SECONDARY—12 Turns 28 Formax Wire
IRON—Aladdin 10-127 Type 520

R_1 = 50 ohms	L_1 = 1.9 μh	C_1 = 50 μμf	C_5 = 15 μμf
R_2 = 100 ohms	L_2 = 10 μh (slug tuned)	C_2 = 93 μμf	C_6 = 100 μμf
	L_p = 26 μh	C_3 = 50 μμf	C_7 = 18 μμf
	L_S = 12 μh	C_4 = 50 μμf	C_8 = 30 μμf
	K = 0.93		

Figure 29. Circuit Diagram of Band 3 Transformer Network

Before work could be started on the transformers it was necessary to spend considerable time and effort in evaluating the electrical constants of the various antennas in the four arrays. It is recognized that the measurement of antenna impedance characteristics is one of the most difficult of measuring problems and one which presents considerable controversy as to the best method even among antenna experts. The problem is magnified somewhat in the case of the DAJ because of the height (about 4 feet) which the antenna is off the ground, by the poor conductivity of the soil, and because each antenna is part of an array. The impedance of Bands 1, 2, 3 and 4 antennas, as measured with a 916-A General Radio bridge is shown in Figures 30, 31, 32 and 33. It will be noted at the overlapping frequencies (3-4.5 Mc) that there is some disagreement in the values of both the reactive and resistive components even though these data represent measurements on a vertical antenna of the same dimension. It is believed that the factors mentioned above may be responsible for these differences. The impedance data as shown in Figures 30, 31, 32 and 33 are believed to be representative of the values that can be expected in an average installation for each of the four arrays and although they may not be of the highest order of accuracy, they are suitable for the transformer calculations.

In order to test the transformers it was necessary to build dummy antennas that would represent as closely as possible the impedances of the actual antennas. It turned out that dummy antennas with values as shown in Figures 27, 28 and 29 very closely approximated the impedance curve of actual antennas and they provided not only a means of measuring the relative gains of the networks but also permitted alignment of the amplitude and phase characteristics of each network. The values of C_1 as shown in Figures 27, 28 and 29 represent the size of the variable condenser that is actually used in the dummy antenna and one is slightly different from the calculated values. For Bands 1 and 2 the calculated value of C_1 is 44 micromicrofarads and for Band 3 is 33 micromicrofarads.

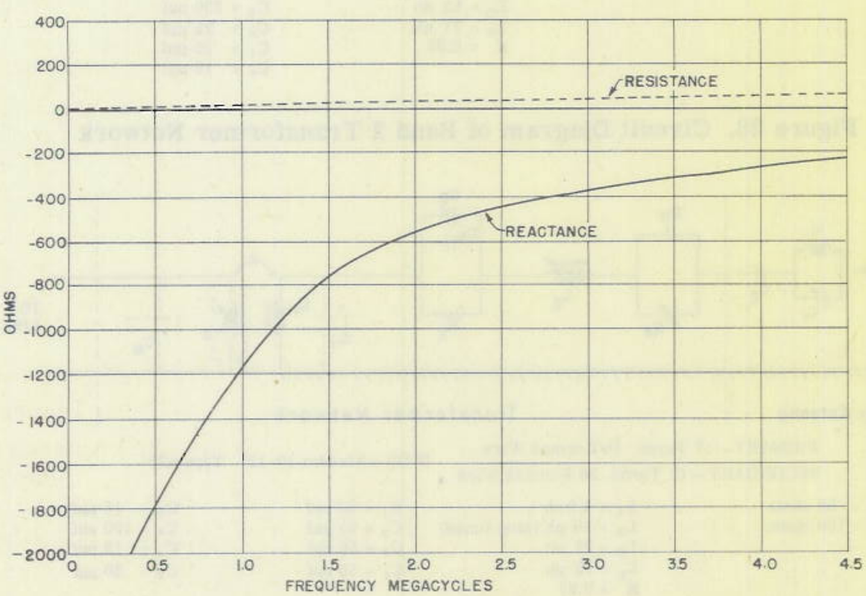


Figure 30. DAJ Antenna Impedance—Band 1

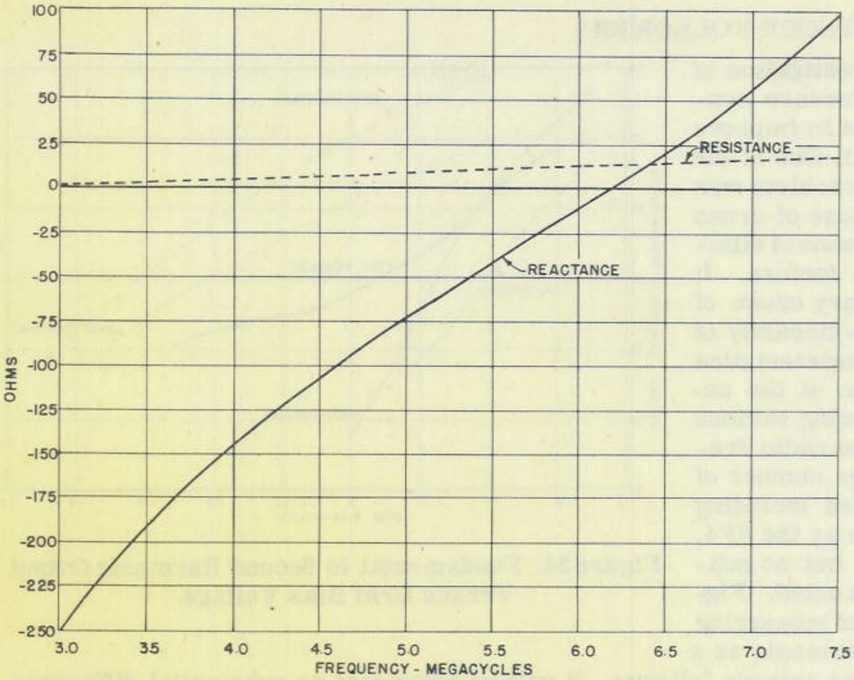


Figure 31.

DAJ Antenna Impedance Band 2

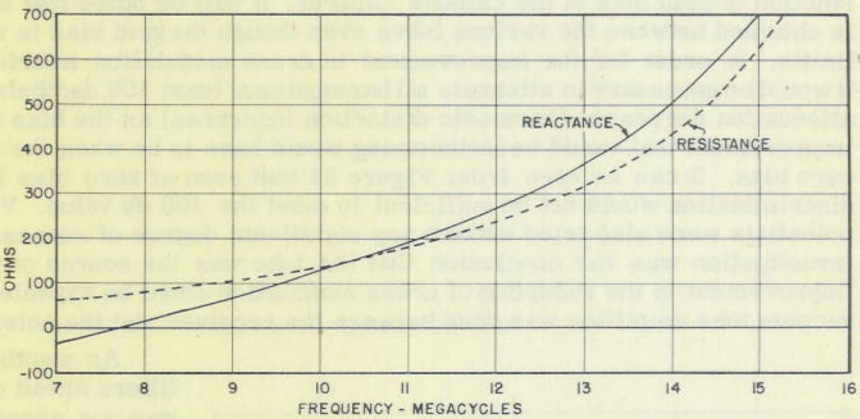


Figure 32.

DAJ Antenna Impedance Band 3

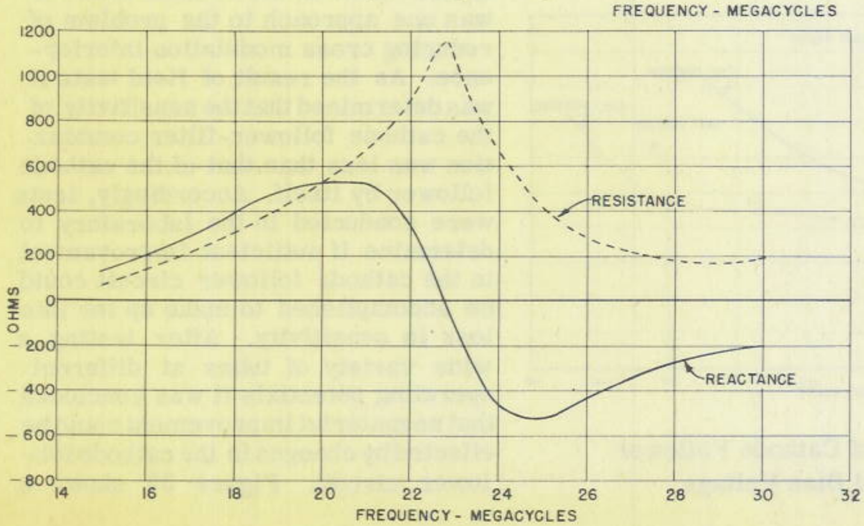


Figure 33.

DAJ Antenna Impedance Band 4

INVESTIGATION OF CATHODE FOLLOWER

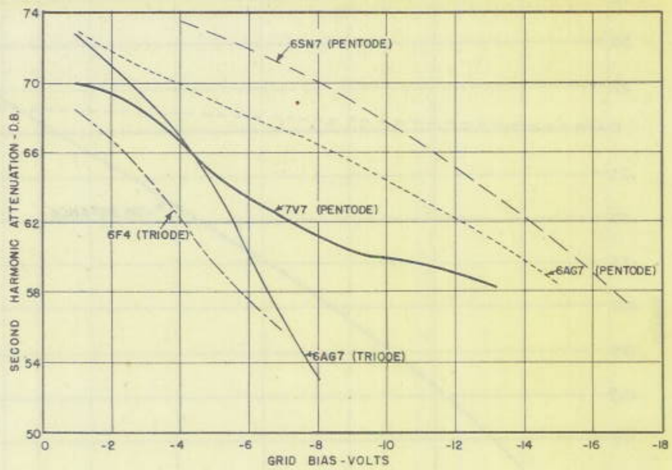


Figure 34. Fundamental to Second Harmonic Output Versus Grid Bias Voltage

During the early investigation of cross modulation interference considerable effort was made to improve the cathode follower itself. One of the first approaches to this problem was to determine the basic cause of cross modulation and to find means of eliminating the troublesome factors. It was found that the primary cause of the trouble was the non-linearity of cathode follower tube characteristics resulting in rectification of the unwanted signal, thus producing various harmonics throughout the radio frequency spectrum. A large number of different tubes were tried including such triodes and pentodes as the 6F4, 6AG7, 7V7, 6SN7, 6L6, but no substantial improvement was noted. Figure 34 shows the results of measuring the amount of second harmonic as a function of grid bias of the cathode follower. It will be noted that no substantial difference is obtained between the various tubes even though the grid bias is varied over rather wide limits. In order for the improvement in cross modulation interference to be worthwhile it would be necessary to attenuate all harmonics at least 100 decibels. Actually the harmonic attenuation decreases (harmonic distortion increases) as the bias is increased so that any improvement that would be forthcoming would have to be when the tube was operating at zero bias. It can be seen from Figure 34 that even at zero bias the harmonic distortion discrimination would not be sufficient to meet the 100 db value. Various other operating potentials were also tried without any significant degree of success. The net result of the investigation was the conclusion that the tube was the source of the trouble and that no improvement in the reduction of cross modulation could be expected as long as an untuned vacuum tube amplifier was used between the receiver and the antenna.

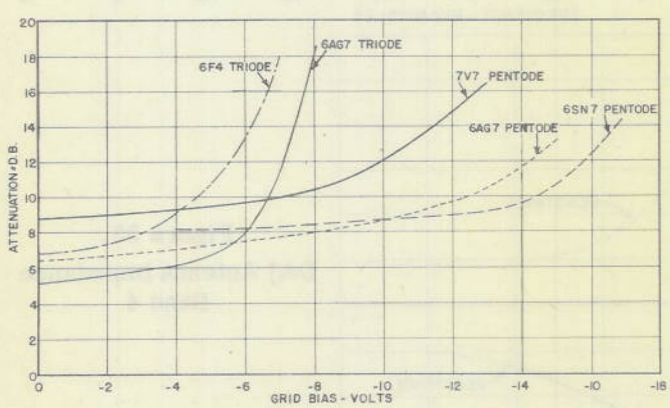


Figure 35. Gain of Cathode Follower Versus Grid Bias Voltage

As mentioned before, the use of filters ahead of the cathode follower was one approach to the problem of reducing cross modulation interference. As the result of field tests it was determined that the sensitivity of the cathode follower-filter combination was less than that of the cathode follower by itself. Accordingly, tests were conducted in the laboratory to determine if sufficient improvement in the cathode follower circuit could be accomplished to make up for this loss in sensitivity. After testing a wide variety of tubes at different operating potentials it was concluded that no material improvement could be effected by changes in the cathode follower circuit. Figure 35 shows a comparison of cathode follower gain as a function of grid bias. It may be noted that the data are plotted as attenuation since the gain of a cathode follower is always less than unity. Because of the higher noise contribution of high gain tubes such as pentodes no appreciable improvement in sensitivity was noted between pentodes and triodes. As the result of these tests it was decided to use an entirely new approach to the problem; the use of transformers as mentioned earlier in the report proved to be a satisfactory replacement for the cathode follower.

CONCLUSIONS

It is concluded:

(a) That the cross modulation interference experienced with the model DAJ Direction Finder is due to the cathode follower.

(b) That the use of filters is not satisfactory due to attenuation.

(c) That no appreciable improvement can be afforded by the cathode follower tube itself.

(d) That transformers for Bands 1, 2 and 3 actually improved sensitivity and completely eliminated cross modulation interference.

(e) That the initial design of Band 4 transformer was unsatisfactory due to high loss resulting largely from difficulty in matching the high impedance of the antenna.

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