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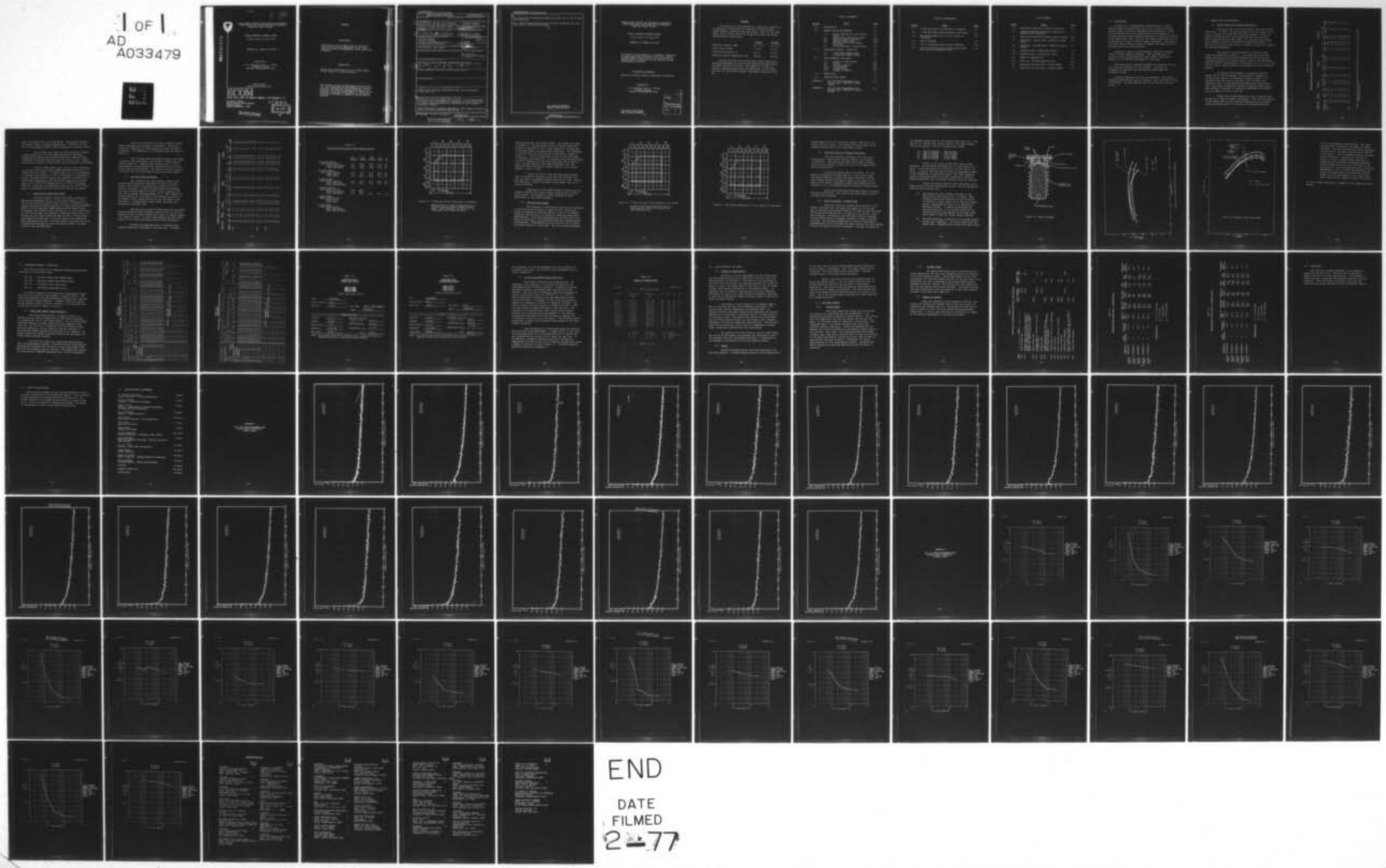

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MANUFACTURING METHODS AND TECHNOLOGY ENGINEERING HIGH EFFICIENCY, HIGH POWER GALLIUM ARSENIDE READ-TYPE IMPATT DIODES

FOURTH QUARTERLY PROGRESS REPORT

1 April 1976 to 30 June 1976

CONTRACT NO. DAAB07-75-C-0045

Prepared By

H. R. Chalifour and S. R. Steele
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Controlled tests have shown that uniformity of diode parameters is largely due to the degree of uniformity in the starting wafer. The nominal characteristics are influenced by diode assembly processes, however.

Diode efficiency is slightly improved by using ribbon in place of mesh on the diode junction metallization.

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The fourth set of engineering samples have met all of the contract specifications.

One X-band failure occurred during the third operating life test. There were no failures at Ku-band.

MANUFACTURING METHODS AND TECHNOLOGY ENGINEERING
HIGH EFFICIENCY, HIGH POWER GALLIUM ARSENIDE READ-TYPE IMPATT DIODES

FOURTH QUARTERLY PROGRESS REPORT

1 April 1976 to 30 June 1976

CONTRACT NO. DAAB07-75-C-0045

The object of this program is to develop a capability to manufacture High Efficiency, High Power Gallium Arsenide IMPATT Diodes meeting the description and specifications of Section F of the contract and the requirements of SCS-481.

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PURPOSE

The objective of this program is to establish a capability to manufacture high-efficiency, high-power Gallium Arsenide IMPATT diodes at specified rates and yields. There are two diode types; one at X-band, and one at Ku-band which have the nominal characteristics listed below.

	X-Band	Ku-Band
Operating Frequency (GHz)	10.0 ±1.0	15.0 ±1.0
Power Output (Watts)	3.5 min.	2.5 min.
Conversion Efficiency (%)	20 min.	20 min.
Operating Junction Temperature (^{o}C)	200 max.	200 max.

Engineering effort is to be directed toward establishing production processes for both Gallium Arsenide epitaxial wafers and diode fabrication and test. The wafers are to meet the material characterization testing as specified, and the diodes must meet the detailed performance requirements outlined in SCS-481.

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1.0 INTRODUCTION

In addition to scheduled wafer growth activity, several special wafers were grown during the period to evaluate certain specific items. Controlled experiments were performed on wafers to establish the source of irregularity of diode parameters. It was concluded that diode parameter uniformity is largely established at the wafer growth level, but that the nominal characteristics can be modified as a result of diode assembly processes. Other wafers were grown having special profiles to improve the diode efficiency and these are still being evaluated.

Attempts to improve diode efficiency resulted in a modification of diode assembly procedures. The gold mesh used to contact the mesa was replaced with solid ribbon, resulting in about 0.5 to 1.0 percent improvement in efficiency.

The fourth set of engineering samples was delivered and met all of the specifications of the contract. A request for permission to proceed to the confirmatory sample phase was forwarded to ECOM.

The third operating life test was completed. The Ku-band diodes survived the test with no failures. One X-band diode failed at 800 hours. The most probable cause of failure was cavity detuning.

2.0 RESULTS AND ACCOMPLISHMENTS

2.1 Wafers Supplied for Device Fabrication

Nine wafers were supplied for device fabrication during this period. Of these, six were intended to provide material from which to manufacture diodes for engineering samples. These were equally divided between X and Ku-bands and met the preliminary wafer specifications for these bands. The remaining three wafers were intended to be used as specification definition wafers. In addition to the device grade wafers, a number of wafers were supplied for process development.

The important characteristics of the device grade wafers are summarized in Table 2-1. All wafers were grown upon highly conducting tellurium-doped substrates which met the specifications described in previous reports. Most of the substrates used had electron concentrations in the range of 1.0 to $1.5 \times 10^{18} \mathrm{cm}^{-3}$ so as to avoid a high incidence of precipitates and other substrate defects.

All wafers were polished to a pregrowth thickness between 280 and 320 micrometers, using bromine in methanol as the polishing compound, as described in previous reports. The thickness, bow, and taper of each wafer after polishing was determined using a contactless probe manufactured by Ade Corporation. This probe is especially suited to pregrowth wafer measurements because it operates by capacitance measurements, and hence does not damage the wafer in any way.

Wafers were cleaned immediately prior to growth using multiple hot rinses of acetone and methanol. About five micrometers of the surface material were removed chemically in the pregrowth cleaning procedure using 7:2:1 sulfuric acid:hydrogen peroxide:

Table 2-1

Read Wafers Supplied for Device Fabrication

Wafer No.		Buffer	Transit		Spike					Contact		
Series	Run	W (μm)	W (μm)	$n \times 10^{16}$ (cm^{-3})	W (nm)	$n \times 10^{16}$ (cm^{-3})	$Q^* \times 10^{12}$ ($c\text{-}cm^{-3}$)	V^* (volts)	x_p (μm)	x_o (μm)	$n_o \times 10^{16}$ (cm^{-3})	Band
818	37	5.8	4.1	1.1	44	60	2.5	8.9	0.24	0.20	9	Ku
	44	5.5	4.0	1.2	41	63	2.4	8.1	0.24	0.20	19	Ku
	53	6.7	3.6	1.1	52	56	2.5	8.5	0.24	0.19	18	Ku
	93	5.5	4.8	0.50	43	60	2.4	7.6	0.23	0.19	21	X
	94	6.4	5.5	0.54	48	73	2.8	9.6	0.24	0.19	18	X**
	95	6.4	4.9	0.54	45	63	2.5	8.4	0.24	0.20	17	X
	97	6.6	5.4	0.52	44	50	2.1	6.9	0.23	0.20	19	X**
	99	6.2	5.0	0.48	43	62	2.3	8.0	0.24	0.20	20	X
819	00	6.2	5.0	0.45	42	64	2.3	8.0	0.24	0.20	15	X

** Note: These wafers were deliberately grown with high and low Q^* as part of specification definition experiment.

water as a moving etch in a teflon beaker. The etch was followed by multiple rinses in eighteen megohm water. Growth was carried out in the standard epitaxial reactor described in previous reports.

After growth, each wafer was characterized by removing a small profile strip from the right-hand edge of each wafer. Standard-area aluminum-gold Schottky diodes were formed by photolithography and vacuum evaporation upon the profile strip. Doping profiles were measured on these diodes using an automatic profilometer.

A heavily doped buffer layer, five to seven micrometers in thickness, was grown on the polished substrate surface prior to growing the active layers. A transit layer, 3.5 to 4.5 micrometers in thickness for Ku-band or 4.5 to 5.5 micrometers in thickness for X-band, was grown prior to growing the avalanche confining spike. The electron concentrations for the transit layers were centered about $1.05 \times 10^{16} cm^{-3}$ for Ku-band and $5.5 \times 10^{15} cm^{-3}$ for X-band. Typically, spikes with an integrated charge of $2.4 \times 10^{12} cm^{-2}$ were grown 1.24 micrometers from the surface for both Ku and X-bands.

2.2 Specification Definition Wafers

The three material characteristics most important to Read device performance are x_p, Q, and transit doping. A vital task of the Engineering Phase of this program is to determine the optimum values and allowable variations of these material parameters which will yield Read-type IMPATT devices meeting specification. Furthermore, the effects of dice fabrication on Q, and in particular x_p, must be evaluated. Our approach to performing these tasks is to process six lots (three X-band and three Ku-band) of three wafers each selected and described in previous reports for standardized diode fabrication and test. The three wafers of each lot are to be processed simultaneously to avoid introducing effects of process variation into the experiment.

Prior to this period, five lots of wafers (fifteen wafers) had been grown and sent to processing. During this period the remaining lot (three wafers) was grown and sent to processing. The properties of all eighteen wafers are shown in Table 2-2.

Most of these wafers have been processed into diodes according to plan and tested. The results of these tests are shown in Table 2-3. These results indicate that to a first approximation the preliminary wafer specifications will yield devices meeting specification. The results are being evaluated critically, and final wafer specifications are being prepared.

2.3 Epitaxial Wafer Uniformity

Data indicates that the breakdown voltage of the finished devices displays considerable variation over most wafers. The variation is particularly evident from top to bottom of the wafer. We have concluded from the preliminary data that the spike depth is the most critical parameter and this can be deduced from measurements of V*. There remains the question however as to how much of the observed variation is introduced in wafer growth and how much is introduced in dice fabrication. An experimental wafer, 81869, was especially processed to determine this.

The wafer after growth was metallized with evaporated platinum through a photolithographic mask and lift-off so as to produce an array of planar diodes 0.007 inches in diameter spaced .025 inches on center. V* values were measured upon each diode. Figure 2-1 is a map of the results before device processing.

The wafer was thereupon sent to processing where standard diodes were fabricated in the usual way. V* values

Table 2-2

Summary Properties Read Wafers Supplied for Specification Definition

Wafer No.		Buffer	Transit			Spike			Contact		
Series	Run	W (μm)	W (μm)	$n \times 10^{16}$ (cm^{-3})	W (nm)	$n \times 10^{16}$ (cm^{-3})	$Q^* \times 10^{12}$ ($c\text{-}cm^{-3}$)	V^* (volts)	x_p (μm)	x_o (μm)	$n_o \times 10^{16}$ (cm^{-3})	Band
818	58	6.7	4.0	1.05	52	56	2.5	8.2	0.23	0.18	18	Ku
	63	7.0	4.5	1.30	50	55	2.3	8.1	0.24	0.20	19	Ku
	62	7.0	4.5	0.89	53	50	2.4	8.2	0.24	0.20	14	Ku
	25	5.6	4.0	1.00	53	57	2.5	8.3	0.23	0.19	14	Ku
	48	7.1	4.8	0.98	52	60	2.7	9.8	0.25	0.20	15	Ku
	52	6.9	4.1	1.30	62	39	2.0	6.4	0.22	0.19	18	Ku
	33	5.2	3.9	1.11	40	62	2.4	8.3	0.24	0.20	14	Ku
	41	5.5	4.4	1.02	36	63	2.2	9.9	0.31	0.26	8	Ku
	42	5.8	4.3	1.10	42	65	2.5	8.0	0.22	0.19	21	Ku
816	16	5.0	5.4	0.50	43	56	2.6	9.2	0.24	0.18	9	X
	19	4.1	4.6	0.55	43	56	2.4	8.7	0.23	0.17	9	X
	21	5.1	5.7	0.42	45	53	2.4	9.3	0.25	0.18	6	X
818	93	5.5	4.8	0.50	43	60	2.4	7.6	0.23	0.19	21	X
	94	6.4	5.5	0.54	48	73	2.8	9.6	0.24	0.19	18	X
	97	6.6	5.4	0.52	44	50	2.1	6.9	0.23	0.20	19	X
	80	7.1	4.8	0.57	46	47	2.2	7.9	0.25	0.21	16	X
	88	6.8	5.0	0.60	60	53	2.7	10.4	0.27	0.21	13	X
	82	6.8	4.7	0.59	46	56	2.4	7.5	0.22	0.19	22	X

Table 2-3

Specification Definition Wafer Summary Results

	V^* (Volts)	V_{BI} (Volts)	V_{OP} (Volts)	F_o (GHz)	η (%)
Ku Transit Doping					
Wafer 81858 control	5.7	22.1	38.0	14.9	20
81863 high doping	6.7	16.8	31.0	17.0	13
81862 low doping	6.4	18.5	35.0	15.0	17
Ku Spike Charge					
Wafer 81825 control	5.5	21.3	37.0	14.3	19
81848 high Q	6.6	14.7	32.0	15.0	17
81852 low Q	4.1	29.7	44.0	13.5	18
Ku Spike Depth					
Wafer 81833 control	6.3	18.0	36.0	15.0	18.5
81841 deep spike	5.2	21.5	39.0	13.5	20
81842 shallow spike					
X Transit Doping					
Wafer 81616 control	4.8	48.0			
81619 high doping	4.2	58.0			
81621 low doping	6.2	34.0	56.0	8.1	21.5
X Spike Charge					
Wafer 81893 control					
81894 high Q					
81897 low Q					
X Spike Depth					
Wafer 81880 control					
81883 deep spike					
81882 shallow spike					

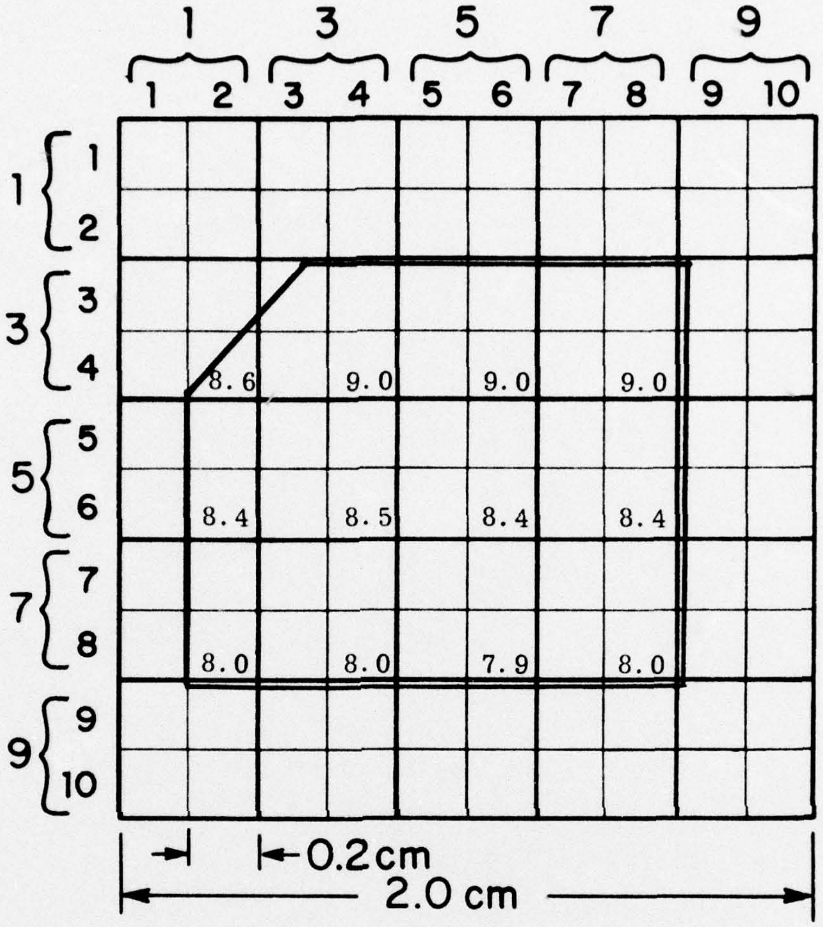


Figure 2-1 V* Map upon Wafer as Delivered to Processing.

Measured upon an array of evaporated planar platinum Schottky diodes formed on wafer 81869. Diode diameters are nominally .007 inch spaced .025 inches on center.

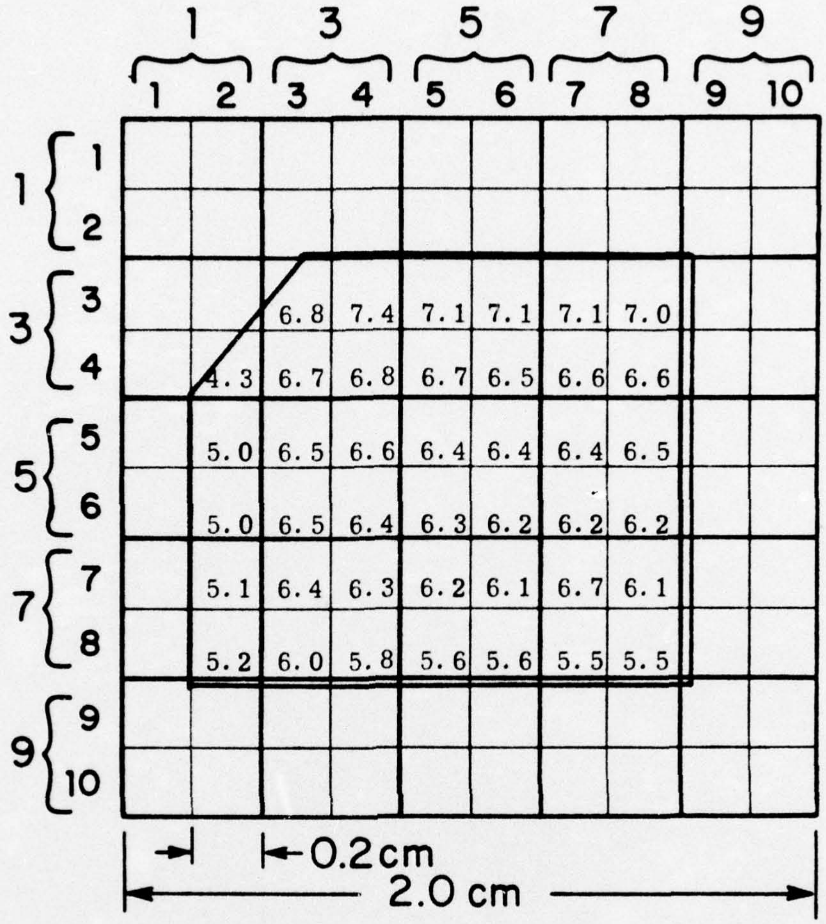
were measured upon the finished diodes. The results are shown in Figure 2-2. An examination of the two figures shows that there is a reduction in the V* value measured in the same area of the wafer before and after device processing. The difference in the two values for each location on the wafer is shown in Figure 2-3. It will be noted that, except for the very edges of the wafer, the reduction in V* resulting from dice fabrication is fairly consistent for this particular wafer and is about 2.3 Volts. We have observed from other measurements that the reduction varies from wafer to wafer; however, it is usually between 2.5 and 3.5 Volts.

Figures 2-2 and 2-1 show that the chief variation over the surface of the wafer occurs from top to bottom, and that the wafer is remarkably uniform from side to side. Further, the variation is chiefly introduced during growth, and not in device processing.

Examination of the growth process indicates that the variation results from a small thermal gradient top to bottom during growth. This problem is easily remedied by slight modification of the growth equipment.

2.4 Multiple Wafer Growth

The production of Read devices would be more economical if the wafers could be grown in greater volume. During this period we attempted to grow Read wafers in one of our standard production reactors which are capable of producing three wafers simultaneously. After some experimentation we found that three wafers can be grown to the preliminary Read wafer specifications simultaneously. Measurements have shown that two of the wafers are almost identical to each other. The third usually possesses



	1	2	3	4	5	6	7	8	9	10
1										
2										
3			6.8	7.4	7.1	7.1	7.1	7.0		
4		4.3	6.7	6.8	6.7	6.5	6.6	6.6		
5		5.0	6.5	6.6	6.4	6.4	6.4	6.5		
6		5.0	6.5	6.4	6.3	6.2	6.2	6.2		
7		5.1	6.4	6.3	6.2	6.1	6.7	6.1		
8		5.2	6.0	5.8	5.6	5.6	5.5	5.5		
9										
10										

Figure 2-2 V* Map upon Wafer after Processing into Diodes

Measured after mesa etching but prior to separation by etching of the heat sink into individual die.

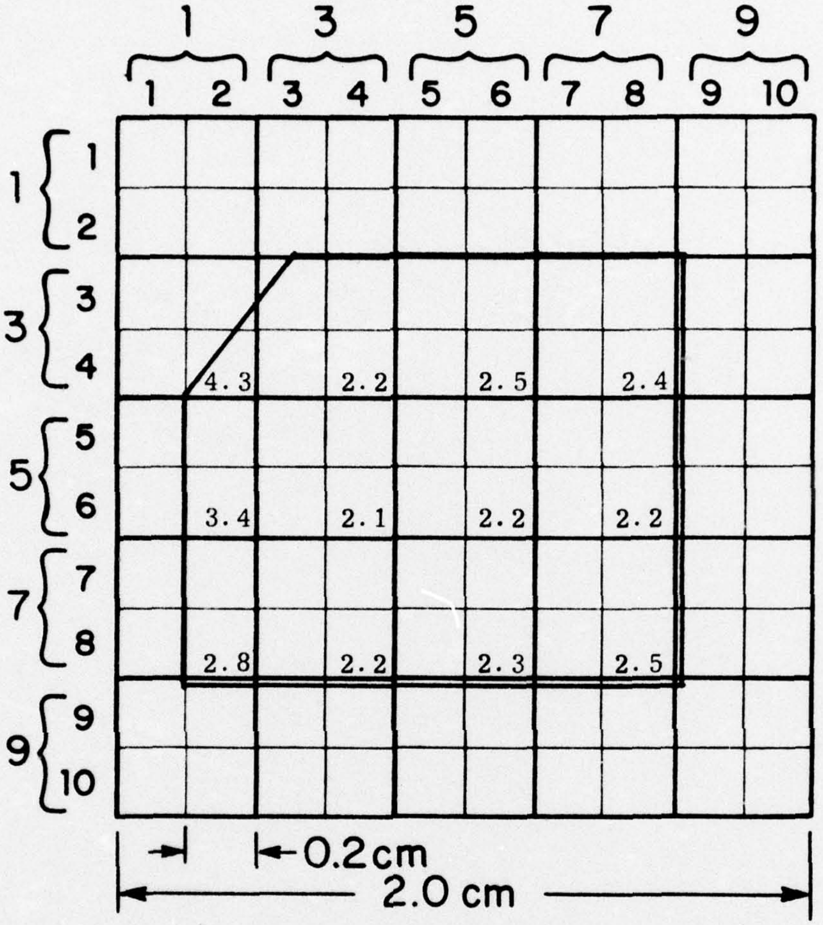


Figure 2-3 Map Showing Reduction in V* as a Result of Processing

layers which are five to ten percent thinner, and five to ten percent higher in doping. We conclude that Read wafers can be produced economically in our triple wafer reactor.

2.5 Modified Profiles for Higher Efficiency

The X-band devices, produced so far, meet every specification. Some Ku-band devices, however, are marginal in efficiency. Some wafers were grown with slightly modified profiles in an attempt to improve the yield of Ku-band devices meeting specification.

The profile changes were of two sorts: (a) the amount of undepleted epitaxial material in the transit layer was reduced stepwise to reduce the series resistance, and (b) punch-through devices were made by reducing the transit layer doping and by adding a moderately doped field termination layer located 2.5 to 3.0 micrometers from the avalanche confining spike.

Devices were fabricated from these wafers by standard fabrication procedures. Test results from these wafers have not yet been fully evaluated.

2.6 Diode Efficiency - Ku-Band Diode

Evaluation results on Ku-band wafers had led to the general conclusion that the diodes were operating in the lower part of the specified frequency band of 14-16 GHz and that the diode efficiency was straddling the specification limit of 20%. Tests were conducted to determine if the efficiency could be improved by minor modifications in assembly procedure in order to enhance the yield. The following summarizes the results of experiments performed with various size mesh and ribbon contacts and also compares results with type 16 and type 18 packages. The type 16 package is the standard package used for this program (see Figure 2-4). The type 18 is a reduced size ceramic mounted on the same threaded stud as the type 16. Five (5) variables were tested:

(1) Type 16 Package - 750 LPI mesh
(2) Type 16 Package - 2000 LPI mesh
(3) Type 16 Package - 5 mil ribbon
(4) Type 16 Package - 10 mil ribbon
(5) Type 18 Package - 750 LPI mesh

Figure 2-5 is a plot of efficiency versus output frequency. The efficiency was measured at an output power of 2.5 Watts. At the band center, more power was available (up to 3.0 Watts). It may be seen that the efficiency is optimized at about 14 GHz independent of construction style. The diode impedance varied as the construction was varied, necessitating different matching impedances, but the optimum operating point was constant.

Figure 2-6 contains plots of diode efficiency versus output power for various construction styles. The two conclusions resulting from this plot are:

(1) The diodes have their optimum efficiency at the specification test point of P_o = 2.5 Watts. This verifies previous data showing that the efficiency is optimum at a power output of 2.5 Watts for diodes having a capacitance of about 1.6 pf (measured at breakdown voltage). It should be noted that for this particular lot, 1.7 is a better value and the optimum value will vary somewhat as the wafer parameters change to keep the current density constant.

(2) The diode efficiency is improved as the screen material becomes less transparent. The solid ribbon gives the lowest loss. Presumably this reflects the lossy nature

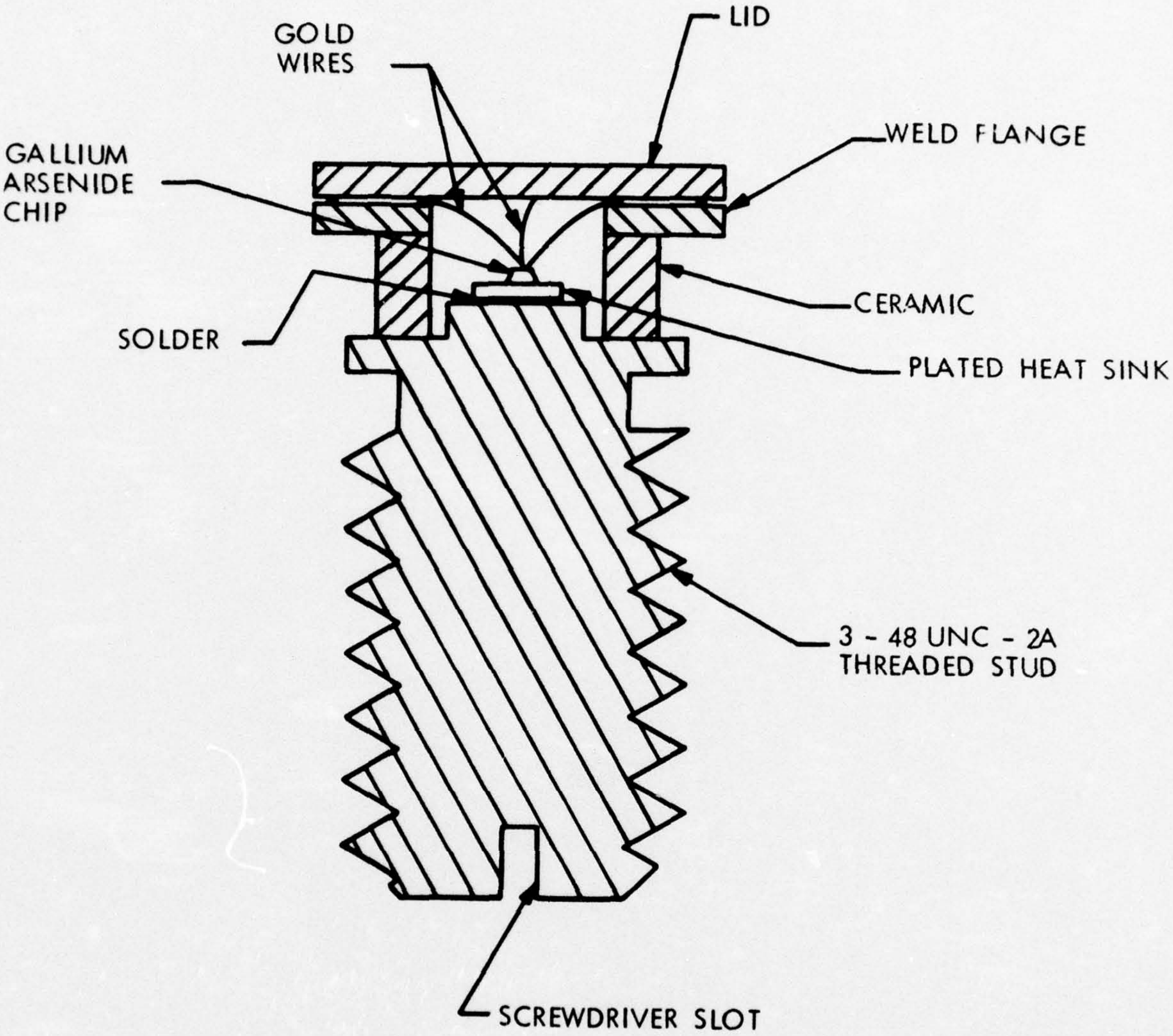


Figure 2-4 Type 16 Package

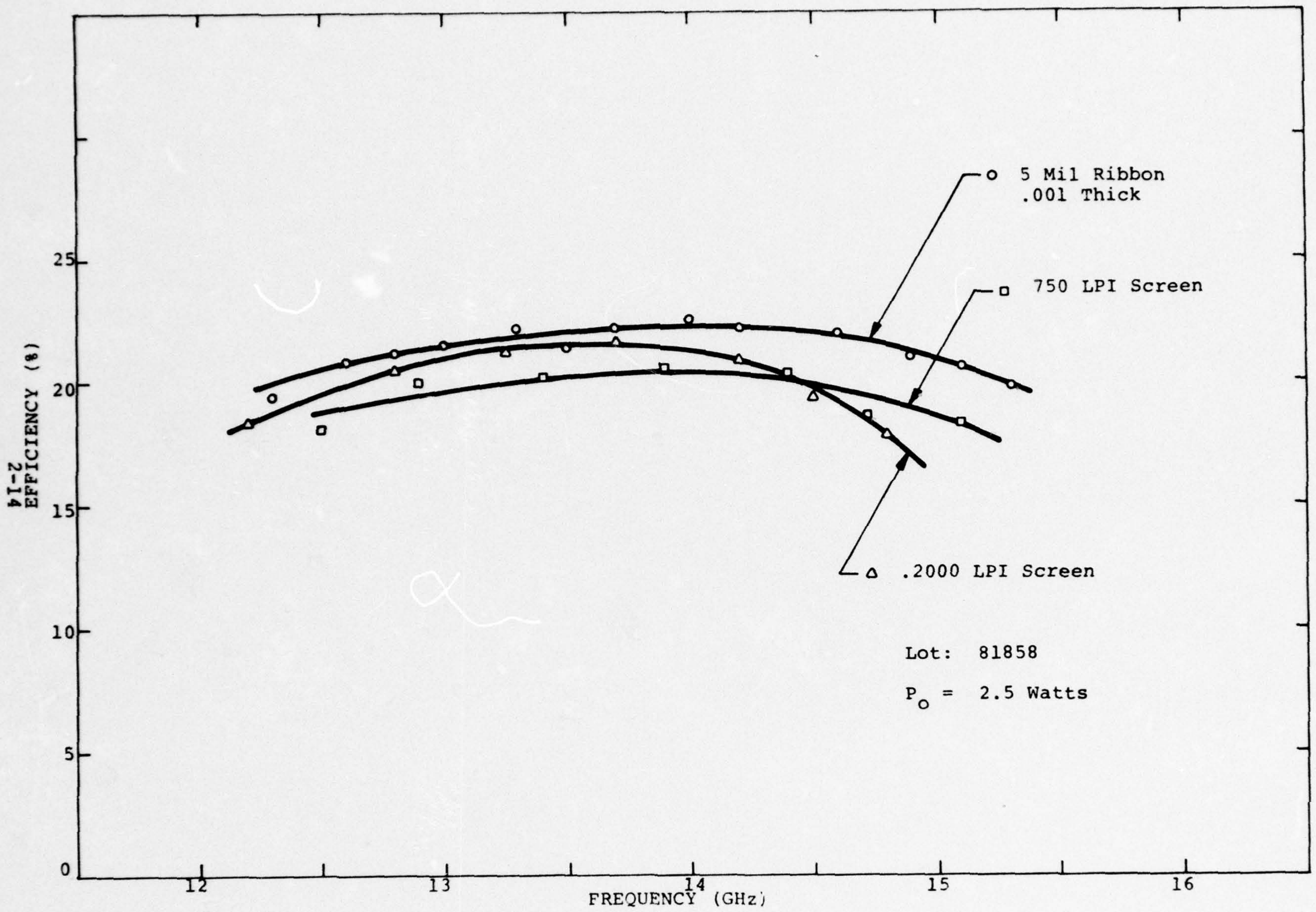


Figure 2-5 Efficiency Versus Operating Frequency

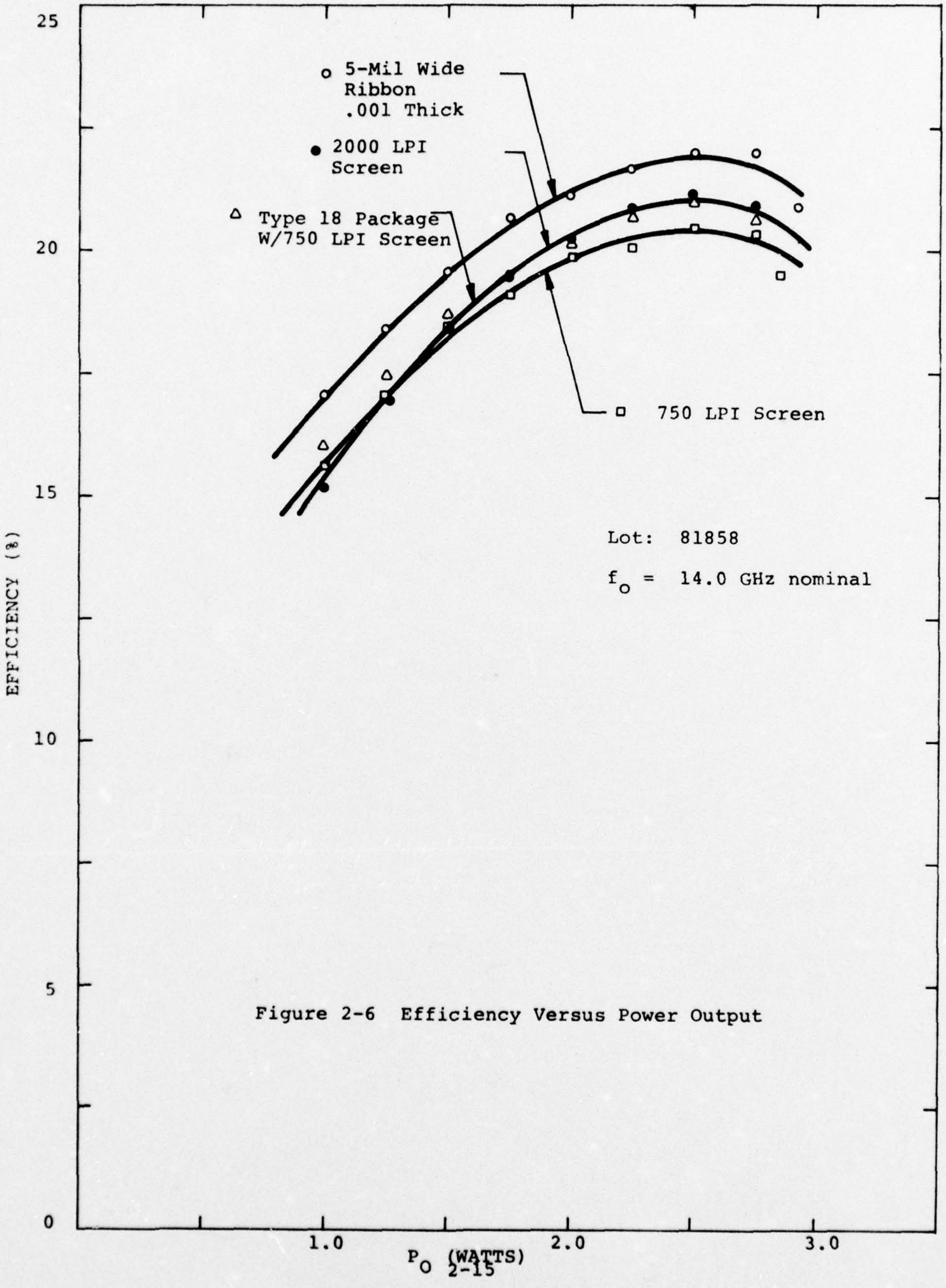


Figure 2-6 Efficiency Versus Power Output

of the electroformed screen material. The cross-sectional area increases as the number of strands increases. The type 18 package has better efficiency than the type 16 and about the same as the 2000 LPI in the type 16. This is probably because the screen length is shorter in the type 18. The data of Figure 2-6 is for a typical diode from each lot. Considering the total data and possible adjusting factors because the data was not all taken at the optimum point, it can be concluded that an efficiency improvement of 0.5 to 1.0% can be achieved by converting to denser material for the diode contact. Ribbon of 5 mil width appears to be a good choice. Wider ribbon (10 mil) shows no further improvement.

In view of these conclusions, a change to 5 mil ribbon was implemented.

3.0 ENGINEERING SAMPLES - FOURTH SET

The fourth and final set of engineering samples was delivered, consisting of the following items:

Ten (10) - MS-50371 X-Band Read IMPATT Diodes
Ten (10) - MS-50372 Ku-Band Read IMPATT Diodes
One (1) - THX-8000B X-Band Test Cavity
One (1) - THK-8000B Ku-Band Test Cavity.

The devices supplied as the fourth set of engineering samples meet all of the electrical requirements of SCS-481, Table I. The results obtained show improved performance in several areas compared to the previous samples submitted. A summary of the test results for the diodes is given in Tables 3-1 and 3-2. The oscillator test cavity data is given in Tables 3-3 and 3-4.

3.1 X-Band Read IMPATT Diodes (MS-50371)

The X-band diodes deliver 3.5 Watts of power at an average operating junction temperature of 164°C which corresponds to a temperature rise of 139°C above ambient. This is the principal difference between the present diodes and those supplied as the third set. The third set of diodes met all specifications except junction temperature, and the reason for this was assigned to a chip mounting problem peculiar to the particular lot supplied. The present diodes have thermal resistance values which are typical of X-band diodes processed recently.

The noise data supplied is preliminary data obtained from a new measurement technique. The CNA-20 Carrier Noise Analyzer manufactured by Raytheon was utilized to obtain direct swept noise data over the frequency range of interest. This method will replace the point-by-point technique previously used. We will incorporate

Table 3-1
Data Sheet
SCS-481 Type 1 (MS50371) X-Band Diodes

CHARACTERISTIC		B_V	C_{TO}	C_{TVR}	V_R	R_{TH}	P_o	F_o	V_{OP}	I_{OP}	η	Mech. Tun.	HAT	T_J	$Q_{Ext.}$	ΔF_{RMS}	(N/S)AM
TEST CONDITION		1ma	V=O	$V = V_R$												Note 1	Note 1
UNITS		Volts	P_F	P_F	Volts	°C/W	Watts	GHz	Volts	ma	%			°C		Hz	db
LIMITS	MIN.						3.5	9			20	± 250					
	MAX.							11	70	500				200	200	50	-115
Serial No.	Diode I. D. Number																
61	81610M1B-11	34.0	21.1	1.90	29.5	12.5	3.5	9.89	52.3	295	22.7	ok	.380	174	<200	0.89	-149
62	-12	36.7	21.7	1.78	32.2	12.4	3.5	9.92	54.7	270	23.7	ok	.380	165	<200	0.89	-150
63	-13	33.8	22.1	1.95	29.3	12.9	3.5	9.81	52.9	280	23.6	ok	.380	171	<200	0.54	-145
64	-14	40.0	22.6	1.75	34.8	12.0	3.5	9.79	56.0	255	24.5	ok	.380	154	<200	0.89	-145
65	-15	37.3	20.0	1.71	32.2	12.7	3.5	9.94	54.8	270	23.7	ok	.380	168	<200	0.54	-145
66	-16	35.4	24.1	1.96	30.0	11.8	3.5	9.78	53.3	280	23.5	ok	.380	160	<200	0.69	-147
67	-17	39.8	22.5	1.66	35.4	12.7	3.5	9.83	56.3	250	24.9	ok	.380	159	<200	0.69	-148
68	-19	35.8	19.0	1.71	31.3	13.0	3.5	9.89	52.3	280	23.9	ok	.380	170	<200	0.31	-135
69	-23	35.8	22.6	1.85	29.9	12.3	3.5	9.71	52.2	280	23.9	ok	.380	162	<200	0.86	-144
70	-25	33.6	22.4	2.09	25.7	12.0	3.5	9.68	51.9	285	23.7	ok	.380	161	<200	0.48	-146

NOTE 1: BANDWIDTH: 1 Hz
FREQUENCY FROM CARRIER: 10-100 KHz

Table 3-2
Data Sheet
SCS-481 Type 2 (MS50372) Ku-Band Diodes

CHARACTERISTIC		B_V	C_{TO}	C_{TVR}	V_R	R_{TH}	P_o	F_o	V_{OP}	I_{OP}	η	Mech. Tun.	HAT	T_J	$Q_{Ext.}$	ΔF_{RMS}	(N/S)AM
TEST CONDITION		lma	V=O	$V = V_R$												Note 1	Note 1
UNITS		Volts	P_F	P_F	Volts	°C/W	Watts	GHz	Volts	ma	%			°C		Hz	db
LIMITS	MIN.						2.5	14			20	± 250					
	MAX.							16	70	500				200	200	50	-115
Serial No.	Diode I. D. Number																
71	81845B-1	21.4	9.5	1.95	15.1	15.3	2.5	14.8	36.0	340	20.4	ok	.160	174	108	6.13	-139
72	-3	20.9	9.0	2.01	14.1	15.0	2.5	14.8	35.8	340	20.5	ok	.160	170	160	6.73	-138
73	-4	20.6	9.0	2.11	12.7	15.5	2.5	14.8	35.2	340	20.9	ok	.160	172	80	14.01	-140
74	-5	23.1	9.7	1.84	16.1	15.8	2.5	14.6	37.4	315	20.9	ok	.180	172	93	3.92	-136
75	-6	20.9	11.2	2.06	13.3	15.9	2.5	14.7	36.0	345	20.1	ok	.175	183	88	3.56	-135
76	-7	20.9	11.1	2.24	12.1	15.2	2.5	14.2	35.7	350	20.0	ok	.175	177	71	17.66	-137
77	-8	20.8	10.4	2.18	12.5	16.1	2.5	14.8	36.7	340	20.0	ok	.160	186	104	5.45	-141
78	-9	20.9	8.4	2.12	12.5	16.8	2.5	14.9	35.9	350	20.0	ok	.160	194	81	27.39	-119
79	-12	20.0	9.7	1.75	13.7	15.4	2.5	14.3	35.8	350	20.0	ok	.180	179	78	11.21	-122
80	-13	20.6	8.1	2.11	11.9	16.0	2.5	14.8	36.8	340	20.0	ok	.180	185	80	6.54	-118

NOTE 1: BANDWIDTH: 1 Hz
FREQUENCY FROM CARRIER: 10-100 KHz

Table 3-3

Operating Data
X-Band Test Cavity

RAYTHEON

IMPATT DIODE TEST CAVITY

TYPE	THX-8000B		
SERIAL NUMBER	S/N 4		
HAT SIZE	0.380	HAT STYLE	.120 x .020 Pedestal
		DIODE	81610M1B-1

OPERATING DATA

VOLTAGE	57.3 V	BREAKDOWN VOLTAGE @ $I_R = 1$ mA	41.2 V
CURRENT	250 mA	CAPACITANCE-C_{TO}	21.9 pF
POWER OUTPUT	3.5 W	CAPACITANCE-C_{TVR}	1.62 pF
FREQUENCY	9.83 GHz		
EFFICIENCY	24.4%	@ V_R	37.0 V

NOTE: The sliding short may be replaced with a precision short for smoother operation in repetitive diode testing.

Table 3-4

Operating Data
Ku-Band Test Cavity

RAYTHEON

IMPATT DIODE TEST CAVITY

TYPE	THK-8000B		
SERIAL NUMBER	S/N 4		
HAT SIZE	0.200	HAT STYLE	Flat
		DIODE	81845B-10

OPERATING DATA

VOLTAGE	34.8 V	BREAKDOWN VOLTAGE @ $I_R = 1$ mA	20.8 V
CURRENT	400 mA	CAPACITANCE-C_{TO}	9.8 pF
POWER OUTPUT	2.5 W	CAPACITANCE-C_{TVR}	1.75 pF
FREQUENCY	14.9 GHz		
EFFICIENCY	18.0%	@ V_R	15.0 V

NOTE: The sliding short may be replaced with a precision short for smoother operation in repetitive diode testing.

the instrument into the RF measurement test set to enhance the production test rates. The AM and FM noise measurement data is given in Appendix A.

3.2 Ku-Band Read IMPATT Diodes (MS-50372)

The Ku-band diodes meet all specifications. For comparison, those supplied in the previous shipment met all requirements except operating frequency. To achieve the proper operating frequency, the Ku-band wafer characteristics were modified. The drift zone thickness was reduced by changing the carrier concentration from $1.0 \times 10^{16}/\text{cm}^3$ to $1.3 \times 10^{16}/\text{cm}^3$. Several wafers were processed to the new requirement and the limits were tested. A tolerance of ±10% on this specification appears to be adequate to control the operating frequency. The diode efficiency is still marginal, as shown by the data. Other lots have shown 10% higher efficiency in the best case. The proximity to the specification limit of 20% creates concern because of the production yield requirements of this program. A program for optimizing the diode efficiency is underway and is discussed in Section 2.0 of this report. The operating junction temperature is higher than the X-band diodes because of the lower average efficiency.

Noise measurements on the Ku-band diodes were obtained using point-by-point measurements. A system similar to that used for the X-band diodes will be designed and built to improve the data presentation and accuracy and to reduce the test cost. In the meantime, a computer program was written to perform the computations from the raw data and to generate the hard-copy curves. A sample of the data is given in Table 3-5. The AM-FM computer-generated curves are in Appendix B.

Table 3-5

Sample of Computer Data

```
6/4/76                                                          DIODE NO 1
                                  AM FM NOISE DATA

FREQ HZ           FM NOISE          AM NOISE          V1     V2     V3     V4
                    RMS                DB

 5000             11.036            -136.349          45     .6     20     16
 10000            6.13066           -139.182          25     .5     14     11
 15000            4.99474           -139.939          20     .42    12     9
 20000            4.16915           -142.369          17     .4     10     8
 30000            3.92498           -142.881          16     .36    9      7
 50000            3.4369            -143.461          14     .35    8      6
 70000            3.19513           -146.793          13     .34    7      6
 100000           3.20335           -149.974          13     .32    6.5    6
 150000           2.97503           -150.336          12     .32    6      5.5
 200000           3.00038           -150.336          12     .32    6      5.5
 250000           3.03266           -150.336          12     .32    6      5.5
 300000           3.07172           -150.731          12     .31    5.5    5


                  V =.0082          V5 =.008           F1 =40000
                  G =32              F =13800          R1 =1.00000E+06
                  U =1.4            P1 =.3             P2 =2500


                                  QEXT =107.98
```

Δ

4.0 DIODE OPERATING LIFE TESTS

4.1 Summary of Requirements

Operating life test requirements of this program specify that diodes periodically be subjected to 1000 hour life tests while operating as oscillators. The tests are to be initiated at the end of the first quarter and repeated quarterly for a total of seven (7) tests. The sample size for each test is five (5) diodes of each type randomly selected from a corresponding wafer. In addition, nine (9) diodes of each type are to be life tested for 1000 hours as a part of the Group B Quality Conformance Inspection at the time of confirmatory sample testing and again at the time of pilot run sample testing.

The testing is to be conducted at an ambient temperature of 25°C with the test cavity temperature held below 75°C and the diode junction temperature not exceeding 200°C. To identify failures, the power output must be monitored with failures defined by a 25% decrease in the power output of a diode relative to its initial value. The Group B life testing will be performed with the diode operating within its rated power output, frequency, efficiency, and junction temperature specifications. The quarterly tests will be conducted in such a way as to demonstrate progress toward successfully meeting these test requirements.

Two operating life test stations, one for X-band diodes and one for Ku-band diodes, were designed and constructed to meet the operating life test requirements described. A description of the equipment was presented in the first quarterly report.

4.2 Status

During the present period, the third operational life test was completed. A Ku-band system malfunction was corrected prior to the test, and all of the Ku-band diodes survived 1080 hours with no change in performance. Four (4) X-band diodes survived 1100 hours. The fifth diode failed at 800 hours. The most probable cause of failure was cavity de-tuning.

Earlier, the first life test was completed near the end of the second quarter. Four (4) X-band diodes and four (4) Ku-band diodes survived the life test with no performance degradation. Four X-band diodes survived the second operational life test with no change in performance. The fifth failure was found to be caused by cavity de-tuning and not by failure of the diode. All of the Ku-band diodes (five devices) failed early due to a system malfunction.

4.3 Life Test Results

4.3.1 X-Band Diodes

The X-band diodes were loaded into the cavities and tuned on the standard RF test set as described in the process specifications presented in earlier reports. The cavities were then loaded onto the life test system, and the test was begun. At 700 hours, diode #2 jumped out of oscillation. The dissipated power in the device increased thus raising the operating junction temperature. Since this happened over the weekend, the diode was operating in this thermal runaway mode for over 60 hours. When reset, the DC operating condition changed slightly, most likely due to the fact that the diode was returned to its oscillating mode by turning the current down and then up again without retuning the cavity. Henceforth, the tuning characteristic for this diode became unstable. Eventually the device thermally ran away and shorted out after 800 hours of operation.

4.3.2 Ku-Band Diodes

The system difficulties that occurred during the second operational life test were successfully solved as described in the third quarterly report. The Ku-band diodes for the third operational life test were loaded into the cavities and tuned on the standard RF test set as described in the process specifications presented in earlier reports. The cavities were then loaded onto the life test system, and the test was begun. The diodes survived 1048 hours uneventfully with the exception of some minor problems as shown in the event log in Table 4-1.

4.4 Summary of Results

After the completion of the respective 1000 hour test cycles, the cavities were removed from the life test system and retested on the standard test set. The initial and final data is given in Tables 4-2 and 4-3 for the X-band and Ku-band diodes, respectively. It may be seen that there is practically no change in the operating performance of the surviving diodes.

Table 4-1

Event Log - RF Operating Life Test - PEM Program

Date	Event	Clock Readings		Elapsed Time	
		X	Ku	X	Ku
4/07	Start Ku-Band Test		02288		0
4/13	Ku-Band power output monitor print-out jitter. Input to recorder measured with a DVM; checked out o.k. Apparent reason for jitter was poor contact.		02426		138
4/16	Start X-Band Test	02104		0	
5/9	Ku-Band diode in Position #1 fell out of oscillation		03015		727
5/10	Diode #1 reset.		03072		787
5/10	X-Band chart recorder print-out Input was checked out o.k.; difficulty due to chart transport.	02679		575	
5/15	X-Band diode #2 fell out of oscillation.	02805		701	
5/17	Diode #2 Reset.				
5/20	Chart transport down for 24 hours.	02919		815	
5/21	Diode #2 shorted.	02943		839	
5/21	Ku-Band test completed.		03337		1049
5/25	Chart transport problems due to slipping chart roll. Chart roll replaced.	03039		935	
6/01	X-Band test completed.	03207		1103	

Table 4-2

Operating Life Test Data - X-Band Diodes

	Diode No.	Rack Position	Resistance (°C/W)	Junction Temp. (°C)	Operating Voltage (Volts)	Operating Current (mA)	Power Out (Watts)	Freq. (GHz)	Dissipated Power (Watts)
Initial	32528M1A-2	1	11.0	184.5	45.0	400	3.5	9.65	14.5
Final					45.0	400	3.5	9.69	
Initial	32528M1A-3	2	11.2	199.6	42.2	450	3.4	9.5	15.6
Final					Short	---	---	---	
Initial	32528M1A-7	3	12.8	201.5	39.5	420	2.8	10.1	13.8
Final					39.0	420	2.8	10.06	
Initial	32528M1A-10	4	11.7	203.3	43.9	420	3.2	9.35	15.2
Final					42.7	420	3.2	9.34	
Initial	32528M1A-11	5	9.5	185.0	45.2	450	3.5	9.3	16.8
Final					44.5	450	3.5	9.29	

Specification:

P_o = 3.5 W minimum

f_o = 9-11 GHz

η = 20% minimum

T_j = 200°C maximum

Table 4-3

Operating Life Test Data - Ku-Band Diodes

	Diode No.	Rack Position	Resistance (°C/W)	Junction Temp. (°C)	Operating Voltage (Volts)	Operating Current (mA)	Power Out (Watts)	Freq. (GHz)	Dissipated Power (Watts)
Initial	81561MC-10	1	19.0	199.4	37.6	300	2.1	12.8	9.2
Final					37.0	300	2.08	12.8	
Initial	81561MC-2	2	18.4	207.9	40.3	295	1.95	12.7	9.9
Final					38.9	295	1.94	12.7	
Initial	81561MC-3	3	17.4	203.5	40.2	305	2.0	12.5	10.3
Final					38.7	305	1.98	12.5	
Initial	81561MC-8	4	19.0	201.5	38.3	300	2.2	12.6	9.3
Final					38.5	300	2.15	12.6	
Initial	81561MC-9	5	16.8	199.5	38.3	330	2.25	12.8	10.4
Final					38.4	330	2.26	12.7	

<u>Specification:</u>

P_o = 2.5W minimum

f_o = 14-16 GHz

η = 20% minimum

T_j = 200°C maximum

5.0 CONCLUSIONS

There has been a steady improvement in performance of diodes from the pilot line. The final set of engineering samples have met all of the specifications. The engineering effort directed to achieving the technical objectives has been completed. Effort will now be directed to yield and rate considerations during fabrication of the confirmatory samples.

6.0 PLANS FOR NEXT PERIOD

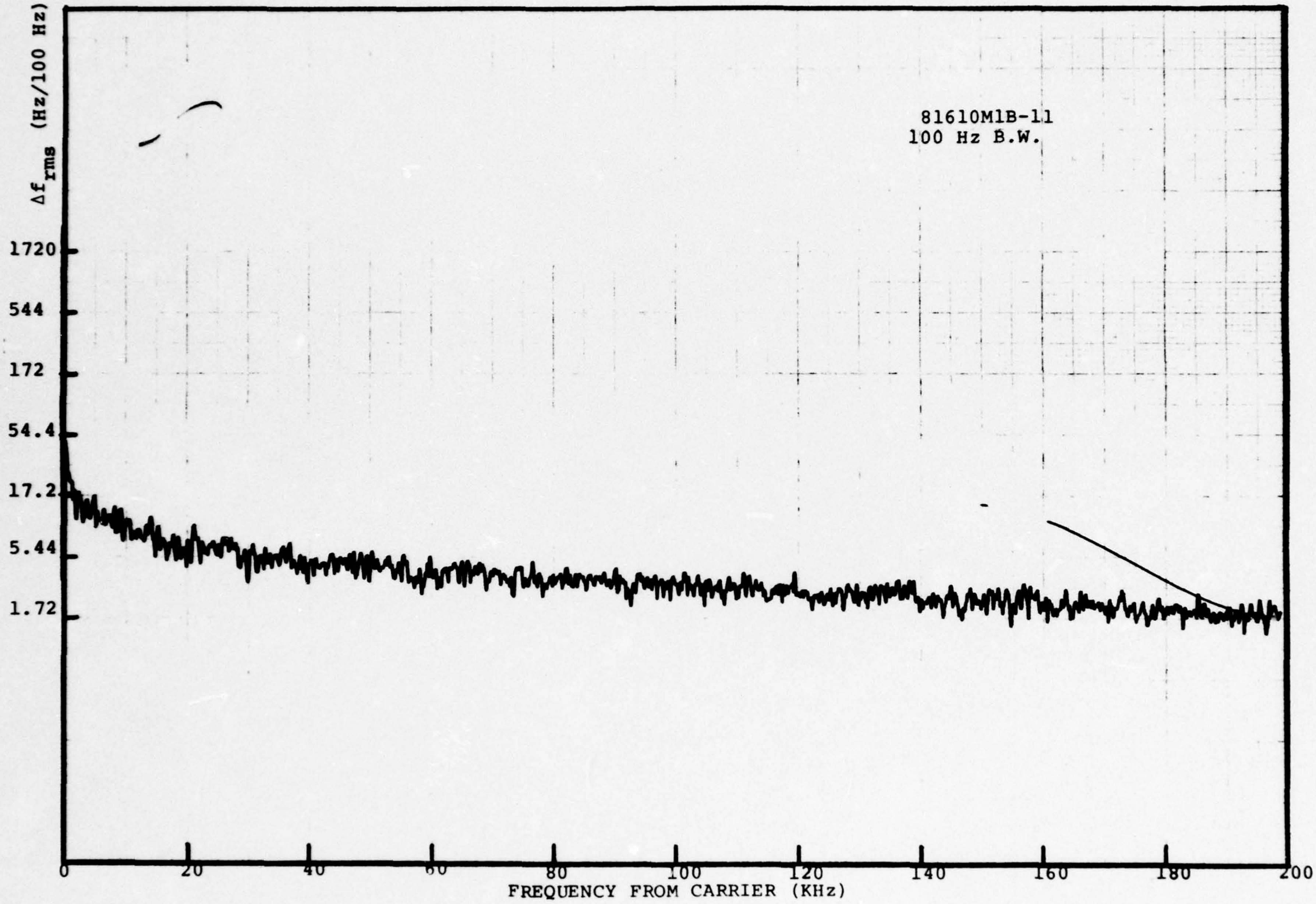
During the next period, we will finalize assembly procedures and begin fabrication of the confirmatory samples. Effort directed to meeting production rate objectives will be continued. The thermal resistance test method must be improved to achieve these rates. Work is in progress on improving the method. The method for measurement of noise is also being productionized.

7.0 IDENTIFICATION OF PERSONNEL

Dr. Michael Adlerstein Senior Scientist - Process Engineering	4 Hours
Michael Benedek Engineer - Production Processes	72 Hours
Robert Bierig Manager - Semiconductor Research Laboratory and GaAs Material Production	6 Hours
Henri Chalifour Manager - Diode Production	48 Hours
Paul Coletti Supervisory Engineer - Dice Fabrication	364 Hours
Jack Curtis Associate Scientist	2 Hours
Dwight Howe Research Assistant	3 Hours
William Labossier Research Assistant - Epitaxial Wafer Growth	152 Hours
Andrew Moysenko Associate Research Scientist - Quality Assurance Wafer Growth	8 Hours
Dr. S. F. Paik Manager - Solid State Engineering	10 Hours
James Simpson Senior Scientist	22 Hours
Samuel R. Steele Senior Scientist - Manager Materials Laboratory	160 Hours
Basil Vafiades Programs Manager - MMTE Program Manager	55 Hours
Drafting	15 Hours
Research Technicians	947 Hours
Machine Shop	47 Hours

APPENDIX A

AM & FM NOISE MEASUREMENT DATA
SCS-481 TYPE 1 (MS-50371)
X-BAND DIODES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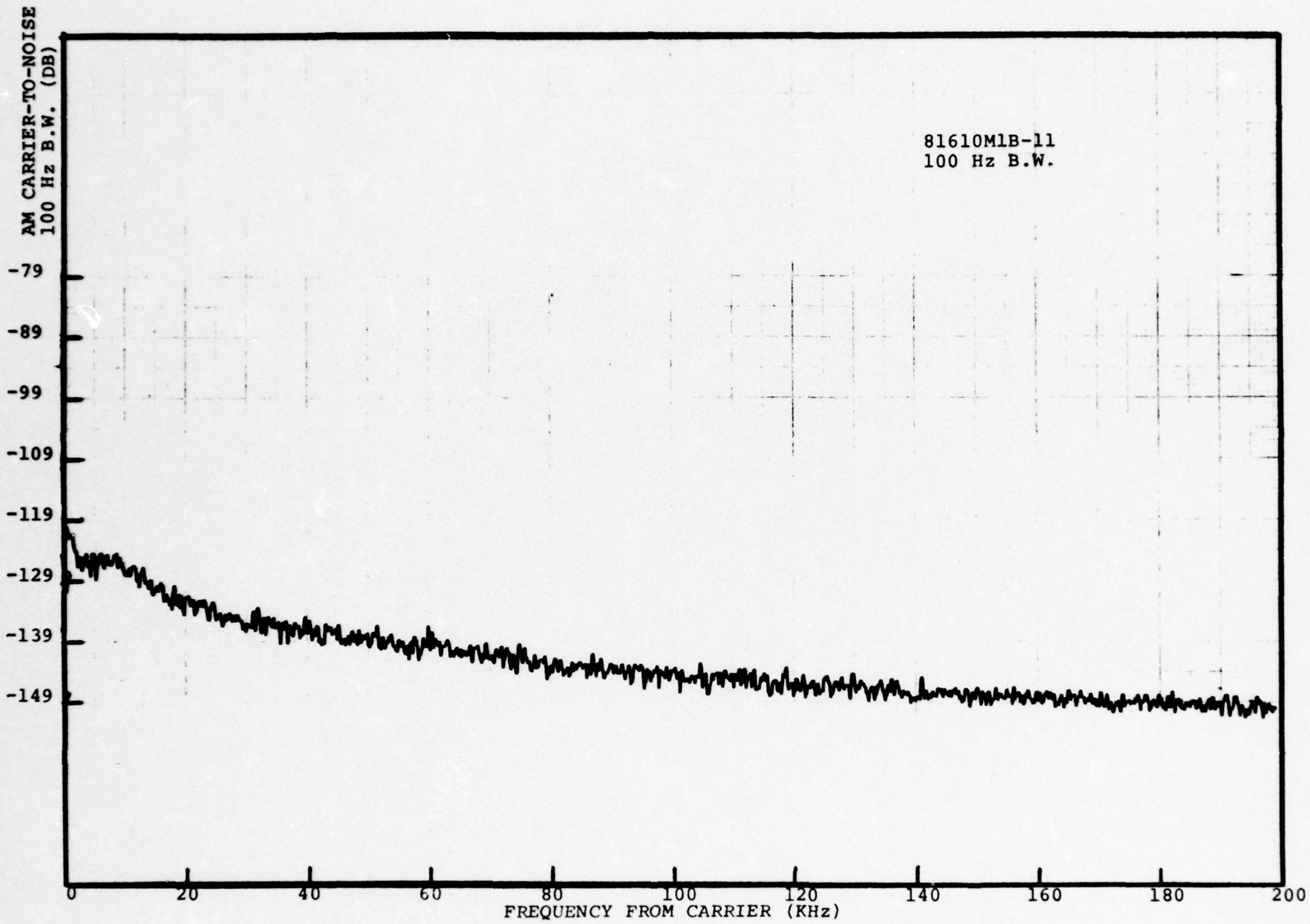
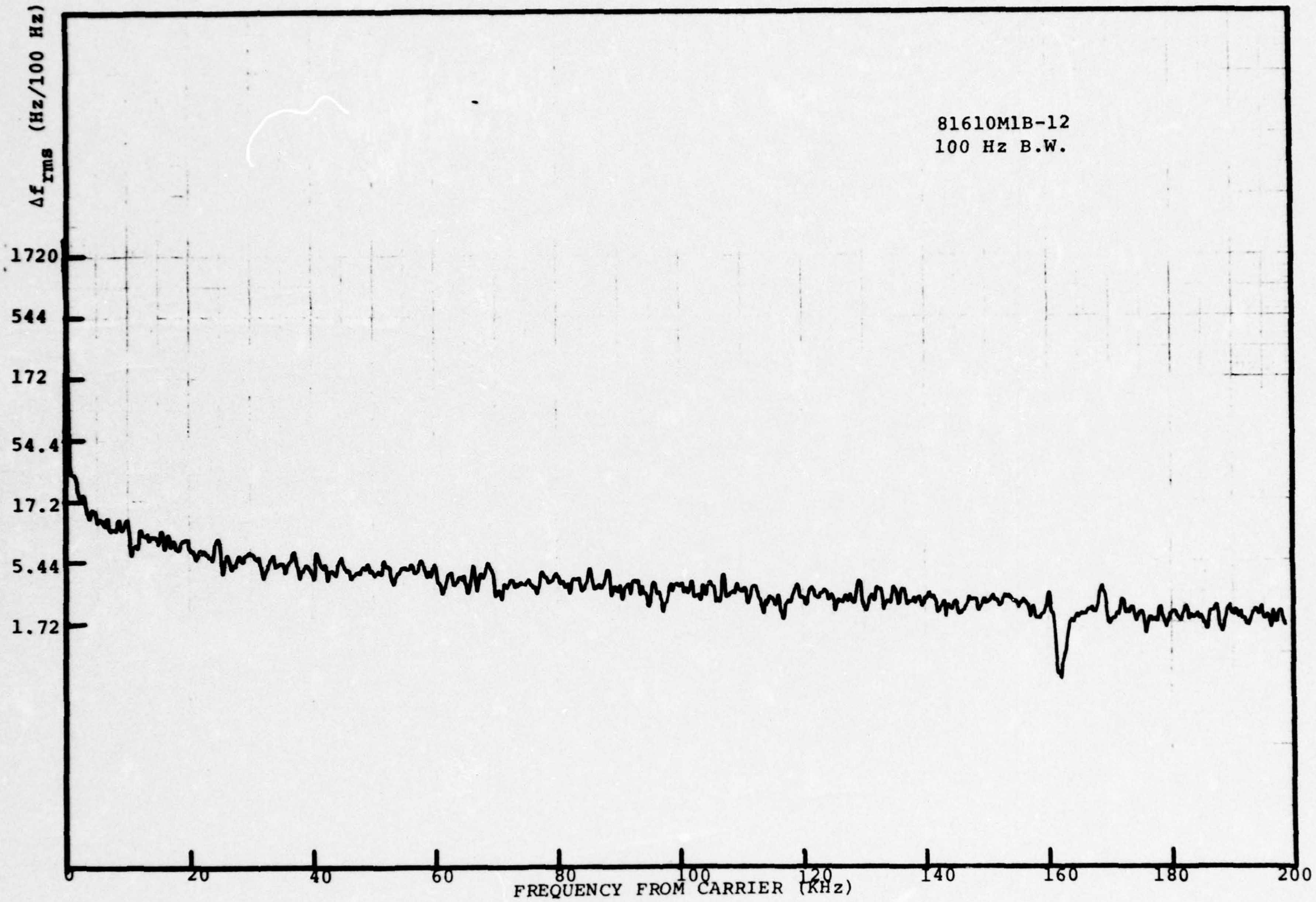
100 Hz B.W.
Δf rms (Hz/100 Hz)
1720
544
172
54.4
17.2
5.44
1.72
0
20
40
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)


AM CARRIER-TO-NOISE
100 Hz B.W. (DB)
-79
-89
-99
-109
-119
-129
-139
-149
81610M1B-11
100 Hz B.W.
0
20
40
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)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Δf_{rms} (Hz/100 Hz)
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544
172
54.4
17.2
5.44
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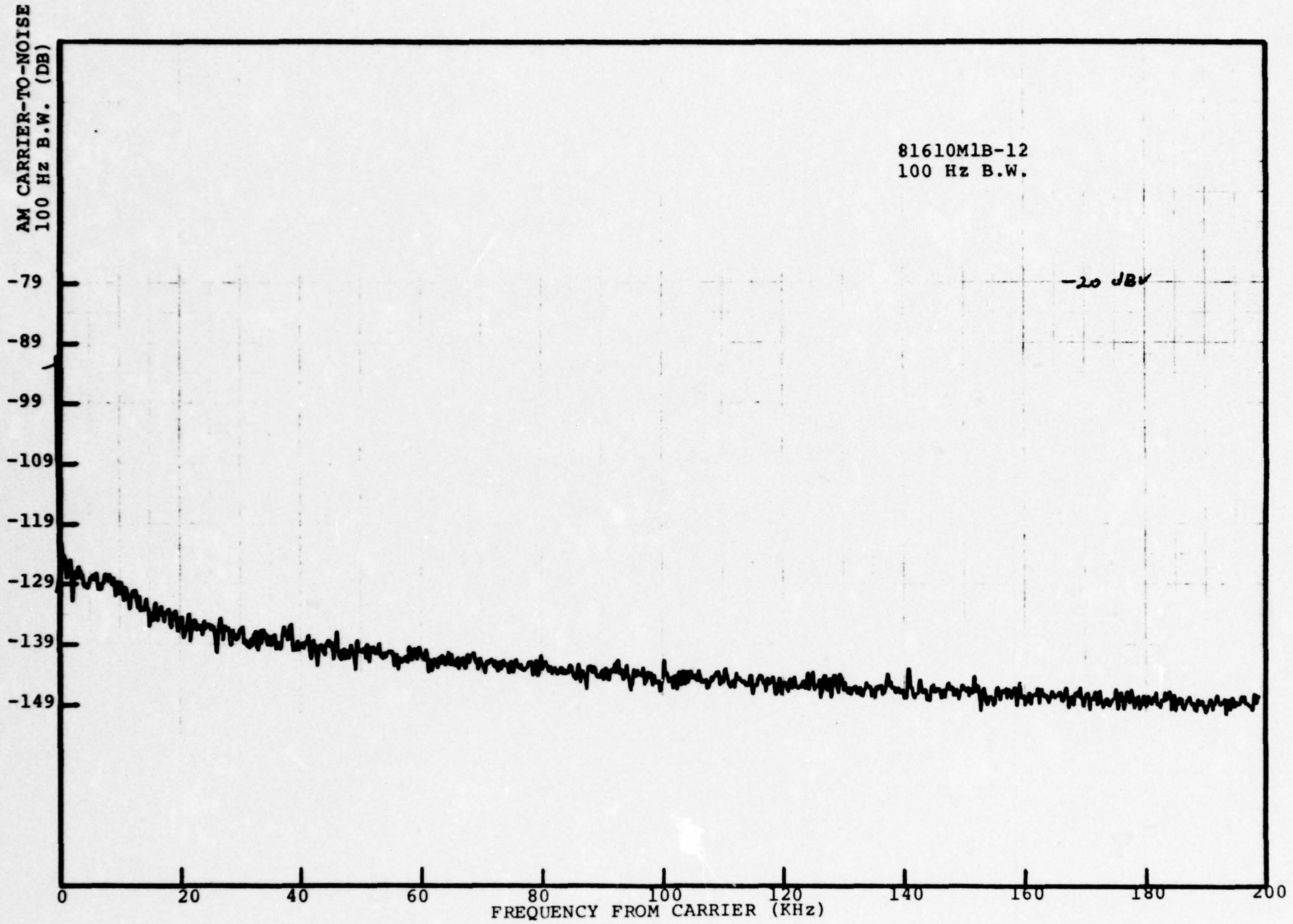
0
20
40
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)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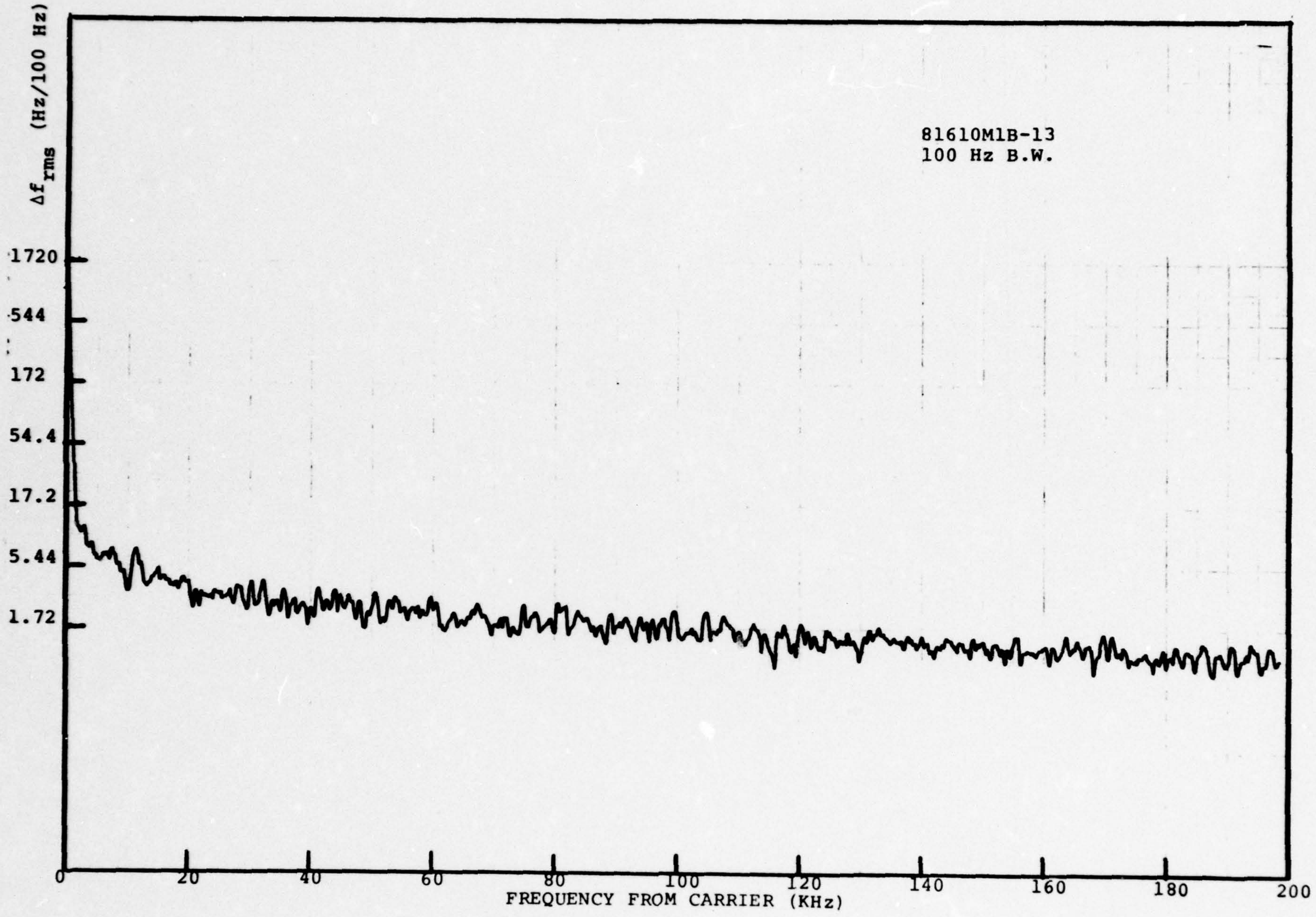
100 Hz B.W. (DB)
-79
-89
-99
-109
-119
-129
-139
-149
81610M1B-12
100 Hz B.W.
-20 dBV
0
20
40
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)

81610M1B-13
100 Hz B.W.
Δf_{rms} (Hz/100 Hz)
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172
54.4
17.2
5.44
1.72
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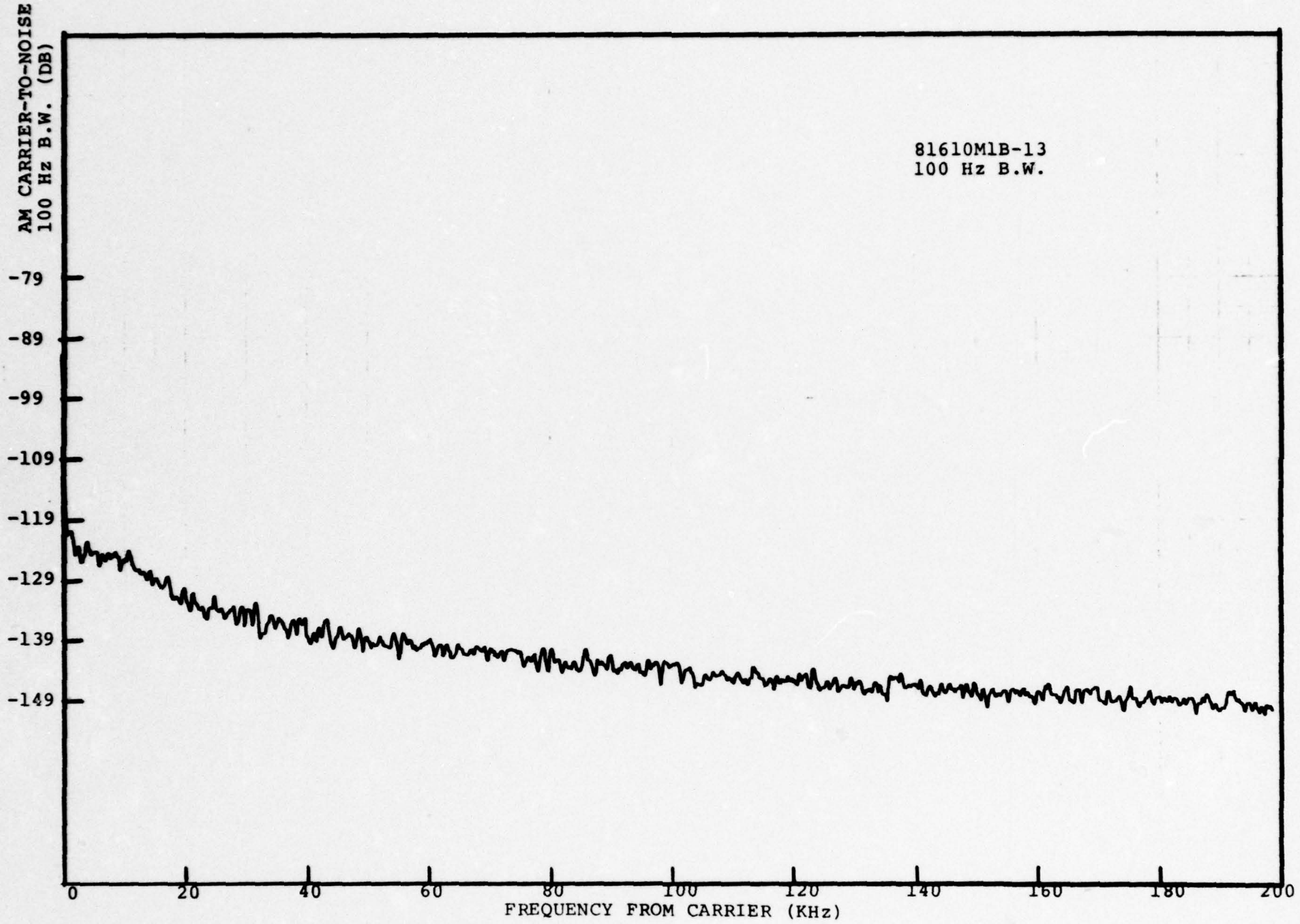
40
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)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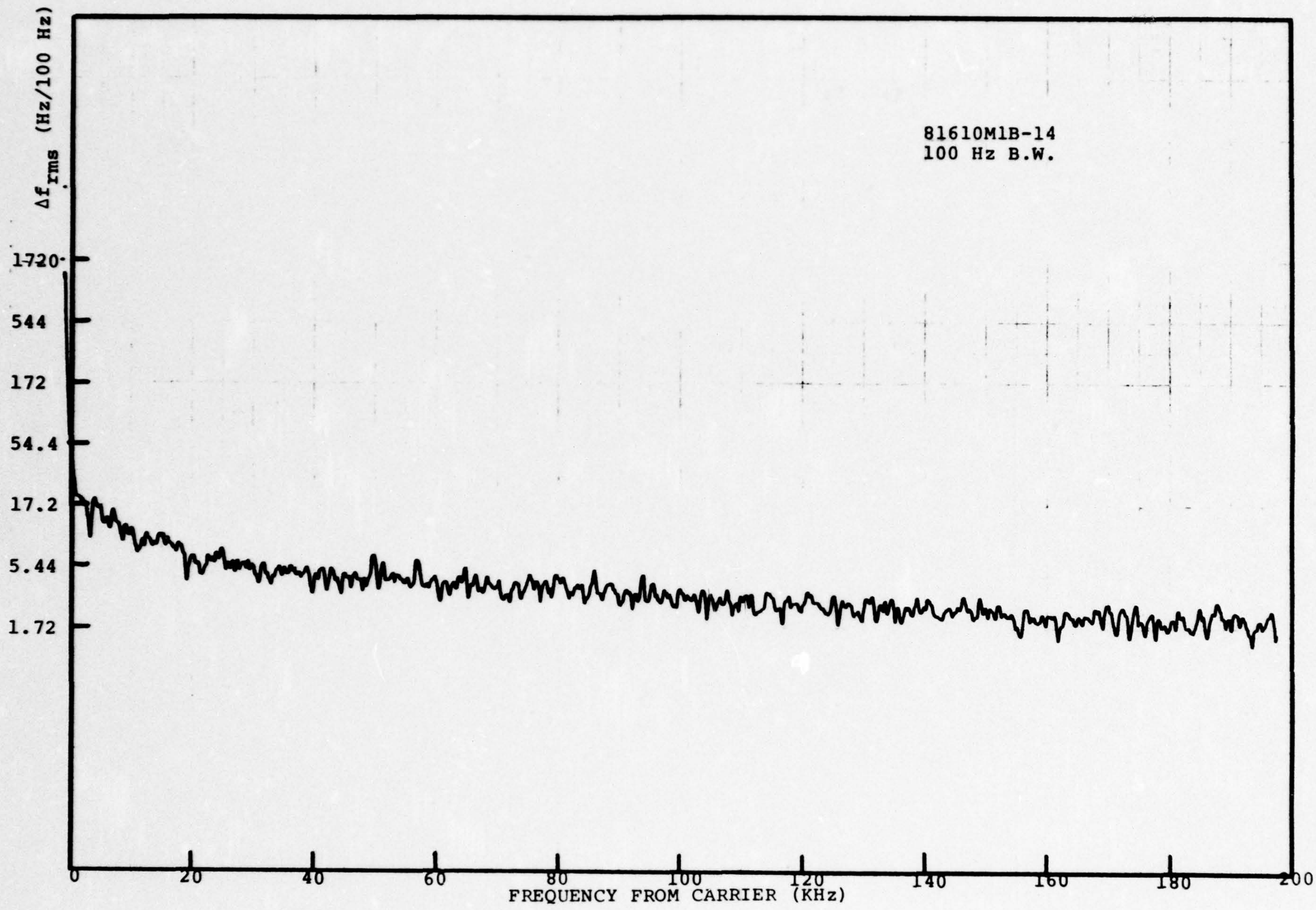
-89
-99
-109
-119
-129
-139
-149
81610M1B-13
100 Hz B.W.
0
20
40
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)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100 Hz B.W.
Δf_{rms} (Hz/100 Hz)
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172
54.4
17.2
5.44
1.72
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20
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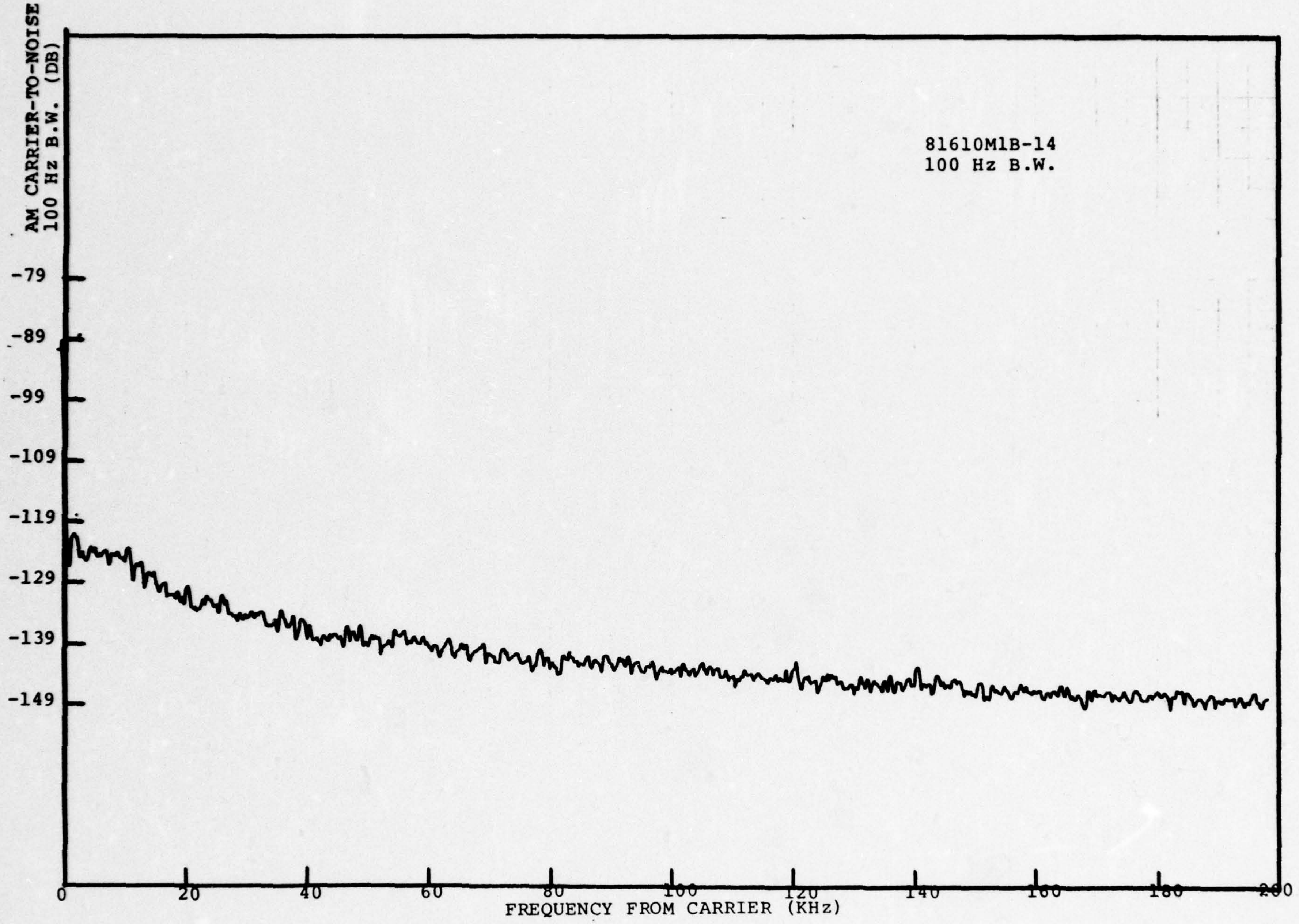
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)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100 Hz B.W.
AM CARRIER-TO-NOISE
100 Hz B.W. (DB)
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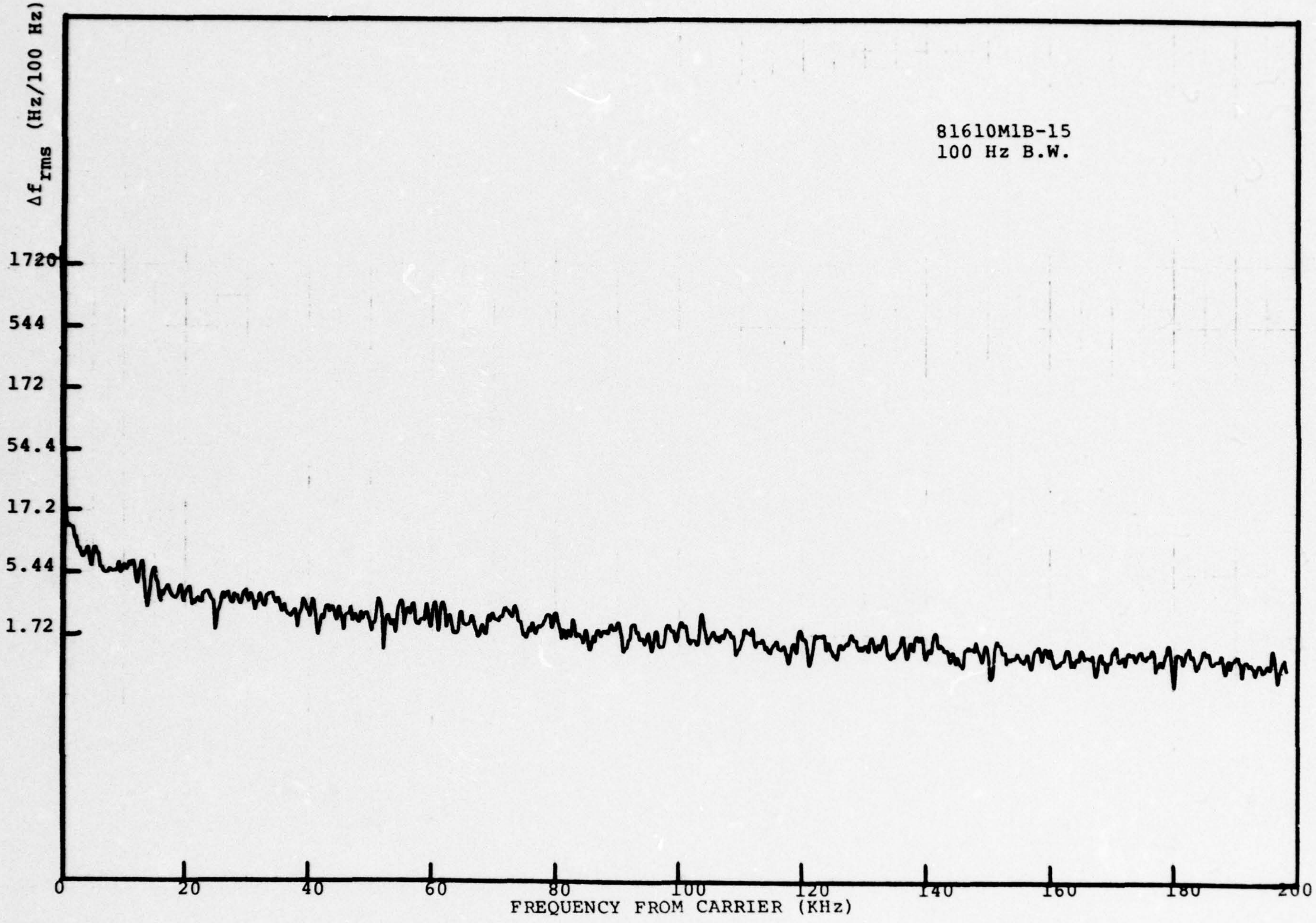
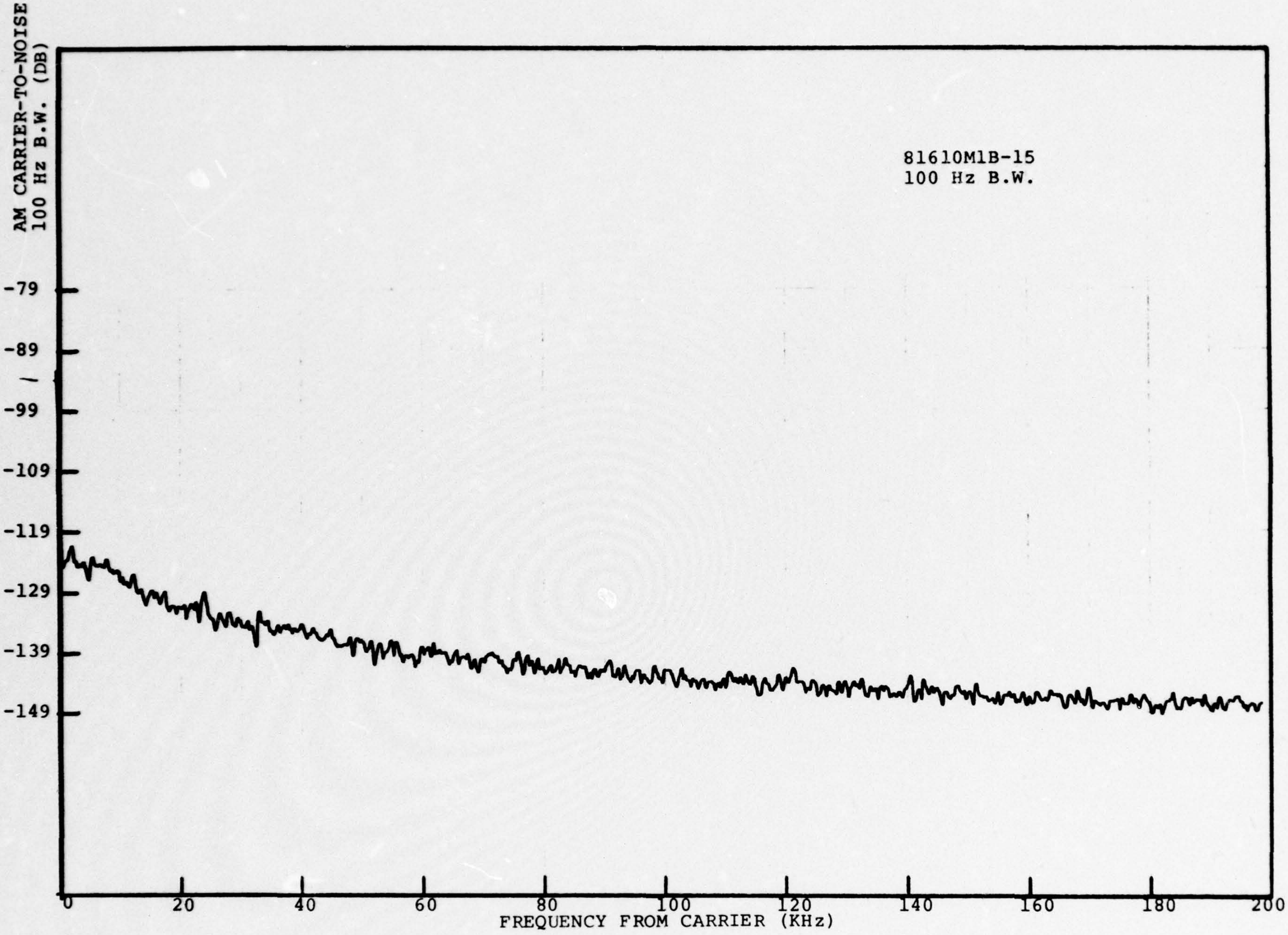
-89
-99
-109
-119
-129
-139
-149
0
20
40
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)



Δf_{rms} (Hz/100 Hz)
1720
544
172
54.4
17.2
5.44
1.72
0
20
40
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)
81610M1B-15
100 Hz B.W.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-99
-109
-119
-129
-139
-149
81610M1B-15
100 Hz B.W.
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120
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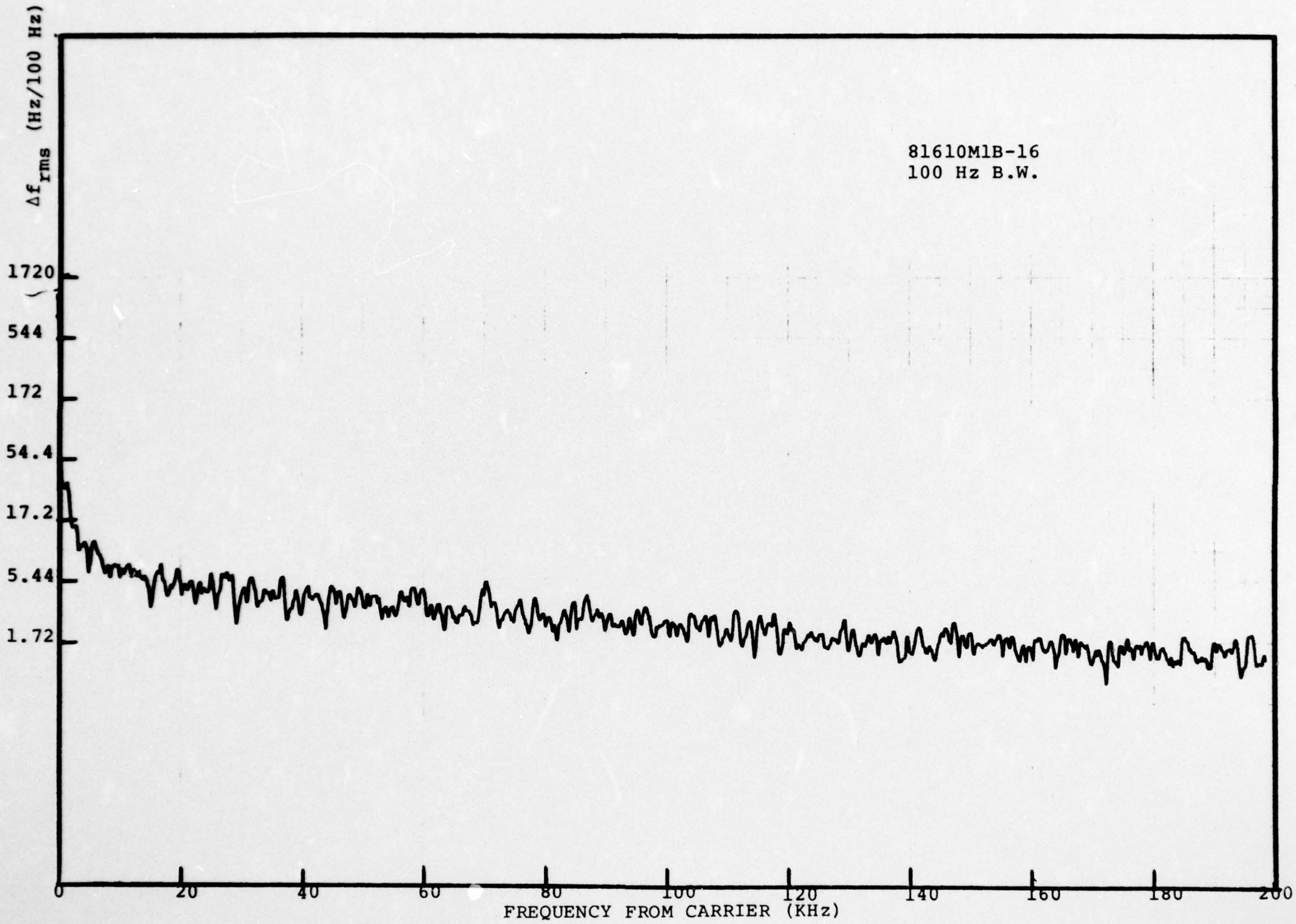
160
180
200
FREQUENCY FROM CARRIER (KHz)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Δf_{rms} (Hz/100 Hz)
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172
54.4
17.2
5.44
1.72
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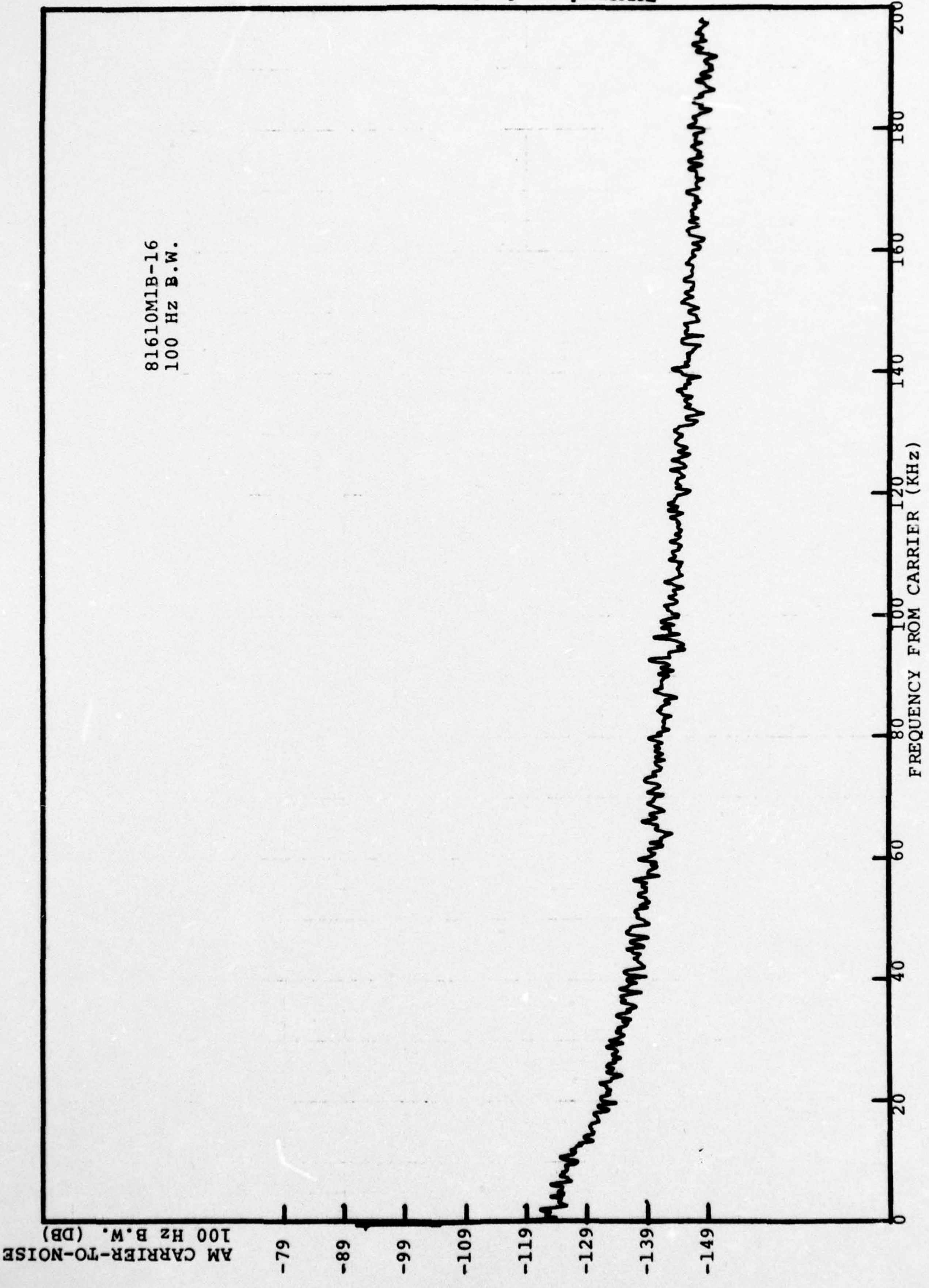
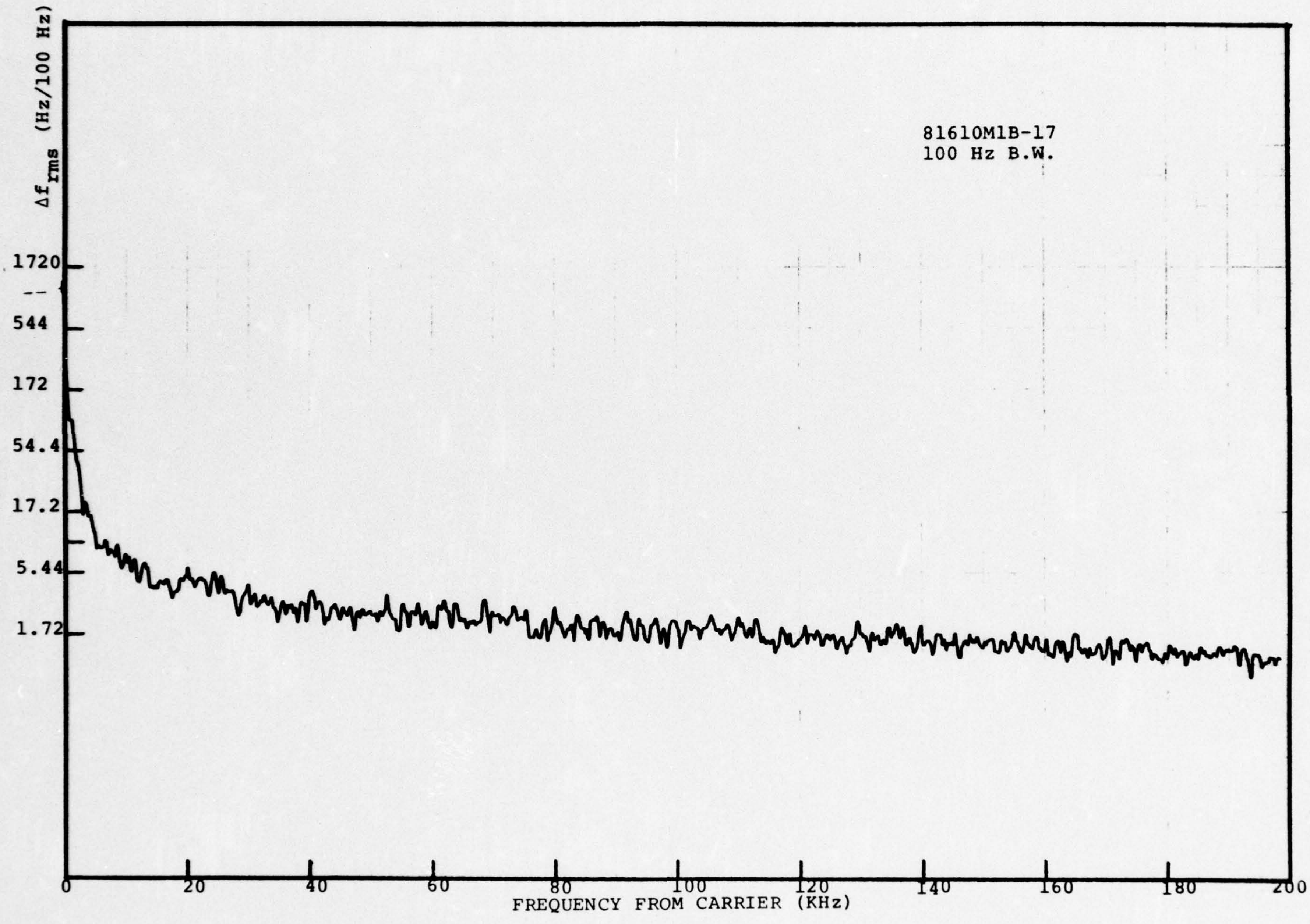
40
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)

Copy available to DDC does not permit fully legible reproduction



81610M1B-17
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Δf_{rms} (Hz/100 Hz)
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--
544
172
54.4
17.2
5.44
1.72
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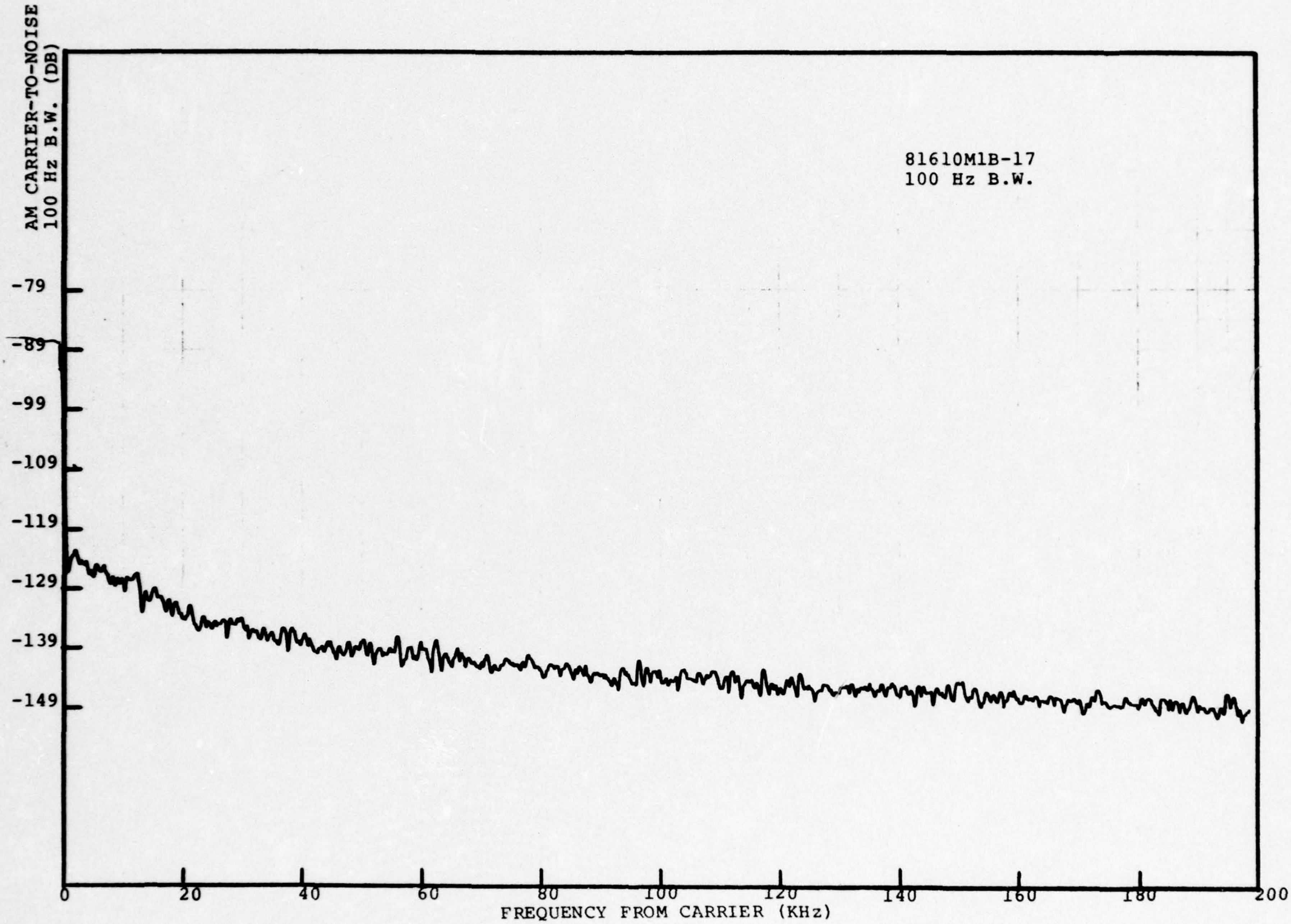
40
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)


AM CARRIER-TO-NOISE
100 Hz B.W. (DB)
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-89
-99
-109
-119
-129
-139
-149
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20
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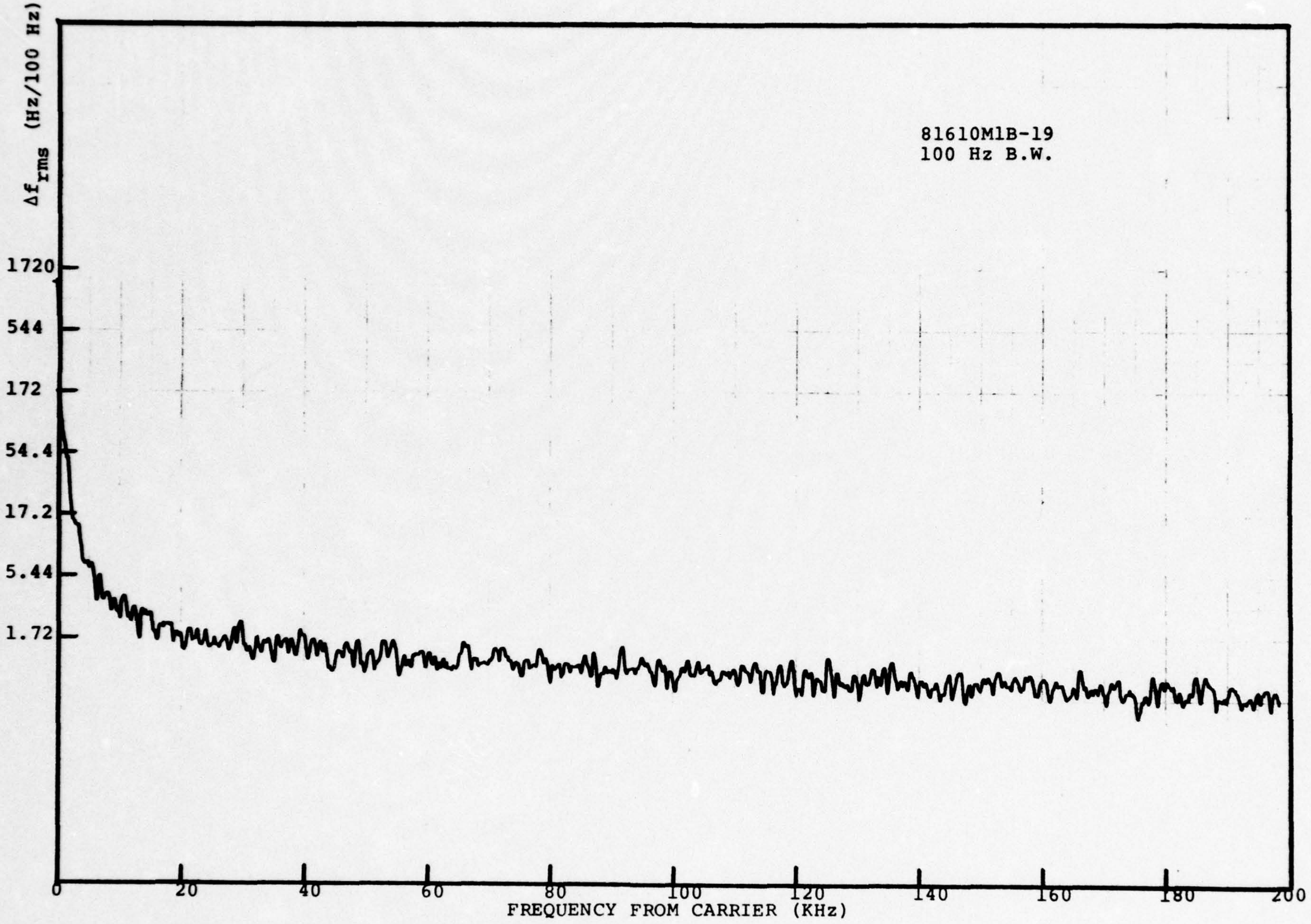
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)
81610M1B-17
100 Hz B.W.


81610M1B-19
100 Hz B.W.
Δf_{rms} (Hz/100 Hz)
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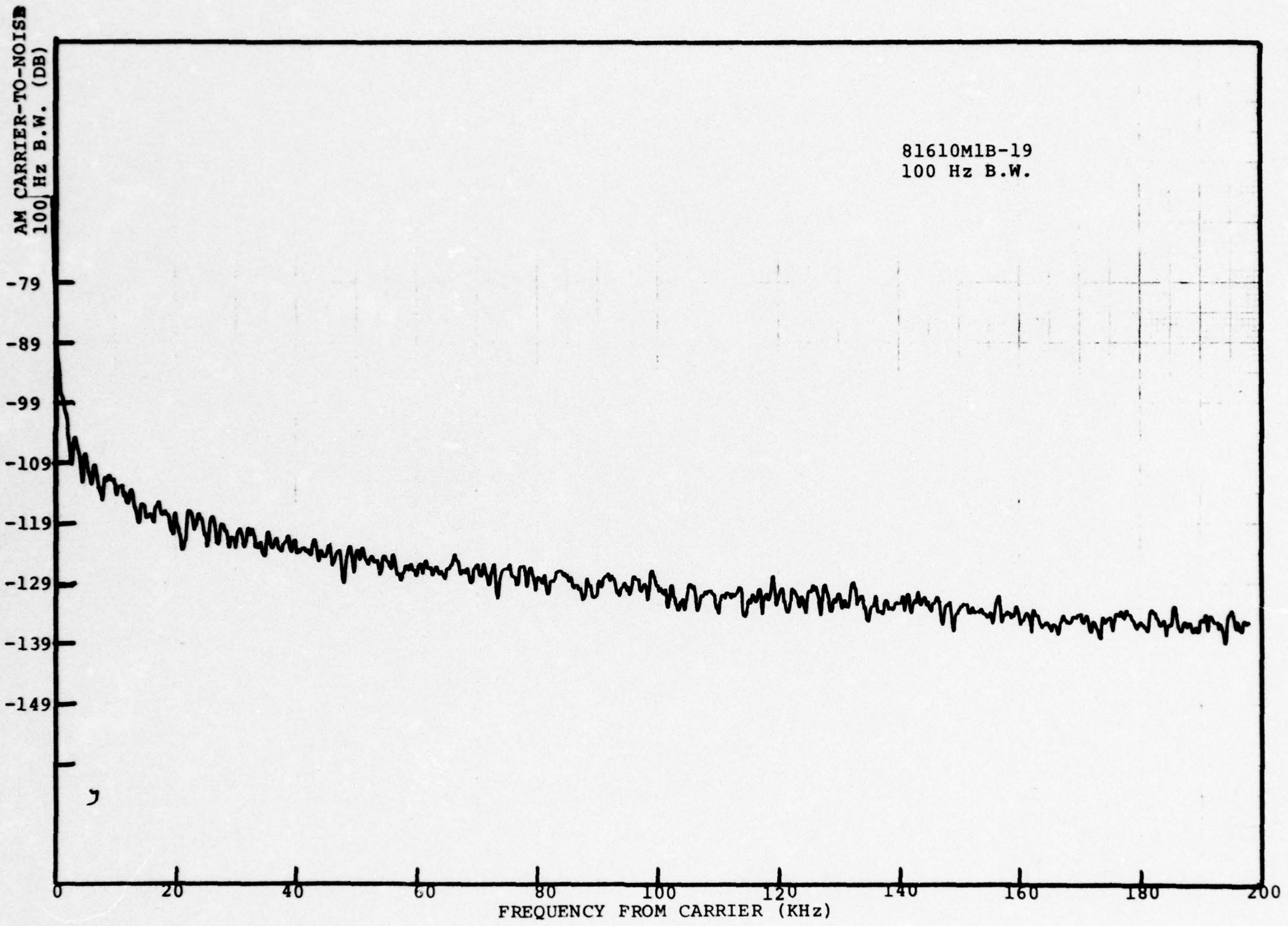
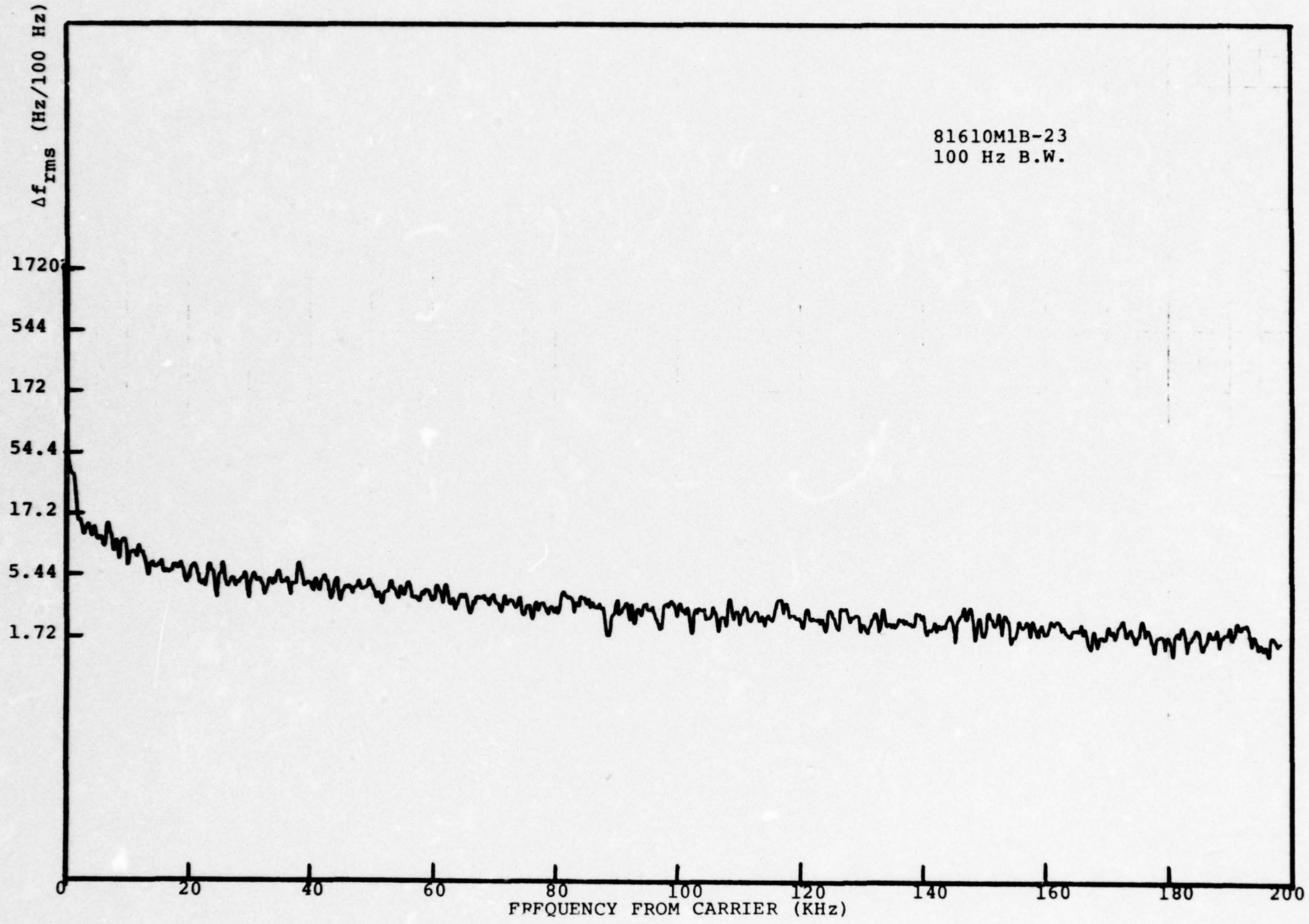
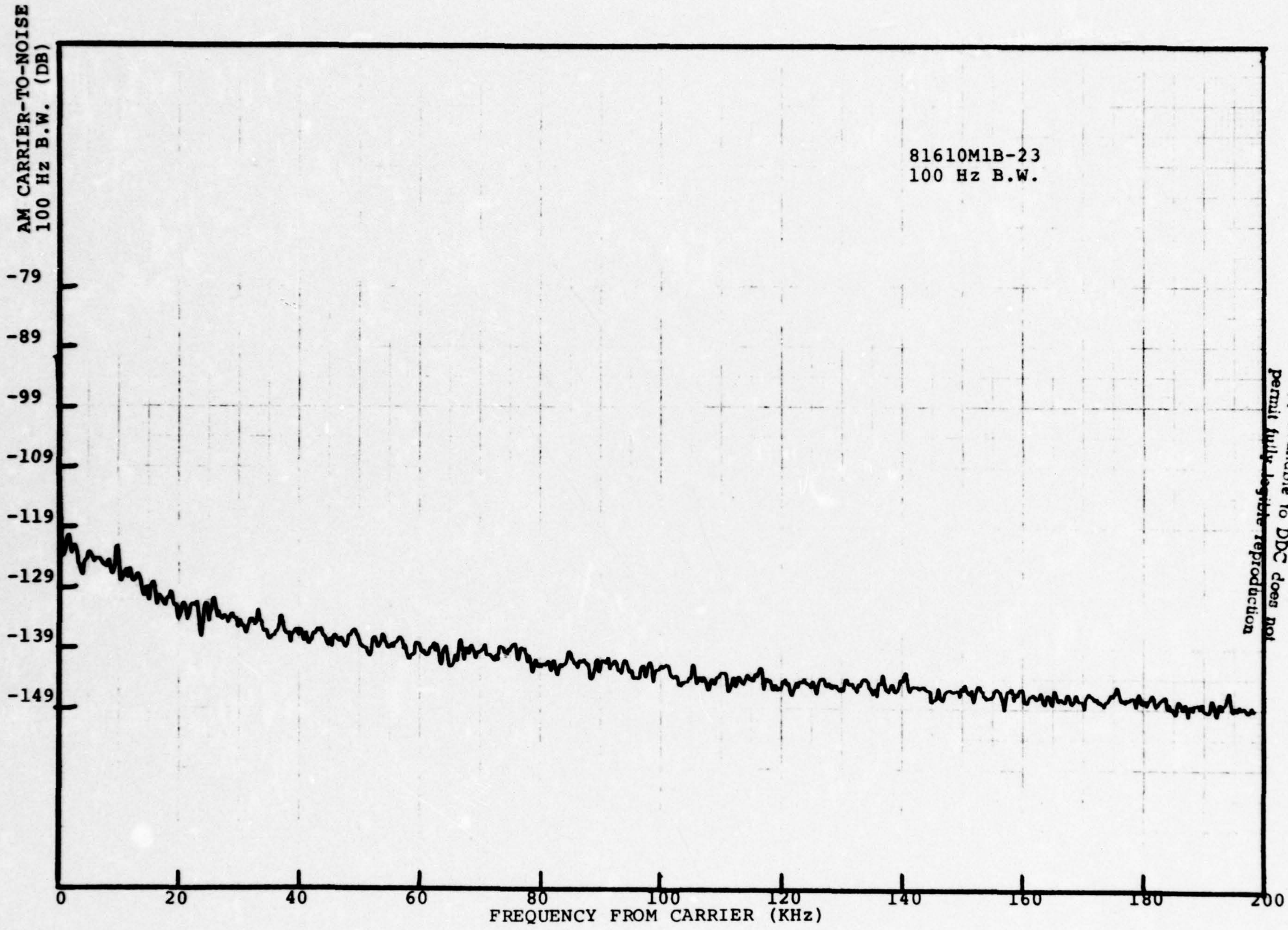
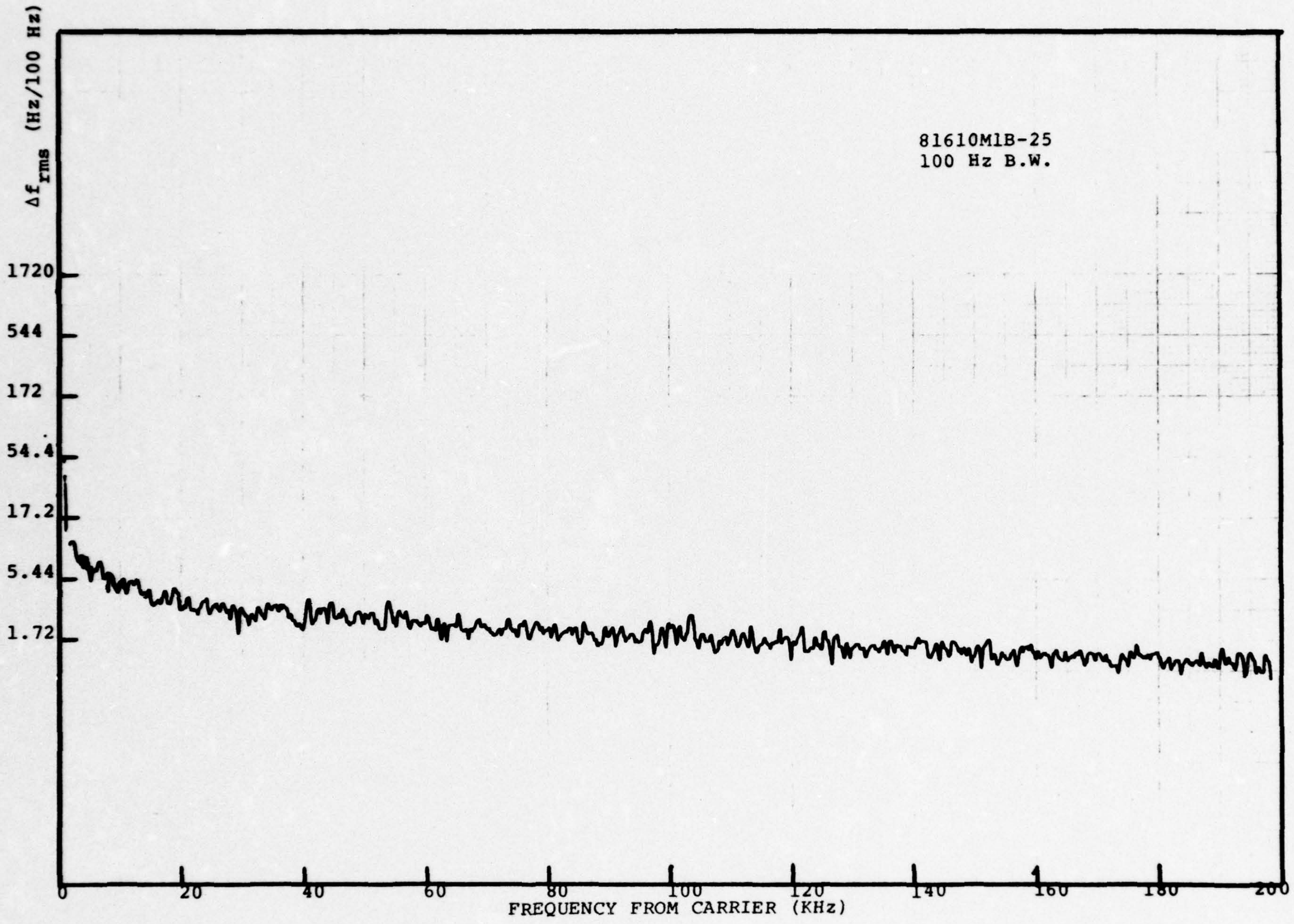
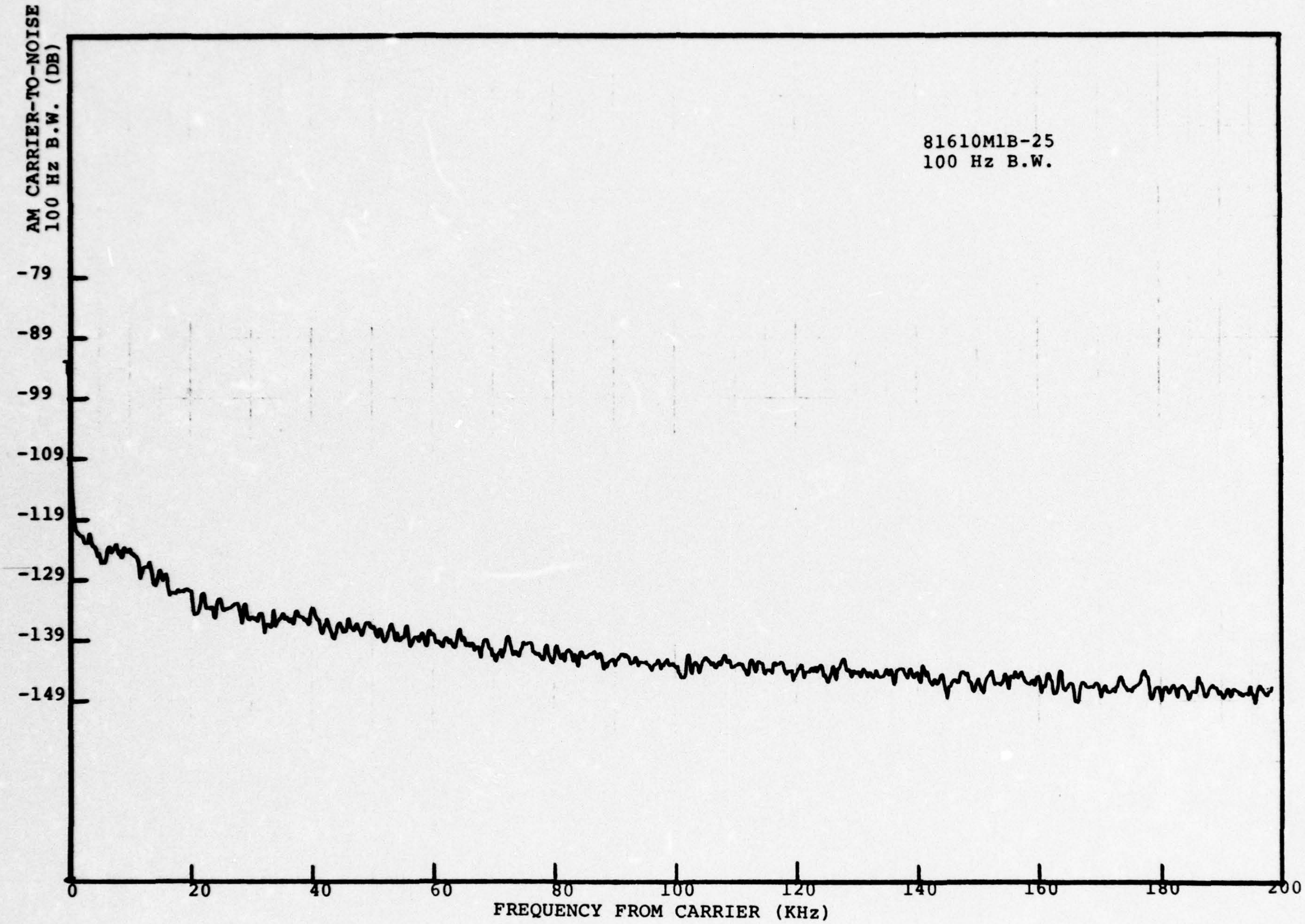
172
54.4
17.2
5.44
1.72
0
20
40
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)


AM CARRIER-TO-NOISE
100 Hz B.W. (DB)
81610M1B-19
100 Hz B.W.
-79
-89
-99
-109
-119
-129
-139
-149
0
20
40
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)


81610M1B-23
100 Hz B.W.
Δf rms (Hz/100 Hz)
1720
544
172
54.4
17.2
5.44
1.72
0
20
40
60
80
100
120
140
160
180
200
FRFQUENCY FROM CARRIER (KHz)


AM CARRIER-TO-NOISE
100 Hz B.W. (DB)
-79
-89
-99
-109
-119
-129
-139
-149
0
20
40
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)
81610M1B-23
100 Hz B.W.


81610M1B-25
100 Hz B.W.
Δf_{rms} (Hz/100 Hz)
1720
544
172
54.4
17.2
5.44
1.72
0
20
40
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)


81610M1B-25
100 Hz B.W.
AM CARRIER-TO-NOISE
100 Hz B.W. (DB)
-79
-89
-99
-109
-119
-129
-139
-149
0
20
40
60
80
100
120
140
160
180
200
FREQUENCY FROM CARRIER (KHz)

APPENDIX B

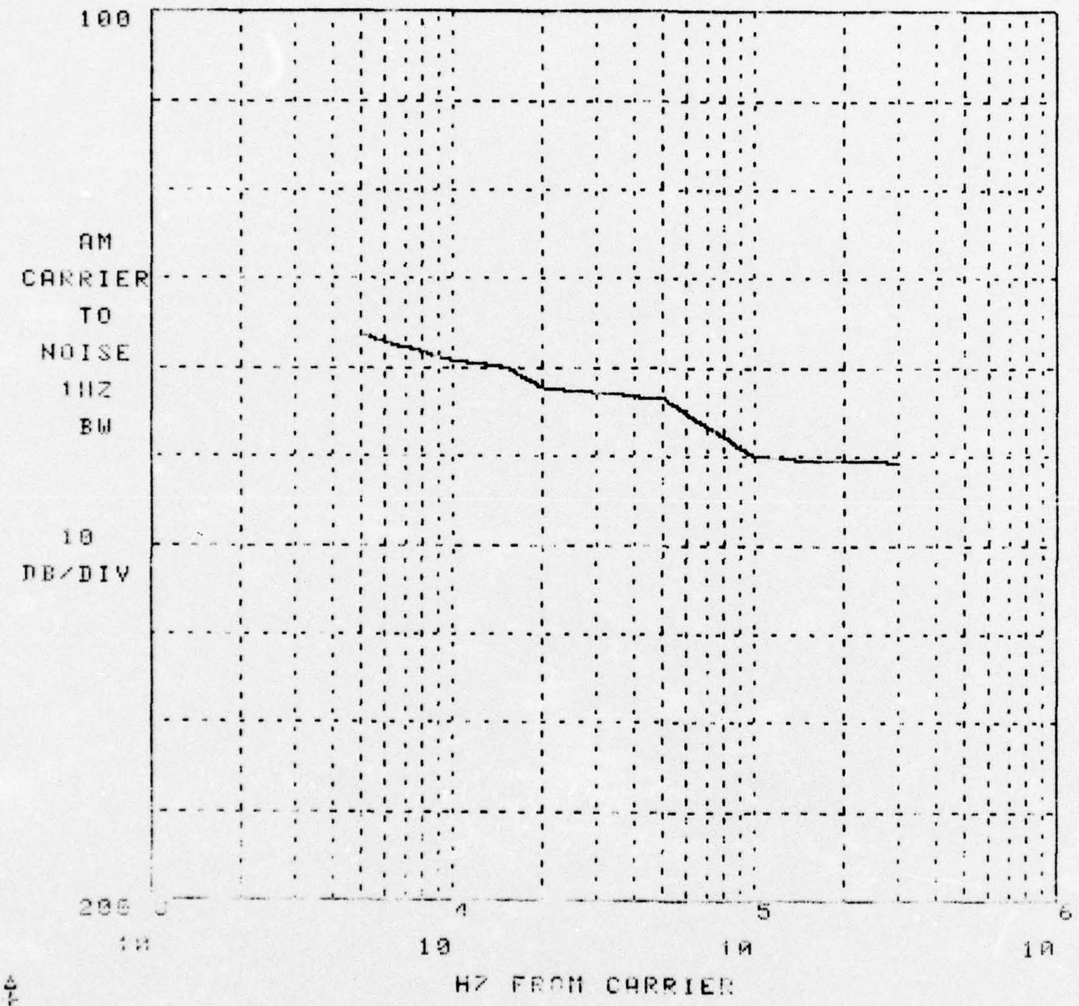
AM & FM NOISE MEASUREMENT DATA
SCS-481 TYPE 2 (MS-50372)
KU-BAND DIODES

6/4/76

DIODE NO 1

AM NOISE

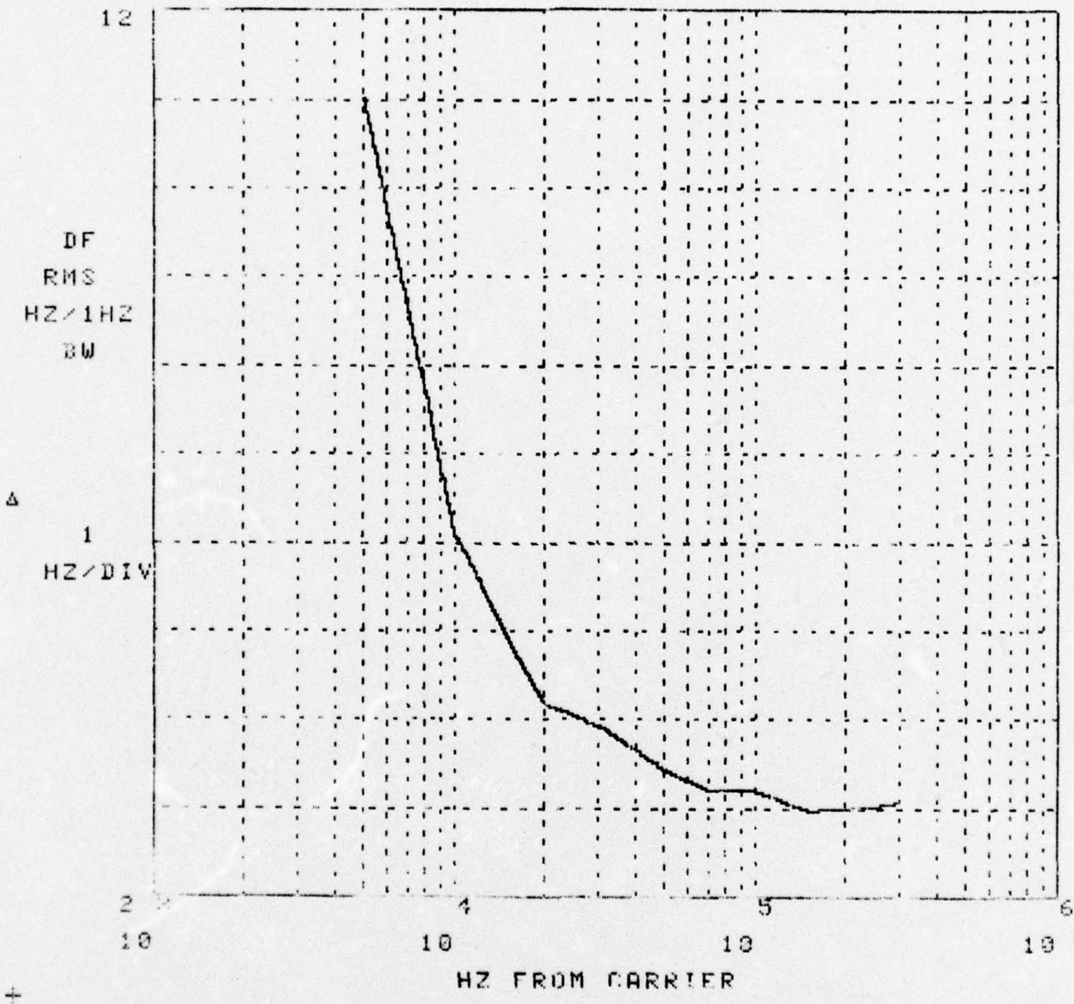
KU-BAND



LOT: 81845-B
POWER: 2.5W
FREQ: 13800 MHz
EFF: 20%
VOLT: 25V
CURR: 350 mA
Q_{EXT}: 108

6/4/76 DIODE NO 1

FM NOISE
KU-BAND

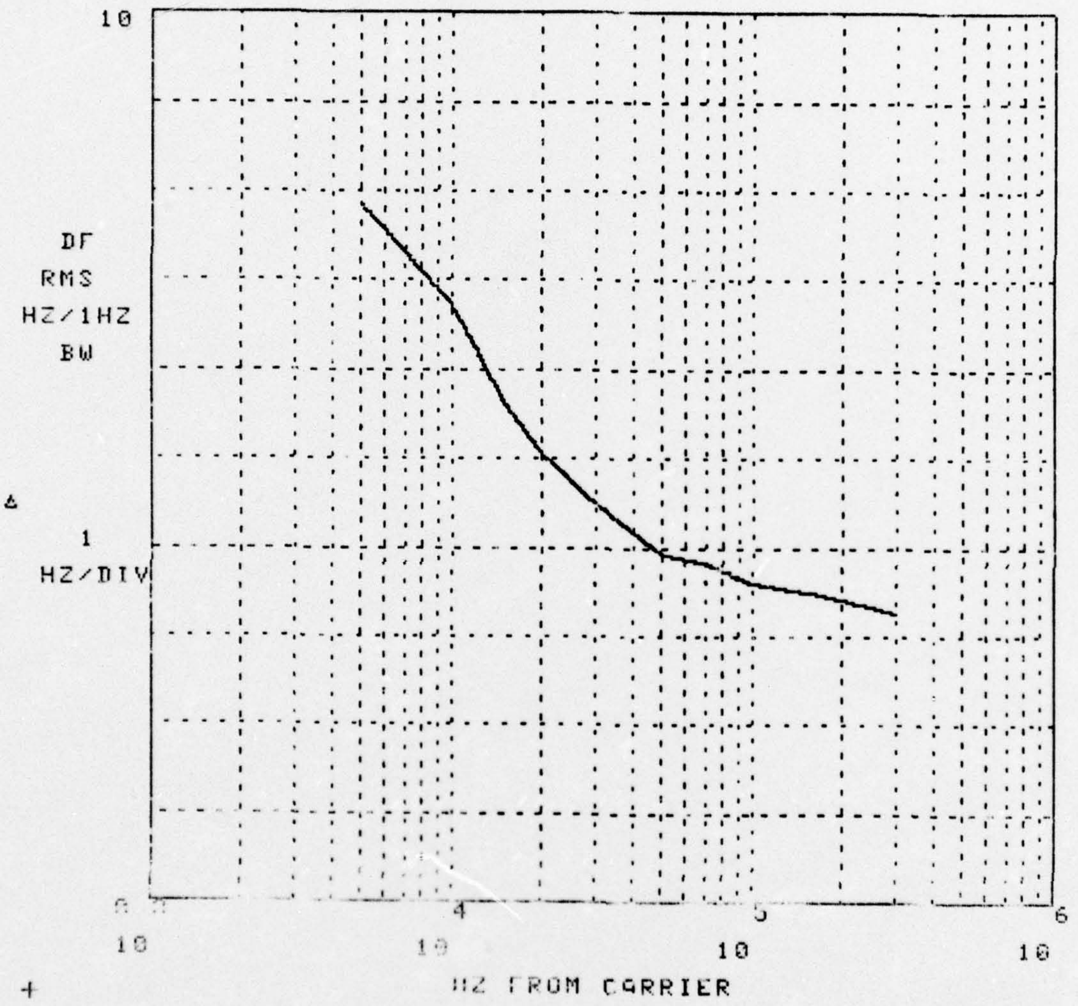


LOT: 81845-B
POWER: 2.5W
FREQ: 13800 MHz
EFF: 20%
VOLT: 25V
CURR: 350 mA
Q_{EXT}: 108

6/4/76

DIODE NO 3

FM NOISE
KU-BAND

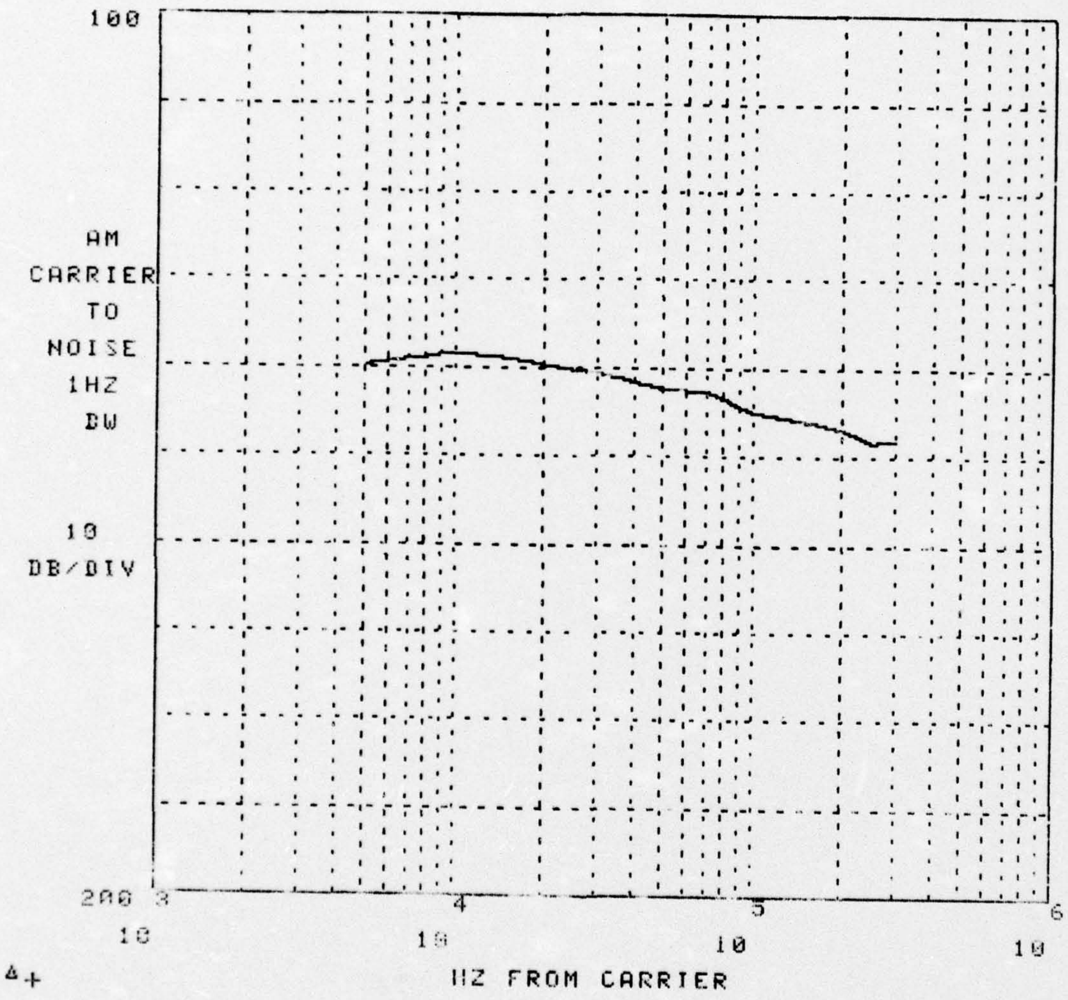


LOT: 81845-B
POWER: 2.5 W
FREQ: 15810 MHz
EFF: 22%
VOLT: 34V
CURR: 330 mA
Q_{EXT}: 160

6/4/76

DIODE NO 3

AM NOISE
KU-BAND

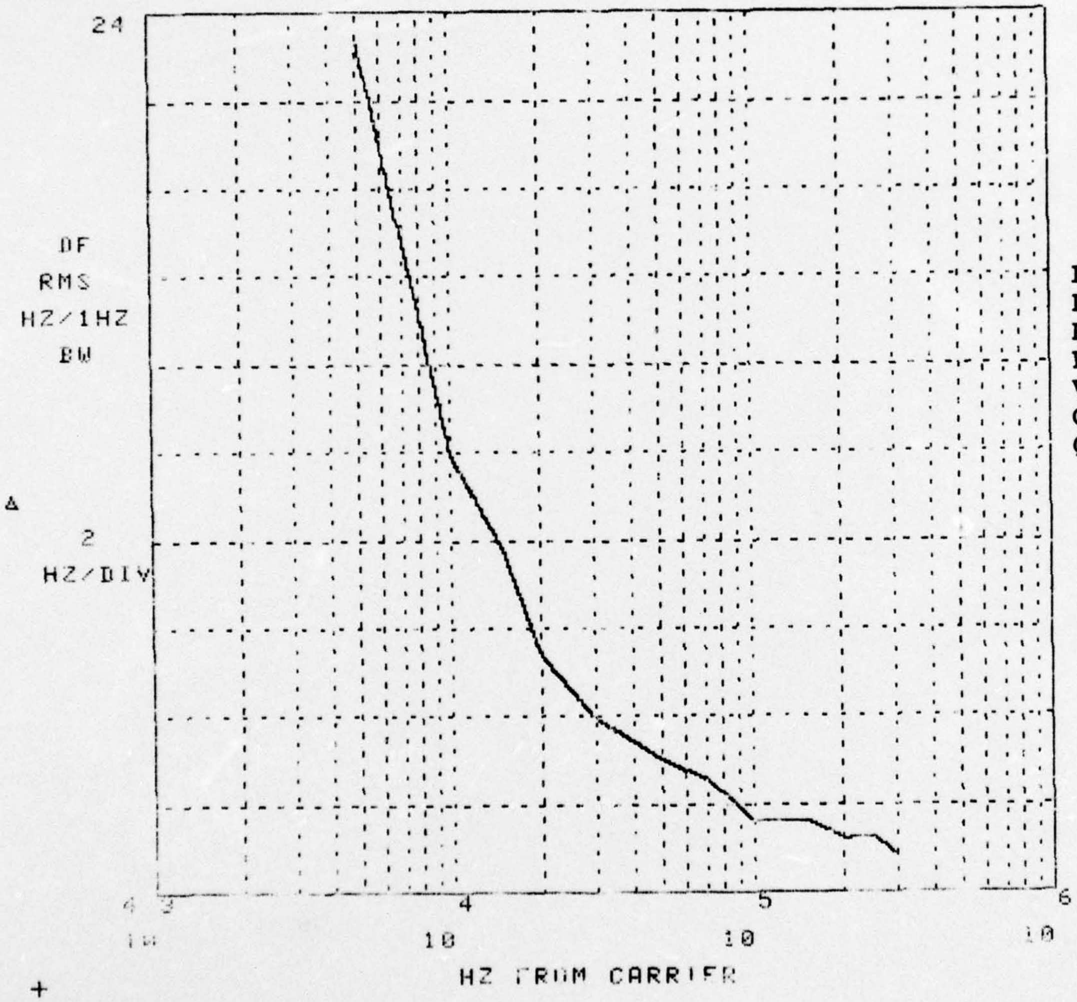


LOT: 81845-B
POWER: 2.5W
FREQ: 15810 MHz
EFF: 22%
VOLT: 34V
CURR: 330 mA
Q_{EXT}: 160

6/4/76

DIODE NO 4

FM NOISE
KU-BAND

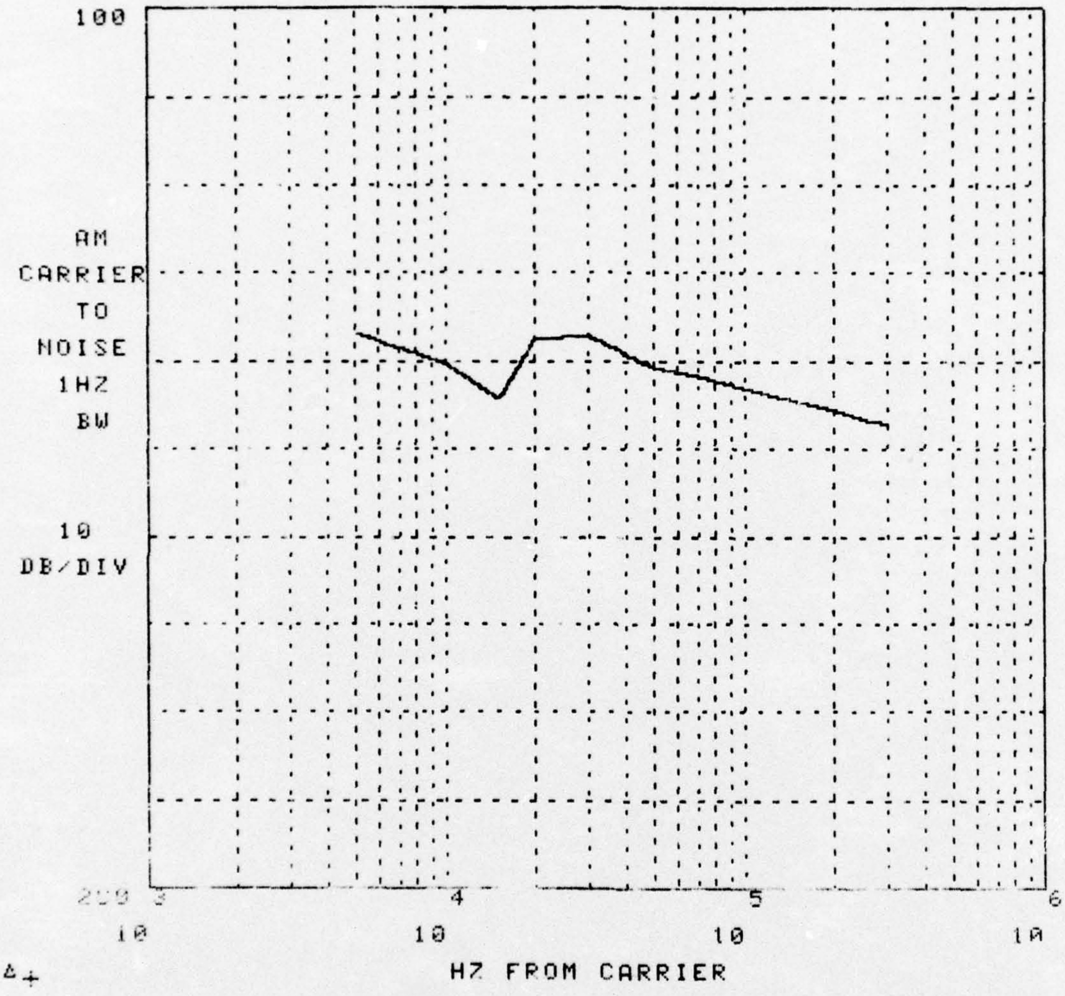


LOT: 81845-B
POWER: 2.5W
FREQ: 14850 MHz
EFF: 21%
VOLT: 35V
CURR: 340 mA
Q_{EXT}: 80

+

6/4/76 DIODE NO 4

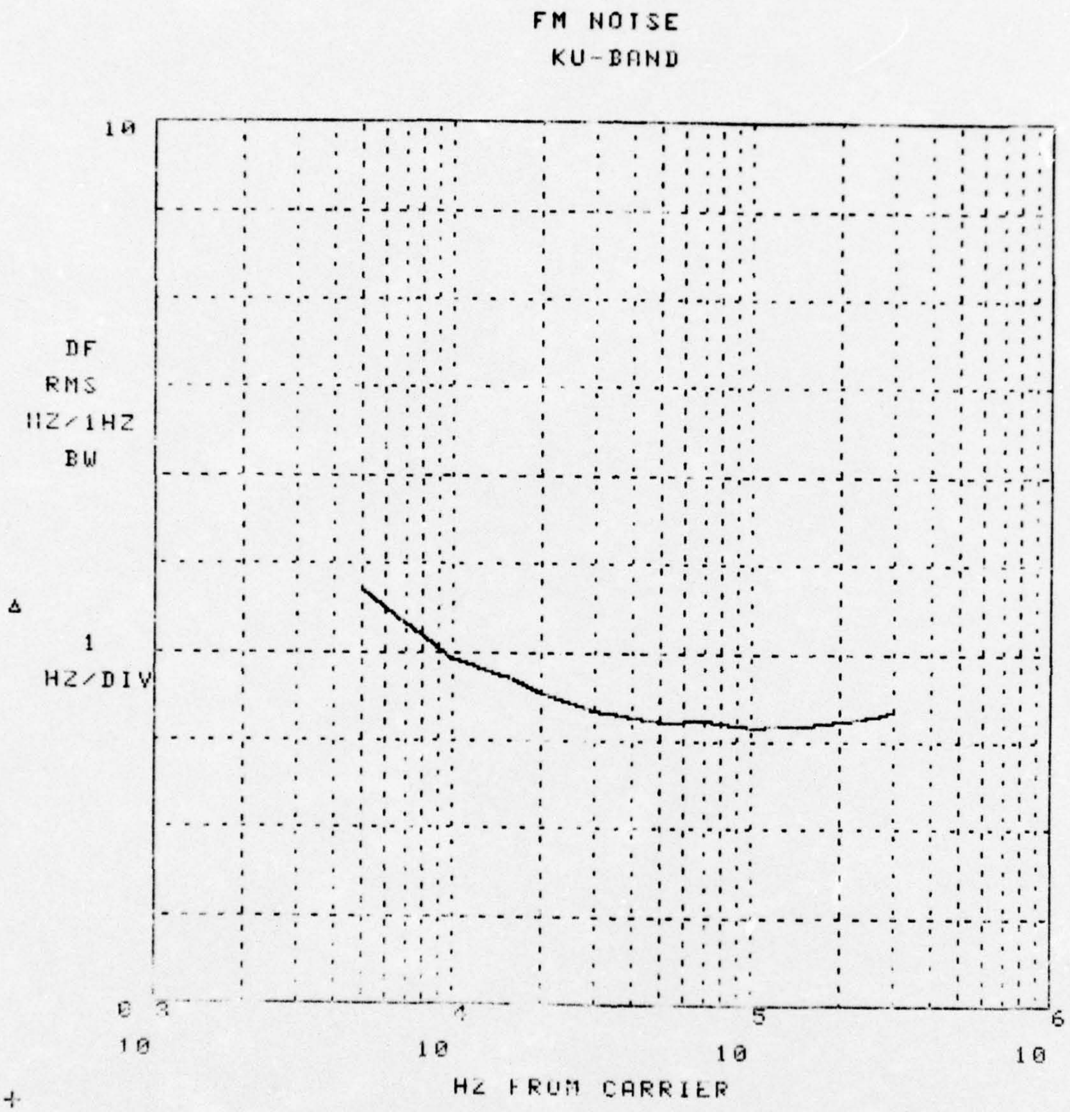
AM NOISE
KU-BAND



LOT: 81845-B
POWER: 2.5W
FREQ: 14580 MHz
EFF: 21%
VOLT: 35V
CURR: 340 mA
Q_{EXT}: 80

6/4/76

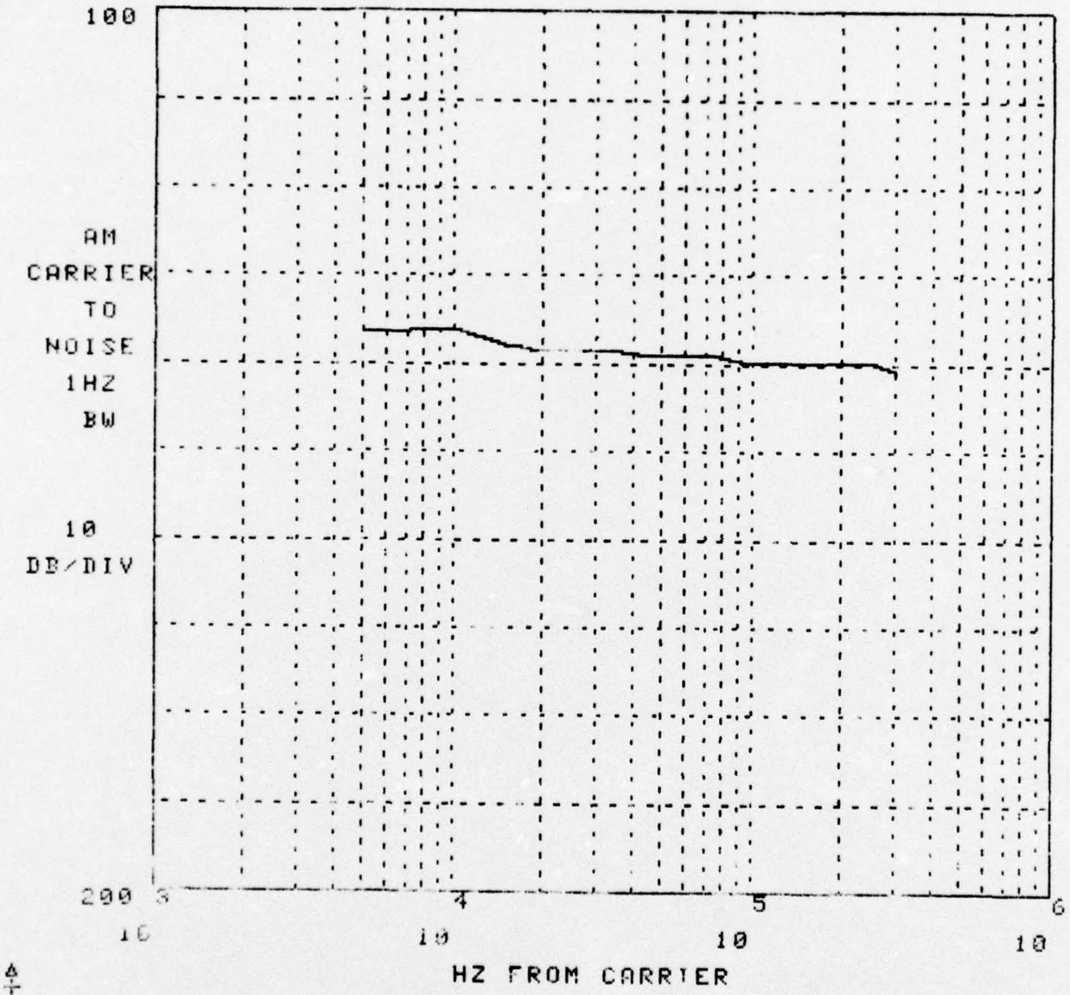
DIODE NO 5



LOT: 81845-B
POWER: 2.5W
FREQ: 15590 MHz
EFF: 22%
VOLT: 37V
CURR: 300 mA
Q_{EXT}: 93

6/4/76 DIODE NO 5

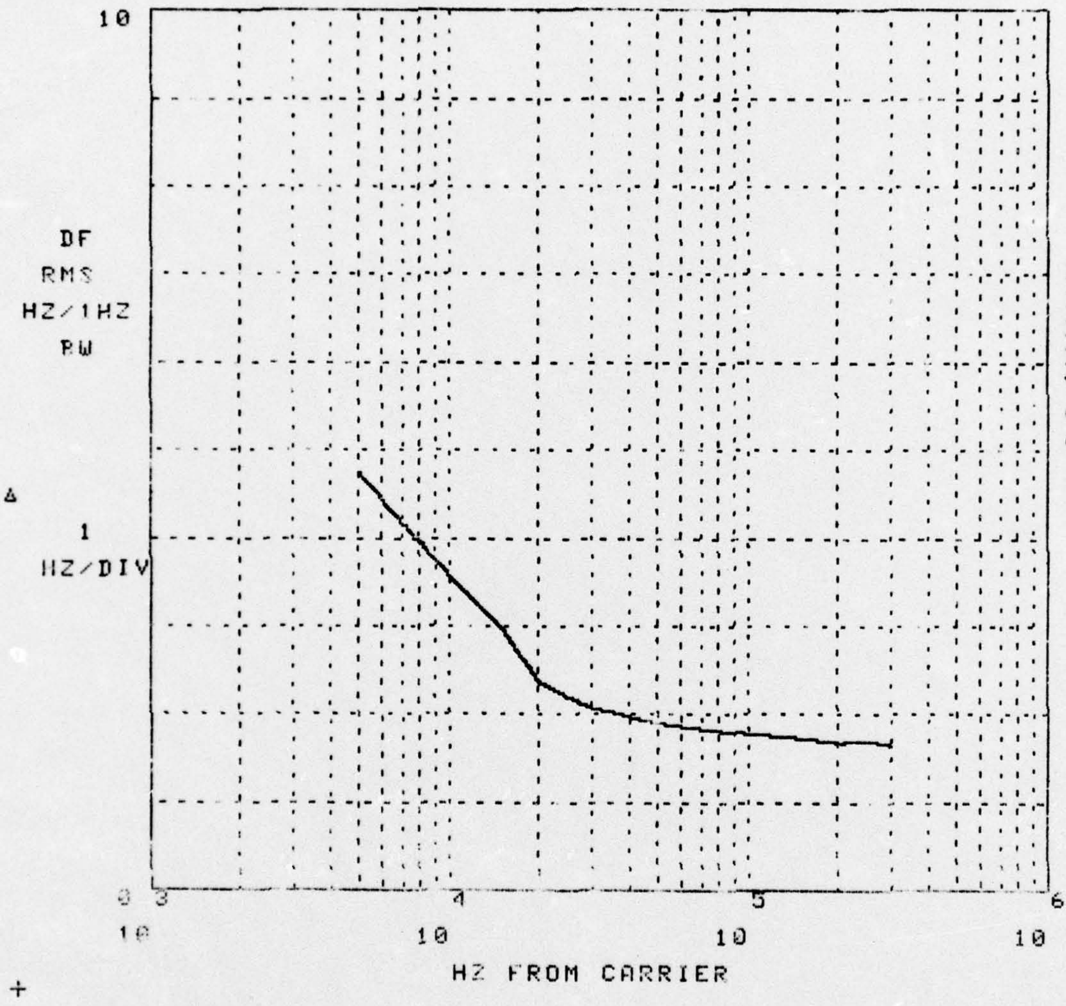
AM NOISE
KU-BAND



LOT: 81845-B
POWER: 2.5W
FREQ: 15590 MHZ
EFF: 22%
VOLT: 37V
CURR: 300 mA
Q_{EXT}: 93

6/4/76 DIODE NO 6

FM NOISE
KU-BAND

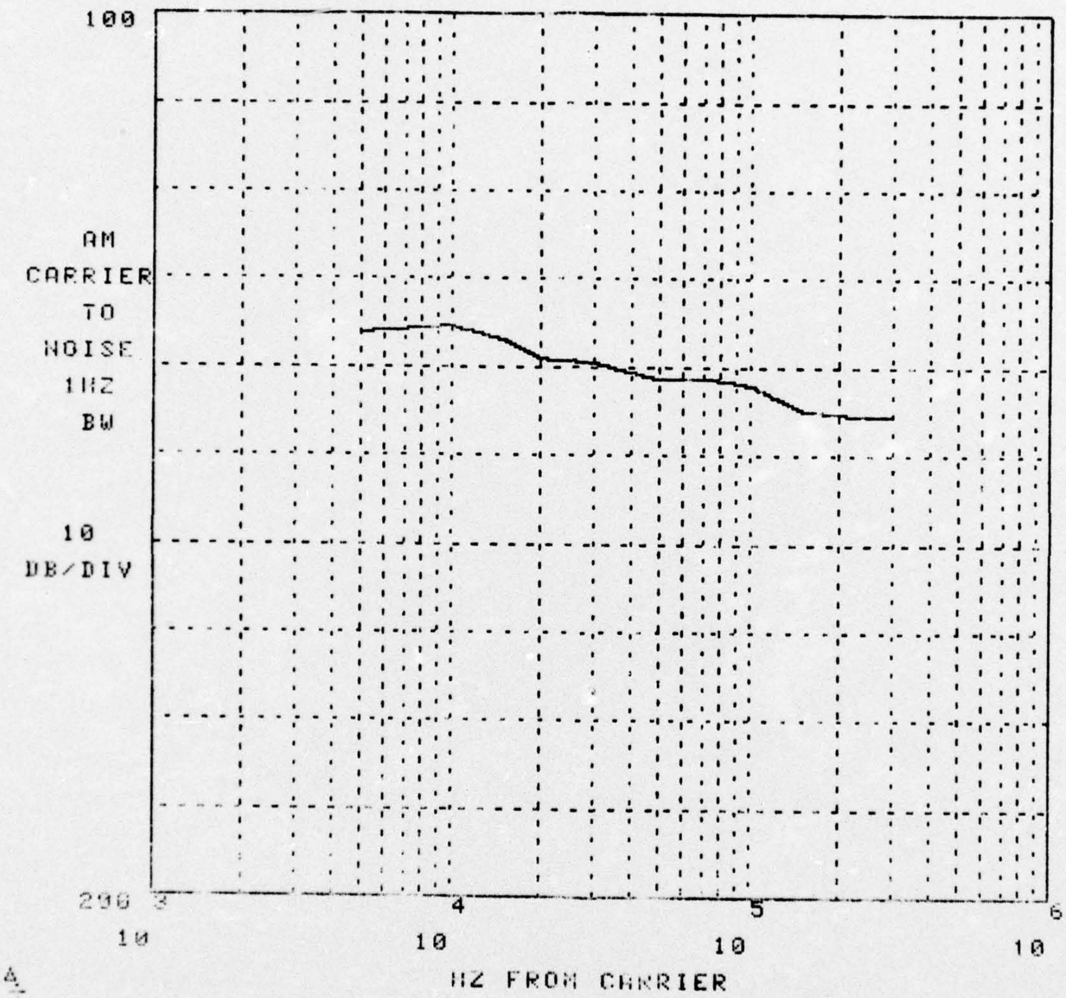


LOT: 81845-B
POWER: 2.5W
FREQ: 15990 MHz
EFF: 21%
VOLT: 39V
CURR: 300 mA
Q_{EXT}: 87

6/4/76

DIODE NO 6

AM NOISE
KU-BAND

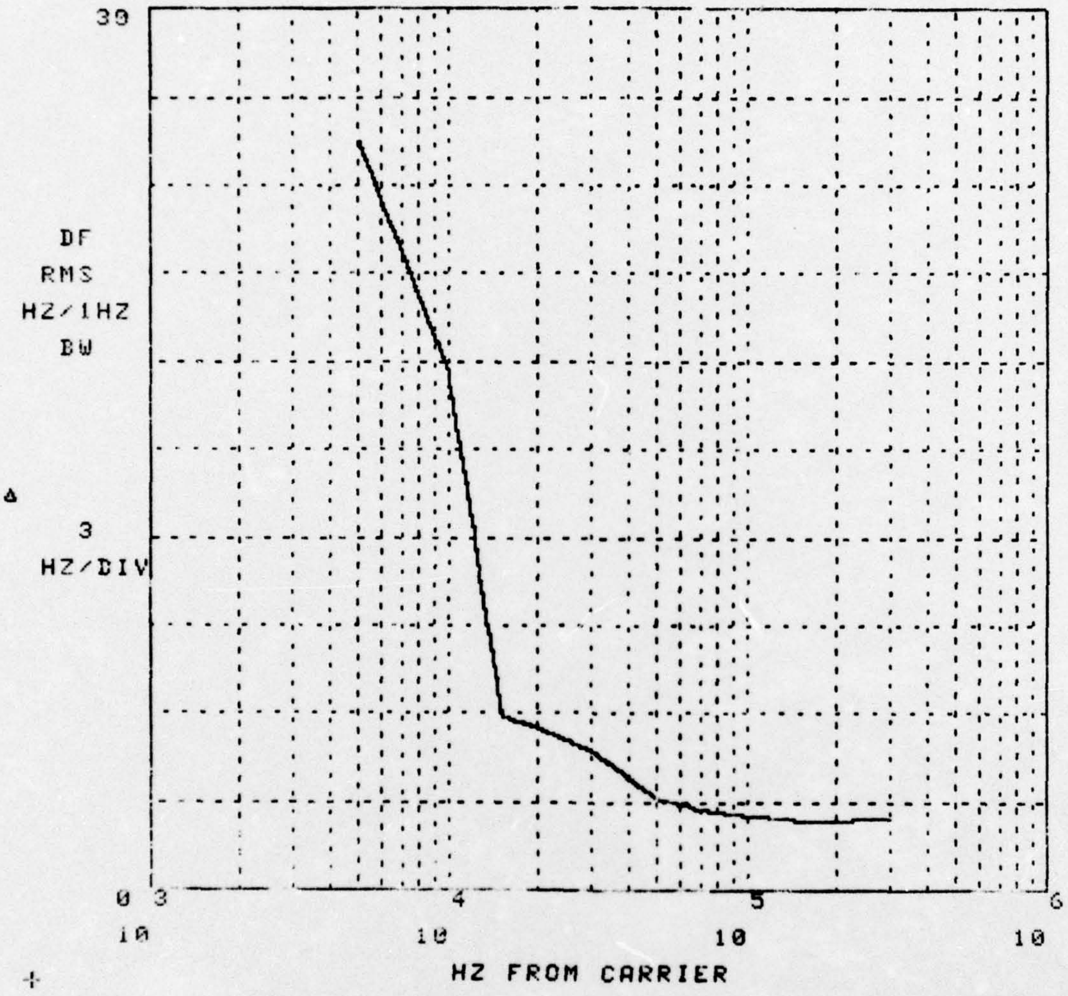


LOT: 81845-B
POWER: 2.5W
FREQ: 15990 MHz
EFF: 21%
VOLT: 39V
CURR: 300 mA
Q_{EXT}: 87

6/4/76

DIODE NO 7

FM NOISE
KU-BAND

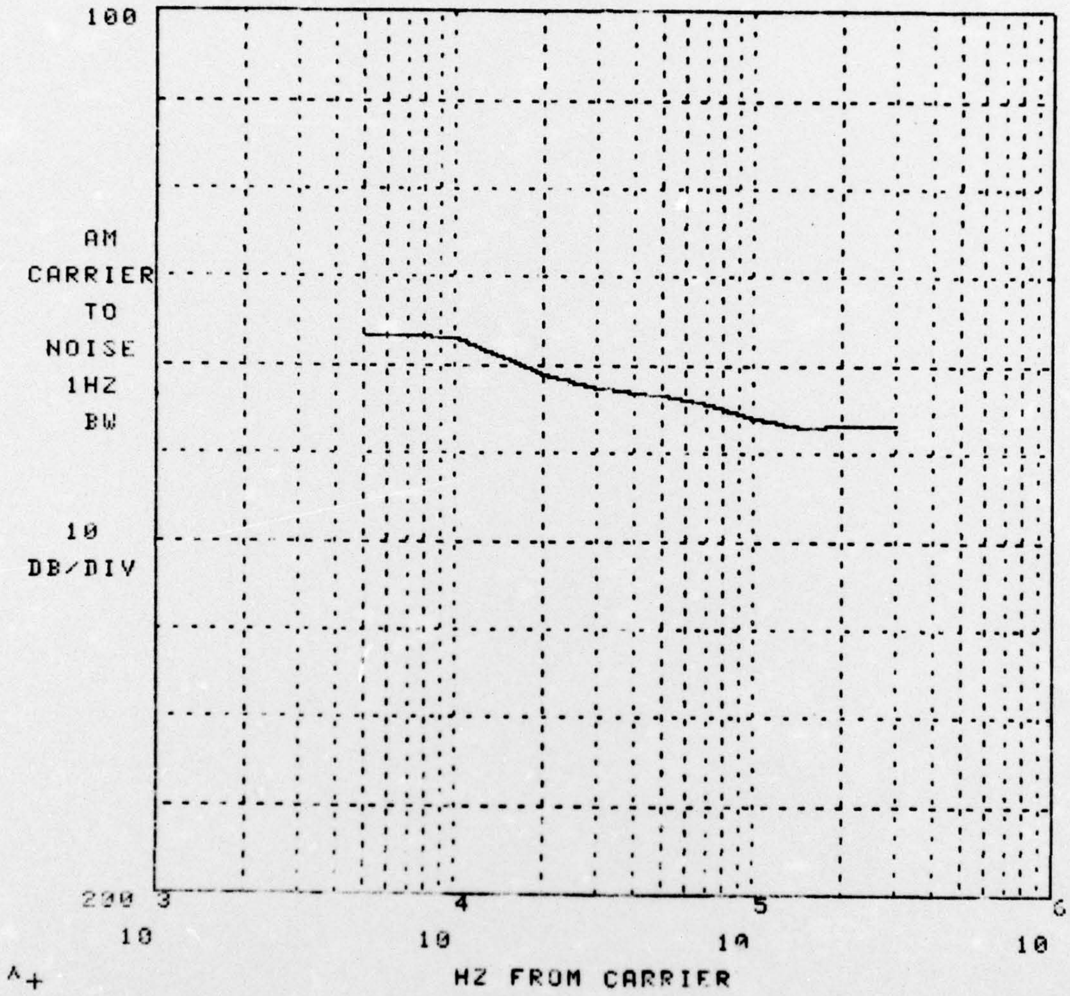


LOT: 81845-B
POWER: 2.5W
FREQ: 14240 MHz
EFF: 20%
VOLT: 35V
CURR: 350 mA
Q_{EXT}: 71

6/4/76

DIODE NO 7

AM NOISE
KU-BAND

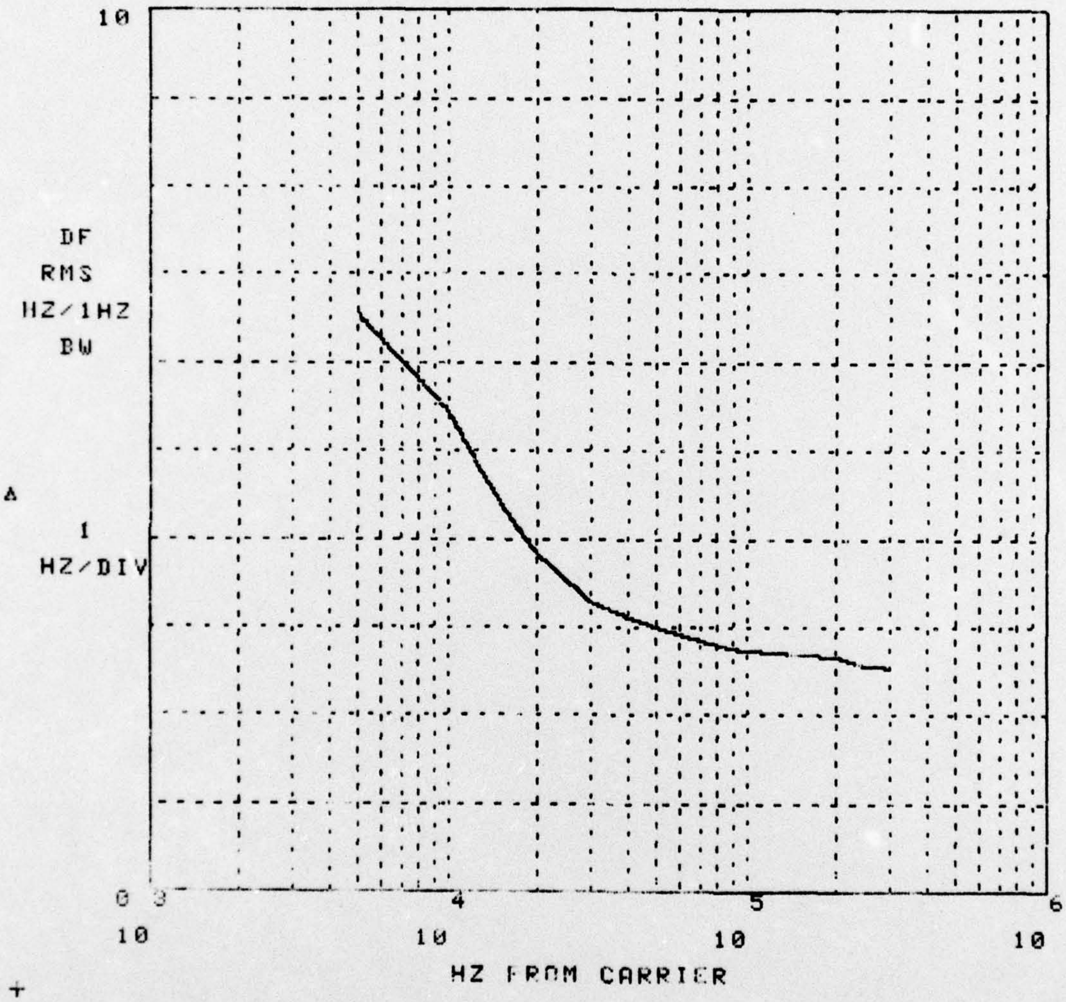


LOT: 81845-B
POWER: 2.5W
FREQ: 14240 MHz
EFF: 20%
VOLT: 35V
CURR: 350 mA
Q_{EXT}: 71

6/4/76

DIODE NO 8

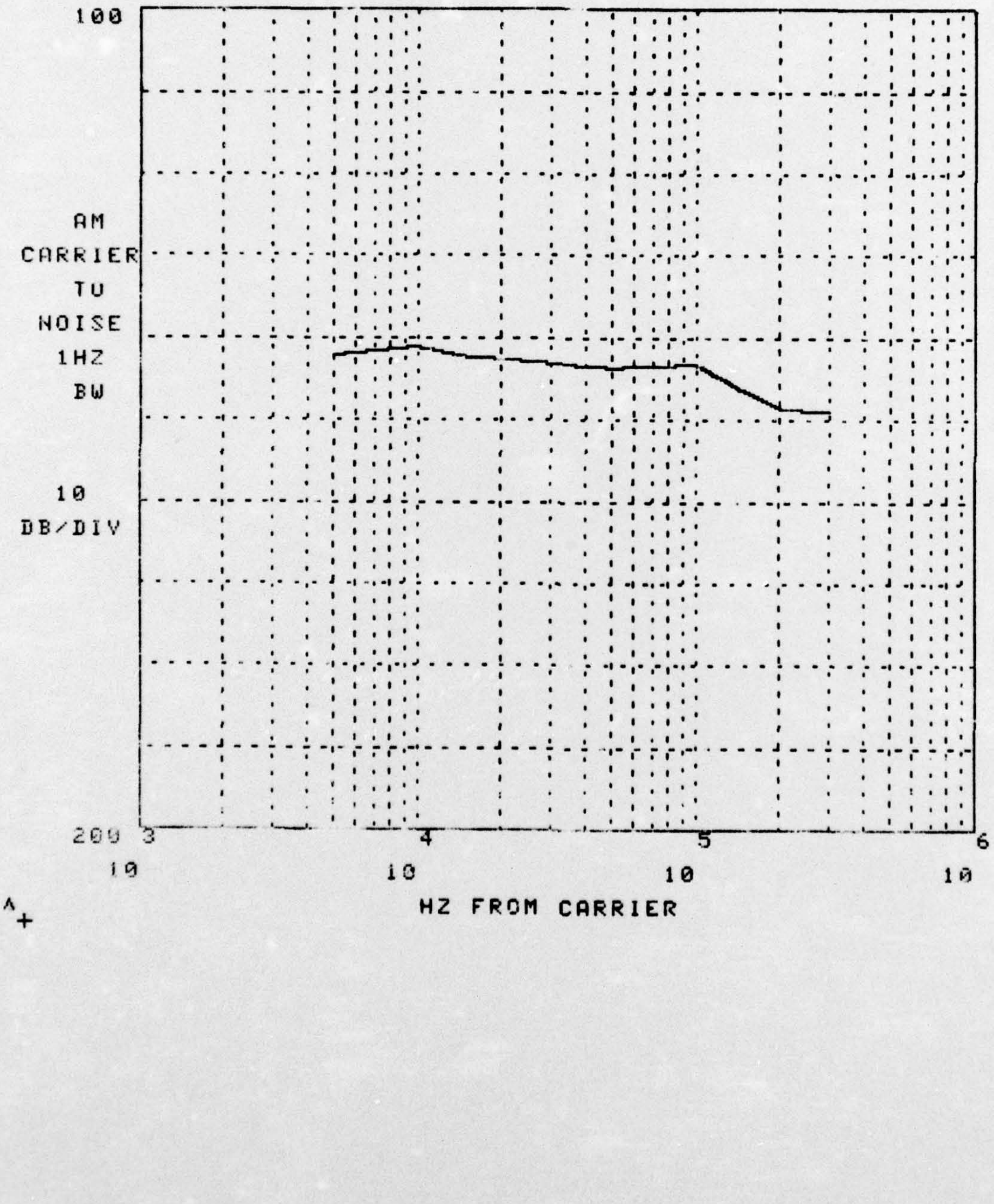
FM NOISE
KU-BAND



LOT: 81845-B
POWER: 2.5W
FREQ: 15985 MHz
EFF: 22%
VOLT: 36V
CURR: 310 mA
Q_{EXT}: 103

6/4/76 DIODE NO 8

AM NOISE
KU-BAND

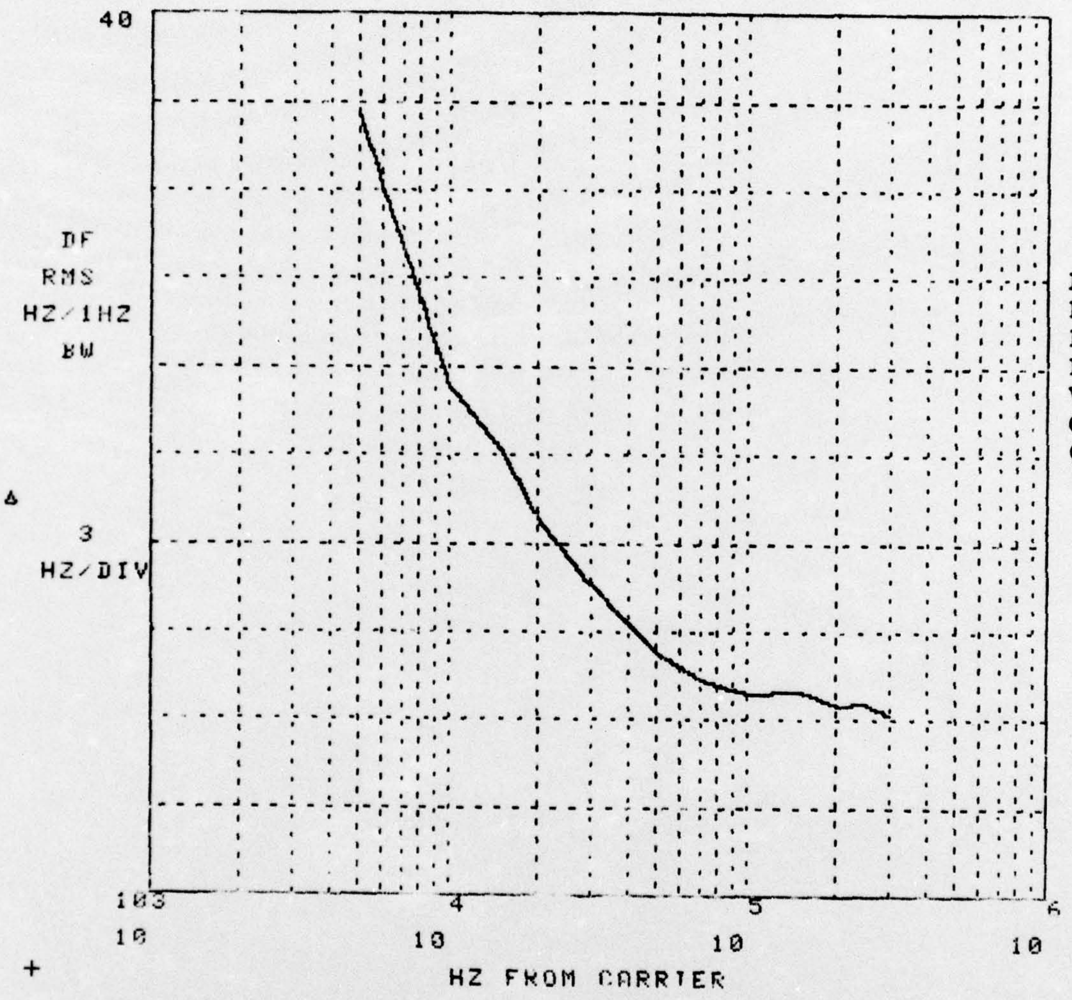


LOT: 81845-B
POWER: 2.5W
FREQ: 15985 MHz
EFF: 22%
VOLT: 36V
CURR: 310 mA
Q_{EXT}: 103

6/4/76

DIODE NO 9

FM NOISE
KU-BAND

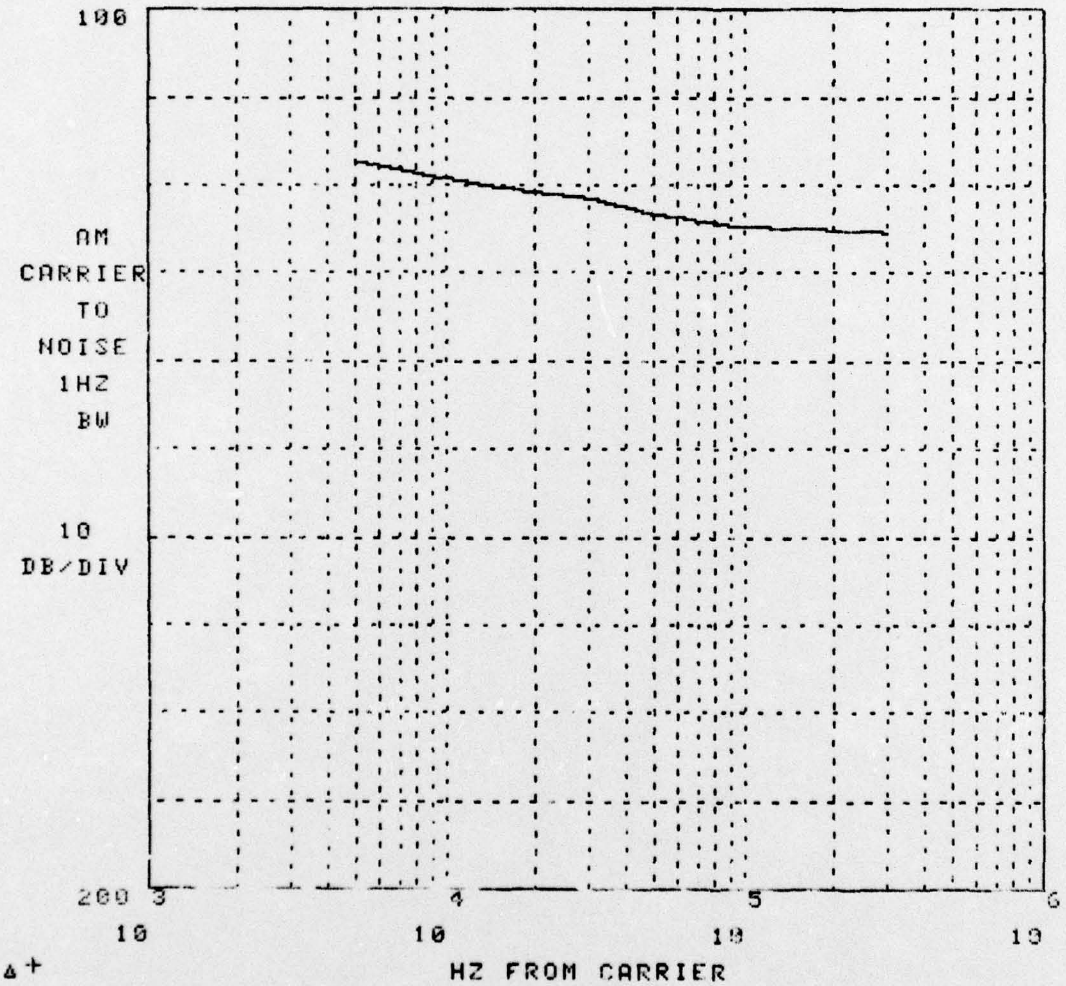


LOT: 81845-B
POWER: 2.5W
FREQ: 14765 MHz
EFF: 23%
VOLT: 36V
CURR: 300 mA
Q_{EXT}: 81

6/4/76

DIODE NO 9

AM NOISE
KU-BAND



LOT: 81845-B
POWER: 2.5W
FREQ: 14765 MHz
EFF: 23%
VOLT: 36V
CURR: 300 mA
Q_{EXT}: 81

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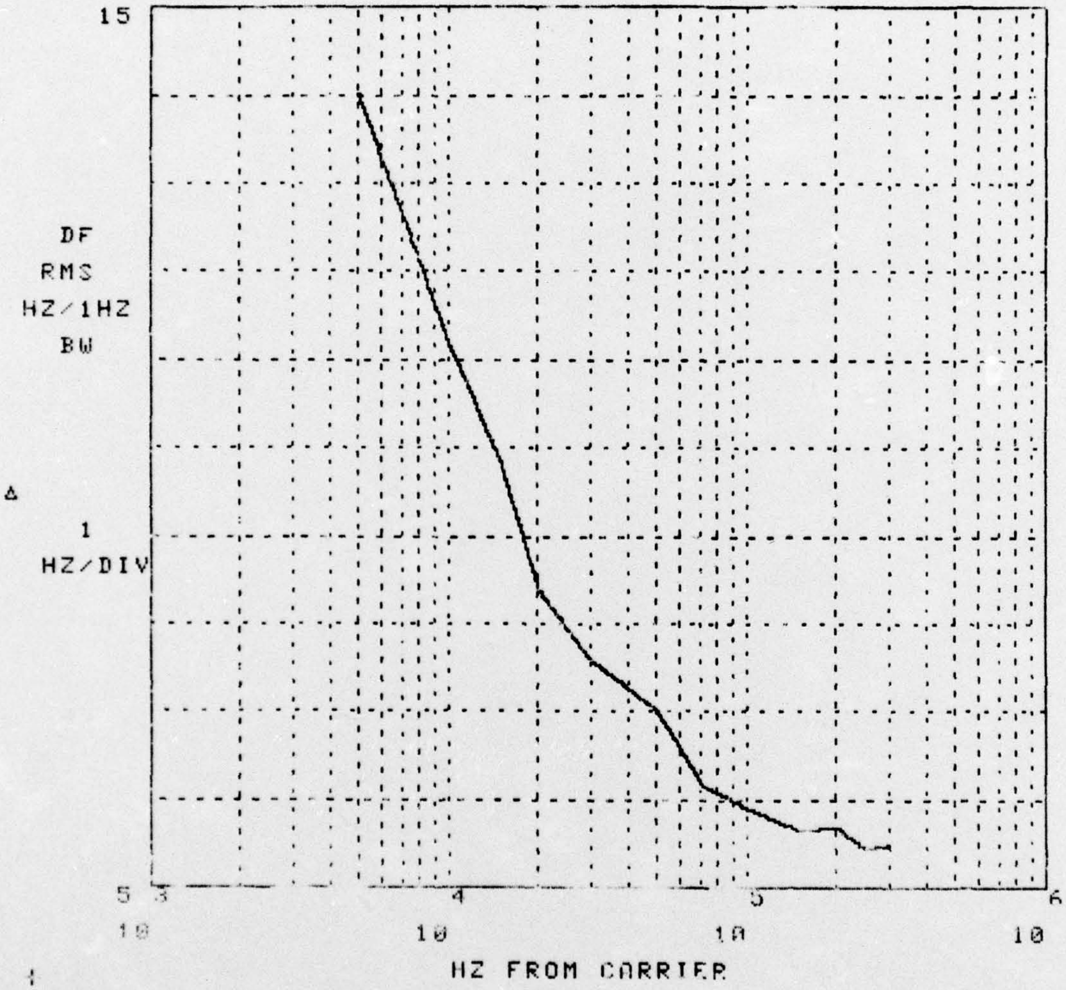
permit fully legible reproduction

6/4/76

DIODE NO 12

FM NOISE
KU-BAND

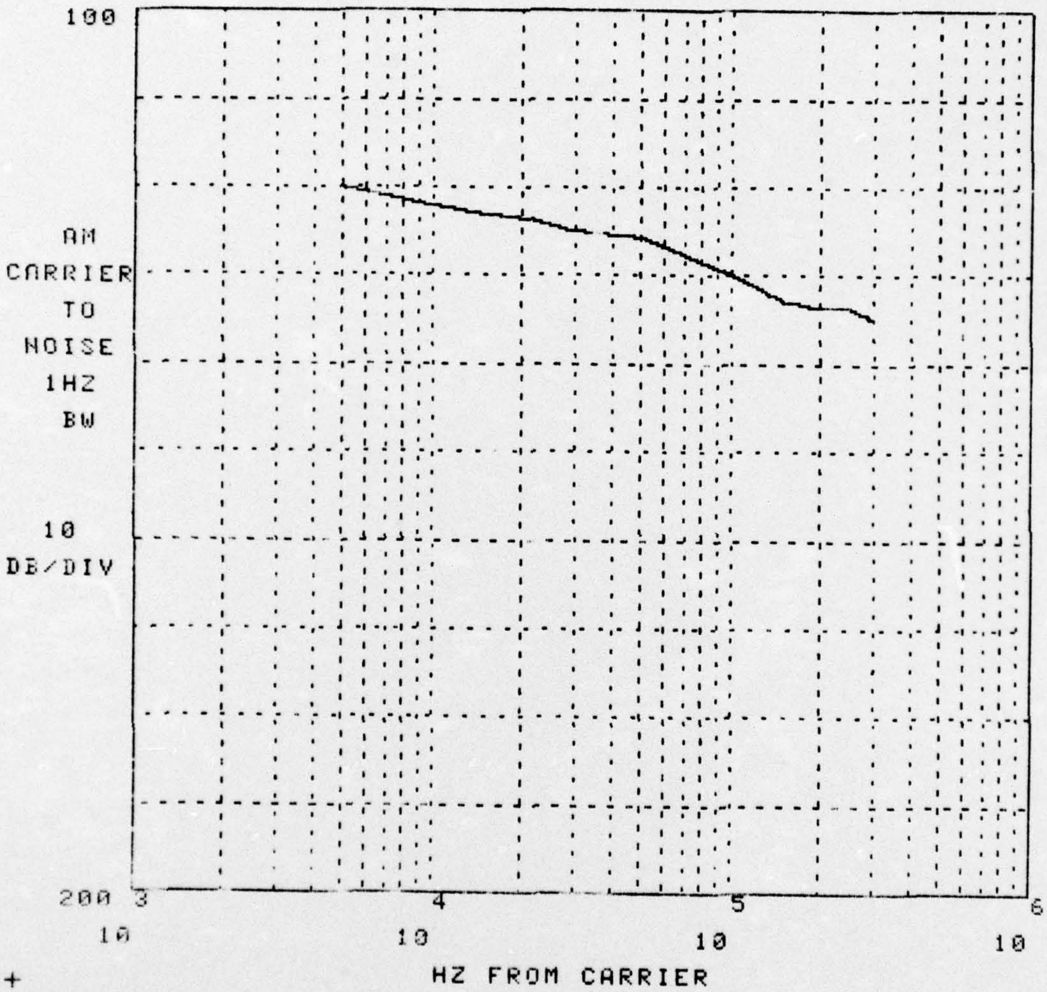


LOT: 81845-B
POWER: 2.5W
FREQ: 14310 MHz
EFF: 21%
VOLT: 34V
CURR: 350 mA
Q_{EXT}: 78

6/4/76

DIODE NO 12

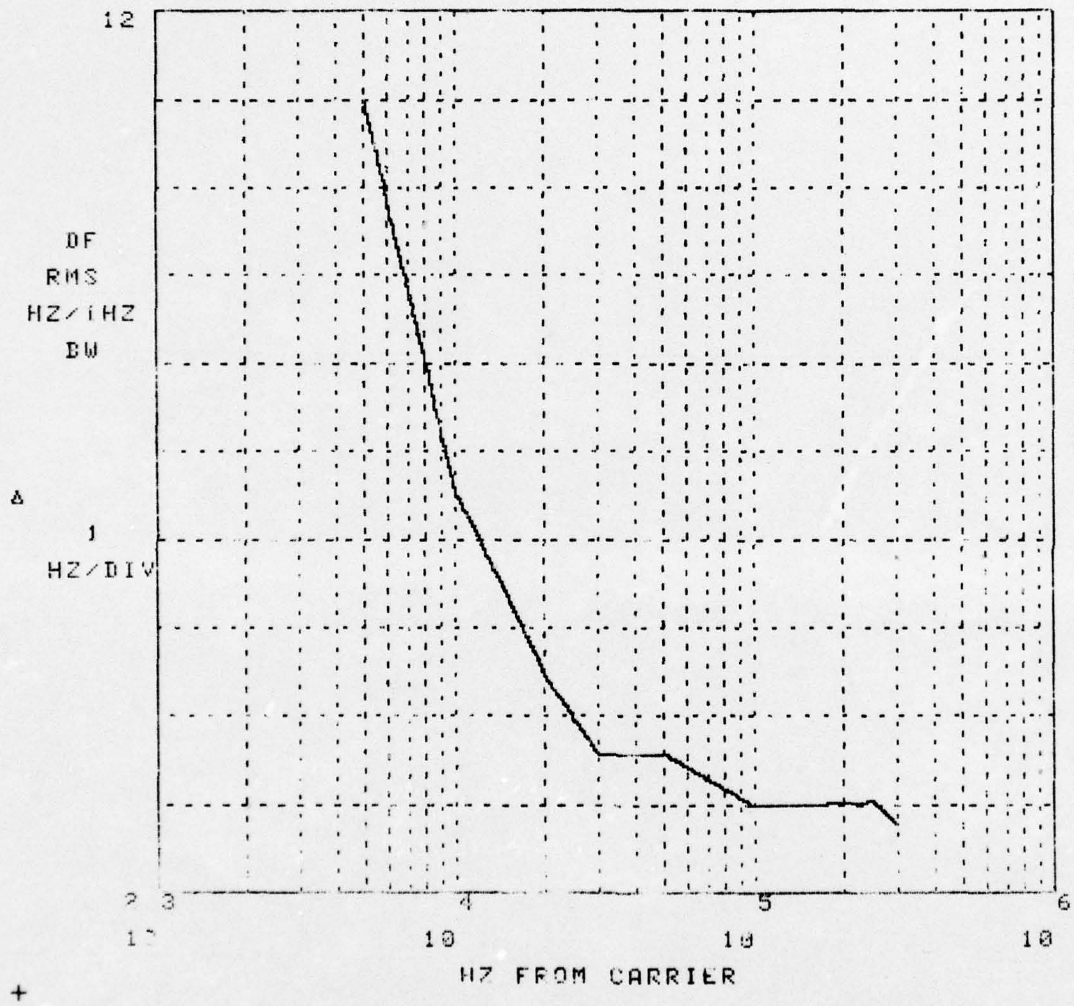
AM NOISE
KU-BAND



LOT: 81845-B
POWER: 2.5W
FREQ: 14310 MHz
EFF: 21%
VOLT: 34V
CURR: 350 mA
Q_{EXT}: 78

6/4/76 DIODE NO 13

FM NOISE
KU-BAND

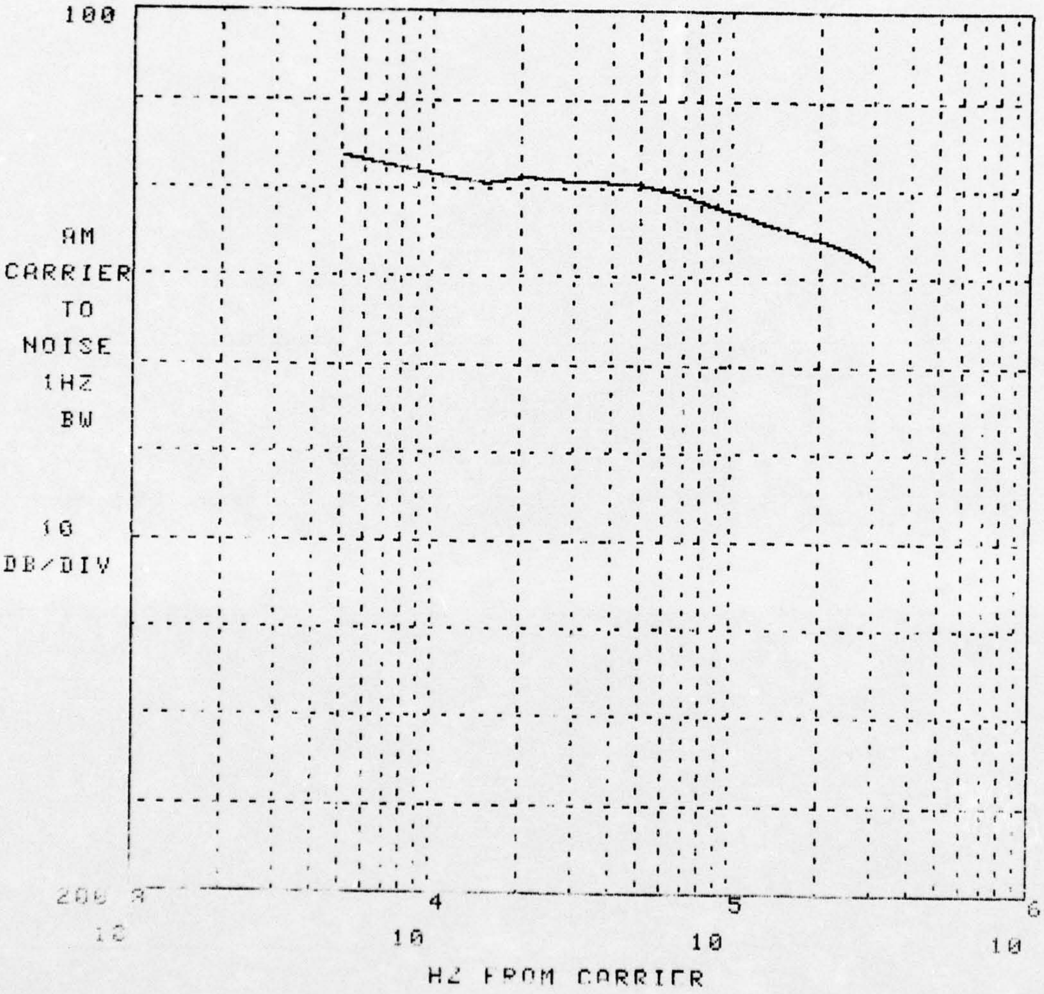


LOT: 81845-B
POWER: 2.5W
FREQ: 14595 MHz
EFF: 20%
VOLT: 35V
CURR: 350 mA
Q_{EXT}: 80

6/4/76

DIODE NO 13

AM NOISE
KU-BAND



LOT: 81845-B
POWER: 2.5W
FREQ: 14595 MHz
EFF: 20%
VOLT: 35V
CURR: 350 mA
Q_{EXT}: 80

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