MSS-D

MULTISPECTRAL SCANNER

FLIGHT MODEL (F-1)

RADIOMETRIC CALIBRATION AND ALIGNMENT HANDBOOK

DECEMBER 1981

Prepared for
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

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1. INTRODUCTION

This calibration handbook presents the basic data on the calibration of the MSS-D Flight Model (F-1). It provides both the relevant data and a summary description of how the data were obtained for the system radiometric calibration, system relative spectral response, and the filter response characteristics for all 24 channels of the four band MSS-D F-1 scanner.

System radiometric calibration discussed in Sections 2 and 3 involves the calibration test procedure and resulting test data required to establish the reference light levels of the MSS-D internal calibration system. This calibration test was performed several times during the course of MSS-D system test and evaluation. The history of these tests and the resulting data are given in Section 4. Section 5 then provides the final set of data ("nominal" calibration wedges for all 24 channels) for the internal calibration system.

The system relative spectral response measurements for all 24 channels of MSS-D F-1 are given in Section 6. These data are the spectral response of the complete scanner, which are the composite of the spectral responses of the scan mirror primary and secondary telescope mirrors, fiber optics, optical filters, and detectors.

Section 7 provides unit level test data on the measurements of the individual channel optical transmission filters. Measured performance is compared to specification values.

The detailed procedures and extensive additional supporting data are being provided separately. Further discussions of system test performance evaluation will be provided in the MSS-D Final Report.

2. INTEGRATING SPHERE CALIBRATION

The GSFC 30 inch integrating sphere is the primary standard for the radiometric calibration of the MSS-D. The objective of the MSS-D radiometric calibration using this sphere is to establish the reference light levels of the MSS-D internal calibration system (called cal wedge nominals) for all of the channels in the four bands.

This calibrated scanner is used as a transfer standard to calibrate the test collimator for corrected signal level and signal-to-noise ratio performance estimation during system acceptance testing.

The calibration of the integrating sphere utilizing the Kepco power supply was accomplished at GSFC by means of a grating spectroradiometer to compare the output from the sphere with that of a standard of spectral irradiance (Reference HS 248-6527). The results of that calibration, performed in October 1980, are presented in Table I-2-1. The table lists the spectral radiant emittance, W_λ (in mW per cm^2 per μm), for the 30 inch spherical integrator as a function of wavelength λ (in μm). Table I-2-2 gives the ratio of the sphere's radiant emittance when operated with "N" lamps, $W_\lambda(N)$ to that measurement when operated with 12 lamps, $W_\lambda(12)$. Since only one table was provided by GSFC for all bands, it is assumed that this ratio is independent of wavelength.

This is the basic information together with the integrating sphere data log listing operating currents provided to Hughes Aircraft Company for subsequent calibration of the MSS-D scanner.

In order to express these data in a form more useful for MSS-D system calibration and testing, the spectral radiant emittance, W_λ, must be converted to radiance, N. To do so requires two assumptions:

1) The sphere aperture is a Lambertian source; i.e., its radiant intensity varies as the cosine of the angle from the normal to the aperture.

2) The value of the radiant spectral emittance, W_λ, given is the total power per unit area per unit wavelength interval radiated into the forward hemisphere as is conventional.

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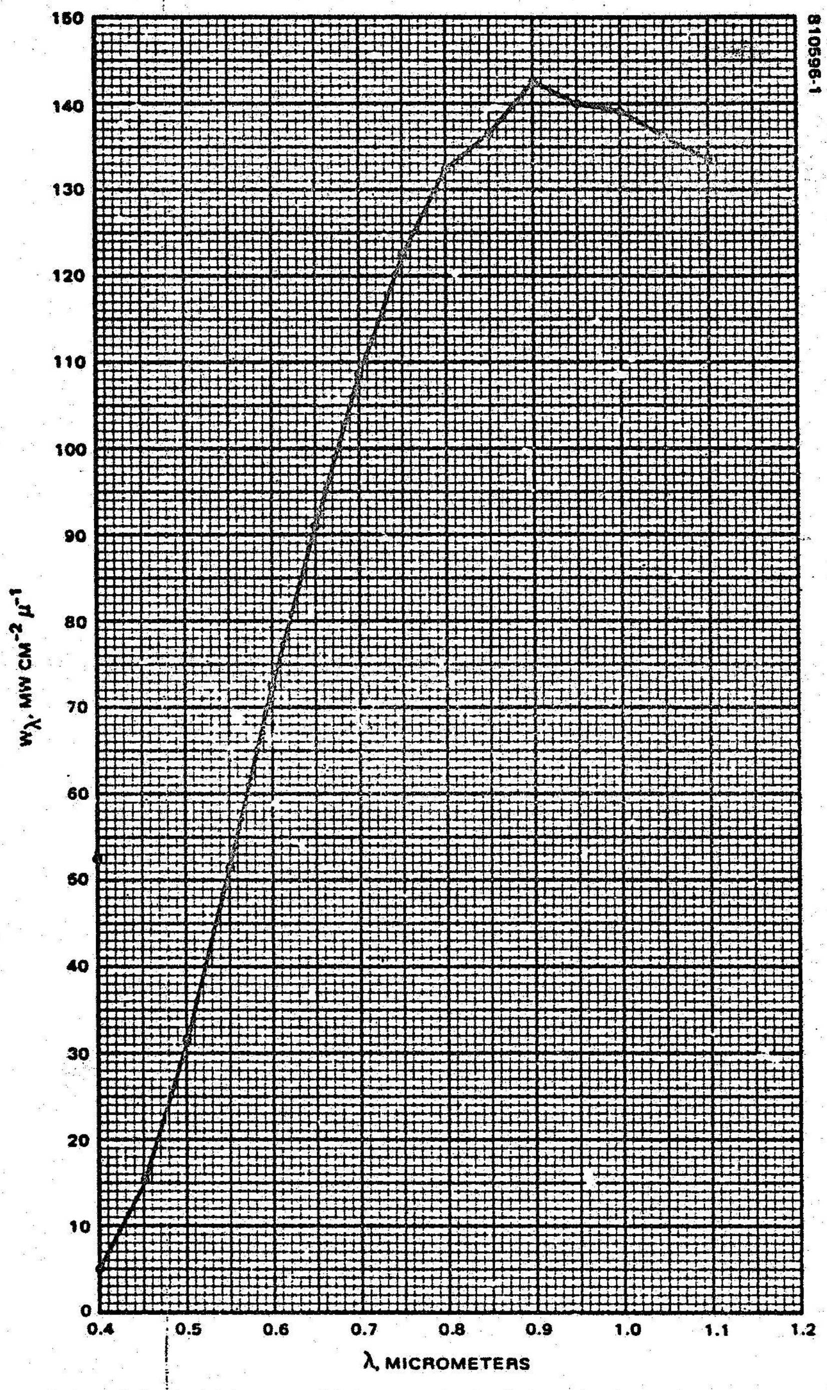

FIGURE I-2-1. 30 INCH INTEGRATING SPHERE SPECTRAL RADIANT EMMITTANCE – OCT. 1980 (KEPCO POWER SUPPLY)

TABLE I-2-1. 30 INCH SPHERICAL INTEGRATOR SPECTRAL RADIANT EMITTANCE (λ IN MICROMETERS; W_λ IN MILLIWATTS $CM^{-2}\mu^{-1}$)

λ	W_λ	λ	W_λ
0.40	5.23	1.2	119.8
0.45	15.64	1.3	107.4
0.50	31.41	1.4	79.47
0.55	51.45	1.5	69.87
0.60	72.31	1.6	62.46
0.65	90.85	1.7	53.25
0.70	108.7	1.8	42.71
0.75	122.8	1.9	28.80
0.80	132.5	2.0	24.27
0.85	136.7		
0.90	142.2		
0.95	140.0		
1.0	139.5		
1.05	136.3		
1.1	133.8		

TABLE I-2-2. N LAMP TO 12 LAMP RATIO OF INTENSITY IN SPHERICAL INTEGRATOR

Number of Lamps	$W_\lambda(N)/W_\lambda(12)$
12	1.000
11	0.912
10	0.827
9	0.734
8	0.651
7	0.566
6	0.487
5	0.406
4	0.330
3	0.251
2	0.171
1	0.0939

Then for the case of a Lambertian radiator the spectral radiance is related to the radiant spectral emittance by the following:

$$W_\lambda = \pi N_\lambda$$

Note that even though the total power is radiated into the forward hemisphere, or 2π steradians, the relationship is as given and $W_\lambda \neq 2\pi N_\lambda$..

Therefore,

$$N = \frac{1}{\pi} \int_{\substack{\text{spectral} \\ \text{band}}} W_\lambda d\lambda$$

The radiance of each spectral band is obtained by summing the radiant spectral emittance over the respective wavelength interval. The data provided in Table I-2-1 is plotted in Figure I-2-1. In this figure the plotted points have been connected by straight line segments. The integration was performed by merely summing the area bounded by these line segments. From the figure it would appear that any error involved in not fitting a smoothly varying function through the points should be quite small.

TABLE I-2-3. RELATIONSHIP OF NUMBER OF LAMPS TO SPHERE RADIANCE

RADIANCE N OF 30 INCH INTEGRATING SPHERE FOR MSS-D

Sphere Lamps	N Band 1			N Band 2			N Band 3			N Band 4		
	Radiance*	Volts	Level	Radiance*	Volts	Level	Radiance*	Volts	Level	Radiance*	Volts	Level
12	1.644	2.652	42	2.886	5.772	63	3.874	8.805	63	13.176	11.457	63
11	1.499	2.418	38	2.632	5.264	63	3.533	8.030	63	12.017	10.450	63
10	1.360	2.194	35	2.387	4.774	63	3.204	7.282	63	10.897	9.476	63
9	1.207	1.947	31	2.118	4.236	63	2.844	6.464	63	9.671	8.410	63
8	1.070	1.726	27	1.879	3.758	60	2.522	5.732	63	8.578	7.459	63
7	0.931	1.502	24	1.633	3.266	52	2.193	4.984	63	7.458	6.485	63
6	0.801	1.292	20	1.405	2.81	44	1.887	4.289	63	6.417	5.580	63
5	0.667	1.076	17	1.172	2.344	37	1.573	3.575	57	5.349	4.651	63
4	0.543	0.876	14	0.952	1.904	30	1.278	2.905	46	4.348	3.781	60
3	0.413	0.666	10	0.724	1.448	23	0.972	2.209	35	3.307	2.876	46
2	0.281	0.453	7	0.494	0.988	15	0.662	1.505	24	2.253	1.959	31
1	0.154	0.248	3	0.271	0.542	8	0.364	0.827	13	1.237	1.076	17

Bright Scene Radiance* 16 376	N		N		N		N	
	Radiance*	Volts	Radiance*	Volts	Radiance*	Volts	Radiance*	Volts
	2.48	4.0	2.00	4.0	1.76	4.0	4.60	4.0

*Radiance in mW cm^{-2} $ster^{-1}$

Band Wavelengths - 16376 p 3.1.1.1
Band 1 (0.5 to 0.6 μM)
Band 2 (0.6 to 0.7 μM)
Band 3 (0.7 to 0.8 μM)
Band 4 (0.8 to 1.1 μM)

October 1980 Calibration
Reference: HS 248-6527

Using these computed values for the radiance, intensity levels for the various lamp ratios from Table I-2-2, and the specification values for the maximum bright scene radiance, voltage range (0 to 4 volts) and quantization (0 to 63 QL intervals) (*SBRC 16376 - para 3.1.1.13 and para 3.1.1.7.1), Table I-2-3 was generated. This table is the fundamental table used in the MSS-D scanner radiometric calibration discussed in the next section.

Radiance values for all bands were scaled by the same factors to take into account the number of lamps being used out of a total of 12. Note that, in general, one might expect to need a different set of ratios for each band.

Quantization levels were calculated either by multiplying the analog signal by 16 and deleting digits to the right of the decimal or by rounding to 63 (binary 111111). In each case the smaller of the two values obtained in this way was entered in the table.

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*SBRC 16376; Development Specification for Multispectral Scanner Unit.

3. MSS-D SYSTEM RADIOMETRIC CALIBRATION

The integrating sphere used for the MSS-D F-1 radiometric calibration was the sphere formerly used with the Costal Zone Color Scanner (CZCS), and utilized a Kepco (dc) power supply. This supply is voltage regulated rather than current regulated as was the EGG (ac) power supply used with the MSS-D protoflight. Since lamp current stability is essential for stable radiance output, a procedure was developed to ensure careful, regular monitoring of lamp currents during radiometric calibration.

The MSS-D System Radiometric Calibration Test Procedure (3617000-623 Rev A, SCN No. 1, July 1981)* provides a detailed description of the operations required to collect the data necessary for internal calibration system evaluation. The specific objective of these tests are to collect and process data to determine the following:

1) Reference calibration wedge characteristics of the MSS-D scanner for both the low and high gain modes.

2) Stability of these nominal wedges throughout the course of testing, to ensure the suitability of the internal calibration system as a reference source for gain and offset estimation for picture correction.

These tests (calibrations using the integrating sphere) were conducted at key points during the MSS-D system test program to detect any potential calibration changes due to environmental exposure.

3.1 RADIOMETRIC CALIBRATION TEST CONFIGURATION

The tests were performed with the MSS-D scanner installed on the scanner alignment fixture (angle plate) as illustrated in Figure I-3-1. The integrating sphere was positioned approximately 8 feet from the scanner and the optical axis of the scanner aligned with the center of the sphere exit port, or aperture, as described in the Integration Sphere (Kepco) Operation and Alignment Procedure (SBRC 17008). During the integrating sphere tests, the field-of-view of the scanner was protected from stray light with an opaque plastic

*SCN No. 1 to Rev. A, written 22 July 1981, incorporates the procedure for use of the integrating sphere with the Kepco power supply.

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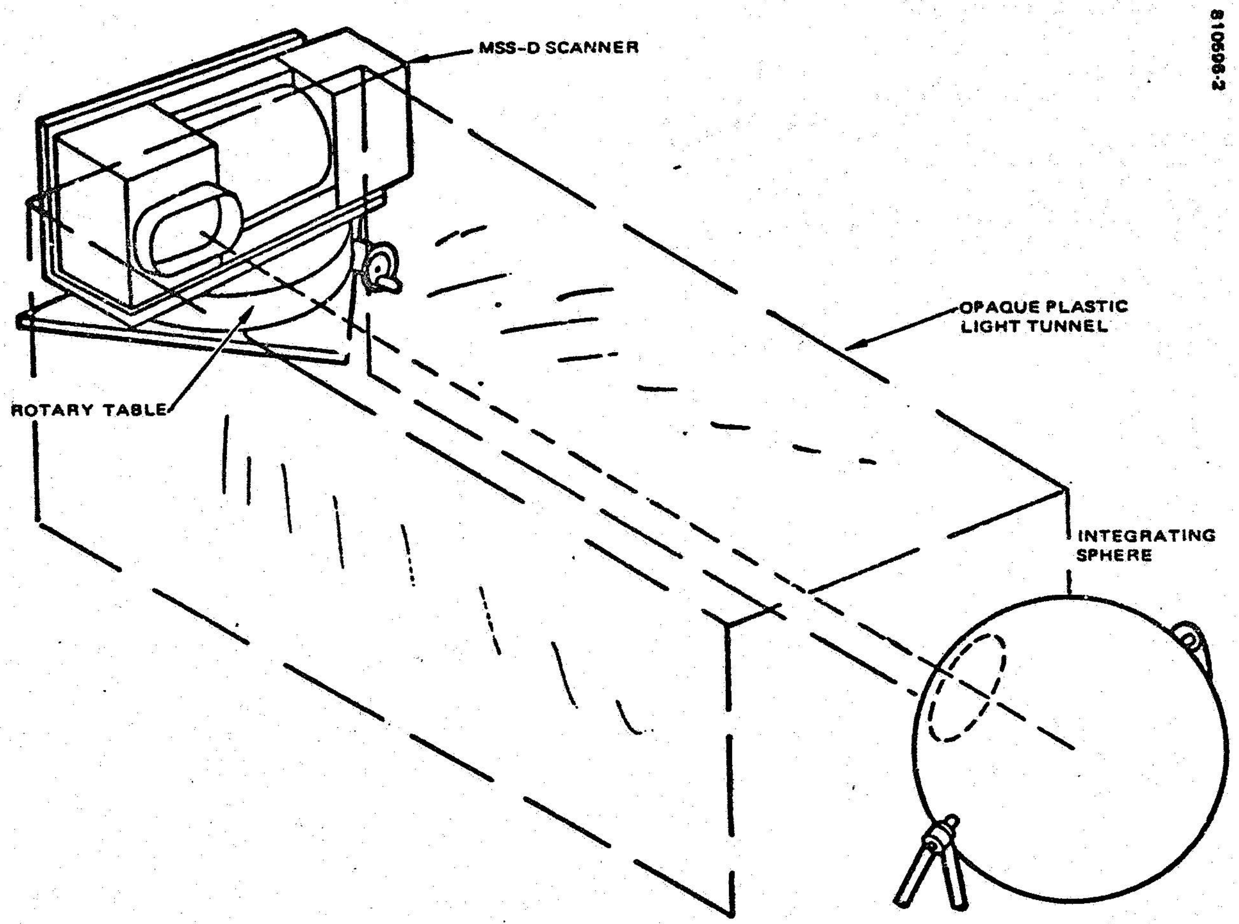

FIGURE I-3-1. RADIOMETRIC CALIBRATION TEST SETUP tunnel, as illustrated. To reduce ambient light interference in the area of the scanner as many room lights as feasible were turned off.

Each MSS system radiometric calibration test was conducted in three parts:

1) Alignment Check: during this operation the optical alignment of the integrating sphere with respect to the scanner was checked. No radiometric test data was taken.

2) Conditioning Orbit: this orbit was used to condition the PMTs at a fixed radiance level. The only test data taken during this orbit was a tape recording of the entire orbit for possible engineering study of PMT characteristics.

3) Data Collection Orbits: these are standard orbits to collect data that is subsequently used to determine reference gains, offsets, and calibration wedge characteristics for both low and high gain modes.

3.2 RADIOMETRIC CALIBRATION DATA REDUCTION

Test procedure 3617000-623 Rev. A, SCN No. 1, describes the test setup and the steps required to obtain the necessary raw calibration data. These data are reduced by the data reduction system (DRS) in a three step process outlined below (Reference H5248-0953, -0939, -0975).

As described earlier, during a radiometric calibration the integrating sphere is set up so that it may be viewed by the scanner. The input data consists of observations of the scanner response to the integrating sphere operating at a particular (calibrated) radiance, and the near simultaneous response of the scanner to its own internal calibration system. These observations are repeated using a variety of integrating sphere radiances. The basic approach of the transfer of calibration procedure is to use the scanner response to the integrating sphere (over all integrating sphere radiances for which data were collected) to determine the scanner gain and offset, which are then in turn used to calculate radiances equivalent to the observed response of the scanner to its internal calibration system. This is complicated by the fact that the scanner gain and offset are allowed to vary, or drift, from one observation of the integrating sphere to the next.

When the scanner gain and offset are allowed to drift, it is not possible to obtain an analytic expression for the gain and offset, and thus also for the internal calibration radiances. This occurs because for each particular gain and offset combination there is only a single integration sphere radiance from which they may be derived. The internal calibration radiances which result from the analysis do not drift in time, however, and this fact can be used to devise an iterative solution to the problem which does converge to the correct internal calibration system radiances (as well as the correct scanner gain and offset at each integrating sphere radiance).

The procedure is initialized by estimating the scanner gains and offsets based on the assumption that they do not drift. These are then used to estimate the internal calibration radiances. A test is then made for convergence using the rms deviation of the observed scanner signal levels from those predicted using the current estimates of the scanner gain and offset, the internal calibration radiances, and also the rms deviation between the present and previous estimates of scanner gain and offset and internal calibration radiances. If the convergence criteria are not satisfied, then the next iteration is begun by using the current estimate of the internal calibration radiances to produce new estimates of the scanner gain and offset at each observation of the integrating sphere (using both internal and external calibration data). The internal calibration radiances are then re-estimated using these revised scanner gains and offsets, and the test for convergence is repeated. This process continues until either it converges or a maximum number of iterations is exceeded.

The above procedure results in:

120 = (6 channels)(20 internal calibration words/channel)

distinct (i.e., independent) radiances for each of the four scanner bands.

3.3 RADIOMETRIC CALIBRATION DATA COLLECTION

Data collection for radiometric calibration of the MSS-D involves precise location of the leading edge of the calibration wedges and the collection of signal amplitude values at 20 words located accurately with respect to that leading edge. Moreover, this must be done repeatably in order to compare radiance values at each of the wedge words in the course of subsequent calibrations.

The step-by-step procedures used are described below.

1) Finding the calibration wedge. The forward edge threshold (FETH) subroutine has to locate the calibration wedge for the data collection (DACOL) subroutine. It assumes the wedge is located within the interval of 4300 to 4500 words after scan monitor pulse 1 (SMP1). The FETH subroutine collects this block of data for the first channel in the data set. This interval corresponds to 43 to 45 ms after SMP1. If the leading edge of the cal wedge is not within this interval, data collection cannot continue.

2) Narrowing the collection window. The DRS does not have the capacity to collect 200 words of leading edge data for all channels. For this reason, FETH examines the 200 words of data on the first channel, and selects a 40 word window to collect for all channels. The window is positioned so that the first word of the cal wedge which has

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a signal level value in quantum levels QL equal to 28 or greater occurs at about word 10 in the window for the first channel. The higher channels will occur somewhat later in the window.

The 40 word window corresponds to 0.4 ms. Since the leading edge of the calibration wedge is spread in time for the different channels, the leading edge must remain stable to about plus or minus 0.10 ms for the duration of the data set (about 40 seconds in the worst case).

3) Slope determination. The FETH routine collects 30 scans of cal wedge for all channels. It then computes the average slope of the leading edge for each channel. FETH determines the slope between the first two words on the leading edge of each scan which have signal level values equal to 28 QL or greater, and averages these 30 numbers for each channel.

4) Calibration wedge data collection. The subroutine DACOL then collects 100 scans worth of data for each channel. In addition to 20 words of video data, 40 words of calibration wedge leading edge and 558 words of trailing edge data are collected. Ultimately, 20 words of data from the calibration wedge are selected out of the trailing edge and used for data reduction.

5) Determining zero crossing. The first word on the leading edge with a signal level value equal to 28 QL or greater is found. Using the average slope determined above, the slope from the threshold value just found is projected back to the zero quanta line. The word position found is used for determining the 20 data words to be selected.

6) Selecting data values. For example, in the low gain mode for band 1, the first calibration wedge data value is the sample at the zero crossing plus 256 words. Every twenty-eighth word is also taken until the last sample at the zero crossing plus 788 words. The following chart gives the first sample, last sample, and delta between samples for each band for high and low gain. These values were selected to maximize the number of samples between quantum levels 4 and 59 (not saturated) for each channel. The final constants selected were a compromise to accommodate the different outputs of the two (System A, System B) calibration lamps.

		Words From Zero Crossing		
Gain	Band	First Sample	Last Sample	Increment Between Samples
Low	1	256	788	28
	2	360	788	22
	3	360	778	22
	4	330	786	24
High	1	460	878	22
	2	580	960	20

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4. RADIOMETRIC CALIBRATION TEST HISTORY

The history of the radiometric calibrations performed during MSS-D Flight Model (F-1) testing is given in Table I-4-1. The calibration test number in the left-hand column is used in the plots which follow to identify the date, location, and special test configurations or conditions for the tests performed.

It will be noted in examining the plots of radiance values at each wedge word that there is a significant difference between System A and System B. The radiance output from the calibration lamp in System A is 15 to 20 percent higher than that for System B. This disparity in lamp radiant output was observed during the first attempt to perform a radiometric calibration. It necessitated careful selection of the nominal wedge words to ensure that a suitable set of radiance values would be available for each system without having to change the word collect locations as a function of system configuration (i.e., A or B). Thus, System A often is in saturation for the first few words of the wedge when system B is not. Moreover, System B on occasion shows values of η_{max} (percent) in excess of 100 percent, which reflects the disparity between A and B, since at those values of radiance System A is in saturation.

TABLE I-4-1. SYSTEM RADIOMETRIC CALIBRATION SUMMARY

Calibration Test Number	Date of Calibration	Location	Description/Summary
1	29 Jul 81	ES, Bldg S3 Area S1	First radiometric calibration performed on flight model (F-1)
2	18 Aug 81	ES, Bldg S3 Area S1	Radiometric calibration done after 1) acoustic test, 2) replacing capacitors on boards A1A3 and A1A4
3	28 Aug 81	ES, Bldg S3 Area S1	Post-EMI and post-vibration radiometric calibration pre-thermal vacuum radiometric calibration
4	22 Sep 81	ES, Bldg S3 Area S1	Post-thermal vacuum radiometric calibration
5	1 Oct 81	ES, Bldg S3 Area S1	First radiometric calibration after replacement of flex pivots
6	9 Oct 81	ES, Bldg S3 Area S1	Radiometric calibration done after penalty acoustic test

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It will be noticed as well that the eighth word of the wedges is not located at a value commensurate with the near exponential decay of the wedge. This is due to a hole (discontinuity) in the wedges and is evident in all of the wedges in varying degrees. It is particularly evident in System B, Band 4, where the radiance values for the eighth and ninth words actually overlap.

While this feature of the wedge is undesirable, the presence of the "hole" in the neutral density filter, or corresponding "bump" in the generated nominal calibration wedges shown does not affect the utility of these wedges for computing gain and offset as long as the effect is stable (repeatable). This would appear to be indicated by the plots.

The remainder of this section provides computer plots of the calibration history for all 24 channels, at each of the 20 words in the channel, for each of the different modes and system configurations. The plots are arranged with System A and System B configurations for each channel on facing pages. Low gain mode performance is presented first for all 24 channels, followed by high gain modes for the first 12 channels. In each case, plots for Systems A and B are presented on facing pages.

For convenience of plotting, the plots are all normalized to radiance in percentage of η_{MAX}, where η_{MAX} is the specification value of the maximum bright scene radiance given in Table I-2-3. These values are the following:

Band 1 = 2.48 (mW cm^{-2} ster^{-1})

Band 2 = 2.00 (mW cm^{-2} ster^{-1})

Band 3 = 1.76 (mW cm^{-2} ster^{-1})

Band 4 = 4.60 (mW cm^{-2} ster^{-1})

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CALIBRATION HISTORY PLOTS

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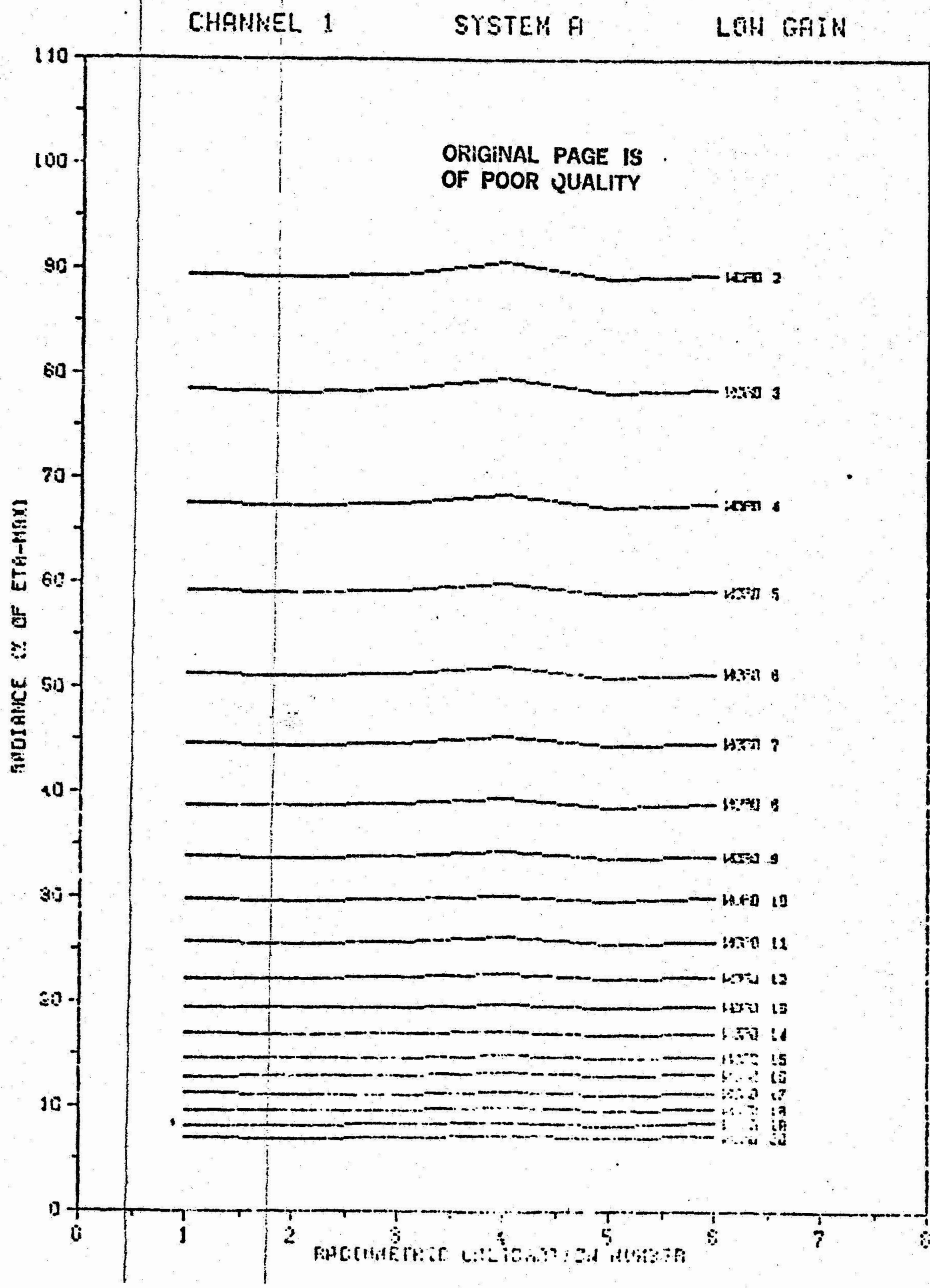

CHANNEL 1 SYSTEM B LOW GAIN

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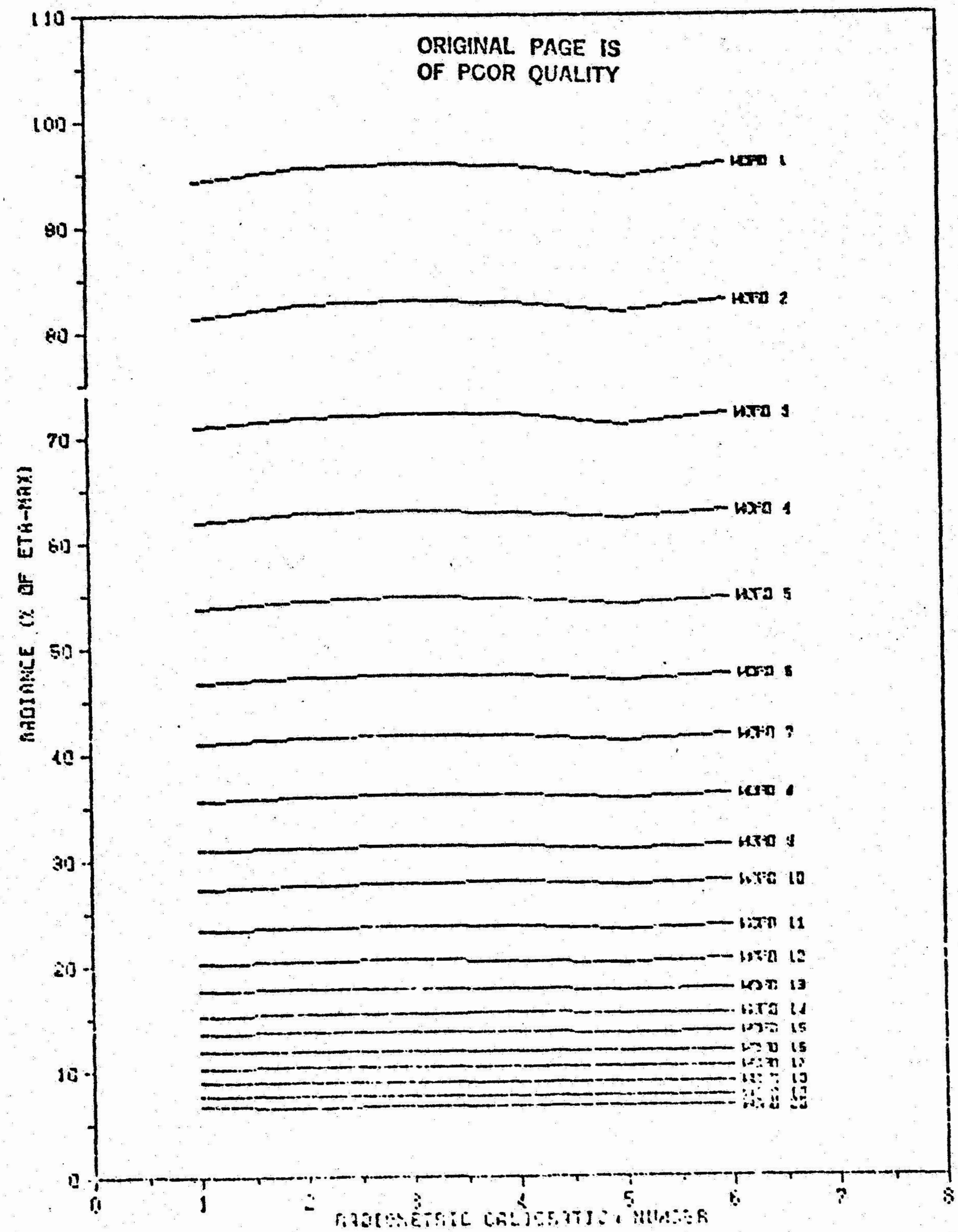
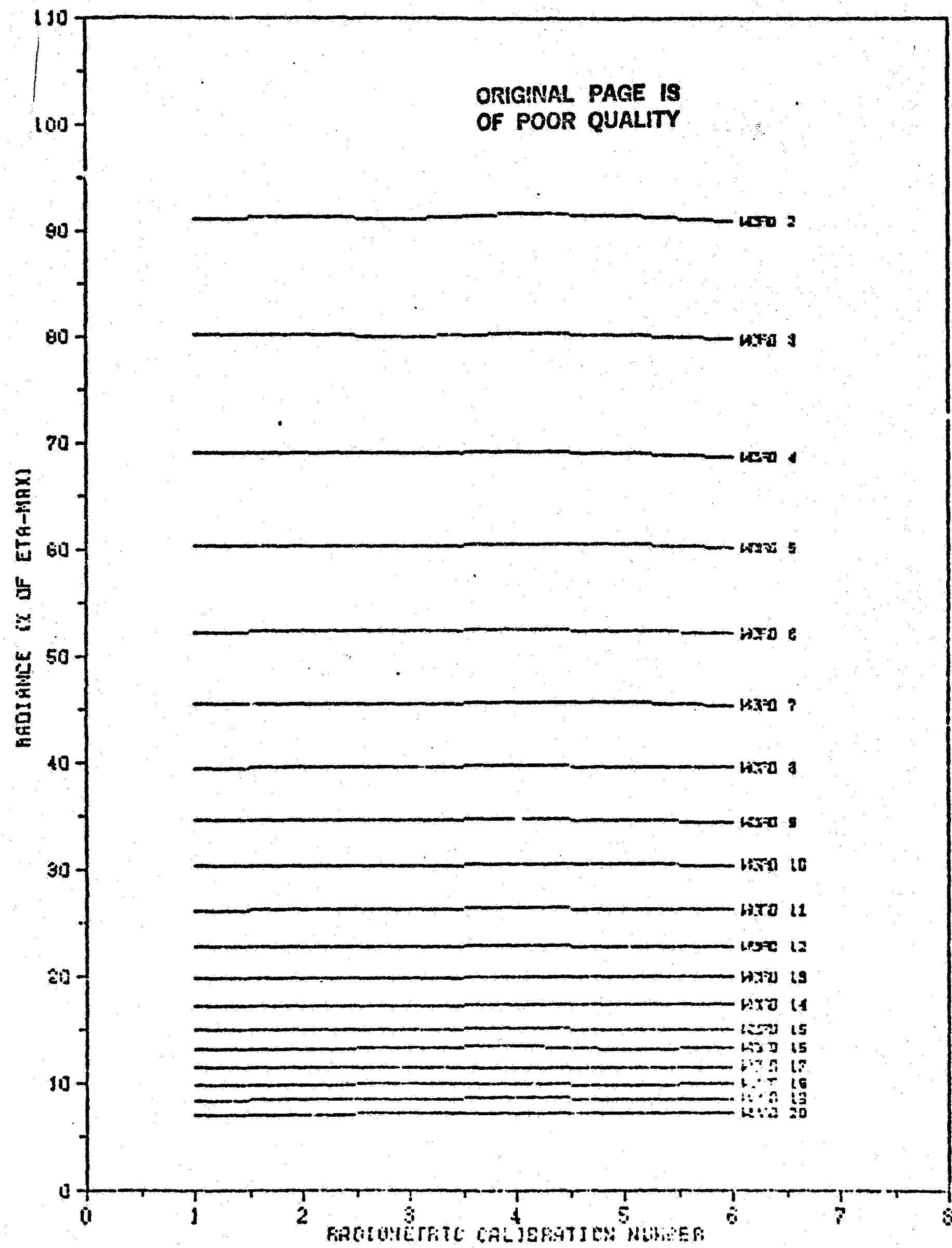
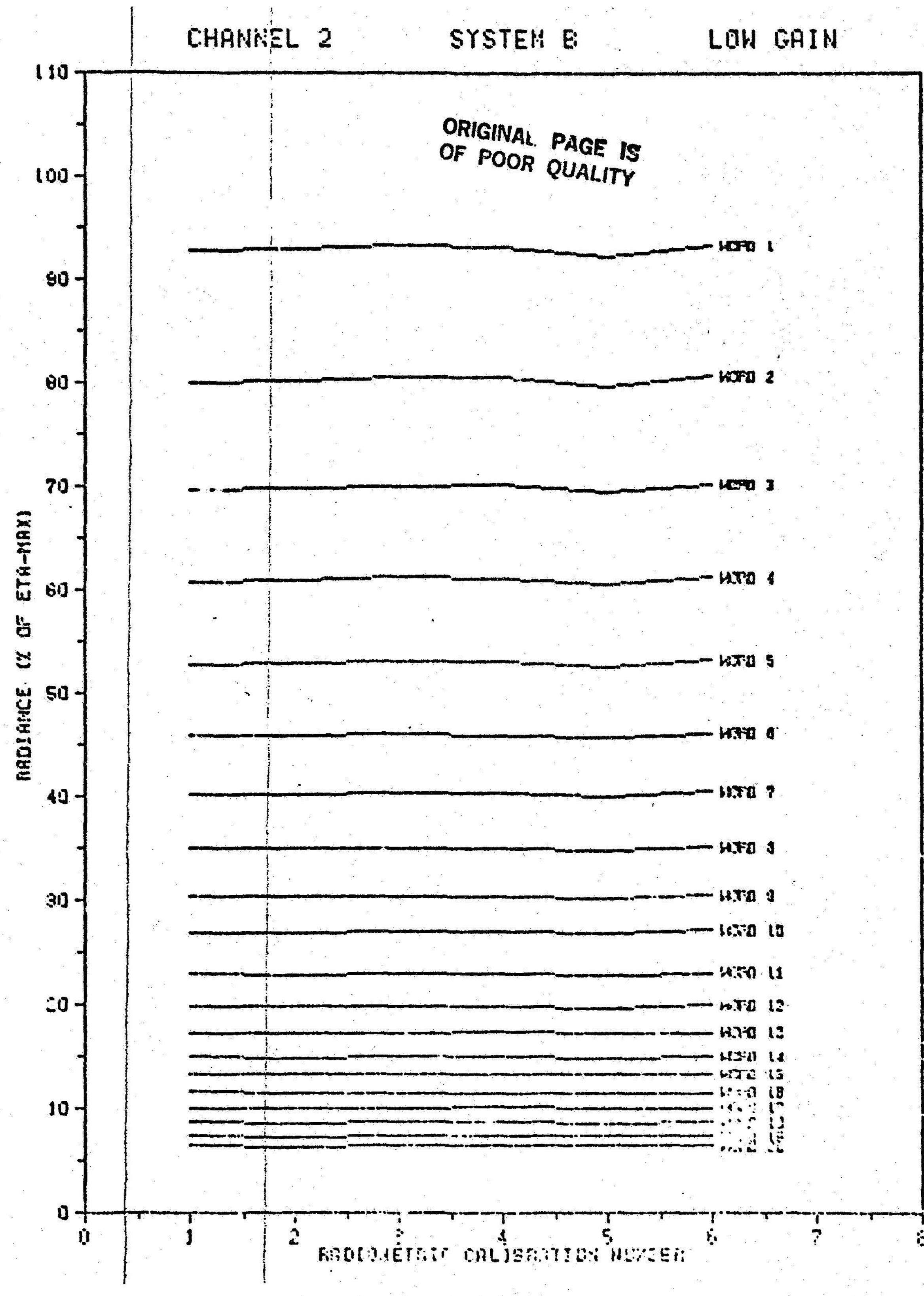


CHANNEL 2 SYSTEM A LOW GAIN





CHANNEL 2
SYSTEM B
LOW GAIN
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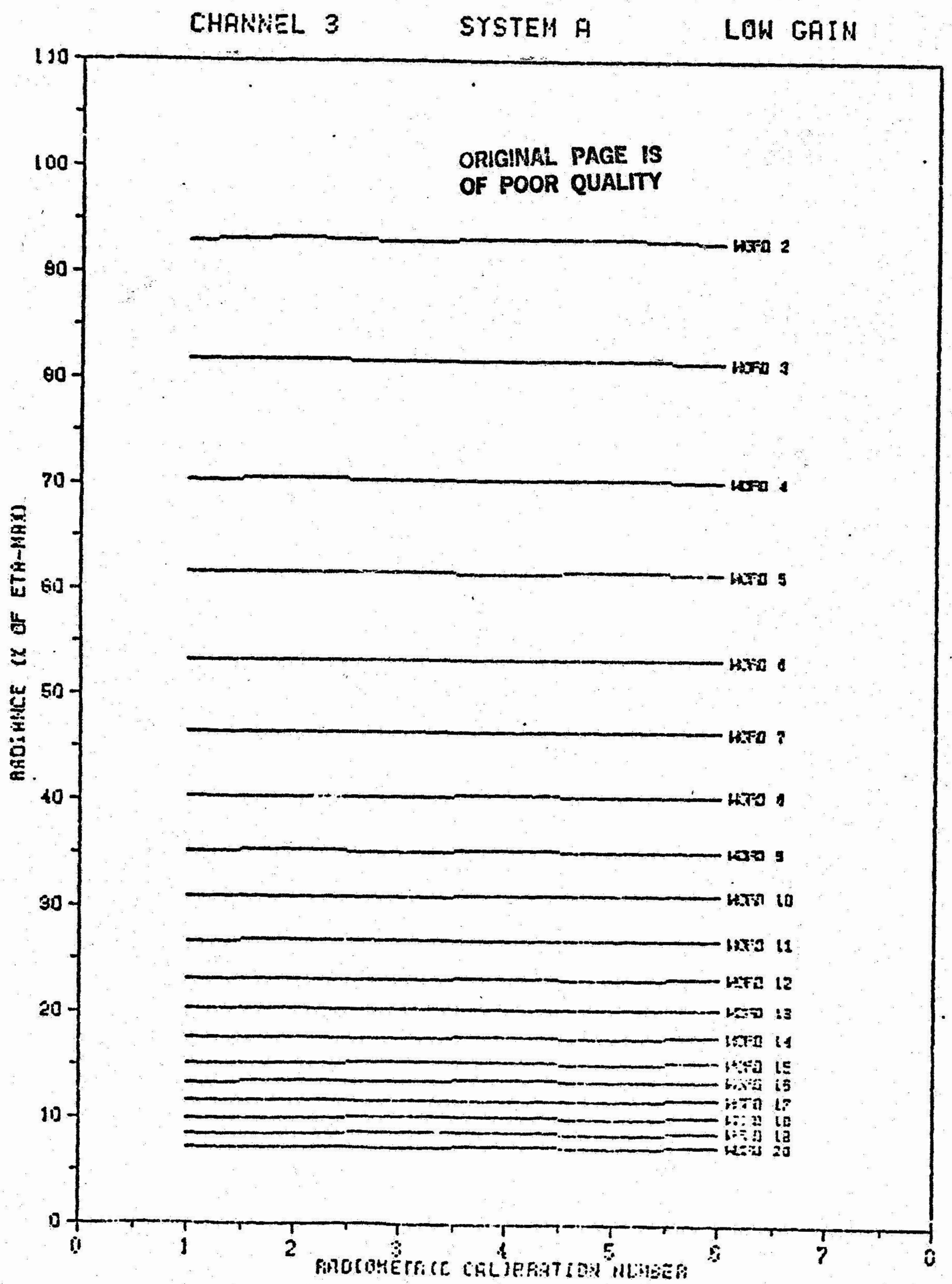
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER



CHANNEL 3
SYSTEM A
LOW GAIN
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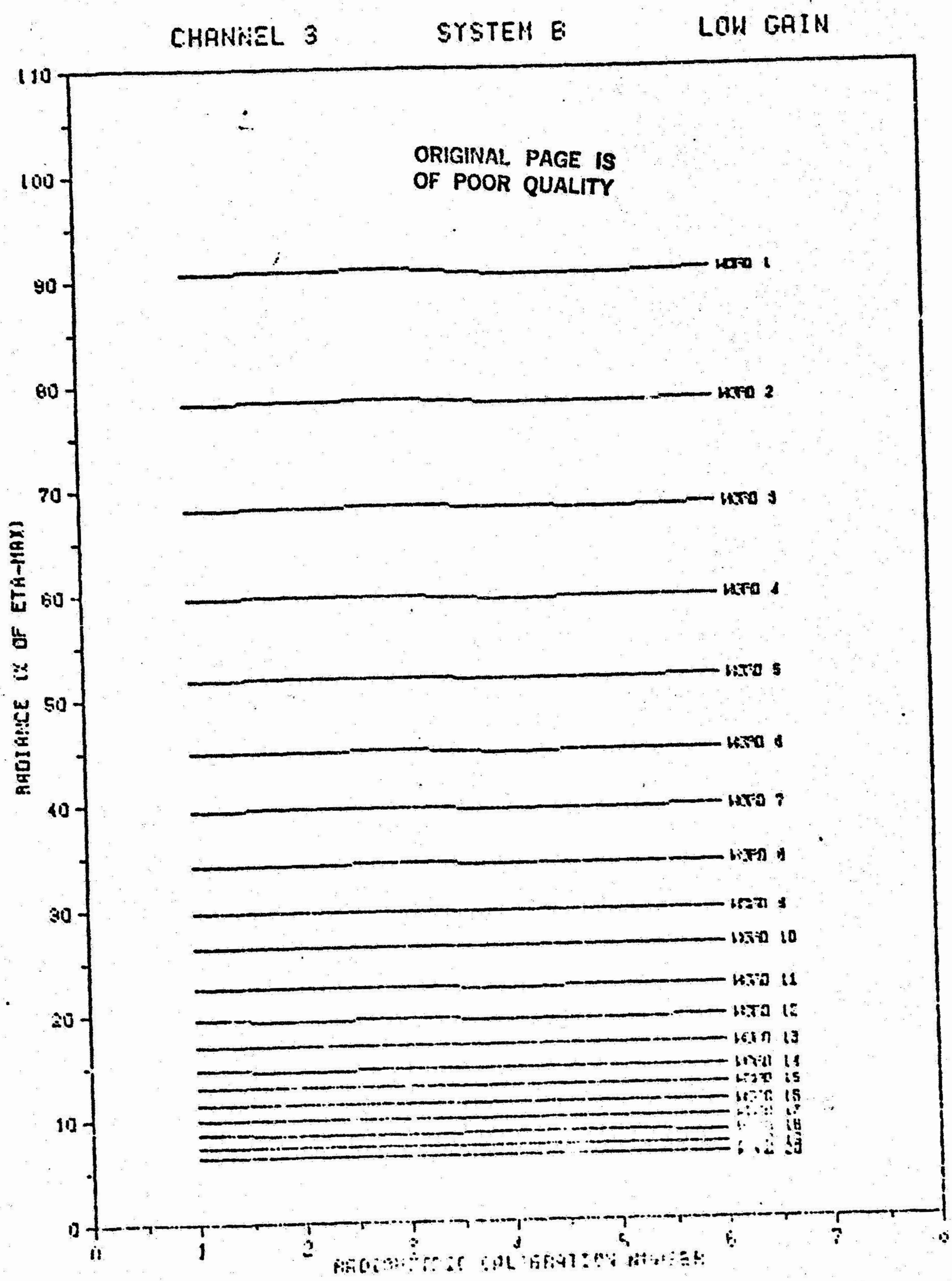
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER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SYSTEM B
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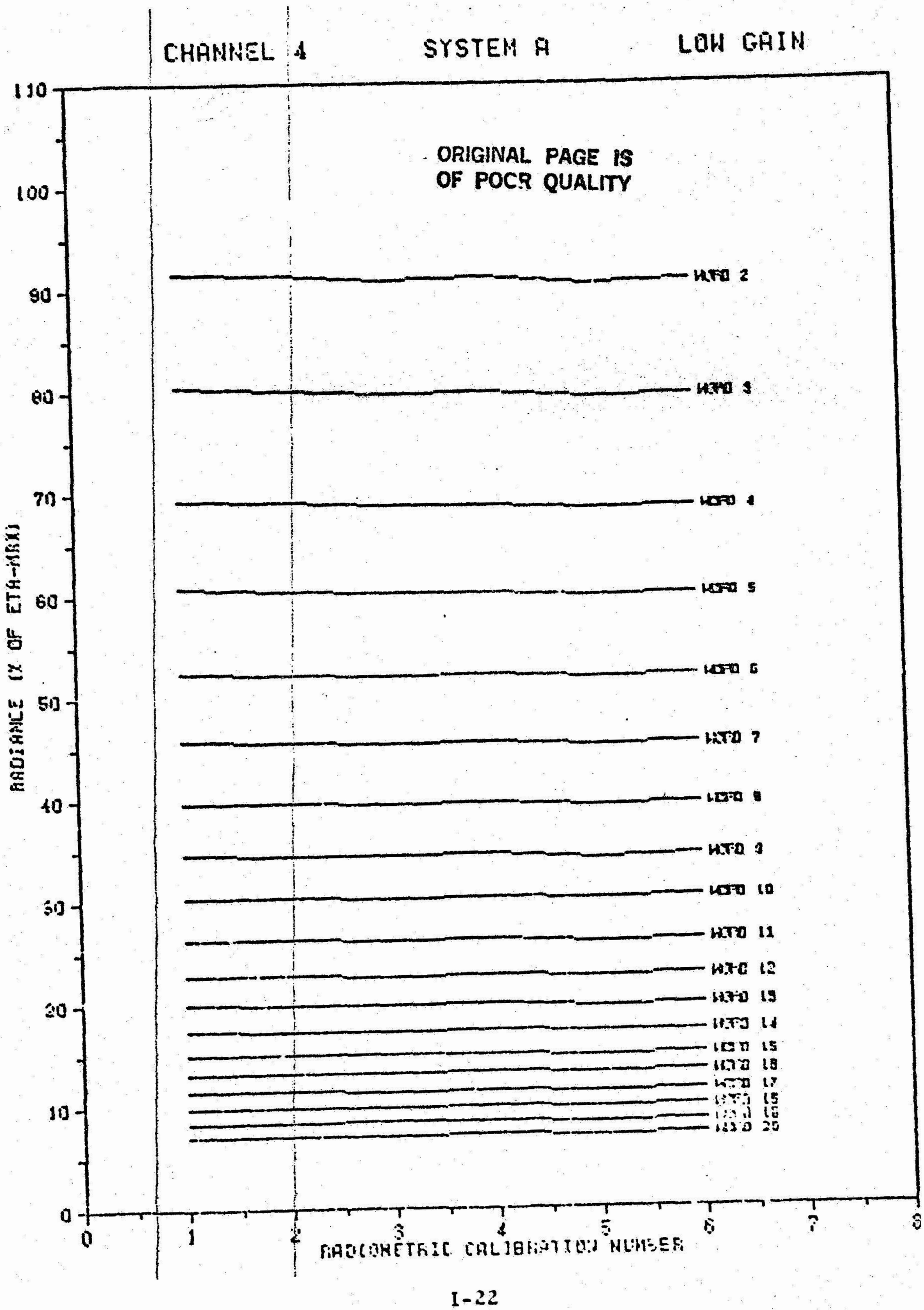
RADIANCE (% OF ETA-MAX)



CHANNEL 4
SYSTEM A
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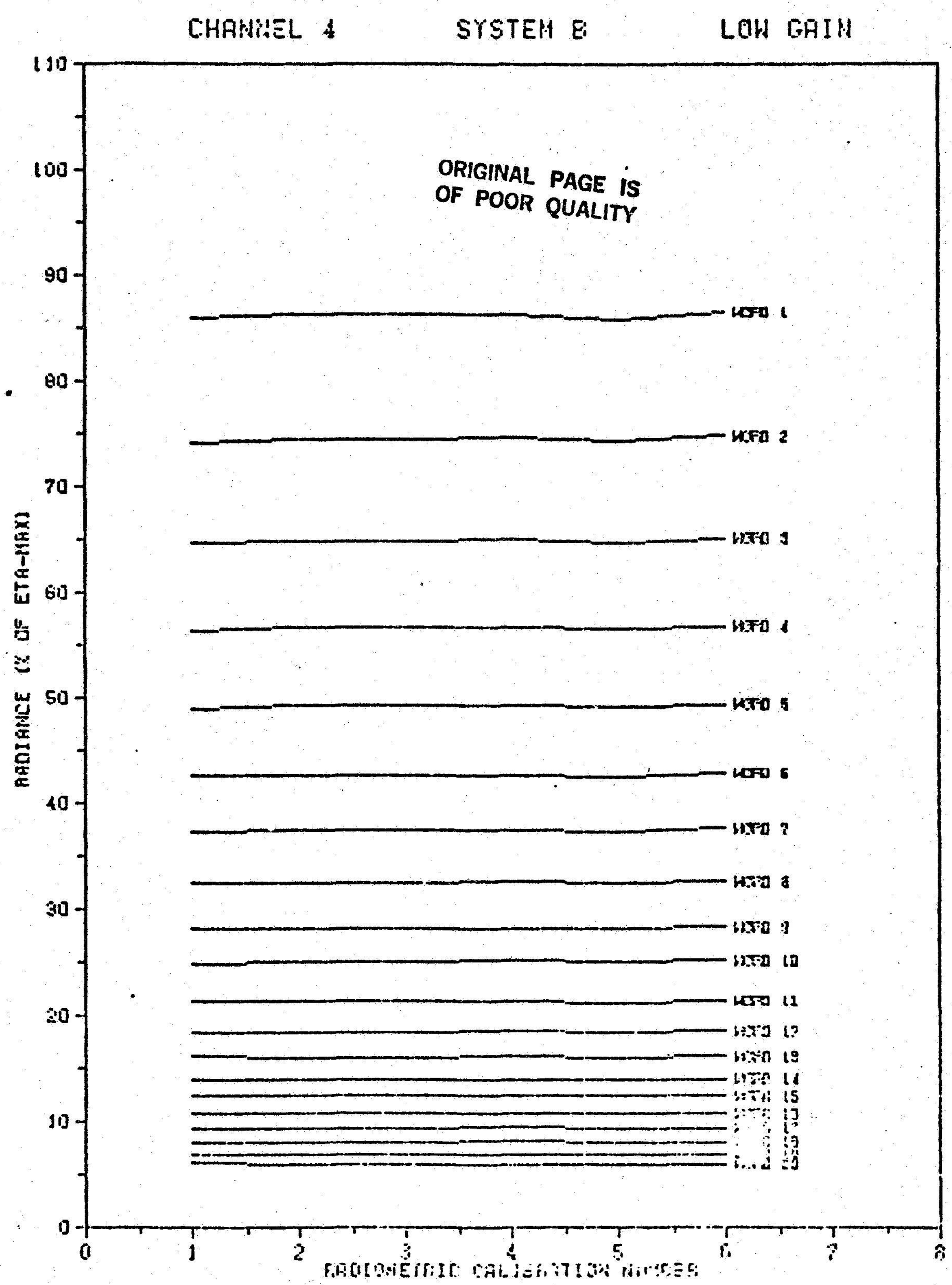
RADIOMETRIC CALIBRATION NUMBER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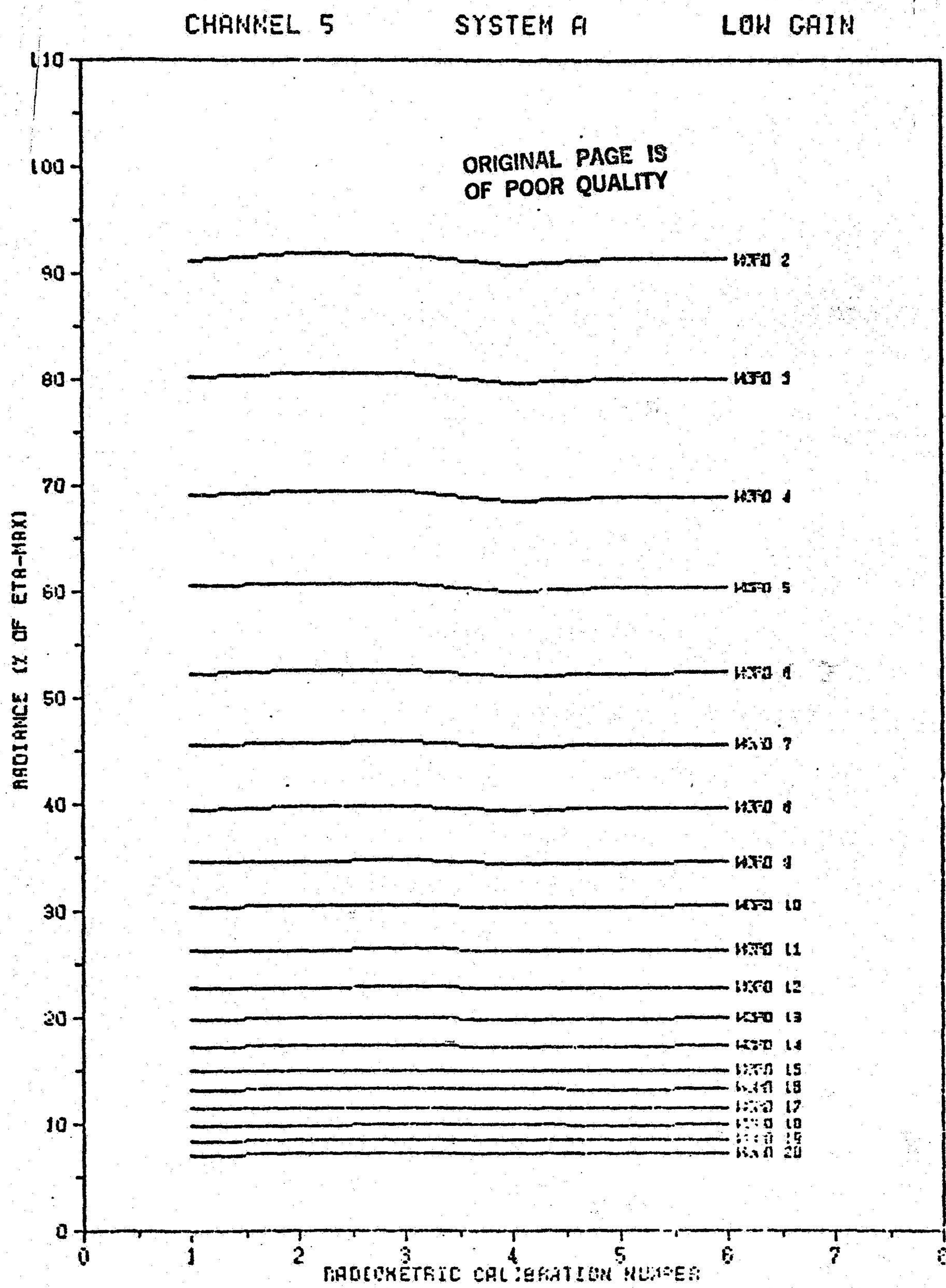

CHANNEL 5
SYSTEM A
LOW GAIN
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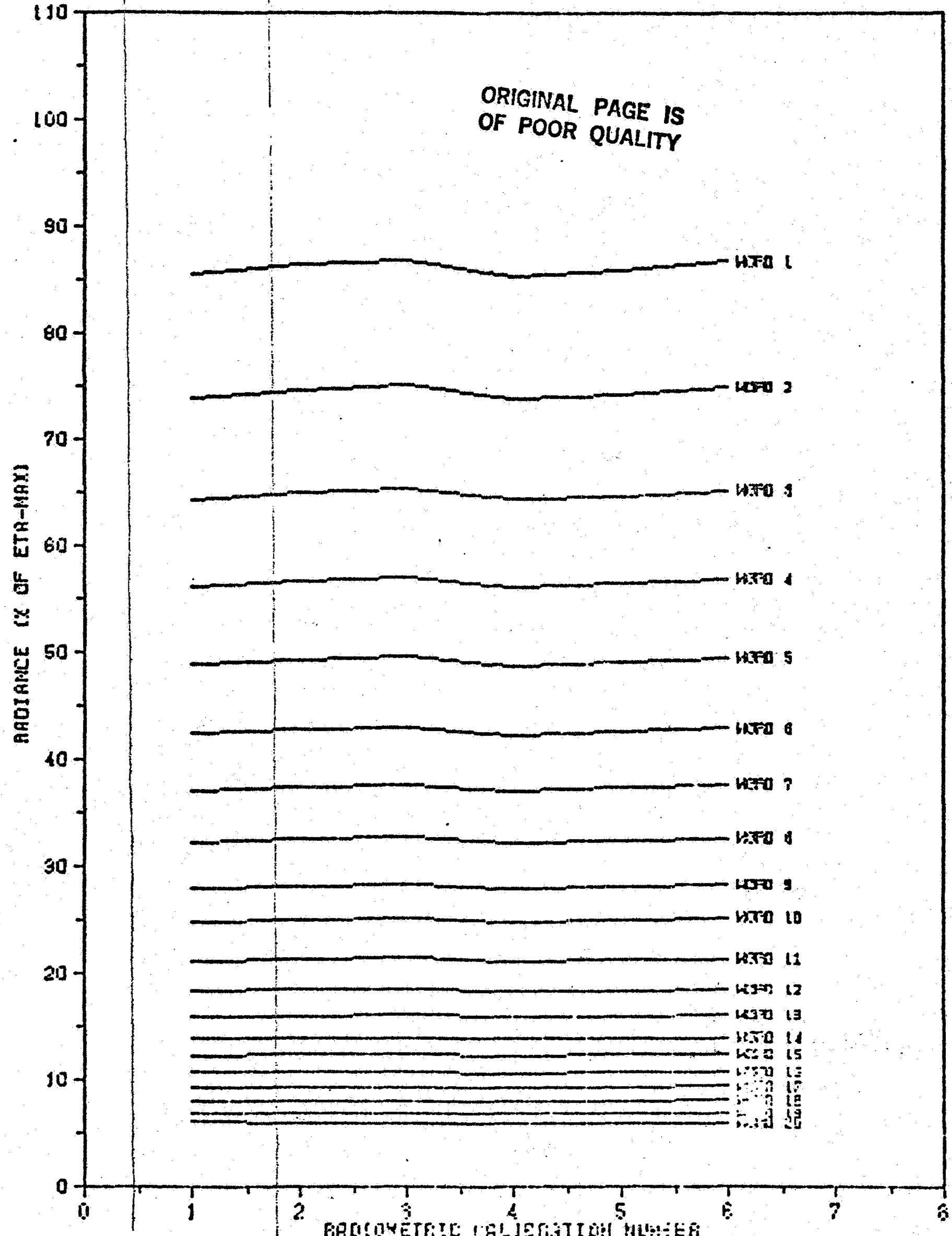
CHANNEL 5 SYSTEM B LOW GAIN



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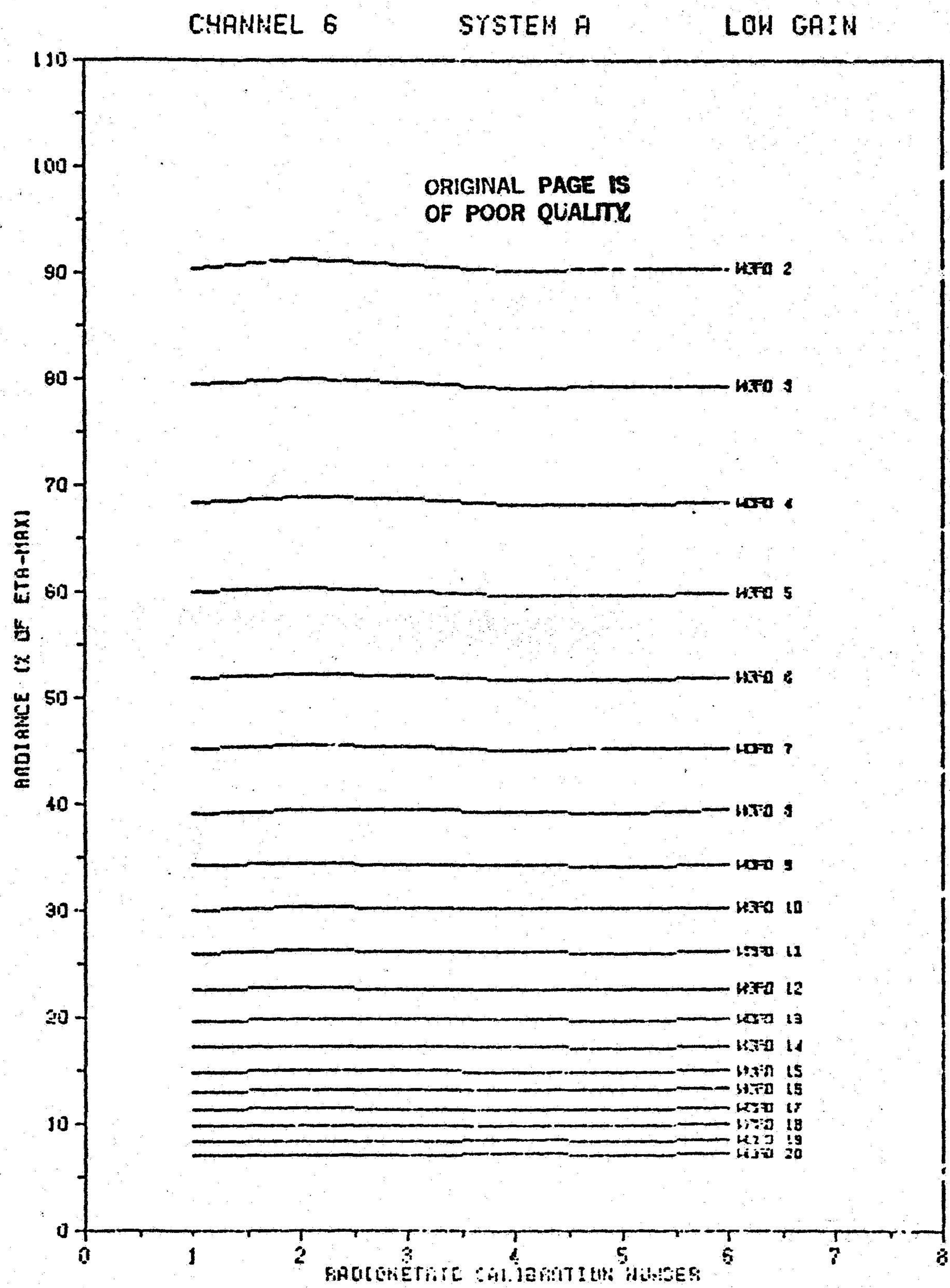

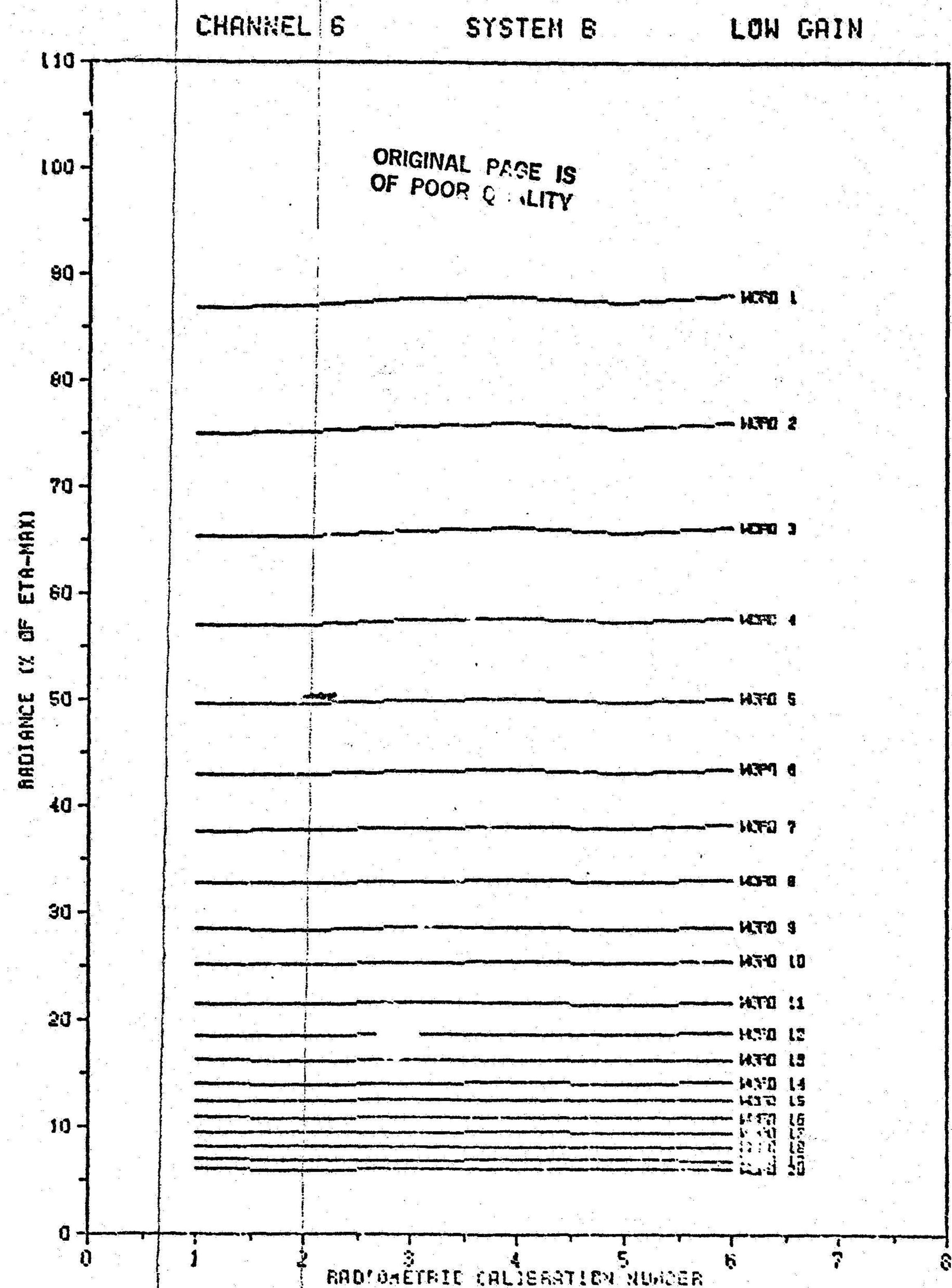
CHANNEL 6
SYSTEM B
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RADIANCE (% OF ETA-MAX)
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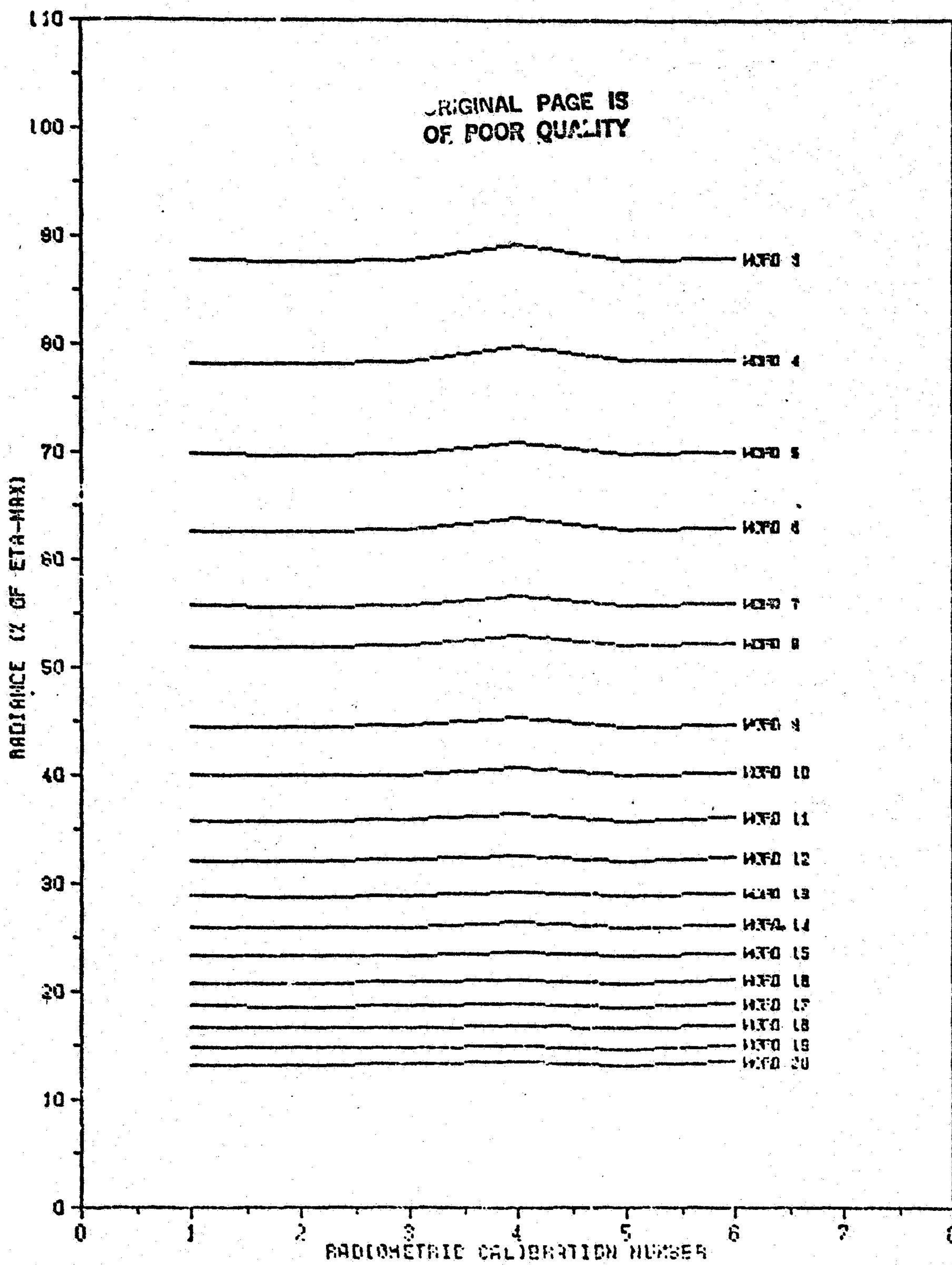
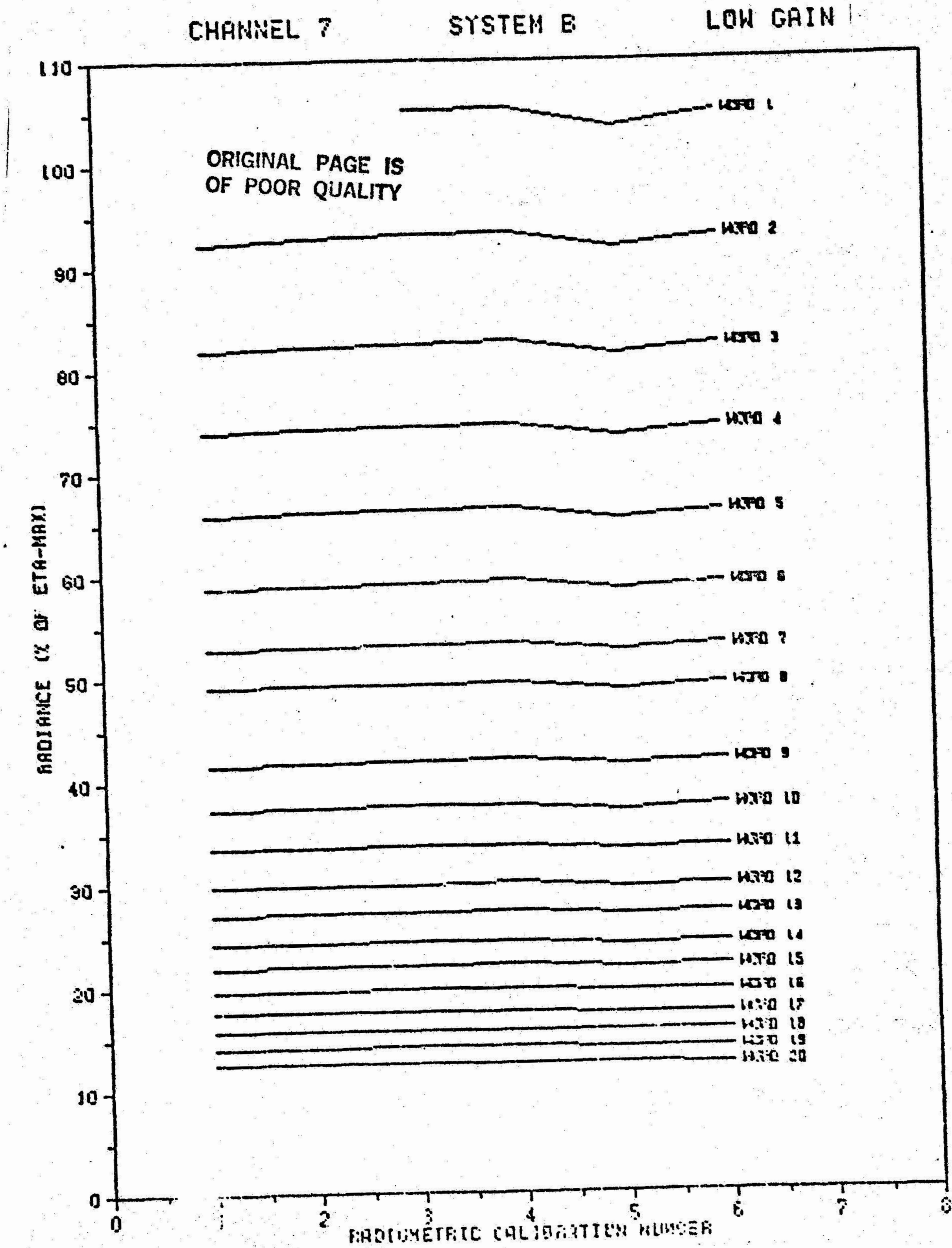
CHANNEL 7 SYSTEM A LOW GAIN





CHANNEL 7
SYSTEM B
LOW GAIN
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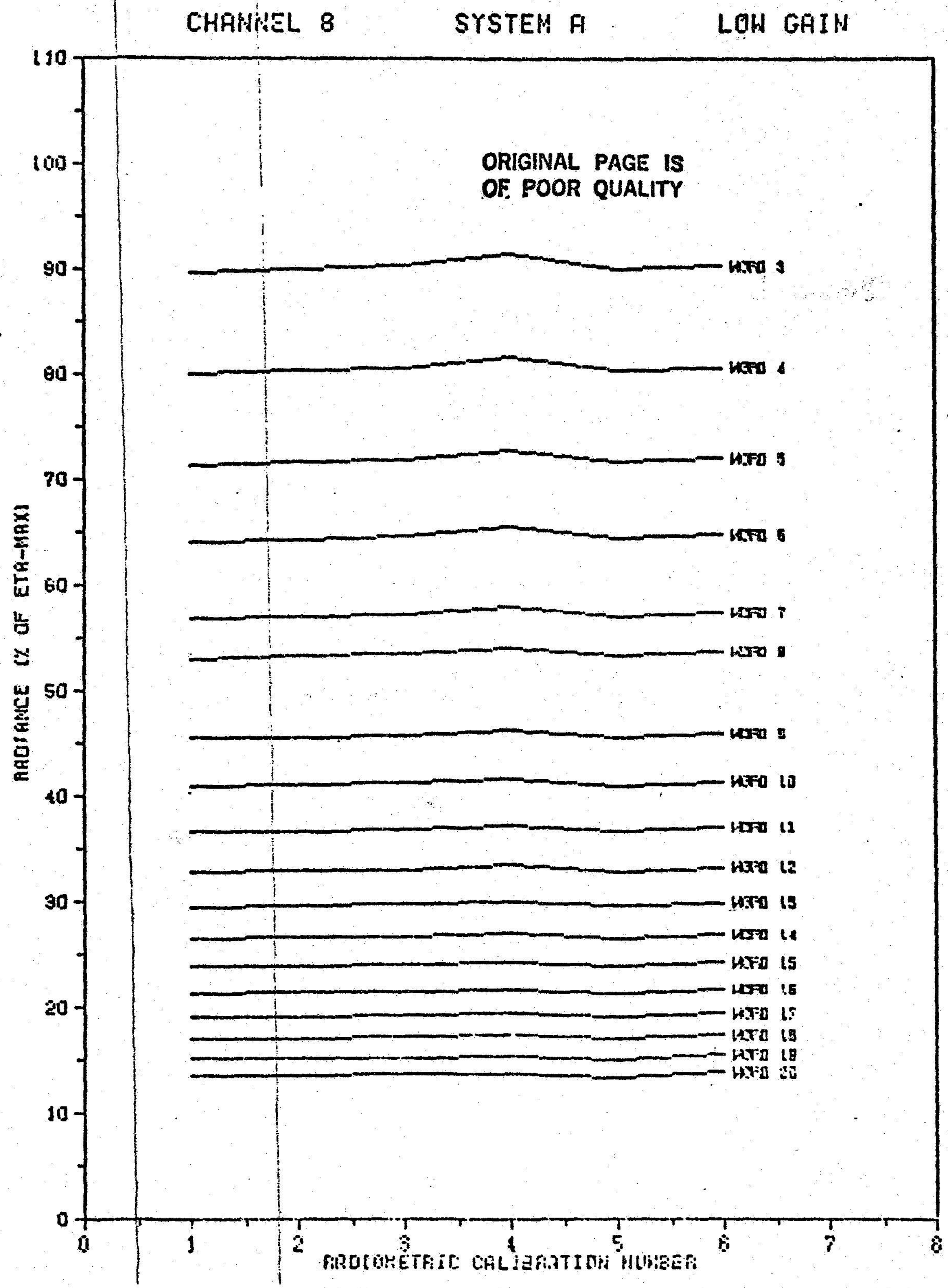
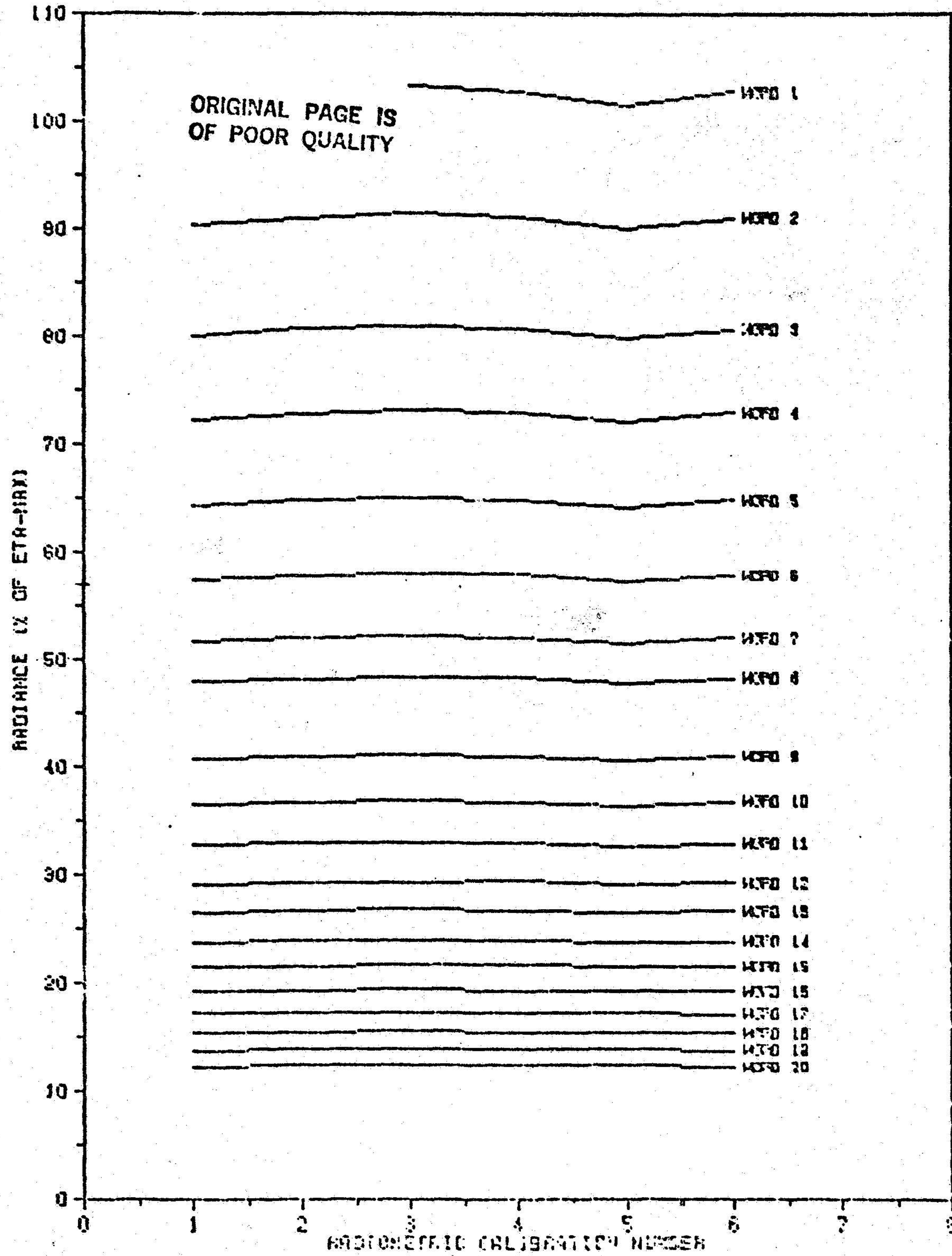
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER

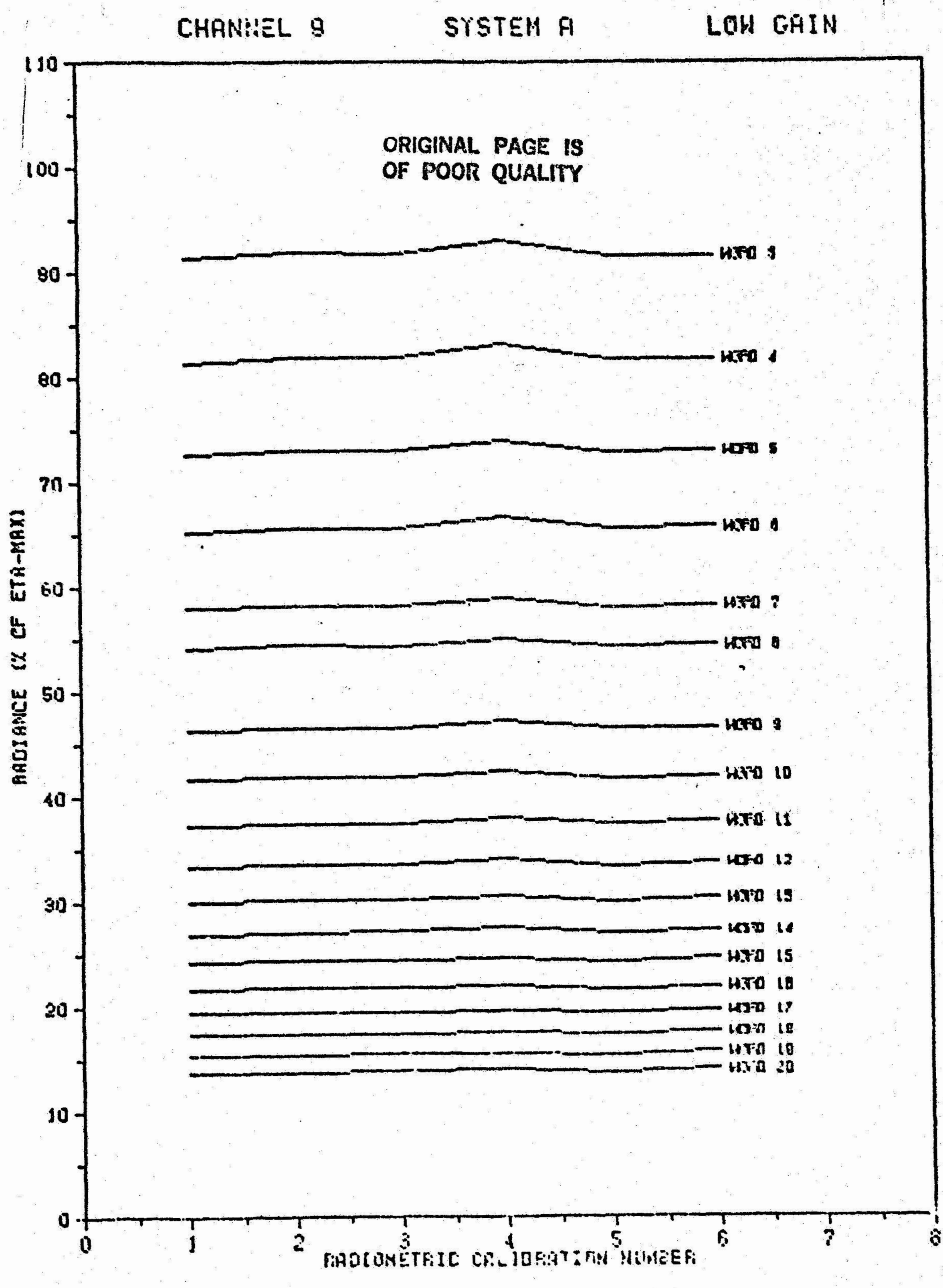


CHANNEL 8
SYSTEM A
LOW GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER

CHANNEL 8 SYSTEM B LOW GAIN



ORIGINAL PAGE IS OF POOR QUALITY


CHANNEL 9
SYSTEM A
LOW GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER
0
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20
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60
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90
100
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1
2
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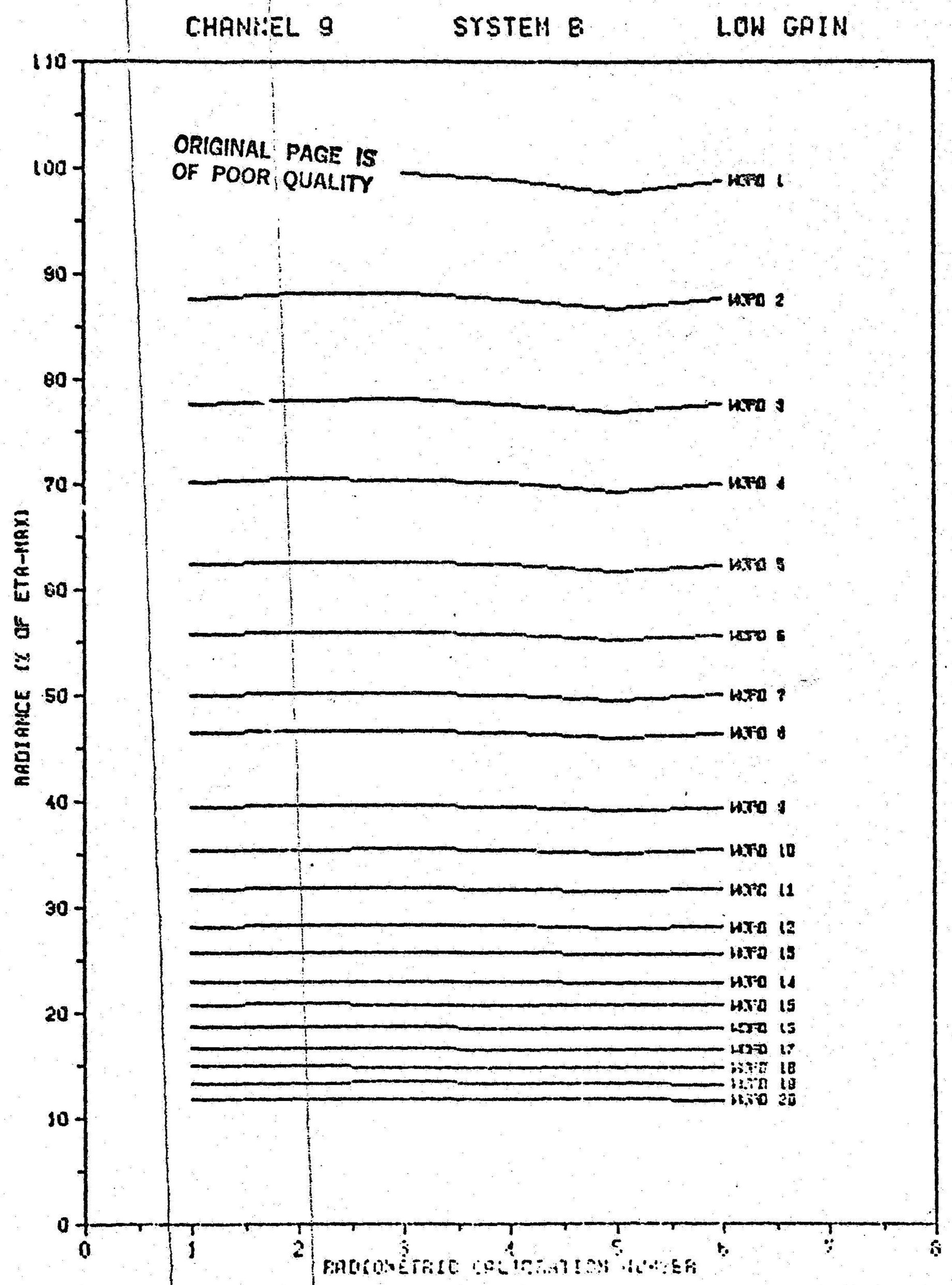
7
8


CHANNEL 9
SYSTEM B
LOW GAIN
ORIGINAL PAGE IS OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER
WDFD 1
WDFD 2
WDFD 3
WDFD 4
WDFD 5
WDFD 6
WDFD 7
WDFD 8
WDFD 9
WDFD 10
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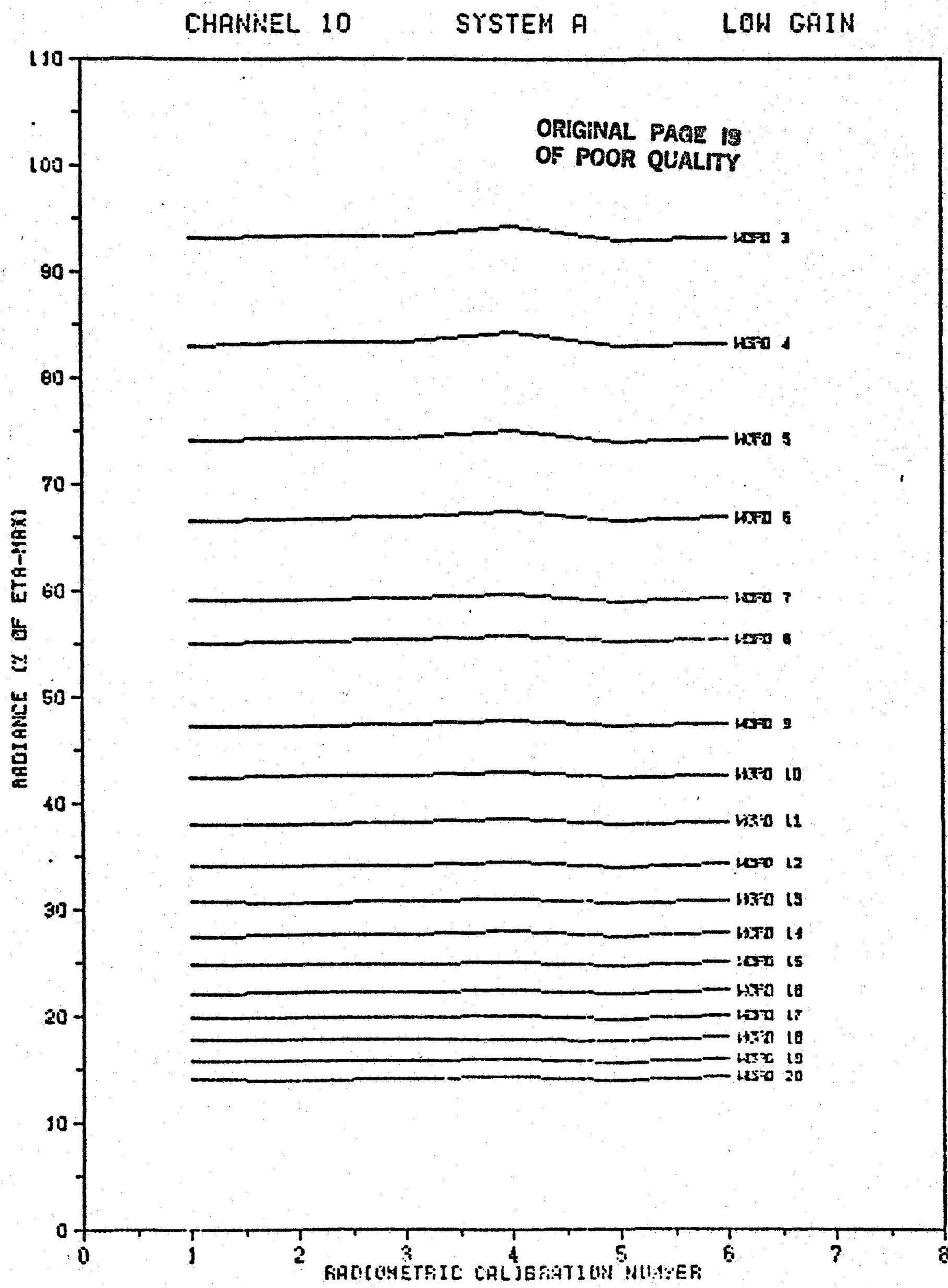
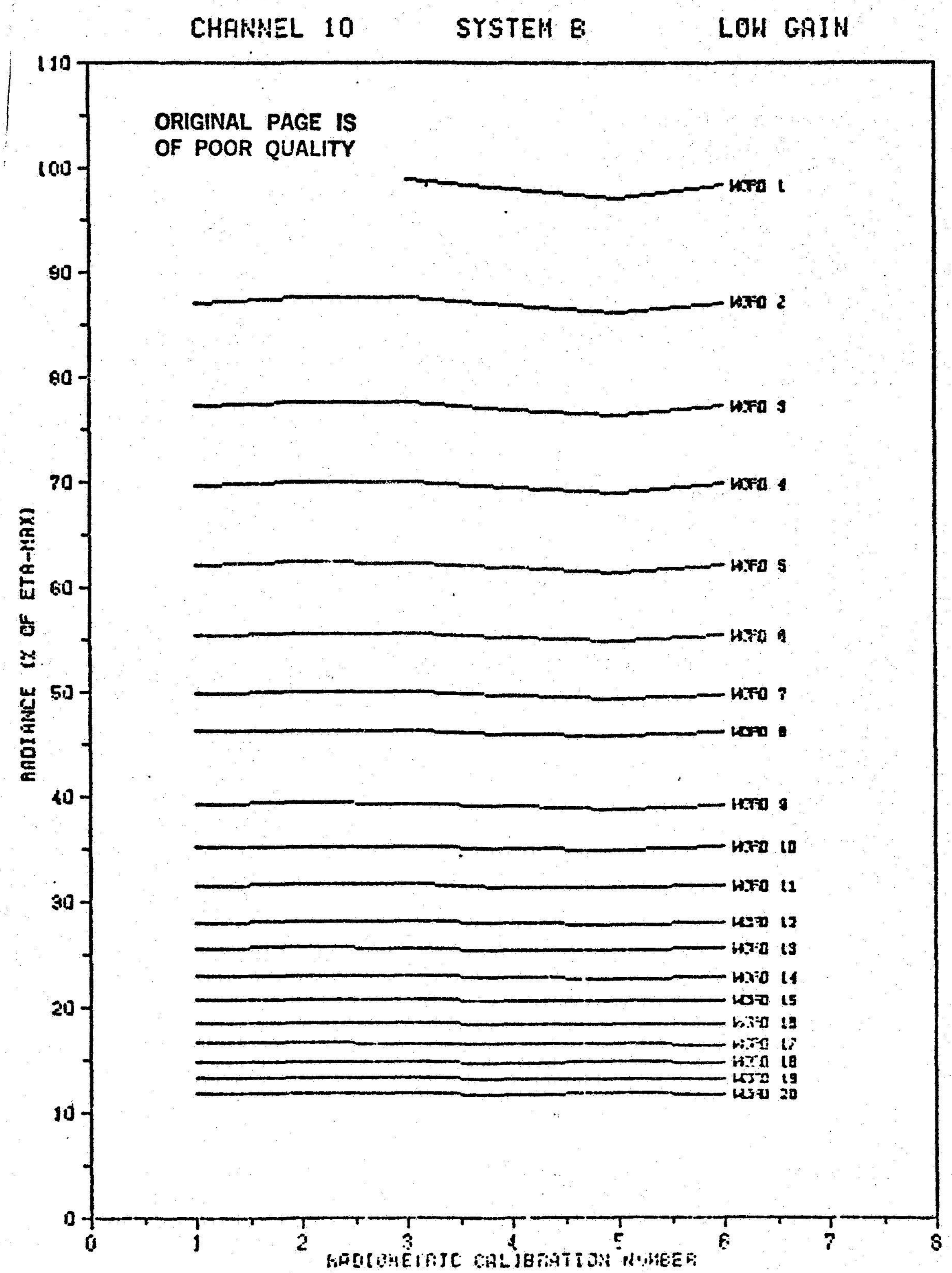
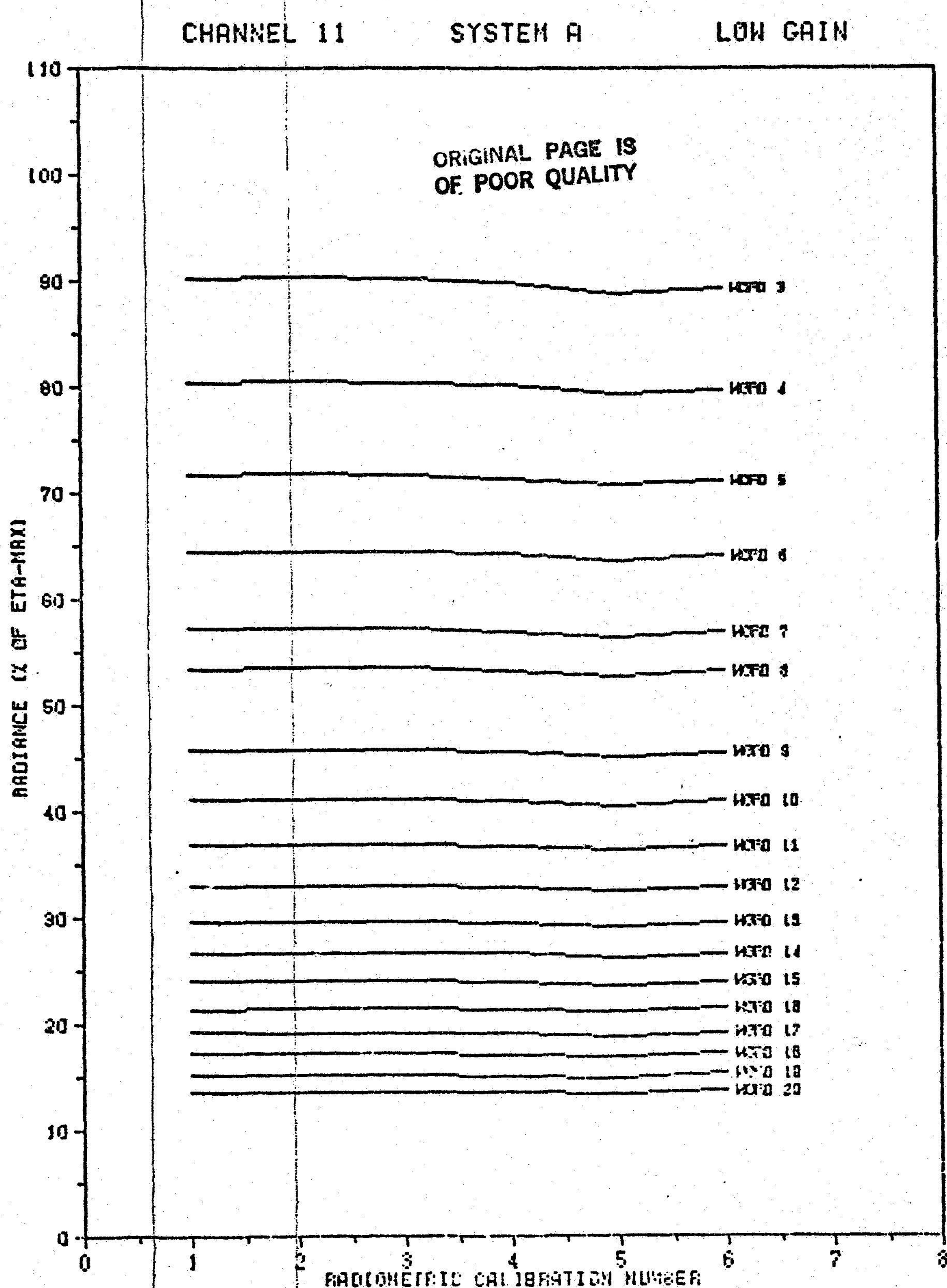
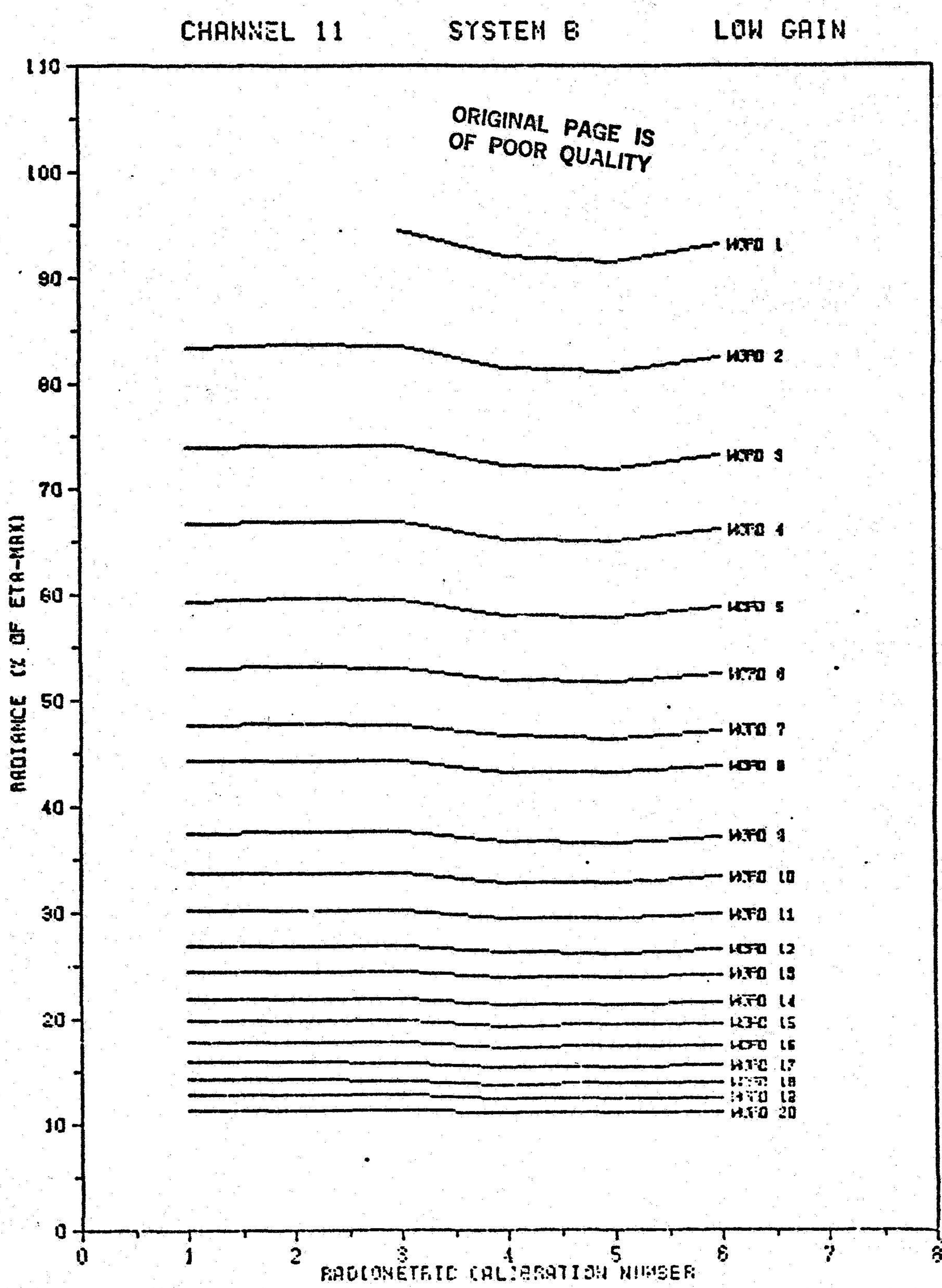
WDFD 18
WDFD 19
WDFD 20


CHANNEL 10 SYSTEM A LOW GAIN
ORIGINAL PAGE IS OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER

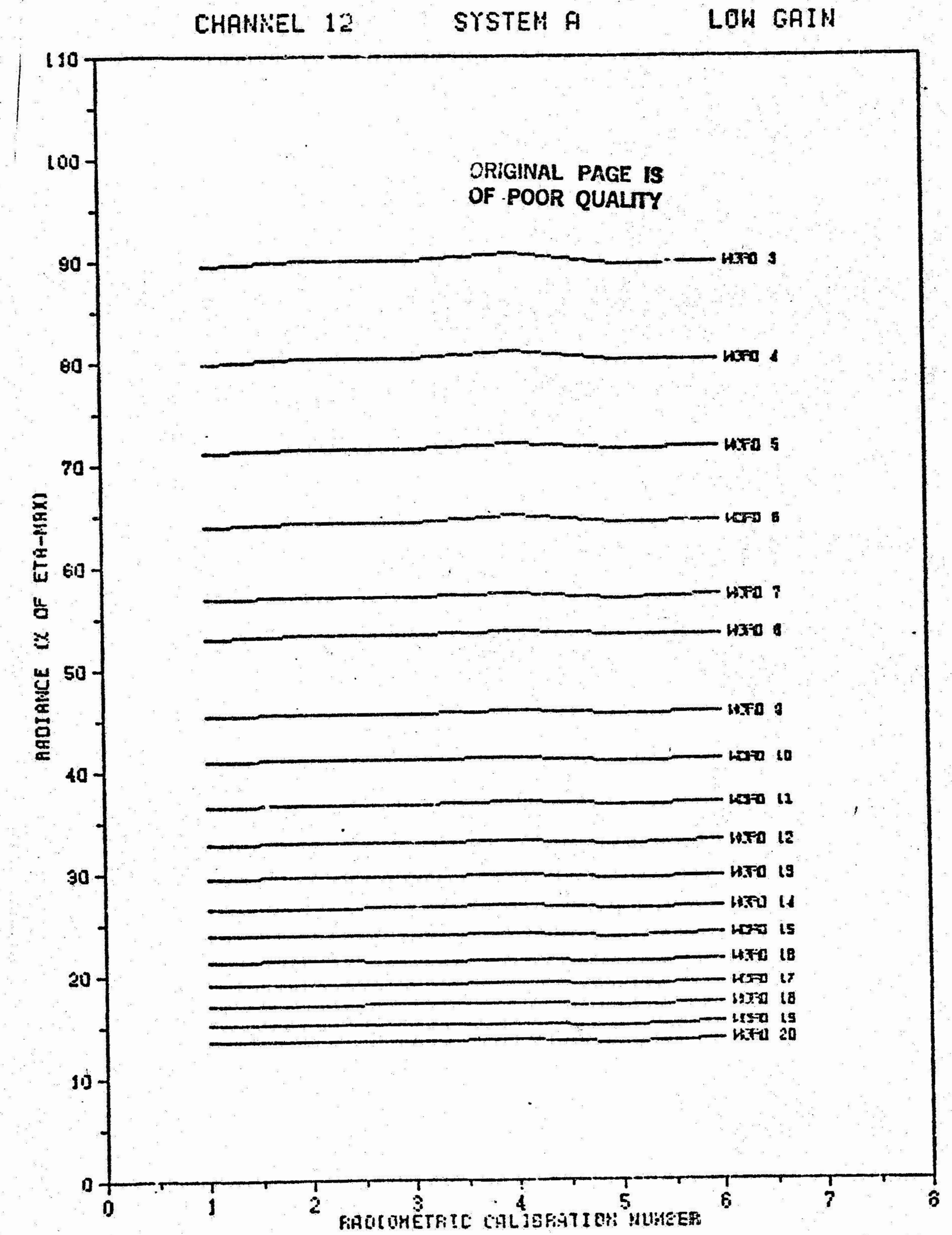

CHANNEL 10 SYSTEM B LOW GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER



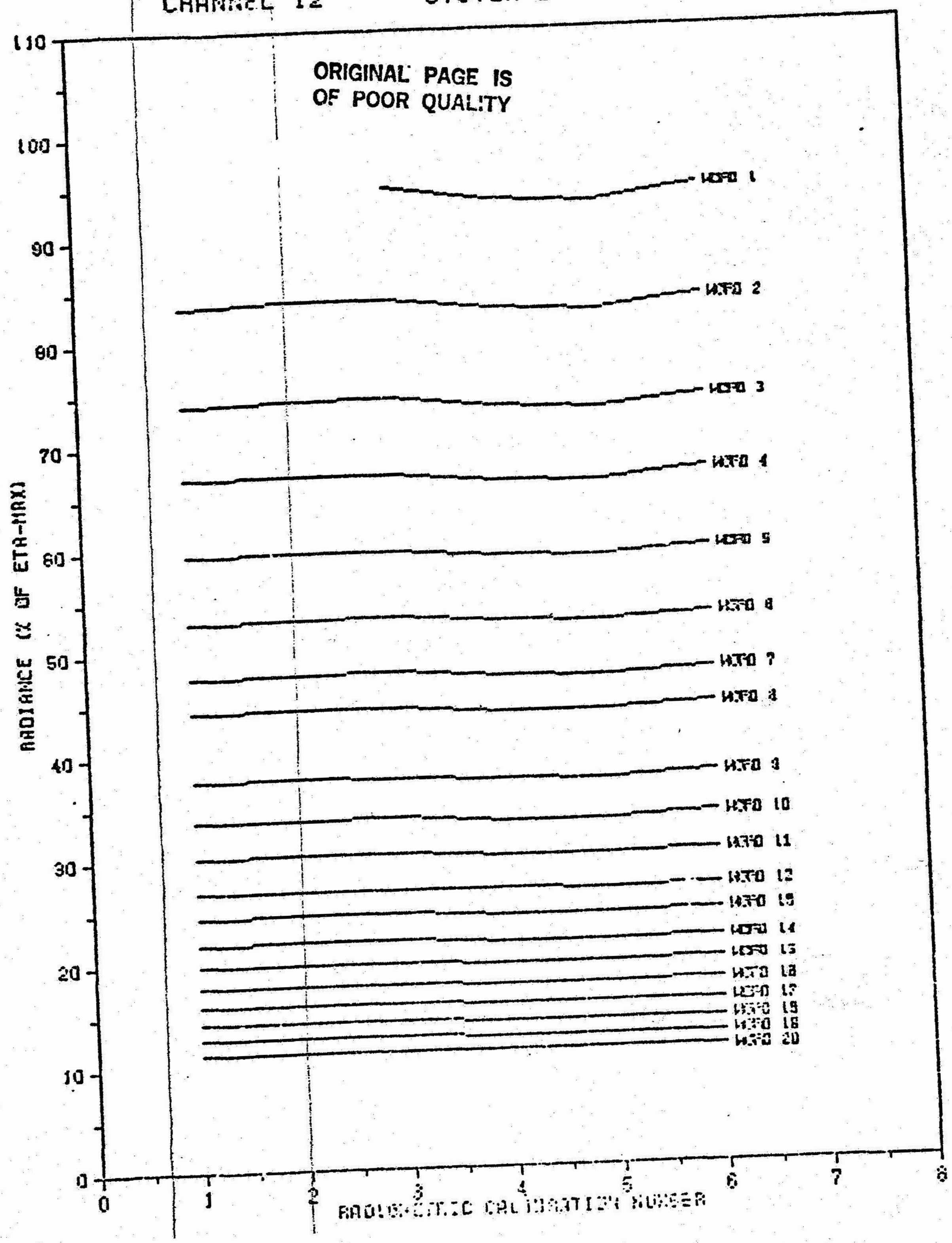
CHANNEL 11 SYSTEM A LOW GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER



CHANNEL 11
SYSTEM B
LOW GAIN
ORIGINAL PAGE IS OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER

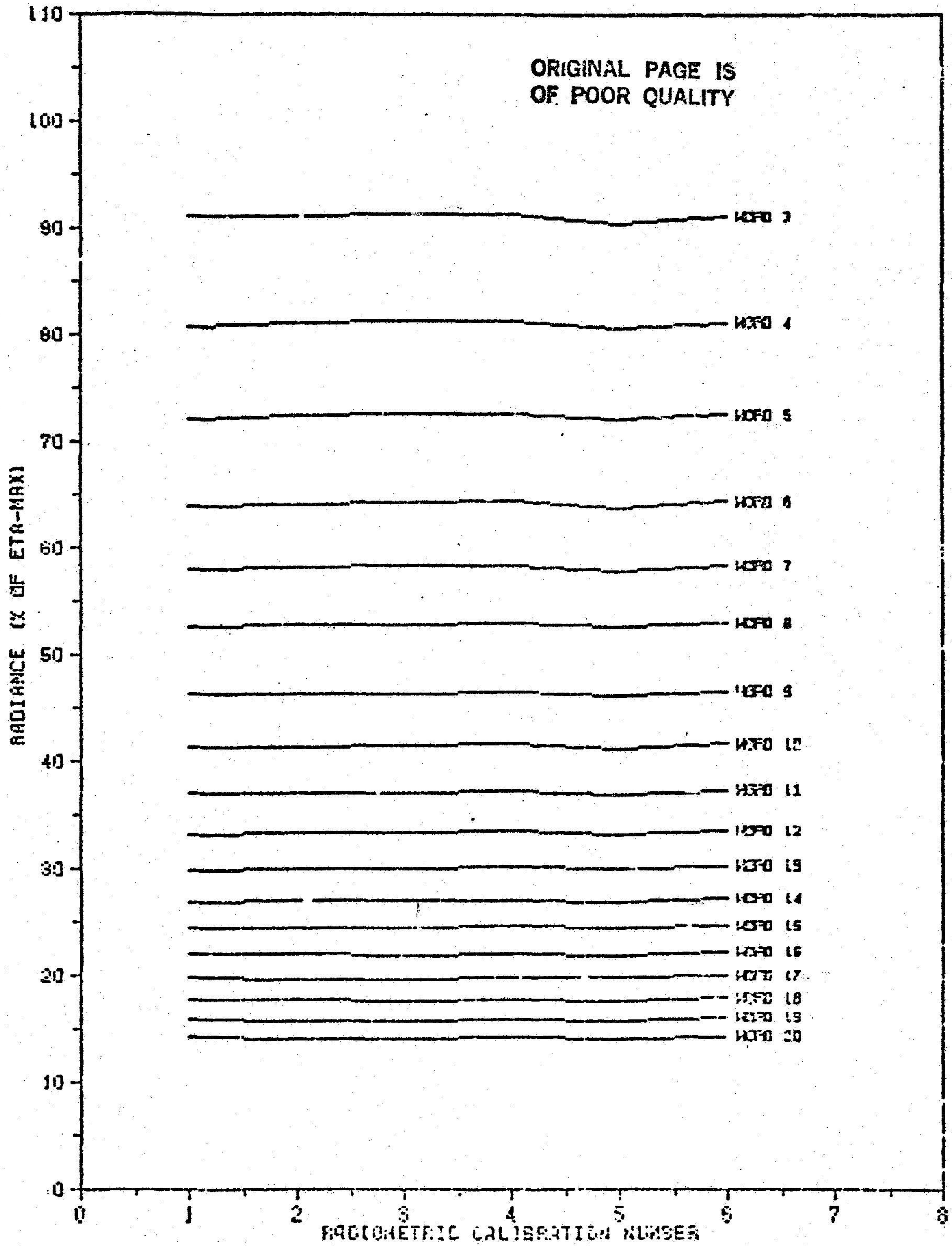

CHANNEL 12 SYSTEM A LOW GAIN
ORIGINAL PAGE IS OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER
110
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8

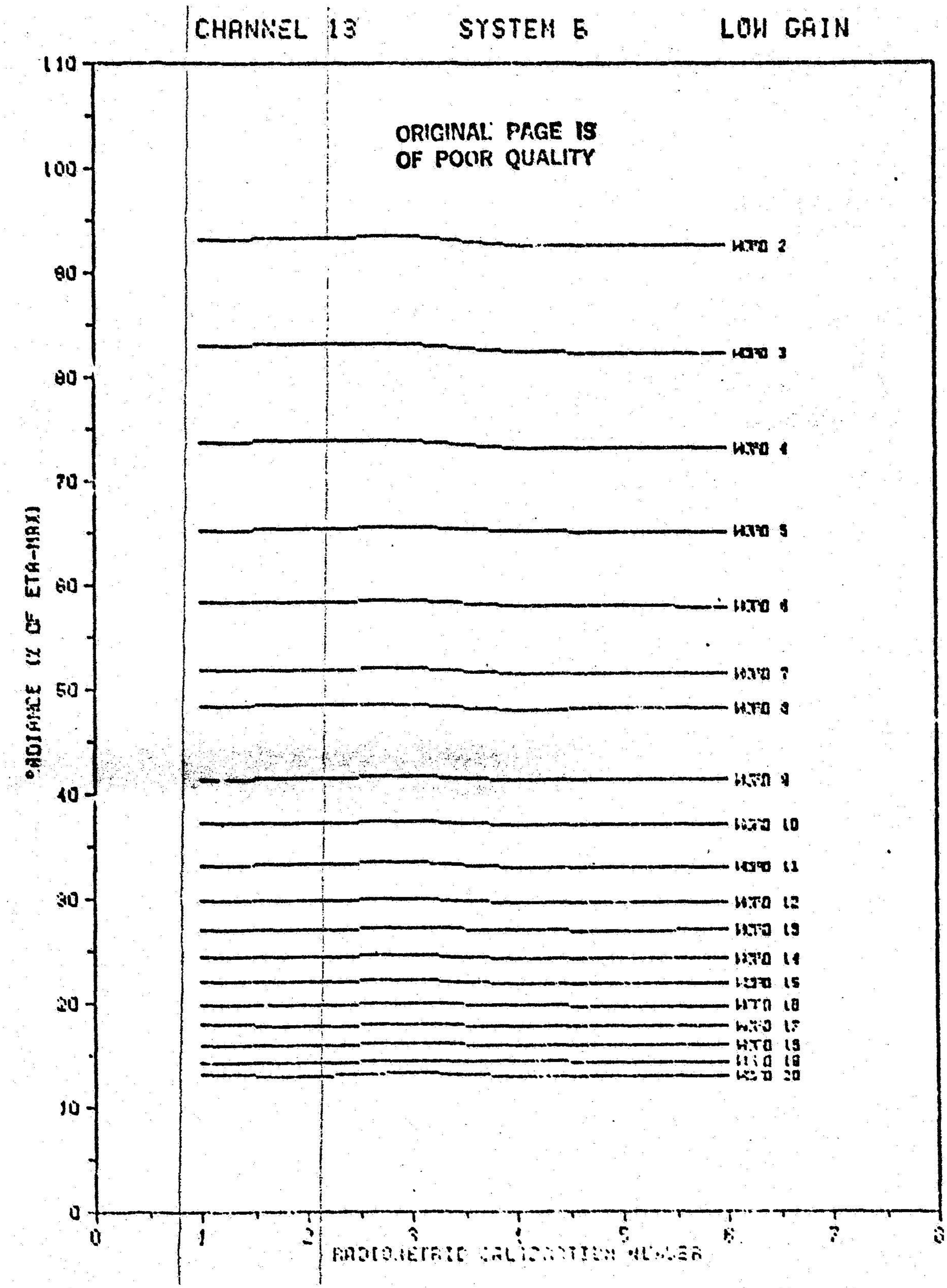
CHANNEL 12 SYSTEM B LOW GAIN



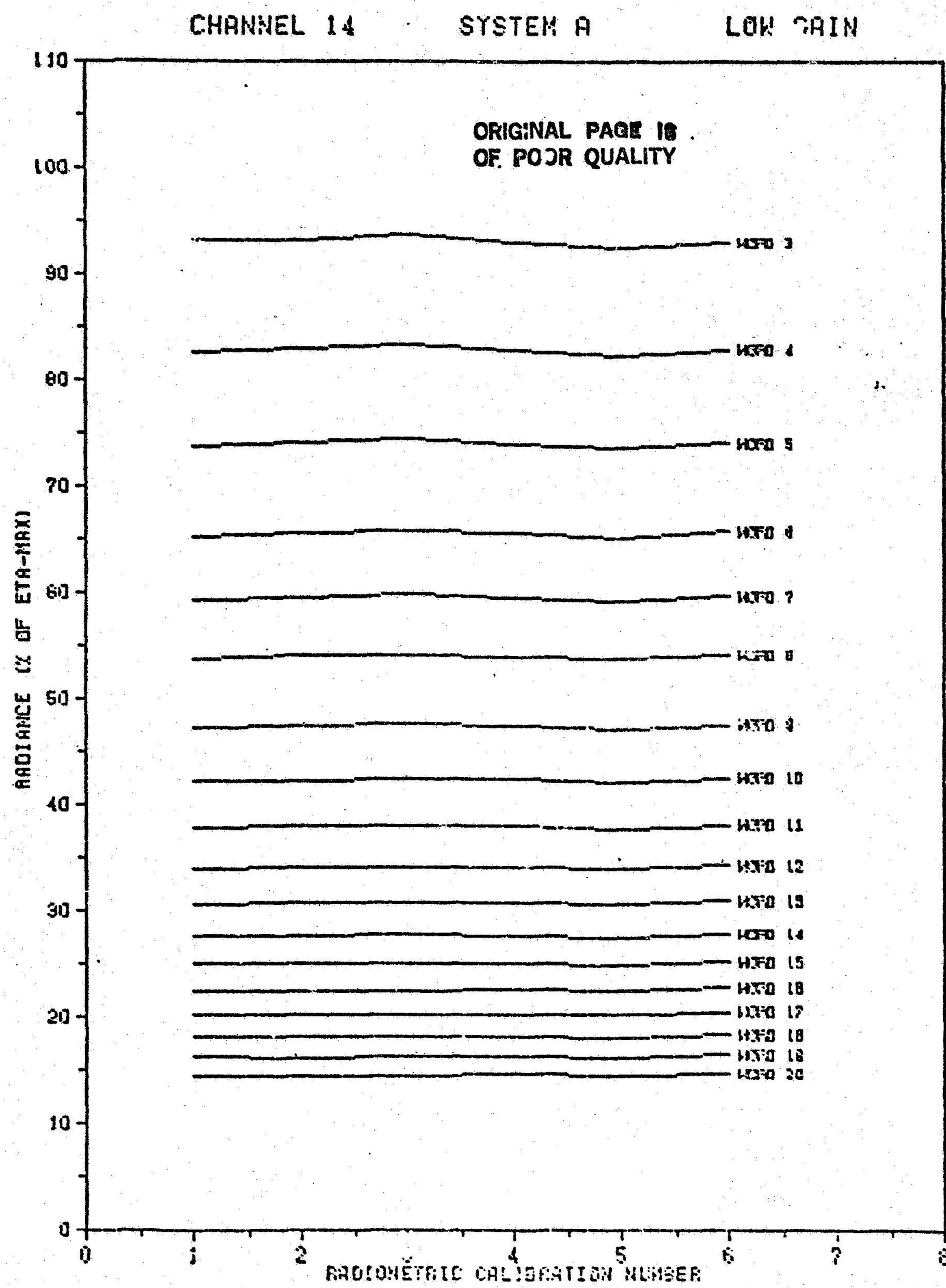
ORIGINAL PAGE IS
OF POOR QUALITY

CHANNEL 13 SYSTEM A LOW GAIN



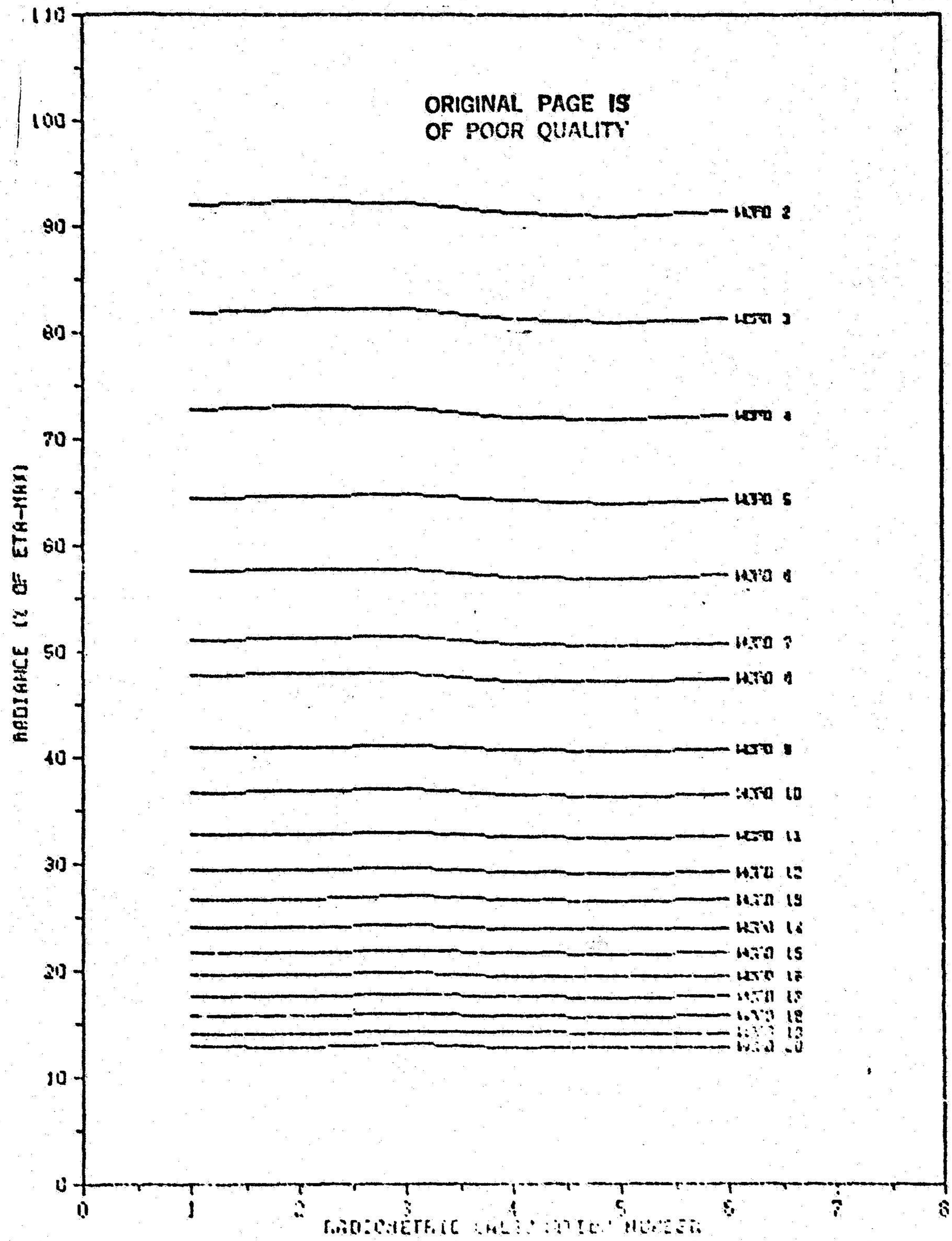


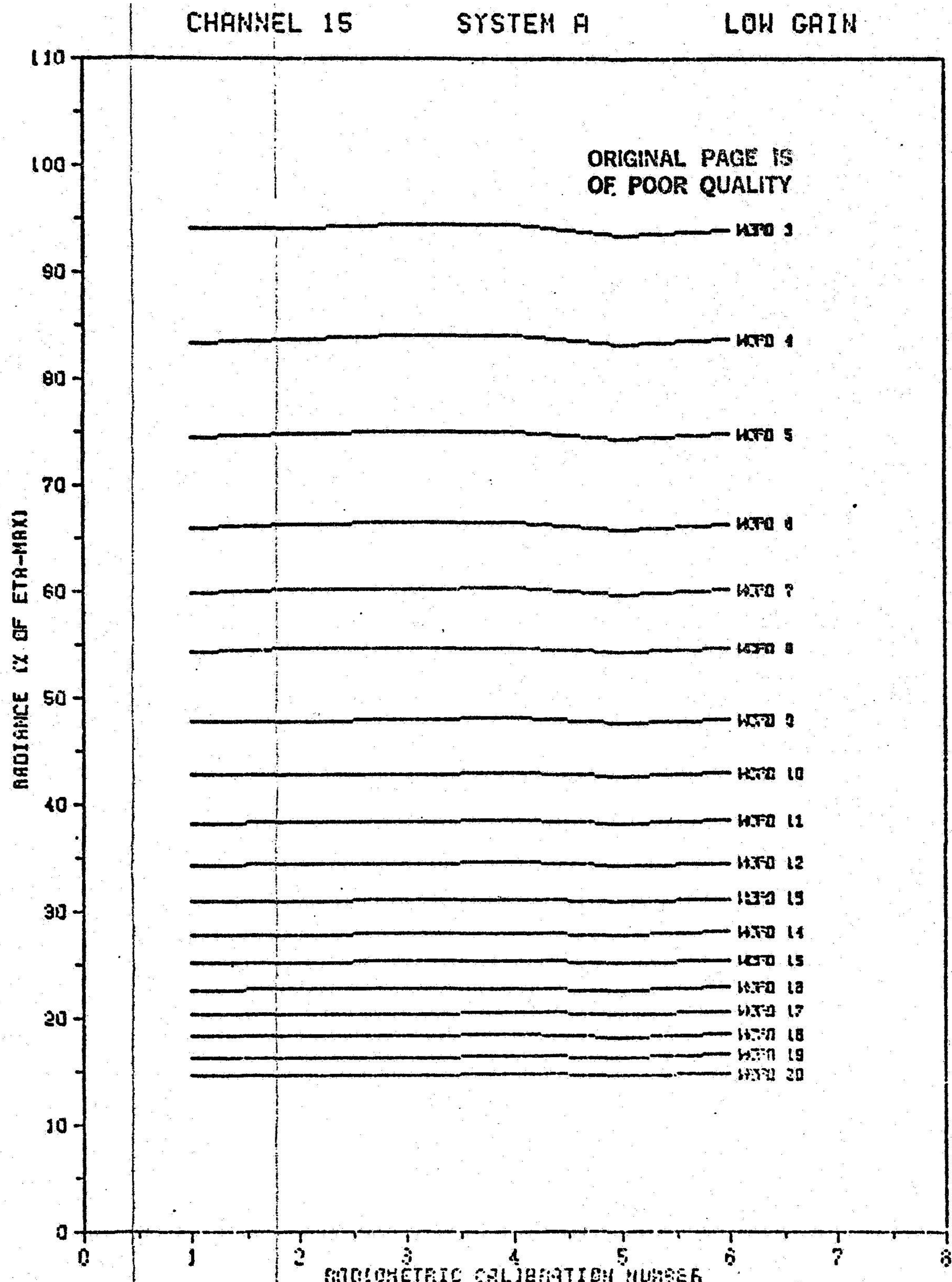
CHANNEL 13
SYSTEM 6
LOW GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER

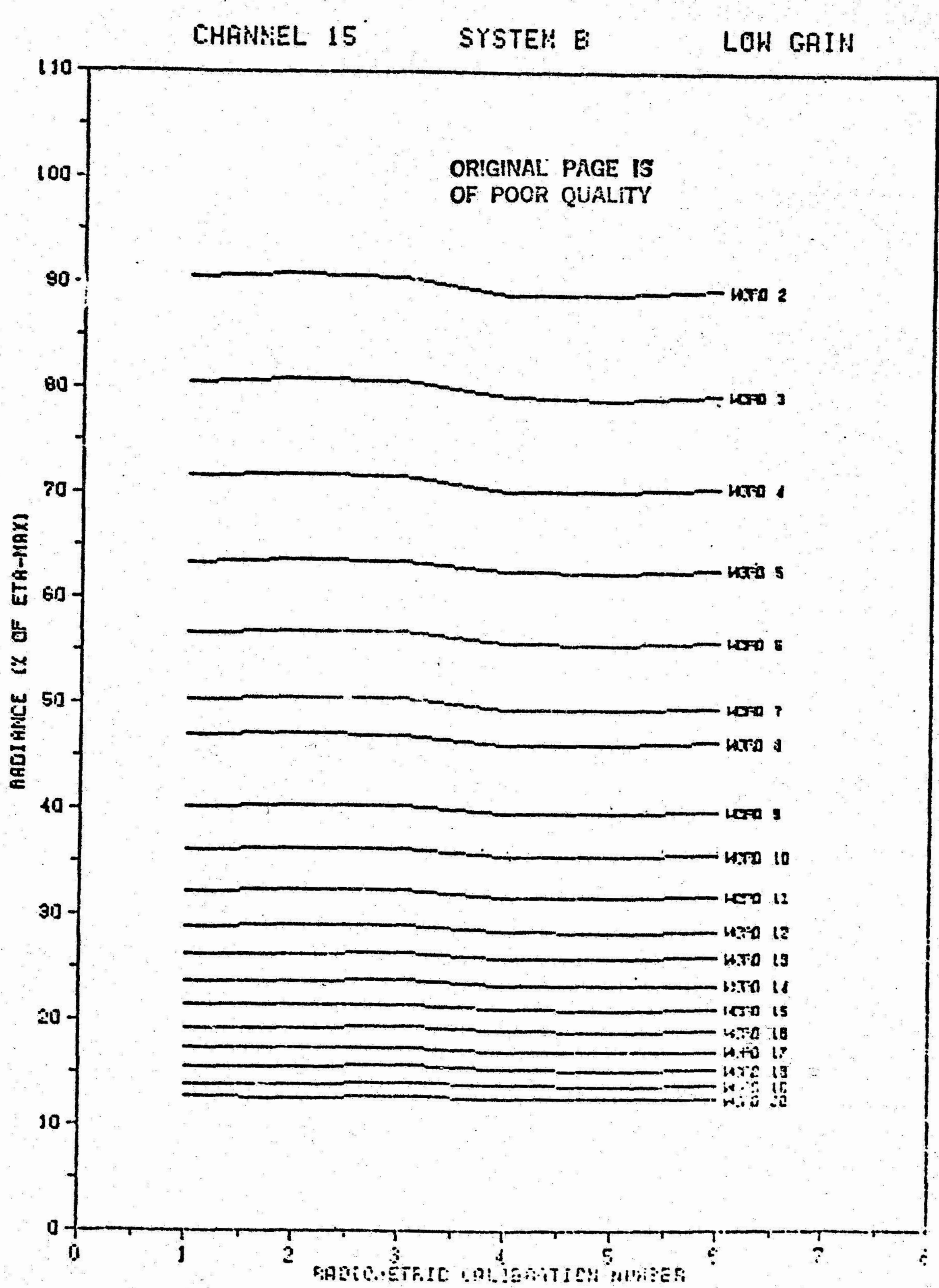


CHANNEL 14
SYSTEM A
LOW GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER

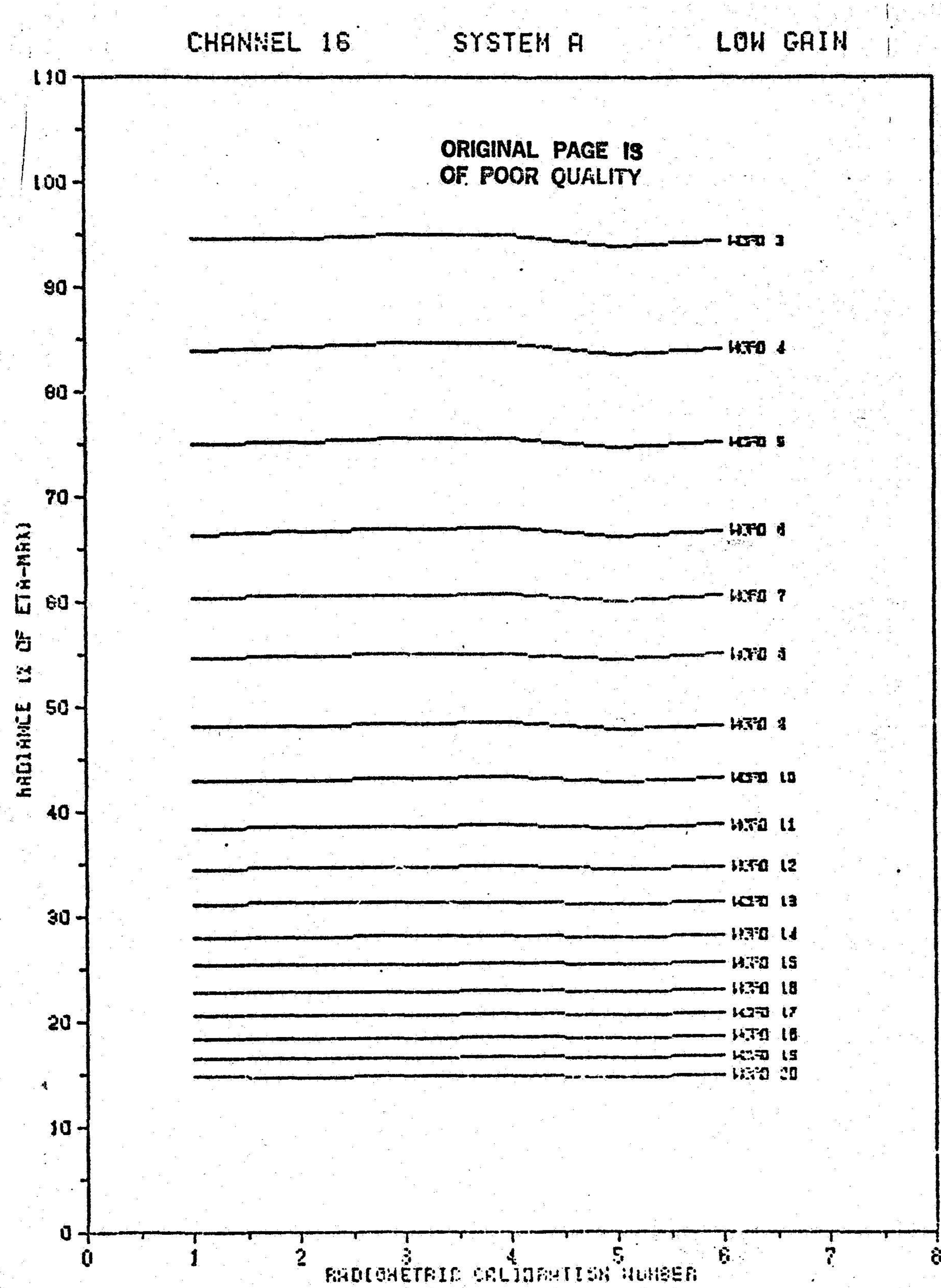
CHANNEL 14 SYSTEM B LOW GAIN



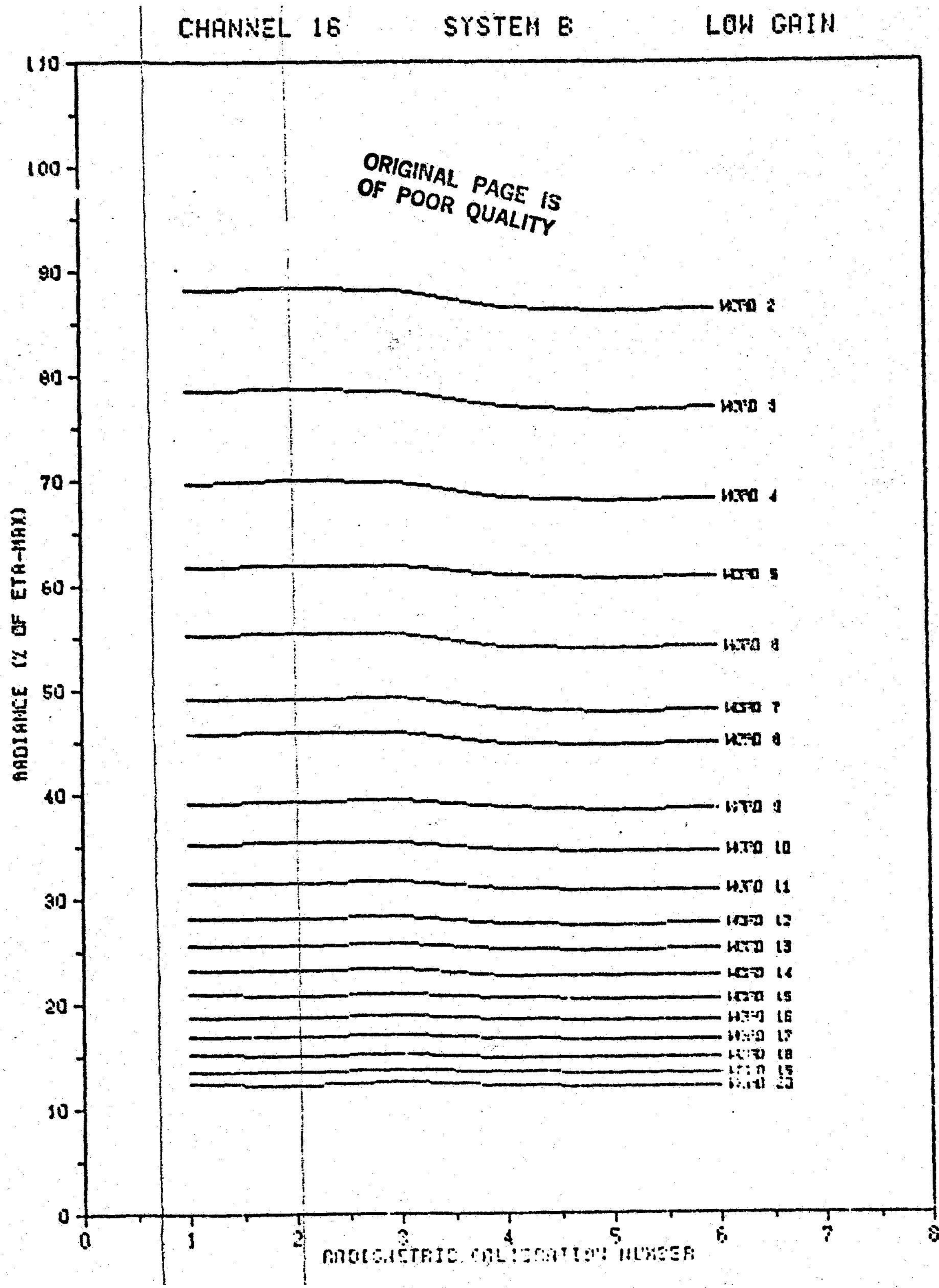

CHANNEL 15 SYSTEM A LOW GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER



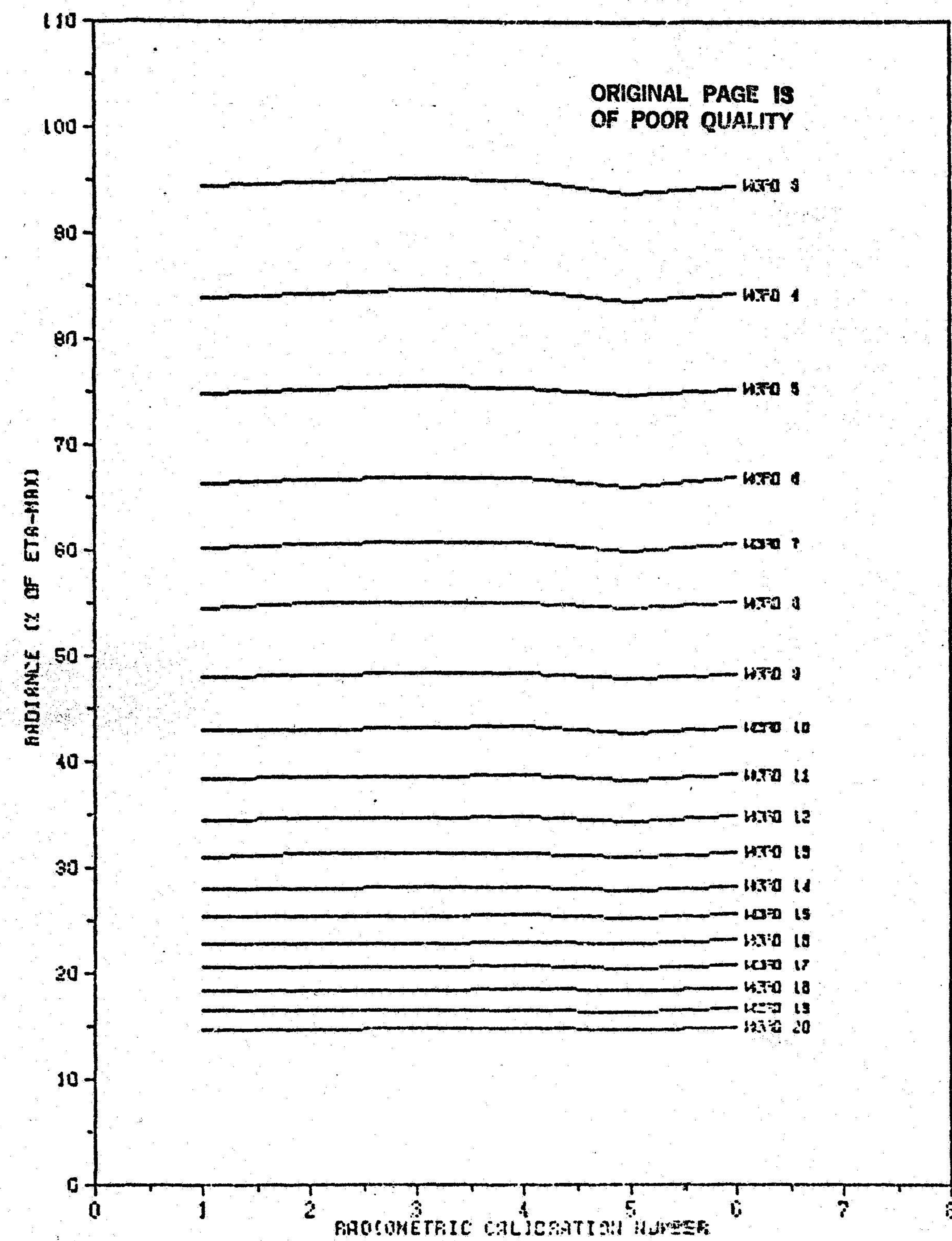
CHANNEL 15
SYSTEM B
LOW GAIN
ORIGINAL PAGE IS OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER
WORD 2
WORD 3
WORD 4
WORD 5
WORD 6
WORD 7
WORD 8
WORD 9
WORD 10
WORD 11
WORD 12
WORD 13
WORD 14
WORD 15
WORD 16
WORD 17
WORD 18
WORD 19
WORD 20

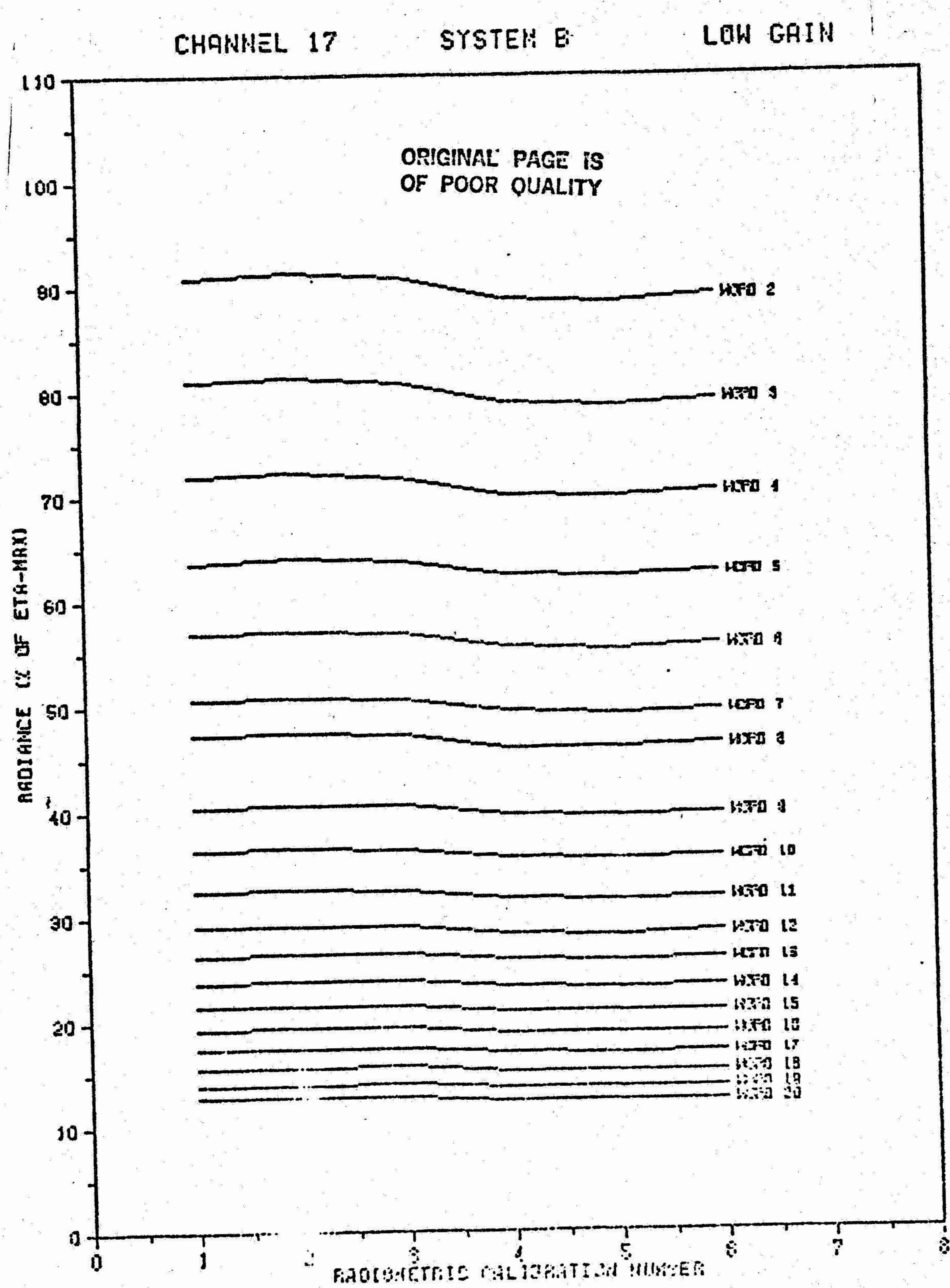


CHANNEL 16
SYSTEM A
LOW GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER


CHANNEL 16
SYSTEM B
LOW GAIN
ORIGINAL PAGE IS OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
0
10
20
30
40
50
60
70
80
90
100
110
0
1
2
3
4
5
6
7
8

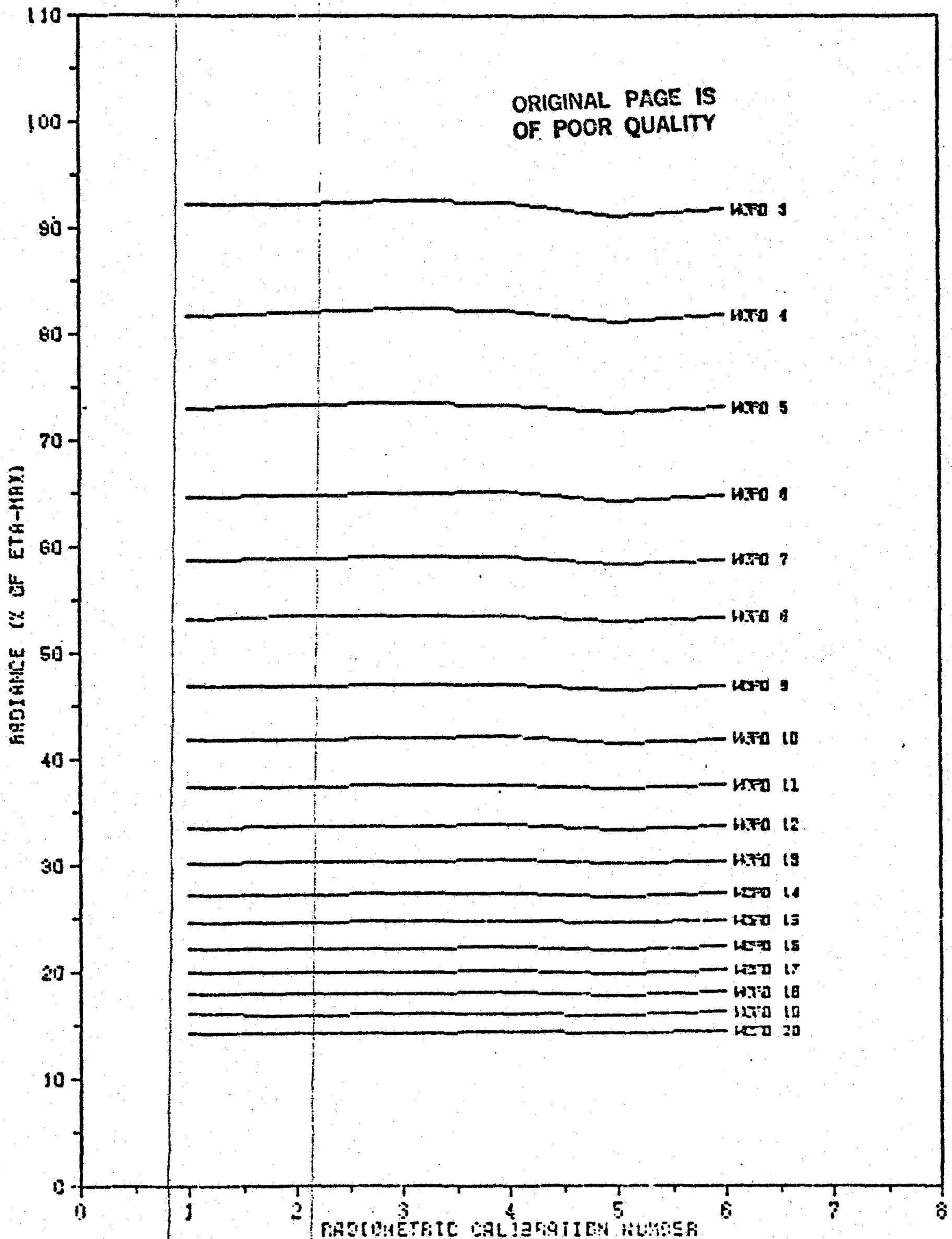
CHANNEL 17 SYSTEM A LOW GAIN

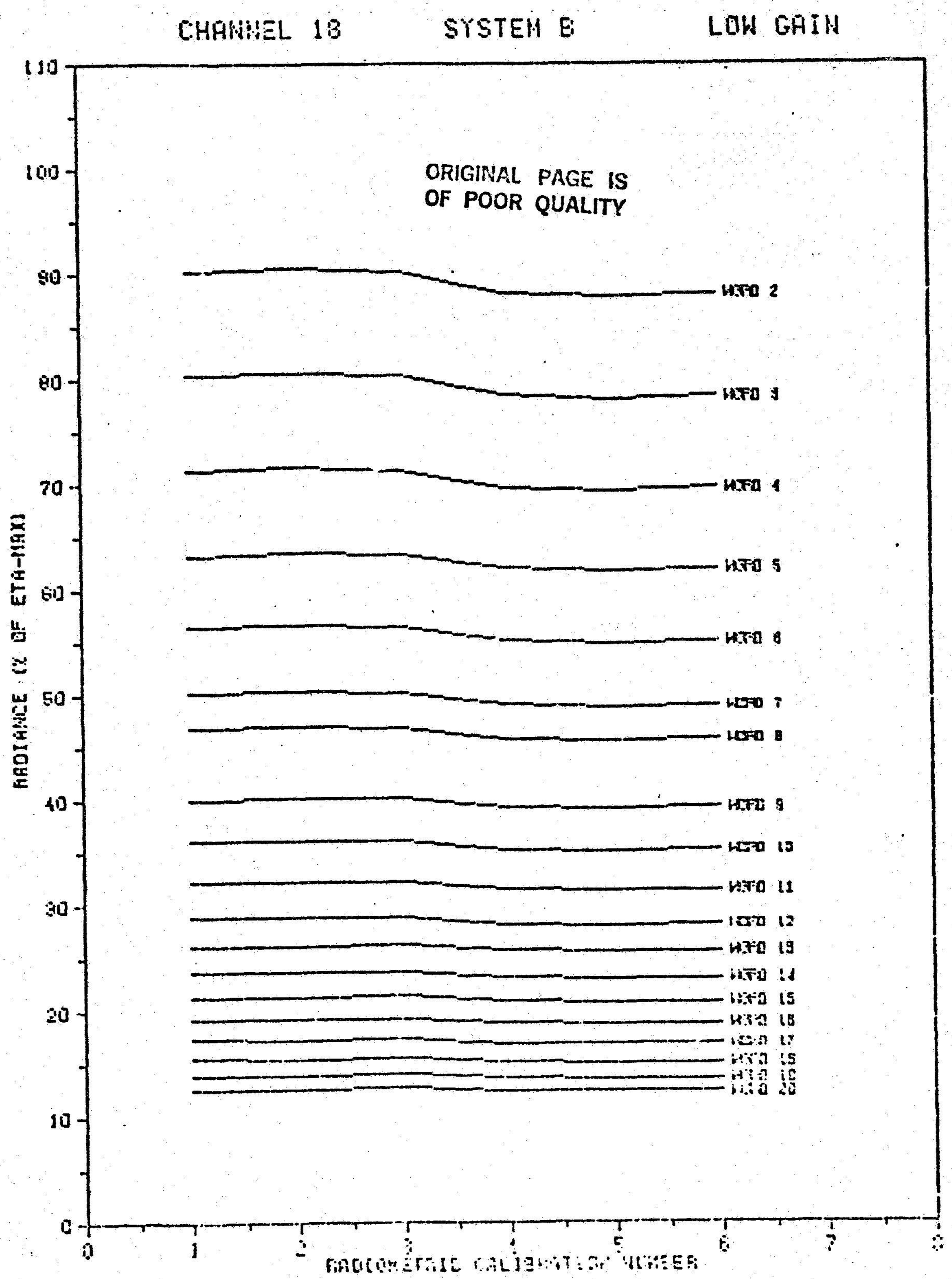




ORIGINAL PAGE IS
OF POOR QUALITY

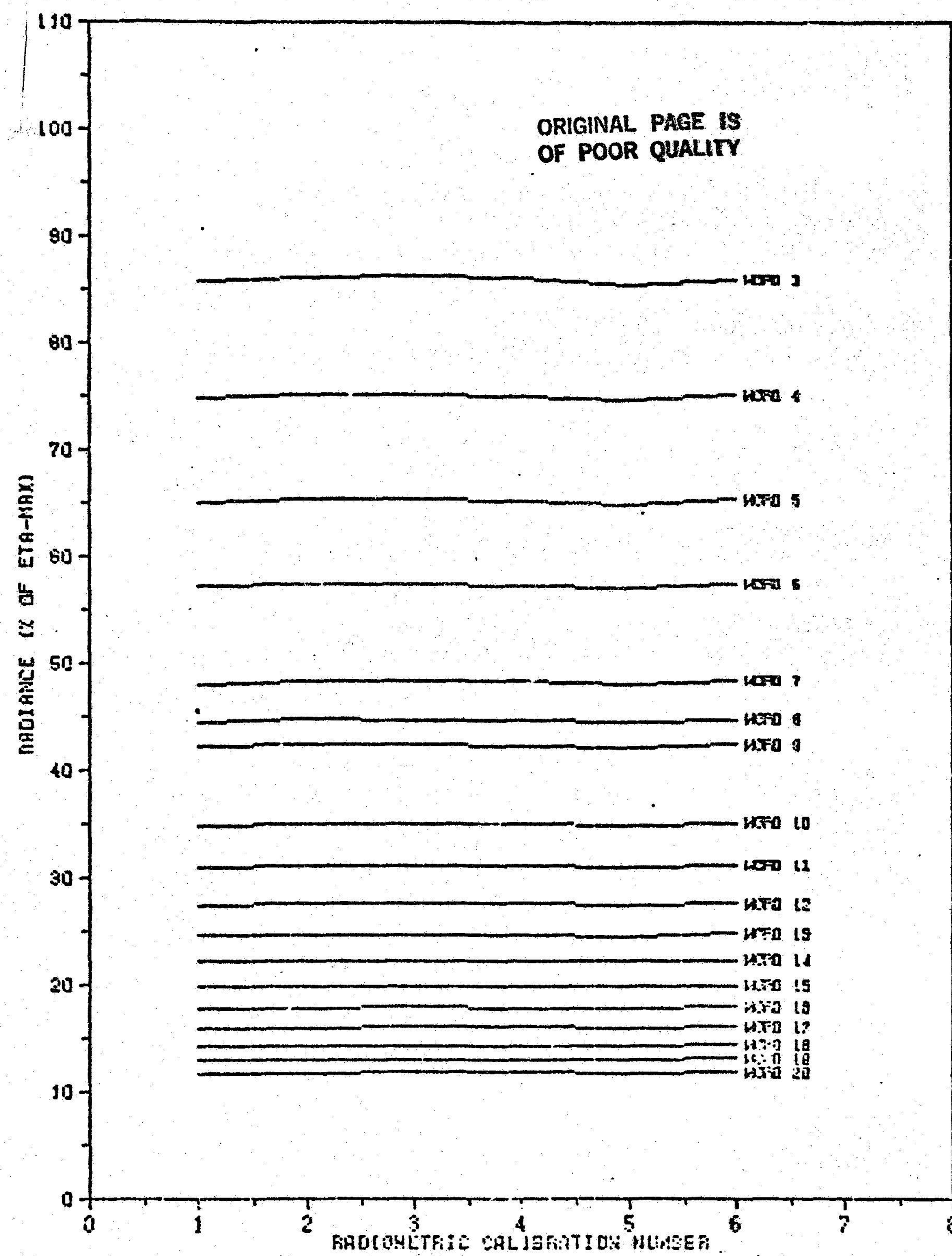
CHANNEL 18 SYSTEM A LOW GAIN

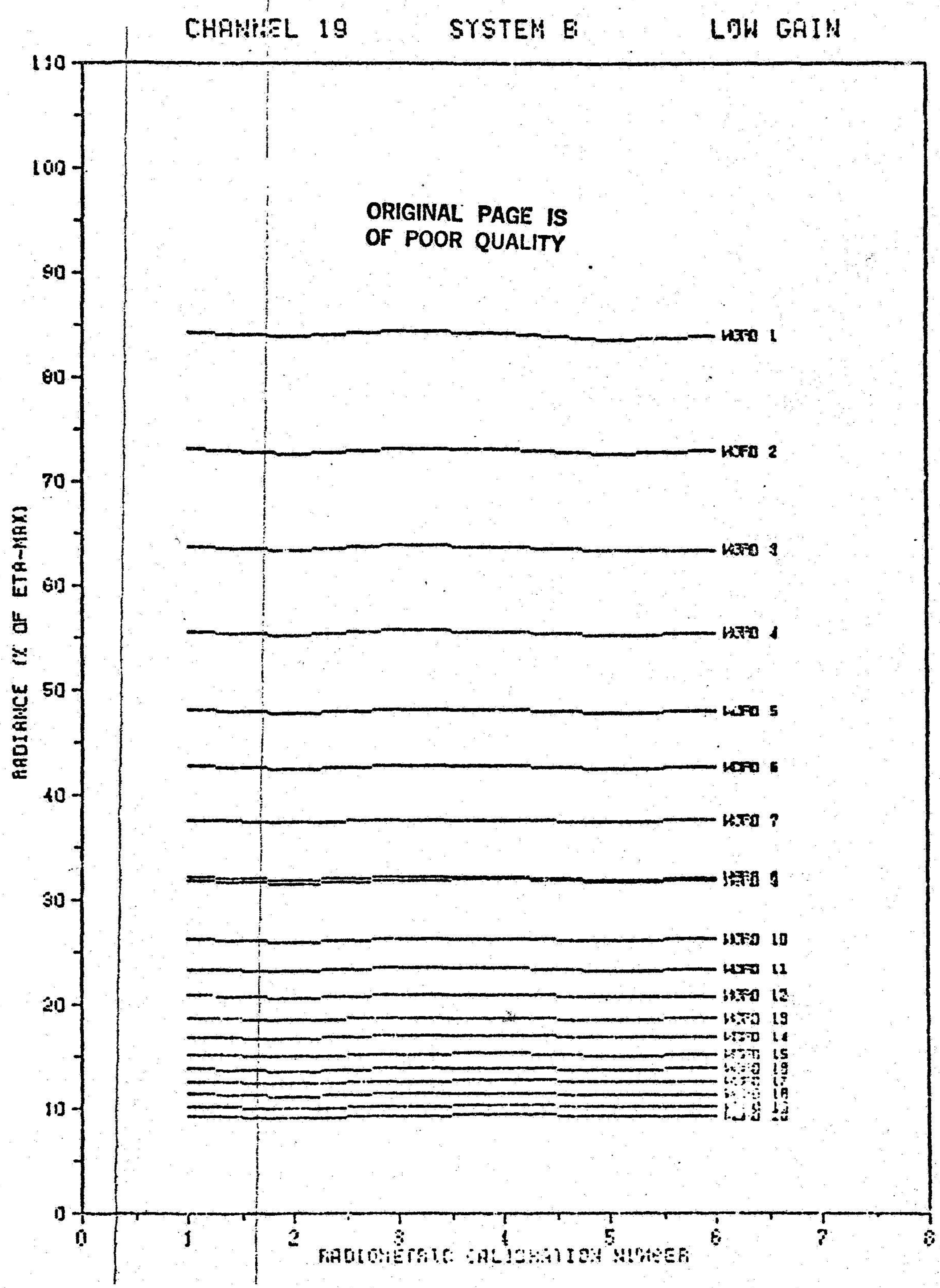




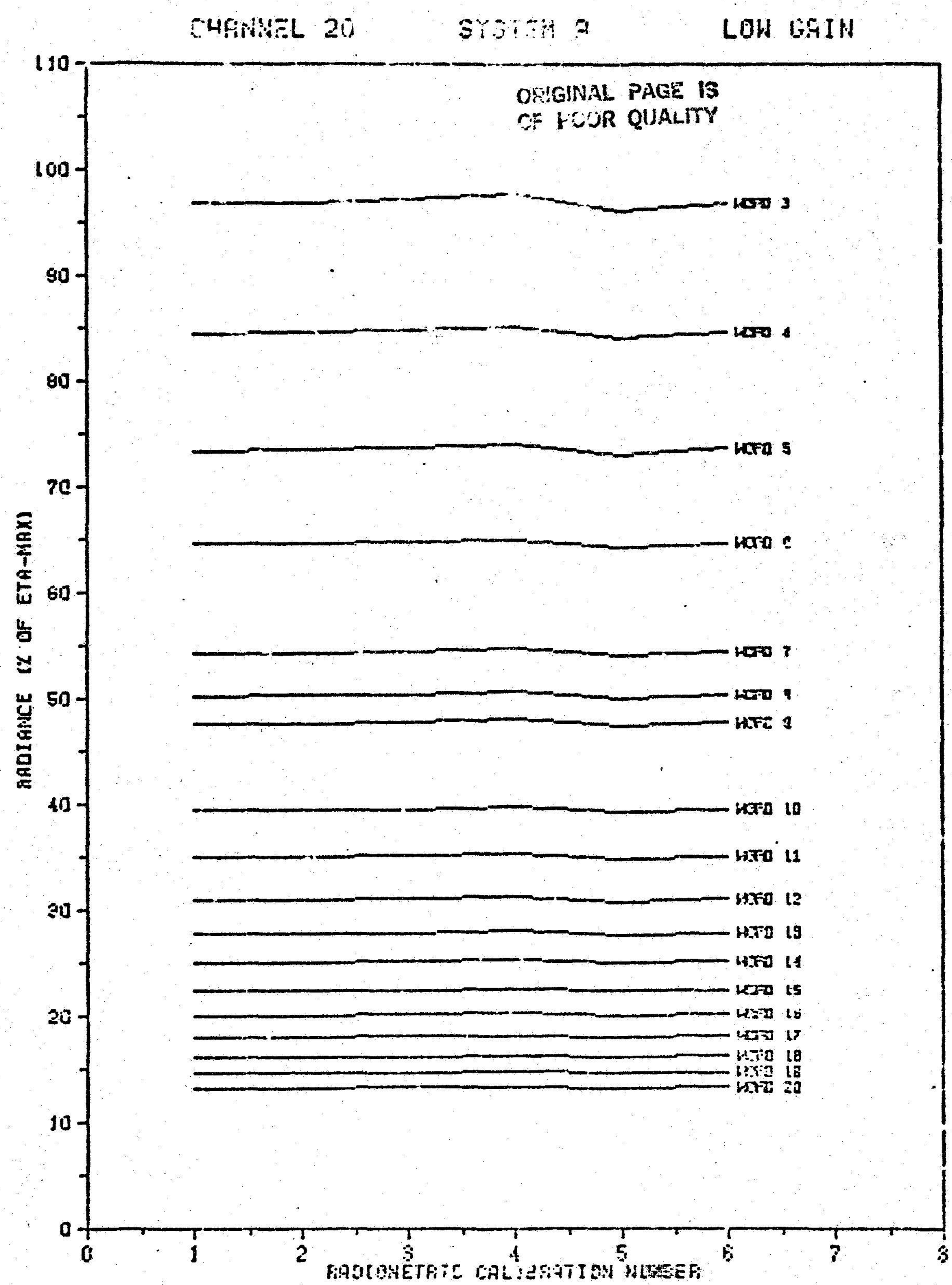
CHANNEL 18
SYSTEM B
LOW GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER

CHANNEL 19 SYSTEM A LOW GAIN

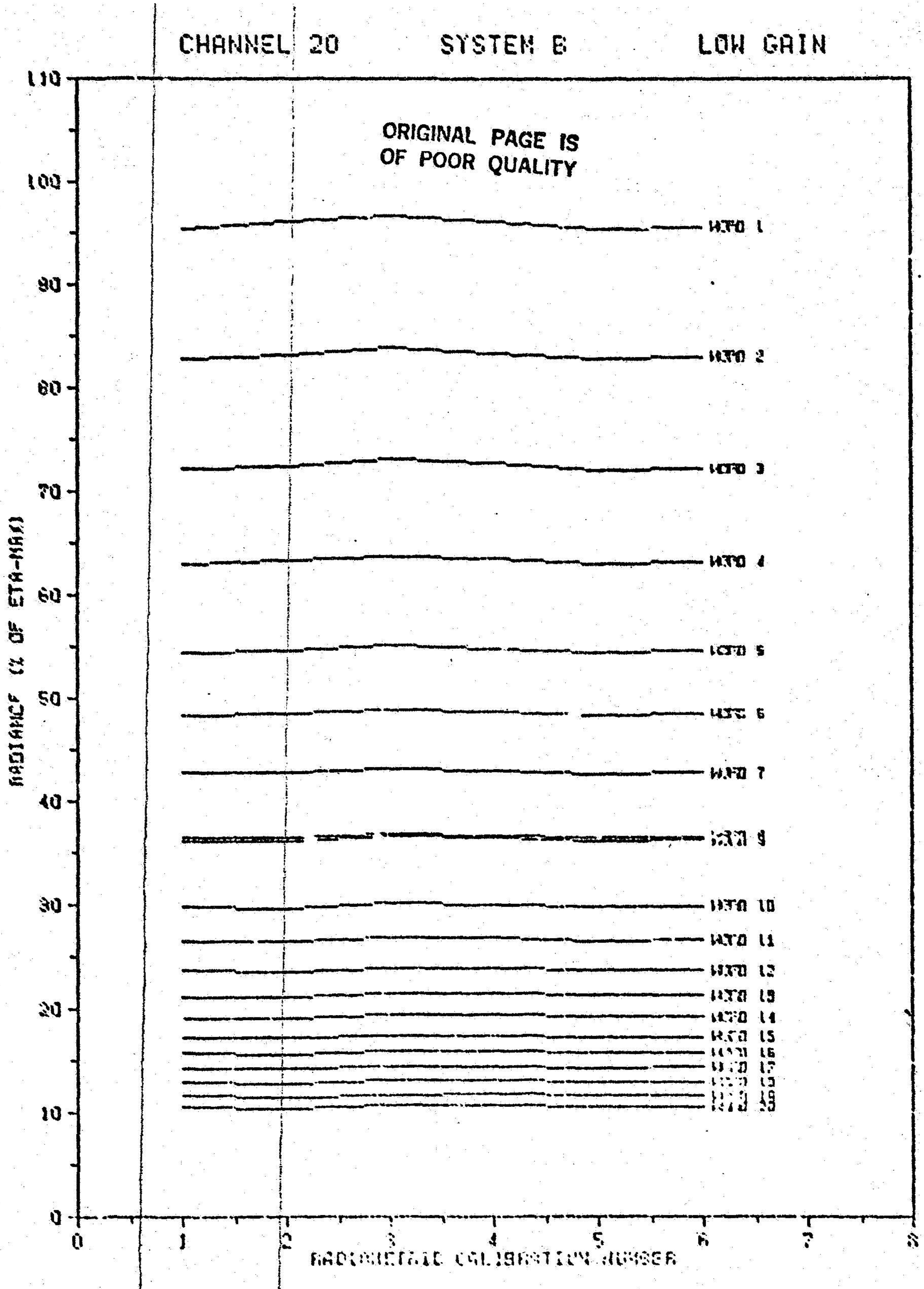




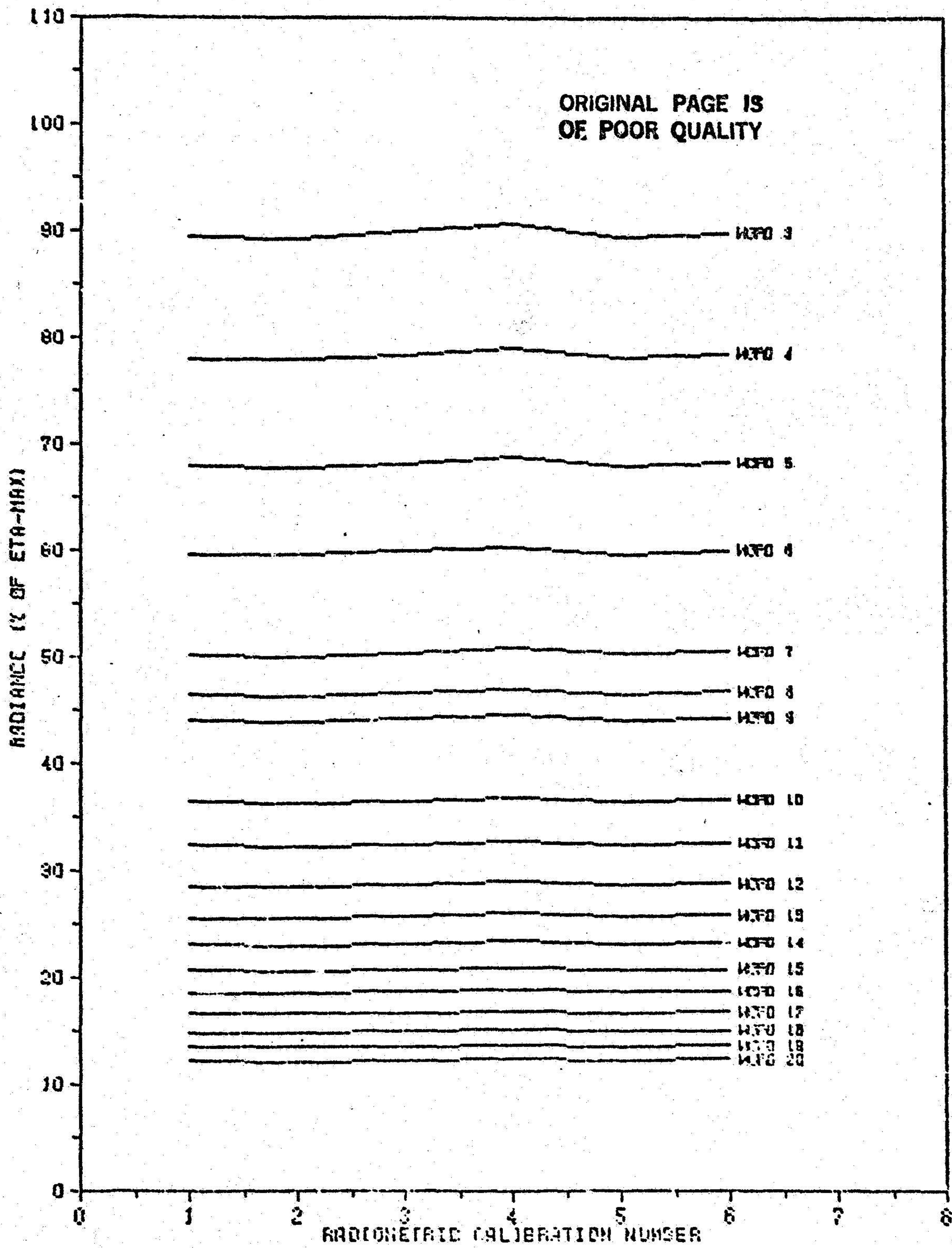
CHANNEL 19
SYSTEM B
LOW GAIN
ORIGINAL PAGE IS OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER



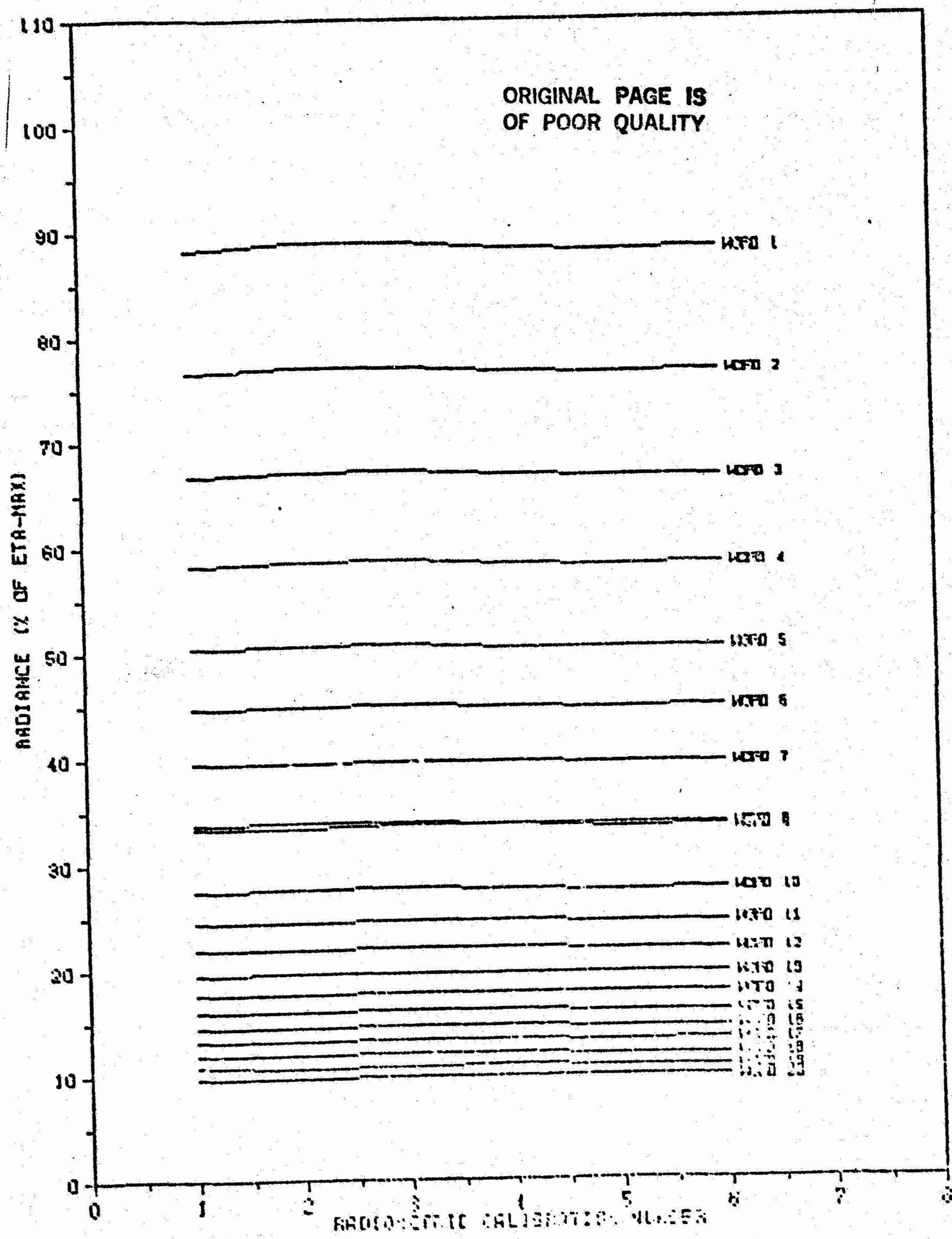
CHANNEL 20
SYSTEM A
LOW GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER


CHANNEL 20
SYSTEM B
LOW GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
0
10
20
30
40
50
60
70
80
90
100
110
0
1
2
3
4
5
6
7
8

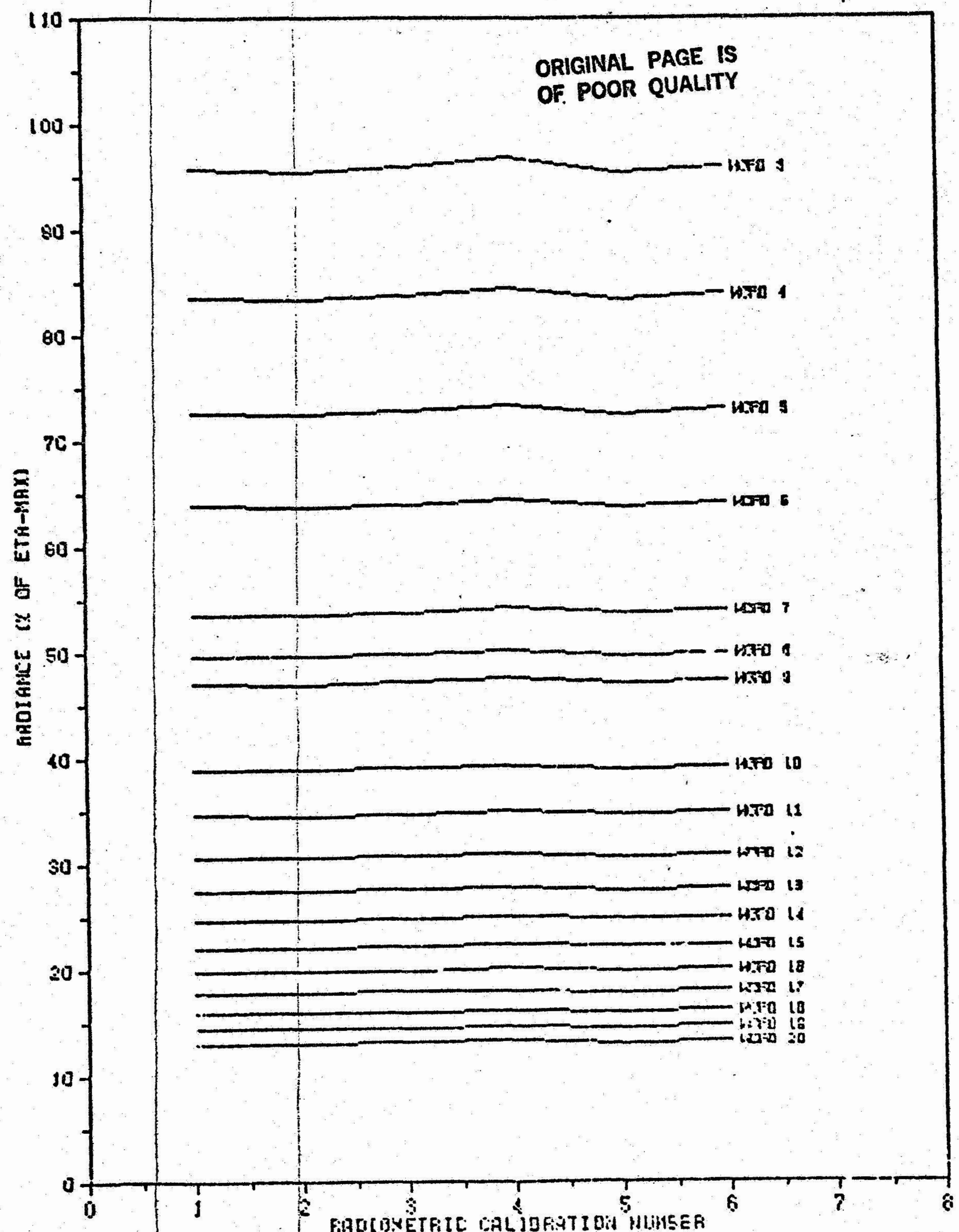
CHANNEL 21 SYSTEM A LOW GAIN



CHANNEL 21 SYSTEM B LOW GAIN

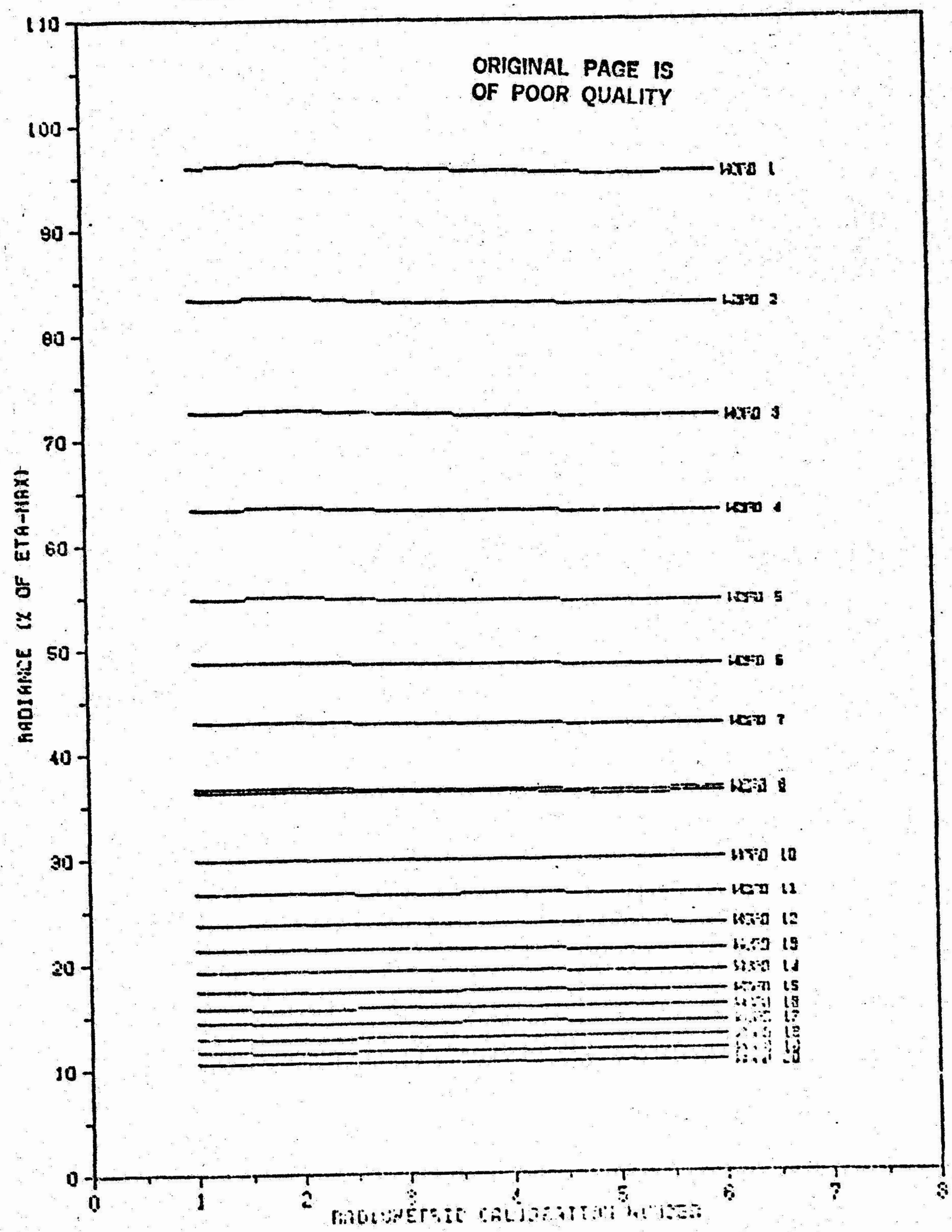


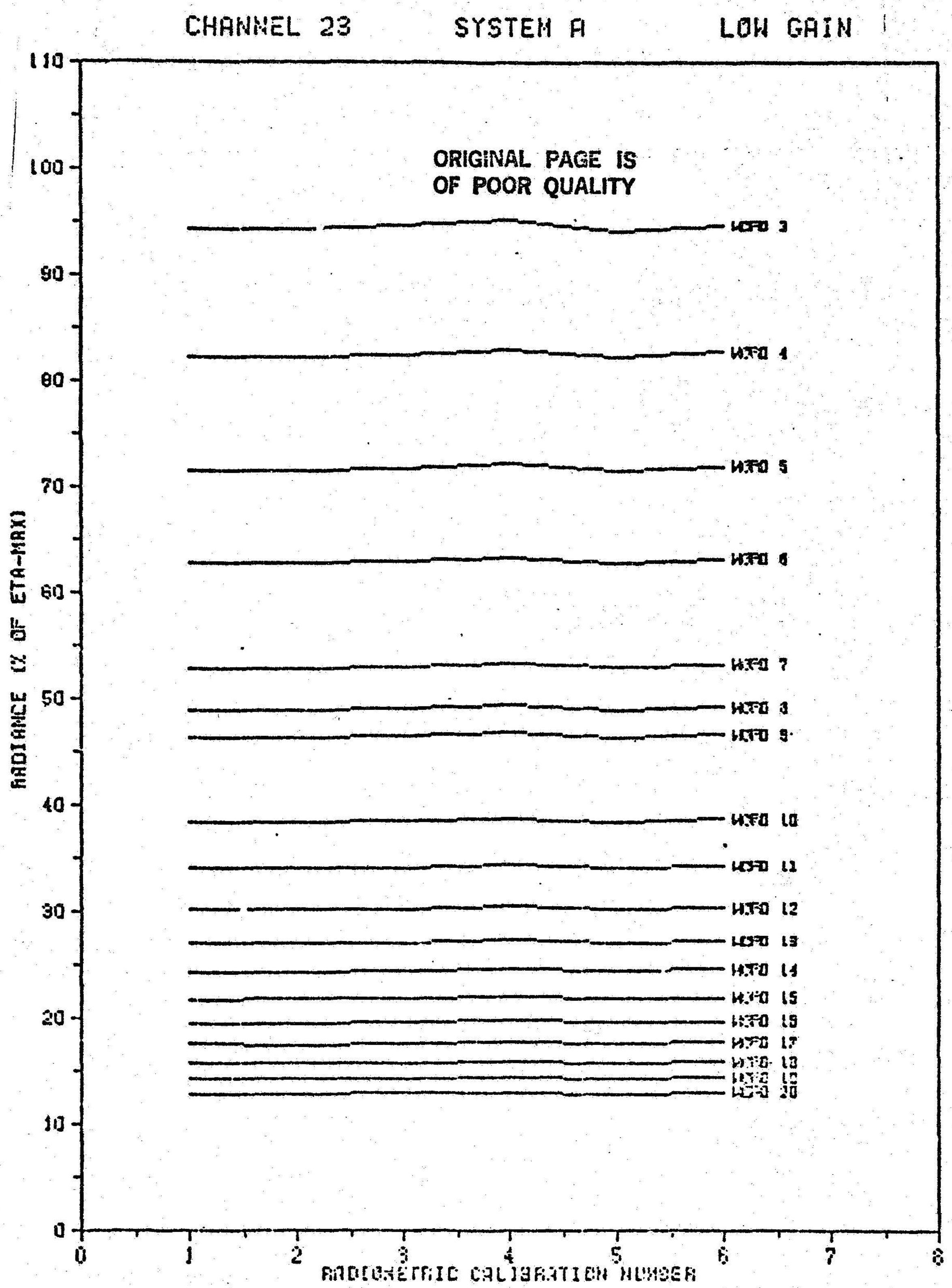
CHANNEL 22 SYSTEM A LOW GAIN

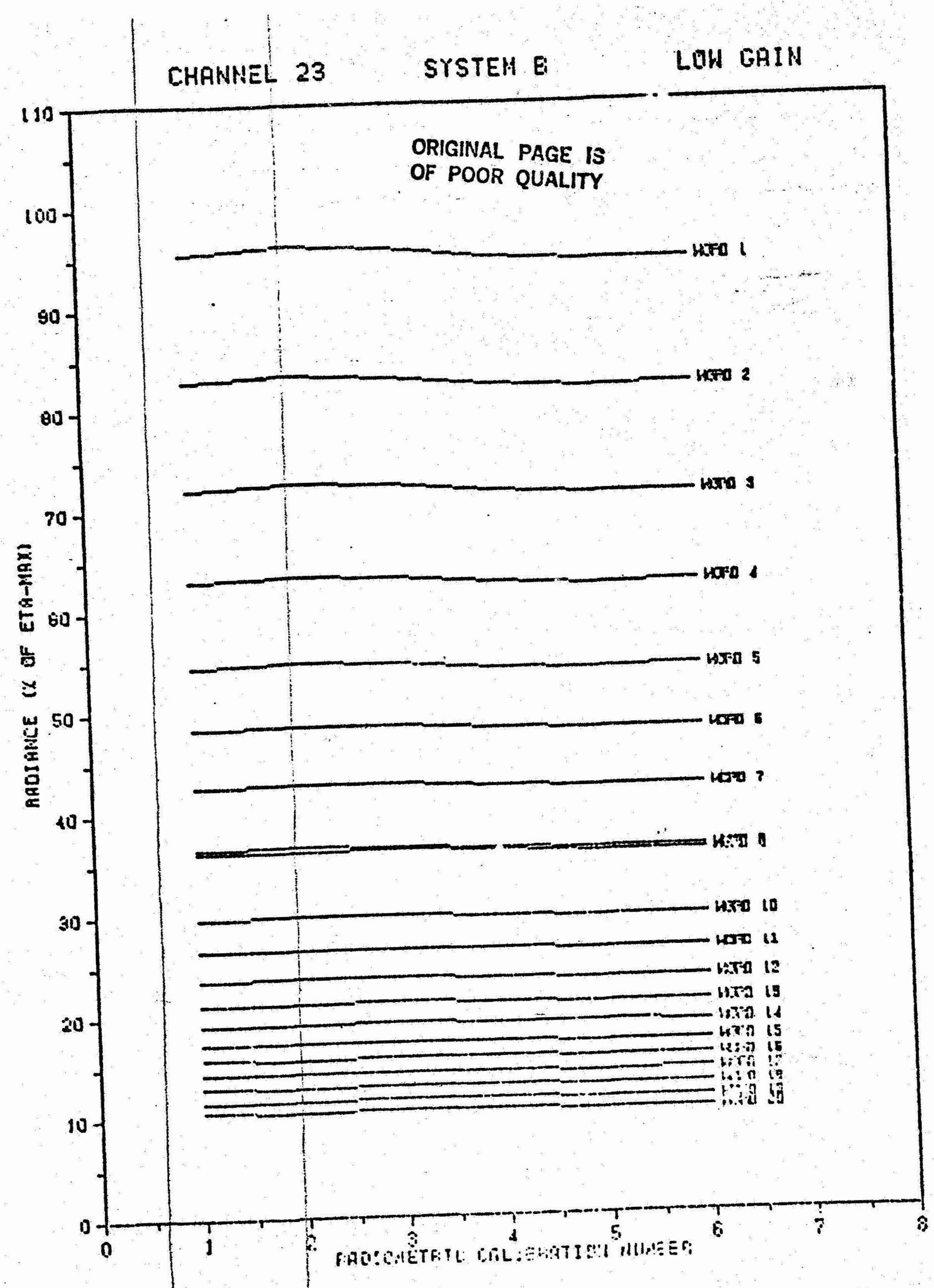


CHANNEL 22 SYSTEM B LOW GAIN

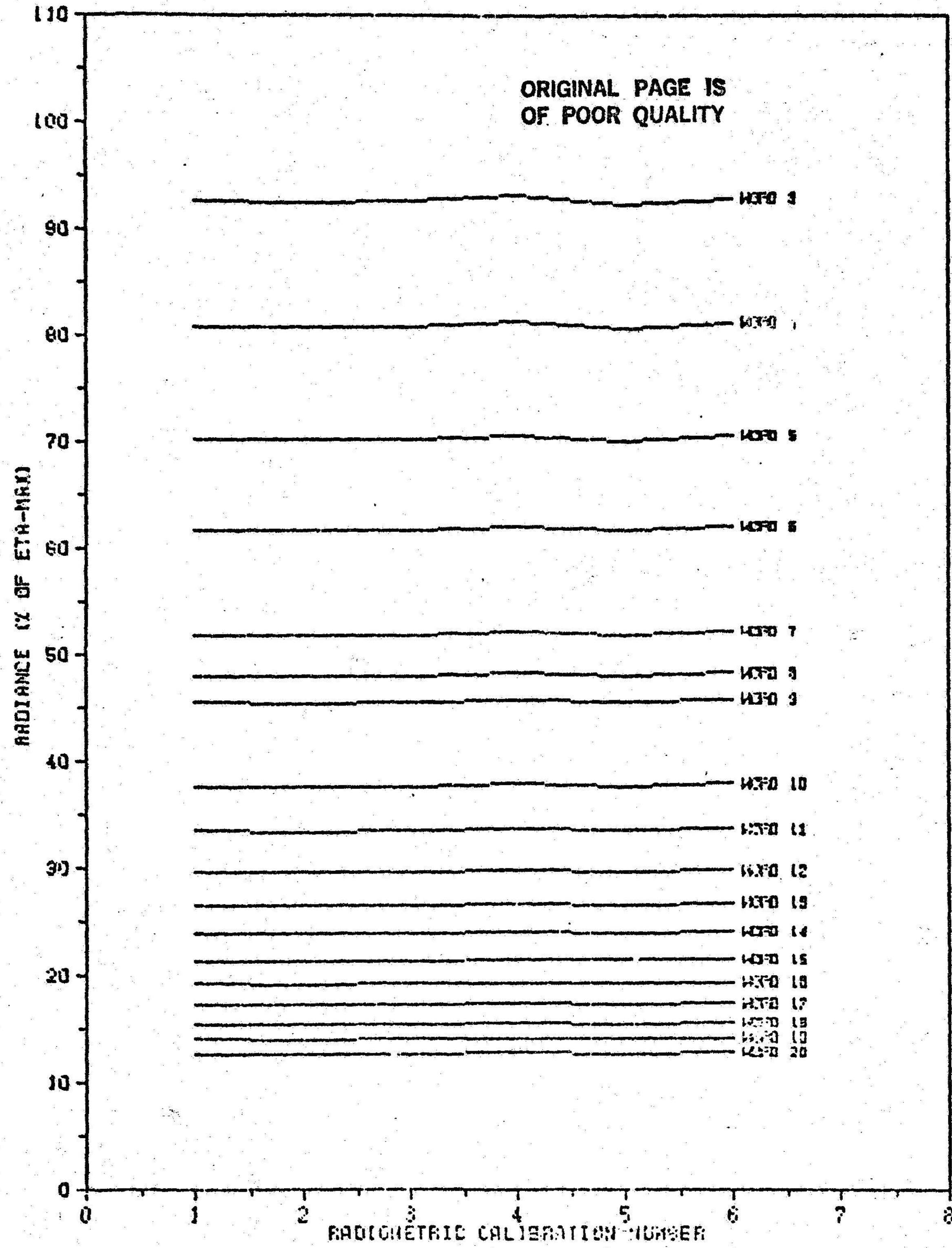
ORIGINAL PAGE IS
OF POOR QUALITY

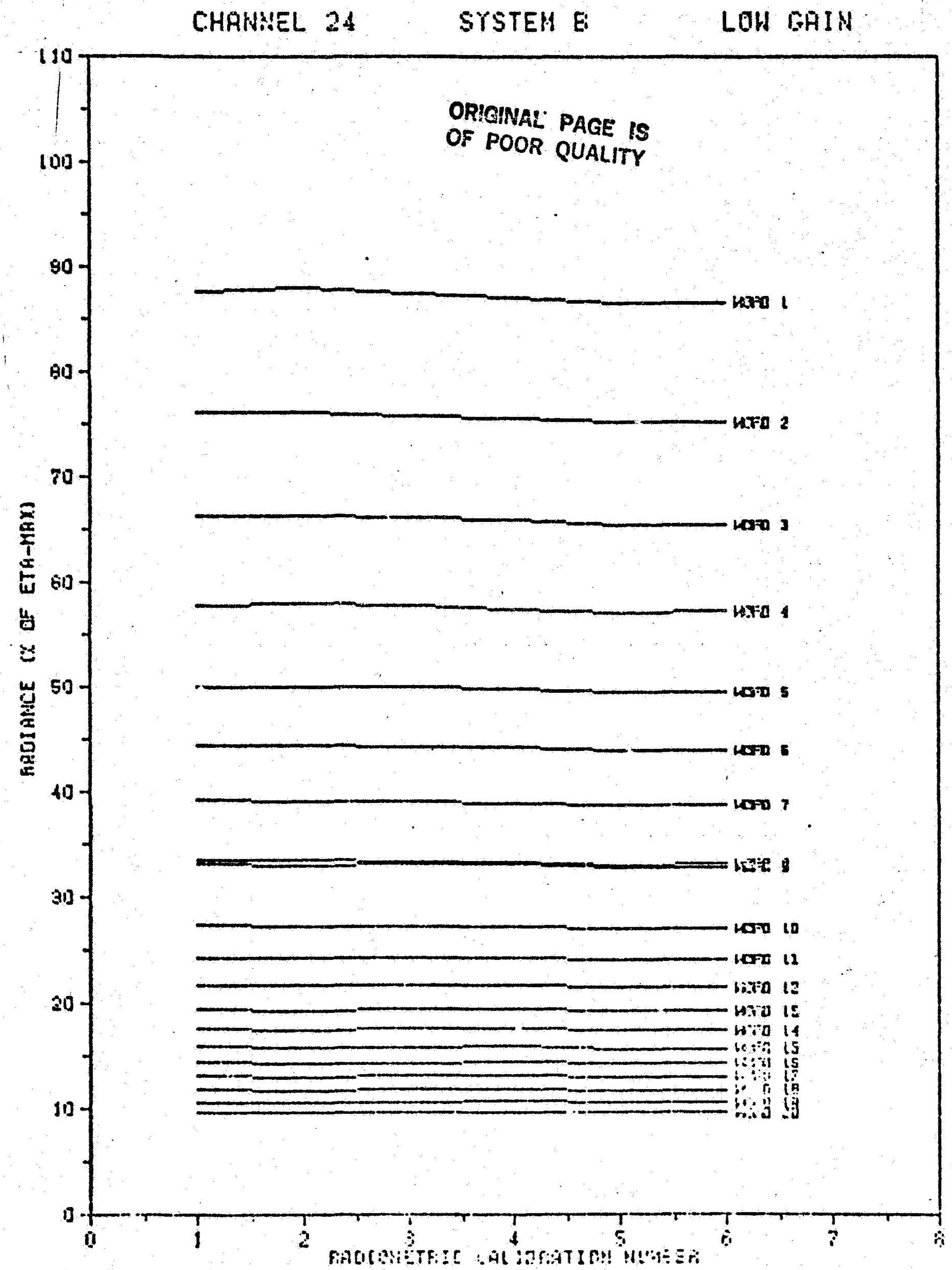



CHANNEL 23 SYSTEM A LOW GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER
0
10
20
30
40
50
60
70
80
90
100
110
1
2
3
4
5
6
7
8

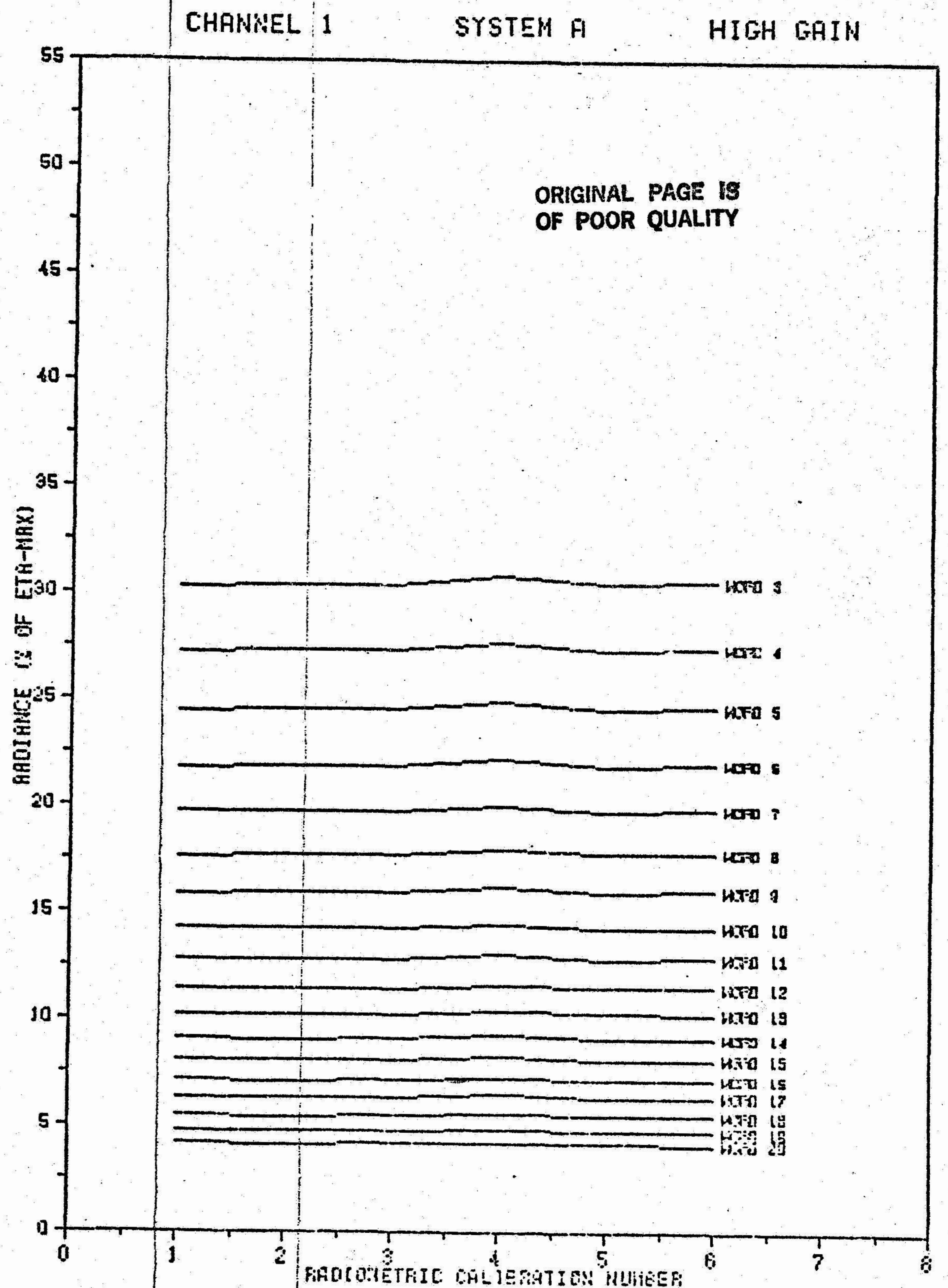

CHANNEL 23
SYSTEM B
LOW GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER
WORD 1
WORD 2
WORD 3
WORD 4
WORD 5
WORD 6
WORD 7
WORD 8
WORD 10
WORD 11
WORD 12
WORD 13
WORD 14
WORD 15

CHANNEL 24 SYSTEM A LOW GAIN



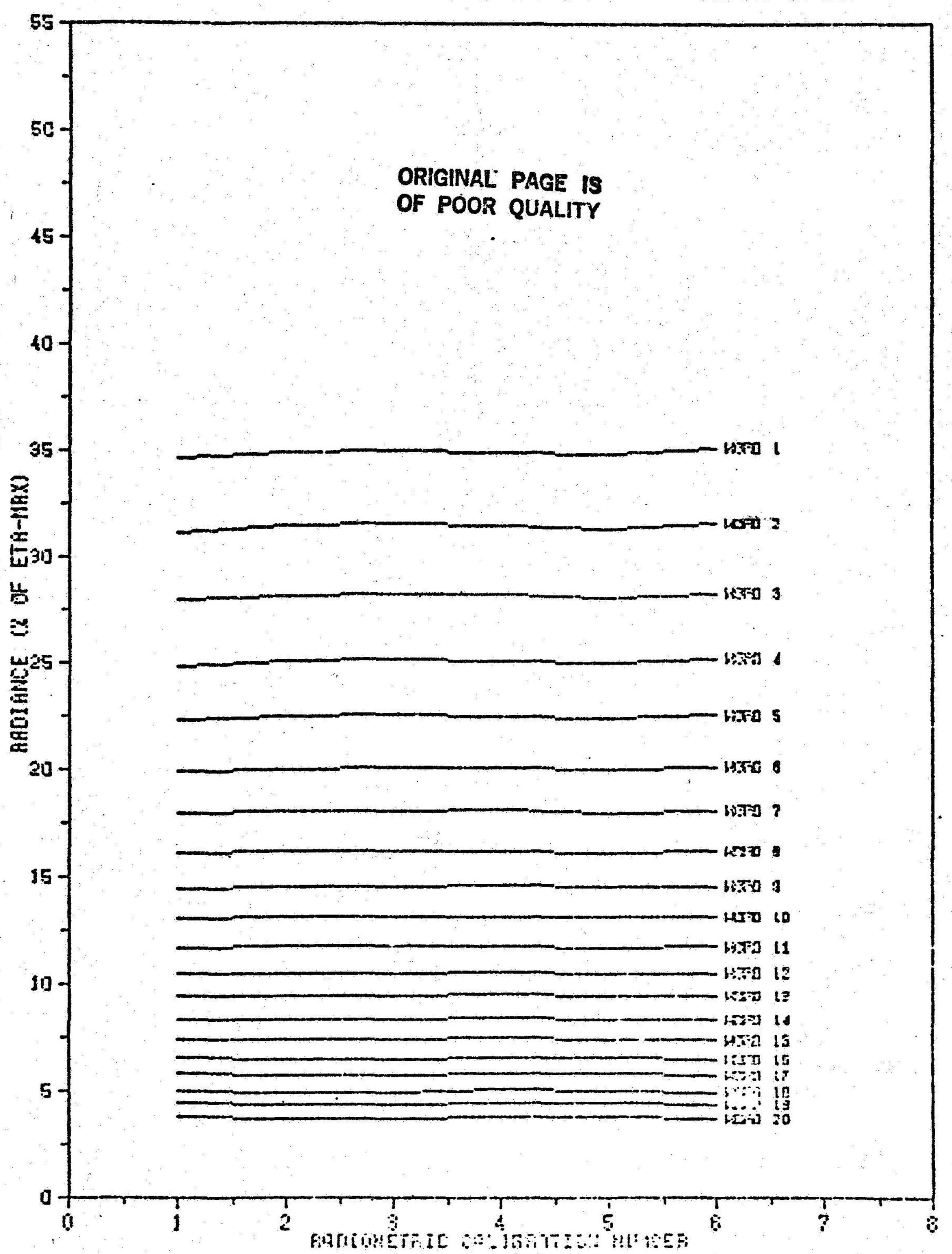


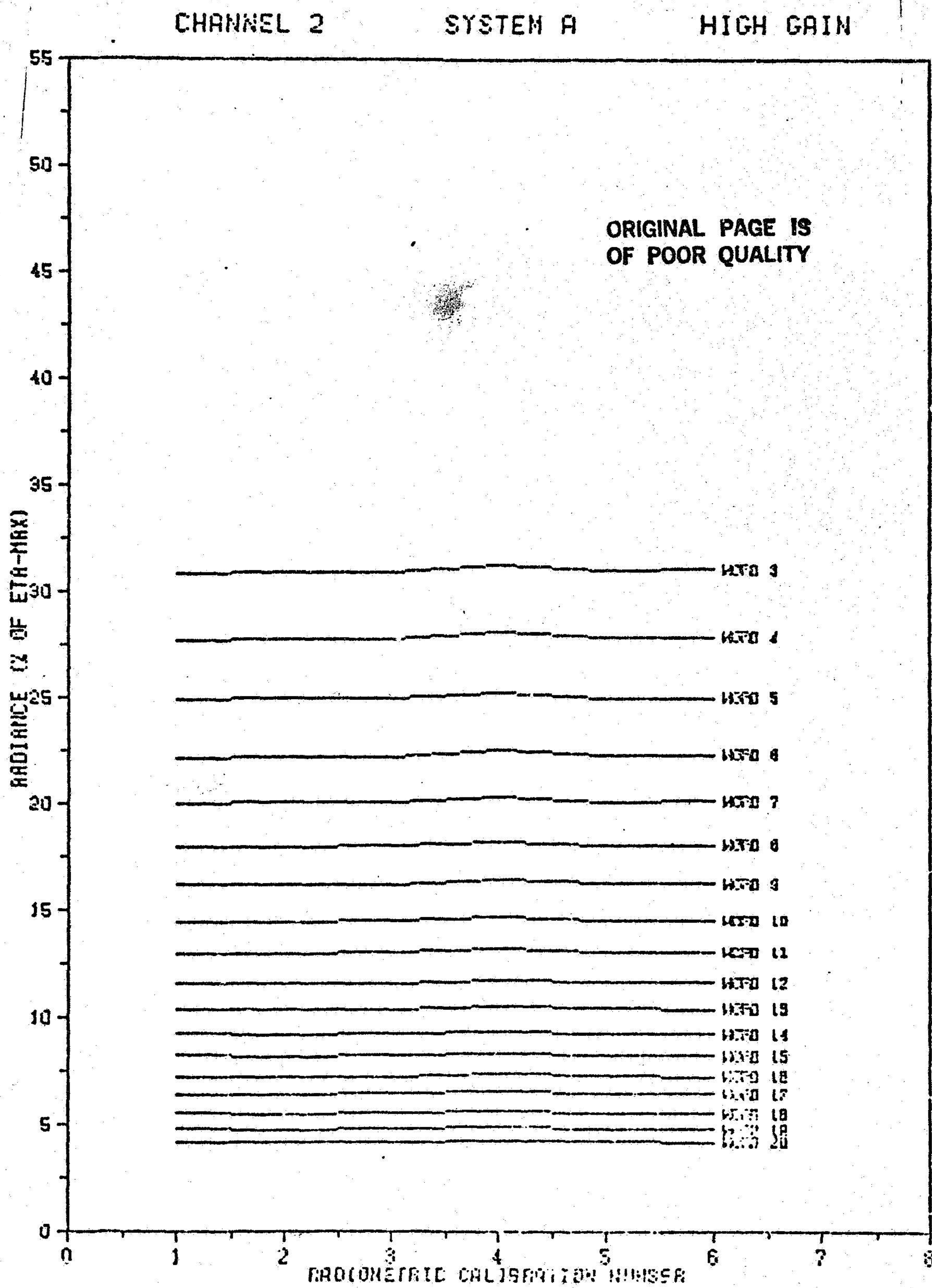
CHANNEL 24
SYSTEM B
LOW GAIN
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER
ORIGINAL PAGE IS OF POOR QUALITY



CHANNEL 1
SYSTEM A
HIGH GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER

CHANNEL 1 SYSTEM B HIGH GAIN





CHANNEL 2
SYSTEM A
HIGH GAIN
RADIANCE (% OF ETA-MAX)
0
5
10
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25
30
35
40
45
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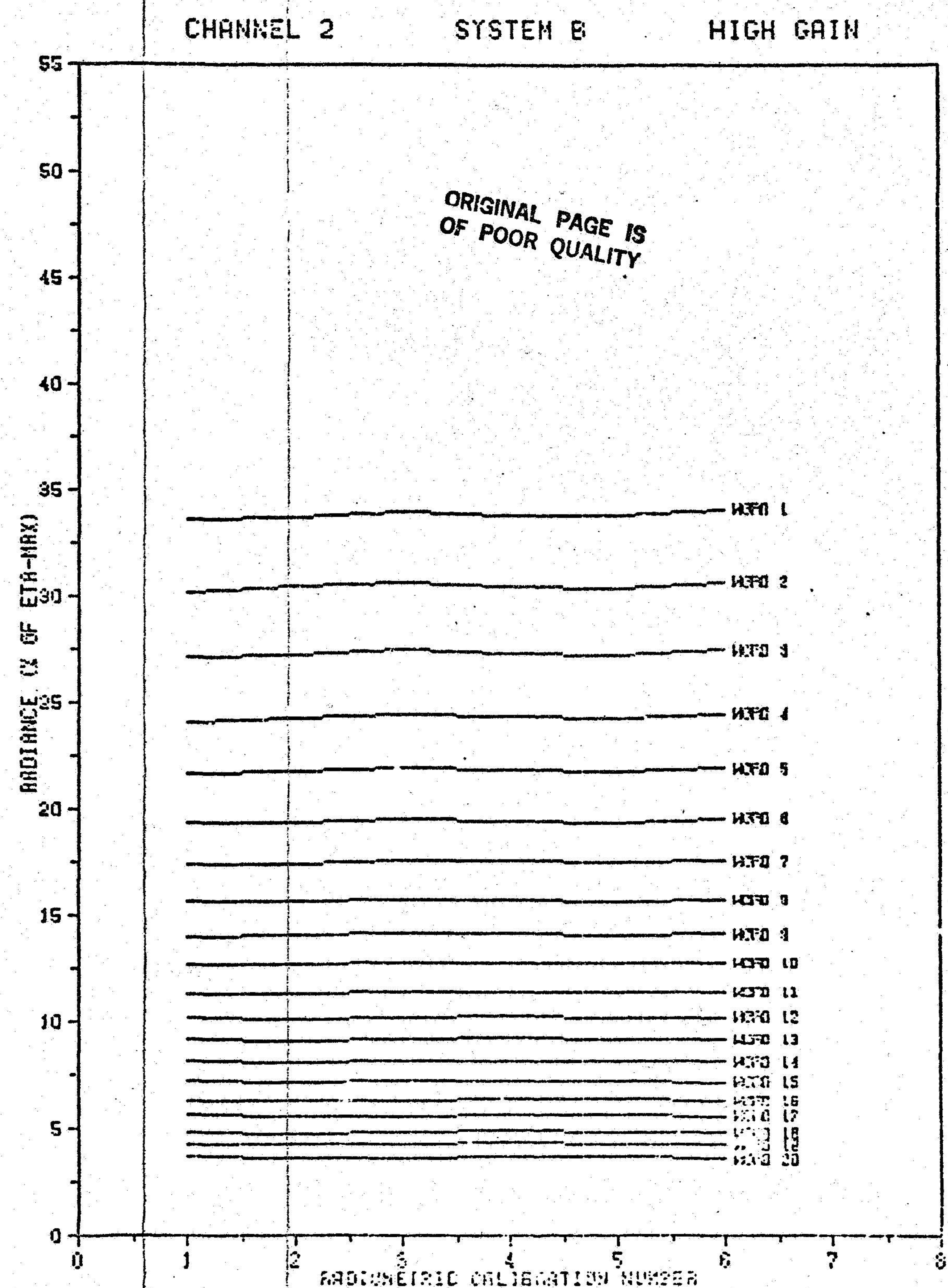
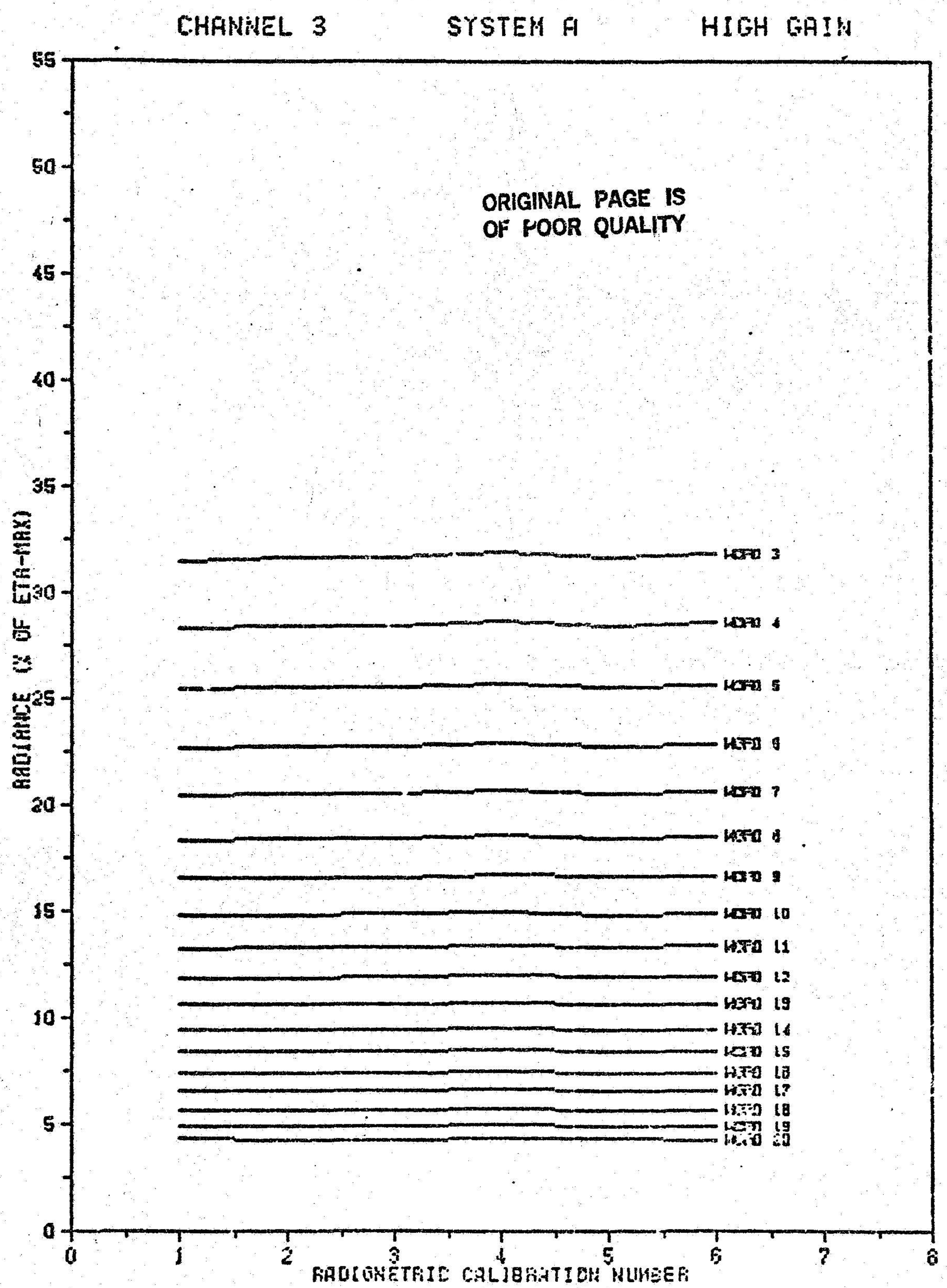
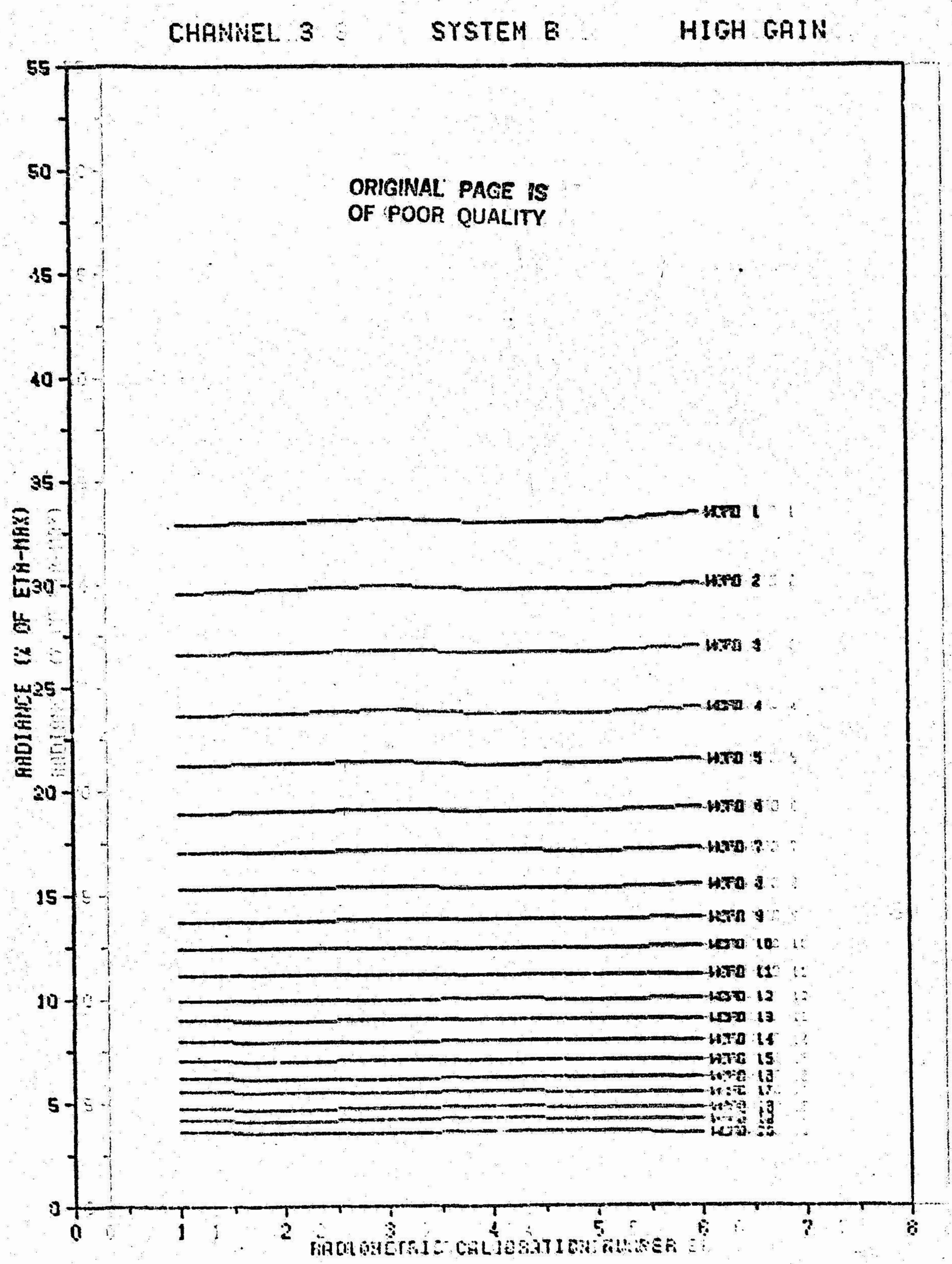
4
5
6
7
8



CHANNEL 2
SYSTEM B
HIGH GAIN
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER
ORIGINAL PAGE IS OF POOR QUALITY

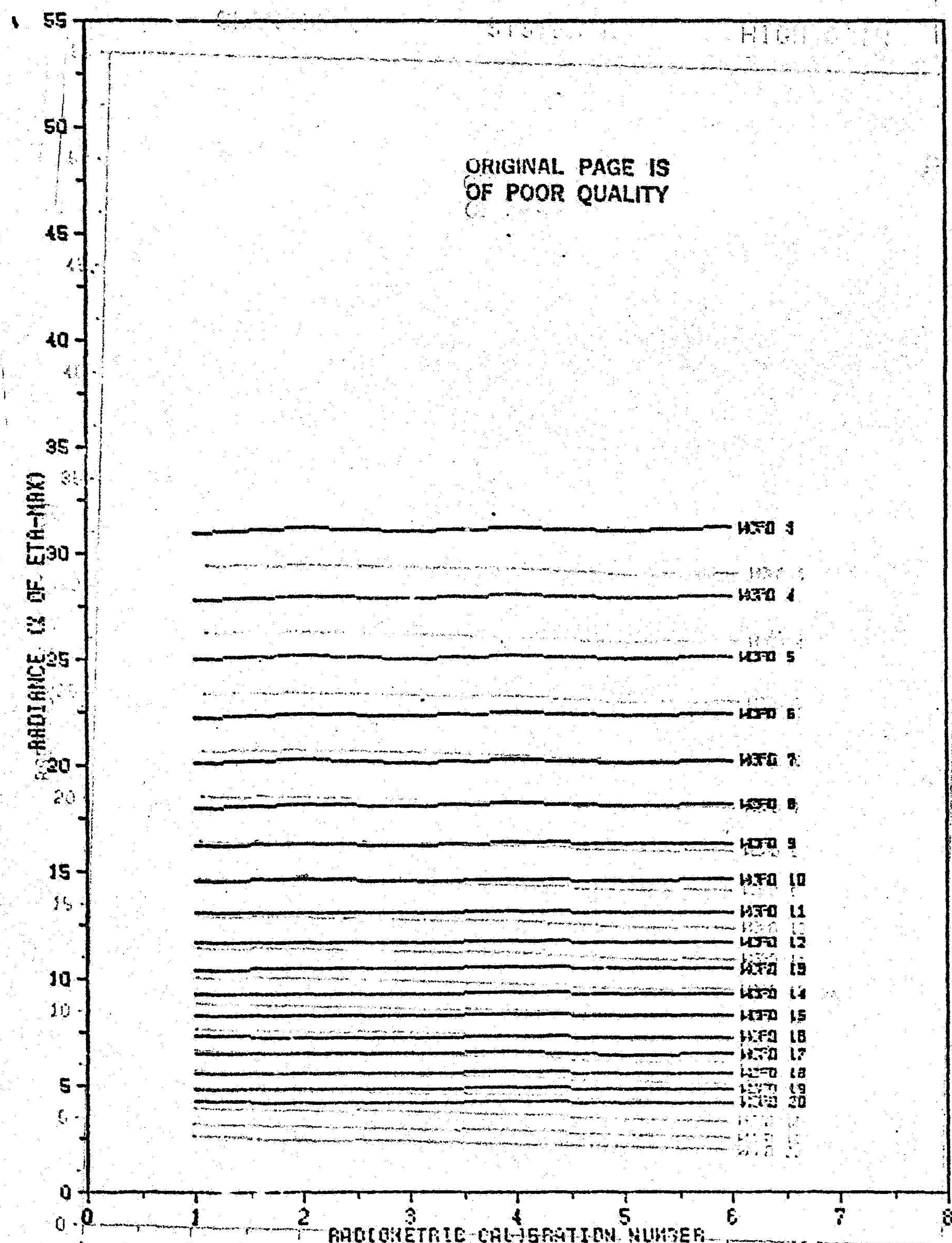


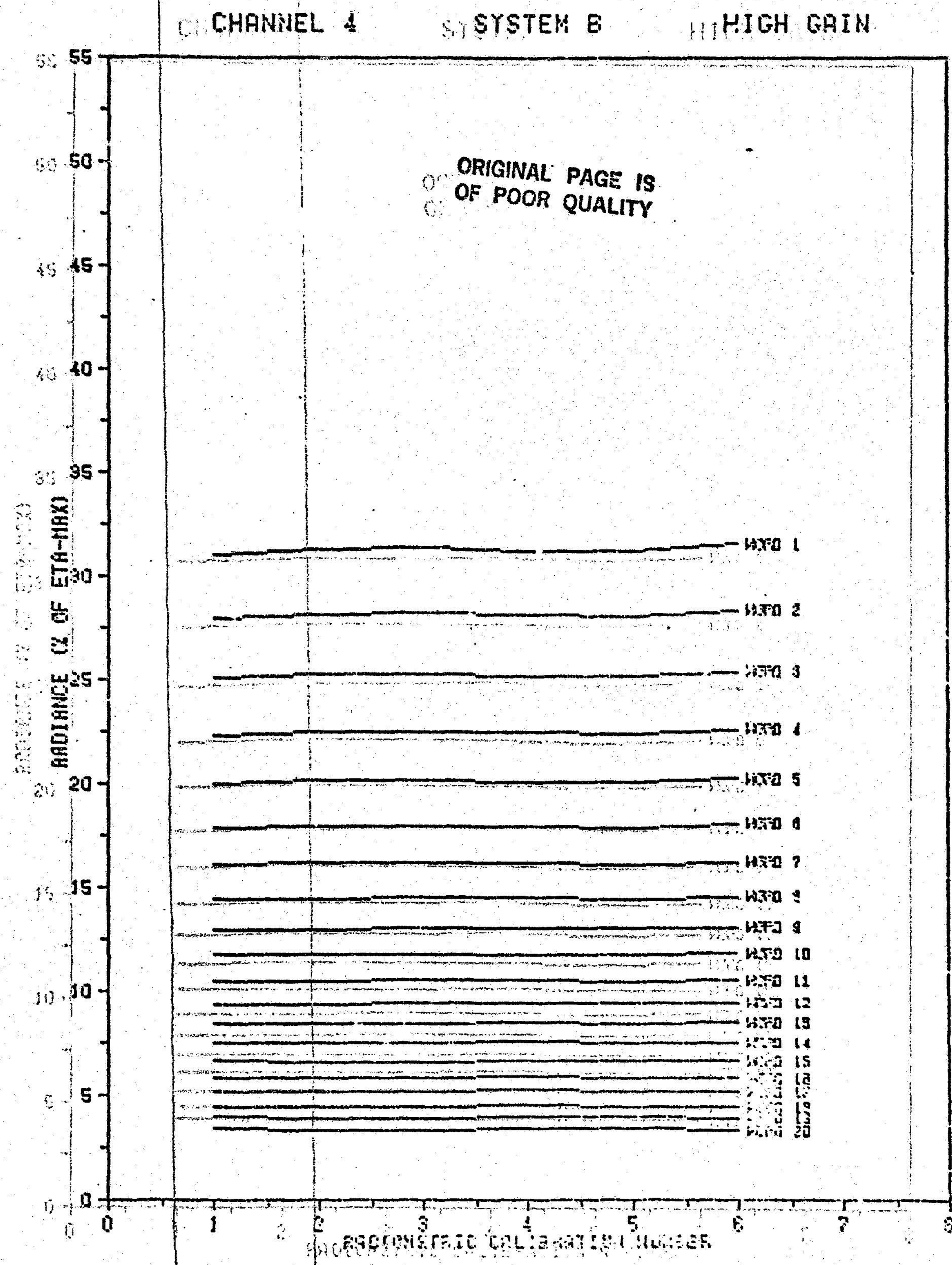
CHANNEL 3 SYSTEM A HIGH GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER



ORIGINAL PAGE IS
OF POOR QUALITY

CHANNEL 4 SYSTEM A HIGH GAIN




CHANNEL 4
SYSTEM B
HIGH GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER
0
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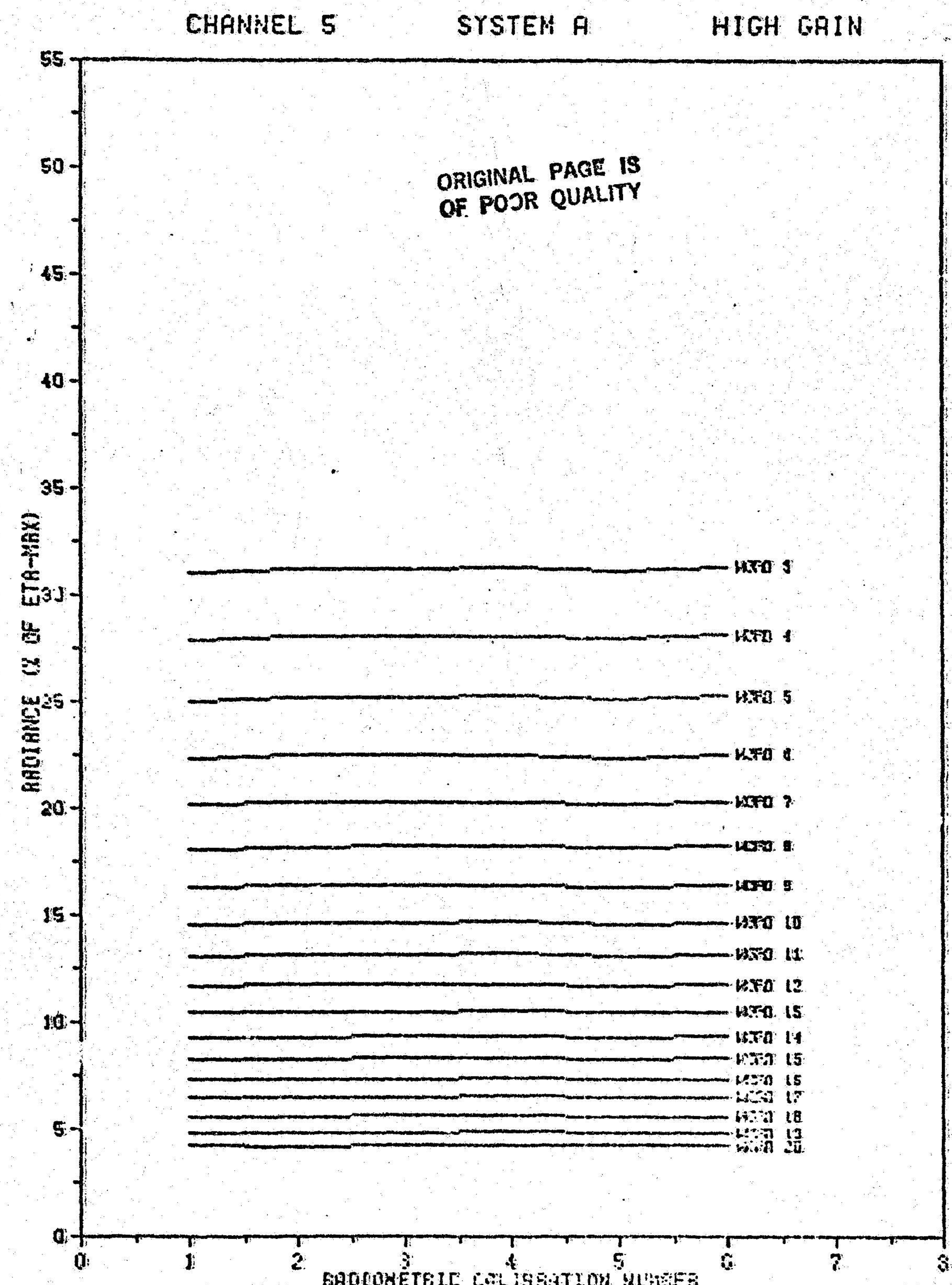
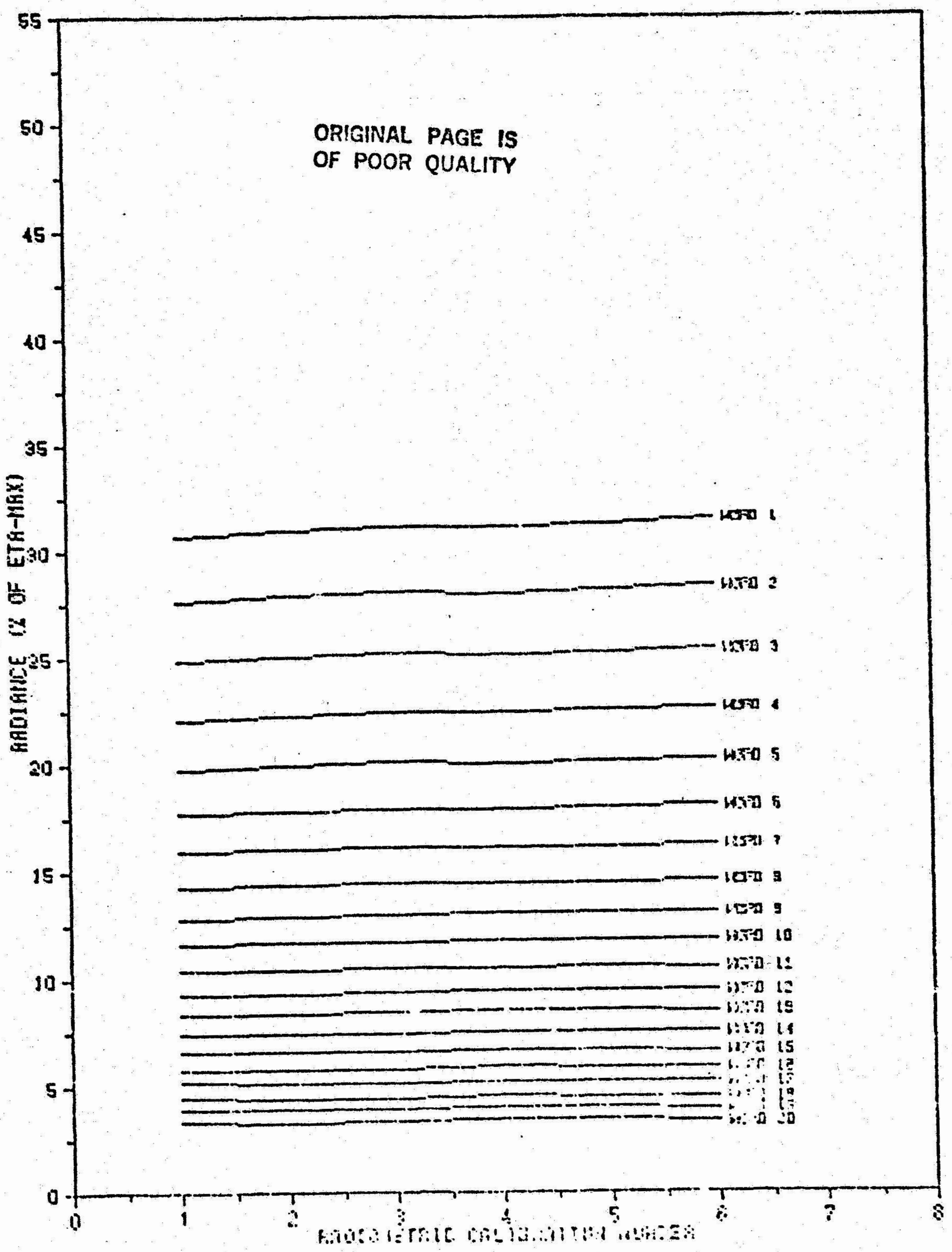
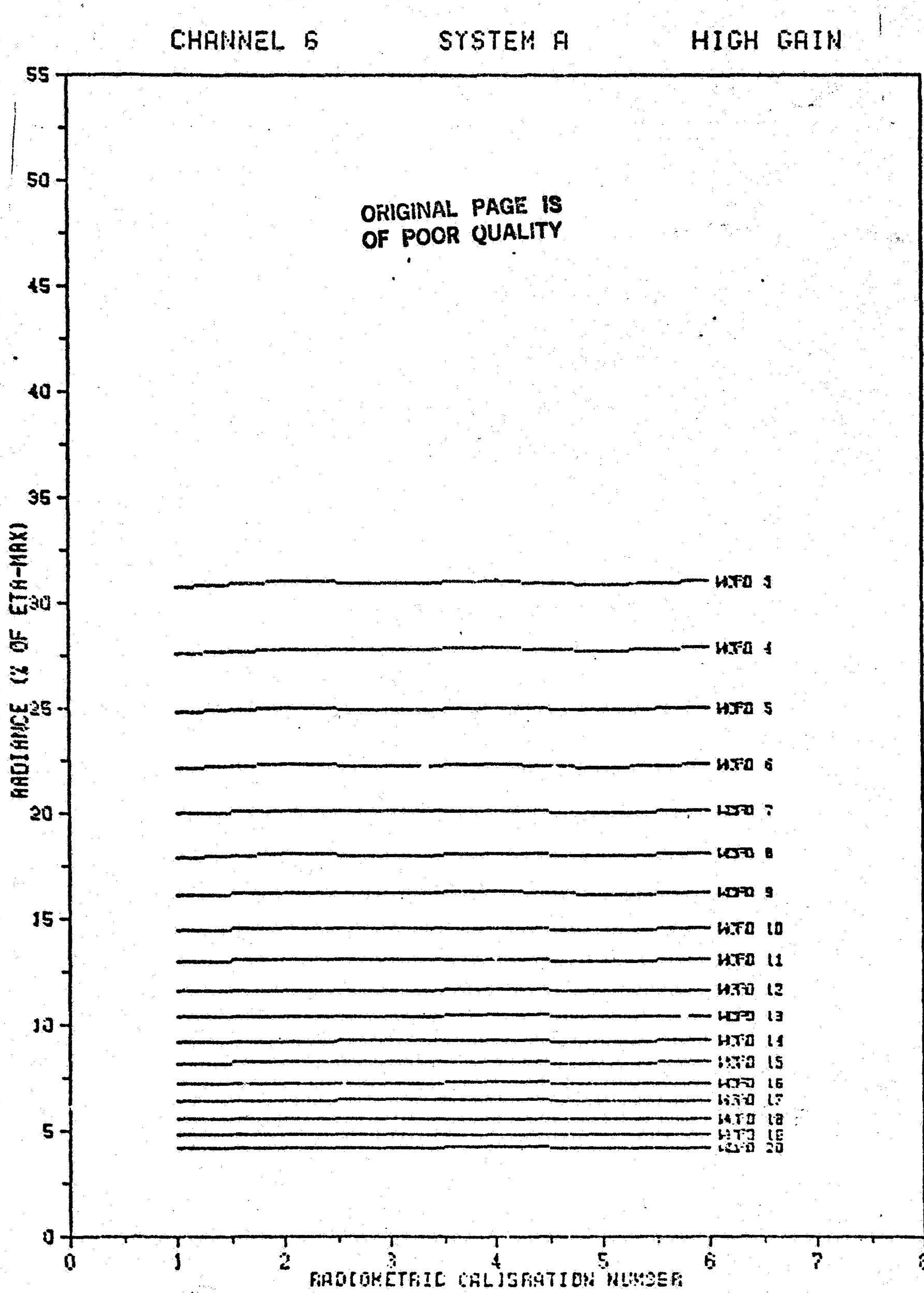
10
15
20
25
30
35
40
45
50
55
0
1
2
3
4
5
6
7
8



ORIGINAL PAGE IS
OF POOR QUALITY

CHANNEL 5 SYSTEM B HIGH GAIN





CHANNEL 6
SYSTEM A
HIGH GAIN
ORIGINAL PAGE IS OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER
0
5
10
15
20
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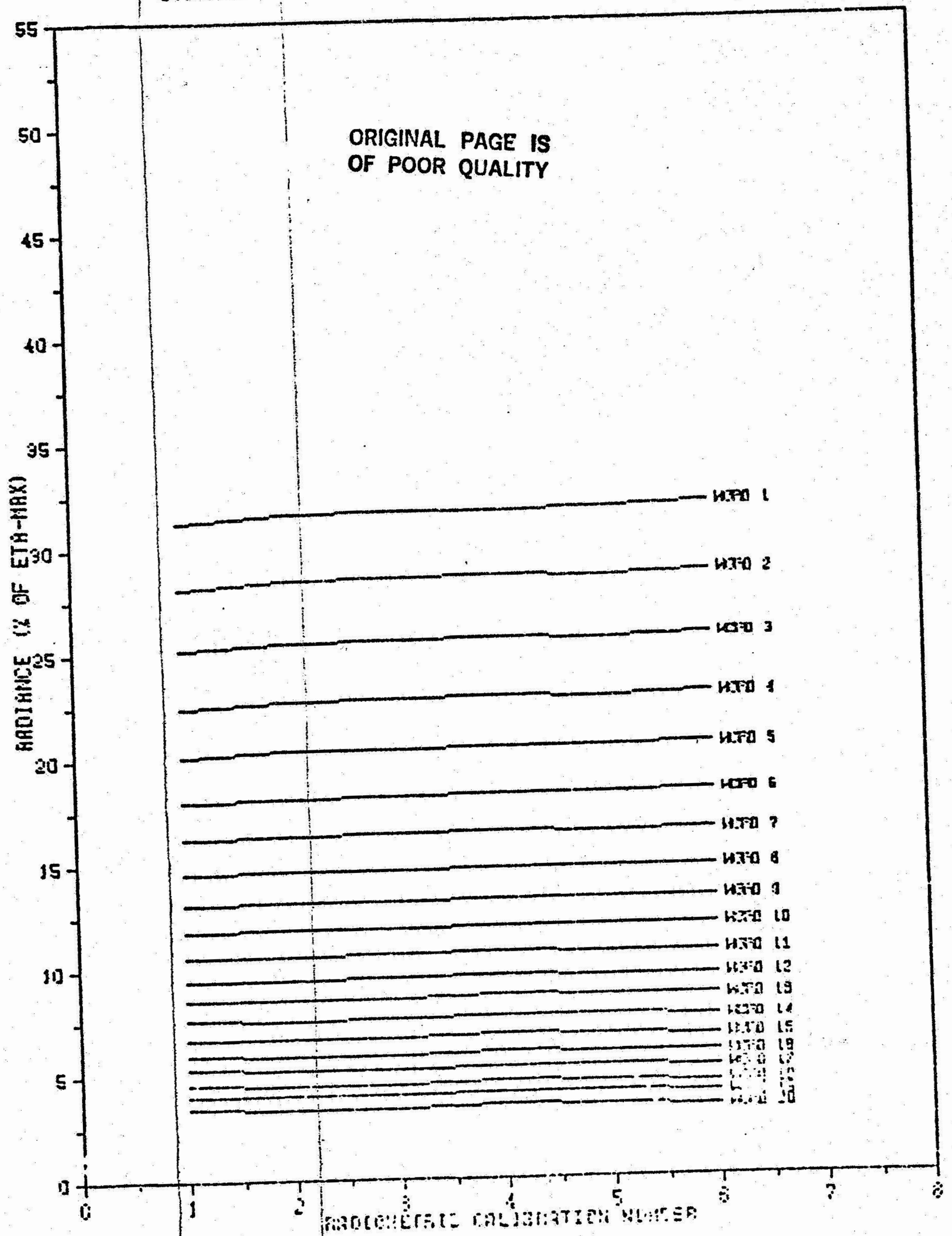
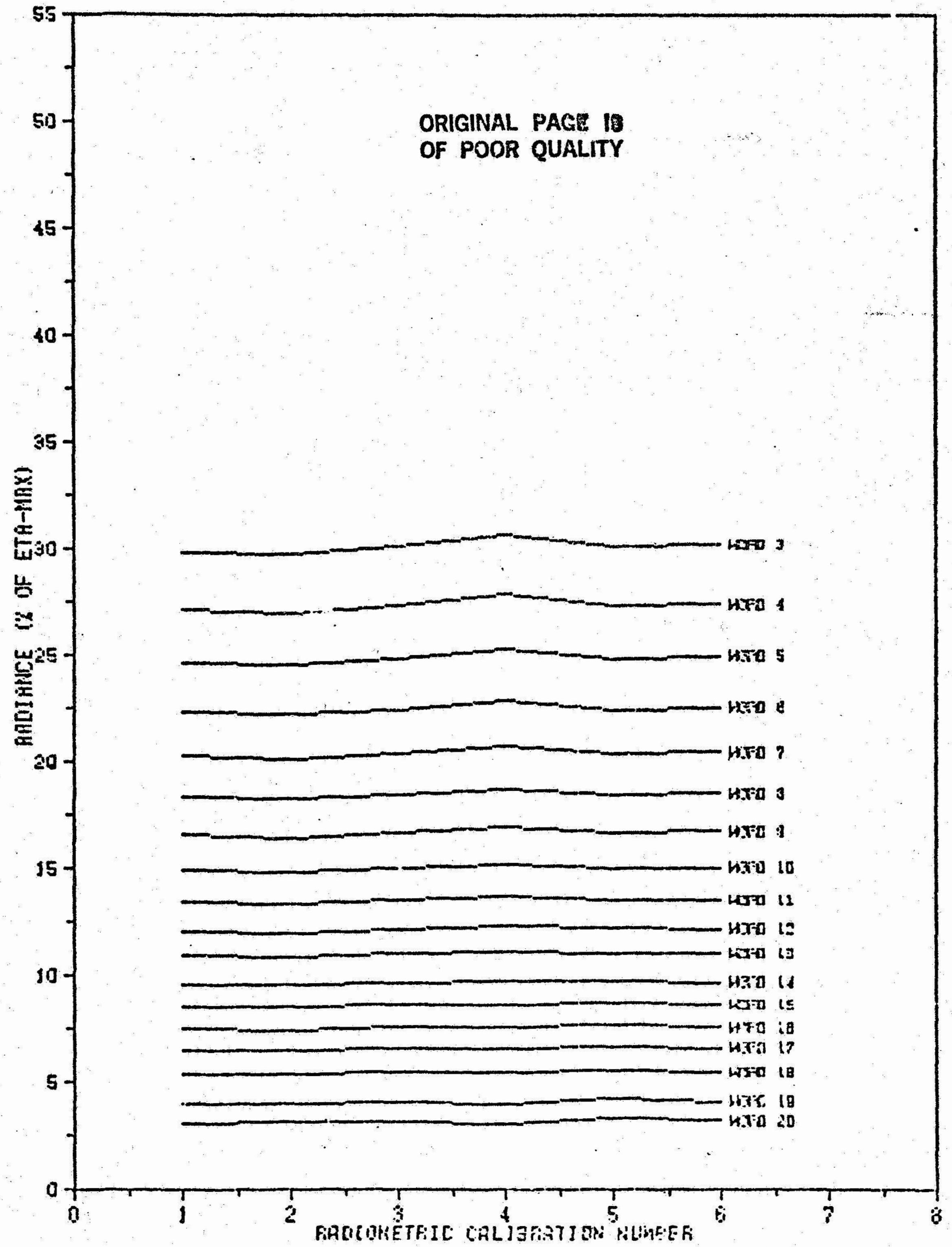
35
40
45
50
55
1
2
3
4
5
6
7
8

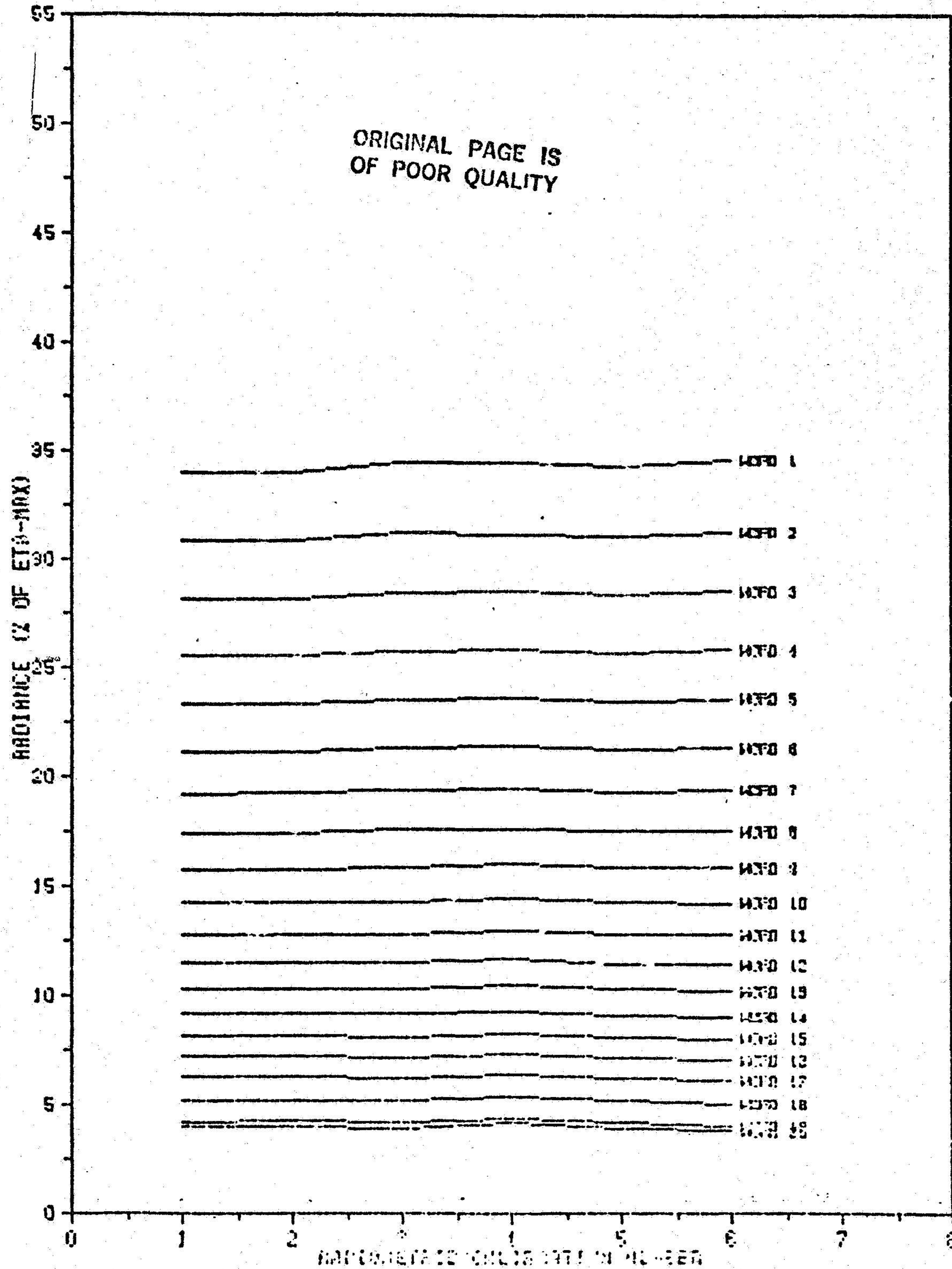
CHANNEL 6 SYSTEM B HIGH GAIN

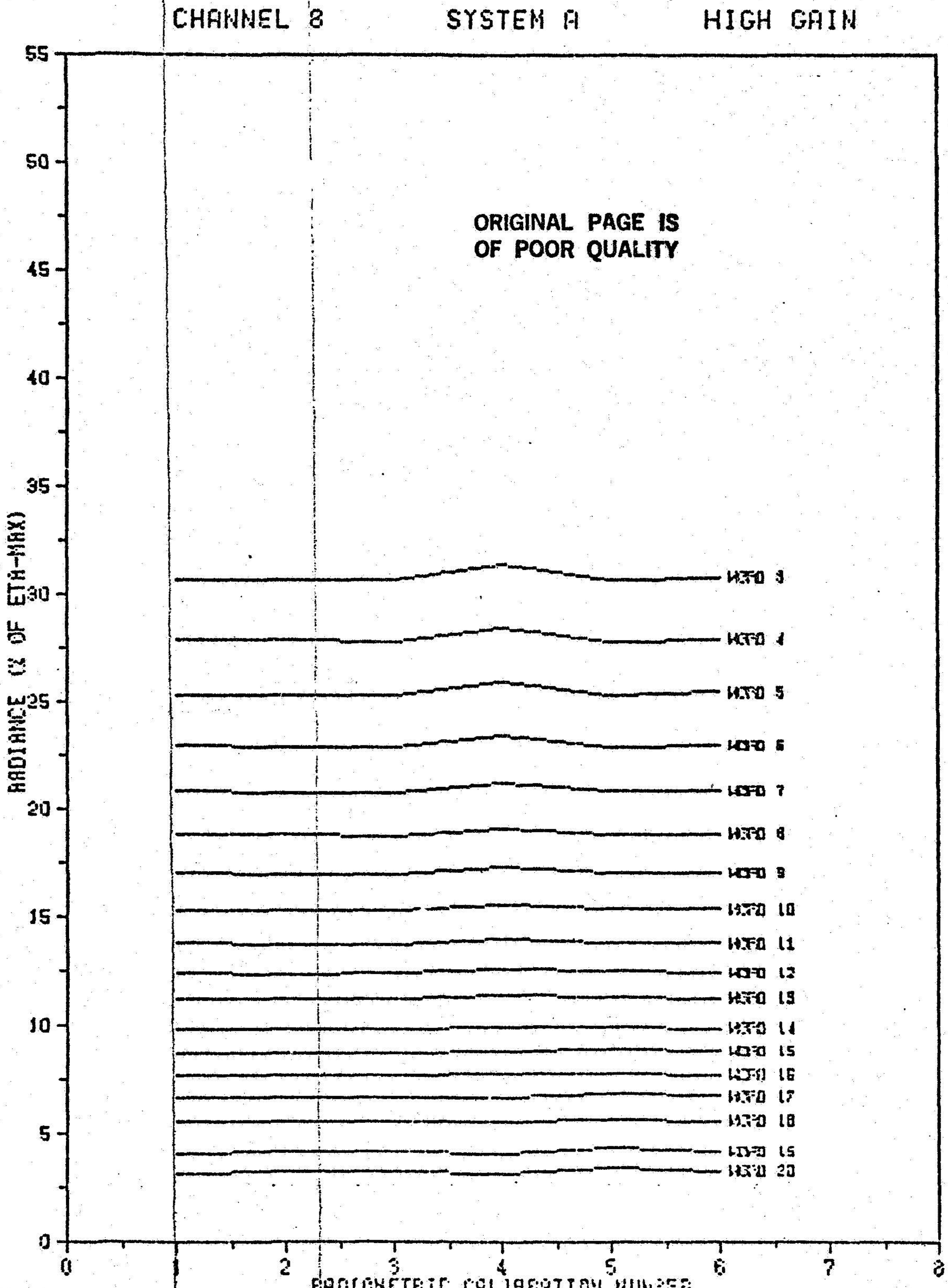


CHANNEL 7 SYSTEM A HIGH GAIN



CHANNEL 7 SYSTEM B HIGH GAIN




CHANNEL 8
SYSTEM A
HIGH GAIN
RADIANCE (% OF ETA-MAX)
55
50
45
40
35
30
25
20
15
10
5
0
RADIOMETRIC CALIBRATION NUMBER
0
1
2
3
4
5
6
7
8
HCFD 3
HCFD 4
HCFD 5
HCFD 6
HCFD 7
HCFD 8
HCFD 9
HCFD 10
HCFD 11
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HCFD 14
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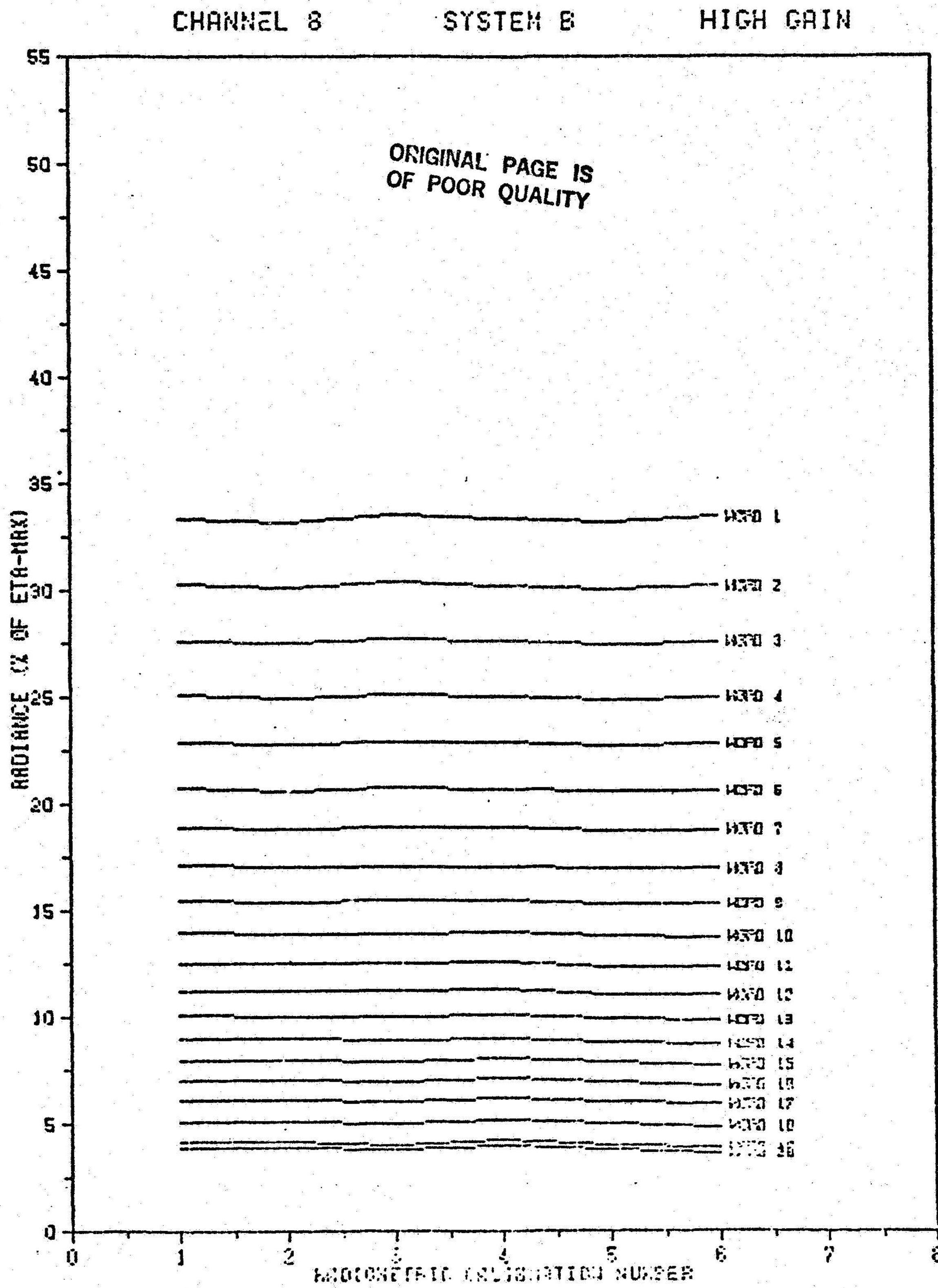
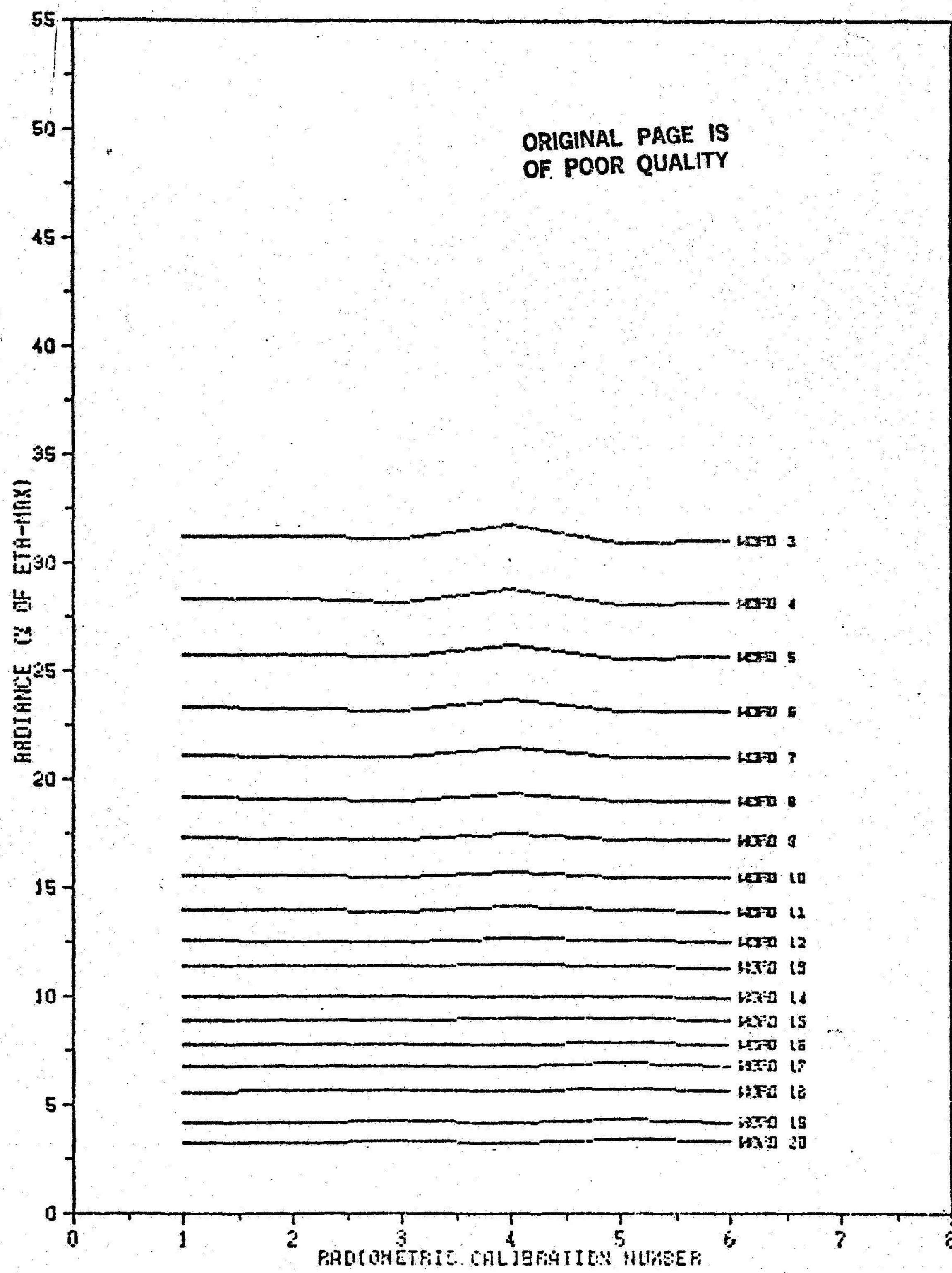
HCFD 17
HCFD 18
HCFD 15
HCFD 20

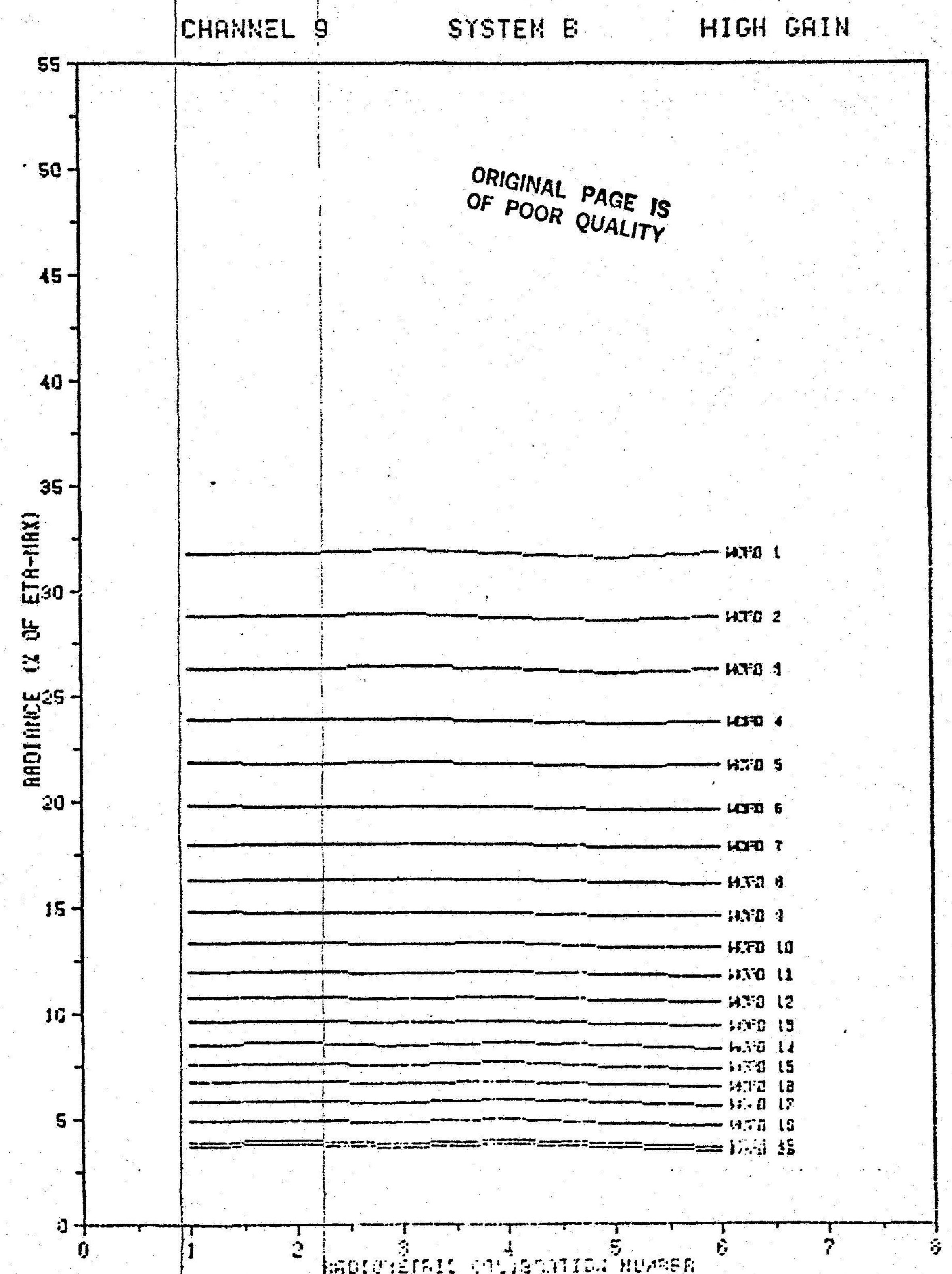


CHANNEL 8
SYSTEM B
HIGH GAIN
RADIANCE (% OF ETA-MAX)
ORIGINAL PAGE IS OF POOR QUALITY
0
5
10
15
20
25
30
35
40
45
50
55
0
1
2
3
4
5
6
7
8

CHANNEL 9 SYSTEM A HIGH GAIN

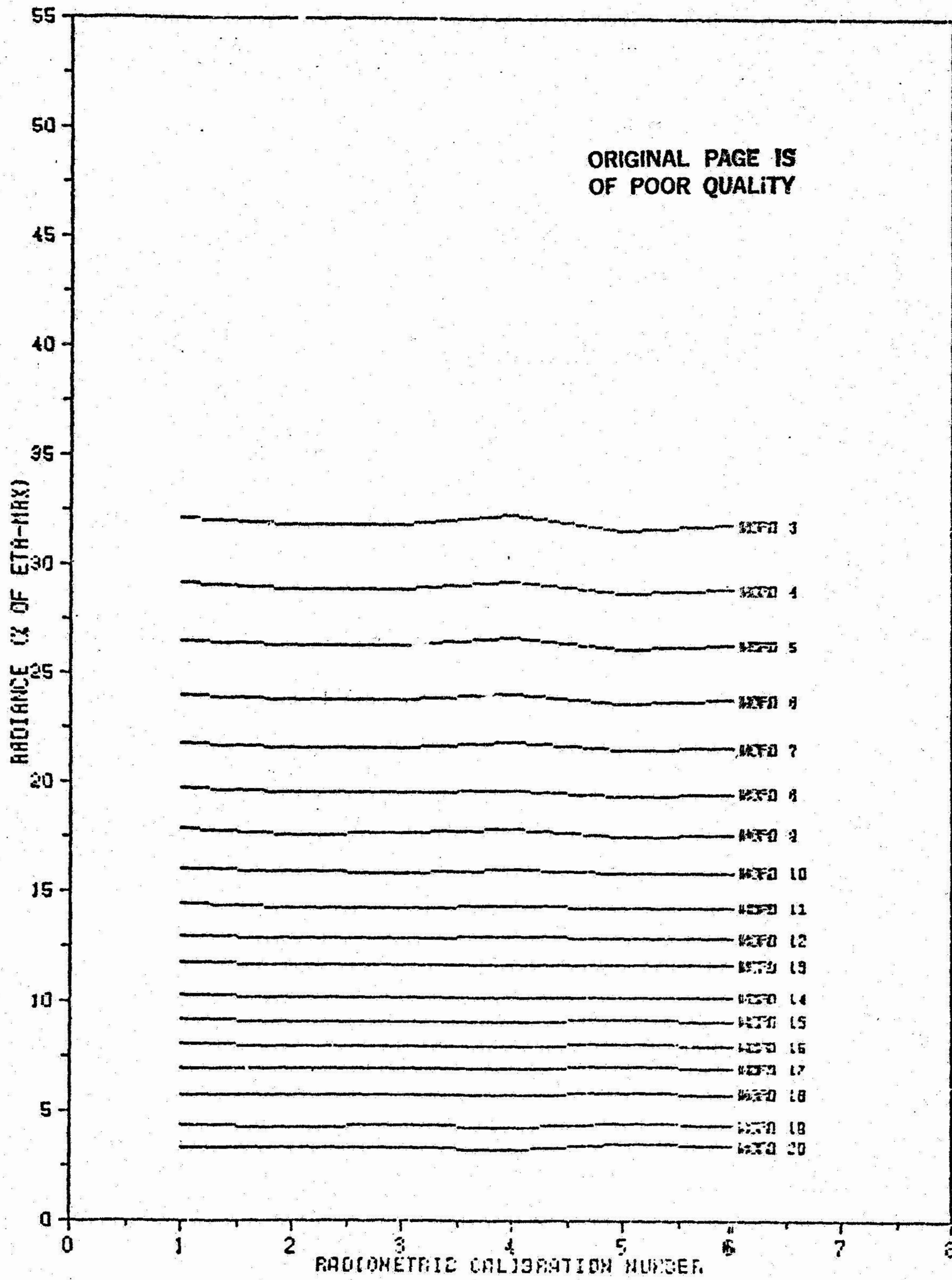


ORIGINAL PAGE IS
OF POOR QUALITY

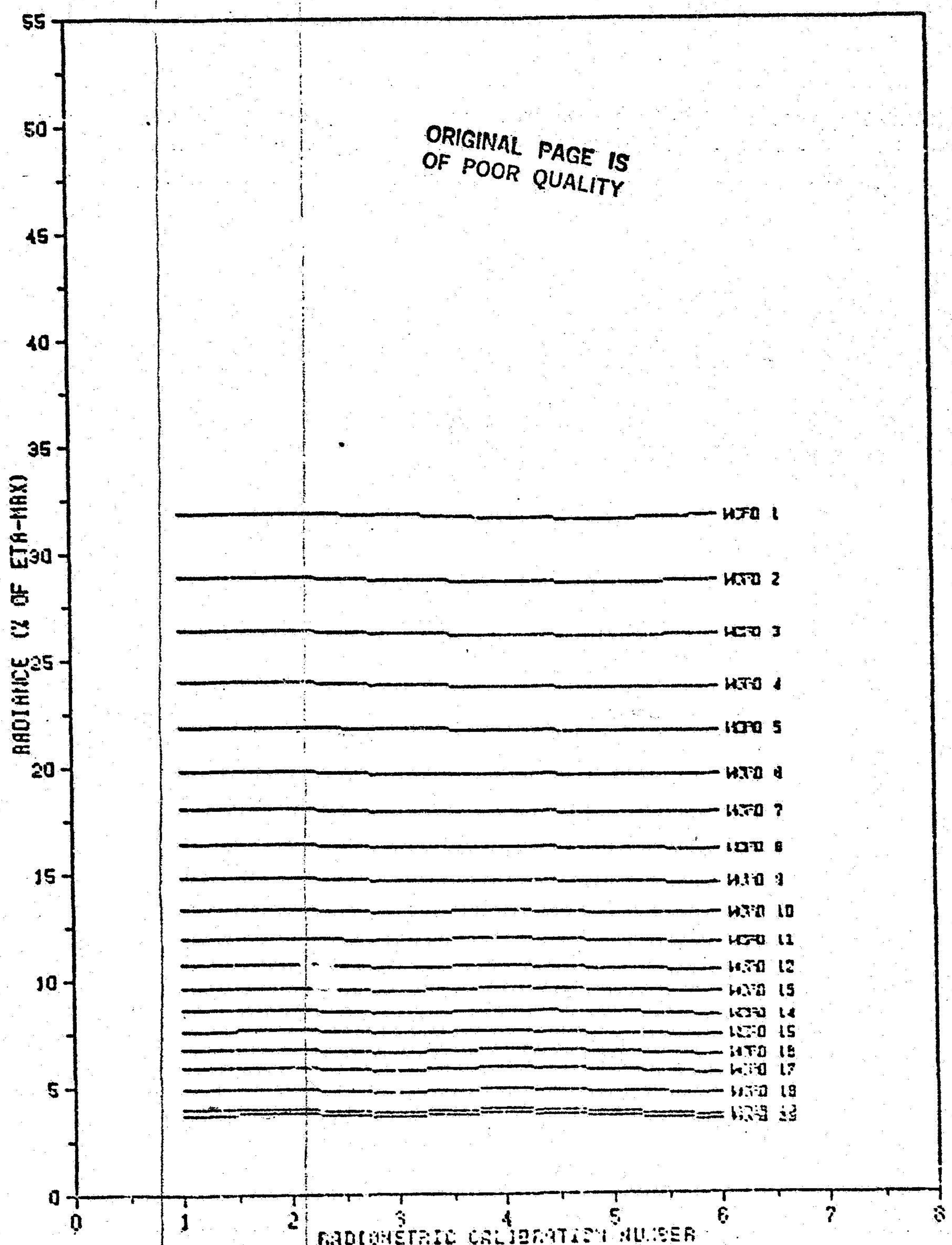


CHANNEL 9 SYSTEM B HIGH GAIN
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER
ORIGINAL PAGE IS OF POOR QUALITY

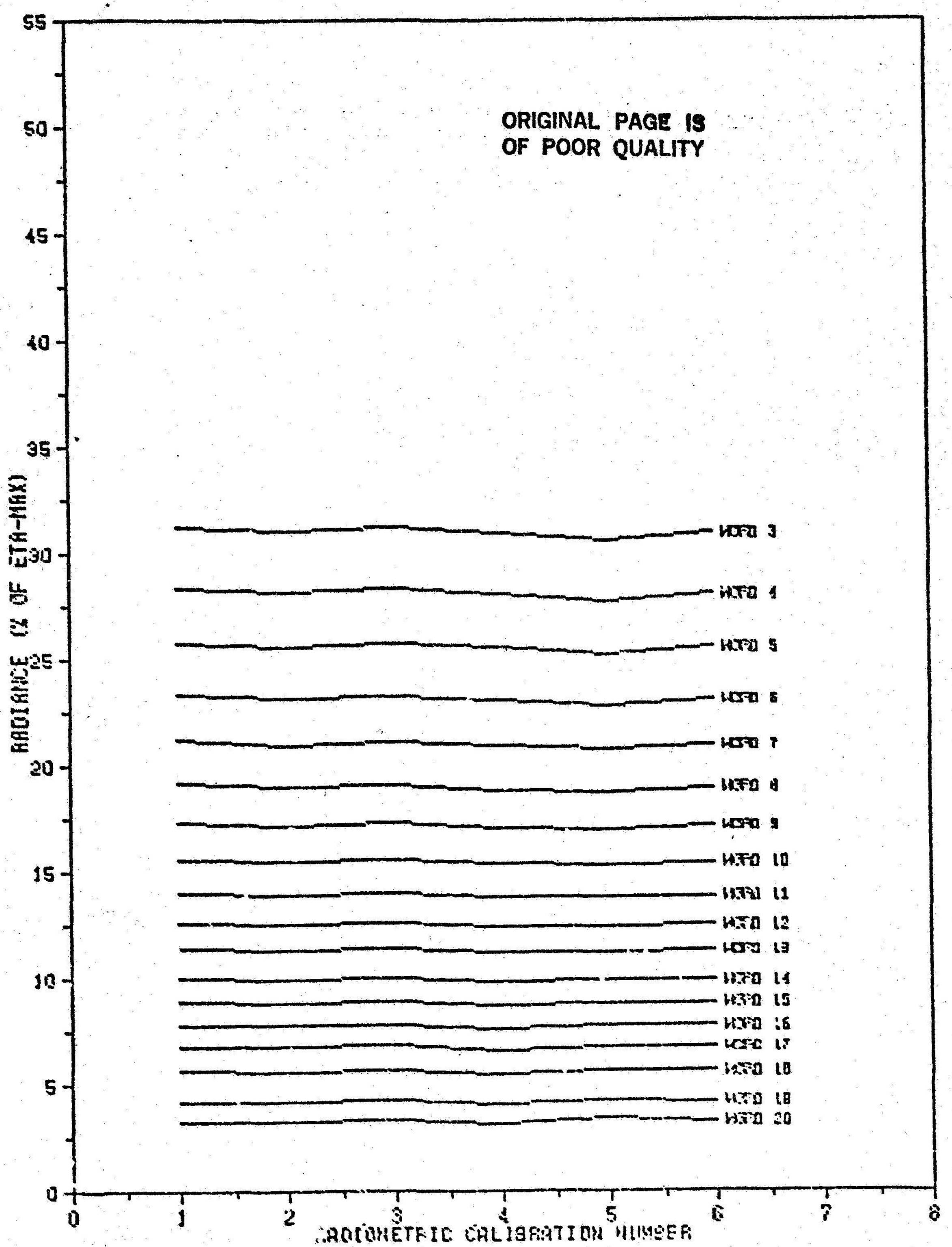
CHANNEL 10 SYSTEM A HIGH GAIN

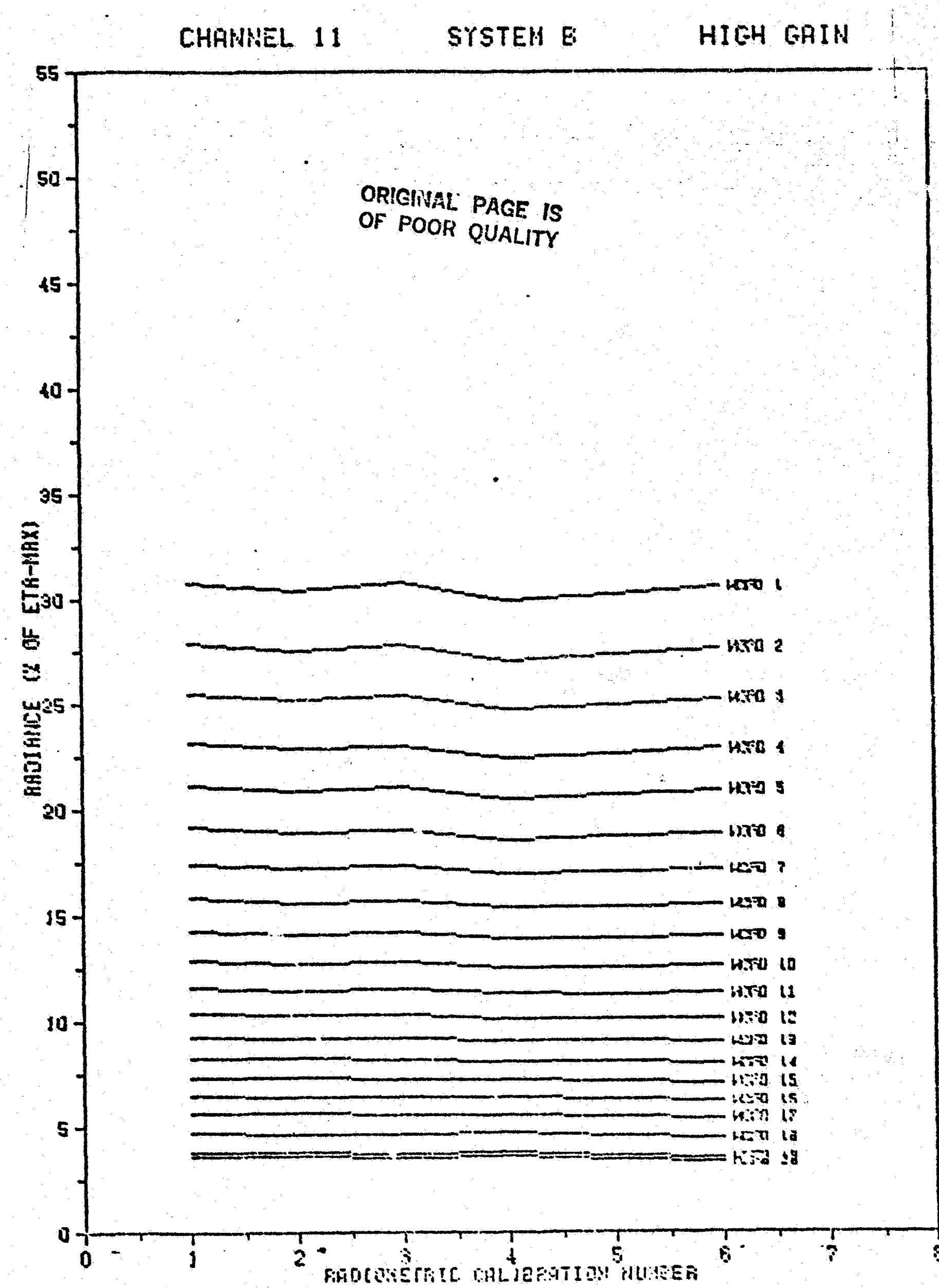


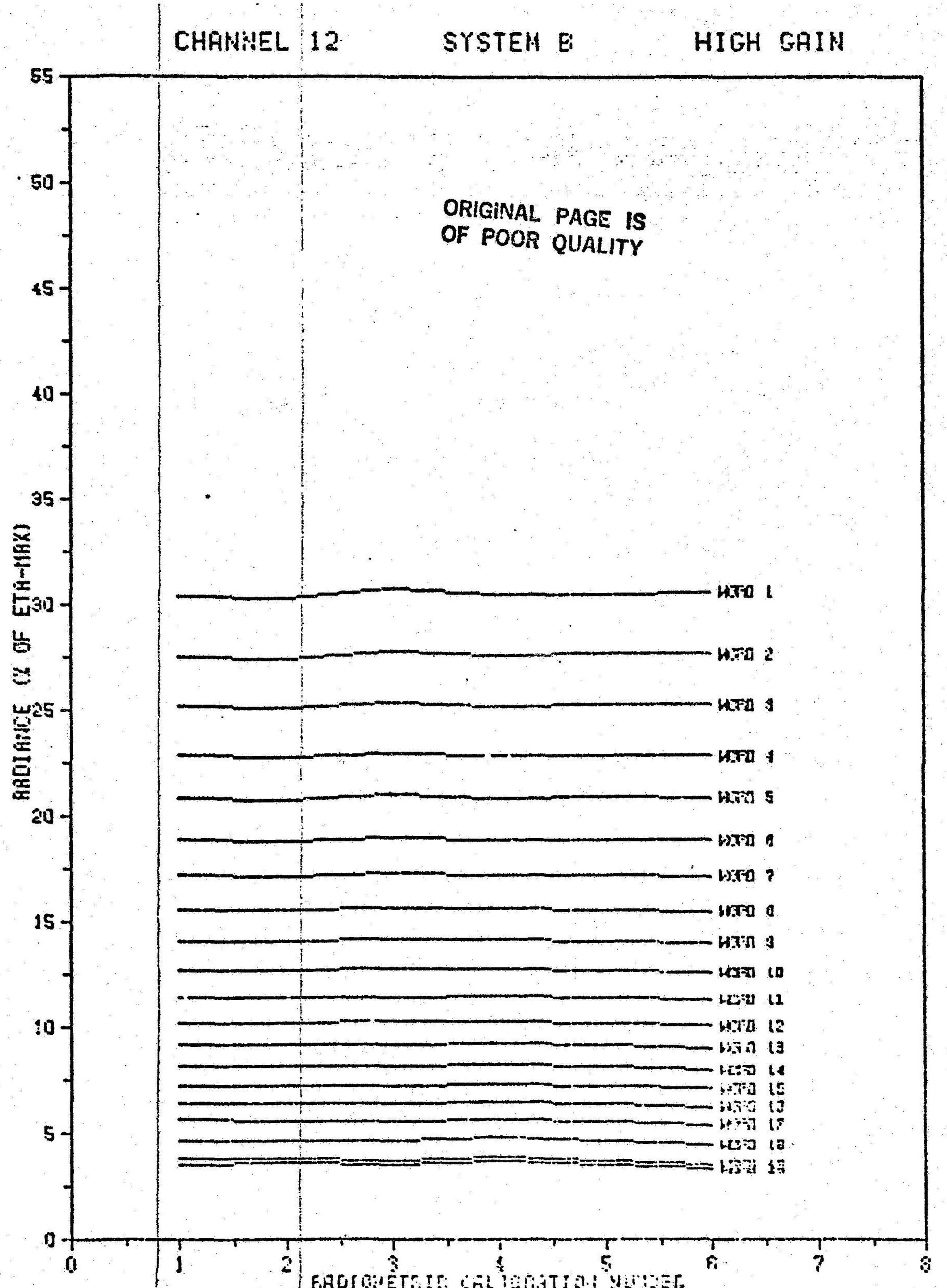
CHANNEL 10 SYSTEM B HIGH GAIN

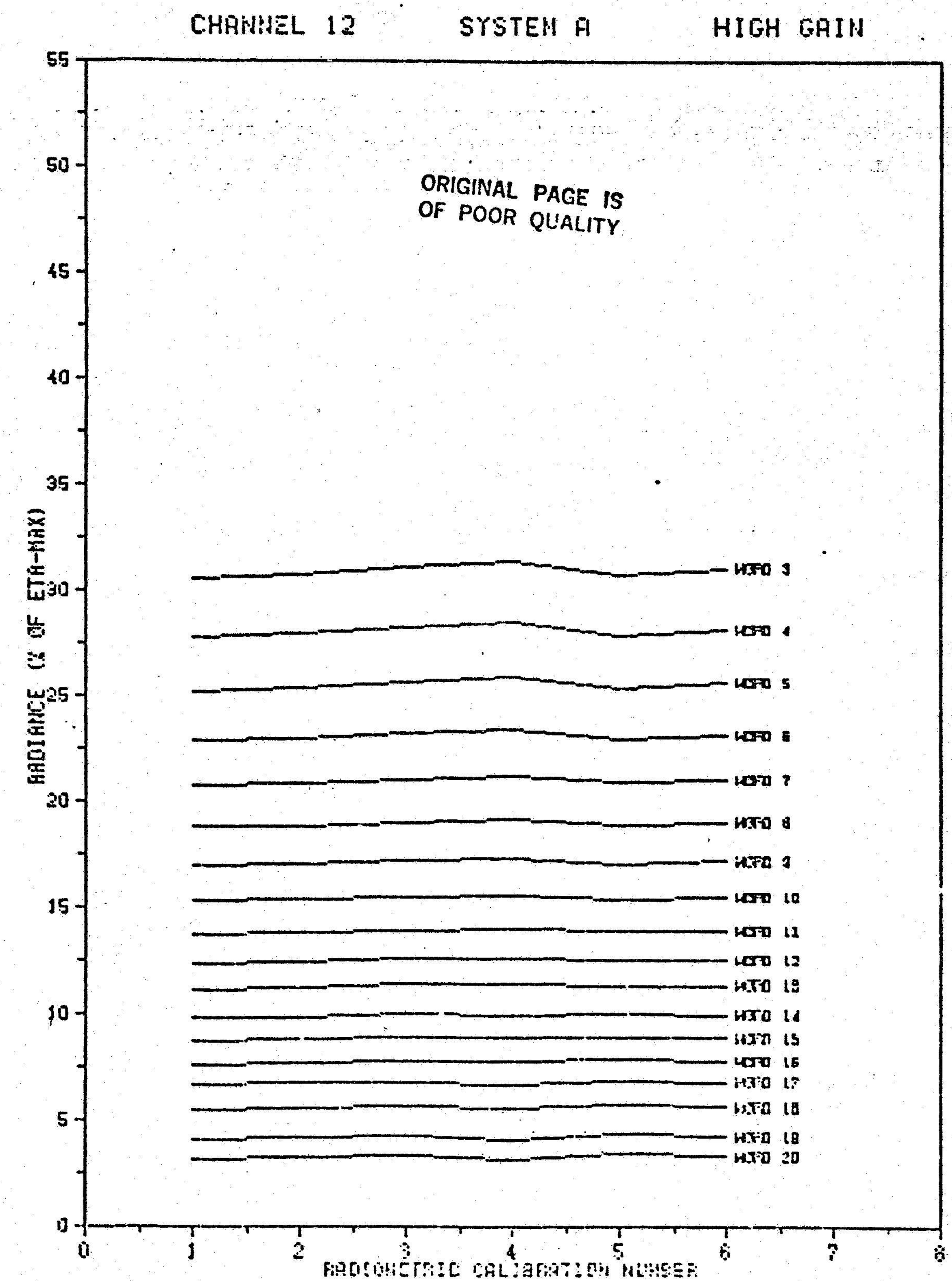


CHANNEL 11 SYSTEM A HIGH GAIN




CHANNEL 11
SYSTEM B
HIGH GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER


CHANNEL 12 SYSTEM B HIGH GAIN
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER
ORIGINAL PAGE IS OF POOR QUALITY


CHANNEL 12
SYSTEM A
HIGH GAIN
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA-MAX)
RADIOMETRIC CALIBRATION NUMBER
WORD 3
WORD 4
WORD 5
WORD 6
WORD 7
WORD 8
WORD 9
WORD 10
WORD 11
WORD 12
WORD 13
WORD 14
WORD 15
WORD 16
WORD 17
WORD 18
WORD 19
WORD 20

5. MSS-D CALIBRATION WEDGES, FINAL CALIBRATION

The final radiometric calibration of the MSS-D Flight Model (F-1) system was performed at Hughes Aircraft Company on 9 October 1981 at the completion of the penalty acoustic test.

The calibration wedges obtained during this calibration test with the 30 inch integrating sphere are presented in this section for all 24 channels of the MSS-D protoflight system, for each of its different modes (low gain, high gain) and system configurations (System A, System B). The plots present the radiance values of the internal calibration system at each of the 20 words of the calibration wedge. These radiance values are presented in terms of the maximum bright scene radiance, η_{MAX} as given by the System Specification. These values of η_{MAX} are as follows:

Band 1 = 2.48 mW cm^{-2} $ster^{-1}$

Band 2 = 2.00 mW cm^{-2} $ster^{-1}$

Band 3 = 1.76 mW cm^{-2} $ster^{-1}$

Band 4 = 4.60 mW cm^{-2} $ster^{-1}$

As discussed in Section 3 these radiance values at the 20 selected words along the trailing ends of the calibration wedge are the cal wedge nominals used for subsequent gain and offset estimation during system test. These values are the basic data describing the internal calibration system.

The 20 words are chosen in the manner described in Section 3.3, and are referenced to the zero crossing of the leading edge of the wedge as given in the chart below.

Gain	Band	Words From Zero Crossing		
		First Sample	Last Sample	Increment Between Samples
Low	1	256	788	28
	2	360	778	22
	3	360	778	22
	4	330	786	24
High	1	460	878	22
	2	580	960	20

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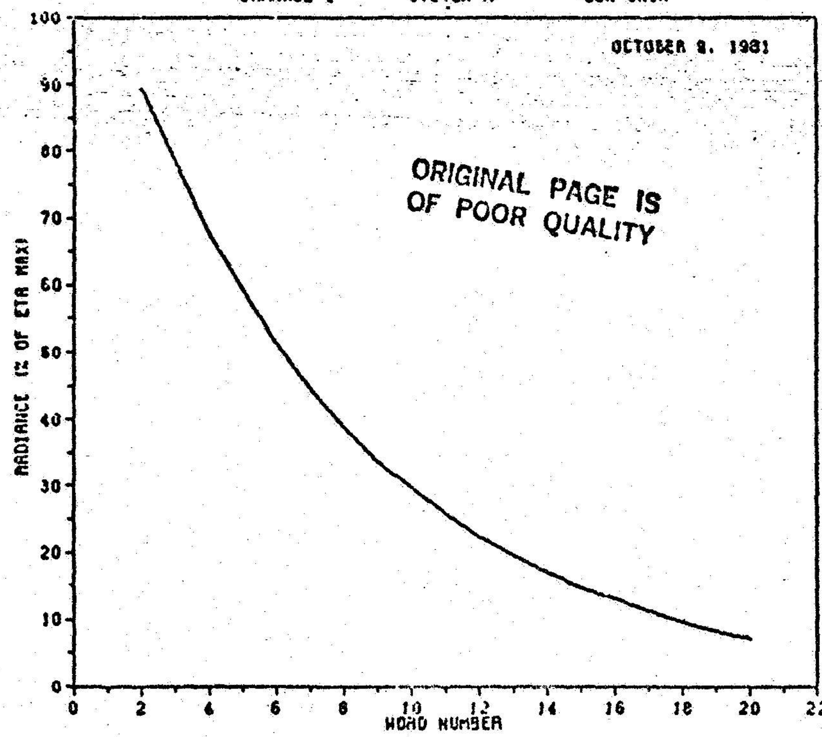
These "profile" views of the cal wedge show clearly the "bump" in the wedge caused by the hole in the neutral density filter wedge. It is barely visible in Band 1, occurring at about the ninth or tenth word of the wedge. In Band 2 it is more evident, occurring at the eighth word. In Band 3 it is more pronounced in the System B wedges, again at the eighth word. Band 4 shows the most pronounced discontinuity in the slope of the "exponential" cal wedge, at word 9, with System B being more abrupt than System A, but both systems exhibiting a significant effect. These plots demonstrate more clearly the feature observed in the history plots of the previous section where the values for words 8 and 9 in Band 4 were nearly overlapping (especially in System B).

It should be noticed from the plots that System A is always more saturated (QL > 59) than System B; the radiance values at corresponding word numbers are higher in System A than in System B. This is the result of the difference between the calibration lamp radiant outputs for Systems A and B as observed earlier.

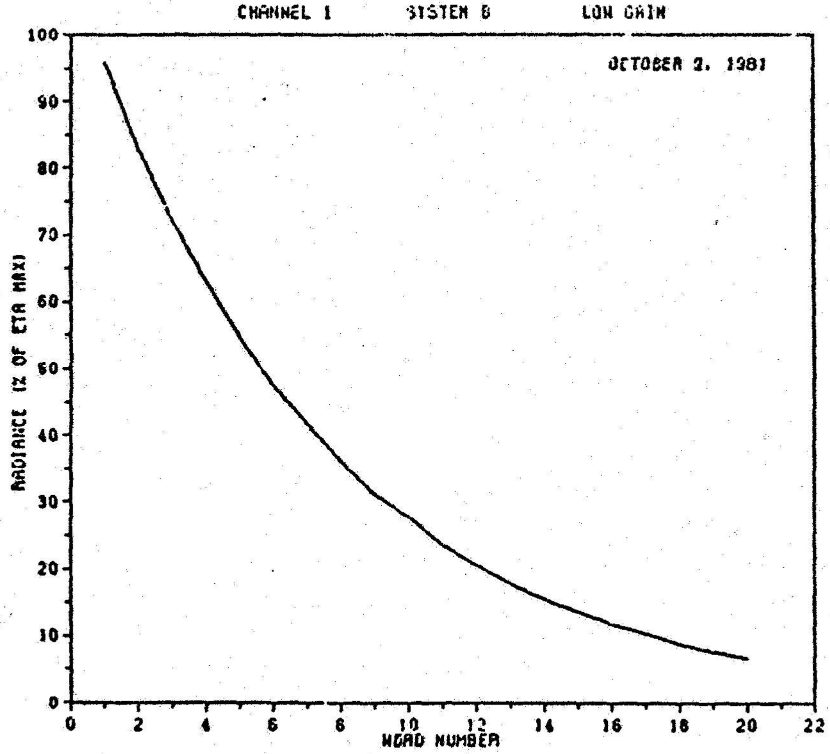
Neither of the two characteristics mentioned above (i.e., the "bump" in the cal wedge and the disparity between System A and System B cal lamp outputs) need have any appreciable effect on the utility of the internal calibration system provided that the calibration is stable and gives repeatable values at the selected wedge words. This type of performance is not ideal, of course. It provides more of a nuisance in the selection of appropriate nominal wedge word sample locations than it does any impact on system performance.

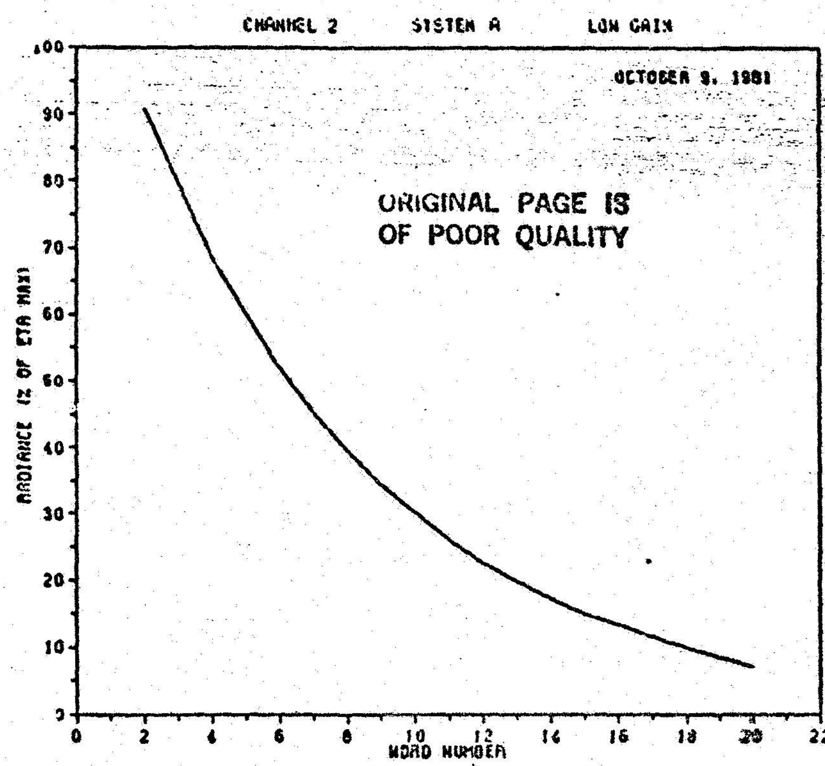
For convenience and accuracy in determining the values of η_{MAX} used to plot the "cal wedges," a set of tables is provided at the end of this section. It should be noted that the processing routine only accepts values (in QL) between 4 and 59. The zeros which appear in some of the tables indicate that the wedge exceeded QL = 59 at these words.

CHANNEL 1   SYSTEM A   LOW GAIN



CHANNEL 1   SYSTEM B   LOW GAIN





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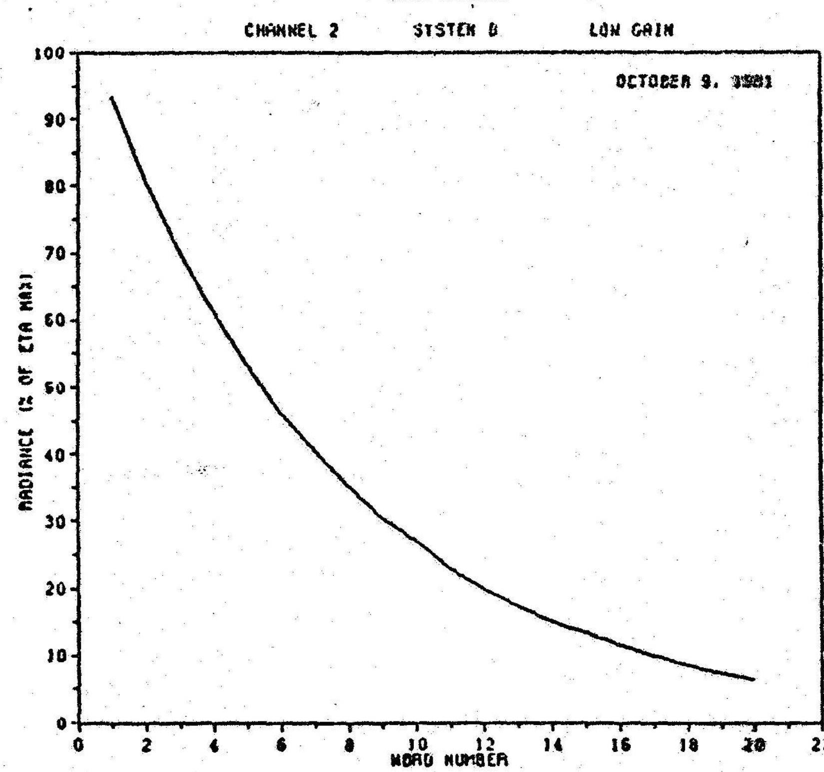

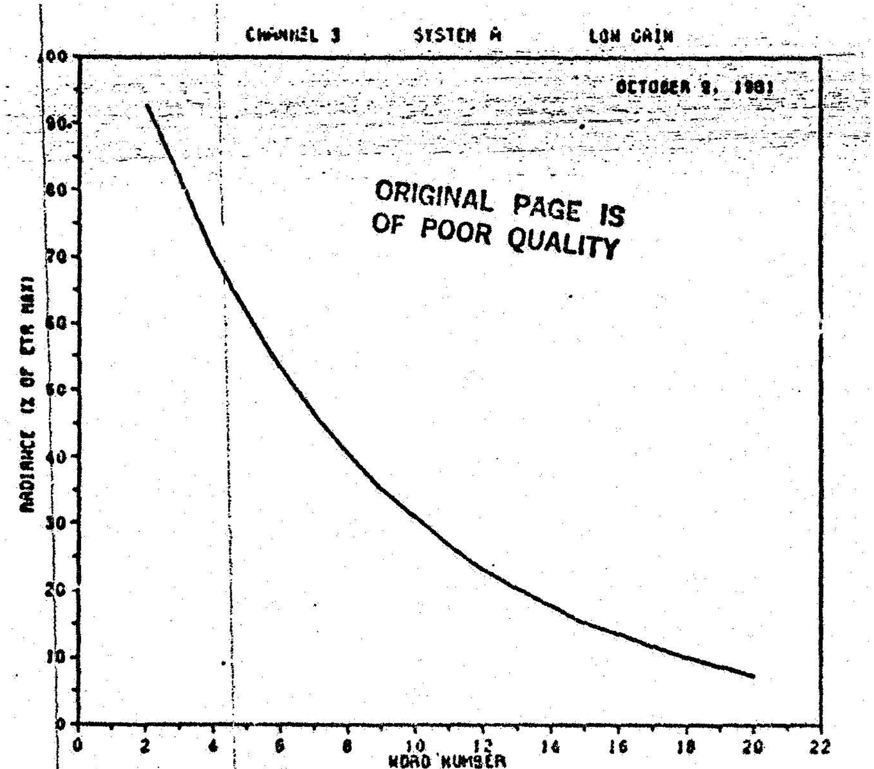

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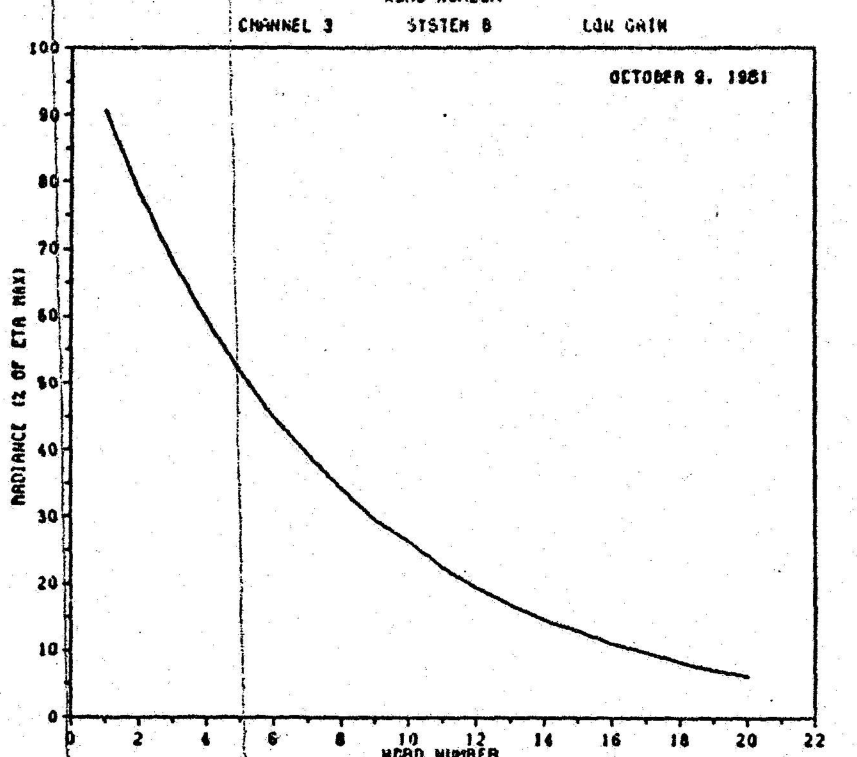

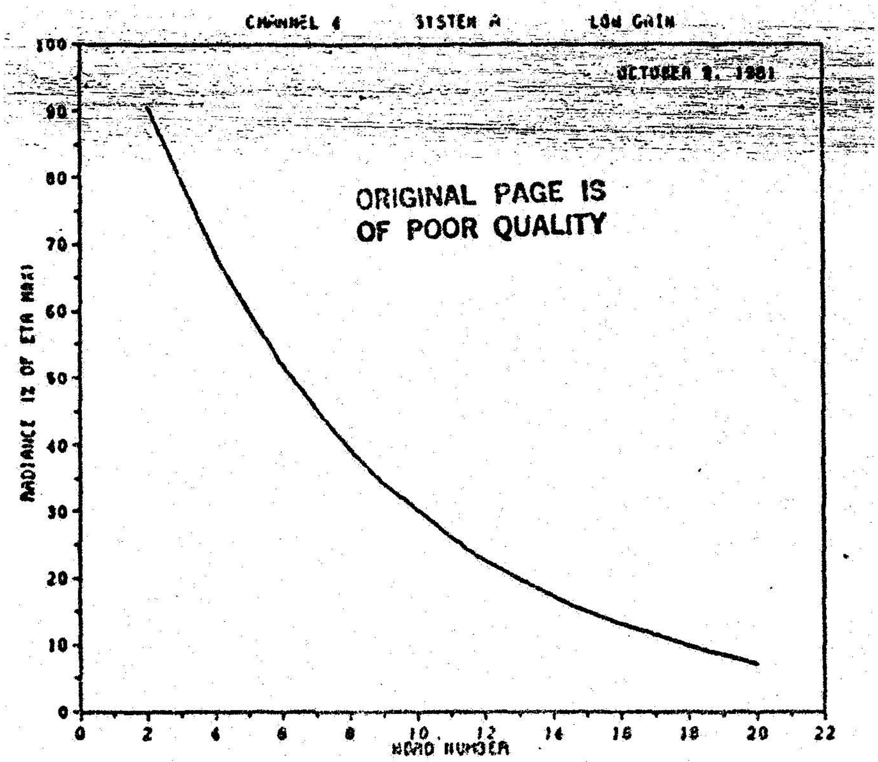

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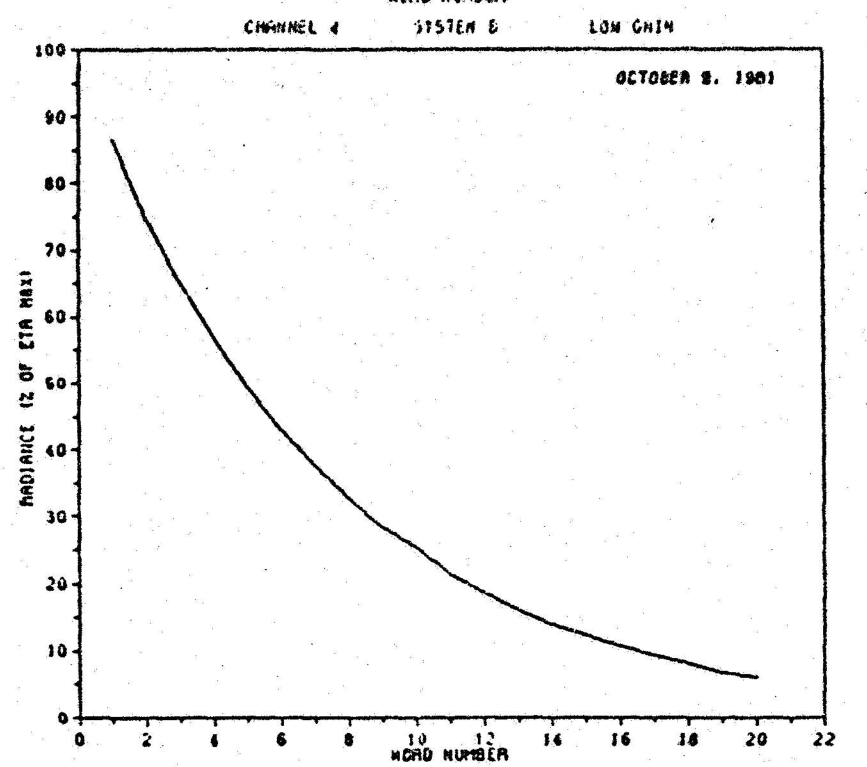
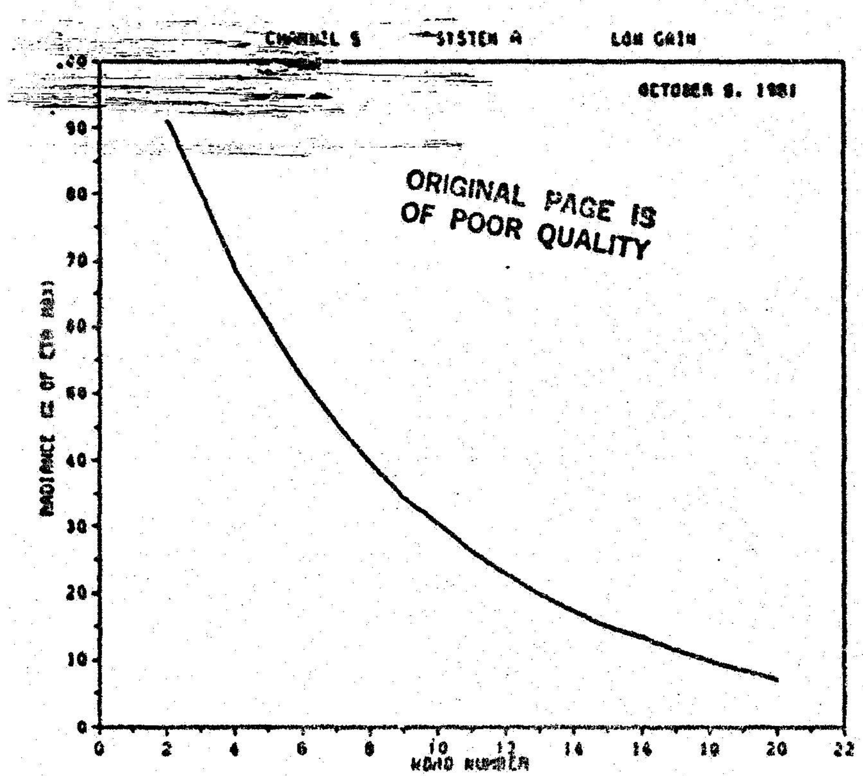
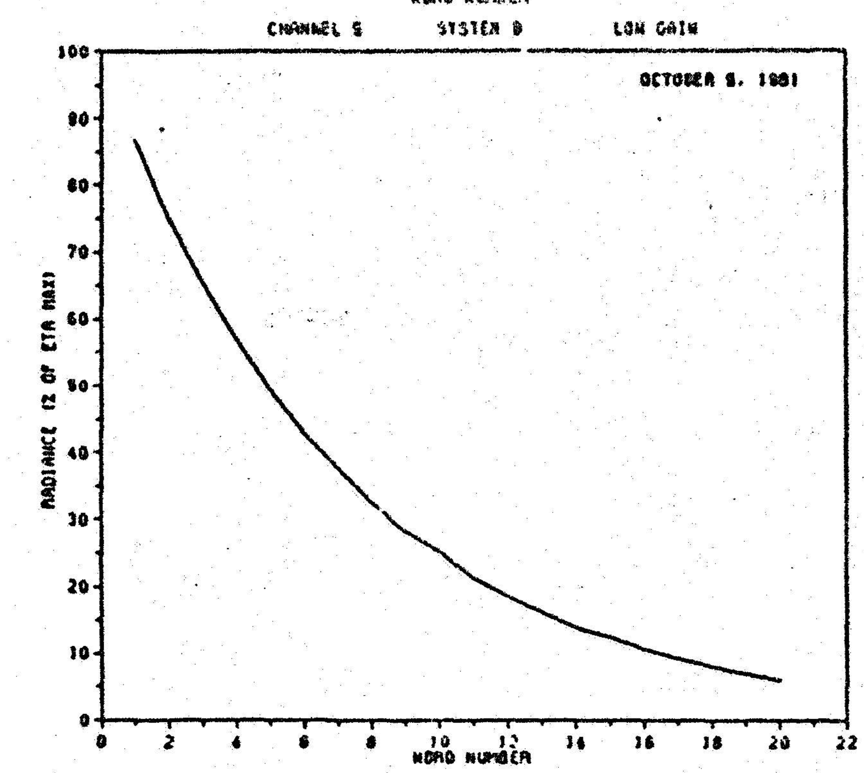
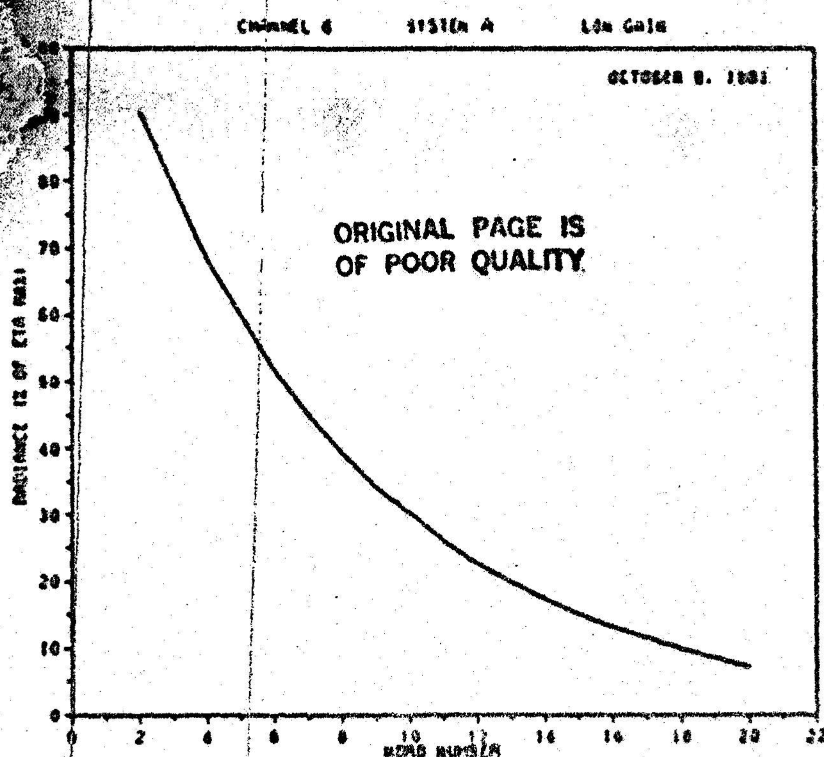



CHANNEL 5
SYSTEM A
LOW GAIN
OCTOBER 8, 1981
RADIANCE (% OF ETA MAX)
WORD NUMBER
ORIGINAL PAGE IS
OF POOR QUALITY


CHANNEL 5
SYSTEM B
LOW GAIN
OCTOBER 8, 1981
RADIANCE (% OF ETA MAX)
WORD NUMBER



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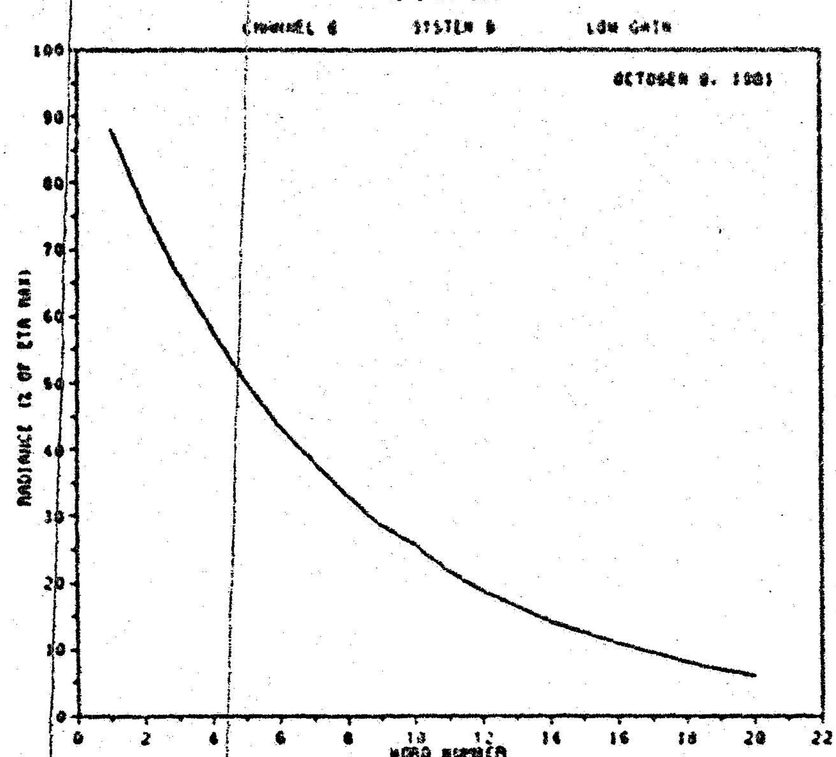

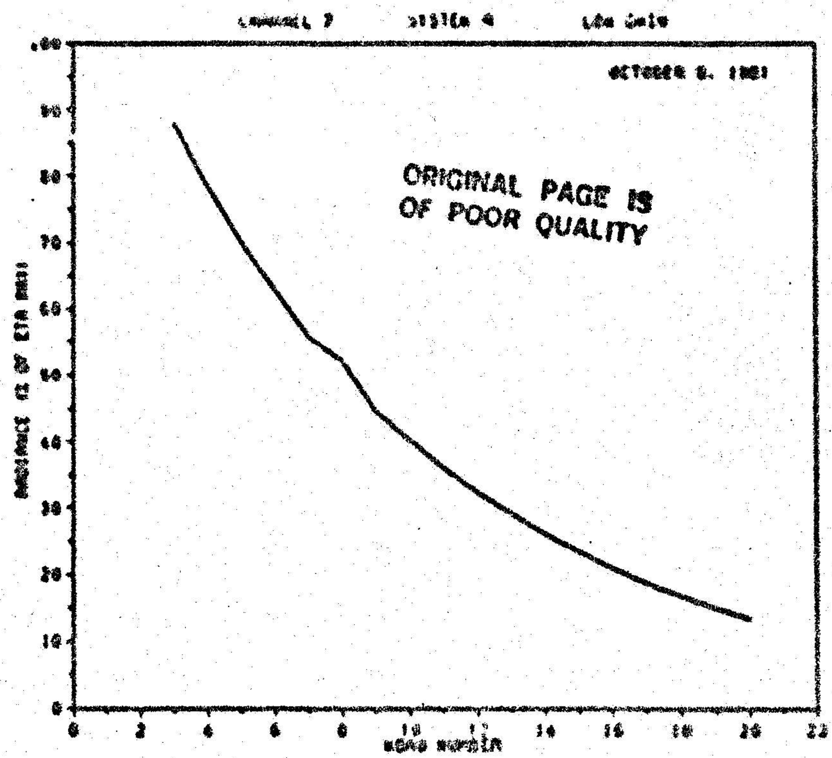
CHANNEL 7
ORIGINAL PAGE IS
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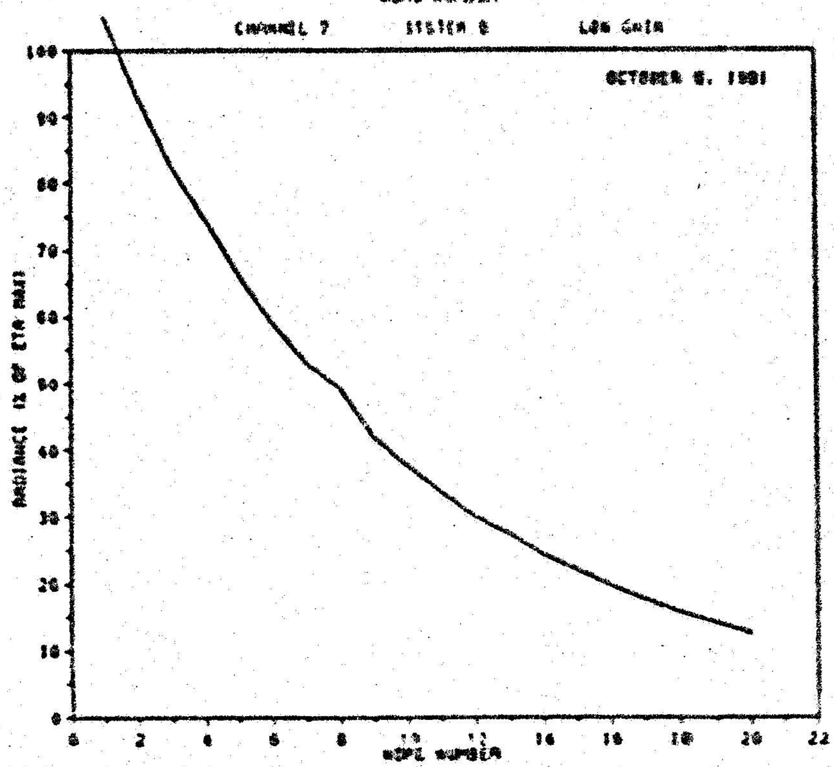
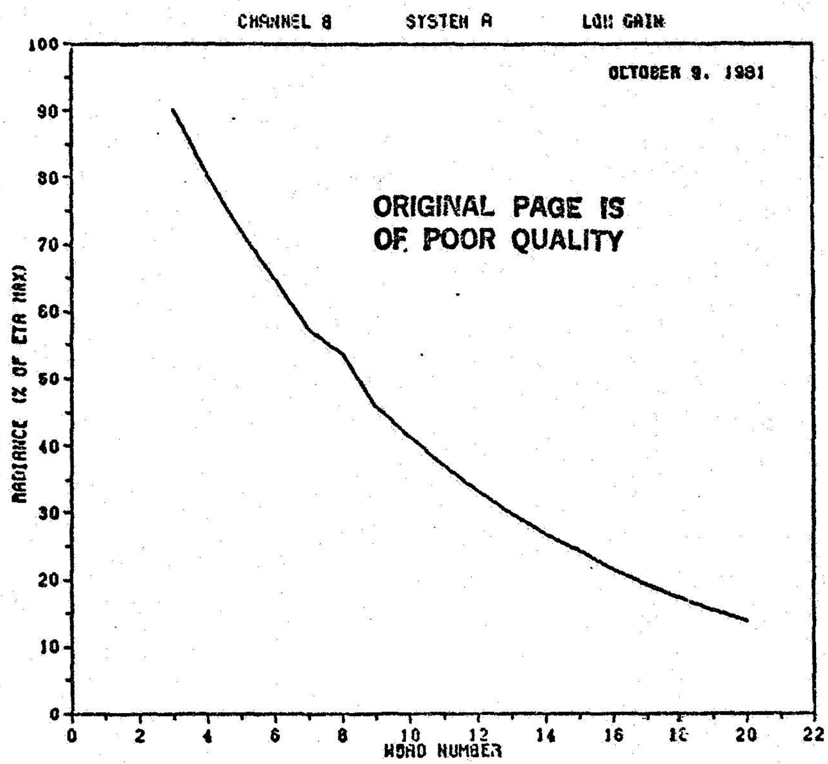

CHANNEL 7



CHANNEL 8
SYSTEM A
LOW GAIN
OCTOBER 9, 1981
ORIGINAL PAGE IS
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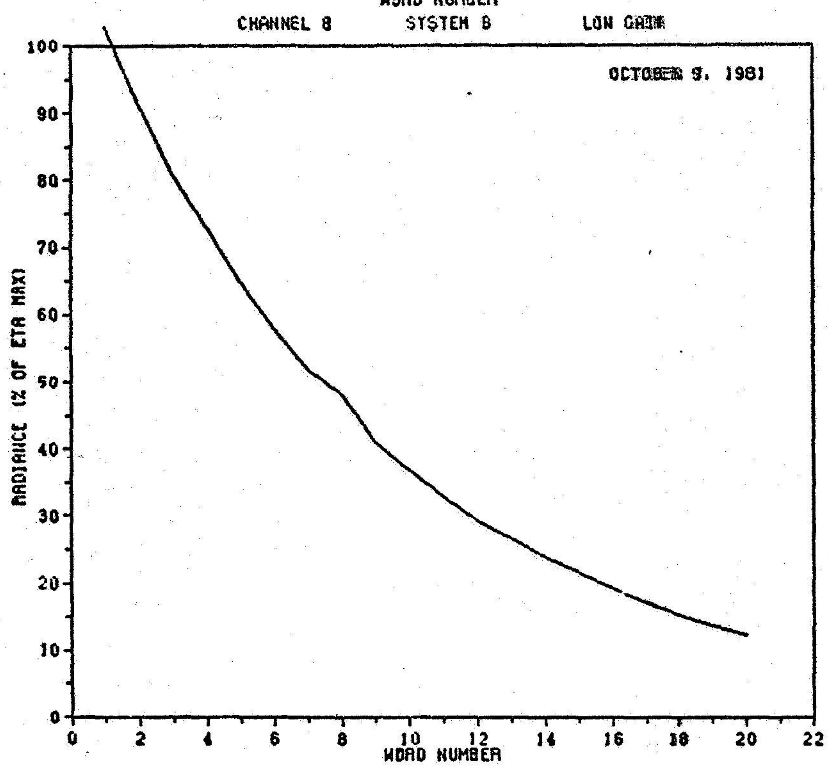
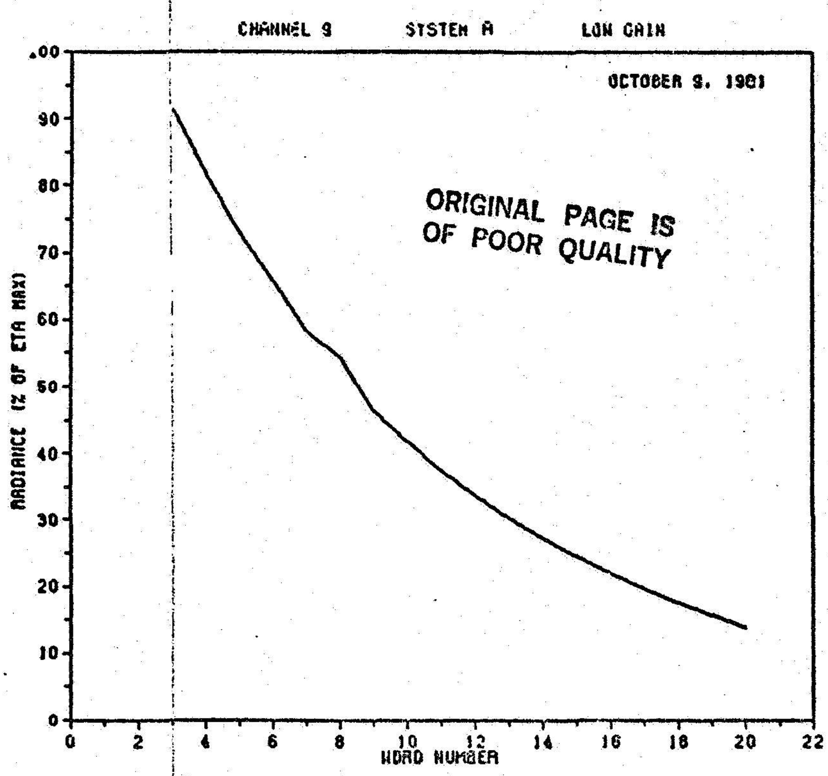
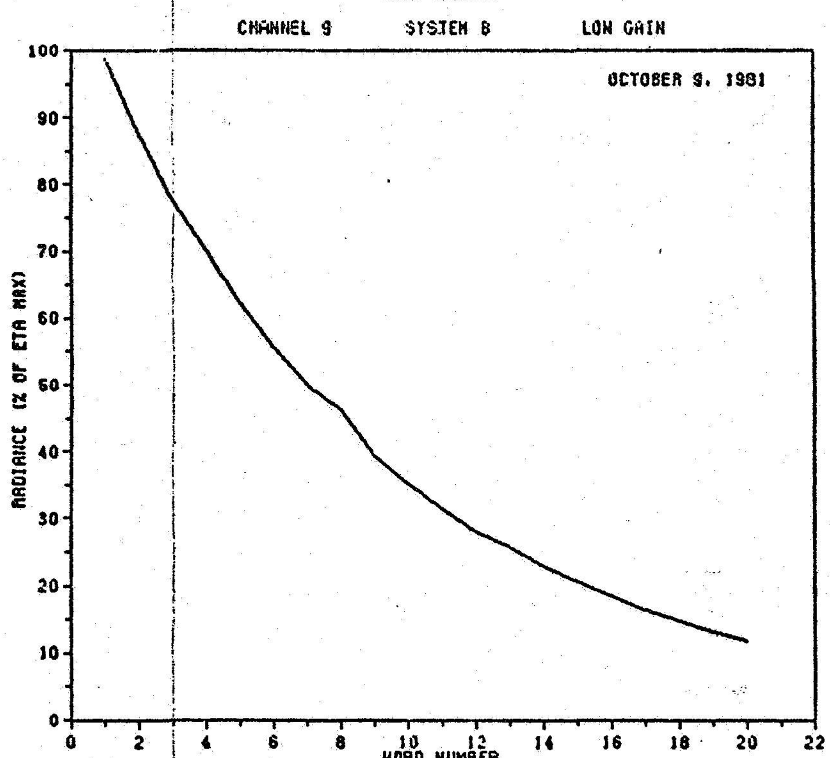
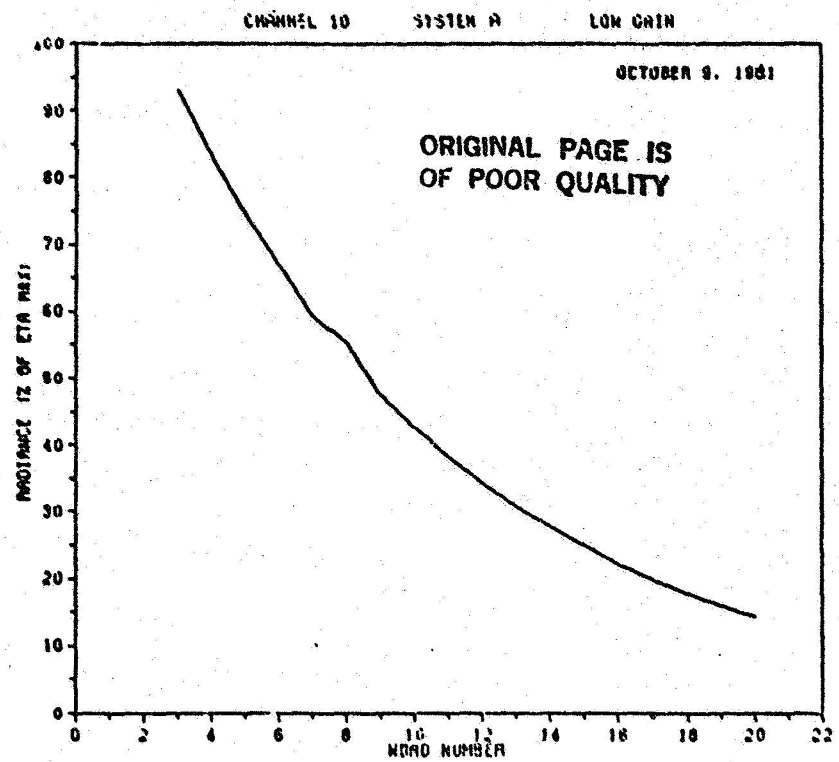
RADIANCE (% OF ETA MAX)
WORD NUMBER

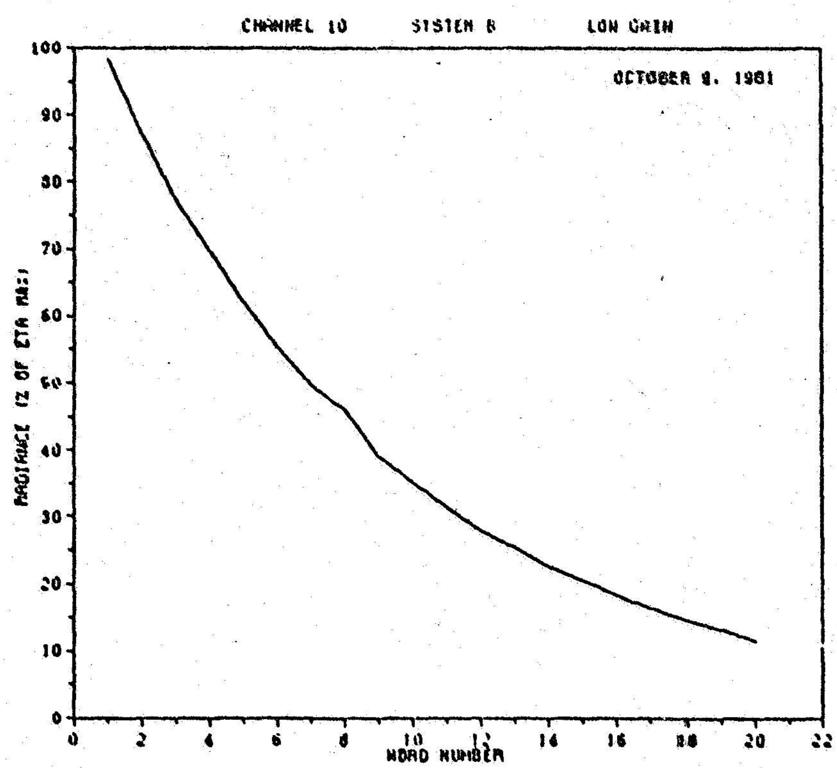


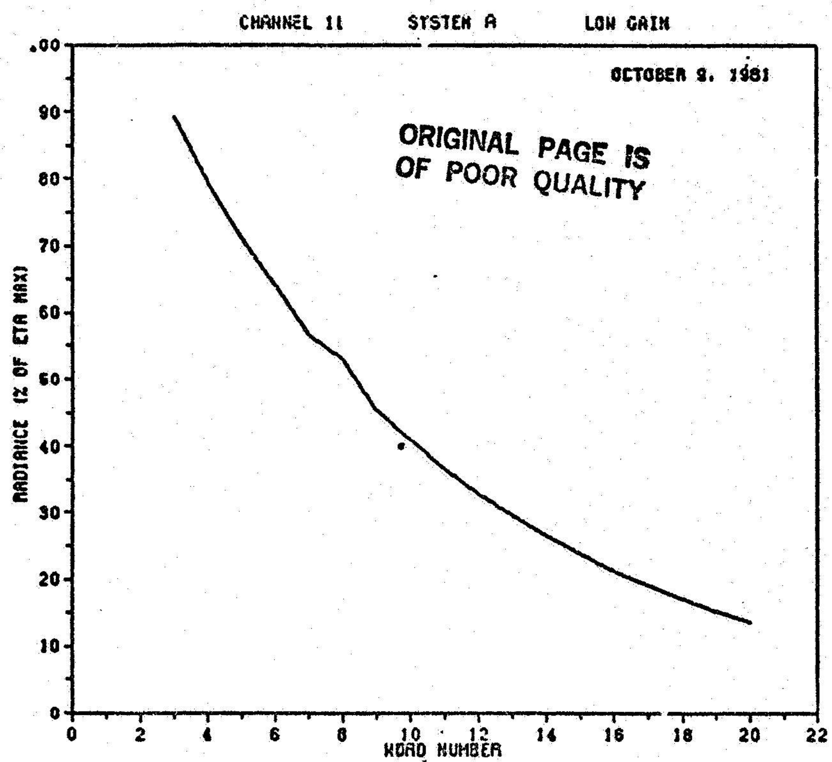
CHANNEL 8
SYSTEM B
LOW GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETA MAX)
WORD NUMBER

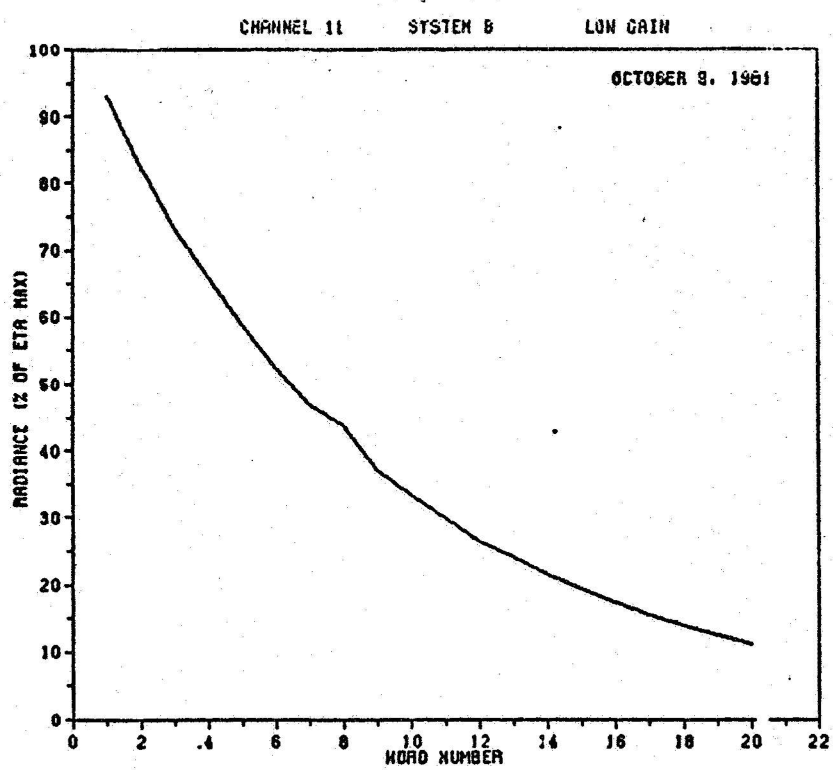

CHANNEL 9 SYSTEM A LOW GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETA MAX)
WORD NUMBER
ORIGINAL PAGE IS
OF POOR QUALITY

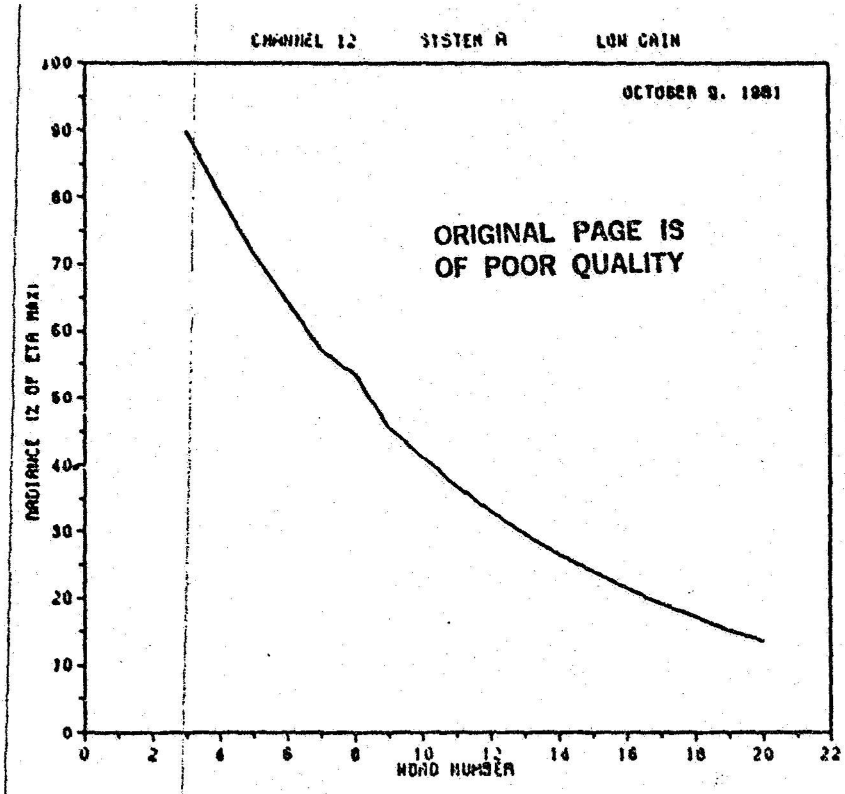

CHANNEL 9 SYSTEM B LOW GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETA MAX)
WORD NUMBER

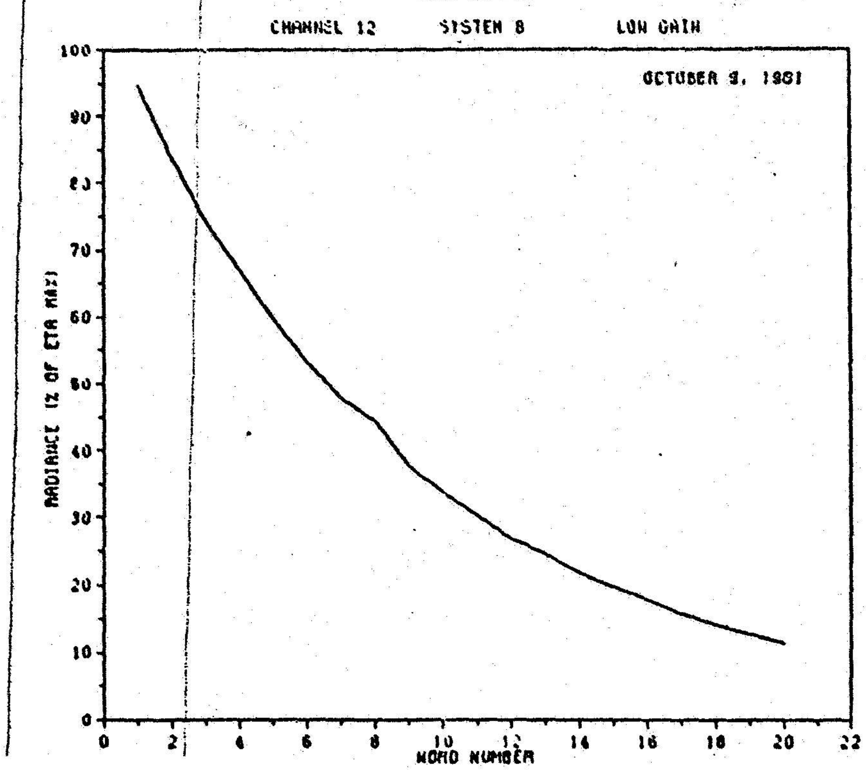

CHANNEL 10 SYSTEM A LOW GAIN
OCTOBER 9, 1981
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA MAX)
WORD NUMBER

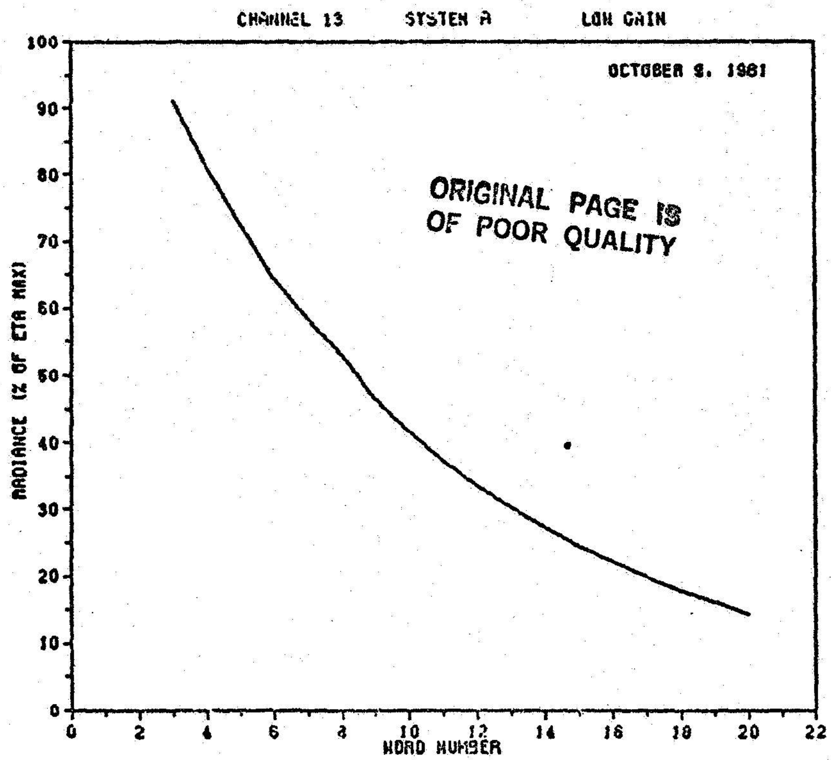

CHANNEL 10 SYSTEM B LOW GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETA MAX)
WORD NUMBER


CHANNEL 11 SYSTEM A LOW GAIN
OCTOBER 9, 1981
ORIGINAL PAGE IS OF POOR QUALITY
RADIANCE (% OF ETA MAX)
WORD NUMBER


CHANNEL 11 SYSTEM B LOW GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETA MAX)
WORD NUMBER


CHANNEL 12 SYSTEM A LOW GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETA MAX)
WORD NUMBER
0
2
4
6
8
10
12
14
16
18
20
22
100
90
80
70
60
50
40
30
20
10


CHANNEL 12 SYSTEM B LOW GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETA MAX)
WORD NUMBER



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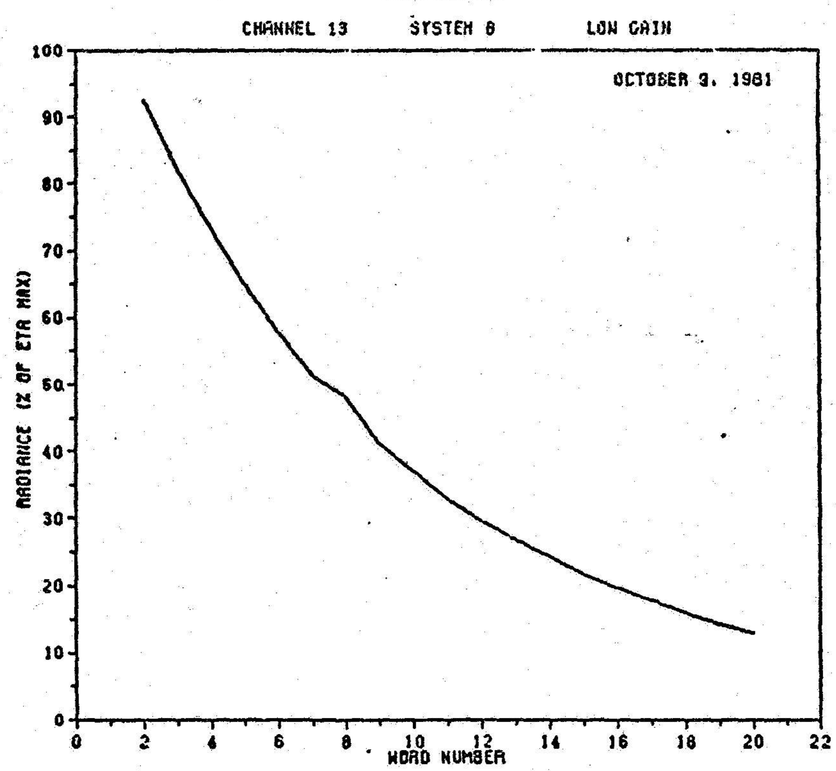

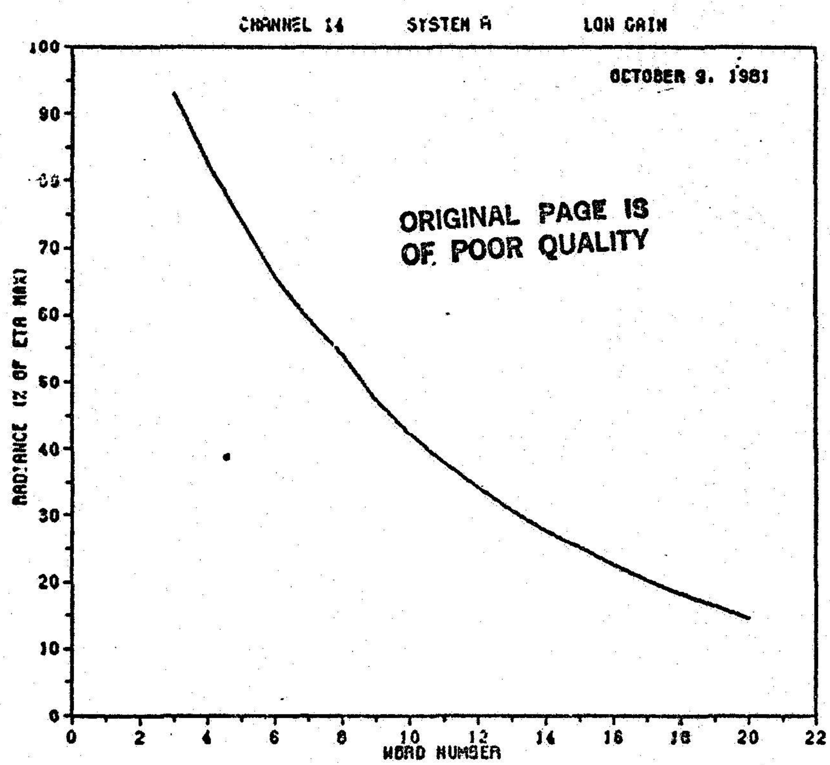

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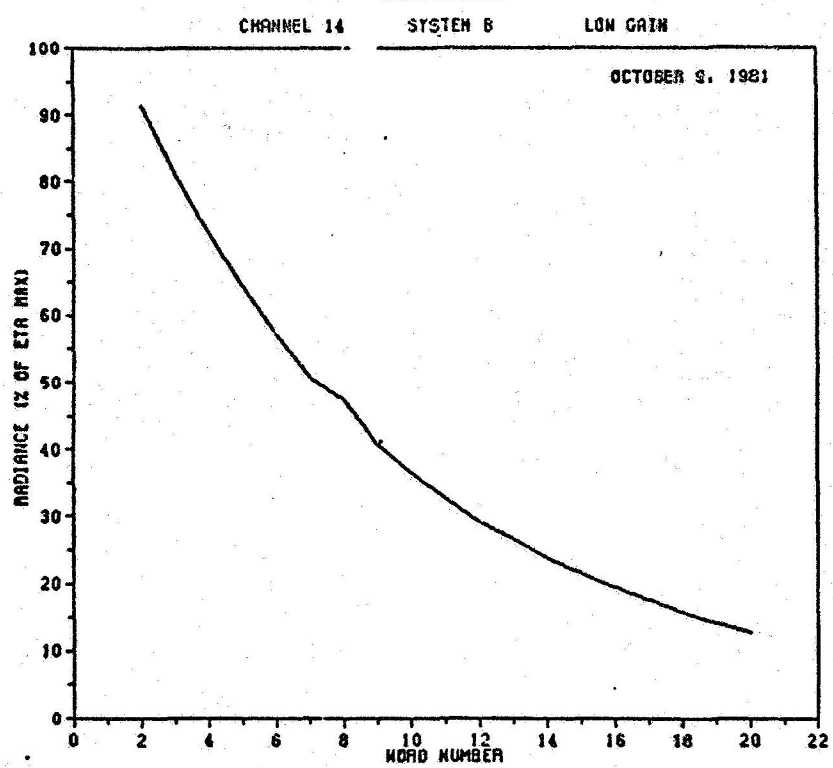

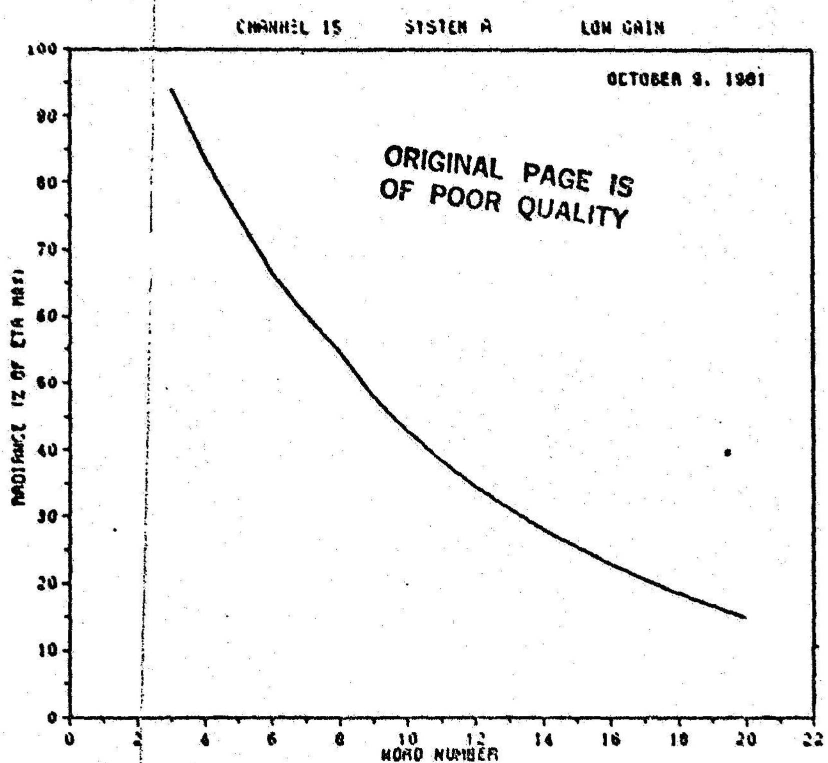

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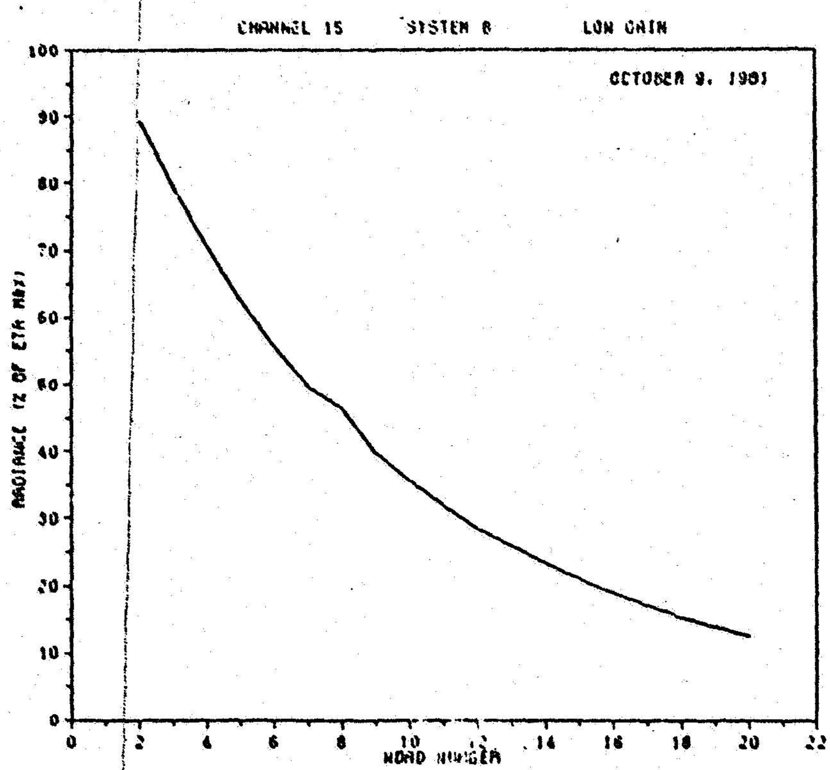
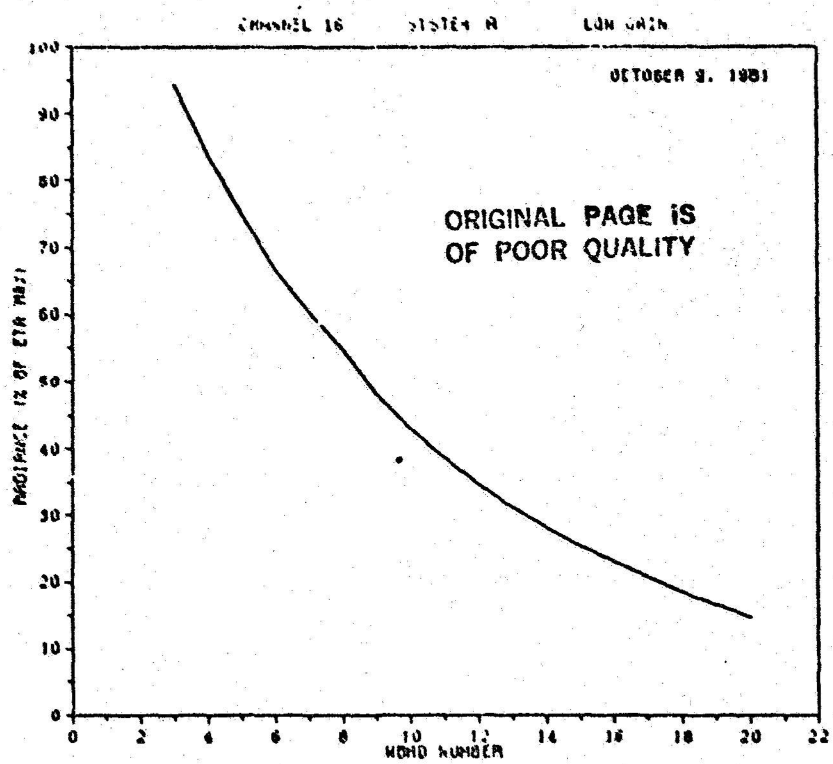
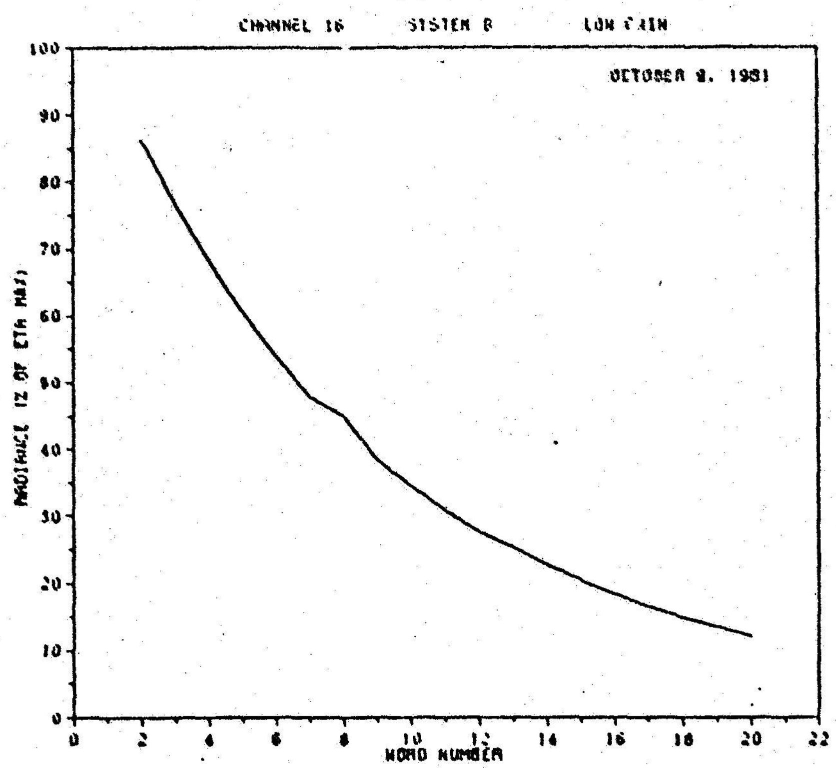
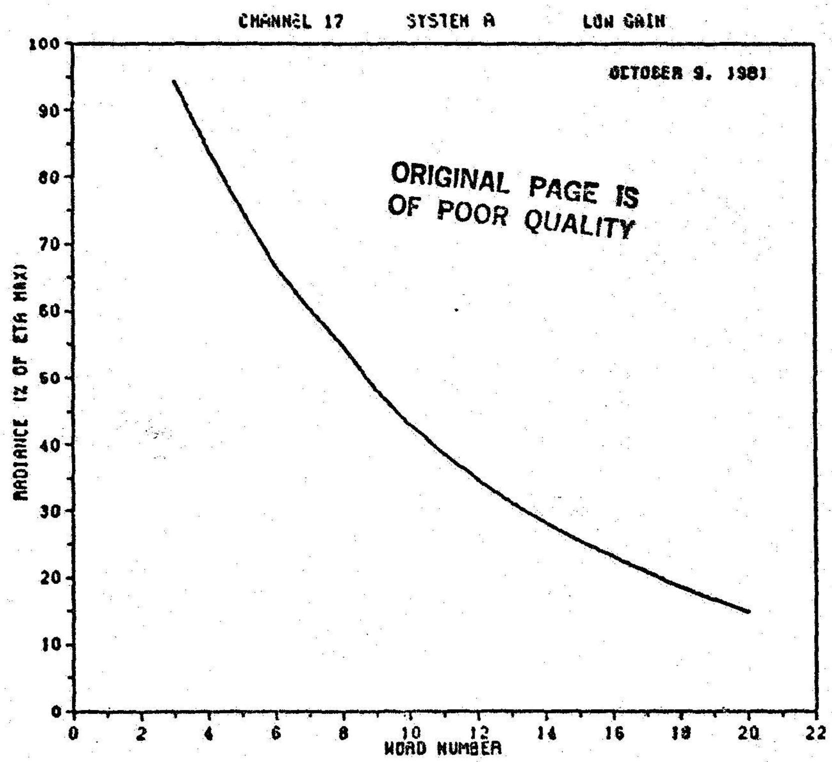
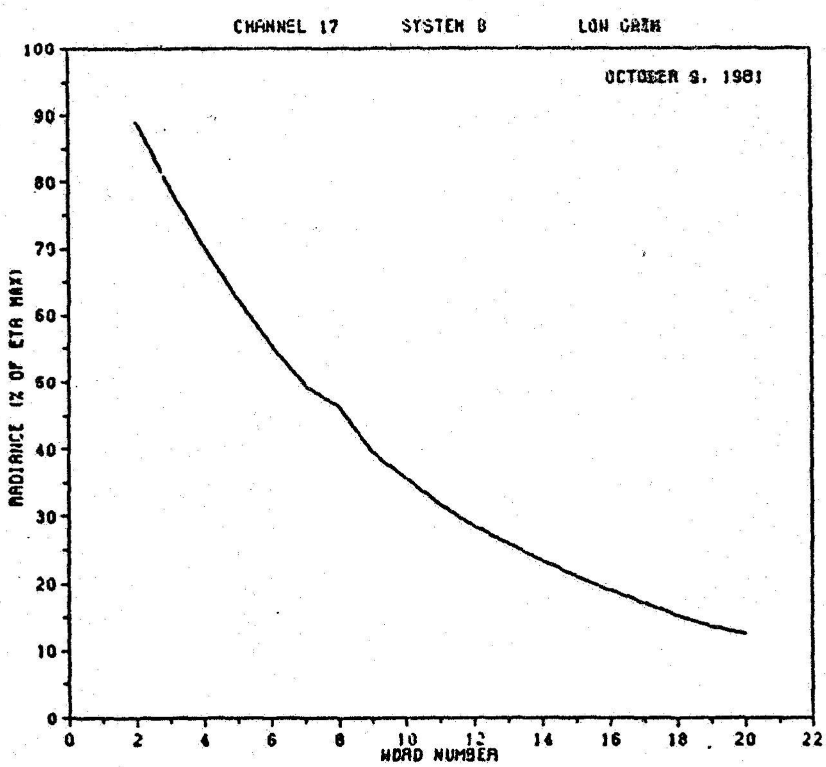
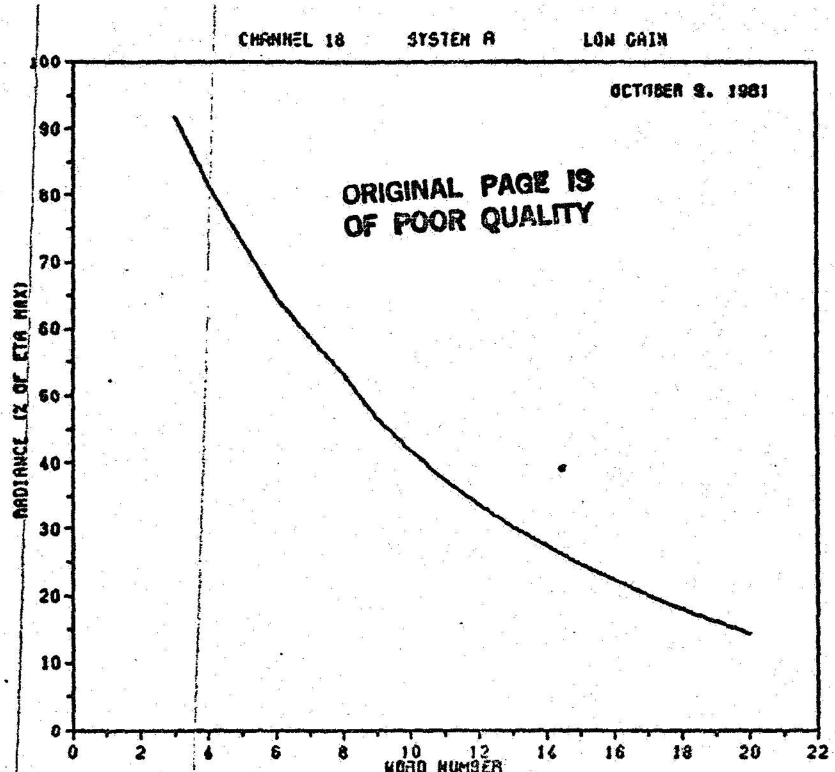


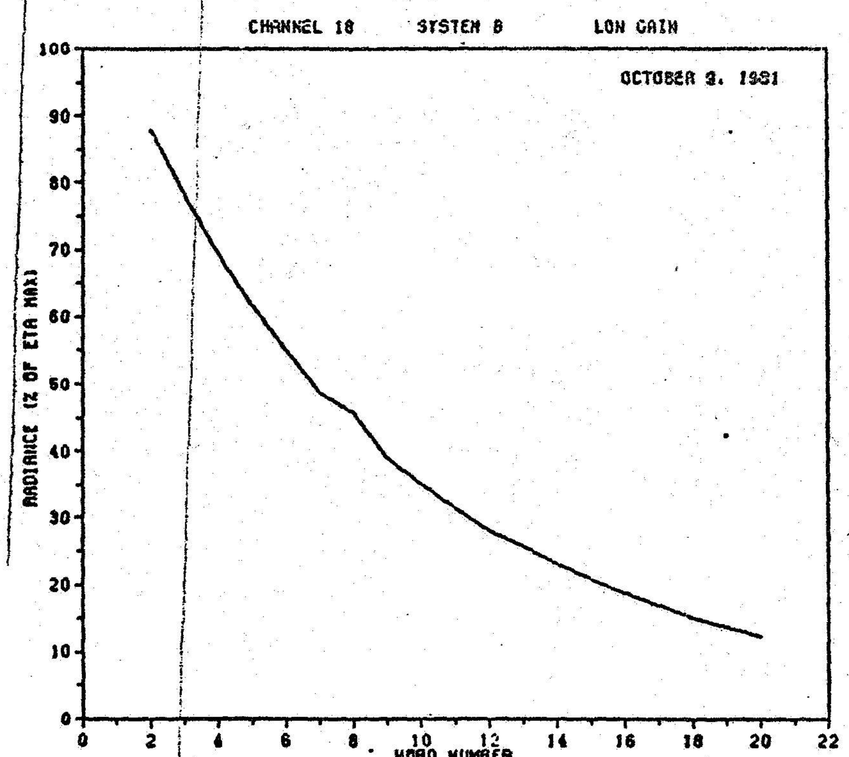

CHANNEL 16 SYSTEM A LOW GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETR MAX)
WORD NUMBER
0 2 4 6 8 10 12 14 16 18 20 22
0 10 20 30 40 50 60 70 80 90 100


CHANNEL 16 SYSTEM B LOW GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETR MAX)
WORD NUMBER
0 2 4 6 8 10 12 14 16 18 20 22
0 10 20 30 40 50 60 70 80 90 100

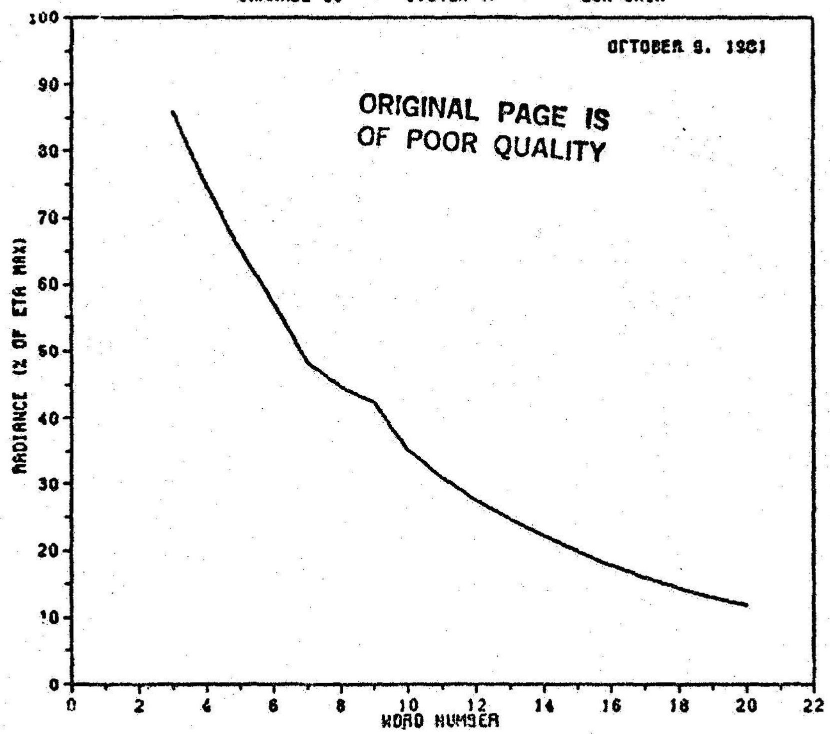

CHANNEL 17 SYSTEM A LOW GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETA MAX)
WORD NUMBER
ORIGINAL PAGE IS
OF POOR QUALITY


CHANNEL 17 SYSTEM B LOW GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETA MAX)
WORD NUMBER

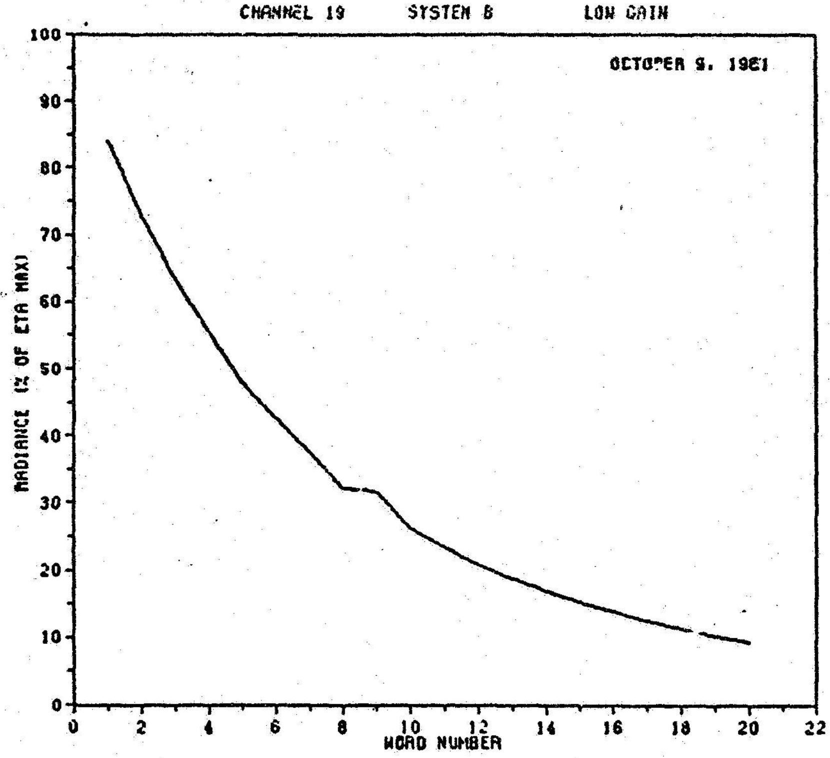

CHANNEL 18 SYSTEM A LOW GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETA MAX)
WORD NUMBER
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10
12
14
16
18
20
22

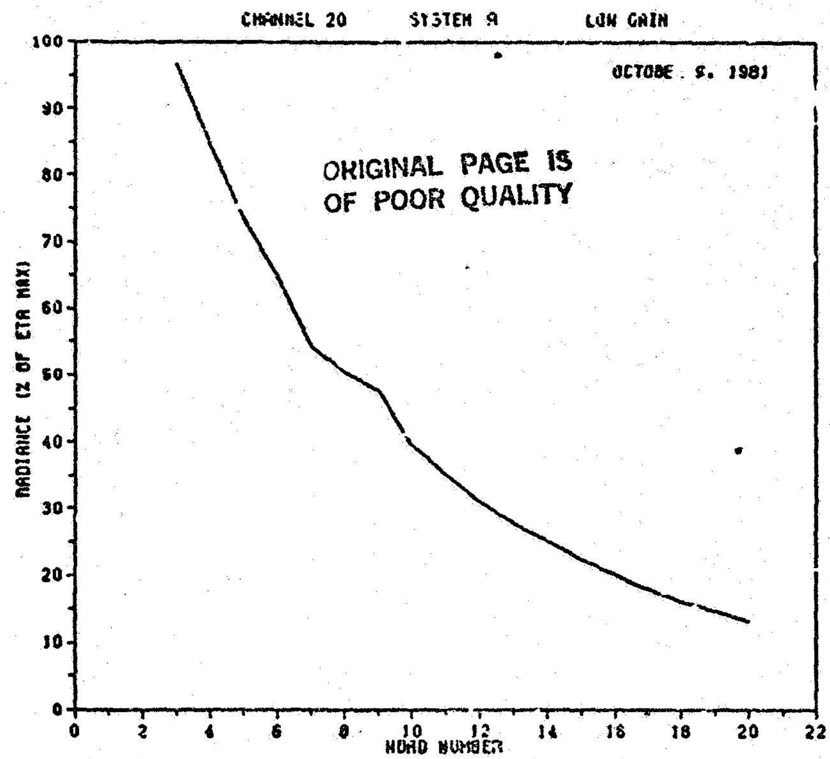

CHANNEL 18 SYSTEM B LOW GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETA MAX)
WORD NUMBER
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10
12
14
16
18
20
22

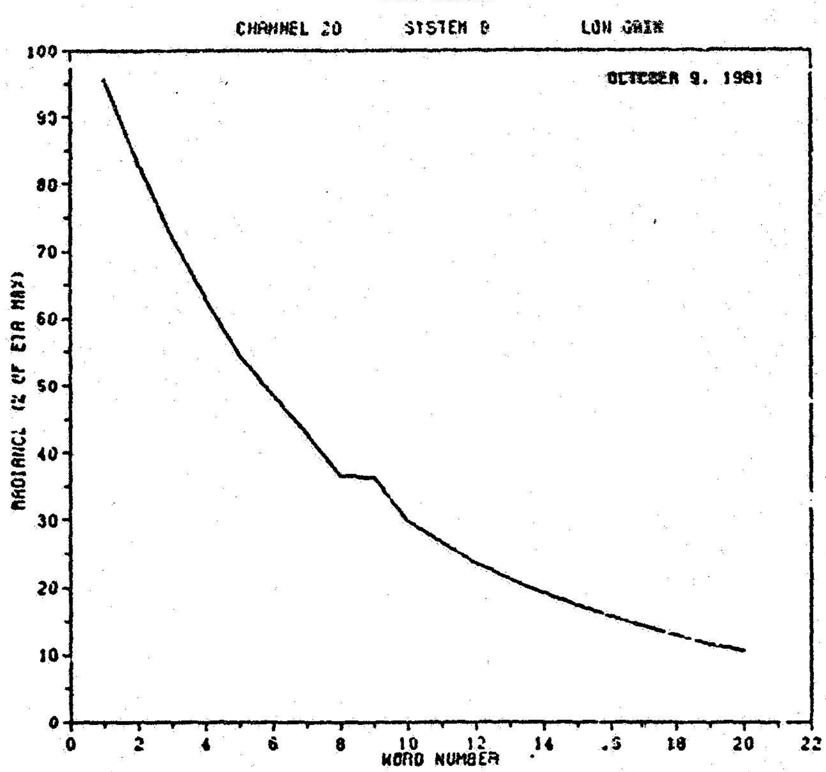
CHANNEL 19 SYSTEM A LOW GAIN

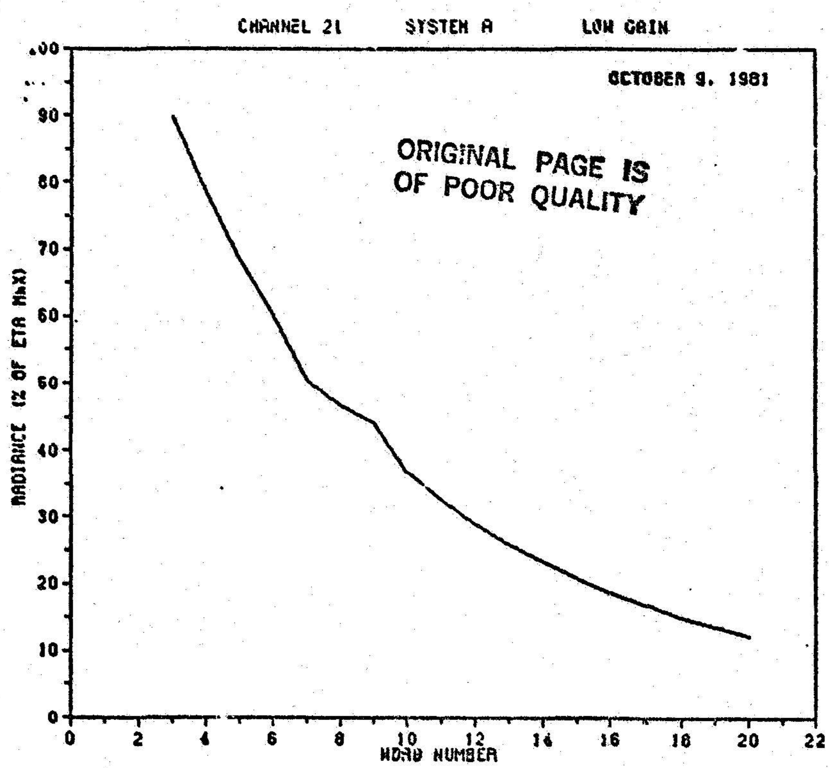


CHANNEL 19 SYSTEM B LOW GAIN




CHANNEL 20
SYSTEM A
LOW GAIN
OCTOBER 9, 1981
ORIGINAL PAGE IS
OF POOR QUALITY
RADIANCE (% OF ETA MAX)
WORD NUMBER


CHANNEL 20
SYSTEM B
LOW GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETA MAX)
WORD NUMBER



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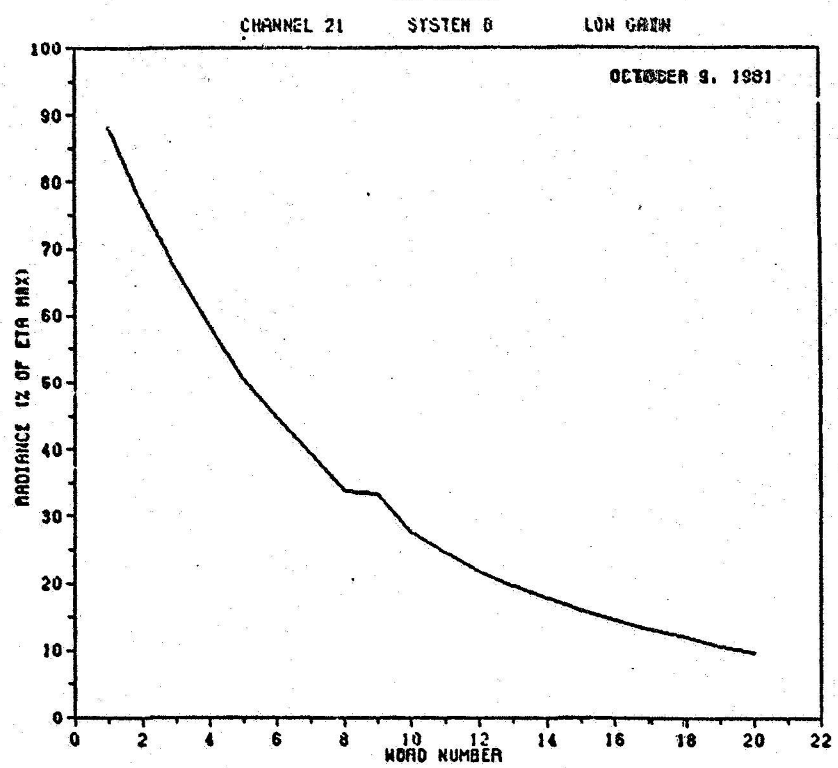

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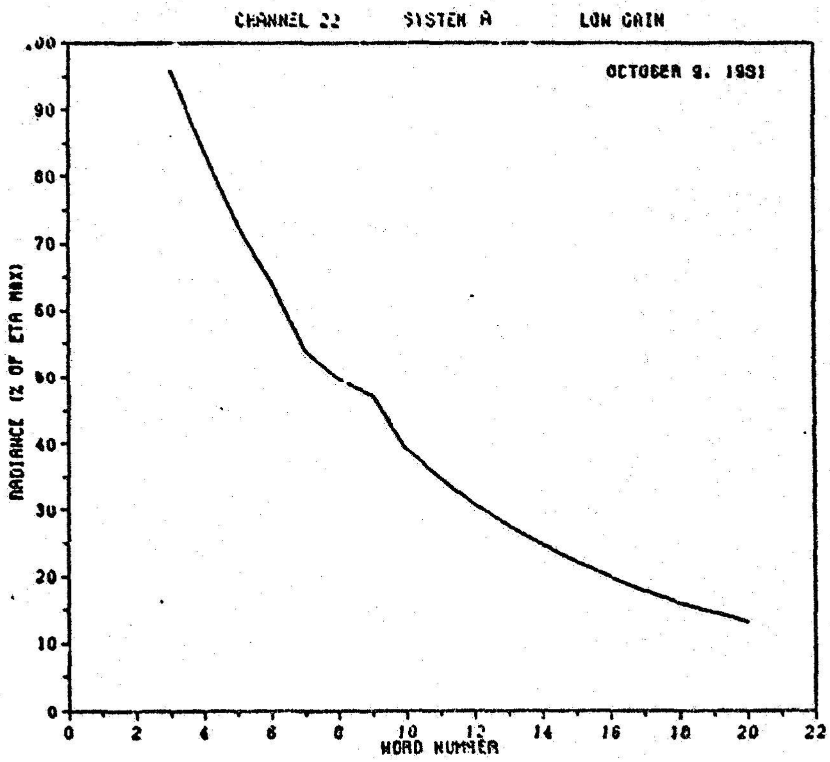
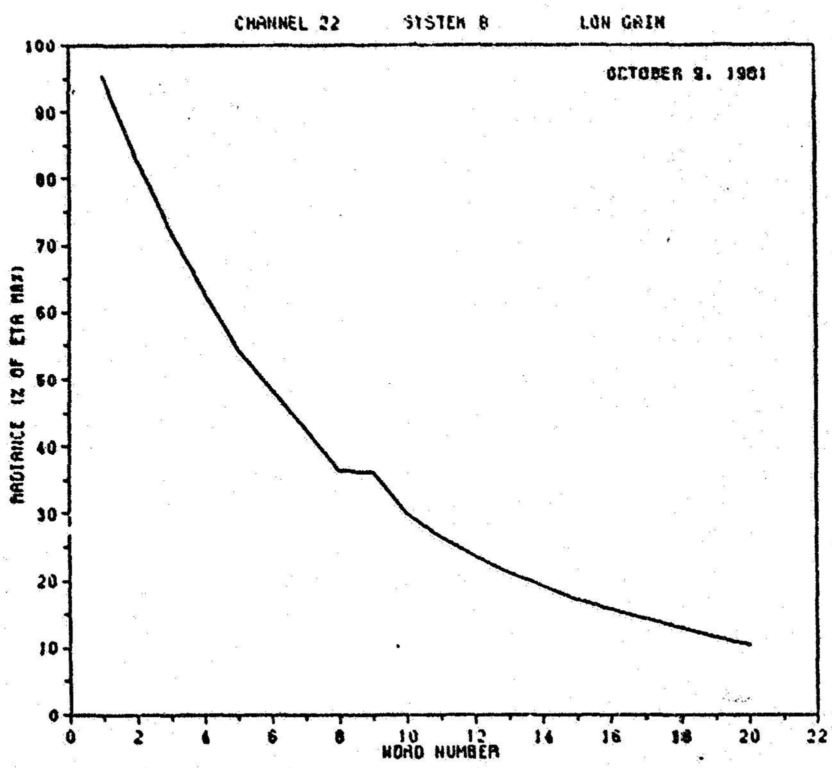
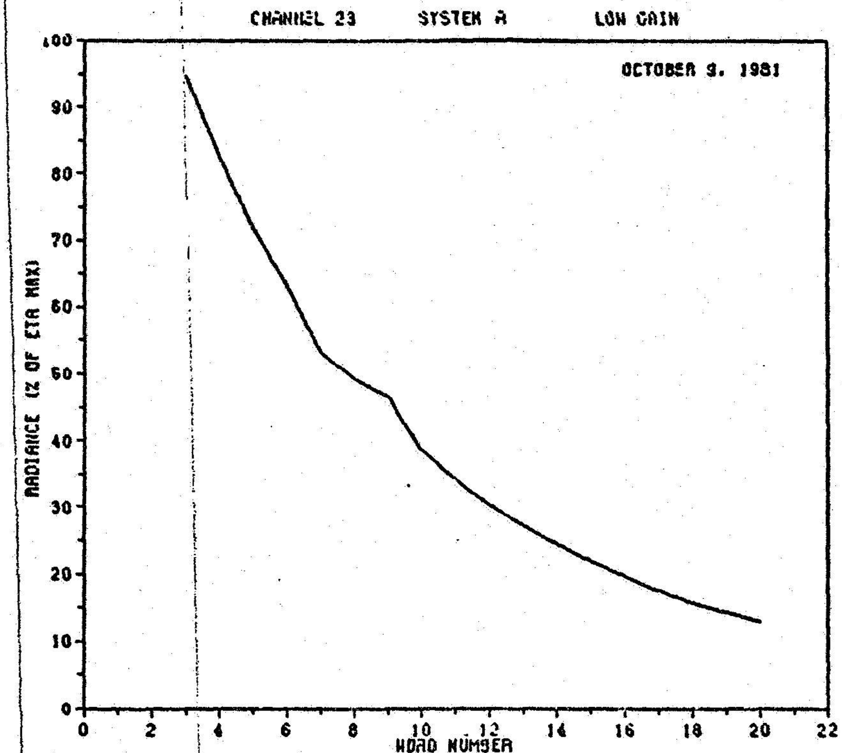
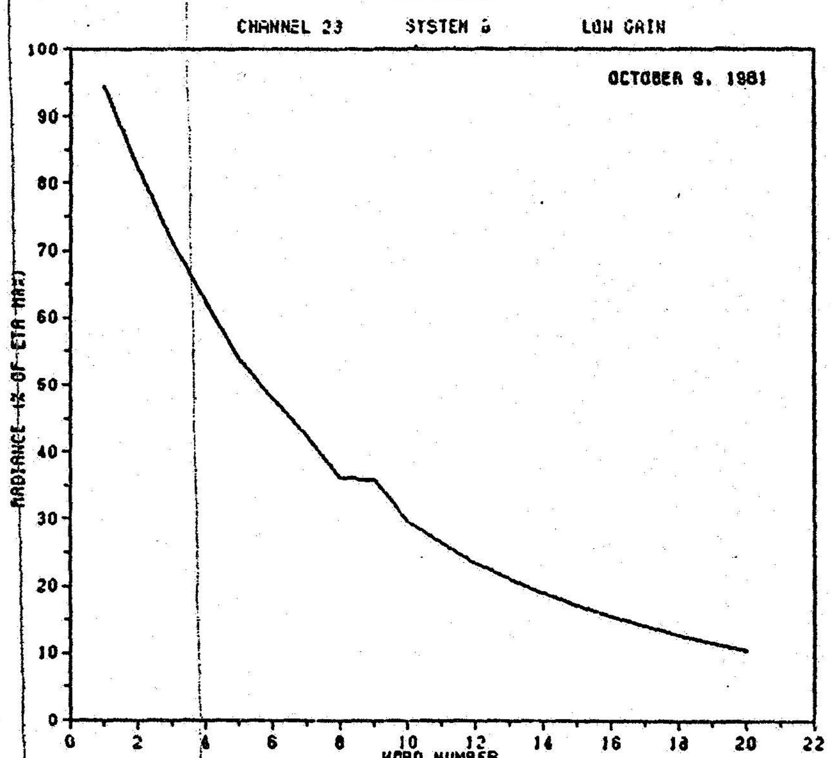
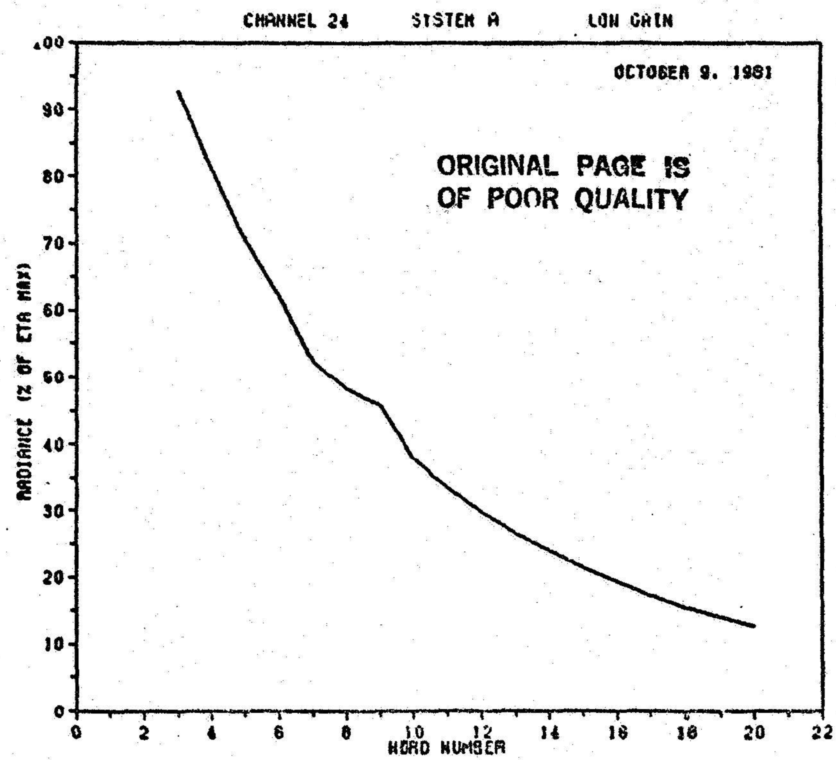





CHANNEL 23 SYSTEM A LOW GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETA MAX)
WORD NUMBER
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10
12
14
16
18
20
22


CHANNEL 23 SYSTEM B LOW GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETA MAX)
WORD NUMBER
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10
12
14
16
18
20
22



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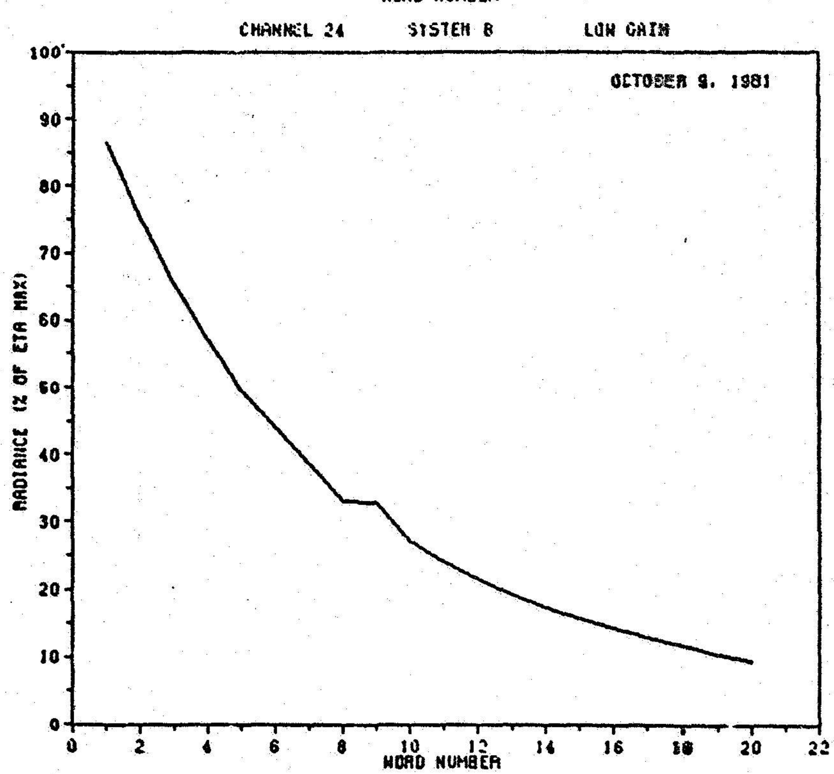
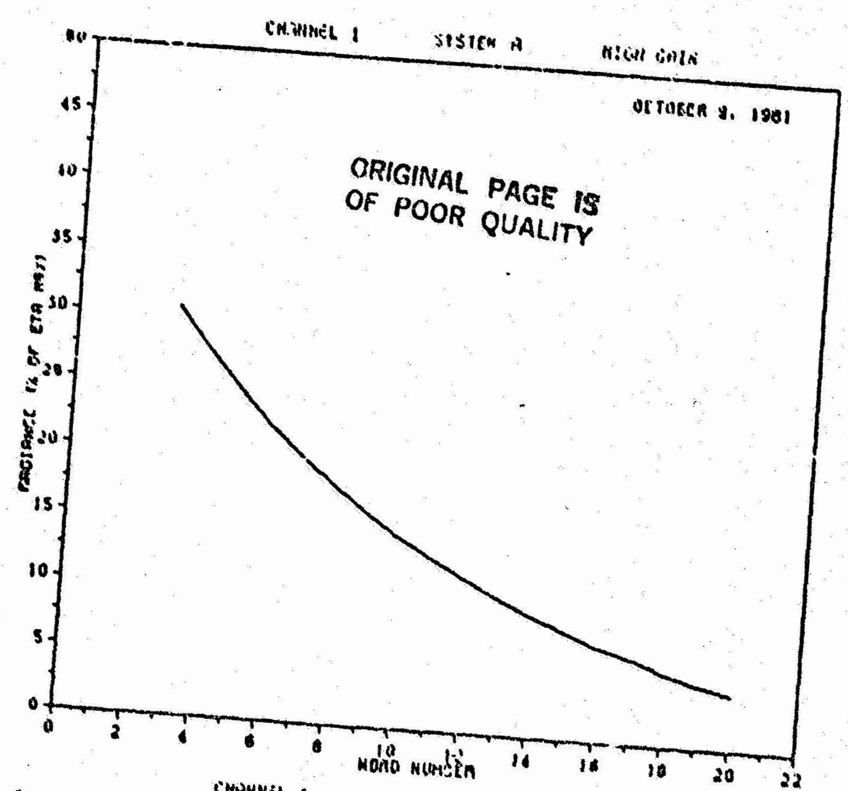
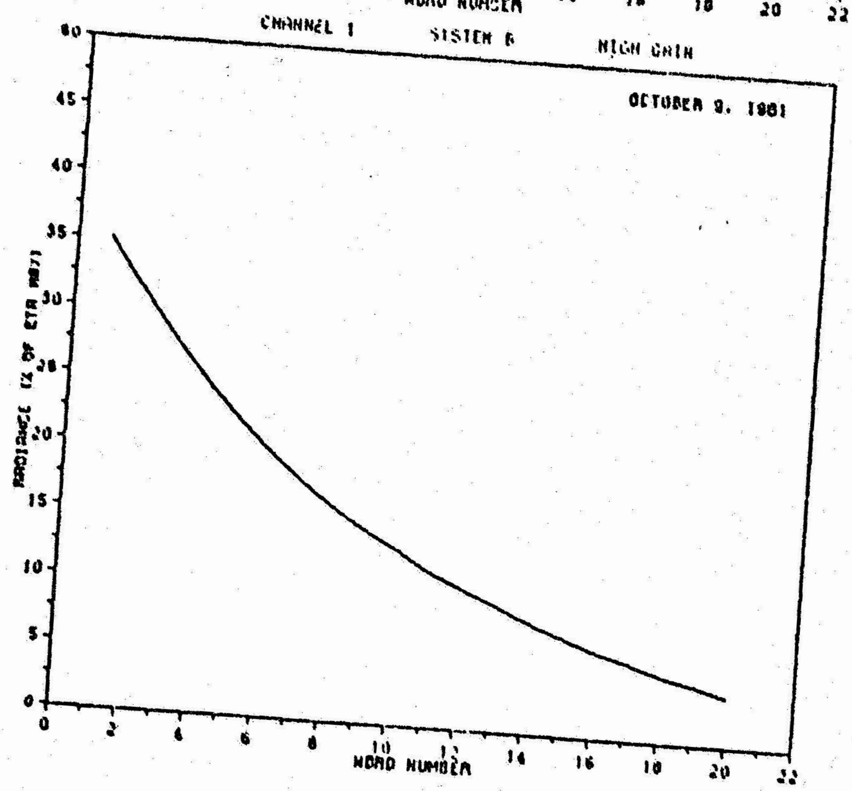
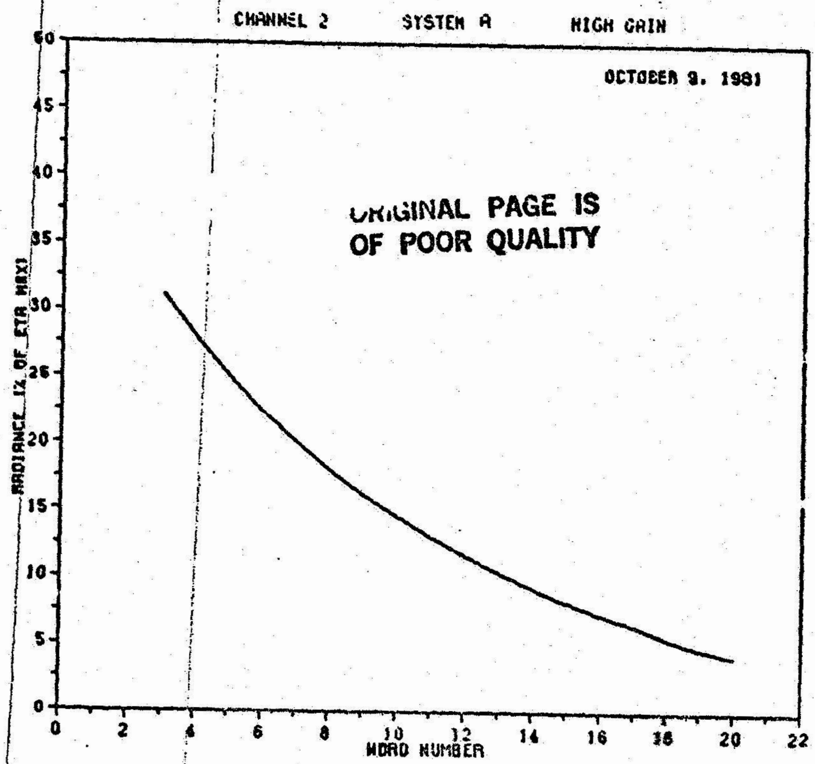



CHANNEL 1
SYSTEM A
HIGH GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETR MAX)
WORD NUMBER


CHANNEL 1
SYSTEM B
HIGH GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETR MAX)
WORD NUMBER



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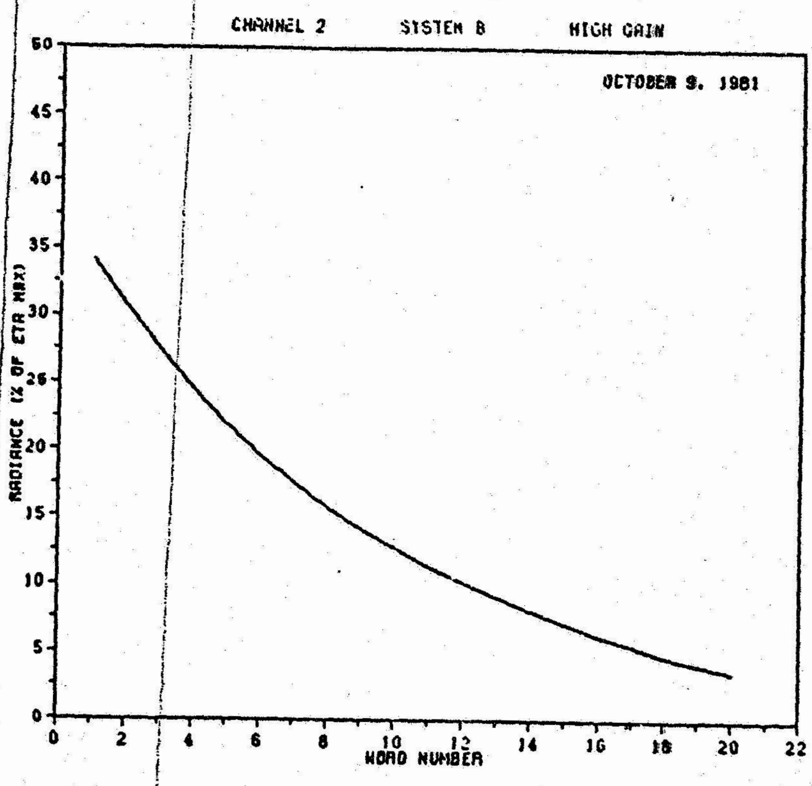

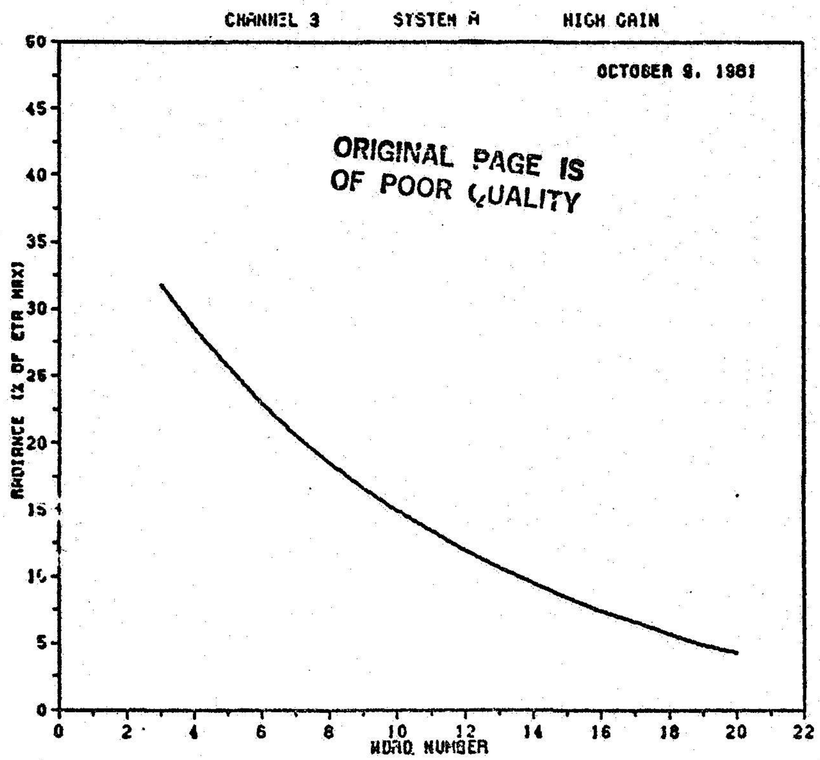
CHANNEL 3 SYSTEM A HIGH GAIN
OCTOBER 9, 1981
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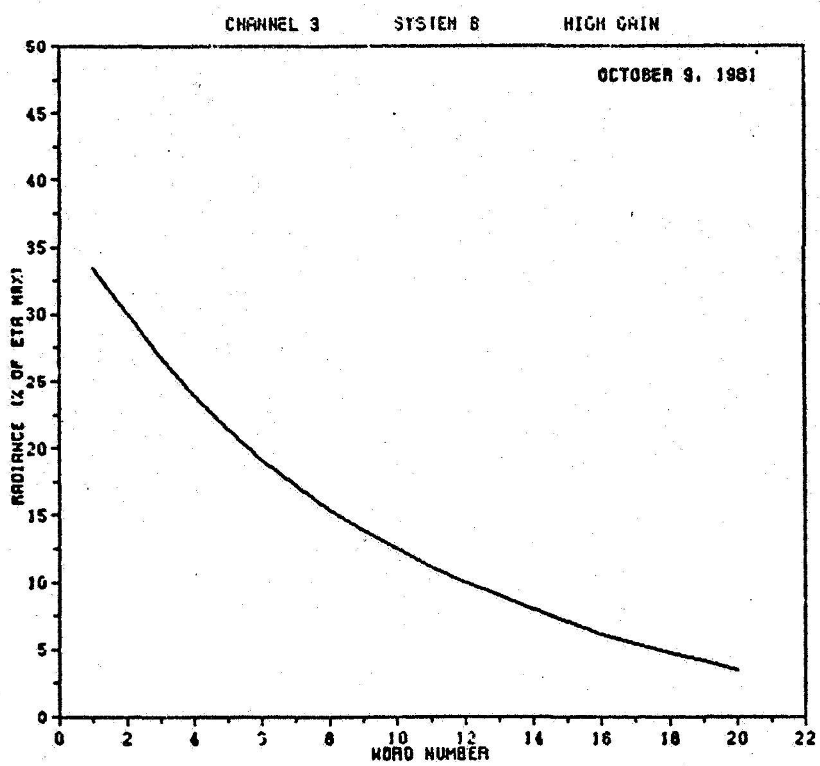
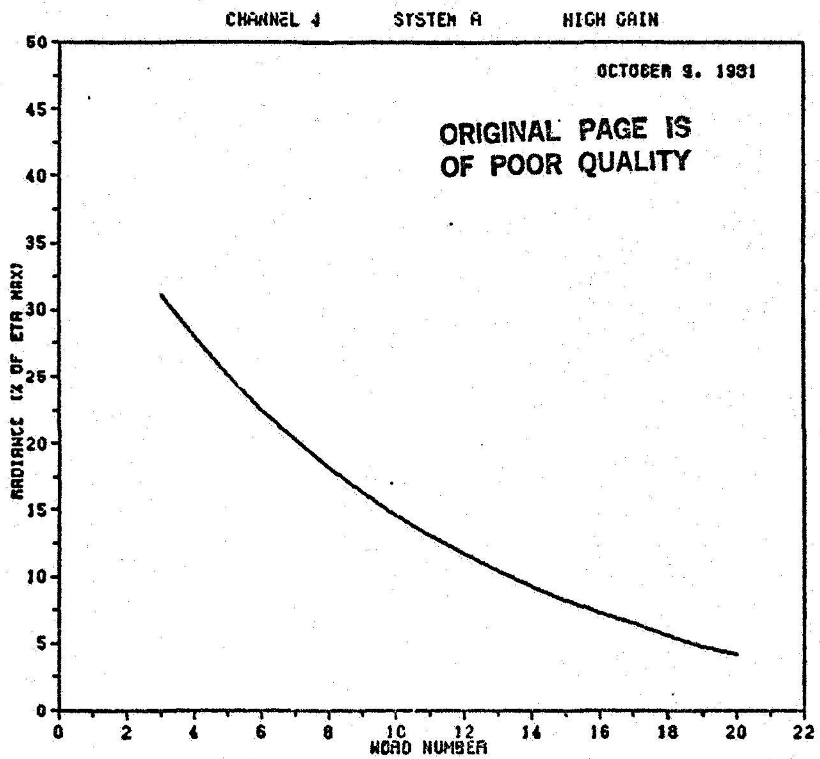
RADIANCE (% OF ETR MAX)
WORD NUMBER


CHANNEL 3 SYSTEM B HIGH GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETR MAX)
WORD NUMBER



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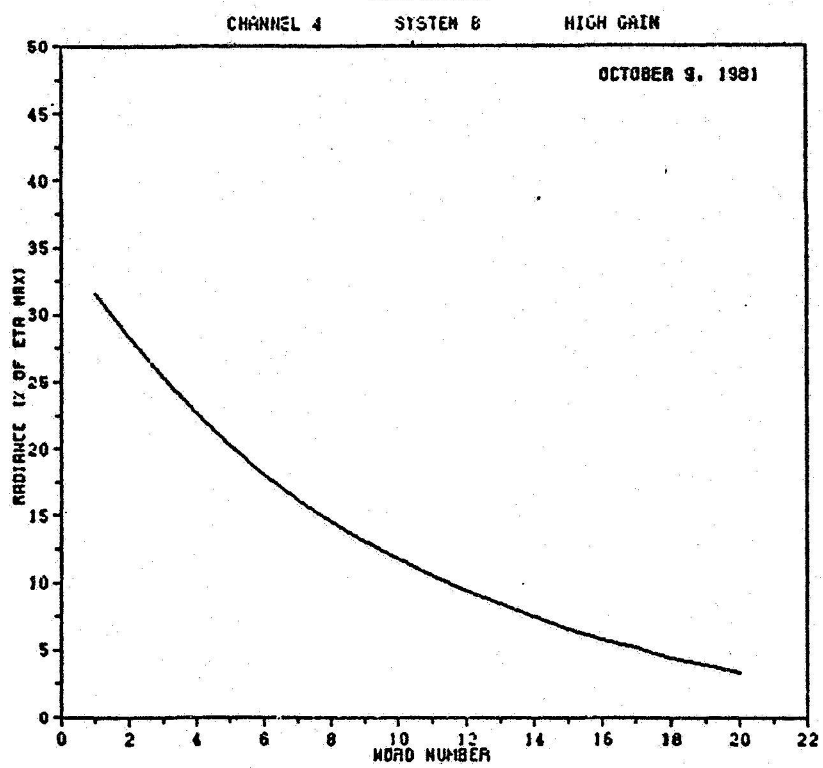

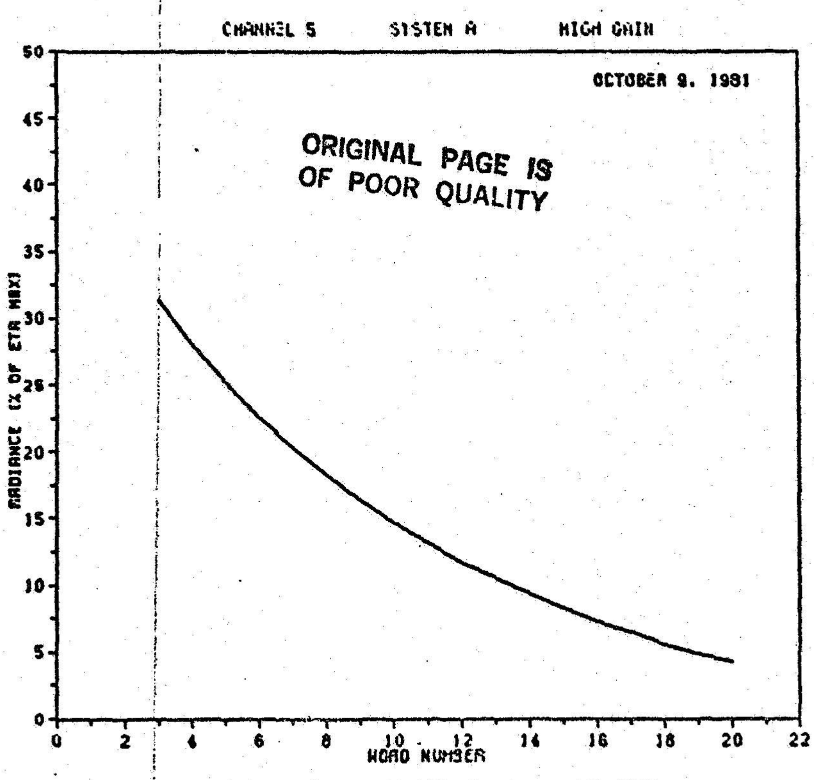

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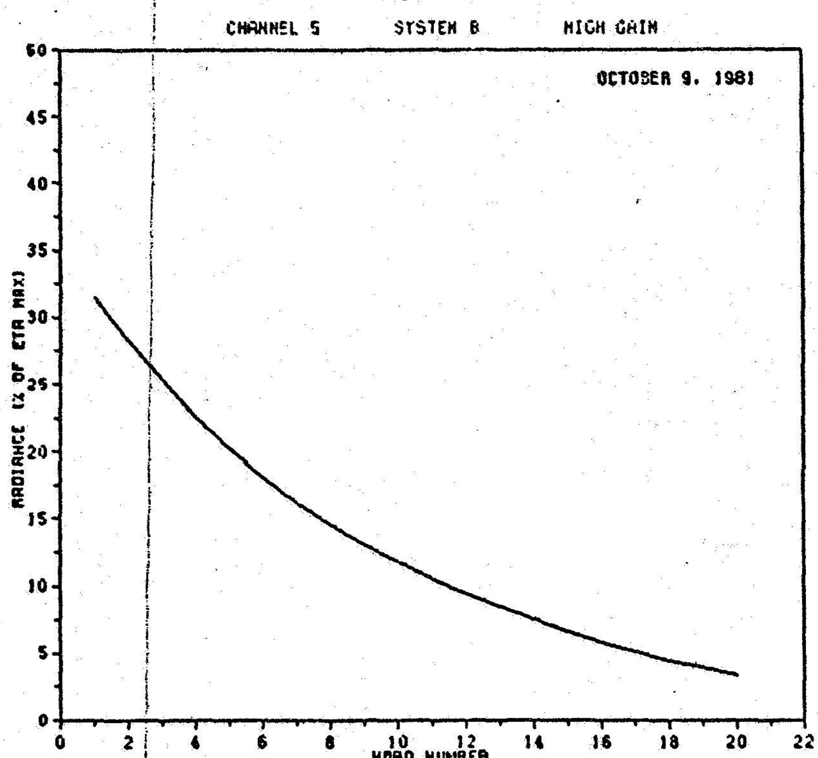

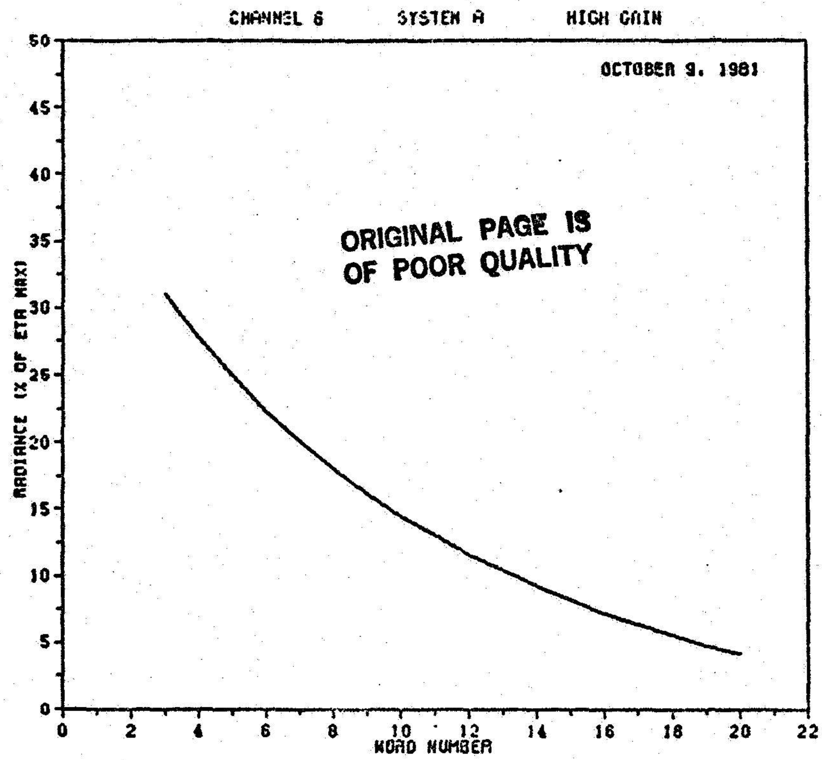
CHANNEL 6 SYSTEM A HIGH GAIN
OCTOBER 9, 1981
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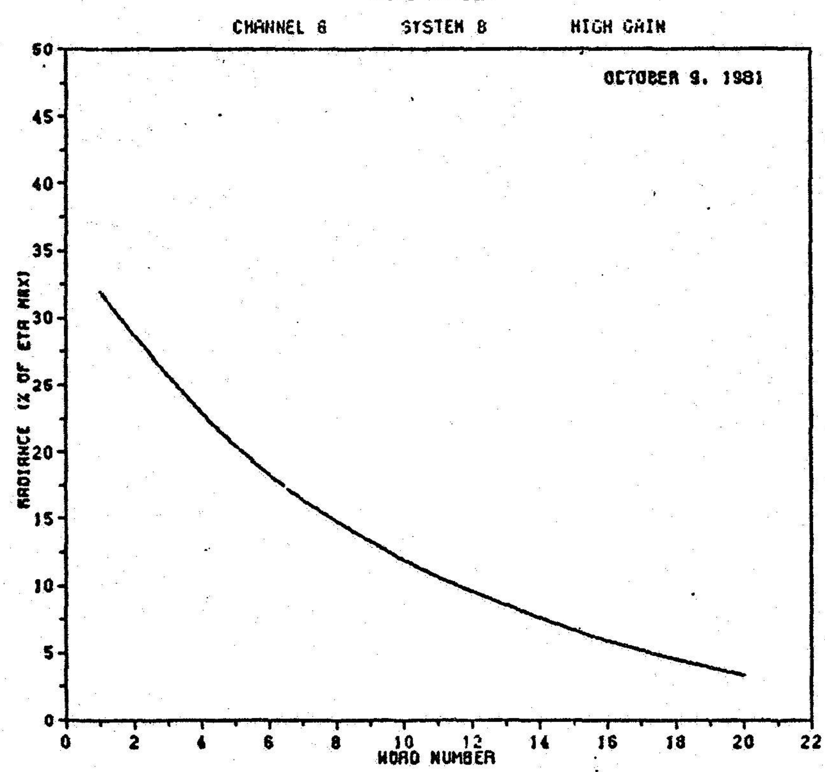
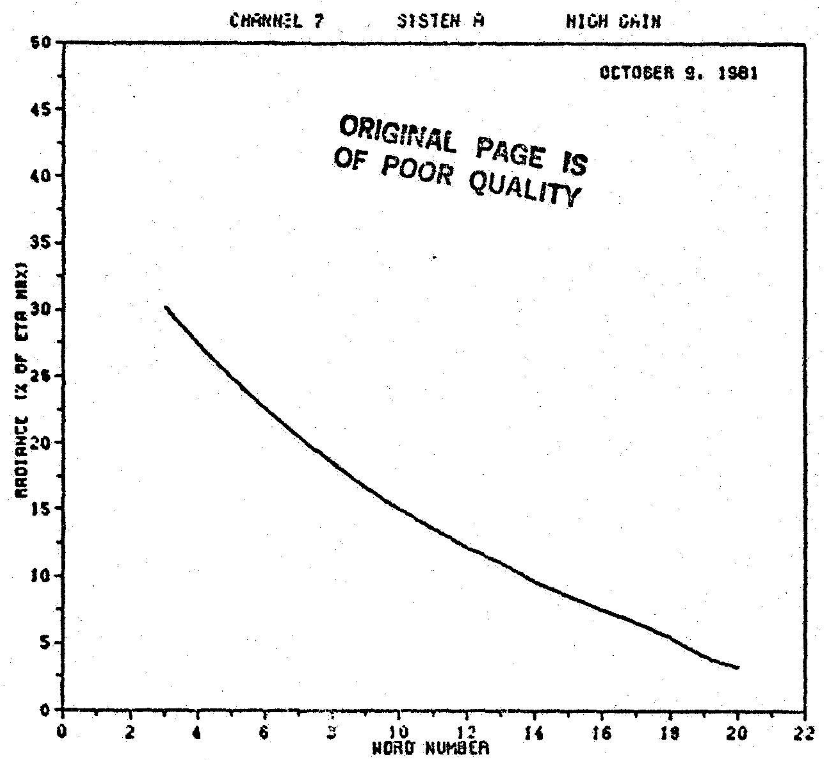
RADIANCE (% OF ETR MAX)
WORD NUMBER


CHANNEL 6 SYSTEM B HIGH GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETR MAX)
WORD NUMBER


CHANNEL 7 SYSTEM A HIGH GAIN
OCTOBER 9, 1981
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RADIANCE (% OF ETR MAX)
WORD NUMBER
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8
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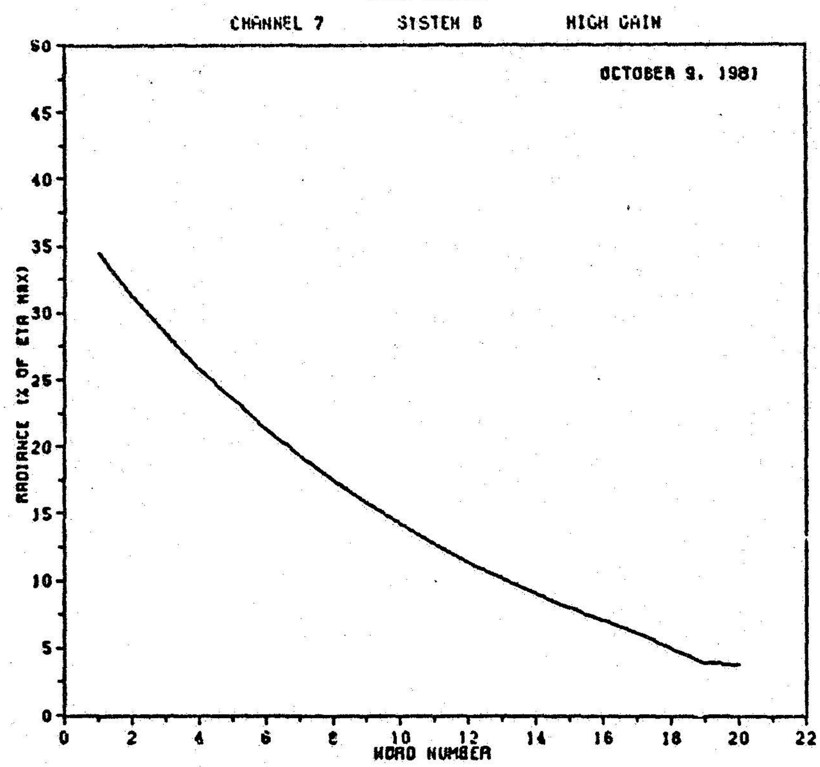
CHANNEL 7 SYSTEM B HIGH GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETR MAX)
WORD NUMBER
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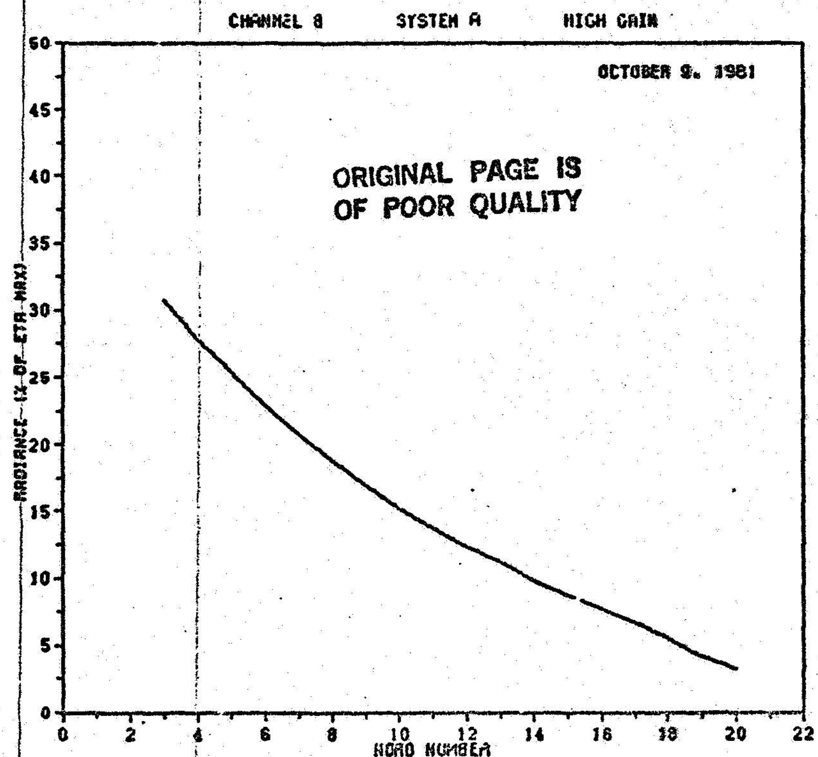

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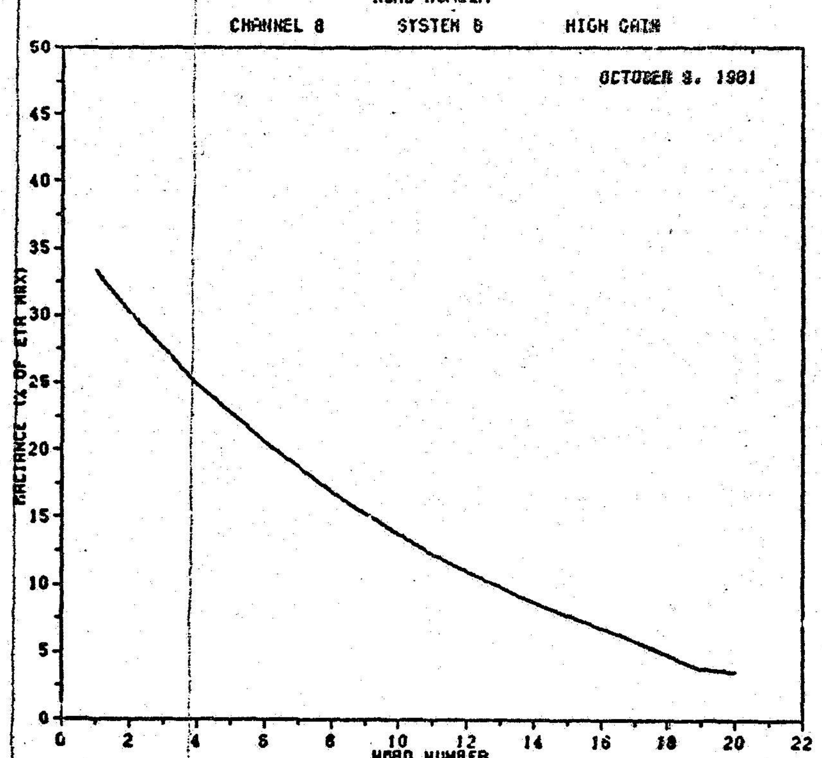

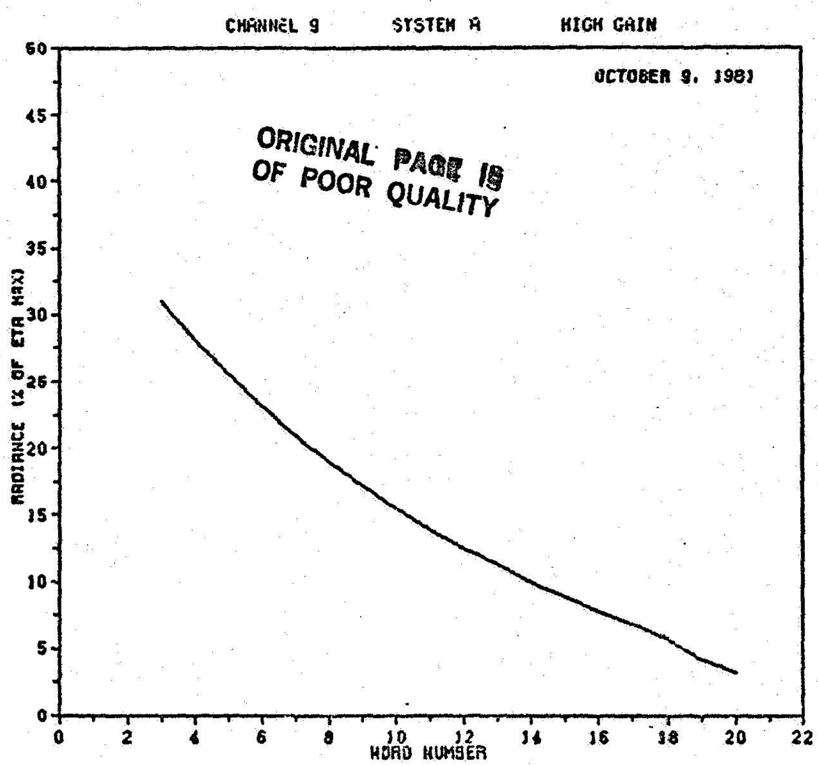
CHANNEL 9 SYSTEM A HIGH GAIN
OCTOBER 9, 1981
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RADIANCE (% OF ETR MAX)
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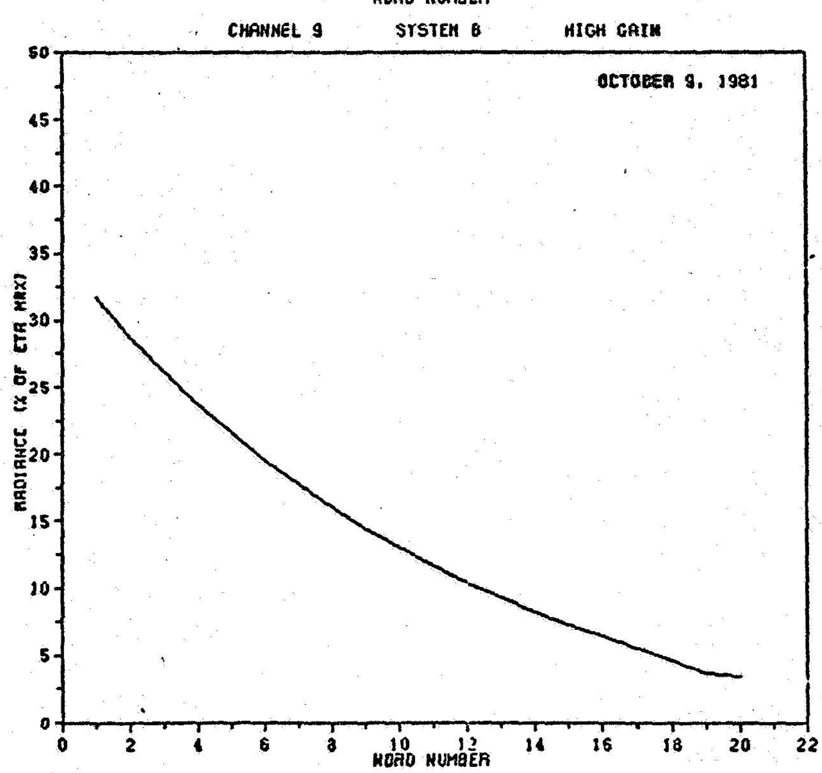
22
WORD NUMBER


CHANNEL 9 SYSTEM B HIGH GAIN
OCTOBER 9, 1981
RADIANCE (% OF ETR MAX)
0
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10
15
20
25
30
35
40
45
50
0
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8
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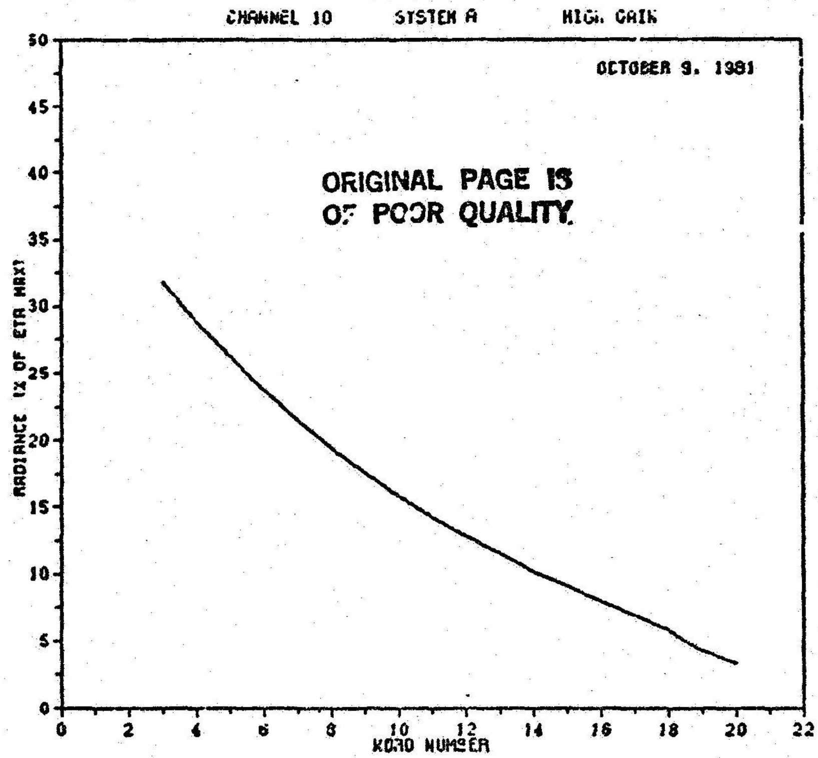
12
14
16
18
20
22
WORD NUMBER



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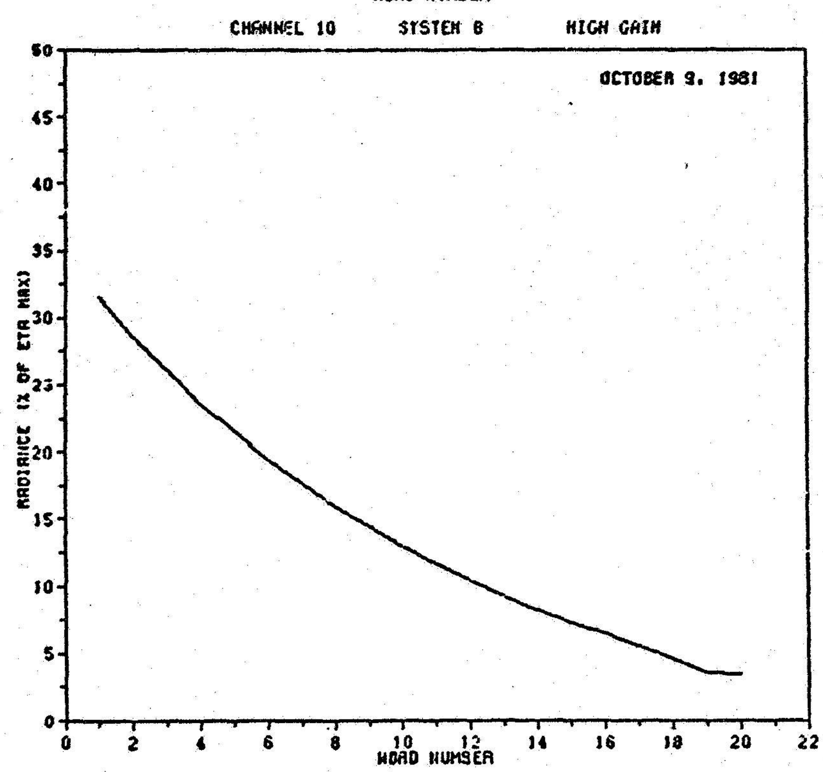
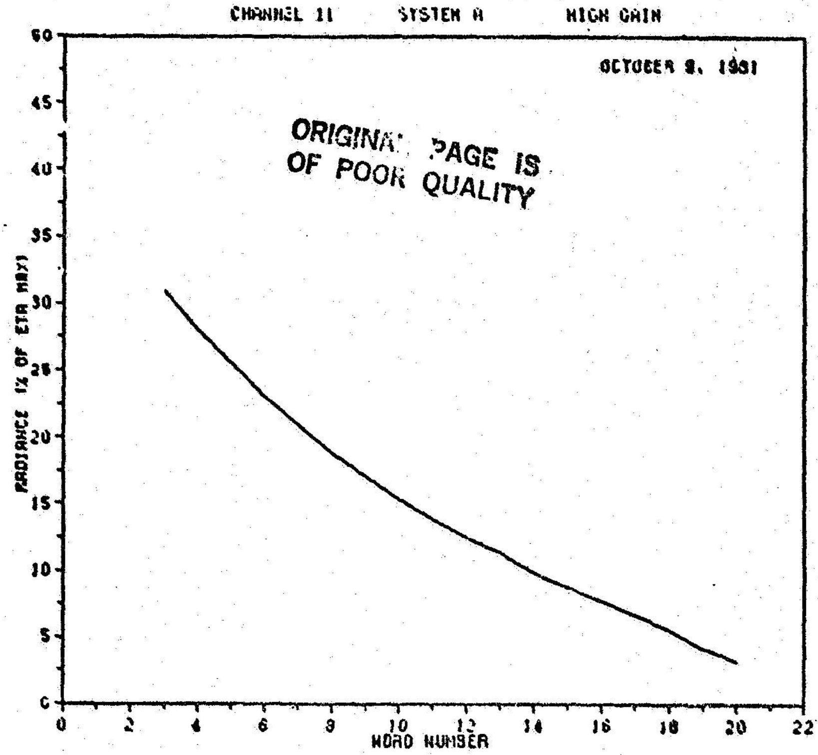
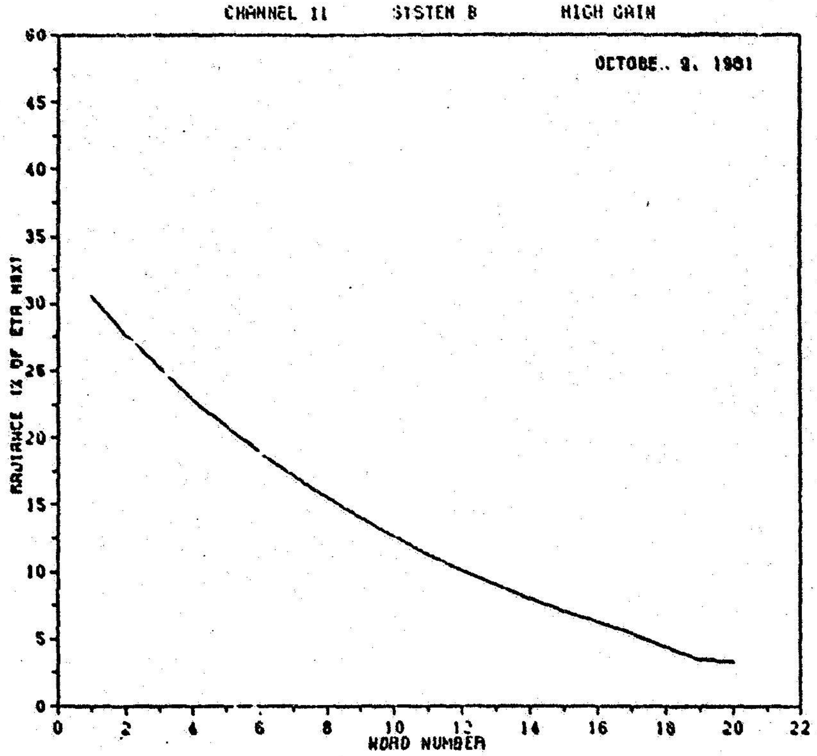
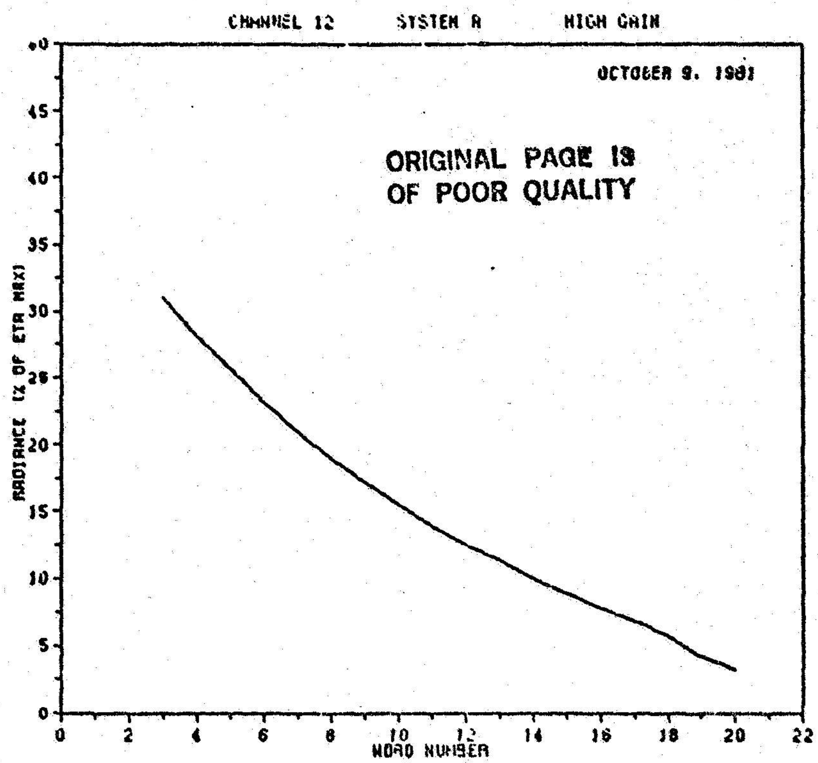


CHANNEL 11 SYSTEM A HIGH GAIN



CHANNEL 11 SYSTEM B HIGH GAIN





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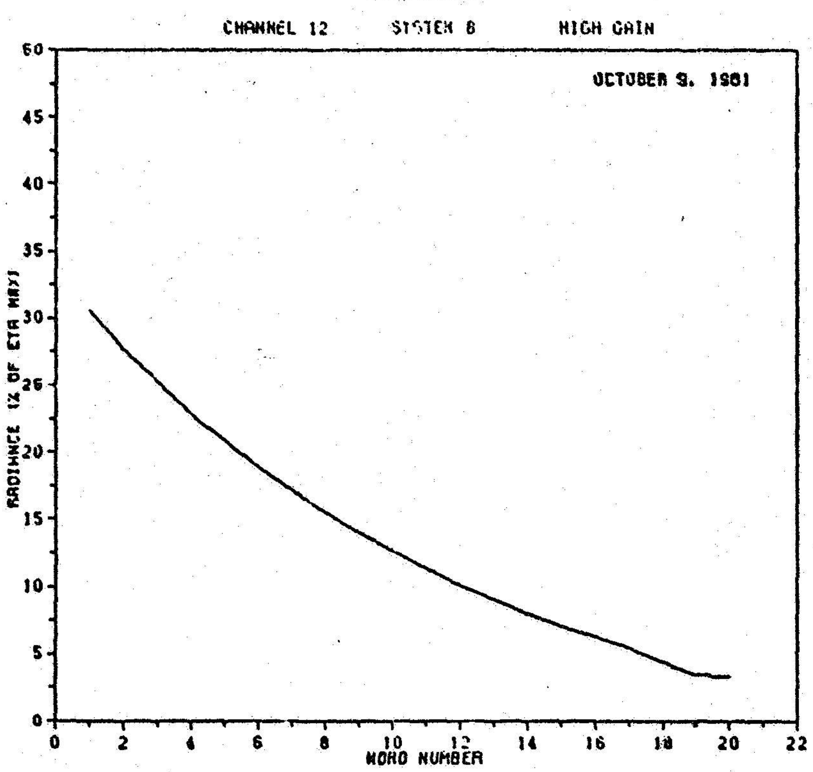

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Band 1 System A Low Gain

Word #	Radiance (% of Eta-max) Channel 1	2	3	4	5	6
1						
2	89.21	90.88	92.84	90.56	91.29	90.50
3	78.25	79.71	81.43	79.42	80.07	79.38
4	67.42	68.69	70.16	68.44	68.99	68.40
5	59.03	60.14	61.43	59.92	60.41	59.88
6	51.20	52.16	53.28	51.97	52.40	51.94
7	44.59	45.42	46.40	45.26	45.63	45.23
8	38.83	39.55	40.40	39.41	39.73	39.39
9	33.83	34.46	35.20	34.33	34.62	34.31
10	29.85	30.42	31.07	30.30	30.55	30.29
11	25.76	26.24	26.81	26.15	26.36	26.13
12	22.35	22.77	23.26	22.69	22.87	22.67
13	19.54	19.91	20.33	19.83	20.00	19.82
14	17.02	17.33	17.71	17.27	17.42	17.26
15	14.74	15.01	15.33	14.96	15.08	14.95
16	13.06	13.31	13.59	13.26	13.37	13.25
17	11.29	11.50	11.75	11.46	11.55	11.45
18	9.77	9.96	10.17	9.92	10.00	9.92
19	8.40	8.56	8.75	8.53	8.60	8.52
20	7.10	7.23	7.38	7.20	7.26	7.20

Band 2 System A Low Gain

Word #	Radiance (% of Eta-max) Channel 7	8	9	10	11	12
1						
2						
3	87.82	90.23	91.48	93.08	89.21	89.76
4	78.44	80.60	81.71	83.14	79.68	80.18
5	69.98	71.90	72.90	74.17	71.09	71.53
6	63.02	64.75	65.64	66.79	64.01	64.41
7	55.86	57.40	58.19	59.21	56.74	57.10
8	52.21	53.65	54.39	55.34	53.04	53.37
9	44.70	45.93	46.56	47.38	45.41	45.69
10	40.22	41.33	41.90	42.63	40.86	41.11
11	36.01	37.00	37.51	38.17	36.58	36.81
12	32.33	33.22	33.68	34.27	32.84	33.04
13	29.06	29.86	30.27	30.80	29.52	29.70
14	26 15	26.87	27.24	27.72	26.56	26.73
15	23.56	24.20	24.54	24.97	23.93	24.08
16	21.07	21.65	21.95	22.33	21.40	21.53
17	18.87	19.39	19.65	20.00	19.17	19.23
18	16.90	17.36	17.60	17.91	17.17	17.27
19	15.04	15.46	15.67	15.84	15.28	15.38
20	13.46	13.83	14.02	14.27	13.67	13.76

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Band 3 System A Low Gain

Word #	Radiance (% of Eta-max) Channel 13	14	15	16	17	18
1						
2						
3	91.13	92.99	93.92	94.45	94.51	91.80
4	81.18	82.84	83.66	84.14	84.19	81.78
5	72.56	74.03	74.77	75.19	75.24	73.09
6	64.39	65.70	66.36	66.73	66.78	64.86
7	58.36	59.55	60.15	60.48	60.53	58.79
8	52.98	54.06	54.60	54.91	54.95	53.37
9	46.51	47.45	47.93	48.20	48.23	46.85
10	41.60	42.45	42.87	43.12	43.15	41.91
11	37.28	38.05	38.43	38.64	38.67	37.56
12	33.49	34.18	34.52	34.72	34.74	33.74
13	30.22	30.84	31.14	31.32	31.34	30.44
14	27.23	27.78	28.06	28.22	28.24	27.43
15	24.61	25.12	25.37	25.51	25.53	24.80
16	22.24	22.69	22.92	23.05	23.06	22.40
17	20.02	20.43	20.63	20.74	20.76	20.16
18	17.93	18.30	18.48	18.59	18.60	18.06
19	16.10	16.43	16.59	16.68	16.69	16.22
20	14.34	14.64	14.78	14.86	14.87	14.45

Band 4 System A Low Gain

Word #	Radiance (% of Eta-max) Channel 19	20	21	22	23	24
1						
2						
3	85.93	96.85	89.90	95.89	94.61	92.86
4	75.10	84.65	78.57	83.80	82.69	81.15
5	65.32	73.62	68.33	72.88	71.91	70.58
6	57.40	64.70	60.06	64.06	63.20	62.03
7	48.31	54.45	50.54	53.91	53.19	52.21
8	44.70	50.38	46.77	49.88	49.21	48.30
9	42.36	47.74	44.32	47.27	46.64	45.77
10	35.07	39.53	36.69	39.13	38.62	37.90
11	31.13	35.08	32.57	34.73	34.27	33.64
12	27.55	31.06	28.83	30.75	30.34	29.78
13	24.73	27.87	25.87	27.59	27.22	26.72
14	22.29	25.12	23.32	24.87	24.54	24.08
15	19.90	22.43	20.82	22.21	21.92	21.51
16	17.89	20.16	18.72	19.95	19.70	19.33
17	16.08	18.12	16.82	17.94	17.70	17.37
18	14.40	16.23	15.06	16.07	15.85	15.56
19	13.06	14.72	13.67	14.58	14.38	14.12
20	11.80	13.30	12.35	13.17	12.99	12.75

Band 1 System A High Gain

Word #	Radiance (% of Eta-max)* Channel 1	2	3	4	5	6
1						
2						
3	30.54	31.08	31.86	31.17	31.34	31.00
4	27.41	27.90	28.60	27.98	28.13	27.83
5	24.60	25.03	25.66	25.10	25.24	24.97
6	21.94	22.33	22.90	22.40	22.52	22.28
7	19.80	20.15	20.66	20.21	20.32	20.10
8	17.78	18.10	18.56	18.15	18.25	18.05
9	15.98	16.26	16.67	16.31	16.40	16.22
10	14.29	14.54	14.91	14.58	14.66	14.50
11	12.83	13.06	13.39	13.10	13.17	13.03
12	11.44	11.65	11.94	11.68	11.74	11.62
13	10.23	10.41	10.67	10.44	10.50	10.38
14	9.08	9.24	9.47	9.27	9.32	9.22
15	8.08	8.22	8.43	8.25	8.29	8.20
16	7.12	7.25	7.43	7.27	7.31	7.23
17	6.33	6.44	6.60	6.46	6.50	6.42
18	5.44	5.54	5.68	5.56	5.58	5.52
19	4.71	4.79	4.91	4.80	4.83	4.77
20	4.12	4.19	4.29	4.20	4.23	4.18

Band 2 System A High Gain

Word #	Radiance (% of Eta-max) Channel 7	8	9	10	11	12
1						
2						
3	30.18	30.76	31.03	31.83	30.91	31.03
4	27.38	27.90	28.14	28.87	28.03	28.14
5	24.94	25.42	25.63	26.30	25.53	25.64
6	22.53	22.96	23.16	23.75	23.07	23.16
7	20.43	20.82	21.00	21.54	20.92	21.00
8	18.48	18.83	18.99	19.48	18.92	19.00
9	16.72	17.04	17.19	17.63	17.12	17.19
10	15.03	15.32	15.45	15.85	15.39	15.45
11	13.51	13.77	13.89	14.25	13.83	13.89
12	12.16	12.39	12.50	12.82	12.45	12.50
13	11.02	11.23	11.33	11.62	11.29	11.33
14	9.65	9.84	9.92	10.18	9.89	9.93
15	8.62	8.78	8.86	9.09	8.82	8.86
16	7.55	7.70	7.76	7.96	7.73	7.76
17	6.60	6.72	6.78	6.95	6.75	6.78
18	5.47	5.58	5.63	5.77	5.60	5.63
19	4.09	4.17	4.21	4.32	4.19	4.21
20	3.20	3.27	3.29	3.38	3.23	3.29

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Band 1 System B Low Gain

Word #	Radiance (% of Eta-max) Channel 1	2	3	4	5	6
1	95.92	93.35	90.73	86.50	86.77	88.11
2	82.89	80.67	78.41	74.75	74.99	76.15
3	72.15	70.21	68.25	65.06	65.27	66.27
4	62.90	61.21	59.50	56.72	56.90	57.78
5	54.72	53.26	51.76	49.35	49.51	50.27
6	47.41	46.15	44.85	42.76	42.90	43.55
7	41.63	40.51	39.38	37.54	37.66	38.24
8	36.10	35.13	34.15	32.56	32.66	33.16
9	31.34	30.50	29.65	28.27	28.35	28.79
10	27.88	27.14	26.38	25.15	25.23	25.61
11	23.63	23.00	22.35	21.31	21.38	21.71
12	20.49	19.94	19.38	18.48	18.54	18.82
13	17.79	17.31	16.82	16.04	16.09	16.34
14	15.43	15.02	14.60	13.92	13.96	14.18
15	13.71	13.34	12.97	12.36	12.40	12.59
16	11.86	11.54	11.22	10.69	10.73	10.90
17	10.35	10.07	9.79	9.33	9.36	9.50
18	8.90	8.67	8.42	8.03	8.06	8.18
19	7.55	7.35	7.15	6.81	6.83	6.94
20	6.63	6.45	6.27	5.98	6.00	6.09

Band 2 System B Low Gain

Word #	Radiance (% of Eta-max) Channel 7	8	9	10	11	12
1	104.98	102.72	98.76	98.29	93.10	94.60
2	93.02	91.01	87.51	87.08	82.49	83.82
3	82.42	80.64	77.54	77.16	73.09	74.27
4	74.50	72.89	70.08	69.75	66.06	67.13
5	66.17	64.74	62.25	61.95	58.68	59.63
6	59.05	57.78	55.55	55.29	52.37	53.22
7	53.10	51.95	49.95	49.71	47.09	47.85
8	49.27	48.21	46.35	46.13	43.69	44.40
9	41.83	40.93	39.35	39.16	37.09	37.69
10	37.51	36.70	35.29	35.12	33.27	33.80
11	33.56	32.83	31.57	31.42	29.76	30.24
12	29.85	29.21	28.08	27.95	26.47	26.90
13	27.22	26.63	25.60	25.48	24.14	24.53
14	24.27	23.75	22.84	22.73	21.53	21.88
15	21.96	21.48	20.66	20.56	19.47	19.79
16	19.65	19.23	18.49	18.40	17.43	17.71
17	17.50	17.12	16.46	16.38	15.51	15.77
18	15.66	15.32	14.73	14.66	13.89	14.11
19	14.07	13.76	13.23	13.17	12.47	12.68
20	12.47	12.20	11.73	11.67	11.05	11.23

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Band 3 System B Low Gain

Radiance (% of Eta-max)

Word #	Channel 13	14	15	16	17	18
1						
2	92.52	91.43	89.37	86.35	89.02	88.03
3	82.24	81.27	79.45	76.76	79.13	78.25
4	73.09	72.22	70.60	68.22	70.32	69.54
5	65.06	64.29	62.85	60.72	62.60	61.90
6	57.86	57.18	55.90	54.01	55.67	55.05
7	51.40	50.80	49.65	47.97	49.45	48.90
8	48.06	47.49	46.43	44.86	46.24	45.73
9	41.23	40.74	39.83	38.48	39.67	39.23
10	36.97	36.53	35.71	34.51	35.57	35.18
11	32.98	32.59	31.86	30.78	31.73	31.37
12	29.56	29.21	28.56	27.59	28.44	28.12
13	26.95	26.63	26.03	25.15	25.93	25.64
14	24.22	23.93	23.39	22.60	23.30	23.04
15	21.84	21.58	21.10	20.38	21.01	20.78
16	19.70	19.47	19.03	18.39	18.96	18.75
17	17.73	17.52	17.12	16.55	17.06	16.87
18	15.86	15.67	15.32	14.80	15.26	15.09
19	14.30	14.13	13.81	13.35	13.76	13.60
20	12.98	12.83	12.54	12.11	12.49	12.35

Band 4 System B Low Gain

Radiance (% of Eta-max)

Word #	Channel 19	20	21	22	23	24
1	83.93	95.63	88.24	95.28	94.52	86.52
2	72.90	83.05	76.64	82.76	82.09	75.15
3	63.39	72.22	66.65	71.96	71.39	65.35
4	55.46	63.18	58.31	62.96	62.45	57.17
5	47.95	54.63	50.42	54.44	54.00	49.43
6	42.60	48.53	44.78	48.36	47.97	43.91
7	37.52	42.75	39.45	42.59	42.25	38.68
8	32.08	36.55	33.73	36.42	36.13	33.07
9	31.81	36.24	33.44	36.11	35.82	32.79
10	26.23	29.88	27.57	29.77	29.53	27.04
11	23.33	26.58	24.53	26.48	26.27	24.05
12	20.78	23.67	21.85	23.59	23.40	21.42
13	18.64	21.23	19.59	21.16	20.99	19.21
14	16.85	19.19	17.71	19.12	18.97	17.37
15	15.17	17.29	15.95	17.23	17.09	15.64
16	13.81	15.73	14.52	15.68	15.55	14.24
17	12.60	14.36	13.25	14.31	14.19	12.99
18	11.36	12.94	11.94	12.90	12.79	11.71
19	10.21	11.63	10.73	11.59	11.49	10.52
20	9.26	10.55	9.73	10.51	10.42	9.54

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Band 1 System B High Gain

Radiance (% of Eta-max)

Word #	Channel 1	2	3	4	5	6
1	35.13	34.12	33.41	31.54	31.47	31.97
2	31.58	30.67	30.04	28.36	28.29	28.74
3	28.28	27.47	26.90	25.40	25.34	25.74
4	25.20	24.48	23.97	22.63	22.58	22.94
5	22.55	21.90	21.45	20.25	20.20	20.52
6	20.13	19.56	19.15	18.08	18.04	18.32
7	18.08	17.57	17.21	16.24	16.21	16.46
8	16.21	15.75	15.42	14.56	14.53	14.76
9	14.56	14.15	13.85	13.08	13.05	13.26
10	13.15	12.77	12.51	11.81	11.78	11.97
11	11.73	11.39	11.16	10.53	10.51	10.67
12	10.50	10.20	9.99	9.43	9.41	9.56
13	9.44	9.17	8.98	8.48	8.46	8.59
14	8.35	8.10	7.94	7.50	7.48	7.60
15	7.37	7.16	7.01	6.62	6.60	6.71
16	6.48	6.29	6.16	5.81	5.80	5.90
17	5.74	5.58	5.46	5.16	5.15	5.23
18	4.93	4.79	4.69	4.43	4.42	4.49
19	4.35	4.22	4.13	3.90	3.89	3.96
20	3.69	3.59	3.52	3.32	3.31	3.36

Band 2 System B High Gain

Radiance (% of Eta-max)

Word #	Channel 7	8	9	10	11	12
1	34.53	33.38	31.72	31.64	30.56	30.60
2	31.20	30.17	28.66	28.59	27.62	27.65
3	28.49	27.54	26.17	26.11	25.22	25.25
4	25.79	24.93	23.69	23.63	22.83	22.85
5	23.55	22.77	21.64	21.59	20.85	20.87
6	21.27	20.57	19.54	19.49	18.83	18.85
7	19.36	18.72	17.79	17.74	17.14	17.16
8	17.48	16.90	16.06	16.02	15.47	15.49
9	15.80	15.27	14.51	14.48	13.98	14.00
10	14.19	13.72	13.04	13.01	12.56	12.58
11	12.74	12.32	11.70	11.67	11.27	11.29
12	11.36	10.98	10.44	10.41	10.06	10.07
13	10.16	9.82	9.33	9.31	8.99	9.00
14	8.99	8.69	8.26	8.24	7.96	7.97
15	7.99	7.73	7.34	7.33	7.08	7.08
16	7.02	6.79	6.45	6.43	6.21	6.22
17	6.09	5.89	5.59	5.58	5.39	5.39
18	5.00	4.84	4.60	4.59	4.43	4.43
19	3.98	3.84	3.65	3.64	3.52	3.52
20	3.77	3.64	3.46	3.45	3.33	3.34

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6. SYSTEM RELATIVE SPECTRAL RESPONSE

The system relative spectral response (RSR) for all 24 channels of MSS-D F-1 has been measured using a grating monochromator. This instrument was set up and used as described in Procedure 16889, Relative Spectral Response. The calibration of the reference silicon photodiode used to monitor the output of the monochromator is described in HS248--6283, 1 May 1980. The relative spectral response curves obtained are shown in the figures which follow in this section.

The final system relative spectral response measurement was performed on 10 June 1981. The data presented are the results of that test and represent the present description of the relative spectral response of the complete system, which is the composite of the spectral response of the scan mirror, primary and secondary telescope mirrors, fiber optics, transfer and relay lenses, optical filters and detectors.

In the monochromator, dispersion is accomplished by means of a plane diffraction grating equipped with a sine bar motion. A counter on the drive screw reads wavelength directly in nanometers. With the monochromator set on zero order, the entrance and exit slits were adjusted to where white light from the source lamp was visible at the termination of the fiber bundle between counter readings of 99998 (-00002) and 00002. Therefore 4 nm is the approximate range in wavelength of the light transmitted by the monochromator at any particular wavelength setting.

Two checks on error were made. Repeat measurements of channels were made and compared with the original measurements. A second check was to place a calibrated silicon photodiode, SBRC 801338(B) at the output of the monochromator fiber bundle and measure its relative spectral response in the same way as had been done for the MSS. The resultant curve was then compared with that supplied by Optronic Labs. for this detector.

The following are the complete RSR data for MSS-D F-1 scanner with the spare fiber plate (P/N 51687, S/N 301D) as its transfer optics assembly. During the initial measurement it was discovered that channels A's and F's of all bands were showing significant nonrepeatability. This was due to a marginal filling of detector arrays by the filament image coming out of the monochrometer giving erratic S/N data. This was corrected by rotating the monochromator fiber bundle 90° so that the filament's longer dimension completely overfilled all 24 channels. After that the repeatability of data was excellent.

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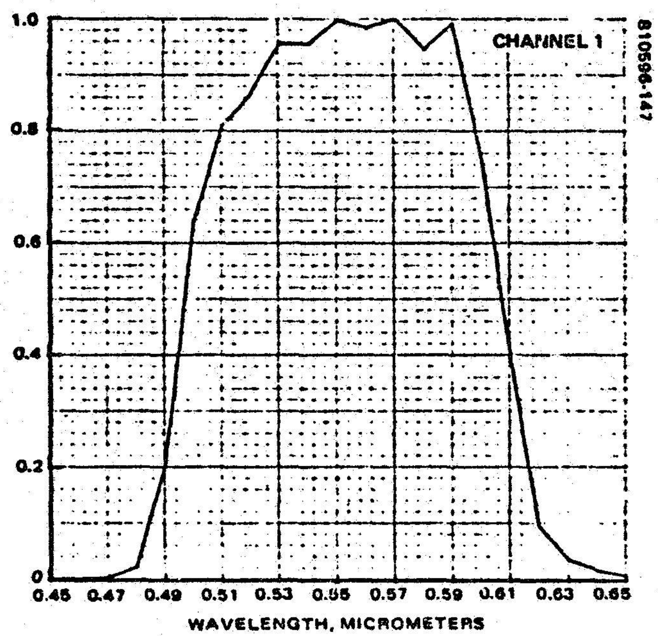

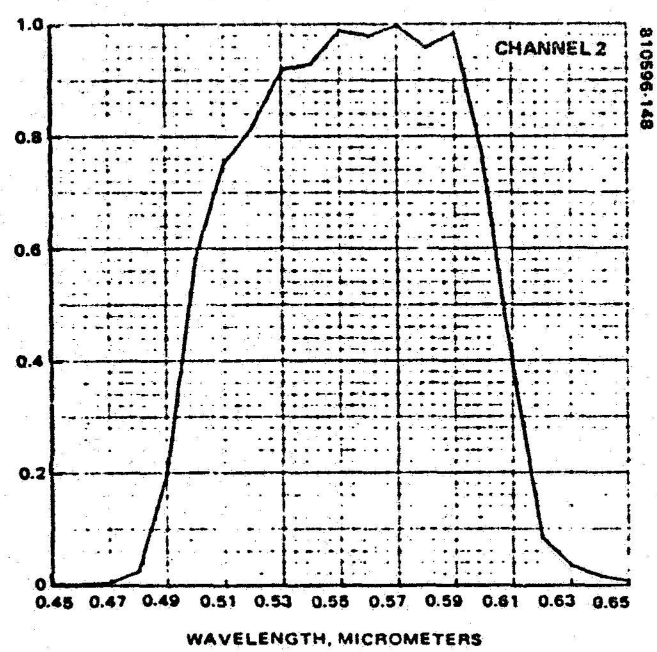

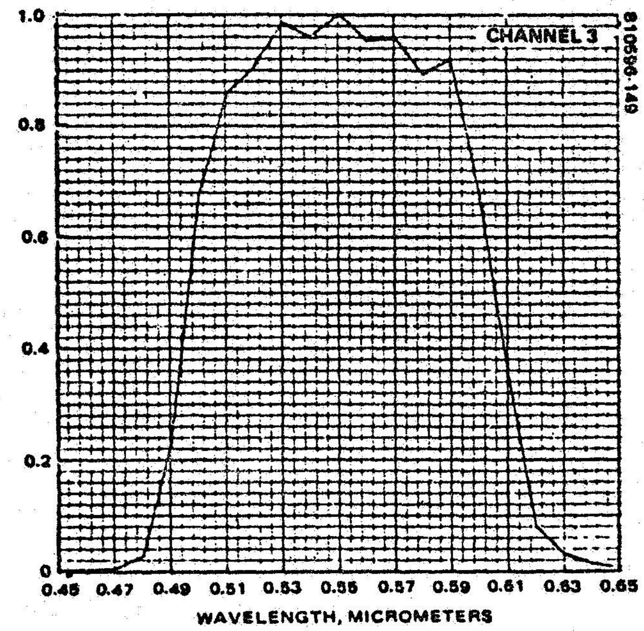
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0
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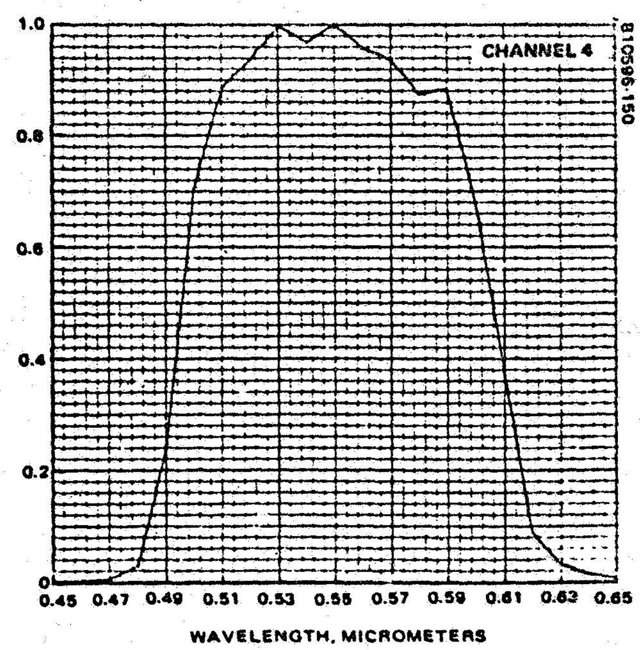
WAVELENGTH, MICROMETERS
CHANNEL 3
810596-149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WAVELENGTH, MICROMETERS
CHANNEL 4
810596-150

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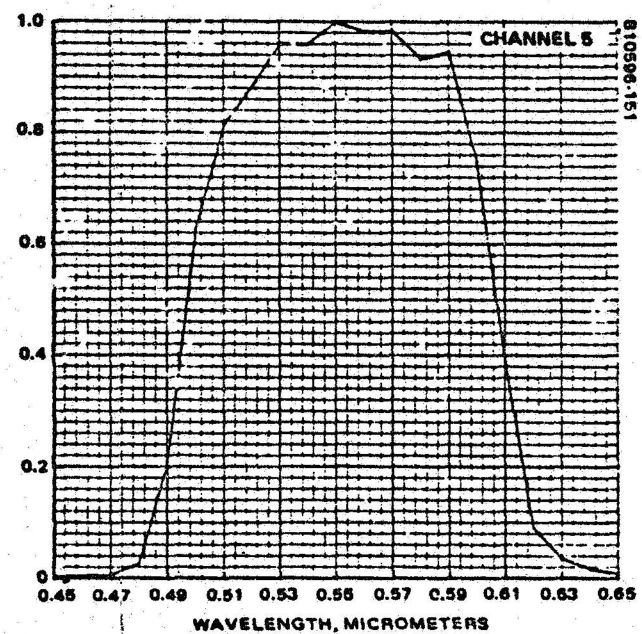

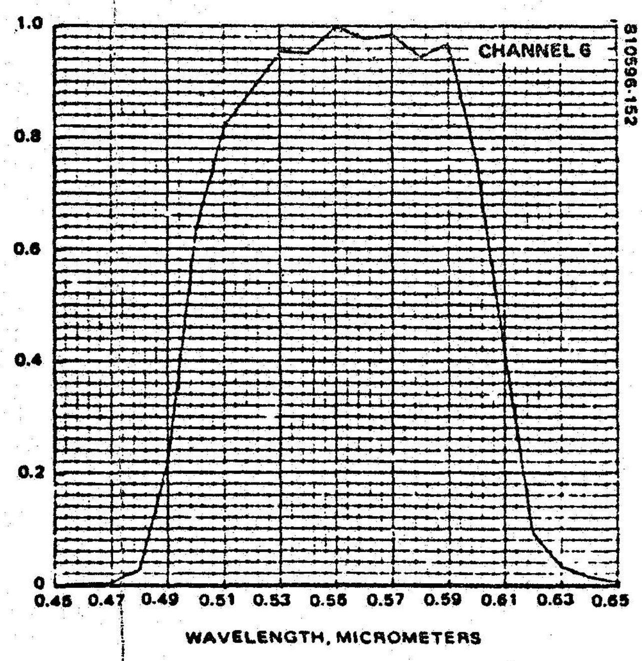

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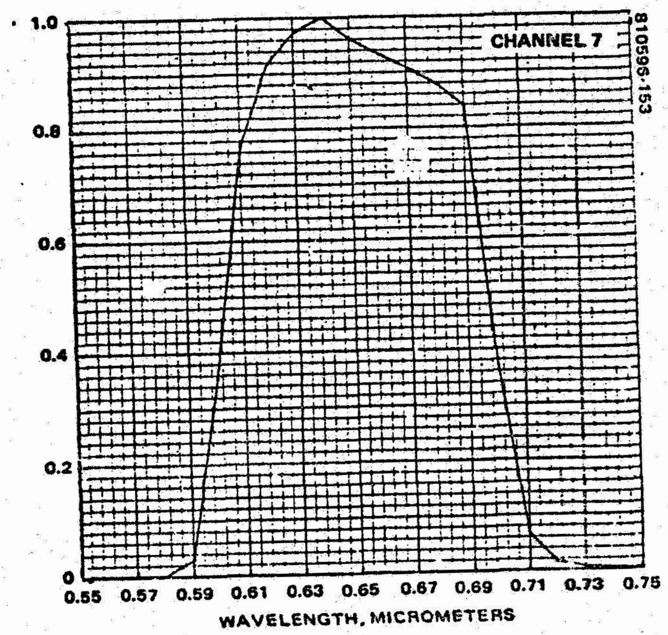

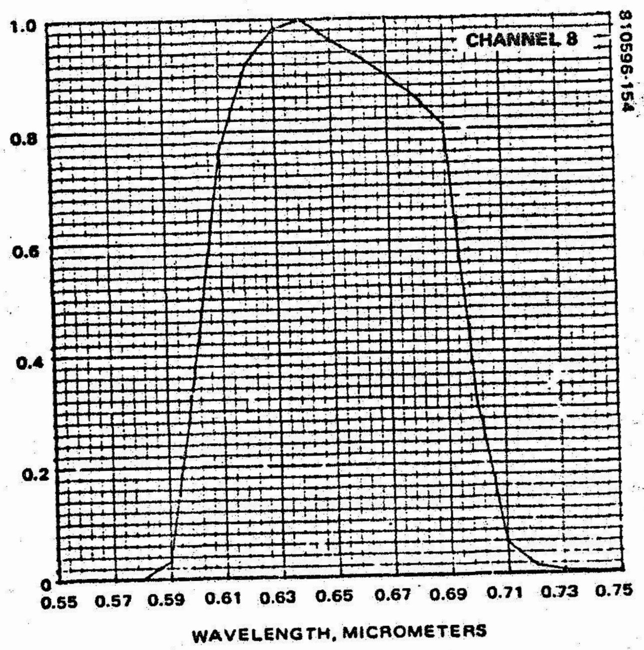

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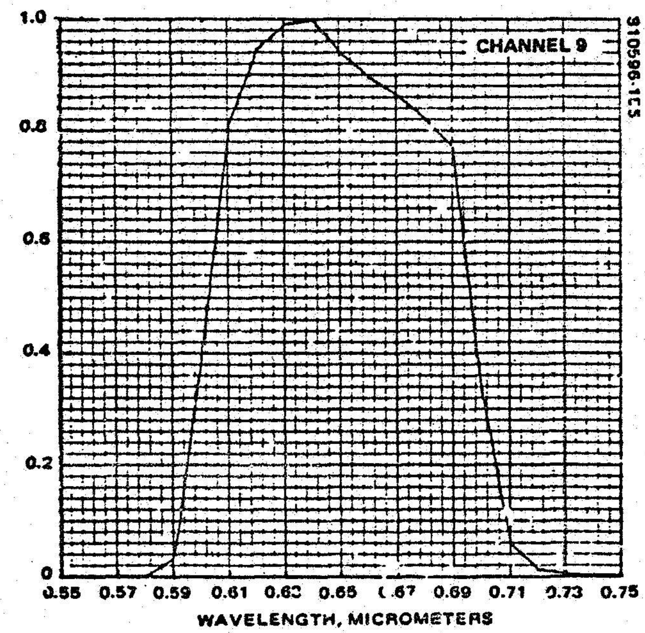

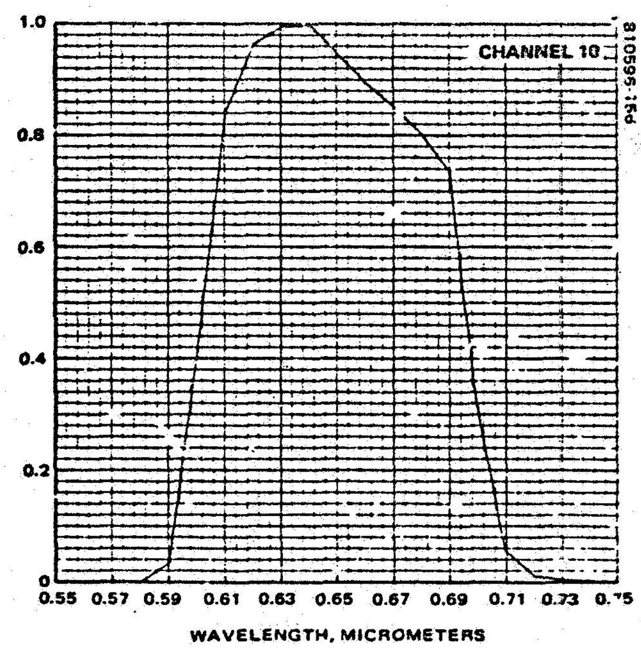

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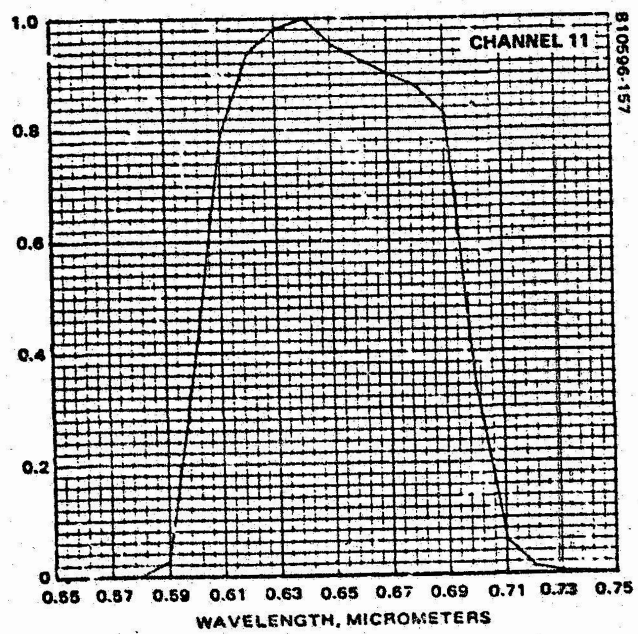

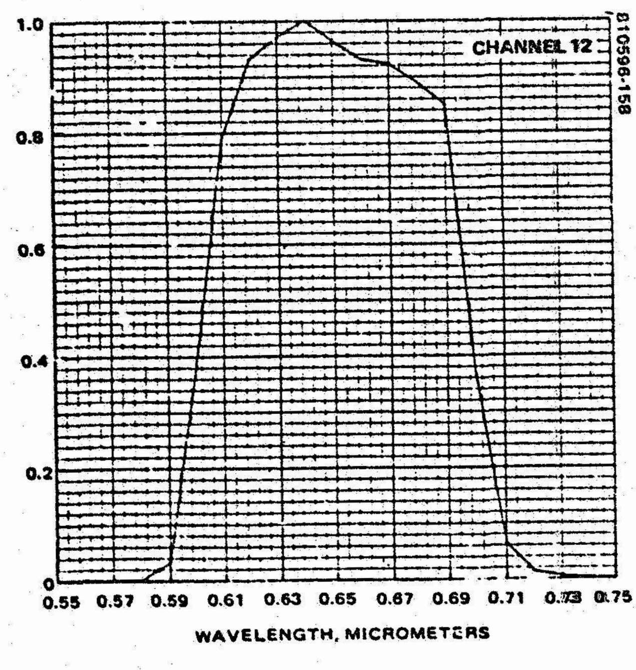

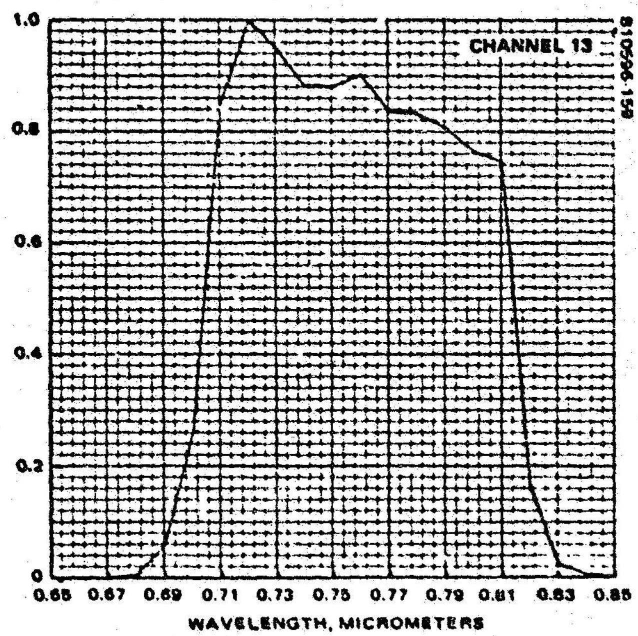
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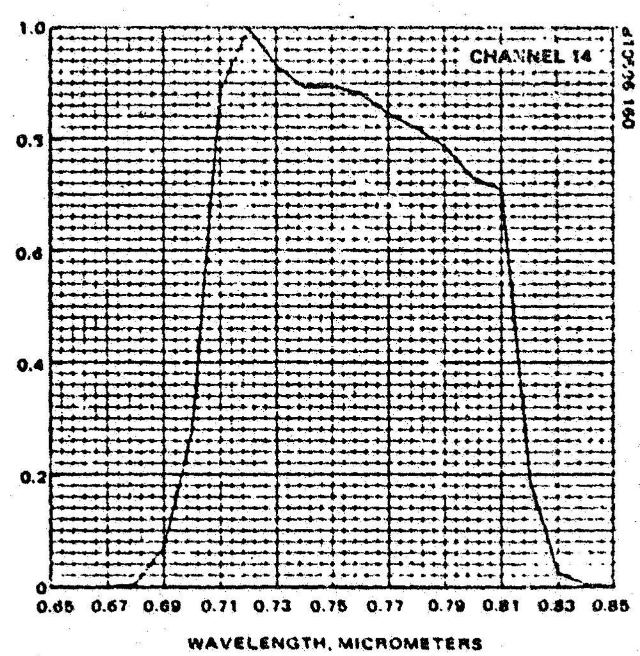
WAVELENGTH, MICROMETERS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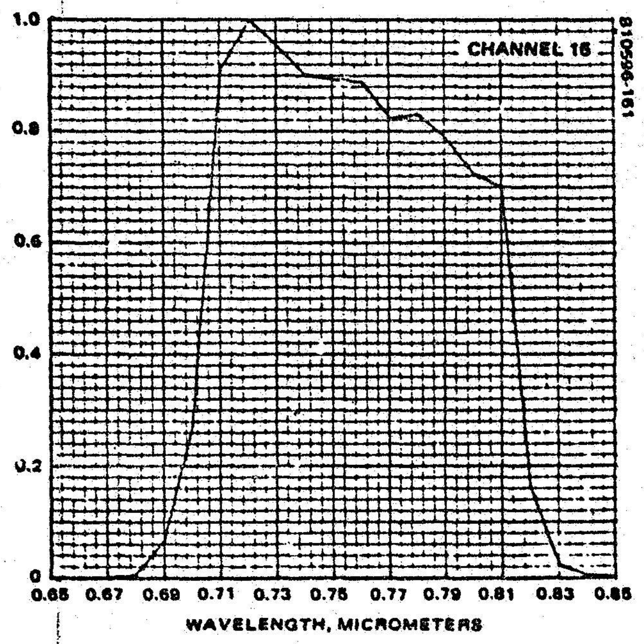
WAVELENGTH, MICROMETERS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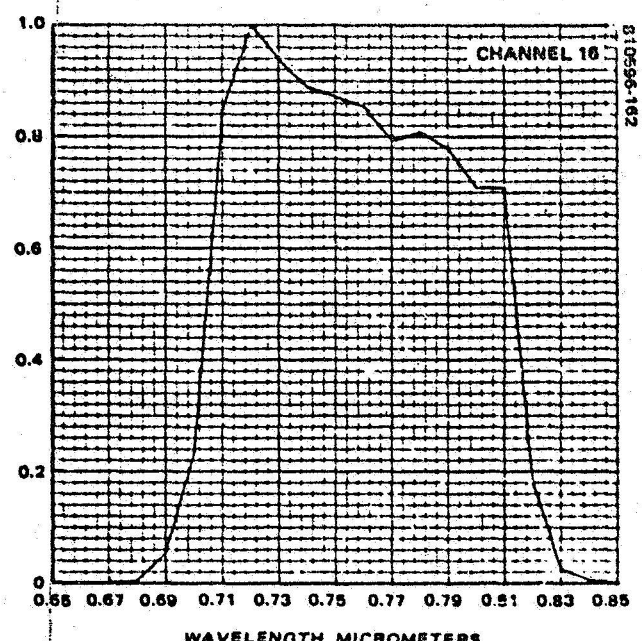
0.6
0.4
0.2
0
0.65 0.67 0.69 0.71 0.73 0.75 0.77 0.79 0.81 0.83 0.85
WAVELENGTH, MICROMETERS


CHANNEL 16
810596-162
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0.8
0.6
0.4
0.2
0
0.65 0.67 0.69 0.71 0.73 0.75 0.77 0.79 0.81 0.83 0.85
WAVELENGTH, MICROMETERS

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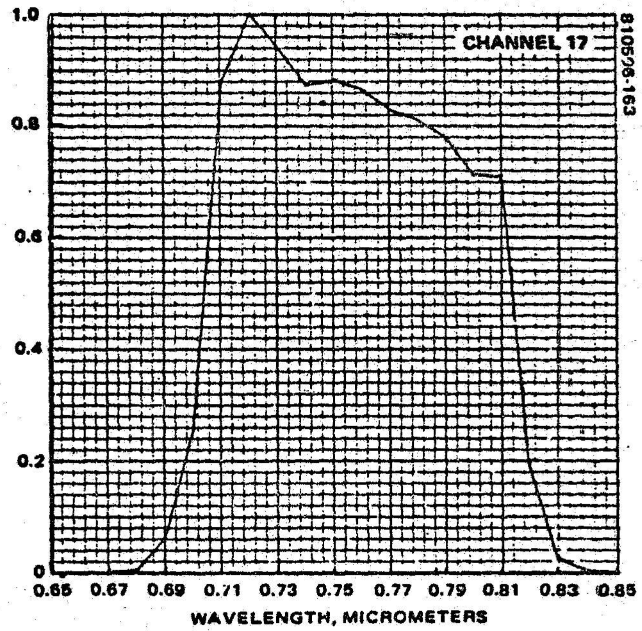

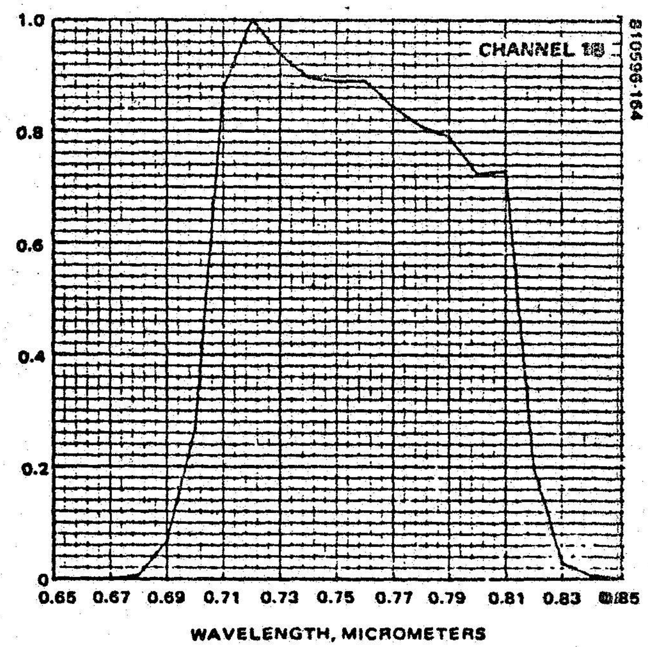

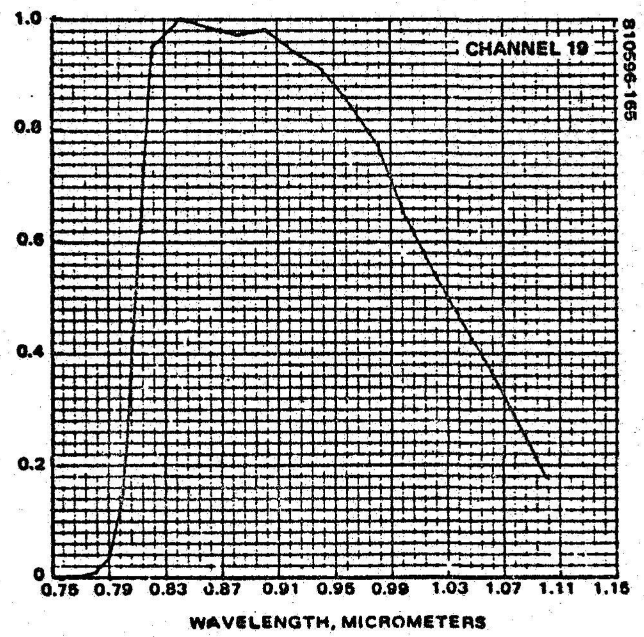
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0.2
0
CHANNEL 19
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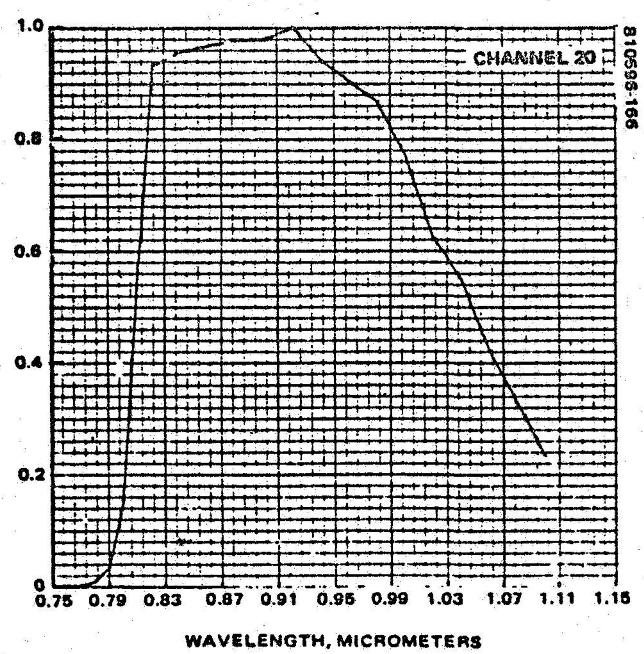
WAVELENGTH, MICROMETERS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0.2
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CHANNEL 20
810596-166
0.75 0.79 0.83 0.87 0.91 0.95 0.99 1.03 1.07 1.11 1.15
WAVELENGTH, MICROMETERS

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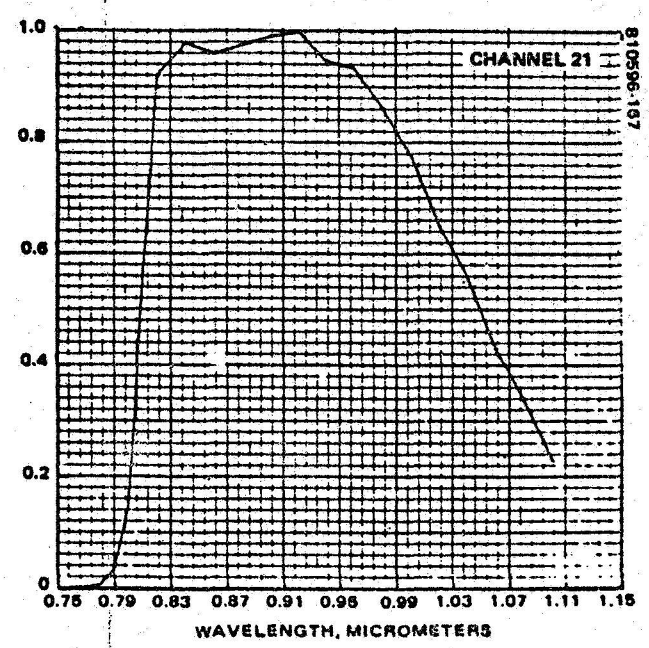

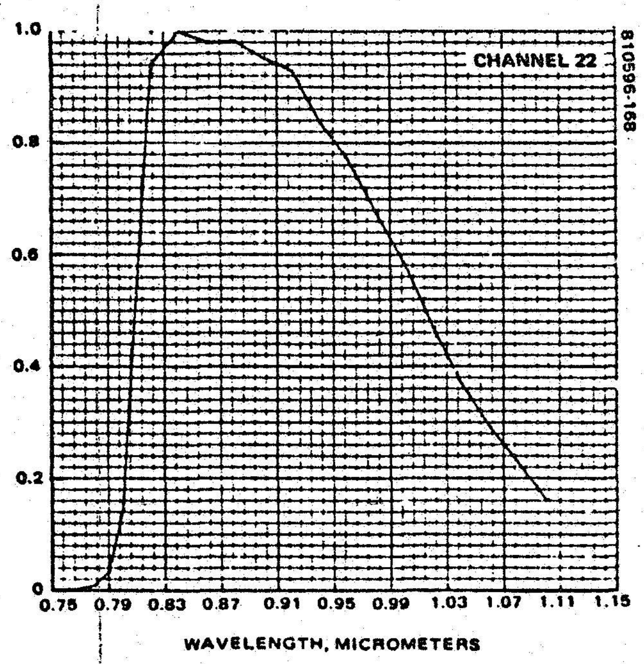

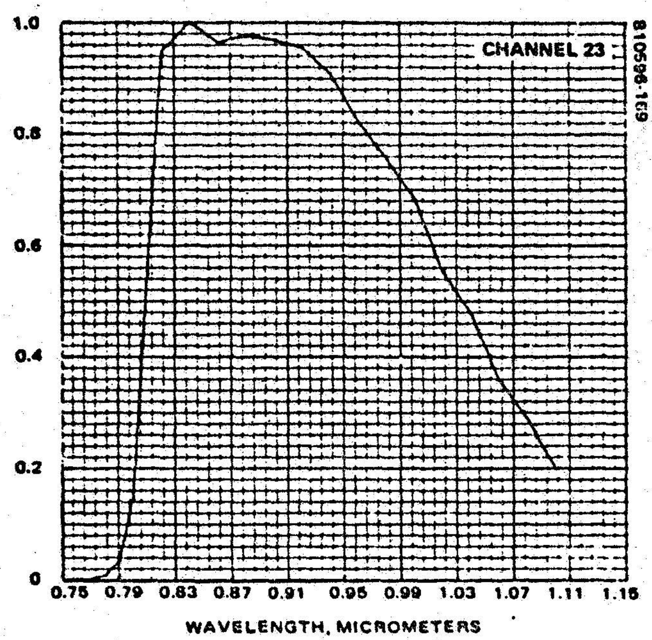
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0.4
0.2
0
CHANNEL 23
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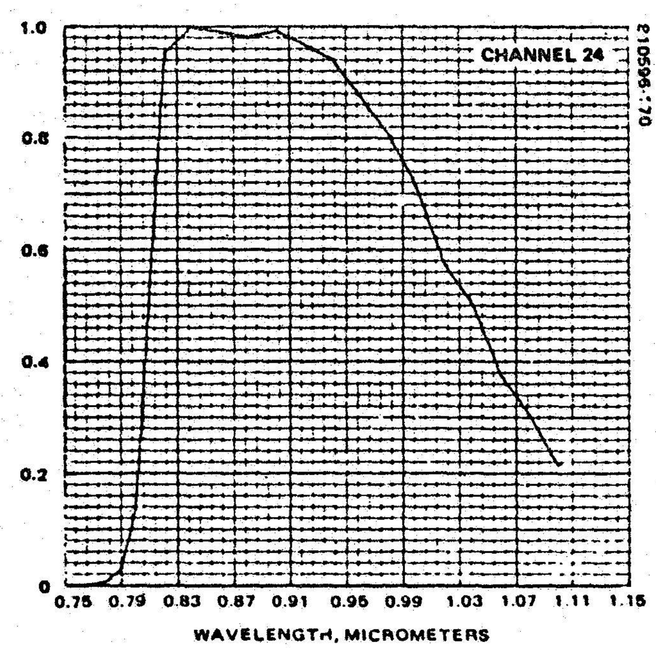
WAVELENGTH, MICROMETERS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0.6
0.4
0.2
0
CHANNEL 24
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WAVELENGTH, MICROMETERS

7. OPTICAL TRANSMISSION FILTER CHARACTERISTICS

A major constituent of the system relative spectral response presented in Section 6 is the relative spectral responses of the optical transmission filters. The importance of these filter characteristics was recognized and a detailed specification was developed at the unit level for these components. For ease of reference the specification on these filters is given below from the MSS-D System Specification, SS32238-10 (Rev B), 8 June 1981.

3.1.1.1.12 Optical Filter Characteristics.

3.1.1.1.12.1 Absolute Transmission. Absolute transmission for each band shall be 70 percent minimum at the peak of the spectral response characteristics.

3.1.1.1.12.2 Spectral Flatness. Spectral flatness shall be maintained to ±5 percent over the central 70 percent bandwidth region for bands 1, 3, and 4; it shall be ±7.5 percent for band 2.

3.1.1.1.12.3 Half Power Points. The half power transmission points (50 percent of peak transmission) shall be within ±0.01 μm of the spectral end point (band edge) designated in 3.1.1.1.1.

3.1.1.1.12.4 Band Edge Slope. The wavelength between 5 percent absolute and 50 percent of peak transmission shall be less than 0.02 μm on the short wave side for Bands 1 to 3, and on the long wave side, 0.04 μm for Band 1, 0.045 μm for Band 2, and 0.05 μm for Band 3. Band 4 shall be 0.035 μm on the short wave side and will have no slope requirements for the long wave side.

3.1.1.1.12.5 Spurious Response. Response outside the 5 percent points shall not exceed 5 percent of the in-band spectral response for a solar equivalent input over the wavelength interval from 0.4 to 0.8 μm.

The engineering data taken during the measurement of these filters is given in this section. The values handwritten on the plots are readings required to determine that the filters meet the unit specifications. The serial numbers written in the annotation boxes were assigned control numbers for each filter. During unit level assembly of the MSS-D F-1 scanner the assignment of these filters to the various channels was as shown in Table I-7-1.

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TABLE I-7-1. F-1 BANDPASS FILTER ASSIGNMENT (SBRC P/N 43918-1 THROUGH 43918-4)

Band 1 (P/N 43918-1)		Band 2 (P/N 43918-2)	
Channel	Filter S/N	Channel	Filter S/N
1	318	7	334
2	314	8	336
3	317	9	333
4	316	10	331
5	313	11	332
6	315	12	335
Band 3 (P/N 43918-3)		**Band 4 (P/N 43918-4)**	
Channel	Filter S/N	Channel	Filter S/N
13	317	19	319
14	314	20	314
15	316	21	313
16	315	22	318
17	313	23	316
18	318	24	317

A comparison of the specification values given on the previous page with the recorded values on the graphs that follow is given in Table I-7-2. As seen, the filters are within specification for all filter characteristics.

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TABLE I-7-2. FILTER SPECIFICATION PERFORMANCE

Channel	Flatness Transmission Uniformity		Transmission Percentage		λ (50% Peak)		λ (5% Absolute)		Half Power Points (Band Edge Limits, |λ-λ edge| ≤0.01 μm)		Band Edge Slope						
	Required, Percent	Actual Maximum Variation, Percent									Spectral Interval of Slope				Spectral Interval of Slope Using 3 dB		
			Peak	50% Peak	Short	Long	Short	Long	Short	Long	Short	Spec	Long	Spec	Short	Long	Spec
1	±5	8.5	94.9	47.4	0.4936	0.6048	0.4815	0.6216	0.0064	0.0048	0.0121	0.02	0.0168	0.04	0.0168	0.0233	0.04
2		5.0	92.0	46.0	0.4932	0.6057	0.4793	0.6240	0.0058	0.0057	0.0139		0.0183		0.0186	0.0240	
3		7.6	93.9	47.0	0.4930	0.6046	0.4803	0.6213	0.0070	0.0046	0.0127		0.0167		0.0173	0.0232	
4		9.5	93.7	46.9	0.4933	0.6049	0.4800	0.6221	0.0067	0.0049	0.0133		0.0172		0.0180	0.0244	
5		6.0	91.5	45.8	0.4938	0.6056	0.4802	0.6235	0.0052	0.0056	0.0136		0.0179		0.0183	0.0179	
6		6.0	92.0	46.0	0.4934	0.6063	0.4796	0.6245	0.0066	0.0063	0.0138		0.0182		0.0184	0.0241	
7	±7.5	11.4	93.0	46.5	0.6011	0.6968	0.5903	0.7102	-0.0011	-0.0032	0.0108	0.02	0.0134	0.045	0.0159	0.0157	
8		10.8	94.5	47.6	0.6010	0.6957	0.5901	0.7089	-0.0010	-0.0043	0.0109		0.0132		0.0161	0.0156	
9		12.5	94.0	47.0	0.6008	0.6965	0.5900	0.7100	-0.0008	-0.0035	0.0108		0.0135		0.0161	0.0159	
10		11.5	93.8	46.9	0.6009	0.6964	0.5901	0.7093	-0.0009	-0.0036	0.0108		0.0129		0.0160	0.0155	
11		11.0	93.0	46.5	0.6011	0.6962	0.5904	0.7092	-0.0011	-0.0038	0.0107		0.0130		0.0157	0.0154	
12		11.0	93.8	46.9	0.6010	0.6967	0.5902	0.7100	-0.0010	-0.0033	0.0108		0.0133		0.0159	0.0161	
13	±5	5.0	96.5	48.25	0.6995	0.8087	0.6858	0.8211	0.0005	0.0087	0.0137	0.02	0.0124	0.05	0.0175	0.0153	0.05
14		4.75	97.0	48.5	0.6972	0.8028	0.6839	0.8146	0.0028	0.0028	0.0133		0.0118		0.0167	0.0142	
15		5.0	96.0	48.0	0.6993	0.8082	0.6859	0.8203	0.0007	0.0082	0.0134		0.0121		0.0173	0.0148	
16		3.89	95.5	47.5	0.6979	0.8027	0.6845	0.8145	0.0021	0.0027	0.0133		0.0118		0.0170	0.0143	
17		4.0	96.0	48.0	0.6979	0.8030	0.6842	0.8146	0.0021	0.0030	0.0137		0.0116		0.0170	0.0142	
18		5.5	97.5	48.75	0.6995	0.8087	0.6861	0.8208	0.0005	0.0087	0.0134		0.0121		0.0170	0.0148	
19	±5	5.0	94.0	47.0	0.8056		0.7898		-0.0056		0.0158	0.035			0.0158		
20		4.0	93.5	46.8	0.8047		0.7877		-0.0047		0.0170				0.0208		
21		4.5	95.0	47.5	0.8045		0.7860		-0.0045		0.0185				0.0225		
22		4.5	92.5	46.25	0.8064		0.7905		-0.0064		0.0159				0.0198		
23		4.5	93.0	46.5	0.8060		0.7902		-0.0060		0.0158				0.0196		
24		5.0	93.0	46.5	0.8067		0.7908		-0.0067		0.0159				0.0197		

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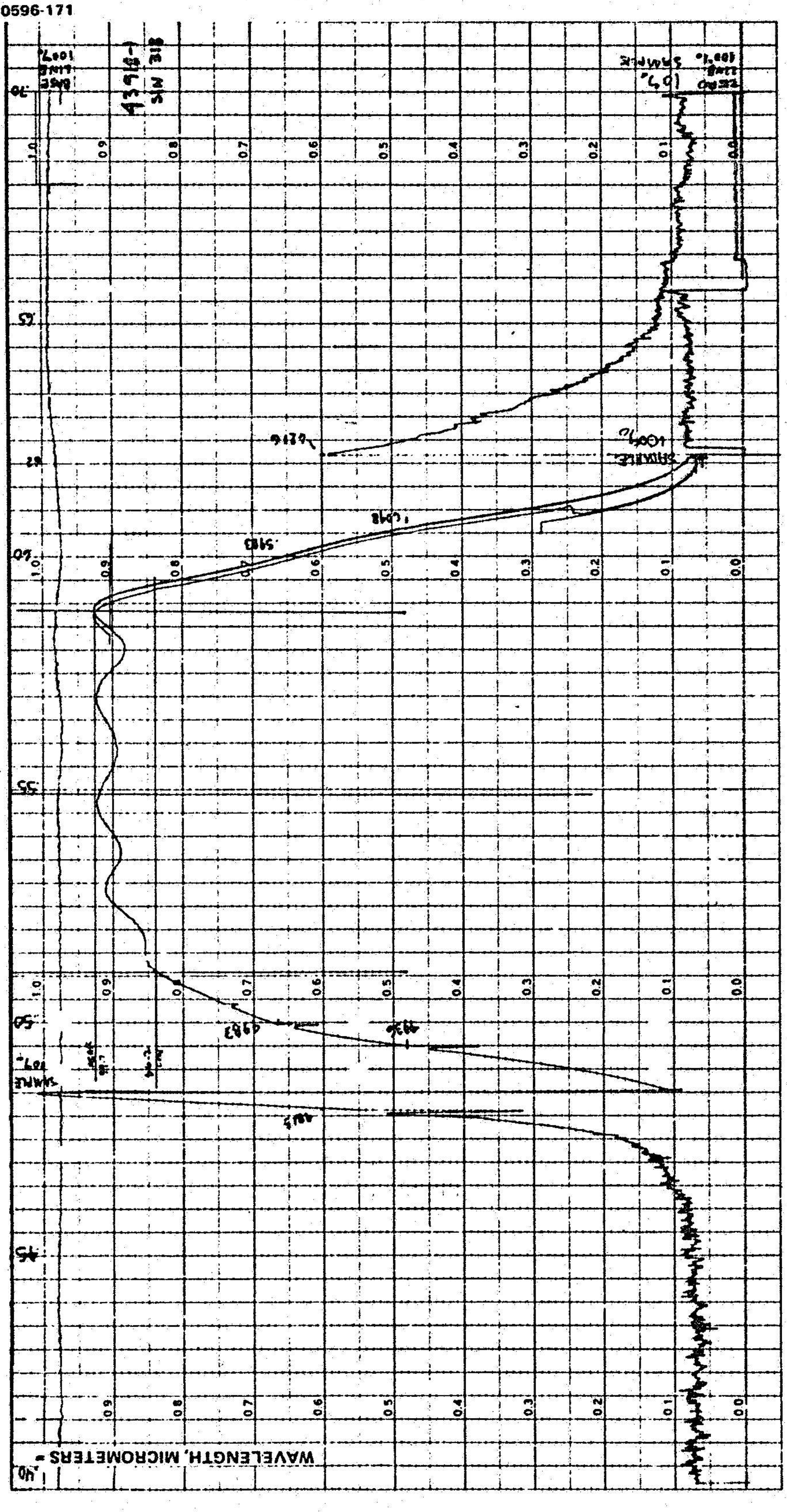

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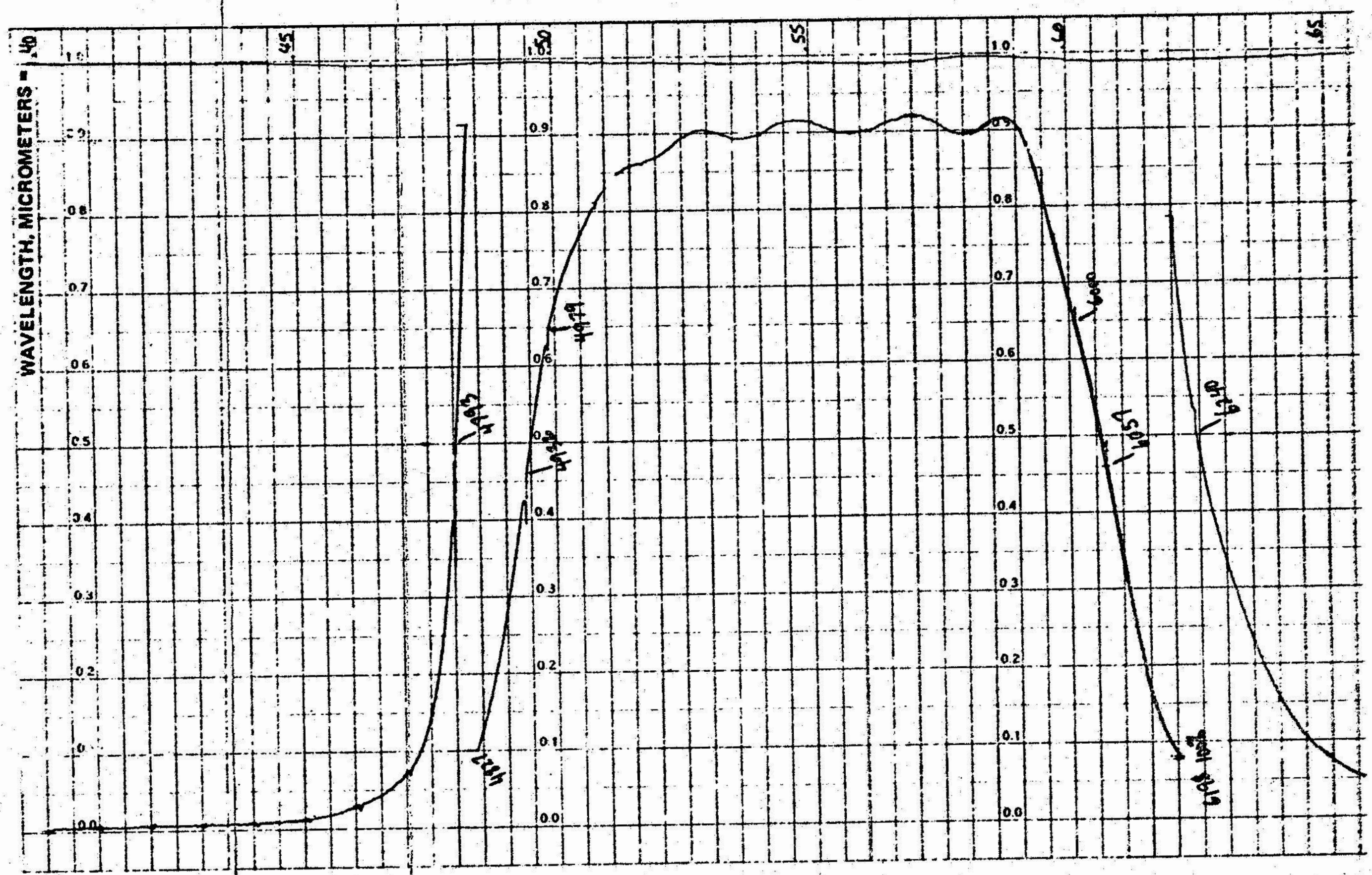

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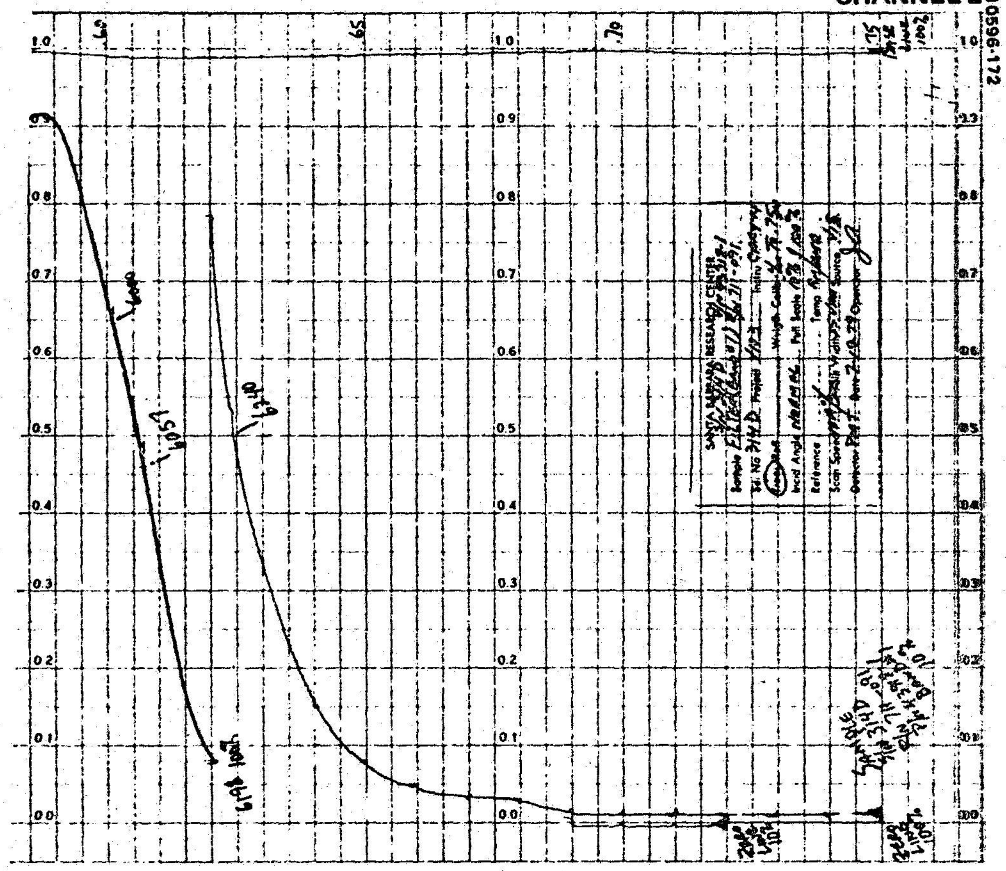

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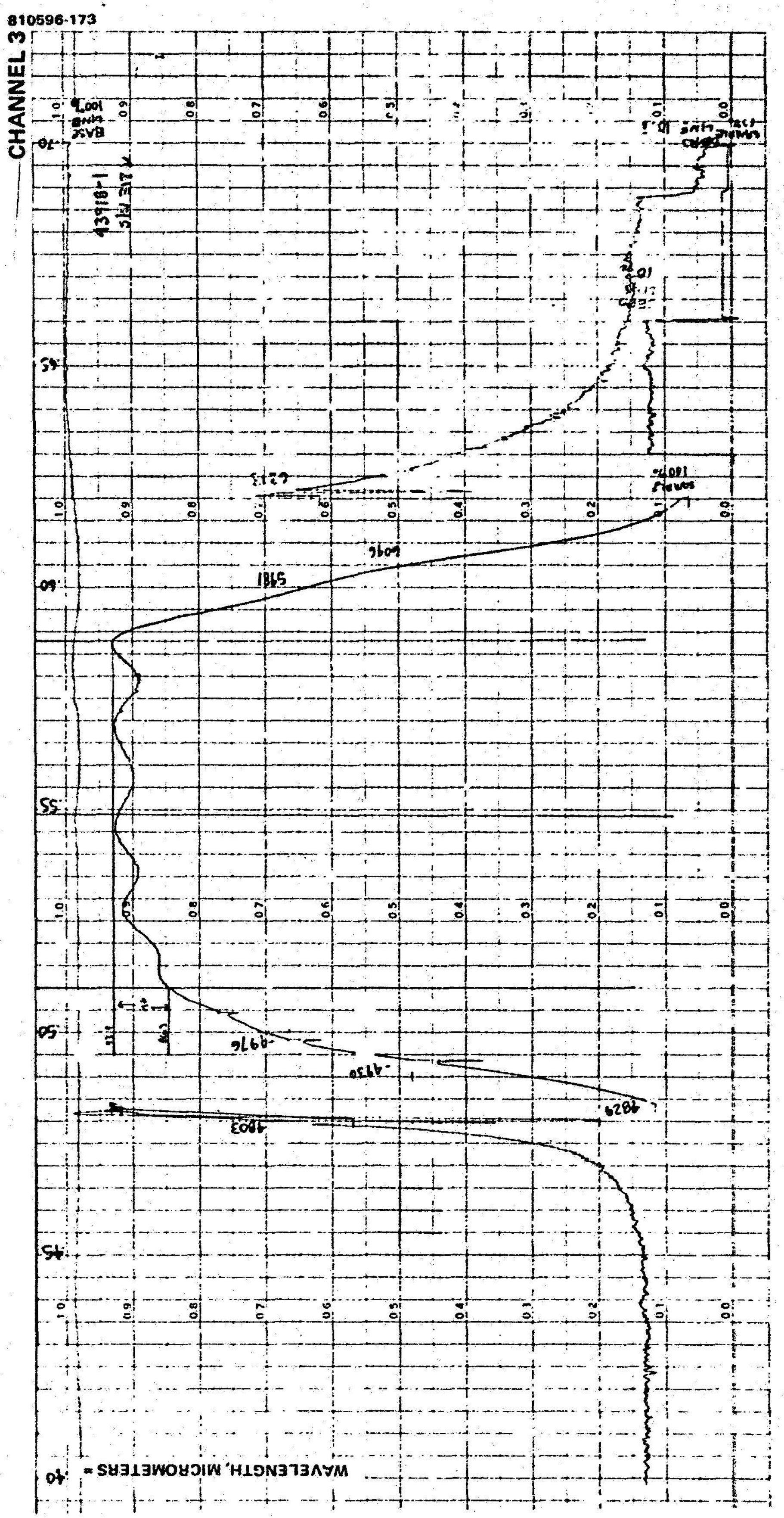

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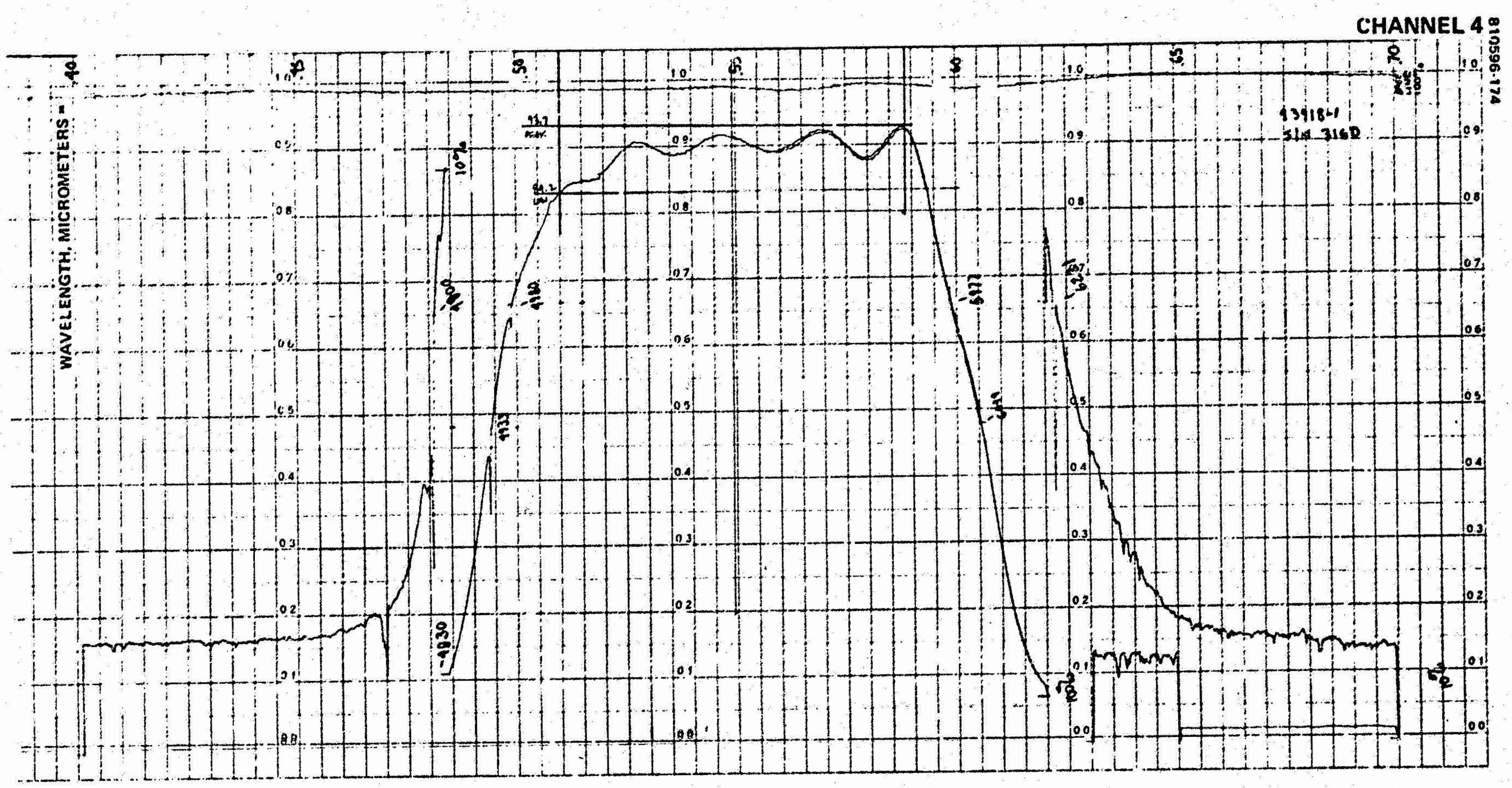

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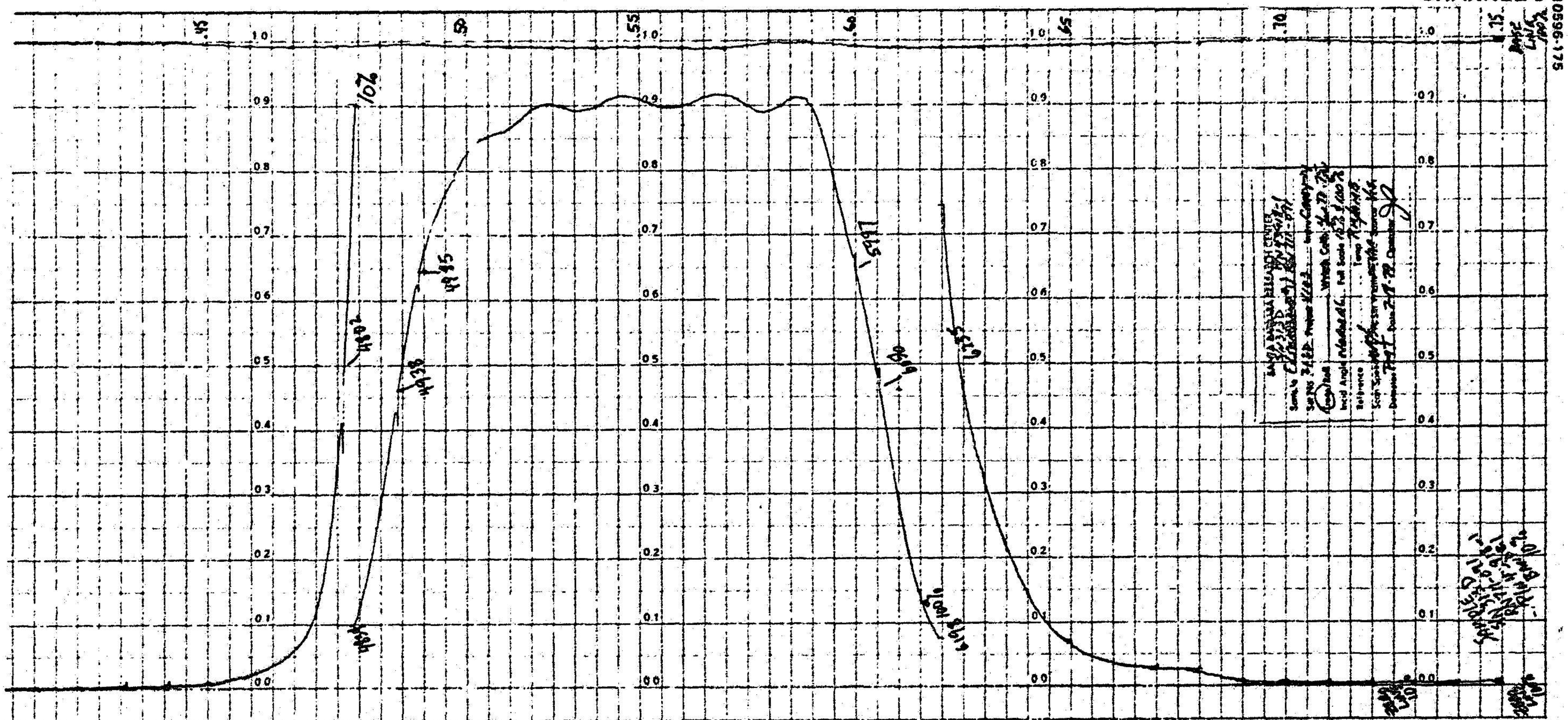

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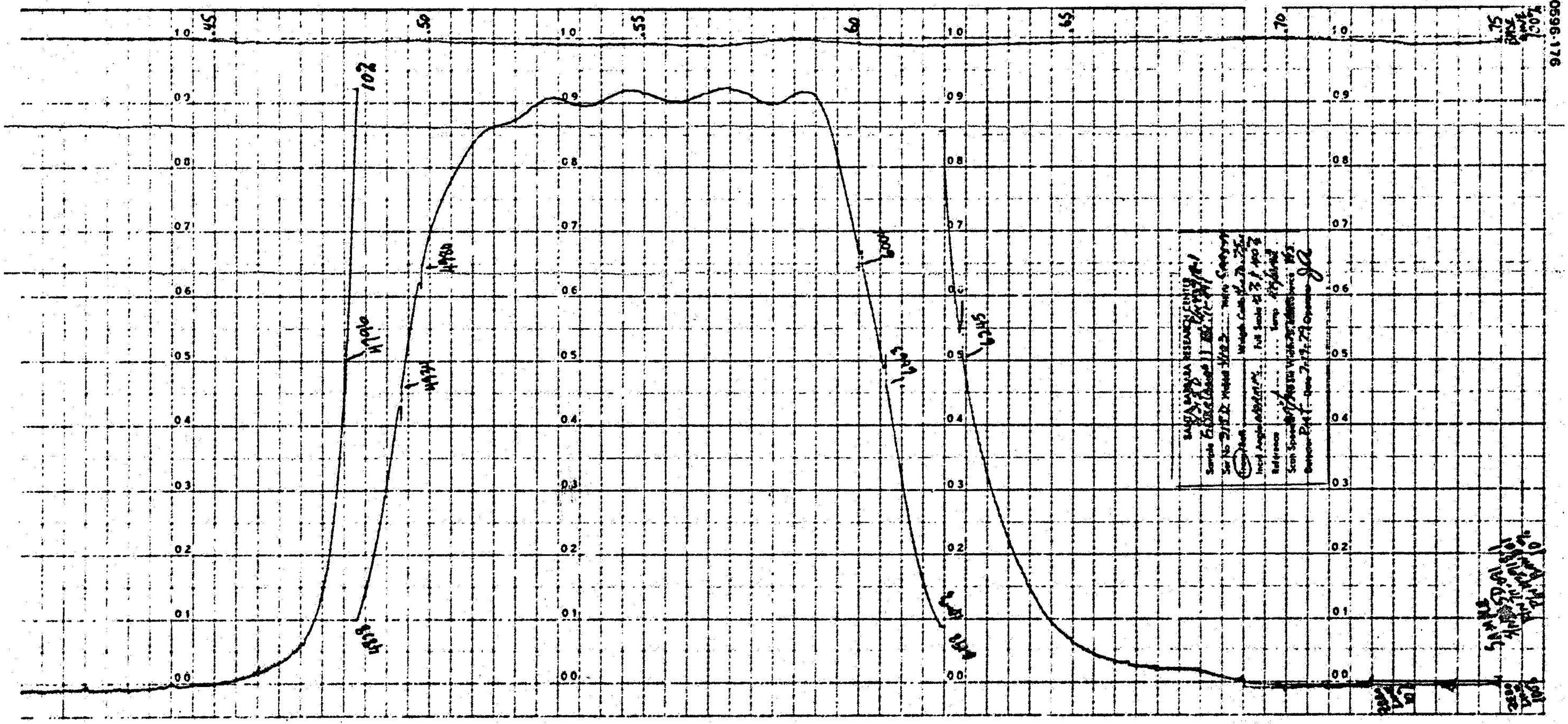

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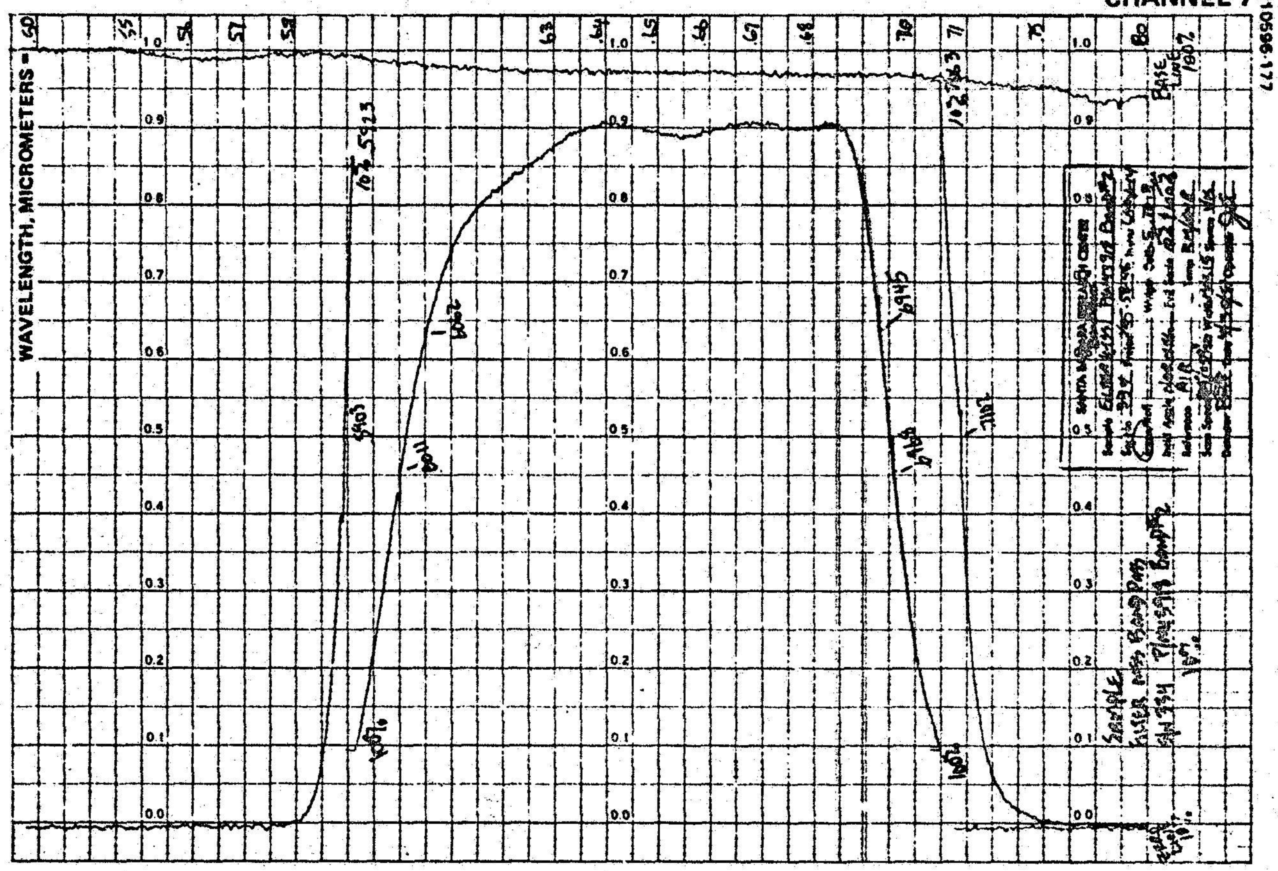

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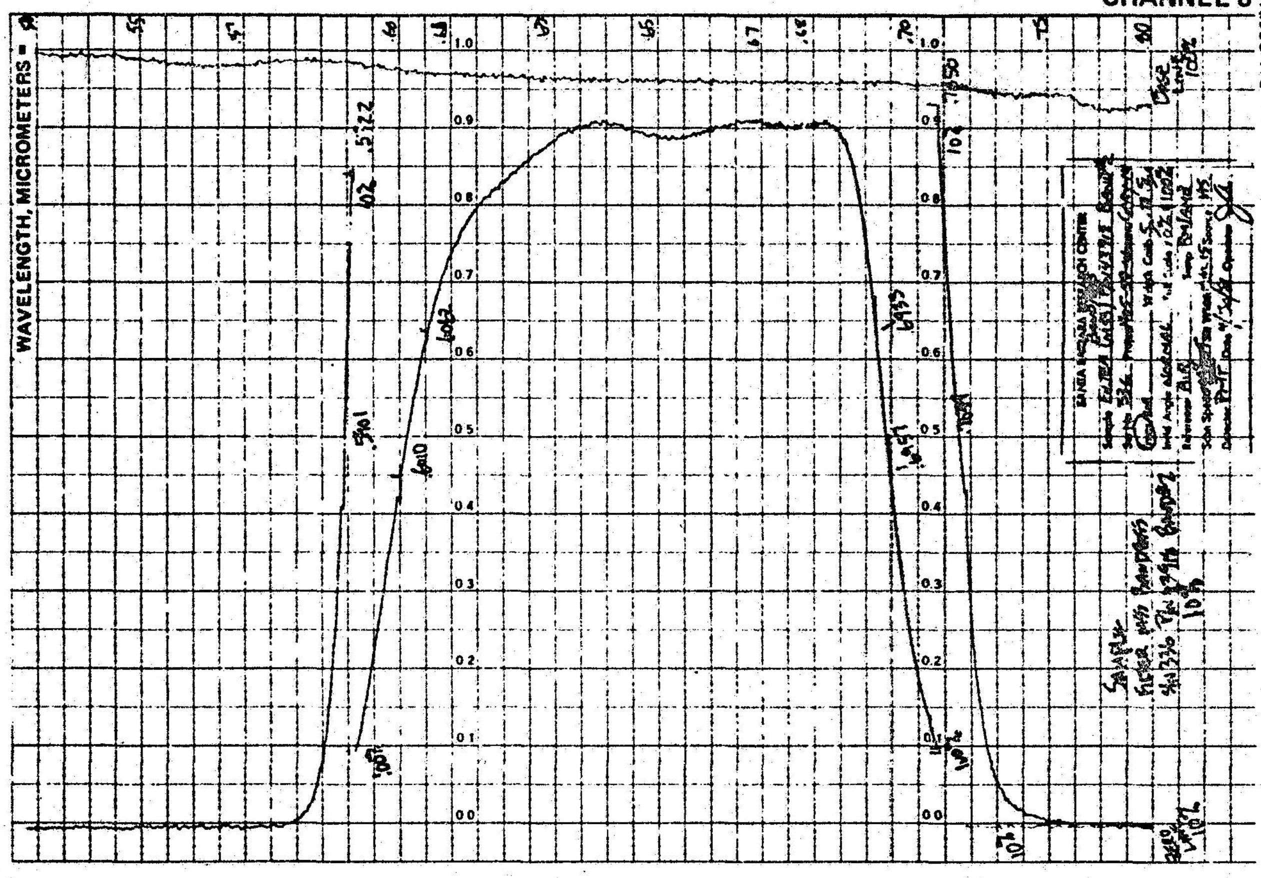

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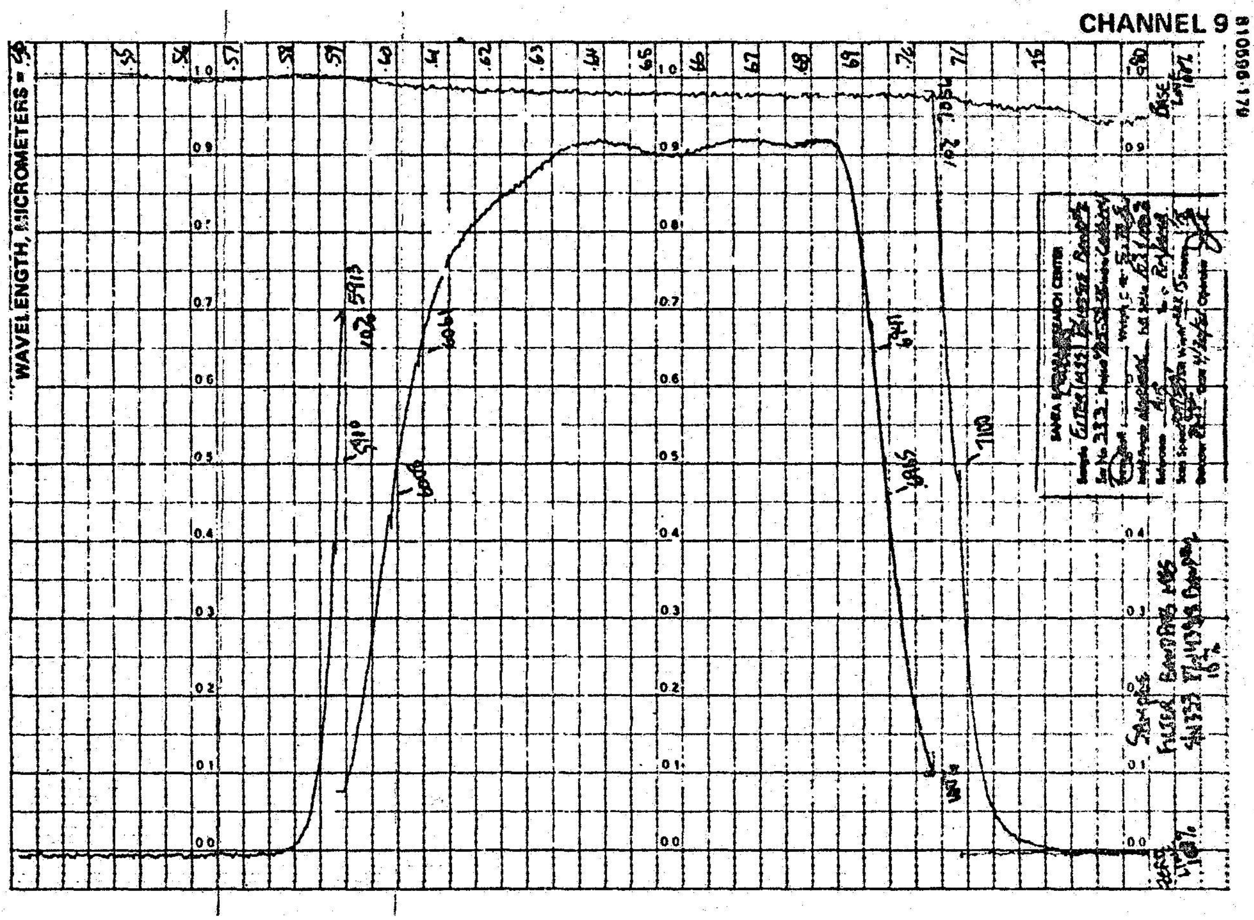

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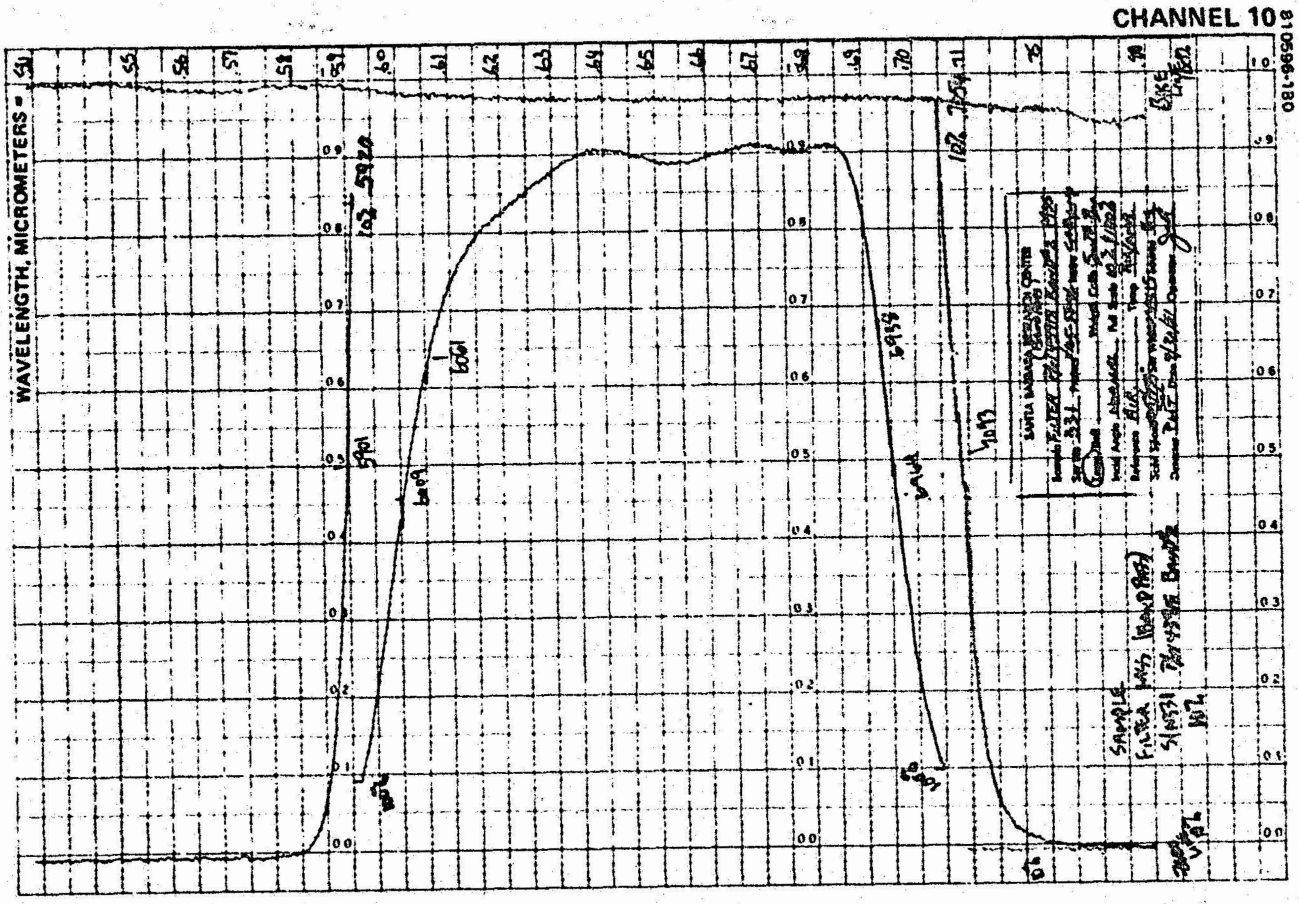

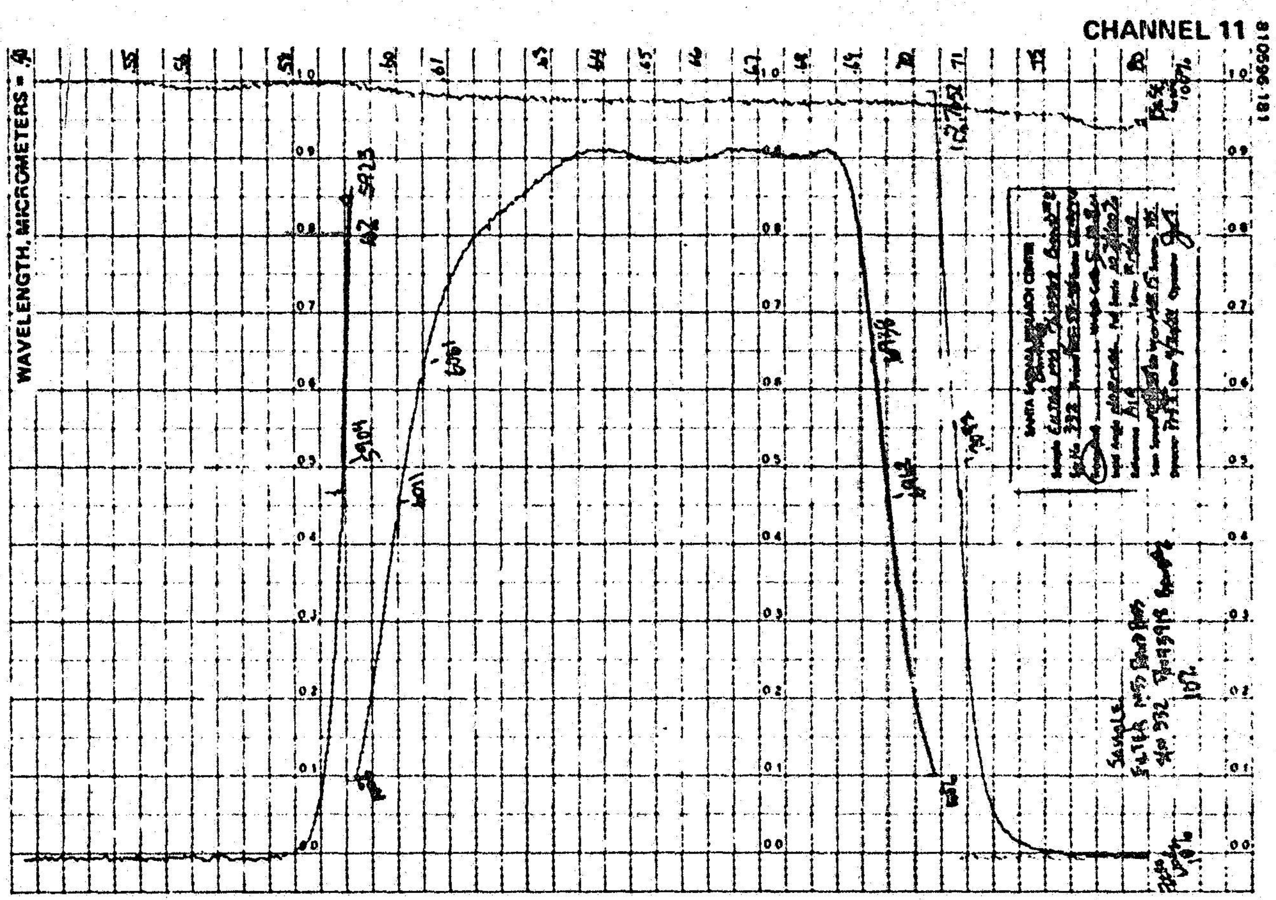
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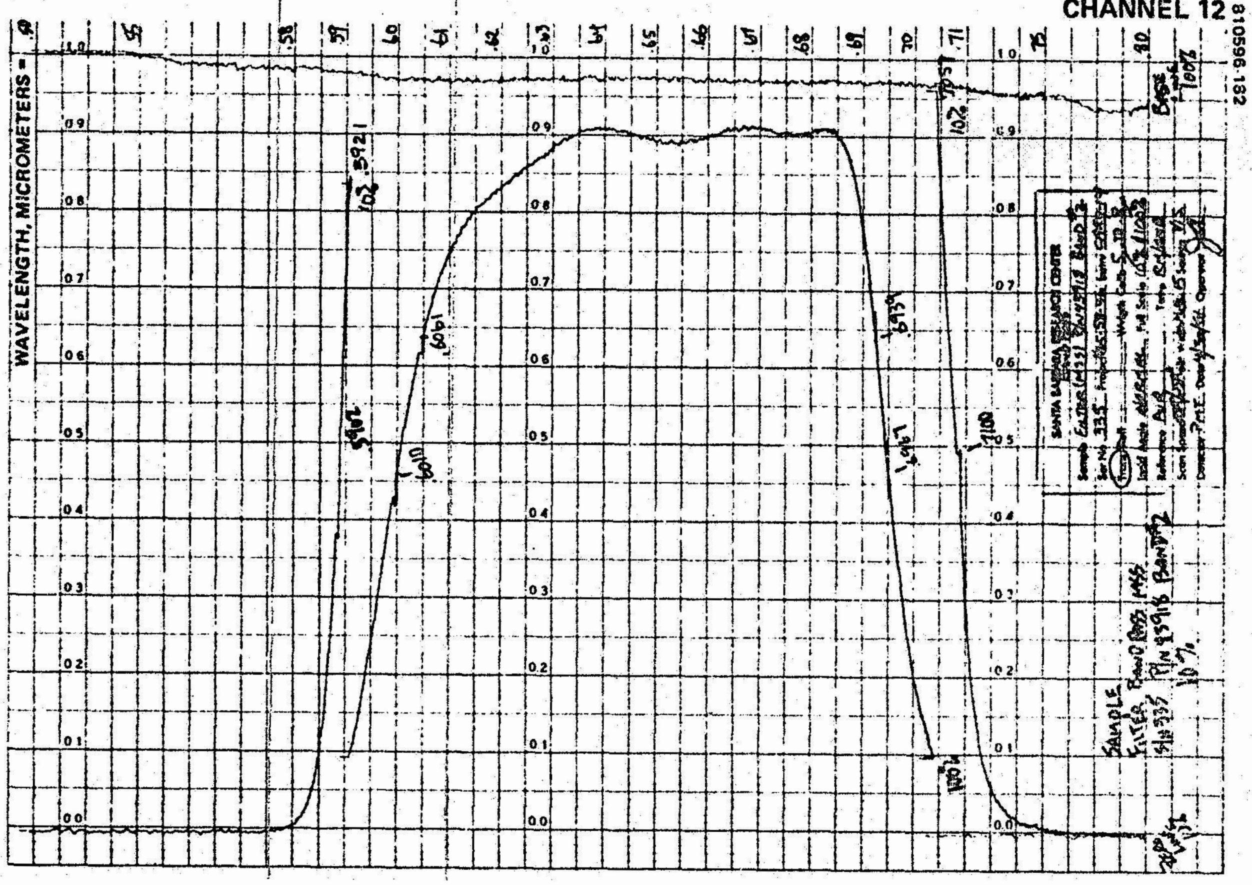

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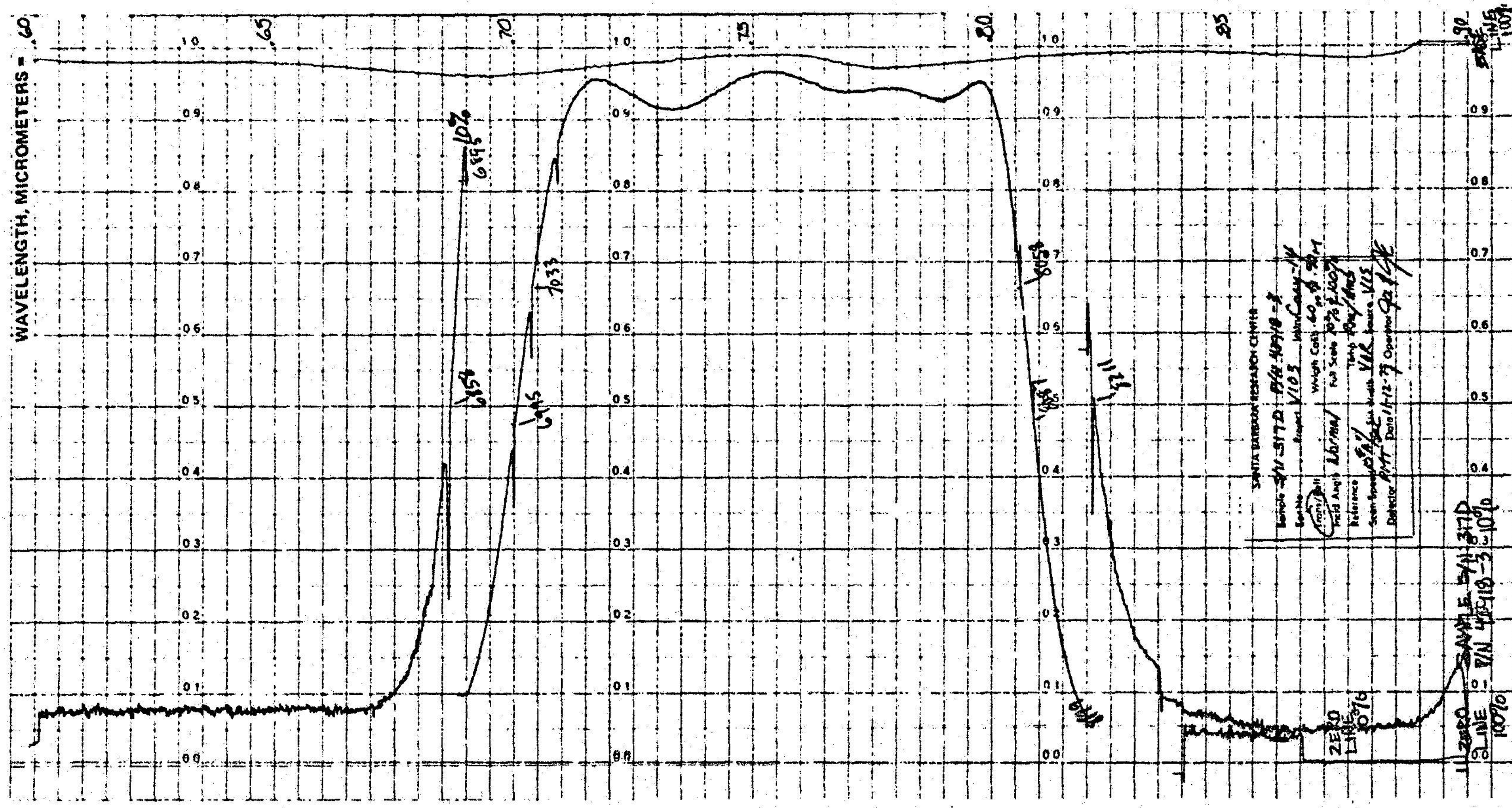

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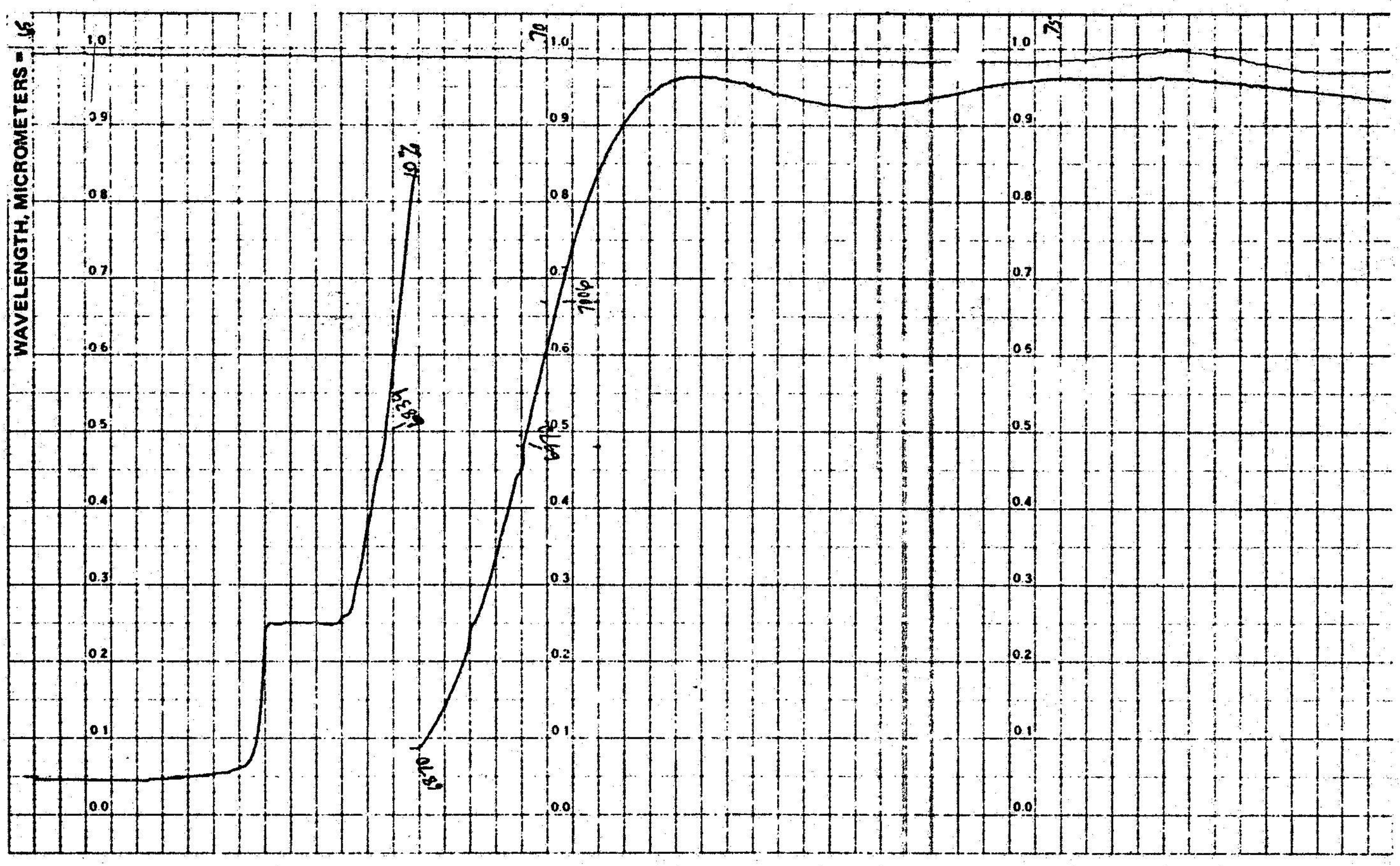
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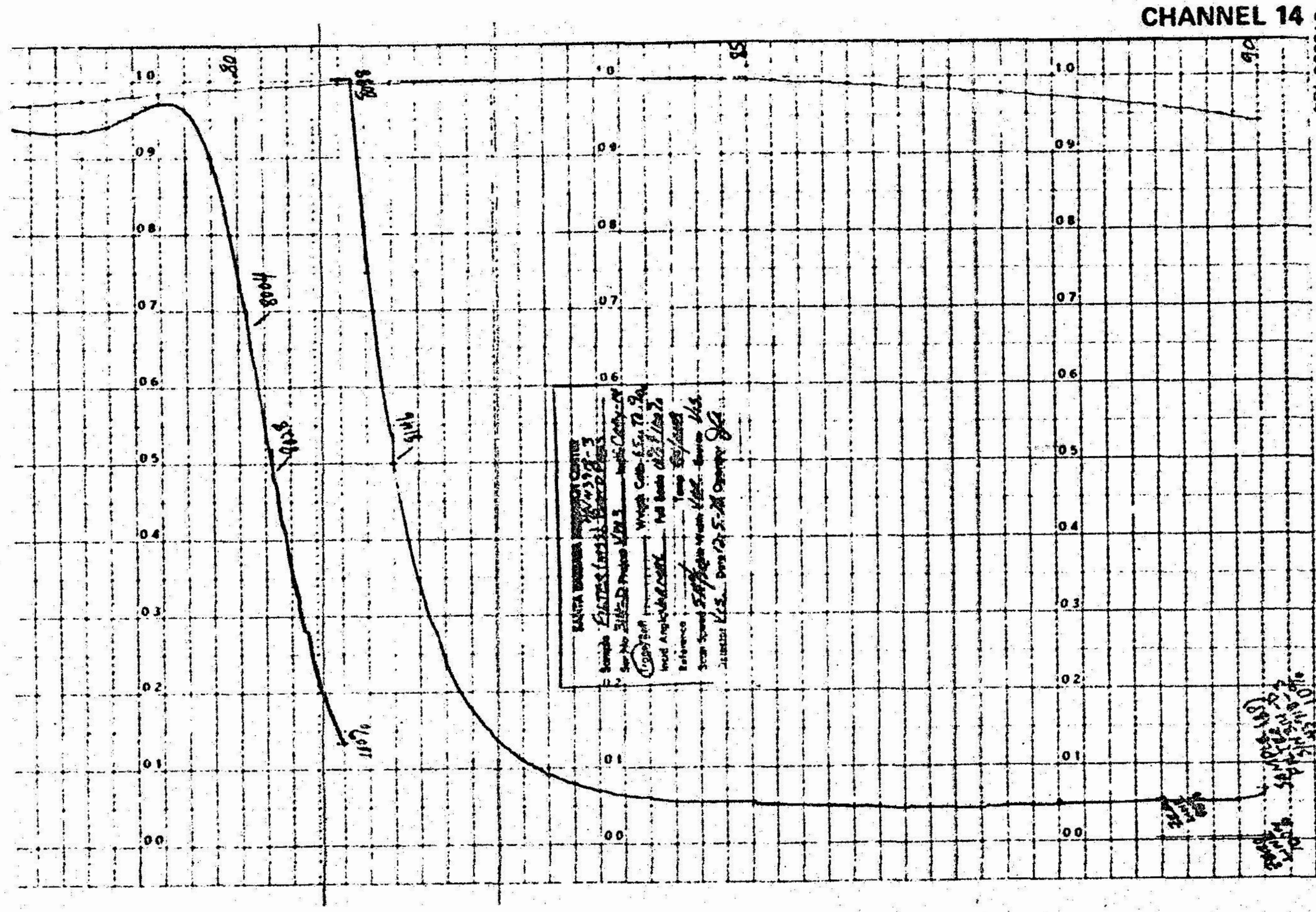

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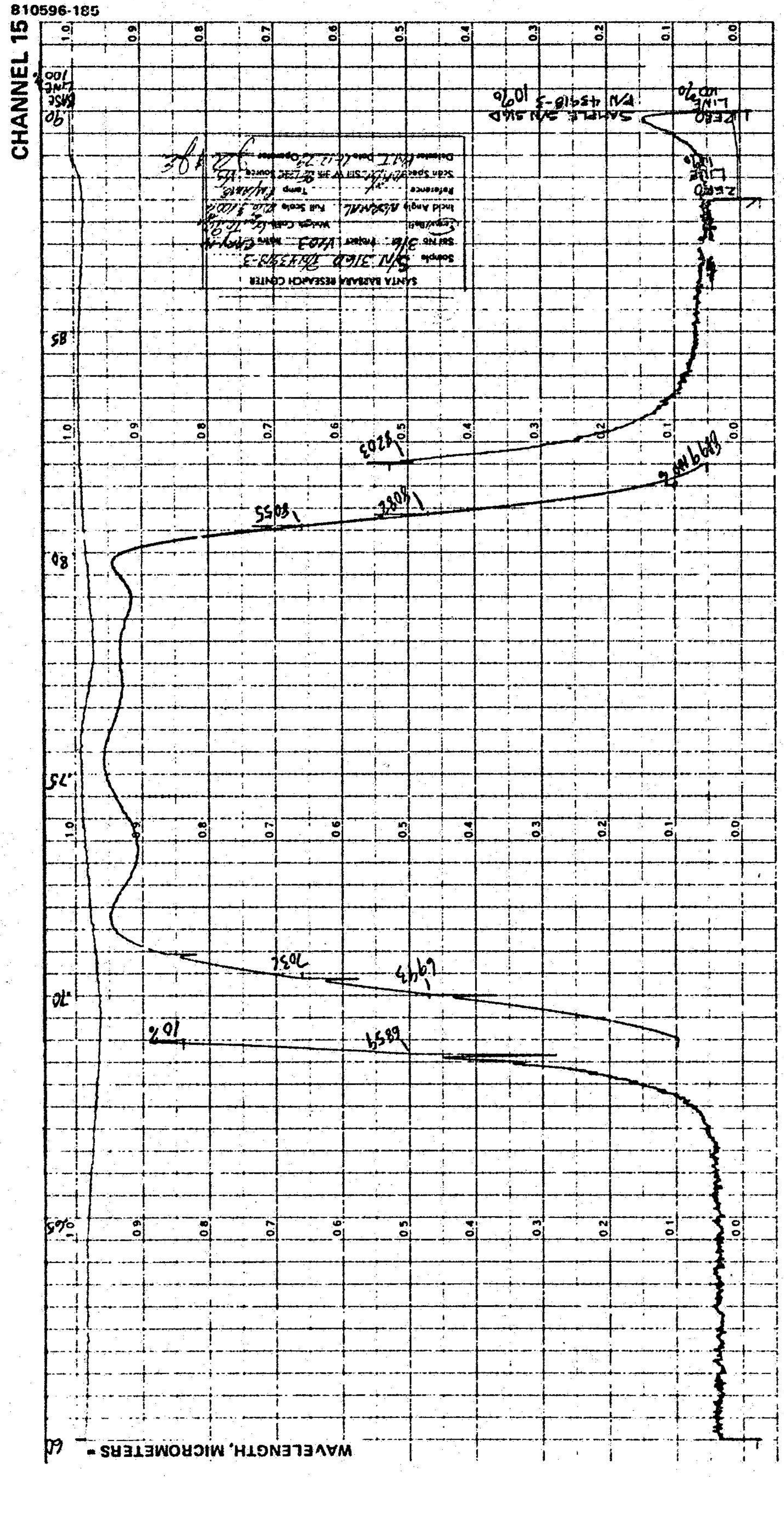

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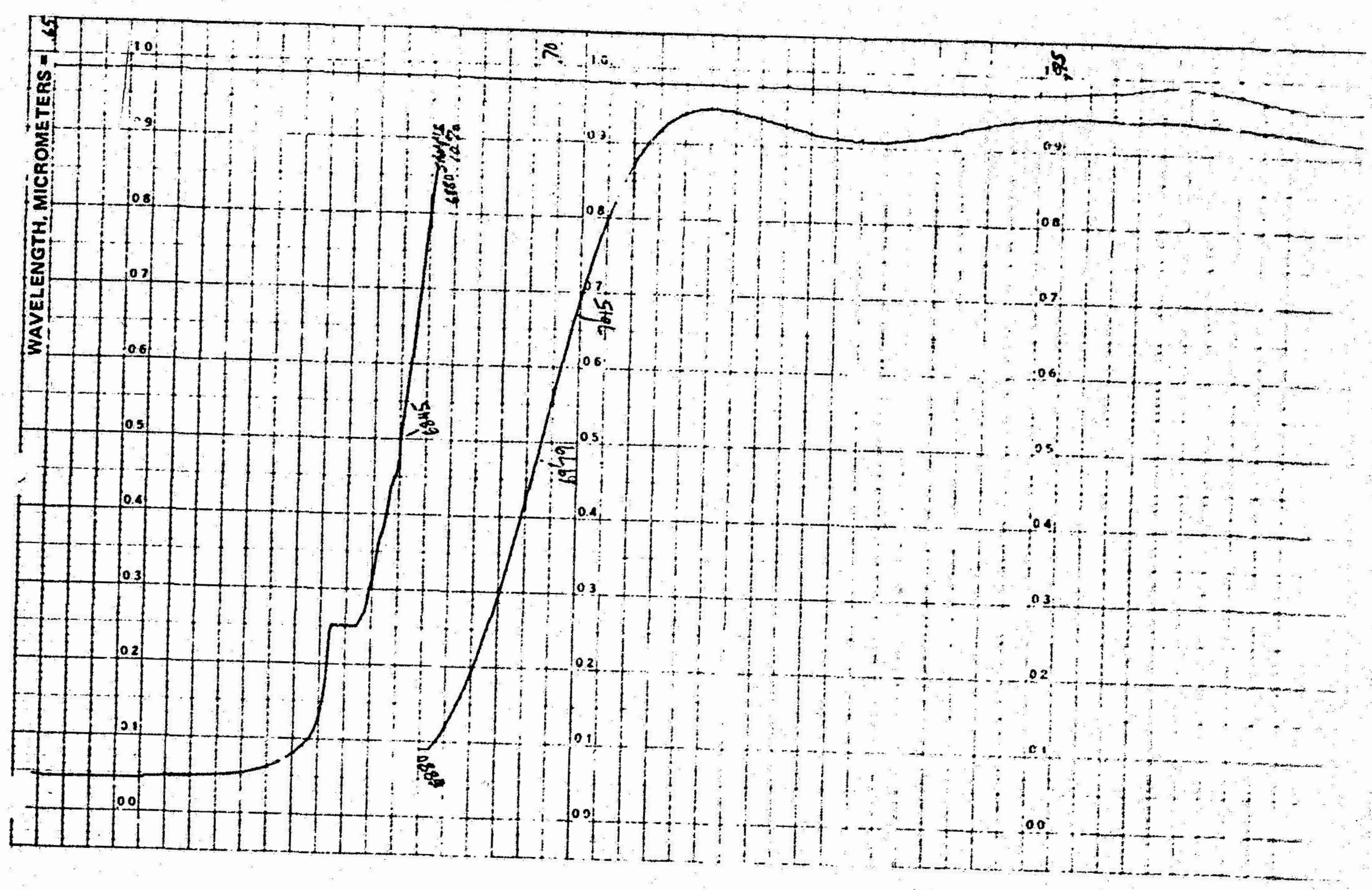

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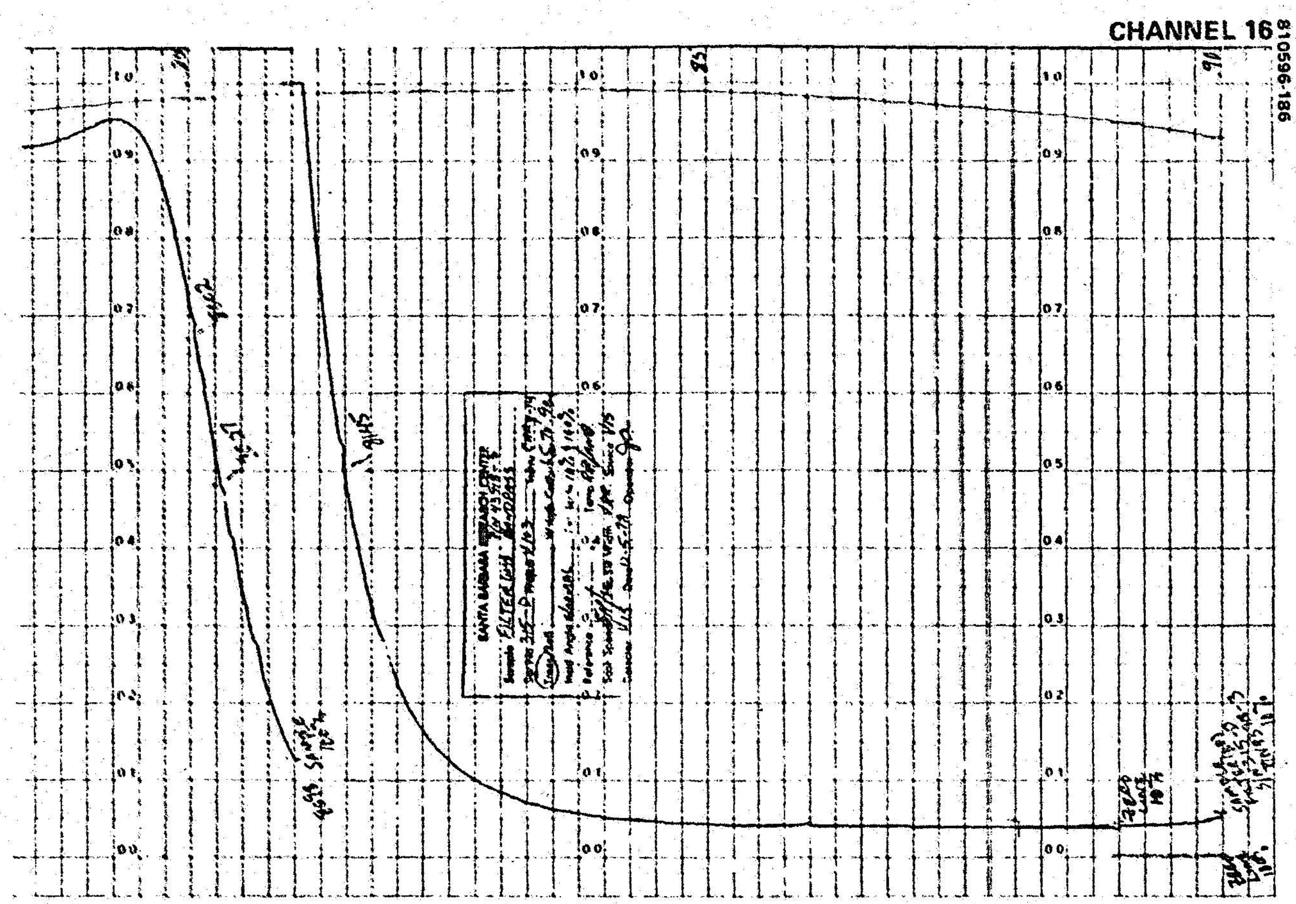

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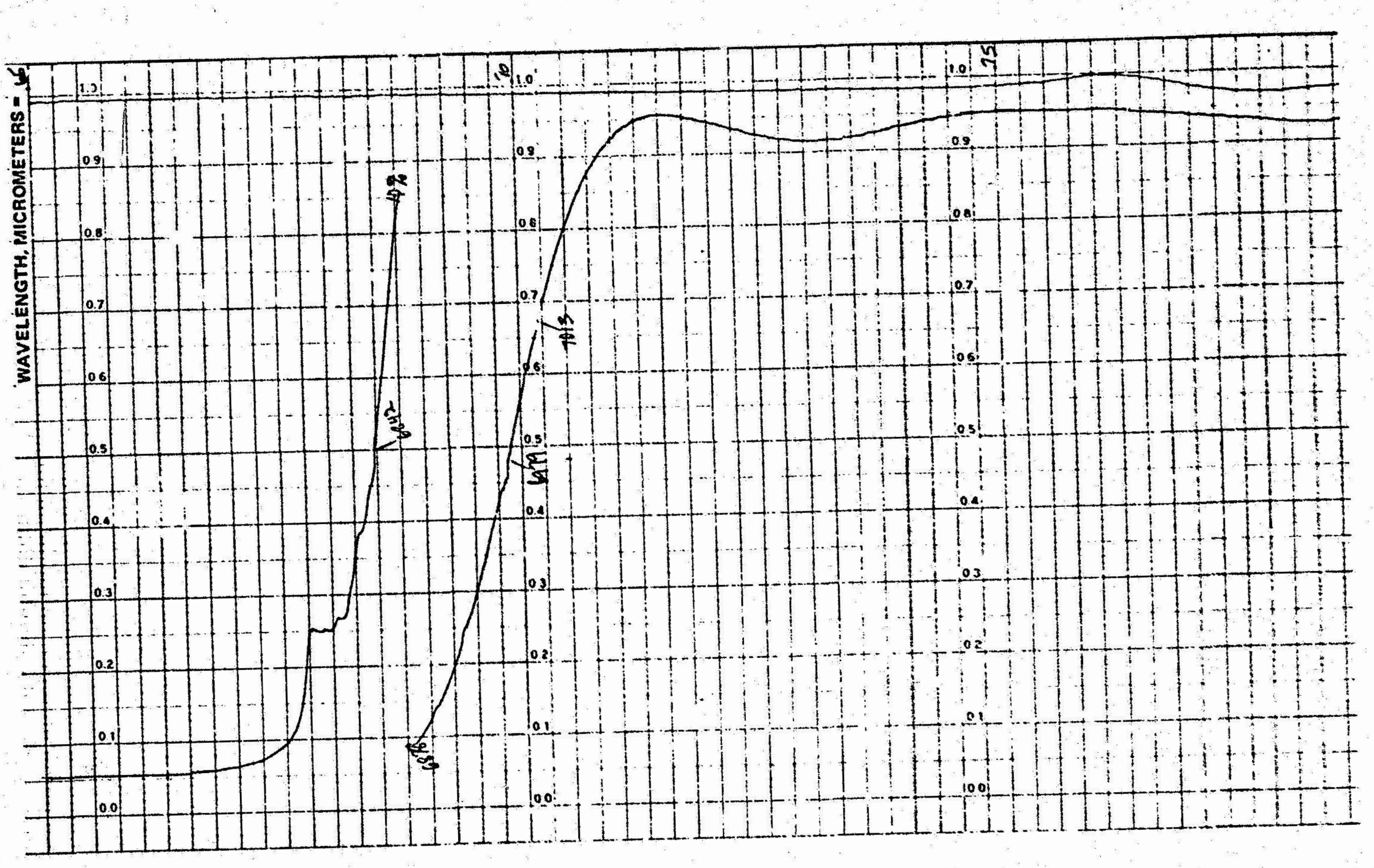

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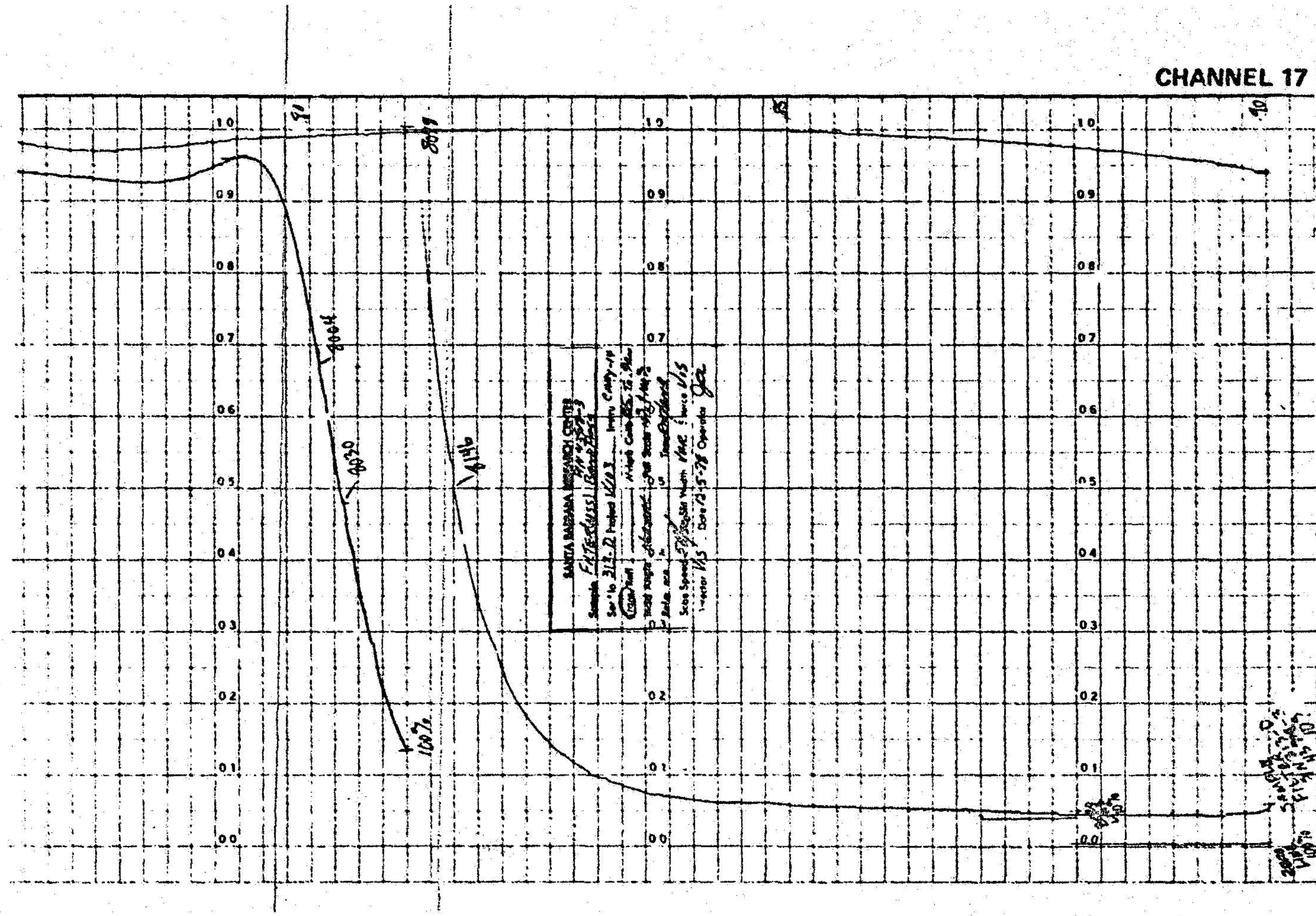

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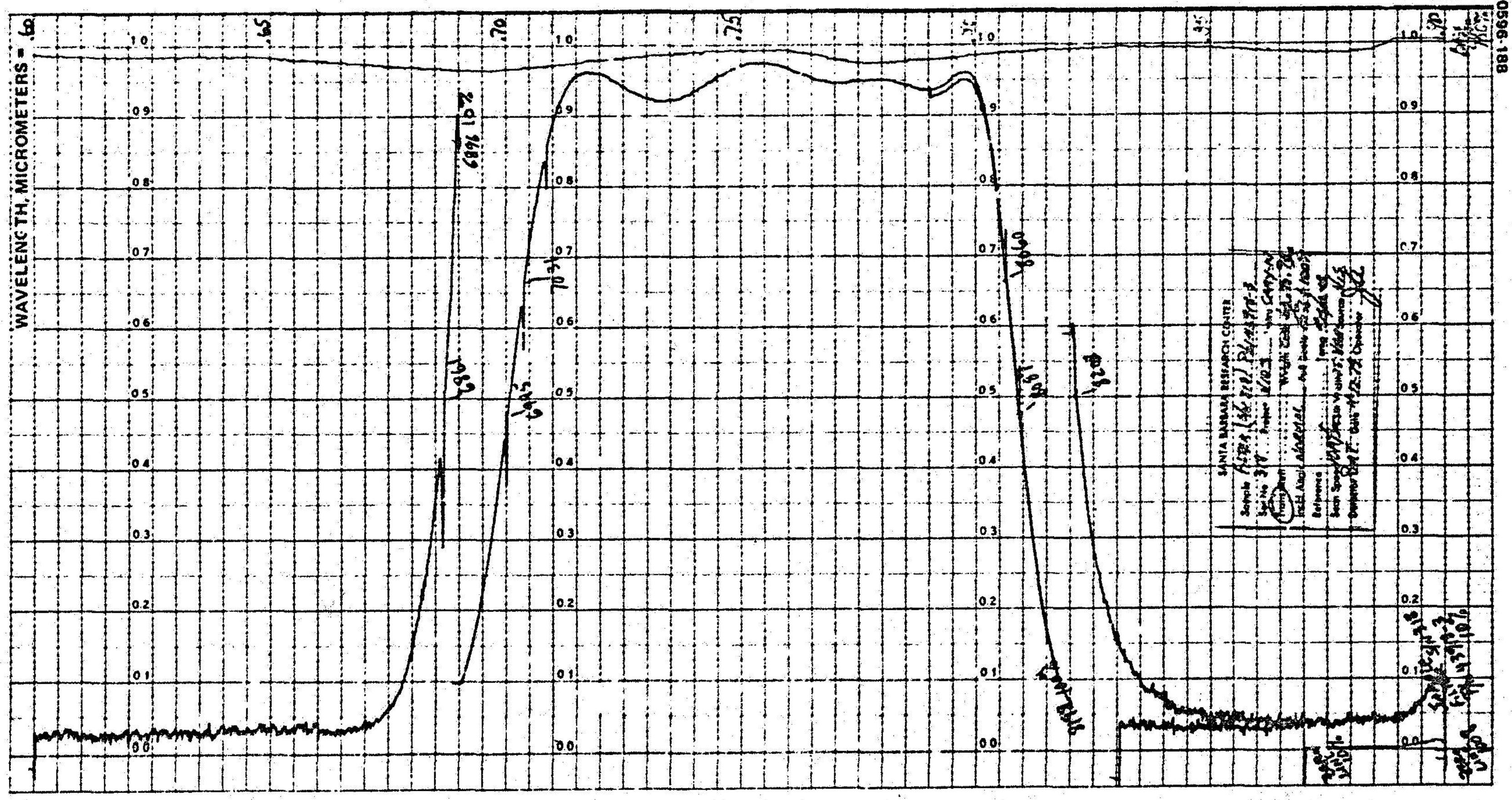

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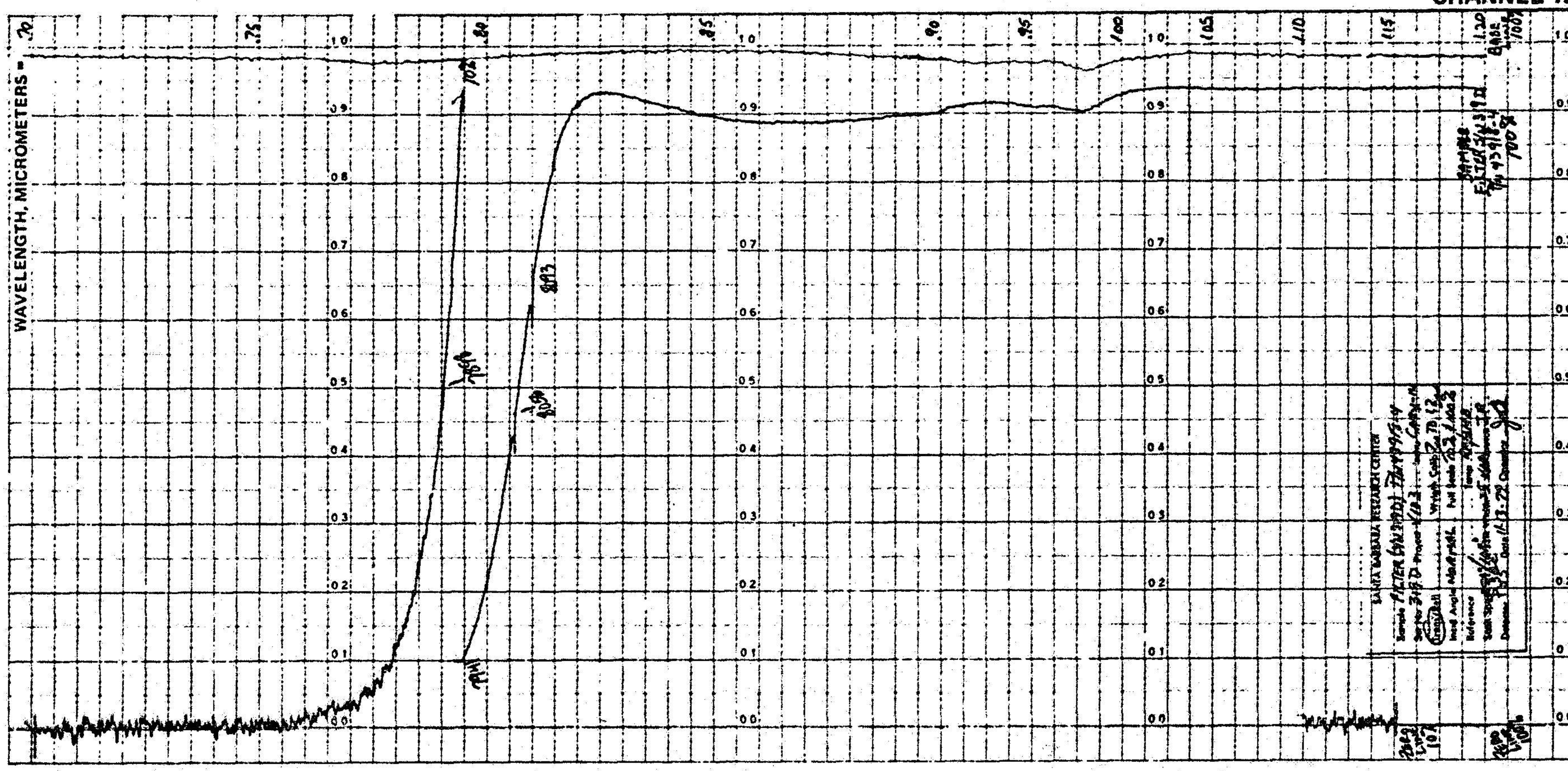

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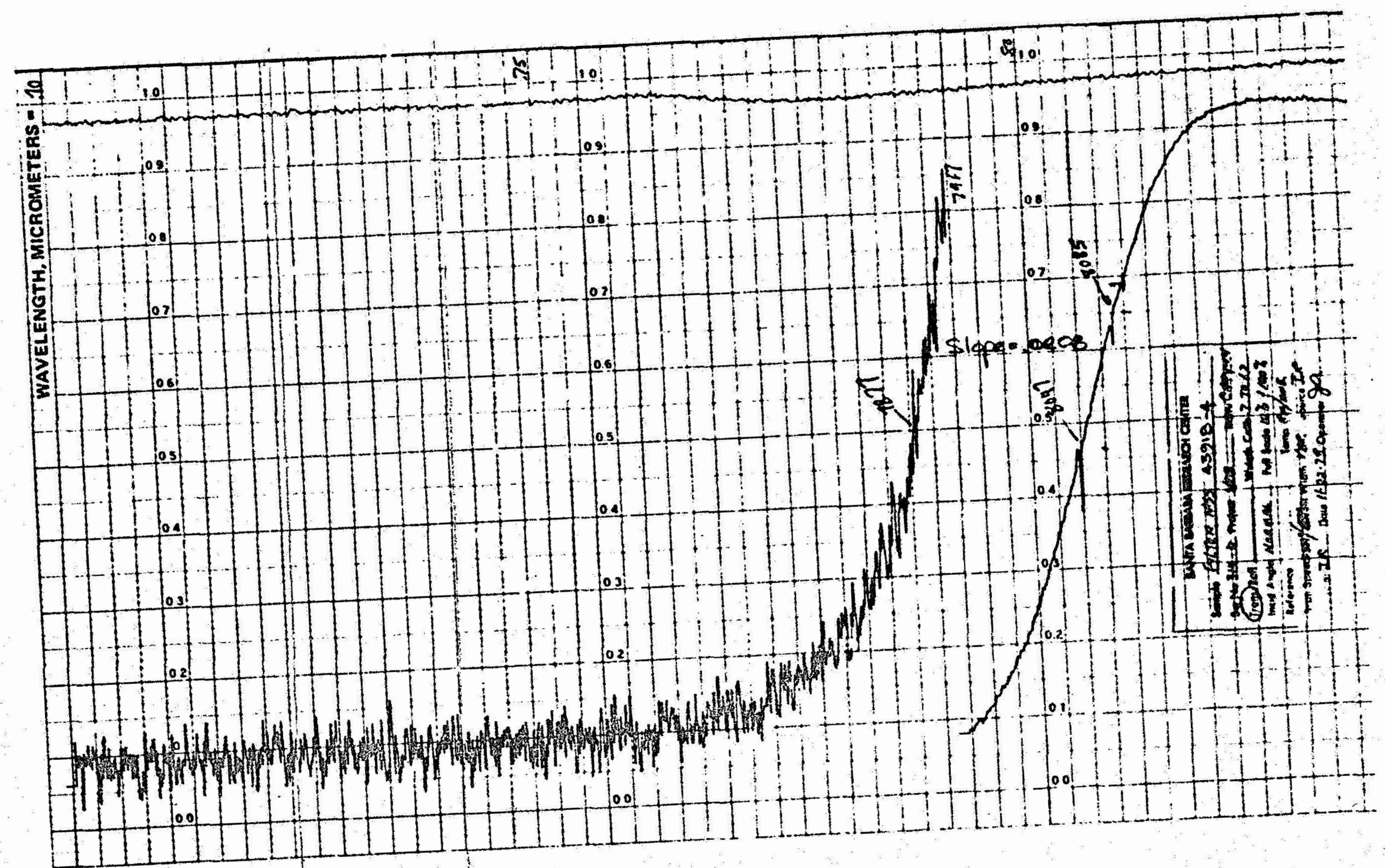

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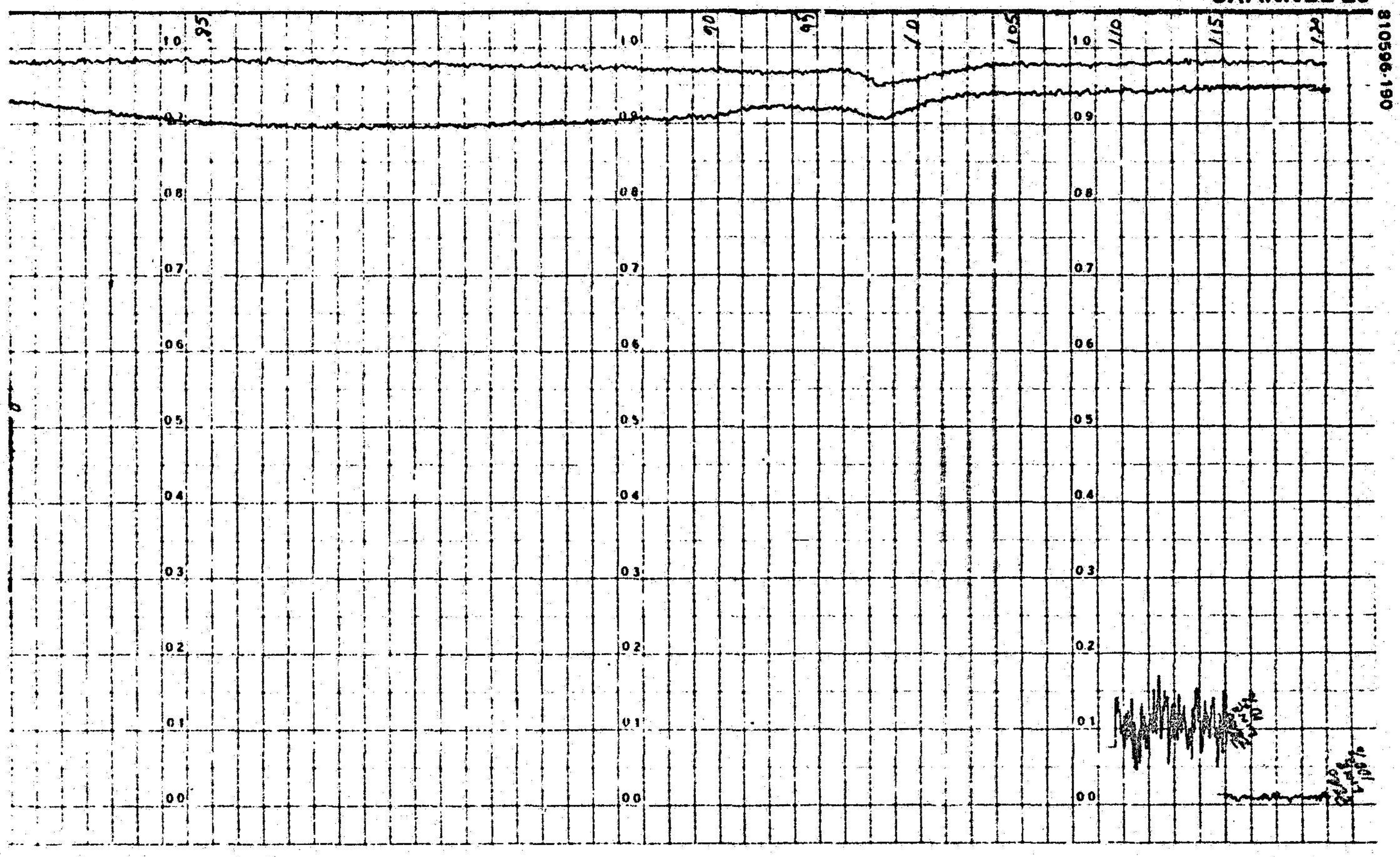

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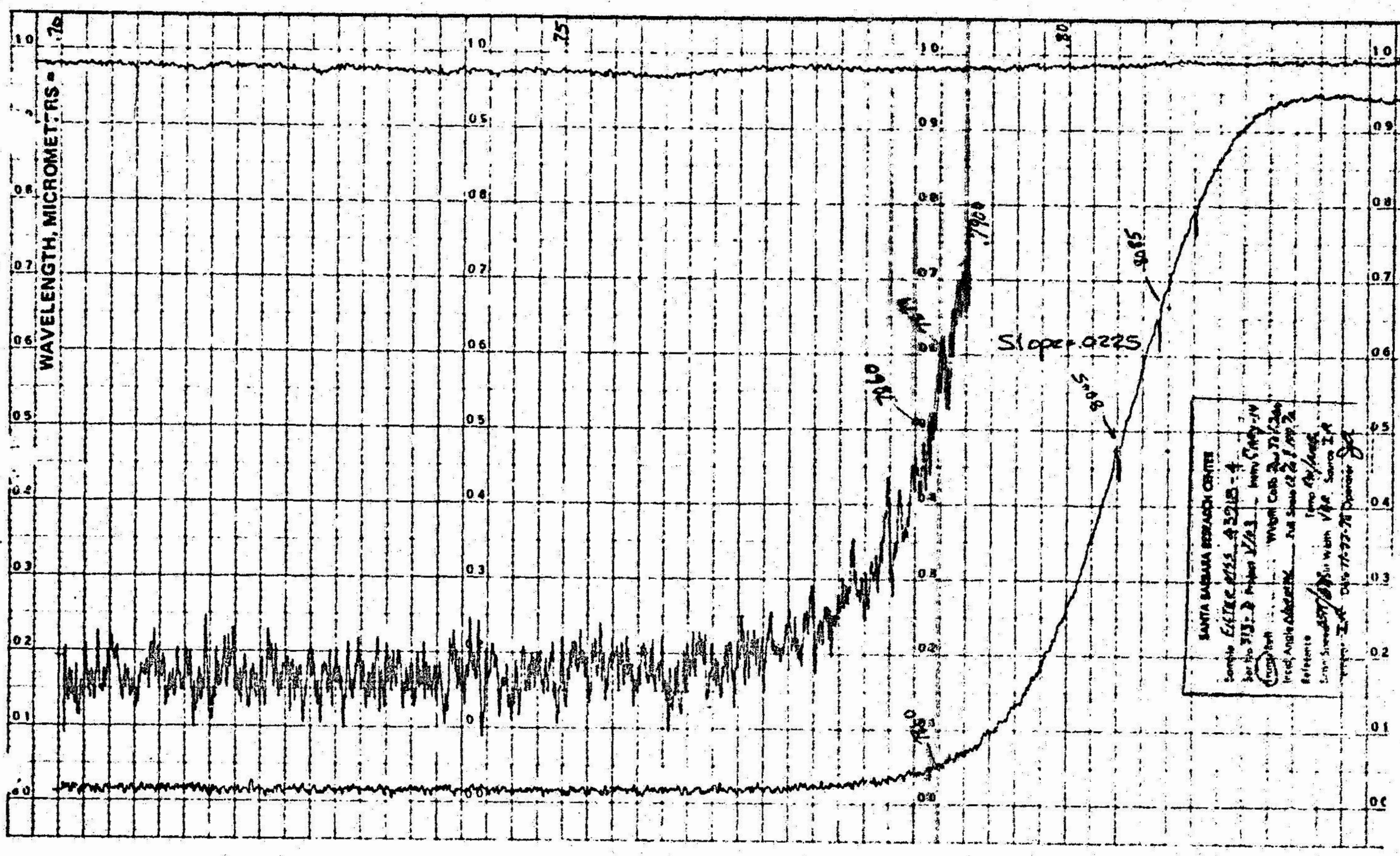

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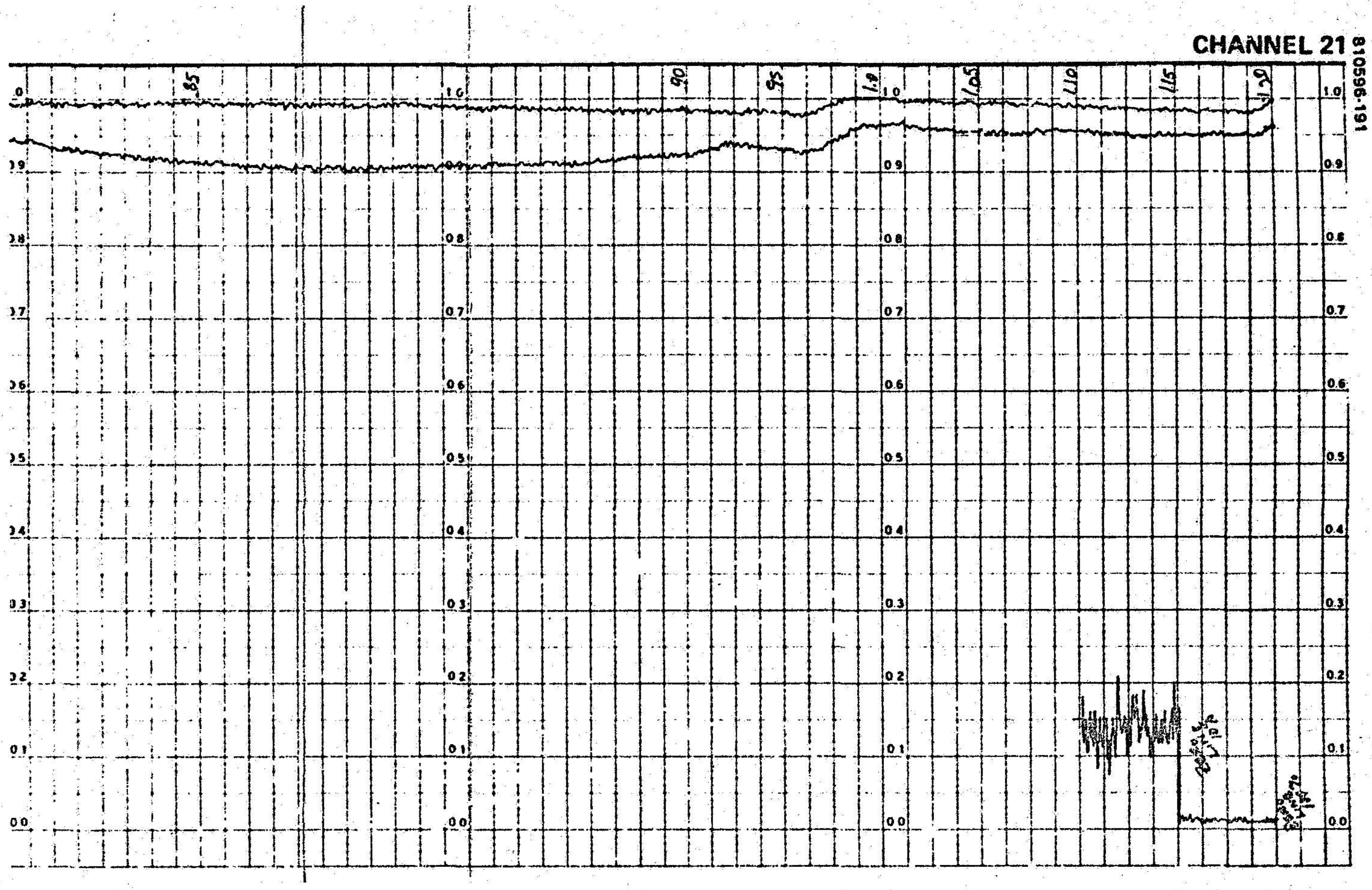

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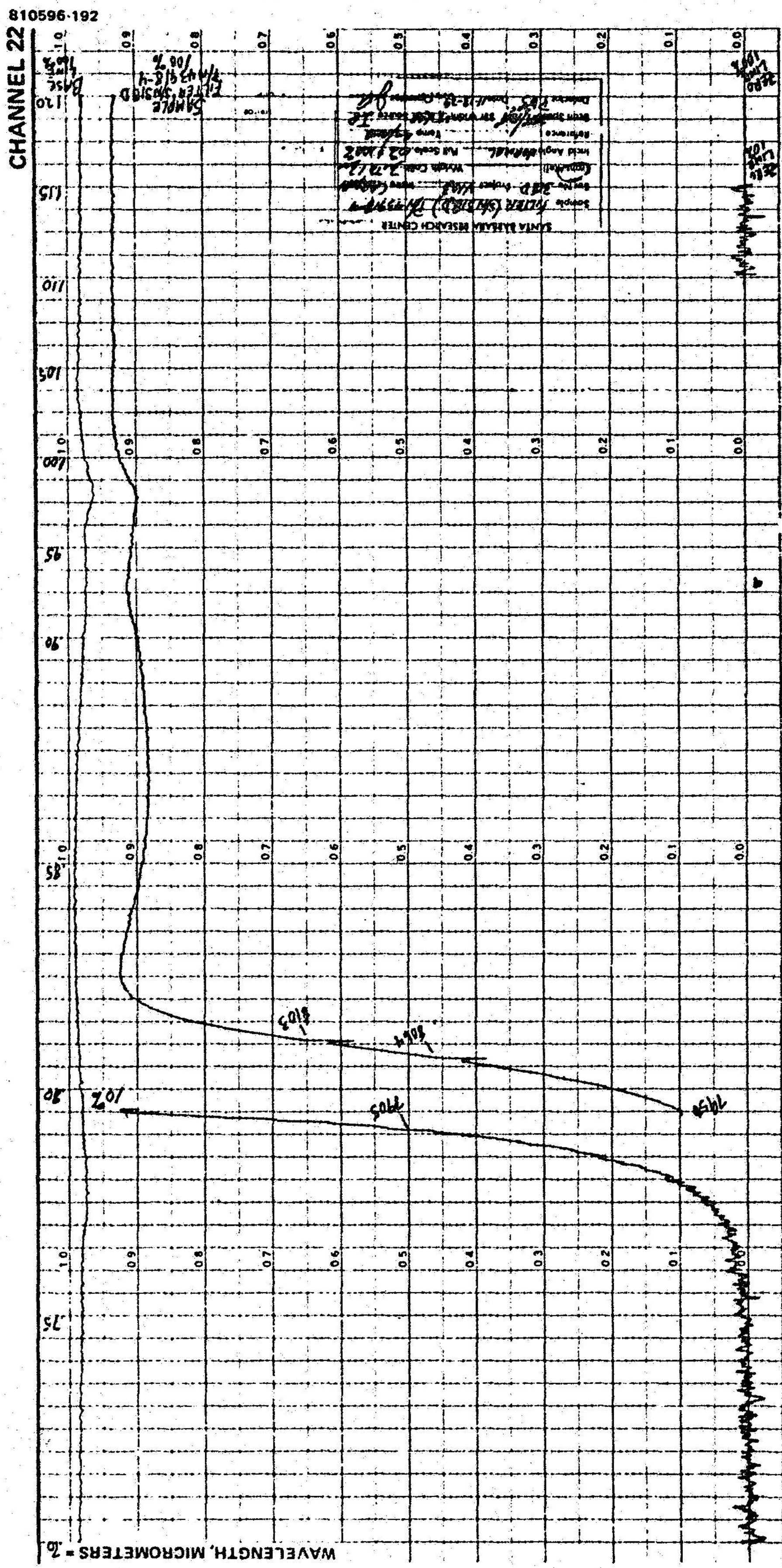
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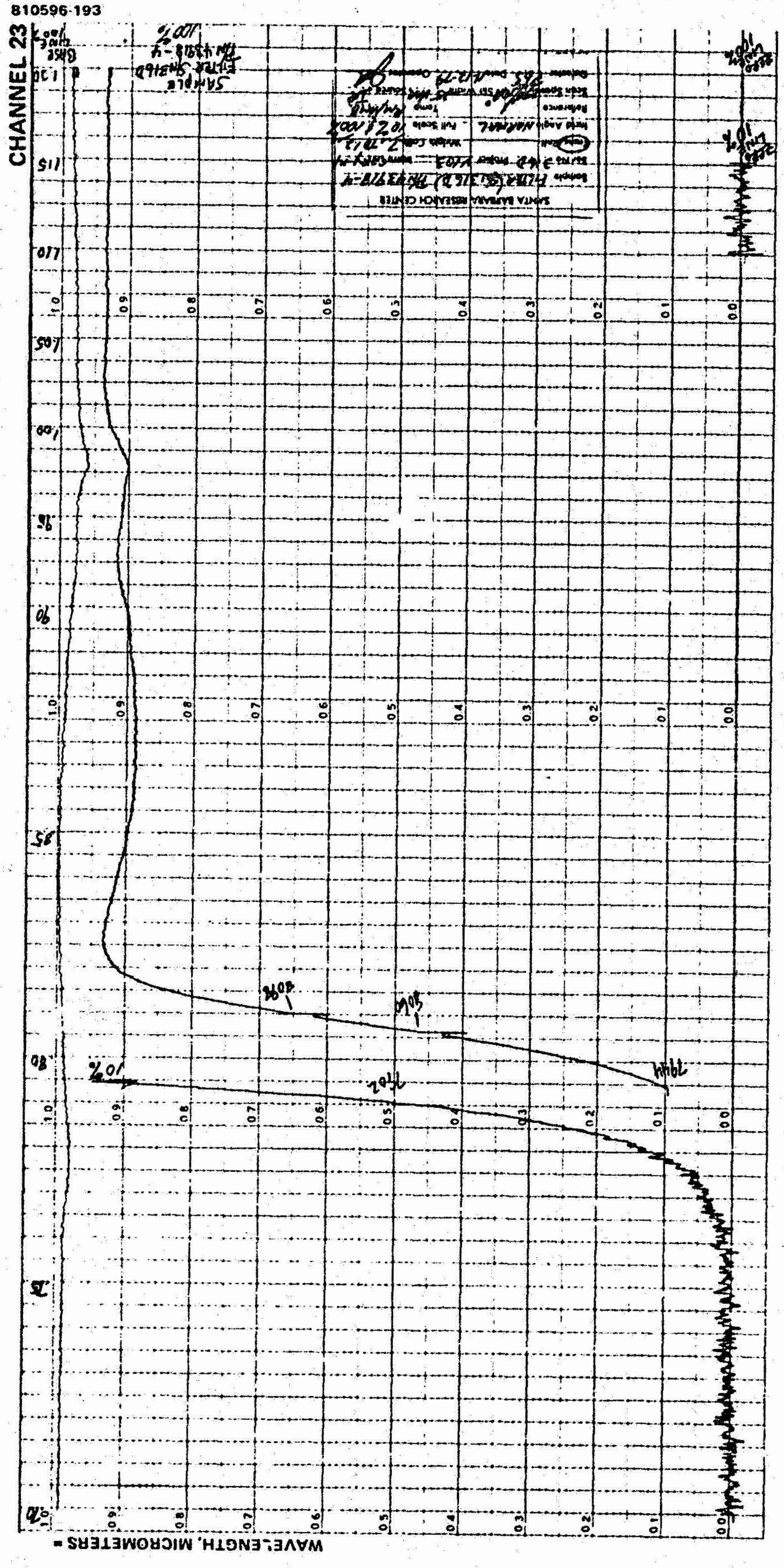

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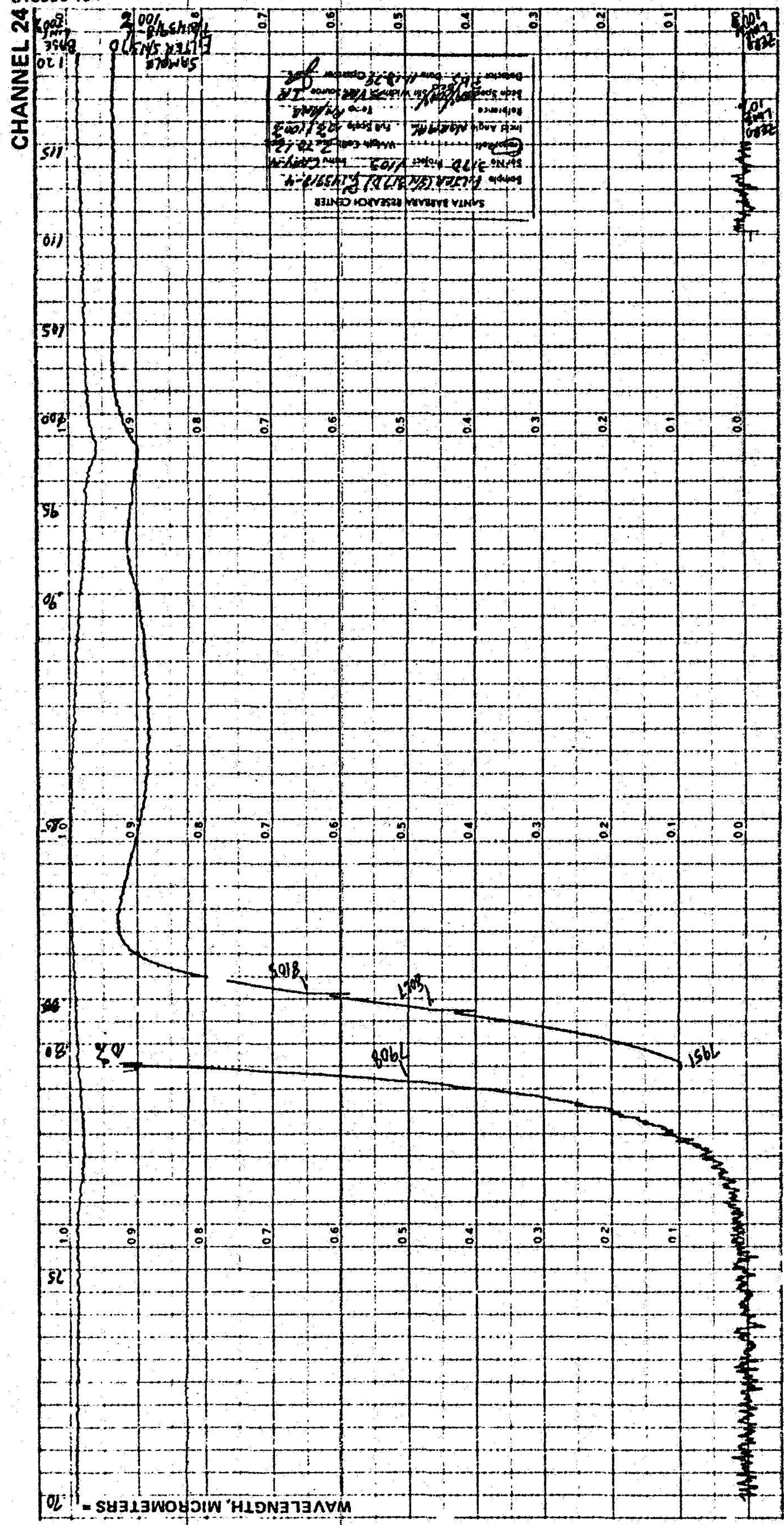

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1. INTRODUCTION

The MSS-D scanner must be mounted on the Landsat spacecraft with the instrument line of sight accurately oriented with respect to a reference coordinate system within the spacecraft. To facilitate the installation of the instrument on the spacecraft Hughes Aircraft Company provides a mirrored reference cube mounted on the MSS-D scanner, a drill fixture for drilling instrument mounting holes with its associated reference cube, and the data which establish the angular relationships among the coordinate frames associated with these cubes and the MSS-D line of sight (LOS).

These data and a summary description of the method of measurement are the subject of this document. Detailed descriptions of the alignment procedures used are given in HS 248 MSS System Alignment Procedure 3617000-1 7 (SBRC Procedure 16890).

1.1 ANGLE CONVENTION

The relative orientation of one orthogonal coordinate system with respect to a second orthogonal coordinate system can be described by the group of three rigid rotations of one system about each of its coordinate axes which will align these axes with those corresponding in the second system. If the rotation angles are small, as is the case for the data presented here, the result is independent of the order in which the rotation operations are performed.

Let X, Y, Z be the set of original orthogonal coordinate axes required to express the angular orientation of a second set of orthogonal axes, X', Y', Z' with respect to X, Y, Z. As illustrated in Figure 1, successive rotations (see Figure II-1-1a) through angles α, β, and γ about the axes X, Y, and Z respectively are required to align these axes with the axes X', Y', and Z' (see Figure II-1-1b).

This convention is used throughout the measurements made for this report.

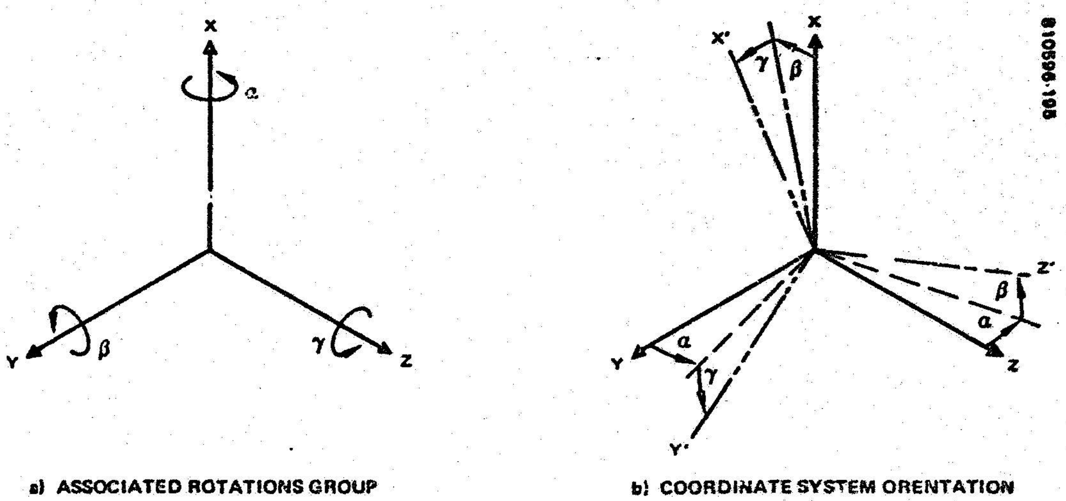

FIGURE II-1-1. COORDINATE SYSTEM CONVENTION

2. ALIGNMENT TEST CONFIGURATION

The test configuration used for the alignment angle measurements is illustrated in Figure II-2-1. It consists of a theodolite, its azimuth reference mirror (RM), and an alignment fixture mounted on a rotary table which is mounted on a tangent plate.

2.1 THEODOLITE AND REFERENCE MIRROR

The theodolite is set up with its azimuth axis vertical. The azimuth axis is vertical when the reading of a level on the theodolite does not change as the theodolite is rotated in azimuth.

A reference azimuth is established by autocollimation from a rigidly mounted RM. In addition to its use as an azimuth coordinate reference the RM provides a reference azimuth during movement of the theodolite.

It is not possible to autocollimate from both the target mirror (TM) and the alignment cube from the same theodolite position. The theodolite can be moved to where autocollimation from the alignment cube is possible provided that the following procedure is followed:

1) Move the RM and theodolite alternately in steps short enough so that azimuth reference is never lost.

2) Re-level theodolite after the move.

The theodolite and RM establish a set of coordinate axes in which the orientation angles of the various coordinate reference systems can be measured and compared.

The scale convention for the theodolite was the following:

Azimuth: 0 to 360°; magnetic compass convention

Elevation: 0 to 360°; horizontal at 0° and 180°, zenith at 90°

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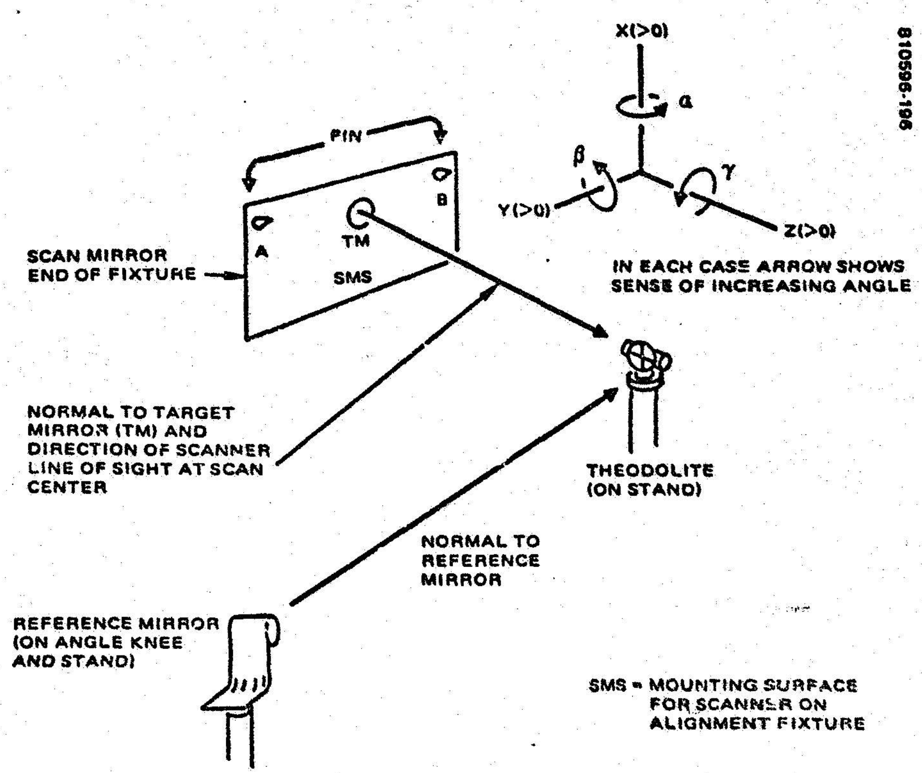

FIGURE II-2-1. ALIGNMENT TEST CONVENTION

A "reverse and plunge" set of measurements was taken to provide redundant data as a check against error.

2.2 ALIGNMENT FIXTURE (ANGLE PLATE)

The alignment fixture is a mounting bracket which provides a rigid structure on which the scanner and, separately, the drill fixture are mounted for orientation measurements.

A TM attached to the alignment fixture lies in the scanner mounting surface (SMS) of that fixture. This mirror is used to establish the orientation of the normal to the SMS. The SMS also contains a pair of pins (pins A and B) used to establish orientation in the plane of the SMS (i.e., orientation in "γ"). Measurement of the deviation of the normal to the TM from the normal to the SMS is made by the use of a separate mirror temporarily placed on the mounting surface for that purpose.

The alignment fixture (angle plate) is mounted on a rotary table used in the initial alignment setup. This rotary table is supported by the tangent plate which is equipped with leveling screws used to set up the initial orientation of the angle plate. A reference level indicator consisting of two spirit levels mounted at right angles monitors angular deflections of the angle plate during mounting of the scanner.

2.3 SCANNER MOUNTING SURFACE ORIENTATION MEASUREMENT

The normal to the TM and the line through pins A and B (in the SMS) form an orthogonal coordinate reference system the orientation of which can be established in the system defined by the level theodolite and RM.

The theodolite, RM, and the alignment fixture are set up as illustrated in Figure II-2-1, so that the theodolite telescope LOS is directed toward the TM and is very nearly parallel to the normal and the TM as determined by autocollimation. The leveling screws on the tangent plate are used to set pins A and B at the same height. Zero points for angles α, β, and γ are determined with respect to the level plane of the theodolite and an orbiting reference azimuth as follows:

1) "α_o" is measured by autocollimation through the TM with the azimuth scale.

2) "β_o" is measured by autocollimation through the TM with the elevation scale.

3) "γ_o" is obtained by the method illustrated in Figure II-2-2.

Precise convention for reading the scales are included in the alignment procedure.

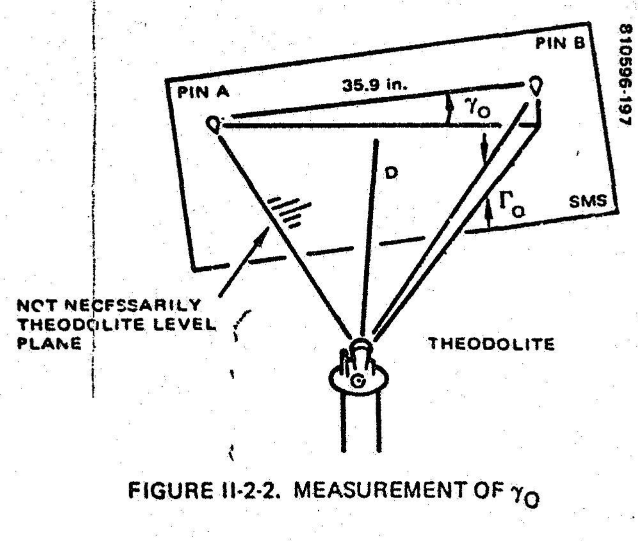

FIGURE II-2-2. MEASUREMENT OF γ_O

First the theodolite is used to sight on pin A. Then it is rotated azimuthally along the negative "y" direction to sight on pin B. The difference in elevation readings is Γ_o. If D (in inches) is the distance from theodolite azimuth axis to the target mirror and the distance between the two pins is 35.9 inches,

γ_o is given by the following relation:

$$\gamma_o = \tan^{-1}\left[\frac{\tan \Gamma_o \sqrt{D^2 + \left(\frac{35.9}{2}\right)^2}}{35.9}\right]$$

γ_o is positive when pin B is higher than pin A.

These measurements form the bases for orientation measurements made on the drill fixture and the scanner when they are mounted, separately, on the SMS as describeo in the following sections.

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3. DRILL FIXTURE ALIGNMENT CUBE

The drill fixture is a drill jig of the scanner mounting holes to be used in drilling the scanner mounting holes in the spacecraft. An alignment cube is affixed to the drill fixture to enable transfer of scanner LOS orientation during the drilling operation. Special ground pins are used to maintain alignment in γ when the drill fixture is bolted to the alignment fixture.

3.1 DRILL FIXTURE ALIGNMENT CUBE ORIENTATION

A system of orthogonal axes is established by the normal to the TM and the line connecting pins A and B on the SMS of the alignment fixture (angle plate). The orientation of this reference frame in theodolite coordinates was established by the procedure described in the previous section.

Let α_d, β_d, and γ_d be the angles which express the orientation of the drill fixture alignment cube with respect to the alignment fixture axes when the drill fixture is mounted on the alignment fixture (see Figure II-3-1). In the figure the drill fixture alignment cube is shown displaced and enlarged, but in the same orientation as when mounted on the alignment fixture.

3.2 DRILL FIXTURE ALIGNMENT CUBE ORIENTATION RESULTS

Orientation angles for the alignment cube on MSS drill fixture HAC-2630-24649-2/2 have been measured with the drill fixture mounted on the same alignment fixture on which the MSS-D protoflight instrument has been mounted for the alignment measurements to be described subsequently.

The results of the measurements of drill fixture alignment orientation made on 10 March 1981 have been revised using data taken at General Electric on 16 June 1981. These values are considered to be more reliable because of their repeatability than those originally reported in the PF version of this handbook. These values are:

$\alpha_d = -0^\circ\ 2'\ 26''$

$\beta_d = -0^\circ\ 4'\ 51''$

$\gamma_d = -0^\circ\ 8'\ 06''$

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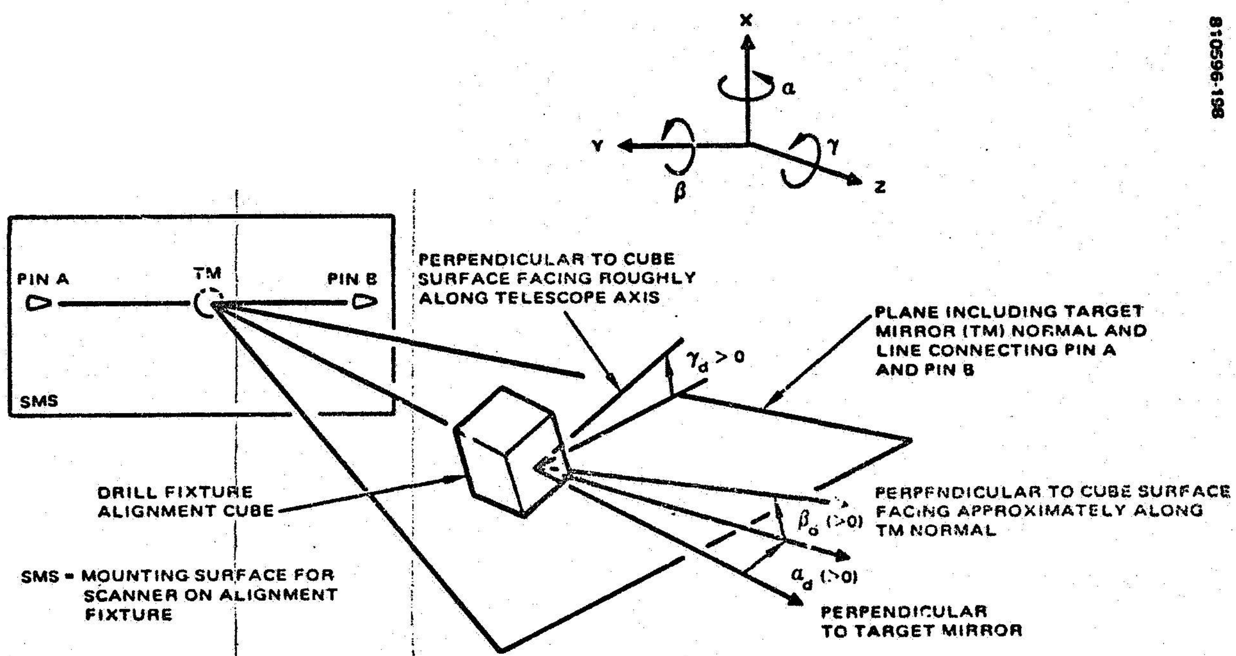

FIGURE II-3-1. DRILL FIXTURE ALIGNMENT CUBE ORIENTATION

4. MSS-D SCANNER ALIGNMENT

The objective of the scanner alignment procedure described herein and the measurement data which result is to establish to within $\pm 0.03^{o}$ the angular orientation of the scanner LOS with respect to the SMS and to measure, also to within $\pm 0.03^{o}$, the angular orientation of the scanner alignment with respect to the MSS center scan LOS. It is necessary also to verify that the scanner LOS is perpendicular to the SMS to within 0.25^{o}.

4.1 SCANNER LINE OF SIGHT

The scanner LOS orientation is defined by means of the orthogonal coordinate system formed by the instrument scan plane and the plane orthogonal to it which contains the center scan LOS. The center scan LOS is defined by the position of the scan mirror with its center lock engaged. The scan plane is defined by the plane which contains the center scan direction and the two end scan directions.

The scan monitor was adjusted to mark center scan as the scan mirror rotates through the locked position (see SBRC Procedure 19050, Sections 3.5.6.1 and 3.5.5.3). When the center lock was removed, the center scan LOS was reconstructed from measurements made with the scan mirror turned against each of its limit stops and from results of initial measurements made with the lock in place.

Two types of orientation (alignment) measurements were made using the scanner LOS coordinate system. The first relates the scanner LOS to the alignment fixture reference frame and the second relates the scanner alignment cube to the scanner LOS reference frame.

The scanner LOS is established by theodolite sightings made on the center of the scanner focal plane fiber optics assembly. Figure II-4-1 illustrates the sighting method. The insert depicts the appearance of the MSS-D focal plane assembly and theodolite telescope reticle when the telescope is sighted on the center of the assembly. Note that there is no centrally located channel.

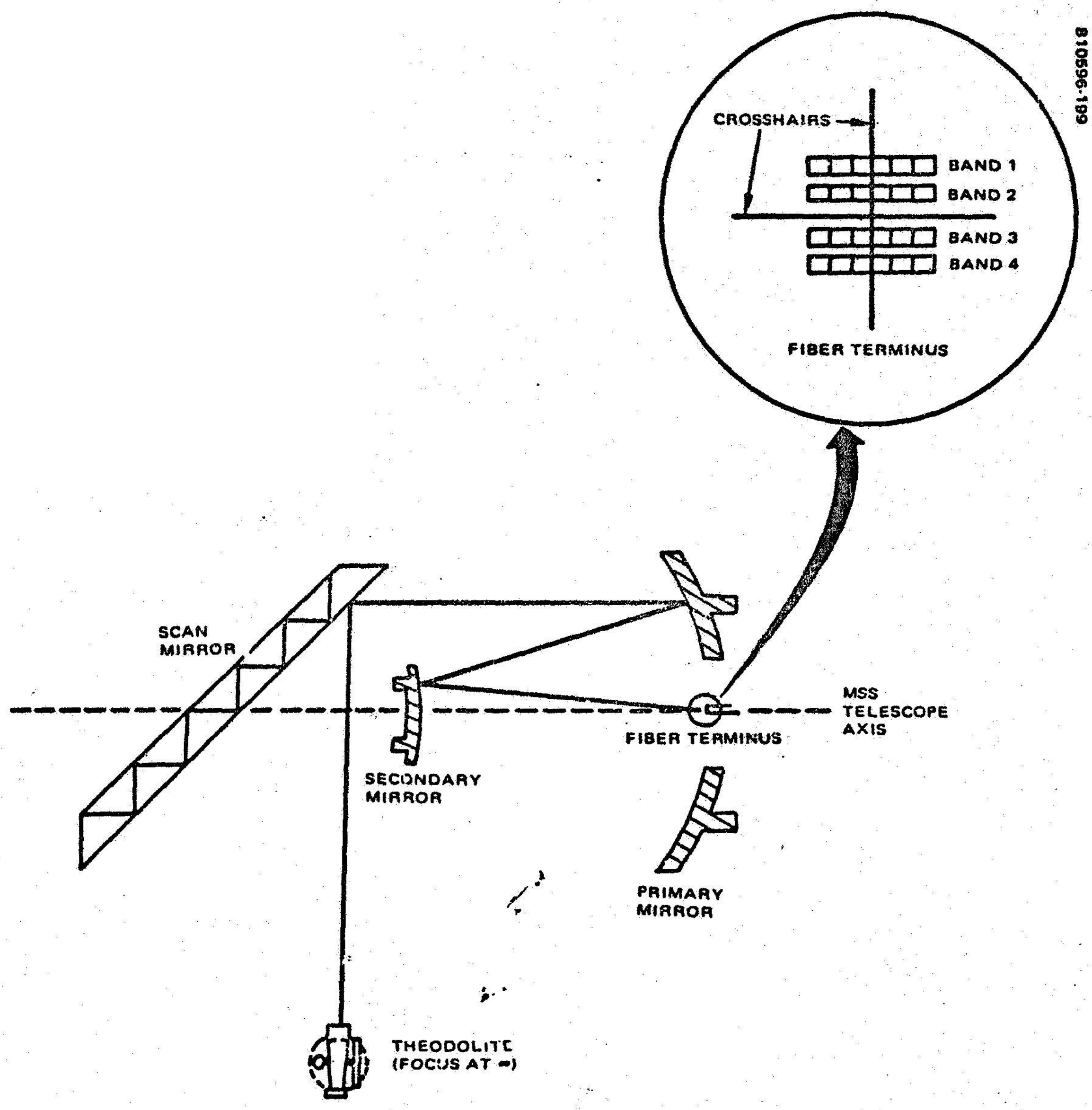

FIGURE II-4-1. SCANNER LINE OF SIGHT MEASUREMENT

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Since the scanner is focused at infinity, the theodolite telescope is also focused at infinity, as is the case when it is used for autocollimation measurements for alignment cube orientation.

4.2 SCANNER LINE OF SIGHT ORIENTATION RELATIVE TO SCANNER MOUNTING SURFACE

The orientation of the MSS-D scanner LOS relative to the SMS is measured in a manner analogous to the measurement of the drill fixture alignment cube orientation with respect to the SMS orientation.

Initially the orientation of the SMS is established using the TM and the line connecting pins A and B. Then the scanner is bolted to the scanner mounting plate.

When the scanner is mounted on the angle plate, angles α_ε, β_ε, and γ_ε describe the orientation of the scanner LOS coordinate system to the system of orthogonal axes established by the normal to the TM and the line connecting pins A and B on the SMS of the angle plate.

This relationship is illustrated in Figure II-4-2. For clarity the MSS is depicted behind the SMS but in the same orientation as when it is mounted on the SMS.

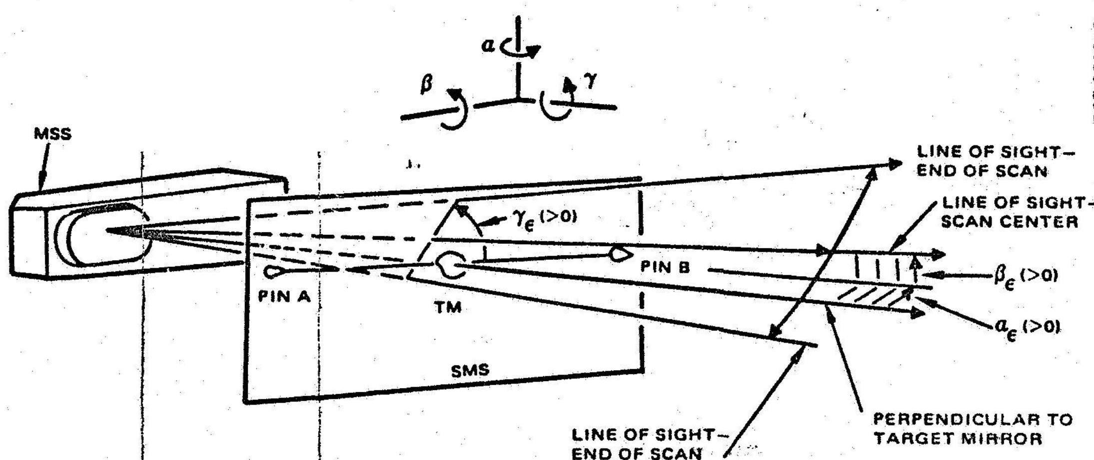

FIGURE II-4-2. SCANNER LINE OF SIGHT TO SCANNER MOUNTING SURFACE

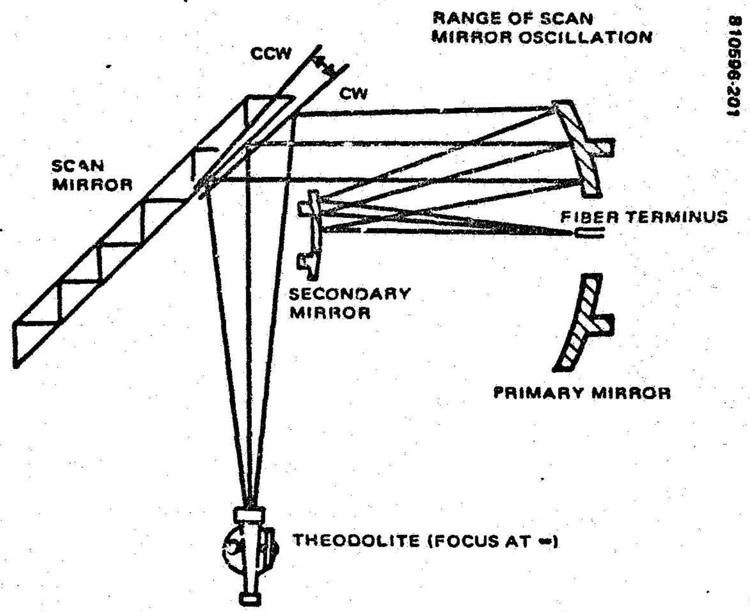

FIGURE II-4-3. TECHNIQUE FOR MEASURING γ_ϵ

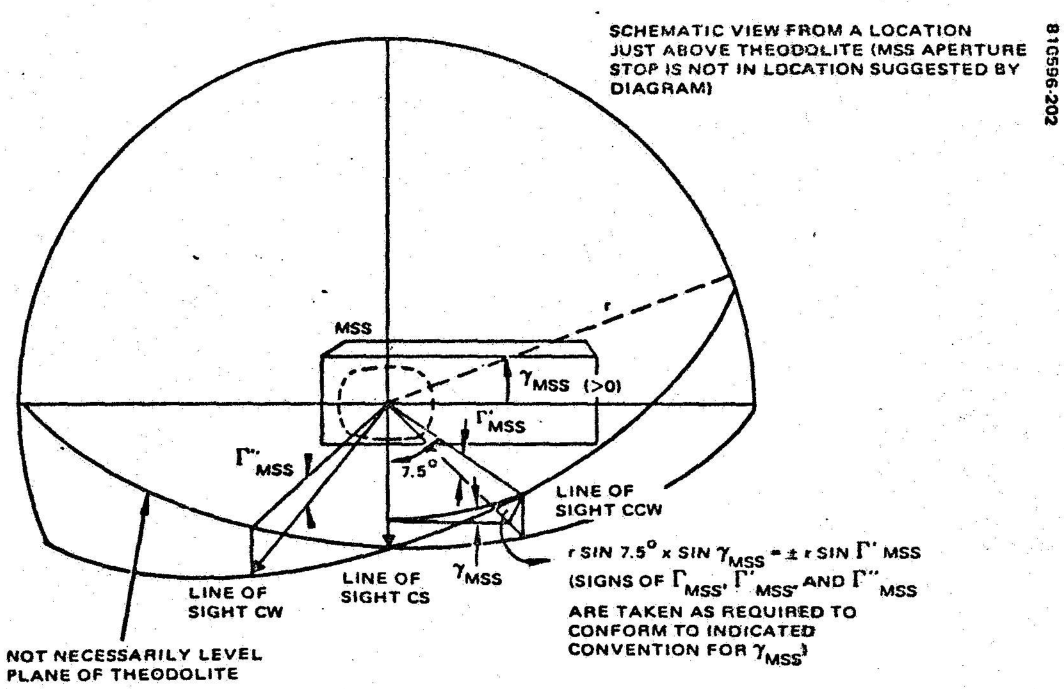

FIGURE II-4-4. MEASUREMENT OF γ_{MSS}

4.3 SCANNER LOS MEASUREMENT TECHNIQUES

With the MSS-D scanner mounted on the SMS the angles α_ε, β_ε, and γ_ε are measured in the following manner. With the scan mirror locked at scan center the theodolite telescope is focused on the center of the fiber optics focal plane array (field stop center). The angles α_ε and β_ε are obtained from the differences between corresponding angles (α and β) measured with the theodolite for the MSS-D PF LOS and the TM normal. The angles for the TM normal must be measured prior to mounting the scanner on the angle plate.

The method of measuring γ_ε is illustrated in Figure II-4-3. As the figure indicates, measurement of γ_ε involves not only focusing on the array center when the scan mirror is in the center scan lock position, but also measuring the altitude and azimuth of the array center when the scan mirror is against the scan bumper at each end of scan. Figure II-4-3 shows these cases as seen from above. CCW is the case when the scan mirror is fully counterclockwise against the bumper, and CW is the case when the scan mirror is fully clockwise against the opposite bumper. Figure II-4-4 illustrates the relationship of the measured angles for the purposes of establishing the value of γ_ε, the orientation of the scan plane.

In Figure II-4-4, γ_{MSS} designates the orientation of the scan plane relative to theodolite coordinates and not with respect to the SMS. If the superscript "T" represents a theodolite scale reading, then the angles indicated can be defined in the following manner:

1) $\Gamma'_{MSS} = \Gamma^T_{MSS}(CCW) - \Gamma^T_{MSS}(CS)$

2) $\Gamma''_{MSS} = \Gamma^T_{MSS}(CS) - \Gamma^T_{MSS}(CW)$

3) $\Gamma_{MSS} = \Gamma^T_{MSS}(CCW) - \Gamma^T_{MSS}(CW)$

where CCW, CS, and CW designate measurements made when at the counter clockwise, center scan, and clockwise positions respectively.

Γ_{MSS}, Γ'_{MSS} and Γ''_{MSS} are each individual measurements of differential elevation used to compute γ_{MSS} from the following relation for Γ' and similar relationships for Γ'' and Γ:

$$\sin 7.5^\circ \times \sin \gamma_{MSS} = \pm \sin \Gamma'_{MSS}$$

If the angles Γ'_{MSS} and γ_{MSS} are small, $\sin \Gamma'_{MSS} \approx \Gamma'_{MSS}$ and $\sin \gamma_{MSS} \approx \gamma_{MSS}$

then

$$\gamma_{MSS} = \pm \frac{\Gamma'_{MSS}}{\sin 7.5^\circ}$$

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OF POOR QUALITY

The value of γ_{MSS} used is that gotten from taking the mean of the three estimates, $\bar{\gamma}_{MSS}$. When referred to the SMS $\bar{\gamma}_{MSS}$ becomes γ_ε through the relationship:

$$\gamma_\varepsilon = \bar{\gamma}_{MSS} - \gamma_o$$

4.4 SCANNER ALIGNMENT CUBE ORIENTATION RELATIVE TO SCANNER LINE OF SIGHT

An alignment cube is mounted on the MSS-D scanner to serve as a reference for alignment of the scanner on the spacecraft. This measurement provides the information that gives the angular orientation of the orthogonal coordinates associated with the cube with respect to the orthogonal reference defined by the MSS-D scan plane and the center scan LOS, as described in the previous sections.

Measurements by autocollimation through the cube are performed in a manner identical with that done for the drill fixture alignment cube, but are referred to the measurements of the scanner LOS (described in the previous section) rather than to the SMS orientation

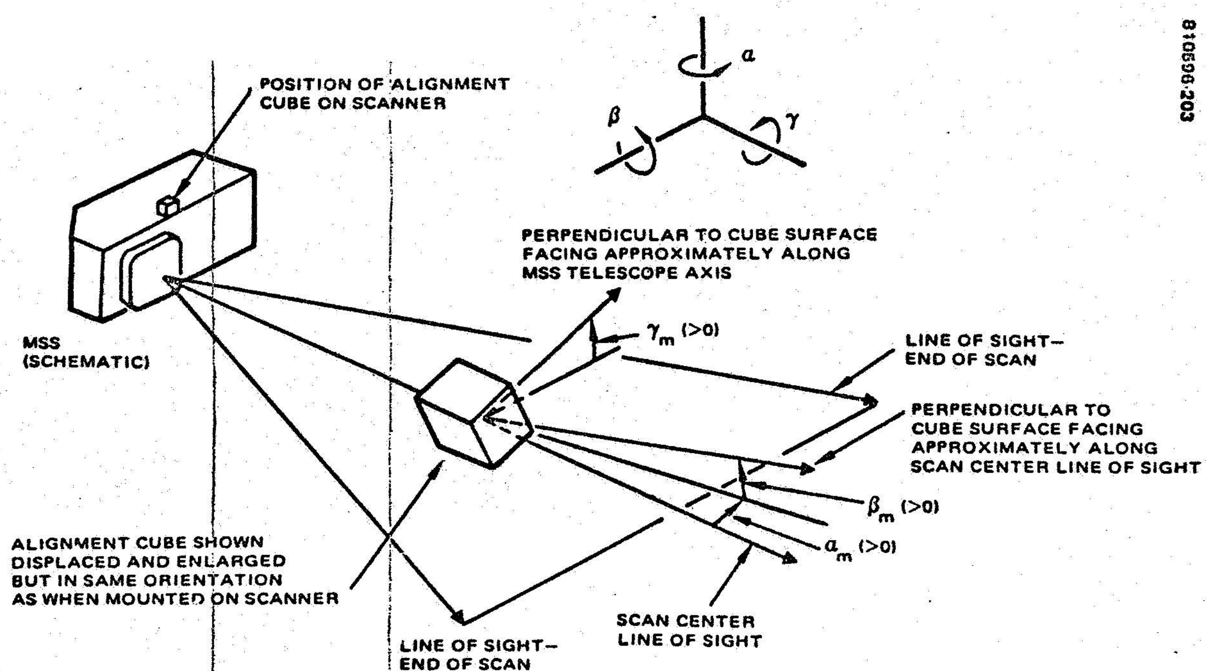

FIGURE II-4-5. SCANNER ALIGNMENT CUBE ORIENTATION RELATIVE TO SCANNER LINE OF SIGHT

Since it is not possible with the theodolite telescope to sight on the focal plane fiber array termination and autocollimator through the scanner alignment cube from the same location, the theodolite must be moved after the coordinates of the scanner LOS have been established. This can be done without serious degradation in measurement accuracy as long as the caveats of Section 2 (i.e., re-leveling and maintaining reference) are observed.

α_{AC} and β_{AC} are derived from the theodolite azimuth and elevation readings of the scanner alignment cube for the surface that faces in about the same direction as the MSS scan center LOS. To obtain a measurement of γ_{AC}, the theodolite is moved to view and autocollimate on the alignment cube at the scan mirror end of the MSS.

α_m, β_m, and γ_m are the angles which the cube axes make with the scanner LOS as illustrated in Figure II-4-5. They are obtained by subtracting out corresponding angles for the LOS.

4.5 MSS-D SCANNER ALIGNMENT RESULTS

A time history of the results of the measurements of (α_ε, β_ε, γ_ε) and (α_m, β_m, γ_m) are given in Table II-4-1. The dates on which the measurements were made are given at the top of each column. Comments on any special condition which may be significant to the measurement results are listed at the bottom.

As is evident from the closeness and repeatability of the measured values the alignment more than meets the specification for accuracies to within 0.03°.

The requirement for orthogonality of the scanner LOS to the mounting surface of less than 0.25° is given by:

$$\sqrt{\alpha_\varepsilon^2 + \beta_\varepsilon^2} < 0.25^\circ$$

4.5.1 Summary of Angle Definitions

For ease of reference to the numbers in Table II-4-1 the following list of Summary Definitions is provided.

(α_m, β_m, γ_m) $\triangleq$ orientation of the scanner alignment cube with respect to orthogonal axes established by the scanner LOS (at scan center) and the scan plane of the LOS.

(α_ε, β_ε, γ_ε) $\triangleq$ orientation of the scanner LOS to the orthogonal axes established by the normal to the TM and the direction converting pins A and B on the mounting surface (angle plate).

(α_d, β_d, γ_d) $\triangleq$ orientation of the drill fixture alignment cube with respect to orthogonal axes established by the normal to the TM and the lines connecting pins A and B on the SMS.

TABLE II-4-1. MSS-D (F-1) ALIGNMENT HISTORY

	Performance	Requirement
• Line-of-sight perpendicular to mounting surface, $\sqrt{\alpha_E^2 + \beta_E^2}$ =	0.013°	≤0.25°
• Line-of-sight pointing measurement	(Probable error) 0.01°	≤0.03°

	Preacoustic	Post-Acoustic	Post-Vibration	New Flex Pivots Installed	Post-TV	Post-Penalty Acoustic
	7/22/81	8/18/81	8/28/81		9/30/81	10/8/81
α_E	-0° 0' 51"	-0° 0' 38"	-0° 0' 58"		0° 0' 26"	0° 0' 44"
β_E	-0° 0' 31"	-0° 0' 34"	-0° 0' 44"		-0° 0' 32"	-0° 0' 20"
γ_E	0° 0' 27"	0° 0' 28"	-0° 0' 14"		0° 0' 33"	0° 0' 18"
α_m	0° 1' 54"	0° 1' 51"	0° 1' 41"		-0° 0' 4"	-0° 0' 14"
β_m	0° 2' 14"	0° 2' 0"	0° 1' 34"		0° 2' 27"	0° 1' 59"
γ_m	0° 12' 50"	0° 12' 50"	0° 12' 40"		0° 12' 0"	0° 11' 55"

END
DATE
AUG. 11, 1983