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Dual Frequency Feed System for the CTS

Commications Link Characterization

Experiment

Alpha

WOBURN, MASSACHUSETTS 01801

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16. Abstract

This final report describes the developing, testing and installation of a dual frequency feed assembly which is to be used to modify the existing 15 foot antenna at Rosman, N. C. for CTS Communications experiments.

This feed has been designed to receive signals in the frequency range 11. 7 to 12. 2 GHz and transmit signals in the frequency range 14.12 GHz $\pm$ 250 MHz. Complete performance data of the feed alone and installed in the 15 foot antenna is included herein. Drawings and descriptive information of the feed assembly are also given in this report.

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1.0 INTRODUCTION

This final report describes a dual frequency feed system with a remote polarization positioner which will simultaneously receive signals in the 11.7 to 12.2 GHz frequency range while transmitting orthogonally polarized signals in the 14.120 $\pm$ 0.250 GHz frequency range. This feed was developed as part of the modification of the existing 15 foot Cassegrain antenna at the NASA Tracking Station, Rosman, N. C. for the CTS communications Link Characterization Experiment. The feed development was performed by the TRG Division of Alpha Industries under contract number NAS5-22398 for NASA, Goddard Space Flight Center.

This report describes the physical configuration of the feed assembly, its installation in the fifteen foot antenna, the feed electrical performance values (measurements compared with specification values) and electrical performance with the fifteen foot antenna.

2.0 DESCRIPTION

The mechanical features of the feed assembly and its relationship to the fifteen foot antenna are described in the drawings of Appendix I.

D 60046700	Dual Frequency Feed Assembly
D 60046800	Dual Frequency Feed Outline
D 60056000	Dual Frequency Feed Installation
C 60078900	Polarization Control Schematic

Referring to the Assembly Drawing (D 60046700), the major RF components are listed below:

Find Nos.	Description
(2) (3) (4) (5)	Scalar Feed Horn Assembly
(14)	Orthomode Transducer Assembly
(17) (22)	Transmitter Rotary Joint
(18) (21) (24)	Receiver Rotary Joint
(16) (25)	Receiver Filter Assembly
(9)	Waveguide Assembly

The major mechanical parts of the feed assembly are:

Find Nos.	Description
(1) (8) (19) (23) (15)	Feed Assembly Housing
(10) (11) (27)	Gear Motor Assembly
(12) (11) (28)	Potentiometer Assembly
(39)	Microswitches
(6) (7) (13)	Forward Bearing Assembly
(6) (7) (21)	Rear Bearing Assembly

The purpose of all these items is apparent when we consider the functions which the feed assembly must provide. As the title implies, this is a dual frequency system. Therefore, two channels are required as shown in the drawings. (The two external waveguide ports are designated in drawings D-60046800 and D-60056000).

Much of the complexity of the feed assembly is due to the remote polarization implementation. The external waveguide connections to the receiver and transmitter remain stationary with the fifteen foot antenna. The feed polarizations must be rotated about the central axis of the feed assembly to align them with the satellite polarization. Therefore, the feed waveguides and components must rotate with the feed horn. The transmitter and receiver rotary joints provide the junction between the rotating feed components and the fixed waveguide connections to the transmitter and receiver. The feed rotation is accomplished by the gear motor on the housing face plate. Polarization position information is determined by the orientation of the potentiometer which is mechanically slaved to the motor and feed. This information is fed back electronically to the polarization positioner panel in the terminal equipment. Two limit switches are also included in the polarization mechanism to limit the feed rotational range and protect the feed assembly waveguides. Note that the two tandem rotary joints and the position of the external waveguides limit the rotational excursion of the feed assembly to approximately 200°. A schematic diagram, showing the electrical connection of these devices is included in Appendix I (C-60078900). The electrical interconnections between the feed assembly and the polarization control panel were made in conformance with Martin Marietta Corporation drawings D SK-ATSG-224.

The prime objective of this program was to provide a polarization insensitive feed horn to efficiently illuminate the fifteen foot Cassegrain antenna with specified illumination characteristics and minimum beam spreading over the total frequency range. The TRG patented* Scalar feed horn is ideally suited for this purpose. Reactive corrugations in the walls of the Scalar feed reduce radiation in the E-Plane in the vicinity of the walls so that the E-Plane radiation is almost identical to that of the H-Plane at the horn aperture. This results in some excellent radiation characteristics including the required polarization insensivity. In order to achieve the specification illumination with the horn over the frequency range, careful control must be exercised in the design so that the phase deviation in the aperture field partially compensates for the beam narrowing at the higher frequencies (transmitter band). The measured feed performance is described in Section 4.0 of this report.

*Patent Numbers 3, 216, 018 and 3, 274, 603.

The Scalar feed horn, as indicated previously, supports both the transmitter and receiver frequencies. These signal frequencies are combined (or separated) in the orthomode transducer by means of polarization orthogonality and frequency diplexing. The circular waveguide section connecting the orthomode transducer to the Scalar feed horn and the horn itself are both polarization insensitive and hence support two orthogonally polarized TE_{11} modes in the transmitter and receiver bands. The transmitter signals enter through the exterior waveguide port, pass through the rotary joint and are converted by a mode transition just before the orthomode junction from a TE_{10} to TE_{11} mode. The transmitter signals, now propagating in the TE_{11} mode in the orthomode transducer, are transmitted out through the Scalar horn with a minimum amount of leakage into the receiver channel (-40 dB). The low level transmitter leakage is further attenuated by the filter in the receiver channel so that the net transmitter power level is attenuated by more than 75 dB before arriving at the receiver. Incoming signals in the 11.7 to 12.2 GHz range are captured by the feed horn and converted to TE_{11} modes. These signals arrive at the orthomode junction and are coupled out the side port in a TE_{10} mode into the receiver channel. The signals then pass through the filter and rotary joint with minimum loss and onto the receiver.

3.0 INSTALLATION, OPERATION AND MAINTENANCE

3.1 Installation

The feed assembly has been designed for ease of installation and maintenance. Reference to the installation drawing (D-60056000) in Appendix I will aid the installation procedure given below:

1.) Loosen the eight set screws on the forward removable mounting flange which bind it to the feed cylinder.

2.) Remove the flange by sliding it up over the cylinder and feed horn.

3.) Insert feed assembly into the center hole of the existing fifteen foot antenna until rear mounting flange mates with antenna bolt holes. Attach feed assembly with the eight sets of hardware (#4, 5 and 6 on parts list).

4.) Remove feed cone assembly.

5.) Replace the forward removable mounting flange over feed and cylinder and align the four mounting holes with those at the vertex of the fifteen foot antenna.

6.) Fasten this flange with the four sets of hardware (#3, 7 and 8 on parts list).

7.) Tighten the eight set screws to bind the flange to the feed cylinder.

8.) Replace the feed cone and tighten all bolts.

9.) Connect polarization plug to recepticle at rear of feed assembly.

10.) Connect air pressure hose to air valve at rear of feed assembly and apply air pressure ($\approx$ 1 to 3 p.s.i.g.)

Notes:

a.) The polarization positioning mechanism has been checked by TRG to insure proper operation with the controller per Martin Marietta Corp. drawing D SK-ATSG-224. In the present configuration, the two limit switches ensure the safe travel limit of the rotary mechanism.

CAUTION:

If any wiring changes are made within the feed assembly or in the controller which changes the operation of the limit, SEVERE DAMAGE could result in the feed assembly because of the high gear ratio in the motor drive assembly. If any malfunction should occur with this circuitry, such as a short circuit across one of the limit switch, the circuit should be checked out immediately. An observer should watch the waveguide travel to ensure proper operation of the limit switches before normal operation of the polarization controller is resumed.

b.) One variation may be made in the above procedure to ease the installation. The horn assembly may be removed by disconnecting the small flange at the end of the cylindrical housing before Step 3. The horn assembly should then be replaced after Step 7.

CAUTION:

Do not loosen the potted screws on the other flanges nor the potted tuning screws or the electrical characteristics of the feed assembly will be altered.

c.) The rear mounting flange of the feed assembly has a gasket which is permanently attached, (Item #9 of TRG drawing # 60056000). If the mating mounting surface at the rear of the fifteen foot antenna is clean and flat, the feed mounting flange will form a good weather seal with it. The feed assembly will then be completely sealed when the feed cone is installed with a similar gasket and the external waveguides are connnected with suitable seals.

3.2 Operation and Maintenance

The feed assembly will not require any periodic maintenance. All of the components, especially the rotating sections, have been selected for high reliability and long life expectancy. The most vulnerable parts are, of course, the bearings which are doubly sealed and self-lubricated. The motor is rated for approximately 5000 hours of continuous duty which will insure at least 10 years of operation for this application. The potentiometer and limit switches have comparable life spans. All of the RF components, with the exception of the rotary joints*, are passive devices and hence will require no maintenance. Reasonable care should be taken, however, to ensure that foreign matter, dust or water do not get into the feed assembly. This can be assured if the feed assembly is properly sealed as above and the dry air is constantly maintained. If the feed cone is removed for any long period, the feed should be protected with a temporary cover such as a plastic bag. If any water should enter the feed, the following procedure should be followed:

1.) Remove as much water as possible by appropriately tilting feed assembly with external waveguides disconnected.

    CAUTION:

    Do not disconnect any internal waveguides in the feed assembly.

2.) Allow remaining water to evaporate in a warm dry environment.

3.) External heating may be applied, but it should not exceed 150°F.

*The rotary joints each have two bearings. Like the bearings on the drive assembly, these are doubly sealed and self-lubricated and, therefore, have a long life expectancy.

4.0 MEASURED PERFORMANCE

4.1 Feed Assembly

Radiation patterns and transmission line measurements were made on the feed assembly at the TRG facilities in Woburn, Mass. to determine its performance characteristics over the transmitter and receiver bands. A summary of the complete feed electrical performance characteristics as compared with specification values is given in Figure 1. Feed radiation patterns number 1 through 4 are shown in Appendix II. These are respectively the principle E and H-Planes at 11.7 GHz and the principle E and H-Planes at 14.12 GHz. The measured transmission line characteristics (VSWR, insertion loss and isolation) of the feed assembly are given in Figures 2 and 3 for the respective transmitter and receiver bands. Note that the isolation given in Figure 2 is the sum of the isolations of the orthomode transducer (-50 dB average in Figure 4) and the bandpass filter (-41 dB average is Figure 5) in the transmitter frequency range (14.1 GHz). Measured transmission line characteristics for the individual components (orthomode-transducer, bandpass filter, receiver rotary joint and transmitter rotary joint) are tabulated in Figure 4, 5, 6 and 7.

Reference to Figure 1 indicates that all of the measured performance values have been achieved well within the specification limits. The average ten dB beamwidths in each band are 31° to 36° at 14.12 and 11.7 GHz. No tolerance was given in the contract specification for the beamwidths and their relationship to the overall efficiency and gain of the fifteen foot antenna was not established. We have established this relationship by integrating the measured feed radiation patterns on a computer to predict the efficiency factors and gain. The results are shown in a later section of this report.

SUMMARY OF ELECTRICAL PERFORMANCE

CHARACTERISTICS FOR DUAL FREQUENCY

FEED SYSTEM (12-14 GHz)

PARAMETER	SPECIFICATION LIMIT	MEASURED VALUE
Frequency	14.120 $\pm$ 0.250GHz (Tx) 11.7 TO 12.2GHz (Rec.)	14.120$\pm$0.250GHz (Tz) 11.7 TO 12.2GHz(Rec.)
10dB Beamwidths	32° at 14.120 GHz	E-Plane H-Plane 30.9° 31.0°
10dB Beamwidths	35° at 11.7 GHz	E-Plane H-Plane 36.3° 35.7°
Polarization	Linear Rotatable $\pm 90^{\circ}$	Linear Rotatable $\pm 100^{\circ}$
Diplexer Configuration	Tapered Mode Transition Plus Orthomode Transition Plus Filter	Tapered Mode Transition Plus Orthomode Transition Plus Filter
Diplexer Isolation:		
Filter Rejection.	40 dB Minimum	40 dB Minimum
OMT Isolation	35 dB Minimum	45 dB Minimum
Total Isolation	75 dB Minimum	85 dB Minimum
Insertion Loss	1.6 dB Maximum 1.0 dB Goal	0.5 dB Maximum 0.4 dB Typical

Figure 1

FINAL TEST DATA FOR

DUAL FREQUENCY, FEED SYSTEM

(12-14 GHz)

THRU-ARM (TRANSMIT-PORT)

Freq. (GHz)	VSWR	Insert. Loss (dB)	Isolation (dB)
13.900	1.22	.28	Greater Than 60
14.000	1.06	.28	Greater Than 60
14.027	1.08	.29	Greater Than 60
14.037	1.14	.28	Greater Than 60
14.052	1.20	.28	Greater Than 60
14.067	1.18	.35	Greater Than 60
14.100	1.18	.36	Greater Than 60
14.200	1.12	.38	Greater Than 60
14.027	1.08	.38	Greater Than 60
14.227	1.10	.28	Greater Than 60
14.242	1.14	.25	Greater Than 60
14.257	1.20	.35	Greater Than 60
14.300	1.15	.35	Greater Than 60
14.370	1.15	.33	Greater Than 60

Figure 2

FINAL TEST DATA FOR

DUAL FREQUENCY, FEED SYSTEM

(12-14 GHz)

SIDE-ARM (RECEIVE - PORT)

Freq, (GHz)	VSWR	Insert. Loss (dB)	Isolation (dB)
11.700	1.13	.48	51.5
11.800	1.20	.51	50.0
11.860	1.10	.52	49.5
11.871	1.12	.45	48.0
11.886	1.13	.30	49.0
11.900	1.15	.32	48.0
11.901	1.15	.32	48.0
12.000	1.19	.40	49.5
12.040	1.25	.42	49.5
12.066	1.15	.42	51.0
12.081	1.14	.42	51.5
12.096	1.15	.45	51.0
12.100	1.20	.40	52.5
12.200	1.15	.40	53.0

Figure 3

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DUAL FREQUENCY

ORTHOMODE TRANSDUCER

WITH SCALAR FEED - ONLY

FREQ. (GHz)	VSWR	ISOLATION (dB)	FREQ. (GHz)	VSWR	ISOLATION (db)
11.7	1.12	50	13.87	1.02	48
			13.90	1.02	50
11.8	1.06	50	14.00	1.08	51
11.9	1.10	48	14.10	1.08	49
12.0	1.03	48	14.20	1.05	52
12.1	1.08	47	14.30	1.06	50
			14.37	1.02	48
12.2	1.08	47	14.40	1.02	50

FIGURE 4

PASS BAND FILTER

POINT INSERTION LOSS

DATA

FREQ. (GHz)	INSERTION LOSS (dB)
11.00	46.9
11.45	14.6
11.70	0.2
11.95	0.2
12.20	0.2
12.70	22.8
13.30	36.7
13.90	41.2
14.10	41.2
14.37	40.8

FIGURE 5

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RECEIVER

BAND ROTARY JOINT

FREQ. (GHz)	VSWR	INSERTION LOSS (dB)
11.7	1.05/1.06	$\angle$ 0.1 dB
11.8	1.04/1.05	0.1
11.9	1.04/1.05	0.1
12.0	1.03/1.04	0.1
12.1	1.05/1.06	0.1
12.2	1.05/1.06	$\angle$ 0.1 dB

FIGURE 6

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TRANSMITTER

BAND ROTARY JOINT

FREQ. (GHz)	VSWR	INSERTION LOSS (dB)
13.87	1.04/1.05	0.1 dB
14.00	1.03/1.04	0.1
14.10	1.02/1.03	0.1
14.20	1.02/1.03	0.1
14.30	1.02/1.03	0.1
14.40	1.03/1.04	0.1 dB

FIGURE 7

More extensive radiation measurements were made with the feed horn at the NASA, Goddard facilities. Pattern numbers 5 through 18 in Appendix II are the measured feed amplitude radiation characteristics. Numbers 5, 6, 12 and 13 are the same conditions as numbers 1 through 4 taken at TRG in Woburn, Mass. There is very good correlation between the two sets of measurements. Numbers 7 and 14 are composite E and H-Plane patterns at 14.12 and 11.7 GHz respectively to demonstrate the circular symmetry of the scalar feed. Numbers 8/9 and numbers 5/16 are expanded amplitude cuts to demonstrate the low level wide angle radiation of the scalar feed horn at the respective transmitter and receiver bands. E and H-Plane cross-polarized levels are shown in numbers 10/11 and numbers 17/18 for the respective transmitter and receiver bands.

Phase measurements were also made at the NASA, Goddard facilities. (See pattern numbers 19 to 22 in Appendix II). These patterns were measured over $\pm 60^{\circ}$. Large perturbations exist in the regions from 30° to 60° which correspond to the sidelobe regions and diffraction from the edges of the horn. These perturbations are negligible since they are well outside of the illumination area of the subreflector ($\pm 15^{\circ}$). Within this illumination area, the maximum phase deviation from linear is less than 20° which corresponds to 0.05λ. Reference 1 gives the relationship between phase error at the edge of an aperture to overall antenna efficiency and corresponding gain loss. This relationship for phase error efficiency (N_{Δ}) is given in the illustration below for the worst case with uniform illumination:

$$N_{\Delta} = \left[\frac{\sin\left(\frac{\Delta}{2}\right)}{\frac{\Delta}{2}} \right]^2$$

Where: Δ is the magnitude of the phase error in radians at the edge of the aperture.

Using the phase error value determined above, the resulting phase error efficiency is 0.99 (99%).

The major efficiency factors which effect the overall antenna gain are the aperture distribution due to the feed illumination (Na) and the spillover radiation from the feed (Nsp). These values have been determined by integration of the feed radiation patterns #1 to 18 on a digital computer according to the well known expression given below. Reference 2 and 3.

$$N_F = \mathrm{Cot}^2\left(\frac{\Psi}{2}\right) G_{of} \left| \int_0^{\Psi} \frac{E_E(\Psi) + E_H(\Psi)}{2} \tan\left(\frac{\Psi}{2}\right) d\Psi \right|^2$$

Where: N_F is the total feed efficiency (=Na· Nsp)

Ψ is the feed pattern angle

$E_E(\Psi)$ and $E_H(\Psi)$ are the feed E and H plane radiation patterns.

G_{of} is the feed gain.

The results are tabulated in Figures 8 and 9 for the respective transmitter (14.12 GHz) and receiver (11.7 GHz) bands. These feed efficiency factors along with efficiency losses due to the fifteen foot Cassegrain antenna are tabulated in Figure 10. The net efficiency for the transmitter and receiver bands are 54.9% and 54.5% respectively. These values are related to the overall Cassegrain antenna gain by the following expression:

$$\mathrm{Gain} = N_T \left(\frac{\pi D}{\lambda}\right)^2$$

Where: $N_T = N_\phi \cdot N_a \cdot N_{sp} \cdot N_b \cdot N_{rms} \cdot N_d \cdot N_x \cdot N_e \cdot N_v$

(efficiency values expressed as fractions)

D = Diameter of Cassegrain main reflector

λ = Wavelength at operating frequency

14.12 GHz

GJGAIN 17:52 MON. 02-02-76

Z= 25 I= 26
TOTAL AREA= .928809 DIRECTIVITY= 20.912 DB
DIR= 123.375

THETA	AMPEDBI	PERCENT POWER
1	0	96.3162
3	-.174926	86.0521
5	-.649705	71.3275
7	-1.49883	54.9822
9	-2.69537	39.8725
11	-4.44276	27.7606
13	-6.38154	18.7094
15	-8.42664	12.4641
17	-10.9437	8.57181
19	-13.6468	6.15038
21	-15.8672	4.48476
23	-17.6265	3.22877
25	-19.0013	2.25204
27	-20.5151	1.52352
29	-22.2013	1.02329
31	-24.4853	.725988
33	-27.4432	.569017
35	-30.5778	.465925
37	-31.0012	.365883
39	-31.2494	.269759
41	-31.7471	.182502
43	-32.467	.110188
45	-33.7852	5.45946E-02
47	-35.0583	1.53315E-02
49	-37.2893	8.36328E-05
51	-59.9994	0

Spillover

8.57%

Spillover .9143 (N_{sp})

Amp. Illumination .8202 (N_a)

Total Feed Eff. .7499 $= N_{sp} \cdot N_a$

52.2439 1.16349E-04 .749935

TOTAL FEED EFF = .749935 OR=-1.24975 DB

65 .283667 -5.47186

TIME: 7 SECS.

Figure 8. Transmitter Feed Efficiency

11.7 GHz

GJGAIN 18:01 MON. 02-02-76

Z= 25 I= 26
TOTAL AREA= 1.33869 DIRECTIVITY= 19.3245 DB
DIR= 85.5997

THETA	AMP[DB]	PERCENT POWER
1	0	97.4223
3	-.099999	90.0363
5	-.399996	78.8669
7	-.949702	65.6052
9	-1.84969	51.9777
11	-2.89882	39.3056
13	-4.24737	28.5653
15	-5.79879	19.995
17	$\boxed{-7.44273}$	13.6593
19	-9.58955	9.35825
21	-11.7427	6.51085
23	-14.0427	4.70667
25	-16.4987	3.5538
27	-18.4998	2.72369
29	-19.8495	2.06104
31	-20.9986	1.51788
33	-22.0952	1.07074
35	-23.171	.715993
37	-24.6072	.4585
39	-26.4466	.287755
41	-28.6457	.182046
43	-31.0172	.120063
45	-33.7106	8.22575E-02
47	-35.3722	5.12412E-02
49	-35.567	1.80589E-02
51	-35.0709	0

Spillover

13.65%

Spillover .8635 (N_{sp})
Amp. Illumination .8536 (N_a)
Total Feed Eff. .73705 = $N_{sp} \cdot N_a$

52.2439 1.64812E-04 .737049

$\boxed{\text{TOTAL FEED EFF = .737049}}$ OR=-1.32502 DB

.65 .424482 -3.72137

TIME: 7 SECS.

Figure 9. Receiver Feed Efficiency

Efficiency Factor	Method of Determination	Receiver (12.0GHz)	Transmitter (14.1GI
Aperture Illumination (N_a)	Reference #2 & #3 (Feed pattern	.854	.820
Feed Spillover (N_{sp})	integration of Figures 8 and 9)	.864	.914
Total Feed Efficiency (N_F)	Product of N_a and N_{sp}	(.737)	(.750)
Phase Error Efficiency (N_ϕ)	Reference #1 (Computed from Pattern #19 to #22)	.990	.990
Aperture Blockage (N_b)	Reference #4 ($\frac{d}{D} \approx 0.1$) (Subreflector and Spars)	.886	.886
Reflector Surface Accuracy (N_{rms})	Reference #1 (.020 RMS)	.933	.923
Edge Diffraction (N_d)	Reference #1 (Figure 6.)	.920	.920
Cross Polarization (N_x)	Reference #1 (Estimated)	.995	.995
Ohmic Loss Eff. (N_e)	(Estimated)	.999	.999
VSWR Efficiency (N_v)	Reference #1 (VSWR = 1.25)	.988	.988
Net Efficiency	Product of the above	.545 (54.5%)	.549 (54.9%)

FIGURE 10.

Efficiency Factors for 15 Foot Cassegrain Antenna

From these values, the gain of the Cassegrain antenna was computed to be 54.0 dBi and 52.6 dBi respectively at 14.12 and 11.7 GHz. The net gain at the antenna external wave guide ports is determined by subtracting the feed assembly losses of 0.4 dB (transmitter) and 0.5 dB receiver (see Figures 2 and 3). Including these values, the net gain of the Cassegrain antenna at the exterior waveguide ports were determined to be 53.6 dBi and 52.1 dBi respectively at 14.1 and 11.7 GHz.

4.2 Fifteen Foot Cassegrain Antenna

Complete performance values were measured with the feed assembly installed in the Cassegrain antenna at the NASA Tracking Station in Rosman, N. C. The purpose of these tests were to ensure that the TRG feed assembly would operate efficiently with the Cassegrain antenna. Performance values for the Cassegrain antenna were not, however, specified in the TRG feed development program.

The antenna far field distance ($2D^2/\lambda$) at these frequencies is approximately 6000 feet. The choice of "call" towers at Rosman were the "near" tower at 2000 feet and the "Ball Knob Hill" tower at 21,000 feet. Thus, the 21,000 foot range was chosen for the antenna measurements to appreciate the full far field of the Cassegrain antenna. The problem with this selection, as it was later discovered, was that there was severe multipath on this range. The field of view from the transmitter tower to the tracking station was limited by trees and hills. The transmitter antenna was a 36 inch diameter parabolic reflector which produces a beamwidth of approximately 2°. Although this is a narrow beam, it subtends an area of approximately 700 feet square at the tracking station. Therefore, a large portion of the transmitted energy was incident on the trees and hills. Some of this intercepted energy was absorbed, but most of it was scattered. The portion of the energy scattered in the direction of the tracking station competed with the main beam to produce constructive and distructive interference. This multipath phenomenon is fairly well described in Reference 5 and is characterized by a multi-lobed beam, particularly in the elevation plane, because of the strong reflections from the earth. This situation is not as bad in the azimuth plane because the trees and shrubbery tend to be more absorptive and are less dense than the ground.

Because of the large area of the fifteen foot antenna which captures a substantial portion of the beam, these multipath effects tend to be averaged out. Thus, on rotating the antenna to measure patterns, the total captured power density did not change significantly. The multipath had very little effect on the azimuth because of the favorable conditions described above and because the antenna phase center was close to the center of rotation of the antenna. In the elevation plane, however, the unfavorable geometry described above showed a definite evidence of multipath in the radiation patterns. Also, the center of rotation in the elevation plane was displaced behind the phase center of the antenna so that the antenna phase center was moving relative to the ground while measuring elevation patterns. This caused large phase variations between the direct transmitted beam and the ground reflections. The final measured radiation patterns of the complete fifteen foot Cassegrain antenna are shown in Appendix II. Pattern numbers 23 and 24 are the E and H planes at 12.0 GHz; numbers 25 and 26 are the E and H planes at 14.1 GHz. Note the "shoulders" in the beams of pattern numbers 24 and 26 in the elevation plane which indicate the severe multipath problem.

Several attempts were made to measure the antenna gain using the comparision technique with a standard gain horn. The standard gain horn has a relatively small area and hence signals received by it were very susceptable to multipath interference, especially with position variation of the horn. The first attempt to measure gain yielded values which were 2 to 3 dB above the predicted value at 12 GHz and 1dB below the predicted value at 14.1 GHz. A special mounting fixture was then made to position the standard gain horn and the gain measurement was repeated at 12.0 GHz. This resulted in a measured gain of 63.3 dBi which was 11 dB over the predicted value and 8 dB over the theoretical maximum for this antenna. One additional problem which may have contributed to this situation was the weather conditions. High winds and low temperatures (approximately -20^{o}F chill factor) caused the signal source output to fluctuate. Also, the system sensivity was marginal with the signal received by the standard gain horn. At this point, the gain measurements were abandoned. Inspection of the radiation patterns showed that the measured beamwidths were in the expected range and, therefore, the antenna was functioning properly. In order to obtain more meaningful results, we decided to calculate the gain by integrating the measured radiation patterns on a computer. The computed results, shown in Figure 11, yield directive gain values of 55.68 and 54.26 dBi respectively at 14.12 and 12.0 GHz. These values are higher than the values predicted in the previous section because several factors were not included in the pattern integration: feed spillover, aperture blockage, edge diffraction, cross - polarization, VSWR and feed insertion loss. In the previous section, the insertion losses were expressed in dB and subtracted from the computed gain values of 54.0 dBi and 52.6 dBi for the respective transmitter and receiver bands. Omitting these insertion loss values, we determined the net efficiencies of 54.5% and 54.9% as shown in Figure 10. The first four factors described above, corresponding to N_{sp}, N_b, N_d and N_x in the designations of Figure 10, all produce scattered energy which contributes to the wide angle radiation from the antenna. In the pattern measurements, we were not able to measure these wide angle sidelobes because of our limited dynamic range (approximately 33 dB). Therefore, the radiation pattern integration results of Figure 11 only took into account the main beam and first sidelobes. Expressing the directivity values of Figure 11 in efficiency fractions, we have 0.807 and 0.806 for the respective transmitter and receiver bands. These values are products of the factors N_a, N_ϕ, N_{rms} and N_e corresponding to the designations of Figure 10. Multiplying these values by N_{sp}, N_b, N_d, N_x and N_v, we have for the transmitter and receiver bands .558 and .590. From these values, the net antenna gain for the transmitter and receiver, excluding feed losses, are 54.1 and 52.9 dBi.

14,12 GHz

```
GJGAIN     10:12    TUE.    02-03-76

Z= 25          I= 26
TOTAL AREA= 3.09946E-04
DIR= 369715.
```

$\boxed{\texttt{DIRECTIVITY= 55.6781 DB}}$ Eff. = .8074

```
TIME:    5 SECS.
```

a.) 14.12 GHz - Transmitter Port

12,0 GHz

```
GJGAIN     10:25    TUE.    02-03-76

Z= 25          I= 26
TOTAL AREA= 4.29776E-04
DIR= 266631.
```

$\boxed{\texttt{DIRECTIVITY= 54.2585 DB}}$ Eff. = .80613

b.) 12.0 GHz - Receiver Port.

FIGURE 11

Computed Gain for 15 Foot Cassegrain Antenna

Subtracting the feed losses (0.4 and 0.5 dB of Figures 2 and 3), the net gains at the transmitter and receiver external waveguide flanges are 53.7 and 52.4 dBi respectively. These values are within 0.3 dB of the values predicted from the feed radiation properties in the previous section of this report.

The final VSWR measurements were made by personnel at the NASA, Rosmann, N. C. tracking station with the feed installed in the fifteen foot antenna. These results are shown in Figure 12. Comparing these results with the VSWR measured data for the feed alone (Ref. Figures 2 and 3), it can be seen that the VSWR values have increased with the feed assembly installed in the Cassegrain antenna. This is due to the additional reflections of the feed cone and the subreflector. From examination of the test data in Figure 12, particularly the VSWR values of the receive port with and without the feed cone, it appears that both the feed cone and subreflector contribute reflections with an equivalent VSWR of 1.2 back at the feed. These component VSWR's, along with the feed assembly VSWR (≈ 1.2) vary in their relative phase relationships with frequency. The worst case is one in which all of these components are in phase such that the resultant VSWR could be 1.72 (product of all three components). This is almost the case at 12.104 GHz where there is a narrow-band VSWR "spike" of 1.62. This value was reduced to 1.43 by removing the feed cone. Other VSWR reinforcements are seen at 11.7 and 14.1 GHz. At other frequencies, these component VSWR's interfere with each other and partially cancel each other. This is apparent at the freqiencies 11.8, 14.0 and 14.4 GHz in Figure 12.

As seen in Figure 12, the feed cone has a significant effect on the overall VSWR. This is because of the high dielectric constant of the existing teflon fiberglass window material ($\epsilon_r \approx 3$). As seen in the bottom of Figure 12, the effect of the feed cone on the overall antenna VSWR is significant. Thus, by substituting for the existing window, a thin

Teflon window (.010 to .050), significant improvements would be realized in the overall antenna VSWR. Additional improvements in the VSWR may be realized by incorporating a small disk ($\approx$1" diameter) at the center of the subreflector and varying its axial position relative to the feed. Care must be taken so that the radiation patterns and gain of the Cassegrain antenna are not appreciably altered. These procedures were not pursued since they were beyond the scope of the present contract. Also, it was not determined whether a lower antenna VSWR would be required to justify the additional effort described above.

One additional point which was not previously covered was the position of the feed in the Cassegrain antenna. Since the subreflector and main reflector relationships had already been established on previous programs and this relationship was fixed by optical principles, there was no need to disturb this condition. The feed horn had been designed with several waveguide shims so that its axial position could be incrementally changed relative to the subreflector and main reflector. However, the measurement difficulties previously described (i.e., amplitude level fluxuations due to wind and multipath) precluded any decernable measurement changes due to the small effects such as the feed axial positioning. Thus, the feed was positioned with the existing Cassegrain geometry shown previously by the Martin Company. A sketch of the final feed geometry is shown in Figure 13. The center of phase for the feed horn was 2 inches from the horn aperture as determined from the phase measurements (patterns #19 to #22). The final feed aperture position is shown as 24.1 inches from the main reflector vertex which puts the feed phase center at approximately 22 inches as defined in the latest Martin report.

Final V.S.W.R. Measurements For

15 Foot Cassegrain Antenna

Transmit Port

Freq. (GHz)	V.S.W.R.
13.9	1.10
14.0	1.07
14.05	1.05
14.08	1.39
14.10	1.40
14.12	1.18
14.2	1.23
14.3	1.16
14.4	1.11

Receive Port

Freq. (GHz)	V.S.W.R.	*
11.7	1.42	(1.16)
11.8	1.12	(1.12)
11.9	1.36	(1.27)
12.0	1.36	(1.22)
12.0974	1.55	(1.40)
12.1043	1.62	(1.43)
12.1206	1.48	(1.38)
12.1	1.55	(1.45)
12.2	1.36	(1.24)

*Measurements repeated with feed cone removed.

Figure 12

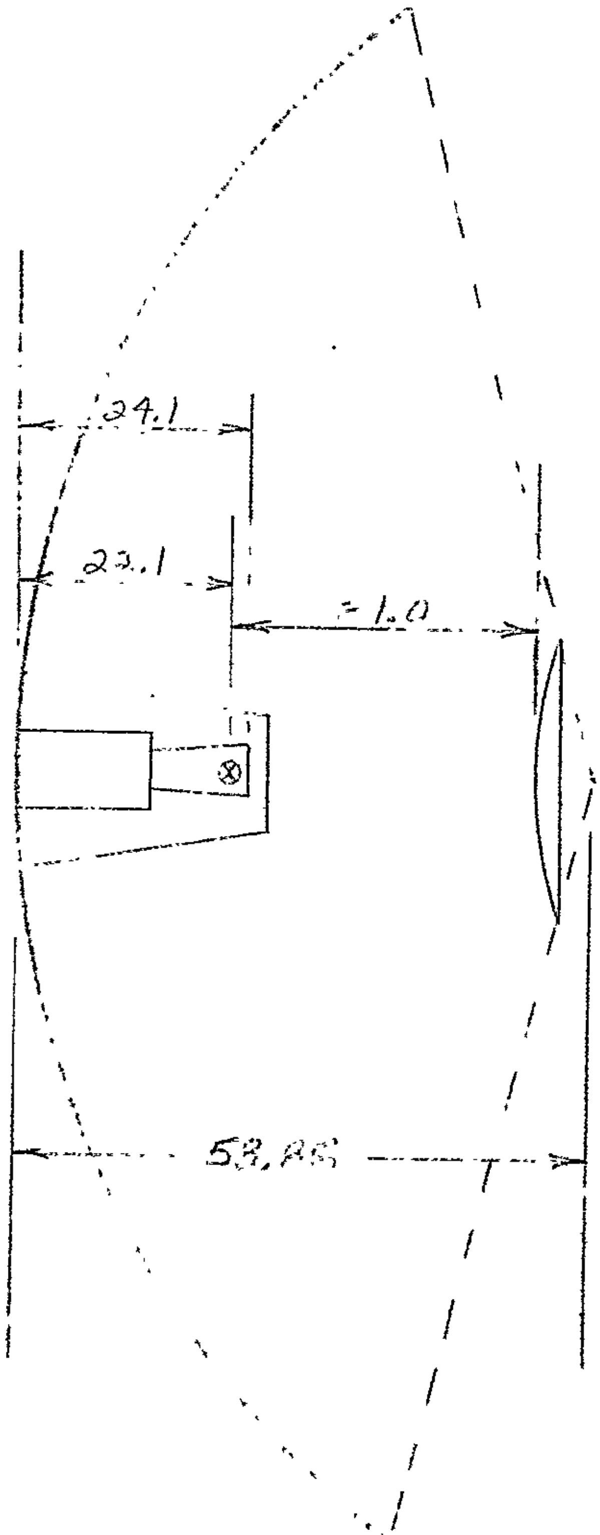

FIGURE 1

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5.0 SUMMARY

A dual frequency feed assembly with a remote polarization positioner was developed under contract number NAS5-22398 for NASA, Goddard Space Flight Center to modify the existing 15 foot Cassegrain antenna at the NASA tracking station, Rosman, N. C. for the CTS Communications Link Characterization experiment. This feed was designed to receive signals in the 11.7 to 12.2 GHz frequency range while simultaneously transmitting orthogonally polarized signals in the 14.120 $\pm$ 0.250 frequency range.

The feed assembly is completely described in Section 2.0 with the referenced drawings in Appendix I. Complete installation and operation instructions are given in Section 3.0. These two sections, along with Appendix I, may be extracted from this report to serve as an Addendum to the Instrumentation Manual. The results of comprehensive feed measurements are described in Section 4.1 with predicted gain values of the full Cassegrain antenna (53.6 dBi at 14.1 GHz and 52.1 dBi at 11.7 GHz). Installation of the feed assembly in the Cassegrain antenna and field tests at the NASA tracking station in Rosman, N. C. are described in Section 4.2. Because of the adverse conditions at the tracking station, it was not possible to obtain reliable gain measurements. Therefore, the measured radiation pattern was integrated by computer to predict the gain of the Cassegrain antenna. This data, with allowances for wide angle scattering which could not be measured, resulted in computed gain values of 53.7 dBi and 52.4 dBi respectively for the transmitter and receiver bands. These results were in very close agreement to the gain values predicted from the feed measurements.

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1.) EIA STANDARD #RS411, "Electrical and Mechanical Characteristics of Antennas for Satellite Earth Stations", Electronic Industries Associations, Washington DC, August, 1973. Appendix I.

2.) S. Silver, "Microwave Antenna Theory and Design", McGraw-Hill Book Co., New York, 1947 Pp. 417-437.

3.) W. Rusch and P. Potter, "Analysis of Reflector Antennas", Academic Press, New York, 1970.

4.) P. Hannan, "Microwave Antennas Derived from the Cassegrain Telescope", IRE Trans. A. P., Pp. 140-153, March, 1961.

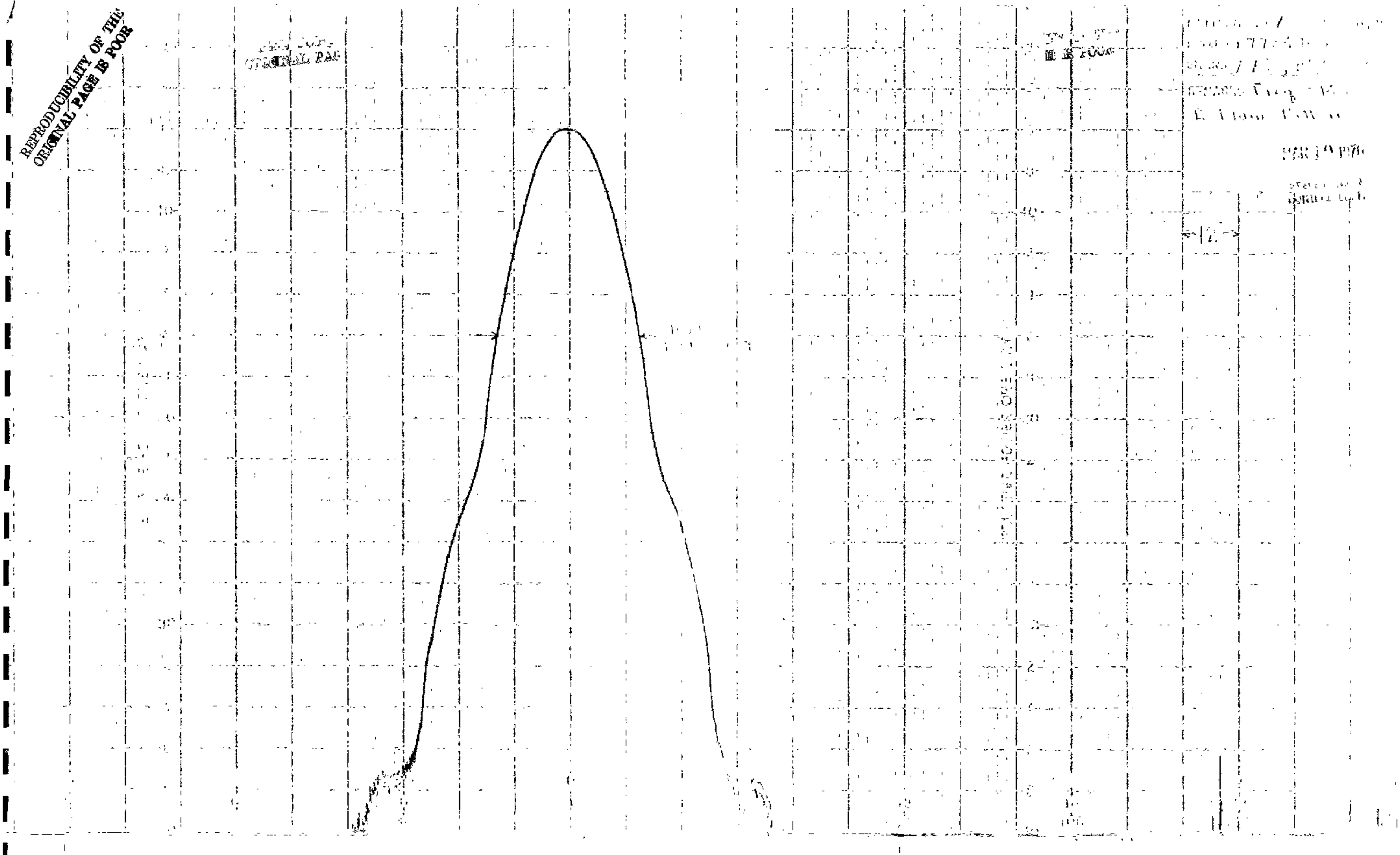
APPENDIX I

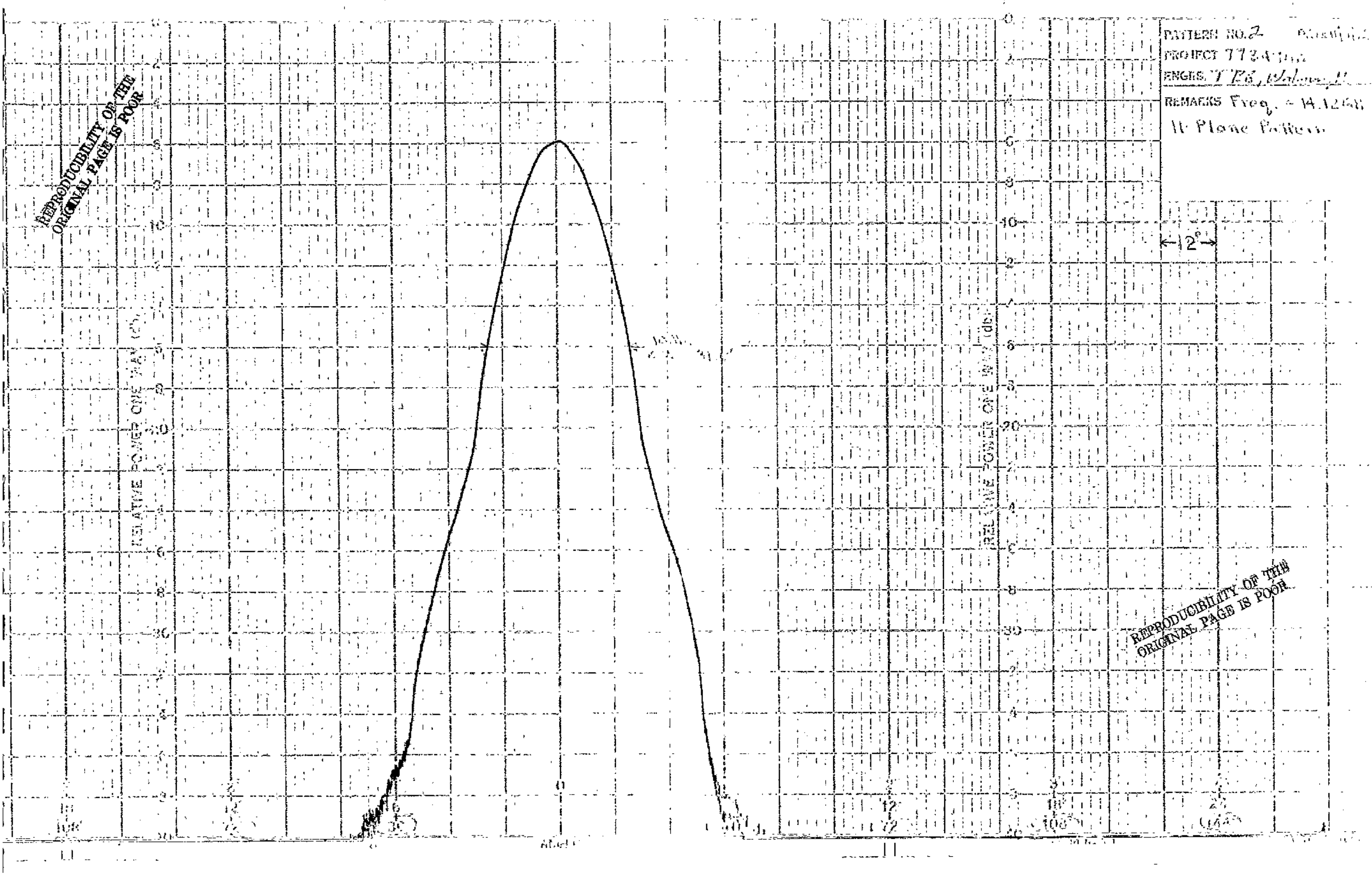
Reference Drawings

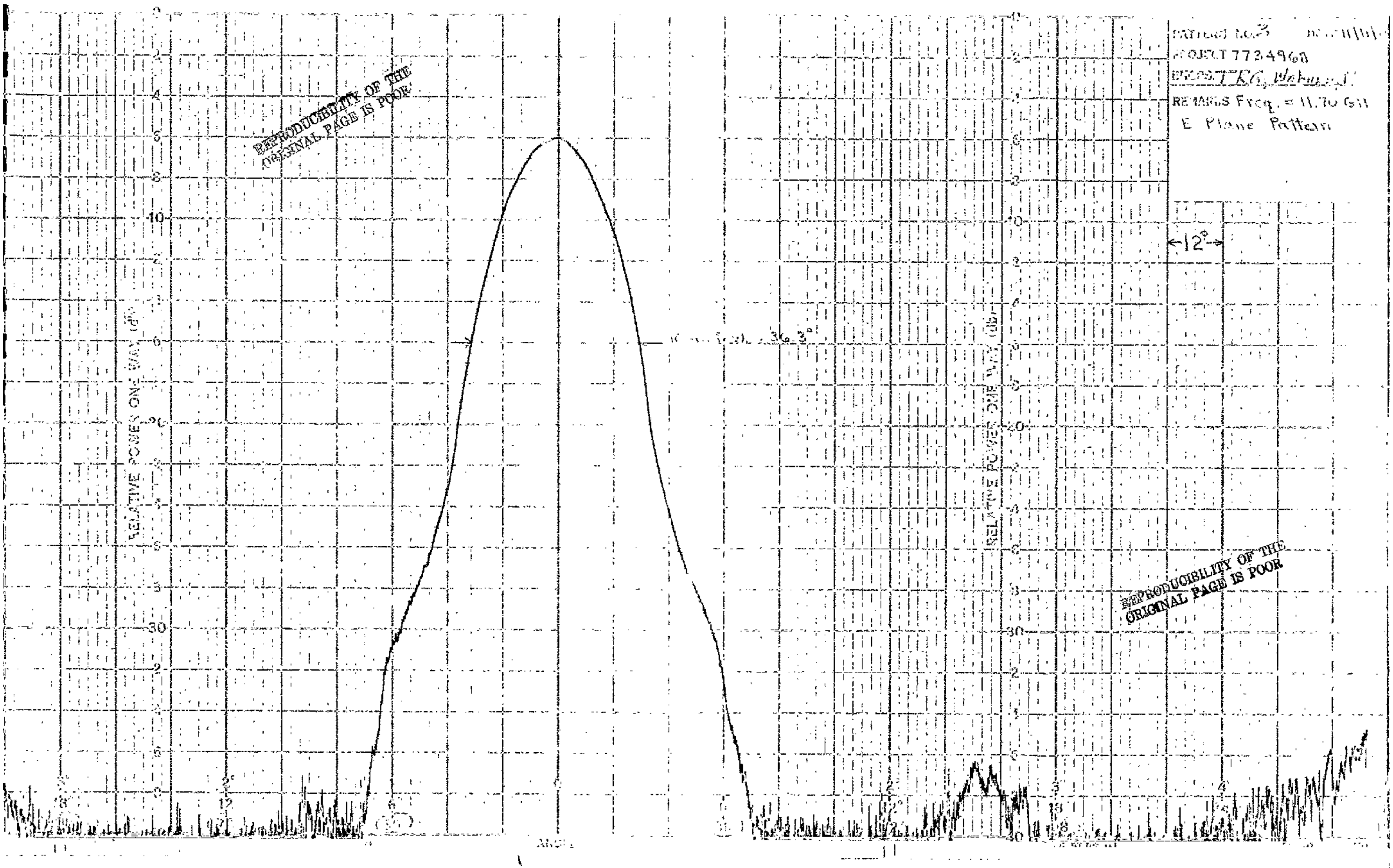
D 60046700	Dual Frequency Feed Assembly
D 60046800	Dual Frequency Feed Outline
D 60056000	Dual Frequency Feed Installation
C 60078900	Polarization Control Schematic

APPENDIX II

Radiation Patterns




PATTERN NO. 2
PROJECT 7734
ENGRS.
REMARKS Freq. =
H Plane Pattern
RELATIVE POWER ONE WAY (db)
12°



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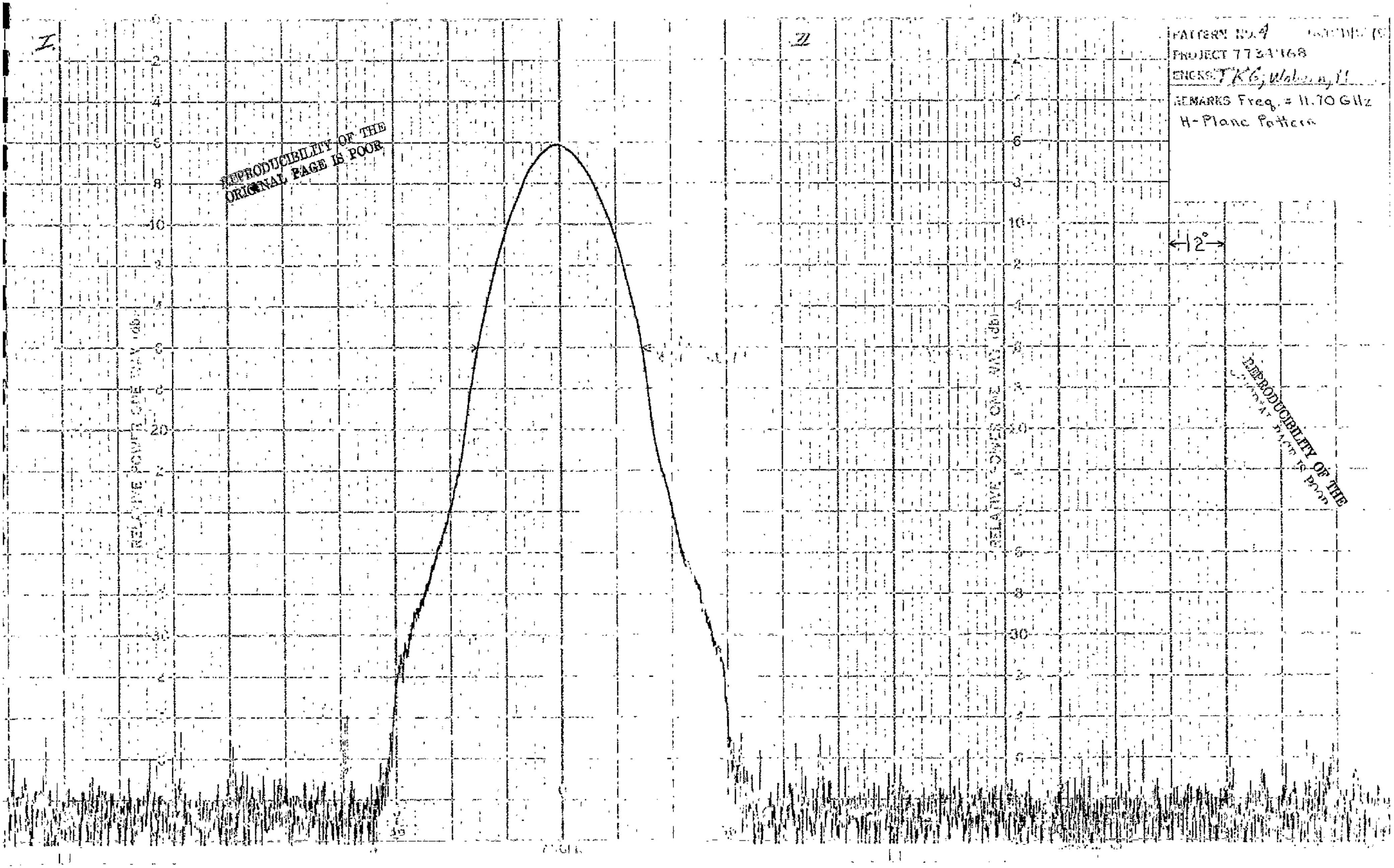
I.
II.
PATTERN NO. 4
PROJECT 7734168
REMARKS Freq. = 11.70 GHz
H-Plane Pattern
2°
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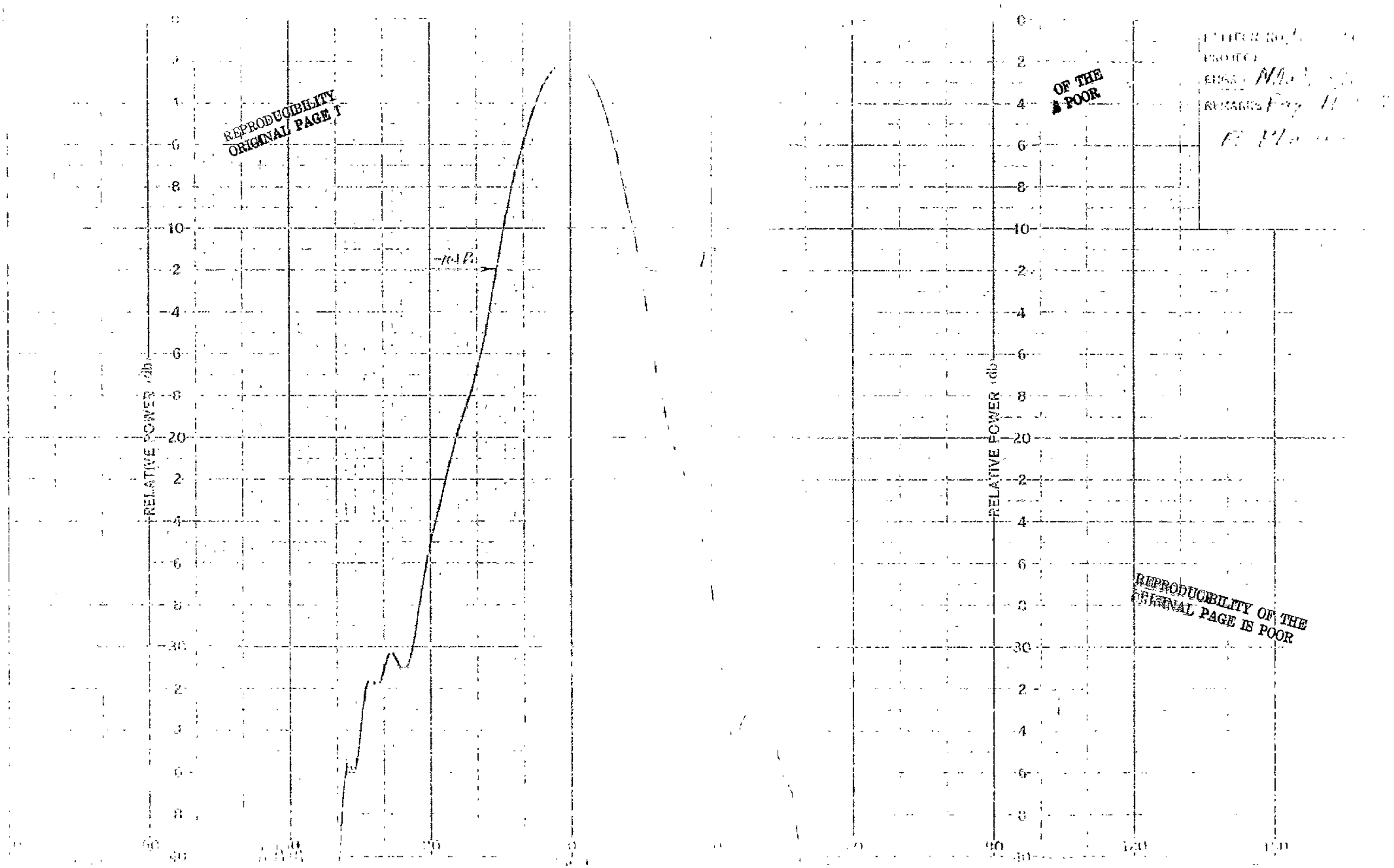
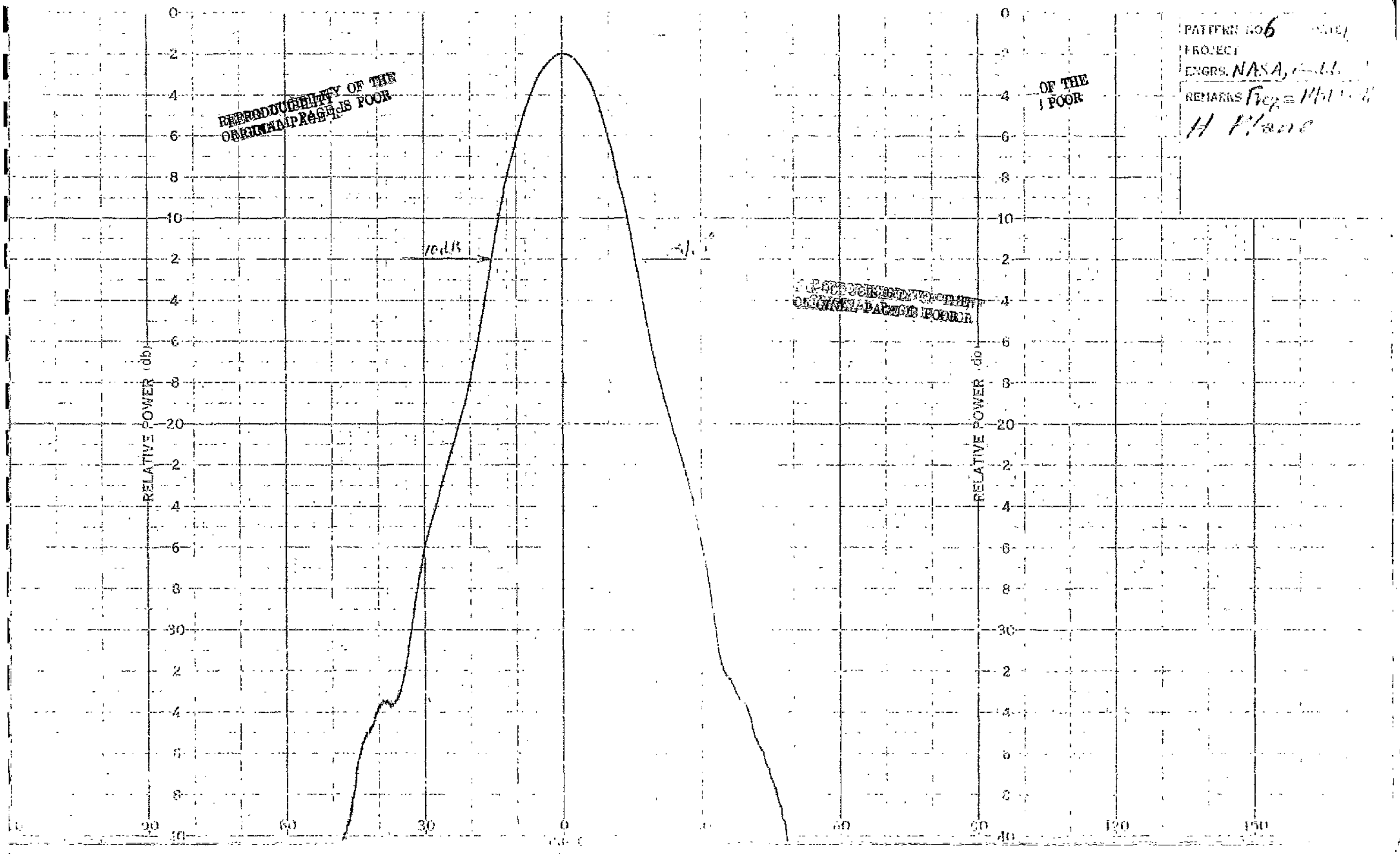
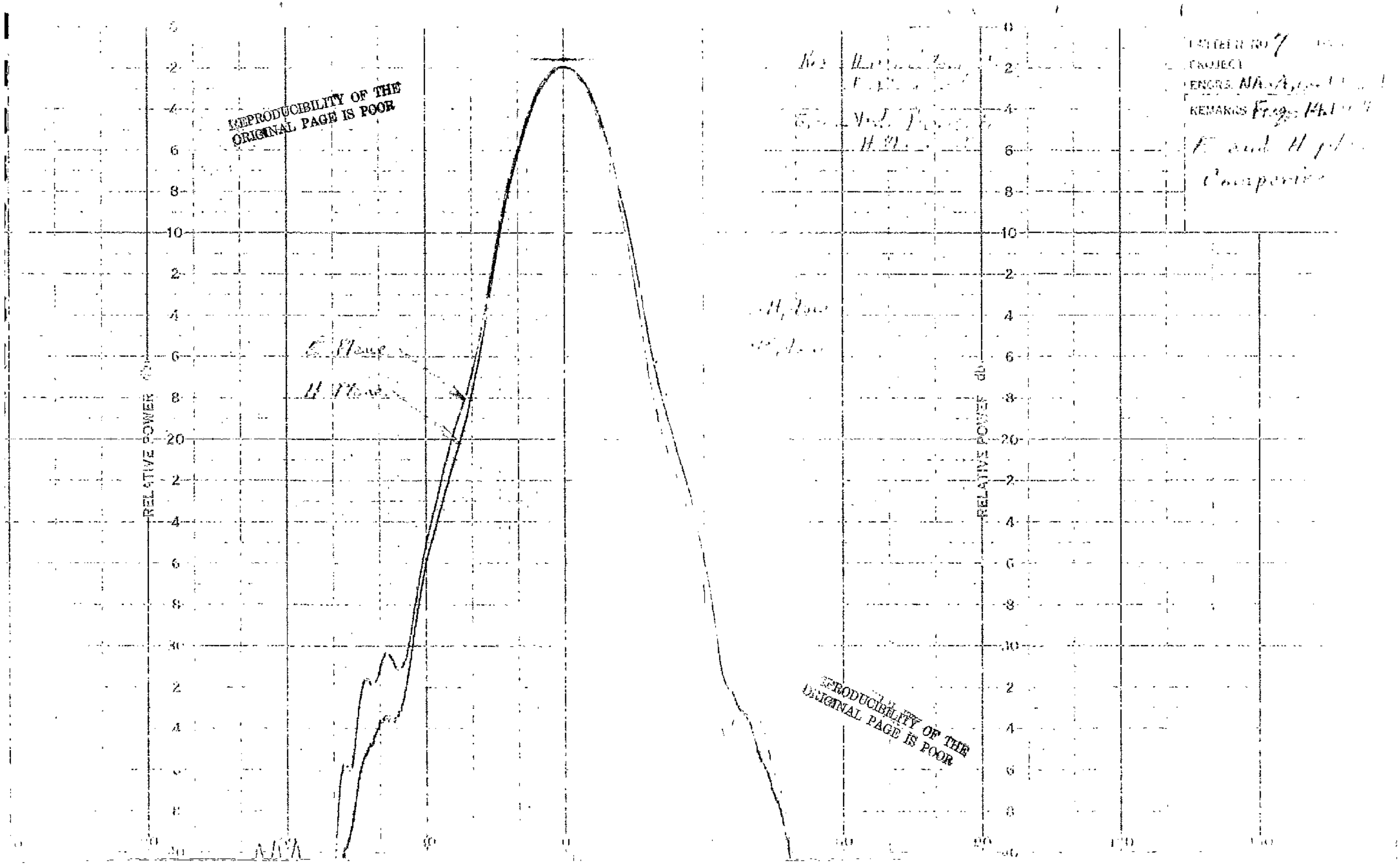


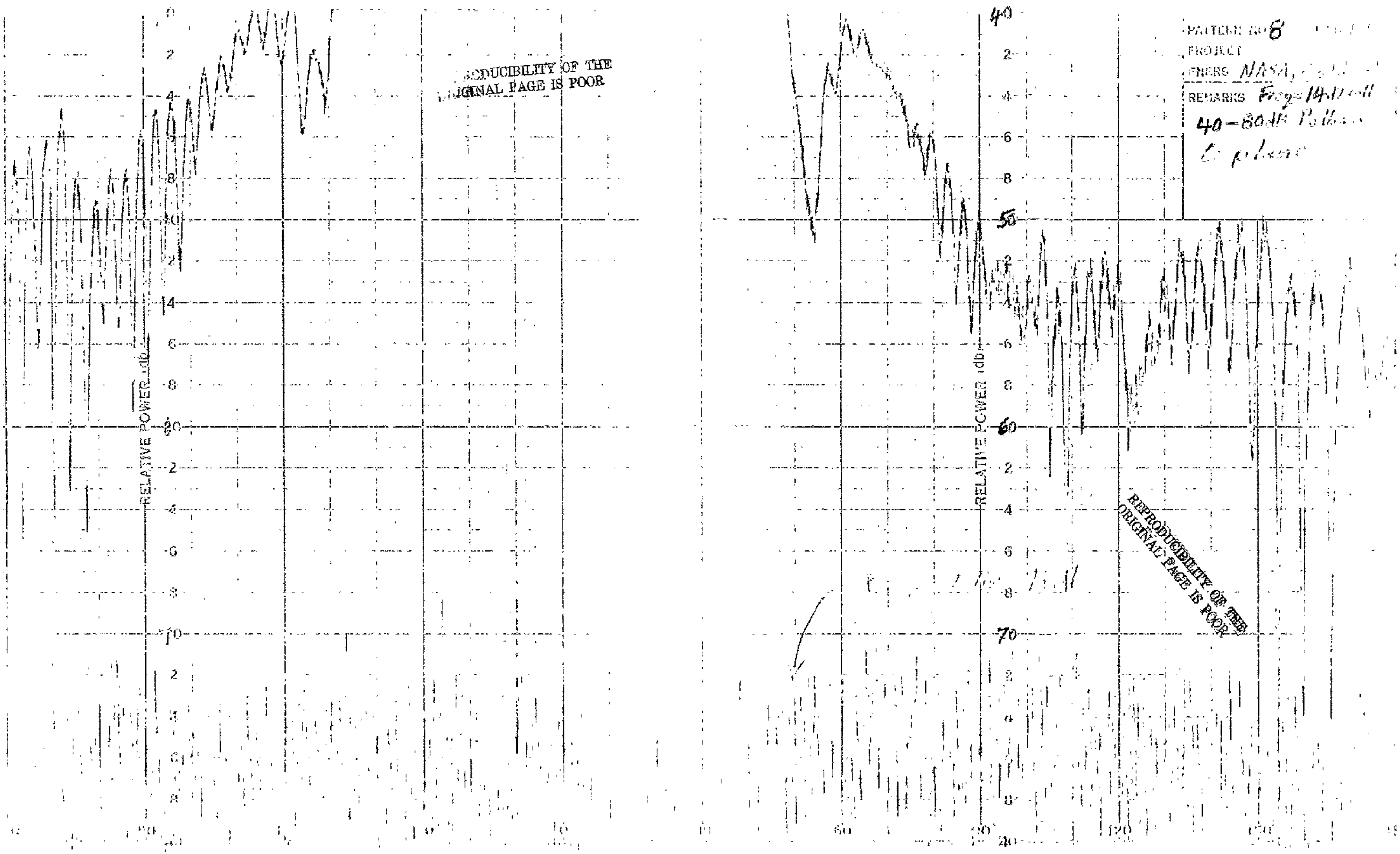
RELATIVE POWER (db)
-10
-20
-30
-10 dB
RELATIVE POWER (db)
-10
-20
-30



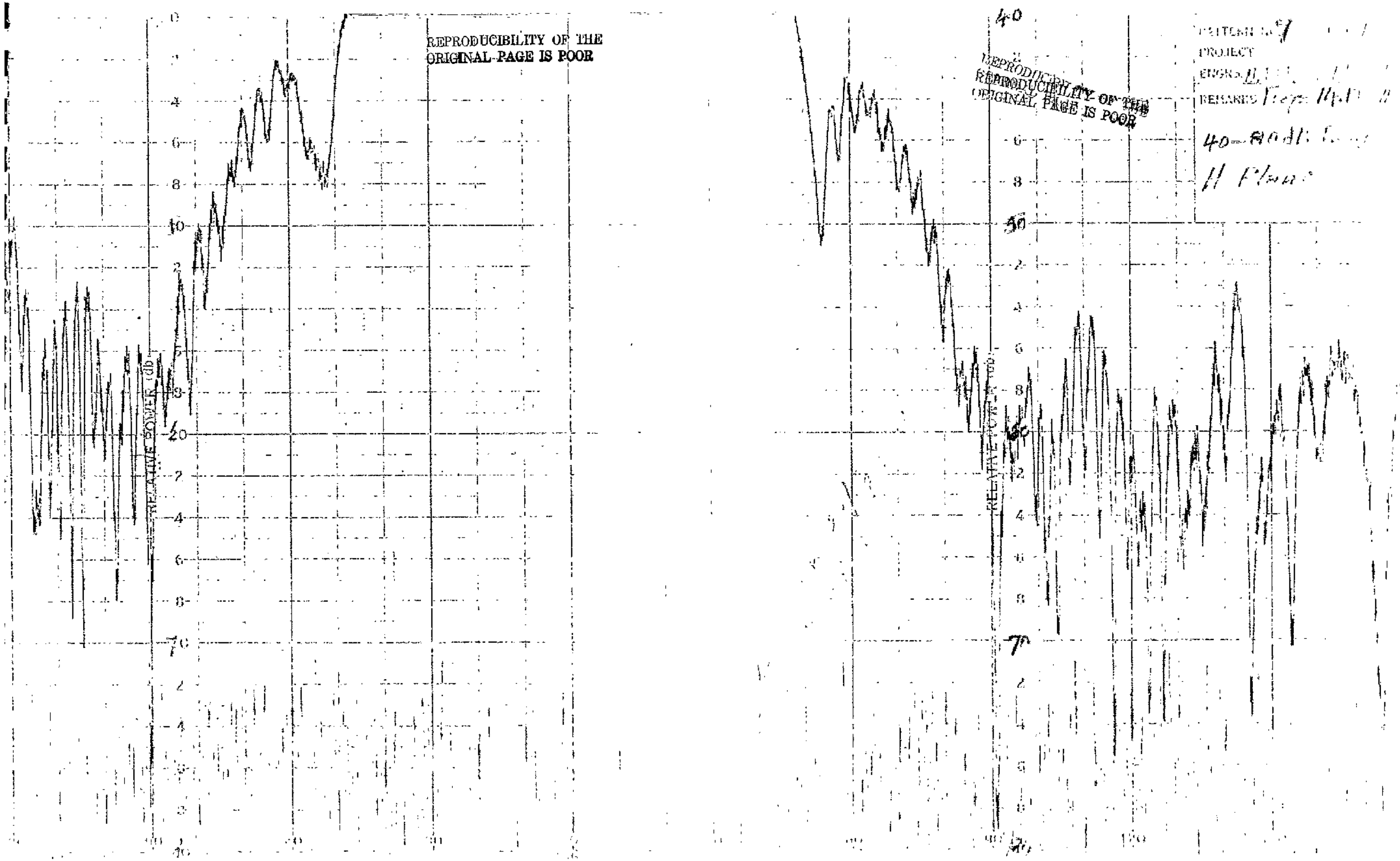
PATTERN NO 6
PROJECT
ENGRS. NASA,
REMARKS
H Plane
RELATIVE POWER (db)
10dB
0
30
60
90
120
150



RELATIVE POWER db
E Plane
H Plane
PROJECT
ENGRS.
REMARKS



PATTERN NO 8
PROJECT
ENGRS NASA,
REMARKS
40-80
RELATIVE POWER (db)
RELATIVE POWER (db)
40
50
60
70
60
80
120



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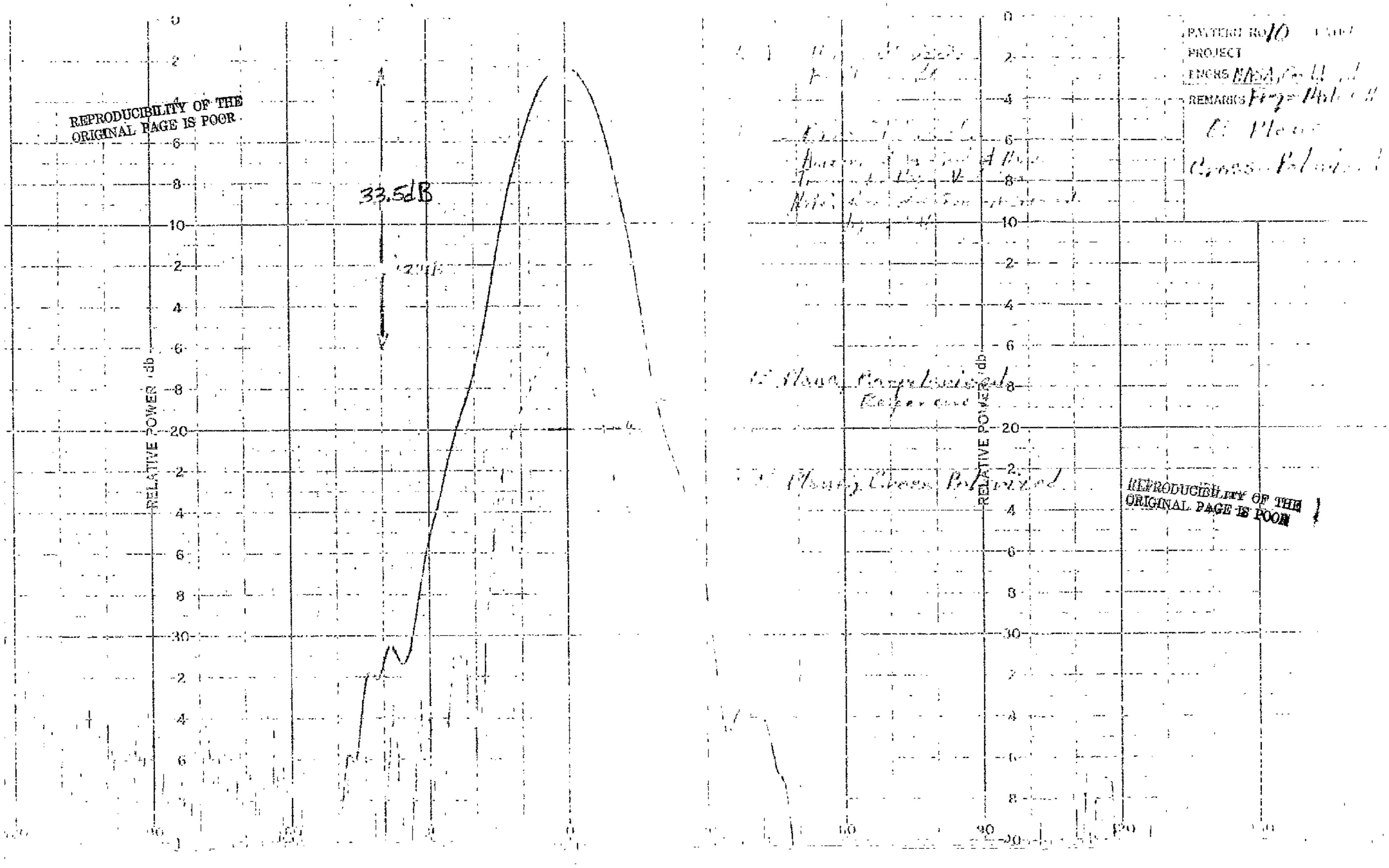

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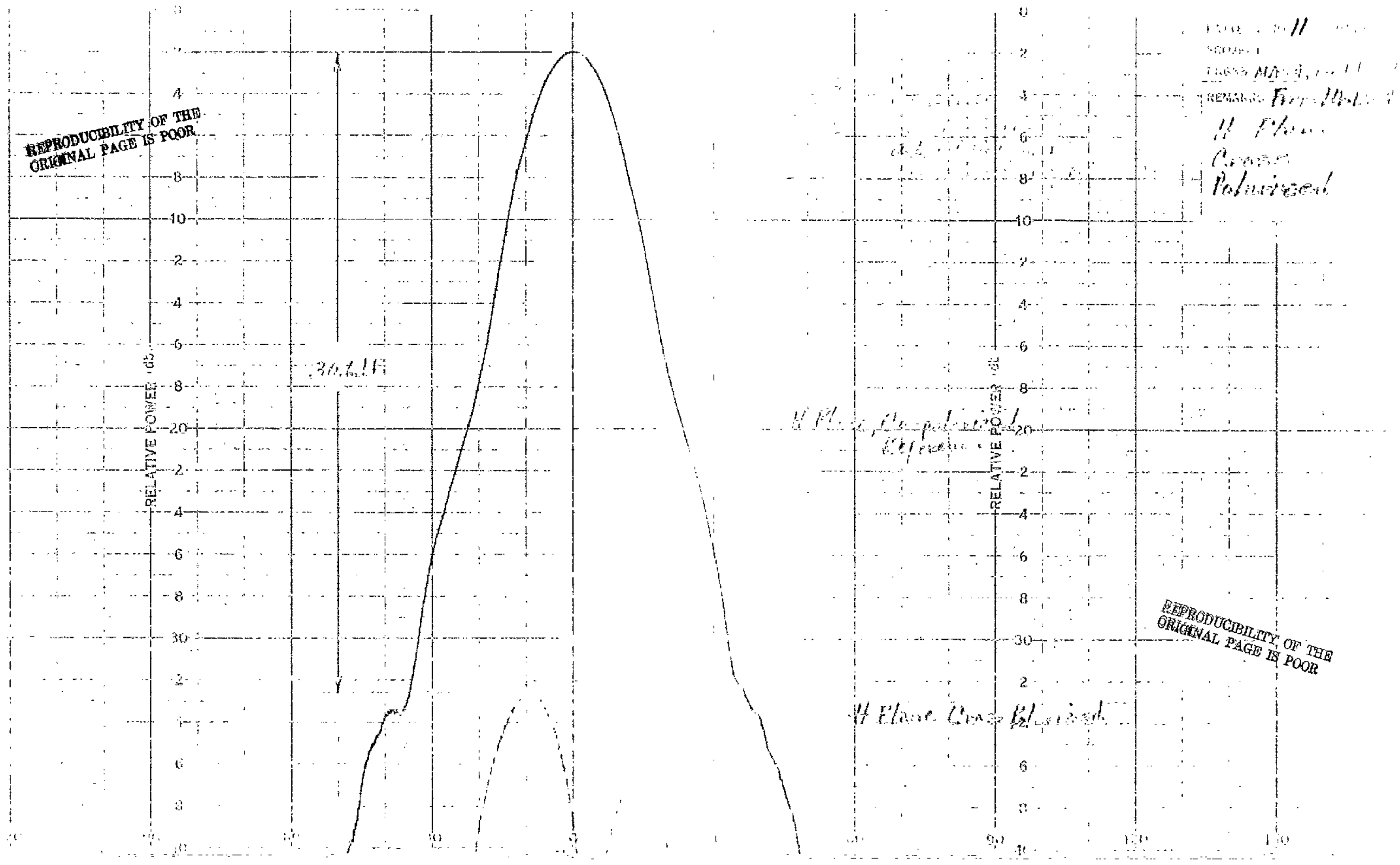

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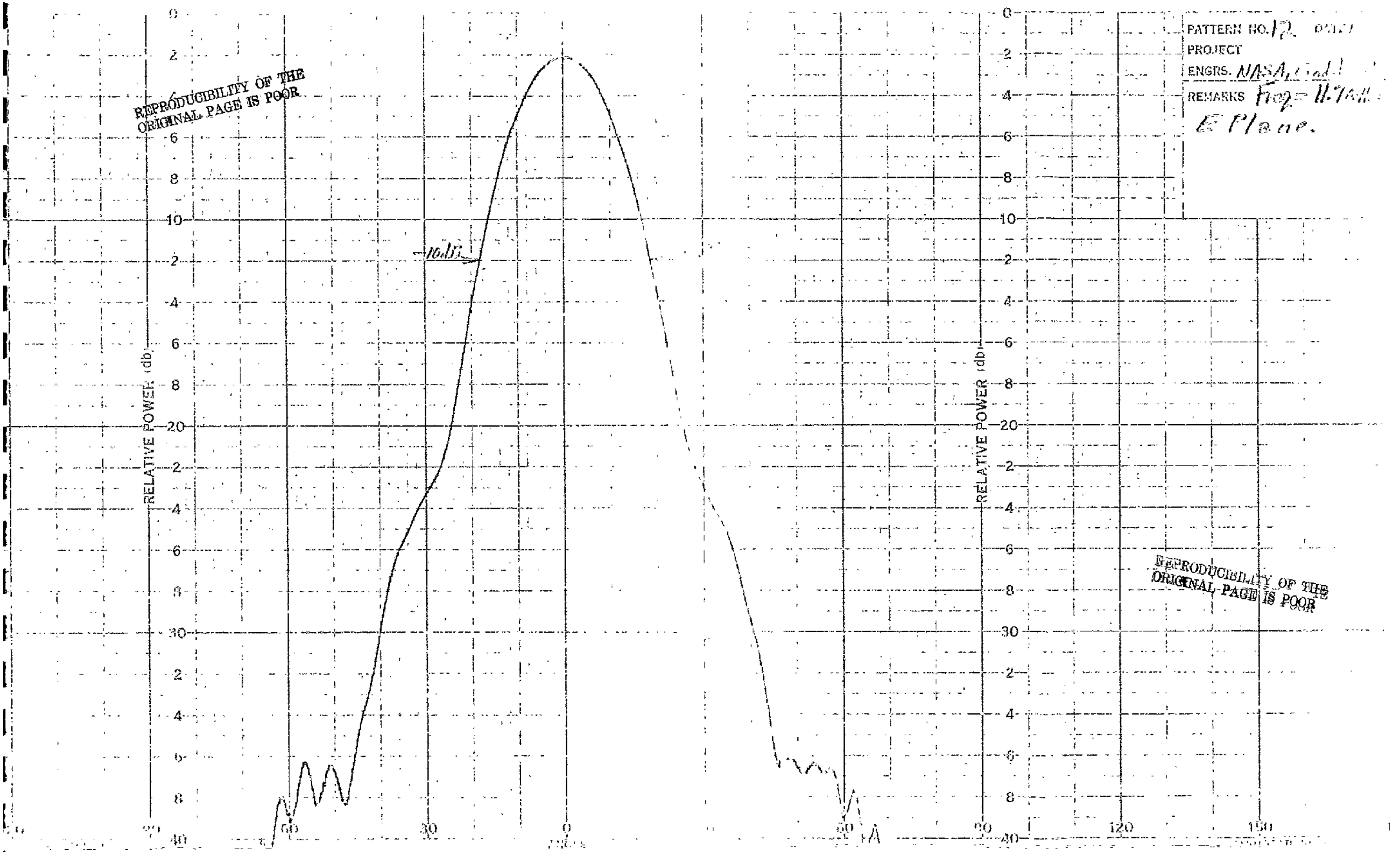

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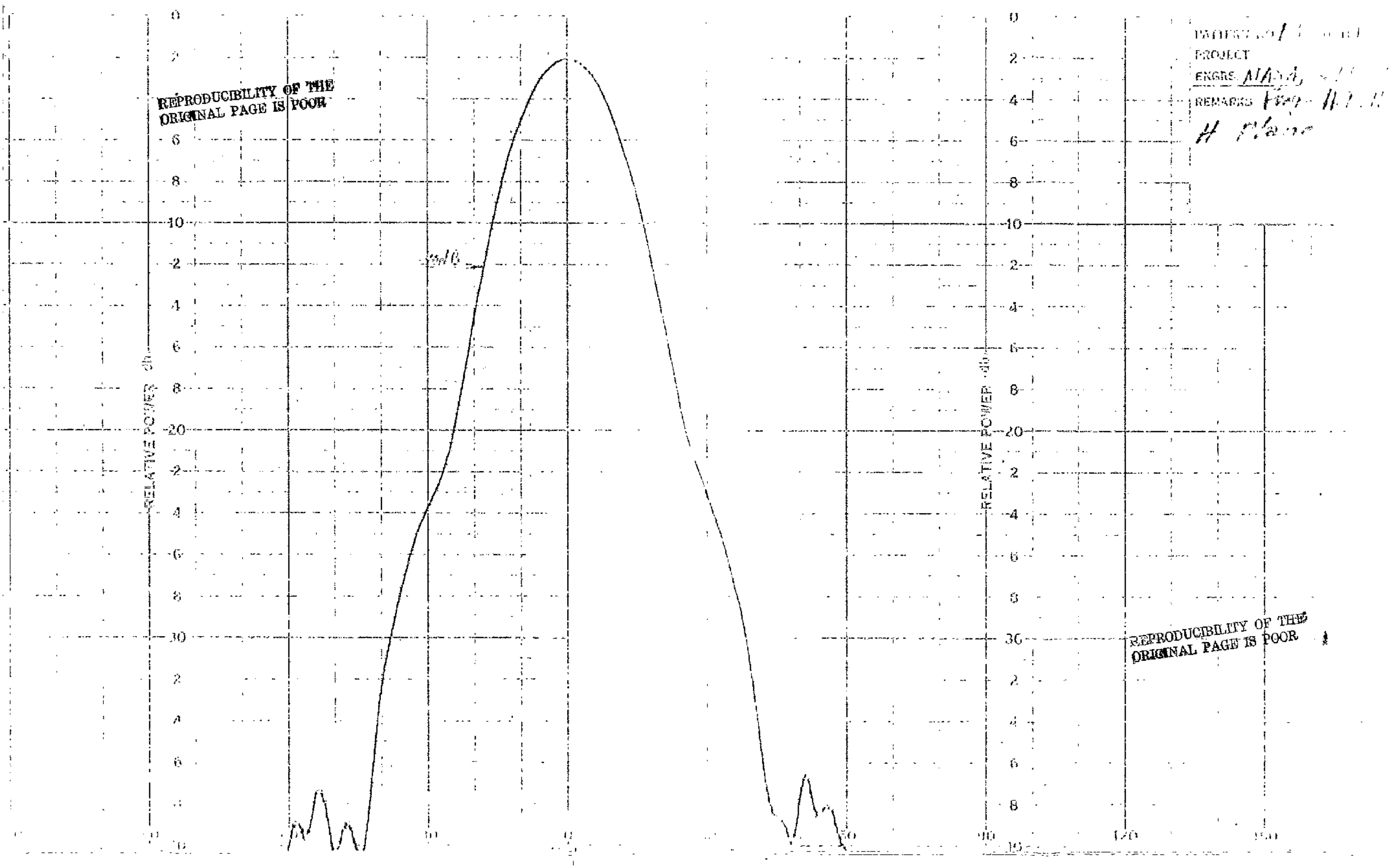
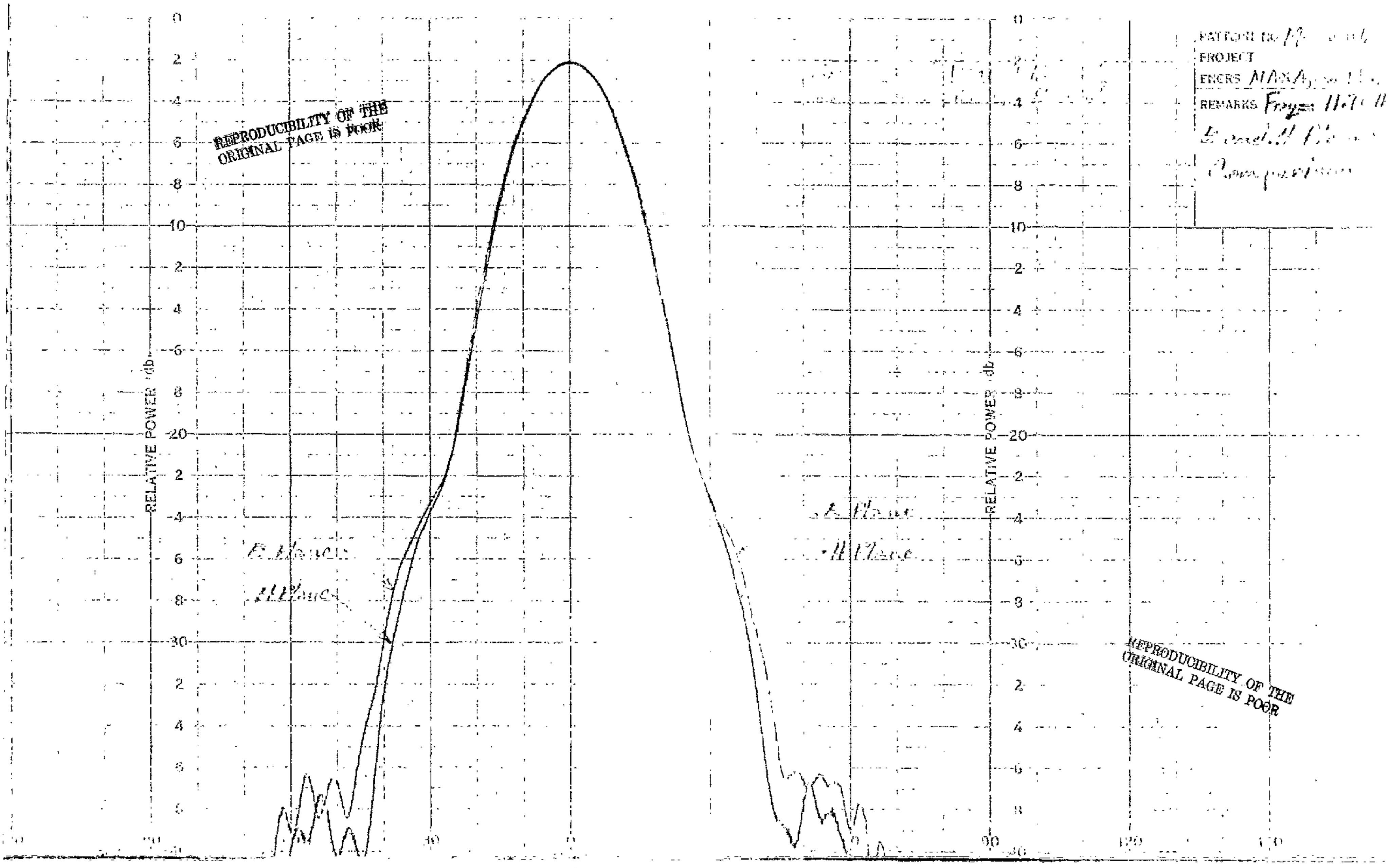

RELATIVE POWER - db
PROJECT
ENGRS.
REMARKS



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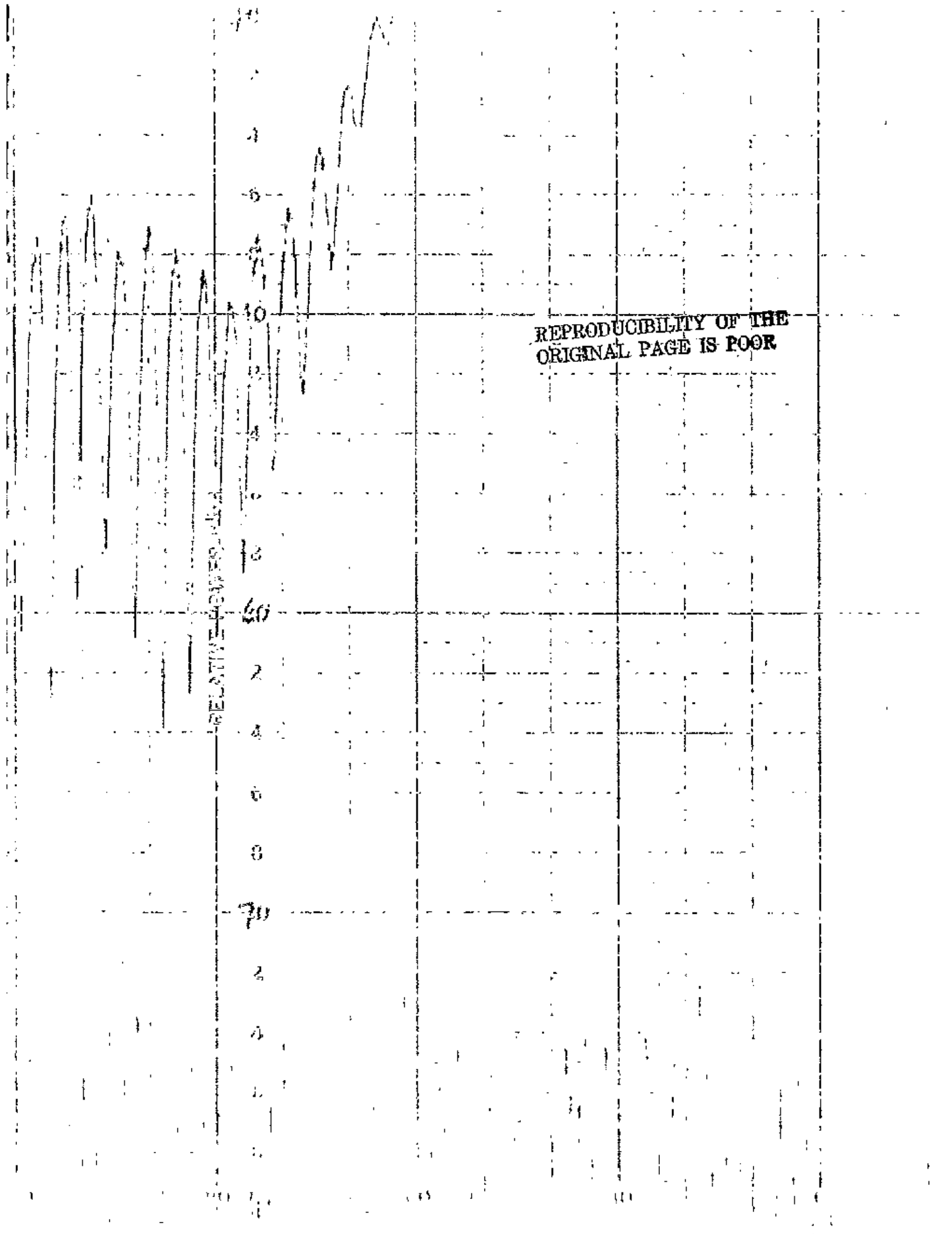
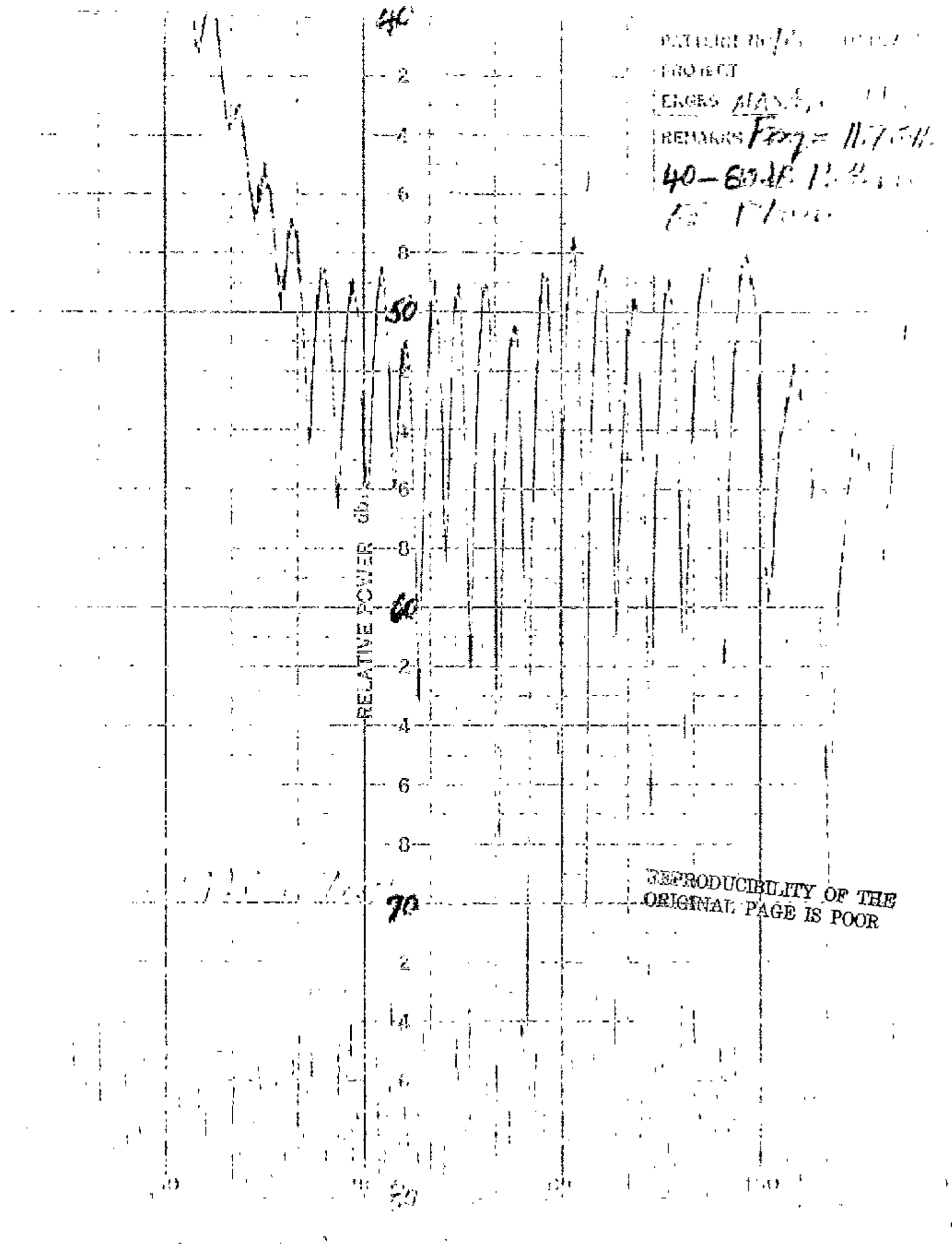
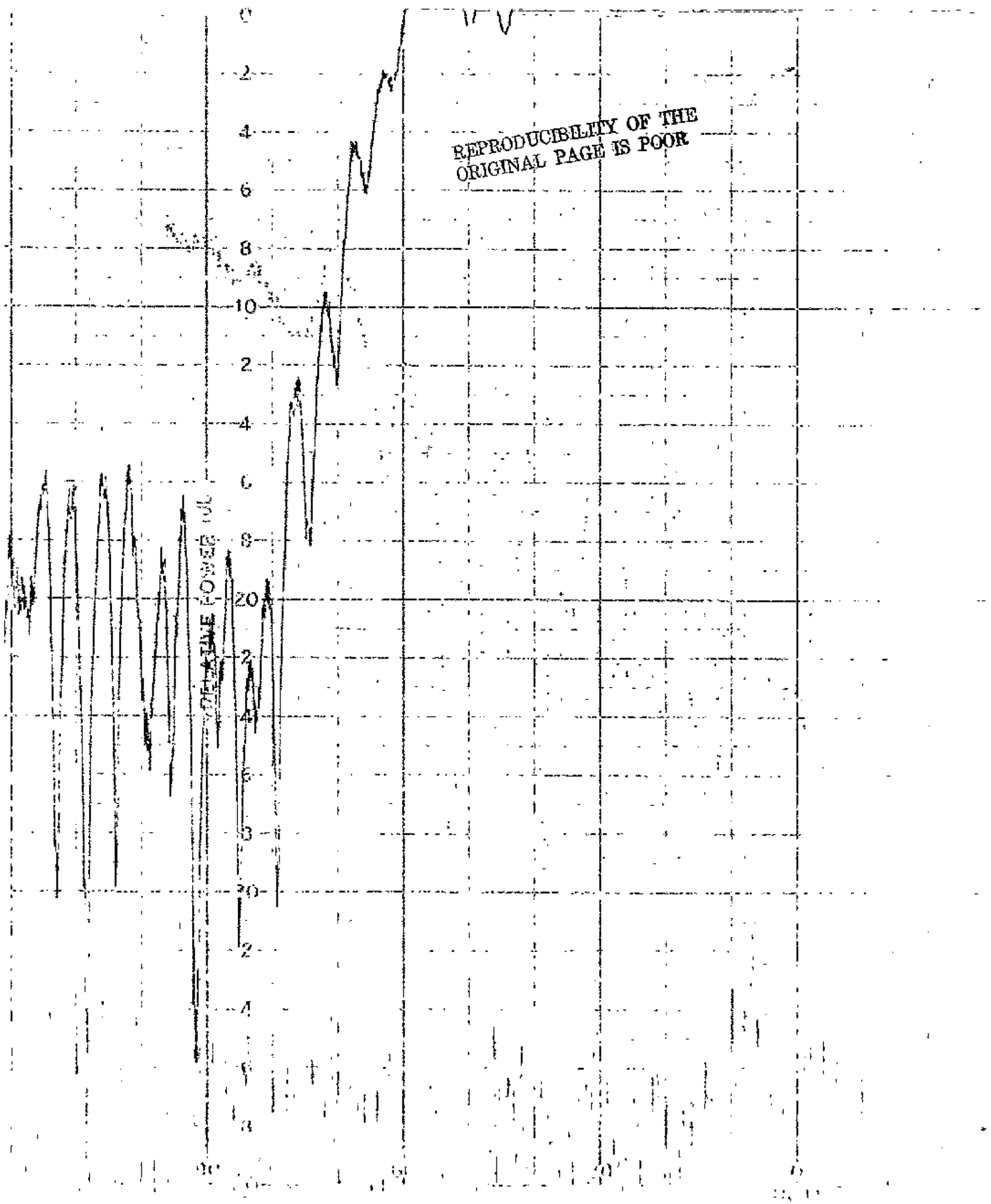
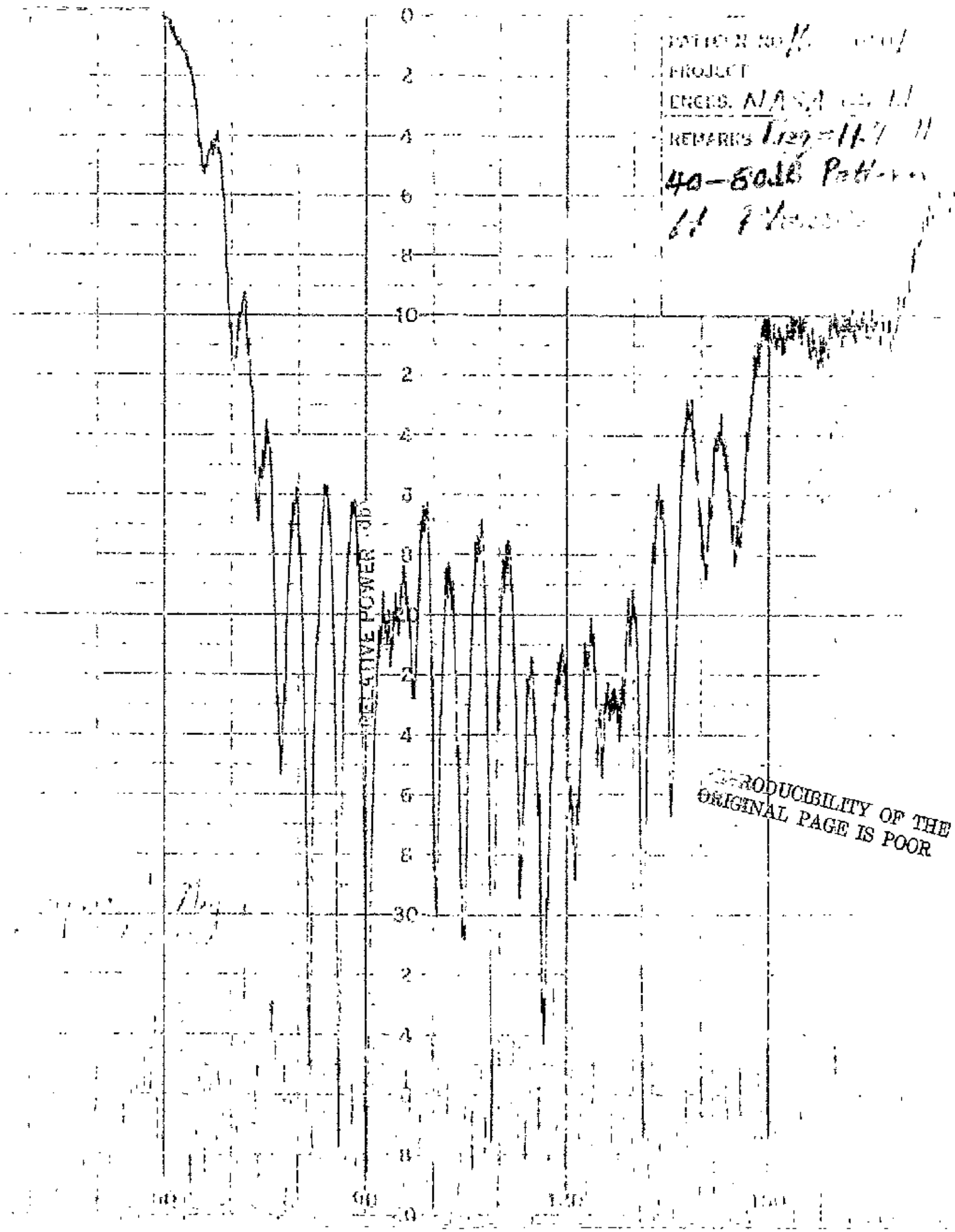
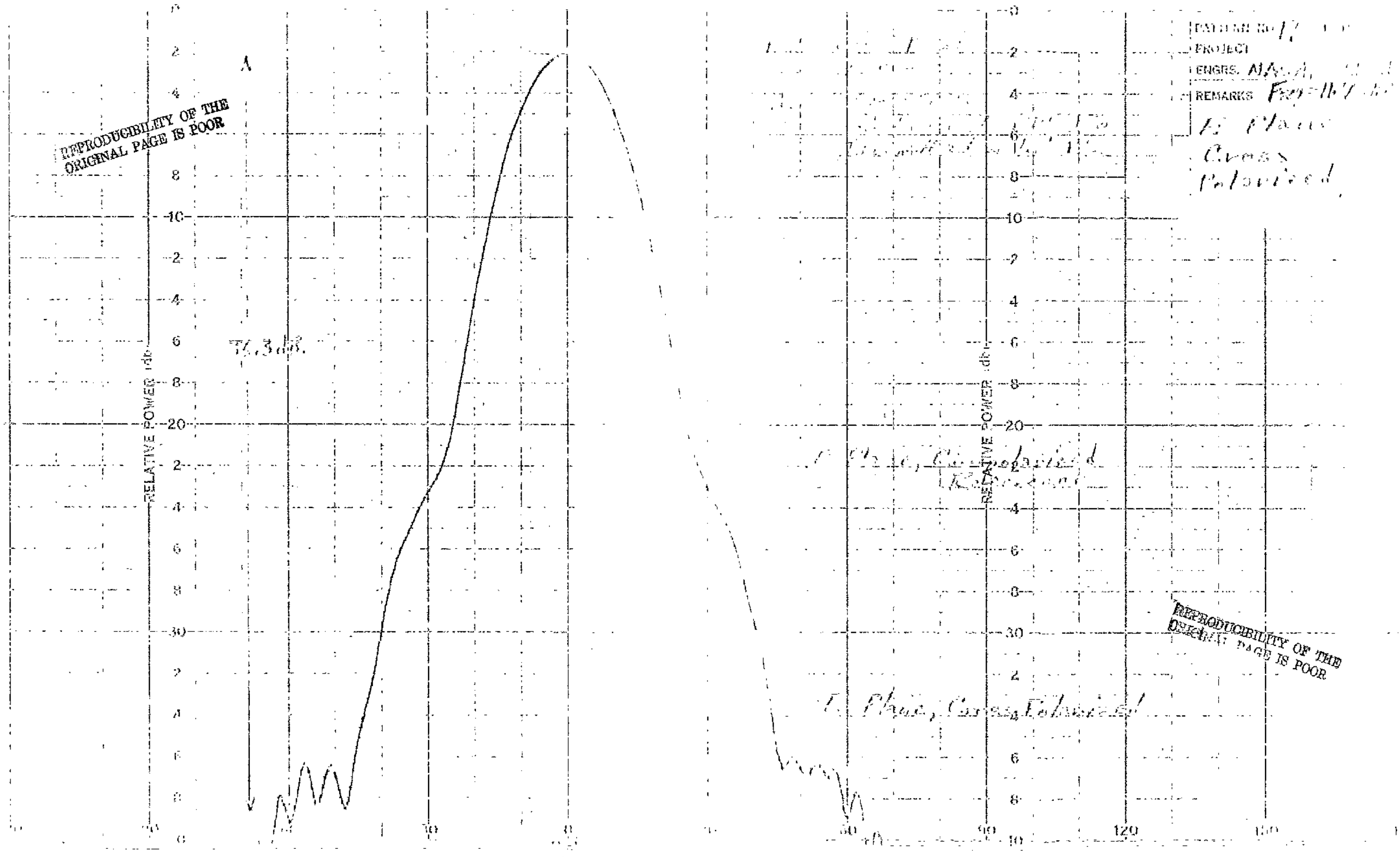

RELATIVE POWER db
10
60
70


PROJECT
ENGRS
REMARKS
40
50
60
70
RELATIVE POWER db


RELATIVE POWER dB


PROJECT
ENGRS. NASA
REMARKS
40-60 dB Pattern
RELATIVE POWER dB



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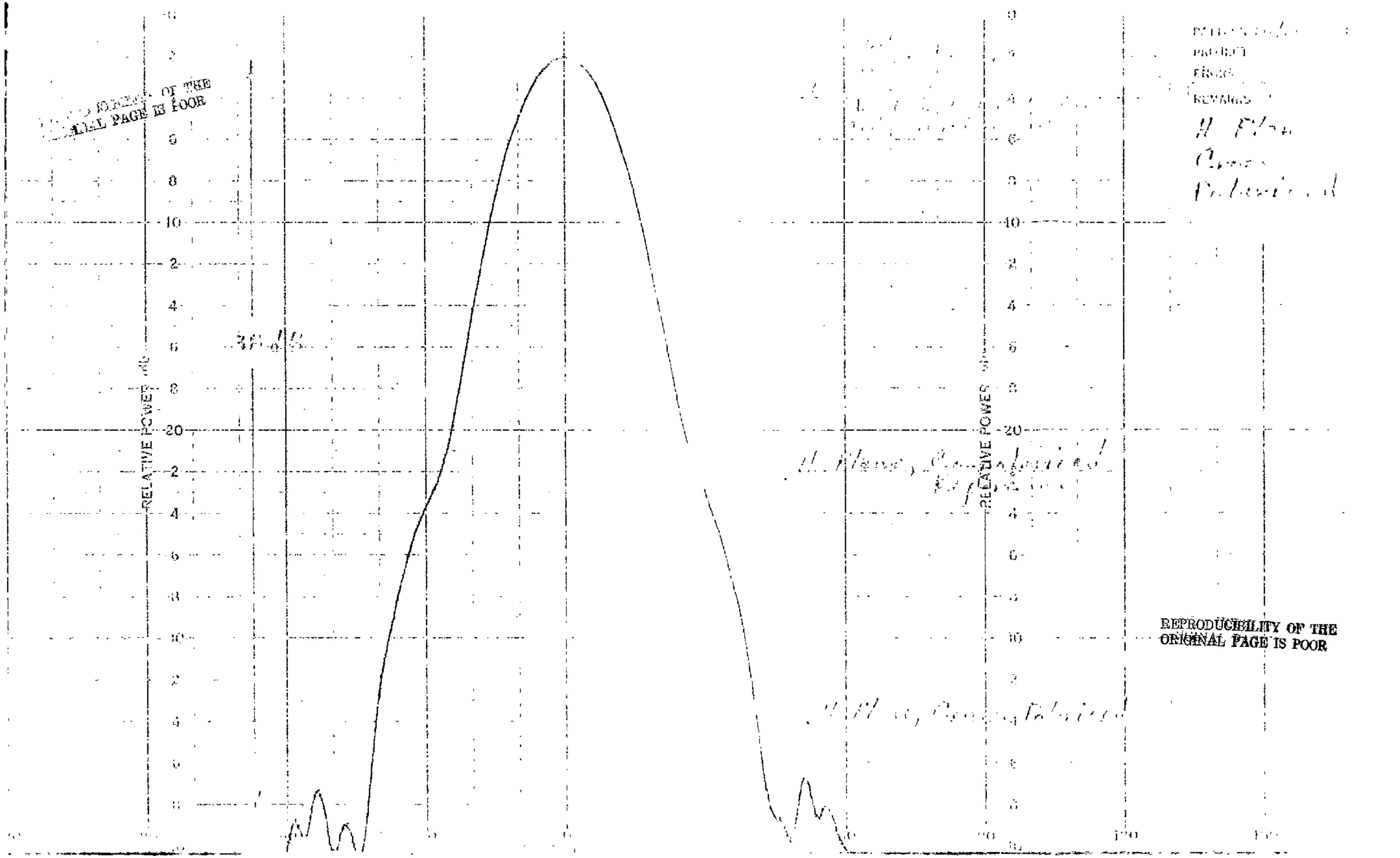
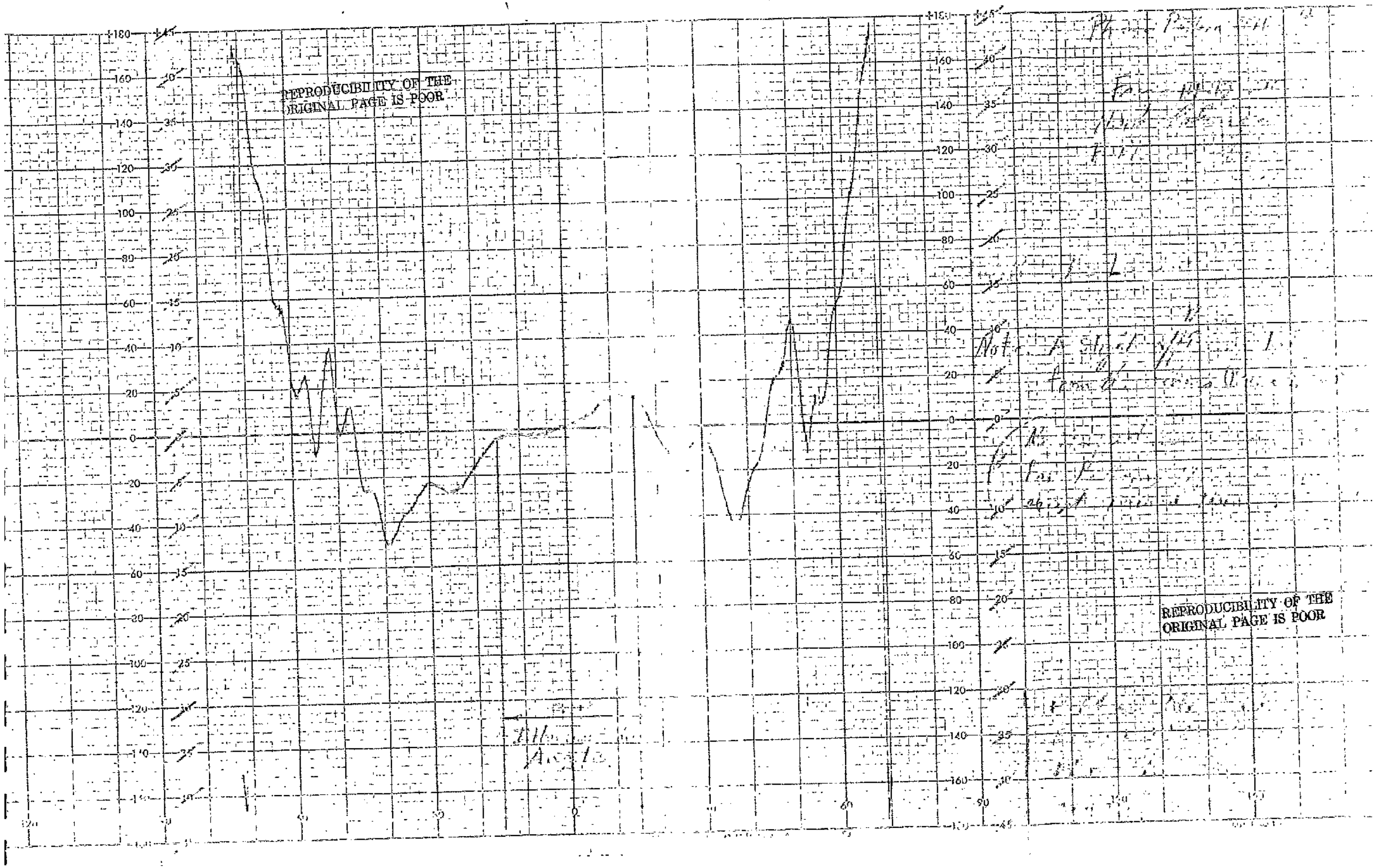

RELATIVE POWER
35 dB
RELATIVE POWER



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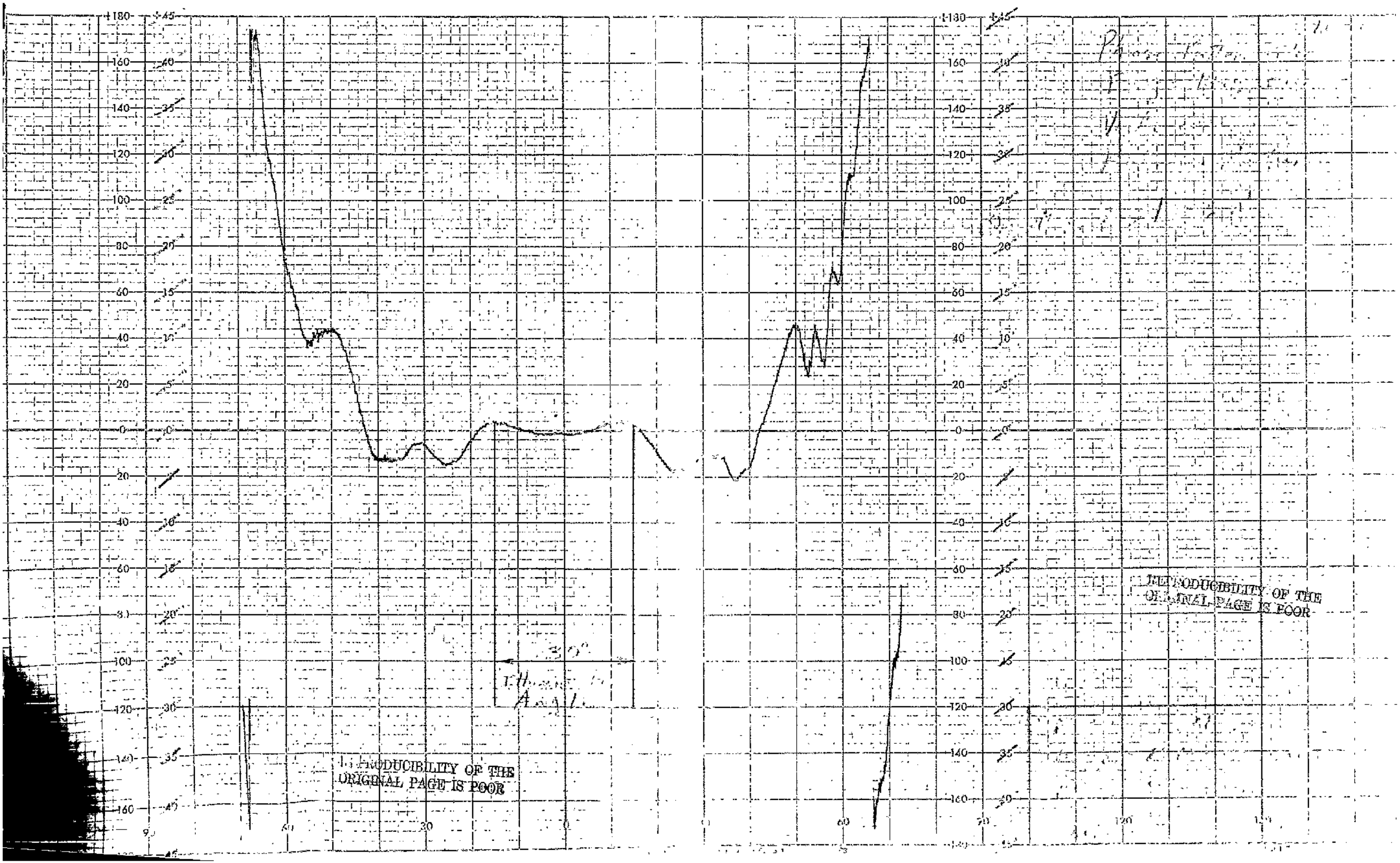
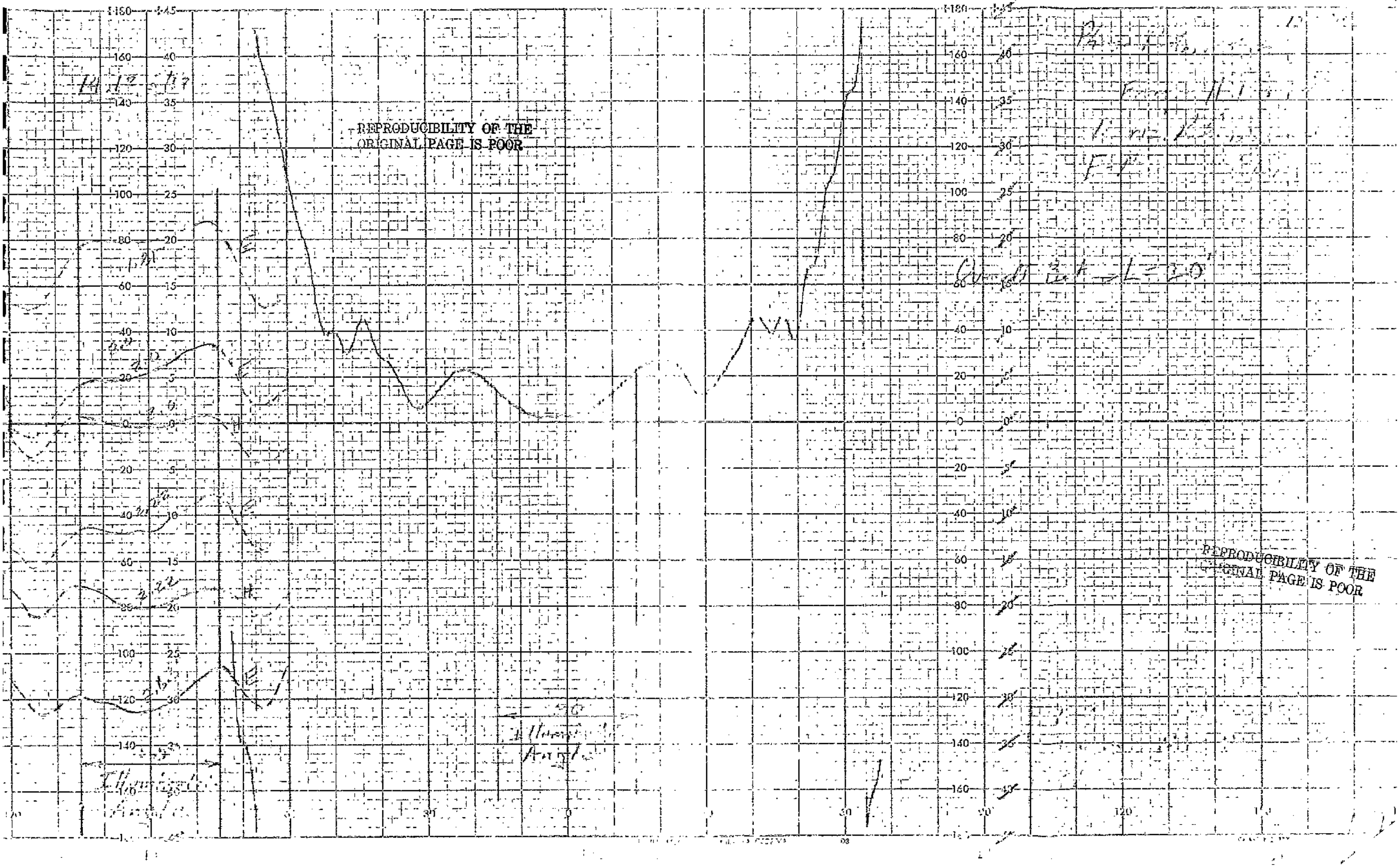
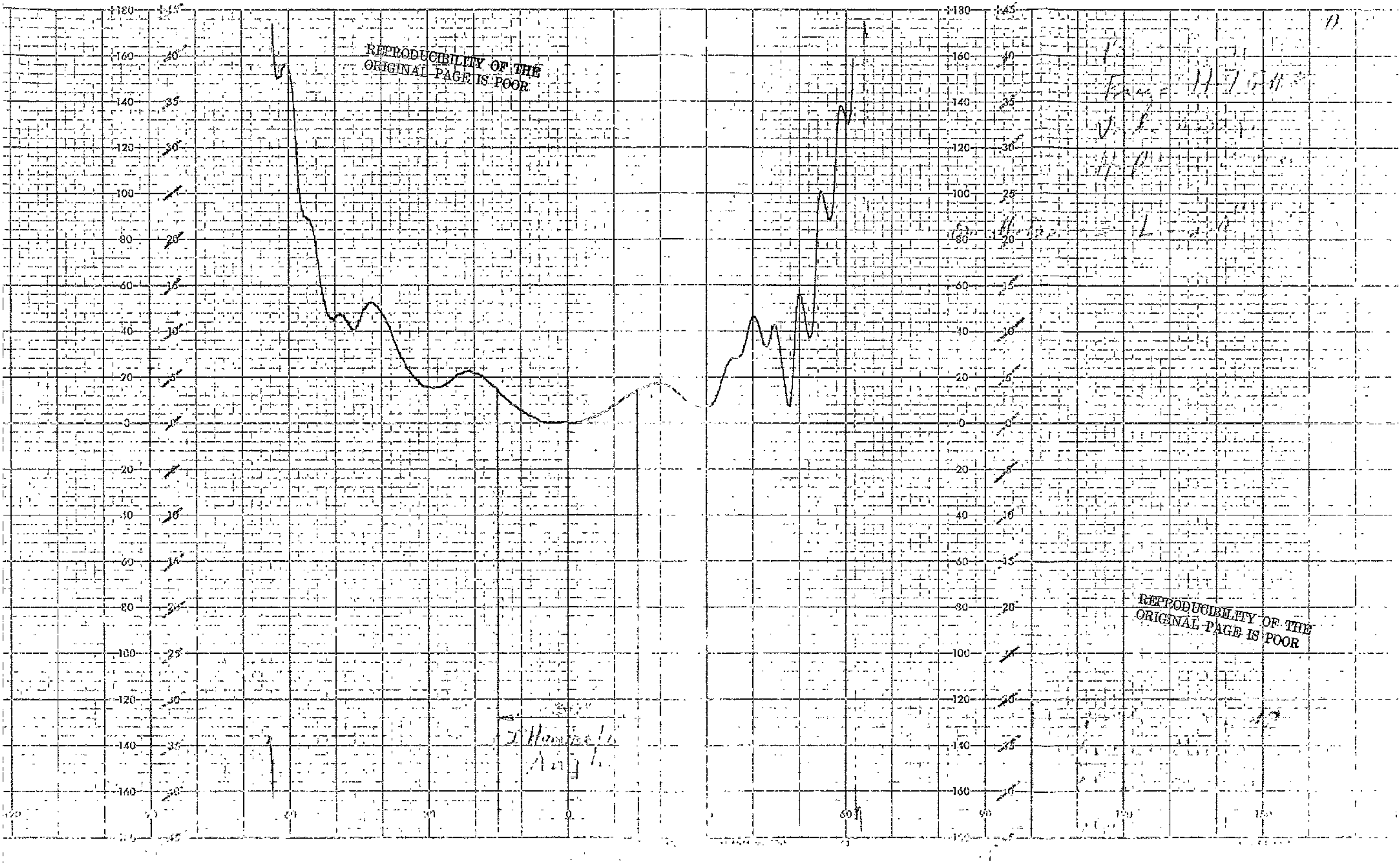
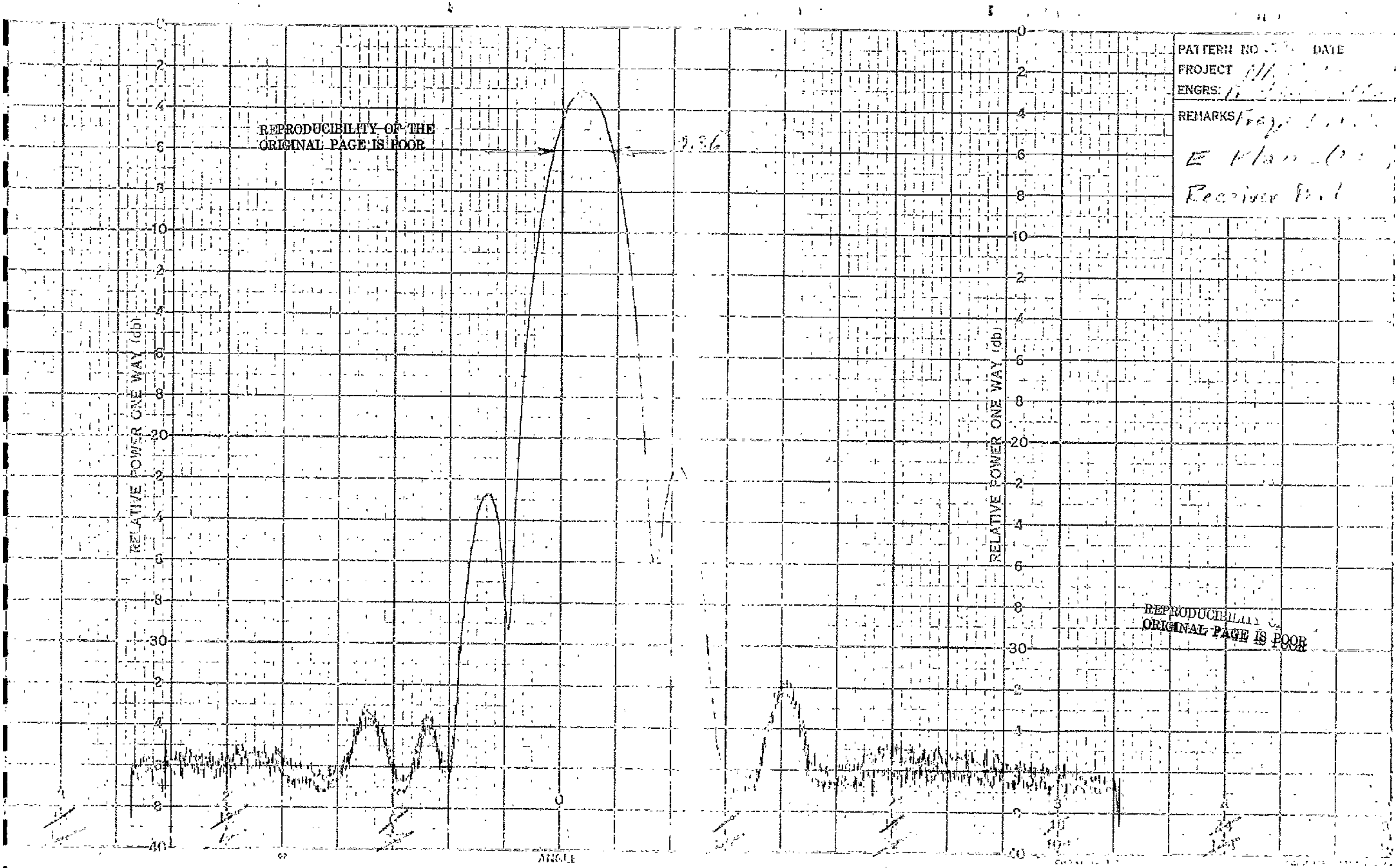

30°







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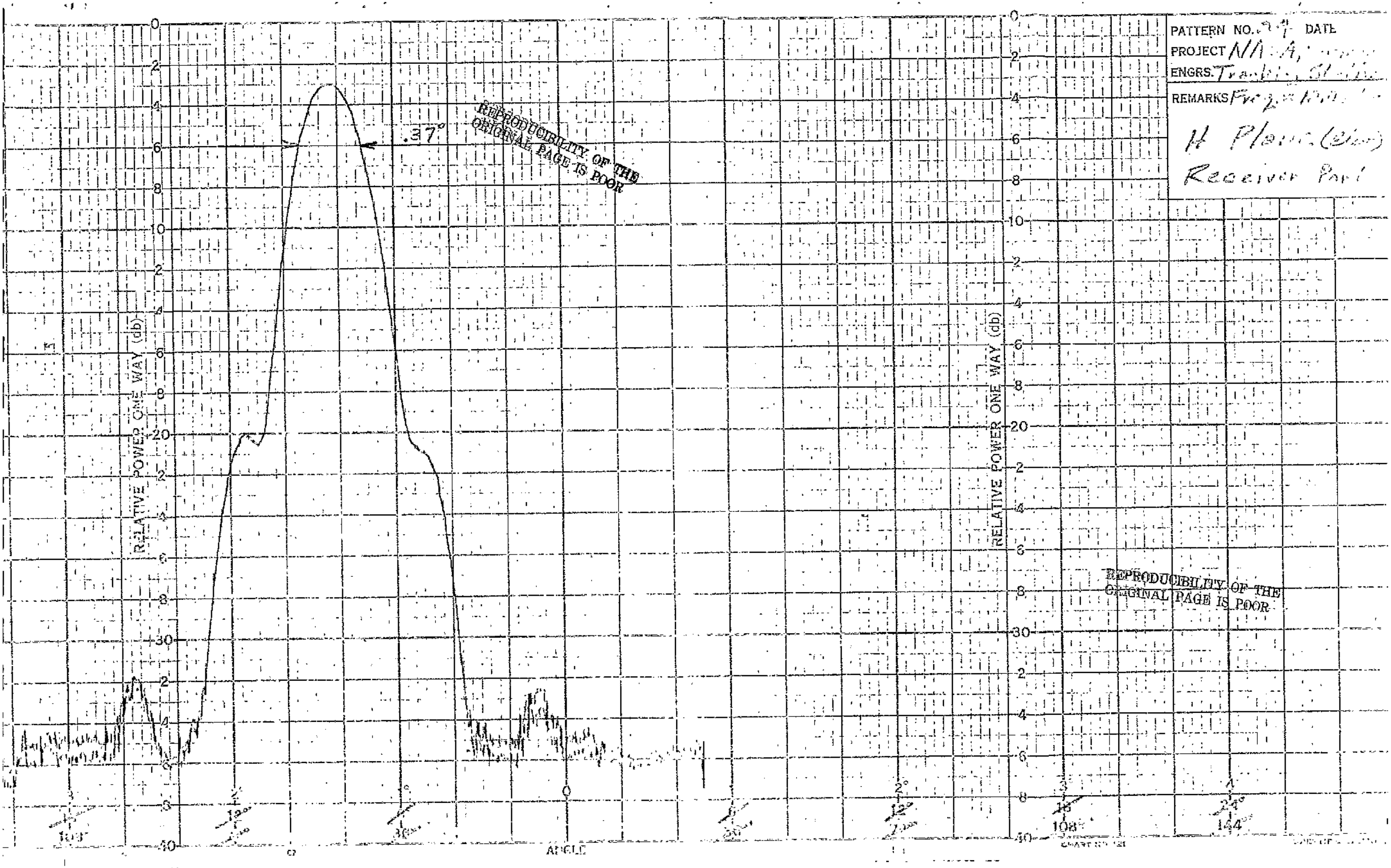
RELATIVE POWER ONE WAY (db)
ANGLE
PATTERN NO
DATE
PROJECT
ENGRS:
REMARKS
E Plane
Receiver



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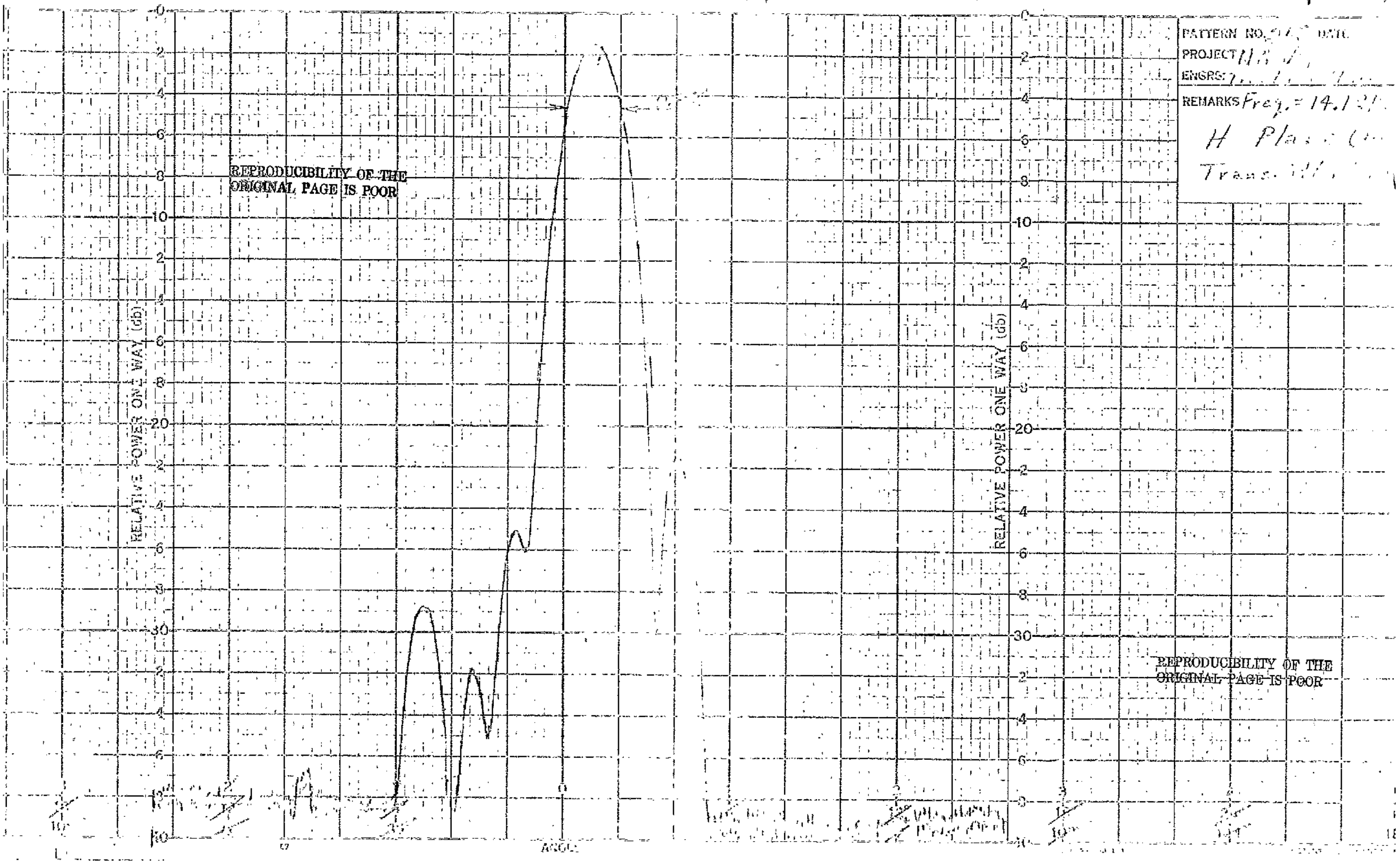

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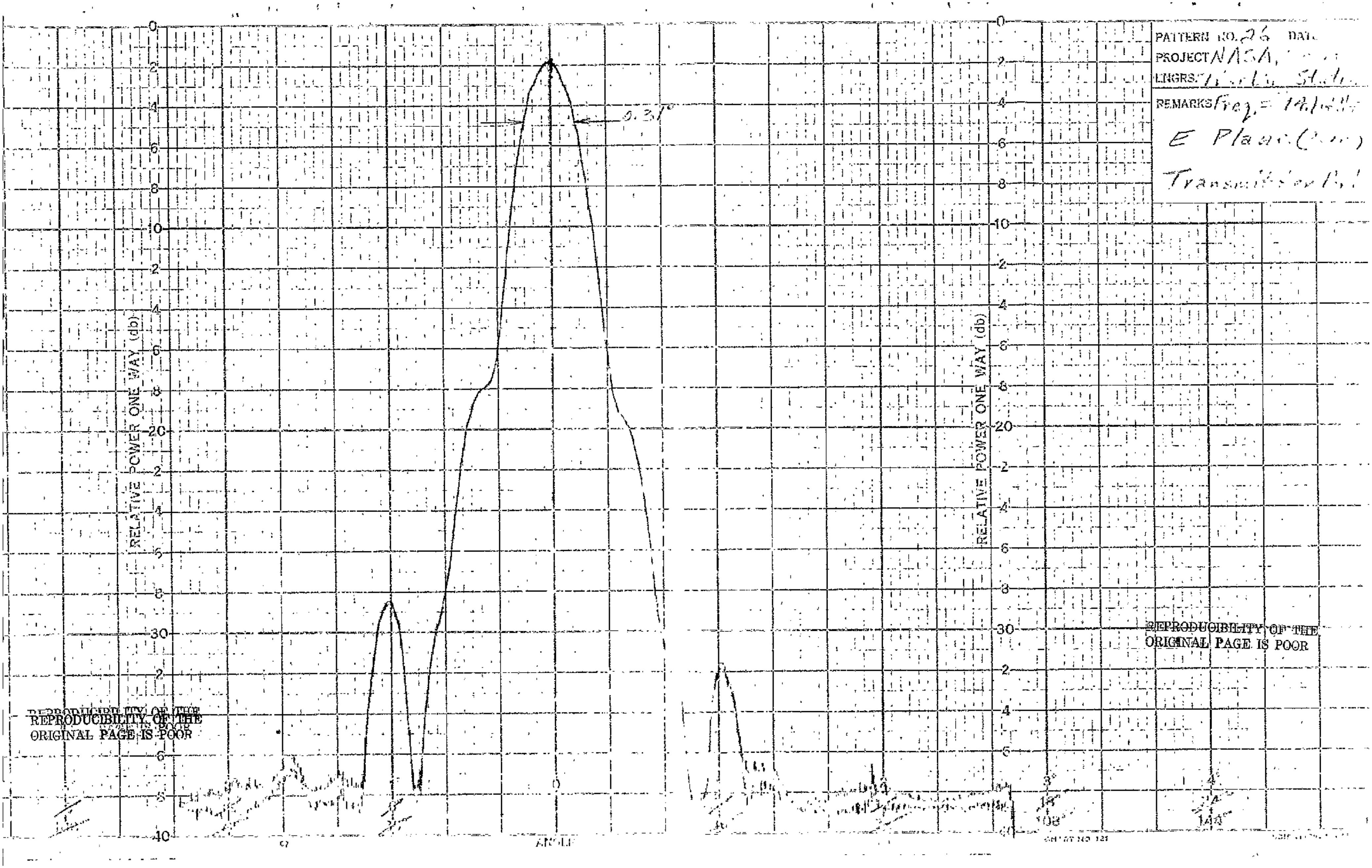

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