BACKSCATTERING MEASUREMENTS

Final Report

by

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to

Williams International
2280 West Maple Road
Walled Lake, MI 48088

27 January 1983

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This is the Final Report on purchase order No. 156083 from Williams International for the performance of a sequence of back-scatter measurements at X-band. The measurements were carried out in the anechoic chamber at our Willow Run facility during the last five weeks of 1982 and the first two weeks of 1983.

Background

The Laboratory was initially contacted by Mr. Lou Danis of Williams International requesting information concerning the Laboratory's capability for making scattering measurements. As a result of this contact, the following personnel from Williams International visited us during the afternoon of 13 October 1982:

Doug Brown	Tim Nielsen
Lou Danis	William Schimmel
Ron Jones	John Schuldie

After a tour of our experimental facilities at Willow Run and in the East Engineering Building, the group met with Thomas B.A. Senior, Joseph E. Ferris and Valdis V. Liepa of the Radiation Laboratory to discuss the measurements that were needed. We learned that the objective of the proposed measurements was to demonstrate the effect of certain improvements in blade and spinner design. Williams International required such data for a proposal that they hoped to submit in early 1983.

Senior described the nature of scattering measurements, and the source of scattering contributions in the case of a duct with various terminations, and indicated how data could be analyzed.

Although interest was confined to the scattering resulting from the rear or termination, a duct of some form is necessary to limit the aspects at which the termination can be seen, and it was recommended that a simple metal tube, e.g., a piece of heating duct, be used. However, Williams' personnel felt that such a duct would not seem realistic and proposed that a duct which they would fabricate themselves should be used instead. In addition, for confirmation and comparison purposes, a few preliminary measurements were requested for a complete structure whose weight would be about 100 lbs.

On 3 November Tim Nielsen, Scott Cruzen and Henry Moore of Williams International revisited the Laboratory to decide on the details of a test program. Techniques for supporting the model were discussed, along with the type of data to be measured. Based on the size and weight of the model and the termination geometries, the test procedures were decided upon, and the Radiation Laboratory was asked to submit a proposal for performing the measurements in conjunction with personnel from Williams International. The proposal was submitted on 4 November 1982 and covered backscatter measurements for about 30 different configurations, each for horizontal and vertical polarizations, at a single X-band frequency. Along with the necessary calibration measurements, a total of about 70 different measurements was envisaged.

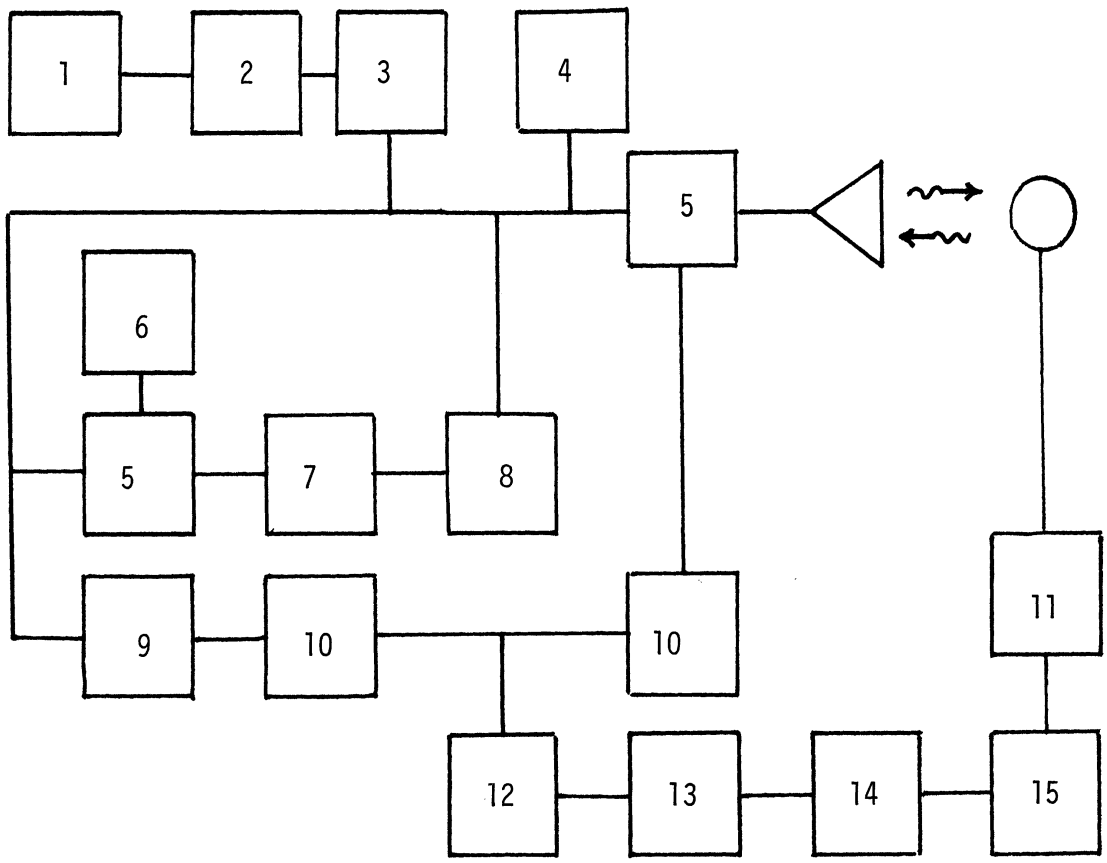
On 18 November Tim Nielsen and Henry Moore visited the Willow Run facility to finalize the test program and make plans for bringing the models in for testing. It was agreed that the measurements would start on 22 November.

Measurements

The measurements were carried out at 10.5 GHz using a standard CW backscatter system in the anechoic chamber at our Willow Run facility. A block diagram of the system is shown in Fig. 1. The target was supported by a styrofoam pedestal placed on the turntable at a distance of about 35 ft from the common transmit/receive antenna, and backscatter patterns were recorded over the angular range $-30 < \phi < 30$ degrees, where $\phi = 0$ is looking directly into the duct. Before and after each group of measurements (and at other times if deemed desirable) a calibration pattern was recorded using a 10-inch diameter sphere whose cross section σ at 10.5 GHz is -12.9 dBm^2.

The first measurements were made on 22 November and we were assisted in these by Messrs Nielsen, Moore, Woodruff and Cruzen of Williams International. Patterns were recorded for the complete structure with the fan in different rotational positions to demonstrate that this had no significant effect. Additional patterns were taken with the model, consisting of the complete structure with the engine removed, and from time to time calibration runs were carried out using the sphere. It is worth noting that the variation throughout the day was less than ±0.5 dB. A total of 15 patterns and 5 calibration runs were performed using horizontal and vertical polarizations.

A second set of measurements was carried out on 2 December with the assistance of Messrs Nielsen and Woodruff. Using horizontal and vertical polarizations, 22 patterns and 13 calibration runs were



1. Power meter
2. Thermistor
3. Frequency meter
4. Test cable
5. Circulator
6. Termination
7. Klystron
8. Stabilizer
9. Phase shifter
10. Precision attenuator
11. Positioner
12. Crystal mixer
13. Microwave recorder
14. Pattern recorder
15. Positioner control

Fig. 1: Block diagram of the backscatter CW measurement system.

made for various blade and spinner combinations in the model. As on the earlier occasion, the raw data was immediately handed to the sponsor for evaluation. In the course of this evaluation, certain peculiarities were observed, and Messrs Nielsen and Moore visited the Laboratory on 14 December to discuss the data and its implications. It was concluded that the lip return was masking the effects that the experiments were seeking to measure, and Senior suggested a number of tests that should be made to verify this conclusion. The verification was provided by the measurements carried out on 21 December with the assistance of Messrs Nielsen and Woodruff. By covering the lip with a piece of 2-inch thick hairflex absorber it was shown that the lip was a major contributor to the scattering, and the effect of placing other pieces of absorber in the duct was also examined. A total of 20 scattering and 5 calibration patterns were recorded using horizontal and vertical polarizations.

Although the number of measurements (57 target plus 23 calibration, for a total of 70) was now at the maximum envisaged in our proposal, we agreed to perform a few additional ones in order to provide some meaningful results from the project. These measurements were made on 12 January 1983 in the presence of Messrs Nielsen and Woodruff. The measurements were all made with the lip treated with absorber and were confined to vertical polarization. The 23 scattering and 2 calibration runs were made with different blade and spinner combinations. As on the previous occasions, the raw data was immediately supplied to the sponsor.

Retrospective

It is our belief that the measurement program has not been fully successful for the purposes for which it was intended. This is due to a failure to appreciate an important feature of all scattering measurements: in the case of a complex target having many individual sources of scattering, it is impossible to display the true effect of reducing the scattering from a single source unless it is the dominant one by at least 10 dB, and remains the dominant one throughout the entire sequence of measurements. Thus, with a duct, it is necessary to ensure that the lip is so constructed or treated that it will not mask the effect of changes in the termination. This was not done in the present program and, as a result, the measurements have merely demonstrated that for an ill-designed duct geometry and/or lip it is not productive to seek a reduction in the scattering from the blades and/or spinner. In reality, however, such reduction would be desirable, and though it may not be the responsibility of Williams International to design a duct or its lip, the measurements must (if they are to be meaningful) employ a duct whose lip return is 20 dB or more less than that of a metal termination.

For a thin-walled metal tube of diameter d = 12 inches at a frequency of 10.5 GHz (wavelength λ = 1.12 inches), the maximum (on-axis) cross section that could be observed with a flat metallic plate termination is

$$\sigma = \frac{4\pi}{\lambda^2}\left(\frac{\pi d^2}{4}\right)^2 = 19 \text{ dBm}^2 .$$

For a realistic termination consisting of metal blades, etc, the likely return is somewhat less, and an empirical estimate that is often cited is

$$\sigma \simeq 0.4 \frac{\pi^3 d^3}{\lambda} = 10.8 \text{ dBm}^2 .$$

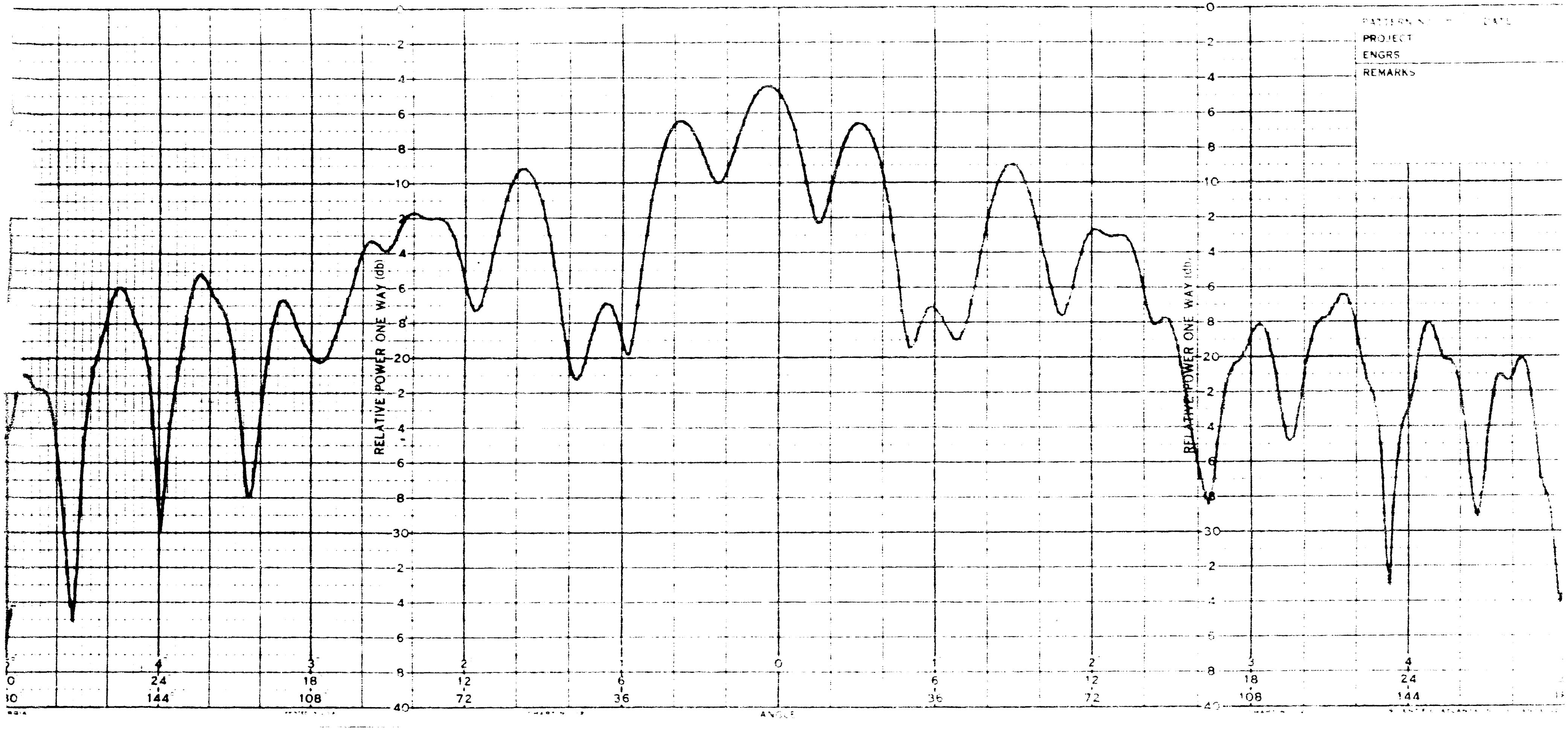
By contrast, the maximum return of a thin metal lip (treated as a wire ring) is

$$\sigma \simeq \pi \left(\frac{d}{2}\right)^2 = -11.4 \text{ dBm}^2 .$$

Thus, by using a thin-walled metal pipe as the duct, we would have the opportunity to demonstrate (and measure accurately) reductions of 10 or more dB in the scattering from the termination. It is our contention that this is the minimum that is needed to display the effect of improvements in the blade and/or spinner design; and consistent with this objective, the duct is, in fact, a "realistic" one. An even smaller lip return would actually be desirable, and this is not difficult to achieve using available technology. In contrast, for the duct that was actually used in the measurement program, the return of the lip considered as a torus of diameter d and "wire" radius b is

$$\sigma \simeq 2 \frac{\pi^3 b d^2}{\lambda} = 6.4 \text{ dBm}^2 .$$

This is so large as to nullify the objective of the measurements.



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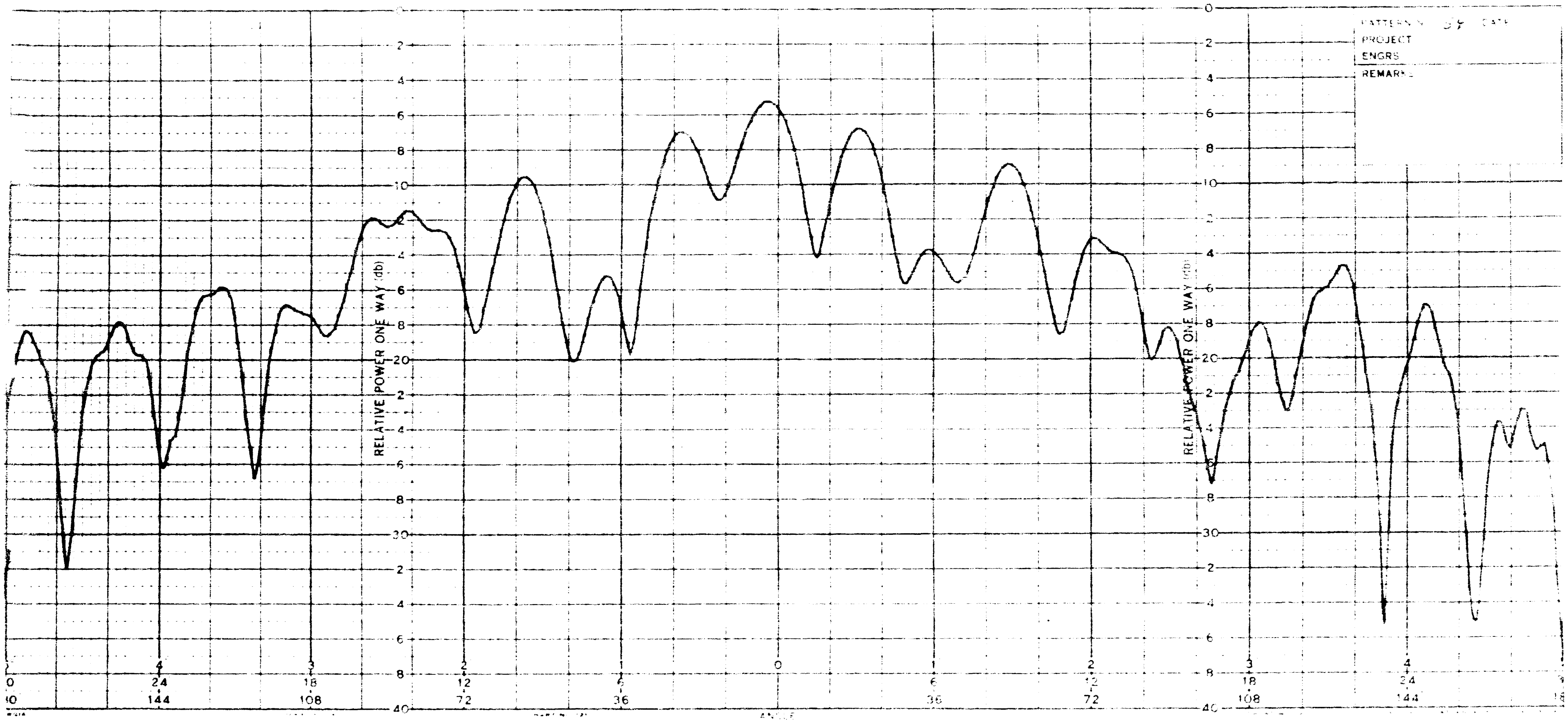
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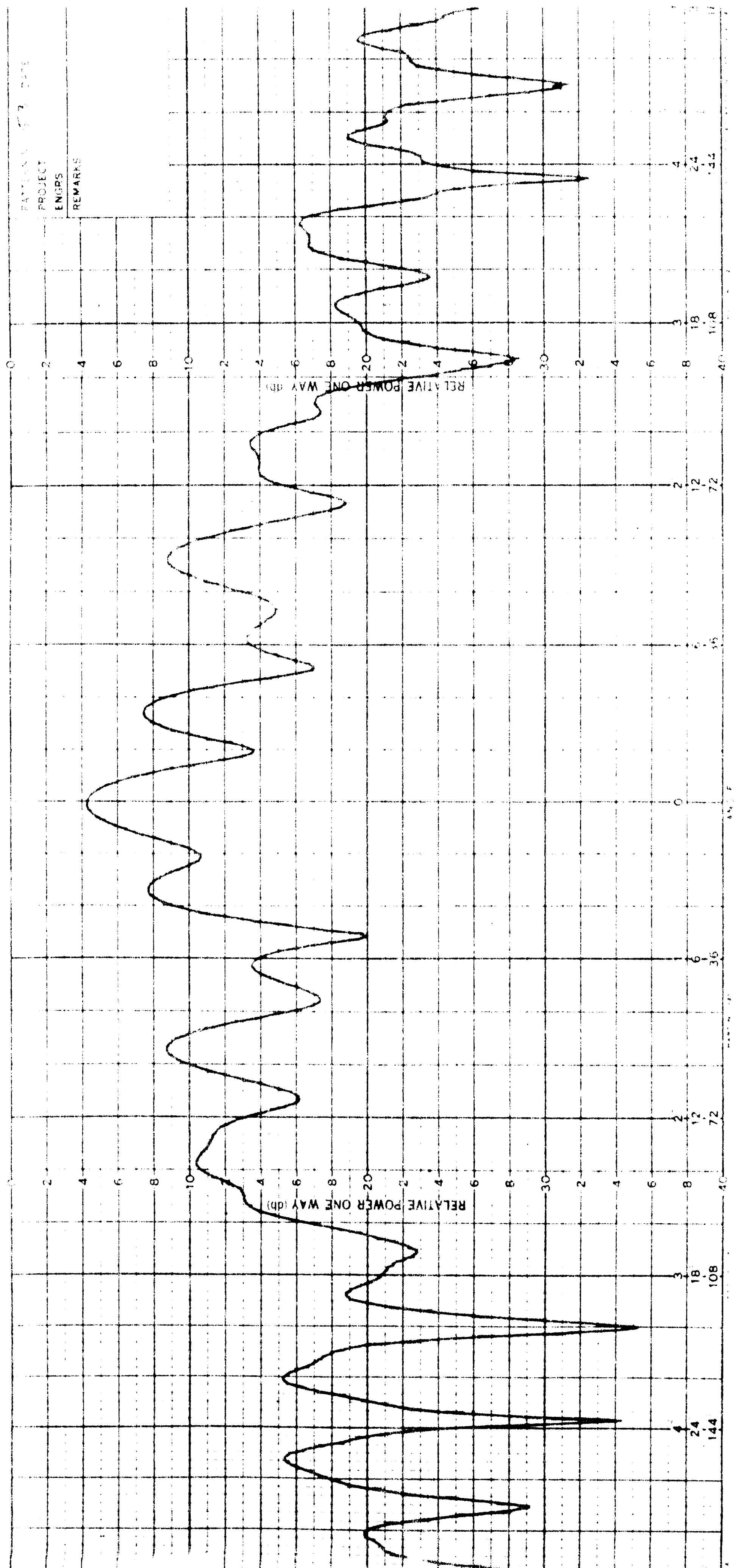
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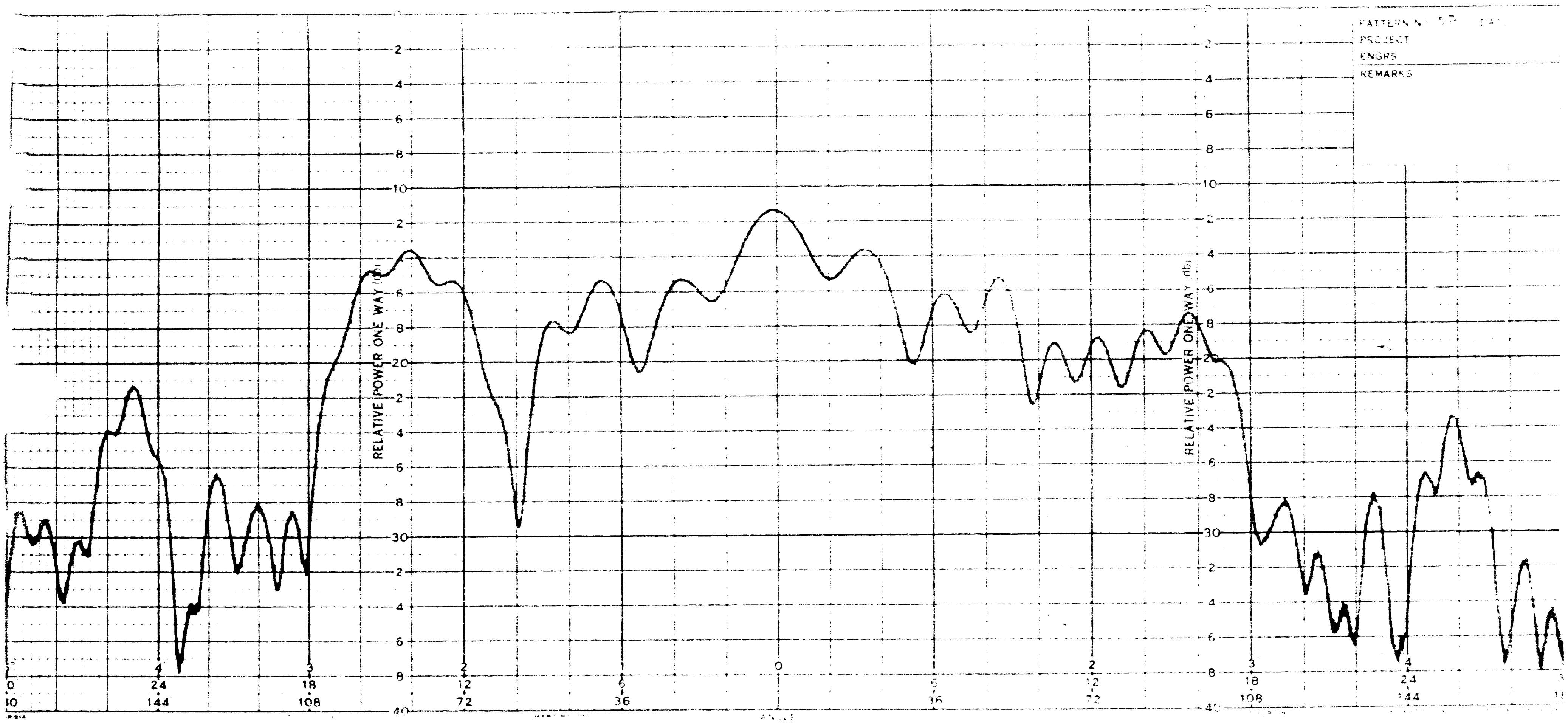
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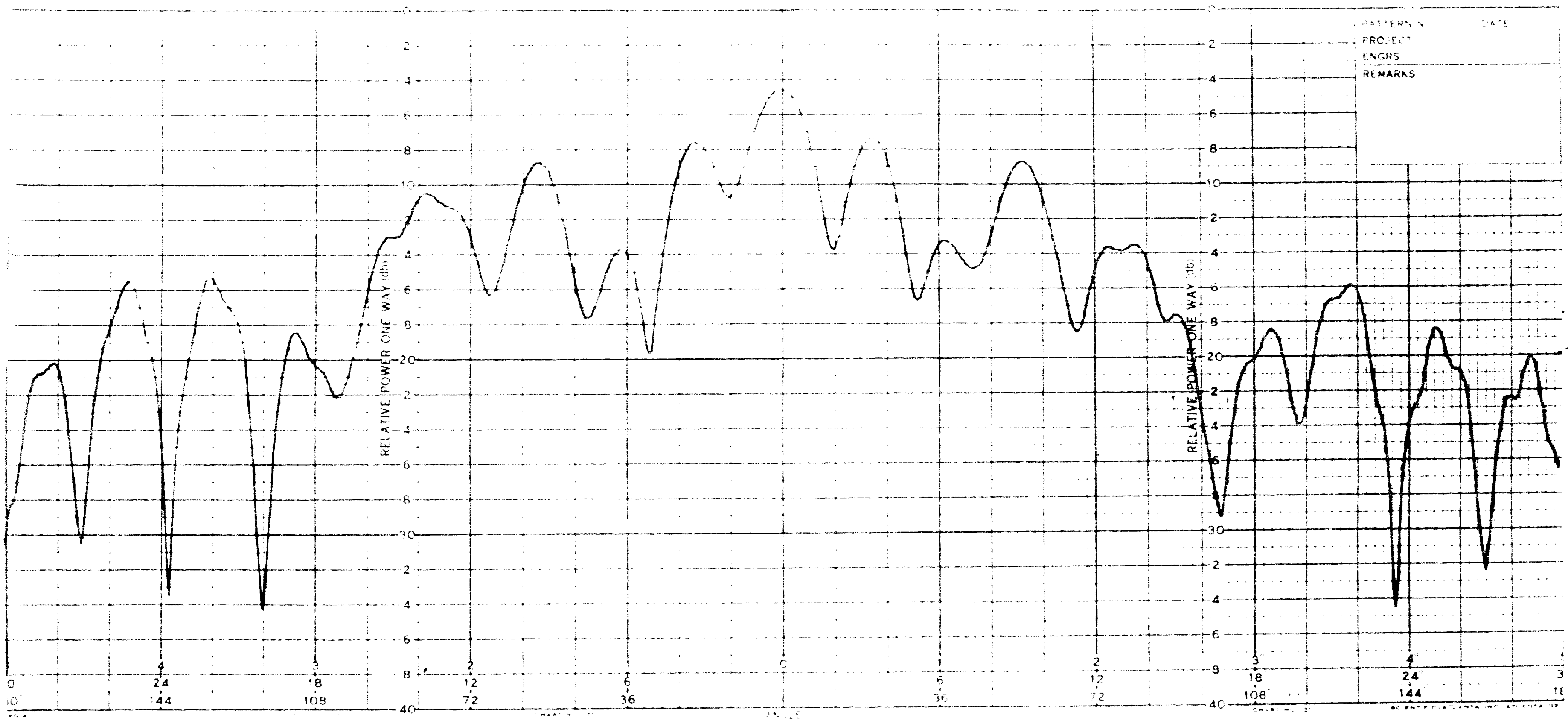
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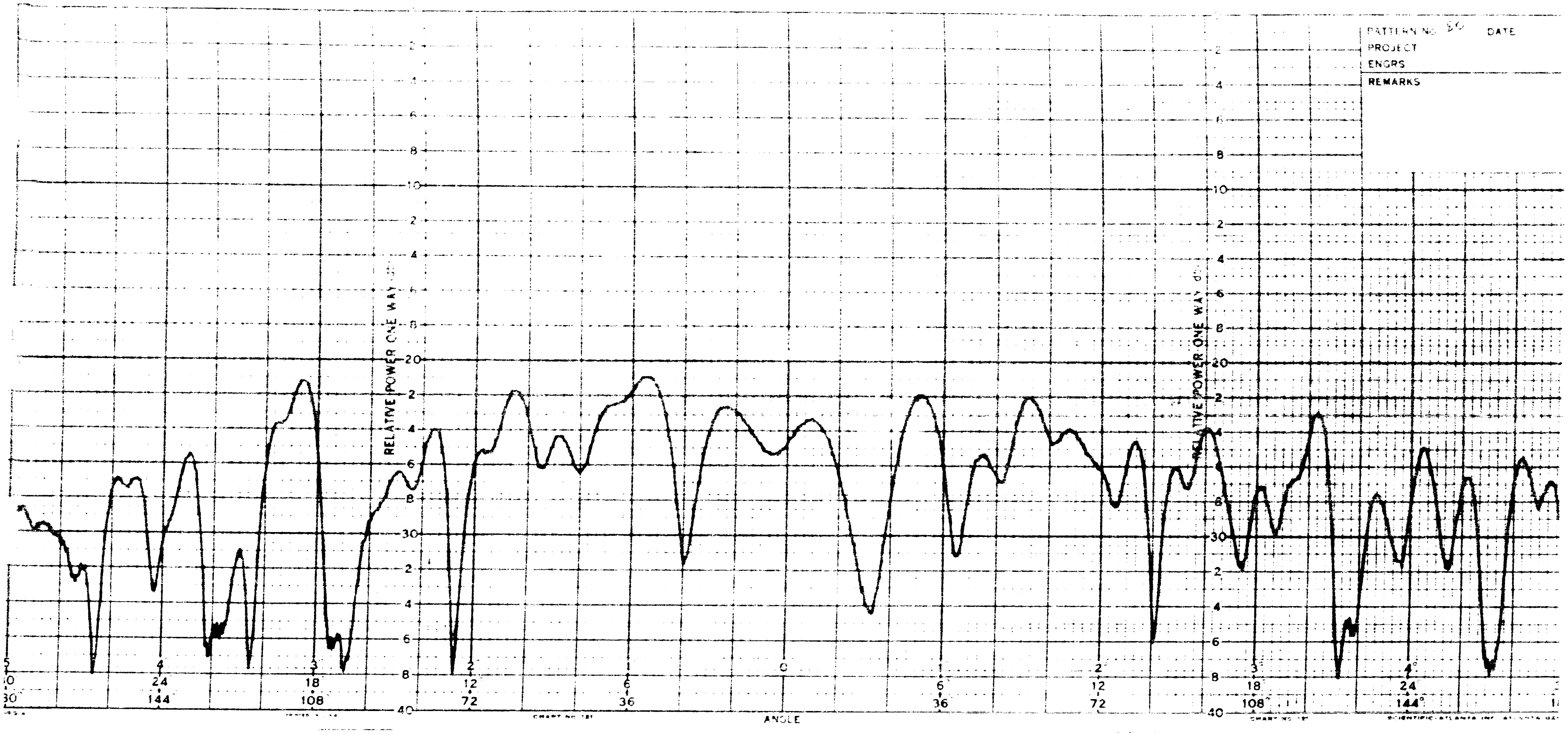
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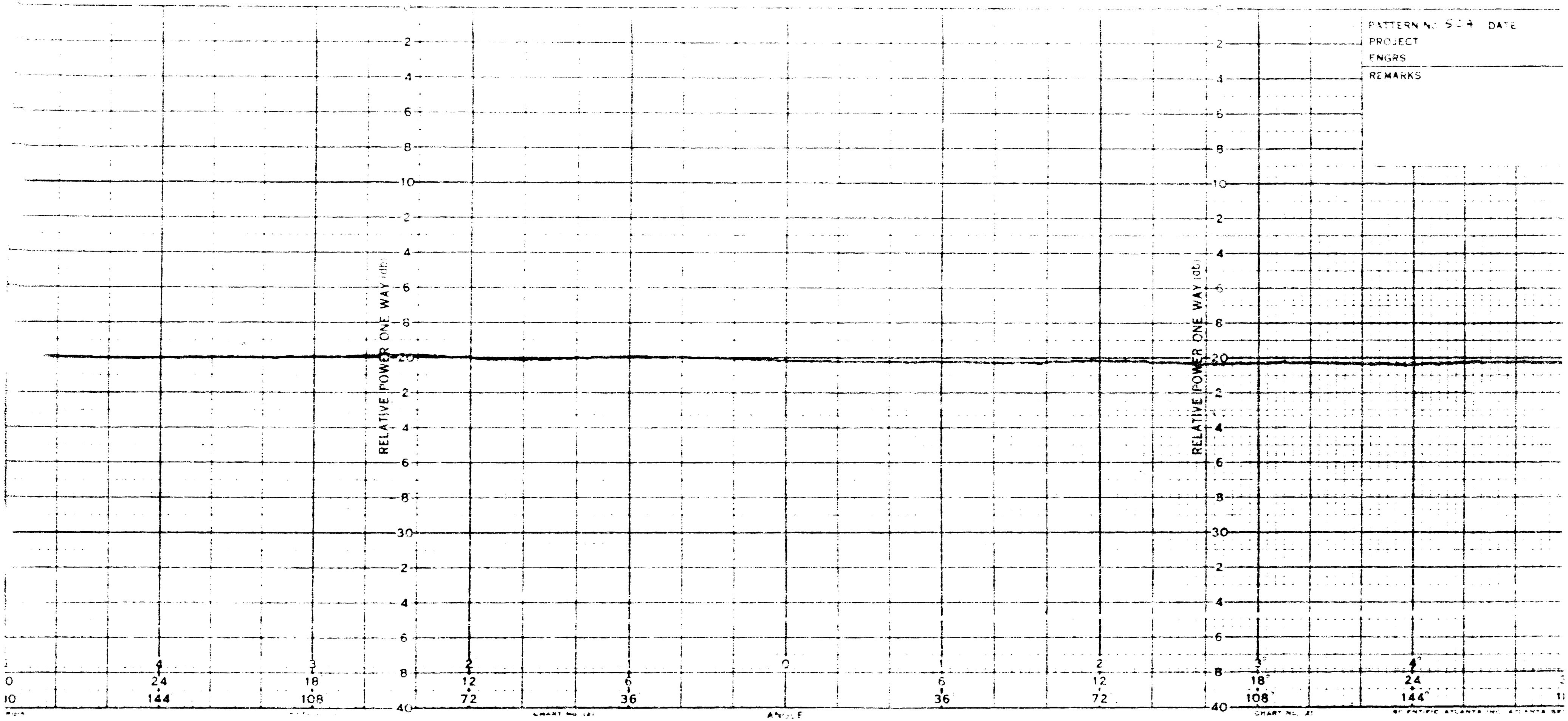

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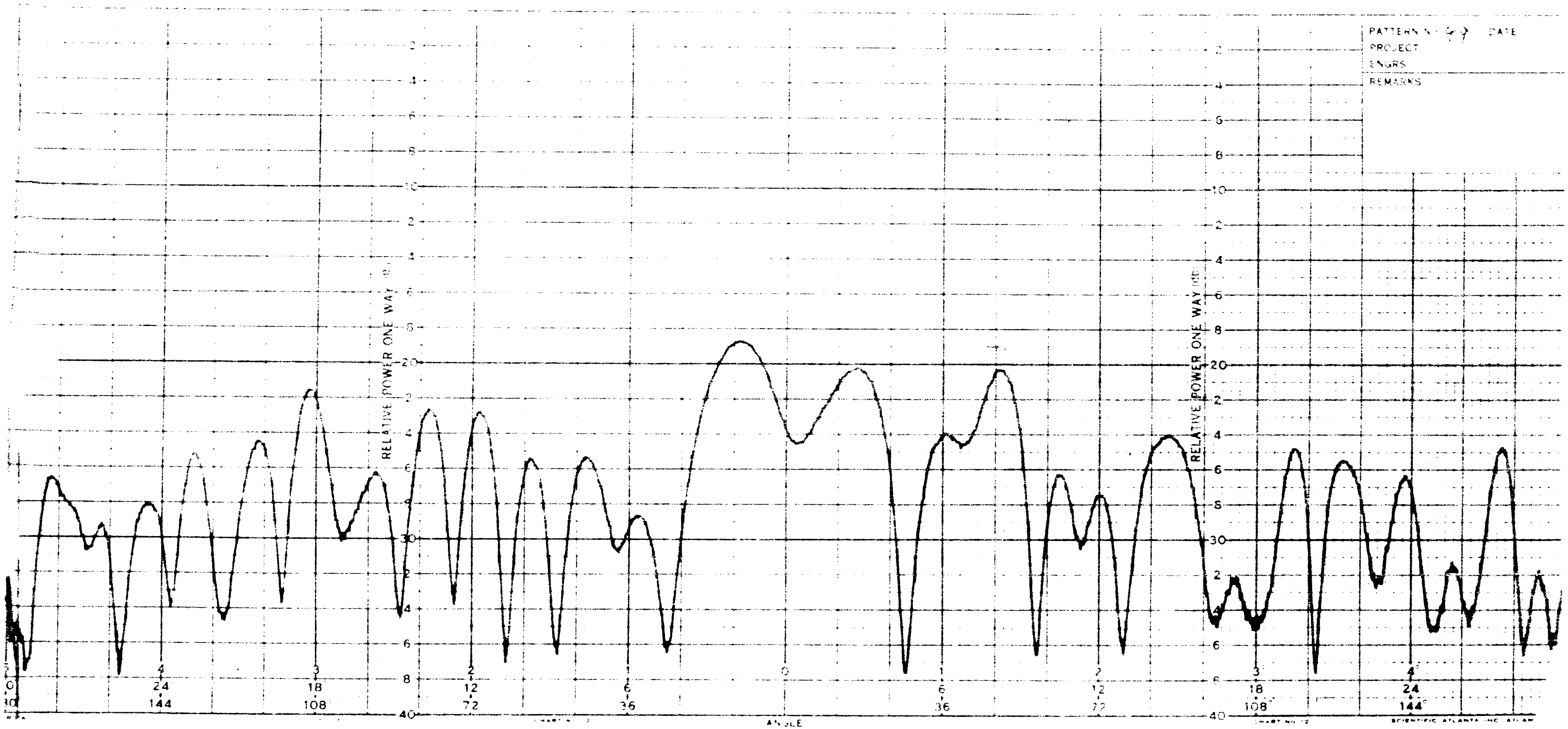
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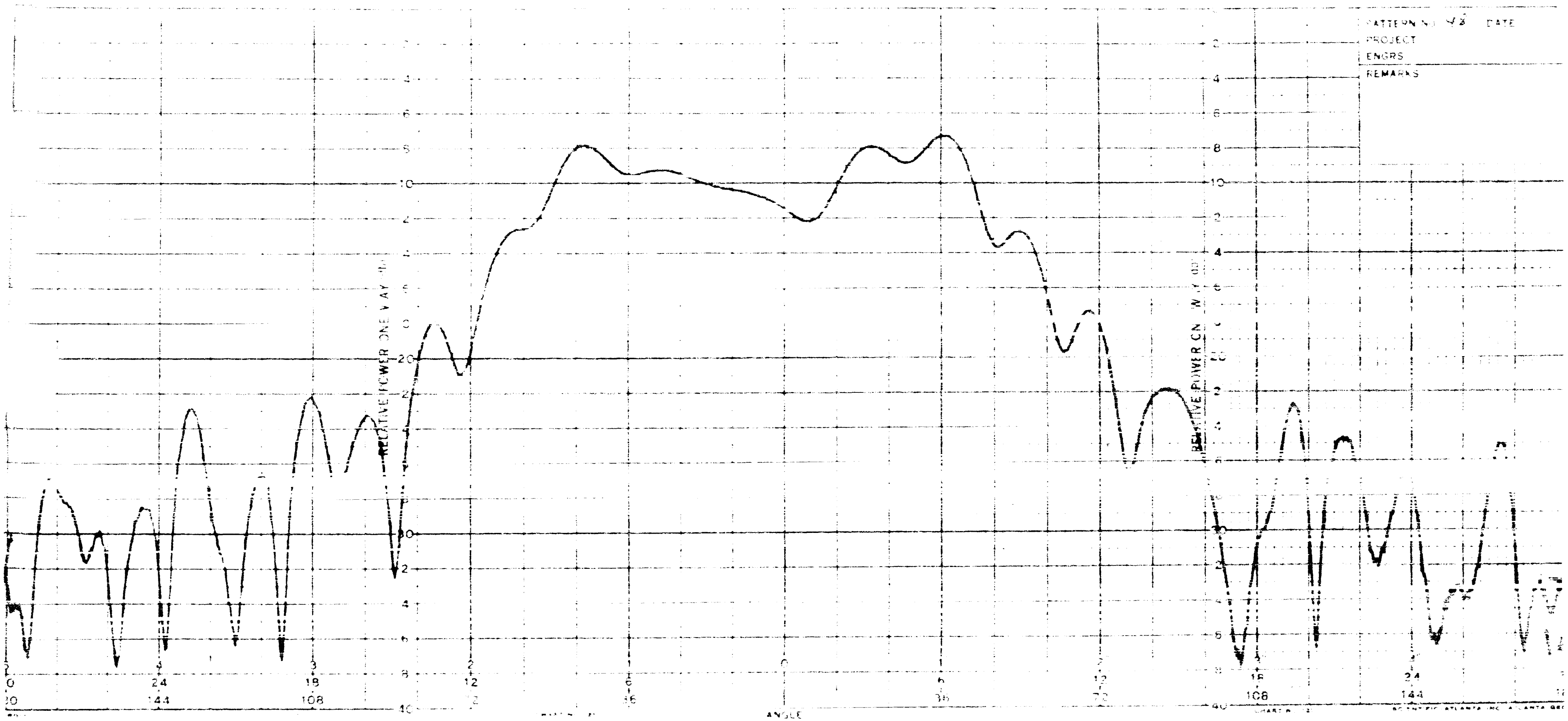
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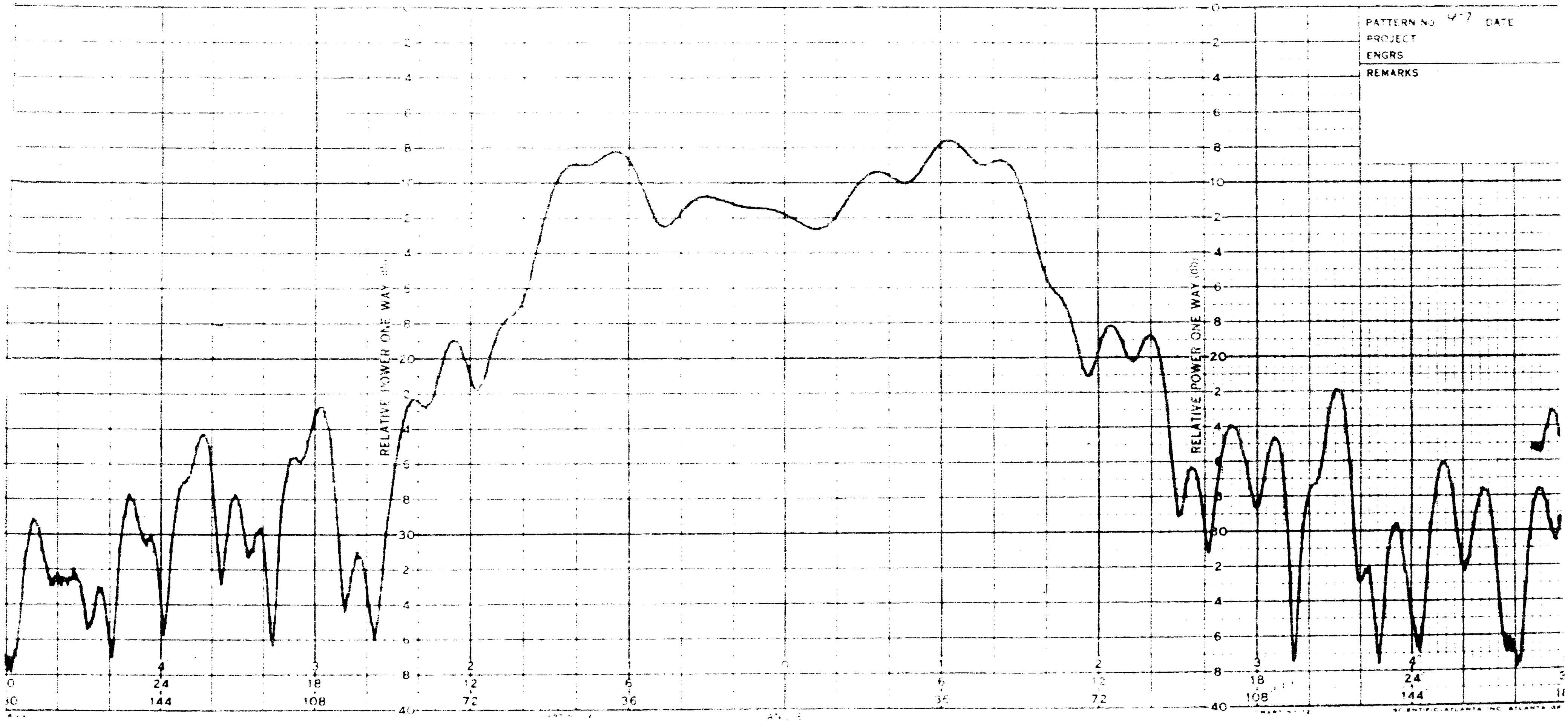

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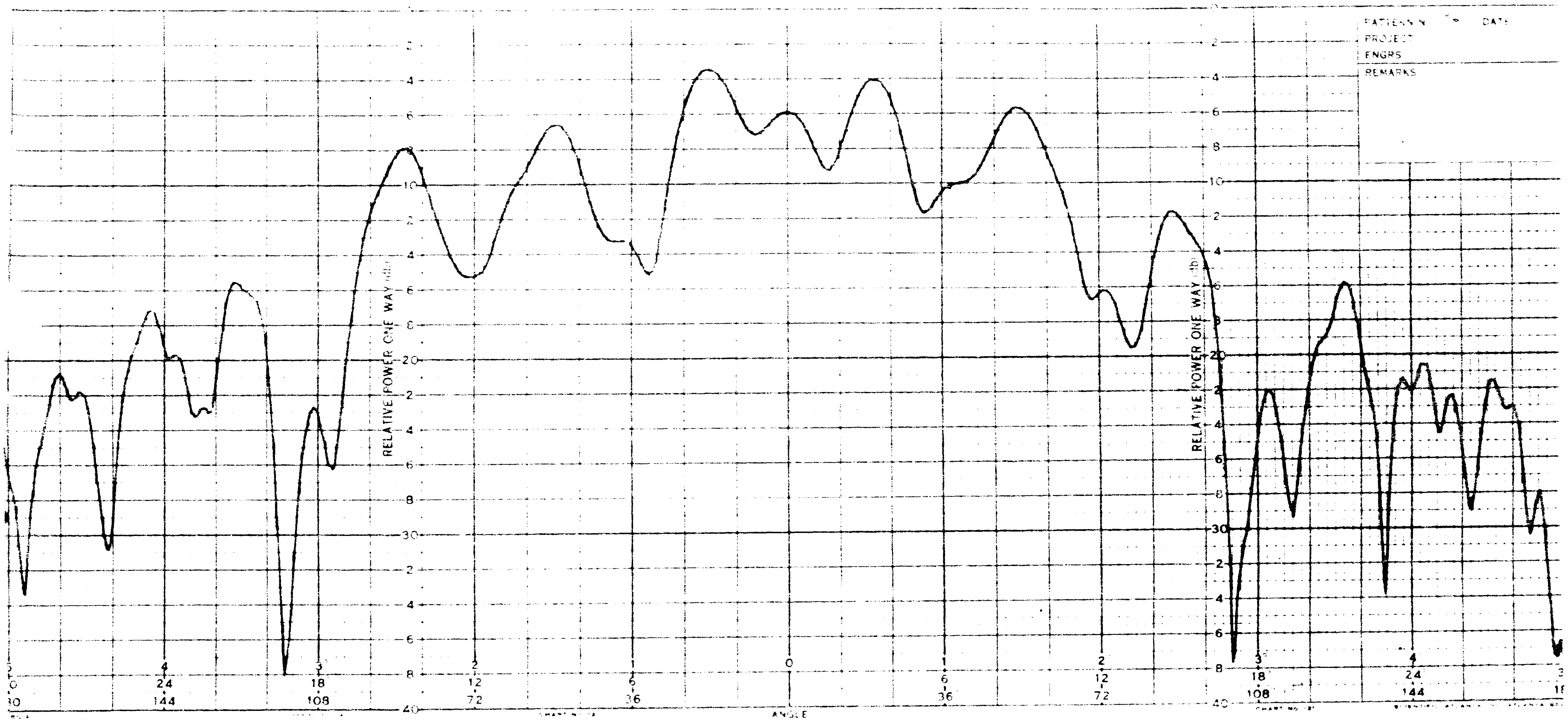

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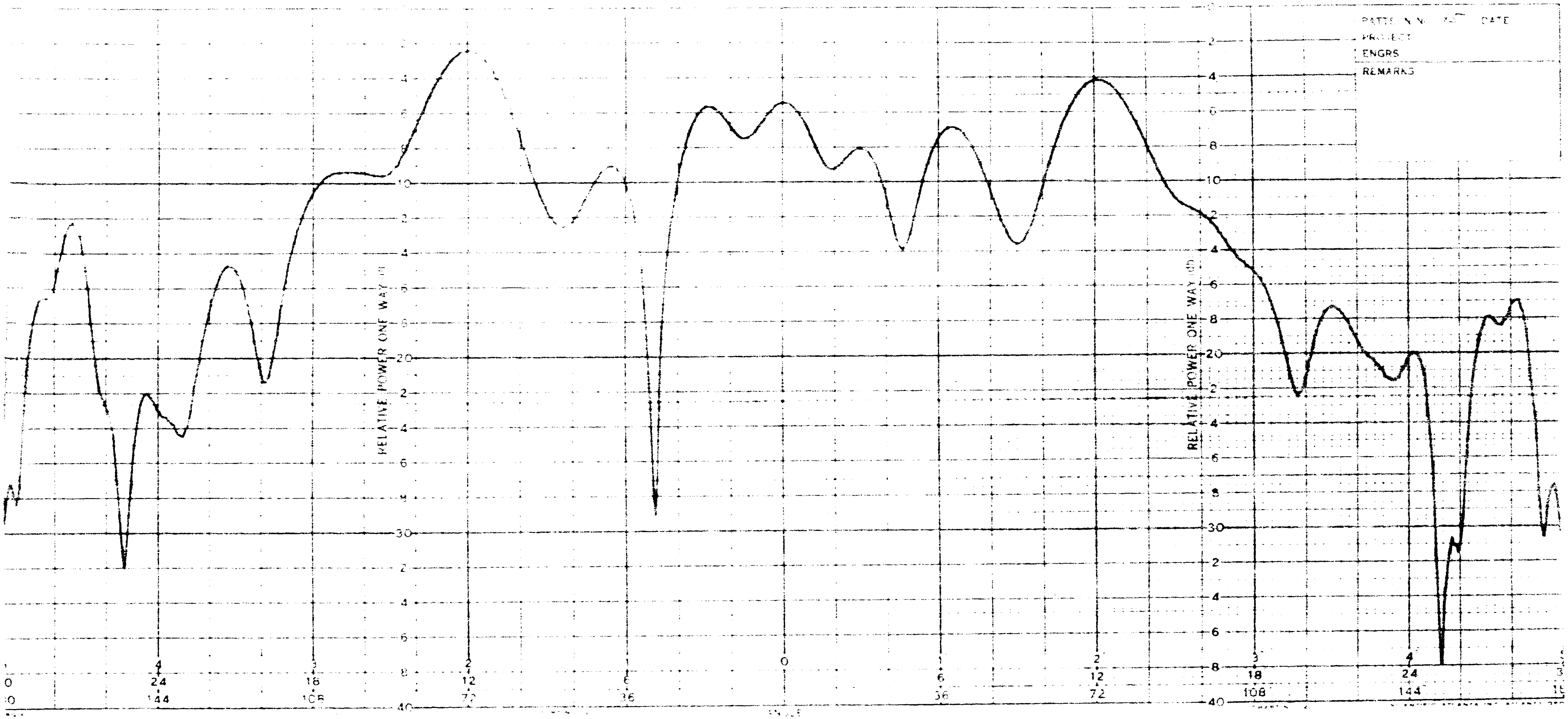
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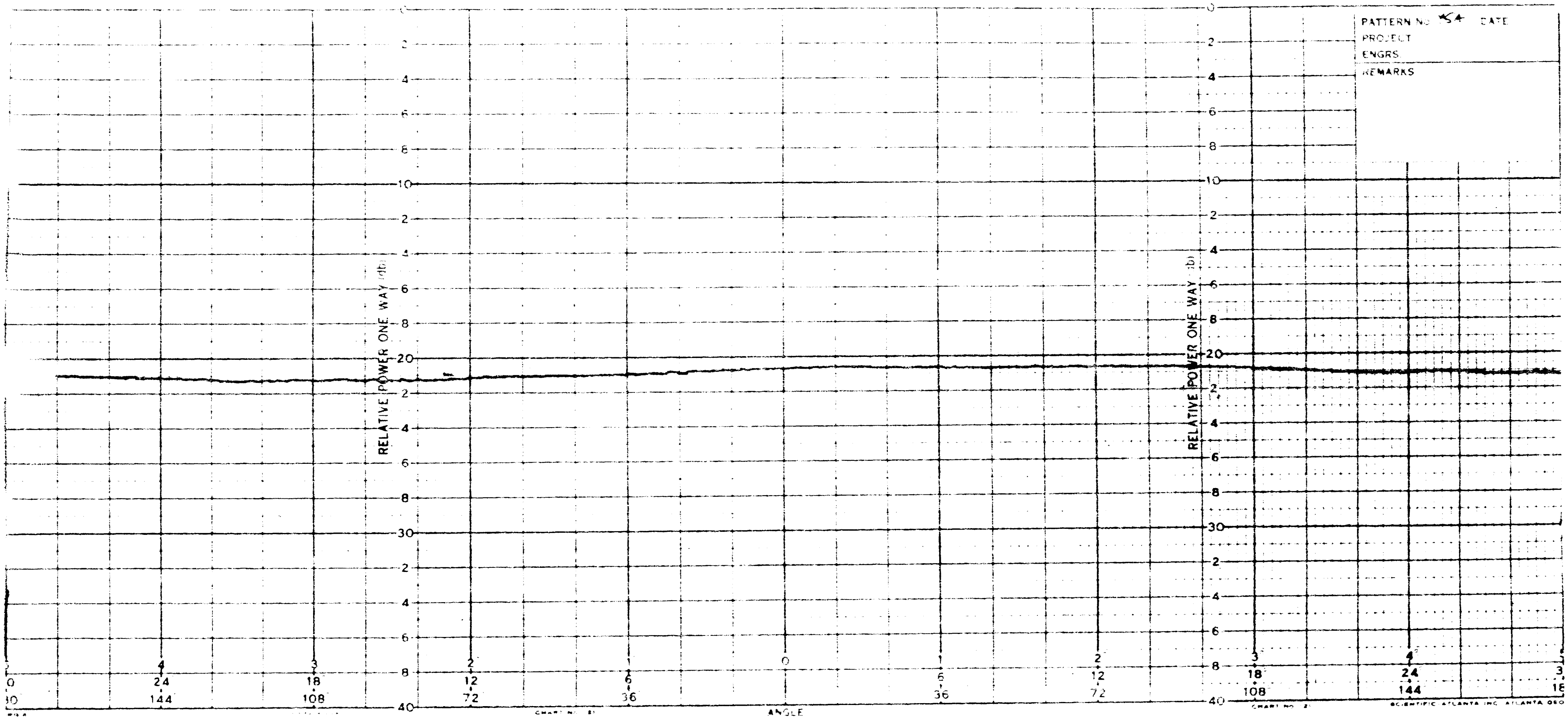

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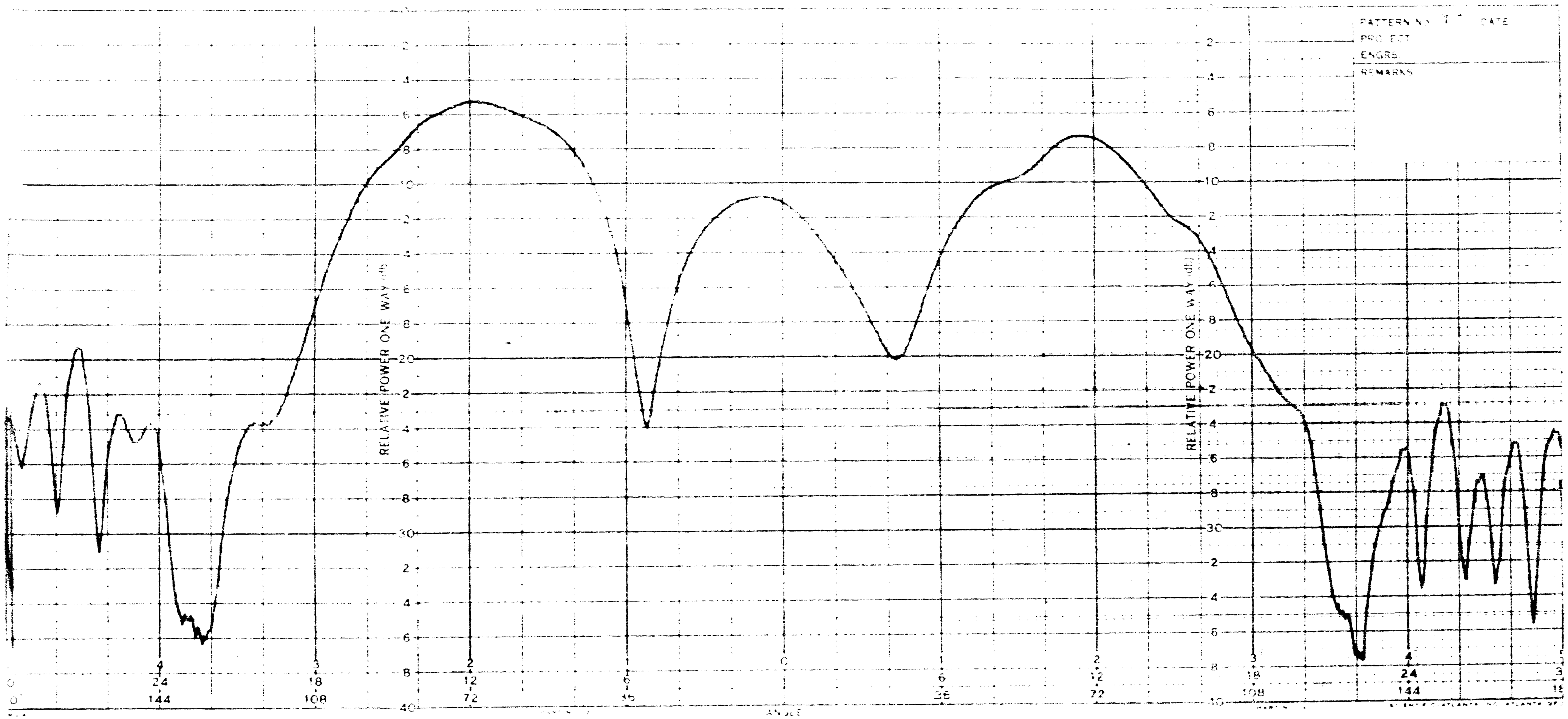
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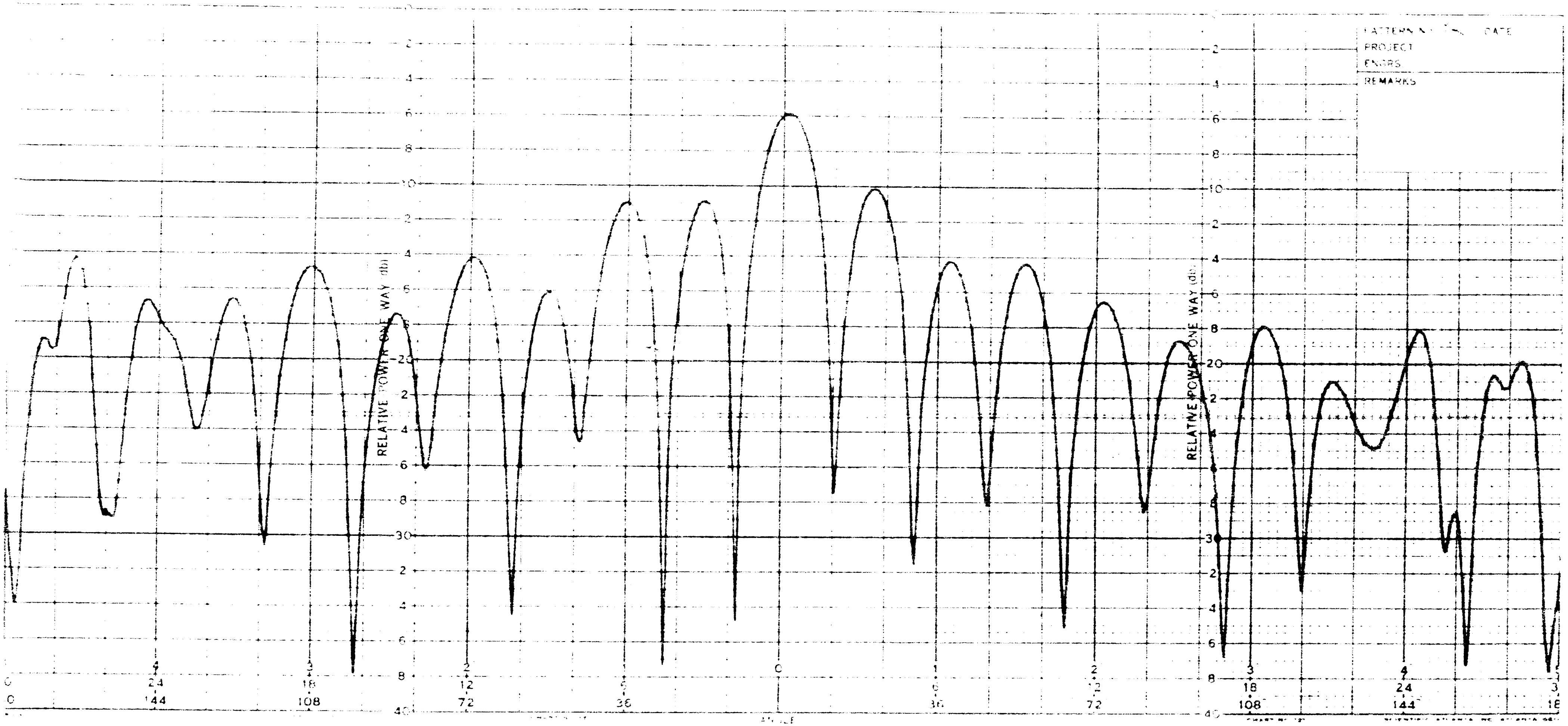
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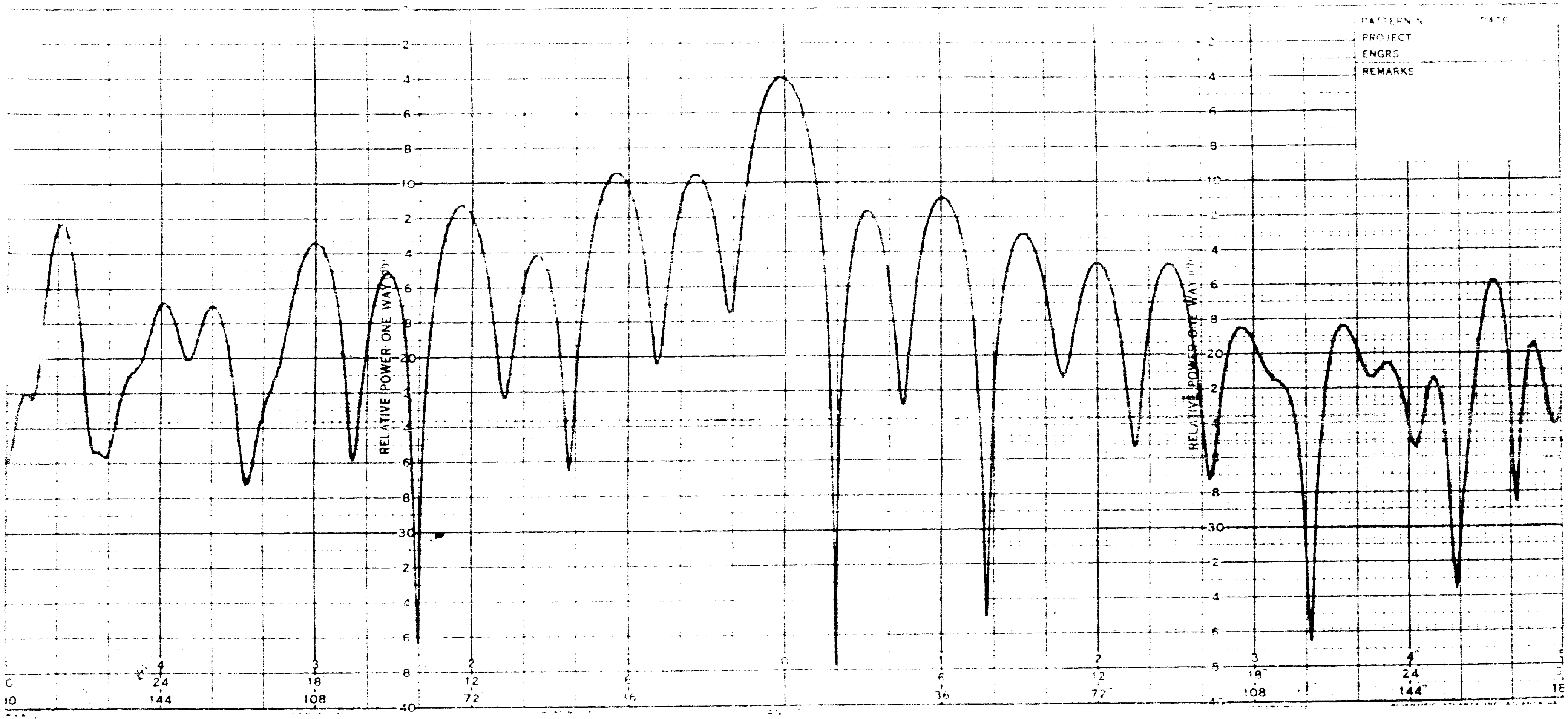
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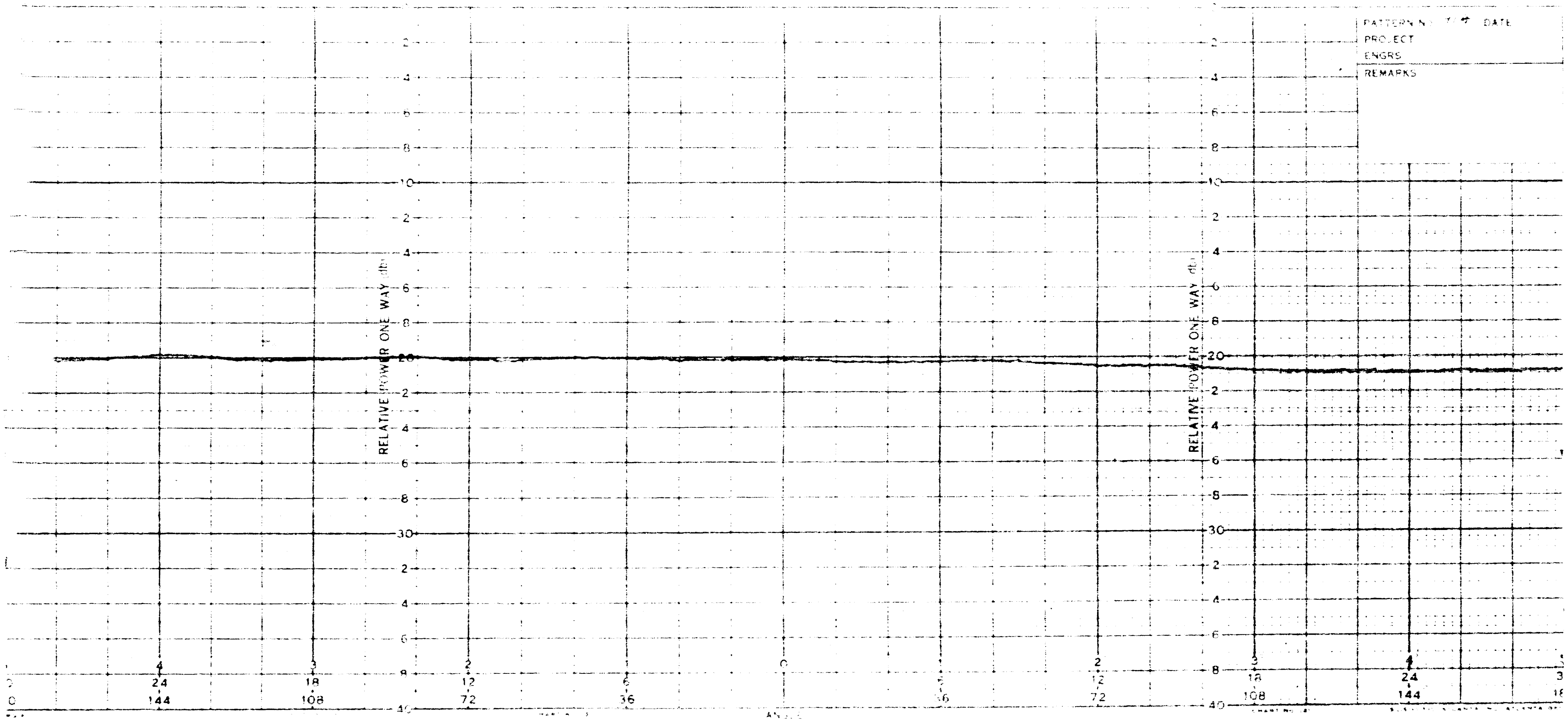

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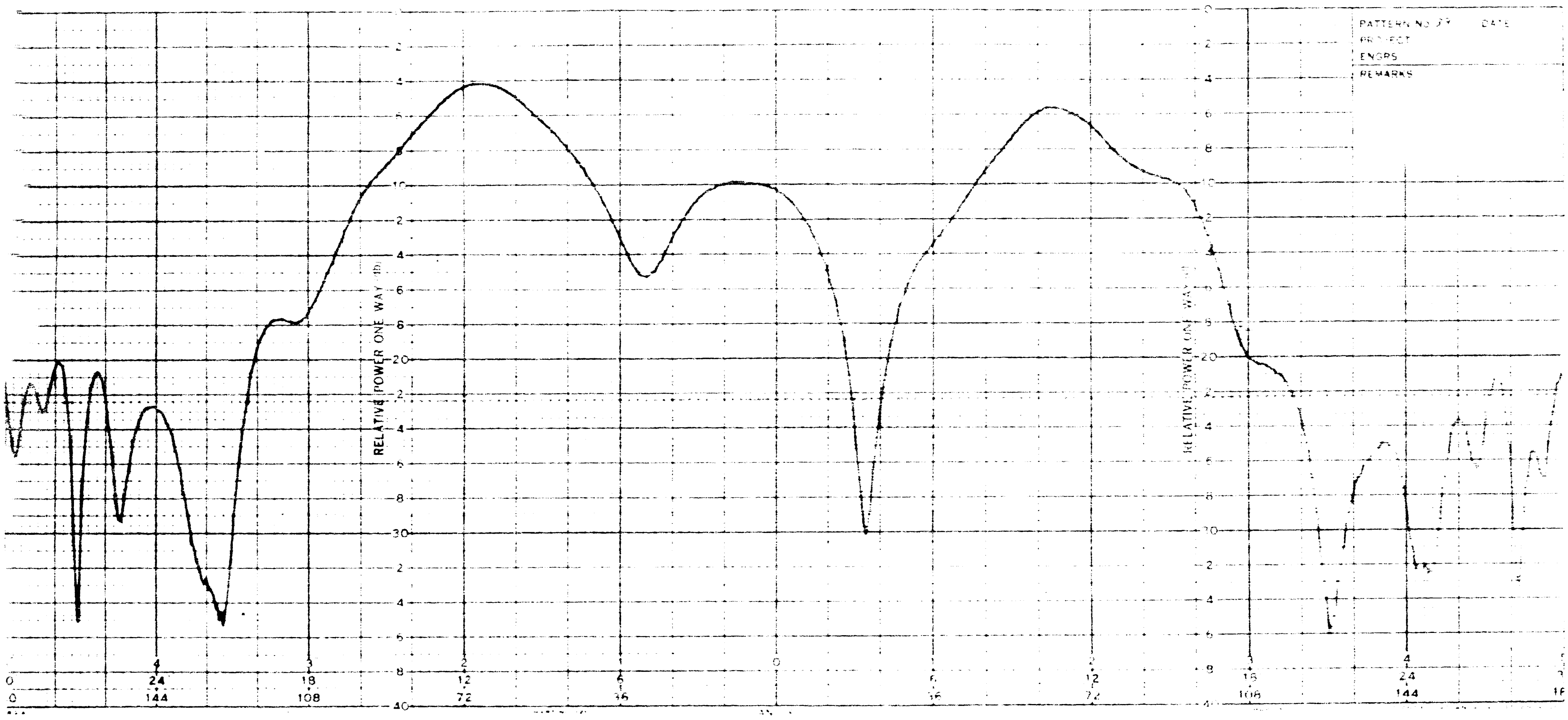
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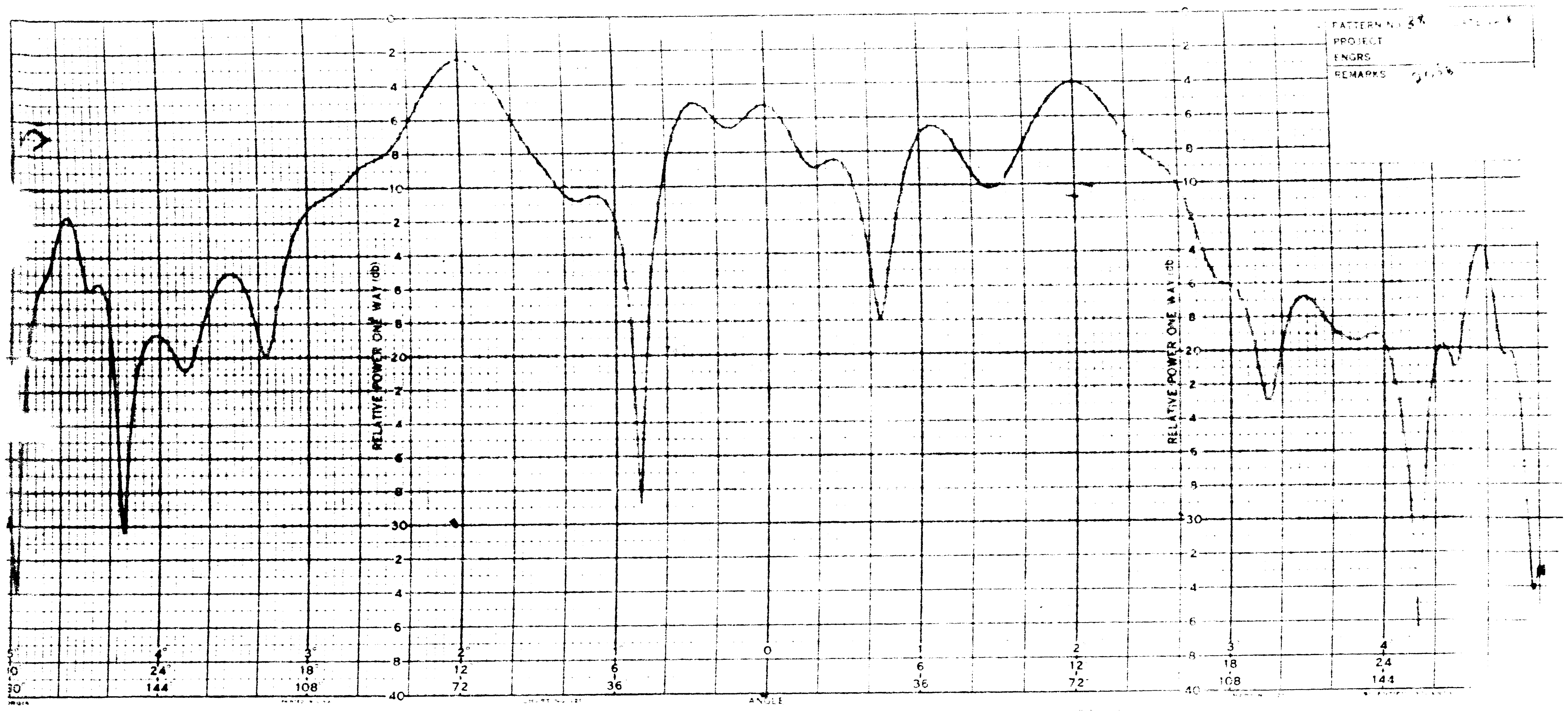
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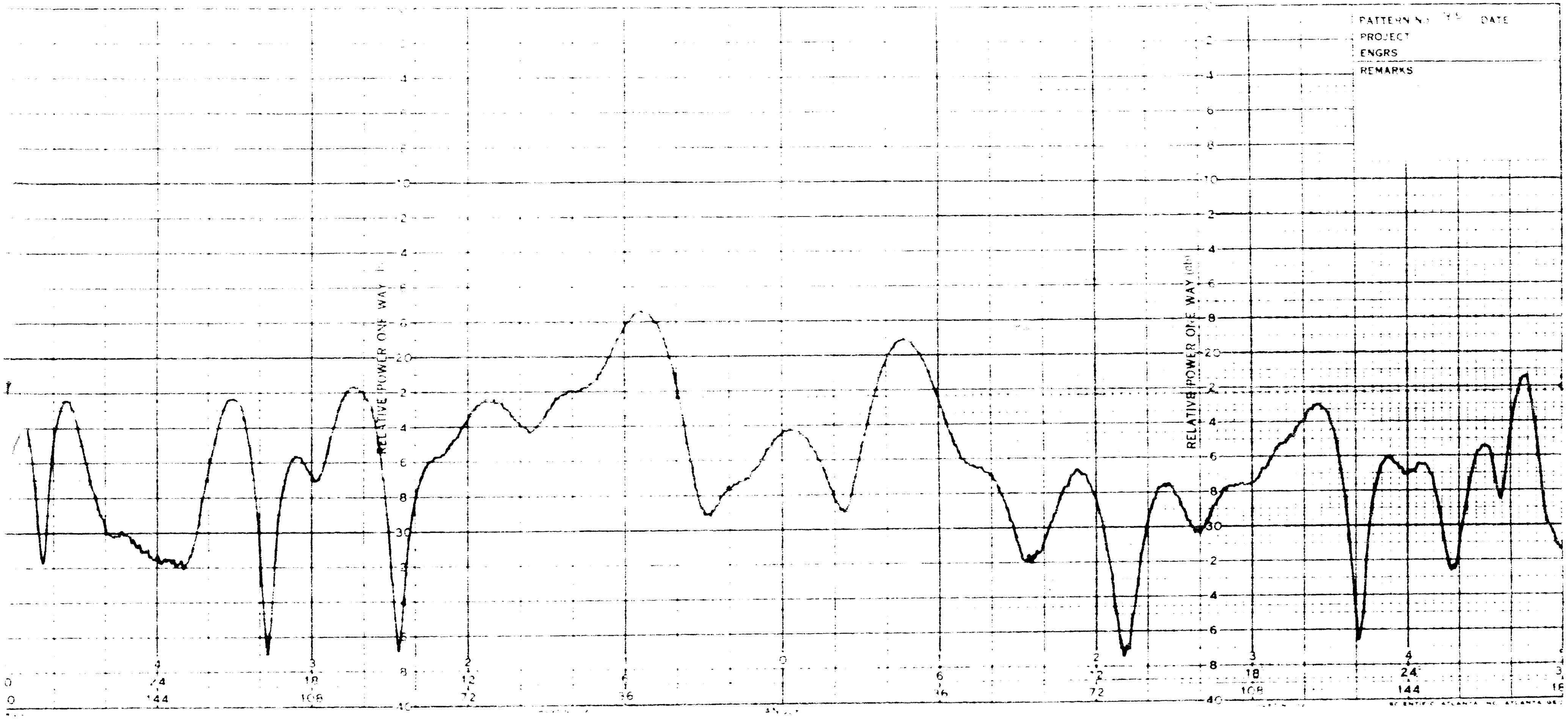

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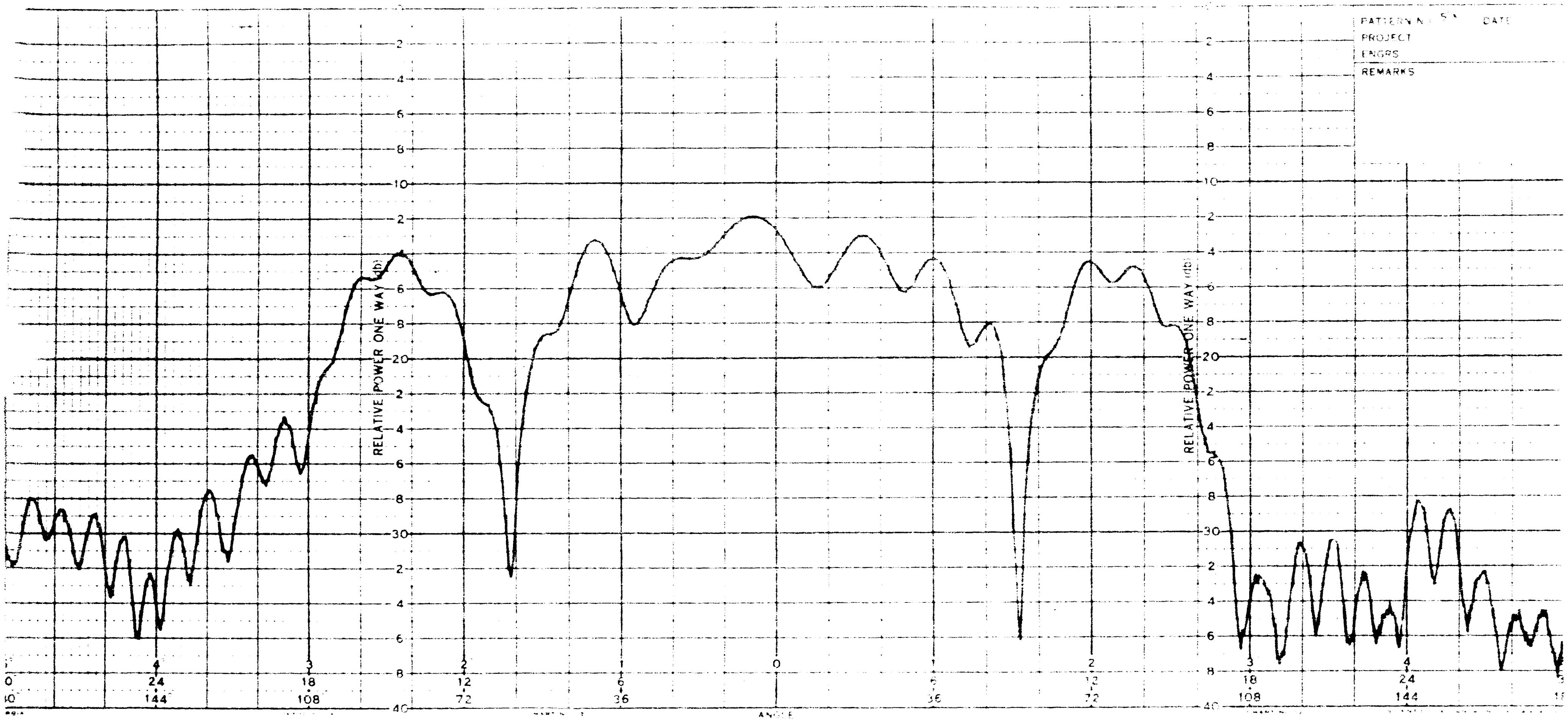
#	Polarization	Test Configuration
38	Vertical	Full Engine with a lined duct
39		Full Engine, Lined duct, Lip Shield
40		Absorber in front of engine, Lined duct, Lip Shield
41		Absorber in front of engine, Lined duct
42		Same as 41
43		Same as 40
44		Same as 39
45		Same as 38
46	Horizontal	Full Engine, Lined duct
47		Full Engine, Lined duct, Lip Shield
48		Full Engine, Lined duct, Lip Shield, Rear Wrapped in a
49		Absorber in Front of engine, Lined duct, Lip Shield, Rear Wrapped in a
50		Absorber in Front of engine, Lined duct, Lip Shield
51		PCC Model, Lined duct
52		PCC Model, Lined duct, Lip Shield
53		Same as 51
54		Same as 51, but moved forward 1/4"
55		PCC Model, absorber behind 2nd Fan, Lined duct
56		PCC Model, absorber behind 2nd Fan, Lined Duct, Lip Shiel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