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MARY DYNAMIC NULL STUDY

October 2, 1968

FROM: L. H. Baker

TO: M. H. Arck,
Mgr., Beta S/S Engr.

cc:
F. Millis
T. Emory
S. Hobbs

M. Schiffman
J. Holmes

F. Woestemeyer
J. Cavanagh
D. Reid/F. Niedz

50357-98-5

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MARY DYNAMIC NULL STUDY

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SUMMARY

A model scene is used both analytically and experimentally to explain the manner in which the Hycon IVS works, and to show the nature and cause of the dynamic null and dropout phenomena. The analysis is extended to the more general case of a standard scene and the prediction made that reducing the number of chopper cycles within the field of view would allow a longer departure from nadir without experiencing the dynamic null effect. Runs were made with Mary on the Beta Open Loop tester with a reduced aperture and the prediction confirmed. Based on a limited number of runs the percentage of time that Mary is out of spec. for zero obliquity cases between +20 and -30 degrees stereo is reduced from 17.3% for the 2.8 inch aperture with Gaussian shading to 5.7% for a 1/2 inch aperture.

It is strongly recommended, because of the seriousness of the dynamic null problem to the performance of the Mary sensor, that time be scheduled on the open loop tester as soon as possible after the Mary EPEM unit is received (due Oct. 8) and checked out, for the purpose of determining the best aperture size and location for use in the EPEM unit, and that this aperture be implemented, and all evaluation tests be run with the reduced aperture as well as with the Gaussian shaded aperture.

It is estimated that one day, possibly including some overtime, will be sufficient for obtaining the information needed to make the recommended aperture size determination.

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Mary Three Square Analysis and Test

As an aid to understanding the working of the Hycon IVS, consider a scene composed of three white squares on a black background, sized so that at the nadir position each square is equal in width to one clear or dark space on the Mary chopper, and such that one square is at the center of format and the others at five full chopper cycles on either side of the center of format.

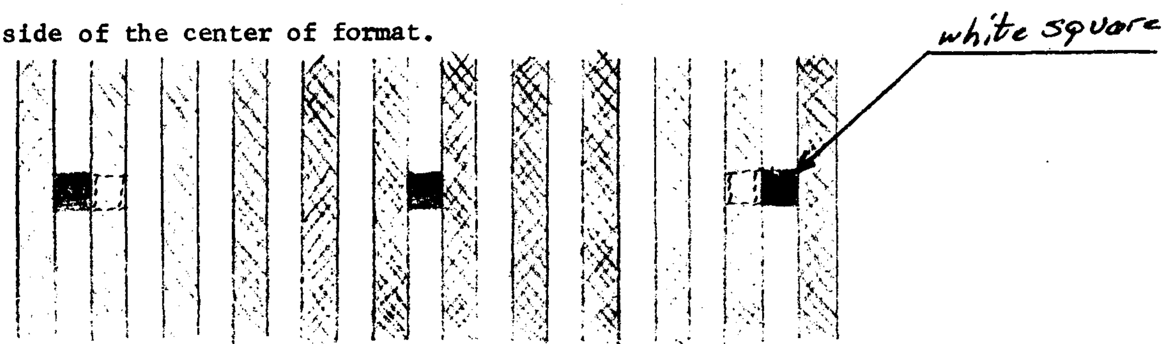


FIGURE 1

The superimposed chopper and scene pattern at nadir will then appear as shown in Figure 1. We will now assume a constant demagnification of the scene and examine the resultant instantaneous signal outputs from the photomultiplier for successive stages of demagnification. This will correspond in the real world and the Beta tester to vehicular orbital movement from the nadir position. For small angles we will ignore the asymmetrical effects of the real world and tester cases, and the concurrent decrease in size of the squares, since these are second order effects and as will be evident later, do not affect the results of this study.

If we now assume the movement of the chopper across the scene, the modulated light signal input to the photomultiplier, and thus the electrical output will have the form shown in Figure 2, m=1, where m is the relative scene magnification. The waveforms for m=.99-.95 are also shown in Figure 2. All curves are shown with the ac component normalized to the same scale & the dc component eliminated.

The Mary Sensor processes the waveform output of the photomultiplier by extracting the fundamental frequency component and comparing its phase with the phase of a generated reference signal at the same frequency. Since the rate of change of phase of the scene signal relative to the reference signal is directly proportional to scene velocity, the sensor then outputs a voltage proportional to the measured rate of phase change.

If we examine the curves of Figure 2 fom m=1.00 to m=.95, it is evident that no change takes place in the phase of the fundamental, and therefore the sensor should give no velocity indication. This is confirmed by Fourier analysis.

A similar examination of the curves of Figure 3 for m=.95 to m=.90 yields different conclusions. In this interval, the phase of the fundamental has shifted by one-half cycle and the sensor will interpret this as a scene velocity. In fact, a Fourier analysis shows that the phase of the fundamental shifts 180° in the interval between m=.94 and m=.93. This is a striking example of the phenomena referred to as the "Mary dynamic null error".

It is obvious from Figure 1 why this scene phase shift should occur. A demagnification of .90 corresponds to the dotted location of the outer squares, so that each square is 180° out of phase with the center square. Either outer square will cancel out the center square, and the output signal is being generated solely by one outer square. It is also obvious that as the demagnification continues, at m=.80, all squares will be in phase again, and another 180° signal phase shift will have occurred, and so on for m=.70, .60, etc.

Referring again to Figure 3, it appears that somewhere between m=.94 and m=.93, the PMT output waveform will have zero amplitude of the fundamental frequency component. This then is an example of what has been referred to as "Mary dropout", since, as previously mentioned, the fundamental frequency component is the only one used by Mary in her signal processing. Due to the symmetry of the pattern, it is probably not unreasonable to expect somewhat similar signal behavior at the other null shift points predicted. The relative amplitude of the fundamental as a function of m obtained from a Fourier analysis is shown in Figure 4.

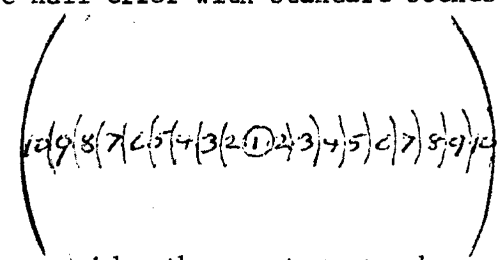
A test was made on the Beta Open Loop tester to support the preceeding analysis and the recorder outputs from this test are shown in Figure 5. The scene setup was an exact duplicate of Figure 1. The sensor was run down the track in the zero obliquity condition with zero X and Y axis input velocity, so that ideally both axes should read constant zero velocity. As predicted by the analysis, the X-axis does not.

The dynamic null and dropout points (all coincident) occur at angles of $\pm 14.6^{\circ}$, $\pm 27.3^{\circ}$, and 33.2°. Since the magnification in the in track direction is directly proportional to the square of the cosine of the angle from nadir, these positions correspond to magnifications of .936, .794, and .700 which is in excellent agreement with the analytical predictions. This same pattern, using circles rather than squares, was analyzed in ref.1, and similar results predicted.

The appearance of the dynamic null run, except for its extreme symmetry, is quite similar to the majority of runs made on standard scenes, that is, the flat portion from nadir out to 15 or 20 degrees, then repeated excursions from null.

If we make the assumption that the dynamic null error that occurs with standard scenes is caused by the same effect as that occurring with the three square scene;namely, a phase shift of the total scene modulation signal due to scene demagnification, then we can attempt to use the insight gained from this analysis to predict the occurrance of dynamic null error with standard scenes.

FIGURE 6



For a first attempt, consider the aperture as shown in Fig. 6 , divided into equal zones along the X direction. As the scene is demagnified to the point where zone 6 has shifted phase relative to zone 1 at the center, then zone 7 will have shifted an equal phase relative to zone 2, zone 8 to zone 3 and so on. The outer half of the scene will then have shifted phase relative to the inner half, and encompassing more area, should dominate the scene as the two outer squares did in the model and produce a phase shift of the scene modulation signal. Points entering the field of view on either side of the aperture, due to aperture sizing, will be out of phase with those entering on the other side, and should tend to cancel each other. In any event, points at the edge of the field are heavily deweighted by aperture shading or defocussing, and will not contribute to the location of the first phase shift in most cases.

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Pursuing this somewhat less than rigorous argument, since the Hycon sensor contains 28 full chopper cycles within the 28 inch aperture, the point halfway from the center to the edge, corresponding roughly to zone 6, is 14 half cycles from the center. To shift this point one half cycle, a demagnification of $13/14=.929=(\cos^2)^{-1}$ of 15.4 degrees, is needed. It is interesting to note that a large majority of dynamic null runs with the Hycon sensor shows the first null error between 15 and 20 degrees on either side of nadir. Given this correlation, we can stretch the theory yet further to predict that the fewer the number of chopper cycles within the aperture, the further from nadir the first null error would appear. For example, if the aperture contained 10 cycles, the halfway point would be five half cycles from the center, and would require a demagnification of $4/5=.80=(\cos^2)^{-1}$ of 26.6 degrees for a half cycle phase shift.

The easiest way to reduce the number of chopper cycles within the aperture for the Hycon sensor is to reduce the aperture. This was done on the Beta Open Loop tester, with the results shown in Fig. 7 thru 10. The traces produced have been measured and two important parameters are shown in Table 1 for the various apertures; the percentage of time the sensor was out of spec.(.01 ips) between +20 and -30 degrees, and the average distance from nadir of the first departure from spec.

TABLE 1

aperture	2.8" Unshaded	Standard Shaded	Gaussian Shaded	1"	1/2"
percent of time out of spec. from +20° to -30°	29.2	25.3	17.3	8.5	5.7
average distance from nadir of first departure from spec.	11.3°	15.5°	16.3°	24.1°	29.7°

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In Table 1, the results given for the standard aperture are based only on one run. In general there appears to be little if any difference in performance between the standard and Gaussian apertures, but the Gaussian is preferable because of its construction.

Based on a limited number of runs it seems evident that reducing Mary's aperture increases null tracking accuracy. The trend towards longer error free dynamic null runs as the aperture is reduced is definite and consistent. Even the improvement shown by the standard and Gaussian shaded apertures over that with the unshaded aperture could be attributed to the effective aperture reduction caused by the shading.

The primary trade-off involved in aperture reduction is decreased signal to noise ratio because of the decreased scene input. This is, however, an area in which Hycon is in good shape and can afford to make trade-offs. There would be a favorable trade-off in the size and weight area, since the optics and its support structure now accounts for more than 75% of the sensor head weight, and a substantial reduction could be made if the aperture were reduced.

The writer recommends that one to two days of Beta Open Loop tester time be allocated for the determination of the optimum aperture configuration for the Hycon EPEM as soon as possible after it is received (scheduled for delivery October 8). This aperture could then be implemented and all EPEM evaluation testing done with it, as well as with the Gaussian shaded aperture.

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REFERENCES:

1) "Mathematical Model of Mary IVS with Test Results and Computer Simulation" PIR 7170-MOL-3639, May 23, 1968, I. Livingston.

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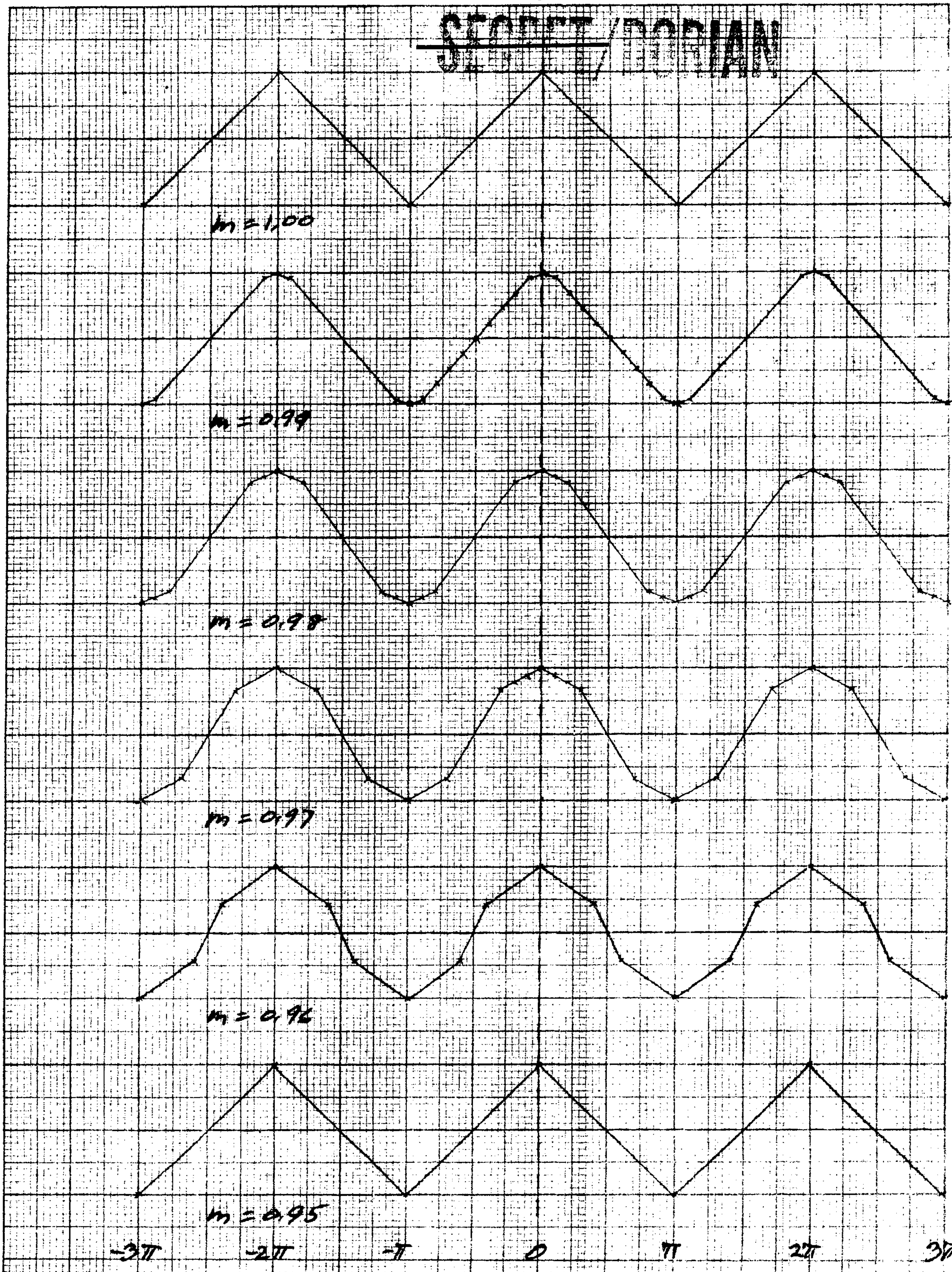


FIGURE 2

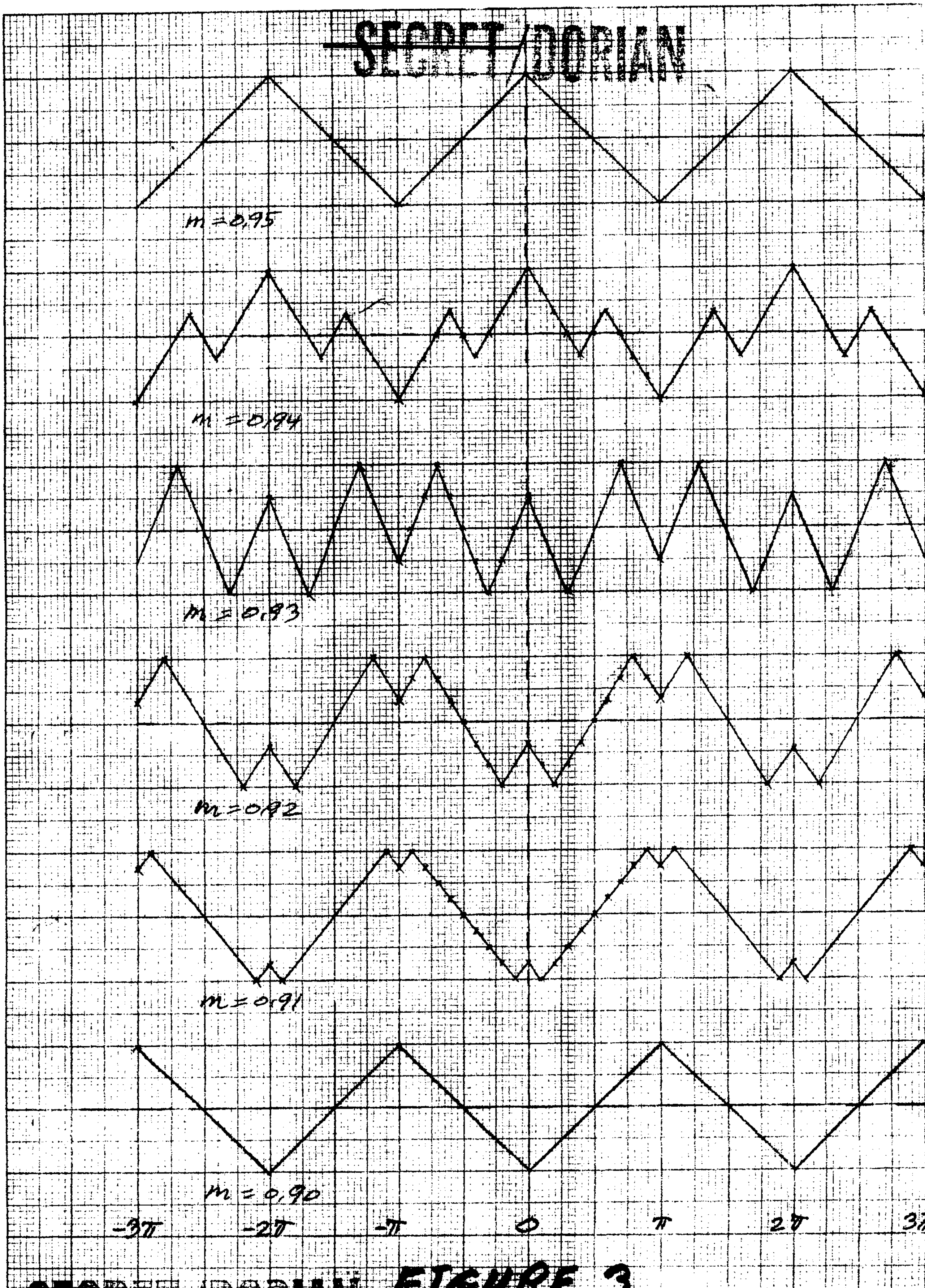
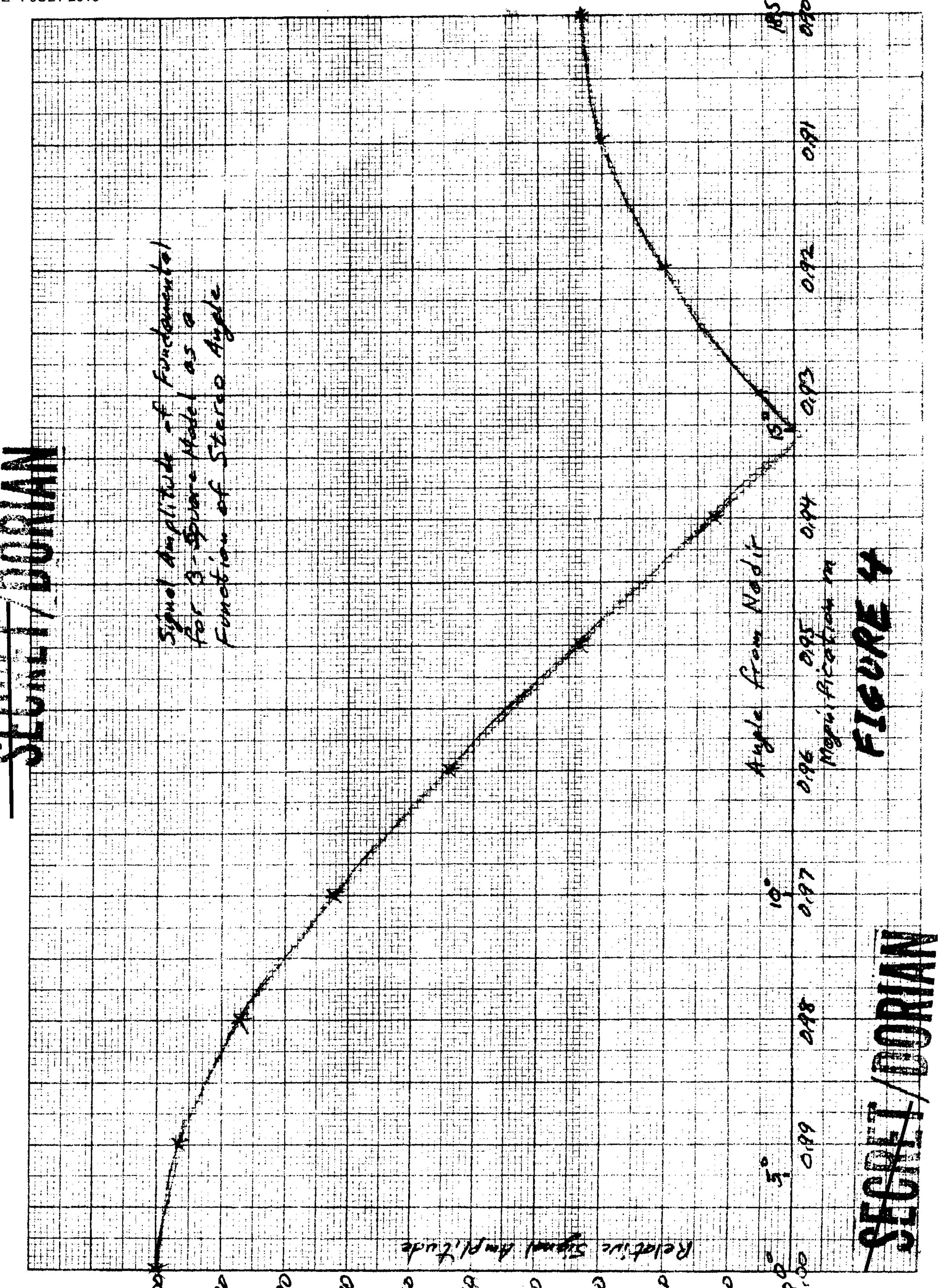


 FIGURE 3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Signal Amplitude of Fundamental for 3-Square Model as a Function of Stereo Angle
Angle from Nadir
Magnification m
Relative Signal Amplitude
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0.0
1.00
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
0.90
5°
10°
15°
18.5°
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FIGURE 4

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RELEASE 1 JULY 2015

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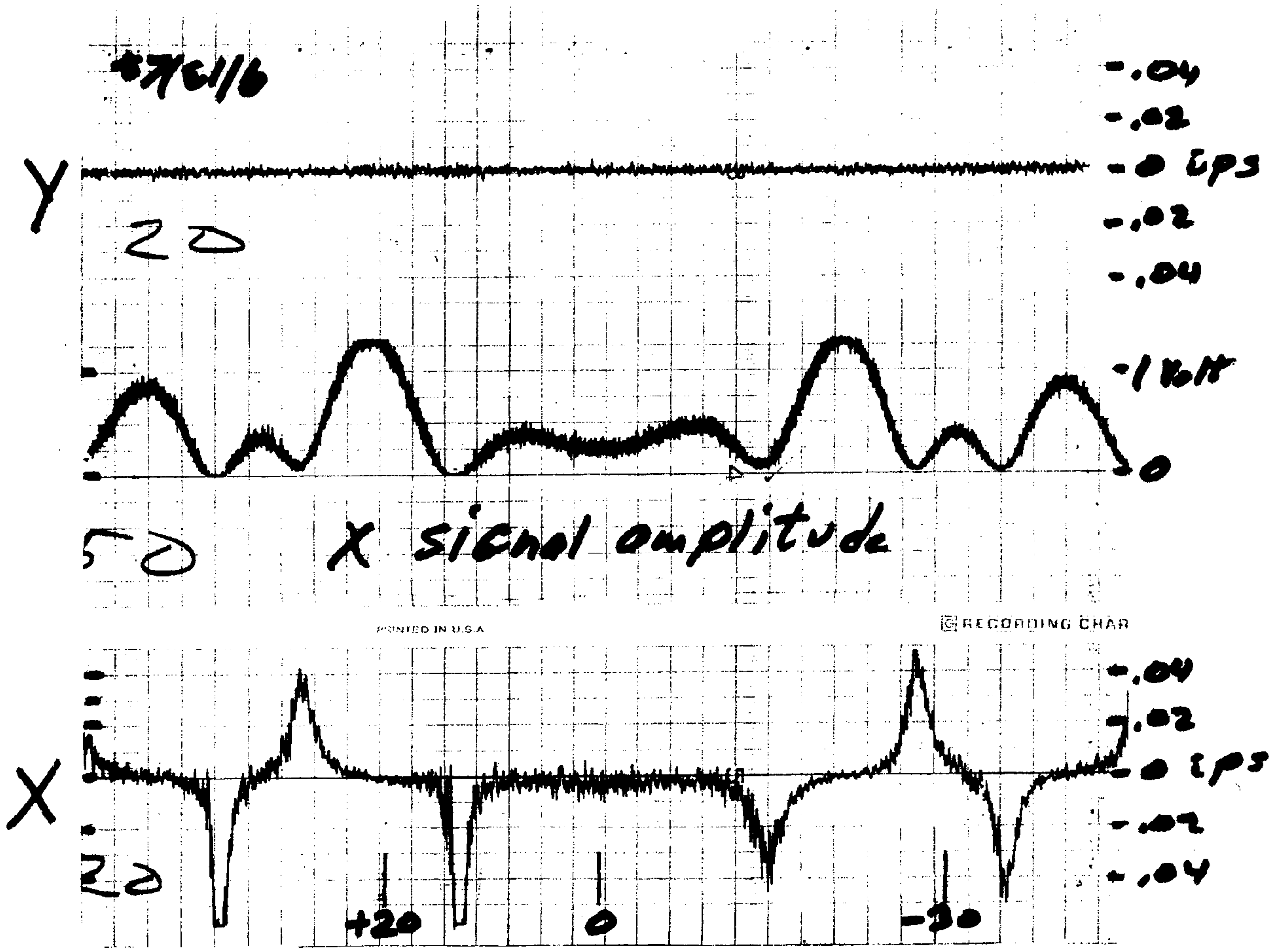

Dynamic Null Run for Mary
3-Square Model

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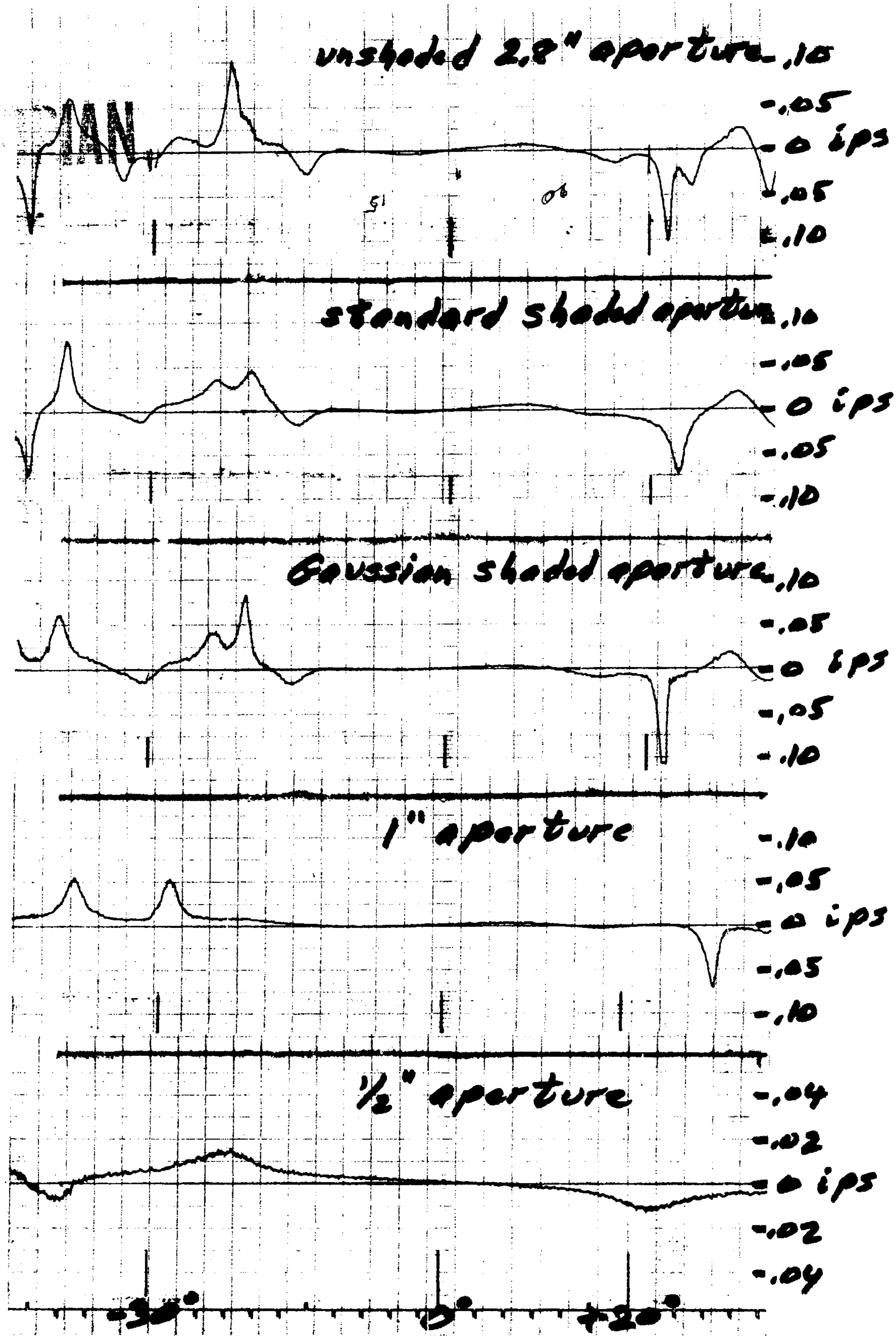
Figure 5



X axis runs for HD scene
0° orientation, C power
FIGURE 7

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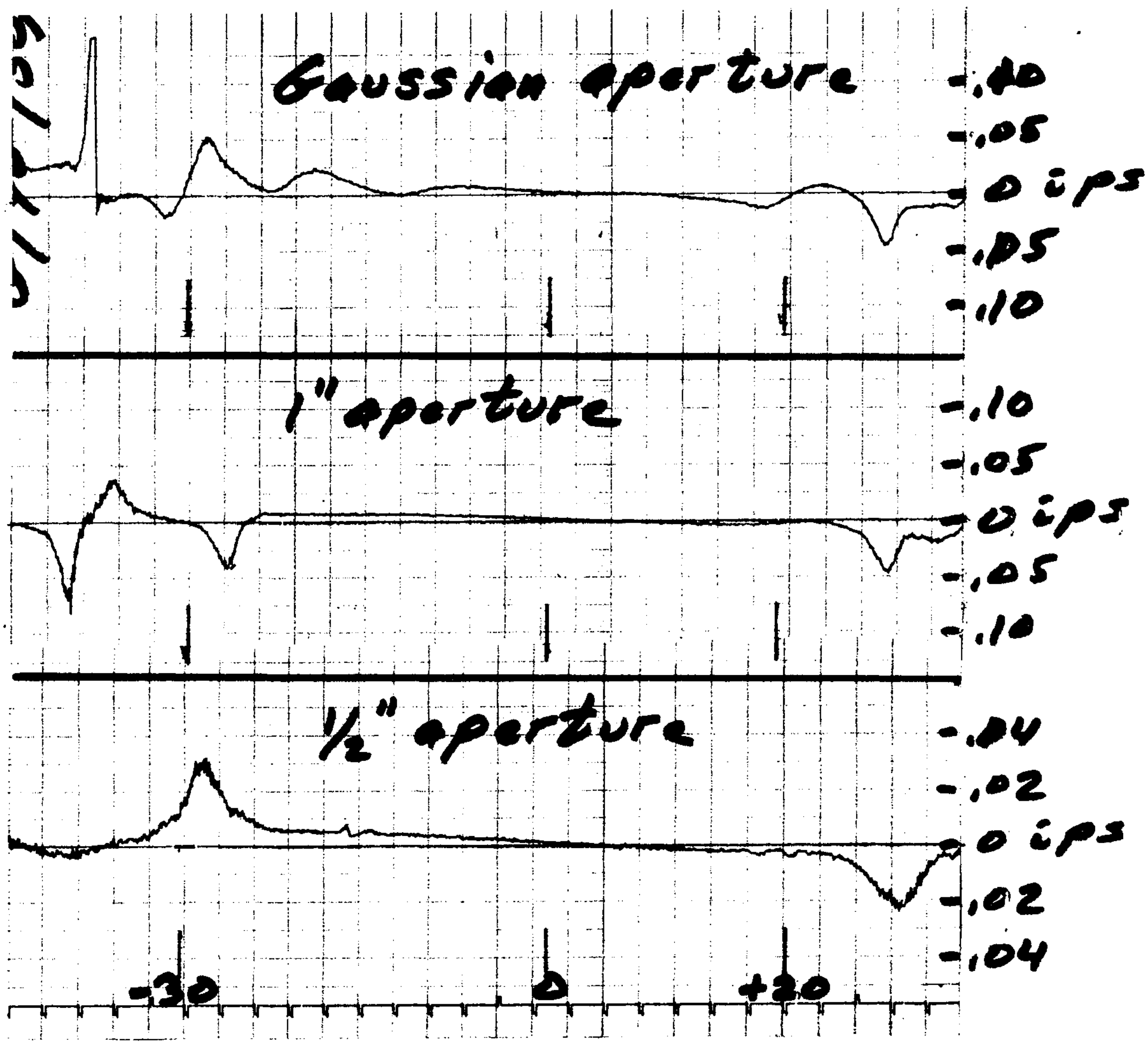

X axis runs for HD scene
90° CW orientation, C power

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FIGURE 8

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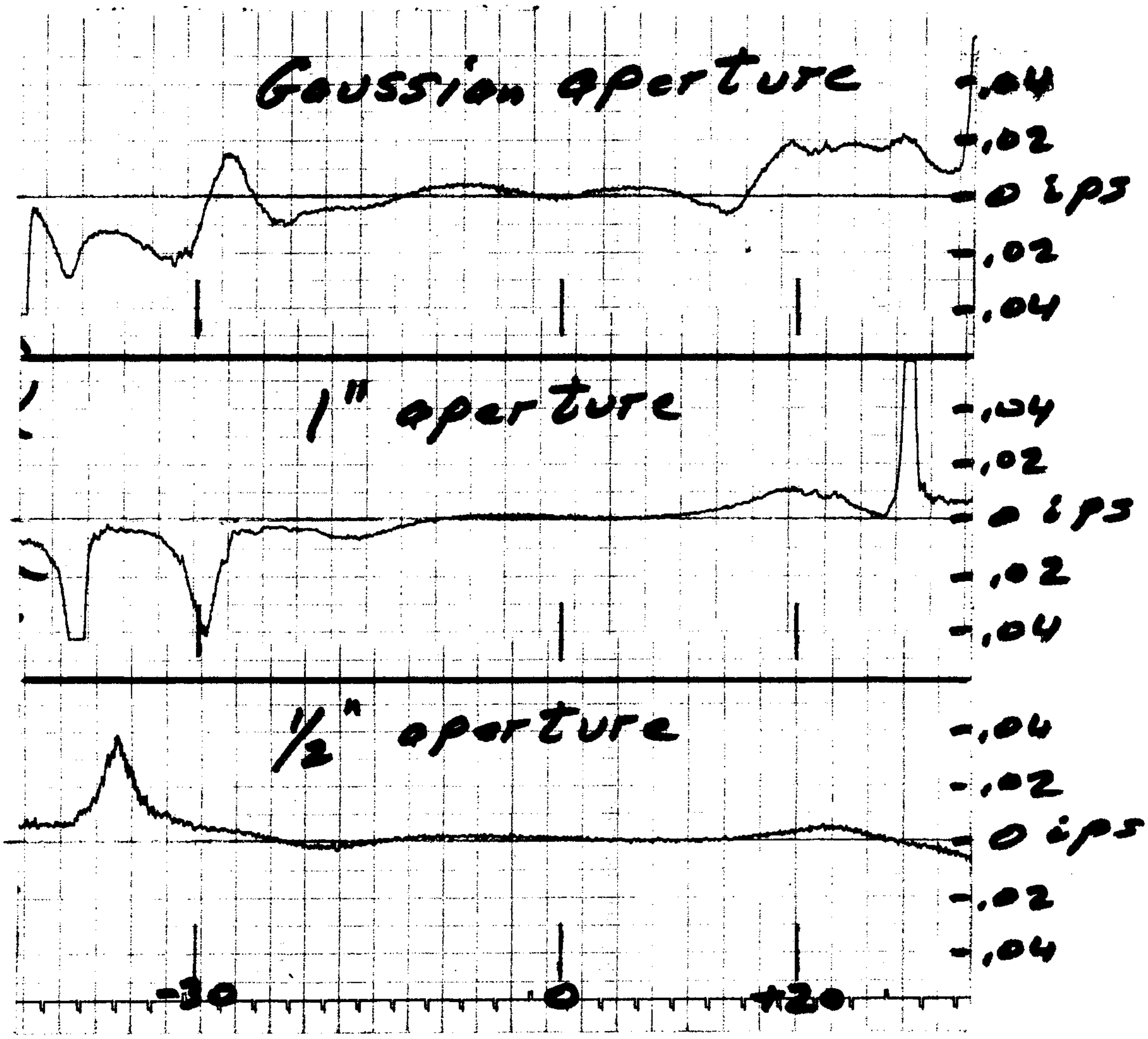

X axis runs for HD scene
180° CW orientation, C power

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FIGURE 9

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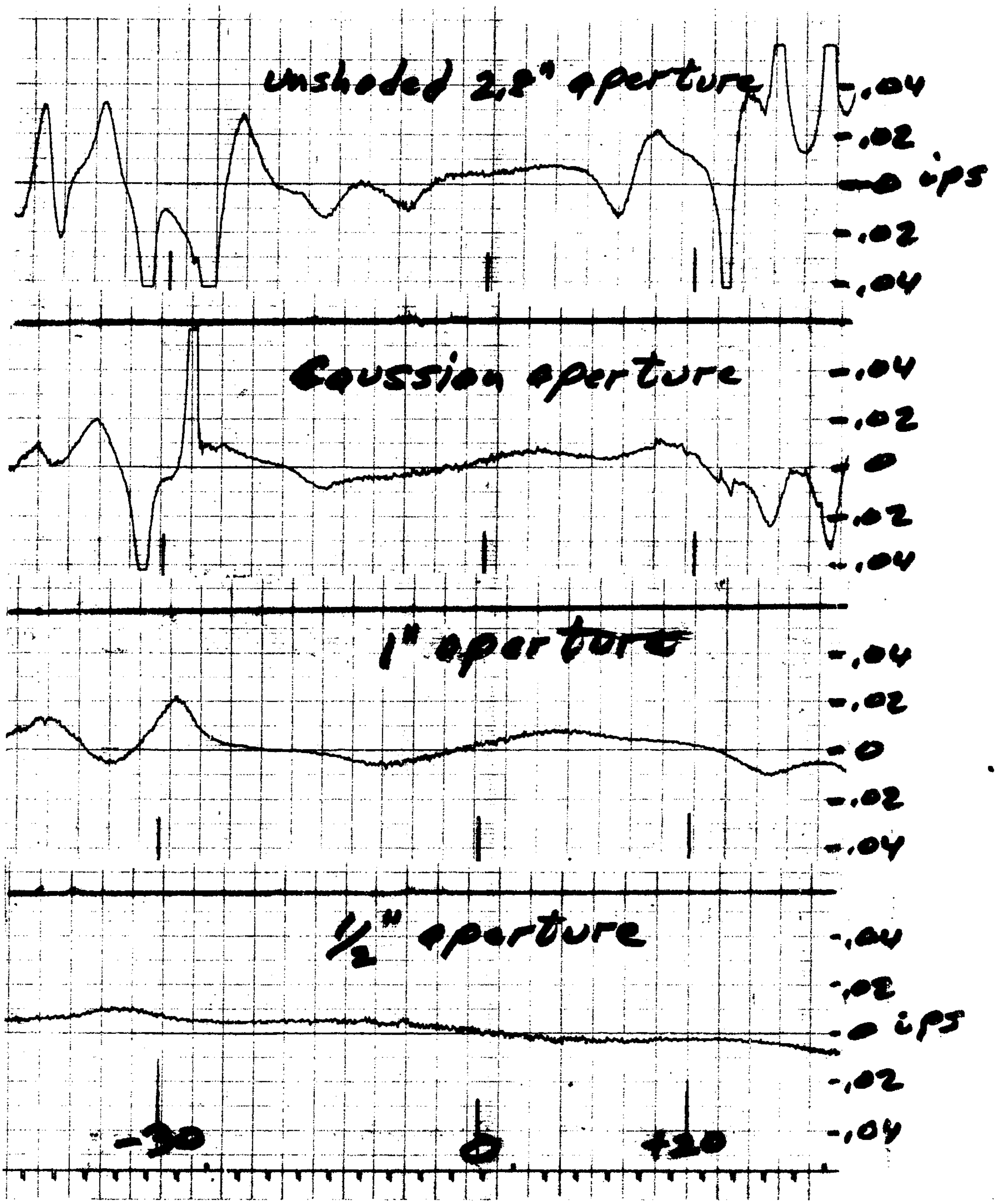

X axis runs for HD scene
270° cw orientation, C power

FIGURE 10

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