TARGET SIGNATURE STUDY

Interim Report

1 September through 30 November 1963

Contract Nr. DA 36-039 SC-90733
Target Signature Research
Department of Army Project Nr. 3A99-23-001

November 1963

OBJECT

Conduct a Study and Investigation to Determine an Optimum Method of Identifying Military Targets by Radar

5172-6-Q = RL-2123

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1. PURPOSE

The purpose of this program is to conduct an investigation to determine an optimum method of identifying military targets by radar means.

2. ABSTRACT

The mixed filter is analyzed in detail using machine simulations. A quantitative estimate of the resolution as a function of the filter parameter is obtained for a given target.

The uniform method of describing targets in terms of their frequency signatures is further developed. Included is a tentative criterion for choosing the representations in terms of translates of a given function.

3. VISITS AND CONFERENCES

There were no visits made or conferences held during this reporting period.

4. TECHNICAL WORK - 1 September through 30 November 1963

4.1 Introduction

The technical work for the sixth quarter has been concentrated in two areas. First, we have further studied the mixed filter and by use of simulations found a more or less quantitative relationship between the filter parameter and range resolution; however, we have only found a qualitative relationship between the filter parameter and the appearance of spurious target signals due to noise.

Second, we have continued our study of a uniform means of frequency signature representation by means of translates. We have a possible means of finding the optimum function to use in the representation.

4.2 Computer Simulation of Mixed Filter-Target Signature Study.

A computer simulation study of the mixed filter for target identification was undertaken during the current reporting period. In general, the results seem to corroborate the expectation that a mixed filter is an effective compromise between a matched filter (noise suppression and identification) and an inverse filter (resolution). Optimum results were obtained for values of the filter parameter over the range $m = 1$ to $m = 10$.

The targets considered are linear arrays of n elements oriented at an arbitrary angle, θ, relative to the receiver. The signature of the target array is

$$\frac{\sin \frac{\omega n d \sin\theta}{c}}{\sin \frac{\omega d \sin\theta}{c}} \, e^{\frac{i\omega d(n-1)\sin\theta}{c}} , \qquad (1)$$

where d is the spacing between elements and c is the speed of light. The mixed filter corresponding to a target α is

$$X_m(\omega) = \frac{1}{A_{\alpha, m}} \; \frac{S_\alpha^*(\omega)}{m^2 + |S_\alpha(\omega)|^2} \quad , \tag{2}$$

$$A_{\alpha, m} = \int_{-r}^{r} \frac{|S_\alpha(\omega)|^2 \, d\omega}{m^2 + S_\alpha(\omega)^2} \quad . \tag{3}$$

The normalization factor, $A_{\alpha, m}$ is chosen so that a return consisting only of a single target of the type sought will give a peak of unit height at the required distance.

The matched filter limit, m → ∞ , is found from (2) and (3) to be

$$X_m^M(\omega) = \frac{S_\alpha^*(\omega)}{\int_{-r}^{r} |S_\alpha(\omega)|^2 \, d\omega} \quad . \tag{4}$$

The inverse filter, m → ∞ , is

$$X_m^I(\omega) = \frac{1}{2r} \; \frac{S_\alpha^*(\omega)}{|S_\alpha(\omega)|^2} \quad . \tag{5}$$

The simulation study contains about 60 individual computer runs over which several parameters vary. These include the filter parameter, m, the signal to noise ratio, orientation of target, number of elements in the target array, and the number and distance of targets. A summary of these runs is included in tabular form in the following tables, giving both a qualitative and quantitative description of the results.

Figure 1 displays the range resolution as a function of the filter parameter. The information is obtained from computer runs by measuring peak widths.

Figures 2 through 11 present a representative sample of the computer runs.

Run No.	m	STNR	Target Description θ	n	Distance meters	Noise Suppression	Separation	Remarks
1	0	∞	30°	6	1500 1503	N. A.	Excellent	
2	10	∞	30°	6	1500 1503	N. A.	Fair	
3	2	20	30°	6	1500 1503	Good	Good	
4	5	20	30°	6	1500 1503	Poor	Poor	Poor effects seem to result from noise sample.
5	5	10	30°	6	1500 1503	Good	Good	
6	10	10	30°	6	1500 1503	Excellent	Good	
7	5	5	30°	6	1500 1503	Poor	None	Peak at 1500 is absent.
8	10	5	30°	6	1500 1503	Fair	Fair	
9	20	5	30°	6	1500 1503	Fair	Poor	
10	99	5	30°	6	1500 1503	Good	None	
11	20	∞	30°	6	1500 1503	N. A.	Poor	
13	1	20	30°	6	1500 1503	Very Poor	Good	Left peak is lower than several spurious peaks.
14	1	10	30°	6	1500 1503	Very Poor	Good	Left peak is lower than several spurious peaks.
17	5	10	30° 0°	6	1500 1503	Good	Good	
18	2	10	30° 0°	6	1500 1503	Poor	N. A.	Peak at 1503 is not suppressed. Spurious peak is higher than signal peaks.
19	5	10	30° 0°	6	1500 1503	Good	N. A.	Peak at 1503 is completely suppressed.

			Target Description					
Run No.	m	STNR	θ	n	Distance meters	Noise Suppression	Separation	Remarks
20	2	10	30° 20°	6	1500 1503	Fair	N. A.	Peak at 1503 is completely suppressed.
21	5	10	30° 25°	6	1500 1503	Good	N. A.	Desired peak (1500) is displaced one meter to left. Undesired peak (1503) is suppressed.
22	2	10	30° 25°	6	1500 1503	Very Poor	N. A.	Poor noise conditions outweigh target discrimination evaluation.
23	25	10	30° 25°	6	1500 1503	Excellent	N. A.	Undesired peak (1503) is suppressed.
24	5	10	30°	6	1500 1503	Excellent	Excellent	
25	2	10	30°	6	1500 1503	Fair	Good	Spurious peaks.
26	25	10	30°	6	1500 1503	Excellent	None	
27	5	10	30° 35°	6	1500 1503	Good	N. A.	Undesired peak is suppressed.
28	2	10	30° 35°	6	1500 1503	Fair	N. A.	Undesired peak is suppressed. Spurious peaks.
29	25	10	30° 35°	6	1500 1503	Good	N. A.	Undesired peak is suppressed.
30	5	10	30° 40°	6	1500 1503	Poor	N. A.	Peak at 1503 is suppressed. Spurious peaks at 1484 and 1506.
31	2	10	30° 40°	6	1500 1503	Fair	N. A.	Undesired peak is suppressed.
32	5	10	30° 90°	6	1500 1503	Fair	N. A.	Peak at 1500 displaced 1.5 meters to right. Peak at 1503 not completely suppressed.
33	2	10	30° 90°	6	1500 1503	Poor	N. A.	Poor noise conditions preclude evaluation.
34	10	10	30° 31°	6	1500 1504	Good	N. A.	Peak at 1500 is 1.1. Peak at 1504 is .8.

Run No.	m	STNR	Target Description			Noise Suppression	Separation	Remarks
			θ	n	Distance meters			
35	10	10	30° 32°	6	1500 1504	Good	N. A.	Peak at 1500 is 1.3 Peak at 1504 is .8.
36	10	10	30° 33°	6	1500 1504	Good	N. A.	Peak at 1500 is 1.1 Peak at 1504 is .6.
37	10	10	30° 34°	6	1500 1504	Good	N. A.	Peak at 1500 is 1.1 Peak at 1504 is .5.
38	10	10	30° 35° 40°	6	1500 1504 1510	Fair	N. A.	Undesired peaks are suppressed.
39	10	10	30° 30°	6 4	1500 1504	Fair	N. A.	Peak at 1500 is 1.1. Peak at 1504 is .5.
40	10	10	30°	6 5	1500 1504	Good	N. A.	Peak at 1500 is 1.0 Peak at 1504 is .5.
41	10	10	30°	6 7	1500 1504	Good	N. A.	Peak at 1500 is .9 Peak at 1504 is 1.2.
42	10	10	30°	6 8	1500 1504	Good	N. A.	Peak at 1500 is .9 Peak at 1504 is 1.4.
43	10	10	30°	6 9	1500 1504	Poor	N. A.	Peak at 1500 is .7 Peak at 1504 is 1.8.
44	10	10	30°	4,5 6,7 8,9	1500 1504 ⋮ 1520	Poor	N. A.	No peaks above .25 Possible cancellation effects.
45	10	10	30°	4-9	1500 ⋮ 1520	Poor	N. A.	No peaks above .25 Possible cancellation effects.
46	10	10	30°	4-9	1500 ⋮ 1520	Poor	N. A.	No peaks above .25 Possible cancellation effects.
47	1.25	10	30°	6	8 targets at 4243	Fair	N. A	

			Target Description					
Run No.	m	STNR	θ	n	Distance meters	Noise Suppression	Separation	Remarks
48	.01	∞	30°	6	1500	N. A.	N. A.	Runs 48 through 55 inclusive were made to measure peak width (resolution)as a function of m.
49	.50	∞	30°	6	1500	N. A.	N. A.	
50	1.00	∞	30°	6	1500	N. A.	N. A.	
51	5	∞	30°	6	1500	N. A.	N. A.	
52	10	∞	30°	6	1500	N. A.	N. A.	
53	20	∞	30°	6	1500	N. A.	N. A.	
54	50	∞	30°	6	1500	N. A.	N. A.	
55	100	∞	30°	6	1500	N. A.	N. A.	
56	15	∞	30°	6	2 targets at 2121	N. A.	N. A.	
57	15	∞	30°	6	2 targets at 2121	N. A.	N. A.	
58	.01	∞	30°	6	1500 1504 ⋮ 1520	N. A.	Excellent	
59	5	20	30°	6	1500 1504 ⋮ 1520	Good	Good	Peaks: 1.1, .8, .6, 1.2, 1.1, .5.
60	.01	∞	30°	4-9	1500 1504 ⋮ 1520	N A.	N. A.	Interference appears to give spurious peaks.

Run No.	m	STNR	Target Description			Noise Suppression	Separation	Remarks
			θ	n	Distance meters			
61	.01	∞	30°	4–9	1500 1503.5 ⋮ 1517.5	N. A.	N. A.	Interference appears to give spurious peaks.
64	1000	∞	30°	6	1500	N. A.	N. A.	Runs 64 and 65 were made to measure peak width as a function of m.
65	10,000	∞	30°	6	1500	N. A.	N. A.	
66	5	∞	30°	4 6 9	1475 1500 1525	N. A.	Good	Peaks: .7, 1.0, 1.2.

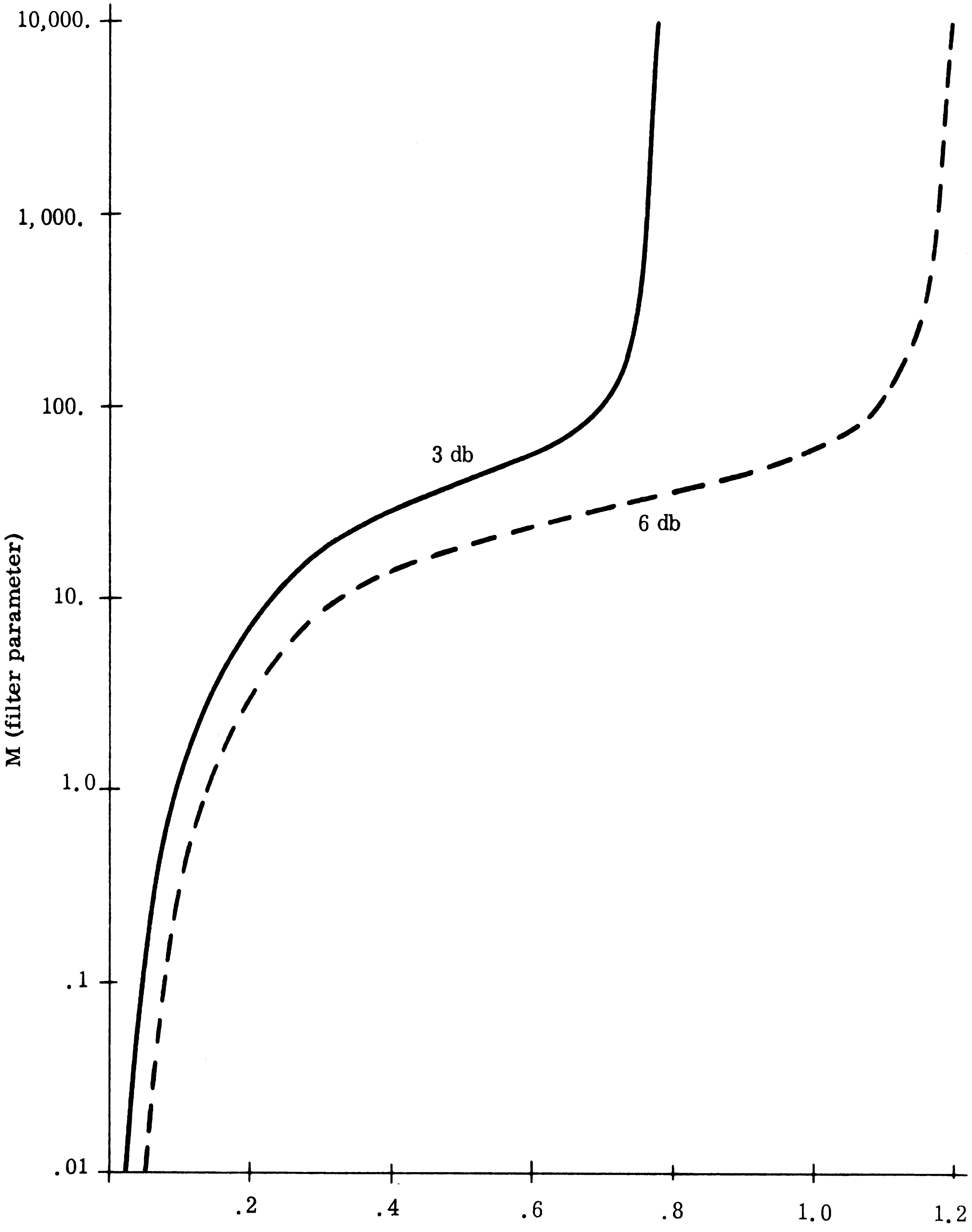

FIG. 1: Range Resolution (peak width/incident pulse length).

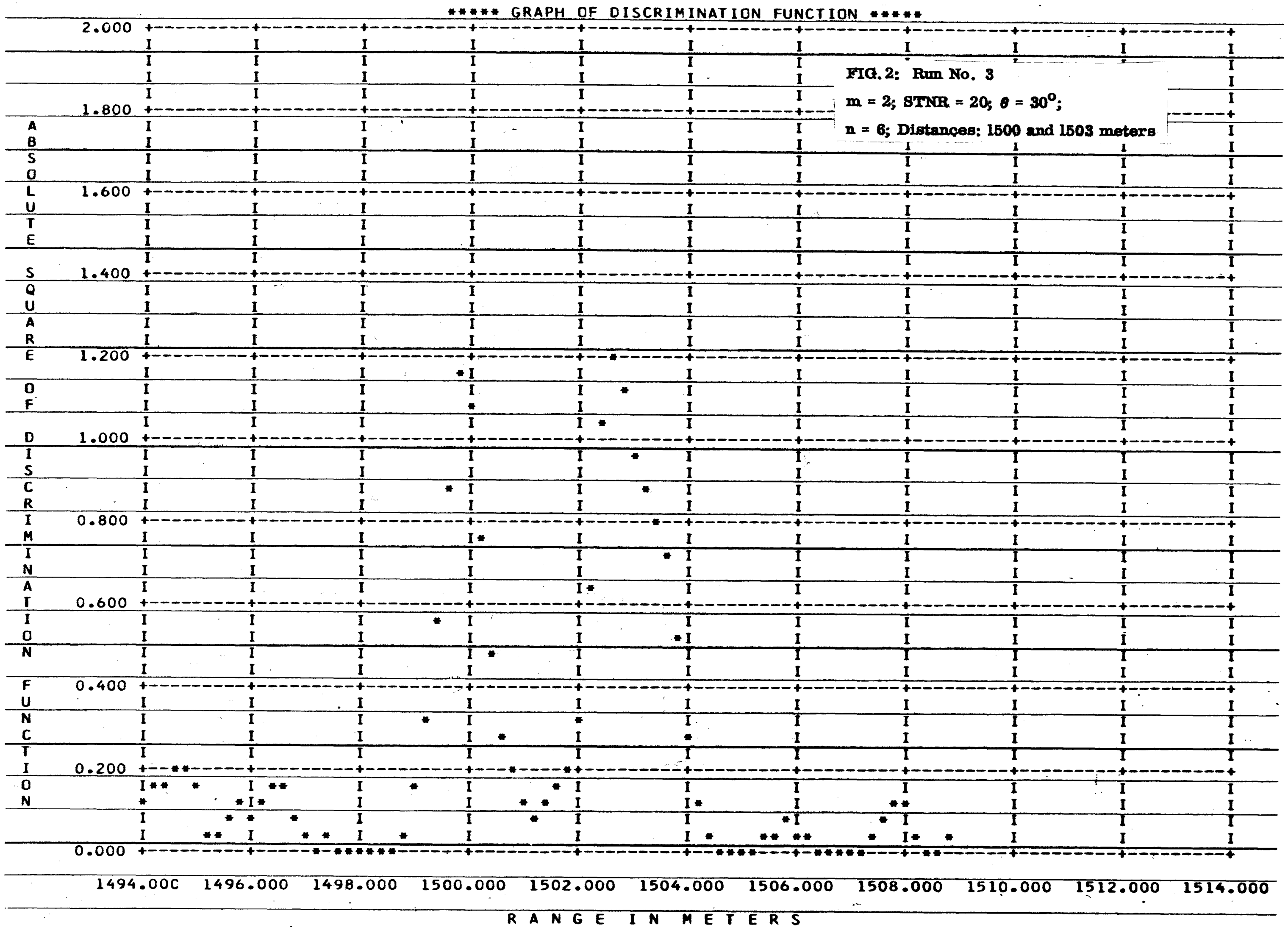

FIG. 2: Run No. 3

m = 2; STNR = 20; θ = 30°;

n = 6; Distances: 1500 and 1503 meters

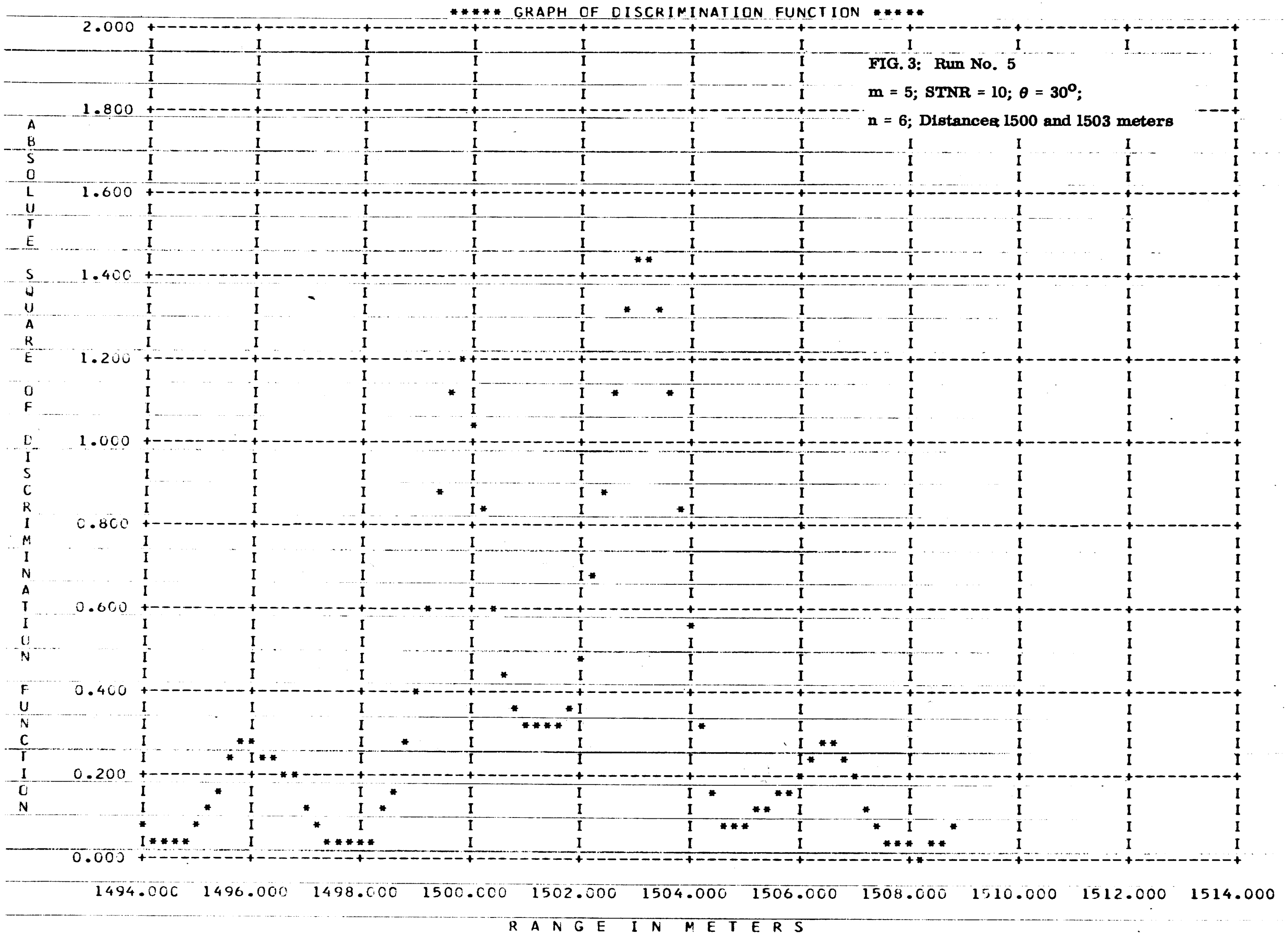

FIG. 3: Run No. 5

m = 5; STNR = 10; $\theta = 30^\circ$;

n = 6; Distances 1500 and 1503 meters

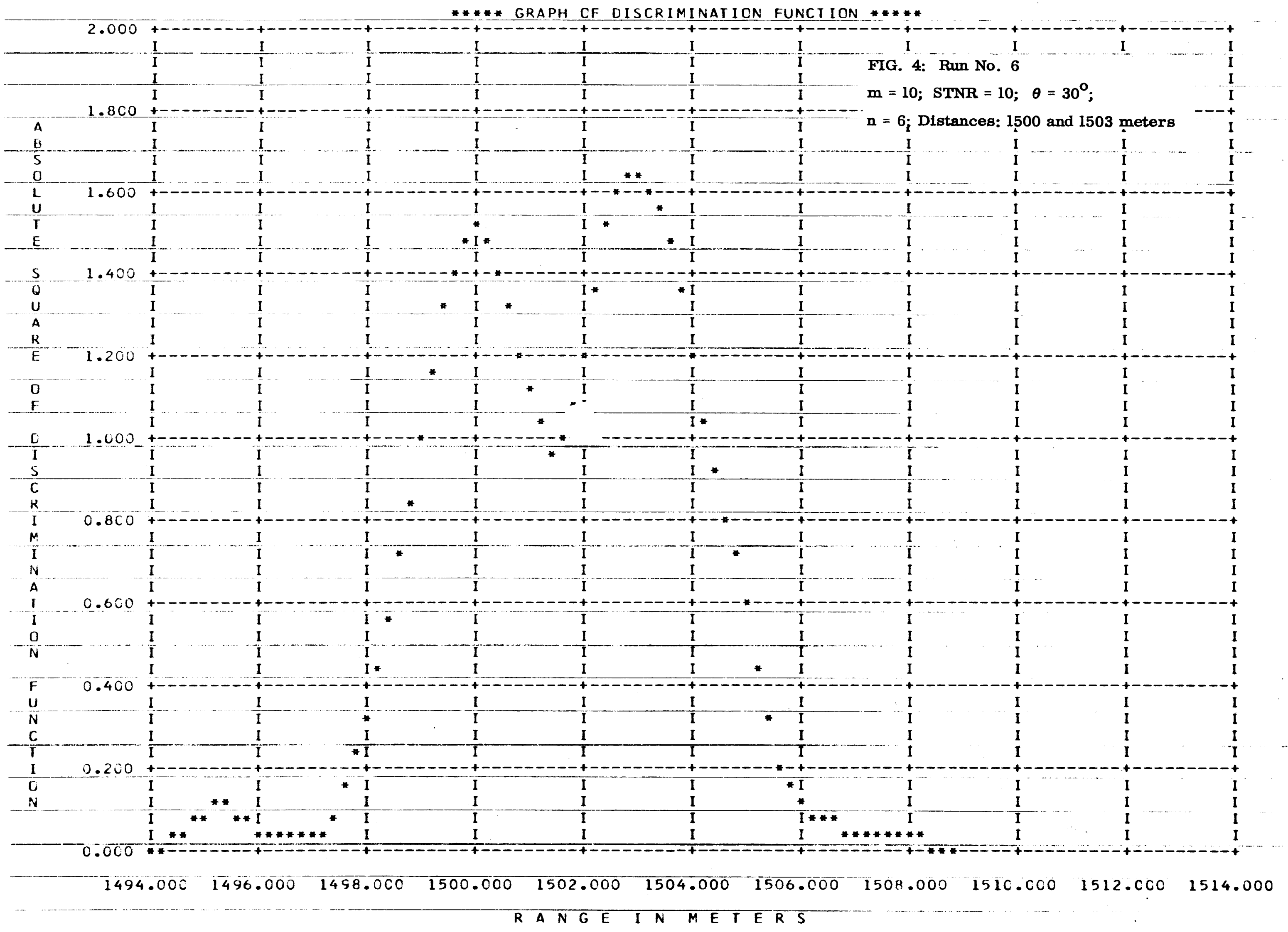

FIG. 4: Run No. 6

m = 10; STNR = 10; $\theta = 30^o$;

n = 6; Distances: 1500 and 1503 meters

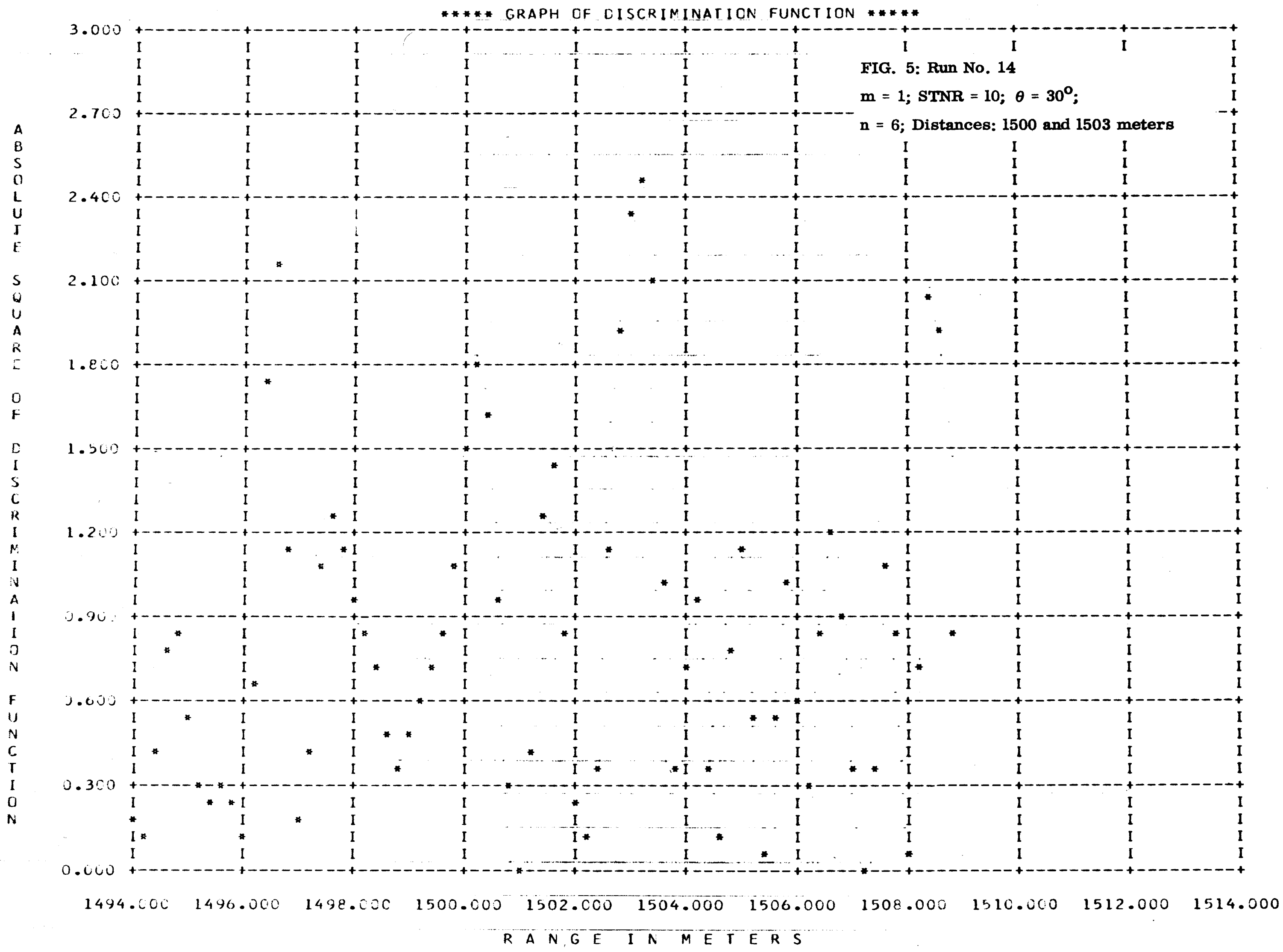

FIG. 5: Run No. 14

m = 1; STNR = 10; $\theta = 30^{o}$;

n = 6; Distances: 1500 and 1503 meters

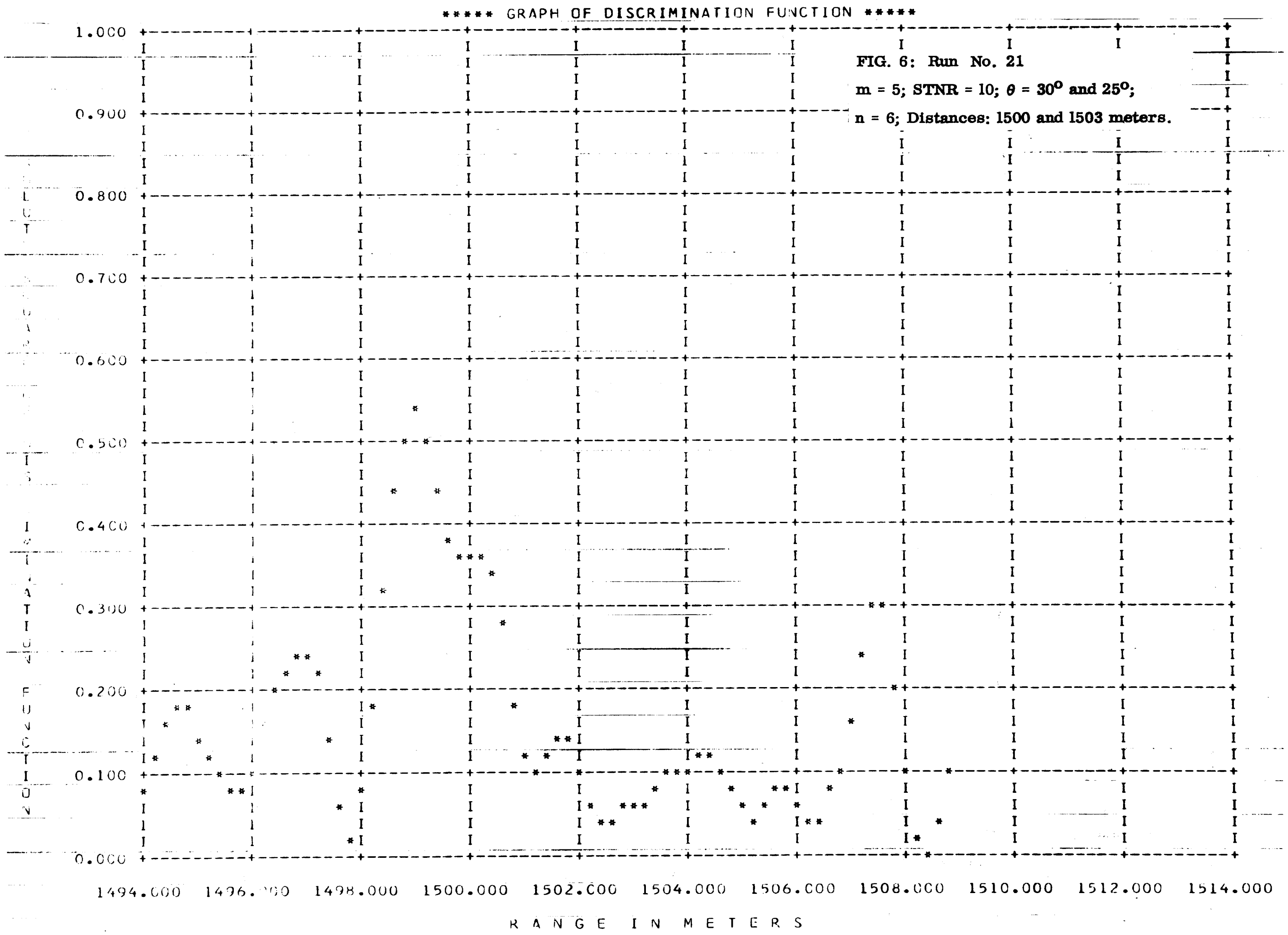

FIG. 6: Run No. 21

m = 5; STNR = 10; θ = 30° and 25°;

n = 6; Distances: 1500 and 1503 meters.

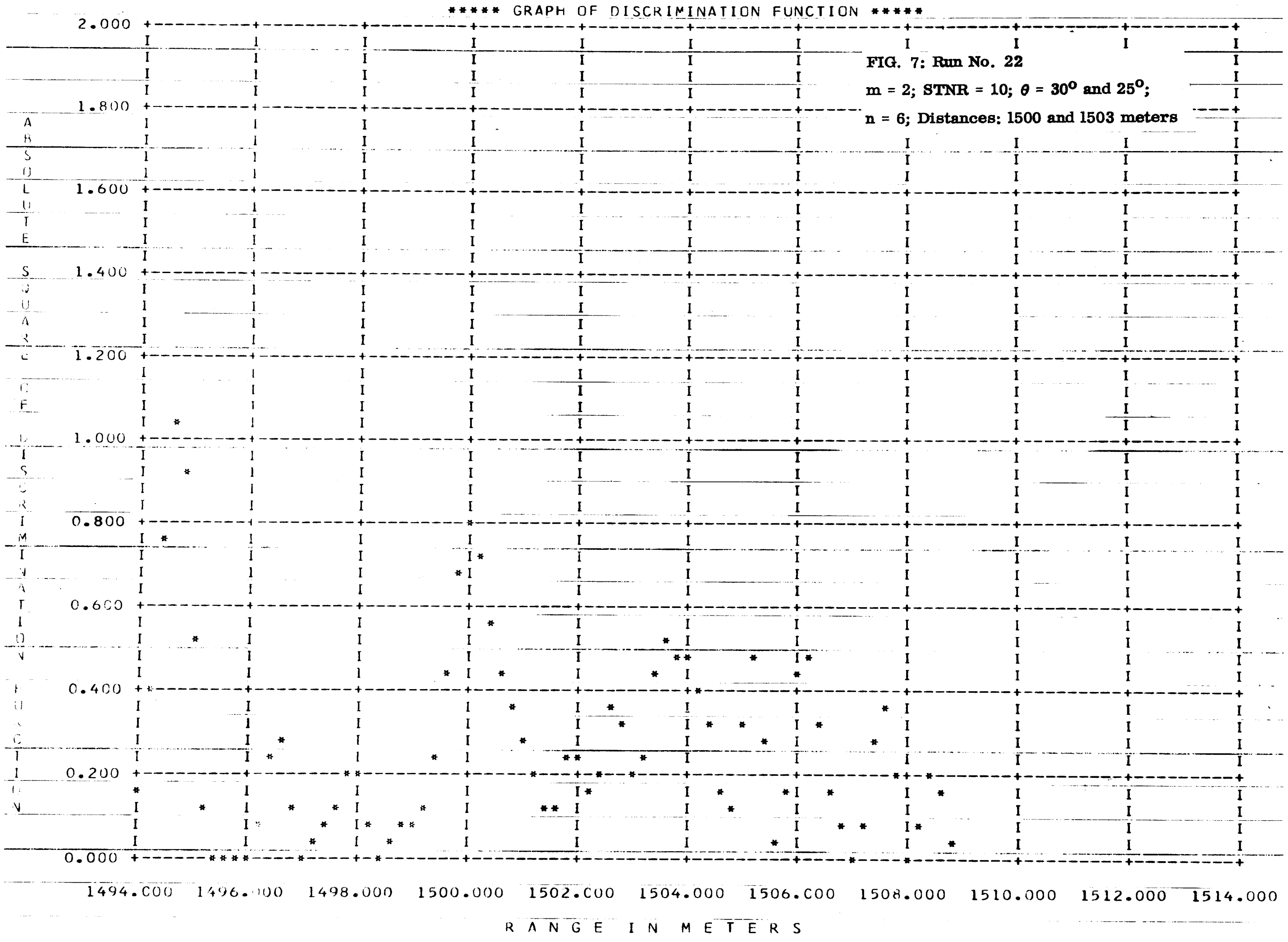

FIG. 7: Run No. 22

m = 2; STNR = 10; θ = 30° and 25°;

n = 6; Distances: 1500 and 1503 meters

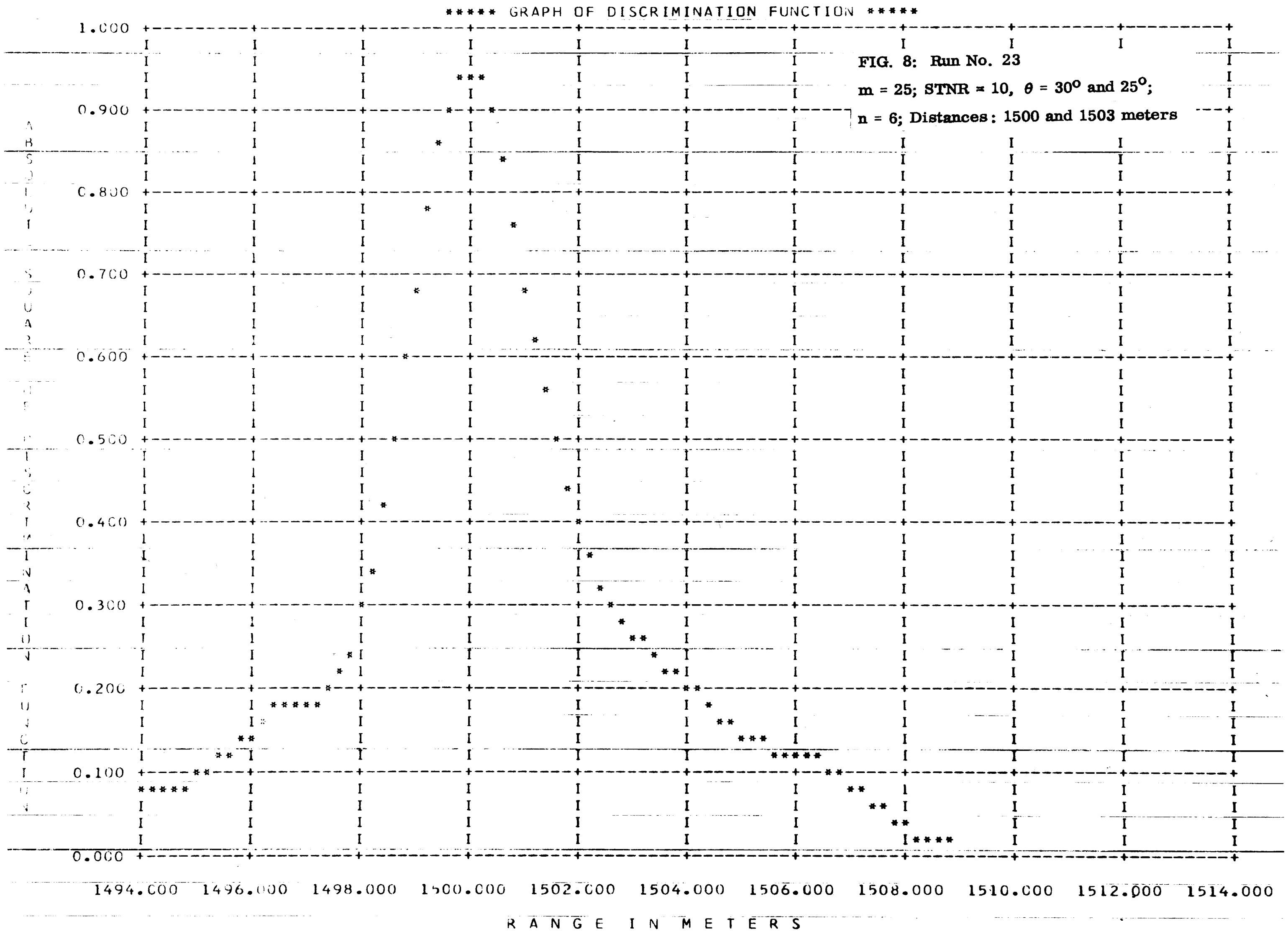

FIG. 8: Run No. 23

m = 25; STNR = 10, θ = 30° and 25°;

n = 6; Distances: 1500 and 1503 meters

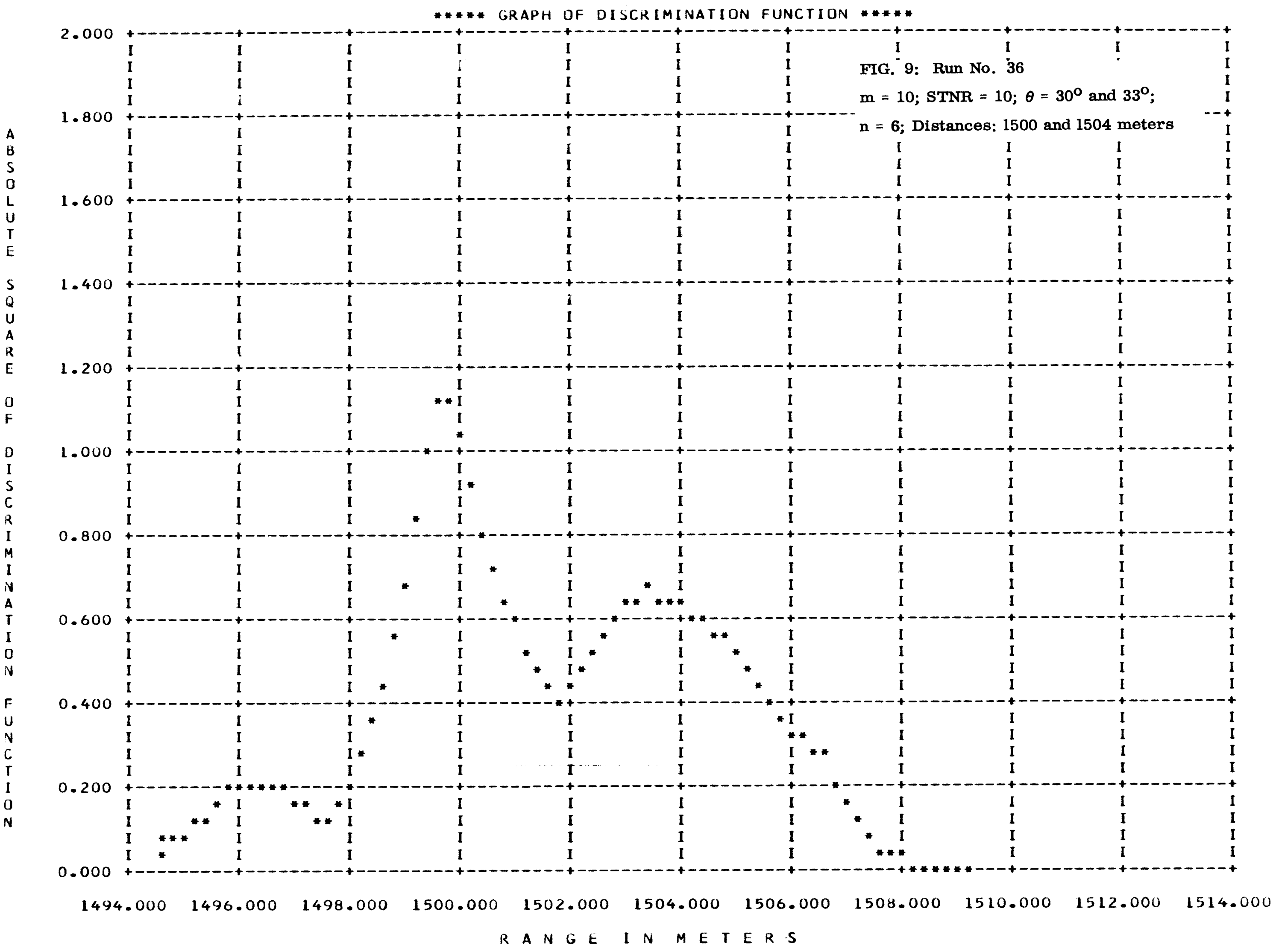

FIG. 9: Run No. 36

m = 10; STNR = 10; θ = 30° and 33°;

n = 6; Distances: 1500 and 1504 meters

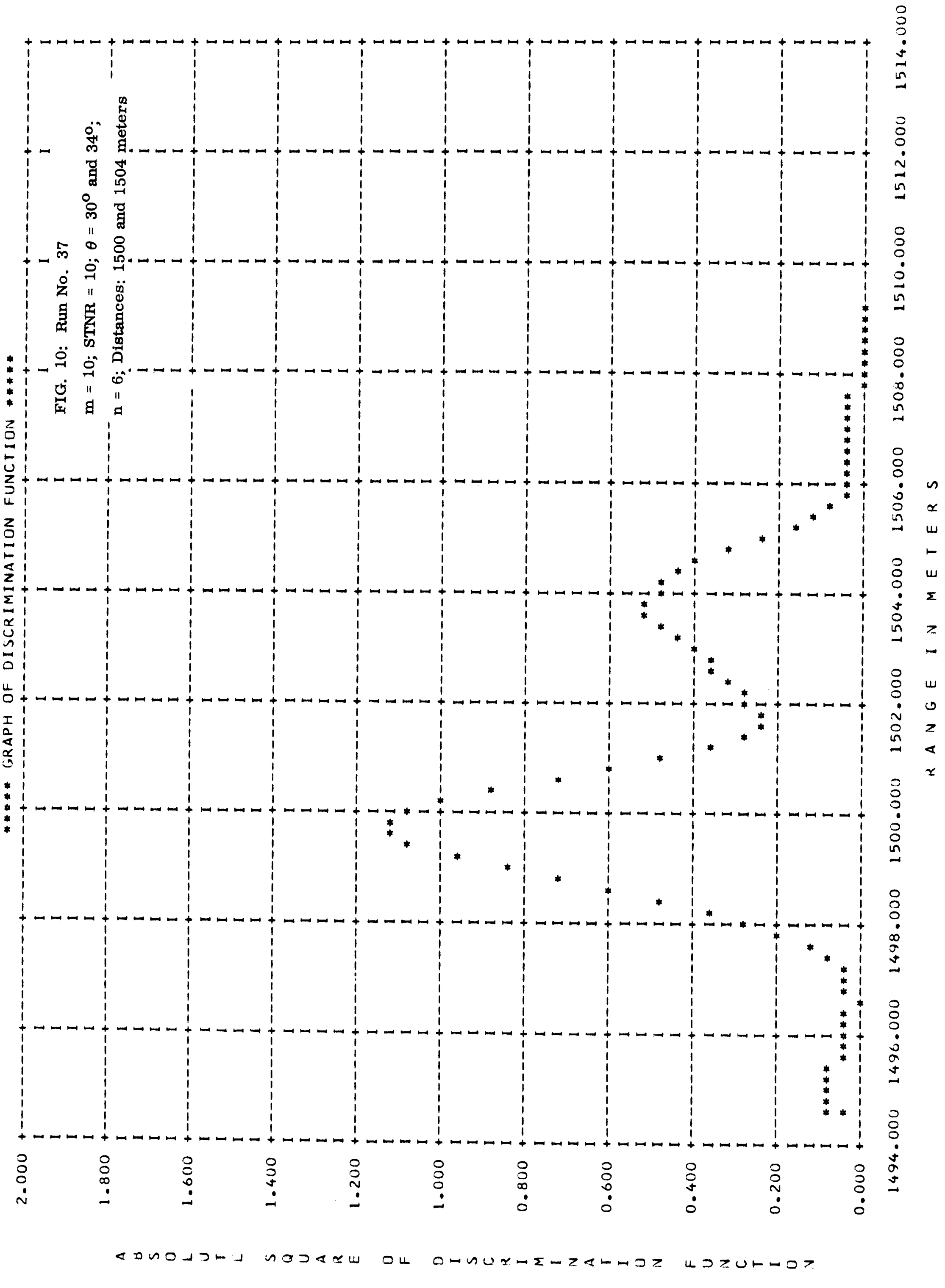

FIG. 10: Run No. 37
m = 10; STNR = 10; θ = 30° and 34°;
n = 6; Distances: 1500 and 1504 meters

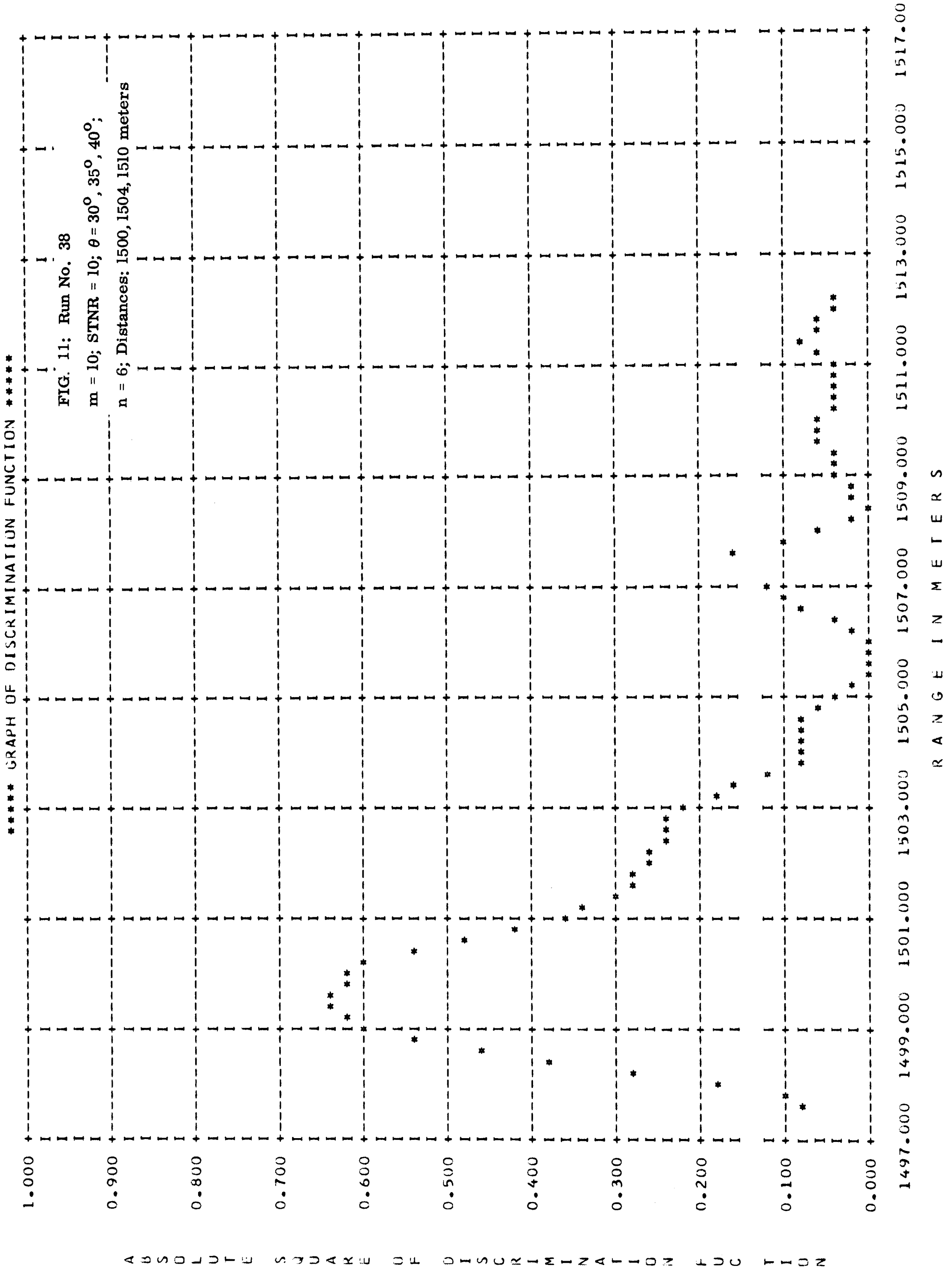
FIG. 11; Run No. 38
m = 10; STNR = 10; $\theta = 30^{\circ}, 35^{\circ}, 40^{\circ}$;
n = 6; Distances: 1500, 1504, 1510 meters

4.3 Representation of the Target Signatures

We continue with our analysis of the use of Wiener's theorem on translates for the representation of target signatures. Briefly, we summarize the problem of target signature representation as follows.

Given a set of signature functions $S_\alpha(\omega)$, where α designates the α'th target, we wish to find a representation in terms of translates of a function $S(\omega)$ in the sense

$$S_\alpha(\omega) \cong \sum_k A_k^\alpha \, S(\omega + \omega_k^\alpha) \ ,$$

where we leave the question of convergence for later. We have from the Wiener theorem that for a sufficiently broad class of functions the approximation is possible. What we need to find is ; 1) a constructive method of realizing the expansion, and 2) a criterion for choosing the best S for our filter scheme.

On obtaining the representations for a given set of targets we can define a set of translates which can be used for any of the targets by simply forming the union of the translates for each of them. The coefficients $\left\{A_k^\alpha\right\}$ now can be used to characterize the target signatures;

$$S_\alpha(\omega) \leftrightarrow \left\{A_k^\alpha\right\} \quad . \tag{6}$$

To form a filter which can detect target α and discriminate against target β we need to modify $S_\alpha(\omega)$ so that the overlap between S_α and S_β is as small as possible. If we look for

$$\tilde{S}_\alpha(\omega) \leftrightarrow \left\{\tilde{A}_k^\alpha\right\} \quad , \tag{7}$$

where $\tilde{S}_\alpha(\omega)$ is formed by putting

$$\tilde{A}_k^\alpha = \begin{cases} 0 \\ A_k^\alpha \end{cases} ; \qquad \tilde{S}_\alpha(\omega) = \sum \tilde{A}_k^\alpha S(\omega + \omega_k) \quad , \tag{8}$$

in order that

$$\left| \sum \tilde{A}_k^\alpha \bar{A}_k^\beta \right| < \epsilon$$

and (9)

$$\sum \left| \tilde{A}_k^\alpha \right|^2 > M$$

where ϵ and M are positive numbers. Then a filter constructed from $S_\alpha(\omega)$ should in some sense satisfy the discrimination requirements.

We still need a criterion for choosing S . For a given set of targets and for a given S we define a set of translations and we need put some limitation on

$$\left| S * S\,(\Delta\omega) \right| < \eta$$

where $\Delta\omega$ is the smallest interval between translations. We have made some progress in this wise. We, for convenience, have represented the signature functions in terms of convolutions rather than translations.

Let there be given a set of spectra

$$S_1(\omega),\ S_2(\omega),\ \ldots\ ,\ S_n(\omega) \quad .$$

We wish to find a function (spectrum) $S(\omega)$ such that in the representation

$$S_\alpha(\omega) = \int \phi_\alpha(\eta)\, S(\omega - \eta)\, d\eta$$

the functions ϕ_α are "as different as possible". To obtain a criterion of difference (discrimination) we let

$$c_\alpha^2 = \int |\phi_\alpha|^2 \; ;$$

then the set $\left\{\phi_\alpha\right\}$ is correspondingly different, according as the sum

$$\sum_{\alpha,\beta} \int \left| \frac{\phi_\alpha}{c_\alpha} - \frac{\phi_\beta}{c_\beta} \right|^2$$

is large. Thus we want to find an S to maximize this sum.

Now

$$\int \left| \frac{\phi_\alpha}{c_\alpha} - \frac{\phi_\beta}{c_\beta} \right|^2 = \int \left(\frac{\phi_\alpha}{c_\alpha} - \frac{\phi_\beta}{c_\beta} \right) \left(\frac{\phi_\alpha}{c_\alpha} - \frac{\bar{\phi}_\beta}{c_\beta} \right) = 2 - 2\, R\ell \int \frac{\phi_\alpha}{c_\alpha} \; \frac{\bar{\phi}_\beta}{c_\beta} \quad ,$$

and we want to minimize the sum

$$R\ell \int \sum_{\alpha,\beta} \frac{\phi_\alpha}{c_\alpha} \; \frac{\bar{\phi}_\beta}{c_\beta} = \int \left| \sum \frac{\phi_\alpha}{c_\alpha} \right|^2 \quad .$$

Denoting Fourier transforms by $\sim$ we have

$$\sum \frac{\phi_\alpha}{c_\alpha} = \frac{1}{2r} \int e^{-i\omega x} \; \frac{\sum \frac{1}{c_\alpha} \tilde{S}_\alpha(x)}{\tilde{S}(x)} \; dx$$

$$\left|\sum \frac{\phi_\alpha}{c_\alpha}\right|^2 = \frac{1}{4\pi}\int e^{-i\omega x+i\omega y}\, \frac{\sum \frac{1}{c_\alpha}\tilde{S}_\alpha(x)}{\tilde{S}(x)}\; \frac{\sum \frac{1}{c_\beta}\tilde{S}_\beta(x)}{\overline{\tilde{S}(x)}}\, dx\, dy \quad .$$

Hence

$$\int \left|\sum \frac{\phi_\alpha}{c_\alpha}\right|^2 = \frac{1}{2\pi}\int \frac{\left|\sum \frac{1}{c_\alpha}\tilde{S}_\alpha(x)\right|^2}{\left|\tilde{S}(x)\right|^2}\, dx \ ,$$

and we want to minimize this last expression on S, subject, say, to

$$\int \left| S(x)\right|^2 = 1 \quad .$$

We set

$$c = \frac{1}{2\pi}\int \left|\sum \frac{1}{c_\alpha}\tilde{S}_\alpha(x)\right| dx \ ,$$

then by Schwartz inequality

$$c = \frac{1}{2\pi}\int \left|\sum \frac{1}{c_\alpha}\tilde{S}_\alpha(x)\right| = \frac{1}{2\pi}\int \frac{\left|\sum \frac{1}{c_\alpha}\tilde{S}_\alpha(x)\right|}{\left|\tilde{S}(x)\right|}\, \left|\tilde{S}(x)\right| dx$$

$$\leqslant \frac{1}{2\pi}\int \frac{\left|\sum c_\alpha \tilde{S}_\alpha(x)\right|^2}{\left|\tilde{S}(x)\right|^2}\, dx \int \left| S(x)\right|^2 dx$$

$$= \frac{1}{2\pi}\int \frac{\left|\sum c_\alpha \tilde{S}_\alpha(x)\right|^2}{\left| S(x)\right|^2}\, dx \quad .$$

Hence the minimum value of the integral is c, and can be achieved by setting

$$\frac{\left| \sum \frac{1}{c_\alpha} \tilde{S}_\alpha(x) \right|}{| \tilde{S}(x) |} = 2\pi c \, |\tilde{S}(x)|$$

or

$$|\tilde{S}(x)|^2 = \frac{1}{2\pi c} \left| \sum \frac{1}{c_\alpha} \tilde{S}_\alpha(x) \right| \quad .$$

As soon as the c_α are known, this gives S(x) as any function whose modulus satisfies the above. To determine the c_α we have

$$c_\alpha^2 = \int |\phi_\alpha(\omega)|^2 = \frac{1}{2\pi} \int \frac{|\tilde{S}_\alpha(x)|^2}{|\tilde{S}(x)|^2} = \frac{1}{2\pi} \int \frac{|\tilde{S}_\alpha(x)|^2}{\frac{1}{2\pi c} \left| \sum \frac{1}{c_\beta} \tilde{S}_\beta(x) \right|}$$

$$c_\alpha^2 = c \int \frac{|\tilde{S}_\alpha(x)|^2}{\left| \sum \frac{1}{c_\beta} \tilde{S}_\beta(x) \right|} \quad .$$

This gives n equations in the n unknowns $c_1, c_2, \ldots, c_n$ to solve .

The extension of this criterion to the representation in terms of translations is immediate on nothing that

$$\sum A_k f(\omega + \omega_k) = \int \mathcal{A}(\eta) \, f(\omega + \eta) d\eta$$

where

$$\mathcal{A}(\eta) = \sum_k A_k \, \delta(\eta + \omega_k) \quad .$$

4.4 Review of Technical Work

We divide the technical work into three topics:

1. The development of the mixed filter concept so as to be able to affect a compromise between best discrimination (matched filter) and best resolution (inverse filter).

2. The test of the scheme using a complex target. We are now prepared to use a vehicle as the target in our simulation experiments.

3. The development of a representation of the target frequency signatures in terms of translates of a suitably chosen function so as to facilitate the construction of filters and so as to be able to decide whether two given targets can be discriminated one from the other.

At this point we can make a somewhat quantitative evaluation of the mixed filter in that we can suggest a range of the filter parameter for suppressing a certain noise level or for a certain range resolution. Since we have developed our analysis on the basis of essentially one target we would wait for a more extensive target analysis before we make any more definite predictions as to resolution and discrimination criteria as a function of the filter parameter. We should be able to make a sharper statement after the vehicle simulation.

The preliminaries to the vehicle simulation are complete. We have waited with the actual run until we obtained a better understanding of the mixed filter. The vehicle simulation is the next task in our program. In the future other complex targets will also be simulated.

The development of a means of representing the frequency signatures in terms of the translates of a given function is the most difficult and, we believe, the most important of our problems. Such representations exist and we need a systematic way of realizing them and a means of choosing the best given function. We have a tentative method of choosing the function but as yet no systematic way of realizing the representations.

We attach such importance to the representation of the signature since these representations will permit a systematic way of constructing the best possible filters for discriminating a group of targets one from another.

5. PROGRAM FOR NEXT INTERVAL

Due to the amount of effort devoted to the analysis of the mixed filter the planned simulation of a vehicle was not completed. This is, however, a main task for the next period.

The analysis if the uniform representation will be continued. The goal is a constructive method of obtaining the representation and a sharp criterion for choosing the expansion function.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions of Dr. Ziya Akcasu, Mr. John Ducmanis and Mr. Leon Zukowski to this research.

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Marine Corps Liaison USAERDL Fort Monmouth, N. J. 07703	1	37
AFSC Sci/Tech Liaison USAERDL Fort Monmouth, N. J. 07703	1	38
CO USAERDL Technical Documents Center Fort Monmouth, N. J. 07703	1	39
U. S. Army Research Liaison Colonel M. F. Bavaro MIT-Lincoln Laboratory Lexington, Mass 02173	1	40
CO, U. S. A. Intelligence Materiel Agency Fort Holabird Baltimore, Md. 21219	1	41
CO USAERDL SELRA/SR(T), Thence to FU Nr. 2 (Record Copy) Fort Monmouth, N. J. 07703	1	42
C. G. Desert Test Center Fort Douglas, Utah	1	43
CO AFCRL - CRZW 1065 Main Street Waltham, Mass	1	44
President, U. S. Army Arctic Test Board Fort Greely, Alaska	1	45
CG, U. S. Army Test and Evaluation Command AMSTE-EL Aberdeen Proving Ground, Md.	1	46
CG, U. S. Army Test and Evaluation Command AMSTE-BAF Aberdeen Proving Ground, Md.	1	47
CG, U. S. Army Missile Command - AMSMI-RB Redstone Arsenal, Alabama 35809	1	48

CG, U. S. Army Missile Command - AMSMI-RR Redstone Arsenal, Alabama 35809	1	49
CO, USAERDL Logistics Division (For: SRD) Fort Monmouth, N. J. 07703	11	50-60

This contract is supervised by the Advanced Development Branch, Radar Division, Surveillance Department, U. S. Army Electronics Research and Development Laboratories, Fort Monmouth, New Jersey, 07703. Telephone - Eatontown, N. J., Area Code 201, 596-1655. Contracting Officer's Technical Representatives are: Mr. V. L. Friedrich and Mr. J. Maresca.